SYSTEM DESIGN / 45-MINUTE INTERVIEW EDITION

Understand the idea. *Practise the answer.*

System design
Learning and interview practice

Plain explanations, concrete request traces, worked estimates, and interview questions with complete model answers and answered follow-ups. Learn the mechanism, then rebuild the design from a blank page.

26	36	500
concept lessons	design walkthroughs	answered questions

500 answered follow-ups and 197 recall cards.

BUILD A CONNECTED EXPLANATION

Explain the problem, trace a working system, then justify each improvement.

Using this practice guide

Learn. Explain. Apply.

Concept chapters start with a definition and visual model, then explain terminology, mechanisms, guarantees, trade-offs, and interview questions. Short worked examples illustrate specific operations and failure cases. The default design lessons build from a working example, explain the decisions needed for a 45-minute interview, and provide a separate revision table. Advanced versions retain the full detailed designs and stronger guarantees. Each version includes answered questions, failure handling and stated limitations.

Amber notes labeled Interview critical highlight distinctions, correctness boundaries, and common mistakes to rehearse. The target icon and label identify these notes even when printed without color.

Answer each interview prompt aloud before reading the model answer. Try the follow-up separately, then compare the reasoning and the stated cost. Complete the blank-page exercise and its checklist. Use recall cards later to retrieve definitions and mechanisms. Explain why each design decision satisfies a requirement and what it costs.

A 45-minute practice interview



Adjust this time split when the interviewer redirects you. Clarify the functional and non-functional requirements, estimate quantities that affect design choices, trace one request, and defend a failure/recovery decision. Shorter concept exercises use their own stated time.

Scope and assumptions

The guide covers distributed-systems foundations and system designs, including permission-aware RAG, model inference, and durable agent workflows. Technical references accompany each chapter. Technology choices are scoped implementation options rather than a requirement to select the newest release.

Workload, latency, storage, and cost examples are stated design assumptions, not current company measurements. A finite practice bank cannot enumerate every possible interview prompt.

Matching HTML edition

Open system-design/index.html for the library, practice.html for searchable answered questions, book.html for continuous reading, and cards.html for recall practice. Concept terms, prerequisite links, and contents links in this PDF jump to their explanations. In HTML, concept links open in a new tab. Both editions use the same chapter data. The default designs teach the core interview through connected decisions; advanced-book.html retains the extended walkthroughs and stronger failure guarantees. These stages follow common interview frameworks; adapt their depth and sequence to the interviewer. Detailed diagrams occupy vector foldout pages so their labels remain readable when zoomed or printed on a larger sheet.

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FOUNDATIONS / 01

System design interview framework

DEFINITION

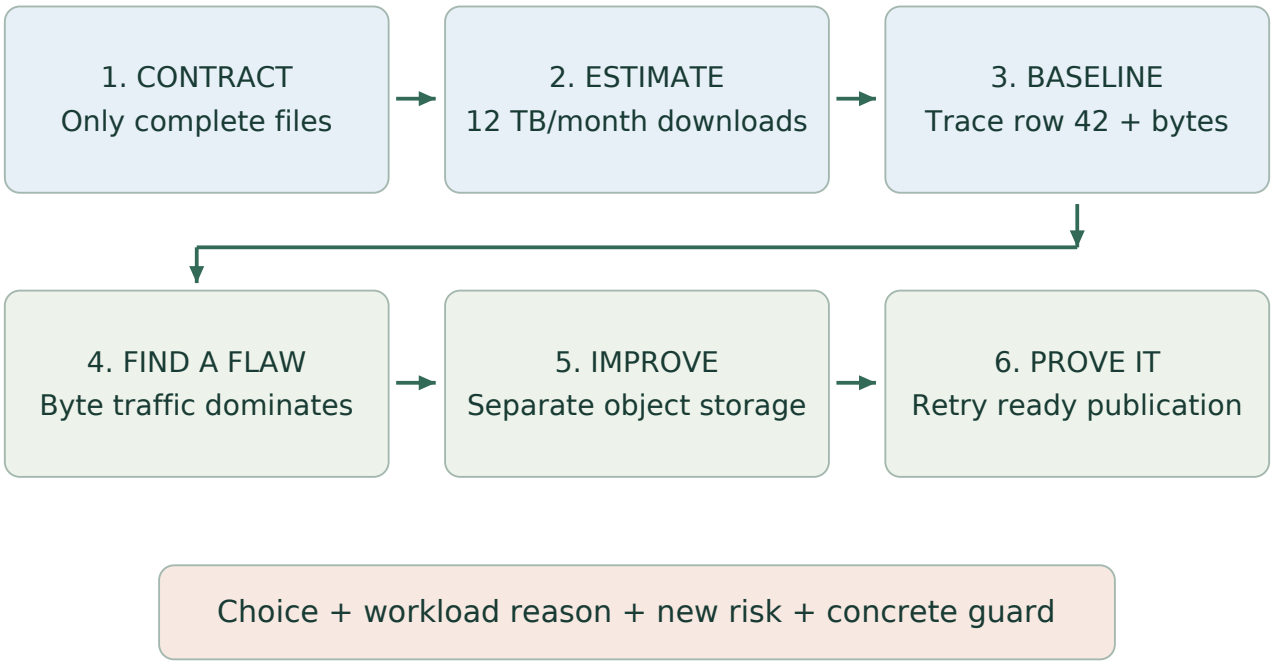
System design is the process of defining a service's components, data, interfaces and interactions so it meets stated functional and quality requirements. A system-design interview asks you to explain and defend those choices under an explicit workload and failure model.

Why it matters: A feature description says what a user wants; a design explains which component performs each step, where the facts are stored, and what happens if a step fails.

System-design interview: requirements, baseline, and trade-offs

State the requirements, trace a working request, then justify each design change using a capacity limit or failure it must handle. Explain both the benefit and the cost.

File-sharing example: justify each design decision



Every added component should answer a requirement, a bottleneck, or a failure.

Worked example

Upload record 42 refers to a 2 MB PDF. The application stores state uploading, verifies the complete file, then changes the record to ready; downloads require a ready, permitted file.

Key takeaways

• Requirements determine the design.

• Trace one complete request and its durable result.

• For each change, explain the benefit, cost and failure behavior.

Read the visual model

1. For a file-sharing service, define upload and download requirements. The publication contract permits downloads only after a complete file is ready.

2. Estimate download bytes and metadata separately, then trace upload, completion and abc123 lookup.

3. Large file bytes justify object storage; the new publication gap requires uploading and ready states.

4. Prove retry after a lost completion response, then close with the invariant, bottleneck and next test.

requirements • APIs • data model • interview structure

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Turn an ambiguous prompt into agreed user actions, measurable targets, and rules the design must preserve.

• Draw and explain one complete request before scaling.

• Answer follow-ups by changing the design and stating the cost.

• Distinguish scaling an application from splitting it into independently deployed services.

9 interview questions with model answers and answered follow-ups.

01 / System design: definition and purpose

System design is the process of defining components, data, interfaces and interactions that satisfy a service's requirements. A component is a part with a specific job: an application accepts a request, a database stores searchable records, and file storage holds uploaded bytes. An interface is the agreement for asking a component to do work. The interview asks you to show how these parts cooperate and how the design behaves when traffic increases or a part fails.

You are not expected to guess a company's private architecture. You are expected to build a plausible design under stated requirements. A requirement states what the product must do or how well it must work. A tradeoff is a benefit gained by accepting a cost or limitation elsewhere. For example, keeping a second copy of an uploaded photo helps survive a disk failure, but uses more storage and requires a rule for when the upload is considered safe.

A complete answer covers requirements, workload estimates, API contracts, data ownership, component responsibilities, and failure behavior. Use one operation to verify that the proposed components form a working system. A bounded example throughout the method is a file-sharing API for PDF worksheets, with upload, download, and deletion; record 42 identifies a 2 MB PDF.

02 / Functional and non-functional requirements

INTERVIEW CRITICAL

State the correctness invariant

Functional requirements describe actions and observable results: create an upload, retrieve a permitted file, and revoke future downloads. **Non-functional requirements** describe the quality and constraints of those actions: latency, availability, scale, durability, consistency, security, and retention. A correctness invariant is a rule that must remain true across concurrent requests and failures. State a priority when these requirements conflict; an isolated replica must not grant a revoked download merely to improve availability.

Start by identifying actors, operations, and access rules. Clarify account requirements, file-size limits, link expiration, and revocation. These decisions determine the API and how current its permission checks must be: a public permanent link needs different read checks from a link that must stop authorizing downloads immediately after revocation.

Functional requirements: what the product does

1. **Upload.** An authenticated uploader can create an upload for a PDF up to 10 MB.
2. **Share.** Create an unlisted download link, with optional expiration. "Unlisted" means the link is hard to guess but possession permits access; private group sharing needs an additional authorization policy.
3. **Download.** Retrieve a permitted file through its link.
4. **Delete.** The owner can revoke future downloads.

These capabilities need file storage and link metadata. Collaborative editing and document grading are outside this example's scope.

Terms used in the targets

Here, **latency** is the time one request takes; **p95** is a threshold met by approximately 95% of the measured requests. **Availability** measures whether the requested operation can be used successfully. **Authoritative** means the component whose recorded decision is treated as truth. These terms make a requirement testable instead of merely saying "fast and reliable."

Non-functional requirements: how well it must work

1. **Performance.** Start an allowed download within 200 ms at p95. Measure lookup and first-byte delay separately.
2. **Correctness.** A deleted link cannot start a new download. Check the authoritative deletion policy.
3. **Availability.** Target 99.9% successful eligible download attempts per month. Define the measurement and a failure plan.

The numeric targets here are assumptions for practice. State them, then invite the interviewer to change them.

03 / Workload and capacity estimates

Assume 100,000 uploading accounts, two files per account per month, a 2 MB average file, and 30 downloads per file. Use the numbers to identify the dominant work:

Step	Calculation	Design implication
1. New file data	`100,000 x 2 x 2 MB = 400 GB/month`	Retention determines accumulated storage
2. Delivered bytes	`400 GB x 30 = 12 TB/month`	Downloading bytes dominates uploading bytes
3. Average downloads	`6,000,000 / 2,592,000 seconds ~ 2.3 requests/s`	An average hides concentrated bursts
4. Peak downloads	Assume a measured or interviewer-supplied 1,000 downloads/s	Use the peak before deciding server capacity

These figures justify separating file delivery from metadata requests. They do not establish that the metadata database needs hundreds of shards.

Interview checklist:

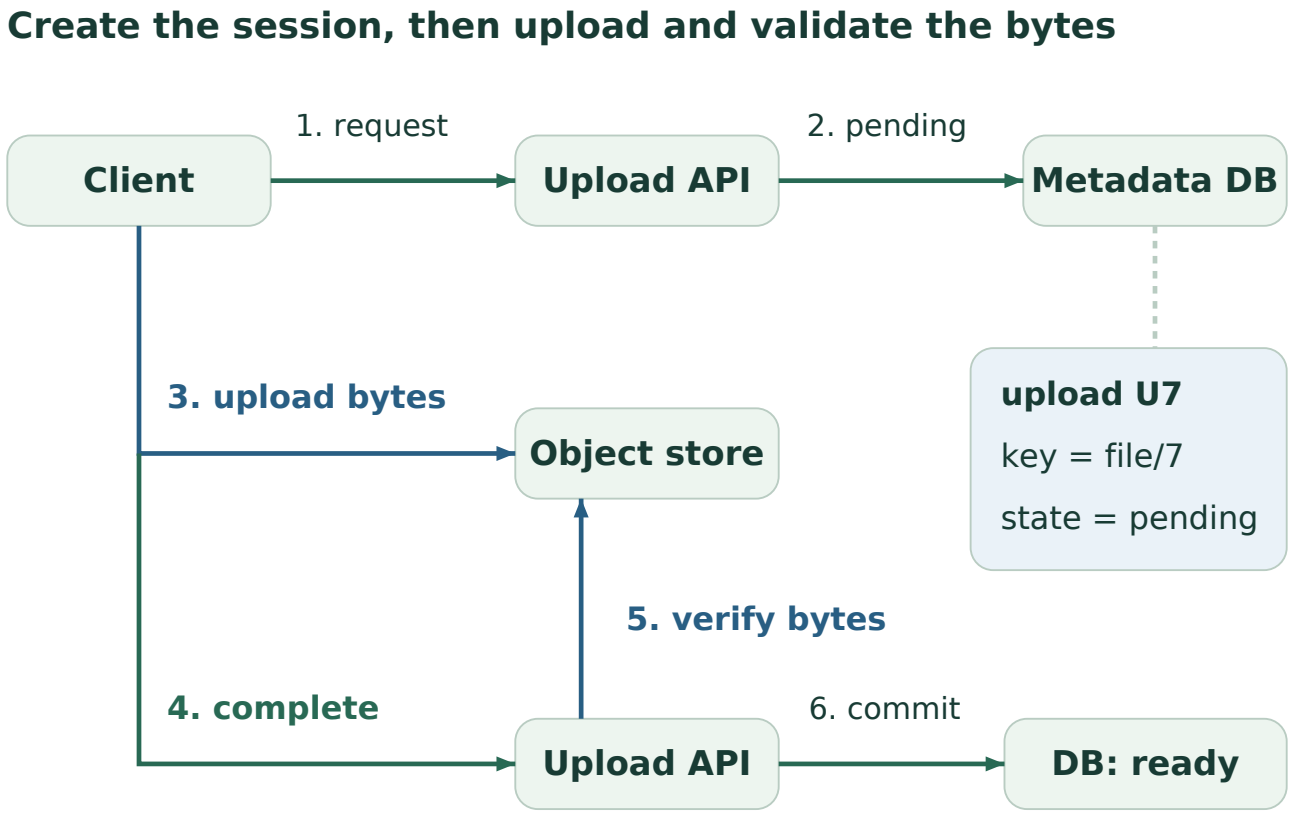
1. **Show units.** "400 GB" is storage; "400 GB/month" is growth; "1,000 requests/s" is a rate.
2. **Ask about retention.** Do this before multiplying monthly growth into lifetime storage.
3. **Estimate to decide.** Do not spend ten minutes estimating a number that will not change the architecture.

04 / APIs, data model and source of truth

An API is the agreement between a caller and a service. For example, use `POST /worksheets` with a filename, size, and expiry to create an upload session. A response returns `worksheetId=42` and an upload destination. A completion call validates that the file exists before changing its state to ready. `GET /links/abc123` looks up a download, and an authorized `DELETE /worksheets/42` revokes future access.

Where do the file and its metadata go?

Follow an upload through the API, database and object store. Mark ready only after upload validation.



Only verified completion permits ready; metadata holds the object reference.

Remember: The database locates the file; the object store holds its bytes.

Try from memory: Would copying the metadata row copy the uploaded file?

Answer: No. The row contains an object reference and state; copying the file requires copying its bytes.

Metadata is information about a file rather than the file's own bytes. Keep one metadata row: `Worksheet(id, ownerId, objectKey, objectVersion, state, expiresAt, deletedAt)`. The bytes live separately under an object key such as `worksheets/42/v1`. An object key is the storage address of the file, not the public permission to download it. The query you must support is a point lookup of one link or worksheet, so a primary-key index is a useful first choice.

A **primary key** uniquely identifies a database row. An **index** is a maintained lookup structure that helps the database find matching rows without inspecting every row. Here the link token identifies one mapping, and the worksheet ID identifies one metadata record; neither lookup needs to search the file bytes.

The initial implementation can be one application and one database plus durable file storage. Splitting APIs into many services before describing this contract adds complexity without establishing a correct request path.

The public token also needs a stored mapping: `Link(token PRIMARY KEY, worksheetId)`. Generate an unpredictable token for an unlisted link; the short `abc123` above is only a readable example, not an adequate

security design. A unique owner/request-key record can make upload-session creation retryable. The file row and its request result commit together; repeating that request returns the same session rather than allocating another file.

05 / Worked example: upload, download and retry

Publishing a worksheet requires agreement between two stores: the metadata database and the file store. The database must not advertise a file whose upload is incomplete. An **immutable object version** is a particular stored version whose bytes do not change; completion verifies that version and makes the metadata point to it. The following sequence uses states to coordinate that publication.

1. An authenticated `POST /worksheets` validates the caller's quota and stores row 42 with state `uploading`.
2. The upload writes bytes to the designated object key. The storage layer must record the complete object; an interrupted transfer does not make it downloadable.
3. The completion operation verifies a specific immutable object version, records its checksum and size, and conditionally changes row 42 from `uploading` to `ready` only if it has not been deleted. A checksum summarizes bytes so corruption can be detected. Atomic means the state transition is indivisible; another request cannot observe half of the row change.
4. `GET /links/abc123` checks row 42's readiness, expiry, and deletion state before allowing transfer.
5. An authorized delete records revocation first. Later cleanup removes unused bytes; delayed cleanup does not reauthorize the link.

The server can save a change successfully even if its response never reaches the client. Handling retries after this failure requires **idempotency**: repeating one logical operation must recover the same business result. If completion commits but its response is lost, retrying with the stable upload ID returns row 42's existing ready state instead of creating another file. This failure test identifies where the deduplication record and result must be durable.



INTERVIEW CRITICAL

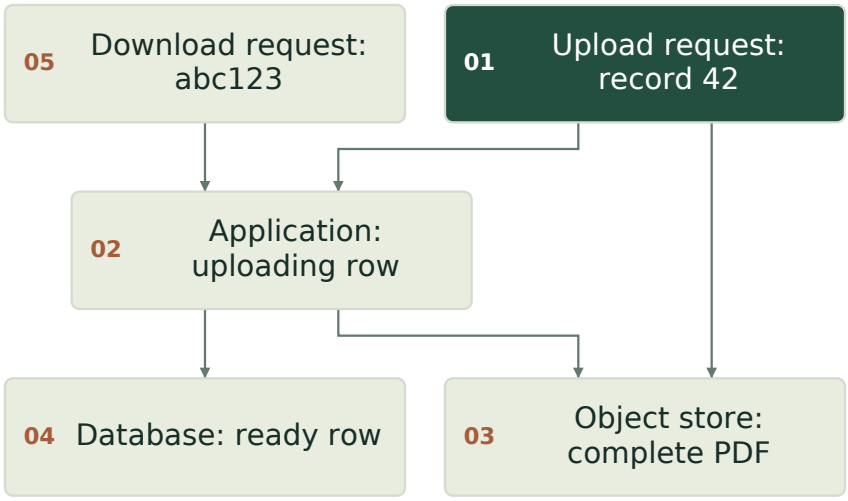
Cached delivery must preserve revocation

To block new downloads immediately after deletion, send each download through an application gateway that checks the current metadata. The gateway streams the verified, unchanging object version; clients cannot bypass it with a reusable storage URL. A transfer already authorized may finish. If we later add signed URLs or cached access checks, define how long revocation may take or add a mechanism that blocks access everywhere. A CDN alone does not provide immediate revocation.

Test deletion during upload completion as well as a lost response. If deletion commits first, completion must fail its state check and leave the row deleted. If completion commits first, deletion revokes the published file. A late upload must not overwrite the verified object version. For downloads, the access check determines the order: a transfer authorized before deletion may finish; a check after deletion must reject it. If current metadata is unavailable, block new downloads. HTTP methods and object storage do not enforce these rules on their own.

WORKED EXAMPLE DIAGRAM

Trace worksheet 42 from an unpublished upload to an authorized download. Storage of bytes and publication of metadata are separate steps.



1 -> 2	create upload session: Upload request: record 42 -> Application: uploading row
1 -> 3	send file bytes: Upload request: record 42 -> Object store: complete PDF
2 -> 4	verify bytes, publish ready: Application: uploading row -> Database: ready row
5 -> 2	check link and permission: Download request: abc123 -> Application: uploading row
2 -> 3	authorize permitted download: Application: uploading row -> Object store: complete PDF

06 / Scaling, replication and recovery

When one application cannot handle the measured peak, add stateless application instances and a **load balancer**, which distributes incoming requests among them. Stateless means another instance can handle the next request because essential worksheet state lives in shared durable storage. If popular public worksheets account for most bytes, a content delivery network can serve permitted cached files close to clients. Revocable/private files need a compatible authorization and cache-expiration design.

Replicate important records, decide what a successful upload promises about durability, and test restoration from backups. Replication means maintaining live copies; a backup lets you recover an older version after a bad deletion. They solve different failures.

In a 45-minute practice session, spend approximately five minutes clarifying, seven on quantities and contracts, ten drawing and tracing, fifteen on the most important bottleneck and failure, and eight reviewing. The interviewer may redirect you. Follow that signal rather than treating the time allocation as a script.

07 / Monoliths, modular monoliths and service boundaries

INTERVIEW CRITICAL

Scaling servers and splitting services are different decisions

When application processing is the bottleneck, adding instances can increase capacity. A separate decision is whether parts of the application should be released independently. A **monolith** is one application deployed as a unit. A **modular monolith** keeps clear internal responsibilities, such as orders and inventory, within that unit. It can run on many servers behind a load balancer: one deployable application does not mean one server.

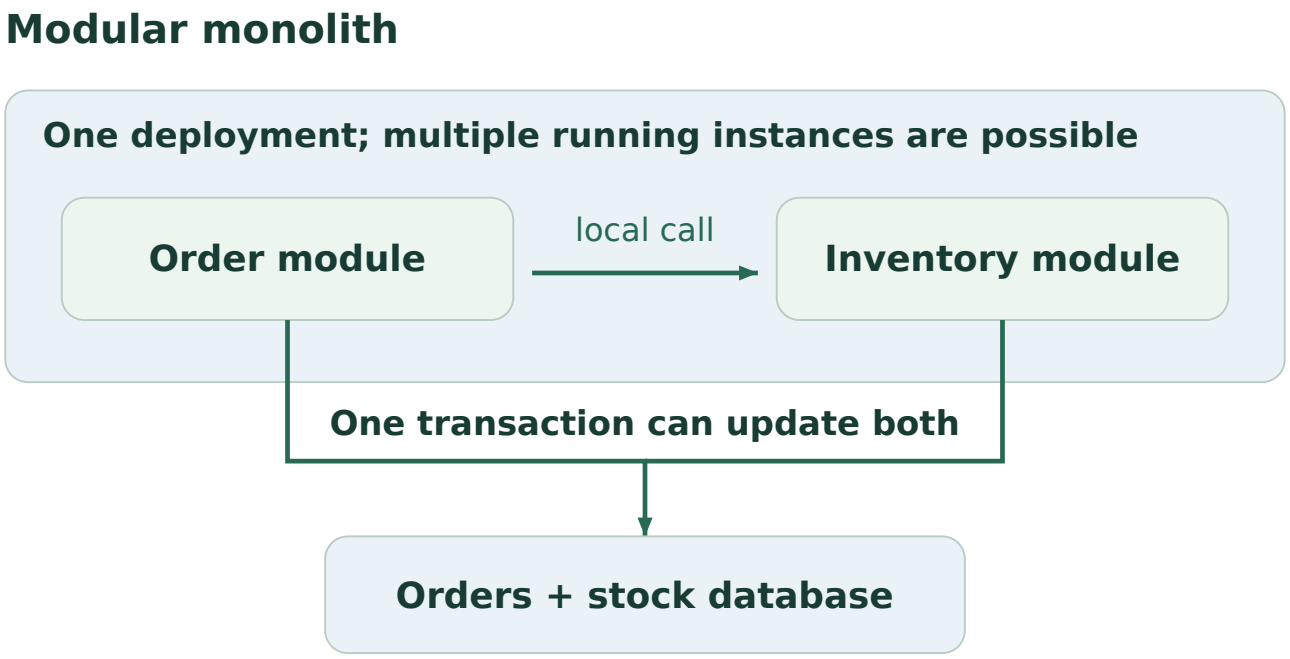
A **microservices architecture** separates capabilities into independently deployable services that communicate through APIs or messages. Each service controls changes to its own data; other services use its contract instead of changing its tables directly. This can help teams release independently and give a demanding component its own resources. It also adds network calls, compatibility work and more components to operate. See Martin Fowler's discussion of microservice trade-offs.

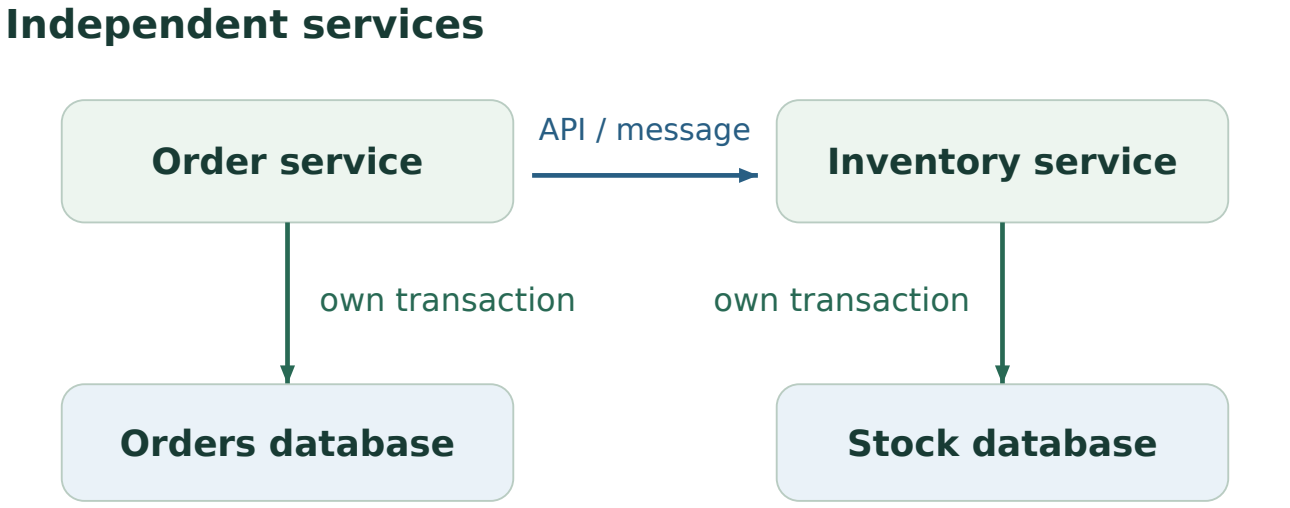
For a concrete example, the checkout design initially keeps order creation and stock reservation in one database transaction. The application can have separate order and inventory modules without splitting that transaction across services. If browsing grows much faster than purchasing, a separate catalog search service can scale its derived product index while checkout keeps authoritative prices and stock checks together.

Splitting inventory into an independent service needs a stronger reason, such as a shared reservation capability serving several products with its own release schedule. The order and reservation would then commit separately. Define reservation expiry, retries and recovery before claiming the purchase succeeds; use the distributed-workflow lesson for that coordination. Moving code into separate processes does not make the two commits atomic.

Deployment boundaries can change transaction boundaries

The top design keeps order and inventory modules in one deployment with a shared database transaction. The bottom design gives each service its own data; an API call does not commit both databases atomically.





Separate commits need an explicit recovery workflow.

Remember: More application instances do not require more service boundaries.

Try from memory: Does putting an order module and an inventory module on separate servers preserve their original local transaction?

Answer: No. Separate service-owned databases change the transaction boundary. Define a distributed transaction or durable reservation workflow with retries and recovery.

Decision	Benefit	Cost to explain
Keep related modules together	Local calls and simpler transaction boundaries	Components share a release and resource allocation
Extract a service with a clear responsibility	Independent releases, capacity and ownership	Remote failures, compatible contracts and cross-service recovery

Choose boundaries around responsibilities that can evolve independently. A diagram box may be a module, a process or a replicated service; say which you mean. Explain how a caller behaves when a service fails, because separation alone does not prevent an outage from spreading. Microsoft's architecture guidance describes these deployment, data-ownership and failure-handling concerns.

08 / Interview example: explain a storage choice

Interviewer: "Why not store the PDF in the database?"

Candidate: "The database needs small records for ownership and link lookups. Our estimated 12 TB of monthly downloads is mostly file bytes, so I would put those bytes in object storage and keep their keys in the database. That allows downloads to scale independently. The added problem is publication across two stores; I handle it with uploading and ready states, and make completion retryable."

This answer contains a choice, a workload-based reason, a new failure risk, and a concrete mechanism. If you cannot explain those four parts for a component, revisit whether it belongs in the first design.

Choice	Useful when	Added cost or limit
One application and database	The workload fits and a complete request is easy to explain	One process may limit capacity; recovery still matters
Multiple application instances	Application processing or availability is the limit	Essential state must be shared or recoverable
Separate object storage	Large files dominate retained or delivered bytes	File publication and metadata need explicit states
CDN for repeated public files	Nearby copies materially reduce origin work	Cached authorization must respect the revocation promise

When answering a follow-up, identify which requirement has changed before adding or replacing components in the diagram. If the interviewer changes worksheets from unlisted to private groups, the concrete new requirement is "only authorized group members may download." Add a per-reader permission check and explain its failure behavior; the PDF storage itself does not have to change.

09 / The complete interview sequence

The 36 design chapters expand this method into a full practice interview. Their sections are preparation material: do not recite every paragraph or spend equal time on every stage. In a live interview, establish the complete outline, trace the central request, and use the interviewer's questions to decide which part of the design to explain in greater detail.

Pass	Sections to reconstruct	Evidence your answer should contain
Agree on the problem	Scope, functional requirements, non-functional requirements	A specific API operation, acceptance criteria, quantitative assumptions, exclusions and one hard invariant
Make a working system	Estimates, APIs, data model, baseline	An actual payload, key/index, query and durable commit point
Discover limits	Baseline flaws and ordered improvements	A measured or estimated bottleneck, or an ordering of concurrent operations that breaks a requirement; then a proposed fix, its benefit, its cost and an alternative you rejected
Defend the developed system	Detailed architecture, write path, read path, correctness deep dive	How requests reach each component, which component can update each record, when success is acknowledged, where background work begins, and what happens when two clients act concurrently or a component crashes
Operate and conclude	Failures, operations/cost, decision ledger, closing	User-visible degradation, surviving state, recovery, remaining limitation, and a concise spoken recap

Draw the baseline first. When changing it, point to the failed requirement: "This cache removes repeated reads, but introduces up to 25 seconds of stale access, so it violates our original immediate-revocation promise unless we change that contract." The change is not justified merely because a cache is conventional. A mature answer may keep the simpler design when the requirement does not pay for the added complexity.



INTERVIEW CRITICAL

An architecture diagram needs a failure trace

Use the final architecture to identify responsibilities, then use a sequence or state diagram to prove the hardest behavior. A queue arrow does not establish when work is durable; a database icon does not explain the transaction; a replica line does not establish safe failover. The accompanying request and failure traces supply those missing facts.

Close in roughly 60-90 seconds: restate the requirement, describe the resulting request path, name the invariant and its mechanism, acknowledge the largest cost, and propose the next measurement. Then practise changing one requirement. Changing public file sharing to private group sharing introduces per-reader authorization and revocation; the existing object store remains useful, but the permission decision must change.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is system design, and how would you begin "design file sharing"?

Model answer

"System design defines the components, stored data, interfaces and interactions needed to meet requirements. For file sharing I first ask who uploads, who downloads, size limits, and whether links are public, private, expiring or revocable. Then I agree on volume and what success means, and trace one upload before adding capacity."

Interviewer follow-up

Should you ask twenty questions before drawing?

No. Resolve the few ambiguities that change the first design, state reasonable assumptions for the rest, and validate them while drawing. Excessive questioning can prevent you from demonstrating a working solution.

What the answer must demonstrate: Connect each clarification to an architectural consequence.

02 / FOUNDATION

What is a correctness invariant? Give one for an upload-and-download API.

Model answer

"An invariant is a condition the system must preserve. Here, an incomplete upload must never become downloadable. I represent upload state explicitly and allow downloads only after completion is verified. The download handler can enforce this rule by checking the stored upload state before serving the file."

Interviewer follow-up

Is "the service is fast" an invariant?

"Fast" needs a performance target and measurement window. The upload rule applies to every relevant request: verify the unchanging object version, then atomically mark it ready only if its metadata still permits that change. A completion arriving after deletion must leave the file deleted. The file store and metadata database do not share one transaction.

What the answer must demonstrate: Give an enforceable rule, not an adjective.

03 / APPLIED

Why start with one application and database?

Model answer

"It makes the complete request and stored state understandable. I can show which changes must succeed together, verify the rules that keep the data correct, and measure capacity. I split or replicate components when a workload, reliability requirement, or ownership boundary creates a reason, rather than assuming that a distributed diagram is inherently better."

Interviewer follow-up

What if the interviewer immediately requires global scale?

I still explain the logical operation, then show regional routing, data ownership, and replication. Starting from a clear operation does not require deploying only one machine.

What the answer must demonstrate: Logical clarity should survive changes in physical scale.

04 / APPLIED

A file service averages 2.3 downloads/s but may peak at 1,000/s. Is average QPS enough to choose one server?

Model answer

"Not from that average alone. I need peak request rate, average and large-file sizes, connection duration, and a per-server load test at the target latency. Traffic can be concentrated into short bursts. I would state the peak assumption and size for it, including a server failure."

Interviewer follow-up

If metadata QPS is modest but downloads total 12 TB/month, what motivates separate object storage?

Byte delivery dominates metadata traffic: the example has 12 TB/month of downloads. Separating bulk bytes gives an independent delivery path even if metadata QPS is modest.

What the answer must demonstrate: Do not equate average QPS with capacity.

05 / APPLIED

Why define a data model before naming a database product?

Model answer

"The model tells me what must be stored together and which queries must be efficient. For file sharing I need ownership, upload state, expiry and the public-token mapping checked by identifier. A transactional metadata database can enforce those relationships; I evaluate products after deciding durability, throughput and failure requirements."

Interviewer follow-up

When might that choice change?

Measured limits or global write requirements might justify partitioning or distributed storage. I would describe the new operational and consistency costs alongside the change.

What the answer must demonstrate: Explain access patterns and constraints.

06 / APPLIED

An upload completion commits but its response is lost. How should a retry behave?

Model answer

"A timeout means the client does not know the outcome. I keep a stable upload identifier and make the completion operation inspect its existing state. Retrying completion for an already-ready upload returns the same worksheet. I recover the existing outcome before creating a new upload."

Interviewer follow-up

How would you prove the fix works?

Simulate losing the response after the state transition commits, retry with the same identifier, and verify that exactly one logical worksheet is ready.

What the answer must demonstrate: Explain what happens if the server saves the result but the response is lost.

07 / APPLIED

How do you answer "Why a CDN?" without a buzzword list?

Model answer

"Repeated downloads request identical bytes. A CDN can reduce origin traffic and serve a nearby copy. I would use versioned public objects where possible. If a link is private or revocable, I must define the authorization and cache lifetime so an old edge copy cannot bypass the promised access policy."

Interviewer follow-up

Does a CDN remove the metadata service?

No. Metadata still owns upload state, ownership, and permission decisions. Depending on the access scheme, the edge may enforce a limited authorization token or request validation.

What the answer must demonstrate: Name the benefit and the access-policy cost.

08 / APPLIED

How do you close the interview?

Model answer

"I would recap the agreed user actions, trace the main path briefly, and state the key choices: durable upload states, independent byte delivery, and retryable completion. Then I would identify the first measured scaling limit and one remaining risk, such as revocation latency, with how I would test it."

Interviewer follow-up

What if the design is unfinished?

Identify the part of the design you have not resolved and explain the next concrete decision you would make. A coherent partial design with clear invariants is better evidence of understanding than pretending every problem is solved.

What the answer must demonstrate: Summarize decisions and limits rather than reciting components.

09 / APPLIED

Does growing traffic mean a modular monolith must become microservices?

Model answer

"No. I can run multiple instances of the same application when its durable state is shared appropriately. I would extract a capability when independent capacity, releases or ownership justify the extra coordination. In checkout, keeping orders and stock reservations together preserves a useful local transaction; catalog search can scale separately as a derived view."

Interviewer follow-up

What changes if inventory becomes a separate service?

Order creation and inventory reservation no longer share the original database transaction. The workflow must record progress, identify retries and recover failed or uncertain steps. A reservation needs explicit expiry and confirmation rules. An API call alone does not make the two services commit together.

What the answer must demonstrate: Distinguish server count, deployment boundaries and transaction boundaries.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design worksheet sharing from a blank page. Specify upload state, permission checks, and recovery after a lost completion response.

- State four functional requirements and one enforceable invariant.
- Show calculations with units and one peak assumption.
- Trace upload, download, and response-loss retry.
- Defend one choice and explain its cost.
- Say which application boxes are modules versus independently deployed services, and justify one boundary.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

How do you justify each component in the diagram?

A responsibility in a user request or a specific capacity/recovery requirement.

Follow one request.

What makes a tradeoff answer complete?

State the choice, the reason, the cost, and how that cost is handled.

Choice -> reason -> cost -> mechanism.

What does a timeout tell the caller?

The result is unknown; the operation may already have committed.

Unknown is not failed.

When should part of an application become a separate service?

When independent scaling, releases or team ownership justify the extra network failures, API compatibility work and data coordination.

Separate for a benefit; explain the added cost.

Summary and interview notes

A system-design answer turns requirements into a working request path, a stored data model and explicit success and failure rules. Begin with a correct baseline, then justify each change using a workload limit or a required guarantee.

Remember these points

• Separate user actions, quality targets and invariants before choosing components.

• Say when data is safely saved and which saved result a retry returns.

• Verify the immutable stored version, then atomically mark it ready only if current metadata permits publication.

• Scale the measured bottleneck; modest metadata QPS does not imply modest file-delivery bandwidth.

• A monolith can run on multiple servers; extracting services changes deployment and coordination boundaries.

Interview tips

• For every new box, state its responsibility, benefit, added cost and failure behavior.

• Trace a lost response and two concurrent operations; these reveal gaps that a box diagram conceals.

• Finish with the remaining limitation and the next measurement, not a list of product names.

Important qualifications

• The 45-minute allocation is a practice aid, not an employer-wide interview format.

• For immediate revocation, specify exactly when and where a download is authorized. State separately whether already-authorized transfers may finish; revocation cannot remove bytes a user has already downloaded.

Technical references

Amazon senior SDE interview preparation
Primary employer guidance on practical system-design reasoning and clarifying questions.
https://amazon.jobs/content/en/how-we-hire/sde-iii-interview-prep

HTTP semantics
Reference for request methods, response status, and resource semantics.
https://www.rfc-editor.org/rfc/rfc9110.html

Microservice trade-offs
Deployment and module boundaries, benefits and the costs of remote coordination.
https://martinfowler.com/articles/microservice-trade-offs.html

Microservices architecture style
Independent deployment, data ownership, consistency and operational requirements.
https://learn.microsoft.com/en-us/azure/architecture/guide/architecture-styles/microservices

FOUNDATIONS / 02

HTTP APIs and request lifecycle

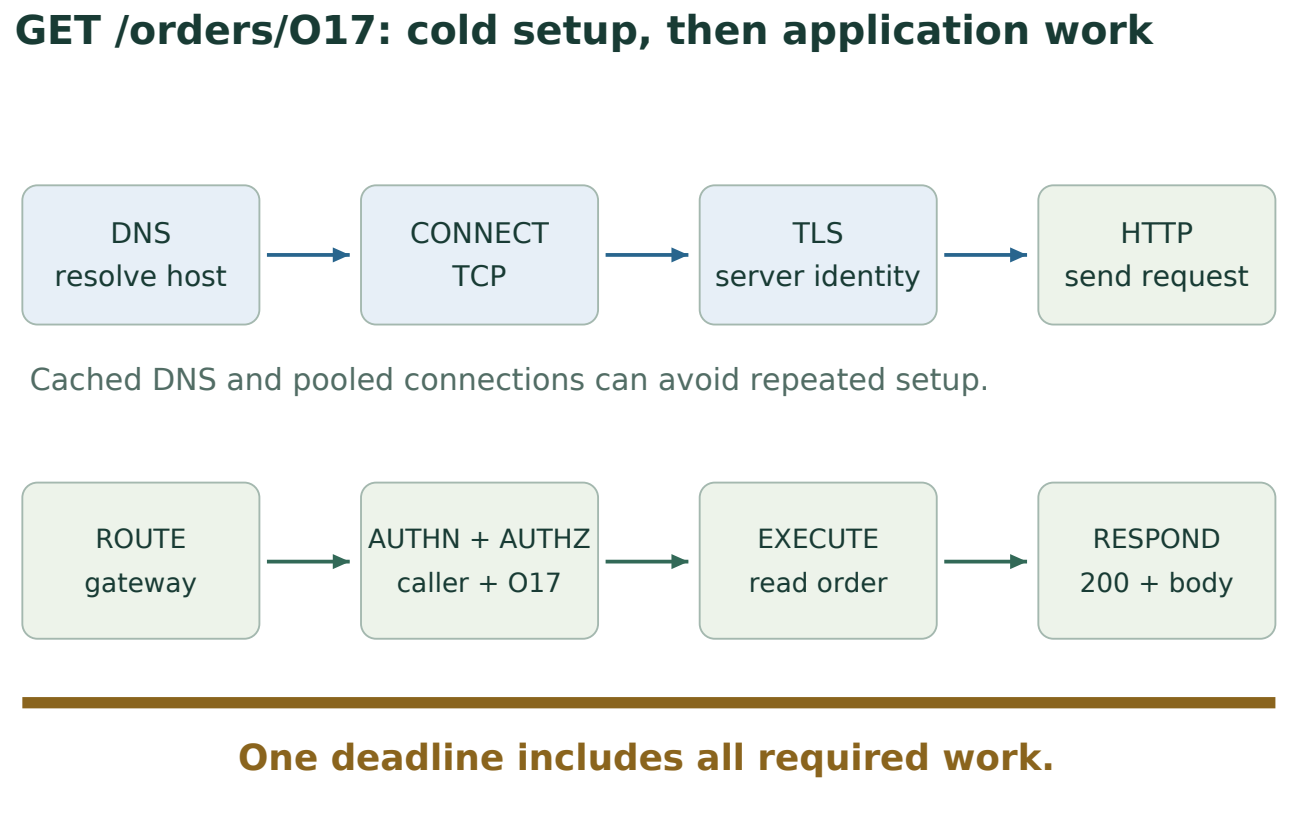
DEFINITION

An application programming interface (API) defines the agreed rules for how programs request data or actions from one another. An HTTP API expresses that contract through methods, resource paths, headers, request bodies, status codes, and response bodies.

Why it matters: Clients and services need to agree on the operation, identity, success meaning, errors, and retry behavior before implementation or scaling.

HTTP request lifecycle and latency budget

DNS and connection setup may be cached or reused. The server still authenticates the request and enforces its data contract.



TCP/TLS shown. HTTP/3 integrates TLS 1.3 into QUIC; warm connections reuse setup.

Worked example

GET /orders/O17 authenticates user U9 and checks access to O17 before returning HTTP 200 with totalMinor=2500 and currency=USD, an order total of $25.00.

Key takeaways

• DNS finds an endpoint; it does not fetch the business record.

• Transport security protects the connection; authentication establishes identity; authorization checks permission.

• A successful HTTP exchange can still report a business rejection or pending work.

Read the visual model

1. A cold request can require DNS lookup, connection establishment and TLS before HTTP reaches the service.

2. The edge routes the request. The service authenticates the caller, authorizes the exact data view/version it reads, and returns the corresponding status and body.

3. A warm pooled connection skips repeated setup. A timeout is the caller waiting limit, not necessarily cancellation of server work.

DNS • TCP • TLS • HTTP • REST • gRPC • API contracts

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Explain each hop of a request without hiding it in a cloud icon.

• Define a concrete API and error contract.

• Choose protocol, pagination, and compatibility behavior deliberately.

8 interview questions with model answers and answered follow-ups.

01 / API and HTTP request: definitions

An **application programming interface (API)** defines the agreed rules for how one program requests data or an action from another. An **HTTP API** represents that contract using a method, path, headers, optional request body, status code, and response body. The caller sends a request and receives a response; the contract defines the operation, input, identity, result, and failure behavior.

The **edge** is the service's public entry point, often a proxy or load balancer. **Authentication** establishes who the caller is; **authorization** checks what that caller may access or change. The request lifecycle consists of name resolution, connection establishment, protocol exchange, routing, authentication, authorization, application execution, and response handling. Some stages can be cached or reused. A `GET https://shop.example/orders/017` example shows their order and distinct responsibilities; the API must identify user U9 and authorize access before returning order data.

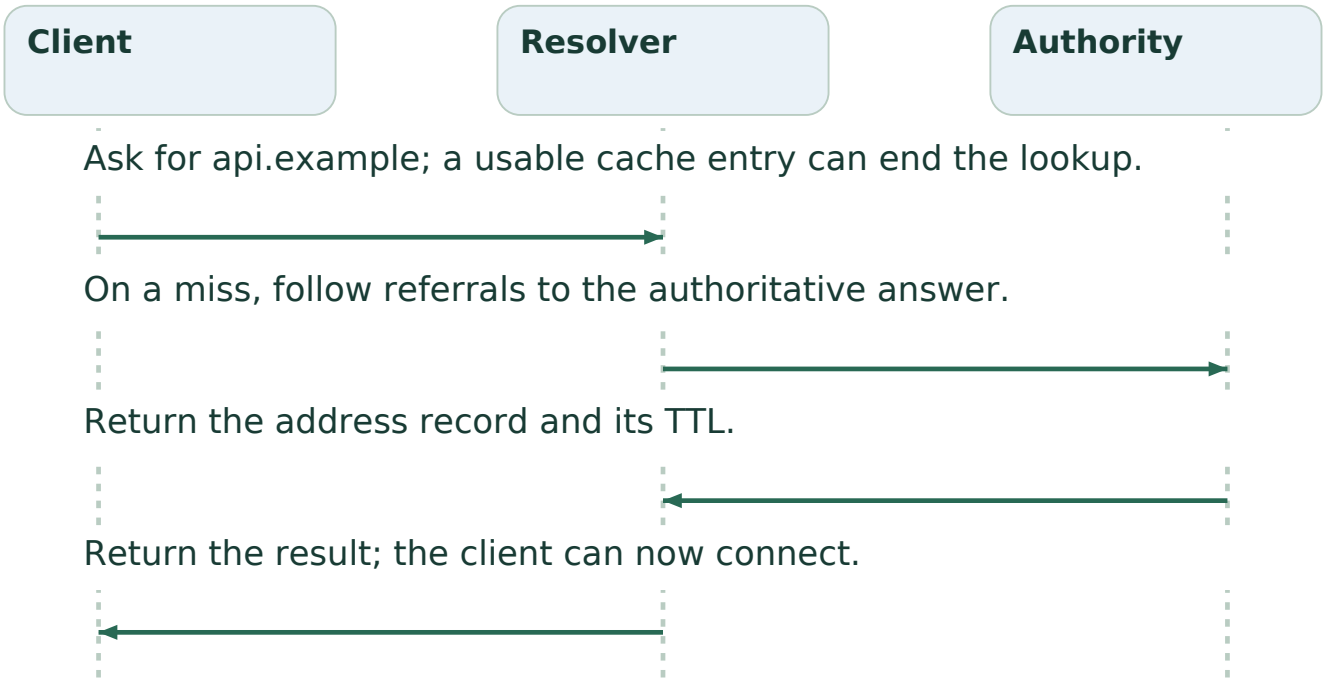
A successful network exchange does not automatically mean a successful business operation. A server might return a valid "order not found," an authentication error, or an infrastructure error. State what each result means before deciding which results are retryable.

02 / DNS and service discovery

DNS, the Domain Name System, maps names to records such as IP addresses. A client checks usable cached results or asks a recursive resolver. If necessary, the resolver follows the naming hierarchy to authoritative servers and returns an address for `shop.example`. A TTL specifies the record's permitted cache lifetime under the protocol rules.

DNS resolution: names to addresses

The authoritative lookup is simplified: root and TLD referrals may be needed. DNS resolves names; it does not process the API request.



Remember: Resolve the address, then connect to it.

The address may point to an edge or load balancer rather than the database host. DNS does not authenticate U9 or return O17. It enables the next communication step. A cached address also explains why changing a DNS record does not instantly move every client during failover.

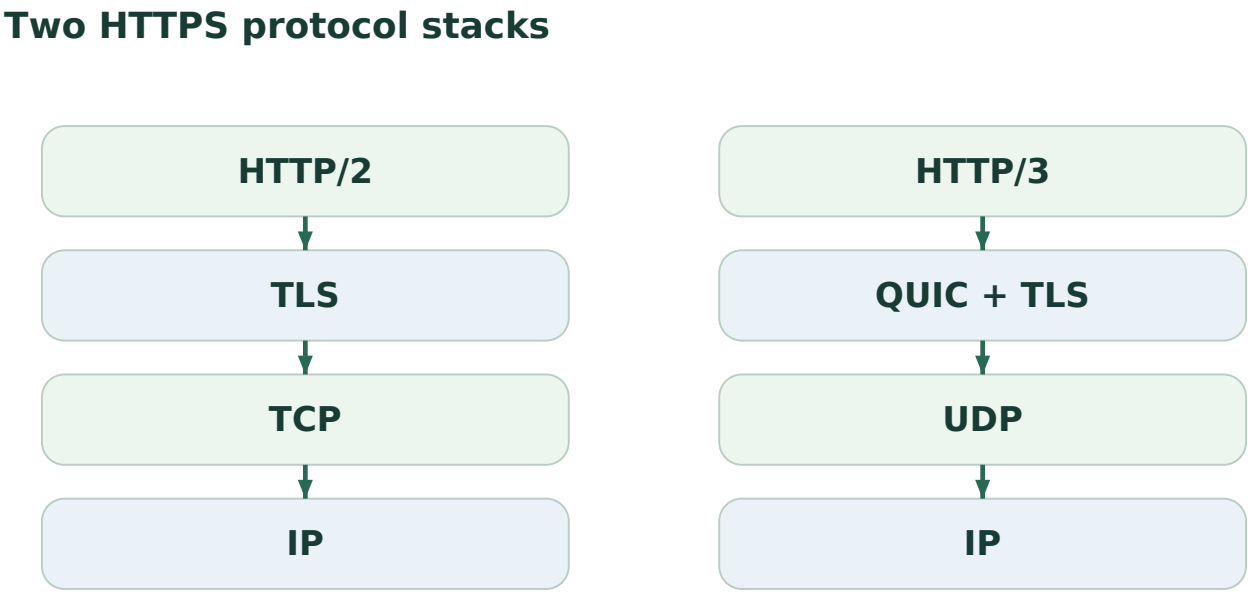
Internal service discovery may use DNS or a registry of healthy instances. It finds a server to contact. That server must still check the request and whether it is allowed to read or change the requested data.

03 / TCP, TLS, HTTP/2, and HTTP/3

For a typical HTTPS request using HTTP/1.1 or HTTP/2, the Transmission Control Protocol (TCP) provides a reliable ordered byte stream between endpoints. Transport Layer Security (TLS) authenticates the server and encrypts the conversation. The browser checks that the certificate is valid for the requested name. Existing connections may be reused, avoiding repeated setup.

Read the HTTPS stack from top to bottom

The arrows mean "uses the layer below." QUIC integrates TLS security with its transport.



Read downward: each layer uses the one beneath it.

QUIC supplies reliable streams; UDP does not supply them.

Remember: HTTP/2 uses TCP; HTTP/3 uses QUIC over UDP.

Try from memory: Does HTTP/3 get its reliable streams from UDP?

Answer: No. QUIC supplies its reliable streams and uses UDP as the underlying transport.

HTTP/2 multiplexes requests into separate application streams on one connection. It improves reuse, but TCP packet loss can stall delivery across those streams. HTTP/3 carries HTTP over QUIC, which uses User Datagram Protocol (UDP) packets and provides reliable streams and integrated cryptographic setup. QUIC avoids that particular cross-stream TCP head-of-line blocking; it does not remove all congestion, loss, or application queueing.

In an interview, start with the transport actually needed. An HTTPS API is usually enough to describe an order read. Choose streaming, bidirectional communication, or a different transport when the user interaction requires it, rather than listing protocols without a reason.

04 / HTTP request lifecycle: worked order read

A simplified request contract is:

```
GET /orders/O17 HTTP/1.1
Host: shop.example
Authorization: Bearer <access-token>
Accept: application/json
```

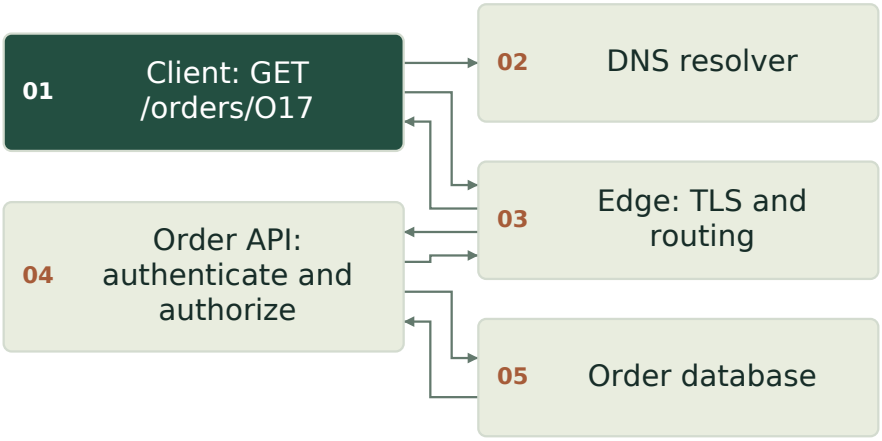
1. The edge accepts the connection and routes `/orders/O17` to the order API.

2. The API validates the credential and derives `userId=U9`. It never trusts a caller-provided user ID as proof of identity.
3. It performs an authorized lookup of O17 under U9's verified scope, returning the row and version to which the access decision applies. Knowing the order ID is not authorization.
4. It serializes the permitted fields from that same authorized version and returns `200` with `{"orderId":"O17","state":"paid","totalMinor":2500,"currency":"USD"}`.
5. The browser parses the result and renders the order. Its total latency includes network, queueing, application, database, and rendering time.

The HTTP/1.1 notation is a readable contract illustration; HTTP/2 and HTTP/3 frame the same method/path/status semantics differently. A trace ID propagated through the servers helps diagnose where this particular request spent time.

WORKED EXAMPLE DIAGRAM

The DNS lookup discovers the endpoint. The order read follows a separate connection and authorization path.



1 -> 2	resolve shop.example: Client: GET /orders/O17 -> DNS resolver
1 -> 3	HTTPS request: Client: GET /orders/O17 -> Edge: TLS and routing
3 -> 4	forward to order handler: Edge: TLS and routing -> Order API: authenticate and authorize
4 -> 5	authorized lookup of O17: Order API: authenticate and authorize -> Order database
5 -> 4	authorized row + version: Order database -> Order API: authenticate and authorize
4 -> 3	response through edge: Order API: authenticate and authorize -> Edge: TLS and routing
3 -> 1	200 permitted representation: Edge: TLS and routing -> Client: GET /orders/O17

05 / HTTP methods, idempotency, and status codes

The method tells the server what kind of operation the client intends. A **safe** method requests read-only behavior; an **idempotent** method has the same intended effect when repeated as when performed once. These properties help decide whether repeating an interrupted request is compatible with the API contract.

Operation	Example	Meaning
Read a resource	`GET /orders/O17`	Retrieve a representation without requesting a state-changing purchase
Create a logical resource	`POST /orders`	Validate and create; use an operation key for safe retries
Replace a named representation	`PUT /profiles/U9`	Repeating the same intended replacement has idempotent method semantics
Delete a resource	`DELETE /orders/O17`	Enforce the resource's deletion/cancellation policy



INTERVIEW CRITICAL

Idempotency concerns effects, not identical responses

HTTP defines safe and idempotent method semantics; those labels are not permission to implement a GET that charges money. "Idempotent" concerns the intended effect of repeating a request, not identical timestamps or identical response bytes every time. POST can be made idempotent at the application level with a request key.

Use distinct results so the caller can decide what to do next:

Result	Meaning in this contract
400	Invalid input
401	Authentication is required or invalid
403	Forbidden access, where disclosure is appropriate
404	Resource unavailable or deliberately not disclosed
409	State conflict
429	Rate limit
Relevant 5xx	Server-side failure
202	Accepted for processing; not completed. Return an operation ID the client can inspect

The exact privacy and retry policy belongs in the API contract.

A **conditional request** adds a precondition about the current representation. A reader can ask whether its cached version is unchanged; an editor can require that the version it edited is still current before replacing it. Both use a server-issued version identifier rather than assuming nothing changed between requests.

Conditional requests connect HTTP to versioned data:

Request condition	Purpose	Outcome
GET with `If-None-Match` for a cached ETag	Revalidate without downloading unchanged bytes	If unchanged, 304 lets the client reuse its cached representation
PUT with strong `If-Match` for the edited version	Prevent overwriting a representation changed since it was read	412 rejects an unmet version precondition



INTERVIEW CRITICAL

An ETag does not authorize access

An **ETag** is an identifier the server assigns to a version of a response so clients can check whether it has changed. It is not an access credential. Authenticate and authorize before deciding what private representation the caller may reuse. Use explicit cache policy: `private` prevents shared-cache storage, while `no-store` tells caches not to store the response. Neither removes copies already disclosed.



INTERVIEW CRITICAL

A 202 status alone does not establish durability

To recover accepted work after a crash, save the operation and its pending job before returning 202 with a status URL. The application must implement that storage step; the status code alone does not save anything.

06 / Resource-oriented HTTP, RPC, and pagination

The same order operation can be exposed by naming a resource and an HTTP method, or by naming a remote procedure with typed arguments. These are interface choices: they determine how the caller expresses its request, while the service still defines ownership, permissions and success.

Contract style	Example	Useful when	Limit
Resource-oriented HTTP	GET /orders/O17, POST /orders	Broad web-client support and familiar HTTP semantics	URLs and JSON alone do not satisfy every REST constraint
Typed RPC	ReserveSeats(show, seatIds)	Explicit service operations and generated client schemas	Requires compatible clients, deadlines, and error contracts

Contract style	Example	Useful when	Limit
gRPC implementation of RPC	Typed unary or streaming call	Internal typed calls and supported streaming clients	Browser/intermediary compatibility may need a gateway; no storage guarantee is implied

A resource-oriented HTTP API exposes orders and profiles through URLs and standard methods; REST is an architectural style with additional constraints, not merely a synonym for JSON. **RPC** means remote procedure call. An RPC API names an operation on another service, such as `ReserveSeats`, with typed input and output. gRPC commonly uses protocol buffers and HTTP/2 for typed calls and streaming. Browser clients and intermediaries may require compatible gateways or gRPC-Web support.

Choose a style for clients, tooling, and communication needs. A public web API benefits from familiar HTTP behavior and broad client support. Internal typed service calls may benefit from generated clients and schemas. Neither choice determines database consistency or business correctness.

Pagination contract

Bound response sizes. For order history, use a page size and cursor based on a stable ordering such as `(createdAt, orderId)`. Validate the cursor and preserve tie-breaking semantics. Pagination is part of the API; it must match the query/index design rather than being added after the storage choice.

For descending order history, the continuation predicate is `(createdAt, orderId) < (lastCreatedAt, lastOrderId)` with the same `ORDER BY createdAt DESC, orderId DESC` and a bounded limit. Include the verified tenant, filters and ordering version in the cursor's validated scope. A cursor is not permission to switch tenants.



INTERVIEW CRITICAL

A pagination cursor does not create a snapshot

Keyset pagination avoids repeatedly scanning a large OFFSET and avoids shifts caused solely by newer rows inserted before the cursor. It does not create a frozen snapshot: deletions, backdated inserts and mutable sort keys can still affect later pages. A reproducible export needs a retained database snapshot or a versioned materialized result. An opaque cursor hides representation details; it does not itself provide integrity or snapshot semantics.

GraphQL: client flexibility and server cost

GraphQL provides a typed API schema and lets a client request a particular selection of fields. A query such as an order with selected item fields can reduce over-fetching and combine related reads. Field resolvers may call databases or services; one client request can still trigger many backend requests. Batch related lookups to avoid an N+1 pattern, where fetching N items adds N individual calls.

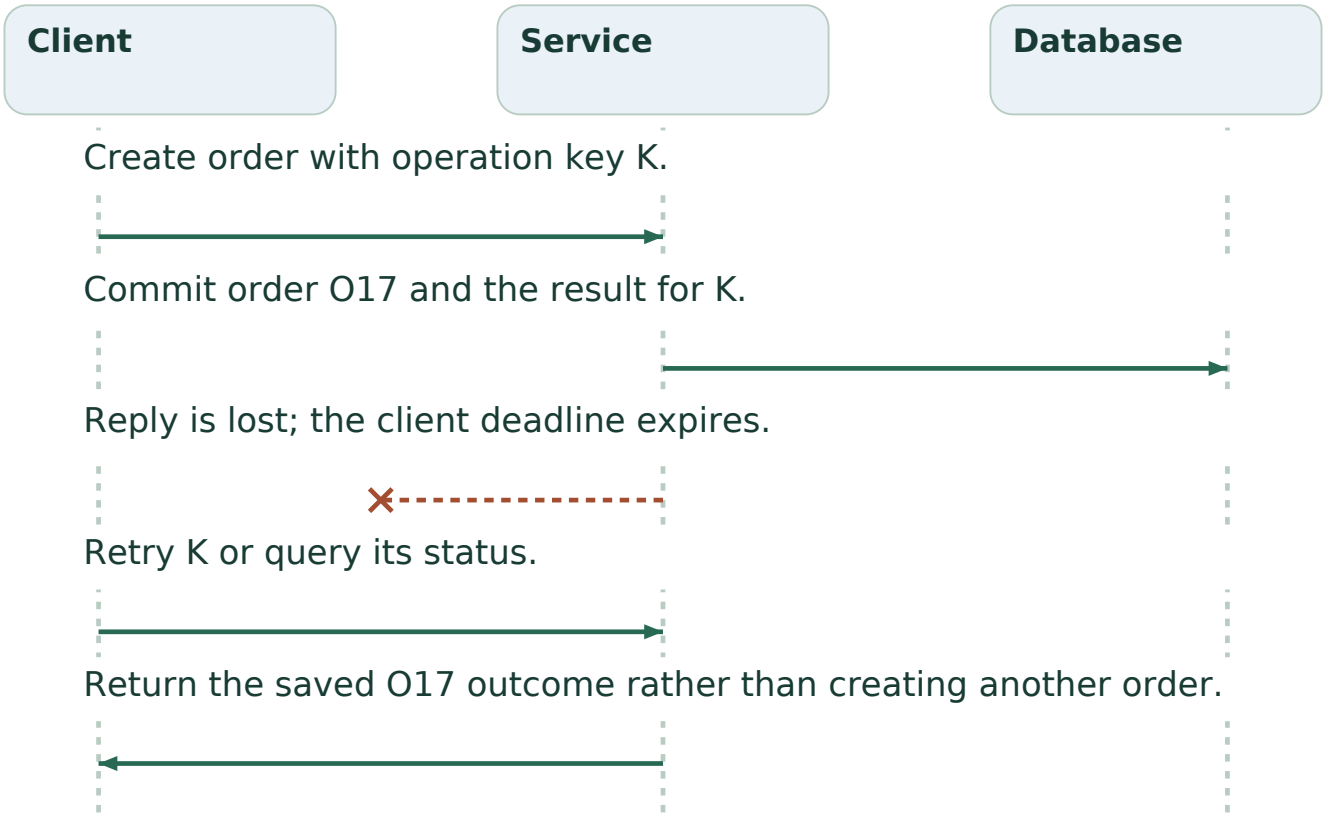
Use object/field authorization and bounded pagination. Limit expensive query shapes with complexity, depth and execution budgets or an approved operation set. A shared endpoint does not make all queries equally cheap, and authentication alone does not authorize nested objects. Prefer this flexibility when clients genuinely need different composed views; a small REST or gRPC contract is often simpler for a fixed workflow.

07 / API retries, deadlines, and version compatibility

A create-order timeout leaves the result unknown: the server may already have committed. A stable request key and status lookup recover the original outcome. A deadline bounds the caller's wait; it does not roll back work committed elsewhere.

A timeout leaves the outcome unknown

The crossed message stops before reaching the client. A timeout describes what the caller observed, not whether the server committed.



Remember: No reply does not mean no effect.

Version the contract when making incompatible changes. Additive optional fields are often easier to roll out than renaming a required field, but clients must actually tolerate unknown fields and defaults. Deploy producers and consumers in an order that supports mixed versions. For a breaking change, define an explicit migration/version policy rather than assuming all clients upgrade at once.

Spoken answer: "I define the order operation and its success meaning first. Then I trace DNS, connection, edge routing, authentication, authorization, database lookup, and response. I measure the time spent in each stage, limit request size and execution time, and make timeout recovery and compatibility part of the contract."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is an API, and what happens in a GET /orders/O17 request?

Model answer

An API is a contract between programs for an operation and its inputs, results, and failures. For GET /orders/O17, the client resolves the service name and establishes or reuses a protected connection. The edge routes the request; the order service validates the credential, derives user U9, checks U9's permission for O17, and returns an authorized representation.

Interviewer follow-up

Which part can DNS perform?

DNS supplies endpoint-discovery information such as an IP address. It does not fetch order data, authenticate the caller, or perform the database operation.

What the answer must demonstrate: Define the contract before tracing the complete request path.

02 / FOUNDATION

Why use TLS if the API already checks a token?

Model answer

"The token identifies or authorizes the caller, but a plaintext network could expose or alter it. TLS protects the communication and authenticates the server endpoint. I still validate the token and resource permission inside the service."

Interviewer follow-up

If TLS ends at the edge, is the backend hop protected?

Only if I explicitly protect that hop too. Edge termination and backend encryption are separate connections.

What the answer must demonstrate: Separate transport protection from access checks.

03 / APPLIED

Does HTTP/3 eliminate head-of-line blocking everywhere?

Model answer

"No. QUIC avoids TCP's cross-stream loss-delivery blockage, but each stream still has ordering requirements and the application, queues, or shared resources can block progress. I choose it for actual transport needs, not as a blanket latency guarantee."

Interviewer follow-up

Can HTTP semantics stay the same?

Yes. Methods, status, and resource meaning can remain the same while transport framing changes.

What the answer must demonstrate: Name the specific bottleneck that changes.

04 / APPLIED

How are safe and idempotent requests different?

Model answer

"Safe methods do not ask for a state-changing action. Idempotent methods have the same intended effect when repeated. A deletion can be idempotent while still changing state. I do not use a GET to trigger a purchase merely because it is easy to call."

Interviewer follow-up

Can POST be retry-safe?

Yes, if the application binds a stable operation key to one request and its stored outcome. HTTP method choice alone does not implement that protocol.

What the answer must demonstrate: Explain intended effect, not identical response bytes.

05 / APPLIED

What does 202 Accepted tell the caller?

Model answer

The request was accepted for processing, not completed. For our recoverable API, I durably commit an operation record and outgoing intent before 202, then return an operation ID and status location. HTTP 202 alone does not establish that storage guarantee.

Interviewer follow-up

What if the worker later fails?

The durable operation state must expose failure or a retry/recovery state. A successful enqueue is not the same as successful business completion.

What the answer must demonstrate: Distinguish acceptance and completion.

06 / APPLIED

Would you choose REST or gRPC for every service?

Model answer

"I choose from client compatibility, schema tooling, and streaming needs. A public browser-facing API may use resource-oriented HTTP/JSON; internal typed calls may use gRPC. Both still need deadlines, authorization, and a defined retry contract."

Interviewer follow-up

Does gRPC imply strong consistency?

No. The transport style says nothing about replica ordering, transactions, or the state behind the handler.

What the answer must demonstrate: Avoid assigning storage guarantees to a protocol.

07 / APPLIED

What belongs in a cursor for order history?

Model answer

"A stable position in the chosen order, such as the last creation timestamp plus a unique order ID. The service validates it, applies the same ordering, and caps page size. I also define whether new or deleted records can change later pages."

Interviewer follow-up

Why isn't timestamp alone always enough?

Two orders can share a timestamp, so add a unique order ID. For descending history, continue strictly below the last (createdAt, orderId) pair. A cursor does not freeze the rows between requests; reproducible exports need a retained snapshot or saved result set.

What the answer must demonstrate: Match the cursor to the index and contract.

08 / APPLIED

How do you rename a required response field safely?

Model answer

"I cannot assume all clients update together. I might serve both fields during migration or introduce a versioned contract, measure adoption, and retire the old field under an explicit policy. I test mixed client/server versions."

Interviewer follow-up

Are all added fields automatically safe?

Only if existing consumers tolerate unknown fields and the new field does not change required semantics. Strict deserializers or signature schemes can make even additive changes significant.

What the answer must demonstrate: Describe a mixed-version rollout.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Explain a browser-to-order read, then define an asynchronous create-order API that survives a lost response.

- Name each hop and responsibility.
- Distinguish TLS, identity, and permission.
- Specify accepted versus completed results.
- Define request identity, pagination, and one compatibility change.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

One request path

Name lookup -> protected connection -> routing -> identity/permission -> data operation -> response.

Trace the request.

Does 202 Accepted mean the order is complete?

No. It means the server accepted the work. Return an operation ID or status URL so the client can check progress.

Accepted -> check progress -> completed.

API design

Define success, error, retry, size, pagination, and compatibility behavior.

A URL is not the whole contract.

Summary and interview notes

An API defines behavior as well as URLs and JSON. Trace name lookup, connection, routing, access checks and the data operation. Specify success, errors, result-size limits, retry behavior and compatibility with older clients.

Remember these points

• DNS discovers an endpoint; TLS protects a connection; the application still authenticates and authorizes the caller.

• Safe and idempotent describe intended method effects, not identical responses or unlimited retry safety.

• 202 means accepted, not complete; a durable operation record is an explicit application mechanism.

• ETags support representation validation and conditional writes but never replace authorization.

• A page cursor needs a unique tie-breaker and must preserve the query's tenant and filters. To reproduce an export, also keep a fixed snapshot of its results.

Interview tips

• Walk one request through actual boundaries and account for reused connections and caches.

• Define one asynchronous response, one conflict response and one lost-response retry.

• Show a concrete pagination predicate and a mixed-version client rollout.

Important qualifications

• HTTP/3 avoids TCP cross-stream loss blocking, not every source of queueing or stream delay.

• Authorization must apply to the returned representation version; a later unrelated body read can invalidate an earlier permission decision.

Technical references

HTTP semantics
Methods, responses, and intermediary semantics.
https://www.rfc-editor.org/rfc/rfc9110.html

HTTP/3
HTTP over QUIC and its specific stream-delivery properties.
https://www.rfc-editor.org/rfc/rfc9114.html

Domain names: concepts and facilities
DNS resolution roles and caching.
https://www.rfc-editor.org/rfc/rfc1034.html

HTTP Caching
Private versus no-store cache directives and validation scope.
https://www.rfc-editor.org/rfc/rfc9111.html

GraphQL learning and security guidance
Official guidance on authorization, pagination and demand control; API flexibility does not remove server-side resource limits.
https://graphql.org/learn/security/

FOUNDATIONS / 03

Capacity estimation: throughput, latency, concurrency and storage

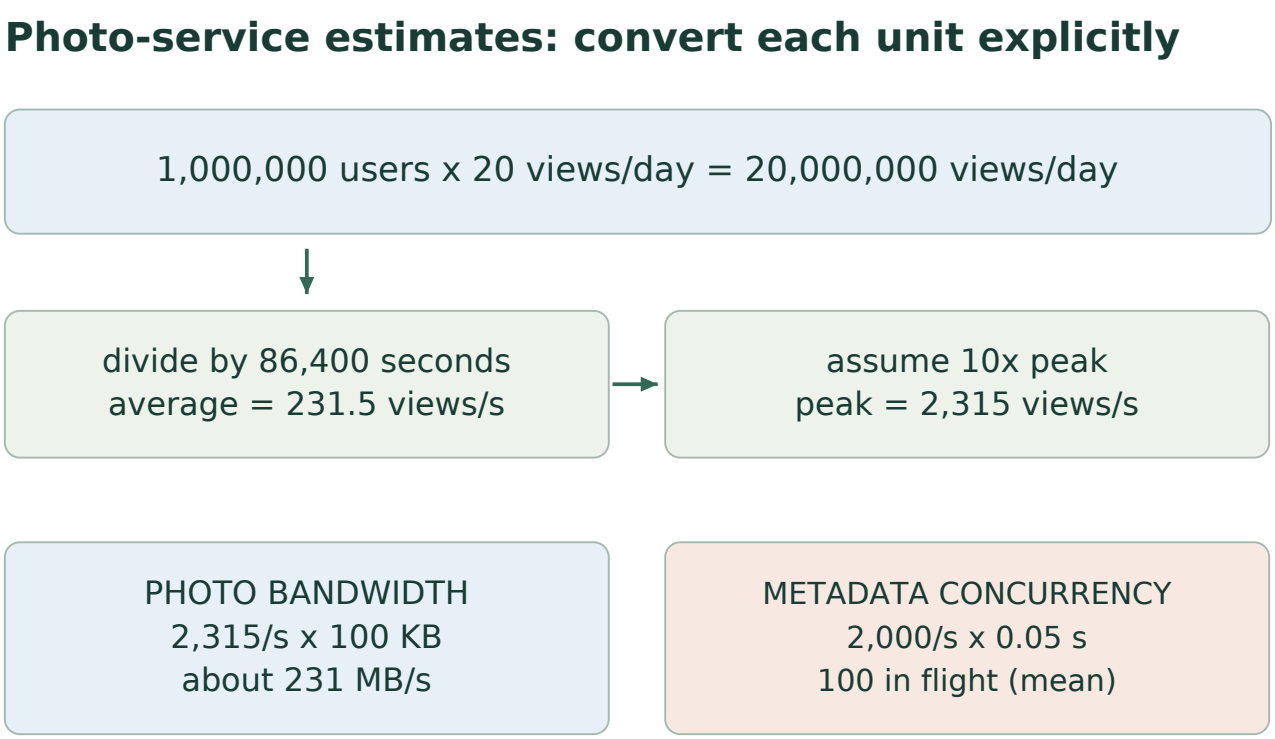
DEFINITION

Capacity estimation translates an assumed workload into the compute, memory, storage and network resources needed to meet performance and failure targets. Throughput is work completed per unit time, latency is time per operation, and concurrency is work in progress.

Why it matters: Without a workload and units, "millions of users" cannot tell you how many servers or how much storage a design needs.

Capacity estimates: request rate, bandwidth, and concurrency

Estimate request rate and bandwidth from the photo workload. Apply Little's law separately at the metadata-service boundary.



Little's law uses means in a stable system. Photo bytes and metadata QPS are distinct loads.

Worked example

One million users making twenty requests a day create 20,000,000 / 86,400 = about 231.5 requests/s on average. A stated 10x peak is about 2,315 requests/s; it is an assumption to validate, not something implied by the user count.

Key takeaways

• Count requests, bytes and retained data separately.

• Use peak load and surviving capacity when sizing.

• Average concurrency = average arrival rate x average time spent in the same measured system, assuming stable operation.

Read the visual model

1. One million daily users each view twenty photos: twenty million views per day, about 231.5/s on average.

2. The assumed ten-times peak is 2,315 views/s. At 100 KB per thumbnail it requires about 231 MB/s before overhead.

3. Separately, a metadata service at 2,000/s and mean time 0.05 s has about 100 requests in flight in steady state.

4. A daily user count is not a simultaneous connection count. State decimal bytes and the measurement boundary.

QPS • latency • throughput • Little's law • storage

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Calculate average and peak rates with units.

• Distinguish throughput, latency, concurrency, and storage.

• Use an estimate to justify a design change.

Useful foundations: System design interview framework

8 interview questions with model answers and answered follow-ups.

01 / Capacity estimation and its units

Capacity estimation translates a workload into the resources needed to meet its targets. A workload specifies what users do, how often, how large their requests are and how concentrated the traffic becomes. The estimate should be accurate enough to choose a design; a load test must later measure the actual implementation. Begin with four separate ideas. **Throughput** is completed work per unit time, such as 500 uploads per second. **Latency** is how long one operation takes. **Concurrency** is the number of operations in progress at once. **Storage** is how much retained data exists at a point in time.

A restaurant can serve many meals an hour while one customer's meal takes a long time. A batch service can likewise have high throughput and high latency. More concurrent work helps use idle resources; once the limiting resource is fully busy, extra work mostly waits. A claim of "10,000 users" needs to say what they do and when.

QPS means queries per second; in an API discussion people often use it for requests per second, so state whether you are counting API requests or database queries. **Network capacity**, often called bandwidth, is the maximum data rate a link or path can carry under stated conditions, usually measured in bits/s. **Network throughput** is the rate actually achieved. Requests/s x bytes/request estimates the required transfer rate;

provision capacity above that demand, including protocol overhead and headroom. **Peak** means the busiest declared interval, while an average spreads all work over the entire measured period. These are different quantities even when one calculation produces another.

Quantity	Example and unit	Decision it informs	What it cannot establish alone
Throughput	2,000 completed requests/s	Required processing rate	How long one user waits
Latency	50 ms per request on average	Response-time objective	Total sustainable traffic
Concurrency	100 requests in progress	Connections and memory	Whether queues are stable
Storage	73 TB retained originals	Disk/object capacity	Read/write operations per second
Required transfer rate	231 MB/s at peak	Network and delivery path	CPU cost of producing each byte

02 / Worked example: average and peak QPS

Define a workload before estimating resources. For this photo-service example, assume one million daily active users, 20 photo views and 0.1 uploads per user per day, a 2 MB average upload, a 100 KB thumbnail, and 1 KB of metadata per photo. Use decimal units: 1 KB = 1,000 bytes, 1 MB = 1,000,000 bytes, and one day = 86,400 seconds.

Quantity	Calculation	Approximate result
Uploads per day	1,000,000 x 0.1	100,000
Average uploads/s	100,000 / 86,400	1.16
Photo views per day	1,000,000 x 20	20,000,000
Average views/s	20,000,000 / 86,400	231.5
Assumed 10 x peak	231.5 x 10	2,315 views/s

The calculation is a sequence: first count actions per day, then divide by seconds per day, then apply an explicitly assumed peak factor. For these inputs, `1,000,000 x 20 = 20,000,000` image views/day, `20,000,000 ÷ 86,400 ~ 231.5` views/s average, and `231.5 x 10 ~ 2,315` views/s peak. We size thumbnail delivery against the last rate, then verify it against measured bursts.

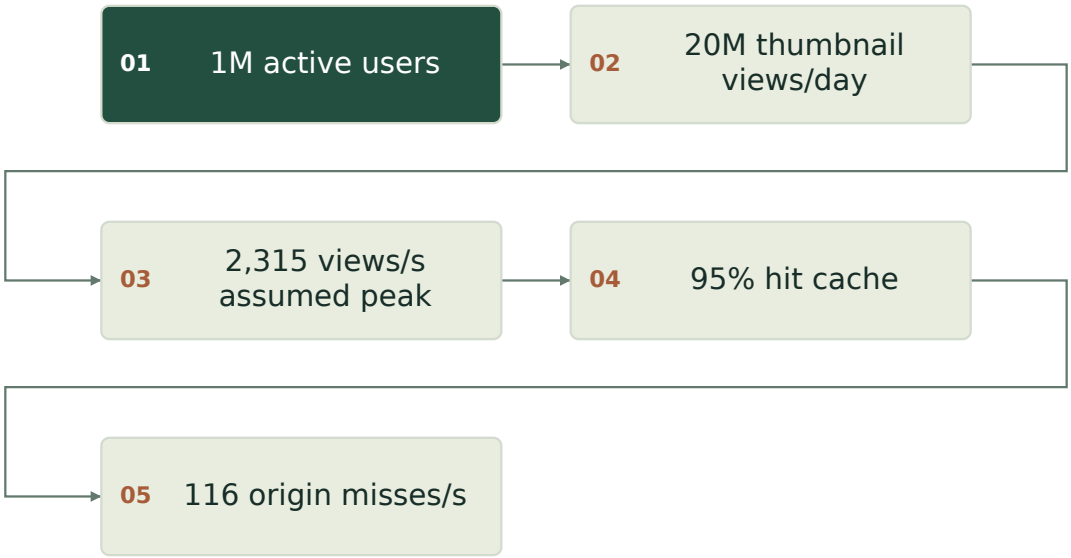
INTERVIEW CRITICAL

Users, actions, and requests are different counts

Daily active users are not simultaneous connections. Also, a user action may cause multiple requests: a gallery page with 20 thumbnails can fetch 20 objects plus metadata. Define whether your rate measures page views, image requests, or database queries before sizing the next component.

WORKED EXAMPLE DIAGRAM

This chart follows the example's rate calculation. A cold cache changes the last value from 116 to as much as 2,315 requests/s.



1 -> 2	20 views per user: 1M active users -> 20M thumbnail views/day
2 -> 3	divide by 86,400; then x 10: 20M thumbnail views/day -> 2,315 views/s assumed peak
3 -> 4	cacheable lookup: 2,315 views/s assumed peak -> 95% hit cache
4 -> 5	5% miss fraction: 95% hit cache -> 116 origin misses/s

03 / Storage, retention and network bandwidth

The photo workload creates two different demands: storage for retained objects and network capacity for repeated delivery. **Logical data** counts one copy of each retained object; replicas and backups consume additional physical storage. Keep those counts separate from bytes sent to viewers:

Category	Calculation	Result and scope
New originals	`100,000 x 2 MB`	200 GB/day

Category	Calculation	Result and scope
One year of originals	`200 GB/day x 365`	73 TB before deletion, compression, indexes or redundancy
Three full copies	`73 TB x 3`	219 TB for originals alone
Metadata growth	`100,000 x 1 KB`	100 MB/day; 36.5 GB/year before indexes
Thumbnail delivery	`20 million x 100 KB`	2 TB/day
Average transfer demand	`2 x 10^12 / 86,400`	About 23.1 MB/s, or 185 megabits/s
Assumed 10 x delivery peak	`23.1 MB/s x 10`	About 231 MB/s before headers and retransmissions

Keep these quantities separate:

1. **Count other stored data separately.** Thumbnail variants and backups are additional categories; the replication multiplier does not include them.
2. **Bytes and metadata scale differently.** Their large size difference is a reason to store them separately. The metadata database need not carry every byte transferred to viewers.
3. **Convert units explicitly.** Network links are often rated in bits/s: multiply bytes by eight. State whether you mean MB or MiB.

04 / Little's law and latency percentiles

Request rate alone does not tell us how many connections or request buffers are occupied. A request continues using some resources while it waits for storage or another service. To size those resources, relate the completion rate to the time each request remains in the service.



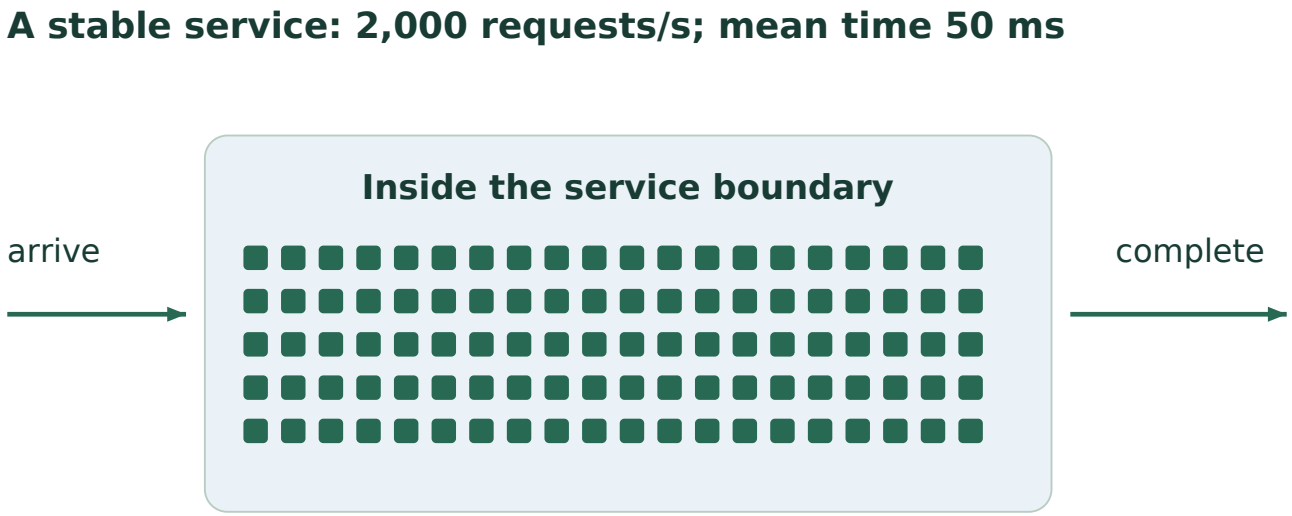
INTERVIEW CRITICAL

Little's law needs a stable system and one boundary

The metadata service completes 2,000 requests/s, and each request spends an average of 0.05 seconds inside it. In a stable system, about `2,000 x 0.05 = 100` requests are in progress at once. This is Little's law: average work in progress equals average arrival rate x average time in the system. Measure both rate and time over the same part of a system whose workload is stable.

How many requests are inside the service?

Each square represents one request. These are long-run averages for a stable service.



Each square is one request: 100 in flight on average.

L = 2,000/s x 0.050 s = 100. Use the same boundary and averages.

Remember: 2,000 requests/s x 0.050 seconds = 100 requests in flight.

Try from memory: If mean time doubles at the same stable throughput, what happens to average in-flight requests?

Answer: It doubles from 100 to 200: L = 2,000/s x 0.100 s. This assumes the service remains stable at that throughput.

If average time rises to 0.5 seconds while admitted traffic stays at 2,000/s, concurrency becomes about 1,000. The extra 900 requests need memory, sockets, and possibly database connections. An unbounded queue hides overload briefly while increasing latency. It does not create processing capacity.

INTERVIEW CRITICAL

Adding p99s does not establish the end-to-end p99

Percentiles describe the distribution: p95 of 200 ms means roughly 95% of observed operations finished in 200 ms or less within the measured population and window. It does not mean every request takes 200 ms. Do not add independently measured p99 values and call the sum the exact end-to-end p99; trace distributions and correlation matter.

The stable-system condition matters. If arrivals stay at 1,200/s while only 1,000/s complete, an unbounded backlog grows by 200 requests/s, or 12,000 requests in one minute. There is no steady finite average latency to insert into this calculation. Bound the queue and reduce admissions, or increase the bottleneck's measured service capacity.

05 / Bottlenecks and failure headroom

A **bottleneck** is the resource that first limits the workload: for example, CPU, database writes or network transfer. **Headroom** is spare capacity reserved for bursts, uneven load and failures. Once a load test identifies the limiting resource, size enough instances to meet the target even with the chosen failures.

Assume a load test measures 800 requests/s per application instance while meeting the latency objective, and the target peak is 2,315 requests/s.

Losing one machine uses up the spare capacity

Each server block represents 800 requests/s at the measured latency target. The lower bar compares peak demand with surviving capacity.

Peak demand: 2,315 requests/s

Four healthy instances



One instance lost





2,315 used / 2,400 surviving = 96.5%

Only 85 requests/s of spare capacity remain at this tested limit.

Remember: Four servers can hide a problem that appears after one fails.

Try from memory: Is 2,400 requests/s enough for a peak of 2,315?

Answer: It covers the point estimate but leaves only 85 requests/s, about 3.5% of surviving capacity. That is little room for workload variance or measurement error.

Fleet	Normal capacity	Capacity after one loss	Assessment
Three instances	2,400 requests/s	1,600 requests/s	Almost no normal spare capacity; insufficient after failure

Fleet	Normal capacity	Capacity after one loss	Assessment
Four instances	3,200 requests/s	2,400 requests/s	Little failure headroom for uneven load

The notation `ceil(x)` means the smallest whole number at least as large as x; a partial server cannot satisfy the remaining load. For a chosen maximum of 70% of tested capacity after one failure:

1. **Budget each survivor:** `800 x 0.7 = 560 requests/s`.
2. **Find the survivors needed:** `ceil(2,315 / 560) = 5`.
3. **Add failure capacity:** five survivors require six instances.

This is illustrative sizing, not a universal 70% rule. Real benchmarks, cost, autoscaling lag and failure domains determine the target.

Check downstream amplification

The database, network, and object store must support the same workload. Six application servers do not help if they all wait for one slow query. Estimate the read/write amplification: if each API call issues five database queries, 2,315 API calls/s can become 11,575 database queries/s.

Size CPU from CPU time

Compute demand has a different unit from elapsed latency. If a measured request uses 2 ms of CPU time:

1. **CPU demand:** `2,315/s x 0.002 CPU-seconds = 4.63 CPU-seconds/s`, about 4.63 fully busy cores.
2. **Utilization headroom:** at a chosen 70% limit, `ceil(4.63 / 0.7) = 7` usable cores before additional failure capacity.



INTERVIEW CRITICAL

Elapsed latency is not CPU demand

A request taking 50 ms while waiting on storage does not necessarily consume 50 ms of CPU. Measure CPU, disk operations, network and per-request memory separately; the first saturated resource limits throughput.

06 / Cache working set and cost model

A cache stores copies of reused data. Its size depends on distinct hot entries, not total requests. Suppose 500,000 frequently viewed photo records occupy 1.4 KB each including key and bookkeeping overhead. That is about 700 MB per full cache copy. Ten million reads of those same entries do not require ten million stored entries.

A **cache hit** finds the requested value in the cache; a **miss** must fetch it from the underlying database or storage service, called the **origin**. The request hit rate is the fraction of cacheable requests served as hits. This rate turns the delivery estimate into an estimate of work still reaching the origin.

A 95% request hit rate reduces 2,315 cacheable lookups/s to about `2,315 x 0.05 = 116` misses/s under the same workload. But when the cache is empty, the origin can suddenly see all 2,315/s. Protect that origin and

warm popular entries gradually. Track byte hit rate separately: a few missed large images may dominate bandwidth despite a high request hit rate.

For cost, write a symbolic model before using current provider prices: storage GB-month + read/write operations + delivered GB + compute time + replication/backup. A cheaper storage tier can have retrieval fees and slower access. The interview value is identifying the dominant cost and a way to measure it, not memorizing a vendor price that may change.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is capacity estimation? Estimate QPS for one million users making ten requests a day.

Model answer

"Capacity estimation converts a workload into rates and resource needs. Here one million users x ten requests is ten million requests/day. Dividing by 86,400 seconds gives about 116 requests/s average. I still need peak concentration, bytes per request, latency targets and failure headroom before choosing server capacity."

Interviewer follow-up

Is 116 QPS the server capacity target?

No. The average is only a baseline. Peak rate, request cost, latency objectives, and failure headroom determine capacity.

What the answer must demonstrate: Show denominator and units.

02 / FOUNDATION

Can a system have high throughput and high latency?

Model answer

"Yes. A batch worker may finish thousands of items a second while each item waits minutes in a queue. Throughput describes the completion rate; latency measures one item's elapsed time. I would measure queue wait and processing time separately."

Interviewer follow-up

Would more queued work always raise throughput?

Only until it helps saturate usable capacity. Beyond the bottleneck, more queued work generally raises wait time and resource pressure.

What the answer must demonstrate: Distinguish work rate from wait time.

03 / APPLIED

How much storage do 200 GB/day of uploads need after a year?

Model answer

"Without deletion, 200 x 365 is 73,000 GB, or 73 TB in decimal units. That is logical originals. I would separately add derived images, indexes, copies, and backups, then apply the retention policy."

Interviewer follow-up

Should three replicas be included twice for multi-region?

No. Enumerate the actual physical copies and locations. Multipliers represent specific copies, not labels to stack without a physical model.

What the answer must demonstrate: Separate logical data from physical overhead.

04 / APPLIED

What happens at 2,000 requests/s if average latency grows from 50 to 500 ms?

Model answer

"Assuming both measurements cover the same system in stable operation, the average number of requests in progress grows from about 100 to 1,000. That can exhaust memory or connection pools even without a traffic increase. I would inspect downstream latency and bound admitted work."

Interviewer follow-up

Can you substitute p99 into Little's law?

Not to calculate average concurrency. The relation uses averages; percentiles need separate distribution analysis.

What the answer must demonstrate: Use seconds and matching averages.

05 / APPLIED

Should a cache hold 20% of yesterday's requests?

Model answer

"Requests are not stored objects. I estimate distinct hot keys and bytes per entry. If a million requests hit one record, that is one cache entry. I use observed reuse and eviction behavior to choose the working set, then account for replication and overhead."

Interviewer follow-up

How can a 99% hit ratio be misleading?

The remaining 1% may be huge objects or expensive queries. Measure byte hits, expensive misses, and cold-cache behavior.

What the answer must demonstrate: Count distinct retained entries.

06 / APPLIED

Three servers can just meet peak. Is that a resilient design?

Model answer

"Not if the requirement includes surviving a server failure at that peak. I calculate the remaining capacity after the failure and keep headroom for imbalance. If two survivors cannot meet the objective, I add capacity, reduce admitted work, or agree on degraded behavior."

Interviewer follow-up

Can autoscaling replace all spare capacity?

Autoscaling has detection and startup delay, and dependencies may scale more slowly. A sudden failure needs capacity or load shedding during that interval.

What the answer must demonstrate: Calculate surviving capacity.

07 / APPLIED

An API runs five database queries. Which QPS matters?

Model answer

"Count both. At 2,315 API requests/s and five queries per request, the database receives about 11,575 operations/s before retries or cache effects. I would check whether each query is needed, indexed and independent of the others."

Interviewer follow-up

What if all five run in parallel?

Parallel execution can lower one request's latency, but it still creates roughly five operations of load. Latency and total work are different.

What the answer must demonstrate: Explain amplification rather than hiding it.

08 / APPLIED

A photo service serves 2,315 peak views/s at 100 KB each. Which measurements would change the storage or delivery design?

Model answer

"The stated peak is 2,315 x 100 KB = 231.5 MB/s, about 1.85 Gb/s before overhead. I would measure repeated-key reuse and permission constraints to evaluate a CDN, and measure metadata and CPU costs separately to decide where scaling helps. Peak QPS alone cannot determine daily delivered bytes or metadata growth; those require daily volume and stored bytes per upload."

Interviewer follow-up

What observation could invalidate your CDN assumption?

If most images are viewed only once or authorization prevents useful sharing, cache reuse may be low. I would measure the access distribution and policy constraints.

What the answer must demonstrate: Use a number to justify a decision.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Estimate a file-sharing service with 2 million daily users, five 200 KB downloads each, and a 6 x peak. Defend one architecture decision.

- Compute average and peak requests/s.
- Compute delivered bytes/day and peak bytes/s.
- Explain one failure-headroom calculation.
- Distinguish assumptions from measurements.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Rate conversion

Daily operations ÷ 86,400 gives average operations per second.

Actions -> daily count -> seconds.

At 2,000 requests/s and 0.05 seconds per request, how many are in progress?

About 100 on average: 2,000 x 0.05. Little's law requires a stable workload and matching measurement boundaries.

Rate x time = work in progress.

Cache size

Distinct hot entries x bytes per entry, then copies and headroom.

Keys, not requests.

Summary and interview notes

Capacity estimates translate a declared workload into rates, retained bytes, concurrent work and resource demand. Size each component for its peak load and for the capacity it must retain after the failures you plan to tolerate, then validate the assumptions against a load test.

Remember these points

• Average requests/s = daily requests / 86,400; a peak multiplier is a separate assumption.

• Logical storage, replicas, derived objects, indexes and backups are separate physical categories.

• Little's law uses average arrival rate and average time for the same system in stable operation; substituting a latency percentile does not give average concurrency.

• CPU-seconds per request differ from elapsed request time; both affect sizing in different ways.

• A warm-cache miss rate is not the capacity requirement after cache loss.

Interview tips

• Write units at every conversion, especially bits versus bytes and MB versus MiB.

• Show the surviving capacity after the required failure, rather than counting only healthy servers.

• End an estimate by naming the architectural decision it changes.

Important qualifications

• The 10 x peak and 70% utilization figures are example assumptions, not universal defaults.

• If accepted requests keep arriving faster than they finish, the queue keeps growing. A stable-workload concurrency estimate no longer describes that overload.

Technical references

Google SRE service-level objectives
Definitions of throughput, latency, measurements, and the limitations of averages.
https://sre.google/sre-book/service-level-objectives/

Google SRE handling overload
Capacity limits and overload behavior; numerical examples here are original practice assumptions.
https://sre.google/sre-book/handling-overload/

RFC 5136: Defining Network Capacity
Distinguishes capacity from actual usage and explains why the informal term bandwidth is ambiguous.
https://www.rfc-editor.org/rfc/rfc5136.html

FOUNDATIONS / 04

Distributed systems: scalability, reliability, availability and efficiency

DEFINITION

A distributed system consists of independent computers that coordinate by exchanging messages. Its quality must be assessed separately: scalability concerns increased workload, reliability concerns correct service over time, and availability concerns whether service is usable when requested. Efficiency measures useful work per resource spent; manageability concerns safe diagnosis, repair and change.

Why it matters: Running on several computers introduces partial failures: the application can be alive while the database is unreachable. Separate quality targets tell you which failure matters and how to respond.

Scalability, reliability, availability, efficiency, and operability

Scalability, reliability, availability, efficiency and manageability are distinct quality attributes. Each needs its own definition and measurement.

Checkout service: five measurable quality attributes

SCALABILITY	**500 to 2,000 requests/s** Maintain the agreed latency at higher load
RELIABILITY	**One purchase becomes O17** No duplicate order or charge after a retry
AVAILABILITY	**99.9% of eligible attempts** 1,000 misses per 1,000,000 attempts
EFFICIENCY	**Useful work per resource** Measure CPU, network and cost per checkout
MANAGEABILITY	**Operate and change safely** Detect, repair, roll back and verify

Correctness and availability depend on the defined user outcome, not just a responding server.

Worked example

Order O17 is a $25 purchase. A second application server can accept traffic after the first fails, but a repeated request still needs to recover O17 rather than create a second $25 charge.

Key takeaways

- Reachable processes do not prove a correct user outcome.
- More application servers do not remove a shared database bottleneck.
- State the failure being tolerated and the capacity left afterward.

Read the visual model

1. Scaling asks whether 500 checkout requests/s can become 2,000 while maintaining latency.
2. Reliability asks whether one intended purchase yields O17 and one correct charge, including retries.
3. Request availability counts successful eligible checkouts; one million attempts at 99.9 percent permits 1,000 unsuccessful attempts.
4. Efficiency measures useful work per resource; manageability covers diagnosing, repairing and changing service safely.

scalability • availability • reliability • latency • operations

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain each system quality using an observable user outcome.
- Calculate an availability/error budget and surviving capacity.
- Identify why adding machines can leave a bottleneck unchanged.

Useful foundations: Capacity estimation: throughput, latency, concurrency and storage

8 interview questions with model answers and answered follow-ups.

01 / Distributed system quality attributes: definitions

A distributed system consists of independent computers that coordinate by exchanging messages. One part can fail while others keep running; this is a partial failure. An online shop might run its request-handling application on two machines, keep live copies of orders on several database machines, and send receipts through a background worker. The customer sees one checkout experience, even though these parts can fail or respond at different times.

The qualities below answer different questions about that experience. **Scalability** asks whether the service can handle a larger workload while maintaining its targets. **Reliability** is the ability to perform the specified function correctly under stated conditions over a period of time. **Availability** is the degree to which the service is usable when requested, often measured as successful eligible requests divided by all eligible requests. **Efficiency** asks how much useful work it gets from its resources. **Manageability** asks how safely operators can observe, configure, operate, and change it. The related term **serviceability** focuses on diagnosing and repairing faults.

INTERVIEW CRITICAL

Reachable servers can still produce incorrect results

Quality attributes describe observable service behavior, not merely process health. In a checkout example, order O17 being charged twice is a correctness failure even if every server is reachable. A successful-purchase availability metric must exclude that incorrect outcome. Refusing checkout during a database outage can preserve the no-duplicate-charge invariant while sacrificing availability for that operation.

Quality	Question for checkout	Example design decision	Remaining limit
Scalability	Can 500 requests/s become 2,000 at the same latency?	Distribute independent application work	One hot inventory row may remain serial
Reliability	Does one purchase create the intended order and charge?	Save request identity and reconcile payment outcomes	A remote payment requires its own retry contract
Availability	Can an eligible customer complete checkout now?	Keep spare replicas and fail over safely	A partition may require refusal rather than unsafe writes
Efficiency	How much CPU, data and communication does one order consume?	Remove repeated lookups and batch safe work	Larger batches may increase wait time
Manageability	Can an operator diagnose and repair O17?	Trace IDs, durable states and staged rollouts	Automation still needs safe thresholds

02 / Vertical scaling, horizontal scaling and serial bottlenecks

At first, one application server handles 500 checkout requests/s. **Vertical scaling** replaces it with a larger machine: more CPU, memory, or faster disks. It can be the simplest improvement, but hardware has practical limits and a single machine still fails as one unit.

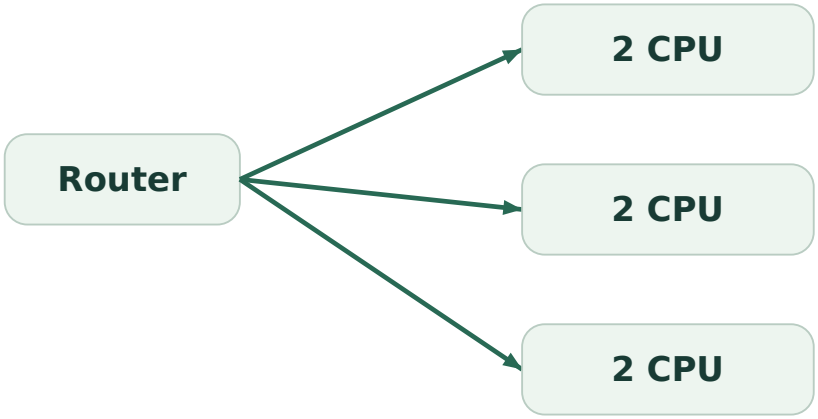
Bigger machine or more machines?

Machine size represents resources per instance; separate boxes represent independent instances. Neither change removes a shared database bottleneck.

Vertical: enlarge one machine



Horizontal: distribute work across machines



Three independent instances

Remember: Vertical changes the size; horizontal changes the count.

Try from memory: Which approach spreads work across several server instances?

Answer: Horizontal scaling adds independent instances. It can tolerate an instance loss only if routing, surviving capacity and state management support it.

Horizontal scaling adds machines. Put two application servers behind a load balancer, and either can handle a request if essential state is stored outside the process. This can grow application capacity and tolerate one application failure if the survivor can meet the admitted workload. It does not automatically double database write capacity.

Some work remains **serialized**: operations must take turns because they update the same protected state. Adding application machines does not remove that ordering requirement. This matters both for the time one checkout takes and for how many checkouts can update the same inventory record.

For a separate latency calculation, suppose one request spends 80 ms on parallelizable work and 20 ms executing a serialized operation on one inventory key, excluding queue wait. Making the first part four times faster yields `80/4 + 20 = 40 ms`, a 2.5 x improvement, not 4 x . Even infinitely fast application work cannot

eliminate the remaining 20 ms. This is the intuition behind a serial bottleneck: improve the part that limits the actual operation.

The workload also matters. Adding nodes can help independent product lookups while thousands of purchases of the same final item still contend on one record. Measure distribution, not just total QPS.

INTERVIEW CRITICAL

A hot key can limit throughput across many servers

This arithmetic bounds one request's latency; it is not a throughput benchmark. If all updates to one key require that same exclusive 20 ms service time, the key can complete at most about `1 / 0.020 = 50` such updates/s, even with many application servers. Requests for other independently owned keys may proceed concurrently. State whether a claimed speedup applies to latency, aggregate throughput or one contended key.

03 / Availability and error-budget calculations

An **error budget** is the amount of unsuccessful service allowed by the chosen availability target over a defined measurement window. The target supplies the permitted fraction; the number of requests or the duration of the window turns it into a count or time allowance. Choose that denominator before interpreting an outage.

INTERVIEW CRITICAL

Request availability and uptime use different budgets

Assume checkout should successfully handle 99.9% of eligible requests in a 30-day month. With one million eligible attempts, the unsuccessful-request budget is `1,000,000 x 0.001 = 1,000`. If instead the agreement is time-based, 0.1% of 30 days is `30 x 24 x 60 x 0.001 = 43.2 minutes`. These are different measurement definitions; a quiet-hour outage and a peak-hour outage affect request-based availability differently.

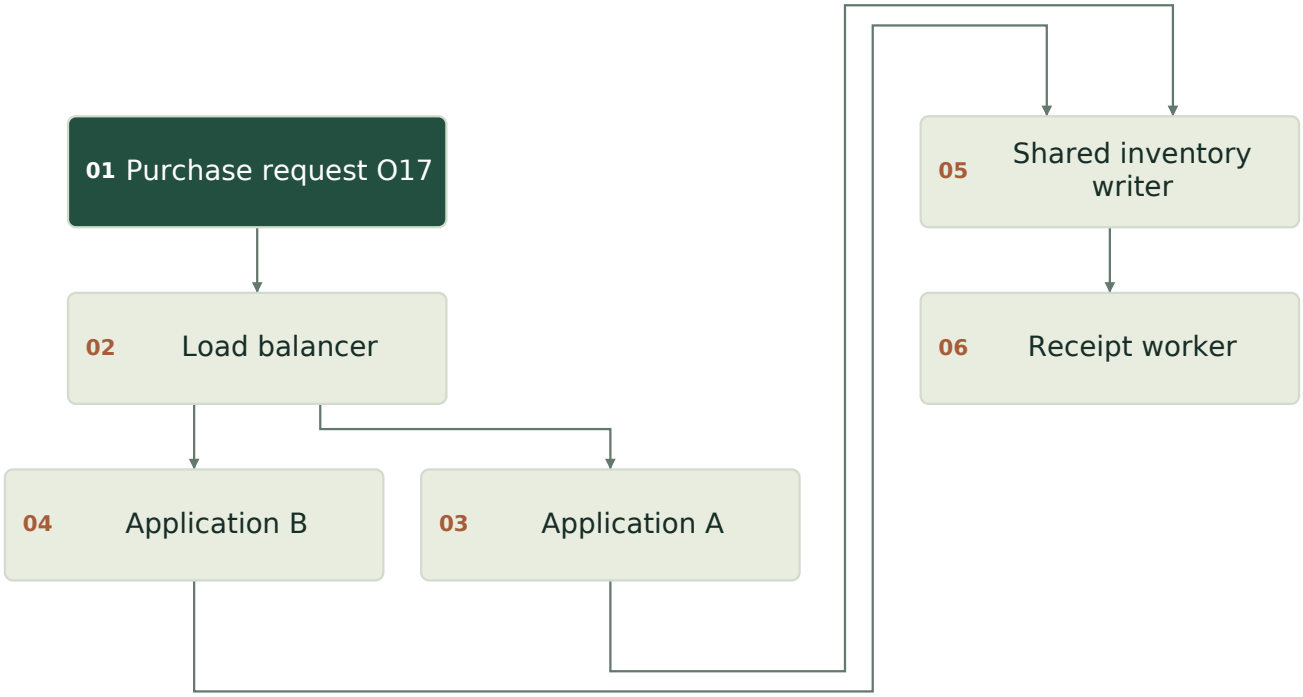
At 10:00 the only order database stops responding. Automated detection fires at 10:01. An operator finishes failover and verifies writes at 10:07. Checkout was unavailable for seven minutes, not merely the six minutes spent repairing after detection. Monitoring delay is part of the user impact.

For a simple recurring up/down model, availability can be approximated by `mean uptime / (mean uptime + mean downtime)`. Real services have partial and correlated failures, so a single formula is not a substitute for measuring user requests. Faster detection and repair can improve availability even when the underlying failure frequency is unchanged.

Dependencies also affect the result. In a deliberately simplified model, if two required dependencies are independently available 99.9% of the time, the path is available `0.999 x 0.999 = 99.8001%` of the time before other failure sources. Redundant alternatives instead help only when at least one is usable and routing can reach it. Shared power, bad configuration and overload make failures correlated, so multiplying advertised service percentages is not a production reliability proof.

WORKED EXAMPLE DIAGRAM

Two application servers still converge on one inventory writer. The shared write can limit scalability even while the application tier has spare CPU.



1 -> 2	checkout request: Purchase request O17 -> Load balancer
2 -> 3	healthy instance: Load balancer -> Application A
2 -> 4	another healthy instance: Load balancer -> Application B
3 -> 5	reserve inventory: Application A -> Shared inventory writer
4 -> 5	same shared writer: Application B -> Shared inventory writer
5 -> 6	receipt after committed order: Shared inventory writer -> Receipt worker

04 / Reliability, durability and failure domains

If order O17 commits but its response is lost, a retry can create O18 and charge again. Save the result under a stable request ID so a retry returns O17. Save the order and request result in one **atomic** database transaction: both commit or neither does. An external payment is outside that transaction. Reuse the same payment identifier under the provider's retry rules, and check an uncertain result before issuing another charge.

Durability is retention of acknowledged data. Replicated records can survive a machine loss if the acknowledgment and recovery protocol make that promise. A backup can restore an earlier state after

accidental deletion. Both require verification; merely drawing duplicate cylinders does not prove an acknowledged purchase survives.

A **failure domain** is a set of components that one event can disable together, such as machines sharing a power supply or deployment zone. A **network partition** prevents some machines from communicating even though they may still be running. Replica placement must match the failures the service is meant to survive.



INTERVIEW CRITICAL

Replicas must survive the failure you claim to cover

Define the failure model: one process crash, one disk failure, a lost zone, a network partition, or an operator deleting rows. A mechanism sufficient for one failure may do nothing for another. Two replicas powered by the same failed supply are not independent protection against that supply's loss.

The following failure sequence shows which records and identifiers must survive a lost response. (1) Purchase key K17 requests $25 and the order authority records O17. (2) Payment action `charge-017` produces confirmed provider charge C81. (3) The application response is lost. (4) Retrying K17 returns O17/C81 rather than allocating O18 or a new charge identity. If the provider response was lost instead, the charge remains unknown until lookup or the provider's documented same-key retry resolves it. A timeout establishes uncertainty, not failure.

05 / Resource efficiency and communication cost

Efficiency is useful outcomes divided by the resources spent. For O17, ten internal RPCs - remote procedure calls - may each transfer a small record. One giant catalog transfer may use fewer messages but far more bytes. Count both messages and data size, then account for network distance and repeated work.

Suppose design A makes ten sequential 5 ms calls and design B makes two 20 ms calls. Their network wait contributions are about 50 and 40 ms respectively in this simplified example. A third design could batch data into one call, but might waste bytes or postpone the response. Message count alone does not identify the best design.

Symptom	Likely resource to inspect	Example improvement
CPU saturated on every server	Computation per request	Remove repeated parsing or cache a safe result
Database reads dominate	Query plan and indexes	Fetch O17 by an indexed identifier
Large transfers dominate	Bytes and distance	Compress or deliver static bytes nearer readers
Only one partition is hot	Work distribution	Revisit ownership, split a hot workload

Mixed machine sizes, topology, and uneven load make ideal linear speedup unlikely. Compare designs with the same workload and objective.

06 / Manageability, monitoring and safe change

An operator should be able to answer what failed, which customers are affected, and which action is safe. Attach one request/trace ID to O17 across services, record state transitions without payment secrets, and measure both successful outcomes and latency. A health endpoint that only says the process is alive does not prove orders can commit.

Use different controls for different problems. **Readiness** decides whether an instance receives new requests. A **restart policy** decides when to restart its process. **Admission control** limits accepted work so existing requests can finish. If a dependency fails, accept less work where necessary; restarting otherwise healthy application processes will not fix that dependency.

Roll out a new version to a small fraction first, compare outcomes, and retain a rollback path. A database change should let old and new application versions coexist during the rollout. Stop assigning new work to a known dead instance, and bound or shed the excess traffic if survivors lack capacity. Separately, avoid ejecting or repeatedly restarting every live instance merely because a shared dependency is slow: that reaction can reduce useful capacity further. Readiness, restart policy and admission control have different jobs.

Candidate explanation: "I separate checkout availability from order correctness. I can temporarily refuse new purchases when I cannot confirm which database node is allowed to update inventory, while keeping browsing available. I add application redundancy, make retries return the original order, and measure the full checkout outcome. My recovery plan includes detection, failover, validation, and enough remaining capacity."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is the difference between reliability and availability?

Model answer

"Availability asks whether an eligible checkout operation can complete under its success definition. Reliability asks whether the service performs its specified function correctly over time and under promised conditions. A reachable system that double-charges an order is incorrect; that purchase must also count as unsuccessful in an end-to-end availability measure. I define the outcome and measurement window rather than treating reachability as either guarantee."

Interviewer follow-up

Can you preserve correctness while losing availability?

Yes. Refusing a purchase when the service cannot confirm which node may update inventory avoids accepting an order it cannot safely reserve stock for, but the customer still cannot complete the operation.

What the answer must demonstrate: Use the same example for both qualities.

02 / FOUNDATION

When would you scale vertically before sharding?

Model answer

"If the database fits on one larger instance and measured CPU, memory, or I/O is the bottleneck, vertical scaling can buy capacity with a smaller operational change. I would also keep redundancy and test the new capacity. I shard when independent data needs to exceed that practical limit."

Interviewer follow-up

What does vertical scaling not fix?

A logical lock on one hot inventory record can remain a serial bottleneck. Bigger hardware is not a concurrency protocol.

What the answer must demonstrate: Separate physical resources from contention.

03 / APPLIED

Why does doubling application servers not double checkout throughput?

Model answer

"They may still share the same database, lock, or downstream service. I trace a purchase and measure where time and work accumulate. Adding application capacity helps only the work those instances own; the shared inventory writer may remain the limiting resource."

Interviewer follow-up

What if browsing scales but checkout does not?

That is plausible because browsing can distribute read work while checkout changes shared inventory. I would size and design those operations separately.

What the answer must demonstrate: Find the shared bottleneck.

04 / APPLIED

What does 99.9% availability permit?

Model answer

"First I would define the measure. Over a 30-day time-based window, 0.1% is 43.2 minutes. Over a million eligible requests, it is 1,000 unsuccessful attempts. These budgets are not interchangeable when traffic changes through the day."

Interviewer follow-up

Can a fast error count as successful?

Only if it is a valid business response under the defined metric, not because the network responded quickly. An infrastructure refusal of a valid purchase is an unavailable outcome.

What the answer must demonstrate: Define eligible and successful requests.

05 / APPLIED

Why include detection time in a recovery plan?

Model answer

"The customer experiences the outage before the operator starts repairing. If detection takes one minute and verified failover takes six more, checkout is unavailable for seven. I improve both detection and repair and practise the complete sequence."

Interviewer follow-up

Would aggressive health checks always help?

No. Noisy checks can eject or restart live capacity during a shared dependency incident. Stop sending work to a known dead instance, but use bounded admission and careful failure thresholds to prevent overload from cascading through the survivors.

What the answer must demonstrate: Measure end-to-end recovery.

06 / APPLIED

Do two copies guarantee durability?

Model answer

"No. I need to specify when a write is acknowledged, whether the second copy is durable, and which failures it survives. Copies in the same failure domain may disappear together, and a bad deletion can replicate to both. I also need backups and tested recovery."

Interviewer follow-up

What is a failure domain?

A set of resources that can fail together because they share a dependency, such as power, a rack, a zone, or an administrative change.

What the answer must demonstrate: Name the failure being tolerated.

07 / APPLIED

Is fewer network messages always more efficient?

Model answer

"No. One message may contain a huge unused payload, while several small messages may run in parallel. I compare bytes, round trips, CPU, and end-to-end latency for the same user operation. Reducing repeated calls can help, but the workload decides."

Interviewer follow-up

What changes across regions?

Each sequential round trip can cost substantially more time because of distance. I would reduce cross-region dependencies on the critical path and measure the actual network.

What the answer must demonstrate: Count bytes and sequential waits, not just arrows.

08 / APPLIED

What makes a system manageable in an interview answer?

Model answer

"I show how an operator diagnoses one failed order using a trace identifier and durable states, how alerts reflect failed purchases, and how a rollout can be stopped or reversed. I include schema compatibility and verify recovery rather than ending the design at deployment."

Interviewer follow-up

Which metric would you alert on first?

The user-facing purchase-success or latency objective, supported by component metrics to locate the cause. A low-level CPU signal alone does not establish customer impact.

What the answer must demonstrate: Explain a concrete operator action.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Explain why a reachable checkout can be unreliable, then redesign it to survive one application failure.

- Give one example for each of the five qualities.
- Calculate a stated availability budget.
- Trace a lost-response retry for one purchase.
- Identify one shared failure domain and one serial bottleneck.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Five system qualities

Scalability: more work; reliability: correct work; availability: usable now; efficiency: resource cost; manageability: safe diagnosis and change.

Ask five different questions.

Availability budget

Choose a request-based or time-based definition and a window before calculating.

Define the denominator.

Why might adding application servers fail to speed up checkout?

If every server still waits on the same overloaded database, adding servers leaves the bottleneck in place. Distribute or reduce the limiting work.

Find the bottleneck before adding machines.

Summary and interview notes

A distributed service must be evaluated at the user-visible operation, not by counting reachable machines. Scalability, reliability, availability, efficiency and manageability describe different qualities, and each needs its own workload, failure model and measurement.

Remember these points

• Adding machines helps work that can run independently; updates to one heavily used key may still have to run one at a time.

• A request-based availability budget differs from a time-based outage budget.

• Reliable retries reuse the original operation ID and stored result. If an external action such as a charge has an unknown outcome, check its status before attempting a new action.

• Copies protect only against the failures covered by their placement, acknowledgment and recovery protocol.

Interview tips

• Use one operation to contrast the five qualities, then explain how each is measured.

• Separate a per-request latency speedup from aggregate throughput and hot-key capacity.

• Include detection, failover and verified service recovery in the outage timeline.

Important qualifications

• End-to-end success should count incorrect results as failures; process reachability alone is a weaker metric.

• Independence-based availability arithmetic is a simplified model; shared dependencies and correlated failures require direct measurement.

• Stop routing to failed nodes. Limit accepted work so redirected traffic does not overload the survivors.

Technical references

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User-facing measures of availability, latency, and correctness.
https://sre.google/sre-book/service-level-objectives/

Google SRE addressing cascading failures
Failure amplification, remaining capacity, and recovery behavior.
https://sre.google/sre-book/addressing-cascading-failures/

FOUNDATIONS / 05

Databases, data models, and ACID transactions

DEFINITION

A database is an organized collection of related data; a database management system (DBMS) is the software that stores, retrieves and updates it. A data model defines how the data is represented and related. A transaction treats one or more operations as a single logical unit: its changes commit together or are rolled back together. ACID names atomicity, ACID consistency, isolation and durability; the database and its settings determine the precise concurrency and failure guarantees.

Why it matters: A product needs to answer specific queries and keep shared facts correct when requests overlap or fail. The database choice must support both the access patterns and the required transaction boundary.

Data models and an atomic inventory transaction

Choose records by the query, then use an atomic transaction for the inventory/order relationship.

Choose the access pattern; protect the purchase

RELATIONAL

Order(id, user, date, total)
query: user + date

DOCUMENT

Order {items:[...]}
query: one full order

KEY-VALUE

cart:u7 = cart body
query: exact key

GRAPH

user -BOUGHT-> product
query: connected records

One transaction: require stock >= 2

stock: 5 becomes 3 **AND** insert Order O81: 2 mugs

Commit both records, or roll back both. A database family is not a correctness proof.

Worked example

Buying two mugs must change stock from 5 to 3 and create order O81 for $24. A local transaction can commit both changes or neither; if the two changes are saved independently, a crash between them can leave stock reduced without a matching order.

Key takeaways

• Start with access patterns and invariants before choosing a database family.

• ACID names four distinct guarantees; its C differs from CAP consistency.

• Relational and NoSQL are not synonyms for strong and weak consistency.

Read the visual model

1. A relational row supports constraints and joins; a document groups an aggregate; a key-value record addresses one known key; graph edges support traversal.

2. Model choice does not by itself make a purchase safe.

3. For two mugs with stock five, decrement stock and insert the order atomically. Either both changes commit or neither does.

SQL • NoSQL • data model • ACID • queries

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Compare relational, key-value, document, wide-column, and graph records.

• Connect schema, query, scaling, and transaction needs to a storage choice.

• Explain ACID using a purchase that changes inventory and order state.

Useful foundations: Database indexes: B-trees, composite keys and query access

8 interview questions with model answers and answered follow-ups.

01 / What is a database, data model, and transaction?

A **database** is an organized collection of related data. A **database management system (DBMS)** is the software that stores, retrieves and updates it. In everyday engineering conversation, "database" often refers to the combined system. Its **data model** determines whether the application thinks in tables, documents, key-value pairs, or relationships. An **access pattern** is a concrete query or update, such as "find recent orders for customer U7." An **invariant** is a rule that must remain true, such as "available stock never becomes negative."

A **transaction** groups database operations so their changes commit together or roll back together. **ACID** names four properties: atomicity, ACID consistency, isolation and durability. They describe what commits together, which rules remain valid, how concurrent transactions interact and which failures saved data survives. Check the database's guarantees against your reads and writes.

One database is a sensible starting point. As the service grows, its limit might be storage, popular-item contention, history reads, or expensive analytics. The label SQL or NoSQL does not identify which limit we have. First write the questions and rules; then choose a model and implementation that support them.

Assume this purchase must create the order and allocate stock together or do neither. We have not yet introduced independent payment and warehouse services. Keeping inventory and orders in one database lets

us explain a local transaction before considering a workflow that spans separate services. The quantities and prices are assumptions for this example.

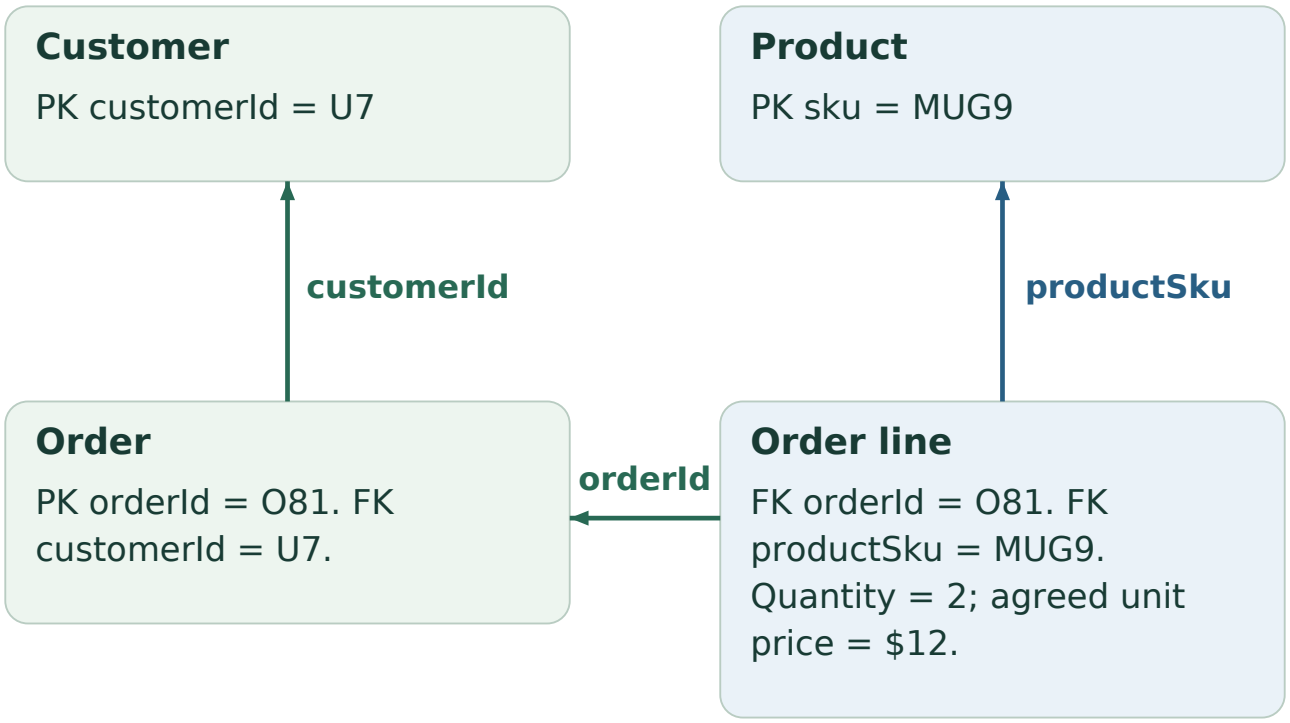
Derive the model from the required operations: conditional stock allocation, order lookup by ID, and customer history ordered by time. In the example, order O81 contains two MUG9 items at an assumed $12 each. Creating the $24 order changes available stock from five to three. That joint state transition defines the required transaction boundary.

02 / Relational data: tables, keys, joins, and constraints

A relational database represents facts as rows in tables. Columns name fields and usually assign their types. Relationships connect records through keys. Separate shared inventory from each order's agreed commercial terms.

Relational keys connect facts

Arrows point from foreign keys to the records they reference. This is a simplified key relationship diagram; an order line also needs its own unique identity in the real schema.



PK = primary key; FK = foreign key. Arrows point from the referencing field to the referenced record.

Remember: Primary key identifies; foreign key references; constraints protect rules.

Table	Example record	Important question
Customer	U7	Who owns the order?

Table	Example record	Important question
Inventory	MUG9, available = 5	Can two units be allocated?
Orders	O81, customer U7, total 24	What is its current state?
OrderLine	O81, MUG9, quantity 2, unitPrice 12	Which quantity and price were committed?

OrderLine retains the purchase price if tomorrow's catalog price changes. This deliberate duplication preserves history; eliminating every repeated field is not the goal.

SQL is a language for querying and changing relational data. A join combines O81 with its lines. An index beginning with customer and then creation order supports customer U7's order history. Constraints such as a unique order identifier or a valid customer reference enforce specific rules within the database's supported scope.

A useful history index is `(customer_id, created_at DESC, order_id DESC)`, supporting a query shaped like `SELECT ... FROM Orders WHERE customer_id = 'U7' ORDER BY created_at DESC, order_id DESC LIMIT 20`. The final key breaks equal-time ties. It does not make an unrelated full-catalog search cheap. Store money as integer minor units or an exact decimal plus currency; the illustrative $12 unit price can be `1200` cents, and two units total `2400` cents.

03 / Key-value, document, wide-column, and graph models

The order, its line items and the customer relationship can be represented in several models. The choice changes which related facts are stored together and which queries need additional lookups or indexes. Compare each alternative against the same two needs: fetch O81 as a complete order and list U7's recent orders.

A key-value store retrieves a value by a key, such as `order:O81 -> complete order data`. That fits exact lookup. Listing every order for U7 needs another supported access path; one key does not automatically answer every question.

A document store can keep the order and its lines together: `{id: O81, customer: U7, lines: [{sku: MUG9, qty: 2, price: 12}]}`. This makes a complete-order read natural. Shared inventory remains separate because many orders refer to MUG9. Convenient embedding does not automatically make that cross-document rule atomic.

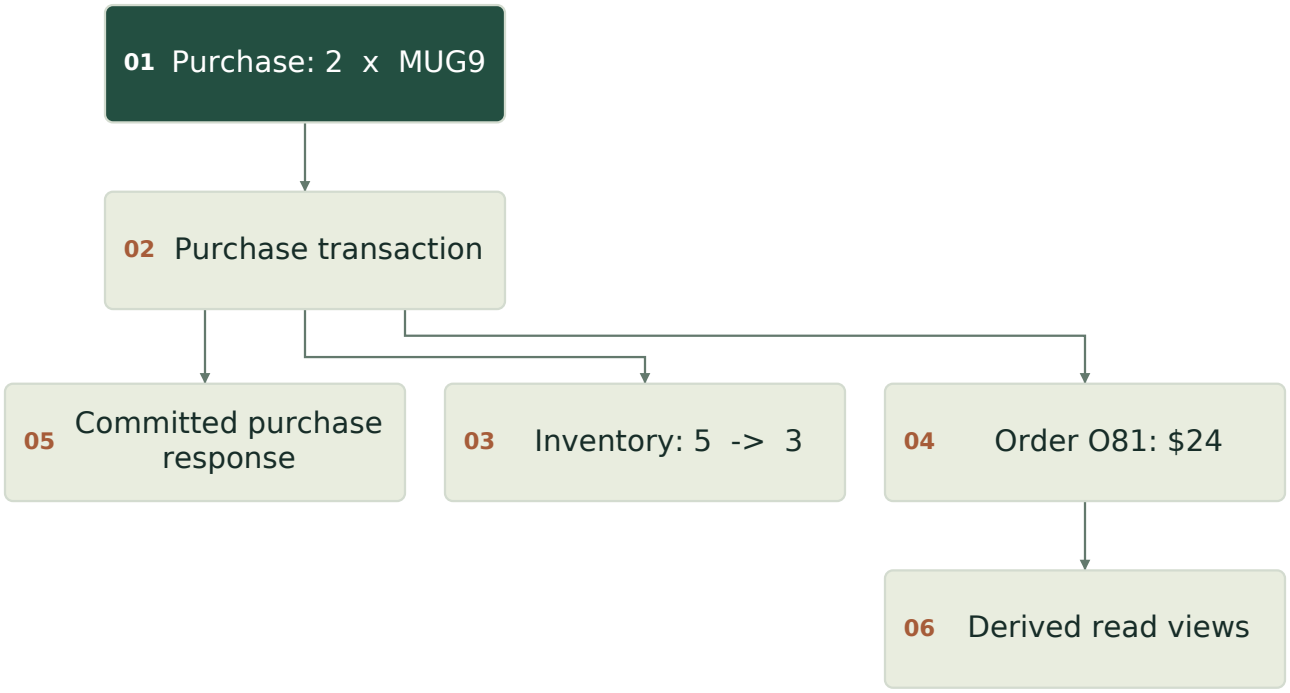
Family	Representation	Natural access
Key-value	order:O81 -> order payload	Fetch O81
Document	Order with embedded lines	Read the whole order aggregate
Wide-column	Partition U7; keys ordered by time and order ID	Read U7's recent orders
Graph	U7 -> placed -> O81 -> contains -> MUG9	Traverse relationships

Wide-column systems organize application queries around **partition keys**, which select a group of records, and **clustering keys**, which order records within that group. They differ from analytical columnar engines that scan selected columns over many rows. Graph storage is useful when traversals are central, not merely because two records are related.

Choose by both fit and the operation that becomes awkward. A key-value layout needs a separate access path for customer history. A document layout makes one bounded order aggregate easy, but very large embedded arrays and shared inventory need another strategy. A wide-column layout favors planned partition-key queries and can concentrate a very large customer partition. A graph model makes multi-hop traversal expressive, but a relational foreign key alone does not justify adding a graph engine.

WORKED EXAMPLE DIAGRAM

A purchase transaction allocates two MUG9 units at an assumed $12 each: stock changes 5 -> 3 while order O81 records $24. Derived views do not authorize inventory allocation.



1 -> 2	validate and deduplicate: Purchase: 2 x MUG9 -> Purchase transaction
2 -> 3	conditional allocation: Purchase transaction -> Inventory: 5 -> 3
2 -> 4	create matching order: Purchase transaction -> Order O81: $24
2 -> 5	reply after commit: Purchase transaction -> Committed purchase response
4 -> 6	publish committed changes: Order O81: $24 -> Derived read views

04 / SQL versus NoSQL: choose from workload and constraints

Schema is the agreed structure and meaning of records. A relational schema can enforce types and constraints. A flexible document schema can permit different shapes, but the application still needs rules for quantity, currency, and missing fields. Either model needs a compatible plan when old and new software versions coexist.

NoSQL describes a broad family, not one query language or consistency setting. Different systems expose document queries, keyed operations, graph languages, or SQL-like syntax. Some support multi-record transactions; MongoDB documents transaction support.

For this purchase, choose a relational database with appropriate transaction support. The reasons are the shared stock/order rule and useful history queries. We pay for indexes, contention on a hot product, and operating the database. We are not assuming that relational databases cannot distribute or that document stores cannot transact. If search or analytics requires another engine, treat it as a derived view of committed orders with a stated freshness delay and rebuild path.

05 / ACID: atomicity, consistency, isolation, durability

A transaction groups changes under specified guarantees. For O81, begin the transaction, reduce MUG9 stock by two only if at least two remain, insert the matching order and line, then commit. If a required step fails, roll back the transaction.

Letter	Meaning for O81
Atomicity	Stock and order commit together or neither does
C: ACID consistency	A correct transaction takes the database from one valid state to another, preserving rules such as nonnegative stock
Isolation	Limits which intermediate or concurrent changes a purchase transaction can observe; the selected isolation level determines the exact guarantees
Durability	Committed O81 survives the failures covered by storage/replication settings

Keep the meanings separate

INTERVIEW CRITICAL

Name the exact consistency and atomicity guarantee

1. **ACID consistency means valid database state.** Constraints and correct application logic preserve declared rules. It does not mean that every replica returns the latest write; that is CAP consistency.
2. **ACID atomicity means all-or-nothing transaction effects.** An indivisible update or a script that runs without interleaving also uses the word atomic, but that alone does not promise rollback after an error or survival after a crash. For example, Redis script execution and database transaction rollback are different guarantees.

INTERVIEW CRITICAL

A fresh stock read is not an atomic allocation

Consider concurrent transactions T1 and T2, each requesting two units when available stock is two. Separate reads can both return two before either write occurs. A protected conditional allocation combines the stock predicate and decrement so only an operation whose condition still holds can commit.

Rules involving several records may require stronger isolation or explicit locking. "ACID" does not mean every default isolation mode prevents every anomaly. The transactions-and-isolation chapter develops those traces; PostgreSQL's isolation reference describes actual engine behavior. Application logic must still express the right invariant.

The transaction also records which logical purchase it is performing. `purchase_key` stays the same across retries; `request_hash` summarizes a consistently normalized request so the same key cannot silently mean different quantities or items. A **row lock** prevents competing updates to the same inventory row from proceeding simultaneously. That protection lets the database wait for an earlier updater and then test whether stock is still sufficient.

Here is the key part of a PostgreSQL-style transaction, assuming the tables and their uniqueness/foreign-key constraints already exist:

```
BEGIN;
INSERT INTO Orders
  (order_id, customer_id, purchase_key, request_hash, total_cents, currency)
VALUES ('O81', 'U7', 'purchase-71', 'hash-of-canonical-request', 2400, 'USD');
UPDATE Inventory
SET available = available - 2
WHERE sku = 'MUG9' AND available >= 2
RETURNING available;
-- Continue only if exactly one row was returned; otherwise ROLLBACK.
INSERT INTO OrderLine
  (order_id, sku, quantity, unit_price_cents)
VALUES ('O81', 'MUG9', 2, 1200);
COMMIT;
```

The comment is an application decision, not SQL that automatically aborts. Also enforce `UNIQUE(customer_id, purchase_key)` and a nonnegative-stock constraint. At PostgreSQL Read Committed, a competing updater waits for the row lock and rechecks its predicate against the updated row. Starting from two units, T1 changes 2 -> 0 and commits; T2 then finds `available >= 2` false and must roll back its transaction, removing the order it inserted earlier in that attempt. Starting from five, the single purchase changes 5 -> 3. More complex multi-row rules still need the stronger strategy described above.

Claim the unique purchase key before allocating stock, as in this SQL order. A duplicate waits for the first transaction and recovers its existing outcome even if the successful purchase exhausted inventory. The new order remains uncommitted until all steps succeed; an insufficient-stock rollback removes it too. Performing the stock check first without resolving a prior purchase could incorrectly return out-of-stock for a retry of an already successful order.

06 / Unknown commits and changing transaction boundaries



INTERVIEW CRITICAL

Recover an unknown commit with the same purchase identity

A lost commit response creates an **unknown outcome** at the caller. Durability does not make a new retry safe: creating O82 after O81 already committed could decrement stock twice. Bind one stable purchase identifier to the order and enforce uniqueness in the same transaction. Retrying then recovers O81 rather than creating another purchase.



INTERVIEW CRITICAL

Splitting owners changes the transaction boundary

Growth changes the choices. Read replicas can serve some history queries if their lag is acceptable. Partitioning orders by customer spreads that work, but MUG9 inventory is shared across customers. Moving order and inventory to independent owners changes the transaction boundary. It requires a deliberate distributed transaction or reservation workflow, not unchanged local code aimed at two database URLs.

Large images belong in storage suited to media bytes and delivery, with authoritative metadata references. Analytics can scan a derived store so monthly reports do not crowd out purchases. Add those paths when requirements and measurements justify their maintenance cost. Each derived view needs committed input, a freshness policy, and a recovery mechanism.

Two concurrency failures also require a fresh attempt. A **serialization failure** means the database cannot safely commit the attempted concurrent execution under its isolation rules. A **deadlock** occurs when transactions wait on one another's held resources in a cycle; the database aborts an attempt to break that cycle. In either case, the application must reevaluate the purchase from fresh reads.

If the purchase key already exists, roll back the whole attempt. Then read the earlier order and its request hash in a new transaction. In this example, the duplicate is detected before stock is allocated. Return the

saved result only if the normalized request matches. After a serialization failure or deadlock, retry the whole transaction with the same purchase ID and a retry limit, not just the final INSERT.

07 / Interview answer: choose a database for orders

Interviewer: "Would you use SQL or NoSQL for orders?"

Candidate: "I would list the queries and atomic rules first. The workload needs O81 by ID, recent orders for U7, and a purchase changing shared inventory from five to three while creating the matching order. A relational model with indexes and a suitable transaction is a straightforward starting point.

"A document can make complete-order reads convenient, but inventory is shared across many orders. I still need a supported transaction, or an explicit stock-reservation workflow, to coordinate that change with order creation. I would not claim one family always scales better or always lacks transactions. If history reads dominate later, I can add a read model. If inventory becomes an independent service, I must redesign the workflow."

The answer connects a storage choice to the work the product performs and names what would make us reconsider. That is more useful than choosing from vendor slogans or treating a flexible schema as permission to skip data modeling.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What are a data model, access pattern, invariant, and transaction? How do they guide database choice?

Model answer

A data model describes the representation: tables, documents, key-value pairs, or graph relationships. An access pattern is a specific query or update, such as recent orders for customer U7. An invariant is a rule that must remain true, such as stock never becoming negative. A transaction treats operations as one logical unit whose changes commit or roll back together. ACID names atomicity, ACID consistency, isolation and durability; the engine and its settings determine the exact guarantees.

For an order service, write down order-by-ID, customer history, and conditional stock allocation. If reducing stock from 5 to 3 must commit with creating a $24 order, a relational database with suitable indexes and a local transaction is a straightforward starting point. Then test expected volume, hot-item contention, and the actual engine's features. SQL and NoSQL labels alone do not determine scale or transaction support.

Interviewer follow-up

Would a billion rows automatically change your choice?

"No. Row size, access locality, indexes, request rate, and partitioning capabilities determine the bottleneck. I would identify the limiting operation first."

What the answer must demonstrate: Size alone does not describe a workload.

02 / APPLIED

An order contains its item lines, while product inventory is shared across many orders. Would storing each order as one document make the whole purchase atomic?

Model answer

"Embedding O81's lines makes the order read convenient, but MUG9 stock is shared by many orders. Copying available quantity into each order creates competing truths. I would keep stock in one authoritative inventory system and use a supported transaction, or an explicit reservation workflow, to coordinate stock allocation with the order."

Interviewer follow-up

When is embedding a good idea?

"When related data is normally read or updated together and remains bounded. It simplifies that aggregate without removing relationships outside it."

What the answer must demonstrate: Distinguish one aggregate from all shared state.

03 / FOUNDATION

How does wide-column differ from analytical columnar storage?

Model answer

"A wide-column model can place U7's orders in one partition and order them by time for a known serving query. Analytical columnar storage supports scans of selected attributes across many records. Similar names do not make their access shapes or guarantees interchangeable."

Interviewer follow-up

Where would a monthly aggregate report run?

"I would consider a derived analytical path if scans disrupt purchases, then define its lag and reconciliation. A serving database and report workload need not share one bottleneck."

What the answer must demonstrate: Avoid treating column-related names as one category.

04 / FOUNDATION

A purchase must create order O81 for two $12 items and reduce stock from 5 to 3. Explain ACID for that transaction.

Model answer

"Atomicity makes stock allocation and order insertion succeed together or have neither change take effect. Correct logic preserves nonnegative stock. Isolation governs concurrent buyers. Durability defines which failures committed O81 survives. I would show the transaction and its settings because saying 'ACID database' does not prove the application rule."

Interviewer follow-up

Is ACID consistency the same as CAP consistency?

No. ACID consistency preserves database and application rules, such as nonnegative stock. CAP consistency means linearizability: after a write completes, a later read must see it or a newer write. A store can serve fresh values while bad transaction logic breaks a business rule.

What the answer must demonstrate: Name the rule and distinguish the two meanings.

05 / APPLIED

Two concurrent purchases each request two units when stock is two. What prevents overselling?

Model answer

"I put UPDATE Inventory SET available = available - 2 WHERE sku = the_requested_sku AND available >= 2 in the same transaction as the order insertion, and require one affected row before continuing. In PostgreSQL Read Committed, the second updater waits and rechecks the predicate. If the first commits stock 2 -> 0, the second affects zero rows and rolls back instead of creating an order. A stock CHECK constraint is useful defense, but I still need the transaction and affected-row check."

Interviewer follow-up

What if the rule spans several products?

"I need a transaction strategy protecting the whole rule or a deliberate reservation workflow. One row's condition cannot enforce an unstated cross-row invariant."

What the answer must demonstrate: A fresh read is not an atomic allocation.

06 / FOUNDATION

Why does a flexible schema still need planning?

Model answer

"Old and new consumers must agree on quantity, currency, and record versions. Permitting multiple shapes does not tell the application how to interpret them. I would validate required fields and stage compatible readers and writers so a storage change does not silently change meaning."

Interviewer follow-up

Must a relational schema alteration require downtime?

"Not universally. The exact operation and engine determine locks and rewrite costs; many changes can be staged compatibly."

What the answer must demonstrate: Flexibility does not eliminate migration work.

07 / APPLIED

Order O81 commits but the response is lost. How should the application recover the outcome?

Model answer

"The retry carries the same customer-scoped purchase key and request. I claim that unique key when inserting the uncommitted order, before allocating stock. If the key conflicts, I roll back the attempt, then use a fresh transaction to read and validate the original order's request hash. This returns the original success even if it exhausted the remaining stock. A new purchase ID or a stock check performed before resolving the duplicate would give the wrong retry behavior."

Interviewer follow-up

What if the retry changes the quantity?

"I reject reuse of the same identifier for different request data, or apply an explicit documented policy. It cannot silently mean another purchase."

What the answer must demonstrate: Unknown commit is different from known rollback.

08 / FOLLOW-UP

What changes when inventory becomes an independent service?

Model answer

"The stock and order updates no longer share the original local transaction. I must choose a distributed transaction or durable reservation workflow with explicit intermediate and compensation states. Moving tables across owners without revisiting that boundary loses the guarantee my first design depended on."

Interviewer follow-up

Could a search index become the stock authority?

"No. Search is a derived discovery path and may lag. A purchase still requires the system that enforces the stock rule."

What the answer must demonstrate: Ownership changes can change correctness, not only performance.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Model order O81 for two MUG9 items at $12 each using relational tables and an embedded document. Specify indexes and the transaction that creates the $24 order while changing stock from 5 to 3.

- Show keys for order lookup and customer history.
- Distinguish shared inventory from the immutable purchase-price snapshot.
- Trace two competing buyers through conditional allocation.
- Recover an order whose commit response was lost.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What comes before SQL versus NoSQL?

The important read/write patterns and the rules that must hold together.

Questions first, product second.

How does one purchase explain ACID?

Stock allocation and order creation commit together, preserve rules under the chosen concurrency model, and survive the configured failures.

One purchase, one protected decision.

Does flexible schema mean no schema?

Applications still need field meanings, validation, and version compatibility.

Flexible shape still needs shared meaning.

Why keep the purchase price in OrderLine?

It records the price committed at purchase time, independently of later catalog changes.

History is a fact, not a live catalog lookup.

Summary and interview notes

Choose a database from the reads, writes and rules your service needs. Show how concurrent purchases preserve those rules: stock allocation and order creation can share one transaction. Then handle lost replies, copied views and operations in other services separately.

Remember these points

• A data model represents facts; indexes and partition keys make particular access patterns efficient.

• Order-line prices are historical facts, so copying the agreed price is deliberate modeling rather than accidental duplication.

• ACID consistency means preserving application rules; it is different from CAP linearizability.

• An atomic conditional stock decrement must be checked for success and committed with the order.

• A stable customer-scoped purchase key and matching request data recover duplicate or uncertain attempts.

Interview tips

• Write one important read query and one multi-record invariant before naming a database product.

• Act out two concurrent buyers with stock equal to two; identify the lock, predicate recheck, and zero-row outcome.

• When splitting services, redraw the transaction boundary before discussing horizontal scaling.

Important qualifications

• Read Committed behavior in the worked SQL is PostgreSQL-specific; verify another engine before transferring that proof.

• Transactions and isolation levels vary within both relational and NoSQL families.

• The SQL excerpt omits table creation and production error handling; its affected-row branch is required application logic.

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MongoDB: Transactions
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https://www.mongodb.com/docs/manual/core/transactions/

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https://cassandra.apache.org/doc/latest/cassandra/developing/data-modeling/data-modeling_logical.html

Oracle Database Concepts: database and DBMS
Basic distinction between an organized data collection and the software managing it.
https://docs.oracle.com/en/database/oracle/oracle-database/21/cncpt/introduction-to-oracle-database.html

PostgreSQL tutorial: Transactions
Introduces transactions as all-or-nothing units, then explains concurrent visibility and durability.
https://www.postgresql.org/docs/current/tutorial-transactions.html

FOUNDATIONS / 06

Database indexes: B-trees, composite keys and query access

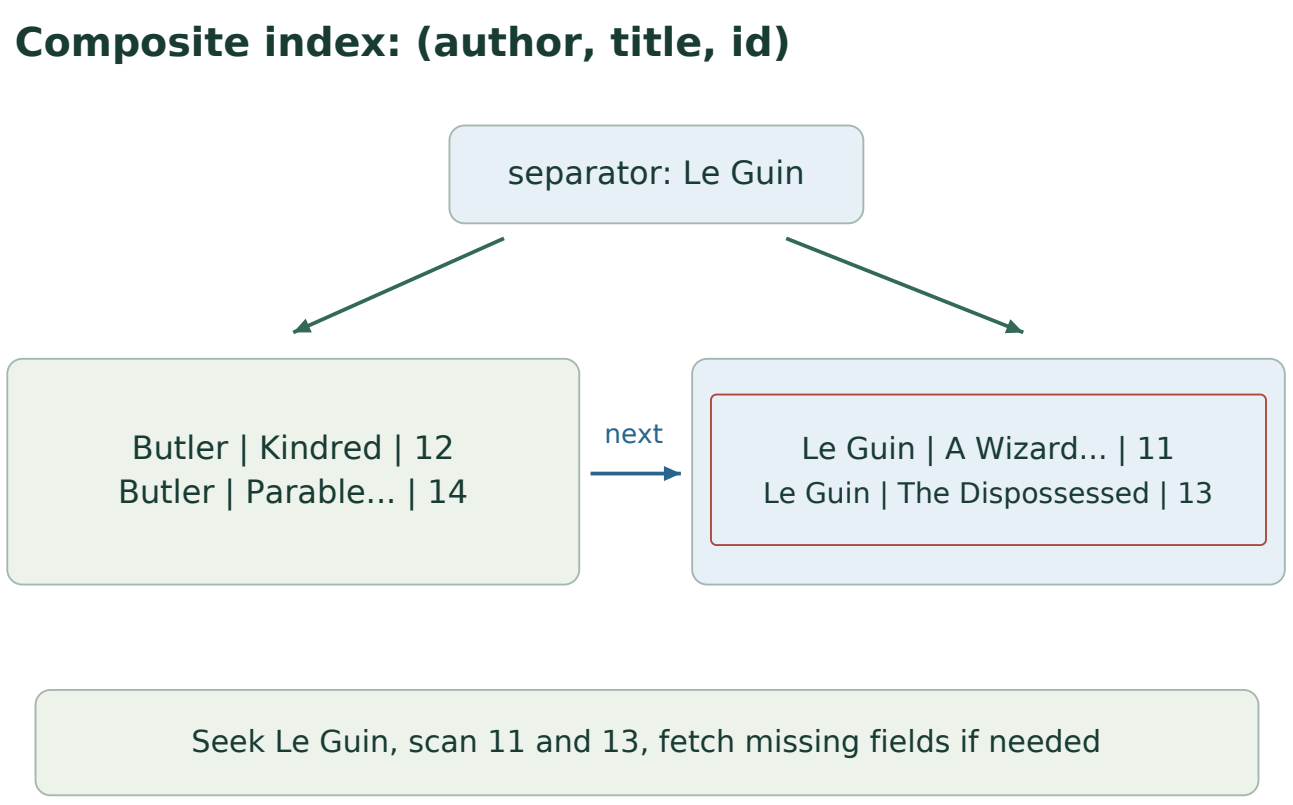
DEFINITION

A database index is a maintained data structure that maps searchable keys to records or contains the data needed by a query. It can reduce the records inspected for a read, at the cost of extra space and maintenance on writes.

Why it matters: Without a suitable index, finding a few rows can require scanning a large table. The right index organizes keys for the specific filter, order and limit that the application asks for.

Composite B-tree index: seek, range scan, and row lookup

The ordered index on (author,title,id) places one author's books together in title order. Additional table reads depend on which output fields are covered.



Column order determines the useful range. Every extra index also adds write and storage work.

Worked example

An author/title index places Le Guin's books next to each other. A query seeks to Le Guin, reads the entries for IDs 11 and 13 in title order, and fetches base rows when needed for missing fields or visibility checks.

Key takeaways

- Start with the query's filter, order and limit.
- Composite key order determines which ranges are easy to search.
- Each maintained index adds work to relevant writes.

Read the visual model

1. Sorted entries are Butler/Kindred/12, Butler/Parable/14, Le Guin/A Wizard/11, and Le Guin/The Dispossessed/13.
2. A query for Le Guin ordered by title seeks to the first Le Guin entry, then scans the two adjacent keys.
3. IDs 11 and 13 identify the base rows. Missing output fields require row fetches; a covering index can still need heap visibility checks, depending on the database and visibility state.
4. Filtering title alone cannot generally use the same narrow author-first range. Index writes and bytes are the cost.

B-tree • composite index • query plan • pagination

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain how an index narrows a lookup.
- Order a composite index for a concrete filter and sort.
- Show the write, memory, and storage cost of maintaining indexes.

Useful foundations: Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / Database index: definition and tradeoff

A database index is a maintained data structure that maps searchable keys to records or contains data needed by a query. A key is the field or ordered combination of fields used for lookup, such as author and title. Think of a library catalog: to find books by Ursula Le Guin, you consult the author catalog rather than walking past every shelf. The catalog points to books; it is not a second copy of every page inside them.

Suppose our database has `Book(id, author, title, publishedYear)`. Without a useful index, a query for one author may inspect every book row. With an author index, the engine can locate the relevant author entries and then fetch their rows. An index trades extra stored structure and write work for less work on selected reads.



INTERVIEW CRITICAL

Choose the index from the actual query

The word "selected" matters. An index that helps one query may do little for another. Choosing an index begins with the actual filter, ordering, result count, and fields returned by the query - not with an instruction to index every column.

02 / Worked example: author and title lookup

Consider a `Book` table containing the following four rows. We want to find Le Guin's books and return them in title order:

ID	Author	Title
11	Le Guin	A Wizard of Earthsea
12	Butler	Kindred
13	Le Guin	The Dispossessed
14	Butler	Parable of the Sower

The query is:

```
SELECT id, author, title
FROM Book
WHERE author = 'Le Guin'
ORDER BY title, id;
```

It returns IDs 11 and 13, in that order. Adding `id` makes the order deterministic if two books have the same title. For this example, assume an ordinary alphabetical collation; the database's configured collation determines the actual text ordering.

A simplified ordered index on `(author, title, id)` contains `(Butler, Kindred, 12)`, `(Butler, Parable..., 14)`, `(Le Guin, A Wizard..., 11)`, and `(Le Guin, The Dispossessed, 13)`.

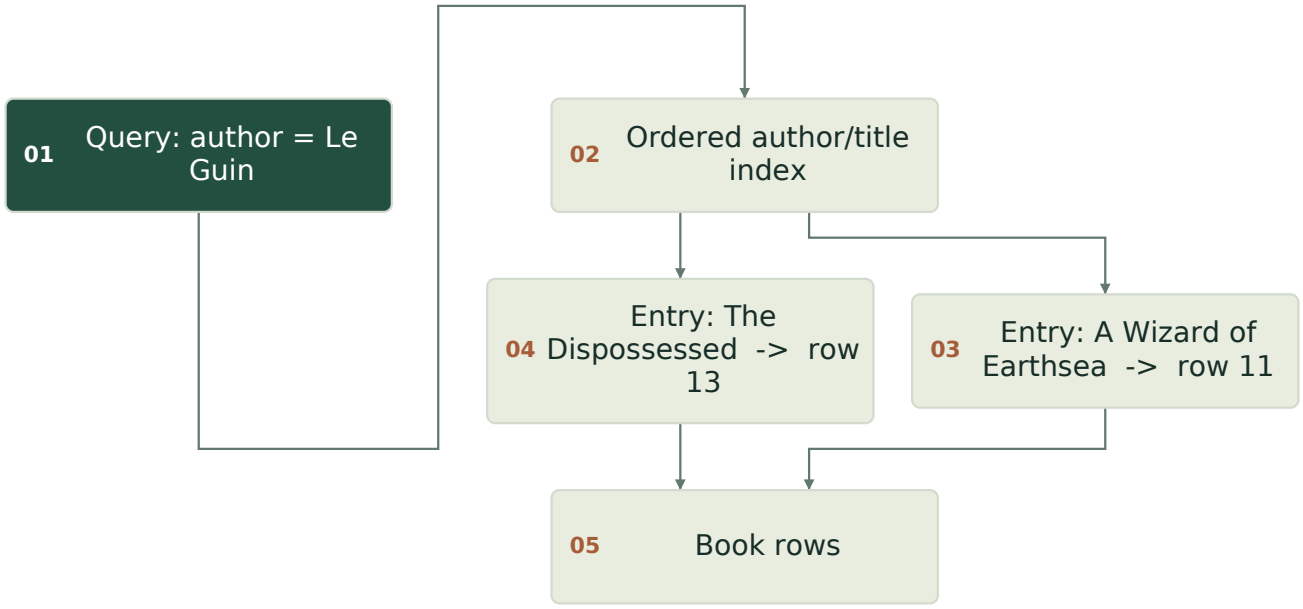
1. The query asks for `author = 'Le Guin'` ordered by title and ID.
2. The database seeks to the first index entry with that author.
3. It scans the adjacent Le Guin entries in title order.
4. It reads rows 11 and 13 if the requested output needs fields unavailable from the index.
5. It stops when the author changes or the requested limit is met.

A **seek** navigates directly to a relevant key range; a **scan** then walks entries. Here the index has converted a whole-table search into a narrow seek and scan. If the table is tiny, a scan may still be cheaper; the query optimizer estimates these costs rather than treating any existing index as mandatory.

Selectivity describes how narrowly a predicate filters records. State the matched fraction to avoid terminology ambiguity: 100 matching rows out of one million is 0.01%, while 900,000 matches is 90%. The first query may avoid much table work with an index; the second may be cheaper as a sequential scan. Physical row placement, cached pages and which columns are returned still affect the decision. The mere existence of an index cannot establish the faster plan.

WORKED EXAMPLE DIAGRAM

The query touches the matching index range and its rows. It need not inspect every author; the example table shows the actual keys.



1 -> 2	seek author range: Query: author = Le Guin -> Ordered author/title index
2 -> 3	first matching title: Ordered author/title index -> Entry: A Wizard of Earthsea -> row 11
2 -> 4	next matching title: Ordered author/title index -> Entry: The Dispossessed -> row 13
3 -> 5	fetch row 11 if needed: Entry: A Wizard of Earthsea -> row 11 -> Book rows
4 -> 5	fetch row 13 if needed: Entry: The Dispossessed -> row 13 -> Book rows

03 / B-tree, hash and inverted indexes

The book example needs both an author lookup and title ordering. Index structures organize searchable keys differently, so a structure that narrows an exact lookup may not support an ordered range or a word search. Compare the structures by how they reach the candidate records.

A **B-tree index** keeps search keys in sorted order inside a balanced tree of storage pages. It lets a database find a key without checking every row, and it can scan a consecutive range of keys.

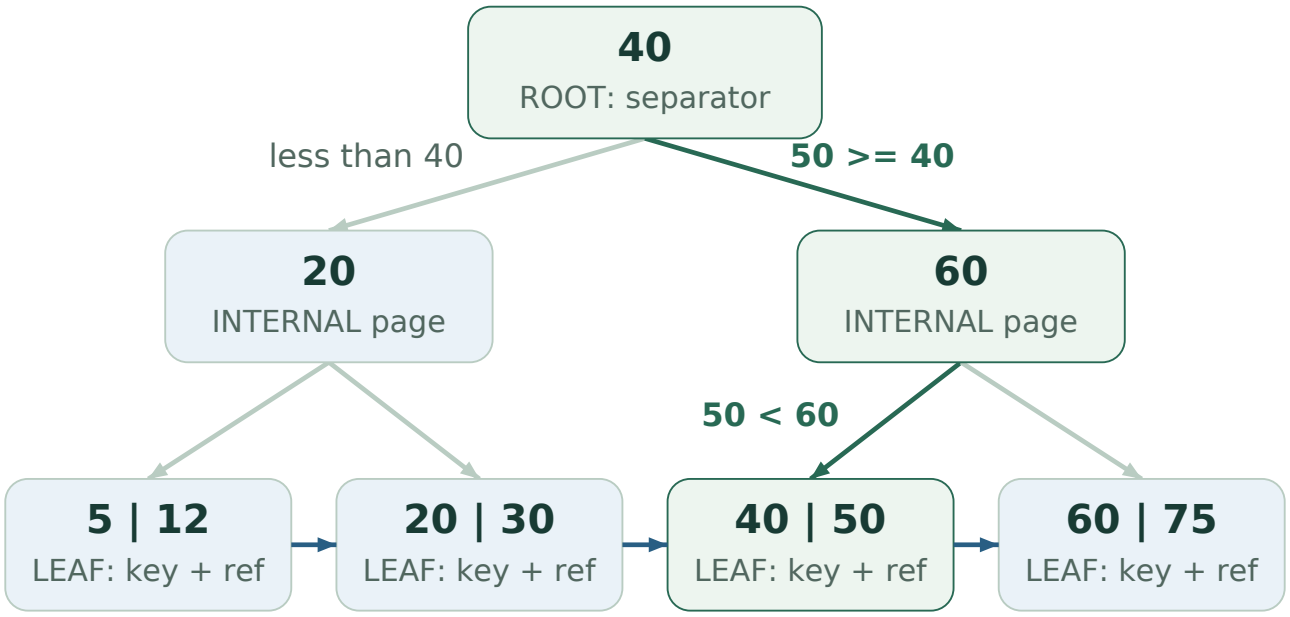
To read the tree below, start with three terms:

1. A **page** is a block of data that the storage engine manages as a unit. One page can contain many keys.
2. The **root** is the entry page. Keys in internal pages act as signposts to the next page. For example, a separator at 40 sends a search for 50 to the side containing keys 40 and above.

3. A **leaf** is a page at the bottom. **Balanced** means every root-to-leaf path has the same number of levels. The example is a B+ tree, a common B-tree variant: its searchable record entries are in the leaves, which are linked for scans.

B-tree anatomy: pages, pointers and equal depth

A small B+ tree illustrates the B-tree family. Separator keys route searches; record entries are in leaves here. General B-tree variants may also store records in internal nodes.



Remember: Root chooses a range; internal pages narrow it; a leaf finds the entry.

An **equality query** asks for one exact value, such as `id = 42`. A **range query** asks for values between bounds, such as years 2000 through 2010. A B-tree can answer both: descend to the first matching key, then follow the ordered entries if more matches are needed.

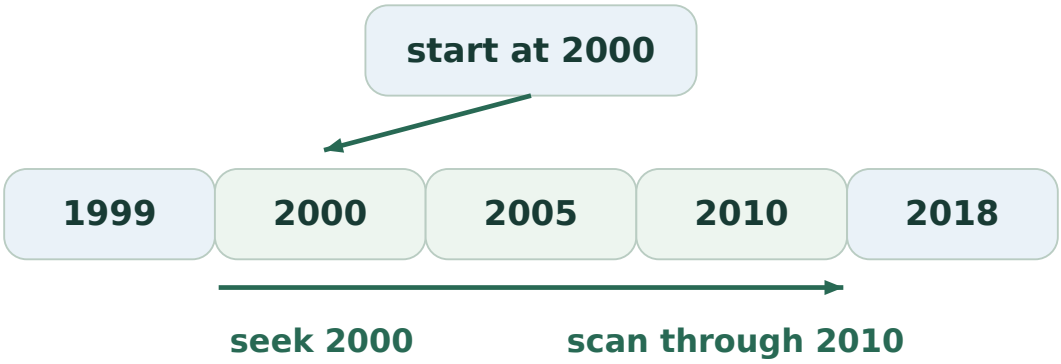
A **hash index** applies a hash function to a search key to choose a **bucket**, a group of candidate entries. Different keys can share a bucket, so the engine still checks which entry actually matches. Hash buckets group by hash value, not by the original key's order; they do not naturally support scanning consecutive years.

An **inverted index** maps a term to the documents containing it. Its **postings list** contains document IDs and may also include counts or positions. For example, `green -> [D1, D3]` means documents D1 and D3 contain "green." It is called inverted because it goes from term to documents, reversing the document-to-terms view.

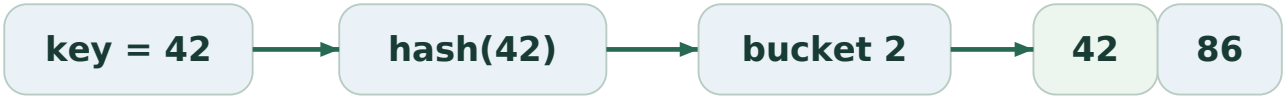
Watch each index answer a different query

Follow each query to the entries it matches. The bucket assignment is illustrative; a real hash function determines it.

1 B-tree range scan: years 2000 through 2010

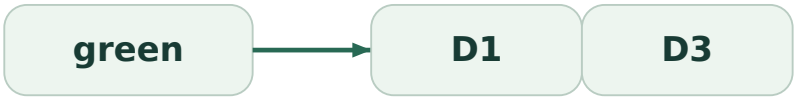


2 Hash: find the record whose key is 42



A bucket is a group of candidates. Check the key: 42 matches; 86 does not.

3 Inverted: find documents containing "green"



D1: green chair

D3: green desk

The list [D1, D3] is a postings list: document IDs for this term.

Remember: A year range needs order. An exact key needs a match. A search term needs document IDs.

Try from memory: Which of these supports scanning the next ten years in order?

Answer: The B-tree. It preserves year order, so it can seek to the first year and scan onward. A hash bucket does not preserve that order; a term postings list answers a different question.

Query you need to answer	Useful structure	What the engine follows
Find `id = 42`	B-tree or a suitable hash index	Ordered search path, or bucket candidates
Find years 2000 through 2010 in order	B-tree	First qualifying key, then ordered entries
Find documents containing "green"	Inverted index	The term's postings list
Find one customer's newest orders	Composite B-tree	Customer group, then timestamp/ID ordering

Interview tip: start with the query, then justify the index. Equality does not automatically make a hash index better than a B-tree; consider the database's supported operations, measurements and other query needs.

An index does not necessarily sort the underlying table the same way. Some engines cluster table records around a primary key; others keep index entries separate from table pages. An index-only scan also depends on coverage and visibility rules in the chosen database.

Composite means the key contains several fields; it is not a competing tree algorithm. **Covering** means the index contains the fields needed by a query; it is not a separate universal storage structure.

04 / Composite indexes, key order and covering queries

The author/title example used several fields to group related records and order them within a group. Apply the same idea to customer order history: first isolate one customer, then return only that customer's newest orders. Consider this query:

```
SELECT orderId, createdAt, total
FROM Orders
WHERE customerId = 'C27'
ORDER BY createdAt DESC, orderId DESC
LIMIT 20;
```



INTERVIEW CRITICAL

Column order and tie-breaking determine the access path

An index beginning `(customerId, createdAt DESC, orderId DESC)` groups C27's orders and provides the requested ordering. `orderId` breaks ties when two orders share a timestamp, making pagination deterministic. A different index beginning with `createdAt` primarily groups records across all customers by time; it may inspect many irrelevant customers to find C27's rows.

The **leftmost prefix** rule says that a composite B-tree index most directly supports lookups using its first column, or its first several columns together. It is a useful starting point for B-tree reasoning, not a universal claim that an engine can never use a later column. Optimizers may use skip scans or combine indexes depending on data distribution and implementation. In an interview, explain why your selected leading columns narrow the work directly, then inspect a plan in a real system.

A covering index includes fields needed by the query, such as `total`, to reduce row fetches where the engine allows it. The cost is a larger index and more updates when those fields change.

For PostgreSQL, the concrete candidate is:

```
CREATE INDEX orders_customer_newest
ON Orders (customerId, createdAt DESC, orderId DESC)
INCLUDE (total);
```

INTERVIEW CRITICAL

A covering index may still require table reads

`total` is stored as payload, not as an additional ordering key. PostgreSQL also checks whether rows are visible to the query's transaction snapshot. Its visibility map can let an index-only scan avoid table reads; recently modified pages may still require them. Thus this is a candidate to test, not a promise of zero table access. See index-only scans.

A composite key sorts in stages

Read down the rows. Customer comes first, timestamp second, and unique order ID breaks timestamp ties.

Sort by customer, then time, then unique ID

customer ASC	time DESC	ID DESC
C26	10:05	O410
C27	10:03	O402
C27	10:00	O400
C27	10:00	O399
C28	10:09	O420

C27 stays together

At equal times, O400 precedes O399. The tuple is the sort key.

Remember: Group by the first field; sort inside that group by the next.

Try from memory: Why is C28's 10:09 order below C27's older orders?

Answer: Customer is the first sort field. Timestamps order entries only within each customer group.

The query expression must match the access path too. An ordinary index on `email` does not provide the same ordered keys as `lower(email)`. PostgreSQL supports an expression index on `lower(email)` when case-normalized lookup is the intended rule. That normalization has to match the product's equality semantics; adding an index does not decide which spellings should count as the same address. See expression indexes.

05 / Index maintenance and write amplification

An index must stay consistent with changes to the records it describes. **Write amplification** is the additional physical write work created by one logical application change. Index maintenance contributes to that cost because changing one row can require updating several stored structures.

Insert book 15: `(Le Guin, The Left Hand of Darkness, 1969)`. The database writes the row and adds entries to each maintained index: the primary-key index, author/title index, and perhaps a publication-year index. Updates of indexed fields remove or supersede old entries and install new ones; deletes must maintain the indexes too.

The engine also writes recovery logs. Index pages may split, use more cache memory and add disk writes. Ten indexes do not make every read ten times faster; a write affecting all ten must maintain ten extra structures.

Choice	Read benefit	Cost
Author index	Find one author's books	Extra entry per book
Author/title index	Filter author and return ordered titles	Larger composite key
Covering order index	Potentially fewer table fetches	Copies more fields into index
Unused index	No observed query benefit	Still consumes writes, space, maintenance

Measure actual query use before removing an index: a rare month-end report or constraint may still depend on it. An index used to enforce uniqueness is part of correctness as well as read performance.

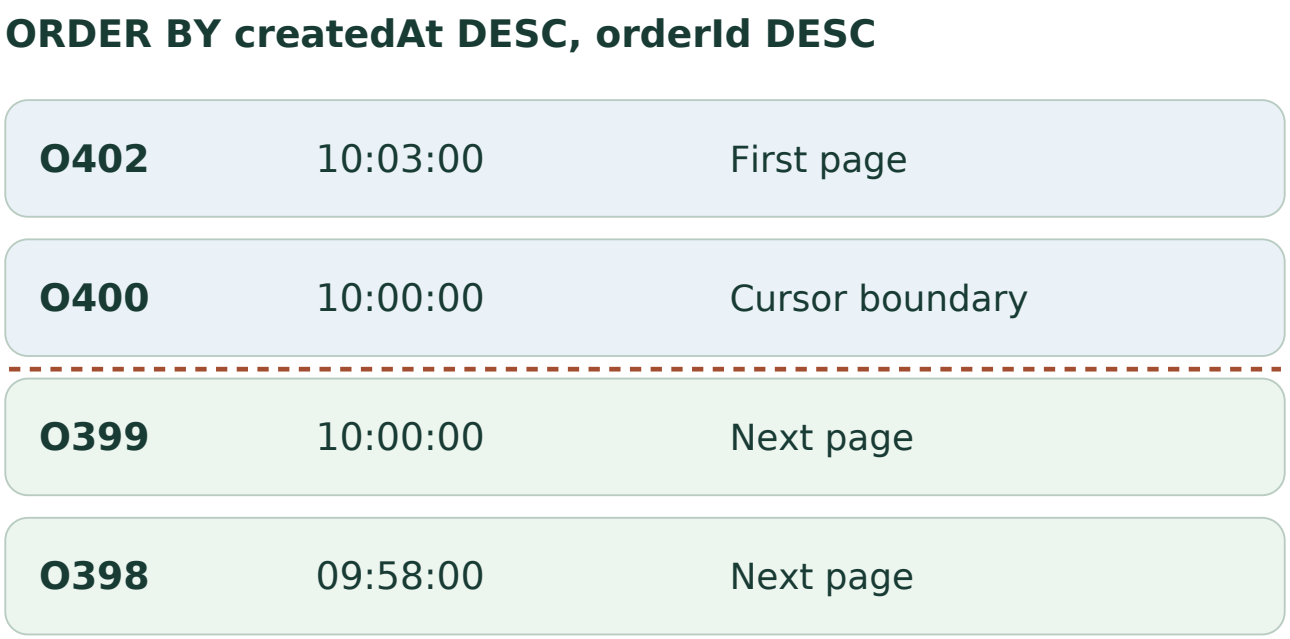
06 / Keyset pagination versus OFFSET

Pagination returns a bounded portion of a result instead of every matching row at once. After C27's newest orders have been returned, the next request needs a continuation rule. An **offset** skips a count of earlier results; **keyset pagination** continues after the last ordering key that the client received.

For C27's next page, a cursor can encode the last seen `(createdAt, orderId)`. The next query continues below that tuple in the same ordering. A cursor is a position in a chosen ordering, not necessarily a database transaction kept open between requests.

A cursor marks a boundary in the ordered keys

The first and next pages share one descending ordering. The dashed line is the exclusive cursor boundary, not a snapshot of the database.



Same time; unique ID breaks the tie.

Continue strictly below (10:00:00, O400): return O399, then O398. All times are UTC on 2026-09-22; all orders belong to C27.

Remember: Continue after a tuple, not after a count.

INTERVIEW CRITICAL

A stable cursor does not freeze the dataset

With `OFFSET 100000`, the engine may still need to walk past many earlier qualifying entries. Keyset pagination can seek from a known key instead. Define behavior when records are inserted or deleted between pages; deterministic keys reduce duplicates from ties but do not automatically create a fixed snapshot.

In a sharded database, first find the shard holding C27's orders. A local index finds rows within that shard; it does not tell the client which shard to contact. Global searches need a distributed index or queries to several shards. Explain the API query, shard key and local index together.

For a compact example, use two rows per page instead of twenty. Assume `createdAt` is non-null and never changes, `orderId` is unique, and all four orders belong to C27:

Order ID	Creation time (UTC)	Page
O402	2026-09-22 10:03:00	First
O400	2026-09-22 10:00:00	First; cursor boundary
O399	2026-09-22 10:00:00	Second
O398	2026-09-22 09:58:00	Second

After returning O402 and O400, the next PostgreSQL query is:

```
SELECT orderId, createdAt, total
FROM Orders
WHERE customerId = 'C27'
  AND (createdAt, orderId) <
      (TIMESTAMPTZ '2026-09-22 10:00:00+00', 'O400')
ORDER BY createdAt DESC, orderId DESC
LIMIT 2;
```

It returns O399 and O398. The strict tuple comparison handles the timestamp tie without repeating O400 or skipping O399. This assumes `createdAt` has type `timestamptz` and the ID comparison orders O399 before O400; use matching types and ordering in the real schema.

An order inserted with a newer timestamp belongs before this boundary and appears when the user refreshes the first page. A backdated insert may appear on a later page. That is why a stable cursor prevents shifts from newer inserts but does not freeze the dataset. See PostgreSQL's LIMIT and OFFSET documentation.

07 / Interview example: index customer order history

Interviewer: "How would you make customer order history fast?"

Candidate: "The request filters one customer and returns the newest twenty orders. I would use a composite index with customer first, then descending creation time and an order-ID tie breaker. The database seeks into that customer's range and reads a small ordered slice. A cursor carries the last timestamp and ID for the next page. I accept extra index writes and space, and verify the plan and latency using realistic customer sizes."

This is more useful than saying "add a B-tree": it explains which keys the tree contains and which work the query avoids.

A **query plan** describes the operations the database intends to use, such as an index seek, a table scan or a sort. Inspecting that plan tests whether the engine actually uses the access path the design relies on.

To verify the candidate in PostgreSQL, begin with `EXPLAIN` on the exact SELECT, including its filter, sort and limit. On a representative test workload, `EXPLAIN (ANALYZE, BUFFERS)` executes that query and reports actual work. Compare estimated and actual row counts, rows discarded by filters, sort work, buffers touched and table fetches. If estimates are poor, inspect statistics and skew before assuming another index is the answer. Repeat for a large customer and for cold versus warm cache conditions, then measure write cost. These observations test why the index helps; an "Index Scan" label alone is not a success criterion. See using EXPLAIN.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is an index, in plain language?

Model answer

"It is a maintained search structure that helps locate records without checking every row. An author catalog points to books by an author. In a database, the index stores searchable keys and enough information to find or return matching data."

Interviewer follow-up

Why not create one for every field?

Every maintained index consumes space and adds work to relevant inserts, updates, and deletes. I choose indexes from actual queries and constraints.

What the answer must demonstrate: Explain the read/write tradeoff.

02 / FOUNDATION

How does an index on (author, title, id) answer author = Le Guin ordered by title?

Model answer

"It seeks to the first Le Guin entry and scans that contiguous author range in title order. It fetches the matching book rows only if required fields or visibility checks need them, then stops at the range end or limit. The benefit is avoiding unrelated authors, not assuming every query can be served entirely from the index."

Interviewer follow-up

Would it help a query on title alone equally well?

Not necessarily: author is the leading ordering. The engine may use another access method, but a title-leading index directly matches that different query.

What the answer must demonstrate: Walk the keys rather than naming the structure.

03 / APPLIED

Which index fits customer history sorted newest first?

Model answer

"I start with customerId, then createdAt descending, then orderId descending for ties. Equality on customer narrows the range and the remaining order supports the requested slice. I would include returned columns only if reducing row lookups justifies a larger index."

Interviewer follow-up

Why include orderId when timestamps exist?

Two orders can share a timestamp. A unique tie breaker creates a deterministic order and a complete pagination cursor.

What the answer must demonstrate: Explain equality, ordering, and tie breaking.

04 / APPLIED

When inserting a new book row with ID 15, what additional work do maintained indexes require?

Model answer

"The table gets a row and each maintained index gets a corresponding entry. The storage engine also performs its logging and any page maintenance required. Extra indexes therefore increase write amplification, memory pressure, and storage even if this insert is only one business operation."

Interviewer follow-up

What about an update to an indexed title?

The author/title index must reflect the new key. The exact update mechanism depends on the engine, but later queries must find the correct title for the row version they are allowed to read.

What the answer must demonstrate: Account for all maintained structures.

05 / APPLIED

What is a covering index?

Model answer

"It contains the fields needed to answer a query, potentially avoiding separate row fetches. For order history I might include total with the ordering keys. Whether an index-only scan is actually possible also depends on the engine's visibility rules and query plan."

Interviewer follow-up

What is the cost of including total?

More index bytes and maintenance when total changes. I measure whether saved reads justify that cost.

What the answer must demonstrate: Do not promise every covered query avoids all table access.

06 / APPLIED

Why can a large OFFSET be expensive?

Model answer

"The database may still walk past the earlier matching entries before returning the requested page. A keyset cursor lets the next query seek after the last seen ordering tuple. I use a stable tie breaker and define how concurrent inserts affect the browsing session."

Interviewer follow-up

Does a cursor guarantee an unchanged snapshot?

No. It identifies a position. A snapshot across pages requires an additional consistency/version mechanism if the product needs it.

What the answer must demonstrate: Separate ordering and snapshot consistency.

07 / APPLIED

Why might the optimizer ignore an index?

Model answer

"A query matching 90% of a table may do more work through index-to-row lookups than through a sequential scan; a query matching 100 rows in a million has a different cost. I inspect estimated versus actual rows, buffers, filtering and sort work for the exact query. Small tables, stale statistics and data skew can change the plan."

Interviewer follow-up

Would a low-cardinality boolean index always be useless?

No. It can help selective partial queries or specific engine strategies. The useful question is how much work it avoids for this query and distribution.

What the answer must demonstrate: Avoid absolute rules disconnected from data.

08 / APPLIED

Does an index solve finding data across shards?

Model answer

"A local index searches within its storage owner. The request still needs to identify the right shard, or query a distributed index or multiple owners. For customer history, customer-based routing and a customer/time local index work together."

Interviewer follow-up

What if the query does not include the shard key?

I need a separate location/index path or bounded fanout, with its latency and consistency costs.

What the answer must demonstrate: Explain routing before local lookup.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Design an index and cursor for customer order history. Trace one read and one insert.

- Write the query with filter, ordering, and limit.
- Show at least four actual ordered keys.
- Explain the write cost of each index.
- Describe ties and concurrent changes between pages.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

How do you justify the cost of an index?

Show the filter, order, and limit that it accelerates.

Query first, index second.

For one customer's newest orders, what should a composite index put first?

Customer ID narrows the search, followed by the ordering fields and a tie-breaker. Their order must match the query.

Find the customer -> order their rows -> take the page.

Write overhead

One row write can update several indexes plus recovery logs.

Every index must be maintained.

Summary and interview notes

An index exchanges extra storage and write maintenance for less work on specific queries. Choose its keys from the filter, requested ordering and limit, then verify the plan on representative data rather than assuming an index is always faster.

Remember these points

• B-tree key order supports equality, ranges and compatible ordering; composite and covering describe properties, not separate tree algorithms.

• Equality on customer plus ordered timestamp and unique ID supports a deterministic history page.

• A covering index may reduce row fetches, but engine visibility rules can still require them.

• Finding a few rows and scanning most of a table have different costs; measure rows examined and actual work.

• A keyset cursor gives an ordering boundary, not an unchanged snapshot across requests.

Interview tips

• Write the actual query before proposing an index, then trace seek, scan and any row fetch.

• Explain the write and storage cost of every added key or included field.

• Use a plan to compare estimated and actual work; do not treat an Index Scan label as sufficient evidence.

Important qualifications

• Leftmost-prefix reasoning is a useful starting point, but current PostgreSQL can use skip scans in suitable distributions.

• Normalization, collation and expressions must match the intended query semantics.

• The PostgreSQL DDL is an implementation example; other engines have different clustering, coverage and visibility rules.

Technical references

PostgreSQL multicolumn indexes
B-tree column-order behavior and implementation-specific optimizations.
https://www.postgresql.org/docs/current/indexes-multicolumn.html

PostgreSQL index documentation
Index types, ordered access, covering indexes, and maintenance considerations.
https://www.postgresql.org/docs/current/indexes.html

PostgreSQL index-only scans and covering indexes
INCLUDE payload columns and transaction visibility constraints.
https://www.postgresql.org/docs/current/indexes-index-only-scans.html

PostgreSQL using EXPLAIN
Estimated versus actual query work, row counts and buffer observations.
https://www.postgresql.org/docs/current/using-explain.html

PostgreSQL indexes on expressions
Indexing an expression such as lower(email) to match a query.
https://www.postgresql.org/docs/current/indexes-expressional.html

FOUNDATIONS / 07

Storage engines and data models

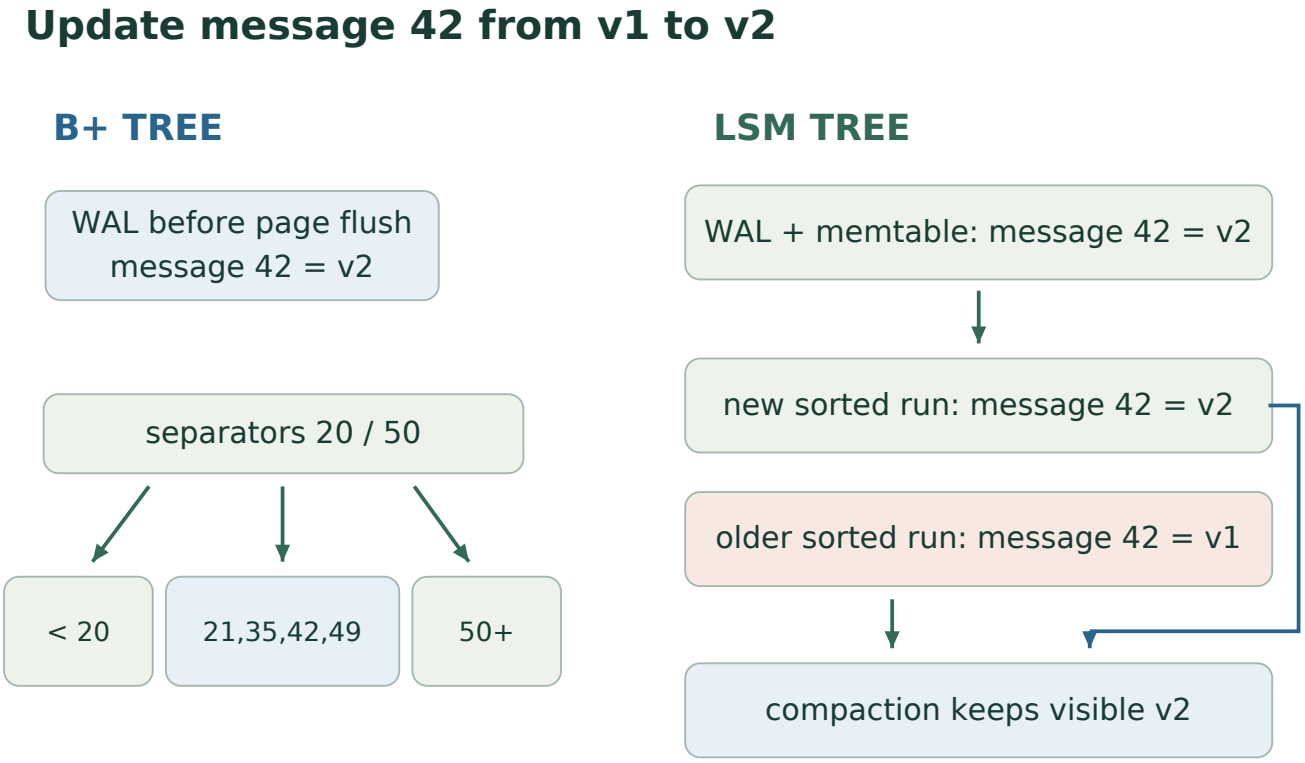
DEFINITION

A data model defines how an application represents and addresses records. A storage engine implements how those records and indexes are organized in memory and on disk, updated, and recovered after failure.

Why it matters: The same logical write can create very different disk, memory, and background-maintenance work depending on the engine.

B+ tree and LSM tree write paths

B+ trees update indexed pages. LSM engines append and merge immutable sorted runs; read and write amplification trade off.



WAL supports recovery; page/run layout affects access cost. Compaction consumes I/O.

Worked example

Message 42 changes from "Train at five" to "Train at six." A B-tree updates relevant pages; an LSM can retain the old file and place version 2 in a memory table and later a new sorted file.

Key takeaways

• SQL, documents, and key-value interfaces are a different choice from B-tree or LSM storage.

• A write-ahead log (WAL) supports crash recovery from durable records; surviving loss of the log's storage still requires replication or backups.

• Measure read, write, and space amplification during steady-state maintenance.

Read the visual model

1. A B+ tree routes through separator keys to a leaf page. WAL requires recovery records before dirty data pages reach durable storage; this example also flushes the commit record before acknowledging a durable transaction.

2. An LSM write records a WAL entry and updates a memtable, which later flushes to a sorted run.

3. Reads merge visible versions from memory and runs. Compaction rewrites runs and removes obsolete entries when safe.

4. Keep a tombstone until older data cannot resurrect, accounting for replicas and retained snapshots as well as local files.

B-tree • LSM • WAL • compaction • data modeling

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Separate an application's logical data model from the engine's physical layout.

• Trace B-tree and LSM reads, writes, recovery, and deletion using actual keys.

• Explain read, write, and space amplification before choosing an engine.

Useful foundations: Database indexes: B-trees, composite keys and query access; Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / Data model versus storage engine

INTERVIEW CRITICAL

A data model and a storage engine are different layers

A **data model** defines how an application represents and addresses records. A **storage engine** implements how their bytes and indexes are organized in memory and on disk, updated, and recovered after failure. Relational tables, documents, and key-value APIs are logical interfaces; B-trees and log-structured merge trees are physical techniques. These choices describe different layers and can be combined.

Choose the logical key independently of the storage engine. A message record can be `(room_id, sequence, author_id, body, version)`. Fetching the latest fifty messages in one room favors an ordered key beginning with room and sequence. For example, a request updates message 42 in room R7 from "Train at five" to "Train at six" and deletes message 8, whose old value is "Hello."

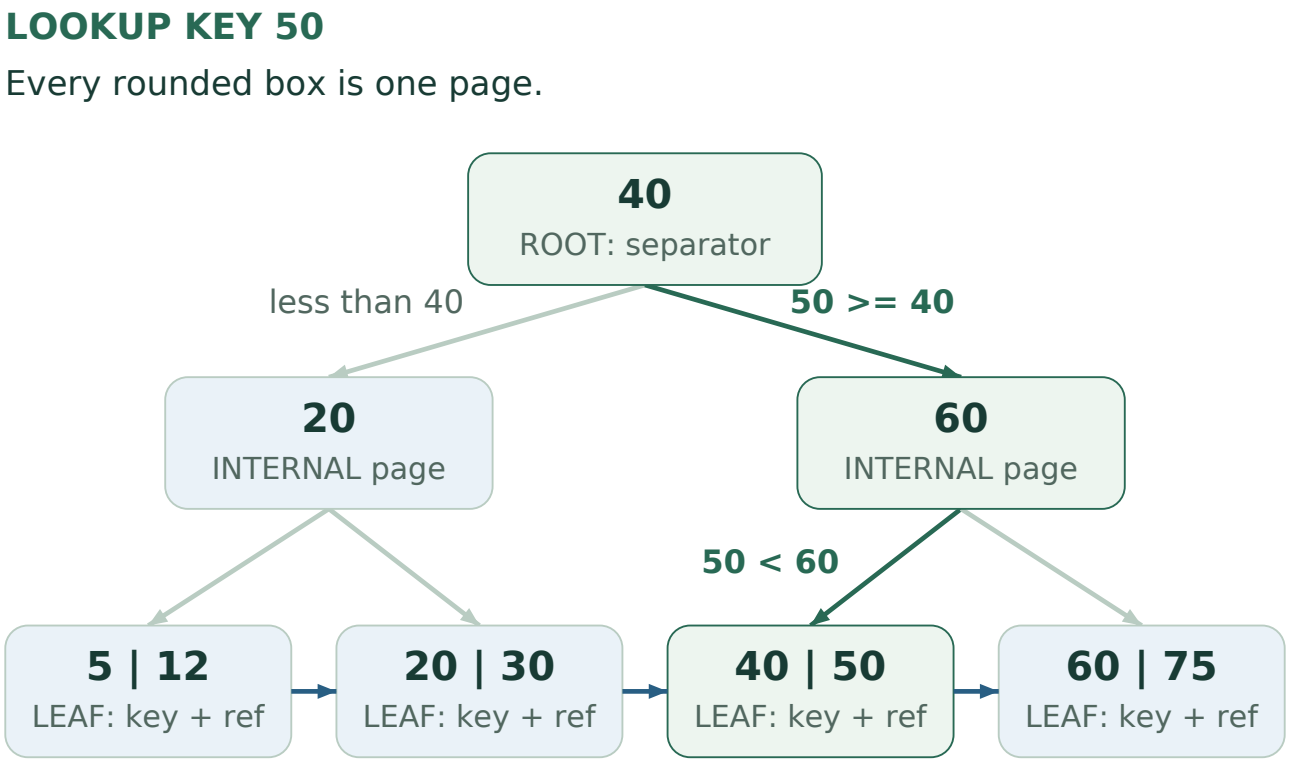
One machine can store this correctly. It becomes slow when the active data no longer fits memory or disk work exceeds capacity. Before adding shards, understand which physical work each logical write creates. A write-heavy service can saturate its storage while the incoming request count appears modest.

02 / B-trees and B+ trees: ordered page lookup

A B-tree keeps keys ordered in a branching tree of pages. A page is a block that the engine reads or writes as a unit. Internal pages guide a search toward a child; leaf pages contain index entries, with the exact record layout depending on the engine. A B+ tree keeps record-bearing entries in leaves and supports walking adjacent leaves for ranges.

B-plus tree: routing pages and linked leaves

This schematic B+ tree stores record entries at the leaves. Internal separator keys guide the search; all leaves are the same distance from the root.



Remember: Seek through the hierarchy; scan across leaves.

Imagine the root's separators for R7 are message 20 and message 50. Looking up 42 follows the middle child to a leaf containing 21, 35, 42 and 49. If that index entry points to a separately stored row, fetching the message body is additional work. A latest-fifty query can seek near the end of R7's range and walk backward through ordered entries.

Changing 42 updates the relevant data and index structures rather than scanning every message. A full leaf may split, requiring parent changes. Cached upper pages reduce physical reads, but cache misses, page splits,

transaction versions, and recovery logging still matter. "Logarithmic lookup" describes growth; it does not specify a fixed number of disk operations for every product.

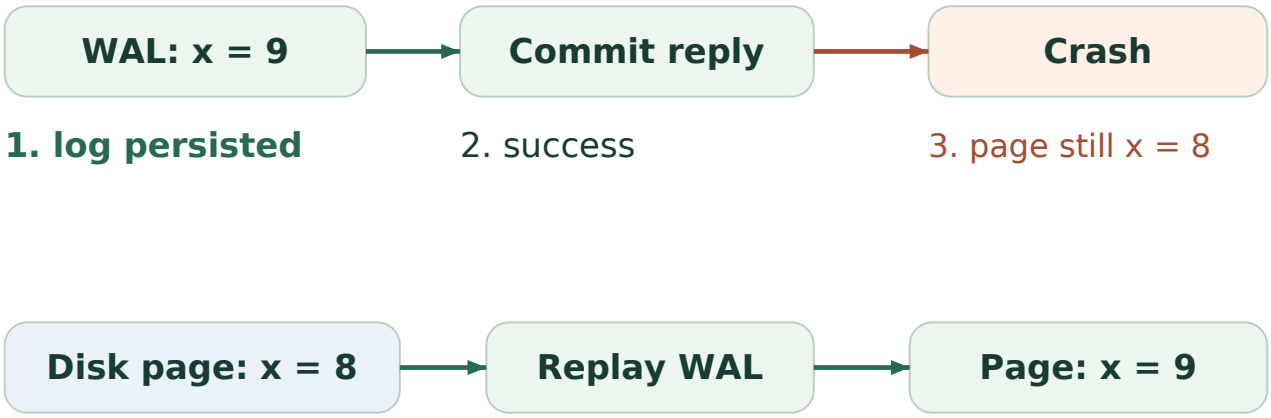
03 / Write-ahead logging: recovery and acknowledgment

A write-ahead log, or WAL, makes the recovery records for a change durable before the corresponding changed data pages are written to durable storage. That is the write-ahead ordering rule: the log reaches durable storage first. After a crash, the engine can reconstruct committed state from durable records and its persisted files. The exact protocol varies; a log is a recovery mechanism, not automatically an application event stream.

Why a committed write can survive an old data page

Read the top row before the crash, then the bottom row during recovery. This example assumes synchronous local durability.

Commit x = 9; crash before the data page is flushed



Recovery can redo the change because its log record survived.

Synchronous local commit shown; replica waits depend on policy.

Remember: Log first; recovery can redo a page update later.

Try from memory: What makes x = 9 recoverable when the page still contains 8?

Answer: The recovery record is durable before success. Recovery can redo the committed change from WAL.

Assume the database acknowledges an edit only after its required recovery and commit records are durable under the configured local storage policy. At time 0 it logs message 42 version 2. At time 1 it acknowledges the edit. If the process crashes before the ordinary data page is flushed, recovery can replay the relevant durable information. If the service instead acknowledges only an in-memory buffer, the same crash may lose the edit.

INTERVIEW CRITICAL

A local log does not cover every failure

A local write-ahead log can help recover from a process crash, but losing its disk may require a replica or backup. Decide separately when to flush the local log and when to wait for replicas. Explain which failures a successful save must survive.

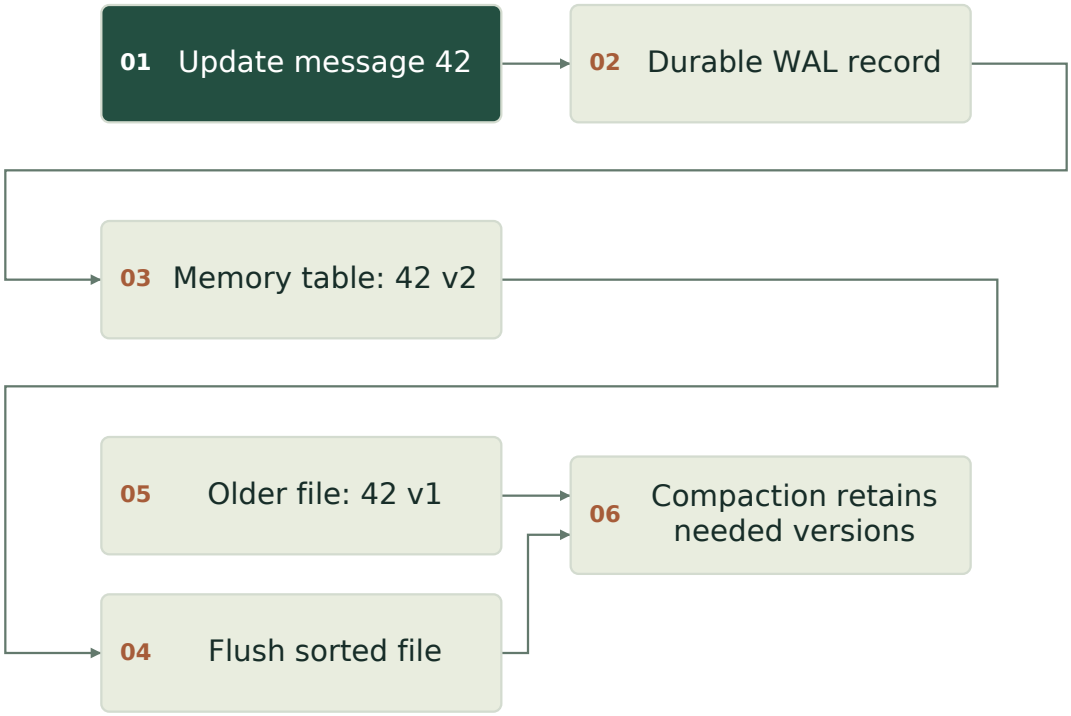
State which failures each storage stage can survive:

Acknowledged bytes have reached	Failure they can survive under the stated assumptions	Remaining risk
Only a process buffer	No guarantee after that process dies	Buffered records may vanish
Operating-system cache	A process crash if the OS and its buffered bytes survive	Reboot or power loss can lose unsynchronized data
Synchronized recovery log on durable media	Process or machine restart with that media intact	Device loss or a storage stack that violates synchronization
Required remote durable replicas too	The failures covered by the replica placement and commit protocol	Correlated loss beyond that failure model

Synchronization asks the storage stack to persist the necessary bytes; it does not make one local device indestructible. **Group commit** lets several transactions share one synchronization operation. This can improve throughput, but a transaction may wait for the group before receiving its acknowledgment.

WORKED EXAMPLE DIAGRAM

An LSM update first lives in the recovery log and memory table. Flushing and compaction reorganize it without changing the logical message value.



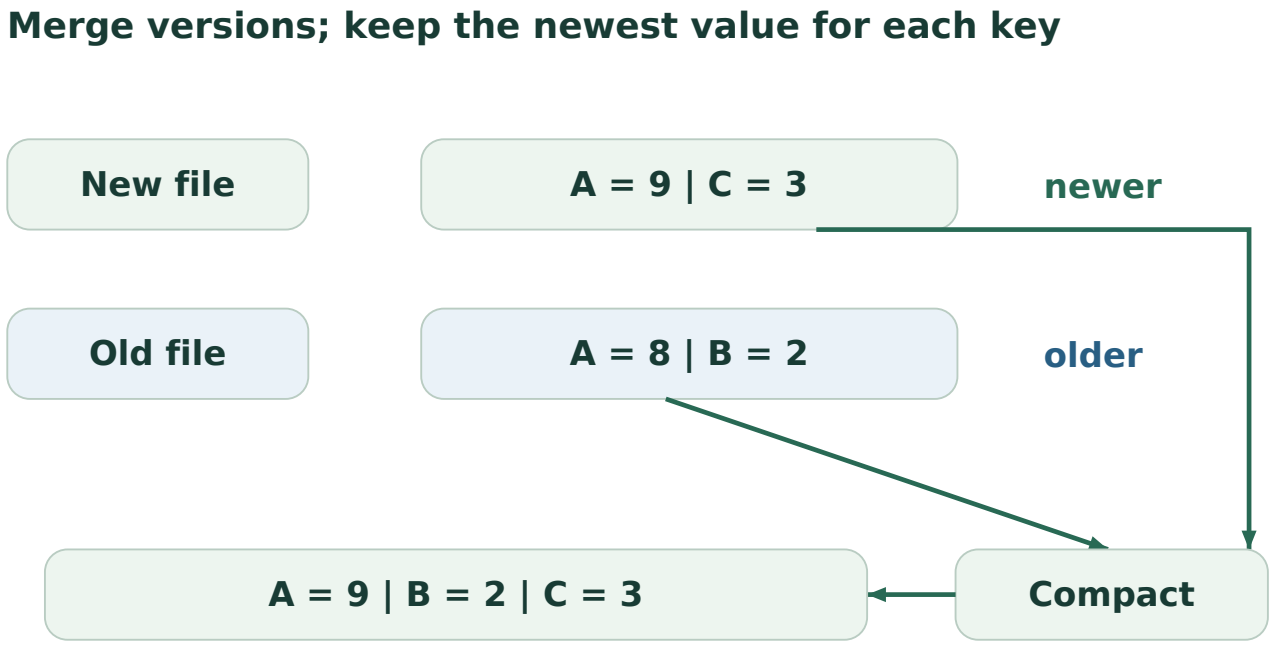
1 -> 2	log under chosen policy: Update message 42 -> Durable WAL record
2 -> 3	apply: Durable WAL record -> Memory table: 42 v2
3 -> 4	flush: Memory table: 42 v2 -> Flush sorted file
4 -> 6	merge: Flush sorted file -> Compaction retains needed versions
5 -> 6	compare versions: Older file: 42 v1 -> Compaction retains needed versions

04 / LSM trees: memory tables and immutable sorted files

A log-structured merge tree, abbreviated LSM, accumulates updates in a memory table and writes sorted immutable files as buffers fill. The WAL protects updates that have not yet become durable table files under the chosen configuration. Immutable means a later edit is stored as another version rather than rewriting that old file in place.

Compaction chooses among stored versions

Two sorted files contain different versions of A. This example assumes no snapshot needs the old version.



A = 8 is obsolete here. A snapshot that needs it would change this decision.

Remember: Merge keys; resolve versions; retain anything still required.

Try from memory: Why does A = 8 disappear, but B = 2 remain?

Answer: A has a newer value, 9, and no required snapshot needs 8 in this example. B has no replacement, so it remains.

Location after the update and deletion	Entries for R7	Meaning
Older sorted file F1	8 v1 = Hello; 42 v1 = Train at five	Earlier stored values
Newer memory table	8 v2 = deletion marker; 42 v2 = Train at six	Latest changes
New file F2 after flush	Same newer entries, sorted by key	Memory can be reclaimed when safe

A read of message 42 must select the newest visible version according to the engine's ordering and snapshot rules. It cannot stop at v1 merely because F1 was convenient to open. A read of message 8 encounters a deletion marker, often called a tombstone, which suppresses its older value. Range reads merge ordered streams from relevant files. They are supported, but their cost depends on how many streams and obsolete versions must be considered.

05 / Compaction, tombstones, and amplification

INTERVIEW CRITICAL

Discarding a tombstone can resurrect deleted data

Compaction merges selected sorted files, keeping versions needed by current reads and discarding obsolete material when safe. For room R7, it can eventually consolidate message 42 as v2. It cannot blindly discard message 8's tombstone while an older visible copy can still reappear from a file outside the merge or while a retained snapshot needs older history.

Cost	Plain definition	Example consequence
Read amplification	Extra data or storage operations needed for one logical read	Several candidate files for message 42
Write amplification	Physical bytes written per logical byte ingested	Rewriting retained records during compaction
Space amplification	Physical storage relative to live logical data	Old versions and temporary compaction outputs

Assume an illustrative workload ingests 100 MB/s and the measured total local write amplification, including the log in this measurement, is 8. The device must sustain about 800 MB/s of writes, before adding other workloads or safety margin. This is arithmetic from assumed inputs, not a hardware guarantee. Compaction also consumes read bandwidth and CPU. Deferring it forever makes later reads and space usage worse.

Two common compaction policies move that cost differently. Leveled compaction limits overlap within deeper levels, usually reducing read and space amplification but rewriting overlapping data. Tiered compaction accumulates several sorted runs before merging them, often reducing write amplification while increasing read sources and temporary space. These are tendencies, not universal benchmark results: key order, skew, overwrite rate and tuning matter.

06 / Storage-engine comparison and row versus column layouts

Two different physical choices are being compared. B-trees and LSM trees organize key lookup and update work. Row-oriented and column-oriented layouts determine whether fields of one record or values of one field are stored together. These choices can be combined; select them from whether the workload fetches individual messages, scans room ranges, or analyzes a few fields across many messages.

Physical approach	How it handles work	Useful starting point	Cost to measure
B-tree/B+ tree	Seek through ordered pages; update affected structures	Point lookups and ordered ranges	Cache misses, page changes/splits, logging, and version cleanup

Physical approach	How it handles work	Useful starting point	Cost to measure
LSM tree	Buffer updates; flush and merge immutable sorted files	Sustained writes with an ordered-key design	Compaction, multiple read sources, obsolete versions, and temporary space
Row-oriented layout	Keep one record's fields together	Fetch a message and its metadata	Scans of a few columns may read unnecessary fields
Column-oriented analytical layout	Group values by column	Scan selected fields across many records	Reconstructing or updating individual records can cost more

Where are the bytes needed for SUM(total)?

Green cells are totals. The first layout groups each person's fields; the second groups each field's values.

Same records, two physical layouts

Rows: all fields of one record together

1	Ada	20
2	Bo	30
3	Cy	40

Columns: one field from many records together

1	2	3
Ada	Bo	Cy
20	30	40

SUM(total) needs the green values: scattered fields versus one column.

Remember: Whole row: fields together. Column scan: one field together.

Try from memory: Which layout groups the bytes needed for SUM(total)?

Answer: The column layout groups 20, 30 and 40. The row layout stores each total beside that record's other fields.

For an assumed room-history workload dominated by appends and bounded room-range reads, I would evaluate an LSM-backed ordered store. The key `(room, sequence)` makes the common range explicit. I would benchmark it against an indexed relational design before assuming its extra operational complexity is worthwhile. The choice depends on latency targets, transactional requirements, updates, retention and operating experience.

A key-value API does not remove the need to design keys. Hashing every entire message key across shards scatters a room's range; partitioning by room preserves locality but creates a hot partition for a huge room. Time buckets or subpartitions can bound growth at the cost of merging reads. Physical engine selection does not solve those ownership decisions.

Row-oriented storage places a record's fields together, useful when fetching a message. Column-oriented analytical storage groups values by column, useful when scanning a few fields across many records. A wide-column database's data model is not synonymous with a columnar analytics layout. Ask which query the layout accelerates rather than matching names.

A practical baseline is PostgreSQL with an ordered B-tree index for transactional room history. Evaluate RocksDB when the application needs an embedded ordered key-value engine and can own the surrounding service protocol; RocksDB alone is not a replicated database service. Its write options distinguish asynchronous WAL writes from synchronized writes. If an acknowledged edit must survive machine restart, verify that WAL is enabled and the required synchronization policy is applied rather than assuming the default write call provides it.

07 / Storage failure, recovery, and benchmarking



INTERVIEW CRITICAL

Storage capacity must include background maintenance

When write latency rises during a compaction backlog, adding application servers increases pressure on the same disk. Inspect pending compaction bytes, read and write latency, cache hit rate, disk space, and write stalls. A stall can be the engine deliberately slowing ingestion so background maintenance can catch up. Capacity plans must include that maintenance budget and temporary space.

After a crash, check that every acknowledged change covered by the durability policy survived, including the new value of message 42 and the deletion of message 8. A deleted message disappearing from ordinary reads does not prove its bytes vanished from snapshots, old files, replicas or backups; physical erasure follows a separate retention and cleanup policy.

In an interview I would say: "The key supports room-history reads. An LSM may suit frequent appends, but edits and deletion markers leave versions that reads and compaction must resolve. I will state which failures saved messages survive, budget the extra reads, writes and disk space, and test range reads while background maintenance runs."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is a storage engine, and how is it different from a data model?

Model answer

The data model describes records and access semantics, such as messages keyed by room and sequence. The engine organizes their bytes and indexes and performs updates and recovery. B-trees and LSM trees are engine techniques; relational tables and documents are logical models. Choosing SQL does not by itself select a B-tree or define its disk cost.

Interviewer follow-up

Can a document database use a B-tree?

Yes. A document representation does not force one physical engine. I compare the actual implementation's transactions, indexes, durability, and maintenance work for the required queries.

What the answer must demonstrate: Distinguish the logical interface from physical organization.

02 / APPLIED

A B-tree has separators 20 and 50; its middle leaf contains 21, 35, 42, 49. Explain lookup for key 42.

Model answer

"The root separators guide me to the relevant leaf range, where I find 42's index entry. Depending on the layout, that entry contains the needed data or points to a separate row. Cached pages can avoid disk reads."

Interviewer follow-up

Why not say it always takes three I/Os?

"The tree's height, cached pages, record layout and overflow data all affect physical work."

What the answer must demonstrate: Distinguish logical search steps from physical I/O.

03 / APPLIED

An update is acknowledged before its changed data page reaches disk. Under what WAL policy can it survive a process crash?

Model answer

It can survive when the required recovery records, including the commit decision, were made durable before acknowledgment and recovery correctly replays them. Log-before-data ordering alone does not prove commit-before-ack durability. I must verify the configured synchronization policy and failure model.

Interviewer follow-up

What if the disk is destroyed?

"Then a local WAL alone is insufficient; the replica or backup durability policy determines what survives."

What the answer must demonstrate: Name the acknowledgment boundary and failure model.

04 / FOUNDATION

Why can an LSM contain two values for message 42?

Model answer

"The old sorted file cannot be changed. An edit first enters a newer memory table and later another file. Reads use the engine's sequence and snapshot rules to choose the right version. Compaction removes old versions once they are no longer needed."

Interviewer follow-up

Can a read return the first copy it finds?

"Only if the search protocol proves it is the correct visible version. Arbitrary file traversal is not sufficient."

What the answer must demonstrate: Explain version visibility, not just file count.

05 / FOLLOW-UP

An LSM contains a tombstone for key 8 and older files may contain key 8's value. When may the tombstone be removed?

Model answer

"Only when the engine can prove older values cannot reappear for supported reads and no required snapshot needs that history. Removing the marker merely because it is old can expose an older stored copy."

Interviewer follow-up

Does removing it erase backups too?

"No. Backup and replica retention are separate lifecycle policies."

What the answer must demonstrate: Logical deletion, compaction and physical erasure differ.

06 / APPLIED

What does write amplification of 8 mean at 100 MB/s ingestion?

Model answer

"With a measurement that includes all the relevant local writes, it implies roughly 800 MB/s of device writes. I would also budget compaction reads, CPU, replication and headroom, and verify the figure under a steady workload."

Interviewer follow-up

Can you compare two quoted amplification numbers directly?

"Only if their numerator, denominator, workload and inclusion of logs or replication match."

What the answer must demonstrate: Define the measurement before multiplying it.

07 / APPLIED

Why does an ordered engine not automatically give fast room history?

Model answer

"The logical key and partitioning still matter. If each full message key is independently hashed to a different shard, a room query fans out. Keeping room and sequence together gives locality but may create a hot room partition."

Interviewer follow-up

What does bucketing change?

"It bounds one partition's size or traffic, while making history retrieval merge results from several buckets."

What the answer must demonstrate: Connect query shape to both ordering and partitioning.

08 / FOLLOW-UP

How would you test the engine choice?

Model answer

"I would load representative data, sustain ingestion until compaction reaches normal behavior, and measure tail latency for latest-fifty reads, edits, deletions and recovery. An empty database's short insert burst hides the deferred maintenance cost."

Interviewer follow-up

What failure would make you reconsider the choice?

"A persistent backlog of compaction work or range-read latency percentiles exceeding the target would prompt layout and resource changes, or a simpler engine better suited to the actual workload."

What the answer must demonstrate: Evaluate steady-state operation, not only peak foreground throughput.

Build the answer yourself

BLANK-PAGE EXERCISE / 16 MINUTES

Design storage for room R7 history: append messages, fetch the latest fifty, edit one message and delete another. Draw where two versions and a deletion marker exist before and after compaction.

- Specify the logical record, partitioning boundary and ordered key.
- Show which records are durably stored before the write is acknowledged and how recovery uses them after a crash.
- Explain how a read selects the newest visible value across files.
- Budget compaction, snapshots and recovery instead of counting only live payload bytes.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What is the difference between model and engine?

The model defines records and access semantics; the engine defines physical pages, files, logs and update behavior.

Meaning above; mechanics below

Why does a tombstone exist?

It records deletion so an older value in another file does not become visible again.

A delete must outlive the old copy

Is a buffered append free of later work?

No. Flushing and compaction convert fast foreground writes into later I/O, CPU and space costs.

Append now, organize later

Does WAL imply survival of disk loss?

No. Local recovery logging and off-machine redundancy cover different failures.

Log repairs a crash; copies cover loss

Summary and interview notes

Choose a logical key that serves the query, then choose an engine and durability policy that can maintain it within the workload budget. B-trees and LSM trees move work differently; neither removes the need to account for versions, background maintenance, recovery and partitioning.

Remember these points

• Logical SQL/document/key-value models are distinct from physical B-tree, LSM, row and column layouts.

• Persist recovery information in the log before the corresponding data pages reach disk. To promise crash recovery, also persist the required commit information before reporting success.

• An LSM read chooses the visible version using values and deletion markers in memory and relevant sorted files.

• Compaction exchanges foreground speed for later reads, rewrites and temporary space; benchmark steady state.

• A tombstone may be dropped only when old values cannot reappear for supported reads and retained snapshots.

Interview tips

• Trace one acknowledged update through log, memory, file and recovery before comparing throughput.

• Multiply measured write amplification by ingress bytes and include compaction reads, replication and headroom.

• Name the query and key layout before saying B-tree or LSM; test hot partitions separately from engine speed.

Important qualifications

• RocksDB is an embedded engine; replication, failover and application transaction ownership need a surrounding system.

• Logical deletion is not proof of physical erasure from old files, snapshots or backups.

Technical references

RocksDB Overview
Verified implementation reference for memory tables, sorted files, point reads, and range traversal.
https://github.com/facebook/rocksdb/wiki/RocksDB-Overview

PostgreSQL: Write-Ahead Logging
Official explanation of log-before-data ordering, acknowledgment, and crash recovery; the lesson separately identifies LSM-specific memory-table flushing.
https://www.postgresql.org/docs/current/wal-intro.html

RocksDB: Compaction
Verified reference for sorted-run organization and amplification tradeoffs.
https://github.com/facebook/rocksdb/wiki/Compaction

PostgreSQL: B-Tree Indexes
Official reference for ordered B-tree indexing. The tiny page and throughput examples are illustrative, not engine benchmarks.
https://www.postgresql.org/docs/current/btree.html

RocksDB: Basic Operations
Checked synchronous/non-synchronous writes, OS-buffer boundary and disableWAL behavior; durability remains configuration dependent.
https://github.com/facebook/rocksdb/wiki/Basic-Operations

FOUNDATIONS / 08

Load balancing: definition, algorithms and failover

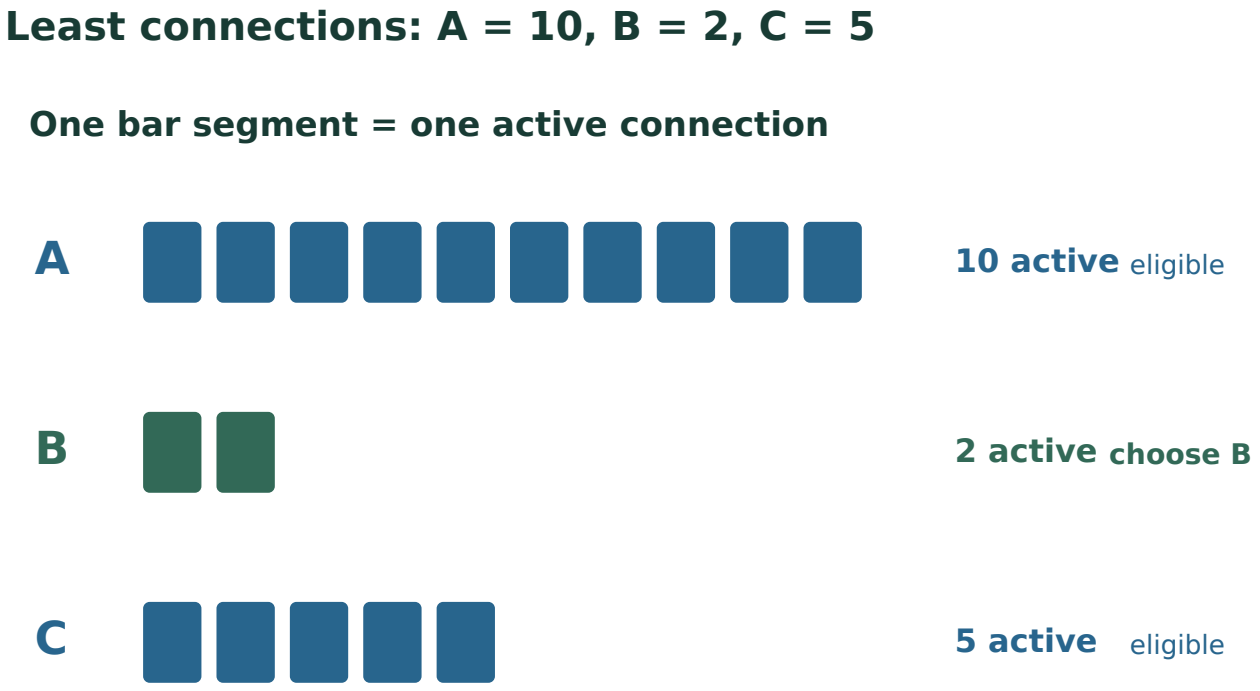
DEFINITION

Load balancing distributes incoming network connections or application requests across eligible backend servers. A load balancer selects a destination using a routing policy and available health or load information.

Why it matters: When one server cannot handle the workload or fails, callers need a way to reach other servers without choosing them manually.

Load-balancing algorithm: least connections

Round robin ignores work already in flight. Least connections is useful only when those connections are comparable.



Health decides eligibility first. Two busy streams may cost more than ten idle connections.

Worked example

With healthy equal-capacity servers A, B and C, round robin sends requests R1-R6 to A, B, C, A, B, C. If B fails and is removed, later requests use A and C; those survivors still need enough capacity.

Key takeaways

- Choose what to balance: connections, requests, bytes or work.
- Health checks detect failure after a delay.
- Routing elsewhere does not preserve state stored only on the failed server.

Read the visual model

1. For equal-cost short requests, round robin sends R1...R6 to A,B,C,A,B,C.
2. The chapter snapshot has A=10, B=2, C=5 active connections. Least connections selects B if all are eligible and work is comparable.
3. Counts can mislead when one connection carries many expensive streams.
4. Remove unhealthy targets from new routing and use bounded, retry-safe recovery for failed requests.

L4 • L7 • round robin • health checks • affinity

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain what a load balancer does and where it sits.
- Replay round robin, weighted routing, and least-connections choices.
- Handle health detection, draining, failover, and overload.

Useful foundations: Distributed systems: scalability, reliability, availability and efficiency; HTTP APIs and request lifecycle

8 interview questions with model answers and answered follow-ups.

01 / Load balancing: definition and purpose

Load balancing distributes connections or requests across eligible servers. A load balancer selects a backend for traffic addressed to one logical service. The client uses that service address; routing determines whether application instance A, B, or C receives the work.

Horizontal application scaling introduces multiple instances behind the same service address. A load balancer distributes work among them using a routing policy. Essential session state must be available to every eligible instance: rerouting a request cannot recover a cart stored only in a failed process.



INTERVIEW CRITICAL

Load balancing does not grant write authority

Balancers can sit between users and web servers, between web and application tiers, or before suitable cache/database read pools. They cannot make arbitrary database replicas interchangeable: a write must reach a node authorized to write that data. Data-partition routing and load balancing solve different decisions.

02 / Layer 4 versus Layer 7 load balancing

"Layer" refers to the kind of network information the intermediary understands. **Layer 4 (L4)** is the transport layer: TCP/UDP connections or flows identified by network addresses and port numbers. A port identifies a service endpoint on a machine. L4 balancing commonly chooses a backend using this connection information. It can forward a connection without interpreting each application request. **Layer 7 (L7)** is the application layer. L7 balancing understands an application protocol such as HTTP, the request/response protocol used by web applications. It can route `/images` to an image service and `/checkout` to a checkout service, or use a hostname or header.

TLS termination means the encrypted client connection ends at the balancer, which can inspect the decrypted HTTP message. The balancer may then create a separately encrypted connection to the backend. If TLS passes through untouched, a transport balancer does not get the same HTTP routing information. Say where encryption ends and which network segments remain protected.



INTERVIEW CRITICAL

Connection counts do not measure equal work

HTTP/2 can carry many requests over one connection. A connection carrying heavy downloads and one carrying occasional metadata requests are not equal workloads. This is why you must name the unit of balancing - connection, request, bytes, or estimated work - before choosing an algorithm.

Choice	Information available for routing	Choose it when	Limit to explain
L4 connection/flow balancing	Addresses, ports and transport state	Distribute transport traffic without needing HTTP paths	A long connection can carry uneven application work
L7 HTTP balancing	Hostname, path and permitted headers after HTTP is visible	`/images` and `/checkout` need different service pools	Parsing and TLS termination add processing work; the balancer must be trusted with decrypted request data

For `GET /images/P7.jpg`, an L7 rule can first choose the image pool; a balancing algorithm then chooses A or B inside that pool. Choosing the right service and distributing work among its instances are two separate decisions.

03 / Worked example: round robin, weights and least connections

After choosing the service pool, the balancer still needs a rule for selecting an instance. The main choices use a fixed schedule, a configured share of capacity, a measurement of current work, or a stable caller identity. Compare them by asking which signal best represents the work in this pool.

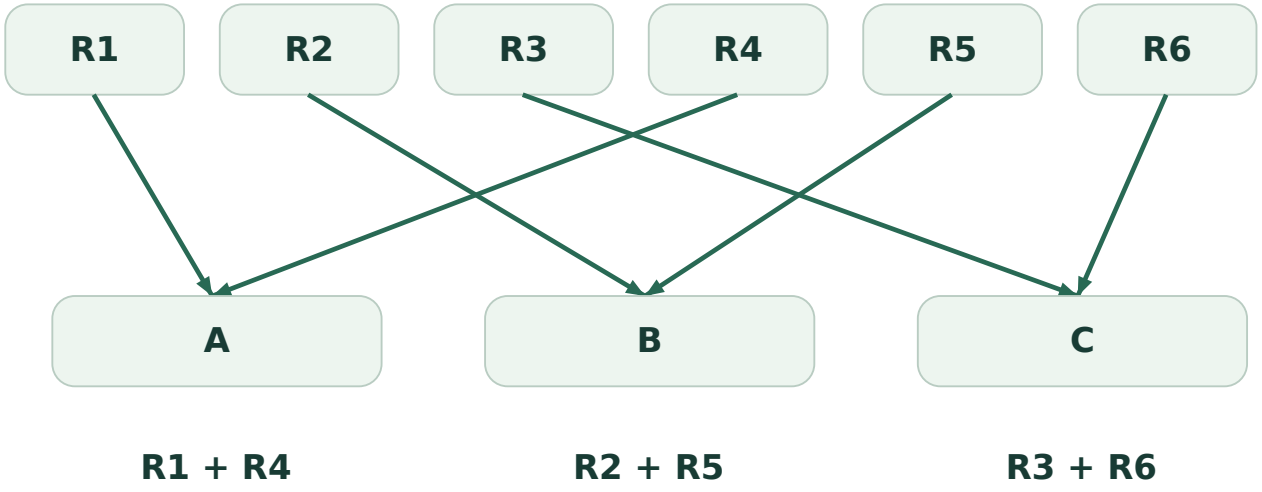
Assume A, B, and C are healthy and serve equal-cost short requests. **Round robin** visits them in order. Requests R1 through R6 go to A, B, C, A, B, C. Step one: R1 arrives and A is next. Step two: R2 advances the cursor to B. Step three: R3 advances to C. Step four: R4 wraps to A; R5 and R6 repeat B and C. Each server

receives two requests, but equal counts imply equal work only under our equal-cost assumption. It is easy to operate, but it ignores work already running.

Trace six requests through round robin

Follow each request arrow to A, B or C. All three backends are eligible and equally weighted in this example.

Round robin with three eligible backends



The pattern repeats A, B, C; it does not measure request cost.

Remember: A, B, C, then repeat; equal request counts need not mean equal work.

Try from memory: Which backend receives R7?

Answer: A, provided the same three backends remain eligible and the rotation continues.

Now A has twice the tested capacity of B and C. A weighted schedule such as A, B, A, C repeats, giving A about half the requests and B/C a quarter each. Weights express capacity assumptions; they do not detect a new slow dependency.

For long-lived connections, suppose A has 10 active connections, B has 2, and C has 5. **Least connections** sends the next comparable connection to B. But if B's two connections each carry many expensive streams, the count may misrepresent actual load.

Policy	What guides the choice	What can go wrong
Round robin	Next eligible server	Unequal request cost is ignored
Weighted round robin	Configured capacity share	Old weights miss changing capacity
Least connections	Active connections, sometimes weighted	Connections can carry unequal work

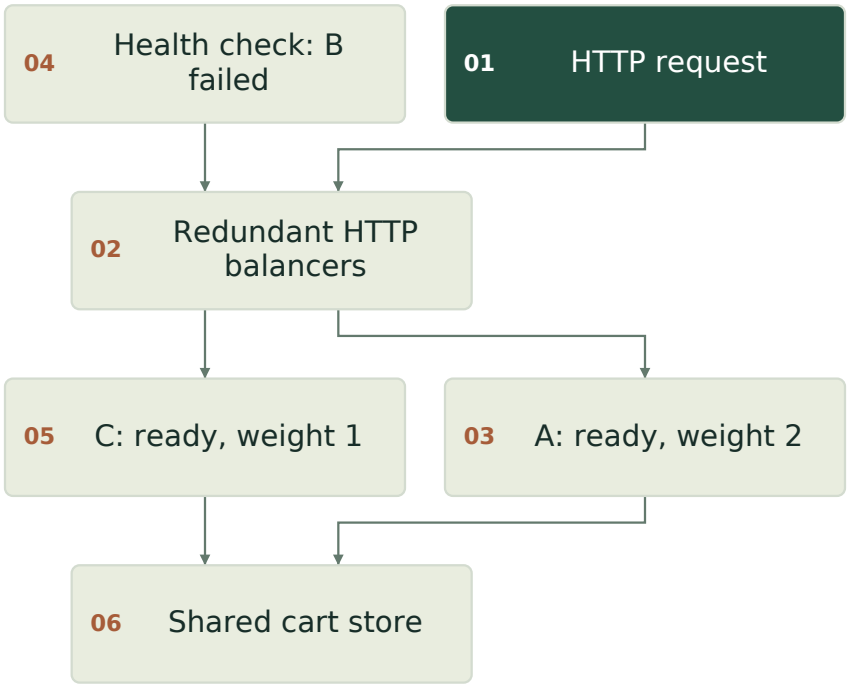
Policy	What guides the choice	What can go wrong
Power of two choices	Sample two eligible servers, choose the less loaded	The load signal can be stale or unrepresentative
Least response time	Observed latency, often plus active work	Stale measurements or oscillation
Least bandwidth	Current transferred bytes	CPU-heavy small requests look cheap
IP hash	A stable function of client IP	Many users behind one NAT share a target

Implementations differ, so explain the signal instead of promising an exact universal algorithm.

Power of two choices reduces the need to compare every backend: randomly sample two eligible servers and choose the one with less measured work. With A=10, B=2 and C=5 comparable active connections, sampling A/C chooses C; sampling A/B chooses B. It need not find the global minimum to reduce imbalance. A least-request implementation counts active requests instead of transport connections, which can better match multiplexed HTTP work; neither count captures arbitrary CPU cost.

WORKED EXAMPLE DIAGRAM

After B is removed, new requests reach A and C. Shared cart storage lets either recover the session; surviving capacity still must be checked.



1 -> 2	one service address: HTTP request -> Redundant HTTP balancers
2 -> 3	two shares of new traffic: Redundant HTTP balancers -> A: ready, weight 2
2 -> 5	one share of new traffic: Redundant HTTP balancers -> C: ready, weight 1

3 -> 6	load authoritative cart: A: ready, weight 2 -> Shared cart store
5 -> 6	same cart after reroute: C: ready, weight 1 -> Shared cart store
4 -> 2	health failure stops assignment: Health check: B failed -> Redundant HTTP balancers

04 / Session affinity and persistent state

Affinity, or a sticky session, tries to send a caller back to the same backend. It can improve reuse of a local cache. IP hashing is one way; a routing cookie is another. If many students share one school's public IP through network address translation (NAT), IP hashing can concentrate them on one server.



INTERVIEW CRITICAL

Sticky sessions do not preserve lost state

A sticky session does not make a cart durable. If the cart exists only in A's memory, it disappears when A fails. Save it in shared durable storage, or storage with suitable replication, so B can recover it. Use affinity to reuse local data when helpful; protect the saved cart separately.

Hashing a stable key can also place cached objects consistently. That is useful when the same key should reach the same owner, but the design must explain how keys move when servers join or leave and how it handles a key that receives unusually heavy traffic. A balancer cannot divide one expensive request simply by hashing it.

05 / Health checks and backend failover

At 12:00:00, B's process stops. A health check is a small probe used to decide whether B should receive new work. A **readiness** check asks whether it can serve new requests; a **liveness** check asks whether restarting the process might be necessary.

1. Requests already sent to B may fail before a health probe detects the crash. A health system does not make detection instantaneous.
2. After the configured failure threshold, the balancer removes B from new selection. A and C inherit its traffic.
3. Safe retries use a deadline and an operation identity where needed. Retrying a purchase blindly may duplicate it if B committed just before losing the response.
4. When B restarts, readiness remains false until required initialization completes. Reintroduce it gradually so a cold cache does not create a surge of database work.

A shallow probe can say "healthy" while every database query fails. An overly broad probe can remove all servers when one shared optional dependency fails. Design probes around the work each pool must actually serve.

Distinguish the source of health information. **Active checks** send dedicated probes even when no user traffic arrives. **Passive checks** infer trouble from real request failures, so an idle backend can remain untested.

Thresholds reduce transient ejections but increase detection time. Neither proves future success, and an application error caused by the caller is not automatically evidence that the server is unhealthy.

06 / Connection draining, overload and balancer redundancy

Draining stops assigning new work while allowing existing requests to finish within a deadline. For a deployment, mark C unready, let short requests finish, then stop it. Long-lived sockets need a reconnect protocol or explicit migration; draining does not preserve in-memory conversation state by itself.



INTERVIEW CRITICAL

Failover needs enough surviving capacity

If each of three servers supports 1,000 requests/s and traffic is 2,700/s, losing one overloads the two survivors. Keep failure headroom or reject lower-priority work. Bound queues, connection counts, and timeouts so overload becomes controlled refusal rather than process exhaustion.

The balancer also needs a replacement if it fails. Active/passive keeps a standby and a way to redirect traffic; active/active runs several balancers. Cached DNS answers can delay redirection. Even a managed balancer needs enough surviving capacity for the failures you plan to tolerate. Existing TCP or TLS connections may break when their balancer fails: another balancer does not automatically inherit them. Clients therefore need reconnect and retry limits.

Interview answer: "For similar short HTTP calls I begin with weighted round robin over ready instances. I move essential session state out of individual servers. I calculate surviving capacity, drain during changes, and make retries safe. For long-lived or uneven work, I change the routing signal after measuring which resource is saturated."

These policies become routing configuration in a proxy. In NGINX, an `upstream` group names the available backends, while `proxy_pass` forwards matching requests to that group. Weights and selection rules then control how the group distributes work.

A concrete starting implementation is an NGINX HTTP proxy with an `upstream` group, explicit backend weights and `proxy_pass`; choose `least_conn` when comparable active connections are a better signal. Its upstream module documents passive failure handling through `max_fails` and `fail_timeout`. Dedicated active HTTP checks require the documented health-check module/product support, so verify the installed edition rather than assuming all capabilities follow from the NGINX name. This configuration routes requests. The application and storage design must separately preserve carts, determine which database node may accept writes, and handle retries without losing or duplicating an operation. See the upstream reference and health-check guide.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What does a load balancer do?

Model answer

"It chooses a healthy backend for incoming service traffic. The client uses one service address; the balancer can route its request to A or B. It distributes work and helps route around detected failures, but shared data and correct write ownership still need their own design."

Interviewer follow-up

Does it automatically make the application stateless?

No. If the cart exists only in A's memory, switching to B can lose it. The application must place essential state where another instance can recover or access it.

What the answer must demonstrate: Explain routing separately from state.

02 / FOUNDATION

Where do six equal requests go across A, B, and C?

Model answer

"Under simple round robin: A, B, C, A, B, C. If A has twice the capacity, I can use weights giving A roughly half the traffic. These choices assume requests are similar enough that request count represents work."

Interviewer follow-up

What breaks that assumption?

A large export can use far more CPU or time than a small read. Equal request counts may create uneven load. I would separate pools or consider a work-sensitive signal.

What the answer must demonstrate: Demonstrate a schedule before discussing limitations.

03 / APPLIED

When should a service use L7 routing instead of L4 balancing?

Model answer

"I need to route by HTTP path, such as /images versus /checkout. An L7 balancer understands those fields, usually after TLS termination. I would also protect the backend connection. An L4 connection balancer is sufficient when I only need transport-level distribution."

Interviewer follow-up

Can one HTTP/2 connection represent many requests?

Yes. Multiplexing means connection counts are not request counts, so a connection-level policy can still produce uneven application work.

What the answer must demonstrate: Describe what information the layer can inspect.

04 / APPLIED

A has 10 connections, B 2, C 5. Who gets the next one?

Model answer

"Least connections chooses B if the servers and connection costs are comparable. I would not assume B is least busy if those two connections each contain many expensive streams. I validate the signal against CPU, queueing, and latency."

Interviewer follow-up

Why not always use least response time?

It relies on measurements that may lag or react poorly to small samples. A recently idle slow node may look deceptively good, and routing can oscillate.

What the answer must demonstrate: Qualify the unit of work.

05 / APPLIED

Would sticky sessions solve cart persistence?

Model answer

"They reduce movement while the chosen server works, but they do not preserve a cart when it fails. I store the authoritative cart durably and use stickiness only if locality improves performance. Then another backend can continue the session."

Interviewer follow-up

Why is IP hashing risky behind a school network?

Many users can share one public NAT address and hash to the same backend. A client IP is not a unique user identifier.

What the answer must demonstrate: Separate locality and durability.

06 / APPLIED

A backend B crashes before its next health probe. What happens until the balancer removes it?

Model answer

"Some requests may still be sent to B until failure detection crosses its threshold. I use bounded timeouts and safe retries. After removal, A and C must have capacity for the redirected work; otherwise detection can turn one crash into a broader overload."

Interviewer follow-up

Should readiness check every downstream system?

Only dependencies necessary for that pool's promised work. Active probes exercise a selected path; passive checks observe actual failures. Checking an optional shared service can eject the entire pool unnecessarily, while a shallow process probe can miss failed critical operations.

What the answer must demonstrate: Acknowledge detection delay and correlated failures.

07 / APPLIED

How do you update an instance serving WebSockets?

Model answer

"I stop new assignments, signal clients to reconnect where the protocol allows, and enforce a drain deadline. Message state lives in durable storage so reconnecting to another instance can resume from a cursor. I cannot assume a balancer transfers the old socket's process memory."

Interviewer follow-up

What if a client never disconnects?

The deadline eventually closes it. The application protocol must make reconnection and replay a supported path.

What the answer must demonstrate: Explain the long-lived session explicitly.

08 / APPLIED

Does adding a load balancer eliminate all single points of failure?

Model answer

"No. The balancer, discovery and shared database are separate dependencies. I use redundant balancers with supported traffic failover and enough surviving capacity. If the failed balancer terminated a client connection, that connection may still break: the client reconnects and retries safely. Routing a new request is different from preserving an old connection."

Interviewer follow-up

Why is DNS failover not immediate for everyone?

Resolvers and clients may keep cached answers until their expiration behavior permits a refresh. I would avoid promising universal instant traffic movement.

What the answer must demonstrate: Trace the full failure path.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Route six requests across three servers, then remove one during peak. Explain state, retries, and remaining capacity.

- Compare L4 and L7 with actual request fields.
- Show round-robin and weighted assignments.
- Trace detection, removal, and reintroduction.
- Give a failure-safe session design.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Choose the balancing unit

Connection count, request count, bytes, and CPU work can differ.

Measure the work being balanced.

If one server fails, what must the remaining servers have?

Spare capacity for redirected traffic, or admission limits that reject excess work. Removing a failed server from routing alone cannot prevent overload.

Detect failure -> redirect -> check spare capacity.

Affinity

Sending a caller to the same server can reuse its local cache; essential session data must also survive that server failing.

Sticky is not durable.

Summary and interview notes

Load balancing selects an eligible destination for a connection or request; the chosen unit and load signal determine how well it distributes work. Safe operation also requires health detection, enough surviving capacity, recoverable session state and bounded retries.

Remember these points

• L4 routing uses transport information; L7 routing can use visible application fields such as an HTTP path.

• Round robin spreads request counts; weights reflect server capacity. Least-connections uses active connections as a load estimate, which can mislead when connections carry different amounts of work.

• Power of two choices compares two sampled eligible backends instead of finding a global minimum.

• Affinity improves locality but cannot recover state lost with a process.

• A failed server or balancer may interrupt requests. Reusing a saved operation ID can make retries safe for operations designed to support it.

Interview tips

• Replay a short routing schedule, then explain how requests with different processing costs could make the load uneven.

• Calculate the load on survivors after removing one node.

• Separate active probes, passive error observations, readiness, restart policy and overload controls.

Important qualifications

- Algorithm names and health features vary by implementation and edition; verify the actual configuration.
- HTTP/2 multiplexing means one connection may carry many requests.
- The balancing layer does not determine which database replica owns a write.

Technical references

NGINX HTTP load balancing
Primary implementation reference for request routing and balancing signals.
https://docs.nginx.com/nginx/admin-guide/load-balancer/http-load-balancer/

NGINX upstream module
Details of weights, least connections, health behavior, and upstream configuration.
https://nginx.org/en/docs/http/ngx_http_upstream_module.html

NGINX HTTP health checks
Active and passive health-check mechanisms and product requirements; checked 2026-09-23.
https://docs.nginx.com/nginx/admin-guide/load-balancer/http-health-check/

FOUNDATIONS / 09

Caching: cache hits, misses, write policies and invalidation

DEFINITION

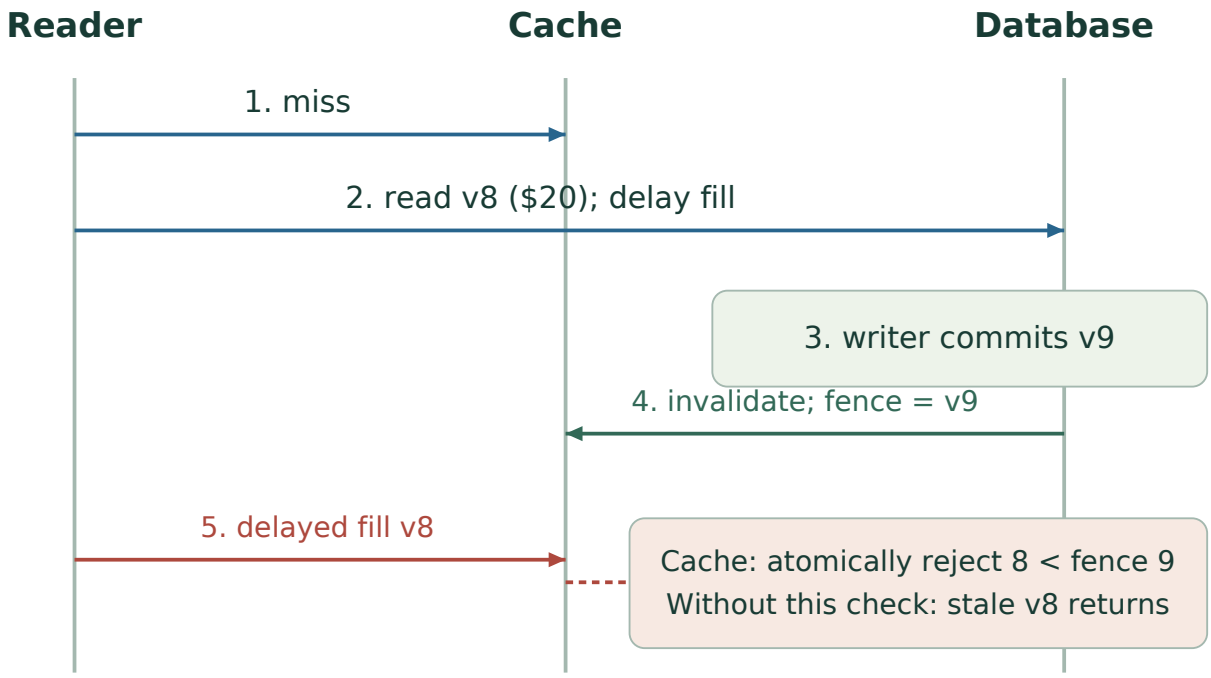
Caching stores a reusable copy of data or a computed result so later requests can avoid repeating a more expensive operation. A cache hit uses an acceptable cached entry; a cache miss must obtain the result from another source.

Why it matters: Many users ask for the same product, image or calculation. Reusing a valid result reduces latency and work at the authoritative source, but creates a freshness problem when that source changes.

Cache invalidation and the stale-fill race

A read may fetch price version 8 before a writer commits version 9, then populate its old result after invalidation. Check the version atomically when inserting the cached value.

P7: a delayed read can refill old price data



The write and fence need a coherent protocol. TTL alone does not close the stale-fill race.

Worked example

The database holds P7 at $20/version 8. Request R1 misses and fills the cache; request R2 hits that copy. When the seller commits $25/version 9, the old copy needs an explicit invalidation or freshness rule.

Key takeaways

• Identify the authoritative source and every cache-key input.

• Expiration, invalidation and eviction solve different problems.

• A cache failure can expose the full request rate to the origin.

Read the visual model

1. Product P7 starts at price $20, version 8. A reader misses and begins fetching that old version.

2. A writer commits a new price at version 9 and invalidates the cache.

3. The delayed reader attempts to fill version 8 after invalidation. Without a guard it resurrects stale data.

4. One solution retains an invalidation fence 9 and atomically compares that fence with insertion, rejecting fills with older versions. Expiry alone does not close a stale-refill race.

cache-aside • CDN • invalidation • eviction • TTL

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Trace a cache hit, miss, and concurrent stale refill.

• Choose a write strategy and an acceptable freshness rule.

• Replay eviction policies and protect the origin during a cache outage.

Useful foundations: Load balancing: definition, algorithms and failover; Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / Caching: definition, hits, misses and TTL

Caching stores a reusable copy of data or a computed result so later requests can avoid a slower or more expensive operation. A cache entry is addressed by a cache key, such as `product:P7`. The **authoritative store** holds the record the application treats as the source of truth, such as the product database. A cache holds a copy. Its freshness policy states how old that copy may be, and its access policy states who may read it.

A **hit** means the cache has an acceptable entry. A **miss** means the entry is absent or cannot be used. A **time to live**, or TTL, is how long an entry may remain usable under the cache policy. A TTL is not the same as a guarantee that the underlying value cannot change.

Suppose P7 costs $20 and thousands of people view it each minute. Reusing a small product record can reduce database work. During checkout, however, the service must check which price applies and whether stock is available under the agreed purchase rules. The displayed cached value is not automatically permission to charge an old price or sell unavailable stock.

02 / Cache placement: local, shared, distributed and CDN

Memory (RAM) is fast temporary working storage; a disk retains bytes with a different access cost. An application can cache in its own memory, avoiding a network call. It can also cache on local disk: slower than RAM, but useful for larger reusable files. With several application servers, these local caches are separate. If the next request reaches another server, that server may miss or hold a different version.

A shared cache gives applications a common network-accessible cache. A distributed cache spreads that cache's keys across several machines. "Shared" describes who can use it; "distributed" describes how its capacity is placed. Neither word specifies durability or the freshness protocol.

A browser cache stores a user's copy. A reverse-proxy cache serves requests in front of the application. A content delivery network, or CDN, keeps copies at edge locations nearer users. For a product image, the first edge request misses and fetches the object from the **origin**, the server or storage service that supplies the original content; later allowed requests reuse it.

A separate hostname for static content, such as `static.shop.example`, makes a later CDN migration easier. Initially it serves image files directly. Later that hostname can point through a CDN while the object paths remain stable. Cache keys, certificates, cache headers, and private-content policy still need configuration; changing DNS alone does not define correct caching.

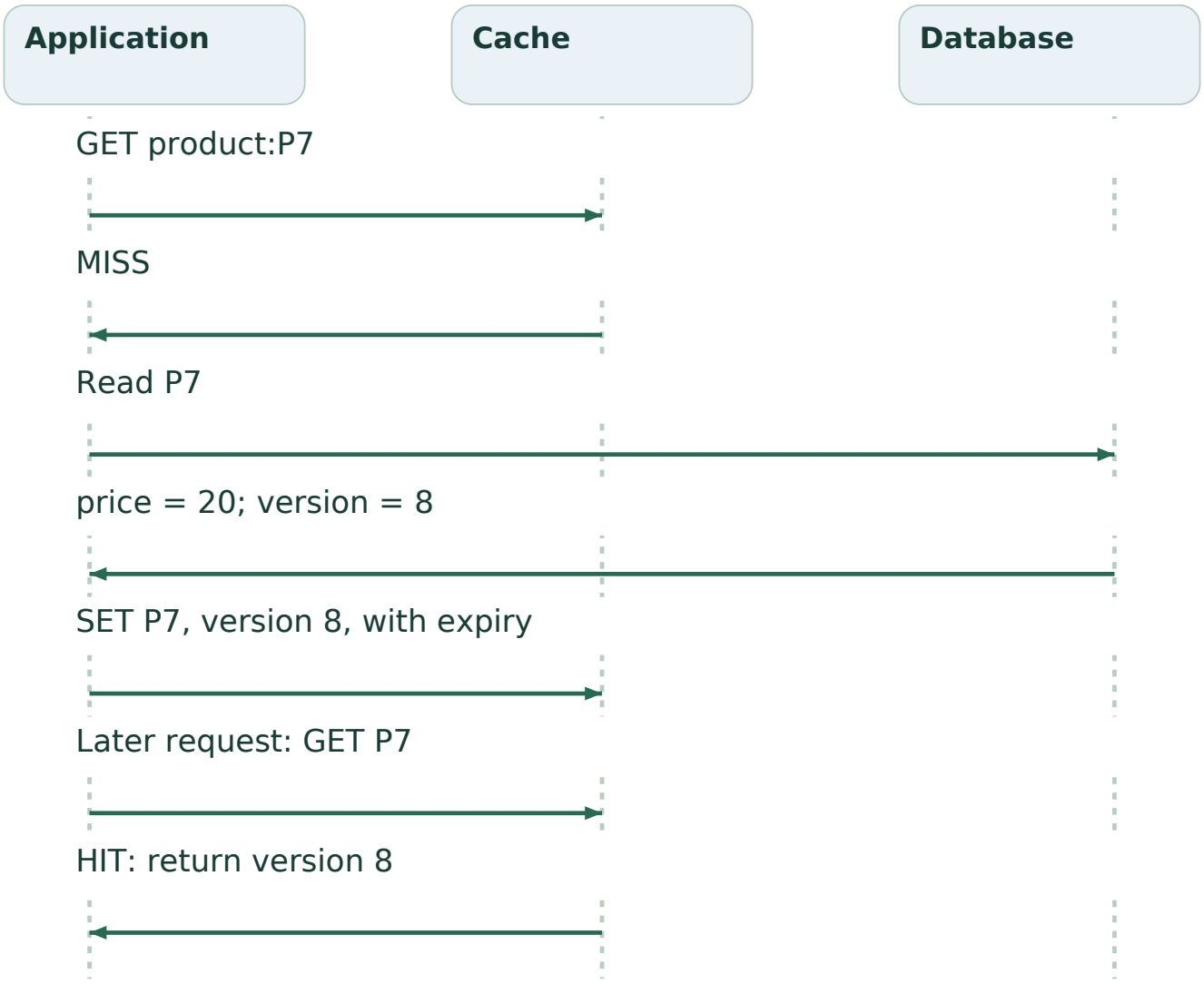
Placement	Benefit	Cost or limit
In-process memory	No cache-network round trip	Each application has a separate copy; restart loses it
Local disk	More reusable bytes per host	Slower access than RAM and still host-specific
Shared network cache	Many applications reuse the same entries	Network dependency and another service to operate
CDN edge cache	Repeated permitted bytes are served nearer users	Cache-key, authorization and freshness rules must be correct at the edge

03 / Worked example: cache-aside read of P7

Cache-aside means the application manages cache lookup and refill. Start with a database record `{id:P7, price:20, version:8}` and an empty cache.

Cache-aside: miss first, hit later

Cache-aside puts lookup and refill in the application. A hit is acceptable only under the cache's freshness and authorization rules.



Remember: Miss -> load -> fill; hit -> reuse.

1. Request R1 reads P7. The application checks key `product:P7` and misses.
2. It reads version 8 from the database, stores a copy with a 30-second TTL, and returns $20.
3. Request R2 reads P7 one second later. The same cache key hits; no database read is needed for that product-page request.
4. When the TTL expires, the next request needs a refresh. The cached copy did not update itself when time passed.

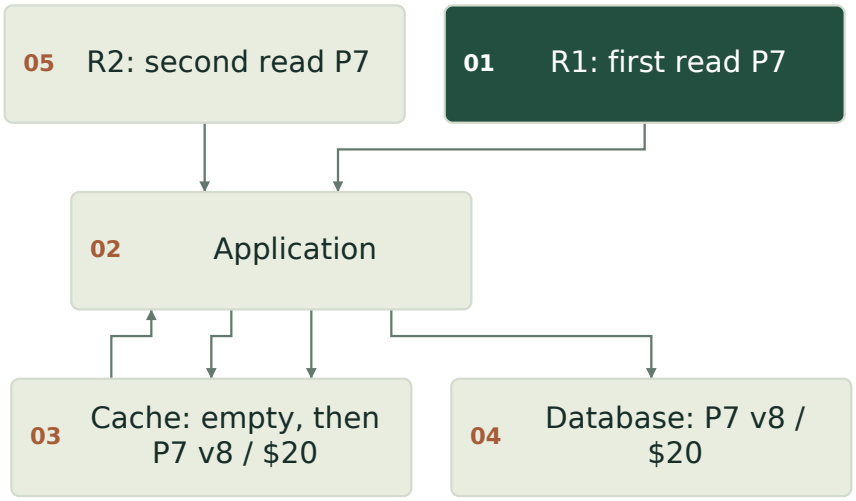
INTERVIEW CRITICAL

The cache key must include the response context

The key must include inputs that change the response. If price depends on currency or tenant, use a key such as `tenant:T1:product:P7:currency:USD`. A shared key that omits authorization-sensitive context can return another user's data. For images, a version or content hash in the URL permits long-lived caching because changed bytes receive a new name.

WORKED EXAMPLE DIAGRAM

First read: application misses, reads the database and fills the cache. Second read: the copy satisfies the request without another product database lookup. A later price change needs the invalidation protocol explained below.



1 -> 2	1. Request product P7: R1: first read P7 -> Application
2 -> 3	2. Look up key: first read misses: Application -> Cache: empty, then P7 v8 / $20
2 -> 4	3. On miss, read authoritative version 8: Application -> Database: P7 v8 / $20
2 -> 3	4. Store copy with expiry: Application -> Cache: empty, then P7 v8 / $20
5 -> 2	5. Second request for P7: R2: second read P7 -> Application
3 -> 2	6. Hit: return acceptable cached copy: Cache: empty, then P7 v8 / $20 -> Application

04 / Cache read and write policies

Cache placement answers where a copy lives. A cache policy answers who loads a missing copy and how a write reaches durable storage and existing cached copies. These are separate decisions: **invalidation** marks or removes a cached value so later readers cannot keep using it as current. For P7, the policy must explain what happens both when a page read misses and when the seller changes the price.

Pattern	What happens on a write or miss	What you must handle
Cache-aside	Application reads database on a miss	Refill races and invalidation
Read-through	Cache layer loads missing data	Loader failures and source access
Write-through	Cache layer writes through to durable storage before success	Partial failure across the two stores
Write-around	Write database directly, invalidate old cached value	Next read misses; avoid stale leftovers
Write-back	Acknowledge cache write, persist later	Loss of acknowledged data unless protected

Read-through describes loading reads; it is not itself a write policy. Write-through can make the write path more explicit, but two independent stores are not automatically one atomic transaction. If the database commits a $25 price while the cache update fails, readers need invalidation, version checks, or a declared staleness limit.

For the public product page, use cache-aside: set a TTL and invalidate the cached price after a database update commits. Accept brief display delays. Checkout must check current price and stock in the purchase transaction. Write-back may suit disposable counters, but important orders need a way to survive cache failure before the service reports success.

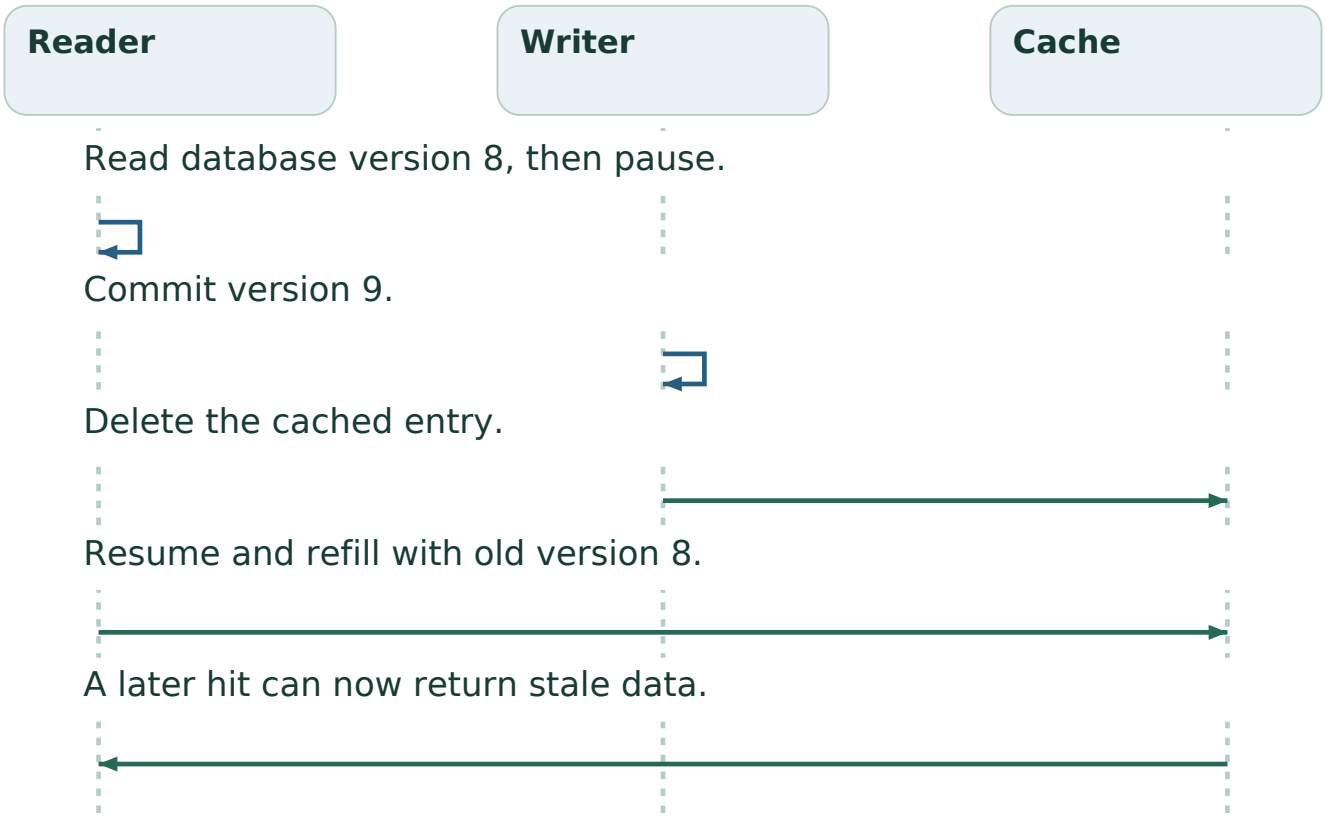
05 / Cache invalidation and the stale-refill race

The seller changes P7 from $20 to $25. Simply deleting the cache after the database write can still race with an earlier reader:

Time	Reader R	Writer W
t1	Cache miss; reads database version 8 ($20)	
t2	Pauses before filling cache	Commits version 9 ($25)
t3	Still paused	Deletes cached P7
t4	Fills cache with old version 8	Write is complete

Stale refill: deletion alone does not close the race

The late refill happens after invalidation. Versions, guarded cache updates or a bounded-staleness policy are additional design choices.



Remember: An old reader can refill after a new writer deletes.

INTERVIEW CRITICAL

A delayed refill can undo invalidation

R has reintroduced stale data after invalidation. One stronger design records a version floor in cache metadata: after version 9 is committed, a refill carrying version 8 is rejected by an atomic compare-and-set: the cache checks the stored minimum version and inserts the candidate as one indivisible operation. A separate "check, then later insert" allows another writer to change the floor between those steps. The floor must survive the stale refill window, and failover must not quietly lose the protection. Another design routes ordered change events through a single cache-update path. Neither mechanism comes for free.

If the business accepts up to a stated stale-display interval, a TTL may be sufficient under a specified refresh policy. If deletion or permission revocation must be immediate, verify current authorization rather than treating a stale cached record as truth. The interview answer should first state how stale a read may be and how quickly a permission change must take effect, then choose a mechanism that meets those requirements.

Suppose the database confirms version 8 at 10:00:00 with permission to reuse it until 10:00:30. A reader receiving it at 10:00:20 has only ten seconds left. Starting a fresh 30-second timer would incorrectly extend use to 10:00:50. Allow for clock differences. After expiry, obtain a newly validated value or return an error if validation fails. This limits age under the stated clock and database assumptions; it still allows stale reads before expiry and does not revoke access immediately.

Recovery also needs a way to distinguish fills started before a cache restart from fills started afterward. A **cache generation** is an identifier for one such cache lifetime. A refill carries the generation it started in; after recovery selects a new generation, the cache rejects results from the old one even if their requests finally resume.

INTERVIEW CRITICAL

A version floor needs its own recovery protocol

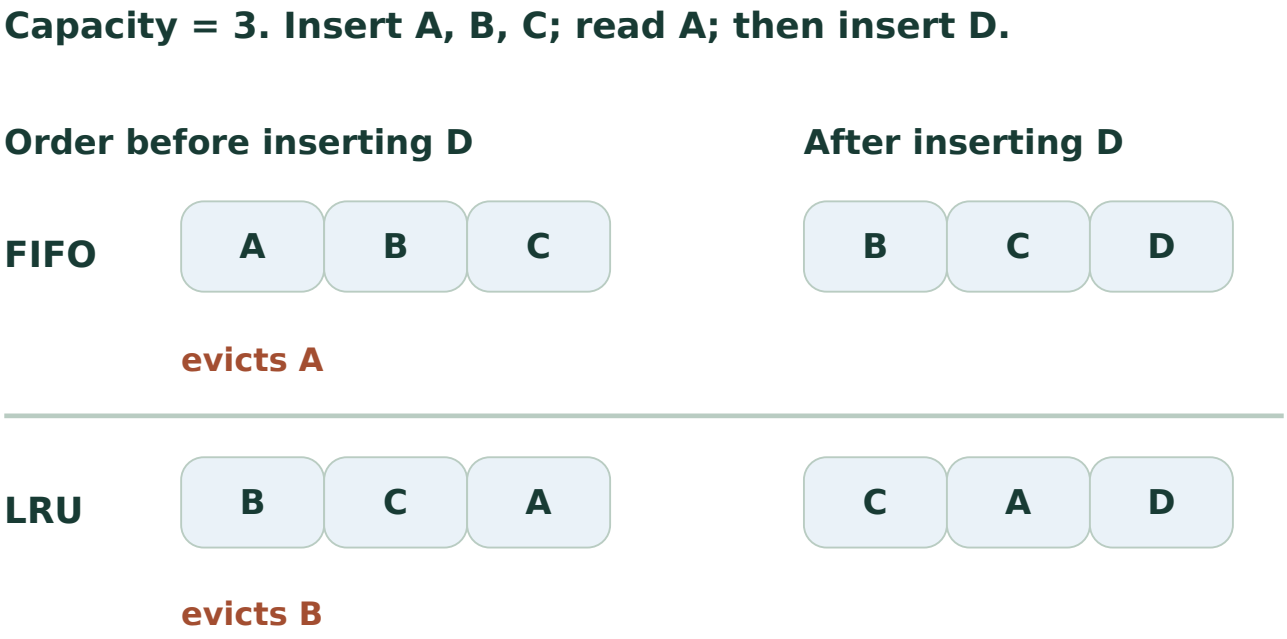
The version-floor protocol protects against fills older than an installed floor; it does not erase the interval between the database commit and floor installation. Recoverable change delivery can close that interval eventually, while immediate freshness needs a stronger coordinated read/write protocol. Do not store the floor as an ordinary evictable data entry. Define a maximum lifetime for outstanding refill attempts and reject expired attempts, or change a cache generation after metadata loss so earlier fills cannot publish into the new generation. A restarted cache cannot safely treat an absent floor as version zero while old readers remain able to fill. Ordered change events help only if competing refill paths obey the same version rule.

06 / Eviction policies: FIFO, LRU, LFU and alternatives

Invalidation removes data because it is no longer acceptable. **Eviction** removes data because the cache needs space. A perfectly fresh entry can be evicted.

The same access history evicts different keys

Each row orders entries from next to evict on the left to last to evict on the right.



Leftmost = next to evict. Reading A changes recency, not arrival order.

Remember: Reading A saves it under LRU; it does not save it under FIFO.

Try from memory: Which key survives because it was read recently?

Answer: A survives under LRU. FIFO ignores that read when deciding which entry arrived first.

Compare the policies on one trace

Take a two-entry cache: insert A, insert B, read A, then insert C. Before C arrives, insertion order is A then B; access recency is B then A.

Policy	What it tracks	Victim in this trace
FIFO: first in, first out	Insertion order	A
LIFO: last in, first out	Insertion order, selecting among existing entries before insertion	B
LRU: least recently used	Access recency	B
MRU: most recently used	Access recency	A

State the insertion convention when illustrating LIFO/MRU.

Other policy	Selection rule	Important qualification
LFU: least frequently used	Least popular over tracked history; with A read twice and B once, B loses	Age popularity so old activity does not dominate forever
Random	Select without recency or frequency bookkeeping	Does not deliberately preserve popular or recent entries

Real implementations may approximate these policies to save CPU and memory. An LRU cache can perform poorly during a large one-time scan because scan entries evict frequently reused data.

Implementation choice and data that must not be evicted

For a disposable shared product cache, one practical option is Redis with an explicit `maxmemory` limit and a measured choice between `allkeys-lru` and `allkeys-lfu`. Redis approximates these policies; LFU also decays old popularity. A volatile-only policy considers only expiring keys, so it is a different capacity policy. Keep durable business records and correctness metadata out of an indiscriminately evictable cache. See the Redis eviction reference; the application still owns freshness and origin-overload protection.

07 / Cache stampedes, negative caching and outages

When a popular key expires, 10,000 simultaneous readers may all miss and query the database. This is a **stampede**.

Technique	What it changes	Boundary
Request coalescing	One refresh runs while other callers wait or use an allowed stale copy	The waiting/stale behavior must fit the request contract
Randomized TTLs	Spreads expiry times across different keys	It does not by itself combine requests for one expired key
Stale-while-revalidate	Serves an acceptable stale value while refreshing	Use only when the freshness contract permits it

Negative caching stores a short-lived "not found" result to reduce repeated lookups of missing keys. It needs a short enough lifetime to let newly created records become visible, and must not reveal to an unauthorized user whether a private record exists.



INTERVIEW CRITICAL

Protect the origin when the cache disappears

A cache outage changes origin load from misses to potentially every request. Bound database fallback concurrency, shed excess work, and warm high-value keys first. Track request and byte hit ratios, stale reads, miss latency, evictions, and origin saturation. A large cache with an excellent aggregate hit ratio can still fail the most expensive requests.

08 / HTTP cache control and conditional revalidation

HTTP caches use response directives and validators to make reuse decisions. These are distinct from an application cache's own TTL configuration.

A **directive** is an instruction carried in response headers, usually `Cache-Control`, about whether and how caches may reuse the response. A **validator**, such as an ETag, identifies a representation version. **Revalidation** asks the origin whether that cached version is still usable, which can avoid sending the full body again.

Response directive	Meaning for reuse	Typical purpose
`max-age=30`	Freshness lifetime is 30 seconds, accounting for response age	Briefly reusable content
`s-maxage=60`	Shared-cache freshness override	A separate CDN/proxy lifetime
`no-cache`	Store if otherwise allowed, but validate before reuse	Reuse bytes only after checking
`no-store`	Do not store this exchange	Sensitive responses
`private`	Shared caches must not store the response	User-specific content

For example, an origin returns `ETag: "v8"`. On revalidation the cache sends `If-None-Match: "v8"`; a 304 response confirms that its selected representation can be reused without resending the body. `Vary` identifies request headers that select different representations, such as language. It does not perform authorization. Cache directives do not recall bytes already downloaded or replace access checks. See RFC 9111.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is caching? Use product P7 at $20/version 8 to explain the first miss and a subsequent hit.

Model answer

"Caching keeps a reusable copy to avoid repeating a more expensive operation. Request R1 for product:P7 misses, so the application loads $20/version 8 from the database and stores a copy. The next permitted request R2 hits that copy. The database remains authoritative; the hit is usable only under the page's freshness and access policy."

Interviewer follow-up

Does the cache update itself when the database changes?

Not generally. We need a write/update/invalidation mechanism or let an expiry trigger a later refresh.

What the answer must demonstrate: Name the source of truth.

02 / FOUNDATION

When would you choose a local cache rather than a shared one?

Model answer

"A local memory cache is fast and avoids a network dependency; a local disk cache can hold larger reusable objects. But copies differ across application instances and vanish or become unavailable with the host. A shared cache simplifies sharing at the cost of a network call and another service to operate."

Interviewer follow-up

What happens under random backend routing?

A repeat caller may land on an instance whose local cache has never seen the key. Hit rate depends on placement and request distribution.

What the answer must demonstrate: Explain per-instance copies.

03 / APPLIED

Does a 30-second TTL guarantee every read is less than 30 seconds stale?

Model answer

"Only under specified fill, age, and refresh rules. If a delayed reader fills an already old value with a new 30-second timer, its data age may exceed that bound. I would carry version or source timestamps when the age limit matters and define which moment starts the TTL."

Interviewer follow-up

What if permissions must change immediately?

I need current authorization or a revocation mechanism that enforces that promise. A general long-lived content cache cannot supply immediate revocation by itself.

What the answer must demonstrate: Distinguish cache residency age and data age.

04 / APPLIED

Why can delete-after-write still return the old price?

Model answer

"Reader R can fetch version 8 before writer W commits version 9, then refill after W deletes the cache. The delete happened, but the late reader resurrected the old copy. I show that timeline and choose either bounded stale display or a stronger version-aware update protocol."

Interviewer follow-up

How does a version floor help?

The cache records that P7 must be version 9 or newer and checks that rule atomically before accepting a refill. It then rejects version 8. Keep the rule while old refills may arrive; if it is lost, reject attempts from the old cache generation and rebuild safely. Stale reads remain possible between the database commit and installing the rule unless those steps are coordinated more strongly.

What the answer must demonstrate: Locate the late refill, then the atomic check.

05 / APPLIED

Why not acknowledge orders from a write-back cache?

Model answer

"If the cache acknowledges before durable persistence and then loses the entry, the customer can lose an order already reported as saved. I would need a replicated durable log and a tested recovery protocol, or acknowledge only after the required durable commit."

Interviewer follow-up

Can write-back ever be reasonable?

Yes, for a workload whose loss model permits it or a cache system designed to provide the required durability. The name of the pattern alone does not prove safety.

What the answer must demonstrate: Tie acknowledgment to a loss model.

06 / APPLIED

A two-entry cache receives insert A, insert B, read A, insert C. What do FIFO and LRU evict?

Model answer

"With two entries and eviction from existing entries, FIFO evicts A because it was inserted first. LRU evicts B because A was accessed more recently. This demonstrates that insertion order and access order are different."

Interviewer follow-up

When can LRU be a poor fit?

A long scan of one-use entries can evict frequently useful keys. Admission policy or frequency-aware policies may help, depending on the access distribution.

What the answer must demonstrate: Replay the actual ordering.

07 / APPLIED

Ten thousand readers miss P7 at once. What do you do?

Model answer

"I allow one refresh for P7 and coalesce the other requests behind it, with bounded waiting. If the product permits it, I serve a stale copy during refresh. I also limit database fallback globally so many different missing keys cannot overwhelm it."

Interviewer follow-up

Does TTL jitter solve the same-key problem?

It spreads expirations of different keys. A single hot key still needs coalescing, pre-refresh, or another hot-key strategy.

What the answer must demonstrate: Distinguish same-key and many-key bursts.

08 / APPLIED

How would you add a CDN to an existing image service?

Model answer

"I keep static objects behind a stable static hostname and point delivery through the CDN. I set origin access, TLS, cache headers, and versioned object paths. On a miss the edge fetches the origin; on a permitted hit it returns its copy. Private objects need a separate authorization-compatible plan."

Interviewer follow-up

Can you cache a personalized product response under only product ID?

No, if tenant, currency or authorization changes the response. Represent safe variation in the key, or exclude the response from shared caching with an appropriate policy. HTTP private prevents shared storage; no-cache permits storage but requires validation. Neither substitutes for checking access.

What the answer must demonstrate: Explain both migration and key correctness.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Design a product cache, then explain a late refill after a price change and a total cache outage.

- Trace first miss and second hit.
- State key dimensions and freshness contract.
- Replay the four-step stale refill.
- Choose which entry to evict and limit concurrent requests to the database when the cache is unavailable.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Cache questions

What identifies the entry, which store has the authoritative record, how old may the copy be, and how is it refreshed?

Key -> source -> allowed age -> refresh.

Invalidation versus eviction

Invalidation addresses validity; eviction addresses capacity.

Freshness versus space.

A reader fetches $20, then a writer saves $25 and clears the cache. What can go wrong?

The delayed reader can refill the cache with $20 after the writer cleared it. The refresh protocol must account for that order of events.

Read old -> write new -> clear -> refill old.

Summary and interview notes

A cache is a reusable copy whose value depends on a correct key, a declared freshness policy and safe behavior when the copy disappears. Choose placement and read/write policies separately, and protect the authoritative source from both stale refills and sudden miss traffic.

Remember these points

• A hit is usable only if its data and access policy are acceptable.

• A delayed refill can resurrect an old value after delete-after-write invalidation.

• A minimum accepted version blocks older cache refills only after it is installed. Keep that protection valid while old refill requests can still arrive.

• Expiration governs age, invalidation governs acceptability, and eviction frees capacity.

• Coalescing combines concurrent refreshes of one key; randomized TTLs spread expiry across different keys.

Interview tips

• Draw the reader/writer timeline before claiming that invalidation is safe.

• State whether freshness is measured from source validation or from insertion into the cache.

• Distinguish no-cache from no-store when describing HTTP behavior.

Important qualifications

• Checkout or permission decisions may need current authoritative state even when a product page tolerates stale display data.

• A Redis eviction configuration does not implement the application's consistency protocol.

• Test an empty or unavailable cache while limiting how many fallback requests the database or origin server accepts at once.

Technical references

HTTP caching specification
HTTP freshness, revalidation, and shared/private cache behavior.
https://www.rfc-editor.org/rfc/rfc9111.html

Redis eviction policies
Primary reference for practical eviction policies and approximations.
https://redis.io/docs/latest/develop/reference/eviction/

FOUNDATIONS / 10

Proxies: forward proxy, reverse proxy and API gateway

DEFINITION

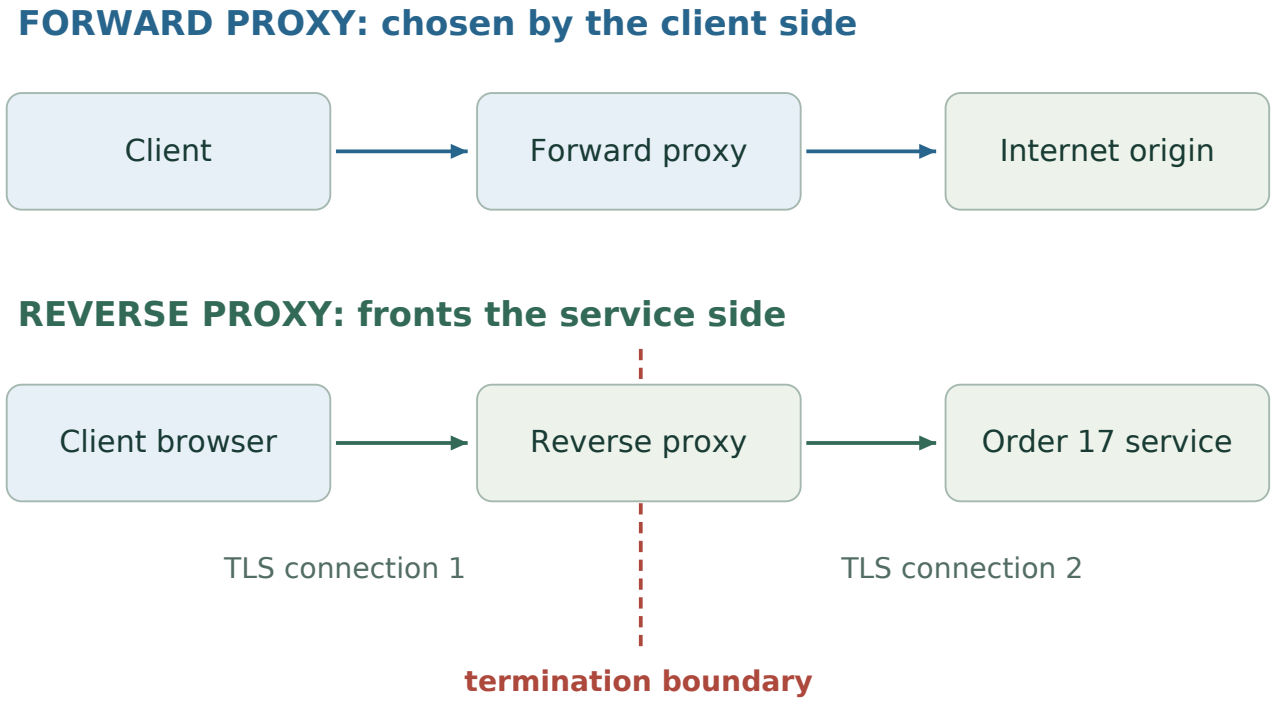
A proxy is an intermediary that forwards communication on behalf of another party. A forward proxy serves clients reaching destinations; a reverse proxy fronts servers receiving requests, and an API gateway commonly adds API-specific policy to that server-facing role.

Why it matters: An intermediary can provide a controlled place for routing, connection handling and permitted caching. Its role determines whose traffic it accepts and what it may trust.

Forward proxy, reverse proxy, and TLS trust boundaries

A forward proxy acts for a client; a reverse proxy fronts a service. TLS termination and forwarded identity create explicit trust boundaries.

Whose side does the intermediary represent?



Trust headers only from your proxy. The origin still authorizes access to order 17.

Worked example

A request to https://shop.example/orders/17 reaches the reverse proxy. The reverse proxy receives that public request, routes it to the order application, and relays the response; the application still checks that order 17 belongs to the authenticated caller.

Key takeaways

• Forward proxy represents clients; reverse proxy fronts servers.

• TLS termination protects one connection segment, not automatically every later hop.

• Forwarding headers and shared caches must preserve identity and authorization.

Read the visual model

1. A client uses a forward proxy to reach an origin; the proxy represents the client side.

2. Public clients reach a reverse proxy which selects a protected origin; the proxy represents the service side.

3. GET /orders/17 terminates TLS at the reverse proxy; the origin hop has its own encryption and authentication decision.

4. Only trusted proxies may supply effective forwarded identity headers. The order service still checks whether the caller may read order 17.

forward proxy • reverse proxy • gateway • TLS • CDN

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Identify which party a proxy represents.

• Trace the request and trust boundary through TLS termination.

• Explain open, anonymous, and transparent proxy properties without confusing them.

Useful foundations: HTTP APIs and request lifecycle; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / Proxy definition: forward versus reverse

A proxy is an intermediary that receives communication and forwards it on behalf of another party. A hop is one connection segment along that path. The same request can travel client -> proxy -> application, with a separate response returning through those components. The proxy can apply access or routing rules, cache a permitted response, or change how the next connection is made. A proxy adds a hop; it does not erase the need to understand the caller and the destination.

A **forward proxy** represents clients accessing remote services; an organizational gateway may filter destinations and record permitted outbound traffic. A **reverse proxy** fronts origin servers and routes incoming traffic to them. For example, `shop.example` can accept a public `/orders/17` request and forward it to an internal order API.

The origin is the service responsible for producing the resource. A proxy may return a cached origin response when the policy allows. "Forward" and "reverse" describe whose side the intermediary serves, not whether packets travel only in one direction.

Role	Whose side it serves	Concrete example	Limit
Forward proxy	Clients choosing external destinations	An employee browser reaches permitted websites through the company proxy	It needs a destination and client-use policy
Reverse proxy	Servers behind a public service name	shop.example routes `/orders/17` to an internal application	It does not automatically establish order ownership
API gateway	Commonly the reverse-proxy/API entry role	Validate credentials, request size and API quotas	The service that reads or changes business data must still enforce its correctness and access rules
Load balancer	Selects among eligible destinations	Choose order server A or B	Selection alone does not add caching or API policy

One deployed component can perform several of these jobs. Explain the responsibilities separately so a product name does not hide an authorization or failure assumption.

02 / Worked example: an HTTPS request through a reverse proxy

For an HTTPS request to `https://shop.example/orders/17`, several protocols have separate responsibilities. **DNS** maps a service name to a network address. **HTTP** carries the request and response. **TLS** encrypts a connection and authenticates its endpoint using certificates; HTTPS is HTTP over a protected connection. **TLS termination** is where that protected connection ends and the receiver can inspect its HTTP content. The following steps use those terms; protocol details are in the request-lifecycle chapter.

1. DNS resolves the public shop name to a reachable edge address.
2. The browser establishes an encrypted connection to the shop's reverse proxy and verifies its certificate for that name.
3. The proxy receives `GET /orders/17`, plus the session credential. That credential is evidence used to authenticate the signed-in account; the URL itself proves no identity. The proxy routes the request to the order service.
4. It opens or reuses a backend connection. If this crosses an untrusted network segment, encrypt and authenticate that hop too.
5. The order service derives the caller's identity from a validated credential and checks permission to read order 17.
6. The response travels back through the proxy to the browser. Private order data is not placed in a broadly shared cache.

An API gateway is often a reverse proxy with additional API policy: authentication checks, quotas, routing, or request validation. A load balancer chooses among eligible backends. One product can perform both roles, but the responsibilities remain separate.

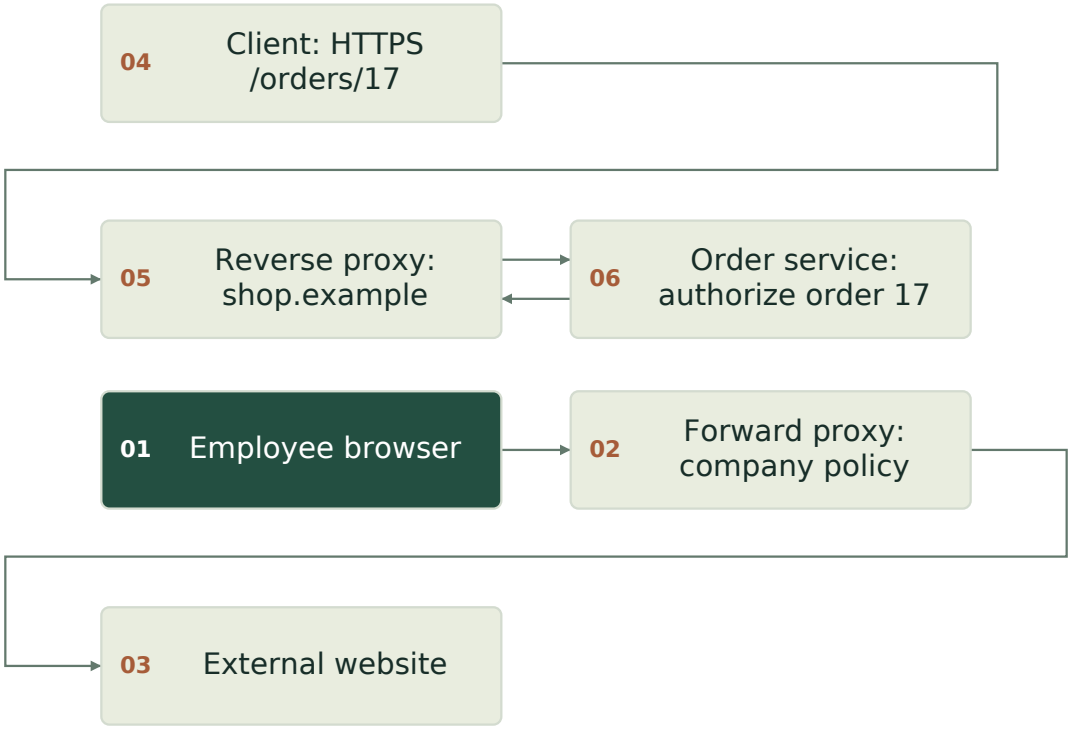
INTERVIEW CRITICAL

Forwarding encrypted bytes does not reveal HTTP content

A forward proxy can instead create an opaque tunnel. A browser asks it to `CONNECT api.example:443`; after successful tunnel setup, the browser negotiates TLS with the destination through that tunnel. The proxy relays encrypted bytes and knows the requested destination, but does not thereby see the HTTP path or body. Client authentication and allowed destination/port rules still apply to use of the proxy. TLS interception is a different trust arrangement, not an automatic property of forwarding. See CONNECT in RFC 9110.

WORKED EXAMPLE DIAGRAM

One request path shows a forward proxy serving an employee client; the other shows a reverse proxy serving the shop. Both relay replies back. The order service still decides whether the caller may read order 17.



1 -> 2	1. Client sends permitted web request: Employee browser -> Forward proxy: company policy
2 -> 3	2. Forward proxy represents client: Forward proxy: company policy -> External website
4 -> 5	3. Request public shop service: Client: HTTPS /orders/17 -> Reverse proxy: shop.example
5 -> 6	4. Reverse proxy fronts order service: Reverse proxy: shop.example -> Order service: authorize order 17
6 -> 5	5. Return authorized order response: Order service: authorize order 17 -> Reverse proxy: shop.example

03 / Forwarding headers and trusted client identity

The backend connection originates at the proxy, so the backend's immediate peer address may be the proxy's address. Forwarding headers can carry earlier connection information. They must be trusted only from known proxy hops, because a public caller can forge ordinary request headers.

Field or connection fact	At the public edge	Safe backend interpretation
Host / authority	shop.example	Route only allowed hostnames
Client network address	Seen by the trusted edge	Use trusted forwarding metadata, not arbitrary caller claims
User identity	Caller credential	Validate credential and resource permission
Request ID	Accept or issue under a policy	Correlate logs without treating it as authentication

Suppose an attacker sends `X-Forwarded-For: 127.0.0.1`. A backend that treats that value as proof of an internal caller may grant unintended access. The edge should normalize forwarding metadata, and the backend should know which upstreams are authorized to supply it. Rewriting a header is a security-sensitive operation when policy depends on that field.



INTERVIEW CRITICAL

Forwarding metadata needs a trusted-hop policy

For a one-edge deployment, suppose the edge actually sees client address `198.51.100.24` and the caller supplies a fake localhost header. The edge replaces untrusted forwarding claims with its observed address; the backend accepts that metadata only from the configured edge, never from a direct public connection. In a multi-proxy deployment, configure the trusted hops and the rule for finding the last untrusted address rather than trusting the leftmost string blindly. Network address is still not account identity. If a gateway forwards a verified account claim, protect that hop and reject caller-supplied identity headers; the application must still authorize the requested resource.

04 / Open, anonymous and transparent proxies

Forward and reverse describe whom a proxy represents. Open, anonymous and transparent describe other properties: who may use it, what identity information it reveals, or how traffic reaches it. These labels can overlap; choosing one does not answer the questions covered by the others.

An **open proxy** accepts use from a broad or unrestricted set of clients. A closed organizational proxy limits who may use it. Openness is an access-control property. It says nothing by itself about whether the proxy hides the client identity or inspects content.

An **anonymous proxy** attempts not to reveal some client-identifying information to the destination. That is not a promise of universal anonymity: accounts, cookies, behavior, or other headers can still identify a user. Explain the exact information hidden rather than using anonymity as a security guarantee.

"Transparent proxy" is overloaded. In common network terminology, a transparent or interception proxy handles traffic without explicit proxy configuration in the client. Older HTTP specifications also used transparent to mean that the proxy does not transform requests or responses beyond changes needed for proxy authentication and identification. These are different properties; name the intended meaning. Intercepting encrypted content requires an applicable trust and certificate arrangement; a device that only forwards encrypted bytes cannot arbitrarily inspect their HTTP content.

The useful interview distinction is role plus policy: who can use the proxy, which destination it represents, what it can see, and what information it forwards.

05 / Reverse-proxy caching and API gateway policies

A reverse proxy can cache public versioned images, compress permitted responses, terminate TLS, filter malformed requests, and route to service pools. For each feature, state which requests it applies to, what it may change, and its resource or security cost. Compression uses CPU; logging can expose sensitive data; transformation can invalidate signatures or cached representations if done incorrectly.

For the private order page, choose authorization-aware forwarding and an explicit cache policy. HTTP `private` prevents shared caches from storing the response but can permit a browser cache; `no-store` tells caches not to store it. Choose the policy required by the product instead of treating those directives as synonyms. For `/images/P7/v9.jpg`, a shared edge cache can reuse the same immutable public bytes. The first request misses and fetches the static origin; the next permitted request hits nearby storage. Different paths can therefore have different cache and authentication policies.

An API gateway may reject excess traffic before it reaches expensive application work, but it must identify users and quota dimensions correctly. Sending all traffic through a single unreplicated gateway creates a new failure point even if the applications behind it are redundant.

06 / Proxy timeouts, retries and redirect rewriting



INTERVIEW CRITICAL

A proxy timeout does not prove the operation failed

If the order service slows down, cap the proxy's queue and waiting time. A proxy timeout means no reply arrived; the order may already be saved. Retry only when repeating the operation is safe. Repeating a GET differs from repeating a payment POST without duplicate protection.

A proxy can **rewrite** the path it forwards so a public URL maps to a different internal path. A **redirect** instead asks the client to make a new request, using the destination in the response's `Location` header. The two mechanisms interact when the public and internal URL layouts differ.

Path rewriting also changes visible behavior. Suppose a public service lives under `/store/` while the origin serves `/`. A redirect from the origin to `/orders/17` can escape the public prefix unless the proxy rewrites the Location header or published links avoid the redirect. Verify both the origin address and the public path; success at one does not prove the other works.

Health-check and replicate the proxy layer, measure added latency and errors, and consider how configurations roll out. A malformed routing rule can fail every healthy backend at once. Keep configuration changes reviewable and validate representative paths, headers, uploads, and redirects.

Parsing must also agree across hops. **Request framing** determines where one HTTP message ends and the next begins. If a proxy and backend interpret ambiguous length information differently, they can disagree about which bytes belong to an authorized request. Prefer standards-compliant parsers, reject ambiguous framing under an explicit edge policy, and apply consistent path normalization before authorization and routing. HTTP/2 or HTTP/3 at the client does not remove this boundary when an intermediary translates to HTTP/1.1 upstream. See the HTTP/1.1 framing specification.

07 / Interview example: justify the proxy boundary

Interviewer: "Why do you need a reverse proxy if you already have an application?"

Candidate: "It gives the public service one controlled entry point for TLS and routing. For an order request, it forwards to an eligible order server, but the server still checks that the caller can read order 17. Public versioned images can be cached at the edge; private orders cannot share that policy. I also configure deadlines, safe forwarding headers, and redundant proxy capacity. The extra hop is useful because it performs these specific responsibilities."

NGINX can implement this reverse-proxy role with explicit upstream routing and header policy. For a protected HTTPS backend, configure certificate verification, the expected backend name and the trusted certificate set; merely selecting an `https://` upstream is not the complete identity check. The current proxy-module reference documents `proxy_ssl_verify` as off by default, so enable verification deliberately where required. The real-IP module separately controls which proxies may supply network-address metadata. Those options do not authenticate the application user. See the proxy module and trusted real-IP configuration.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is the difference between a forward and reverse proxy?

Model answer

"A forward proxy represents clients reaching external destinations, such as employees using a company web gateway. A reverse proxy represents servers to incoming callers, such as shop.example forwarding to an internal order service. Both relay responses back; the names describe role, not one-way packet direction."

Interviewer follow-up

Can one gateway product perform both?

A product can support several roles, but I still configure and explain the client trust and destination policy for each deployment.

What the answer must demonstrate: Say whose behalf the proxy acts on.

02 / FOUNDATION

When a reverse proxy terminates HTTPS for an order API, which connection does TLS protect?

Model answer

"The browser's TLS connection ends at the reverse proxy, which presents the shop certificate and can inspect the HTTP request. The proxy may then establish a separate protected backend connection. I would not assume browser-to-edge encryption automatically protects the entire path."

Interviewer follow-up

What changes with TLS passthrough?

The intermediary forwards encrypted traffic and cannot inspect the HTTP path or headers inside it. A forward proxy can similarly establish a CONNECT tunnel and then relay browser-to-origin TLS. In either case, destination policy and transport metadata remain separate from decrypted application content.

What the answer must demonstrate: Draw both connection segments.

03 / APPLIED

Why can't the backend trust any X-Forwarded-For value?

Model answer

"An external caller can send that ordinary header. In a one-edge deployment I replace untrusted claims at the edge with its observed address, and the backend accepts forwarding metadata only from that trusted edge. Multiple proxies require an explicit trusted-hop traversal rule. A forged localhost value must not grant internal access, and an IP address still does not establish user identity."

Interviewer follow-up

Does the client IP establish the user identity?

No. Users can share addresses, and addresses can change. Authentication and resource authorization need separate credentials and checks.

What the answer must demonstrate: Separate network provenance and identity.

04 / APPLIED

Can a reverse proxy share an authenticated order response using only its URL as the cache key?

Model answer

"No. A private order response must not become another user's response. I choose an authorization-compatible cache policy, often avoiding shared caching for this path. Public versioned product images can use a different policy."

Interviewer follow-up

Would including a user ID in the cache key be enough by itself?

It helps separate entries, but I still validate the identity and permissions, handle revocation, and ensure untrusted input cannot choose another user's key.

What the answer must demonstrate: Protect the authorization decision as well as key separation.

05 / APPLIED

Does "open proxy" mean "anonymous proxy"?

Model answer

"No. Open describes who is allowed to use it; anonymous describes which identifying information it tries to hide. A proxy can be open and still log users or forward identifying headers. Neither term alone establishes privacy or safety."

Interviewer follow-up

What does transparent mean?

Clarify whether it means interception without client configuration, or historical HTTP forwarding of requests and responses without transformations beyond proxy authentication and identification.

What the answer must demonstrate: Treat role, access, and visibility as different dimensions.

06 / APPLIED

The gateway times out on POST /checkout. Can it retry automatically?

Model answer

"Only if the checkout protocol makes repeating that logical request safe. The origin may already have committed the purchase while the response was delayed. A stable idempotency key and saved result let a retry recover the outcome; an arbitrary new POST may create a second purchase."

Interviewer follow-up

Can you just lengthen every timeout?

That can retain more in-flight work and worsen overload. I set an end-to-end deadline and bounded retries based on the user operation.

What the answer must demonstrate: A timeout is an unknown outcome.

07 / APPLIED

The origin works but the public subpath fails. What do you inspect?

Model answer

"I inspect path stripping, relative links, redirects, query strings, and asset routes. If the origin redirects to a root-relative path, it may omit the public prefix. I verify the actual public URL rather than treating origin success as end-to-end proof."

Interviewer follow-up

What is a concrete fix?

Rewrite relevant redirect locations at the proxy or publish links to canonical paths that preserve the public base, then test navigation and assets on both paths.

What the answer must demonstrate: Follow the visible URL through the proxy.

08 / APPLIED

Which responsibilities would you keep out of a generic gateway?

Model answer

"I can centralize routing, TLS, request-size limits, and some authentication or quota checks. The order service must still check who may read or change an order, and the component committing a purchase must enforce rules such as not selling more stock than is available. Otherwise an alternate internal caller could bypass the only business check."

Interviewer follow-up

Does adding two gateways remove all risk?

No. They may share one bad configuration or a saturated dependency. I also need safe rollout, monitoring, and surviving capacity.

What the answer must demonstrate: Explain responsibility and shared failure modes.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Draw an HTTPS order lookup through a reverse proxy, then diagnose a forged forwarding header and an escaped redirect.

- Identify forward versus reverse roles.
- Mark both TLS segments and trusted header hops.
- Separate private order and public image caching.
- Explain one proxy timeout or redirect failure.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Proxy roles

Forward proxies serve clients; reverse proxies front origin services.

Who is represented?

If a proxy terminates TLS, what must the application verify next?

Protect and authenticate the proxy-to-application connection as needed. Trust forwarded identity headers only from approved proxies that replace untrusted client values.

Check who supplied identity at each hop.

Gateway timeout

The origin may already have completed the operation.

Recover the result before repeating the action.

Summary and interview notes

A proxy forwards communication on behalf of clients or servers and can centralize connection handling, routing and caching. For each connection, specify how endpoints are authenticated, what requests are authorized, how messages are parsed, and what happens when the connection fails.

Remember these points

• Forward and reverse describe whose side the proxy serves, not the direction responses travel.

• TLS termination exposes HTTP to the terminator; an opaque CONNECT tunnel does not.

• Trust forwarding metadata only from configured proxy hops, and keep network provenance separate from account identity.

• Private response caching, path rewriting and message framing must preserve the application's access contract.

• A timeout may follow an origin commit; a proxy retry needs the same logical operation identity.

Interview tips

• Draw both TLS segments and label who validates each endpoint.

• Trace one forged forwarding header through the trusted-hop policy.

• Test the externally visible URL, redirect and asset paths rather than checking only the origin.

Important qualifications

• An encrypted upstream connection is not sufficient proof of peer identity unless certificate/name validation is configured.

• A gateway can perform shared checks, but the service that changes or returns business data must also enforce the relevant correctness and access rules.

• Replicated proxies can still share a bad configuration; rollouts and overload behavior need their own controls.

Technical references

HTTP semantics: intermediaries and forwarding
Primary protocol terminology and forwarding behavior.
https://www.rfc-editor.org/rfc/rfc9110.html

HTTP caching
Shared cache policy and response reuse constraints.
https://www.rfc-editor.org/rfc/rfc9111.html

HTTP/1.1 message framing
Message boundaries and parsing consistency across HTTP intermediaries.
https://www.rfc-editor.org/rfc/rfc9112.html

NGINX HTTP proxy module
Upstream TLS verification, naming, forwarding and rewrite controls; checked 2026-09-23.
https://nginx.org/en/docs/http/ngx_http_proxy_module.html

NGINX real-IP module
Explicit trusted proxy sources and recursive client-address interpretation.
https://nginx.org/en/docs/http/ngx_http_realip_module.html

Historical HTTP/1.1 terminology: transparent proxy
Historical terminology only: this obsolete RFC explains the older non-transforming meaning of transparent. Use RFC 9110 for current HTTP semantics.
https://www.rfc-editor.org/rfc/rfc2616.html#section-1.3

FOUNDATIONS / 11

Data partitioning and sharding

DEFINITION

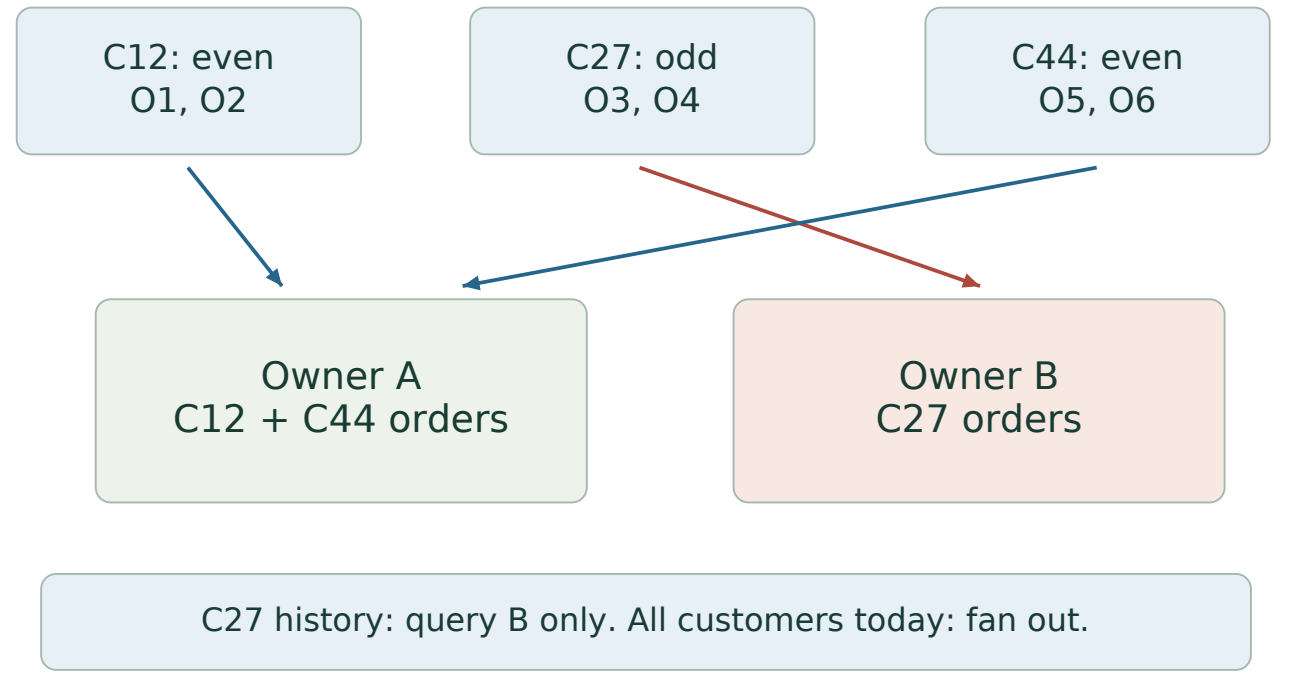
Data partitioning divides a dataset into smaller parts. Sharding is horizontal partitioning across separately managed storage groups: each shard owns different records, while replicas hold copies of the same records.

Why it matters: One database may run out of storage or processing capacity. Dividing ownership lets different groups handle different records, at the cost of routing and operations that cross those groups.

Hash partitioning and shard-local queries

The example uses customerNumber modulo two to choose one owner. A global report still fans out or needs a separate read model.

Toy placement: customerNumber mod 2



The shard key selects the owner; the index finds rows inside that owner.

Worked example

Using customerNumber mod 2, C12's orders O1/O2 go to shard A and C27's O3/O4 go to shard B. A request for C27's history contacts B; a report across all customers needs both owners.

Key takeaways

• A shard divides records; a replica copies them.

• Choose a shard key from queries, related writes and traffic distribution.

• Moving bytes is not enough: transfer write ownership safely.

Read the visual model

1. C12 and C44 are even, so their orders O1/O2 and O5/O6 belong to A. C27 is odd, so O3/O4 belong to B.

2. C27 last ten orders routes directly to B, then uses a local ordered index.

3. All orders today crosses customer owners and needs fanout or an analytical model.

4. When moving ownership, copy and replay, fence old writes, and switch a versioned routing epoch.

partition key • range • hash • directory • resharding

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Distinguish partitioning from replication and indexing.

• Choose a key from concrete queries and related writes.

• Explain skew, cross-shard work, and an online shard move.

Useful foundations: Databases, data models, and ACID transactions; Database indexes: B-trees, composite keys and query access

8 interview questions with model answers and answered follow-ups.

01 / Partitioning and sharding: definitions

Data partitioning divides a dataset into smaller parts. Sharding is horizontal partitioning across separately managed storage groups. Horizontal means dividing records rather than splitting fields of each record. Each shard owns a subset of rows or records; ownership means that a designated storage group is responsible for those records and decides which writes it accepts. Replication instead creates copies of the same records. You can shard orders by customer and also replicate each shard; one choice divides ownership and the other protects each owner's data.

Suppose a shop stores one billion orders and its single database cannot meet the required storage or throughput. Before splitting, inspect inefficient queries and unused indexes; sharding adds routing, movement, and cross-shard complexity. When splitting is justified, choose a **partition key**: a field or combination of fields used to determine ownership.

Our example has customers C12, C27, and C44, and orders O1 through O6. Most screens ask for one customer's recent orders. That query suggests keeping a customer's records together rather than scattering every order randomly.

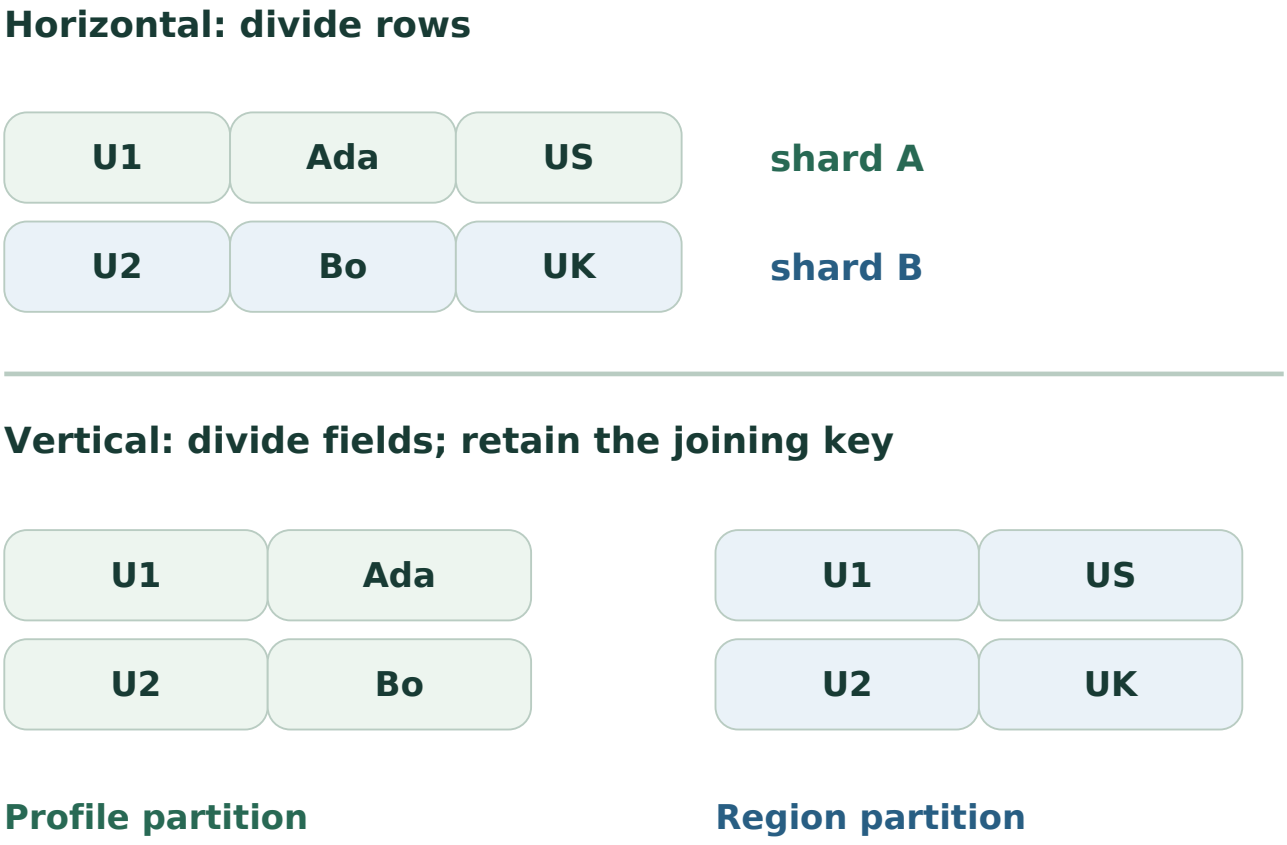
02 / Horizontal, vertical, functional and directory partitioning

Dividing a dataset involves two choices: what to separate, and how to find each part. Horizontal, vertical and functional partitioning describe what is separated. A directory describes how requests find the owner of a part.

Horizontal partitioning divides rows of the same kind: some customers' orders on shard A and others on B. Range partitioning, which groups rows by intervals of a key, is one horizontal method, not another name for all horizontal partitioning.

Split rows or split fields?

The cells show the same small dataset. In the vertical split, both partitions keep the ID needed to join the fields.



Remember: Horizontal cuts between records; vertical cuts between fields.

Try from memory: Why does U1 appear in both vertical partitions?

Answer: It is the shared identity used to join the fields back into one logical record.

Vertical partitioning divides columns or attributes. A frequently read account profile might be separate from large optional biography data. Functional partitioning separates different responsibilities or datasets, such as orders, catalog, and billing. Both can reduce unnecessary work, but a user operation that needs separated data must combine it somewhere.

Directory-based placement keeps a lookup from a logical group to its physical owner. For example, a directory can map tenant T7, a customer organization sharing the service, to shard B, allowing T7 to move later without changing its identity. The directory becomes important routing metadata: cache it carefully, version it, and make stale routes detectable rather than treating it as an infallible box.

03 / Worked example: place and query six orders

Now apply horizontal partitioning to the orders example: keep every order for one customer on the same shard, so that customer's order history can be read locally. The router needs a rule that turns a customer number into a shard destination.

For a two-shard example, use `customerNumber mod 2`. The modulo operation returns the remainder after division by two: even customers go to A, odd customers to B. This simple function is for demonstrating placement, not the final resharding scheme.

Record	Customer	Calculation	Shard
O1	C12	12 mod 2 = 0	A
O2	C12	12 mod 2 = 0	A
O3	C27	27 mod 2 = 1	B
O4	C27	27 mod 2 = 1	B
O5	C44	44 mod 2 = 0	A
O6	C44	44 mod 2 = 0	A

A query for C27's last ten orders computes shard B, then uses a local index on `(customerId, createdAt, orderId)`. It contacts one owner. A report over all customers' orders cannot identify one shard from that key; it requires **fanout**, meaning subqueries to the relevant shards followed by a merge, or a separate analytical/read model organized for reporting.



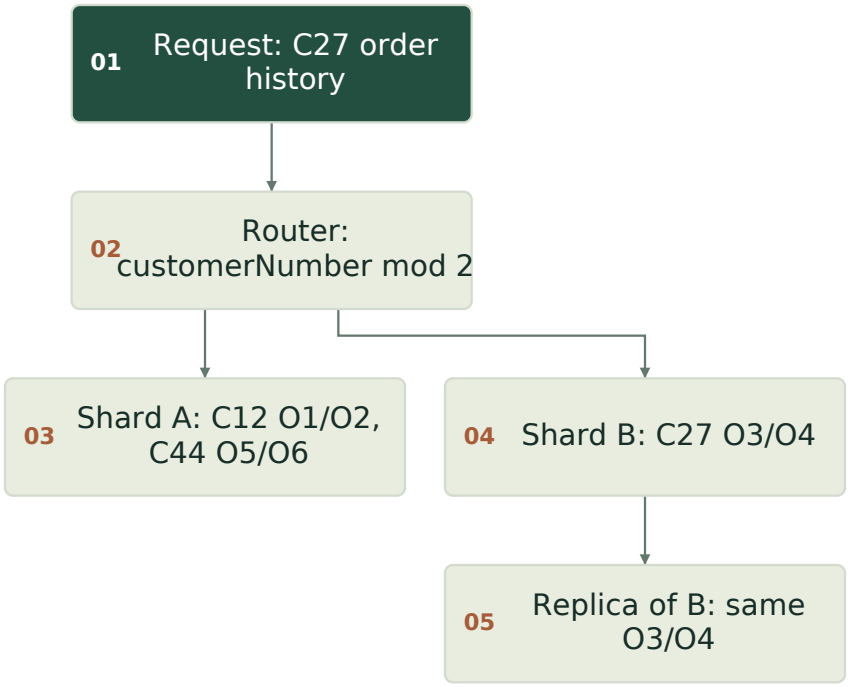
INTERVIEW CRITICAL

An index and a shard key answer different questions

An index speeds lookup within a shard. A shard key determines which shard to contact. Confusing them leaves a missing routing step in the interview design.

WORKED EXAMPLE DIAGRAM

Partitioning puts different customer records on A and B. Replication puts another copy of B's records on its replica. A local index then finds C27's rows inside B.



1 -> 2	1. Read customer C27: Request: C27 order history -> Router: customerNumber mod 2
2 -> 4	2. 27 mod 2 = 1: route to B: Router: customerNumber mod 2 -> Shard B: C27 O3/O4
2 -> 3	Other customer: even keys route to A: Router: customerNumber mod 2 -> Shard A: C12 O1/O2, C44 O5/O6
4 -> 5	Replication copies B; it does not split B: Shard B: C27 O3/O4 -> Replica of B: same O3/O4

04 / Choose a shard key and a placement rule

The previous example chose `customerNumber` as the **shard key** and used `mod 2` as the **placement rule**. The key supplies the value used for routing; the rule determines its destination. Choosing a rule affects which records stay together and which queries must contact several shards.

Range, hash and list partitioning choose a destination from key values. Round-robin placement cycles through destinations for new records. All four assign whole records to partitions, so they are approaches to horizontal partitioning. Each row below is a separate placement example.

Placement method	How records are assigned	When it helps, and the cost
Range	Assign intervals of a key to partitions: customers 1-999 on A, 1000-1999 on B.	Nearby key values stay together for range queries; a popular or growing range can overload one owner.

Placement method	How records are assigned	When it helps, and the cost
Hash	Apply a hash function, which maps the key to a repeatable numeric value, then map that value to a partition or logical bucket.	Spreads many distinct keys; adjacent original values usually scatter, so range scans contact several owners.
List	Explicitly name the key values assigned to each partition, such as selected countries in one group.	Gives direct control over placement; the lists and each group's capacity need maintenance.
Round robin	Assign successive new rows to A, then B, then A again.	Spreads insert counts, but a later key lookup needs stored location metadata or a search across partitions. Equal row counts need not mean equal load.

A **composite shard key** combines fields, such as `(tenantId, customerId)`; it is a choice of key, not a fifth placement algorithm. A system can apply range or hash placement to that combined key. It can also combine rules in stages: choose a tenant's shard group, then hash the customer ID within that group. This gives control over tenant placement while distributing its customers; routing to one customer needs both dimensions.

A further question is how placement changes when machines are added or removed. Separating logical groups of records from physical servers makes those moves easier to manage.

A logical bucket is a named group of keys independent of a physical server. Use many logical buckets and a versioned bucket-to-machine map when machines must change. Directly applying `key mod numberOfMachines` changes many assignments when the machine count changes. Consistent hashing is another way to reduce membership-related movement, but still requires actual data migration and hot-key handling.



INTERVIEW CRITICAL

Uniform hashing does not split a hot key

Hashing is not a promise of equal traffic. A single customer placing half of all requests remains hot even if every customer ID hashes uniformly. For that customer, split by a more granular key if the operations allow it, cache repeated reads, or isolate its capacity. Each choice can make its cross-record operations harder.

Also inspect **cardinality**, the number of distinct key values, and **frequency**, how often each value occurs. Hashing a two-value status field still leaves only two groups; it does not manufacture independently movable keys. Check whether a key grows monotonically, whether one value dominates bytes or traffic, and whether its value can change. Updating a customer's shard-key value can require moving its records rather than changing one local field. Prefer a stable key when it fits the access patterns.

05 / Cross-shard joins, transactions and denormalization

A shard key that makes one query local can separate records needed by another operation. This affects both reading related data (**joins**) and updating related data together (**transactions**); the examples below show where extra coordination or a stored copy becomes necessary.

Suppose O3 and its order items share C27's partition. A local transaction can update them together on B. If an order also changes globally shared inventory, the customer key does not co-locate that inventory. You now need an explicit transaction or workflow across owners, or a different ownership design.

A **foreign key** requires a referenced record to exist, such as an order referring to an existing customer. Foreign keys enforce relationships inside the database scope that supports them; do not assume an arbitrary cross-shard reference gets the same automatic enforcement. A deleted customer and retained order may require a clear retention and deletion workflow.

Denormalization stores a useful copy of related data, such as the product name at purchase time. That can avoid a cross-shard catalog join and may correctly preserve the historical receipt. For a field that must reflect the latest value, however, copied data needs updates or a freshness contract. Explain why that copy's meaning is suitable, instead of adding denormalization to every design by reflex.



INTERVIEW CRITICAL

Local uniqueness does not prove global uniqueness

Uniqueness has a scope too. Independent shards can each accept a locally unique order number 42. If the external contract requires a global order ID, use a global allocation/claim mechanism, a composed identity such as `(customerId, localOrderNumber)`, or an appropriate generated-ID design with collision handling. Likewise, two shards cannot prove a globally unique email merely by checking their own local indexes. Co-locate each unique-name claim under one owner or use a database feature that explicitly coordinates the constraint.

06 / Resharding: copy, catch up and transfer ownership

Resharding changes how records are distributed among shards, for example to add capacity or relieve an overloaded owner. For the bucket-based scheme above, a move has two jobs: transfer the data and transfer permission to accept writes. Clients may still use an old route during the change, so the handover needs an explicit protocol.

Imagine bucket 17, containing C27, must move from B to C. A safe outline is:

1. Copy a consistent snapshot from B to C while B remains the write owner. Bind the snapshot to a committed change-log position L0 and retain all subsequent changes, so there is no gap between snapshot contents and replay.
2. Replay subsequent changes so C catches up. Verify record counts/checksums appropriate to the storage model.
3. Briefly coordinate the ownership cutover, fencing the old owner so it cannot keep accepting writes after transfer. Fencing means the storage owner rejects commands whose authority is obsolete; merely updating clients does not stop a paused old writer. Publish routing epoch 9, a numbered ownership version, pointing bucket 17 to C.
4. A client with epoch 8 reaches B. B rejects or redirects the stale route. The client refreshes metadata and retries the same logical operation safely.
5. Retain the old copy until the recovery and stale-client window is closed, then reclaim it.

INTERVIEW CRITICAL

Copying data does not transfer write authority

Copying bytes and changing a routing map are separate tasks. If both B and C accept unrelated writes during the move without a reconciliation protocol, the move can create lost updates. Replicate the routing directory, version its entries, and specify when the old shard stops accepting writes and the new shard may begin.

To switch bucket 17 from B to C, first stop new writes at B and finish or reject writes already running. Record B's final committed log position; C must apply all changes through it before routing version (epoch) 9 permits writes at C. B then rejects writes using old epoch 8. If the coordinator cannot prove B has stopped accepting writes, it must not enable C. Briefly pausing writes avoids two conflicting histories. A database may use its own consensus or transfer protocol to enforce this handover.

07 / Interview example: defend a customer shard key

Interviewer: "Why shard orders by customer?"

Candidate: "Most interactive requests list one customer's orders, so I keep those orders on one shard and route by customer ID. Global reports must query several shards or use an analytical copy. One large customer can still overload a shard, so I measure customer traffic and can split that customer's data or give it dedicated capacity. To move data, I copy it, apply changes made during copying, then switch write ownership using a new routing version."

This answer explains placement, the read path, an unfavorable query, and how the system evolves. Merely saying "hash the key" leaves all four undecided.

Choose implementation scope deliberately. PostgreSQL declarative table partitioning can improve pruning and retention management within a database; it does not by itself create a cluster of independently writable servers. If document workloads justify distributed sharding, MongoDB provides `mongos` routing, configuration metadata and replica-set shards. Its range/hashed placement and zones are product features, while the epoch cutover above is a conceptual protocol to explain ownership - not a claim that MongoDB implements those exact steps or exposes those epoch numbers. Verify supported transactions and constraints for the selected deployment. See PostgreSQL partitioning and MongoDB sharding.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How is a shard different from a replica?

Model answer

"A shard owns a different subset of records; a replica is another copy of the same records. A and B split customers, while A1 and A2 could be copies of shard A. I need separate rules for routing to an owner and for keeping that owner's copies consistent."

Interviewer follow-up

Does adding replicas always increase write throughput?

Not for a single-authority write path. Replicas improve resilience and may serve reads, but coordinating them can add write work.

What the answer must demonstrate: Draw ownership and copies separately.

02 / APPLIED

Why choose customer ID for order partitioning?

Model answer

"The dominant query asks for one customer's orders. Keeping those records together allows one routed query and local updates of related order data. I would verify the customer traffic distribution and identify global queries that this choice makes more expensive."

Interviewer follow-up

Would order ID be equally good?

It can spread individual orders better, but listing a customer's orders needs a secondary location/index path or fanout. The best key depends on the required queries.

What the answer must demonstrate: Connect the key to an actual query.

03 / FOUNDATION

When does range partitioning help?

Model answer

"Queries over adjacent keys can target a small set of contiguous ranges. It is useful when the range matches the query, such as a time slice. The risk is skew: always appending to the newest timestamp range can concentrate writes."

Interviewer follow-up

Is every horizontal partition a range partition?

No. Horizontal means splitting records; hash, list, and other placement rules are alternative ways to do that.

What the answer must demonstrate: Explain the category and the method.

04 / APPLIED

Hashing is uniform. Why is one shard still overloaded?

Model answer

"Uniform placement distributes keys, not necessarily requests. One customer may account for half the work, or one key may be exceptionally large. I inspect traffic and bytes by key, then consider splitting that workload, replicating reads, or allocating dedicated capacity."

Interviewer follow-up

Can you split a customer without cost?

It can turn a formerly local order listing or transaction into cross-partition work. I explain that cost and preserve the required ordering or atomicity explicitly.

What the answer must demonstrate: Do not promise hashing eliminates hot keys.

05 / APPLIED

What happens to a join between orders and products?

Model answer

"If they live on different owners, a local SQL join may no longer cover them. I can perform bounded application lookups, co-locate relevant data, or keep a suitable read copy. For receipts, recording product name and price at purchase time is often the correct historical data."

Interviewer follow-up

Does denormalization mean every copy must stay current?

No. A historical purchase snapshot should remain historical; a current product description needs an update policy. Similarly, a local index proves uniqueness only in its own scope: a global email claim or order ID requires an explicit cross-shard constraint or single claim owner.

What the answer must demonstrate: Distinguish historical facts from current replicas.

06 / APPLIED

How do you move a shard without losing writes?

Model answer

"Keep B accepting writes while copying a consistent snapshot tied to log position L0. Apply later logged changes at C. To switch, stop B's writes and make C apply through B's final committed position. Then enable C under a new routing version and reject writes using B's old version. Stale clients refresh their routes and retry the same operation. If I cannot prove B can no longer commit writes, I do not enable C."

Interviewer follow-up

Why not switch the directory halfway through copying?

C may lack records or writes that arrived after the snapshot. The directory must not send writes to C until C has the required data and B can no longer accept conflicting writes.

What the answer must demonstrate: Separate data catch-up and ownership transfer.

07 / APPLIED

What if the shard directory is unavailable?

Model answer

"Clients can use a cached version only while the ownership protocol makes stale routes safe. Owners validate epochs and reject invalid writes. For metadata changes I need a durable authoritative directory; guessing a new owner can create conflicting histories."

Interviewer follow-up

Does caching the directory remove the dependency?

It reduces steady-state lookups but does not remove the need for safe membership updates and recovery.

What the answer must demonstrate: Explain how stale metadata is detected.

08 / APPLIED

How do you support a report for all orders today?

Model answer

"Customer-based sharding does not localize a global time query. I can fan out bounded queries and merge results for modest needs, or stream order changes into an analytical store partitioned for reporting. I state the reporting freshness delay and avoid making every checkout wait for analytics."

Interviewer follow-up

What if the report must be an exact cross-shard snapshot?

That needs a defined consistent snapshot or coordinated read protocol. Independently querying owners at different times does not automatically represent one instant.

What the answer must demonstrate: Name the cost of a query the key does not serve.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Place six customer orders on two shards, add a global-report query, then move one customer's bucket safely.

- Show an explicit key-to-shard table.
- Explain one query that becomes expensive.
- Separate replication from partitioning.
- Describe catch-up, routing epochs, and old-owner rejection.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Why choose customer ID as the shard key for order history?

It keeps one customer's orders together, so one shard can answer the query. Check whether large customers create uneven storage or traffic.

Query together -> store together -> check imbalance.

Shard versus index

The shard key finds the owner; the index finds records within it.

Which machine, then which record.

Online movement

Copy, catch up, transfer ownership safely, retire the old copy later.

Copy is not cutover.

Summary and interview notes

Sharding divides record ownership so independent groups can store and serve different parts of a workload. A useful shard key keeps records needed by common queries and correctness rules together; routing, cross-shard work, skew and safe ownership transfer are the costs.

Remember these points

• Horizontal partitioning divides records, replication copies them, and indexing locates records within a query path.

• Ask which queries stay on one shard, how many distinct key values exist, which repeat often, whether they change, and how uneven their data sizes are.

• Uniform hashes distribute distinct keys; they do not split one hot key.

• Joins, global uniqueness and transactions require an explicit supported scope after sharding.

• Copy a consistent snapshot, apply every later change through the final write, then let only the new owner accept writes.

Interview tips

• Show one fast query and one expensive query under the proposed key.

• Ask which related writes and uniqueness claims must remain atomic before choosing a partition boundary.

• During resharding, identify who may write before, during and after cutover.

Important qualifications

• Native table partitioning inside one database is not automatically distributed sharding.

• A cached directory is safe only when storage rejects obsolete ownership.

• The example sacrifices brief cutover availability; a production database may supply a different verified transfer protocol.

Technical references

MongoDB sharding overview
Primary reference for ranged/hashed placement and query routing.
https://www.mongodb.com/docs/manual/sharding/

MongoDB zone placement
An implementation example of policy-based range placement; not a universal database guarantee.
https://www.mongodb.com/docs/manual/core/zone-sharding/

PostgreSQL declarative table partitioning
Partition pruning and partition management are distinct from a distributed shard cluster; checked 2026-09-23.
https://www.postgresql.org/docs/current/ddl-partitioning.html

FOUNDATIONS / 12

Consistent hashing and virtual nodes

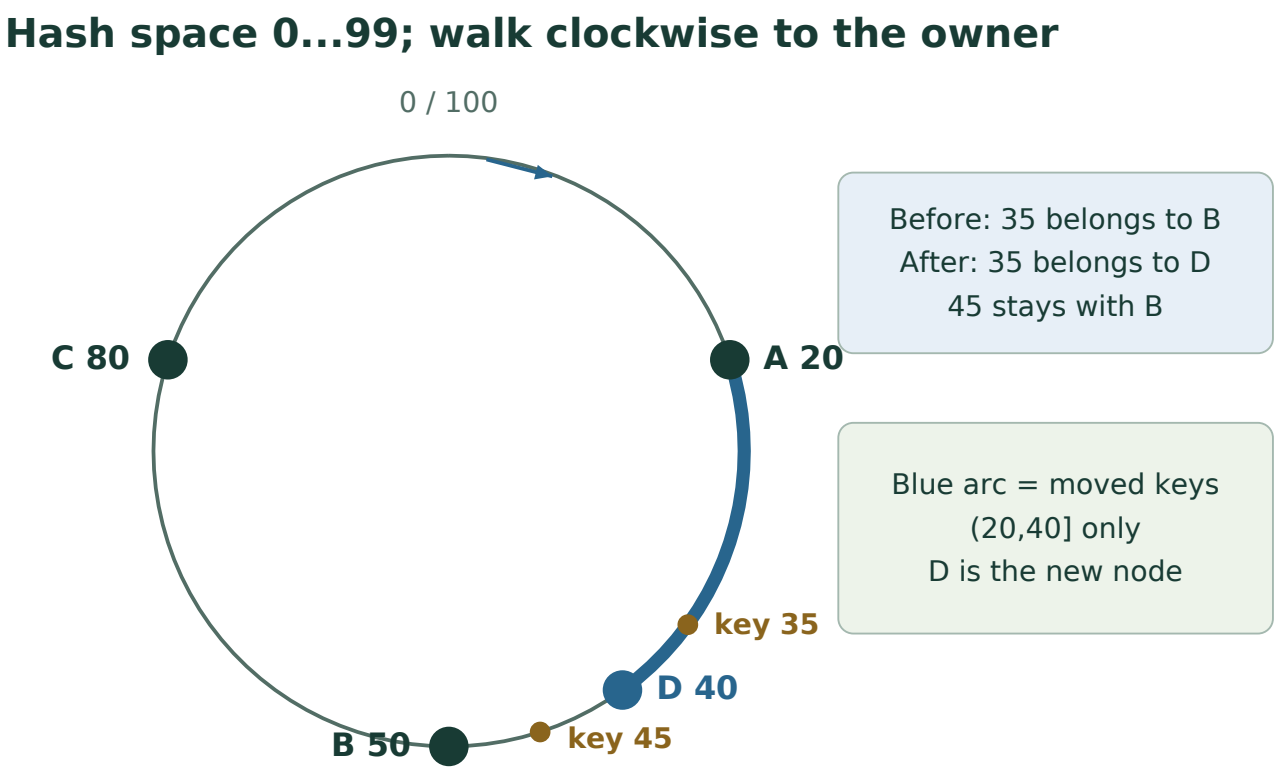
DEFINITION

Consistent hashing assigns keys to owners so that adding or removing an owner changes only a limited portion of existing assignments. In the ring form, both keys and owner positions are hashed into one circular space, and a key belongs to its first clockwise owner.

Why it matters: The rule hash(key) mod N remaps many keys when N changes. A ring limits movement during cache expansion or shard membership changes, reducing cold misses and migration work.

Consistent hashing: ownership before and after adding a node

Keys go clockwise to the first node token. Adding D at 40 moves (20,40] from B to D; other ranges keep their owners.



Placement is not replication. Virtual nodes spread ranges; a hot key still needs care.

Worked example

On a 0-99 ring, owners A20, B50, and C80 place hash 35 at B50. Add D40: hash 35 moves to D40, while hash 45 stays at B50. Only the interval (20,40] changes owner.

Key takeaways

• First clockwise owner determines placement; the rule wraps past the largest token.

• Virtual nodes improve placement balance, but do not split one hot key.

• Consistent hashing is about placement stability, not CAP consistency or automatic migration.

Read the visual model

1. Tokens are positions on a hash space, not geographic servers.

2. Initially A=20, B=50 and C=80. Key 35 belongs to B.

3. Adding D=40 transfers only keys in (20,40] from B to D. Key 45 still belongs to B.

4. Virtual nodes improve distribution. A hot key can remain hot, and replication is a separate policy.

consistent hashing • DHT • virtual nodes • placement • rebalancing

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Map keys to clockwise owners, including wraparound, using actual numbers.

• Calculate which keys move on addition/removal and qualify expected movement.

• Explain virtual nodes, skew, and a safe migration without confusing placement with replication.

Useful foundations: Data partitioning and sharding; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / What is consistent hashing, and why not modulo N?

INTERVIEW CRITICAL

Stable key placement does not imply linearizable reads

Consistent hashing is a key-placement technique that minimizes unnecessary reassignment when machines join or leave. "Consistent" refers to stable placement; it does not mean that reads are linearizable or replicas always agree.

The common ring version hashes both keys and machine positions into the same circular number space. A key belongs to the next machine position clockwise. A **virtual node**, or token, is an additional ring position assigned to a physical machine, not another server. We will compute the placement before discussing migration and balance.

A distributed hash table associates keys with values and uses a deterministic rule to locate their owners. In a metadata-cache example, keys P12 and P35 identify records; a hash function maps each key to a numeric placement position. Placement stability determines how much cached or durable data must move when membership changes.

One cache is easy to address but eventually runs out of memory or throughput. With three caches, the application must decide where P35 lives. A common first rule is `hash(key) mod 3`. Everyone can calculate the same owner without a lookup table for every object.

Here `mod` means the remainder after integer division. Number the three destinations 0, 1 and 2; dividing a key's hash by 3 produces one of those remainders, which selects its destination. All clients using the same hash and machine numbering therefore agree where to send that key.

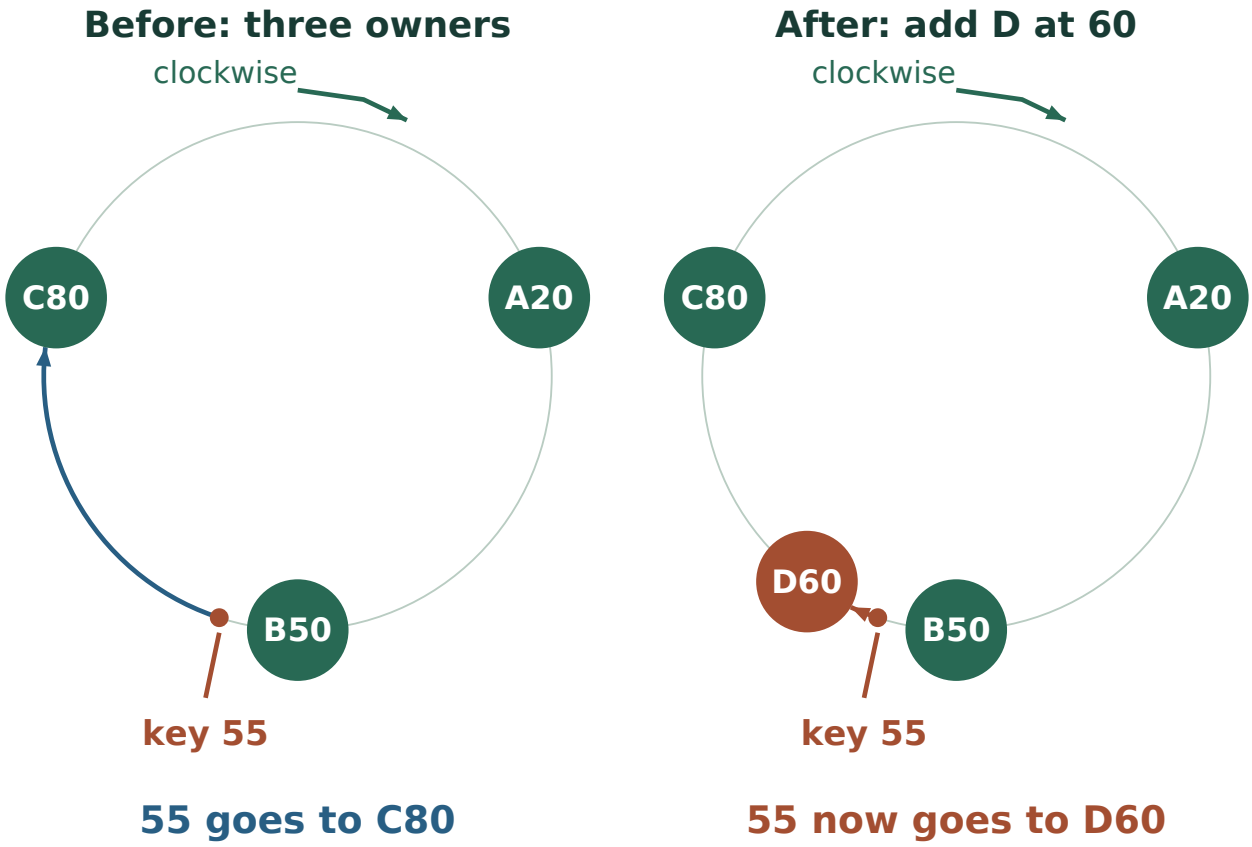
The difficulty appears when a fourth machine joins. Changing the rule to `mod 4` moves many keys. For a numeric hash of 35, the remainder changes from 2 to 3; for 12, it stays 0. Some mappings remain, but widespread movement can create cache misses or durable-data migration. We want a placement rule that changes fewer existing assignments when capacity changes.

02 / The hash ring: clockwise ownership with five keys

For a small worked example, let hashes range from 0 through 99. Connect 99 back to 0 to form a circle. Put cache A at position 20, B at 50, and C at 80. Real systems use a much larger space; the tiny range lets us compute every step by hand.

Add one owner: watch key 55 move

Node labels include their hash positions. The leader line locates key 55; the colored clockwise arc ends at its successor. Compare before and after adding D60.



Only keys in (50, 60] change owner: C gives that interval to D. A and B keep their ranges.

Remember: Only the new owner's predecessor interval moves.

Try from memory: Would key 65 also move to D60?

Answer: No. Clockwise from 65, the next owner is still C80. D60 takes only (50,60].

To locate a key, hash it and move clockwise until reaching the first cache position, including an exact match. That cache owns the key under our convention. P35 hashes to 35, so it reaches B50. P90 reaches the end of the range, wraps through zero, and reaches A20.

Key	Hash	First clockwise position	Initial owner
P12	12	20	A
P35	35	50	B
P45	45	50	B

Key	Hash	First clockwise position	Initial owner
P65	65	80	C
P90	90	20 after wraparound	A

Each position owns the interval after its predecessor and through itself. B therefore owns (20,50]: positions greater than 20 and less than or equal to 50. The round bracket excludes 20; the square bracket includes 50.

Hash collisions are expected in a placement space: two different object keys may map to the same number and therefore the same machine. Store and compare their full keys so they remain different records. Consistent hashing chooses an owner; it does not make a key unique. Clients must also use the same hash function, key encoding, token order, and membership version to calculate the same owner.

03 / Adding and removing a node: which keys move?

Add D at position 40. It becomes the first clockwise owner for hashes in (20,40]. B's old interval splits: D takes (20,40], while B keeps (40,50]. Key P35 moves from B to D; P45 stays with B. Other intervals are unchanged.

Next remove B. Its remaining interval moves to the next position, C80. P45 now moves to C. This removal does not require moving P12, P35, P65, or P90.

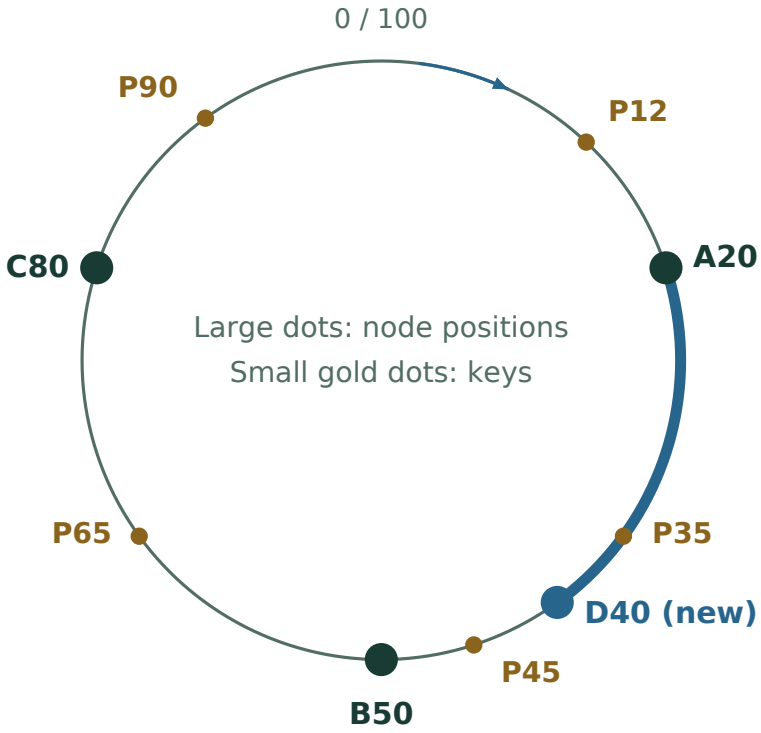
Key	Before addition	After adding D40	After removing B50
P12	A	A	A
P35	B	D	D
P45	B	B	C
P65	C	C	C
P90	A	A	A

Consistent hashing tries to preserve existing assignments where membership change does not require a new owner. The ring is a placement mechanism, not a promise that the new machine already contains the object. We still need to move or rebuild data and coordinate routing.

WORKED EXAMPLE DIAGRAM

A20, D40, B50 and C80 sit at their numeric positions on the 0-99 ring. P35 lies between A20 and D40, so adding D moves P35 from B to D. P12, P45, P65 and P90 keep their owners, including P90 wrapping through zero to A20.

Hash space 0-99: follow the ring clockwise to the first owner



Key ownership

Key	Before D40	After D40
P12	A20	A20
P35	B50	**D40**
P45	B50	B50
P65	C80	C80
P90	A20	A20

Only P35 changes owner.

The other four keys stay put.

Blue arc: (20,40] moves from B to D. D owns 40; A still owns 20.

04 / Virtual nodes, balance, and physical failure domains

Our original intervals are unequal: A owns the wraparound interval (80,20], B owns (20,50], and C owns (50,80]. With uniformly distributed hashes, A owns about 40% of the space while B and C own about 30% each. Randomly choosing one position per machine can produce even larger imbalances.

Virtual nodes assign several positions to each physical machine. For example, A can own tokens A1 and A2 in separate parts of the ring. It then receives several smaller intervals rather than one possibly large interval. More well-distributed positions tend to smooth random imbalance and permit capacity-aware allocation.

INTERVIEW CRITICAL

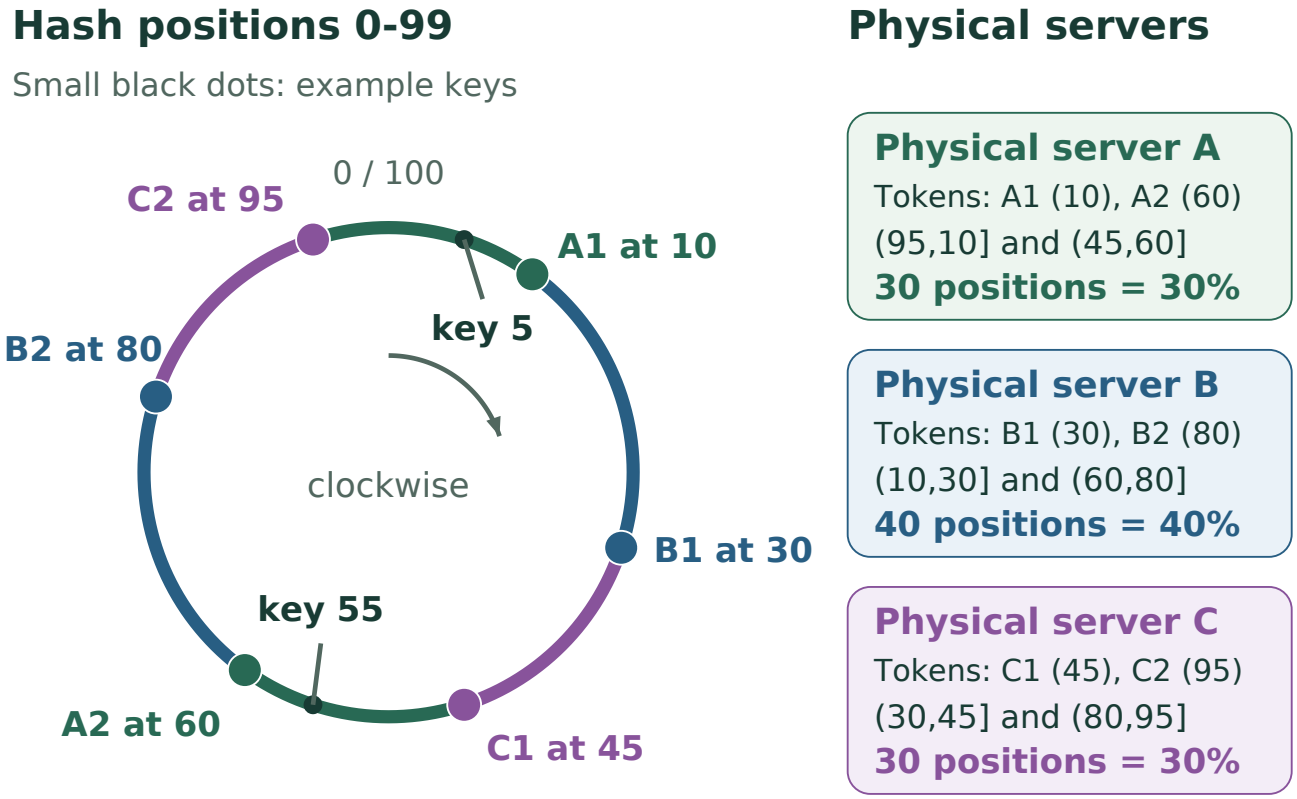
Virtual nodes are not independent replicas

A virtual node is a placement token, not another independent machine or a redundant data copy. If three adjacent tokens all belong to A, storing three "replicas" there still depends on one physical host. A replication policy must deliberately choose distinct physical owners and appropriate failure domains. Dynamo's paper describes virtual-node and replication placement techniques.

To make virtual nodes concrete, use a separate six-token example with A at 10 and 60, B at 30 and 80, and C at 45 and 95. A owns `(95,10]` and `(45,60]`: 15 + 15 = 30 positions. B owns two 20-position intervals, totaling 40; C owns two 15-position intervals, totaling 30. Two tokens per host do not guarantee perfect balance. The benefit appears statistically or through deliberate token allocation across many smaller ranges.

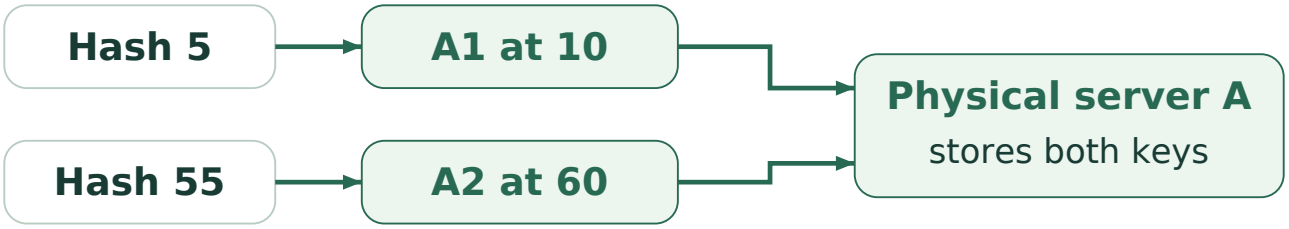
Six virtual nodes, three physical servers

A1 is server A's token at hash position 10; A2 is its token at 60. Matching letters and colors group the tokens by physical server. The colored arcs show primary ownership. Two tokens per server still give unequal 30%, 40%, and 30% shares.



Each colored arc ends at the token that owns it.

Two lookups, one physical destination



A1 and A2 share server A's storage and failure risk.

Replication requires other physical owners.

Remember: Several ring positions can point to one physical server.

Try from memory: If physical server A fails, does its other token keep either key available?

Answer: No. A1 and A2 are positions assigned to the same server, so both lose that server together. Availability would require a usable replica on another physical server and a recovery protocol.

A production example is Cassandra's token-based placement: multiple tokens may belong to one node, while replica selection must skip duplicate physical owners. Increasing token count also adds placement metadata

and more ranges to manage; choose it from operational needs rather than assuming the largest possible value is best.

A ring is not the only way to keep most assignments stable when membership changes. Another approach ranks the eligible machines separately for each key. A newly added machine takes that key only if it outranks the existing winner, avoiding the need for token positions.

Rendezvous hashing, also called highest-random-weight hashing, is another placement algorithm. Compute a deterministic score `hash(key, nodeId)` for each eligible node and choose the highest, using a stable tie-breaker. With illustrative scores A=.31, B=.86 and C=.54, the key belongs to B. Adding D with .70 leaves it on B; adding D with .93 moves it to D. Removing a node changes only keys that selected it. All routers need the same membership and scoring rules.

Unlike a token ring, the simple implementation evaluates all N nodes per lookup. It avoids virtual-node metadata but pays O(N) scoring cost, meaning the number of scores grows in proportion to the number of nodes; optimized variants and weighting require their own analysis. Neither placement method fixes a single hot key or performs safe data migration.

Interview check: Does adding a node move every key? No. A key moves only if the new node outranks its previous owner; moving durable bytes and changing write authority are separate steps.

05 / Estimate movement and recognize hot-key limits

Assume 1.2 million equal-sized metadata objects, equal-capacity machines, and balanced placement. Adding a fourth machine to three should move about one quarter of the keys, roughly 300,000, to the new machine on average. At an assumed 500 bytes per object, that is about 150 MB of payload before indexes, protocol overhead, or redundant copies.

More generally, adding one machine to N existing balanced owners moves an expected fraction near `1/(N+1)`; removing one of N owners moves near `1/N`. These are distribution-based estimates. Our fixed D40 example takes a 20-position interval, not exactly 25% of the ring.



INTERVIEW CRITICAL

More tokens do not divide one hot key

Equal key counts also do not mean equal work. P35 might receive half the service's reads after the client's photo becomes popular. More virtual nodes do not divide that one key. Cache replication, request coalescing, or an application-specific split can help, with their own update costs. Measure bytes and request rates as well as key counts.

Fixed logical buckets offer another way to separate keys from physical machines. A bucket is a stable group of keys; a routing map records which machine currently owns each group. Changing that map can move selected groups without changing every key's grouping rule.

Placement choice	Useful when	Main resizing cost
Direct hash modulo machine count	Membership is fixed or remapping is cheap	Changing the divisor remaps many unrelated keys

Placement choice	Useful when	Main resizing cost
Fixed logical buckets plus an owner map	Explicit migration batches and simple routing are useful	Maintain and distribute the bucket-to-machine map
Consistent-hash ring with tokens	Membership changes and limited reassignment matter	Maintain agreed membership, balance ranges, and migrate/refill them

A logical bucket is a stable group of keys, such as bucket 17 of 1,024, that a routing map assigns to a physical machine. Moving bucket 17 changes its physical host without changing the hash modulus for every key. A ring is one good placement strategy, not a prerequisite for every sharded system.

06 / Data migration: copying, catch-up, and routing cutover

For an ordinary cache, D can start empty and fetch P35 from the authoritative database on a miss. But a sudden transfer of many hot keys can overwhelm that database. Warm selected keys, limit concurrent refills, and keep origin protection active during the change.

For durable storage, keep B's copy until D is ready. Copy a consistent snapshot of the moving range, record and apply updates made during copying, then verify D's data before making it the writer. Give the routing change a version so clients can detect old routes. During the move, keep one writer or use a protocol that explicitly coordinates the handover.

Suppose a write updates P35 while copying occurs. The destination must receive the newer version before it becomes authoritative, or the old owner must forward/reject according to the migration protocol. A stale client sending to B needs a safe redirect or forwarding path. Retain rollback information until verification completes. Ownership math says where P35 belongs; it does not implement this data-transfer protocol.



INTERVIEW CRITICAL

Old bytes do not make routing rollback safe

After D starts accepting authoritative writes, B's retained snapshot becomes stale. Rolling back routing to B is safe only after the protocol transfers D's newer changes back or uses another verified authoritative copy. Keeping old bytes is helpful recovery material, but it does not make an instantaneous map rollback correct. Version checks at owners must prevent an old client from creating a second writable history.

07 / Interview answer: draw the ring and explain the tradeoff

Interviewer: "What does consistent hashing solve when we add a cache?"

Candidate: "It reduces placement changes. On our 0-99 ring, P35 belongs to B50. Adding D40 transfers only the interval (20,40], so P35 moves to D while P45 stays with B. That can avoid the broad remapping from changing a modulo divisor.

"I would add virtual positions to improve placement balance, but I would still check object sizes and hot-key traffic. For a cache I need controlled refill; for durable storage I need snapshot transfer, concurrent-update catch-up, and safe routing cutover. The ring also does not provide read consistency or replication automatically."

This explanation can be replayed on a whiteboard with five keys. It shows why the technique helps, when its balancing assumptions fail, and which essential migration decisions remain outside the hashing algorithm.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is consistent hashing? Draw a ring and explain why adding a node moves fewer keys than changing a modulo divisor.

Model answer

Consistent hashing is a placement scheme that limits remapping when owners join or leave. Draw a ring numbered 0-99 with A at 20, B at 50, and C at 80. Hash a key and choose the first clockwise owner, wrapping at 99. Hash 35 belongs to B50; hash 90 wraps to A20.

Add D40: it takes only (20,40] from B, so hash 35 moves to D while hash 45 stays at B. Changing hash(key) mod 3 to mod 4 would change many unrelated assignments. In balanced equal-capacity placement, adding one to N owners moves about 1/(N+1) of keys on average; this particular D40 interval covers 20% of our toy ring. Virtual nodes improve balance, but data still needs migration or cache refill, and one hot key remains a separate problem.

Interviewer follow-up

What happens for hash 90?

"It wraps through 99 and 0 to A20. That wraparound interval is part of A's ownership."

What the answer must demonstrate: Demonstrate the rule with actual positions.

02 / APPLIED

On a 0-99 ring with A20, B50, C80 and keys at 12, 35, 45, 65, 90, which keys move when D40 joins?

Model answer

"Only P35 moves in our five-key sample. D takes (20,40] from B; P45 is outside that interval and stays with B. A and C keep their existing intervals. I would show the interval, not claim that every key moves to a new server."

Interviewer follow-up

Does moving the sample key at 35 imply exactly one quarter of all keys moved?

"No. In this fixed ring D40 receives (20,40], which is 20 of 100 positions. An expected 25% movement requires four balanced owners and suitable hash-distribution assumptions; a five-key sample need not match either fraction."

What the answer must demonstrate: Keep a concrete trace distinct from a statistical estimate.

03 / APPLIED

On a clockwise ring with A20, D40, B50, C80, which owner receives B50's interval when B is removed?

Model answer

"B's remaining interval (40,50] passes to C80, the next clockwise owner. P45 moves to C. P35 stays with D. For durable data I must also ensure C obtains the required current state; the placement calculation does not transfer bytes."

Interviewer follow-up

What if B fails before a copy is made?

"Recovery needs another durable replica or retained history. A ring alone cannot reconstruct missing data."

What the answer must demonstrate: Placement and durability are separate responsibilities.

04 / FOUNDATION

Why not just change hash(key) mod 3 to mod 4?

Model answer

"That changes many assignments at once, even though most existing machines are still healthy. Hash 35 changes remainder from 2 to 3, while 12 happens to stay at 0. Broad remapping can create expensive migration or cache misses; consistent hashing limits the affected ranges."

Interviewer follow-up

Does modulo become impossible to use?

"No. It is simple for fixed membership or when managed logical buckets absorb physical changes. The issue is the resizing consequence."

What the answer must demonstrate: Avoid claiming every modulo mapping necessarily changes.

05 / FOUNDATION

What do virtual nodes improve?

Model answer

"They give one physical host several separated ring positions, so it owns multiple smaller intervals. With a suitable distribution, this reduces random placement imbalance and can represent differing capacities. It adds token metadata and migration units; it does not create more independent machines."

Interviewer follow-up

How do you place three replicas when several consecutive virtual tokens belong to one physical host?

"I walk eligible token positions but skip owners already selected, and enforce the required zone or rack diversity. Three tokens on one host are one failure domain, not three durable replicas. The token-placement rule and replica-placement policy are separate."

What the answer must demonstrate: Count physical failure domains for replication.

06 / APPLIED

One key P35 receives half of all reads. Will more virtual nodes split that hot key?

Model answer

"No. The same key still maps to one primary owner under this rule. I would consider read replication, caching, or request coalescing, while defining update and freshness behavior. Virtual positions improve distribution across many keys rather than splitting one indivisible key's traffic."

Interviewer follow-up

What other imbalance should you measure?

"Bytes per object. Equal key counts can hide one owner holding much larger values and exhausting storage first."

What the answer must demonstrate: Key count, bytes, and traffic are different load measures.

07 / FOLLOW-UP

How many of 1.2 million keys move when three balanced owners become four?

Model answer

"The expected share for the new equal-capacity owner is about one quarter, or 300,000 keys. I would label the balance and distribution assumptions. At 500 bytes each that is about 150 MB of payload before overhead, which helps estimate a controlled transfer."

Interviewer follow-up

Why can a particular node insertion move a different fraction than that expectation?

"The estimate assumes balanced placements and a suitable key distribution. On a 0-99 ring, adding D40 between A20 and B50 moves (20,40], only 20% of that fixed space."

What the answer must demonstrate: Qualify both arithmetic and assumptions.

08 / FOLLOW-UP

A write updates P35 while its ownership moves from B to D. What must the migration protocol guarantee?

Model answer

"D needs a snapshot and the updates committed while that snapshot is copied. I would catch up, verify, and atomically change the authoritative routing generation under the migration protocol. B must forward or reject stale requests rather than keep an independent writable copy. After D accepts new writes, routing back to B requires reverse catch-up; retaining B's old snapshot alone does not make rollback safe."

Interviewer follow-up

Would a cache need the same durable transfer?

"It may refill from its source of truth instead, but I would protect that origin from a mass cold-cache event."

What the answer must demonstrate: Do not mistake a new ownership map for a complete migration.

Build the answer yourself

BLANK-PAGE EXERCISE / 12 MINUTES

Draw a ring from 0 to 99 with A20, B50, and C80. Place hashes 12, 35, 45, 65, and 90. Add D40, then remove B50.

- Identify every owner before and after each change.
- Explain why hash 90 wraps to A.
- Separate expected movement at large scale from this exact example.
- Explain how writes and stale routing are handled during migration.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What moves when D40 joins?

Keys in (20,40] change from B50 to D40; P35 moves, while P45 stays with B.

A new token takes only its preceding interval.

Why does P90 belong to A20?

Clockwise search wraps from 99 to 0 and first reaches A20.

The number line closes into a circle.

Are virtual nodes extra copies?

No. Several ring positions can belong to one physical machine; redundant copies need separate placement.

Many tokens are not many hosts.

Does balanced key placement solve a viral photo hot key?

No. A single hot key can dominate requests even when key counts are evenly distributed.

Hash spreads keys, not one key's popularity.

Summary and interview notes

Consistent hashing keeps most keys on their existing machines when machines join or leave. Virtual nodes give each machine several smaller ranges. This reduces copying or cache refill work. Replication, safe data transfer, full key identity and heavily requested keys still need separate handling.

Remember these points

• A key belongs to the first clockwise token, including an exact match and wraparound.

• Adding D40 between A20 and B50 moves only (20,40]; hash 35 moves, hash 45 stays.

• The expected 1/(N+1) movement on addition assumes suitable balanced placement; a particular insertion can differ.

• Virtual tokens are not physical replicas, and balanced key counts do not guarantee balanced bytes or request rates.

• After routing cutover, rollback must preserve writes accepted by the new owner.

Interview tips

• Compute both an ordinary key and a wraparound key before discussing virtual nodes.

• Separate movement of primary ownership from copying bytes and from changing replica placement.

• Compare a ring with fixed logical buckets when the interviewer asks whether consistent hashing is required.

Important qualifications

• Placement-hash collisions do not merge records; retain and compare complete object keys.

• All routers need compatible hashing and membership versions.

• The six-token example is independent of the original D40 insertion example and deliberately remains imperfectly balanced.

Technical references

Dynamo: Amazon's Highly Available Key-value Store
Primary reference for consistent hashing, virtual-node placement, and replica placement choices. Numeric ring examples are original.
https://www.allthingsdistributed.com/files/amazon-dynamo-sosp2007.pdf

Apache Cassandra: Dynamo Architecture
Official token, virtual-node, and distinct-physical-replica placement description; no prescribed token count or latest-version claim.
https://cassandra.apache.org/doc/latest/cassandra/architecture/dynamo.html

Thaler and Ravishankar: A Name-Based Mapping Scheme for Rendezvous
Original highest-random-weight placement paper. Scores in the chapter are an illustrative calculation, not benchmark output.
https://www.eecs.umich.edu/techreports/cse/96/CSE-TR-316-96.pdf

RFC 8584: Highest Random Weight algorithm
Standards-track description of object/node scoring, deterministic placement and limited remapping; the chapter uses a general placement example rather than EVPN configuration.
https://www.rfc-editor.org/rfc/rfc8584.html#section-3

FOUNDATIONS / 13

Replication and durability

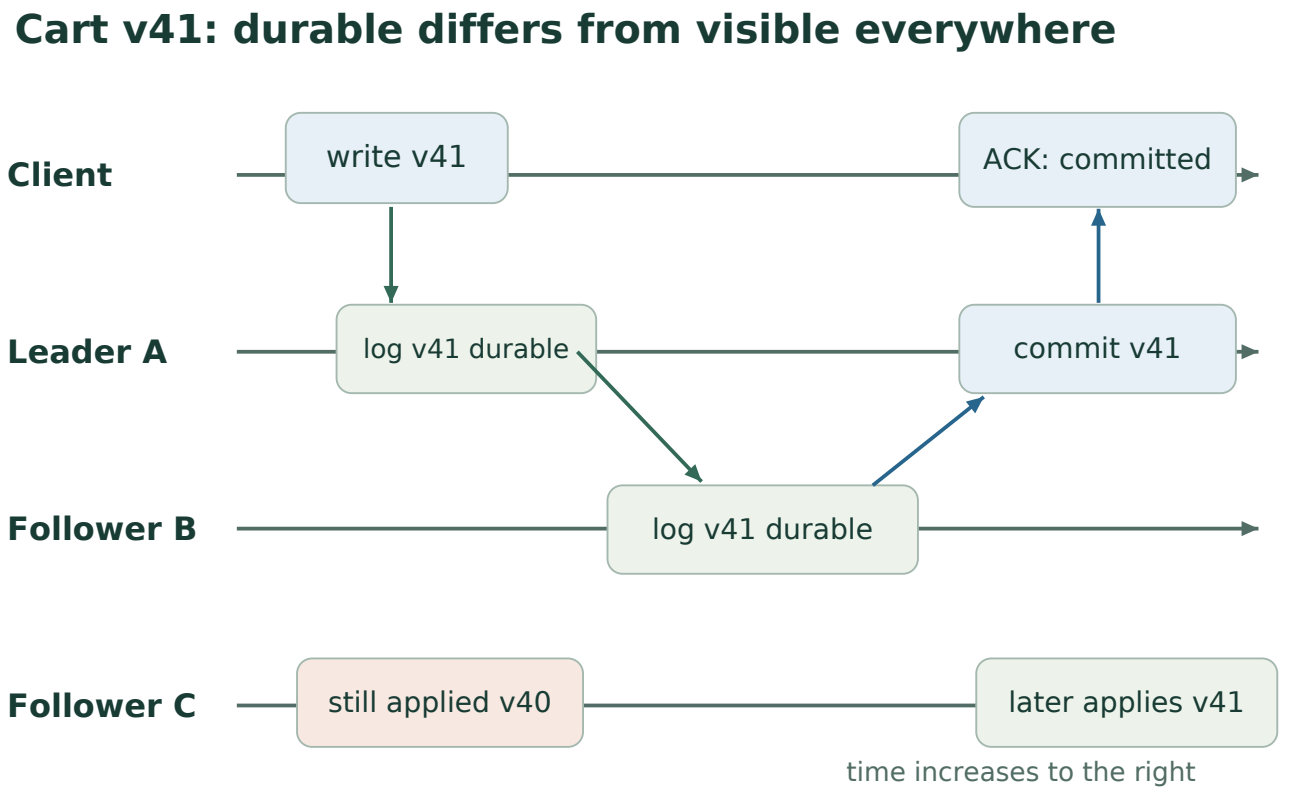
DEFINITION

Replication maintains copies of the same logical data on multiple machines. Durability is the promise that a successfully committed change survives a stated set of failures. Replication can help provide durability, but the write acknowledgment and recovery rules determine what actually survives.

Why it matters: One machine can fail. Copies can keep data available and spread reads, provided we know which copy is authoritative and when a write is safe to acknowledge.

Replication: durable acknowledgement and replica lag

The leader acknowledges cart version 41 after the protocol commits it on two durable copies. Safe elections must preserve that committed history. A follower may still serve an older applied value.



Commit rules protect history; replica reads may still lag behind the acknowledged write.

Worked example

A stores cart version 41 and replies before B receives it. If A is permanently lost, B only has version 40. Waiting for the required durable replica acknowledgments closes that particular loss window, at the cost of latency and write availability.

Key takeaways

• A received update is not necessarily durable or queryable.

• Synchronous and asynchronous replication trade acknowledgment delay against loss exposure.

• Replicas copy bad writes too; backups preserve earlier history.

Read the visual model

1. The leader appends version 41 to its durable log; follower B records it durably and acknowledges the leader.

2. The leader commits and acknowledges according to a protocol whose election rules preserve committed entries. Counting two copies alone does not prove this property.

3. Follower C has applied only version 40. A read there can be stale even while committed version 41 survives one copy loss under the stated protocol.

4. Durable bytes, safe failover, and read freshness are separate guarantees.

replication • durability • failover • acknowledgment • backup

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Distinguish extra copies from the protocol that updates them.

• Identify exactly which failures an acknowledgment promises to survive.

• Explain stale reads, safe leader replacement, and recovery from a replicated mistake.

Useful foundations: Distributed systems: scalability, reliability, availability and efficiency

8 interview questions with model answers and answered follow-ups.

01 / What are replication and durability?

Replication means maintaining copies of the same logical data on several machines. A **replica** is one of those copies; engineers also use the word for the database instance that holds it. **Durability** means a committed change survives the failures covered by the system's guarantee. A replica can exist and still be too far behind to preserve an acknowledged write.

In **single-leader replication**, one leader orders writes and followers copy its log. In **multi-leader replication**, multiple leaders accept writes, so concurrent changes need a conflict rule. In **leaderless replication**, clients or coordinators contact multiple replicas; versioning, quorums, and repair determine the result. This lesson first traces the single-leader case because it makes it easy to see when the service may safely tell the client that a write succeeded.

A single-copy database can acknowledge a write that later disappears with the only usable storage. For a bounded example, cart C17 changes from version 40 to version 41 with `mugs = 2`. The acknowledgment policy must specify whether that result survives a process crash, disk loss, or loss of a complete replica; merely adding machines does not establish the promise.

Redundancy means having additional resources: another database copy, application instance, or network path. Replication is the process that carries changes between copies. Adding an empty second database provides neither a current cart nor a useful recovery path. We need a protocol for moving updates and deciding which state is authoritative.

Assume three database participants, A, B, and C, in separate failure zones. A currently orders writes. Our chosen promise is that an acknowledged cart change survives one participant's failure. All timestamps are illustrative rather than measurements of a product. The version-41 trace tests acknowledgment, read visibility, and recovery separately.

Replication topology	Write path	Main coordination problem
Single leader	One authority orders a shard's writes	Replace it safely; followers can lag
Multiple leaders	Several authorities accept writes	Resolve concurrent changes; a local success may later conflict
Leaderless	A coordinator contacts the selected replicas	Define versions, quorum membership, reconciliation, and repair

These describe who accepts and orders writes, not a universal consistency level. A last-writer-wins conflict rule may discard one concurrent cart edit; merging a set of product IDs cannot by itself preserve a quantity decrement. Choose conflict semantics from the operation, not merely from the desire to write locally.

02 / Replication logs: received, durable, applied, committed

A replication log is an ordered sequence of changes that replicas can receive, persist, and replay. Each entry identifies a change and its position in that history. Queryable data pages are a separate representation, so durable logging and visible application need not happen simultaneously. In the example, A records the C17 version-41 update before forwarding the log entry.



INTERVIEW CRITICAL

Received, durable, and queryable are different stages

A sends new entries to B and C. A follower may have received bytes into memory, made those bytes durable on storage, or applied the change so a query returns it. Memory can disappear on process loss; stored-but-unapplied entries may not yet be visible to ordinary queries.

Participant at 10:00:00.008	Stored log	Queryable cart
A	v41 is durable	v41
B	v41 is durable	May still show v40 until replay
C	Catching up	v40

The protocol determines when an entry is committed: accepted into the authoritative history under its safety rules. Counting network receipts without those rules does not establish commitment.

03 / Synchronous versus asynchronous replication

The acknowledgment policy chooses how much replication must finish before the client hears "saved." **Synchronous replication** waits for a configured stage at designated replicas; **asynchronous replication** allows that work to continue after the reply. In our three-participant example, a majority is two participants, including the leader. Their durable acknowledgments matter only within a protocol that preserves the resulting committed history.



INTERVIEW CRITICAL

Asynchronous failover can lose acknowledged writes

In an asynchronous option, A can reply after its local durability condition without waiting for B. This lowers normal write latency. Suppose A replies at .003 seconds, fails at .006, and B would have received the update at .008. If A's storage is unrecoverable and neither follower has v41, promoting a follower loses an acknowledged change.

For the one-replica-loss requirement, choose a protocol that commits after the required durable majority acknowledgment. A waits until B confirms durable receipt at .008, then returns version 41. A subsequent failure of A leaves the committed information on B, and the election/recovery rules must preserve it.

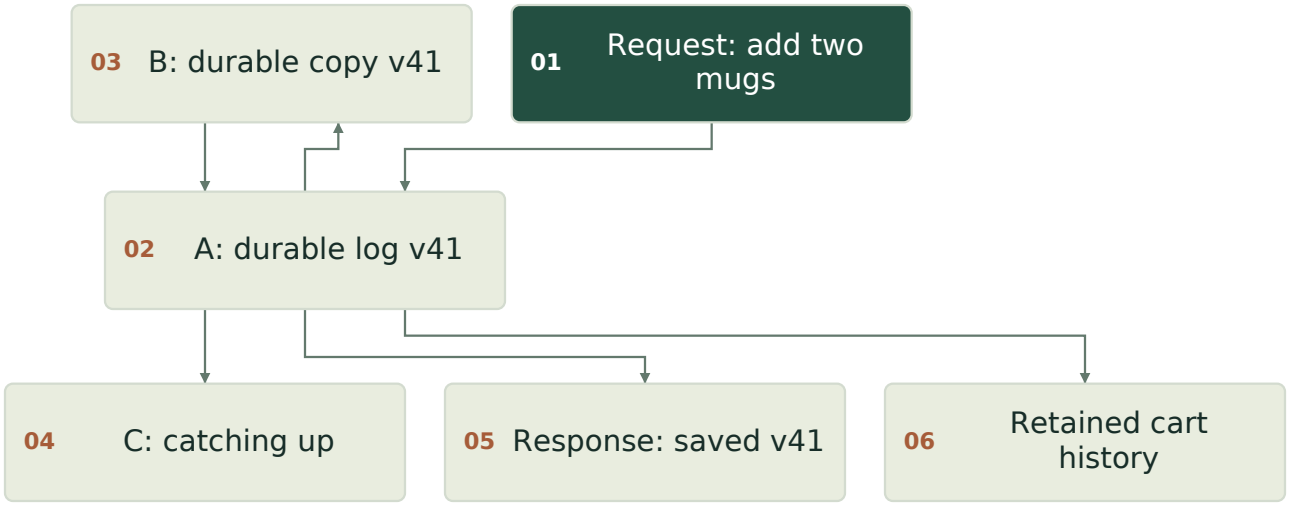
Waiting costs remote network and storage time. It can also prevent writes when the required participants are unreachable. Waiting for every replica often worsens tail latency compared with an appropriate majority protocol. Choose the acknowledgment rule from the failure promise, not from a claim that more copies are always better. PostgreSQL's standby documentation illustrates configurable acknowledgment stages.

The example is a safe majority protocol, not a claim that any database becomes Raft by waiting for a standby. In PostgreSQL, configured synchronous standbys and `synchronous_commit=on` wait for remote durable logging; `remote_write` can stop at the standby operating-system buffer, and `remote_apply` additionally waits for replay. Promotion eligibility and prevention of competing primaries still require a failover design. An acknowledgment setting does not supply that design.

Our three failure zones protect the stated single-participant loss. If all three are within one region, their count does not establish region-loss durability. Cross-region copies add network delay and require a separate placement and acknowledgment decision.

WORKED EXAMPLE DIAGRAM

Hypothetical safe majority protocol: A and B durably log cart C17 version 41 before A commits and acknowledges. C may apply it later. The election protocol must preserve that committed history; this is not a generic guarantee of any two-copy configuration.



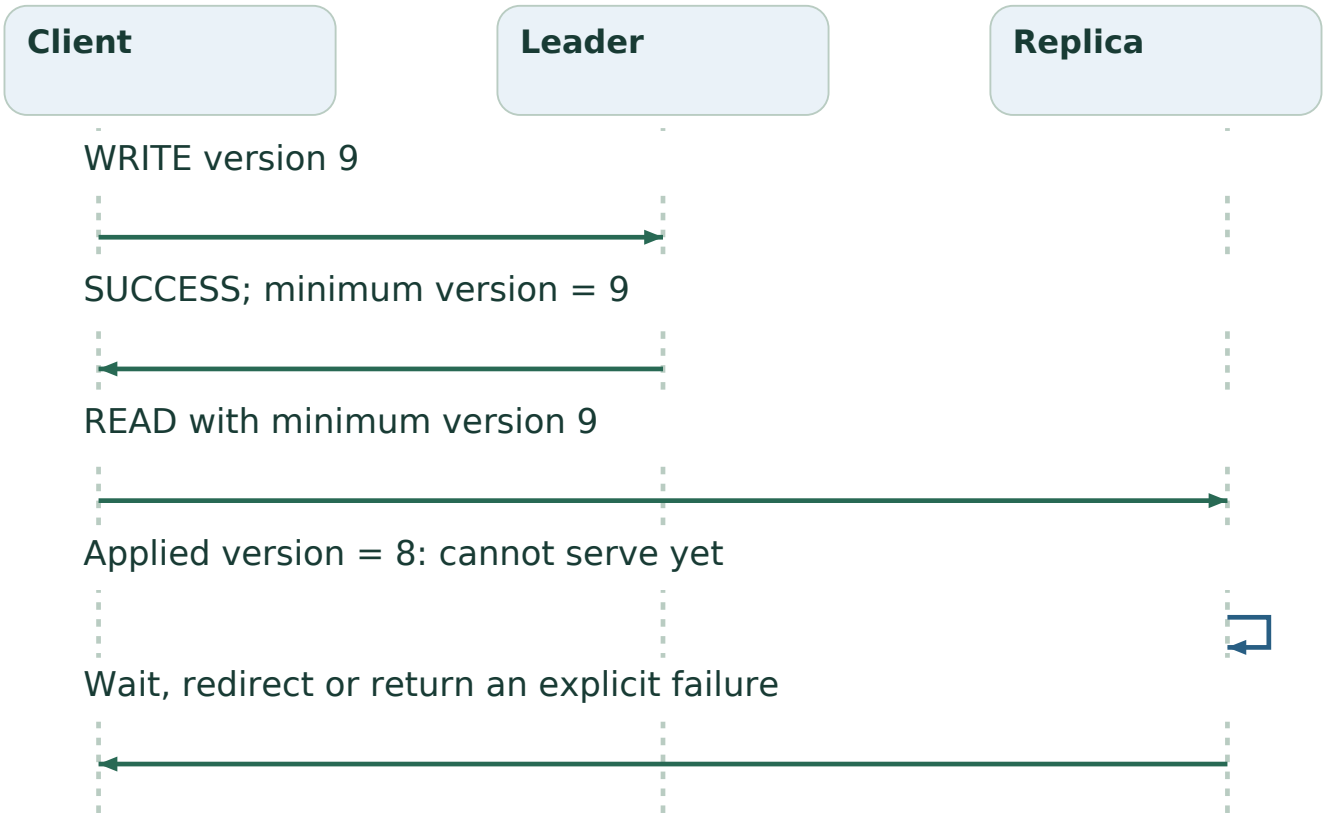
1 -> 2	10:00:00.000 update C17: Request: add two mugs -> A: durable log v41
2 -> 3	replicate and persist: A: durable log v41 -> B: durable copy v41
2 -> 4	catch up: A: durable log v41 -> C: catching up
3 -> 2	10:00:00.008 durable acknowledgment: B: durable copy v41 -> A: durable log v41
2 -> 5	reply after commit: A: durable log v41 -> Response: saved v41
2 -> 6	separate retained history: A: durable log v41 -> Retained cart history

04 / Replica lag and read-your-writes

Replica lag is the gap between a source's progress and a follower's received or applied state. A read can therefore be stale even after the write commits durably. In the example, a read at .010 seconds reaches C, which still serves v40 although v41 has committed elsewhere. Durability and read visibility require separate policies.

Read-your-writes across a lagging replica

Read-your-writes requires a routing or version mechanism when replicas lag; replication by itself is insufficient.



Remember: Carry the required version; do not silently return an older one.

A **commit-position token** identifies the write's location in a particular replication history. A follower's **applied position** identifies how far it has replayed that same history into queryable state. Comparing those positions lets a read wait for its required write instead of guessing how many milliseconds replication needs.

After a write, send the read to the current leader. Alternatively, return the write's log position and make a follower wait until it has applied that position before answering. Use the database's supported mechanism; an application-assigned version number alone cannot prove a follower has caught up.

Read policy	Benefit	Cost
Read the authority	Straightforward current-state path	Concentrates reads and needs reachable authority
Wait for a verified position	Distributes session reads	Waiting and token handling
Read any follower	Low local latency	An explicit stale-read contract

For the cart, we choose read-your-writes: the client should observe its own acknowledged change. Product browsing can use a different policy. A fixed sleep is only a guess because lag can grow under load or failure.

A current-state read needs more than a machine that once accepted writes. A **linearizable read** must fit an order that respects completed operations in real time, so it cannot return a version from before a write that

completed before the read began. Checking current authority is part of establishing that guarantee after failover.

A server calling itself "leader" may be an isolated former leader with old data. For linearizable reads, a consensus-based database must confirm its current leadership and apply the required committed entries before answering. A read-your-writes token must also refer to the correct history after failover. A number from another shard or a discarded history does not prove this replica includes the write.

05 / Leader failover and split-brain prevention

Leader failover lets another replica accept writes when the leader becomes unusable. Missing replies cannot tell us whether A crashed or lost its network connection. If B takes over while A keeps accepting independent writes, their data can diverge: this is split brain. The election and storage protocol must prevent it. Consider A becoming unreachable after the version-41 commit.

Safe failover has four obligations:



INTERVIEW CRITICAL

Safe failover needs more than rerouting

1. **Elect an authority.** Use the election protocol; missing replies alone are not an election.
2. **Preserve committed history.** Select an eligible replacement carrying the committed history.
3. **Fence the former leader.** Have the storage or commit protocol reject writes from the old leader after its right to lead has expired or been replaced.
4. **Route clients.** Clients must discover the replacement.

In this example, B and C form the required majority and the protocol establishes B as leader. A's later return does not automatically restore its authority.

Response loss requires operation deduplication independently of replication. If v41 committed but its reply was lost, retry with the same operation identifier and recover its durable outcome. Applying "add two mugs" twice would turn uncertainty into four mugs. Routing clients away from A changes discovery; it does not itself fence obsolete writes.

06 / Replication versus sharding versus backups

Three copies of C17 are replicas. Three servers each holding different customers are shards. Replication helps survive loss and may add read capacity; sharding divides data and work. Adding followers does not automatically multiply a single leader's write capacity, because every follower still processes the write stream.

Replica, shard and backup: look at the records

Letters stand for records. Compare the copies, subsets and timestamps instead of memorizing three labels.

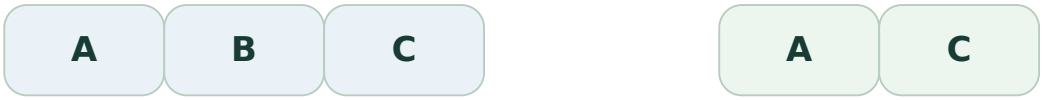
Replica: the same live records in two places



Shards: split the live records



Backup: a retained past state



yesterday: B exists **today: B deleted**

Remember: Copy the present, split the present, or retain the past.

Try from memory: If a bad delete reaches every replica, which arrangement can restore the old record?

Answer: A suitable retained backup or recovery history. Replication alone can faithfully copy the bad delete.

Copies must occupy appropriate failure domains. Three processes on one laptop do not survive laptop loss. Three zones still share risks such as a bad application release or administrator action.

INTERVIEW CRITICAL

Replication also copies mistakes

Replication also copies validly recorded mistakes. If faulty cleanup deletes C17 at 10:30, B and C can reproduce the same deletion. Recovering earlier state needs independently retained history, such as a snapshot plus change log. Restore in isolation, identify affected records, stop the faulty cleanup, and verify the application result before repair. A successful restore exercise provides stronger evidence than a backup job's success status.

07 / Replica repair: anti-entropy, Merkle trees, read repair, and hinted handoff

Replica repair detects and reconciles differences between copies that missed updates. The repair must follow the store's version and conflict rules; it cannot simply trust whichever machine responds first. A leader/follower log normally catches up by replaying missing committed entries or installing a snapshot. The following mechanisms are common in Dynamo-style replicated stores and must not be confused with electing a new leader.

Mechanism	Trigger and action	Main limit or cost
Hinted handoff	A coordinator retains a missed update for an unavailable replica and replays it later	Temporary, best-effort delivery; hints can expire or their holder can fail
Read repair	A read encounters different versions and repairs the data participating in that read	Cold data may never be read; blocking repair adds read latency
Anti-entropy repair	A background or scheduled process compares replicas over shared ranges and transfers differences	Scans and streaming consume disk/network capacity; complete coverage must be verified
Merkle tree	Hierarchical hash summaries locate differing subranges	Detects differences; it does not choose the correct version or resolve a business conflict

Why repair must cover cold data

Anti-entropy means systematically reducing divergence, including records that receive no foreground reads. Suppose A and B contain cart C17 at version 41 while C still has version 40. A surviving hint may deliver the missed update to C. A read comparing B and C may repair that particular cart. Scheduled range repair also discovers the difference when nobody reads C17. Hints and read repair therefore reduce inconsistency but do not replace full repair coverage.

How a Merkle tree locates differences

To compare replicas without first transferring every record, compute compact hash summaries of the same data ranges. A hash is derived from encoded bytes, so the replicas need a **canonical encoding**: the same record must produce the same byte representation on both machines. The tree then organizes those summaries so a mismatch can be narrowed to a smaller range.

A **Merkle tree** summarizes data from the bottom up: leaves hash canonical records or small ranges, and each parent hashes its children. Compare roots for the same range and comparable repair snapshot. If they differ, descend only into mismatching branches. For four leaf ranges, matching left-half summaries let replicas focus on the right half containing C17 instead of transferring every record. After locating differences, exchange the actual versioned data and reconcile it. Matching hashes are equality evidence under the chosen collision assumptions, not a mathematical guarantee of uniqueness. Building the summaries still costs work, even when little data needs streaming.

Why deletion evidence must survive

Deletes require repair too. A **tombstone** is a versioned deletion marker that tells another replica its older value must remain deleted. If A and B delete C17 while C is offline, immediately erasing both the value and its tombstone removes that evidence. When C returns with version 40, repair could resurrect the deleted cart. Retain deletion evidence long enough for every relevant replica to be repaired, or exclude and rebuild a replica that missed the safe recovery horizon. In Cassandra, plan and verify repair completion before the applicable `gc_grace_seconds` horizon; actual tombstone removal also depends on compaction and table settings. Time passing alone does not prove that every replica learned the delete.

Repair promotes convergence under its delivery, retention, and conflict-resolution assumptions. It does not undo a stale response already returned, recover a write absent from every surviving copy, or establish linearizability by itself. Cassandra's blocking read repair supports a specific monotonic-quorum-read behavior; it is not a general transaction guarantee. Monitor completed range coverage, repair age, hint backlog, and repair resource use instead of treating a started repair job as proof of recovery.

08 / Interview answer: defend the acknowledgment and read policy

Interviewer: "Why not just put a read replica behind the load balancer?"

Candidate: "That can improve reads, but I first need to define what an acknowledged cart update survives. With asynchronous replication, A could acknowledge v41 and fail before B receives it. For our one-node-loss promise, I would choose the necessary durable acknowledgments and a safe election protocol.

"I would also avoid sending a read-after-write request to an arbitrary lagging follower. An authoritative read or verified replication position preserves the session's read-your-writes contract. Finally, if a buggy job deletes the cart, every live replica may copy that deletion. I need retained history and a restore procedure for that failure."

This answer separates keeping an acknowledged change, showing the right version, and recovering an earlier valid state. It explains why the extra components exist and what each costs. A diagram of repeated databases becomes useful once those behaviors are explicit.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is replication? How is it different from redundancy and durability?

Model answer

Replication copies changes to additional replicas. Redundancy is the broader idea of spare resources: a spare machine, disk, or network link can be redundant without containing a usable data copy. Durability is the guarantee that a committed write survives a defined failure set. The replication protocol, durable storage, acknowledgment rule, and failover rules jointly determine that guarantee.

Suppose leader A acknowledges cart v41 before follower B receives it. Replication is configured, but permanently losing A can still lose that acknowledged write. Waiting for the required durable copies reduces this loss exposure while adding network/storage latency and making writes depend on those copies being reachable. Replication also copies a mistaken deletion, so it does not replace a backup.

Interviewer follow-up

Could an old backup count as redundancy?

"It is another copy, but a day-old backup supports a different promise from preserving a cart change acknowledged this minute."

What the answer must demonstrate: Name the freshness and failure promise.

02 / FOUNDATION

Why distinguish received, durable, and applied?

Model answer

"Received bytes may be only in memory. Durable bytes survive the specified storage failure model. Applied entries are visible to queries. B can have v41 durably logged while ordinary reads still show v40, so acknowledgment and read policy must account for different milestones."

Interviewer follow-up

Should a save wait until every replica applies?

"Only if that is the required contract. I can use a suitable durable commit rule and separately route or wait for reads that must see the write."

What the answer must demonstrate: Do not equate a network acknowledgment with query visibility.

03 / APPLIED

A leader acknowledges v41 before a follower receives it, then permanently fails. Explain the possible data loss.

Model answer

"A responds at .003, fails at .006, and B would receive the change at .008. If A's storage is lost, the survivors have v40. I either accept that acknowledged-write loss window explicitly or wait for the required durable replica before answering."

Interviewer follow-up

Does synchronous replication prevent every kind of loss?

"No. It covers a stated failure model. Correlated storage loss, a replicated bad delete, or unsafe recovery can exceed it."

What the answer must demonstrate: Avoid universal durability claims.

04 / APPLIED

With three replicas and a one-replica-loss durability goal, why might the commit protocol wait for two durable copies instead of all three?

Model answer

"Two durable copies leave at least one copy of an acknowledged entry after any one participant is lost. With a safe election and commit protocol, the surviving majority preserves that committed history and can continue. Waiting for all three adds a copy but makes the slowest replica control acknowledgment and stops writes if any replica is unreachable. I would choose two only because it meets the stated one-failure contract; the count alone is not the safety proof."

Interviewer follow-up

What if two simultaneous storage losses must be tolerated?

"I must revisit replica count, acknowledgment, and placement together. One surviving copy cannot preserve a write it never received."

What the answer must demonstrate: Failure budget and acknowledgment must agree.

05 / APPLIED

A write of v41 succeeds, but a subsequent session read returns v40. What should you inspect?

Model answer

"Check which replica answered and how far it had applied the write log. It may have saved v41 without making it readable yet. To read my own write, use the verified current leader or wait for a follower to apply the returned commit position. That position must still identify the right history after failover. A former leader or an arbitrary application version cannot prove freshness."

Interviewer follow-up

Why is 100 ms of waiting insufficient?

"Lag is not bounded by that guess during overload or failure. I need evidence that the required update became visible."

What the answer must demonstrate: Waiting a fixed time does not prove that the required update is visible.

06 / FOUNDATION

How do replicas and shards fit together?

Model answer

"A shard owns a subset of records, while replicas store copies of that subset. Cart C17 can belong to one shard with three replicas. Adding shards can divide data and write work; adding followers preserves copies and can spread eligible reads. Each follower still has to process its shard's write stream."

Interviewer follow-up

Will ten followers give ten times the write capacity?

"Not by themselves. A single leader still orders the stream, and each follower must keep up with it."

What the answer must demonstrate: Do not count duplicated processing as partitioned work.

07 / FOLLOW-UP

A new leader B takes over from isolated leader A. What prevents A from continuing to commit writes?

Model answer

"A must lose the ability to commit new writes when B takes over. Missing heartbeats alone does not prove A stopped. Use the database's safe election and fencing protocol to reject the old leader, then update routing so clients find B."

Interviewer follow-up

Can DNS provide the fencing?

"No. Cached addresses and existing connections may still reach A. The protected write path must reject obsolete authority."

What the answer must demonstrate: Routing is discovery, not ownership enforcement.

08 / FOLLOW-UP

Every replica contains a mistaken deletion. What next?

Model answer

"I stop the faulty job, restore retained history in isolation, identify C17's last valid state, and verify the repair. Promoting another current replica cannot undo a deletion they all copied correctly. I would also check the full affected range."

Interviewer follow-up

What proves that recovery plan works?

"A measured restore that validates records and application behavior within the objectives. Backup completion alone proves only part of the path."

What the answer must demonstrate: Replicas and recovery history solve different failures.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Specify received, durable, applied, and committed milestones for a three-replica protocol. Test cart C17 version 41 by failing leader A before and after acknowledgment, then evaluate a stale read and a lost-response retry.

- Label received, durable, applied, and committed separately.
- Show which surviving participant contains v41.
- Explain a read-after-write request and an ambiguous retry.
- Demonstrate why a replicated bad deletion needs retained history.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What must "cart saved" mean?

State where the write must be durably stored before success is returned and which failures it must survive. For example, a safe commit and election protocol can require durable storage on two of three replicas to tolerate one replica loss.

Saved where, before saying saved.

Why might a durable follower show v40?

It may have stored v41 in its log without applying it to queryable state yet.

Received, stored, applied: three milestones.

Are replicas a replacement for backups?

No. A bad delete can reach every live copy; retained history is needed to recover the earlier state.

Replicas copy today; backups preserve yesterday.

Does adding read replicas divide the write stream?

No. Copies still process the same writes; sharding divides different data and work.

Copy versus divide.

Summary and interview notes

Replication keeps copies; durability defines which committed changes survive which failures. The acknowledgment rule, safe failover protocol, read policy, and retained recovery history must be chosen together.

Remember these points

• Received, durable, applied, and committed are different milestones.

• Asynchronous replication can lose an acknowledged write if its only durable copy is lost before followers catch up.

• A safe two-of-three majority protocol can preserve committed history through one participant loss; copy counting alone cannot.

• Define how old follower reads may be. Before trusting a leader's read, verify it is still the leader.

• Replicas help recover from component loss; retained backups and logs help recover from replicated mistakes.

Interview tips

• For every successful write, point to the surviving durable copy after the failure you claim to tolerate.

• Test a lost response, a lagging read, and an isolated former leader separately; each needs a different mechanism.

• Name failure domains explicitly: process, disk, zone, and region are not interchangeable.

Important qualifications

• Synchronous replication settings do not automatically select a safe replacement or fence the former primary.

• A read-your-writes token must identify the relevant committed update even after failover; a sequence number from an unrelated or discarded history is insufficient.

Technical references

PostgreSQL: Log-Shipping Standby Servers
Verified reference for asynchronous streaming and distinct remote acknowledgment stages.
https://www.postgresql.org/docs/current/warm-standby.html

Raft: In Search of an Understandable Consensus Algorithm
Primary reference for safe leader election and preserving committed history. The cart trace is hypothetical.
https://raft.github.io/raft.pdf

Apache Cassandra: Repair
Official range repair, Merkle summaries, repair coverage, and repair-before-tombstone-expiry guidance. Checked 2026-09-23; the page identifies its documentation version as 5.0.
https://cassandra.apache.org/doc/latest/cassandra/managing/operating/repair.html

Apache Cassandra: Hints
Official explanation of coordinator hints, later handoff, and why best-effort hints do not replace anti-entropy repair.
https://cassandra.apache.org/doc/latest/cassandra/managing/operating/hints.html

Apache Cassandra: Read Repair
Official read-repair scope and blocking/none tradeoffs; monotonic quorum reads are narrower than general linearizability or transaction isolation.
https://cassandra.apache.org/doc/latest/cassandra/managing/operating/read_repair.html

Apache Cassandra: Tombstones
Official deletion-marker, resurrection, grace-period, and compaction-removal conditions; no automatic-safe-GC claim.
https://cassandra.apache.org/doc/latest/cassandra/managing/operating/compaction/tombstones.html

Dynamo: Amazon's Highly Available Key-value Store
Primary section 4.7 explains Merkle-tree anti-entropy and hinted-handoff limitations; these are distinct from safe leader election.
https://www.allthingsdistributed.com/files/amazon-dynamo-sosp2007.pdf

FOUNDATIONS / 14

CAP theorem: consistency, availability, and partition tolerance

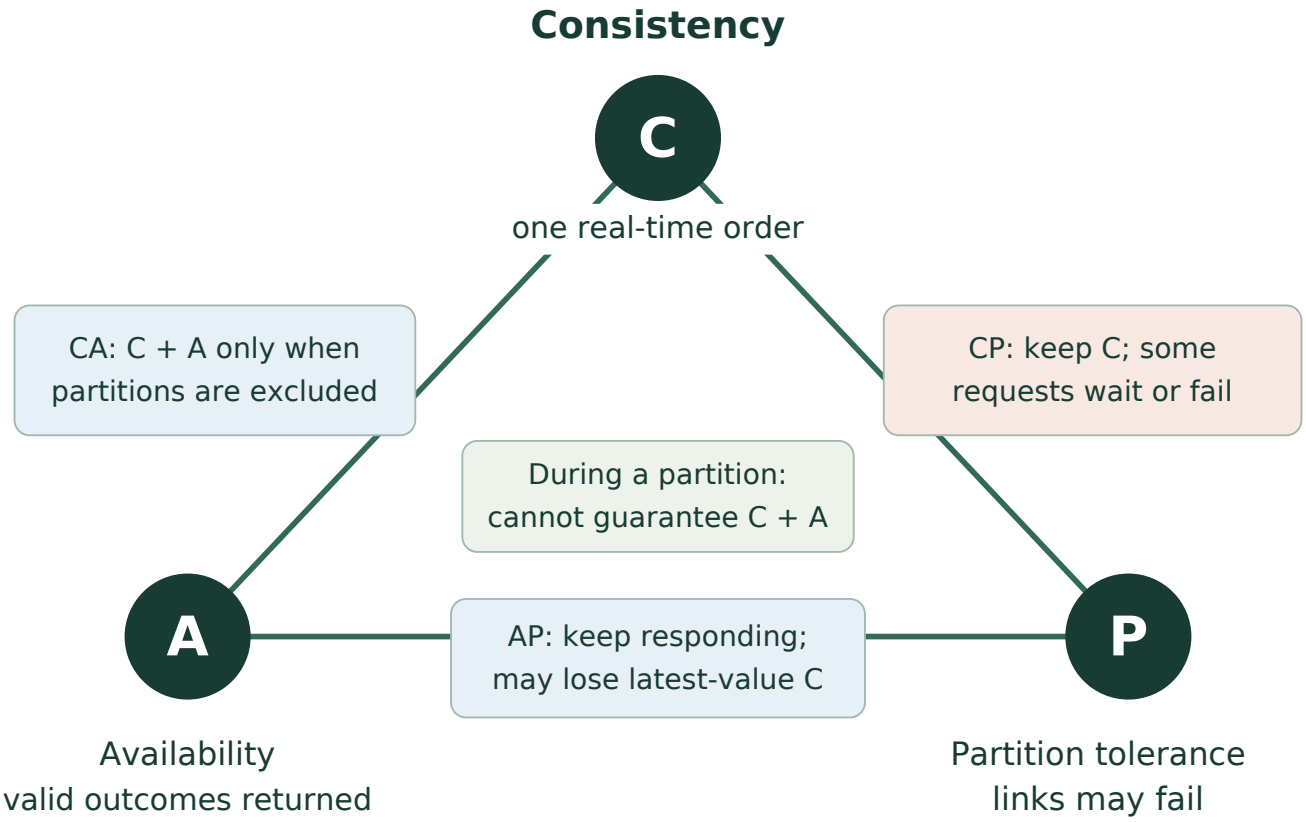
DEFINITION

The CAP theorem states that a distributed read/write system cannot guarantee both consistency (C) and availability (A) when a network partition (P) prevents replicas (copies of the same data) from communicating. C means linearizability: after a write completes, a later read must return that value or a newer write, as if there were one up-to-date copy. A means every request to a nonfailed participant eventually completes according to the operation's contract.

Why it matters: Replicas may be alive but unable to exchange updates. We must decide whether an affected operation waits or fails to preserve one current history, or completes using potentially stale or conflicting state.

The CAP triangle: consistency, availability, and partitions

C is linearizability, A is a successful contract-compliant response from every non-failing node, and P means the model allows broken links. During a partition, the system cannot guarantee both C and A.



Seat S7: isolated replicas cannot promise both a latest answer and a response.

Worked example

East and West both store seat S7 as free. The network splits. East confirms client A's reservation. A later read at West must learn that change to return a current answer; returning "free" breaks C, while waiting indefinitely or refusing the read sacrifices A.

Key takeaways

• During a partition, C and A cannot both be guaranteed for the same read/write contract.

• CP preserves one history but some operations cannot complete; AP permits completion with weaker consistency.

• The triangle is a mnemonic. "Pick any two" hides that partitions are a failure condition, not an optional product feature.

Read the visual model

1. C: reads respect one real-time order of completed operations.

2. A: every request to a non-failing node eventually receives a successful response under the operation contract; this is not an uptime percentage.

3. P: replicas may be unable to communicate.

4. CP preserves linearizability by rejecting or waiting on some partitioned requests. AP continues responding but may return conflicting or stale values.

5. CA is possible only when partition failures are excluded from the model; partition tolerance is not a feature to switch off in a network that can split.

CAP • replication • linearizability • network partitions • inventory

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• State the CAP theorem, define C/A/P, and explain the CP/AP/CA edges of the triangle.

• Use a completed-write/remote-read timeline to show why both guarantees cannot always hold.

• Choose partition behavior per operation without confusing CAP consistency with business rules.

Useful foundations: Replication and durability; Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / What is the CAP theorem?

The CAP theorem: when a network partition separates replicas of a distributed read/write system, the system cannot guarantee both **consistency** and **availability** for every operation. It must allow some operations to remain incomplete, or allow results that do not fit one current, real-time-ordered history.

Letter	Canonical meaning	Plain-language test
C: Consistency	Linearizability: clients observe one up-to-date copy	After a write completes, a read that starts later returns that write or a newer write; overlapping operations must still fit one valid real-time order

Letter	Canonical meaning	Plain-language test
A: Availability	Every request received by a nonfailed participant eventually completes according to the operation contract	An isolated but live node must still complete reads/writes; returning a generic failure does not fulfill that guarantee
P: Partition tolerance	The model permits messages between groups of live nodes to be lost	Both sides may be alive and serving clients while they cannot exchange updates

The familiar CAP triangle names the three properties. Its CP and AP edges describe different promises during a partition. The CA edge applies when partitions are excluded from the guarantee; it is not a way to wish away network failures. "Pick any two" is a memory aid that needs this qualification.

Use a single replicated object to test the guarantees. Seat S7 starts as `Seat(S7, owner = null)`. Reservation is an atomic check-and-set of the owner, preventing two successful allocations from independent reads of `null`. This business invariant is distinct from the freshness promised by a read.

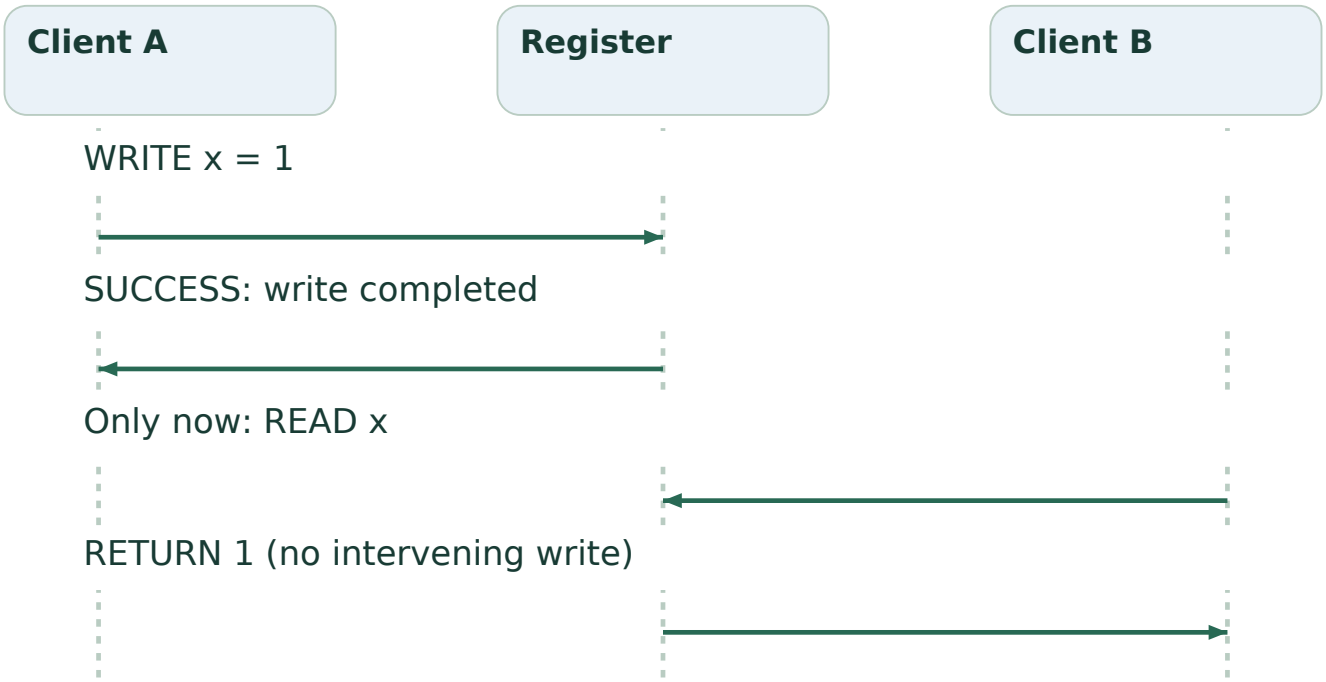
In the example history, client A's reservation completes at 10:00:02 and client B starts a read at 10:00:03. A linearizable read must return client A as owner. Replication introduces an information gap: after communication fails, East can know the completed reservation while West retains the old free value. The following sections derive C, A, and P from that gap.

02 / C = consistency: linearizability and real-time order

CAP consistency means clients observe one up-to-date copy of the data. After a write completes, any read that starts later must return that value or the result of a newer write. This guarantee is called **linearizability**. If the system cannot provide a valid result, it may wait or refuse the operation to preserve consistency; that sacrifices availability for the affected request.

CAP consistency: completed writes constrain later reads

Linearizability requires an order compatible with real-time precedence of non-overlapping operations. It does not mean that every replica changes at the same physical instant.



Remember: A completed write constrains a later read.

The familiar phrase "all clients see the same data" describes this single-copy view. A simple test is to finish one write and then read from different clients, with no intervening writes: every successful read must agree with that write. It does not require every physical replica to update at the same instant.

Step	Operation on seat S7	What CAP consistency requires
1	East confirms client A's reservation	The write has completed
2	Client B then reads through West	Return client A as owner, assuming no later change
3	West is isolated and only knows the old free value	Do not return "free" as a successful current read; coordinate, wait or refuse

The formal definition says the same thing more precisely: each operation appears to take effect at one instant between its start and finish, and all operations fit one legal order that respects completed-before-started relationships. A read overlapping an unfinished reservation may see the earlier or later state, provided the whole history fits that order. This handles concurrency that the word "latest" alone leaves ambiguous.

INTERVIEW CRITICAL

CAP consistency differs from ACID consistency

A lagging replica can be compatible with linearizability if the service routes reads to an authoritative copy or waits for sufficient information. The guarantee is about callers' observations, not simultaneous updates to every machine. **ACID consistency** has a different meaning: preserving database and application rules. A stale seat display can coexist with an authoritative reservation endpoint that still prevents duplicate sales. See the comparison of consistency meanings and the original CAP definition.

03 / A = availability: every nonfailed participant can complete requests

CAP availability asks whether every request reaching a nonfailed participant completes according to the object's operation contract, even in the allowed failure scenarios. For our read, the client receives an owner value. Refusing every read with "cannot contact East" does not meet that availability promise.

A legitimate business rejection is different. An authoritative reservation operation can answer "already reserved" when that is its valid result. An infrastructure refusal says that the service cannot establish or perform the operation at all.

INTERVIEW CRITICAL

CAP availability is not an uptime percentage

Do not substitute a monthly uptime percentage for this theoretical property. A service can meet a practical 99.9% good-request target while intentionally refusing some requests during partitions. Conversely, CAP's availability definition does not impose a specific millisecond latency limit. Our product may additionally require a 200 ms response, but that is a separate service objective. State both promises rather than treating the letter A as a synonym for fast HTTP responses.

04 / P = partition tolerance: live nodes cannot exchange messages

A network partition separates communicating participants. At 10:00:01, the link between East and West stops carrying messages. East still has power and serves client A; West still has power and serves client B. Neither side can reliably learn what the other side is doing.

A partition can come from a routing fault, a firewall mistake, or a failed network path. A machine crash is different, although a disconnected machine can look crashed to a failure detector. Missing replies reveal uncertainty; they do not prove the remote machine stopped accepting work.

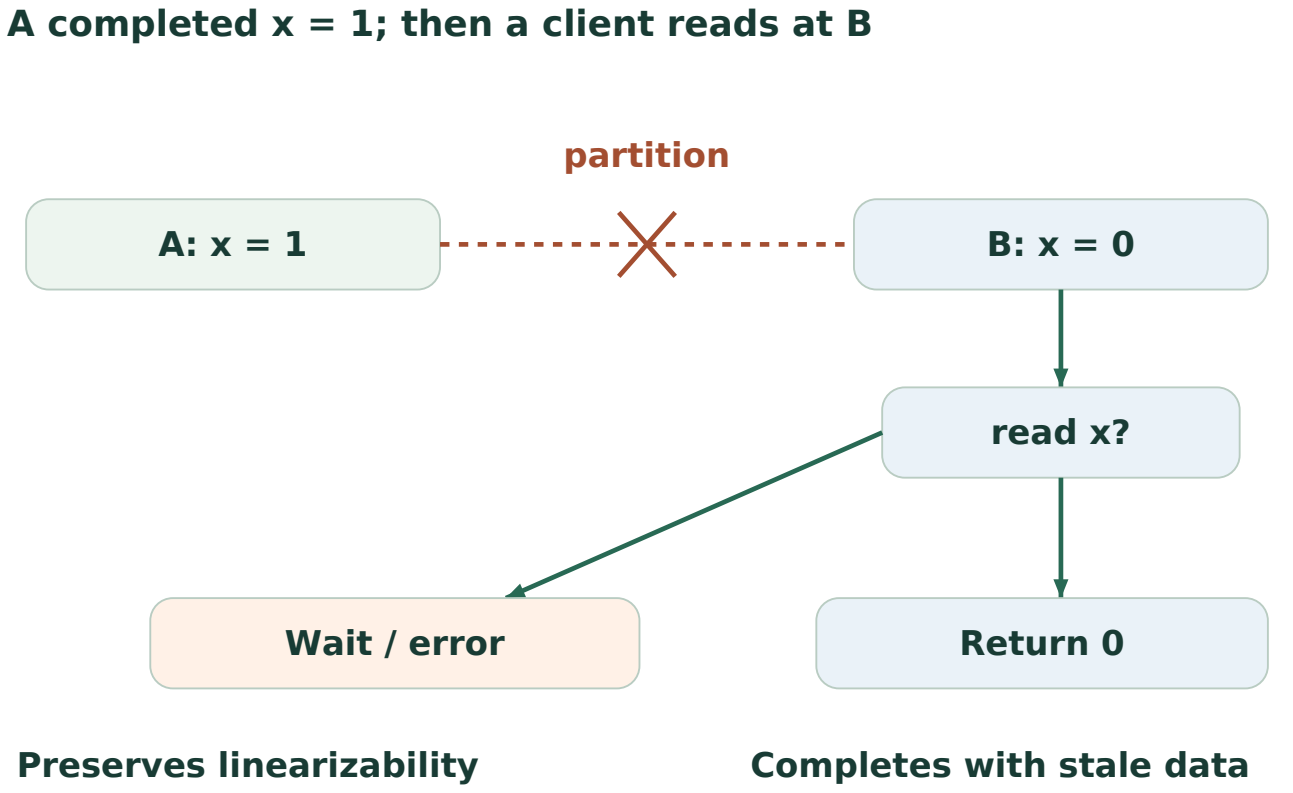
"Partition tolerance" means our failure model permits this communication loss and our design states what remains guaranteed. It does not mean replication can magically cross the broken link. We cannot remove this possibility from a multi-location design merely by choosing a different database label. More independent links can lower the risk, but the question remains: what does each operation do when the messages still cannot arrive?

05 / Worked example: a partition between two seat replicas

Assume both copies initially contain the same record. The following trace deliberately lets East complete a local write while disconnected; it is a thought experiment that exposes the conflict.

What can B return while the link is broken?

The read starts after A has confirmed x = 1. There is no later write. The broken link prevents B from learning that value.



B cannot promise both a successful read and the latest completed value.

Remember: B can refuse or wait, or return stale data; it cannot guarantee both CAP properties here.

Try from memory: Why is returning 0 a consistency violation in this history?

Answer: The read begins after the write of 1 completes, with no intervening write. Linearizability therefore requires 1.

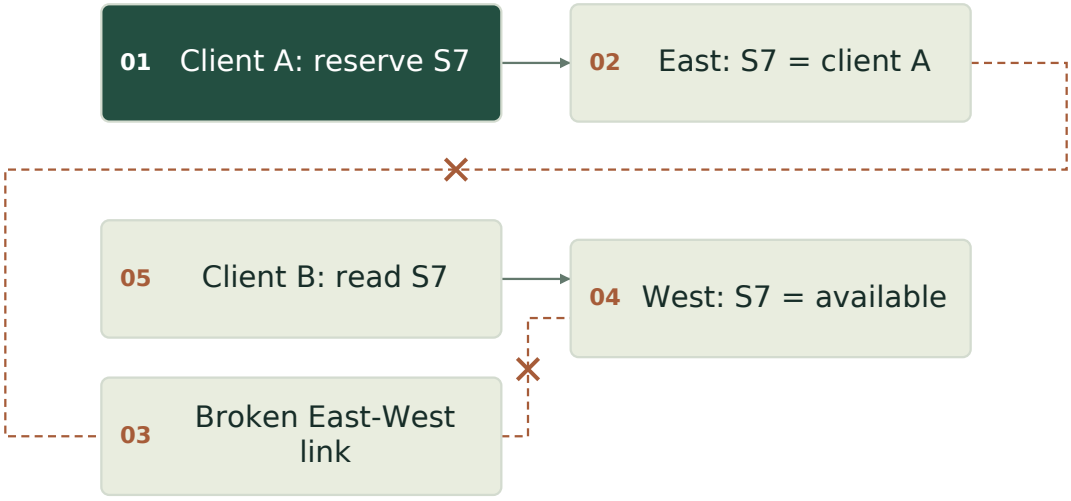
Time	East and client A	West and client B
10:00:00	S7 is available	S7 is available
10:00:01	Messages to West stop	Messages from East stop
10:00:02	Store owner = client A; return success	Still holds owner = null
10:00:03	client A's write has completed	client B asks for S7's owner

West has three plausible responses. Returning null completes a read but violates linearizability in this history. Waiting until it can discover the update preserves the possibility of a correct answer, but an indefinitely partitioned request does not complete. Returning "unavailable" is an explicit refusal of the read.

Guessing "client A" cannot solve the problem: West would have identical local evidence if nobody had reserved S7 or if another client had. It needs information that the partition prevents from arriving. This is the practical intuition behind CAP, rather than a rule to attach two letters permanently to every product.

WORKED EXAMPLE DIAGRAM

Client A reserves S7 in East. During the broken East-West connection, client B can reach West but West cannot learn the completed update. Arrows show the worked timeline, not a recommended deployment.



1 -> 2	10:00:02 reserve; success returned: Client A: reserve S7 -> East: S7 = client A
2 -> 3	replication message cannot cross: East: S7 = client A -> Broken East-West link
3 -> 4	West receives no update: Broken East-West link -> West: S7 = available
5 -> 4	10:00:03 read begins: Client B: read S7 -> West: S7 = available

06 / CP, AP, and CA: interpret the triangle and choose per operation

The seat trace leaves a concrete choice: preserve the current-owner contract by withholding an answer, or keep answering while allowing older information. CP and AP are names for those different guarantees when partitions are permitted. CA describes a different assumption that excludes partitions from the executions being guaranteed.

Triangle edge	Promise during a partition	Concrete behavior and cost
CP: consistency + partition tolerance	Preserve one valid real-time-ordered history; give up completing every request	A side unable to establish authority waits or rejects affected operations. A valid majority may continue, but a disconnected minority cannot promise success
AP: availability + partition tolerance	Complete operations at nonfailed participants; relax linearizability	West can return its last known seat map. If both sides accept writes, define the conflict semantics and reconcile later; this cannot safely promise the same exclusive seat to two buyers
CA: consistency + availability, excluding partitions	Both are possible when communication assumptions exclude partition executions	A single authority or connected replicas can provide both within the assumed model. Once isolated replicas must independently answer, the CAP tradeoff returns



INTERVIEW CRITICAL

Choose partition behavior per operation

These are behavior choices for a specified operation and failure model, not permanent labels that determine every feature of a database product. A service can use CP-style behavior for reservation and accept AP-style stale reads for an advisory map. Choosing CP does not mean the entire service stops on every partition; the unavailable operations are those that cannot meet the required authority or read rule.

For this booking service, choose a single safe reservation authority backed by a replication/election protocol. When a participant cannot establish the authority required to change S7, it declines that change. With only two voters requiring both, a partition can stop new reservations entirely; a properly designed three-voter majority can let the connected majority proceed while the minority refuses writes.

The cost is lost purchasing availability for some customers during a fault. We accept it because promising the same seat twice would break the product. This is a design choice for the reservation operation, not a claim that every endpoint must stop.

Operation	Chosen partition behavior	User-visible cost
Reserve S7	Require the authoritative conditional change	Some attempts receive a retryable refusal
Display seating map	Permit a labeled cached view	Seat inventory display may be stale
Read confirmed order	Read an authority or verified session position	May wait or fail when authority is unreachable

The seating map helps users choose a seat, but only a successful reservation confirms that the seat has been assigned to them.

INTERVIEW CRITICAL

CAP labels do not establish convergence or durability

AP is not a synonym for eventual consistency. CAP alone does not specify whether two divergent copies will ever converge, how they merge, or whether one accepted update is discarded. Eventual convergence requires additional delivery and reconciliation assumptions after communication recovers. Likewise, choosing CP does not specify durability, transaction isolation, or a numerical latency target. Outside partitions, replica coordination still has network and storage costs; the theorem does not choose the fastest normal-operation design for us.

07 / After the partition: recovery and conflict handling

At 10:00:20, communication returns. Before West promises current reads or accepts new reservations, it must recover the committed state and follow the protocol that decides which node may serve those operations. Replicas catch up or reconcile according to their protocol. An old leader must not keep committing conflicting updates merely because it resumed responding; ownership enforcement belongs to the replication design.

Client B retries a purchase using the same request identifier. If an earlier attempt committed but its response was lost, the service should retrieve that outcome rather than create a second operation. If it never committed, the authority can process it and report that client A already owns S7.

A product that deliberately accepted conflicting writes needs a separate merge or compensation policy. "Eventually consistent" does not tell us whether client A or client B receives the seat, and restoring communication does not undo promises already made to clients. For guarantees such as read-your-writes and causal ordering, continue with the consistency models chapter; they answer additional questions beyond CAP's limit.

08 / Interview answer: explain CAP, then apply it

Interviewer: "How should a multi-region service choose consistency and availability?"

Candidate: "The CAP theorem says a distributed read/write system cannot guarantee both linearizability and completion of every request to a nonfailed participant when replicas cannot communicate. C means later reads see a completed write or a newer write, with operations fitting one valid real-time order; A is completion under the operation's contract; P is the allowed loss of communication between live participants. The tradeoff concerns affected operations during a partition.

"I choose the guarantee for each operation. Reserving a seat requires one atomic decision by the service allowed to allocate it; a server unable to reach that service must wait or refuse. The seat display can show older data if the product allows it. During a partition, reservations may stop while the display remains usable.

"For a concrete test, a write completes in East before a read starts in isolated West. West cannot infer the write from its old local state. Returning the old value breaks linearizability; waiting indefinitely or refusing sacrifices availability. I would then specify replica placement, quorum and election rules, fencing, and retry handling. The label CP alone supplies none of those mechanisms."

First explain CAP, then choose what each operation must guarantee and what that choice costs. Preventing two sales of one seat still requires an atomic allocation step. CAP explains which distributed guarantees can conflict; it does not implement that step.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is the CAP theorem? Define C, A, and P, and explain the triangle with a concrete example.

Model answer

CAP says a distributed read/write system cannot guarantee both linearizable consistency and completion of every request to a nonfailed participant when network partitions are allowed. C means clients observe one up-to-date copy: after a write completes, a later read must return it or a newer write. Formally, operations fit one valid history respecting real-time order. A means every such request eventually completes according to its contract. P means live replicas can be unable to exchange messages.

Draw C, A, and P at the triangle's vertices. Label CP as preserving one history while some operations wait or fail, AP as permitting completion with weaker consistency, and CA as requiring that partitions are excluded from the guarantee. Do not present P as a network failure you can disable in production.

For example, East and West both store S7 as free. They lose contact. East confirms client A's reservation. A later West read cannot learn that fact: returning free violates C; refusing or waiting without completion gives up A. The design should state which behavior is acceptable for that operation.

Interviewer follow-up

Why is "every replica has the same data at every instant" an inaccurate definition of CAP consistency?

Linearizability constrains observable operations, not instantaneous physical equality of every copy. A follower can lag if the system routes, waits for, or validates reads so completed operations still fit one legal real-time order. A read overlapping a write may legally appear before or after it. But if the write completed before the read began, an older value is invalid in the absence of an intervening write. The physical replication and the visible consistency promise are different levels.

What the answer must demonstrate: State the theorem before the caveats; define all three letters and use one completed-write/later-read partition trace.

02 / FOUNDATION

Why does a quick 503 not prove CAP availability?

Model answer

"The client reached a working participant but did not complete the requested seat read. The server replied quickly, which is useful operationally, but refused the object operation. I would count that separately from a valid 'already reserved' result and separately from the product's latency target."

Interviewer follow-up

Does returning 'already reserved' sacrifice availability?

"Not when that is a valid result established by the reservation operation. It reports a business outcome. Inventing that result without authority just to avoid an error would violate the operation's contract."

What the answer must demonstrate: Separate infrastructure failure from legitimate business rejection.

03 / FOUNDATION

Can a partition happen while both databases are healthy?

Model answer

"Yes. East and West may both run normally and answer their local clients while network messages between them are dropped. That is why checking each process's health is insufficient. I need to know which communication and authority assumptions an operation requires."

Interviewer follow-up

Would a second network link solve CAP?

"It reduces the chance of losing communication, but cannot prove communication will always work. I still define behavior for the residual case where every usable path fails."

What the answer must demonstrate: A network partition is not necessarily a server crash.

04 / APPLIED

East and West start with S7 free, then become partitioned. East confirms a reservation at 10:00:02; a West read begins at 10:00:03. Why can West not guarantee a linearizable answer while completing every such read?

Model answer

"West has the same local state in several possible histories: client A reserved in East, someone else reserved, or nobody wrote. No East message has arrived. Its old null value cannot distinguish them. Answering immediately may choose the wrong history; waiting for information can prevent completion during a continuing partition."

Interviewer follow-up

Could synchronized clocks reveal the missing write?

"Clocks can tell West that time passed, but not who wrote or whether a write happened. Timing assumptions may support particular protocols, but time alone does not carry the missing data."

What the answer must demonstrate: Explain the missing information, not just repeat 'choose two.'

05 / APPLIED

How would you handle the last seat during a partition?

Model answer

"I would allow only the participant with valid write authority to perform the atomic available-to-reserved transition. A disconnected minority would decline it. That may stop some purchases, but a successful confirmation then means the seat was reserved by the node currently authorized to make that decision. I would specify the quorum and safe leader change rather than relying on a product label."

Interviewer follow-up

What if we have exactly two replicas?

"If safe progress requires both, a split leaves neither side able to complete new writes. I would discuss a third voting participant and failure-domain placement, or accept the two-node availability cost."

What the answer must demonstrate: Adding replicas is not the same as defining a safe election protocol.

06 / FOLLOW-UP

Does preventing double sales imply every read is CAP-consistent?

Model answer

"No. I can send all reservations through one atomic authority while serving a stale seating map elsewhere. The business invariant can hold even when that display is not linearizable. Conversely, a correctly ordered store can still oversell if my application uses an unsafe read-then-write algorithm."

Interviewer follow-up

How would you fix that unsafe algorithm?

"Make checking availability and assigning the owner one protected operation, using a conditional update or suitable transaction. Read freshness alone does not make two separate operations atomic."

What the answer must demonstrate: CAP C and application invariants are related design concerns, not identical definitions.

07 / APPLIED

A reservation request times out without a known outcome. How should the client retry?

Model answer

"Reuse the operation identifier and ask the authority for the durable outcome. A timeout means the response was not received; it does not prove the reservation failed. If the old attempt committed, return that result. If it did not, process the retry under the same ownership rules."

Interviewer follow-up

Should West create a new reservation while East is unreachable?

"Only if West can safely take responsibility for the reservation. If East may already have reserved the seat, creating an unrelated reservation at West could create two conflicting bookings."

What the answer must demonstrate: A missing response is an unknown outcome.

08 / FOLLOW-UP

What must happen after the partition heals?

Model answer

"Replicas must converge on the protocol's authoritative history, and obsolete writers must remain fenced. I would verify catch-up before routing reads that promise current state. If our policy allowed conflicting writes, I also need an explicit business repair policy; network recovery alone cannot choose who deserves a promised seat."

Interviewer follow-up

Can the whole site have one useful AP or CP label?

"Only as shorthand for a specified operation and failure model. A stale advisory map and an authoritative reservation already make different choices. AP also does not define eventual convergence or conflict resolution; I must explain how accepted updates propagate and reconcile after communication returns."

What the answer must demonstrate: Recovery must honor promises made before and during the fault.

Build the answer yourself

BLANK-PAGE EXERCISE / 12 MINUTES

Draw and label the CAP triangle, explaining the assumption behind CA. Then draw East and West storing S7. Show a partition, client A's completed reservation in East, and client B's later read at West. Design separate browsing and purchasing contracts.

- Define C, A, and P before choosing a design, and explain why the triangle does not mean partitions can be switched off.
- Show exactly which information West lacks at client B's read.
- State one operation allowed and one refused during the partition, with the user cost.
- Explain safe catch-up and the outcome of an ambiguous retry.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

State CAP and label the triangle.

The CAP theorem states that a distributed read/write system cannot guarantee both consistency (C) and availability (A) when a network partition (P) prevents replicas from communicating. C means linearizability: after a write completes, a later read must return that value or a newer write, as if there were one up-to-date copy. A means every request to a nonfailed participant eventually completes according to the operation's contract.

Partition present: preserve one history (CP) or complete with weaker consistency (AP). CA excludes the partition case.

Both replicas are running but cannot exchange messages. Which CAP letter describes this?

P: a network partition. Machines can be alive and serve their local clients while communication between them is lost.

Live participants; unavailable communication.

Can returning "temporarily unavailable" preserve every CAP guarantee?

It can protect an authoritative history, but it sacrifices availability for the refused operation. A quick error is not a successful read of the object.

Fast refusal is still refusal.

Does a stale seat display necessarily mean the seat can be sold twice?

No. Display reads may be stale while reservations use one atomic authority. CAP read consistency and the no-double-sale business rule are different claims.

Displaying a seat and reserving it can require different consistency guarantees.

Summary and interview notes

CAP identifies a limit: when live replicas cannot communicate, a replicated read/write service cannot promise both linearizable answers and completion at every nonfailed participant. Choose the behavior per operation, then supply the replication, authority, retry, and recovery mechanisms that implement it.

Remember these points

• C means later reads see a completed write or a newer write; all operations fit one legal real-time order. Physical replicas need not update simultaneously.

• A concerns completing the specified operation at every nonfailed participant, not merely returning a fast error or meeting an uptime percentage.

• A CP-style operation may wait or refuse when it cannot confirm the current state or safely change it. An AP-style operation relaxes linearizability to keep responding during a partition.

• The CA edge excludes partition executions from its promise; it cannot disable network failures.

• An atomic reservation can prevent double sales even when an advisory seating display is stale.

Interview tips

• Explain the missing information with a completed East write followed by a West read during the partition.

• State what a valid response means before deciding whether a business rejection sacrifices availability.

• After choosing partition behavior, describe healing, obsolete writers, and retries with unknown outcomes.

Important qualifications

• The formal availability property has no fixed millisecond bound; product latency objectives are separate.

• AP does not automatically supply eventual convergence, and CAP consistency does not enforce application invariants by itself.

Technical references

Gilbert and Lynch: Brewer's Conjecture and the Feasibility of Consistent, Available, Partition-Tolerant Web Services
Primary proof and definitions. The two-client seat trace is an original bounded example, not a production-system claim.
https://www.cs.princeton.edu/courses/archive/spr22/cos418/papers/cap.pdf

Eric Brewer: CAP Twelve Years Later
The originator explains why pick-two is too simple and why the partition decision and recovery must be explicit.
https://www.infoq.com/articles/cap-twelve-years-later-how-the-rules-have-changed/

FOUNDATIONS / 15

Consistency models

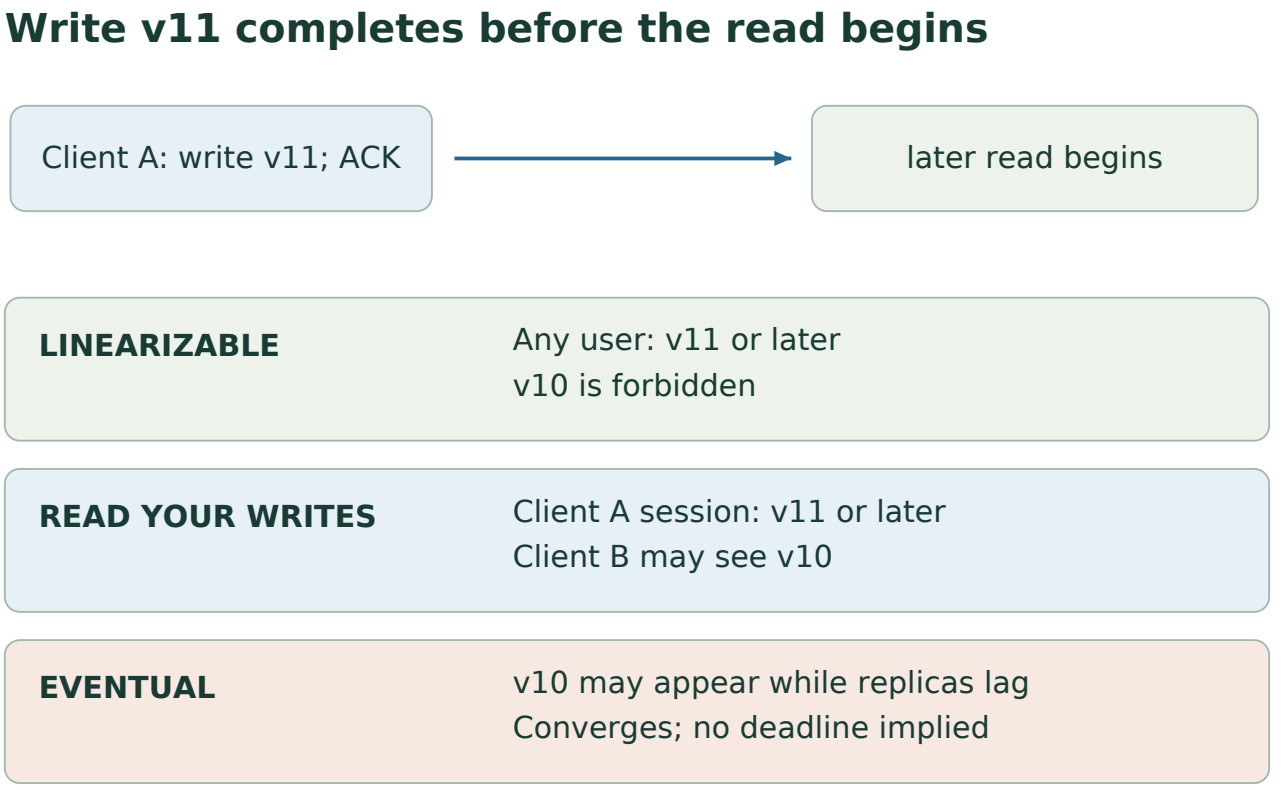
DEFINITION

A consistency model defines when a write becomes visible to readers and which order of operations they may observe. CAP consistency is one specific model, linearizability: after a write completes, a read that starts later must return it or a newer write. Other models, such as causal and eventual consistency, make different promises. ACID consistency instead concerns preserving database and application rules.

Why it matters: Replicas and caches may receive an update at different times. The application needs a precise rule for which old or reordered results are acceptable.

Linearizability, read-your-writes, and eventual consistency

Consistency models constrain observations. Compare a real-time guarantee, a session guarantee, and eventual convergence.



These models differ in whose reads and which ordering constraints they guarantee.

Worked example

Notebook N7 starts at version 10. Client A saves version 11, then client B reads. Linearizability requires version 11 or a later write; eventual consistency can temporarily return version 10.

Key takeaways

• Linearizability respects the real-time order of completed operations.

• Causal and session guarantees preserve dependencies or one client's history.

• Eventual convergence does not provide a freshness deadline.

Read the visual model

1. Client A writes v11 and receives an acknowledgement before the shown read begins.

2. A linearizable read must return v11 or a later write in the agreed order.

3. Read-your-writes requires later reads in client A's session to see v11 or a later version, but client B may still read v10.

4. Eventual consistency permits stale reads during propagation and promises convergence under its stated conditions, not a fixed delay.

consistency • linearizability • causality • session guarantees

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Distinguish real-time order, process order, causal order, and eventual convergence using concrete traces.

• Design read-your-writes and monotonic reads across replicas without promising global freshness.

• Choose separate consistency contracts for an authoritative update and a replicated user interface.

Useful foundations: Replication and durability; CAP theorem: consistency, availability, and partition tolerance

9 interview questions with model answers and answered follow-ups.

01 / Consistency model: definition and example

Consistency has different meanings in different contexts. The familiar CAP definition is that clients observe one up-to-date copy: after a write completes, a later read must return it or a newer write. This is **linearizability**. A **consistency model** is the broader term for the rules governing when writes become visible and how operations may be ordered.

Term	Standard meaning	Quick test
CAP consistency	Linearizability: operations behave as if there were one copy, respecting real-time order	Write v11 succeeds; a read starting afterward must return v11 or a newer write
Consistency model	The rules governing visibility and ordering; linearizable, sequential, causal and eventual consistency are different models	Which old values or orderings may this read observe?
ACID consistency	A correct transaction preserves database and application rules, taking valid state to valid state	Does the purchase preserve the rule that stock cannot become negative?

One example, two models: a record contains v10. Client A writes v11 and receives success. Client B then reads through another server, with no further writes.

1. **Linearizability:** a successful read must return v11. If the server cannot establish the current value, it must coordinate, wait or refuse rather than return stale v10.
2. **Eventual consistency:** the read may temporarily return v10. Once updates stop and propagation and reconciliation succeed under the system's assumptions, reads converge on the settled value; the model alone gives no freshness deadline.

"Strong consistency" commonly refers to linearizability in interviews, but ask for the exact model and operation scope. "All clients see the same data" is shorthand for the observable single-copy behavior, not a requirement that every physical replica update simultaneously. The linearizability section explains overlapping operations.

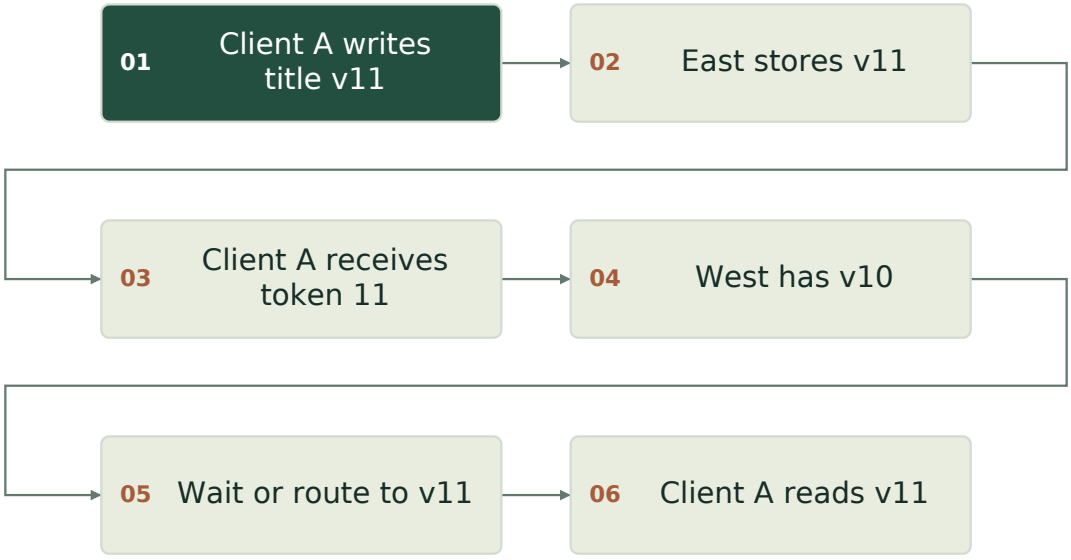
Interview memory aid: CAP consistency asks "Do readers see the current value?"; a consistency model asks "What may readers observe?"; ACID consistency asks "Do the rules still hold?"

Define the scope before choosing a guarantee: one object, one session, or a multi-object operation. The bounded histories below use record N7, version 10 ("Trip"), followed by version 11 ("Autumn trip"). Client A writes the update; client B can read through a different replica in East or West. A **history** is the sequence of observed reads and writes. The timestamps and versions are illustrative, not measurements.

With a single process, an ordinary write followed by a read can access the same in-memory value. Replicas, caches, and concurrent clients break that intuition: the write can finish at East while West still has version 10. Before drawing servers, finish this sentence: "After this operation succeeds, these readers must be able to observe this state." Specify whether the promise concerns one key, a session, or several keys together.

WORKED EXAMPLE DIAGRAM

A session carries a minimum applied-position token of 11. A replica at 10 must wait, redirect, or fail that read; the token does not establish global freshness for other sessions.



1 -> 2	commit: Client A writes title v11 -> East stores v11
2 -> 3	reply: East stores v11 -> Client A receives token 11
3 -> 4	read with minimum 11: Client A receives token 11 -> West has v10

4 -> 5	10 is too old: West has v10 -> Wait or route to v11
5 -> 6	satisfy session: Wait or route to v11 -> Client A reads v11

02 / Linearizability: real-time operation order

Plain-language definition: after a write completes, any read that starts later must return that write or a newer write. Clients observe one up-to-date copy of the object. This is the consistency guarantee used by CAP.

Formal definition: operations can be placed in one valid order, respecting real time, as though each took effect at one instant between its start and finish. This also defines what is allowed when operations overlap; the simple completed-write/later-read example below is one consequence. Herlihy and Wing's original definition is the source of this formulation.

Apply these tests:

1. **Respect completed operations.** If client A's title write finishes before client B starts a title read, client B must see that write or a later write in the object's valid history.
2. **Use the actual history.** There are no intervening writes in this example, so the answer must be version 11.

Time	Notebook operation	Required result under linearizability
10:00:00-10:00:01	client A writes title v11 at East	Success at 10:00:01
10:00:02	client B begins reading at West	Return v11; do not return v10
10:00:03	West still lacks v11	Coordinate, route, or fail to complete successfully

Two limits to remember:

1. **Overlapping operations can have either valid order.** A read beginning at 10:00:00.5 can legally return v10 if its conceptual instant precedes the write's instant. "Latest" is ambiguous during overlap; use the operation intervals.
2. **Separate calls do not become one atomic action.** A linearizable title register does not make a read-title/write-title pair atomic. Use conditional updates or transactions to prevent that race.

Do not confuse ordering individual operations with grouping several operations atomically:

Contract	Unit being ordered	What it does not add by itself
Linearizability	One object operation, respecting real time	A separate read-then-write pair is not one atomic operation
Serializability	Whole transactions, equivalent to a serial execution	Real-time order is not required by the definition alone

Contract	Unit being ordered	What it does not add by itself
Strict serializability	Whole transactions, also respecting real time	External API calls are not automatically participants

INTERVIEW CRITICAL

Linearizable reads and writes do not make a transaction

For example, two clients can each read balance 100 and later write 90 through perfectly linearizable register operations. One debit is lost because the application needed an atomic decrement or a transaction. State what each operation is allowed to do when executed alone and which steps must act as one indivisible operation; the storage label does not define the application algorithm.

03 / Sequential consistency: one order preserving each client

INTERVIEW CRITICAL

Sequential consistency does not require real-time order

Sequential consistency requires one total order of operations that preserves each participating process's own order, but does not require the real-time order between different processes. In the previous trace, client B's independent read can return v10 if the explanation places client B's read before client A's write. That explanation violates linearizability because client A's write had already finished in wall-clock time, but can satisfy sequential consistency.

Now let client A write v11 and then read v10, with no other title write. This cannot be explained while preserving client A's own operation order, so it violates sequential consistency too. The distinction is not "some replicas are usually slow"; it is a precise restriction on the histories clients may observe.

A consistent total order can be useful for reasoning, but sequential consistency alone gives client B no wall-clock freshness bound. Application messages outside the modeled interface also need careful treatment: if client A tells client B that the save finished through a separate channel, that real-world expectation is not automatically enforced by a model that only orders notebook operations.

04 / Causal consistency: dependent writes stay ordered

The preceding models ask whether operations fit one common order. **Causal consistency** instead preserves the order of operations that depend on one another, while allowing unrelated writes to be seen in different orders. In a discussion thread, the useful relationship is that a reply depends on the comment its author read.

Rule: A cause precedes its dependent effect. Program order, reading a value and acting on it, and chains of these relationships create causal dependencies.

Trace the dependency:

1. **Create the parent.** Client A writes comment C41, "Train at six."

2. **Observe and reply.** Client B reads C41 and writes C42, "I will be there."
3. **Enforce visibility.** A causal view exposing C42 must include its dependency C41. Otherwise the reply arrives without the information that explains it.

An implementation can attach dependency identifiers to C42 and delay its visibility at West until C41 is available. A timestamp alone does not fetch a missing dependency. The service must track and enforce the relevant relationships, including dependencies carried when a client changes servers.

Two independent comments, C43 from client A and C44 from client B, can be concurrent: neither author saw the other. Causal consistency does not require every reader to see those independent writes in the same order. If concurrent updates change the same title, conflict handling remains necessary. A deterministic winner converges, but may discard an edit; preserving alternatives or merging application operations gives a different product behavior.

Causal visibility describes applied history, not a requirement to display every earlier value forever. A later authorized deletion can replace a parent comment with a tombstone; the replica must still account for the dependency. Nor does causality make a multi-object update atomic: exposing half a transfer requires a transaction or an additional atomic-visibility protocol to prevent it.

05 / Session guarantees: read-your-writes and monotonic reads

A session is the scope over which the service remembers one client's observations. Read-your-writes means client A's later reads incorporate its completed writes. Monotonic reads mean that after it has observed a version, later reads do not retreat to an earlier state along that history. Neither alone requires every other user to see the globally newest value.

One implementation carries a **session token** describing the minimum history the next server must include. A replica's **applied position** records how far it has incorporated that history into readable state. If its position is behind the token, the service waits, routes to a sufficiently current replica, or refuses the read; merely sending the token does not make the replica catch up.

Guarantee	Notebook trace it prevents	Possible mechanism
Read-your-writes	client A saves v11, reloads and sees v10	Carry a minimum applied-position token
Monotonic reads	client A sees client B's v12, then sees v11	Advance its token after reads too
Monotonic writes	client A's second edit is applied before its first	Preserve client A's write order
Writes-follow-reads	client B's reply becomes visible without C41	Record and enforce the read dependency

The diagram follows a single ordered title history, where one number can identify how far the replica has applied that history. Multiple independently written objects may need a richer dependency representation. Pinning client A to East is simple but failover breaks the guarantee unless the new replica catches up or the request waits. A token must represent a real storage guarantee, not an arbitrary browser counter.

06 / Eventual consistency and bounded staleness

Eventual consistency promises convergence once updates stop and the system can exchange the necessary information under its recovery assumptions. East and West may temporarily disagree about N7. This does not promise that every replica converges within two seconds, nor does it by itself prevent client A from seeing v11 and then v10.

Bounded staleness adds a limit

INTERVIEW CRITICAL

A cache TTL does not prove bounded staleness

Bounded staleness sets a maximum lag in time or versions. Define exactly how that lag is measured. If West cannot meet the limit, wait, route to another replica or report unavailability. A five-second cache TTL is insufficient if the cache fetched a value that was already old: the value's total age includes both delays.

These choices are not one universal ranking. Session guarantees concern a client's continuity, causal consistency concerns dependencies, and a staleness bound concerns distance from a defined reference. State which promises are combined. For notebook search results we may tolerate delayed convergence, while the edit screen combines read-your-writes with monotonic reads. Both can coexist with a stricter ownership service.

Convergence is a promise about the eventual result; an implementation still needs a rule for reconciling updates accepted independently. Some data types can merge both contributions, while other designs choose one winning value and discard the alternative. CRDTs and last-write-wins illustrate these different conflict-handling choices.

CRDT: merge the same state without double counting

Conflict-free replicated data types (CRDTs) use defined update/merge rules so replicas that receive the same updates converge. For a state-based grow-only counter:

1. **Keep local components.** Each replica increments only its own counter entry. In the pair (A-count, B-count), A changes the first entry and B changes the second.
2. **Merge by maximum.** Take the maximum per component: A=(2,0) and B=(0,3) merge to (2,3).
3. **Read by addition.** Sum the components: 2 + 3 = 5. Repeating the merge does not count the increments twice.

For state-based CRDTs, merge must be **associative** (grouping merges differently gives the same result), **commutative** (merging A with B gives the same result as B with A), and **idempotent** (merging the same state again changes nothing). Updates must also obey the type's rules. Operation-based variants have their own delivery requirements.

Last-write-wins chooses a winner

INTERVIEW CRITICAL

Convergence does not preserve every business rule

Last-write-wins selects the value with the largest ordered timestamp and deterministic tie-breaker. It converges but can discard an update; clock order need not equal real-time order. A CRDT's convergence does not establish linearizability or enforce an arbitrary rule such as one remaining seat. Choose merge semantics that fit the product, and account for metadata and deletion history.

Interview check: Does a converged counter prove inventory was never oversold? No. Convergence of replicas and preservation of a business invariant are separate properties.

07 / Consistency-model comparison and failure behavior

Model	What it requires in this example	Useful when	Limit or cost
Linearizable	client B's read after the save cannot return v10	Current ownership or conditional updates	Coordination or refusal when current authority is unreachable
Sequential	All operations fit one order preserving each client's order	A shared logical order is sufficient	Independent clients get no real-time freshness bound
Causal	Reply C42 cannot appear without parent C41	Comments and dependent updates	Independent writes may have different orders
Session guarantees	a session does not fall behind its saved or already observed state	An editing session moves between replicas	Other users can still see older state
Eventual	Replicas converge after updates stop and communication recovers	Delayed search or derived views	No deadline or read-your-writes guarantee by itself
Bounded staleness	Every answer meets a specified time/version lag	Reads can tolerate a measured amount of old data	Wait, route, or fail when the bound cannot be met

For this hypothetical notebook, I choose session guarantees for the editing screen and causal visibility for threaded comments. These preserve understandable interaction without requiring every read to coordinate across regions. I use an authoritative, ordered ownership update and authorization path because a revoked collaborator must not gain access through a stale permissive replica. The security contract must explicitly address cached permissions and already-issued access, too.

Suppose East fails after client A receives token 11, while West has only version 10. The interface may keep the submitted text and show "reconnecting"; it must not present West's older result as the saved current version. Wait for a replica that includes token 11 or return a retryable failure. If the storage policy allowed version 11 to

be lost, routing cannot recover it. Consistency controls what reads may show; durability controls what saved data survives.

In an interview I would say: "I will define consistency per operation. A session's reload must include its acknowledged save; replies require their parent; ownership checks use authoritative state. I will show the token or dependency mechanism, and I will specify what the service does when no reachable replica meets that promise."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is a consistency model? Explain it using a write of version 11 followed by a read.

Model answer

A consistency model defines the read results and operation orders a system allows. If client A completes a write of version 11 and client B then reads, linearizability forbids the old version 10 when no other write intervened. Eventual consistency may temporarily allow version 10. The choice describes a visible contract, not whether the title text is factually correct.

Interviewer follow-up

What must you clarify when an interviewer asks for strong consistency?

I ask which operation and scope need the guarantee. A title read after a completed save suggests linearizability for that object. Updating title and ownership together also requires a transaction contract. I describe one forbidden history before selecting a database.

What the answer must demonstrate: Define permitted observations and the object or transaction scope.

02 / FOUNDATION

An interviewer says "the system must be consistent." Which meaning should you clarify?

Model answer

I ask whether the requirement concerns read visibility or a business invariant. For CAP consistency, a write that completes before a read starts must be visible to that read, or superseded by a newer write. More generally, I name the required consistency model, such as linearizable or causal. ACID consistency means transactions preserve rules such as nonnegative stock. I would state the operation and show a concrete forbidden result.

Interviewer follow-up

If a replica is behind, does that automatically violate linearizability?

No. The service may route a read to an authoritative copy or wait until it can satisfy the guarantee. A stale successful read after a completed write violates linearizability when no later write explains it; a lagging physical copy alone does not. Refusing or indefinitely waiting for an affected operation sacrifices CAP availability.

What the answer must demonstrate: Connect the familiar current-value explanation to the formal model, and keep ACID validity separate.

03 / APPLIED

A write from v10 to v11 overlaps a read on another client. Must a linearizable read return v11?

Model answer

"Not necessarily. Under linearizability the read may take effect before or after the concurrent write. I would inspect invocation and response intervals; a read beginning after the write completed is the clearer test."

Interviewer follow-up

Can the server always return the old value while calling every write concurrent?

"No. The recorded operation intervals constrain that explanation, and completed earlier writes must be respected."

What the answer must demonstrate: Do not replace the definition with a vague latest-value rule.

04 / FOUNDATION

Give a history allowed by sequential consistency but not linearizability.

Model answer

"Client A completes writing v11, then an independent client B starts a read and gets v10. With no other operations, a total order can put client B's read first, preserving each client's order. Real-time completion forbids that placement under linearizability."

Interviewer follow-up

What if the writer performs that later read in the same session?

"With no intervening writer, returning v10 would violate its own write-then-read order, so that history is not sequentially consistent either."

What the answer must demonstrate: Keep process order separate from wall-clock order.

05 / APPLIED

How do you stop replies appearing before their comments?

Model answer

"I attach the parent or a sufficient dependency context to client B's reply. A replica cannot expose the reply until it can expose that history. That is a visibility rule, not just sorting by arrival timestamp."

Interviewer follow-up

Must two unrelated comments have the same order everywhere?

"Causal consistency does not require that. If the product needs one conversation sequence, I add an ordering mechanism and accept its cost."

What the answer must demonstrate: Dependencies do not imply a total order for independent writes.

06 / APPLIED

How can a session preserve read-your-writes when failing over from a replica at v11 to one at v10?

Model answer

"The save response carries a storage position or version context. The next server must prove it has applied that context before answering. If it cannot, it routes or waits; silently returning v10 violates the session promise."

Interviewer follow-up

Is sticky routing enough?

"It helps during normal operation, but cannot preserve the promise when the pinned server fails and the replacement is behind."

What the answer must demonstrate: Describe failover as well as the normal request path.

07 / FOLLOW-UP

Does a five-second TTL guarantee data no older than five seconds?

Model answer

"Only under additional assumptions. If a cache fills from a replica already thirty seconds behind, a fresh cache entry is still stale. I need an authoritative reference, propagation limits, and behavior when the bound cannot be met."

Interviewer follow-up

What would you measure?

"I would measure source-version age or replication lag along the entire read path, with clock assumptions made explicit for time-based bounds."

What the answer must demonstrate: Cache age and source age differ.

08 / FOLLOW-UP

Does causal consistency merge concurrent title edits?

Model answer

"No. It tells us which edits depend on which earlier edits. Independent edits still need a conflict policy, such as preserving both versions for the user or a domain-specific merge. A last-writer rule chooses a winner but can lose intent."

Interviewer follow-up

Would a timestamp winner always identify the last human edit?

"No. Clock error and concurrent work make that claim unsafe; a timestamp can define an arbitration rule without representing human intent."

What the answer must demonstrate: Separate causal ordering, convergence, and application semantics.

09 / APPLIED

Why not require linearizability for every read in a collaborative application?

Model answer

"It may be acceptable, especially at modest scale, but I would compare the added coordination latency and the operations that may become unavailable with what the product requires. The editing session and comment dependencies can often have clear weaker contracts, while ownership still needs stricter enforcement."

Interviewer follow-up

What must you avoid when mixing guarantees?

"I must prevent a weaker cache or replica path from serving an operation whose security or correctness contract is stronger."

What the answer must demonstrate: Make the choice per operation, not per marketing category.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Specify three consistency contracts: a session must read its acknowledged writes, a reply must not appear without its parent, and an ownership read must reflect completed changes. Give an allowed and forbidden history, then explain routing, dependencies, and failure behavior for each.

- Name each operation's object and required guarantee.
- Draw one allowed and one forbidden history.
- Explain replica routing or dependency enforcement.
- Describe behavior when no reachable replica satisfies the requested guarantee.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Do CAP consistency, a consistency model and ACID consistency mean the same thing?

No. CAP consistency is linearizability: later reads see a completed write or a newer write. A consistency model defines the allowed visibility and ordering, including weaker models. ACID consistency means correct transactions preserve database and application rules.

CAP: current value. Model: allowed observations. ACID: valid state.

Does read-your-writes make all readers current?

No. It preserves the writer's session promise; client B may still see an older replica unless that reader's contract requires more.

My save -> my view

What distinguishes linearizable from sequential?

Both admit an ordered explanation, but linearizability also preserves real-time order of non-overlapping operations.

Linearizability also respects completed-before-started order.

Does eventual mean within a deadline?

No. A deadline needs a separately defined and enforced staleness bound.

Eventually has no stopwatch

What must accompany a dependent reply?

The causal history it depends on must already be visible in the reader's view.

Cause before consequence

Summary and interview notes

For each operation, specify which read results and orderings are allowed. Enforce those rules through replicas, caches and failover. When no reachable replica can answer correctly, wait or refuse instead of returning a forbidden result.

Remember these points

• CAP consistency is linearizability; a consistency model is the broader visibility/ordering contract; ACID consistency preserves database and application rules.

• Linearizability preserves real-time order of non-overlapping object operations; sequential consistency preserves each process's order without that cross-process time constraint.

• Causal order preserves dependencies but does not impose one order on independent writes or make several writes atomic.

• Read-your-writes and monotonic reads require session context that survives routing changes.

• Eventual consistency has no freshness deadline; a bounded-staleness contract needs an explicit reference and failure behavior.

Interview tips

• When an interviewer says consistency, name the meaning before choosing a guarantee. Then give one allowed result and one forbidden result.

• Draw invocation and response intervals for one allowed and one forbidden history.

• Ask whether the requirement applies to an object operation, a session, or a multi-object transaction.

• Show the cache and failover paths, since a weaker alternate path can break a stronger API promise.

Important qualifications

• A scalar session token works for one ordered history; independent objects can require dependency vectors or equivalent context.

• Consistency does not recover a write lost under an inadequate durability policy.

Technical references

Herlihy and Wing: Linearizability
Primary definition of operations taking effect between invocation and response.
https://cs.brown.edu/~mph/HerlihyW90/p463-herlihy.pdf

Lamport: How to Make a Multiprocessor Computer That Correctly Executes Multiprocess Programs
Primary definition of sequential consistency and preservation of each process's order.
https://lamport.azurewebsites.net/pubs/multi.pdf

Lloyd et al.: COPS
Primary research on tracking dependencies and causal visibility across replicated data.
https://www.cs.princeton.edu/~wlloyd/papers/cops-sosp11.pdf

Terry et al.: Session Guarantees for Weakly Consistent Replicated Data
Primary reference for the four session guarantees. All notebook traces here are constructed examples.
https://ieeexplore.ieee.org/document/331722/

Preguiça, Baquero and Shapiro: Conflict-free Replicated Data Types
Primary explanation of CRDT semantics, synchronization requirements and limitations. The two-component counter is a teaching calculation.
https://arxiv.org/html/1805.06358v1

Gilbert and Lynch: formal CAP definitions
CAP consistency is atomic/linearizable consistency. The completed-write/later-read rule is a consequence; it is distinct from ACID rule preservation.
https://www.cs.princeton.edu/courses/archive/spr22/cos418/papers/cap.pdf

FOUNDATIONS / 16

Transaction isolation

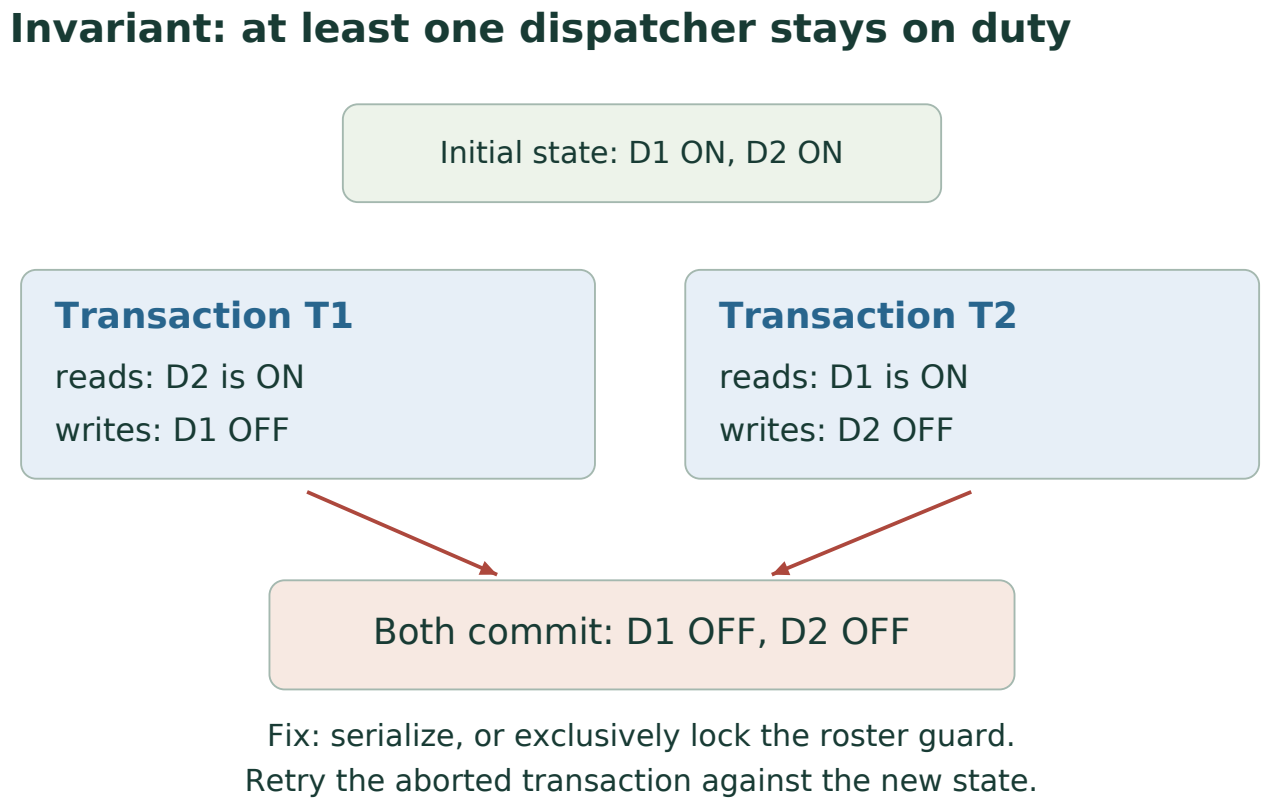
DEFINITION

Transaction isolation defines how concurrent database transactions may observe and affect one another. A transaction groups operations into a unit that commits or aborts; its isolation level determines which interfering executions are permitted.

Why it matters: Two individually valid requests can make incompatible decisions from the same old data, even inside one database server.

Snapshot isolation and the write-skew anomaly

Both transactions see another dispatcher on duty and update different rows. Snapshot isolation can permit both commits.



Different rows can still participate in one cross-row invariant.

Worked example

Rows D1 and D2 are on duty. Concurrent T1 and T2 each read count 2, then disable D1 and D2 respectively. Both committing leaves count 0, violating count >= 1.

Key takeaways

• Atomicity groups changes; isolation governs concurrent decisions.

• A stable snapshot can still permit write skew across different rows.

• Serializable execution or a correctly acquired shared guard can protect the roster rule.

Read the visual model

1. Initially dispatchers D1 and D2 are both on duty. The invariant requires at least one dispatcher to remain on duty.

2. Transaction T1 reads D2 on duty and turns D1 off. Concurrent transaction T2 reads D1 on duty and turns D2 off.

3. They update different rows, so ordinary write-write conflict checks need not stop both.

4. Serializable execution or an exclusively locked common guard row prevents the forbidden combined outcome.

transactions • isolation • MVCC • write skew • serializability

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Explain isolation anomalies with specific concurrent reads and writes.

• Choose an atomic update, shared lock, or serializable transaction for a stated invariant.

• Design safe full-transaction retries without duplicating external effects.

Useful foundations: Databases, data models, and ACID transactions; Consistency models

8 interview questions with model answers and answered follow-ups.

01 / Transaction isolation: definition and example

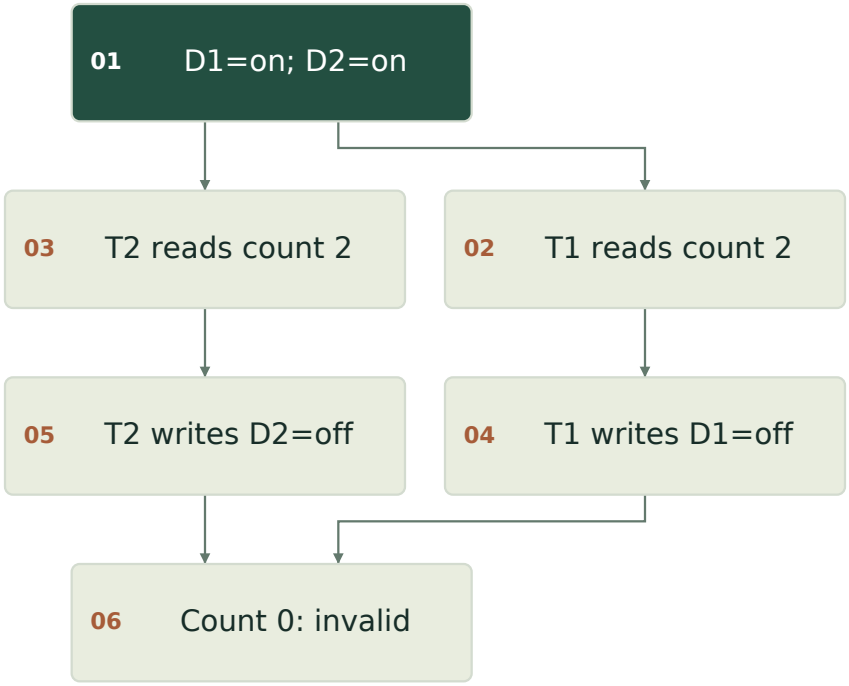
Transaction isolation defines how concurrent database transactions may observe and affect one another. A transaction groups operations into one unit: committing accepts its changes, while aborting discards them. Atomicity provides that all-or-nothing grouping; isolation determines which interfering executions are allowed. Atomicity alone does not keep an earlier decision valid while someone else changes the database.

A cross-row constraint exposes the difference between atomicity and isolation. Roster R7 contains rows D1 and D2, both `on_duty = true`, with the invariant `count(on_duty) >= 1`. Transaction T1 attempts to disable D1; T2 attempts to disable D2. Each procedure reads the count and proceeds only when it exceeds one. The following hypothetical interleavings test whether the isolation mechanism preserves the constraint.

One server does not solve this problem automatically. A database on one machine still runs concurrent transactions; two browser requests can read before either has written. "We use SQL" and "we put it in a transaction" are incomplete answers until we know the isolation level, statements, constraints, and retry behavior. Begin with the invariant - the condition that every committed state must preserve - then examine whether concurrent executions can break it.

WORKED EXAMPLE DIAGRAM

Write skew: two individually reasonable updates to different rows jointly violate the roster's cross-row rule.



1 -> 2	T1 snapshot: D1=on; D2=on -> T1 reads count 2
1 -> 3	T2 snapshot: D1=on; D2=on -> T2 reads count 2
2 -> 4	different row: T1 reads count 2 -> T1 writes D1=off
3 -> 5	different row: T2 reads count 2 -> T2 writes D2=off
4 -> 6	both commit: T1 writes D1=off -> Count 0: invalid
5 -> 6	both commit: T2 writes D2=off -> Count 0: invalid

02 / Read anomalies: dirty, nonrepeatable, and phantom reads

A **read anomaly** is a named observation that a stronger isolation level rules out. The names below distinguish seeing uncommitted data, seeing a previously read row change, and seeing the set of matching rows change. These cases let us compare what concurrent transactions may observe before considering the roster's write rule.

A **dirty read** observes another transaction's uncommitted work. T2 tentatively changes D2 to off-duty; T1 reads that value; T2 then aborts. T1 has used a state that never committed. Read Committed prevents that anomaly, but does not necessarily give every statement in a transaction the same snapshot.

Anomaly	Concurrent operations	What changes
Dirty read	T1 reads D2=off written by uncommitted T2; T2 aborts	Uncommitted value leaks
Nonrepeatable read	T1 reads D2=on; T2 commits D2=off; T1 reads D2=off	Same row differs
Phantom read	T1 counts 2 on-duty rows; T3 inserts D3=on; T1 counts 3	Predicate result gains a row

A predicate is the condition selecting a set, such as `roster_id = R7 AND on_duty = true`. Locking only the rows currently returned does not generally protect every future row matching that condition. Database engines differ in their predicate or range protection. Recognize the exact set-level race before assuming that a row lock covers it.

The familiar four SQL isolation names are minimum contracts, not identical implementations:

SQL isolation level	Dirty reads	Nonrepeatable reads	Phantoms	Serialization anomalies
Read Uncommitted	Permitted by the standard	Possible	Possible	Possible
Read Committed	Prevented	Possible	Possible	Possible
Repeatable Read	Prevented	Prevented	Permitted by the standard	Possible
Serializable	Prevented	Prevented	Prevented	Prevented

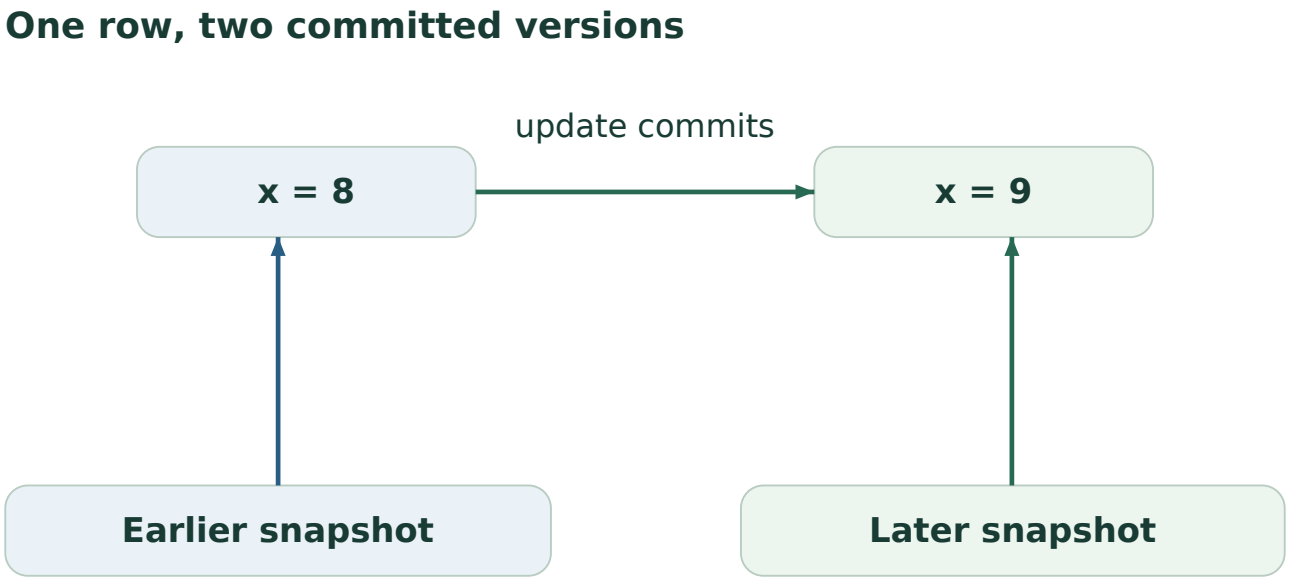
PostgreSQL maps Read Uncommitted to Read Committed and its Repeatable Read also prevents phantoms. That stronger snapshot guarantee still permits the write-skew schedule below. Treat a database's tested behavior and documentation as the implementation contract.

03 / MVCC, statement snapshots, and transaction snapshots

A **snapshot** determines which row versions a query or transaction can see. It provides a defined view of the data while other transactions may be changing it. Multi-version concurrency control, abbreviated MVCC, retains row versions so readers can use such a view while other transactions make progress. Versions cost storage and cleanup work; long-running readers can delay reclamation.

Two readers can see different versions of one row

The arrows show which committed version each snapshot can see. Snapshot timing depends on the database and isolation level.



The earlier snapshot can still read 8 after version 9 commits.

Keep old versions while a required snapshot can still see them.

Remember: A new physical version does not erase an older reader's snapshot.

Try from memory: Does reading 8 prove that version 9 failed to commit?

Answer: No. Version 9 can be committed but outside the reader's earlier snapshot.

In PostgreSQL's Read Committed mode, an ordinary query uses a fresh statement snapshot. Two queries in T1 can therefore observe different committed roster states. PostgreSQL Repeatable Read uses a stable transaction snapshot and also prevents the phantom-read phenomenon shown above, although the SQL standard's minimum Repeatable Read guarantees are weaker. Always name the implementation when discussing that detail.

INTERVIEW CRITICAL

A stable snapshot can still permit write skew

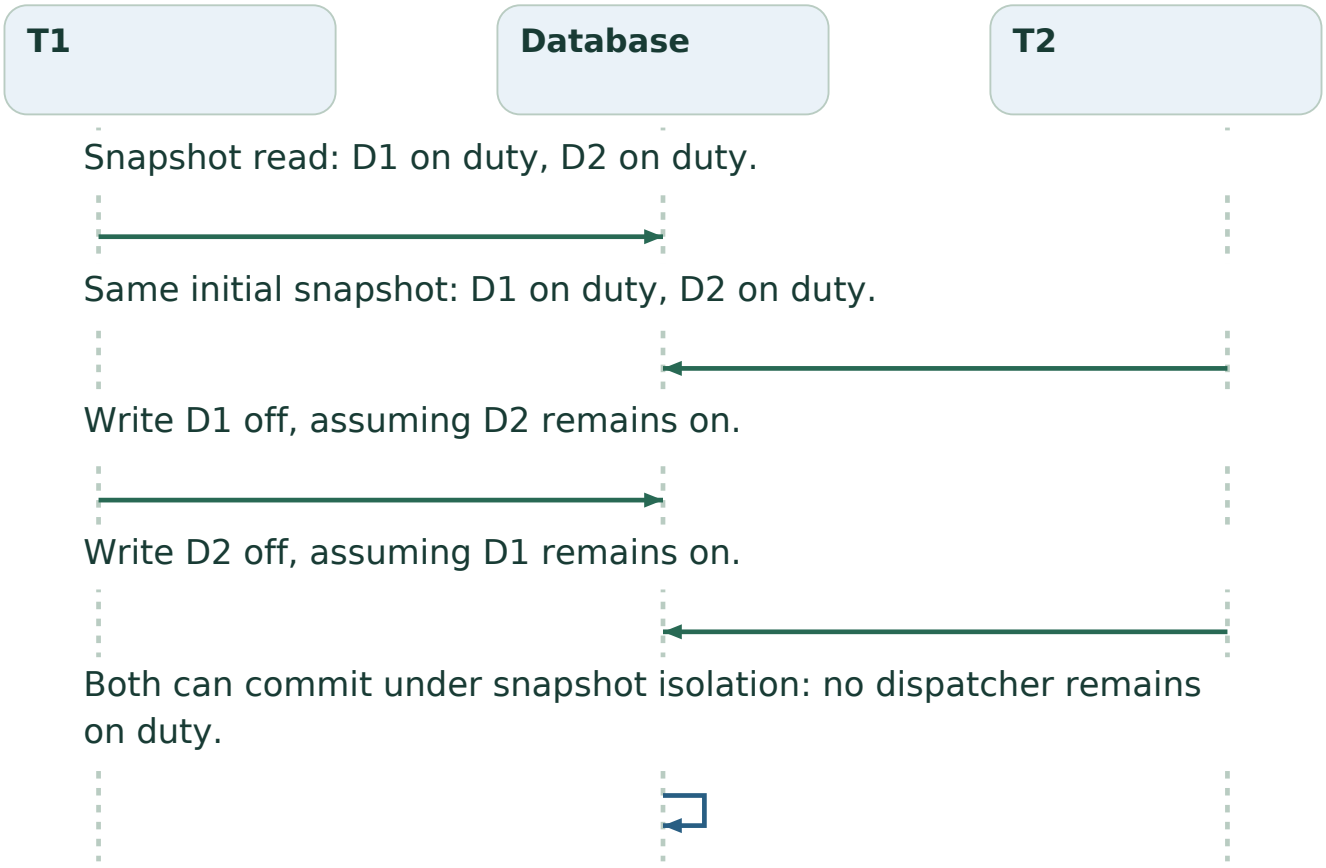
A stable picture can still be old when T1 commits. Snapshot isolation typically detects competing writes to the same item, but transactions writing different items can make incompatible decisions from the same old picture. Snapshot stability is valuable for reports; it is not proof that a multi-row business rule survives concurrent updates. We must run the actual roster trace rather than infer safety from the isolation level's reassuring name.

04 / Write skew versus lost updates

Write skew occurs when transactions read overlapping state but update different items, allowing their combined effects to violate a constraint. In the roster example, T1 and T2 both evaluate the same initial count of two and update different rows.

Write skew: disjoint writes can break one rule

T1 and T2 update different dispatcher rows but share the rule that someone must remain on duty. Snapshot isolation alone may permit this write skew.



Remember: Different rows can still share one invariant.

Step	T1	T2
1	Reads D1=on, D2=on; count=2	Reads D1=on, D2=on; count=2
2	Decides leaving is allowed	Decides leaving is allowed
3	Writes D1=off	Writes D2=off
4	Commits	Commits
Result	No dispatcher remains	Invariant broken

This outcome has no valid serial explanation. If T1 completed first, T2 would read only D2 as on-duty and refuse to disable it. Reversing the order gives the symmetric result. Because the writes affect different rows, detecting only same-row write conflicts is insufficient.

Compare a lost update within this same roster service. Two requests read R7's revision as 8 and both later assign 9; one logical increment disappears. An atomic `revision = revision + 1` or a conditional version check addresses that counter race. Fixing it does not automatically fix the cross-row on-duty rule.

05 / Serializable isolation, conditional updates, and guard locks

Serializable isolation promises that committed transactions have the same effect as some serial execution. It need not literally execute them one at a time. Implementations may block conflicts, detect them and abort work, or combine techniques. This is a transaction-order promise; strict serializability additionally respects real-time order of non-overlapping transactions.



INTERVIEW CRITICAL

Every invariant-changing operation must follow the chosen protocol

For R7, one option is to run every roster-changing transaction serializably and retry aborted attempts. Another is to lock a stable **guard row** representing R7 before reading and changing the on-duty set. This is an ordinary row used as a shared lock target, so roster-changing transactions must take turns holding its lock. All operations that could invalidate the rule - including deleting a dispatcher or moving one to another roster - must follow the same protocol. An uncoordinated maintenance script can bypass an application-only rule.

Approach	Good fit	Price for this roster
Conditional single-row update	Invariant truly fits one authoritative row	Data model may need an aggregate
Exclusive lock on a common guard row	Small, known conflict domain	R7 changes wait behind each other
Serializable transaction	Richer reads and evolving invariants	Detect conflicts and retry whole work

I choose a guard row for this small, frequently reviewed roster workflow. It makes the serialization point explicit: every transaction changing R7 must acquire the lock on the same row. I would revisit that choice if the operation grows into many independent rosters or complex predicates.

Isolation levels describe allowed outcomes; concurrency-control techniques determine how the database prevents disallowed ones. An optimistic approach performs work and validates that relevant state has not changed before accepting the update. A pessimistic approach acquires protection first. Compare-and-set is one atomic conditional-update mechanism that can support such validation.

Name the concurrency technique as well as its implementation:

Technique	Mechanism	Choose when	Cost or trap
Optimistic concurrency control	Read a version; accept the write only if the version still matches	Conflicts are uncommon and retries are cheap	A failed condition requires reread/recompute; every relevant writer must advance the version
Compare-and-set	Atomically change a value only if it equals the expected value or version	One atomic object contains the invariant	Comparing a reused value can miss an intervening change; an ever-increasing version avoids this **ABA problem**, where a value changes from A to B and back to A between the original read and the comparison
Pessimistic locking	Acquire a lock before the protected read and hold it through commit	Contention is expected or the read/modify sequence must be serialized	Waits, deadlocks, and long transactions; use a consistent lock order and bounded work

For example, `UPDATE item SET value = :new, version = version + 1 WHERE id = :id AND version = :seen` succeeds only when the affected-row count is one. A zero-row result means conflict or absence, not permission to overwrite anyway. This protects that row's change; it does not automatically protect a rule spanning other rows.

06 / Serialization retries and external side effects



INTERVIEW CRITICAL

Acquire the guard before making the protected decision

A shared guard serializes the decision. T1 locks the R7 guard, reads count 2, marks D1 off, commits, and releases the lock. T2 then acquires the guard and must read a view containing T1's committed change before deciding. Under Read Committed, acquire the guard before a subsequent count query; T2 sees count 1 and refuses to disable D2. Acquiring a lock after reading an old snapshot does not refresh the earlier decision.



INTERVIEW CRITICAL

Retry the transaction, including its decision

Serializable execution can instead abort T2 on a conflicting schedule. The application starts a new transaction and reruns its reads, validation, and writes. Retrying only the final update preserves the stale decision and can violate the constraint. Bound retry attempts and use randomized delay; persistent contention needs an explicit refusal or queueing policy.

A transaction may abort and rerun, so do not send "you are off duty" inside it. Save a pending notification in an outbox in the same transaction as the roster change. Send it afterward with duplicate protection. If the commit reply is lost, reuse an operation ID so a retry can find the saved result.

A concrete PostgreSQL Read Committed implementation uses separate statements inside one transaction:

```
BEGIN ISOLATION LEVEL READ COMMITTED;
SELECT roster_id FROM roster_guard
WHERE roster_id = 'R7' FOR UPDATE;
-- Require exactly one existing guard row; otherwise abort.
SELECT count(*) FROM dispatcher
WHERE roster_id = 'R7' AND on_duty;
-- If count > 1 and D1 is currently on duty in R7:
UPDATE dispatcher SET on_duty = false
WHERE roster_id = 'R7' AND dispatcher_id = 'D1' AND on_duty;
-- Check the affected-row count; record outcome and outbox intent here.
COMMIT;
```

The application branches on the count; the comments are required control flow, not executable enforcement. Keep the guard held until commit. A missing guard row acquires no row lock, so create it as part of roster creation and reject missing guards. Do not combine lock acquisition and the protected count into one statement whose snapshot may predate a lock wait. This protocol also requires deletes and transfers to acquire the same guard before their decisions.

07 / Interview explanation: invariant, mechanism, and contention

A strong interview explanation begins: "The invariant is at least one on-duty dispatcher per roster. Two concurrent leave transactions can each read two and update separate rows, so atomicity and snapshot isolation alone are insufficient. I will have each transaction lock the R7 guard row before reading the current count, and require every membership change to obey that protocol."

Then describe operational cost. A slow transaction holding the guard blocks other R7 changes, so no user interaction or remote API call belongs inside it. Transactions acquiring several roster guards should use a consistent order to reduce deadlocks; the system must still handle deadlock aborts. Measure lock wait time, transaction duration, abort rate, and retries per completed request.

Test the two requests together: run T1 and T2 concurrently and check that exactly one doctor goes off duty. Then drop the response after commit and retry with the same operation ID; the retry should find the saved result. Check waiting and retry limits too.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is transaction isolation, and why is it different from atomicity?

Model answer

Atomicity makes a transaction's changes commit together or abort together. Isolation controls how concurrent transactions observe and interfere with one another. In the roster example, two atomic leave requests can both read 2 and update different rows, leaving 0 on duty under snapshot isolation. The database needs a concurrency rule that protects the shared business condition.

Interviewer follow-up

Would storing both rows on one database server remove the concurrency race?

No. One database server can execute concurrent transactions. I still need an appropriate isolation level, a constraint, or a shared guard acquired before the decision's read.

What the answer must demonstrate: Separate all-or-nothing changes from safe concurrent decisions.

02 / FOUNDATION

Explain nonrepeatable and phantom reads without jargon.

Model answer

"A nonrepeatable read occurs when transaction T1 reads row D2 twice and observes different committed values because another transaction changed it. A phantom occurs when T1 repeats a predicate query, such as all on-duty rows, and sees a new or missing matching row. The first concerns an existing row's value; the second concerns membership in a result set."

Interviewer follow-up

Does locking the rows currently matching a query prevent a new matching row from being inserted?

"Not generally. Protecting the queried set may require predicate or range protection, or an agreed guard row."

What the answer must demonstrate: Use one row versus a matching set.

03 / APPLIED

Does Repeatable Read prevent phantoms?

Model answer

"I would ask which database. The SQL standard's minimum guarantees allow that phenomenon, while PostgreSQL Repeatable Read uses a stable snapshot and prevents it. Neither statement means PostgreSQL Repeatable Read prevents our write-skew example."

Interviewer follow-up

Why can a stable snapshot still be dangerous?

"Two transactions can make incompatible decisions from it and write different rows without a same-row conflict."

What the answer must demonstrate: Do not generalize product behavior from the level name.

04 / APPLIED

Two transactions read revision 8 and both assign 9. How do you prevent this lost increment?

Model answer

"I use an atomic increment or a compare-and-update against the expected revision, checking whether it succeeded. Reading 8 in application code and later assigning 9 in both requests loses one increment."

Interviewer follow-up

Does fixing a revision counter automatically protect a separate multi-row count constraint?

"Only if the revised protocol actually uses the shared row to serialize or validate the entire decision. A separate counter fix alone does not."

What the answer must demonstrate: A local race fix must cover the business decision to enforce it.

05 / APPLIED

To protect count(on_duty) >= 1 using a shared guard row, when must the guard be locked relative to reading the count?

Model answer

"Before reading the state used to decide whether someone may leave. I use a transaction pattern whose post-lock query observes the previous holder's committed result; with Read Committed, a subsequent query gets a fresh statement snapshot."

Interviewer follow-up

What if the transaction already read its snapshot before waiting?

"I cannot assume acquiring a lock refreshes that earlier snapshot. I must restart or use an isolation-specific safe pattern."

What the answer must demonstrate: Lock timing and snapshot timing must agree.

06 / FOLLOW-UP

T2 receives a serialization failure. What does the application do?

Model answer

"Abort the failed attempt and retry the complete transaction: reads, validation, and writes. If another transaction reduced the on-duty count to one, the new execution must reject the off-duty transition. Retrying only the final write reuses an invalid decision."

Interviewer follow-up

Why not resend only the UPDATE?

"That repeats the write while discarding the validation the transaction was supposed to protect."

What the answer must demonstrate: Retries must recompute the decision.

07 / FOLLOW-UP

How do you emit an off-duty notification only for a committed transition when its transaction may abort and retry?

Model answer

"I record the notification intent atomically with the successful roster transaction. A separate worker sends it using a stable event identifier. The retried transaction body must not perform irreversible external work."

Interviewer follow-up

What happens if the worker sends the message and crashes before acknowledging?

"Delivery may repeat, so the receiver or publication mechanism needs deduplication where required. The outbox closes the database-to-event gap, not every downstream effect."

What the answer must demonstrate: Explain which database changes commit together and which later message delivery still needs deduplication.

08 / APPLIED

What operational costs should you measure for a guard row that serializes all changes to one roster?

Model answer

"I measure wait time, transaction length and contention by roster. A long-held guard is a latency bottleneck even if CPU looks idle. I keep the protected work short and test simultaneous leave, deletion and transfer operations."

Interviewer follow-up

When would you change the design?

"If one roster becomes a hot coordination point or workflows span many rosters, I would revisit the invariant's ownership and transaction scope instead of simply increasing connection count."

What the answer must demonstrate: More concurrency can worsen a serialized bottleneck.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Protect count(on_duty) >= 1 for roster R7. Show T1 and T2 reading count 2 and disabling different rows, then compare a shared guard and serializable execution with full-transaction retries.

- State the cross-row invariant and all operations that can affect it.
- Draw reads, writes, and commits for the bad execution.
- Explain exactly where conflicting operations are detected or serialized.
- Keep notifications outside retried transaction bodies using an outbox.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Why can two valid snapshot transactions create an invalid roster?

They read the same old set and write different rows, so their combined effect may have no valid serial explanation.

Stable picture != safe decision

What must be retried after a serialization failure?

The entire transaction, including the reads and decision that produced its writes.

Reread, rethink, rewrite

What does a guard row protect?

Only operations that acquire it under the agreed protocol before making protected decisions.

All doors use the same lock

Are serializable and linearizable identical?

No. Serializability orders transactions by equivalent effects; strict serializability also enforces real-time order.

Serial is order; strict adds time

Summary and interview notes

Isolation governs concurrent decisions; atomicity only makes one transaction's changes succeed or fail together. Protect the actual invariant with an appropriate database constraint, a correctly acquired guard, or serializable execution with whole-transaction retries.

Remember these points

- A stable snapshot can permit write skew when transactions read shared state and update different rows.
- Lock the guard before the decision and use a read view that includes the previous holder's committed work.
- Every operation that can break the invariant must obey the same concurrency protocol.
- After a serialization failure or deadlock, retry the whole transaction. Save pending external actions so they can run safely after commit.

Interview tips

- Write the invariant as a predicate and demonstrate an interleaving that violates it.
- Name the database and isolation level before claiming which anomalies are prevented.
- Explain lock wait, deadlock handling and the retry limit alongside the successful transaction.

Important qualifications

• PostgreSQL Repeatable Read prevents phantoms but is not serializable; its documented behavior exceeds the SQL minimum for that level.

• SELECT FOR UPDATE cannot lock an absent guard row; the guard must exist and remain protected for the transaction.

Technical references

PostgreSQL: Transaction Isolation
Verified product-specific behavior: Read Committed snapshots, Repeatable Read snapshot isolation, and Serializable retries.
https://www.postgresql.org/docs/current/transaction-iso.html

PostgreSQL: Explicit Locking
Reference for row locks and deadlock handling; the shared-guard-row design is a constructed example.
https://www.postgresql.org/docs/current/explicit-locking.html

Berenson et al.: A Critique of ANSI SQL Isolation Levels
Primary treatment of snapshot isolation and anomalies beyond the basic dirty/nonrepeatable/phantom vocabulary.
https://www.microsoft.com/en-us/research/wp-content/uploads/2016/02/tr-95-51.pdf

FOUNDATIONS / 17

Quorums, consensus, leases, and fencing

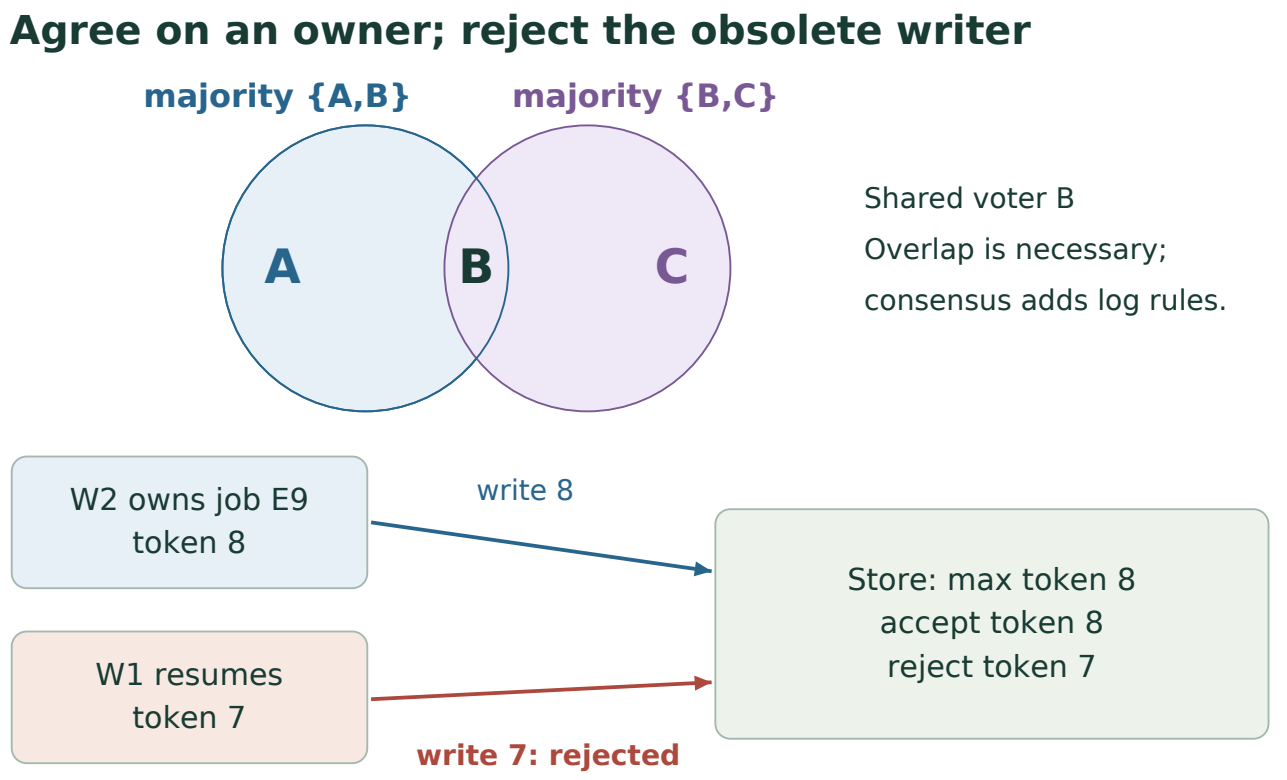
DEFINITION

A quorum is a protocol-defined set of participants whose votes or replies are sufficient for an operation to proceed, often a majority. Consensus is a protocol for agreeing on a value or ordered history despite specified failures. A lease grants time-limited authority; fencing makes the protected resource reject obsolete authority.

Why it matters: A replacement leader or worker must be able to take over without letting an isolated or paused old owner corrupt the result. Counting responses, agreeing on ownership, and enforcing ownership are separate jobs.

Quorum intersection and stale-writer fencing

A majority intersects every other majority. The resource must still reject a stale worker token.



The store must check the token atomically with the write.

Worked example

Of three controllers, two agree to replace worker W1 (epoch 7) with W2 (epoch 8). W2 publishes with token 8. When W1 resumes and presents token 7, the output store rejects the stale write.

Key takeaways

• R + W > N proves read/write set overlap, not linearizability by itself.

• Consensus establishes committed authority; a lease expiring cannot stop a paused process from resuming.

• A fencing check must be atomic with the protected write at the resource.

Read the visual model

1. With three voters, majorities {A,B} and {B,C} share B. Consensus uses rules beyond this overlap to agree on a log.

2. Worker W1 once held fencing token 7. W2 takes over with token 8.

3. The protected store remembers 8 and rejects W1 with token 7 even if W1 wakes after its lease expired.

4. An expired lease alone cannot stop code already running on a paused machine.

quorum • consensus • Raft • lease • fencing

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Calculate quorum overlap and explain what it does not prove.

• Describe how an agreed log preserves one ownership history.

• Show why a resource must reject obsolete ownership even after a lease expires.

Useful foundations: Replication and durability; CAP theorem: consistency, availability, and partition tolerance

8 interview questions with model answers and answered follow-ups.

01 / What are quorum, consensus, lease, and fencing?

A service that replaces failed workers has two problems: agree which worker is now authorized, and prevent a previous worker from publishing afterward. The following mechanisms handle different parts of that handover.

Keep four definitions separate:

1. **Quorum:** a protocol-defined set of participants whose votes or replies are sufficient for an operation to proceed, often a majority.
2. **Consensus:** agreement on a decision or ordered history despite failures within the protocol's model.
3. **Lease:** permission that expires after a defined time.
4. **Fencing token:** a monotonically increasing ownership number checked by the protected resource to reject outdated writers.

These are not four names for a distributed lock. Quorum rules can require read and write groups to share a replica. Consensus makes the controllers agree on the sequence of ownership changes. A lease limits permission in time. Fencing lets the output store reject a write carrying an older ownership number. Start by keeping those responsibilities separate.

Publishing the result of a job shows why agreeing on its owner and protecting its output are separate tasks. Export E9 reads records, writes an output file, and publishes its location in a manifest. One worker can own the job initially, but recoverable execution needs a replacement owner after failure. The replacement decision and rejection of stale publication are separate requirements.

We introduce an ownership record: `E9 -> worker W1, epoch 7`. An **epoch** is a number that increases whenever the job is assigned a new owner. W1 may work while its time-limited permission, called a lease, remains valid. Three controller replicas store this permission so losing one controller need not lose the job's ownership history.

At 12:00:02 W1 pauses for twelve seconds. The controllers later expire its permission and assign W2. A paused process is not dead: W1 can resume with its old instructions. Our design must answer two different questions: how do controllers agree on the new owner, and how does the output store stop the old owner? All times and numbers in this lesson are hypothetical.

02 / Quorum arithmetic: N, R, W, and overlapping sets



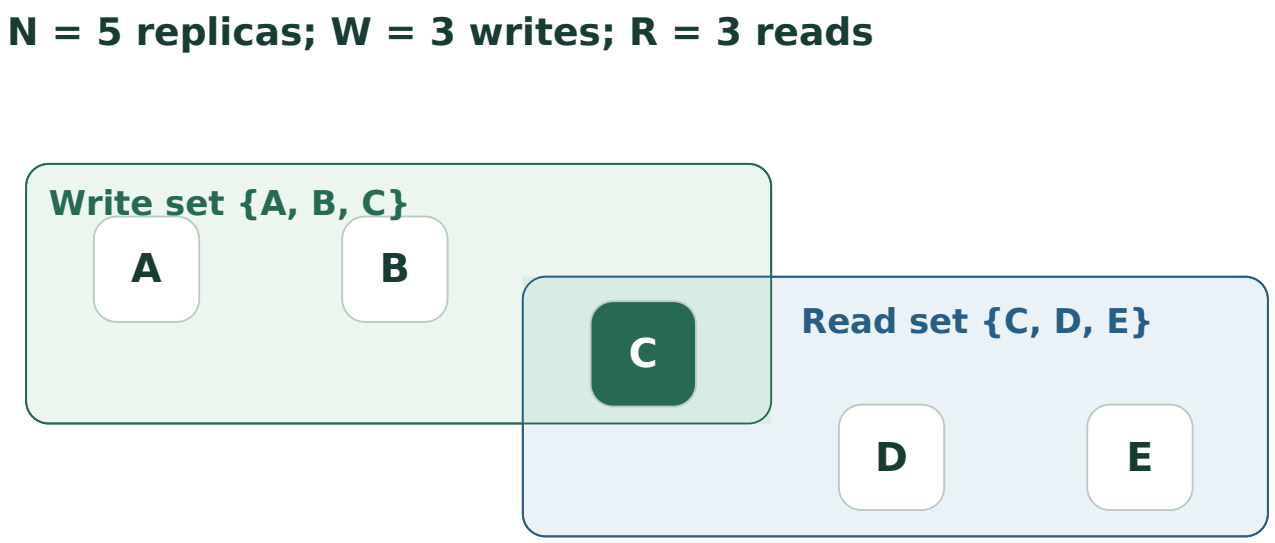
INTERVIEW CRITICAL

Quorum overlap is a set property, not a complete protocol

A quorum is a required number or set of participants whose responses an operation needs. For a fixed set of N replicas, call the write acknowledgment count W and the read response count R. If R + W > N, every such read group overlaps every such write group. This is a statement about sets, not yet a complete storage protocol.

Quorum overlap is set intersection

With N = 5 and R = W = 3, every such read set intersects every such write set. These sets illustrate arithmetic, not a complete consensus algorithm.



Intersection alone is insufficient. The protocol must still resolve versions, concurrent writes and failures correctly.

Remember: Overlap finds a shared participant; the protocol makes its evidence useful.

For N = 3, W = 2, and R = 2:

Write group holding version 8	Possible read group	Shared participant
R1, R2	R1, R2	R1 and R2
R1, R2	R1, R3	R1
R1, R2	R2, R3	R2

Every read has a chance to encounter the acknowledged version. If W is also greater than N/2, any two write groups overlap. One unavailable controller still leaves two participants, but two unavailable controllers leave too few for these operations. These counts describe the chosen fixed membership and response requirements.

There are two counts to keep separate. For simple majority consensus, `N = 2f + 1` participants can continue with `f` unavailable when the remaining majority communicates and the protocol's timing assumptions eventually hold. Four voters still need three votes and tolerate only one unavailable voter; five need three and

tolerate two. Membership changes must themselves follow the protocol: changing N independently on different clients invalidates the fixed-set intersection argument.

03 / Why quorum overlap alone is not a consistency protocol

Suppose a failed update proposing owner version 9 reaches only R1. One read consults R1 and R2 and completes with 9. Only after that response, another read starts, consults R2 and R3, and returns 8; no new ownership update occurred between these reads. Both read groups have size two, yet clients have observed a reversal unless the protocol handles that incomplete write correctly.

We need rules for valid versions, concurrent updates, failed attempts, and read completion. "Take the largest timestamp" is not automatically correct: clocks can disagree and an incomplete proposal may not be committed. Using substitute nodes during a failure also changes the overlap assumptions. This is one reason Dynamo's quorum-style techniques must be understood with their surrounding protocol.

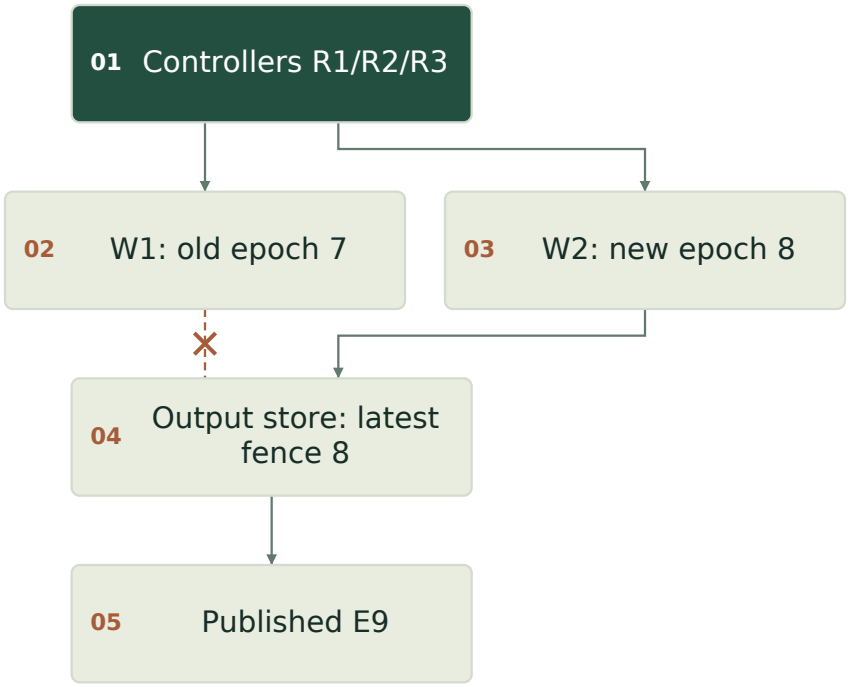
For E9's ownership, we want one agreed committed history. We therefore choose an established consensus protocol rather than invent a lock service from the arithmetic alone. A quorum contributes to the proof; it is not the whole proof. The extra discipline costs coordination and can stop progress without enough connected participants.

A pending write is allowed to take effect even if its caller never receives success. The error in the trace is returning 9 and then reverting to 8 with no intervening write. Some atomic read/write-register protocols address this by making a reader propagate the selected version to a quorum before returning. The Attiya-Bar-Noy-Dolev register is a classic example. That is a different protocol from a one-round 'read two and return the maximum' rule, and from consensus on arbitrary ownership commands.

A **sloppy quorum** may acknowledge on substitute nodes outside a key's normal replica set when home replicas are unavailable. For home replicas A/B/C, two substitutes D/E can accept a write while a read of A/B sees the old value. Counting W=2 and R=2 against N=3 does not prove overlap because those responses came from different sets. Hinted handoff can later deliver the missed data to home replicas. This improves write availability under the chosen contract, but adds repair work and does not supply an immediate latest-value read guarantee.

WORKED EXAMPLE DIAGRAM

Controller replicas agree that W2 owns export E9 at epoch 8. The output store accepts W2's epoch-8 publication and rejects W1's delayed epoch-7 write.



1 -> 2	earlier ownership expires: Controllers R1/R2/R3 -> W1: old epoch 7
1 -> 3	12:00:11 grant epoch 8: Controllers R1/R2/R3 -> W2: new epoch 8
3 -> 4	12:00:12 publish with fence 8: W2: new epoch 8 -> Output store: latest fence 8
2 -> 4	12:00:14 stale fence 7 rejected: W1: old epoch 7 -> Output store: latest fence 8
4 -> 5	retain accepted output: Output store: latest fence 8 -> Published E9

04 / Consensus with Raft: leaders, terms, and committed logs

Consensus lets a group agree on state transitions under a defined failure model. In a replicated-log approach, replicas apply the same committed commands in the same order. For E9, that sequence includes assigning W1, expiring its ownership according to the lease policy, and granting W2 epoch 8.

Raft organizes this around a leader, followers, and election terms. A term is a generation of controller leadership, distinct from E9's job-ownership epoch. The leader replicates log entries; election and commit rules preserve committed history across leader changes. A majority of three is two; a majority of five is three. These are crash-fault protocols, not a claim that any malicious participant can be tolerated. Raft paper.

At 12:00:11, the controllers agree that W2 owns the job under epoch 8. A controller with old data must not grant the job again. Before reporting the current owner, it must also perform the protocol's check that its answer is current. A recent timestamp alone cannot prove that.

Raft: election, replication, commitment, application

1. **Elect.** A candidate gains a majority with the required log-freshness check.
2. **Replicate.** The elected leader replicates an entry from its current term.
3. **Commit.** That entry is committed after the specified majority accepts it.
4. **Apply.** Replicas apply committed entries in order.

A majority containing an old-term entry alone is not enough to infer that entry is committed. For a linearizable read without appending each read, the leader must establish current authority, know the committed position, and apply through it before answering. These rules explain why the label "leader" is insufficient.



INTERVIEW CRITICAL

Consensus safety does not guarantee continued progress

Safety means committed decisions do not conflict; progress means new operations finish. Raft preserves safety through allowed message delays and crash failures, but election progress still needs a sufficiently communicating majority. Putting all voters in one zone does not tolerate that zone's loss.

Basic Paxos: prepare, select, accept

Paxos is another consensus protocol. Basic Paxos chooses one value using proposers and acceptors:

A **proposer** asks the group to choose a value. **Acceptors** retain promises and accepted proposals so later attempts can discover earlier decisions. A **ballot** is a uniquely ordered proposal-attempt identifier; a higher ballot gives an attempt priority, not permission to replace an already chosen value.

1. **Prepare.** A proposer with a unique higher ballot asks a majority to promise not to accept lower ballots. Replies report previously accepted values.
2. **Select the safe value.** Carry forward the value from the highest accepted ballot learned, if any; otherwise propose a new value.
3. **Accept.** A majority accepting that ballot/value makes the value chosen. Durable promises and accepted state protect recovery.

The rule for carrying an earlier value forward, together with intersecting majorities, prevents two different chosen values. Repeated competing proposals can prevent progress; practical systems use leadership and sufficient communication stability. Multi-Paxos builds an ordered log from repeated decisions, often amortizing preparation under stable leadership. Like Raft, it is more than majority arithmetic and is distinct from two-phase commit across independent databases.

Interview check: Can a new proposer ignore a previously accepted value because it has a larger ballot? No; the prepare replies constrain the value it may safely propose.

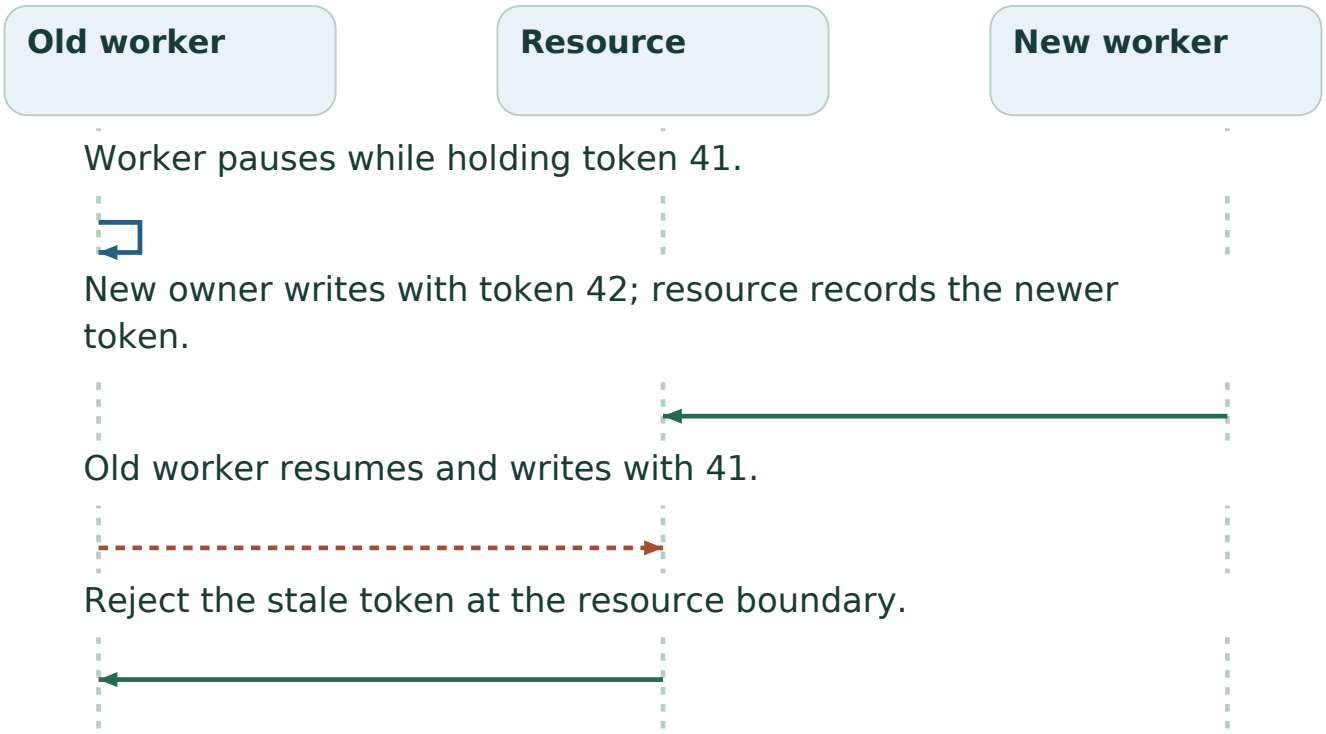
05 / Fencing tokens: reject stale writers at the resource

The controllers agree that W2 owns E9, but the output store still receives worker requests independently. Each publication therefore includes the agreed ownership version (epoch) as a fencing token. When updating the manifest, the store checks that version atomically. Otherwise, a paused old worker could resume and overwrite W2's result despite the controllers' agreement.

W2 finishes quickly. At 12:00:12 it asks the output store to publish file E9-v8 with fence 8. The store atomically compares the fence with its latest accepted ownership generation and records the new manifest. At 12:00:14, W1 resumes and submits E9-v7 with fence 7. The store rejects it because 7 is older than the accepted 8.

Fencing rejects the paused old owner

A lease can expire while a process is paused. The protected resource must enforce the fencing token; issuing tokens alone is insufficient.



Remember: The store rejects the older ownership token.

Time	Attempt	Store decision
12:00:11	Controllers grant W2 epoch 8	Ownership history advances
12:00:12	W2 publishes with fence 8	Accept; remember 8
12:00:14	W1 publishes with fence 7	Reject obsolete owner

INTERVIEW CRITICAL

Check authority atomically at the protected resource

This protection is called fencing. The comparison and protected update must be atomic at the resource; checking ownership, waiting, and then writing leaves a race. A fence blocks an obsolete owner after newer authority reaches the resource. If immediate revocation is required before any new publication, the resource needs a stronger current-ownership validation path.

Persist the highest accepted fence with the manifest so a resource restart cannot forget token 8. Scope that number to the protected job/resource, and accept only tokens issued through an authenticated ownership path; an arbitrary client-supplied large integer is not authority. A repeated token 8 may be valid, so deduplicate its operation separately. This design prevents a lower-generation write after the store has accepted the higher generation; it does not promise that only one worker ever computed an output.

06 / Leases, fencing, and idempotency solve different failures

INTERVIEW CRITICAL

An expired lease does not stop a paused worker

The lease tells the ownership service when permission expires. It cannot physically prevent W1 from executing instructions after a long pause. The resource that accepts a consequential update must enforce the chosen permission rule. If the output API cannot check an epoch or validate ownership atomically, the diagram's lock box has not made publication safe.

An idempotency key solves a different problem: repeating the same valid publication attempt. Fence 8 can be valid for several W2 requests; it does not identify which repeated request is the same operation. Use a stable publication identifier and a conditional manifest change when duplicate effects matter.

Some stores support checking an ownership key in the same transaction as the data update. etcd's concurrency API exposes ownership keys for that pattern. An unrelated external service is not automatically inside that transaction. Keep consensus on small critical ownership metadata where useful; copying the export's large file bytes need not pass through the controller log.

Mechanism	Protects	Does not establish
Quorum intersection	Required response sets share a participant	Which observed proposal is safe to return
Consensus log	One committed sequence of ownership decisions	Atomic completion at an unrelated output service
Lease	A time-bounded permission under the lease service's rules	That a paused process stopped executing

Mechanism	Protects	Does not establish
Resource fence	Reject an older generation after a newer one is installed	Deduplication or instantaneous global revocation
Idempotency key	Recognize the same logical operation again	Whether its caller still has permission

For time-based permission, state which service evaluates expiry and which clock assumptions the implementation uses. A worker's cached wall-clock check is not a resource-side authorization check. Clock jumps and long pauses are reasons to use a proven lease implementation and have the output store check permission as part of the publication itself.

07 / Interview answer: a paused worker returns after takeover

Interviewer: "The lease expired, so why can't W2 just continue?"

Candidate: "The controllers can agree that W2 owns the job while W1 is only paused. When W1 resumes, it may still try to publish its old result. I attach epoch 8 to W2's request and make the output store check it atomically when saving. The store rejects older epochs. The controllers choose the owner; fencing makes the store enforce that choice.

"If the controllers lose their majority, I would stop granting new ownership under this protocol rather than invent two histories. Existing work must obey its remaining permission and publication rules. After recovery, I would reconcile the committed ownership record, the latest published manifest, and any abandoned files."

This answer names what the quorum, consensus log, lease, fence, and idempotency key each contribute. None is a general replacement for the others. The failure drill includes controller loss, an isolated controller, a paused worker, and a publication whose response is lost.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Define quorum, consensus, lease, and fencing. Which problem does each solve?

Model answer

A quorum is a required response set, such as two of three controllers. Consensus makes those controllers agree on an ownership decision or committed log despite the failures it tolerates. A lease gives ownership for a limited interval. Fencing adds an increasing ownership token that the output store checks atomically with a write.

For export E9, controllers grant W1 epoch 7. W1 pauses; the lease expires; controllers agree to grant W2 epoch 8. W2 publishes with token 8. If W1 resumes and presents 7, the store rejects it. The lease did not stop

W1's CPU from executing; the fencing check stops its stale effect after newer authority reaches the resource. Quorum overlap helps the agreement proof but does not supply a complete consensus protocol.

Interviewer follow-up

What changes if R=1 and W=1?

"The groups may be R1 and R3, with no common member. A read can entirely miss an acknowledged write."

What the answer must demonstrate: Start from actual sets rather than a memorized equation.

02 / APPLIED

Why does overlap not prove linearizability?

Model answer

"With three replicas, read groups {R1,R2} and {R2,R3} do overlap at R2. But suppose only R1 saw an incomplete write of v9 while R2 and R3 still have v8. A first read returns v9 from R1, then a later read through R2 and R3 returns v8 without another write. The problem is that the read exposed a value without preserving it for later reads. Quorum intersection alone does not define safe version selection, write-back, commitment, or recovery."

Interviewer follow-up

Can a clock timestamp settle it?

"Not by itself. Clocks may disagree, and a high timestamp does not prove an update belongs to the committed history."

What the answer must demonstrate: Use overlapping replica sets and non-overlapping-in-time reads; explain why a selected value must remain visible to later reads.

03 / FOUNDATION

What does consensus provide when three controllers assign one owner for export job E9?

Model answer

"It gives the controllers one agreed sequence of ownership transitions, so W1 expiry and W2's epoch-8 grant are not independently invented on different copies. I would use a proven replicated-log protocol whose election and commit rules preserve the history after controller failure."

Interviewer follow-up

Does that protocol automatically publish the export once?

"No. Agreement commits the ownership metadata. The output service must enforce ownership and deduplicate publication at its own boundary; otherwise two workers may still produce conflicting external effects."

What the answer must demonstrate: Agreement on metadata does not atomically include every external effect.

04 / APPLIED

What happens when two of three controllers are unreachable?

Model answer

"Only one remains, so the majority protocol cannot safely advance ownership. I would stop new grants and report reduced availability. I would not let the isolated replica infer that its stale state is now authoritative because it is the only one this client can reach."

Interviewer follow-up

Would four or five controllers improve the number of unavailable controllers tolerated?

"Four voters need three votes, so they still tolerate only one unavailable voter. Five need three and can tolerate two, provided the remaining three communicate and satisfy the protocol's progress requirements. The benefit comes from the voting threshold and failure placement, not simply a larger count."

What the answer must demonstrate: Distinguish safety from continued progress.

05 / APPLIED

W1 has fencing token 7; replacement W2 publishes with token 8. W1 resumes. What must the output store check?

Model answer

"W2's publication has fence 8, so the output store has atomically recorded that generation with the manifest. W1 arrives carrying 7. The store rejects 7 before changing the protected state, preventing W1 from replacing W2's newer result."

Interviewer follow-up

What if W1 checks the lock before making a separate write?

"Ownership can change after the lock check but before the write. Check the fencing token, update the manifest and save the accepted token together in one atomic operation. Saving the token also prevents a restart from forgetting which worker is current."

What the answer must demonstrate: A separate preflight check leaves a race.

06 / FOLLOW-UP

Does a fence instantly revoke old work everywhere?

Model answer

"Not necessarily. A resource comparing against its latest accepted fence learns about generation 8 when that newer authority reaches it. It prevents older writes after that point. If the requirement is immediate revocation everywhere, I need current-ownership validation or another stronger coordinated boundary."

Interviewer follow-up

Could W1's computation continue harmlessly?

"Yes, if its consequential publication is prevented. Wasted computation and an unauthorized state change are different concerns."

What the answer must demonstrate: Describe the precise fencing guarantee rather than implying physical process termination.

07 / FOUNDATION

A valid worker retries publication with the same fencing epoch 8. Why is an operation idempotency key still needed?

Model answer

"Epoch 8 says W2 is an eligible owner. It does not distinguish one publication attempt from a retransmission of the same attempt. I use a stable publication ID so a lost response does not create duplicate effects while that ownership is still valid."

Interviewer follow-up

Can an old epoch with a new operation ID be accepted?

"No. Idempotency is not permission. It must still pass the ownership check."

What the answer must demonstrate: Operation identity and authorization are independent checks.

08 / FOLLOW-UP

What do you reconcile after the controller outage ends?

Model answer

"I inspect the committed ownership history, the output store's accepted fence and manifest, and any unfinished files. A worker saying it finished is weaker than the protected publication record. I then resume or retry with stable IDs and valid ownership rather than blindly rerunning every reported job."

Interviewer follow-up

Can a lagging controller issue grants while it catches up?

"Not under our chosen current-authority contract. It must participate according to the consensus protocol before serving authoritative ownership decisions."

What the answer must demonstrate: Recovery must consult the state that actually governs the external result.

Build the answer yourself

BLANK-PAGE EXERCISE / 18 MINUTES

Act out export E9 with three controller replicas and two workers. Pause the old worker, transfer ownership, then let both attempt publication.

- Compute which read/write replica sets intersect.
- Distinguish the controller log's term from the job's ownership epoch.
- Show the output store atomically rejecting fence 7 after accepting fence 8.
- Explain why an idempotency key is still needed for repeated valid operations.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What does R + W > N establish?

For a fixed set of N replicas, a read contacting R replicas and a write acknowledged by W replicas must share at least one replica when R + W > N. Rules for versions, incomplete writes, and failures are still needed.

Overlap is a building block.

Why does W1 need fencing after its lease expires?

It may resume and execute old instructions; the output store must reject its obsolete ownership.

The resource checks the ticket number.

Are Raft term 4 and E9 epoch 8 the same number?

No. One identifies controller leadership; the other identifies ownership of this job.

Different authorities, different generations.

Does a fencing token deduplicate a valid request?

No. A stable operation ID is still needed to identify repeated effects within the same valid ownership epoch.

Who may write is not which attempt this is.

Summary and interview notes

Quorum rules can require response groups to overlap. Consensus commits an agreed history, leases limit permission in time, and fencing makes the output store reject obsolete ownership numbers. None of these alone makes an unrelated external effect exactly once or stops a paused worker from running.

Remember these points

• R + W > N assumes the same fixed replica membership; it does not define safe read selection or failed-write handling.

• A 2f + 1 majority group tolerates f unavailable participants for progress only when the surviving majority can communicate.

• Raft election, current-term commit, and current-authority read rules matter beyond counting acknowledgments.

• Save the job's accepted ownership version and check it in the same atomic update as the result.

• An operation ID identifies a repeated action; a fencing token checks whether its worker may still write. You may need both.

Interview tips

• Draw the actual overlapping sets before applying R + W > N.

• Pause an old worker, let a new generation publish, then resume the old one and point to the exact rejection.

• Ask whether a lease or lock protects the actual destination, not just a separate coordinator key.

Important qualifications

• A maximum-seen fence rejects older writes only after the newer fence reaches that resource; immediate revocation needs a stronger check.

• Do not equate a controller election term with a per-job ownership epoch.

• A proven atomic-register protocol can use quorum reads with write-back; consensus is not synonymous with every linearizable register implementation.

Technical references

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Primary description of leader election, log replication, and safety.
https://raft.github.io/raft.pdf

Dynamo: Amazon's Highly Available Key-value Store
Primary discussion of quorum-style reads/writes and the limitations of substitute replica sets.
https://www.allthingsdistributed.com/files/amazon-dynamo-sosp2007.pdf

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Checked versioned etcd v3.6 documentation: lock ownership keys can guard updates in the same etcd transaction; unrelated output services are outside that boundary.
https://etcd.io/docs/v3.6/dev-guide/api_concurrency_reference_v3/

Attiya, Bar-Noy, and Dolev: Sharing Memory Robustly in Message-Passing Systems
Primary atomic-register construction; distinguishes a full quorum read/write protocol from set intersection alone.
https://groups.csail.mit.edu/tds/papers/Attiya/JACM95.pdf

Leslie Lamport: Paxos Made Simple
Primary prepare/accept, ballot and value-selection rules; the chapter presents only an interview-level outline.
https://lamport.azurewebsites.net/pubs/paxos-simple.pdf

FOUNDATIONS / 18

Idempotency, retries, and timeouts

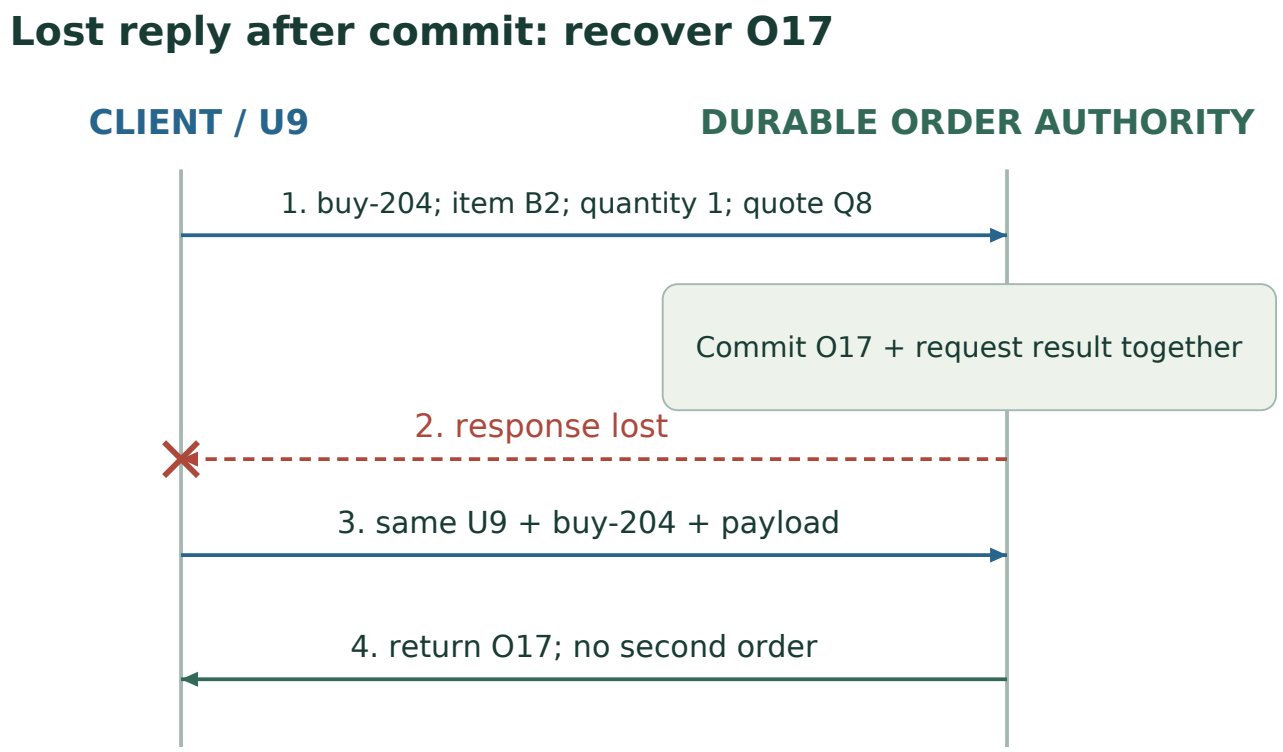
DEFINITION

An operation is idempotent when repeating the same logical request has the same intended effect as performing it once. A retry is another attempt at that request; a timeout only says the caller stopped waiting and does not establish whether the effect happened.

Why it matters: Networks can lose the response after a server commits. A client needs a way to recover the original result without accidentally creating another order or charge.

Idempotency keys and recovery after a lost response

The server binds the caller and idempotency key to the request fingerprint and committed result. A retry must not create a second business operation.



Same identity + changed payload = conflict. The unique request result guards the commit.

Worked example

U9 submits buy-204 and the server commits order O17, but the reply is lost. A retry with the same caller, key, and payload returns O17 instead of creating O18.

Key takeaways

• A timeout means unknown outcome, not proven failure.

• Commit the request identity, the local business change, and its saved result together so a crash cannot separate them.

• Bound retry attempts and elapsed time; external effects need their own recovery contract.

Read the visual model

1. An authenticated client U9 sends POST /orders with idempotency key buy-204. The server commits order O17 and the result for (U9,buy-204) together.

2. The reply is lost. Retrying the same request and identity returns the stored O17 result.

3. Reusing buy-204 with a changed payload is rejected. A distinct intended purchase uses a new key.

4. Bound retries with backoff, jitter and an end-to-end deadline; retry safety is not overload control.

idempotency • retry • timeout • backoff • circuit breaker • bulkhead

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Distinguish a failed operation from an unknown outcome.

• Design an atomic idempotency record with a request fingerprint.

• Budget retries and isolate overloaded dependencies.

Useful foundations: HTTP APIs and request lifecycle; Transaction isolation

8 interview questions with model answers and answered follow-ups.

01 / Idempotency, retry, timeout, and deadline: definitions

Idempotency means that repeating the same logical operation has the same intended business effect as performing it once. A **retry** is another attempt at that operation. A **timeout** is a maximum waiting duration: if no response arrives, the caller does not know whether the server received the request, committed it, or lost its reply. A **deadline** is an absolute point in time by which a call should finish. Propagating one deadline bounds the total waiting budget across a call chain; it does not prove that remote work stopped or undo committed effects.

Idempotency does not require every low-level network message to occur once. Without a stable operation identity, another attempt can accidentally create a second business intent. Our target is one order O17 for checkout attempt `buy-204`, even if three HTTP attempts arrive.

This distinction appears in payments, file uploads, job queues, webhooks, and agent tool calls. First identify the business operation and which transaction or external service durably records its result. Then decide how a retry finds that result.

02 / Lost-response retry: one order from two attempts

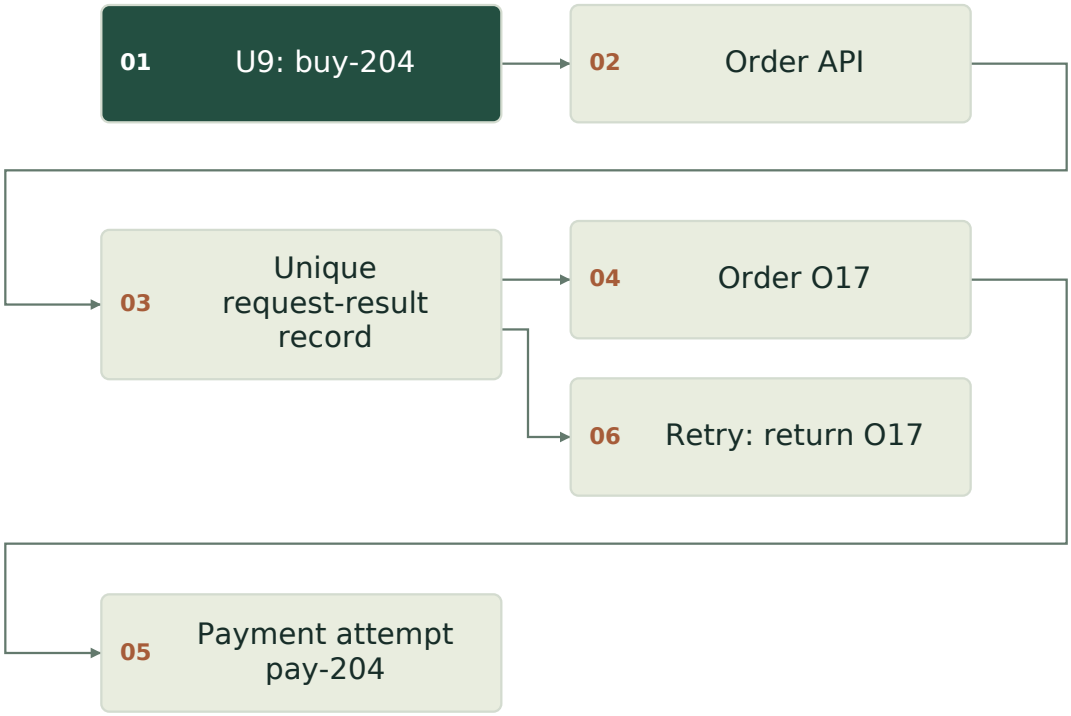
Bind an **idempotency key**, a stable identifier for one logical operation, to the authenticated caller and a normalized representation of the request. For example, `POST /orders` uses `Idempotency-Key: buy-204`, user U9, item B2, quantity 1, and quote Q8. The following trace isolates the failure between committing O17 and returning its response.

Step	Server state	Caller-visible state
1	No record for `(U9, buy-204)`	Request sent
2	Transaction creates O17 and saves the request result	Still waiting
3	Transaction commits	Still waiting
4	Response is lost	Timeout; outcome unknown
5	Same key arrives again	Same logical operation retried
6	Server returns saved O17 result	Purchase confirmed once

The request identity must come from a stable retryable intent, not a fresh random key on every network attempt. A distinct second purchase should use a new key. Reusing a key with a different item should be rejected rather than silently returning a result for the wrong request.

WORKED EXAMPLE DIAGRAM

The request-result record protects the local order identity. The payment remains a separate effect with its own retry and reconciliation contract.



1 -> 2	first attempt or retry: U9: buy-204 -> Order API
2 -> 3	claim caller/key atomically: Order API -> Unique request-result record
3 -> 4	commit order and result together: Unique request-result record -> Order O17
4 -> 5	durable external attempt identity: Order O17 -> Payment attempt pay-204
3 -> 6	retrieve committed outcome: Unique request-result record -> Retry: return O17

03 / Idempotency key, payload fingerprint, and atomic result storage

Store `RequestResult(callerId, key, payloadHash, state, resourceId, response)` with a unique `(callerId, key)` constraint. A **payload hash** is a fingerprint computed from the fields that define the operation, such as item, quantity, and quote. **Canonical** means these fields are normalized consistently before hashing, so equivalent inputs produce the same representation. It detects reuse of the same key for a different intent; it is not authorization.

INTERVIEW CRITICAL

Claim, business effect, and saved result must commit together

Within one database transaction, claim the request identity, validate the purchase, create O17, and save the resulting identity/outcome. Concurrent attempts for the same key must serialize through the unique record or another equivalent atomic mechanism. If checking for an existing request and creating the result are separate unprotected steps, two handlers can both see "not seen" and create two orders.

When work cannot finish in one short database transaction, persist its progress and give a worker temporary ownership, often through a **lease**. Expiry lets a replacement take over, but recovery must still account for requests the previous worker may already have sent. This is why a long operation needs more states than simply "key absent" or "completed."

INTERVIEW CRITICAL

Deleting an operation record can make an old request new

Long operations may need an `in_progress` state and status endpoint. An abandoned owner needs a lease/recovery policy before another worker continues. Do not release the operation identity while an external side effect may already have happened. Retain records for the maximum supported retry horizon; after deletion, the same old key may look new unless the API rejects it by another rule.

INTERVIEW CRITICAL

Recover a retry before rerunning create-time checks

Resolve a retry in a deliberate order: authenticate; locate the scoped operation identity; compare operation type, target and canonical payload; authorize access to the saved outcome; then return or resume that operation. Do not rerun mutable create-time checks, such as whether the original quote is still offered, before discovering that the order already committed. A retry recovers that result, while a new purchase undergoes current validation.

Specify the **key namespace**: the group within which an idempotency key must be unique, such as all requests by one caller. The example uses caller-wide keys, so the fingerprint includes the operation and target as well as item fields. A tenant or service that uses separate namespaces must include that scope in the unique identity. Replaying a saved response still requires current permission; an old idempotency key must not expose a resource after access is revoked.

Stored state	Same identity and payload	Unsafe reaction
No record	Atomically create the effect and outcome, or durably claim a long operation	Check absence and create outside one protected boundary
In progress	Return status, wait within budget, or recover ownership	Launch another uncoordinated worker

Stored state	Same identity and payload	Unsafe reaction
Completed	Return the recorded effect identity and an authorized result	Repeat the business mutation
External outcome unknown	Reconcile the original external operation	Treat timeout as rejection and choose a fresh key
Same key, different fingerprint	Reject the conflict	Return an unrelated old result

A lease lets a replacement worker take over after a deadline. The old worker may resume later, so the store must atomically check the current ownership version (epoch) and expected state before saving a result. That check cannot undo an external request already sent. The receiving service still needs duplicate protection, or a way to check and resolve the uncertain result.

04 / External effects and uncertain payment outcomes

Suppose checkout calls a payment provider after creating an order. The provider charges successfully, but its reply is lost before local state records success. Repeating a new provider request can double-charge even if the local order insert was idempotent.

Use one stable provider attempt key for the payment, record it durably before or as part of scheduling the attempt, and reconcile the provider's status after uncertainty. A webhook may report the result, but duplicate and reordered webhooks need their own identity/state checks. Only finalize the local purchase once the confirmed result satisfies the state machine.

If the provider has no safe retry or status lookup, an uncertain payment may need manual investigation. Explain that limit. To claim duplicate protection, identify the exact action protected, how long its request ID is remembered and which failures are covered. "Exactly once" alone explains none of those.

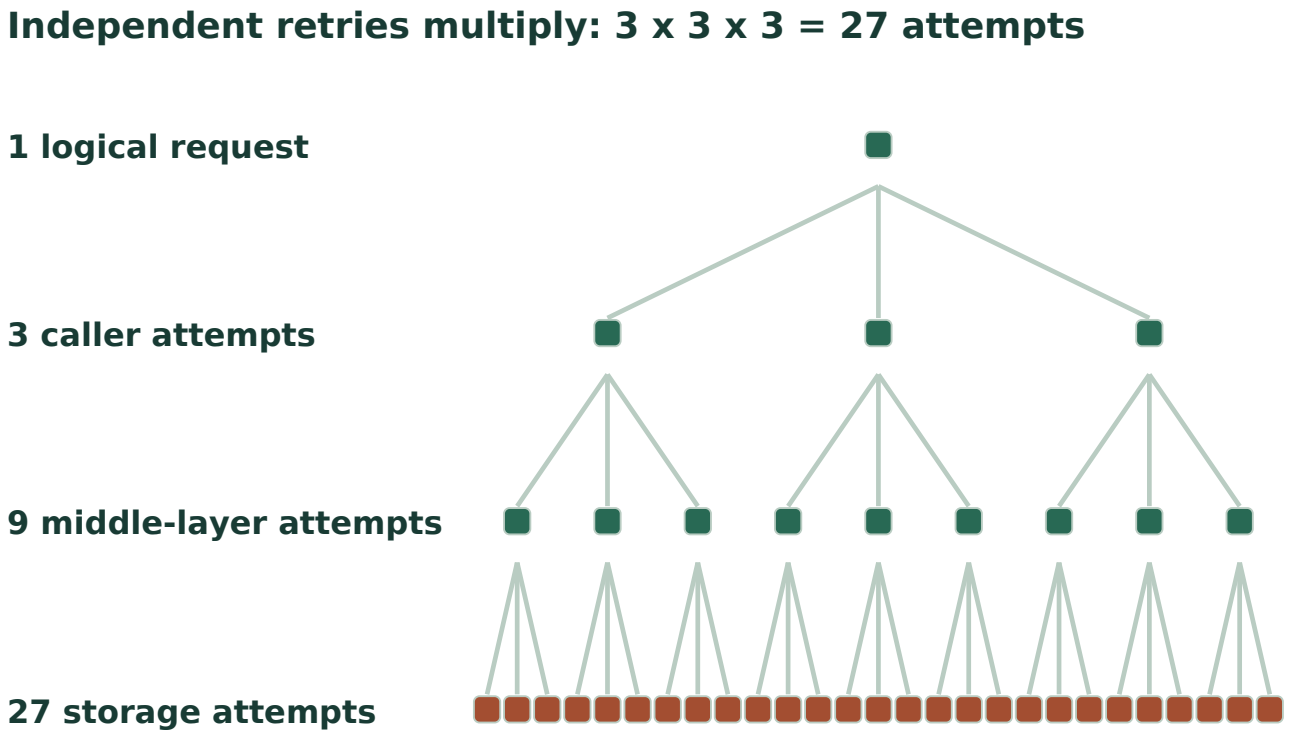
Read the provider's actual contract rather than copying a generic retry recipe. For example, Stripe documents replaying the first saved status and body for an idempotency key, including a saved 500. Reusing that key can therefore replay an error without proving that no effect occurred; using a fresh key simply to escape the saved error can duplicate work. Keep the operation pending and use the supported recovery path.

05 / End-to-end deadlines and retry amplification

A **deadline** is an absolute point in time by which a call should finish; a **timeout** is a maximum waiting duration, often for one step. If the user allows two seconds for checkout, giving three nested services independent two-second timeouts can exceed that budget. Propagate the deadline or its remaining time budget through the call chain and stop work that is no longer useful when safe to do so.

One request can become 27 storage attempts

Every parent branches into three total attempts, including the original. Read from top to bottom.



Remember: Retry budgets multiply across layers.

Try from memory: If only the outer layer permits three attempts, how many storage attempts can one request cause?

Answer: At most three in this simplified chain, assuming each inner layer makes one attempt per call.

Retry transient transport failures or documented retryable responses when the operation is safe and time remains. Do not repeatedly retry invalid input, denied permission, or a business condition that is no longer satisfied, such as an expired reservation. Respect server retry guidance.

INTERVIEW CRITICAL

Retries multiply across layers

If each of three layers makes three total attempts, one user operation can produce up to 3 x 3 x 3 = 27 calls at the deepest dependency. Choose one appropriate retry layer or coordinate retry budgets. Bound both attempts and elapsed time, and include the cost of any work that continues after the client gives up.

Budget connection setup, queueing, processing, backoff and response transfer within the same end-to-end limit. If Retry-After asks for a wait beyond the remaining interactive budget, return a retryable/pending result instead of sleeping and then starting an already-expired attempt. HTTP and RPC clients may have their own automatic retries, so inventory them before multiplying attempts. gRPC clients also need an explicit realistic deadline; deadline propagation and cancellation handling vary by language and application code.

06 / Exponential backoff, jitter, circuit breakers, and bulkheads

Bounding the number of retries still leaves two problems: many clients may retry together, and slow calls may occupy every available resource. The controls below address different parts of that load: when to retry, whether to call a failing dependency, and which workloads share a resource pool.

Exponential backoff increases the waiting interval between retries. For a base interval of 100 ms, caps might be 100, 200, 400, and 800 ms. **Jitter** randomizes each wait, for example choosing a value between zero and the current cap. Ten thousand clients then avoid retrying at exactly the same instant.

A **circuit breaker** stops calls temporarily after sufficient failure evidence and later allows limited probes. It reduces repeated futile work; it does not repair the dependency or authorize dropping important writes. A **bulkhead** gives workloads separate concurrency/resource pools so a slow image export cannot consume every checkout connection.

Control	What it bounds	Example
Deadline	Total useful elapsed time	Stop interactive checkout attempts after its budget
Retry budget	Additional attempts	At most one extra request at the API layer
Backoff + jitter	Timing of repeated work	Spread recovery attempts
Concurrency limit	Work in flight	Only 50 simultaneous provider calls
Circuit breaker	Calls into known failure	Limited recovery probes

Queues also need limits. If work arrives faster than it can complete indefinitely, an ever-growing queue delays the failure while consuming memory or storage; it does not add processing capacity.

07 / Interview walkthrough: safe checkout retries

Interviewer: "The customer presses Buy twice because the first request timed out. How do you prevent two orders?"

Candidate: "Both attempts use buy-204 for the same user and request. I save the unique request-result record and order in one transaction. If the reply is lost after commit, the retry returns O17. For an external payment, I reuse the provider's request key and check uncertain results. I stop retries at the user's deadline and spread them with backoff and jitter so an outage does not trigger a flood."

The answer is grounded because it names the durable state before and after the lost response, rather than assuming the network delivers exactly once.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What does idempotency mean, and why does a timeout make it useful?

Model answer

Idempotency means repeating the same logical operation has the same intended effect as doing it once. A timeout does not prove failure: O17 may have committed before its response was lost. U9 retries buy-204 with the same caller and payload so the service returns O17 instead of making another purchase.

Interviewer follow-up

Does idempotency require the response bytes and every network message to be identical?

No. It concerns the intended effect. Retries can produce additional network messages or different status details while still referring to the same one business operation.

What the answer must demonstrate: Distinguish one business effect from one transport attempt.

02 / FOUNDATION

What exactly does the idempotency key identify?

Model answer

"One caller's logical intent, such as U9's purchase attempt buy-204. I scope it to the authenticated caller and compare a canonical payload fingerprint. A fresh network retry reuses it; a new intended purchase gets a different key."

Interviewer follow-up

What if the payload changes under the same key?

Reject a changed operation, target or canonical payload under the same scoped key. The stored result still needs current authorization; knowledge of the key is not permission to inspect another resource.

What the answer must demonstrate: Separate caller, intent, and payload.

03 / APPLIED

Two requests both see no saved result. How is one order guaranteed?

Model answer

"The claim and business effect must share an atomic boundary, such as a unique request record and order insert in one transaction. A separate check-then-insert can let both proceed. The losing concurrent attempt waits for or retrieves the winner's outcome."

Interviewer follow-up

What if a long-running task is in progress?

Return its status or wait up to a limit. If a new worker takes over, give it a new ownership version and atomically reject old versions when saving local results. For external calls already sent, use the receiving service's duplicate protection or check their outcomes.

What the answer must demonstrate: Show the atomic boundary.

04 / APPLIED

Can idempotency records expire after a minute?

Model answer

"Only if the contract prevents valid retries after that minute or another durable identity prevents repetition. Deleting the record can make a delayed duplicate look like a new operation. I align retention with the retry horizon, business identifiers, and downstream retention."

Interviewer follow-up

What if the provider retains keys for less time than we do?

Our workflow must stop blind retries outside the provider guarantee and reconcile through a durable provider resource ID or another supported status path.

What the answer must demonstrate: Treat deduplication retention as part of correctness.

05 / APPLIED

Why doesn't a local transaction make the external charge exactly once?

Model answer

"The provider is outside that transaction. It can charge and lose its reply before we save the result. I use one durable provider attempt key, query or reconcile its outcome, and process duplicate notifications safely. The local order and remote charge have separate commit boundaries."

Interviewer follow-up

What if the provider lacks those capabilities?

I cannot invent the guarantee. I would state the residual uncertainty and design reconciliation, compensation, or an operational resolution path.

What the answer must demonstrate: Avoid blanket exactly-once claims.

06 / APPLIED

Three layers each make three attempts. What reaches the bottom?

Model answer

"In the worst simple nesting, up to 27 calls for one user operation. That extra work can keep a struggling dependency down. I choose one retry layer or a shared budget, cap attempts and total time, and stop retrying permanent failures."

Interviewer follow-up

Why add jitter?

Without it, synchronized clients can retry at the same intervals. Jitter distributes those attempts in time, reducing repeated spikes.

What the answer must demonstrate: Show the multiplication and the bound.

07 / APPLIED

How do timeouts relate to a two-second user budget?

Model answer

"The two-second budget becomes an absolute deadline two seconds after the request starts. Each downstream call gets at most the remaining time as its timeout, including planned retries. Independent two-second waits at every layer can greatly exceed it and keep doing work after the user has left."

Interviewer follow-up

Does cancellation undo a completed action?

No. Cancellation can stop unnecessary pending work, but committed effects still need normal reconciliation or compensation.

What the answer must demonstrate: Distinguish stopping work from reversing it.

08 / APPLIED

How do you stop a slow export dependency from taking down checkout?

Model answer

"I separate concurrency pools so exports cannot consume all checkout workers or connections. I bound queues and use deadlines, then reject or defer lower-priority work when capacity is exhausted. A breaker can limit calls to the unhealthy dependency while probing recovery."

Interviewer follow-up

Would an infinite queue preserve availability?

It accepts work without a credible completion time and can exhaust resources. Availability must include a meaningful service contract, not merely enqueueing forever.

What the answer must demonstrate: Protect a finite resource and explain overload behavior.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Draw a purchase that commits before its response is lost. Add a concurrent retry and an uncertain payment outcome.

- Name the request key, caller, and payload fingerprint.
- Show the transaction and external-effect boundaries.
- Specify duplicate handling and retention.
- Calculate retry amplification and set a bounded budget.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Timeout

The caller stopped waiting; the durable outcome may already exist.

Unknown is not failed.

The order was saved, but the reply was lost. What makes the retry safe?

The same authenticated caller, request key and matching request recover the saved order and result. A changed request using that key must be rejected.

Same request -> same saved result.

Safe retries

Safe operation + bounded budget + backoff/jitter + reconciliation.

Retry with a reason and a limit.

Summary and interview notes

Retry the same logical operation only when its effect can be recovered safely and the remaining budget justifies another attempt. A durable operation identity prevents duplicate local mutations; also define how external results are checked, how obsolete workers are prevented from publishing, and how long saved results remain available for retries.

Remember these points

• Bind the key to the caller, operation, target and normalized request fields. Reuse it when retrying the same request.

• Save the request claim, business change and result in one atomic transaction.

• A timeout leaves the result unknown. After ownership changes, the store must reject results from the former worker.

• Deduplication retention and provider key lifetime bound safe retry; an expired record can make an old request look new.

• Three retrying layers with three total attempts each can create 27 downstream calls.

Interview tips

• Draw the crash after commit but before reply, then add two concurrent retries.

• Show how a duplicate returns an already committed result before re-running create-time validation.

• Count automatic SDK/proxy retries and include connection, queue and backoff time in the deadline.

Important qualifications

• Saved outcomes still require current resource authorization.

• Cancellation and circuit breakers reduce future work; they do not reverse an external effect already committed.

Technical references

AWS: making retries safe with idempotent APIs
Operation identity and safe retry design.
https://aws.amazon.com/builders-library/making-retries-safe-with-idempotent-APIs/

Stripe idempotent requests
A concrete provider-specific idempotency contract; retention and error behavior are not universal.
https://docs.stripe.com/api/idempotent_requests

Google SRE cascading failures
Overload feedback, resource exhaustion, and bounded recovery behavior.
https://sre.google/sre-book/addressing-cascading-failures/

gRPC: Deadlines
Explicit deadlines, propagation, clock-skew handling and application responsibility for stopped work.
https://grpc.io/docs/guides/deadlines/

FOUNDATIONS / 19

Message queues, event logs, delivery guarantees, and backpressure

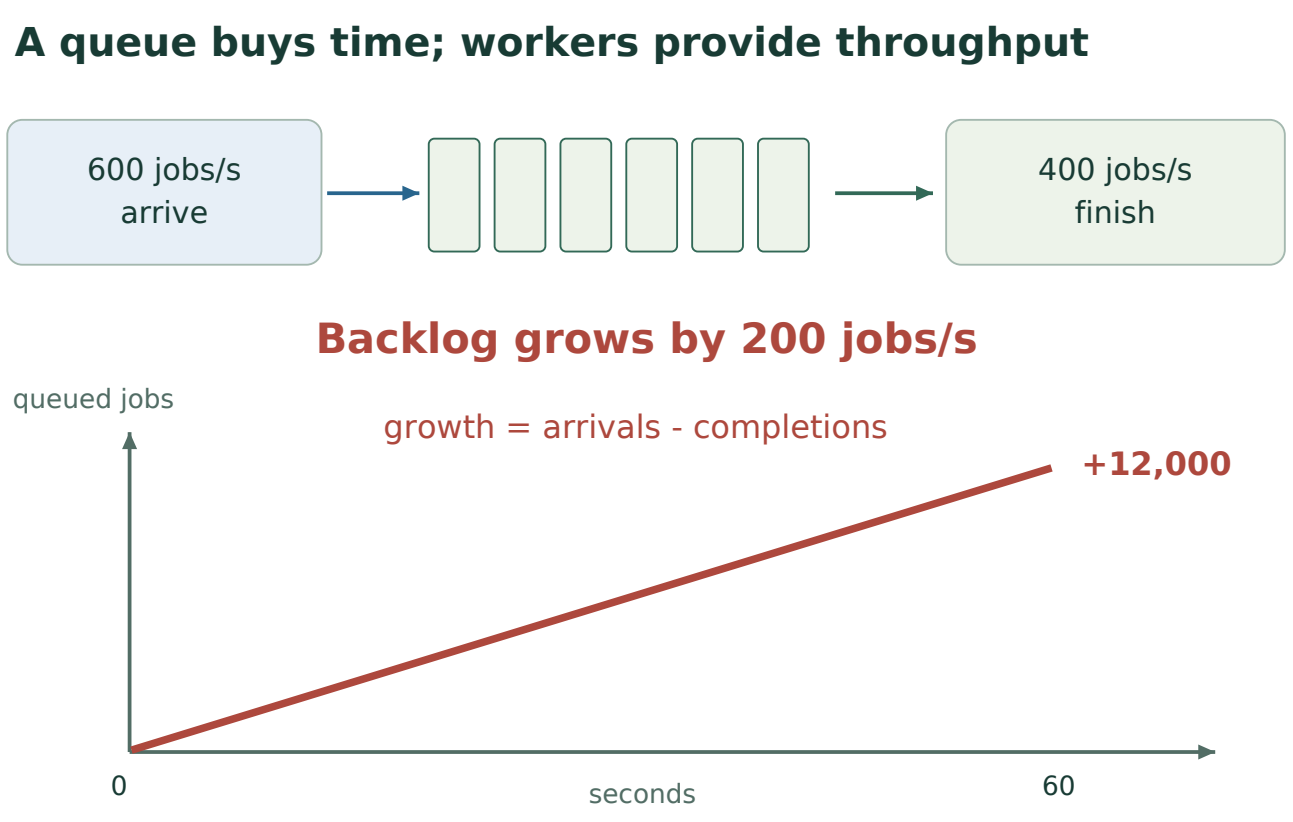
DEFINITION

A message queue buffers work for asynchronous consumers. An event log retains an ordered history for consumers to read or replay. Backpressure controls admission or processing concurrency when downstream capacity cannot keep up with incoming work.

Why it matters: Slow background processing should not hold every foreground request open. Buffering absorbs short bursts, while durable handoff and duplicate-safe processing make accepted work recoverable.

Queue backlog growth and drain time

A queue absorbs a burst but does not create service capacity. Admission limits and bounded retries prevent a growing backlog from becoming an outage.



At 200 arrivals/s and 400 completions/s, the 12,000-job backlog drains in 60 s.

Worked example

Workers process 400 jobs/s while 600 jobs/s arrive for 60 seconds: the backlog grows by 12,000 jobs. When arrivals fall to 200/s, the spare 200 jobs/s drains it in about 60 seconds.

Key takeaways

• Accepted work and completed work are different user-visible states.

• At-least-once delivery requires a safe repeated effect; an outbox prevents lost handoff, not duplicates.

• A queue stores excess work but cannot fix sustained overload without more capacity or less admission.

Read the visual model

1. At 600 jobs per second arriving and 400 per second completed, backlog grows by 200 each second. After sixty seconds it grows by 12,000.

2. To drain an existing backlog, completion capacity must exceed arrival rate.

3. Acknowledge a delivered job only after its durable effect. A crash may cause redelivery, so effects need stable identities.

queue • event log • outbox • idempotency • backpressure

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Separate accepting a job from completing its business effect.

• Trace the database-to-queue gap and a crash after the effect but before acknowledgment.

• Compute backlog growth and recovery while bounding retries and resource use.

Useful foundations: Databases, data models, and ACID transactions; Replication and durability

8 interview questions with model answers and answered follow-ups.

01 / What is a message queue, and what does async mean?

A **message queue** holds work until a **consumer** can process it. The sender is the **producer**; a **broker** is the service that stores and delivers the messages. **Asynchronous** means the request can finish accepting work before that work finishes executing. **Backpressure** is the control that slows, defers, or rejects incoming work when processing capacity is insufficient.

An **event** records something that happened, such as photo-created. A **command** asks for an action, such as create-thumbnail. A queue commonly distributes commands among workers; a retained log allows independent consumers to replay events. These uses can share infrastructure, but their completion and replay contracts differ.

Synchronous processing makes request latency include the entire downstream task and occupies request-serving capacity throughout it. For example, accepting photo P501, rendering a thumbnail, and publishing its ready state can have very different latency distributions. A burst of slow rendering jobs can exhaust request workers even when upload storage is fast.

A queue stores work so another process can handle it later. We create job J501 and return a status saying the uploaded file and a record that it needs thumbnail processing have been durably saved. This is not the same as "thumbnail ready." The client receives a photo ID and can check states such as pending, processing, ready, or failed.

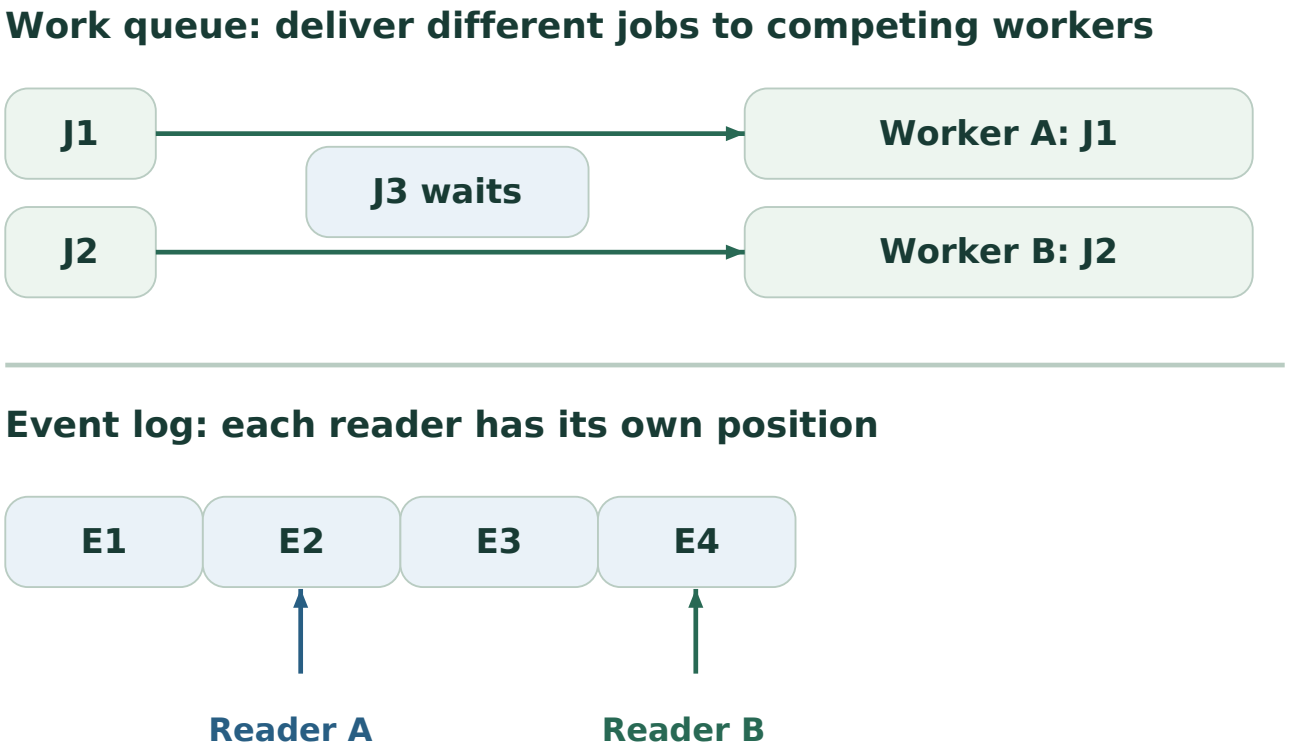
The queue decouples when work arrives from when it executes. It can absorb a bounded burst, but it cannot make sustained excess demand disappear. The first design decision is therefore a user-visible contract: acceptance is quick and recoverable; completion is asynchronous and has a separate objective. All job rates and timestamps below are illustrative assumptions.

02 / Work queue versus event log versus publish/subscribe

A work queue distributes tasks among workers. J501 should be handled by an eligible thumbnail worker, with retry if that worker fails. A visibility lease can temporarily hide the task from other workers, but expiration can lead to another delivery while the first worker still runs.

Who receives the work?

Arrows show delivery; upward arrows under the retained log mark independent reader positions.



Remember: Queue: divide jobs. Log: retain history. Pub/sub: distribute copies.

Try from memory: Which picture lets two readers replay the same retained history at different speeds?

Answer: The event log with independent reader positions. A competing-worker queue instead divides jobs among workers.

A retained event log stores an ordered sequence that consumers can replay from a position. Separate consumer groups can independently process the same photo events: one builds thumbnails, another computes usage statistics. Publish/subscribe describes sending events to multiple subscribers; durability, retention, and replay depend on the actual system.

Mechanism	P501 use	Question to answer
Work queue	Assign thumbnail job J501	When is it eligible for retry?

Mechanism	P501 use	Question to answer
Retained log	Replay photo-created events	How long are events retained?
Publish/subscribe	Notify independent consumers	Does each subscriber receive durable work?

For each system, specify whether messages can repeat, which messages stay ordered, how long history remains available, and what counts as completed work. The names "queue" and "publish/subscribe" do not promise global order or exactly-once effects.

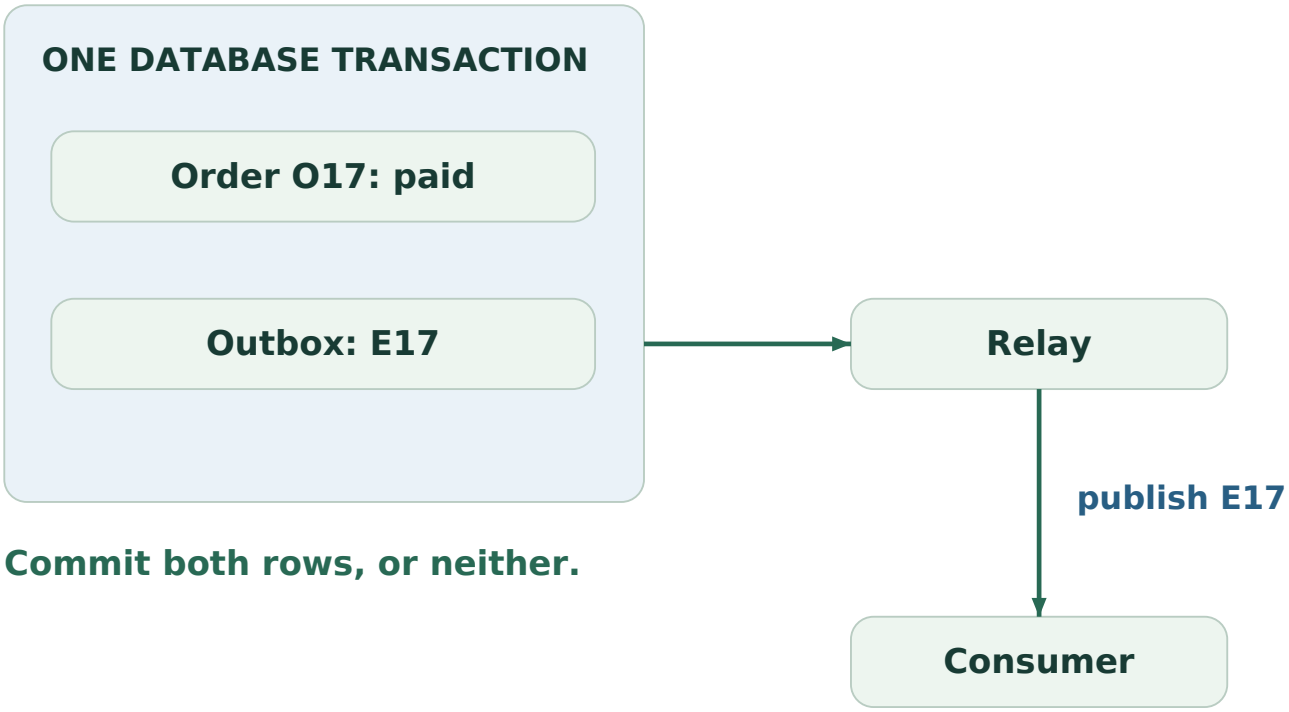
For this thumbnail service, a coherent starting implementation is a PostgreSQL photo/outbox transaction, a retrying relay, an SQS standard work queue, and workers that commit result metadata back to PostgreSQL. The database stores the job's logical state; the queue schedules attempts. A retained partitioned log such as Kafka is useful instead when several consumers need independent replay of photo events. Its order is per partition, so choosing photo ID as a partition key does not provide one global order across every photo.

03 / Transactional outbox: avoid a lost database-to-broker handoff

Suppose the upload service first commits P501 and then sends J501 to the broker. It crashes between those actions. The photo exists, but no worker learns that processing is required. Reversing the order creates another gap: a job may exist for a photo record that never committed.

Put the business change and event in one commit

The shaded boundary is the local database transaction. Publication happens outside it.



Relay may publish twice. Consumer deduplicates E17 with its effect.

Remember: Commit the order and outbox together; expect relay retries.

Try from memory: Can the relay publish E17 twice even though the database committed once?

Answer: Yes. It can lose a publication confirmation and retry. The consumer needs a durable duplicate guard coupled to its effect.

A **transactional outbox** puts the photo record and a row describing the job to be published, including its ID and payload, in one database transaction. They commit together. A relay reads committed outbox rows and publishes jobs. If the broker is unavailable, the intention remains durable for a later retry. This protects the handoff without pretending the database and broker share one local transaction. Outbox reference.

INTERVIEW CRITICAL

An outbox prevents lost handoffs, not duplicate delivery

The relay can publish J501 and crash before recording that it did so. It will publish again on recovery. The outbox closes the missing-publication gap; it does not remove duplicate delivery. Downstream handling must therefore recognize the same job and its intended photo/version.

The relay marks an intention published only after the broker confirms the required durable acceptance. A timeout is an unknown outcome, so it retries with the same event ID. Marking the row first would recreate the

lost-handoff gap. Monitor oldest unpublished-outbox age separately from broker queue age: work can be stuck before it ever reaches the queue.

The relay needs a way to discover newly committed outbox rows. It can repeatedly query the table, or follow the database's committed change stream. Change data capture provides the second option; a saved **checkpoint** records publication progress so a replacement connector can resume.

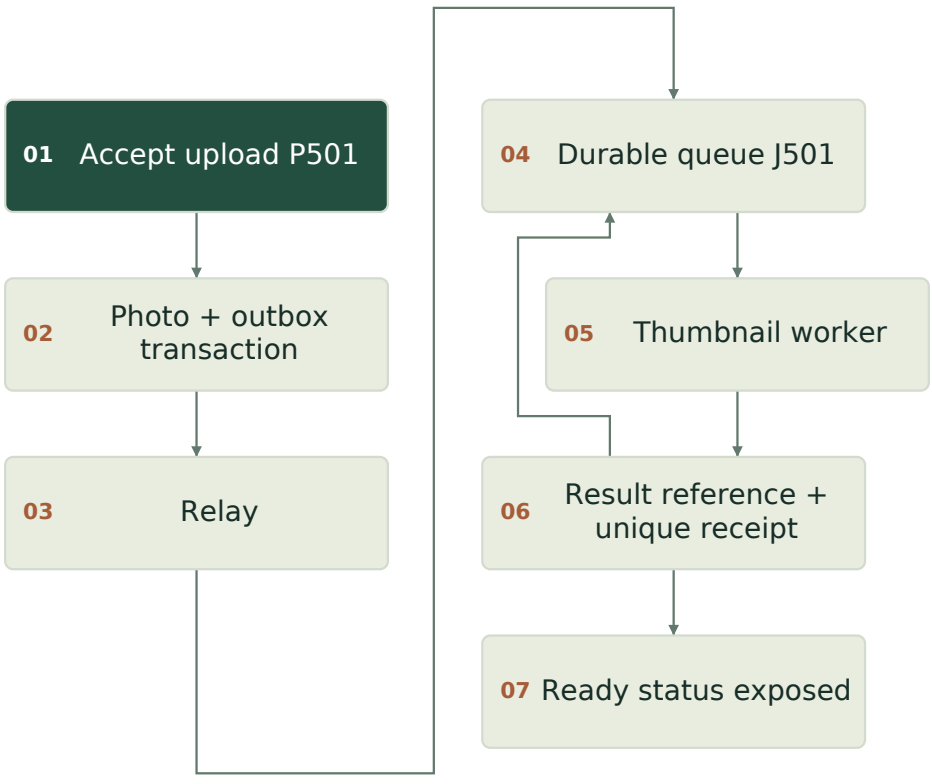
Change data capture (CDC) exports committed database changes to downstream systems, often by decoding the transaction log. A connector takes a consistent snapshot, continues from its matching log position, and checkpoints progress. If a crash occurs after publishing but before checkpointing, the connector can publish a change again; consumers still need replay-safe writes.

CDC can publish an outbox table without application polling. Capturing every table update instead is a different contract: low-level row changes do not necessarily represent a complete business event. Define transaction boundaries, keys, deletion records and schema evolution. In PostgreSQL, a stalled logical replication slot can retain WAL and exhaust storage, so monitor retained bytes as well as connector lag. CDC does not make an external effect atomic with the source transaction.

Interview check: Why retain both an outbox and CDC? The outbox defines the business event within the source transaction; CDC is one transport for publishing it.

WORKED EXAMPLE DIAGRAM

Photo P501 and job intent J501 commit together. The relay can publish duplicates. A worker writes immutable attempt output, then a unique job receipt, current-version check, and authoritative reference share one transaction before queue acknowledgment.



1 -> 2	accept original and processing intention: Accept upload P501 -> Photo + outbox transaction

2 -> 3	read committed outbox: Photo + outbox transaction -> Relay
3 -> 4	publish; duplicates possible: Relay -> Durable queue J501
4 -> 5	lease/deliver J501: Durable queue J501 -> Thumbnail worker
5 -> 6	atomic receipt, version check, and reference: Thumbnail worker -> Result reference + unique receipt
6 -> 4	acknowledge completed work: Result reference + unique receipt -> Durable queue J501
6 -> 7	status becomes ready: Result reference + unique receipt -> Ready status exposed

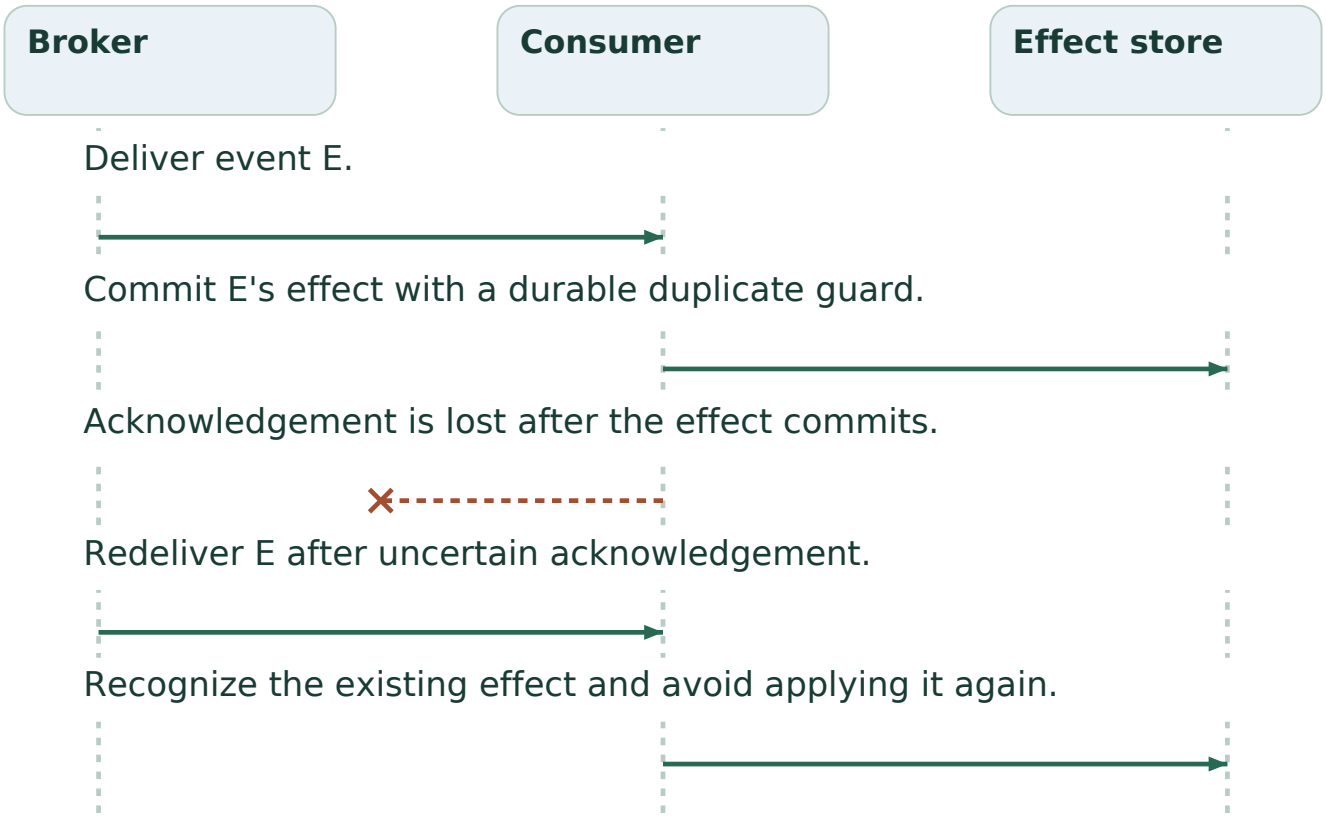
04 / Consumer acknowledgments, duplicate delivery, and idempotent effects

A **consumer acknowledgment** tells the broker that a delivery has been handled and can be marked complete under the queue's contract. The worker must choose that moment carefully: acknowledging before its result is recoverable can lose work after a crash, while acknowledging later allows duplicates that must be safe to handle.

The worker receives J501, whose immutable intent identifies photo P501, its version, and the thumbnail recipe. It creates an immutable output object for this attempt, then commits the authoritative output reference and a receipt for J501 in one database transaction. The receipt is a deduplication record: evidence that this logical operation has a recorded outcome. Only after that commit does the worker acknowledge the queue message.

Acknowledgement must follow the durable effect

Commit the result and its duplicate-detection record together. Acknowledging the message before committing the result can lose work after a crash.



Remember: Effect first, acknowledgement second, replay safely.

Time	Event	Recovery implication
12:00:00.000	P501 and outbox J501 commit	Relay can recover the job
12:00:00.005	Worker receives J501	Job is not yet complete
12:00:00.080	Thumbnail exists; ready record and receipt commit	Effect is recoverable
12:00:00.090	Worker crashes before queue acknowledgment	Redelivery is expected
Later	New worker sees J501 receipt	Return existing outcome and acknowledge

The object-store write and the database transaction still commit separately. The stable logical identity is photo/version/recipe; immutable attempt-specific object keys avoid two concurrent renders overwriting the same bytes. A protected database transaction chooses the authoritative reference. A database receipt alone cannot make an unrelated external API call atomic.

INTERVIEW CRITICAL

Deduplication must commit with the protected result

Checking for a receipt and then writing without a constraint is unsafe: two workers may both see no receipt. Enforce `UNIQUE(job_id)` inside the result transaction. The winner inserts the receipt, checks that the intended photo version is still current, and installs its output reference before committing. If the version is obsolete, record a terminal skipped outcome without replacing the newer reference. A competing duplicate transaction rolls back on the unique conflict, then reads the committed outcome in a new transaction.

Cleanup must coordinate with the transaction that makes the output available to readers. An unreferenced object may belong to an active render that has not committed yet. Keep an attempt record protecting it; cleanup first marks an expired attempt abandoned under the same transactional state that publication checks. An abandoned attempt cannot subsequently publish. Delete only abandoned, unreferenced attempt objects, so a scan that observed no reference cannot race with a later valid commit.

05 / At-most-once, at-least-once, and ordering guarantees

At-most-once handling can avoid repeated attempts by discarding or acknowledging before the effect, but a crash can lose work. At-least-once delivery permits repeats so incomplete or uncertain work can be attempted again. For example, SQS standard delivery explicitly requires duplicate-aware applications.

For J501 we choose at-least-once delivery with an idempotent effect: repeated processing converges on the same recorded thumbnail result. Retain deduplication evidence for the supported retry/replay horizon. Reusing the same job ID for different photo contents must fail or follow a defined versioning rule.

Ordering also needs a scope. If P501 version 3 replaces version 2, a late version-2 job must not overwrite the version-3 ready record. A conditional version check protects that update. Partitioning events by photo can help order their handling, but retries and parallel execution still require a precise rule for applying results.

Delivery/effect promise	What happens after ambiguity	Remaining application responsibility
At most once	No redelivery after the chosen discard/ack boundary	Accept possible lost work
At least once	Delivery may repeat	Deduplicate the effect and define retry/retention limits
Exactly once within a transaction boundary	Result and consumed position commit together	Verify the boundary includes every promised effect

In a retained log, a consumer's **offset** is its recorded position in a partition. Atomically committing that position with new output records prevents one of those facts from advancing without the other. This is useful when consuming one event produces another, but the transaction still has a defined storage boundary.

INTERVIEW CRITICAL

Kafka transactions do not cover arbitrary external effects

Kafka transactions can couple output records and consumed offsets within Kafka when the application follows the transactional protocol and downstream consumers use the appropriate isolation. That does not make a thumbnail object or email provider part of the Kafka transaction. Likewise, bounded retries and dead-letter routing mean an accepted job can end failed; at-least-once delivery is not a guarantee that permanently invalid work eventually succeeds.

06 / Backpressure: calculate queue growth and drain time

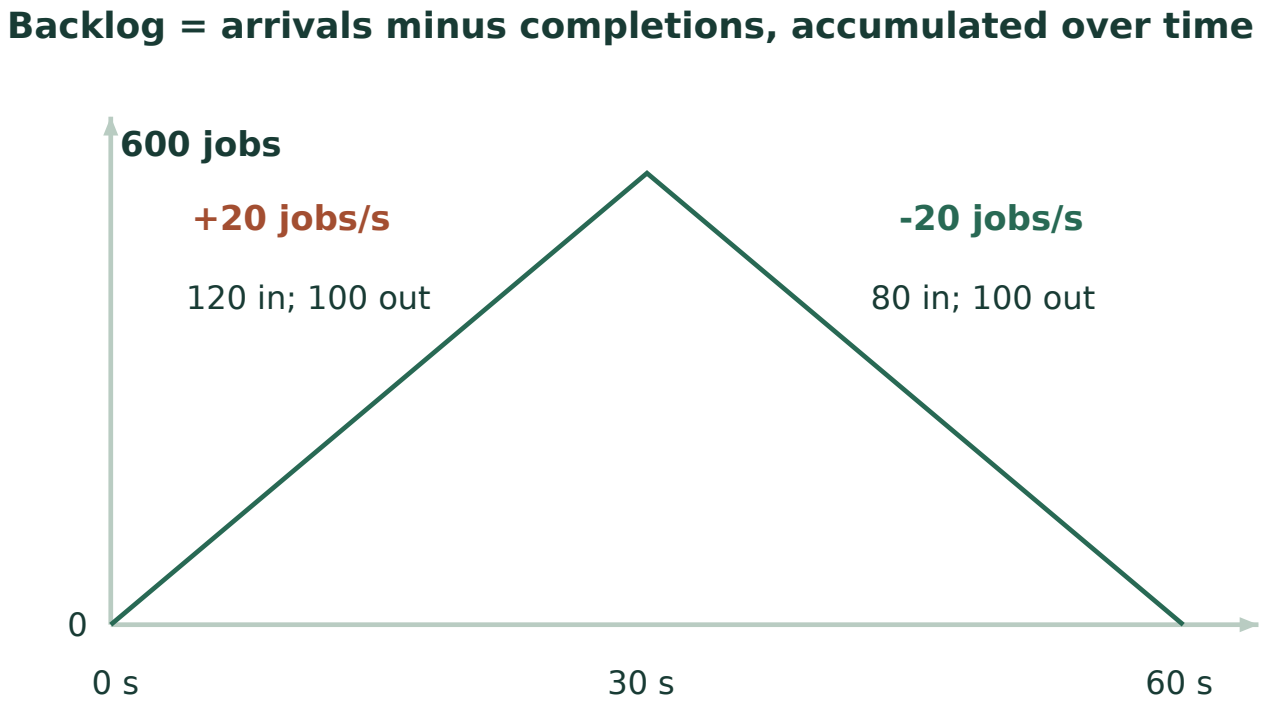
INTERVIEW CRITICAL

Drain a backlog using spare capacity, not total capacity

Assume workers can sustain 400 jobs/second. A burst sends 600/second for 60 seconds, adding `(600 - 400) x 60 = 12,000` waiting jobs. Afterward, arrivals fall to 200/second. Spare processing capacity is 200/second, so draining that backlog takes approximately `12,000 / 200 = 60 seconds`, ignoring changing service times and other overhead.

The queue grows, then drains

Time runs left to right; height is the number of waiting jobs. Rates are constant within each 30-second interval.



After arrivals fall, 600 / (100 - 80) = 30 seconds to drain.

Remember: Drain time uses spare capacity, not the full service rate.

Try from memory: Why does draining take 30 seconds instead of 6?

Answer: New arrivals still consume 80 of the 100 completions/s. Only 20/s is available for the 600 waiting jobs: 600 / 20 = 30 seconds.

If arrivals remain at 400/second, the backlog does not drain. If they stay above 400, it grows. A queue is a buffer, not additional processing capacity.

Backpressure means controlling incoming or concurrent work when downstream capacity cannot keep up. Bound queue size or accepted delay, limit per-tenant demand, and reject or defer new uploads before exhausting durable storage. Retry temporary failures with bounded attempts and randomized backoff. Send permanently invalid images to an explicit failed/dead-letter workflow with diagnostics; retrying malformed bytes forever wastes capacity. Track oldest-job age as well as queue length, because it measures completion delay.

A **dead-letter** destination retains work that exhausted its retry policy or needs intervention, together with enough failure information to inspect it. An operator or recovery process may correct the cause and replay it deliberately. Moving a job there records an unresolved or failed outcome; it does not complete the thumbnail.

Limit work already taken by workers: fetching millions of jobs only moves the backlog into their memory. Cap concurrent render tasks and extend visibility timeouts while valid long jobs run; duplicates remain possible. After an outage, limit replay speed so old retries leave capacity for new work. If job sizes differ greatly, limit estimated resource use as well as job count.

07 / Interview answer: define the exactly-once effect boundary

Interviewer: "Can this queue guarantee thumbnails are processed exactly once?"

Candidate: "I would first distinguish rendering the thumbnail from publishing the result that users can see. J501 can be delivered again after a worker commits the ready record but crashes before acknowledging. I would make output publication safe to repeat and record J501's receipt with the database result, so the retry returns the established outcome.

"I would use an outbox to ensure every accepted photo P501 has a stored job recording the required processing. That relay can also repeat publication, so duplicate handling remains necessary. For overload, I would measure job age and bound admission. A 600-per-second burst cannot be solved indefinitely by workers that process 400 per second."

This answer traces both handoffs: accepting work into the background system and committing the worker's result. It defines observable pending, ready, and failed states. The idempotency-retries-and-timeouts and distributed-transactions-and-workflows chapters develop the related boundaries further.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is a message queue? Define producer, consumer, asynchronous completion, and backpressure.

Model answer

A producer submits a message; a broker stores and delivers it; a consumer processes it. A message queue buffers that work so its execution can happen asynchronously, after the initial request has durably accepted it. Accepted and completed are different states. A photo upload can return a job ID while its thumbnail is still pending.

Backpressure limits incoming or concurrent work when downstream processing cannot keep up. If arrival is 600 jobs/s and workers can process 400 jobs/s, the backlog grows by 200 jobs/s. Bound admission or increase processing capacity instead of treating an unbounded queue as a solution. For reliable handoff, an outbox can commit the photo and job intention together; consumers still need duplicate-safe effects because delivery or acknowledgment can repeat.

Interviewer follow-up

Why not keep the HTTP request open until completion?

"That may be reasonable for short bounded work, but variable processing and bursts tie up request capacity and make retries harder. Our asynchronous contract separates those concerns."

What the answer must demonstrate: Acceptance and completion are different promises.

02 / FOUNDATION

How does a work queue differ from a retained event log?

Model answer

"The work queue assigns J501 and manages retry eligibility. A retained log lets consumers replay an ordered sequence from their positions, possibly in independent groups. I would choose based on work assignment versus replay needs and inspect the real retention and delivery semantics."

Interviewer follow-up

Does pub/sub automatically mean durable history?

"No. Fanout to subscribers and retention are separate properties. I must state whether offline subscribers can recover missed events."

What the answer must demonstrate: Do not infer guarantees from product-category names.

03 / APPLIED

A database commits photo P501, then the process dies before publishing its job J501. How does a transactional outbox close that gap?

Model answer

"I store the photo and an outbox intention in one transaction. A relay can find committed unpublished intentions after recovery. This prevents P501 being accepted without a durable record that processing must happen, while avoiding a false claim of one transaction across database and broker."

Interviewer follow-up

Could the relay still publish twice?

"Yes. It might publish and crash before marking completion, so workers must recognize duplicate J501 deliveries."

What the answer must demonstrate: Outbox solves a missing handoff, not every duplicate.

04 / APPLIED

The worker commits the result and crashes before acknowledging. Walk the retry.

Model answer

"The job is delivered again after the broker did not record completion. A worker reads the durable job receipt and returns the established outcome. If two duplicate workers race before either receipt exists, a unique job-ID constraint and one result transaction choose the winner; the loser rolls back and reads that winner's outcome. A preflight receipt lookup alone would not prevent two concurrent effects."

Interviewer follow-up

What if the receipt was written before the effect?

"A crash could make later workers skip work that never completed. Evidence of completion must be committed with the recoverable effect."

What the answer must demonstrate: Deduplication placement determines correctness.

05 / FOLLOW-UP

Does a consumer's local deduplication receipt make an external API call exactly once?

Model answer

"No. A remote object write is outside the result database transaction. I give each render attempt an immutable object key and use the stable photo/version/recipe identity for the logical job. The database transaction chooses one reference and records its receipt; it never lets a duplicate overwrite the chosen bytes. Cleanup cannot delete an active attempt that may still publish. A different provider effect needs that provider's idempotency contract or reconciliation of unknown outcomes."

Interviewer follow-up

Can you just write 'done' before the remote call?

"No. If the process dies after recording done but before the remote call, recovery can suppress the only attempt. I need a durable state machine that distinguishes intent, an uncertain external outcome, and confirmed completion, plus a safe retry or reconciliation path."

What the answer must demonstrate: Local atomicity does not automatically include a remote effect.

06 / APPLIED

A thumbnail job for photo version 2 finishes after version 3 is published. What should the result commit check?

Model answer

"The authoritative ready update checks which photo version it belongs to. A stale version-2 result may be retained or cleaned up, but it cannot replace the version-3 reference. Ordering events by photo can help, yet the conditional update protects against retry and completion reordering."

Interviewer follow-up

Can J501 be reused for different image bytes?

"Not silently. I would bind it to the request identity/version and reject conflicting reuse or create a distinct job."

What the answer must demonstrate: Stable identity must represent stable intent.

07 / APPLIED

For 60 seconds, arrivals are 600 jobs/s and workers complete 400/s. Arrivals then fall to 200/s. Calculate backlog growth and drain time.

Model answer

"Six hundred arrivals minus four hundred completions gives two hundred extra jobs per second. Over sixty seconds that is twelve thousand jobs. When arrivals fall to two hundred, the spare capacity is two hundred, so recovery takes about sixty seconds under stable-rate assumptions."

Interviewer follow-up

What if arrivals remain at four hundred?

"There is no spare capacity, so the accumulated backlog remains. I need extra processing capacity or lower arrivals to reduce it."

What the answer must demonstrate: Use service rate minus arrival rate when estimating drain time.

08 / FOLLOW-UP

J501 contains an image that can never be decoded. Should it retry forever?

Model answer

"No. I would classify the permanent failure, stop after a bounded policy, store diagnostics, and expose a failed state or dead-letter workflow. Infinite retries consume capacity and can delay valid work. Any operator replay should be controlled and preserve job identity and version rules."

Interviewer follow-up

Which alert reflects the client's experience most directly?

"Oldest pending-job age or completion-latency violations, alongside failure rate. Queue length alone does not tell me how long the client's job has waited."

What the answer must demonstrate: Bound both retry effort and user-visible delay.

Build the answer yourself

BLANK-PAGE EXERCISE / 18 MINUTES

Trace job J501 through upload acceptance, outbox publication, thumbnail creation, and queue acknowledgment. Crash one component between every adjacent pair of steps.

- Store a processing job for every accepted photo.
- Commit the selected thumbnail reference and its unique job receipt in the same database transaction.
- Explain what happens after a permanent processing failure.
- Calculate backlog and drain time for the stated burst.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What does the outbox guarantee for P501?

The photo record and intention to publish J501 commit together; a relay can retry publication after failure.

Save the photo record and pending job together.

Why can J501 arrive again after success?

The worker may commit its result but fail before the broker records acknowledgment.

Result committed, receipt on the wire lost.

How long does a 12,000-job backlog take to drain at capacity 400 and arrivals 200 per second?

About 60 seconds under stable-rate assumptions: 12,000 divided by 200 spare jobs/second.

Drain with spare capacity, not total capacity.

Why should a version-2 job not overwrite version 3?

Delivery order and completion order can differ; condition the authoritative update on the intended photo version.

An old job cannot replace a newer photo version.

Summary and interview notes

A durable queue separates acceptance from execution and absorbs bounded bursts. Reliable completion depends on recovering the database-to-broker handoff, preventing a repeated job from changing the published result twice, and keeping admitted work within processing and storage capacity.

Remember these points

• A transactional outbox commits the business record and publication intention together; the relay can still publish duplicates.

• Commit the result and a uniquely constrained job receipt together before acknowledging delivery.

• Immutable attempt outputs and one authoritative reference prevent duplicate renders from overwriting selected bytes.

• Ordering is scoped, often per key or partition; a version check prevents old work replacing newer state.

• Backlog drain uses spare capacity: 12,000 jobs / (400 - 200 jobs/s) = 60 seconds.

Interview tips

• Crash the producer between database and broker, then crash the consumer between result commit and acknowledgment.

• Make two workers check an absent receipt simultaneously; show the unique constraint or transaction that resolves the race.

• Ask what an exactly-once claim includes: broker records, a database effect, or an external provider.

Important qualifications

• Visibility timeout is a retry mechanism, not proof the previous worker stopped.

• Object cleanup must exclude attempts still authorized to publish; checking for a missing reference once is insufficient.

• Retention, retry limits, and dead-letter policy bound recovery; permanent invalid jobs need an explicit failed outcome.

Technical references

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Verified description of the database/event dual-write gap and duplicate-aware consumers.
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Amazon SQS: At-least-once Delivery
Concrete official example of a queue contract that allows repeated delivery.
https://docs.aws.amazon.com/AWSSimpleQueueService/latest/SQSDeveloperGuide/standard-queues-at-least-once-delivery.html

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https://kafka.apache.org/41/design/design/

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FOUNDATIONS / 20

Distributed transactions and sagas

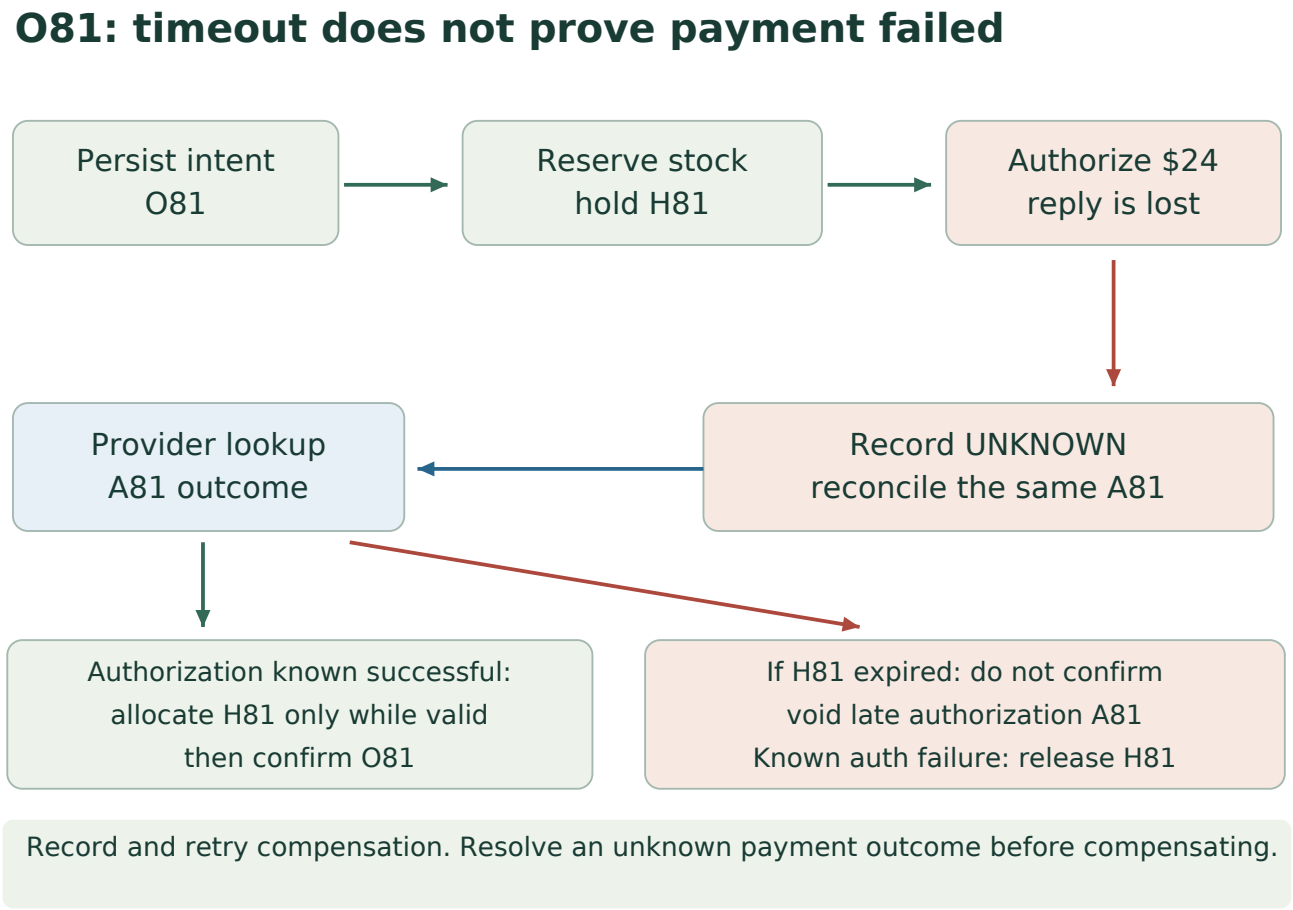
DEFINITION

A distributed transaction is one transaction whose operations span multiple databases or transactional resource managers. An atomic-commit protocol such as two-phase commit coordinates their commit-or-abort outcome. A saga instead coordinates a business operation through committed local transactions and explicit compensating actions.

Why it matters: A local database rollback cannot undo a payment or reservation already committed by another service.

Saga state transitions and payment reconciliation

A payment timeout is an unknown outcome, not proof of failure. Reconcile before retrying or compensating.



Worked example

Order O81 needs 2 mugs and a $24 authorization. Stock is held for 120 seconds. If the hold expires before a delayed authorization succeeds, the workflow voids the authorization rather than confirming an order without stock.

Key takeaways

• Keep related changes in one local transaction when the same database can atomically commit them.

• 2PC coordinates commit or abort; isolation still needs its own concurrency protocol.

• A saga records partial progress, unknown outcomes, and recoverable compensation.

Read the visual model

1. Persist order intent, reserve inventory, and call payment with one stable attempt identity.

2. If the payment response is lost, record UNKNOWN and query or retry that same identity.

3. When authorization succeeds, atomically allocate H81 only if still valid, then confirm O81. A late authorization after hold expiry must be voided. If terminal failure is known, release the hold.

4. A compensating action can itself fail and needs durable retry; a saga is not simultaneous rollback across services.

sagas • two-phase commit • outbox • compensation • workflows

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Distinguish atomic commit from isolation and from business compensation.

• Model a durable workflow with stable operation identifiers and explicit uncertain states.

• Handle delayed success after a resource hold expires without overselling or duplicating an external effect.

Useful foundations: Transaction isolation; Message queues, event logs, delivery guarantees, and backpressure; Idempotency, retries, and timeouts

8 interview questions with model answers and answered follow-ups.

01 / Distributed transaction: definition and local boundaries

A **distributed transaction** is one transaction whose operations span multiple databases or transactional resource managers, such as an order database and an inventory database. An **atomic-commit protocol**, such as two-phase commit, coordinates their commit-or-abort outcome. A **saga** instead coordinates a business operation through committed local transactions and explicit compensating actions. A local database transaction can atomically change its own records, but cannot automatically undo an HTTP request that already succeeded at another service. Crossing independently failing systems therefore requires a protocol for partial completion.

For example, order O81 requests two MUG9 items at $12 each. Inventory starts at five, and hold H81 reserves two units for 120 seconds. Payment action A81 authorizes $24: authorization reserves funds and is distinct from capture. The order can become confirmed only after inventory allocation and the required authorization are established; partial progress remains pending.

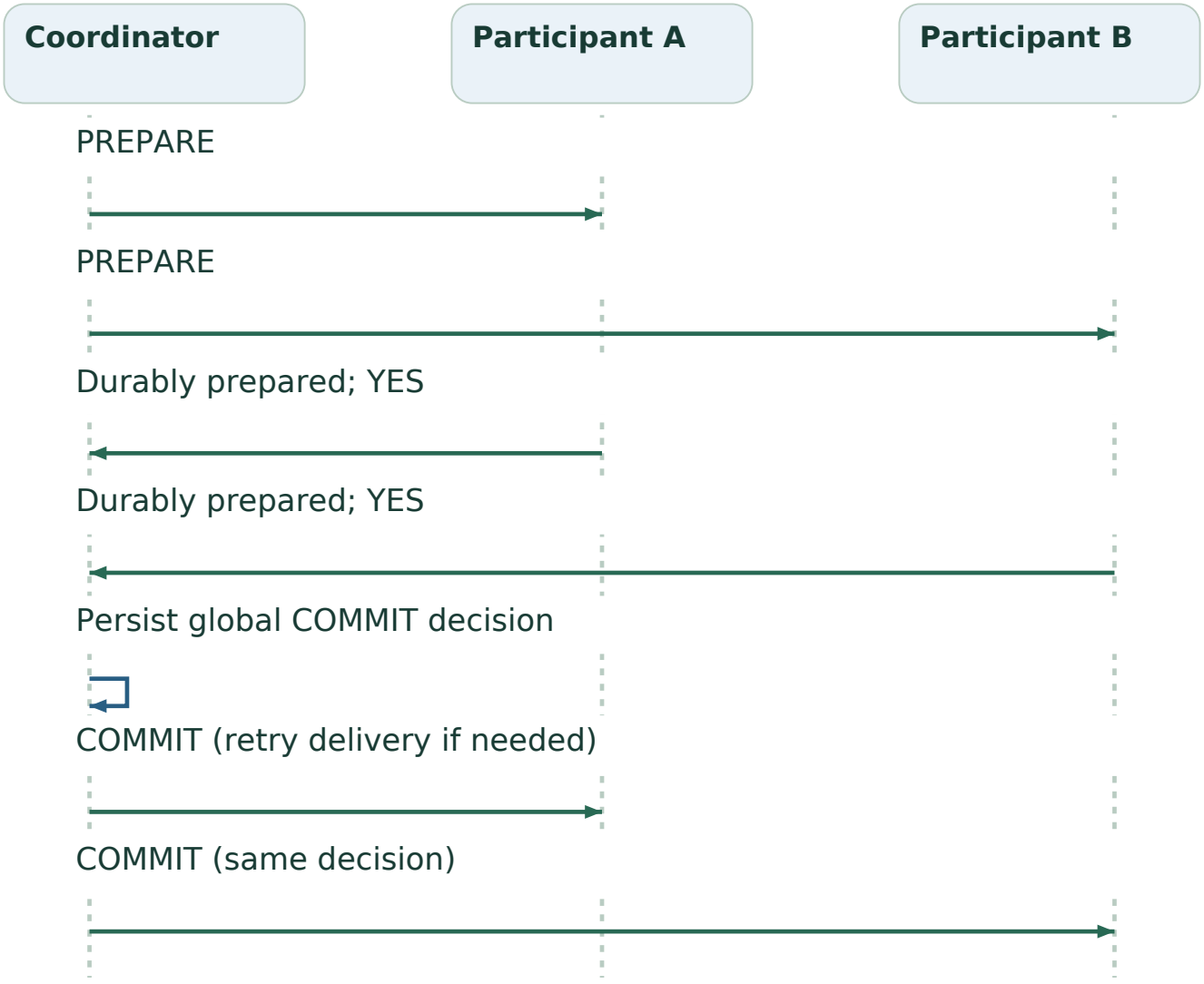
If inventory and orders share one database and ownership boundary, a short transaction is the simplest option. Splitting tables into services prematurely creates a harder problem. We study the split because the provider is external and inventory may have a separate owner, not because every application needs distributed transactions.

02 / Two-phase commit: prepare and commit or abort

Two-phase commit (2PC) makes participating databases agree to commit or abort together. A coordinator records the final decision. First it asks each database to prepare. A database voting "yes" durably saves enough state to finish later and keeps the necessary locks or other protections. If all vote yes, the coordinator durably records "commit" and tells them to commit; otherwise the protocol chooses abort. Each participant must support preparing and honoring that decision.

Two-phase commit has a prepared middle state

An abort vote leads to abort. A prepared participant cannot safely invent the global decision when the coordinator is unreachable; classic 2PC can block.



Remember: Prepare votes; a durable decision; then deliver it.

For O81, suppose the order and inventory databases both support 2PC. They prepare their changes, then follow the same commit-or-abort decision. This prevents one from committing while the other aborts. Their concurrency controls must still provide the required isolation; atomic commit alone does not make all cross-database transactions serializable.

INTERVIEW CRITICAL

A prepared participant cannot simply time out and abort

The cost appears when the coordinator disappears after preparation. A participant that voted yes cannot safely decide to abort merely because its timer expired: a commit decision might exist elsewhere. Traditional 2PC can block while the outcome is recovered. Prepared work can retain locks and other resources. Replicating coordination state improves recovery, but does not eliminate every dependency or partition tradeoff.

03 / Saga: local transactions and compensation

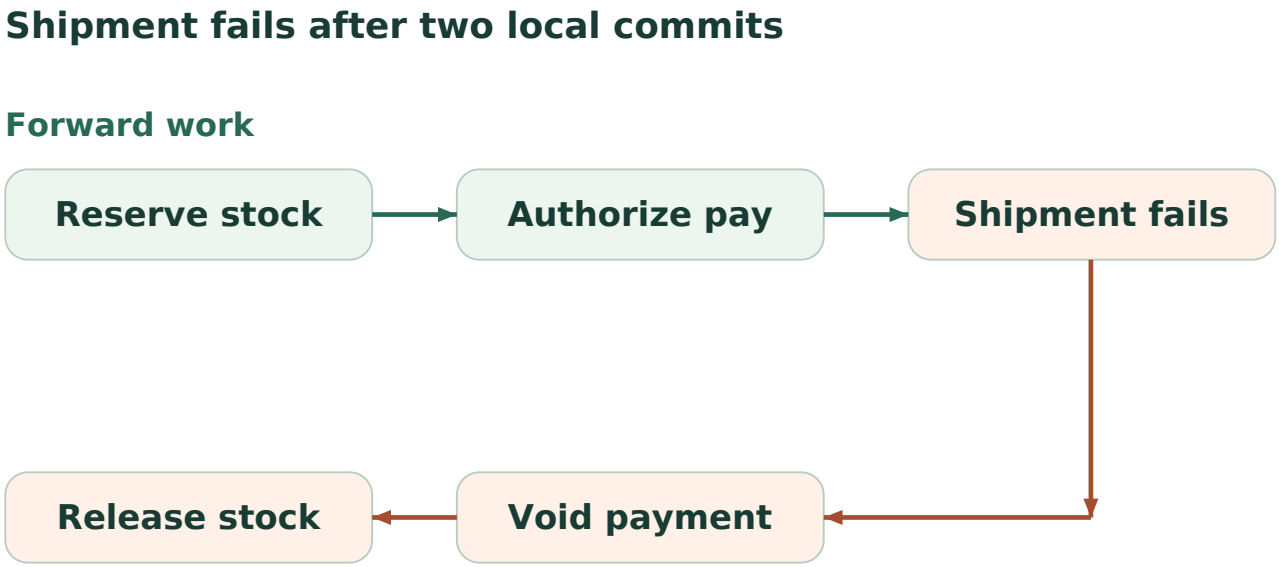
INTERVIEW CRITICAL

Compensation does not erase committed history

A saga is a sequence of committed local steps, with compensating actions when the business operation cannot finish. A compensation is new work that repairs a business outcome; it is not time travel. Other transactions may have observed the intermediate state. Releasing a stock hold compensates a reservation; voiding an authorization compensates a funds reservation. A sent email cannot be unsent.

Compensation travels back through completed work

Green arrows move the workflow forward. Rust arrows perform compensating business actions after a definite failure.



Earlier commits happened. Compensation performs new business actions.

Each action needs safe retries and an explicit unknown-outcome policy.

Remember: A compensation is another action, not erasure of a past commit.

Try from memory: Does voiding payment mean the authorization never occurred?

Answer: No. The authorization occurred and committed. Voiding it is a new action with its own outcome and recovery rules.

A **durable workflow** stores the business operation's progress so another worker can continue after a crash. Model that progress as a **state machine**: named states and allowed transitions, such as awaiting authorization, ready to allocate, or cancellation pending. Each transition records what happened and which action is now permitted.

Our provider does not participate in the database's prepare/commit protocol, so I choose a durable workflow. The order coordinator records O81's state, the inventory hold identifier H81, and authorization operation A81. Each transition checks the expected previous state and records the next outgoing intent in the same local transaction.

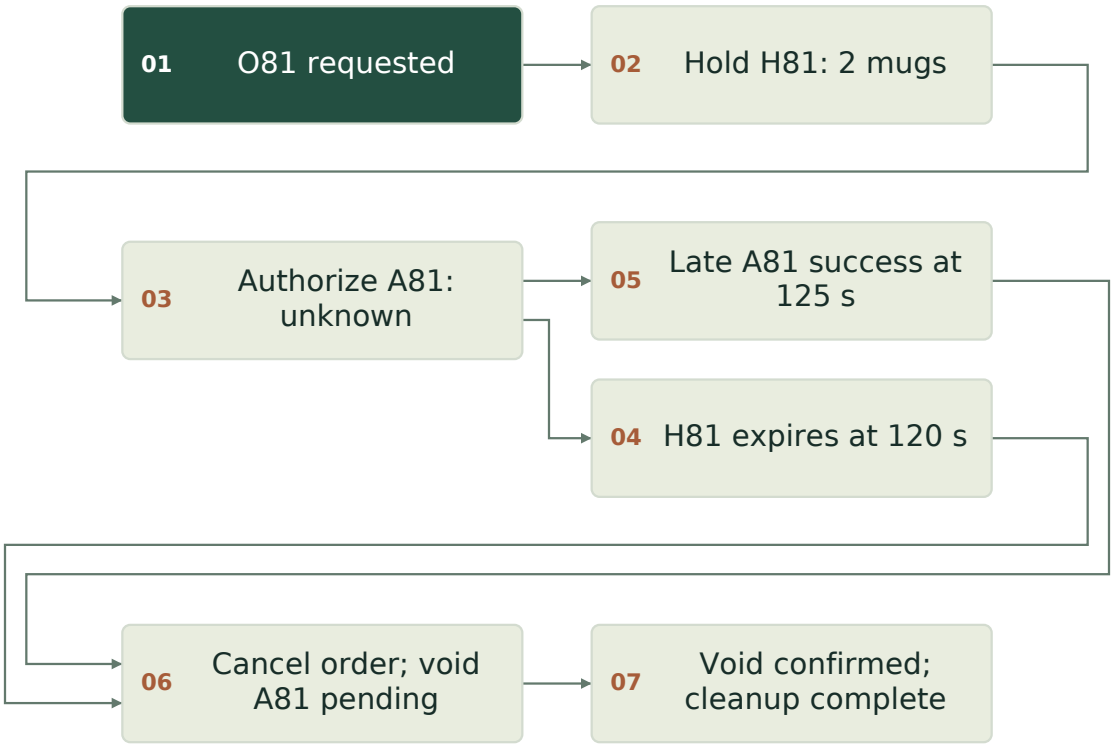
Approach	What it offers	Cost or limitation
One database transaction	One atomic local change	All protected data must fit that ownership boundary
2PC	One commit/abort decision across capable participants	Prepared resources and recovery dependency

Approach	What it offers	Cost or limitation
Saga/workflow	Recoverable progress across independent APIs	Intermediate states and explicit compensation

The workflow needs durably stored state and a service responsible for advancing it. It does not need one process to remain alive throughout: a replacement worker can resume from the stored state.

WORKED EXAMPLE DIAGRAM

After both hold expiry and known late authorization success, cancellation needs a durable compensating void. A lost void response leaves cleanup pending until that operation is reconciled.



1 -> 2	reserve: O81 requested -> Hold H81: 2 mugs
2 -> 3	send once logically: Hold H81: 2 mugs -> Authorize A81: unknown
3 -> 4	deadline passes: Authorize A81: unknown -> H81 expires at 120 s
3 -> 5	reconcile by A81: Authorize A81: unknown -> Late A81 success at 125 s
4 -> 6	cannot allocate: H81 expires at 120 s -> Cancel order; void A81 pending
5 -> 6	compensating action: Late A81 success at 125 s -> Cancel order; void A81 pending
6 -> 7	retry or reconcile same void: Cancel order; void A81 pending -> Void confirmed; cleanup complete

04 / Successful saga: reserve, authorize, allocate, confirm

At time 0, inventory conditionally creates H81 for two mugs: available stock becomes three, and H81 expires at time 120. At time 1, the workflow asks the provider to authorize $24 using stable operation A81. At time 2, it records authorization success. It next asks inventory to convert H81 into an allocation for O81, only if the hold still exists and is valid. Inventory performs that check and transition atomically.

If allocation succeeds, a later coordinator transaction records the order as confirmed and publishes its event through an outbox. If the coordinator crashes after allocation but before recording confirmation, retrying the allocation request with O81 returns the existing allocation. It must not remove another two mugs. The same rule applies to authorization A81.

A distributed workflow is therefore a state machine: a set of allowed states and transitions. "Already allocated to O81" is a meaningful result. A vague boolean success loses the identity needed for recovery. The confirmation contract should also specify authorization validity and any later capture/shipping steps; those are separate transitions with their own failure handling.

Success and cancellation can race, so each state change must atomically check that the order or hold is still in a state that allows it. An allocation request names the order and hold; the inventory owner atomically returns the existing allocation, converts a still-valid hold, or rejects expiry/cancellation. The coordinator accepts confirmation only from its expected pending state. If cancellation won locally but allocation had already committed remotely, recovery records that allocation and releases it through an idempotent compensating transition; simply ignoring the late reply would strand stock. Start shipping only after checking that the order is confirmed and remains eligible for fulfillment.

05 / Unknown outcomes: lost replies and expired reservations

Now let the authorization response disappear. The provider may have processed A81 even though the coordinator received nothing. The workflow records `authorization_unknown`, queries by A81 or retries under the provider's idempotency contract, and avoids inventing a new authorization identifier.

Time	Durable or external fact	Correct reaction
0 s	H81 reserves two mugs until 120 s	O81 remains pending
1 s	A81 sent; response lost	Record uncertainty and reconcile
120 s	H81 expires before allocation	Two mugs become available again
125 s	Reconciliation finds A81 succeeded	Do not confirm from this fact alone
After 125 s	Allocation is no longer possible through H81	Void A81 and finish cancellation

INTERVIEW CRITICAL

Late payment success does not restore expired inventory

The late result does not resurrect the expired hold. A competing order may now own those mugs. Inventory must reject conversion of H81, and the workflow must conditionally reject late confirmation after cancellation has won. Callback handlers require the same state checks as ordinary workers. The expiry is an inventory fact enforced at its authority, not a browser timer or a hopeful coordinator assumption.

06 / Saga recovery: compensation, retries, and outbox

Suppose voiding A81 times out too. Marking O81 simply "cancelled" and forgetting it would hide unfinished work. Record cancellation requested, authorization cleanup pending, and a stable void operation identifier. Retry or query that operation, and retain enough evidence for an operator to resolve a permanently unclear provider outcome. The client can see that the order will not ship while the authorization release is still processing.

For every step, specify how recovery works if a process crashes: before the local commit there is no recorded intent; after commit a worker can rediscover it; after remote success but before recording the result, a stable key or status query resolves ambiguity. The outbox closes the local database/publication gap, but it does not make the provider part of the local transaction.

Compensation is not always a valid business remedy. Shipping an irreplaceable item twice cannot be made correct merely by scheduling a refund. Protect scarce inventory with conditional allocation and gate irreversible steps carefully. If the business rule forbids exposing partial completion and no compensating action can repair it, reconsider which service owns the data or use participants that can commit the required changes together.

INTERVIEW CRITICAL

Automatic retries are bounded by provider retention

A provider's retry window is part of the protocol. Retain the local operation/result long enough for client retries and recovery, and record the provider's idempotency retention and lookup rules. Once the provider may have forgotten an unknown operation, resending its old key can create another effect. Stop automatic resubmission and use reconciliation or an explicit exception process instead.

For implementation, a small workflow can use a transactional state table, an outbox and leased workers. A durable workflow engine such as Temporal provides persisted event history and replay, but workflow code must follow its deterministic execution constraints. External calls belong in retryable activities with stable effect identities; the engine does not give a third-party API transactional rollback or unlimited deduplication.

07 / Orchestration versus choreography and interview explanation

In an interview I would say: "O81 has a durable coordinator record, and each remote step uses a stable operation identifier. Inventory owns the hold's expiry and conversion. The order remains pending while authorization is uncertain. After the hold expires, a late authorization triggers voiding, not confirmation. Every outgoing step is recoverable from an outbox, and every incoming result is checked against the current workflow state."

An orchestrated workflow puts these transitions in one explicit coordinator. An event choreography distributes reactions among services; it may reduce central coupling but makes the overall progress and compensation path harder to inspect. Either approach needs ownership of timeouts, retries and terminal outcomes.

Measure the age and count of stuck pending orders, unknown external outcomes, failed compensations and expired holds. Alert on old unfinished work, not only HTTP errors. A successful request log does not prove that the multi-step business operation finished. The design is complete when another worker can recover O81 from persisted facts without guessing what the previous worker intended.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What problem does a distributed transaction or saga solve?

Model answer

A distributed transaction spans multiple transactional participants and needs a coordinated commit-or-abort outcome. A saga addresses a related business need through separately committed local transactions and compensation. For O81, creating an order, reserving 2 mugs, and authorizing $24 can succeed or fail separately. A capable 2PC system coordinates one commit decision; a saga records local progress and compensates failures. I first ask whether the work could remain in one simpler database transaction.

Interviewer follow-up

When would you avoid a saga?

When the invariant and data already fit one database ownership boundary. A saga adds visible intermediate states and recovery work. Putting separate databases in one application process does not make them one transaction domain.

What the answer must demonstrate: Identify the actual independent commit boundaries.

02 / FOUNDATION

What does a yes vote in 2PC mean?

Model answer

"The participant has prepared enough durable state and retained the necessary protections to honor a later commit decision. It is stronger than saying the request looks valid right now."

Interviewer follow-up

Why can coordinator failure block progress?

"A yes voter may not know whether commit was already decided, so it cannot safely invent an abort solely from a timeout."

What the answer must demonstrate: Prepared is a durable protocol state, not a best-effort check.

03 / FOLLOW-UP

Does 2PC guarantee serializable transactions?

Model answer

"2PC coordinates the final commit or abort outcome. Isolation depends on the concurrency-control protocol over the affected reads and writes. I would not claim serializability just because every participant votes on one decision."

Interviewer follow-up

What would you inspect?

"I would inspect locking or validation across participants and show whether concurrent transactions admit a valid serial order."

What the answer must demonstrate: Atomic commit and isolation solve different parts of correctness.

04 / APPLIED

A payment authorization A81 times out with no known result. What should a durable workflow do next?

Model answer

"Save the outcome as unknown and use A81 to check with the provider. I do not create A82 just to retry: A81 may already have succeeded."

Interviewer follow-up

What if the provider has neither idempotency nor a status query?

"The ambiguity cannot be eliminated by our local database alone. I need another provider-supported reconciliation mechanism or a product process that explicitly handles unresolved outcomes."

What the answer must demonstrate: Do not promise exactly-once effects across an unsupported boundary.

05 / APPLIED

An inventory hold expires at 120 seconds and payment authorization succeeds at 125. Can the order be confirmed?

Model answer

"Not from the authorization alone. Inventory must atomically verify or convert a valid hold, and H81 is expired. I keep confirmation conditional and void the authorization while cancelling the order."

Interviewer follow-up

What if a callback races with cancellation?

"Both transitions check the durable workflow state, and inventory independently checks the allocation condition. A late callback cannot overwrite a terminal cancellation."

What the answer must demonstrate: Two authorities must enforce their own conditions.

06 / APPLIED

What happens if the compensating void also fails?

Model answer

"The cancellation has an outstanding cleanup state with a stable void identifier. A worker retries or queries it, and an age-based alert exposes work that cannot finish automatically."

Interviewer follow-up

Can you report that no authorization exists yet?

No. The order can be blocked from fulfillment while authorization cleanup remains pending. A timeout does not prove the void failed, and retrying after the provider's deduplication window expires may create a different external effect.

What the answer must demonstrate: Do not hide unfinished compensation behind a terminal label.

07 / FOLLOW-UP

What guarantee does a transactional outbox add to a distributed workflow?

Model answer

"It atomically records the local state transition and the intent to send the next message. After a crash, the relay can find that intent. The relay may publish twice, so consumers still need idempotent handling."

Interviewer follow-up

Does it atomically commit the provider's authorization?

"No. That remains a remote effect whose uncertain outcome must be reconciled separately."

What the answer must demonstrate: Keep the outbox guarantee within its actual transaction boundary.

08 / APPLIED

Would you use orchestration or choreography for an order workflow with inventory holds, payment authorization, and compensation?

Model answer

"I would start with an explicit coordinator because the order's deadlines, compensation and user-visible status form one workflow that operators must inspect. Services still own inventory and authorization details."

Interviewer follow-up

When could choreography fit?

"A few independent reactions to a completed fact, such as analytics and notification, may work well as subscribers. I would still assign ownership for failures and avoid an implicit cycle of events nobody can reconstruct."

What the answer must demonstrate: Explain operational ownership instead of declaring one style universally better.

Build the answer yourself

BLANK-PAGE EXERCISE / 18 MINUTES

Draw O81's workflow through inventory hold, authorization, confirmation, cancellation and recovery. Inject a crash after every remote success and a late authorization after hold expiry.

- Distinguish a timeout from a confirmed rejection.
- Persist each transition and outgoing intent atomically.
- Give every retried effect a stable identifier and conditional state rule.
- Show who retries compensation and how unresolved work becomes visible.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What does a remote timeout prove?

Only that the caller did not receive a timely answer; the remote effect may already have succeeded.

Timeout means unknown

Can a prepared 2PC participant simply time out and abort?

After voting yes it must learn a safe final decision; unilateral timeout abort can contradict an existing commit decision.

Prepared means promised

Is compensation a rollback?

It is a new business action after earlier steps committed, so intermediate observations and irreversible effects remain.

Repair forward, not rewind

What must survive a worker crash halfway through checkout?

The current workflow step, stable IDs for remote actions, saved pending requests and rules for advancing state safely. A replacement worker can then check uncertain results and continue.

Save progress -> retry the same action -> check the outcome.

Summary and interview notes

Keep related changes in one local transaction when possible. Across databases, use atomic commit if participants support it, or a saga that saves progress after each local step. A saga must recover uncertain results and perform compensating actions when later steps fail.

Remember these points

• 2PC coordinates one commit-or-abort outcome; it does not by itself prove cross-participant isolation.

• A prepared yes voter cannot unilaterally abort merely because the coordinator timed out.

• Saga steps commit locally, so compensation is new business work and can fail too.

• Save an uncertain action as UNKNOWN and reuse its stable ID while checking its result. Do not invent a second action because the first reply was lost.

• Late payment success must not revive an expired hold. Check the current reservation state atomically when allocating or cancelling.

Interview tips

• Draw one crash after remote success but before saving its reply, then show recovery from persisted facts.

• Show the normal path, timeout path and failed-compensation path on the same state machine.

• Before selecting a saga engine, ask whether keeping the related records in one database would let a local transaction satisfy the requirement.

Important qualifications

• An outbox atomically records local state and sending intent; it does not atomically perform the remote effect.

• Provider idempotency retention limits automatic retry safety; a durable workflow engine cannot extend that external contract.

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https://www.cs.cornell.edu/andru/cs711/2002fa/reading/sagas.pdf

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PostgreSQL: PREPARE TRANSACTION
Prepared state retains locks and requires an external transaction manager to resolve it.
https://www.postgresql.org/docs/current/sql-prepare-transaction.html

AWS: Transactional Outbox Pattern
Verified reference for atomically recording a state change and its publication intent. All order timings are hypothetical.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

Temporal: Workflow Execution
Persisted event history and replay support durable progress; application rules and external-effect contracts remain explicit.
https://docs.temporal.io/workflow-execution

Temporal: Activity Definition
Activities contain external work and must be designed for retry and idempotency.
https://docs.temporal.io/activity-definition

FOUNDATIONS / 21

Real-time communication: polling, long polling, SSE, and WebSocket

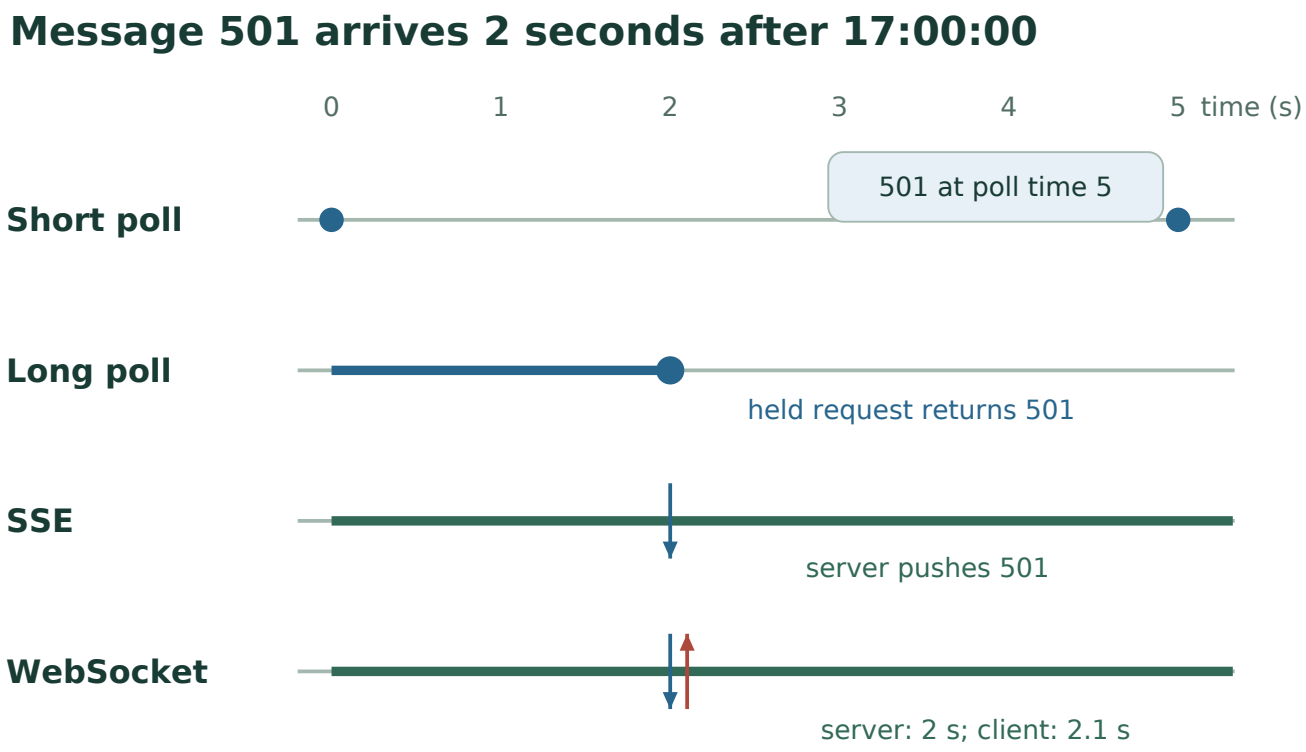
DEFINITION

Real-time application communication delivers updates with a product-defined small delay. Polling repeatedly asks for changes; long polling holds a request until data or timeout; SSE streams server-to-client events over HTTP; WebSocket supports messages in both directions over a persistent channel.

Why it matters: A chat, dashboard, or live notification screen must learn about server changes without a manual page refresh. The transport choice changes latency, idle traffic, connection state, and recovery work.

Polling, long polling, SSE, and WebSocket

Illustrative timing omits network and processing delay. The transports differ in request direction and connection lifetime; reconnect still needs a durable event cursor.



Reconnect: request events after 500; deliver 501 again safely if needed.

Worked example

Message 501 arrives at 17:00:02. A client polling every five seconds might receive it at 17:00:05. A waiting long poll, open SSE stream, or WebSocket can deliver it immediately after processing and network delay.

Key takeaways

- Choose by direction, frequency, and acceptable delay, not by the word real-time.
- An open connection does not provide durable history or exactly-once delivery.
- Reconnect with a cursor and deduplicate messages; define how expired history is recovered.

Read the visual model

1. With polls at time 0 and 5, an event at time 2 waits three seconds for the next poll.

2. Long polling holds a request until an event or timeout. SSE streams server-to-client events. WebSocket sends message 501 at time 2 seconds and allows a client reply at 2.1 seconds on the same persistent channel. Network and processing delays are omitted from this illustrative timeline.

3. None of these transports alone makes delivery durable or exactly once. Resume after message 500 and deduplicate event 501.

HTTP • polling • long polling • WebSocket • SSE

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Describe the request lifecycle and direction of all four update techniques.
- Compare latency and request overhead using the receiving client's message timeline.
- Design authenticated resumption and bounded buffers after a connection fails.

Useful foundations: HTTP APIs and request lifecycle; Replication and durability

8 interview questions with model answers and answered follow-ups.

01 / What does real-time communication mean?

Real-time communication in these interviews means delivering updates quickly enough for the product, such as chat messages appearing within a fraction of a second. It is not a hard real-time guarantee that every deadline is mathematically bounded. First name the acceptable delay and whether traffic is one-way or two-way.

The four common choices are **short polling** (repeat requests), **long polling** (hold one request until an update), **server-sent events or SSE** (keep a server-to-client HTTP event stream open), and **WebSocket** (exchange messages in both directions on one persistent channel). All still need authentication, reconnection, and a policy for missed updates.

A live update needs both a way to transmit messages and rules for storing, acknowledging, and recovering them. In this example, a receiving client has processed every message through ID 500 and saved that progress. We call 500 its **last-applied cursor**, the position from which it can safely resume. The server durably stores message 501 at 17:00:02. Compare how polling, long polling, SSE, and WebSocket deliver that new event; then handle reconnection independently of the transport.

An ordinary HTTP exchange begins when a client asks for something and ends when the server returns a response. The receiving client can request messages after 500, and the server can return an empty list if none

exist yet. A later server event does not automatically produce another ordinary response after that exchange has finished.

HTTP requests can reuse an existing network connection; a new request does not always mean a new TCP or TLS setup. The central distinction in this lesson is the lifecycle of requests and application messages. Our timestamps, five-second polling interval, and client counts are explicit example assumptions, not measurements of a real messenger.

02 / Short polling: periodic requests and delay

With periodic Ajax polling, browser code repeats an HTTP request at a fixed interval. "Ajax" here means the page requests data asynchronously while remaining displayed; XML is not required. The receiving client asks at 17:00:00 and receives no new messages. Message 501 appears at 17:00:02, but its next scheduled request is at 17:00:05. The receiving client waits approximately three seconds plus network and processing time.

Time	Client action	Result
17:00:00	GET messages after 500	Empty response
17:00:02	No request scheduled	501 waits on server
17:00:05	GET messages after 500	Receive 501

Polling is simple and fits modest update frequency or relaxed freshness requirements. At 100,000 clients polling every five seconds, even an idle service receives about 20,000 requests/second. Randomly arriving events wait about half an interval on average under a uniform-arrival assumption. Poll less often to reduce work, but accept more delay.

03 / Long polling: one held request per response

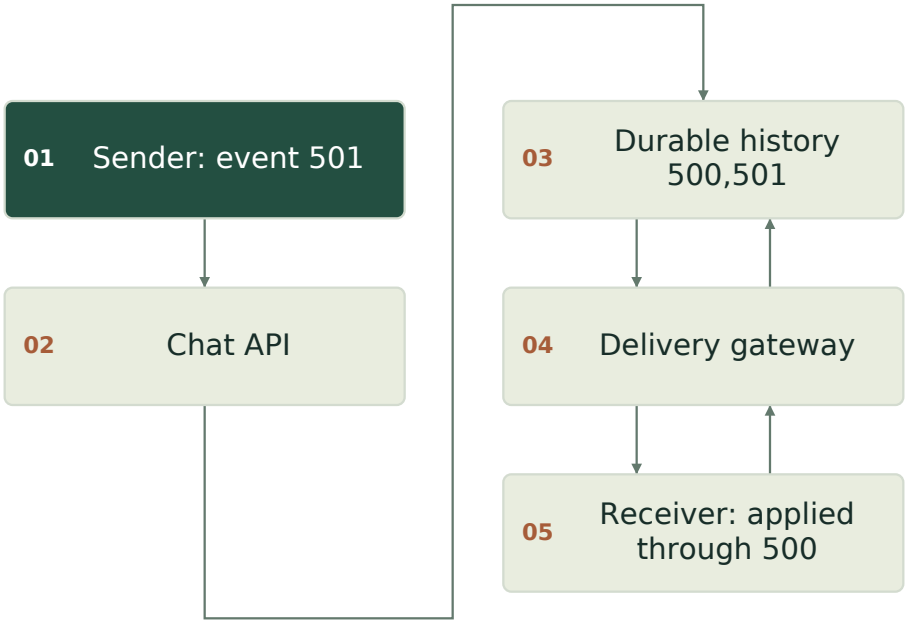
Long polling changes the empty-response behavior. The receiving client requests messages after 500 at 17:00:00. Instead of immediately returning an empty list, the server holds the request. At 17:00:02 it returns message 501. The receiving client then issues a new request after 501, leaving another question waiting for the next message.

The response is still an HTTP response to a client request. The server is not sending an unsolicited second response on a completed exchange. If no message arrives before the configured timeout, it returns or closes according to the API contract, and the client reissues the request.

This avoids frequent empty replies when messages are sparse, but it keeps many requests outstanding and repeats the request lifecycle after each result or timeout. A gap between responses and new requests can be handled by querying durable history after the last ID. Choose server and proxy timeout settings together so an intermediary does not unexpectedly cut every held request short.

WORKED EXAMPLE DIAGRAM

Event 501 is durable at 17:00:02 and the receiver has applied this conversation through 500. Replay follows application-applied progress, not merely sent bytes or SSE transport progress; the gateway joins history to live delivery without a gap.



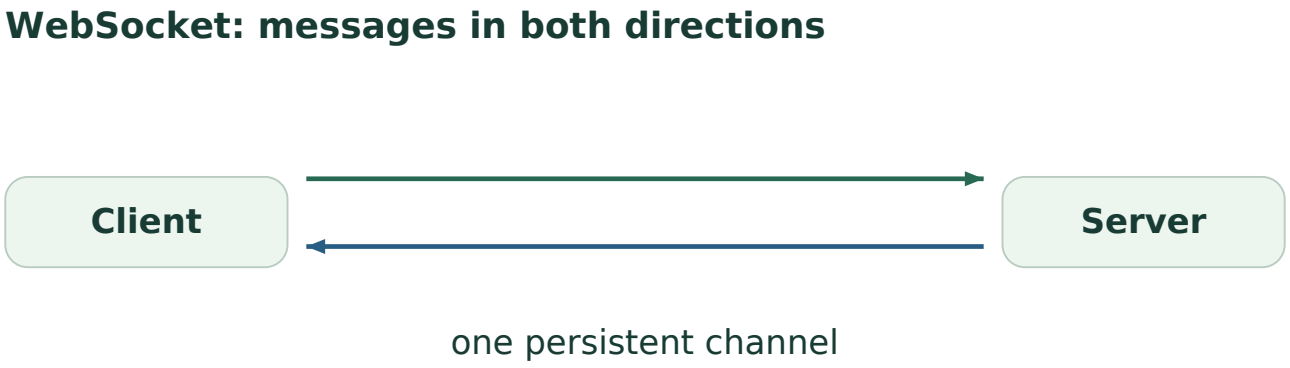
1 -> 2	17:00:02 send: Sender: event 501 -> Chat API
2 -> 3	store before durable acceptance: Chat API -> Durable history 500,501
3 -> 4	new event 501: Durable history 500,501 -> Delivery gateway
4 -> 5	respond or stream by chosen transport: Delivery gateway -> Receiver: applied through 500
5 -> 4	connect/resume after 500: Receiver: applied through 500 -> Delivery gateway
4 -> 3	replay missing events: Delivery gateway -> Durable history 500,501

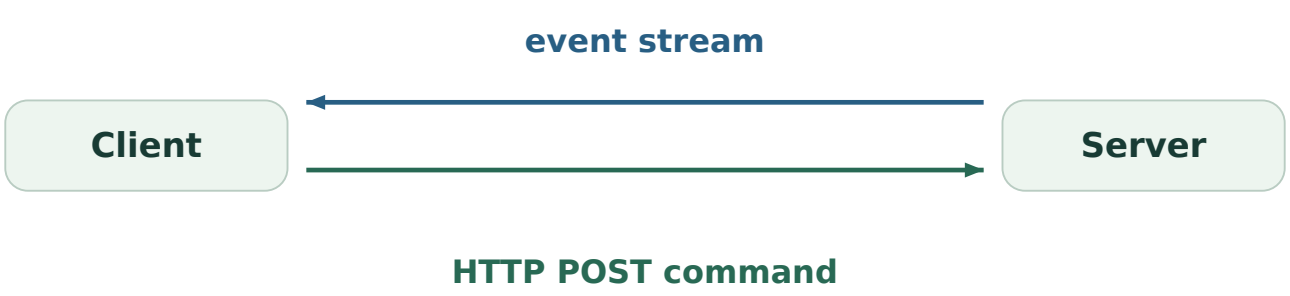
04 / WebSocket: a persistent full-duplex message channel

WebSocket establishes a persistent channel carrying messages in both directions. In the standard HTTP/1.1 opening sequence, the receiving client sends an HTTP request asking to upgrade to WebSocket. A successful server response uses status 101 and the protocol's required validation headers. After that handshake, the peers exchange WebSocket frames rather than ordinary HTTP response bodies for each chat message. RFC 6455.

Which side can send on this channel?

Arrow direction shows message direction. The SSE command arrow is a separate HTTP request.





Remember: WebSocket: both ways. SSE stream: server to client.

Try from memory: Can an SSE event stream itself carry client commands back to the server?

Answer: No. SSE streams server events to the client. The application normally sends commands in separate HTTP requests.

At 17:00:02, the gateway sends frame 501 to the receiving client without waiting for a new application request. At 17:00:02.100, the receiving client can send a typing or acknowledgment message back over the same channel. This full-duplex behavior is useful for frequent two-way interaction.

INTERVIEW CRITICAL

An open socket does not guarantee durable delivery

The connection creates operational state: the gateway must know which user and subscriptions it represents. Framing and an open socket do not provide durable message history or exactly-once effects. If the gateway dies, another gateway needs enough information to authenticate the receiving client and resume the conversation correctly.

The 101 upgrade is specific to the HTTP/1.1 handshake above. RFC 8441 defines extended CONNECT for WebSocket over HTTP/2, and RFC 9220 adapts it for HTTP/3. Client, gateway, and intermediary support must agree; do not assume every deployed WebSocket connection uses the same handshake.

The browser's **Origin** header identifies the web page's scheme, host and port. A WebSocket server can use it to restrict which web applications may initiate browser connections, which matters when browsers attach session cookies. This check answers a different question from which user is signed in.

Use encrypted transport and validate browser Origin according to the allowed application origins, especially for cookie-authenticated connections. Origin checking is an additional browser security boundary, not a substitute for authenticating the user or authorizing each subscription and command.

05 / Server-sent events: a server-to-client HTTP stream

Server-sent events, or SSE, use an HTTP response that remains open while the server sends text events. The response has content type `text/event-stream`. Browser EventSource understands the event format and reconnect behavior. At 17:00:02 the server can send an event containing ID 501 and the new message; IDs can support resumption. The stream is UTF-8 text, so binary payloads need another representation or delivery path. HTML standard.

The receiving client does not send chat commands backwards through that response stream. The receiving client can use a separate ordinary HTTP POST to send a message while receiving new events through SSE. That can be a clean design when most live traffic flows from server to client.

The server must preserve or reconstruct events after a reconnect; EventSource remembering an event ID does not create history storage. Intermediaries also need streaming-compatible behavior. If a proxy buffers the response until it is large, the apparent "live" messages can arrive late in batches.

An SSE event sends `id: 501`, then `data: {"messageId":501,"text":"hello"}`, followed by a blank line. Native EventSource remembers that ID and sends `Last-Event-ID` on reconnect. But receipt does not prove an asynchronous handler finished processing and saving the event. If recovery must resume after saved work, track that position separately in an application cursor. Pass it through an acknowledgment endpoint or an application-controlled reconnect, and make the replay API use it.

06 / Compare transports by traffic, latency, and direction

Technique	When 501 is delivered in the example	Main tradeoff
Five-second polling	Next request at 17:00:05	Simple, but delay and empty requests
Long polling	Held request returns around 17:00:02	Outstanding requests and repeated lifecycle
WebSocket	Server frame around 17:00:02	Two-way channel with connection management
SSE	Streaming event around 17:00:02	One-way live response; commands use another request

For frequent typing, acknowledgments, and chat traffic, choose WebSocket here. The benefit is a convenient two-way channel with less repeated request framing. The cost is gateway connection state, reconnect

handling, and operational limits. For an export-progress display with occasional client commands, SSE may be simpler. For a status page tolerating several seconds of delay, polling may be entirely sufficient.

A persistent channel still consumes sockets, memory, heartbeat traffic, and network capacity. Estimate those separately from requests/second. Moving from polling changes the resource profile; it does not make idle clients free.

A **heartbeat** is a small periodic message used to check whether a connection or peer remains responsive. It adds traffic even when users are idle, and a missed heartbeat is evidence for a timeout policy rather than proof of a crash. Include this background work when comparing persistent channels with polling.

As a separate capacity estimate, 100,000 open connections at an assumed 16 KiB of total connection and bounded-buffer state consume about 1.53 GiB. One application heartbeat per connection every 30 seconds adds about 3,333 heartbeat messages/s in that direction. These are workload assumptions to measure on the chosen gateway, not protocol constants. They show why replacing 20,000 idle polls/s changes costs rather than eliminating them.

07 / Reconnect, replay, and slow-consumer recovery

Suppose the receiving client receives 501 and the connection drops before the receiving client records progress. On reconnect the receiving client reports its last applied ID, possibly still 500. The service replays 501 from durable history. The receiving client deduplicates by message ID so it appears once. The cursor should describe what the client actually applied, not merely bytes sent by a gateway.

If 500 is older than retained history, return an explicit resynchronization path and fetch a snapshot or current history page. Do not silently skip the missing interval. Use heartbeats to detect broken paths when needed, and stagger reconnect retries with randomized delays so every client does not reconnect simultaneously after an outage.

Bound each client's outgoing buffer. A phone receiving more slowly than events arrive cannot accumulate memory forever. Disconnect and resume, reduce optional updates, or send a fresh summarized state according to the product contract. Authenticate connections and authorize subscriptions; an already-open connection must also have a policy for credential expiration or access revocation.



INTERVIEW CRITICAL

A resume cursor must represent contiguous applied progress

A cursor needs a defined ordering scope. Here 500 means every event through position 500 in this conversation has been applied, not merely that some event with the largest numeric ID was seen. If 502 arrives before 501, do not advance that contiguous cursor past the gap. With several independent streams, keep separate positions or use a server-defined composite cursor.

INTERVIEW CRITICAL

Bridge replay to live delivery without a gap

A client catching up on old events must also receive new ones. One safe sequence is: start a live subscription that buffers events; record the latest committed event position H; replay history after the client's cursor through H; then deliver buffered events after H and continue live. Remove duplicates and preserve order. If the limited buffer fills, restart from history. Reading history before subscribing leaves a gap in which events can be missed. This sequence requires the subscription to be active before H is recorded and to deliver every later committed event.

08 / Interview answer: choose a transport for chat

Interviewer: "Should this chat use WebSockets?"

Candidate: "Because our chat has frequent two-way activity, I would use a WebSocket channel after authenticating the connection. But I would separate transport from delivery correctness. The sending client's 501 goes into durable history; the receiving client reconnects with its last applied ID and deduplicates any replay.

"If this were only server-driven progress, SSE plus ordinary command requests would be a reasonable simpler alternative. Polling would be acceptable if we could tolerate its freshness interval and the idle request load. I would also specify proxy timeouts and bounded per-client buffers, because a persistent connection can still fail or fall behind."

The answer explains direction, latency, overhead, and recovery using the same event. It avoids claiming that WebSocket itself supplies offline history, authorization, ordering across all services, or exactly-once business effects.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Compare short polling, long polling, SSE, and WebSocket. What does real-time mean for a chat application?

Model answer

For chat, define a freshness target such as new messages normally appearing within 300 ms; this is an illustrative product target, not a property automatically guaranteed by a transport. Short polling repeats a request on a timer, creating idle traffic and up to roughly one interval of waiting. Long polling holds a request until data arrives or it times out, then the client starts another. SSE keeps an HTTP response open for text events from server to client. WebSocket maintains a full-duplex framed message channel.

For infrequent notifications, polling may be sufficient. For mostly one-way live updates, SSE plus ordinary HTTP commands can be simple. For frequent chat messages, typing, and acknowledgments in both directions,

WebSocket is a reasonable choice. All choices need authentication, bounded buffering, reconnect, and a durable cursor/history policy; the socket alone cannot restore missed messages.

Interviewer follow-up

Does every poll open a new TCP connection?

"No. Requests can reuse connections. I would distinguish request overhead from connection-handshake overhead in the estimate."

What the answer must demonstrate: Separate application exchange lifecycle from underlying connection reuse.

02 / APPLIED

100,000 clients poll every five seconds. An event arrives at :02 between polls at :00 and :05. Estimate idle QPS and event delay.

Model answer

"100,000 clients divided by a five-second interval produce 20,000 requests/s even without updates. An event at :02 waits three seconds until the :05 poll, plus network and processing time. Uniformly timed arrivals wait roughly half an interval on average."

Interviewer follow-up

How would you reduce load?

"Increase the interval, reduce active polling when appropriate, or change the transport. A longer interval has a clear freshness cost."

What the answer must demonstrate: State the arrival and interval assumptions.

03 / FOUNDATION

What exactly is held during long polling?

Model answer

"The server holds one HTTP request until an update exists or the timeout expires. For example, a request after cursor 500 returns event 501, and the client immediately requests after its applied cursor again. The response may contain a batch; long polling means one response per request, not necessarily one event. History bridges the short gap before the next held request."

Interviewer follow-up

Can a message arrive during the reconnect gap?

"Yes. The next request asks after the known ID, so durable history bridges the gap rather than relying on perfect timing."

What the answer must demonstrate: Explain wait, response, reissue, and timeout.

04 / FOUNDATION

Describe how the WebSocket channel begins.

Model answer

"For HTTP/1.1, the client requests an upgrade and the server validates it and returns 101 before exchanging WebSocket frames. HTTP/2 and HTTP/3 have extended-CONNECT mechanisms when supported. I would specify what our gateway and clients actually support, authenticate the session, validate browser Origin, and authorize subscriptions; protocol negotiation alone grants no user permission."

Interviewer follow-up

Does a successful handshake guarantee message persistence?

"No. It establishes the channel. The application still needs a durable history and an acknowledgment/resume contract."

What the answer must demonstrate: Handshake, authentication, and durability are distinct mechanisms.

05 / APPLIED

Could the receiving client send messages while receiving SSE?

Model answer

"Yes. The receiving client can receive a continuing event-stream response and send commands through separate HTTP POST requests. SSE is one-way on that stream, not a prohibition on the browser making other requests. It is attractive when live traffic is primarily server-to-client."

Interviewer follow-up

What happens to binary attachments?

"I would normally upload and retrieve them through a separate media path, using events to carry metadata or references."

What the answer must demonstrate: One-way stream does not mean one-way application.

06 / APPLIED

A client receives event 501 but reconnects with last-applied cursor 500. How should replay work?

Model answer

"Replay event 501 from durable history and apply it idempotently by message ID. Cursor 500 must mean the application applied every event through that position in the relevant stream. Native SSE Last-Event-ID can advance before the handler durably applies an event, so I would use the explicit application cursor for this stronger replay contract. A gateway writing bytes is not evidence that the recipient recorded the update."

Interviewer follow-up

How do you avoid losing events between replaying history and switching to live delivery?

"Register a bounded live buffer first, record the latest committed event position H, replay after the client cursor through H, then deliver buffered events after H and continue live. Deduplicate overlap and preserve stream order. If history expired or the buffer overflows, require an explicit resynchronization instead of silently skipping the gap."

What the answer must demonstrate: Connection delivery and application progress can differ.

07 / FOLLOW-UP

How should a gateway handle a receiving client that consumes events slower than they arrive?

Model answer

"I bound the outgoing buffer. Depending on the event contract, I can drop optional typing updates, summarize state, or disconnect and resume durable messages later. I cannot let one slow client grow gateway memory without limit."

Interviewer follow-up

Can I drop an undelivered durable message silently?

"Not if the product promised recoverable delivery. It must remain available through history and the resume path, or the client must be told the gap cannot be recovered."

What the answer must demonstrate: Separate replaceable hints from durable events.

08 / FOLLOW-UP

Why can a simultaneous reconnect after a gateway outage cause another outage?

Model answer

"A large connection outage can cause every client to reconnect and replay simultaneously. I would use randomized retry delays, admission control, and bounded replay work while protecting the history store. A healthy gateway fleet can still overload its shared dependencies during recovery."

Interviewer follow-up

What access check happens on reconnect?

"Reauthenticate and reauthorize the requested subscriptions, including any changes while the client was offline."

What the answer must demonstrate: Recovery traffic and permission changes are part of the protocol.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Compare delivery from 17:00:00 to 17:00:06 using polling, long polling, SSE, and WebSocket. Event 501 becomes durable at 17:00:02. Then drop the connection after delivery but before applied progress is recorded, and specify replay behavior.

- Show who initiates every request or message.
- Calculate the polling delay and idle request rate.
- Explain opening/response behavior for WebSocket and SSE.
- Resume from the last applied event and deduplicate a replay.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Why does the receiving client's five-second poll delay message 501?

The event arrives at 17:00:02, but the next request is at 17:00:05.

Timer decides when to ask.

What happens after a long-poll response?

The client immediately issues another request after its last received/applied cursor according to the API contract.

One response per request; then request again.

How do WebSocket and SSE differ in direction?

WebSocket carries messages both ways; SSE streams server-to-client events while client commands use another request.

Conversation versus broadcast response.

Does reconnect automatically recover missing messages?

Only if the application stores history, accepts a resume cursor, and handles duplicate replay.

Connection restored != missed messages recovered.

Summary and interview notes

Choose polling, SSE or WebSocket from the allowed delay, message direction and connection cost. To recover missed messages, save history, remember what the client applied, join replay to live updates without a gap, and limit data buffered for slow clients.

Remember these points

• Polling trades a chosen delay for repeated idle requests; long polling waits within each request and then reissues it.

• SSE streams UTF-8 text from server to client; WebSocket provides a bidirectional framed channel.

• Native EventSource Last-Event-ID records transport progress, not a durable application acknowledgment.

• A resume cursor must mean that every event up to that position has been processed and recorded in that stream; seeing a later event is not enough.

• Connection count, memory, heartbeat traffic, and replay bursts need capacity limits even when request QPS falls.

Interview tips

• Use one event-arrival time to compare all four transports and calculate the idle polling load.

• Draw the reconnect failure after delivery but before application progress is saved.

• Explain how history replay meets live delivery without an unobserved gap.

Important qualifications

• WebSocket 101 Upgrade describes HTTP/1.1; HTTP/2 and HTTP/3 use their negotiated extended-CONNECT mechanisms.

• Browser Origin validation complements authentication and subscription authorization; an open connection does not keep permissions valid forever.

• The 16 KiB connection-state and 30-second heartbeat estimates are illustrative and must be measured for the selected gateway.

Technical references

RFC 6455: The WebSocket Protocol
Verified protocol source for the HTTP/1.1 opening handshake, framing, and bidirectional channel.
https://www.rfc-editor.org/rfc/rfc6455.html

HTML Standard: Server-Sent Events
Verified standard for EventSource, UTF-8 event-stream format, event IDs, and reconnect behavior.
https://html.spec.whatwg.org/multipage/server-sent-events.html

RFC 8441: Bootstrapping WebSockets with HTTP/2
Extended CONNECT, distinguishing an HTTP/2 WebSocket setup from the HTTP/1.1 101 upgrade.
https://www.rfc-editor.org/rfc/rfc8441.html

RFC 9220: Bootstrapping WebSockets with HTTP/3
HTTP/3 WebSocket setup; actual endpoint/intermediary support must be verified.
https://www.rfc-editor.org/rfc/rfc9220.html

FOUNDATIONS / 22

Probabilistic data structures

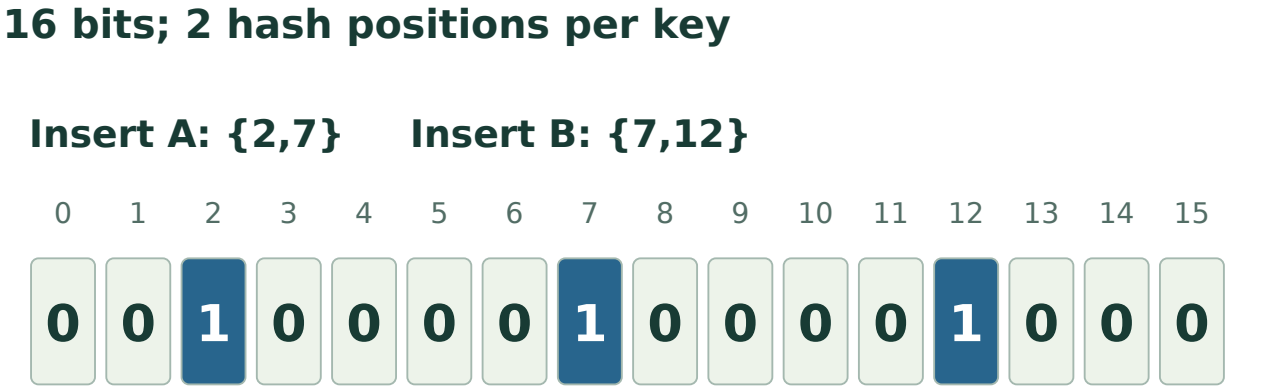
DEFINITION

Probabilistic data structures use randomization, often through hashing, to obtain useful space or performance tradeoffs. This chapter focuses on compact approximate summaries with stated error models: Bloom filters for membership, HyperLogLog for distinct counts, and Count-Min Sketch for frequencies.

Why it matters: Keeping every item in fast memory or checking a database for every query can be expensive; a summary can reduce that work when its possible errors are acceptable.

Bloom filter: membership checks and false positives

Each inserted key sets several bits. If any queried bit is zero, the key was not inserted. All ones can still be a collision.



C asks for bits 2 and 12
Both 1: MAYBE present
C is absent: a false positive

D asks for bits 1 and 12
Bit 1 is 0: DEFINITELY absent
If filter coverage is current: skip read

All ones never proves membership.

No false negatives for the correctly covered inserted set. Exact claims still prevent duplicates.

Worked example

A sets Bloom-filter bits 2 and 7; B sets 7 and 12. C tests bits 2 and 12 and gets "possibly present" although C was never inserted. An exact lookup must resolve that positive.

Key takeaways

• Bloom says definitely absent or possibly present under its correct coverage assumptions.

• HyperLogLog answers how many distinct items, not whether a particular item exists.

• Count-Min estimates a supplied key's frequency; its insert-only errors overestimate.

Read the visual model

1. Insert A with hash positions {2,7}, then B with {7,12}. Set bits 2,7 and 12.

2. Query C at {2,12}: both are one, yet C was never inserted. This is a false positive, so check the real store.

3. Query D at {1,12}: bit 1 is zero, so D is definitely absent under the insertion-only contract.

4. An ordinary Bloom filter has no false negatives for inserted keys, but deleting bits can break that property.

Bloom filter • HyperLogLog • Count-Min Sketch • approximation

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Trace Bloom-filter bits and explain the exact false-positive and false-negative assumptions.

• Estimate filter memory and saved membership reads using an assumed workload.

• Choose Bloom, HyperLogLog, or Count-Min Sketch according to the question and acceptable error.

Useful foundations: Capacity estimation: throughput, latency, concurrency and storage; Caching: cache hits, misses, write policies and invalidation; Storage engines and data models

8 interview questions with model answers and answered follow-ups.

01 / Probabilistic data structures: definition and error models

A **probabilistic data structure** uses randomization, often through hashing, to obtain useful space or performance tradeoffs. The broader category also includes randomized exact structures, such as skip lists; probabilistic does not always mean an approximate answer. This chapter focuses on **compact approximate summaries** with stated error models. A **Bloom filter** approximates set membership, **HyperLogLog** estimates the number of distinct items, and **Count-Min Sketch** estimates how often a supplied item occurs. These summaries save memory or work by discarding information. The engineering task is to know which mistakes are possible and place each summary where those mistakes are acceptable.

Use approximate structures where their error model is acceptable, using exact records and checks for decisions that cannot safely be reversed. The worked crawler calculation assumes one million stored normalized URLs and 100,000 membership checks, of which 80% concern absent URLs. These inputs are illustrative assumptions. The exact URL database remains responsible for unique discovery and scheduling.

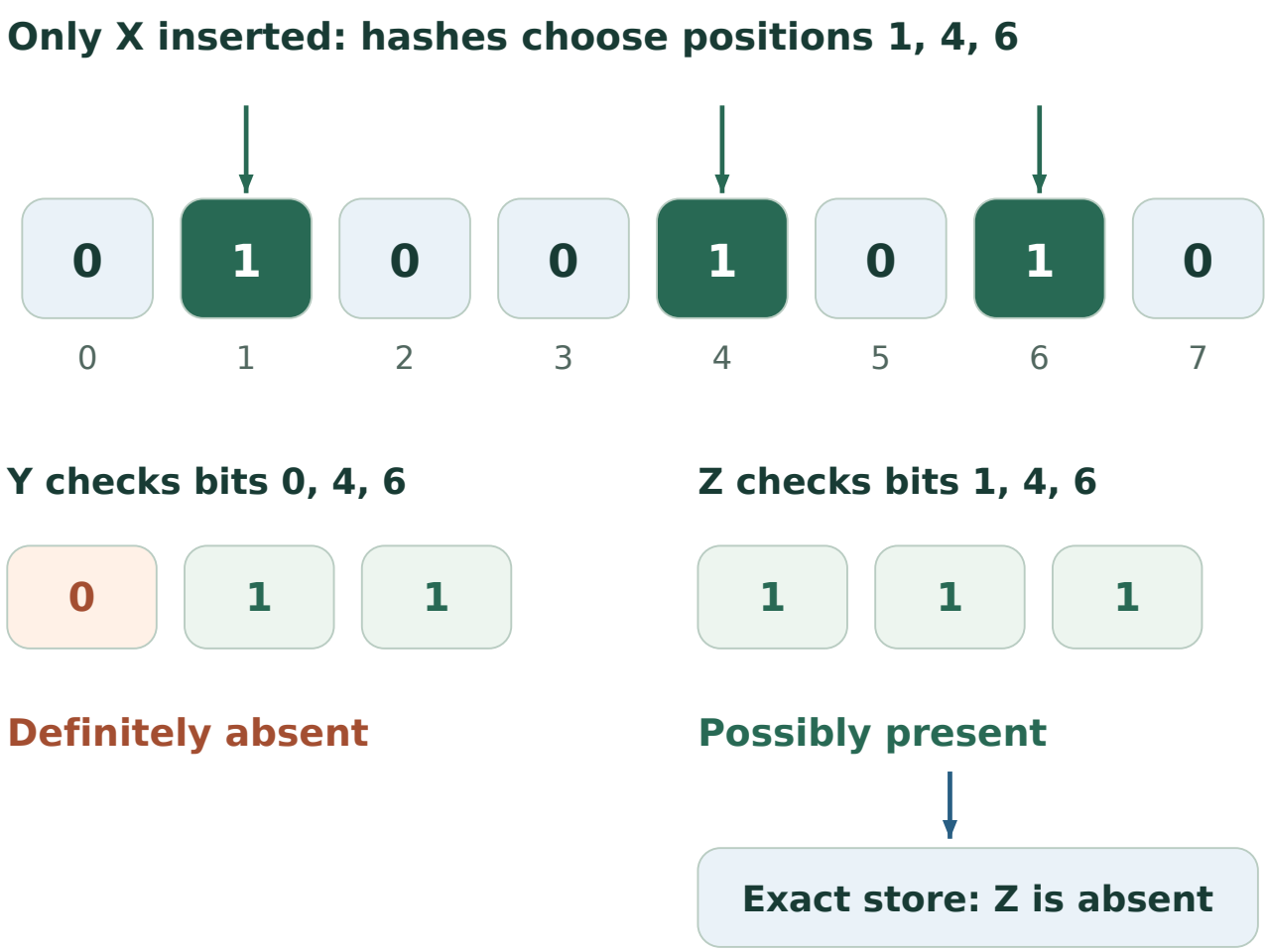
An in-memory hash set can answer membership exactly, but storing every full URL and its indexing overhead may consume too much memory. A database lookup for every candidate can also be expensive. A Bloom filter can cheaply rule out many absent candidates. It does not store the URLs themselves, prove that a page was fetched successfully, or replace the exact claim that prevents two workers from scheduling the same URL.

02 / Bloom filter: bit array, hashes, and false positives

A Bloom filter is a bit array plus several hash functions. A hash function maps an item to a position in that array. To insert a URL, set its positions to one. To test a URL, inspect those positions: any zero proves it was not inserted into this filter; all ones mean only "possibly present."

Bloom filter: bits encode possible membership

The small bit array illustrates the mechanism, not a recommended production size. A standard correctly maintained Bloom filter has false positives but no false negatives for inserted items.



Z is a false positive: shared bits cannot prove that Z was inserted. A zero bit rules Y out if the filter covers every stored key.

Remember: One zero proves absence; all ones require an exact check.

Try from memory: Why can we not delete X by simply clearing its bits?

Answer: Other inserted keys can share those bits. Clearing them can make a present key look absent.

Use a tiny sixteen-bit filter and two illustrative hashes. Initially every bit is zero.

URL	Hash positions	Action or answer
A	2 and 7	Insert: set bits 2 and 7
B	7 and 12	Insert: set bit 12; bit 7 was already set
C	2 and 12	Both are one: possibly present, although C was never inserted
D	1 and 12	Bit 1 is zero: definitely not inserted

C is a false positive created by shared bits. A and B remain discoverable because insertion never clears their positions. "No false negatives" relies on correct insertion, intact state, consistent hashing, and the filter representing the set being queried. It is not a promise about a stale or partially rebuilt copy of the database.

03 / Bloom filter with an exact membership database



INTERVIEW CRITICAL

Bloom membership does not replace an atomic claim

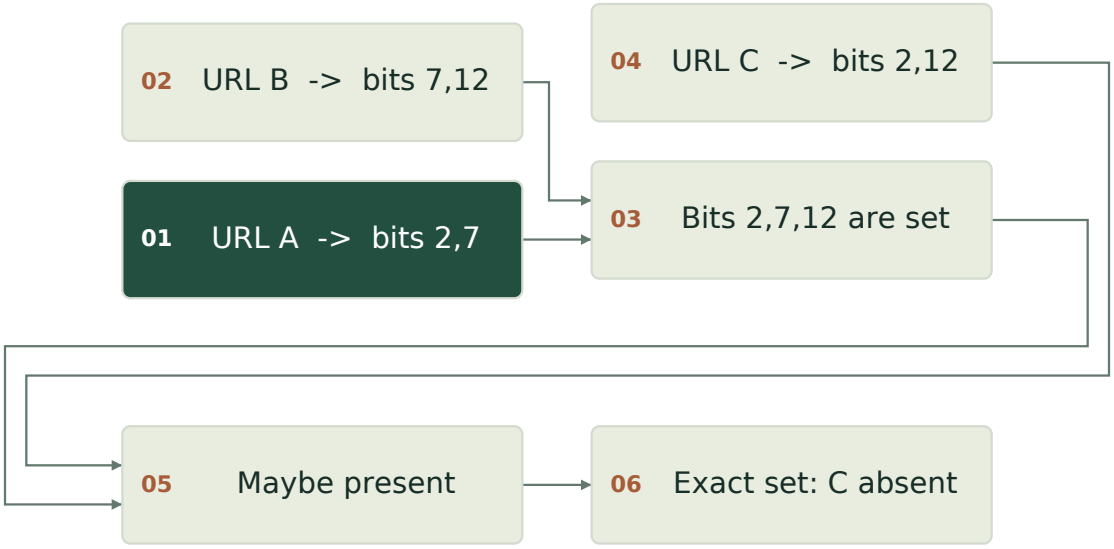
If discovery must be complete, a positive Bloom result must trigger an exact membership lookup: "possibly present" cannot safely mean "skip." A correctly covered negative can avoid that preliminary lookup, but scheduling still needs an atomic claim or unique insert in the exact store. Two workers can both observe a negative before either inserts. The filter is an accelerator, not a concurrency lock.

With the assumed 1% false-positive rate, 80,000 absent queries cause about 800 false positives. The 20,000 present queries also require exact verification. Expected membership reads therefore fall from 100,000 to about 20,800, saving about 79,200. These figures concern preliminary reads, not all database operations: durable inserts and claim checks remain.

If a URL is in the database but missing from the filter, the filter can wrongly report it absent. An atomic database claim can still prevent duplicate scheduling. A design that trusts the filter's negative result without that check cannot. Record which data the filter covers and what changes a rebuild includes.

WORKED EXAMPLE DIAGRAM

C was never inserted, but its two positions are already set by A and B. This is a false positive, so "maybe" must not mean "skip forever."



1 -> 3	insert: URL A -> bits 2,7 -> Bits 2,7,12 are set
2 -> 3	insert: URL B -> bits 7,12 -> Bits 2,7,12 are set
3 -> 5	both queried bits set: Bits 2,7,12 are set -> Maybe present
4 -> 5	test: URL C -> bits 2,12 -> Maybe present
5 -> 6	verify positive: Maybe present -> Exact set: C absent

04 / Bloom filter sizing: bits, hashes, and false-positive rate

Sizing starts with how many distinct URLs the filter must cover and how many unnecessary exact lookups are acceptable. From that expected population and target false-positive rate, choose the number of stored bits and hash positions. The formulas below quantify the memory-versus-error tradeoff under their hashing assumptions.

For an idealized Bloom filter with good hashing, expected false-positive probability is approximately `p ~ (1 - e^(-kn/m))^k`, where `m` is bits, `n` inserted distinct items, and `k` hash positions per item. Here `e` is approximately 2.718, and `ln` denotes the natural logarithm. Near the optimal hash count, useful sizing formulas are `m ~ -n ln(p)/(ln 2)^2` and `k ~ (m/n) ln 2`.

For `n = 1,000,000` and `p = 0.01`, this gives about 9.59 million bits, or 1.20 MB using decimal units, with approximately seven hashes. That excludes object headers, alignment, and implementation overhead. It is roughly 9.6 bits per stored URL, regardless of the URL's length, because the filter does not retain the original text.

Exceeding the planned population sets more bits and raises the false-positive rate. It does not suddenly start forgetting inserted items, but its ability to reject absent queries deteriorates. Capacity and hash quality must

be monitored. A smaller error target costs memory and hash work; choose it using the database work saved, not a habit of demanding the smallest possible percentage.

05 / Bloom filter deletion, rebuilds, and coverage



INTERVIEW CRITICAL

Clearing shared Bloom bits creates false negatives

An ordinary Bloom filter cannot safely delete A by clearing bits 2 and 7: B also uses bit 7. Clearing it would make B falsely appear absent. A counting Bloom filter replaces bits with counters so known insertions can be decremented, but the insertion/deletion accounting must be exact enough to avoid removing another item's contribution or overflowing counters.

For an append-only visited-URL set, an append-only filter rebuilt periodically is simpler. A rebuild must cover a consistent source snapshot plus changes made during construction, or queries must use a safe bypass while coverage is incomplete. On a crash or corrupt filter, fall back to the exact store until a valid filter is available. A performance accelerator should fail into additional work rather than permanent omissions.

If visited URLs expire, define which time period each filter covers or use a supported deletion method. Rotating filters changes the set that membership answers describe. Bitwise OR combines compatible filters into a union, but representing more URLs raises the false-positive rate.

Concurrency is another correctness assumption. Two unsynchronized read-modify-write updates to the same bit-array word can overwrite each other even when each worker only intends to set bits. Use the implementation's supported atomic updates or synchronization. The same care applies to counting-filter increments and decrements; an accelerator implemented with lost updates can violate its advertised error direction.

06 / HyperLogLog and Count-Min Sketch

Distinct-count estimation is a separate query from membership. A HyperLogLog sketch estimates how many distinct URLs occurred. Each register is a small stored number. Some leading hash bits select a register; in the remaining bits, count leading zeros plus one and retain that register's largest observed count. In a toy four-register setup, `01 | 0001...` selects the register numbered 1 and contributes 4. A later `01 | 01...` contributes 2, so the register stays 4. Long zero runs become more likely as more distinct items arrive. HyperLogLog combines all registers using a calibrated estimator, rather than treating one rare hash as an exact count. Repeating the same URL does not represent another distinct item. It cannot answer whether C was present or list the discovered URLs.

Different randomized hash assignments can produce different estimates for the same true distinct count. **Relative standard error** describes the statistical spread of those estimates relative to that count. More registers reduce that spread at the cost of more memory.

INTERVIEW CRITICAL

Standard error is not a per-answer guarantee

For the classic analysis, typical relative standard error is about `1.04 / sqrt(m)` for `m` registers. With 16,384 registers this is about 0.81%. This is a statistical standard error, not a hard guarantee that every answer falls inside that percentage. Implementations apply corrections and can behave differently at small cardinalities.

A Count-Min Sketch answers approximate frequency questions, such as how often host H appeared. It uses several rows of counters, each with its own hash selecting one column. Each occurrence increments one counter per row; querying that key returns the minimum of those same counters. In an insert-only stream with nonnegative increments, collisions can overestimate a frequency but do not make that estimate smaller than the actual count. If H occurred twenty times and its counters are 27, 23 and 22, the estimate is 22. Hash collisions explain the extra two; the sketch does not identify the colliding hosts.

For Count-Min, **width** is the number of counters in each row and **depth** is the number of independently hashed rows. More columns reduce collisions; additional rows make it less likely that every row badly overestimates the same key. The error target determines these two memory costs.

The standard Count-Min dimensions make the tradeoff concrete: choose width `ceil(e / epsilon)` and depth `ceil(ln(1 / delta))`. For a fixed queried key in a nonnegative stream, suitable independent hashes give an estimate between its true count `f` and `f + epsilon * N` with probability at least `1 - delta`, where `N` is the sum of all increments across the stream. `epsilon` sets the allowed additive error as a fraction of N; `delta` is the maximum failure probability for that bound. `ceil(x)` is the smallest integer greater than or equal to `x`, so an integer stays unchanged. `ln` is the natural logarithm, and `e ~ 2.71828`; use the unrounded constant when calculating the width. With `epsilon = 0.001`, `delta = 0.01` and `N = 1,000,000`, width 2,719 and depth 5 use 13,595 counters. The promised additive error can still be 1,000, which is large for a host seen only twenty times. This is not a simultaneous guarantee for every adaptively chosen key; counter overflow or unsupported signed updates also invalidate the simple bound.

07 / Bloom filter, HyperLogLog, and Count-Min comparison

Structure	Crawler question	What it cannot provide
Bloom filter	Might this URL be in the visited set?	Exact positive membership or item retrieval
HyperLogLog	About how many distinct URLs were observed?	Membership, full enumeration, exact billing counts
Count-Min Sketch	About how often was host H observed?	Exact frequency or a list of heavy keys by itself

Count-Min's additive error is related to total stream volume under its stated probabilistic bounds, so a small relative error for the whole stream can be large for a rare host. Finding heavy hosts also needs candidate tracking. Compatible sketches can merge - HyperLogLog by register maxima and Count-Min by counter sums - but parameters, hash conventions, and event semantics must match.

In an interview I would say: "The Bloom filter can avoid a preliminary database read when a URL is definitely absent from the covered set. The database's unique insert still prevents two workers from scheduling the same URL. HyperLogLog drives approximate distinct-count dashboards, and Count-Min helps identify frequency candidates. None is the authoritative record for a decision where an approximate answer can silently lose work."

INTERVIEW CRITICAL

A compatible sketch can still double-count replay

Merging must count the observations you intended. Merging the same HyperLogLog state twice does not change its distinct count. Adding the same Count-Min shard snapshot twice counts its increments twice. For frequency estimates, use shards covering separate events or replace each shard's previous version when combining counts. Matching array sizes alone cannot prevent double counting.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is a probabilistic data structure? Use a Bloom filter to explain its possible error.

Model answer

It uses randomization to obtain a useful space or performance tradeoff. Some probabilistic structures answer exactly; the Bloom filter is an approximate membership summary with a defined error model. In the Bloom example, A sets bits 2 and 7 and B sets 7 and 12. C tests 2 and 12, so the filter says possibly present even though C was never inserted: a false positive. It no longer knows which item set each bit.

Interviewer follow-up

What should a crawler do with that positive result?

Check the exact URL set. Skipping C solely because of a Bloom positive can permanently omit a new page. A negative saves a preliminary lookup only under the filter's coverage assumptions; the exact unique insert still handles concurrent claims.

What the answer must demonstrate: Name the supported question, error direction, and business consequence.

02 / APPLIED

Under what coverage and update assumptions is a Bloom-filter negative safe to trust?

Model answer

"It proves absence from a correctly maintained filter's inserted set. To infer absence from the database, the filter must cover that database state. A stale or interrupted rebuild may omit real entries."

Interviewer follow-up

How do you survive an incomplete filter?

"Bypass the filter, or trust it only for data its coverage record proves complete. Keep the exact atomic database claim when scheduling a URL."

What the answer must demonstrate: State which set the guarantee describes.

03 / APPLIED

Estimate memory for one million URLs at 1% false positives.

Model answer

"Using the standard idealized formulas, I need about 9.59 million bits, or 1.20 decimal MB, and about seven hash positions per item. I would add implementation overhead and headroom for growth."

Interviewer follow-up

What happens at two million entries without resizing?

"More bits are set and false positives rise; the original 1% target no longer holds."

What the answer must demonstrate: Keep bits and bytes distinct and acknowledge the sizing assumptions.

04 / APPLIED

Of 100,000 membership checks, 80% are absent. With a 1% Bloom false-positive rate, how many exact preliminary reads remain?

Model answer

"Of 100,000 checks, 80,000 are absent. At a 1% false-positive rate about 800 absent checks still reach the database, alongside 20,000 present checks. That is about 20,800 reads instead of 100,000."

Interviewer follow-up

Does it save the new URL's durable insert too?

"No. It removes a preliminary read, while the exact claim or insert remains necessary."

What the answer must demonstrate: Do not confuse lookup reduction with eliminating all authoritative work.

05 / FOLLOW-UP

Bloom key A sets bits 2 and 7; B sets 7 and 12. Why can deleting A not simply clear its bits?

Model answer

"B shares bit 7, so clearing it can turn B into a false negative. Ordinary Bloom bits do not record ownership. I need a correctly managed counting variant or a rebuild/epoch policy."

Interviewer follow-up

Can a counting filter delete any item that tests positive?

"No. A positive may itself be false, so decrementing for a never-inserted item can damage other entries. Deletions require reliable membership and accounting."

What the answer must demonstrate: Deletion changes the guarantee unless ownership is accounted for.

06 / FOUNDATION

Could HyperLogLog replace the visited-URL set?

Model answer

"No. HyperLogLog estimates distinct cardinality; it cannot answer whether a particular URL was seen or enumerate URLs. It is useful for aggregate crawler statistics, while exact claim decisions need an exact set or database."

Interviewer follow-up

Is 0.81% a maximum error at 16,384 registers?

"No. It is an approximate relative standard error from the classic analysis, not a deterministic per-answer bound."

What the answer must demonstrate: Separate an aggregate estimator from a membership structure.

07 / FOLLOW-UP

Why does Count-Min take the smallest counter?

Model answer

"Each counter contains the item's own increments plus collisions. Under nonnegative insert-only updates, taking the minimum reduces collision inflation without dropping below the true count. In the example, min(27,23,22) estimates a true count of twenty as twenty-two."

Interviewer follow-up

Can it list the busiest hosts by itself?

No. It answers estimates for supplied keys; heavy-key discovery needs candidate tracking. Also inspect the additive bound against total stream volume: epsilon = 0.001 at one million increments allows error of 1,000 for a fixed key, which can swamp a rare count.

What the answer must demonstrate: Qualify the update model and distinguish estimation from enumeration.

08 / APPLIED

Can two crawler workers merge their sketches?

Model answer

"Yes, when the sketch types, dimensions, hash functions and item normalization are compatible. Bloom union uses OR; HyperLogLog uses register maxima; Count-Min sums counters."

Interviewer follow-up

What could still make the merged answer misleading?

"Different URL normalization or duplicate event delivery changes the represented data. HLL counts distinct identities while Count-Min counts occurrences, so their response to replay differs."

What the answer must demonstrate: Compatible arrays are not enough; semantics must match.

Build the answer yourself

BLANK-PAGE EXERCISE / 15 MINUTES

Design a crawler's visited-URL accelerator for one million stored URLs and a 1% Bloom false-positive target. Explain what happens for a positive, a negative, a filter crash, and two workers discovering the same URL.

- Compute approximate bits and hash count, with units.
- Trace one false positive using shared bit positions.
- Keep the exact claim or uniqueness check for concurrent scheduling.
- Choose a separate structure for distinct URL count and per-host frequency.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What does a Bloom positive mean?

Every tested position is set; another combination of inserted items may have set them. Verify when correctness requires exact membership.

Positive = possible

What does "no false negatives" assume?

A valid filter covering the queried set, correct insertions and hashing, and no unsafe deletion or state loss.

Trust absence only for the set the filter covers.

Which sketch answers which question?

Bloom: membership maybe. HyperLogLog: distinct count. Count-Min: frequency estimate.

Membership -> distinct count -> frequency.

Can a Bloom negative prevent two simultaneous inserts?

No. Both workers may see absence; an exact atomic claim or uniqueness rule resolves the race.

A filter is not a lock

Summary and interview notes

An approximate summary is useful only when its supported question and error model match the decision. Use exact records and atomic uniqueness checks when deciding who may perform an irreversible action; use compact summaries to reduce reads or power explicitly approximate aggregates.

Remember these points

• A valid Bloom negative proves absence only from the filter's covered inserted set; a positive requires verification for exact membership.

• One million items at a 1% Bloom target needs roughly 9.59 million bits and seven hashes, before overhead.

• HyperLogLog estimates distinct count; its typical standard error is not a worst-case per-answer limit.

• Insert-only Count-Min estimates a supplied key's frequency from above, with additive error tied to total stream volume.

• Merge only sketches with compatible hashing and matching definitions of their observations. Do not add the same frequency snapshot twice.

Interview tips

• State the error direction and the business consequence before recommending a sketch.

• Calculate saved authoritative reads separately from inserts and atomic claim checks.

• Test incomplete rebuilds, concurrent updates and replay, not just ideal hash collisions.

Important qualifications

• A standard Bloom filter cannot safely delete by clearing shared bits; counting variants need reliable membership and counter accounting.

• Statistical error formulas assume the stated hashing and update model; implementation races and overflow are not covered by those formulas.

Technical references

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https://commons.apache.org/proper/commons-collections/bloomFilters/intro.html

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Primary analysis of approximate distinct counting and its typical relative standard error.
https://algo.inria.fr/flajolet/Publications/FlFuGaMe07.pdf

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Author-hosted primary paper on approximate frequency summaries; replaces an unavailable older Rutgers URL. All crawler numbers and tiny hashes here are constructed examples.
https://www.cs.ox.ac.uk/people/graham.cormode/pubs/papers/cm-full.pdf

William Pugh: Skip Lists - A Probabilistic Alternative to Balanced Trees
Primary paper on randomized balancing for exact dictionary operations. Establishes the broader meaning of probabilistic data structures; this chapter focuses on approximate summaries.
https://ranger.uta.edu/~weems/NOTES5311/skiplists.pdf

FOUNDATIONS / 23

Keyword search and vector retrieval

DEFINITION

Keyword search retrieves documents by matching searchable terms extracted from text; vector retrieval finds documents whose numeric embeddings are close to the query embedding under a chosen similarity measure. Retrieval selects candidates, ranking orders them, and hybrid search combines term-based and vector signals.

Why it matters: Users may type exact identifiers or describe the same idea with different words. The system needs efficient candidate selection without confusing similarity with correctness or permission.

Inverted-index lookup and vector similarity

The lexical example finds exact analyzed terms; the vector example compares directions. Neither establishes truth or access permission.

Combine exact term matches with learned similarity

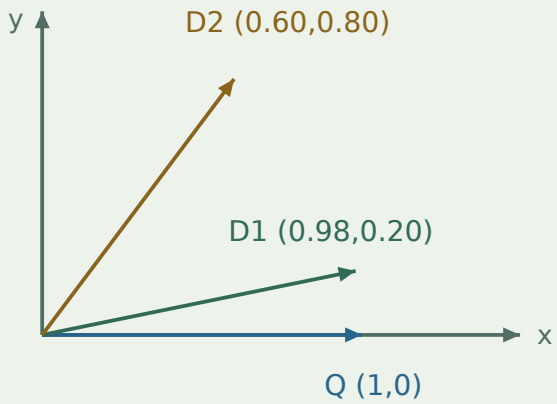
TERM POSTINGS

reset = {D2, D4}

access = {D1, D4}

AND gives {D4}

VECTOR DIRECTIONS



Verify content access, rank, then return sources

Cosine measures similarity. Private Birch document D3 must not appear in Acme results.

Worked example

For reset access, the reset posting list is [D2,D4] and access is [D1,D4], so AND returns D4. Vector retrieval can additionally connect "lost phone" with D1's "recover authenticator" wording.

Key takeaways

• An inverted index maps terms to documents; an embedding represents similarity numerically.

• Approximate nearest-neighbor search (ANN) saves work by allowing missed neighbors; measure the tradeoff.

• Ranking cannot recover missing candidates, and similarity does not grant authorization.

Read the visual model

1. For reset AND access, intersect reset={D2,D4} and access={D1,D4} to retrieve D4.

2. The vector example uses Q=(1,0), D1=(0.98,0.20), and D2=(0.60,0.80). Cosine similarity is about 0.98 for D1 and 0.60 for D2.

3. The vector drawing is two-dimensional intuition, not a map of real language dimensions.

4. Authorize the exact content version before sending private text to a reranker or model. Rank permitted candidates and check release permissions; Birch private D3 must not leak into Acme results.

inverted index • BM25 • embeddings • ANN • hybrid search • retrieval evaluation

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Construct a small inverted index and explain a query.

• Distinguish semantic similarity from factual truth and exact matching.

• Evaluate retrieval quality, freshness, latency, and permissions.

Useful foundations: Database indexes: B-trees, composite keys and query access; Data partitioning and sharding; Authentication, authorization, and tenant isolation

8 interview questions with model answers and answered follow-ups.

01 / Keyword search, vector retrieval, and ranking: definitions

Keyword search retrieves documents by matching searchable terms extracted and normalized from text. **Vector retrieval** finds documents whose numeric representations, called embeddings, are close to a query embedding under a chosen similarity measure. **Retrieval** selects candidates, **ranking** orders them, and **hybrid search** combines lexical (term-based) and vector signals. The source database preserves business facts. A search index is a derived, lookup-optimized representation of those records; asynchronous indexing means a successful source write need not be immediately searchable.

Use separate tests for lexical relevance, semantic relevance, freshness, and authorization. For query `reset MFA phone lost` (MFA means multi-factor authentication), Acme document D1 describes authenticator recovery, while D2 includes "reset MFA" but describes a different administrative procedure. Birch's private runbook D3 must remain excluded. This dataset illustrates retrieval and access constraints without making either a substitute for the other.

Treat relevance, freshness and access as separate acceptance criteria. A highly similar result can still describe an obsolete procedure or belong to another tenant.

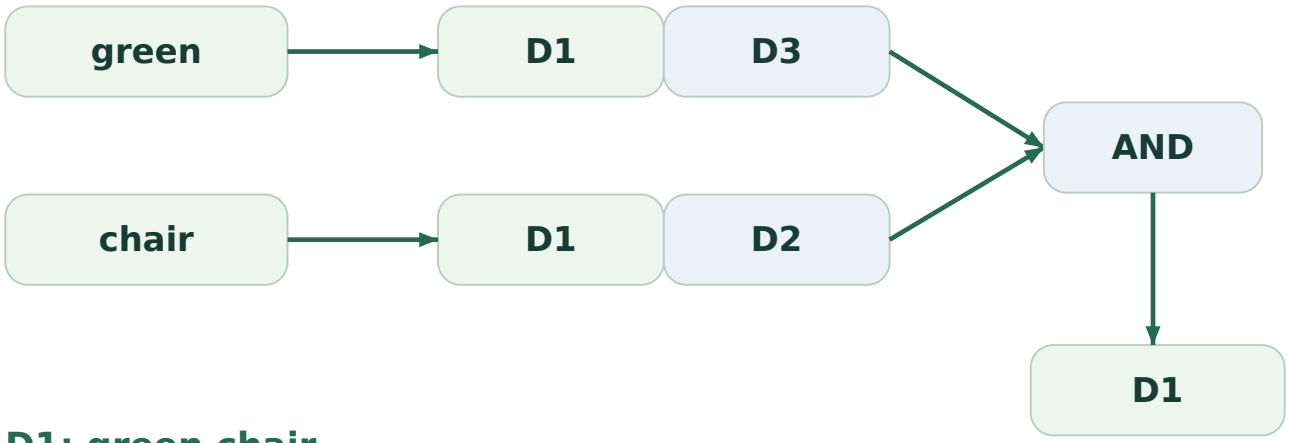
02 / Inverted index, tokenization, postings, and BM25

An inverted index maps a term to the documents containing it. A tokenizer splits text into searchable units; an analyzer may normalize case, handle language, or apply stemming. Exact product codes and identifiers often need a separate exact-match field because ordinary text analysis can alter punctuation or structure.

Intersect two postings lists

A posting here is a document ID. Green D1 appears in both lists, so it satisfies the AND query.

Query: green AND chair



D1: green chair

D2: blue chair

D3: green desk

Intersect the ID lists: D1 is the only document in both.

Remember: AND keeps IDs present in both term lists.

Try from memory: What would green OR chair return from these lists?

Answer: The union is D1, D2 and D3, with D1 included once. AND returns only the intersection, D1.

Suppose the analyzed documents are `D1: recover access authenticator lost`, `D2: admin reset mfa`, and `D4: reset phone access`. Their small index includes:

Term	Posting list
access	D1, D4
reset	D2, D4
lost	D1

Term	Posting list
mfa	D2

For an AND query `reset access`, intersect the posting lists and obtain D4. An OR query can return D1, D2, and D4, then rank them. Positions support phrase matching; document and term statistics support ranking. BM25 is a common lexical ranking function that rewards useful term matches while accounting for frequency and document length. Its score is not a probability that the answer is true.

BM25 combines three ideas: a match on a rarer term carries more information, repeated occurrences of one term have diminishing benefit, and document-length normalization stops long documents winning merely because they contain more words. In the tiny corpus, `mfa` appears in one document while `access` appears in two; their document-frequency signals differ. Phrase positions, required terms and exact identifier fields remain separate query controls, rather than guarantees supplied by a high BM25 score.

03 / Embeddings and cosine similarity



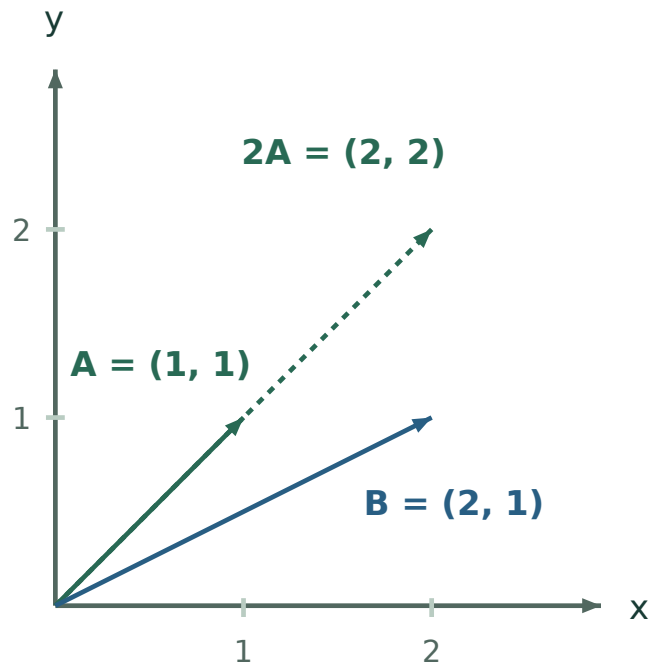
INTERVIEW CRITICAL

Equal vector length does not mean compatible embeddings

An embedding model maps text to a vector of numbers. The query and documents must use compatible embedding spaces and the intended similarity metric. A model change can require re-embedding stored documents; vectors from unrelated models cannot be compared meaningfully merely because they have the same length.

Vector similarity compares directions

A two-dimensional schematic illustrates cosine similarity. Production embeddings often use many dimensions and model-specific geometry.



Cosine of A and B

A dot B = 3

length(A) = sqrt(2)

length(B) = sqrt(5)

3 / sqrt(10) = 0.949

Origin (0, 0)

A and 2A point in the same direction. Doubling the length leaves cosine similarity with B unchanged. Axes have equal scale.

Remember: Dot product divided by both lengths measures direction similarity.

Try from memory: Does doubling A double its cosine similarity with B?

Answer: No. The dot product and A's length both double, so their ratio is unchanged.

For intuition, imagine two-dimensional vectors: query Q=(1,0), D1=(0.98,0.20), and D2=(0.60,0.80). After accounting for normalization, cosine similarity to Q is approximately 0.98 for D1 and 0.60 for D2. Real systems often use hundreds or thousands of dimensions; the two-dimensional numbers only illustrate relative direction.

Semantic retrieval can connect "phone lost" with "recover authenticator" without identical words. It can also retrieve a similar-sounding wrong procedure. Exact IDs, dates, negation, and small wording differences may matter more than broad similarity. Keep lexical matching and metadata constraints when they serve the query contract.

Cosine similarity compares the directions of two nonzero vectors: `dot(Q,D) / (length(Q) * length(D))`. The **dot product** multiplies corresponding coordinates and adds the products. A vector's **length** is the square root of the sum of its squared coordinates. Normalizing a vector divides every coordinate by that length, giving a unit-length vector. For D1, the denominator is `sqrt(0.98^2 + 0.20^2) ~ 1.0002`, so similarity is about `0.9798`; D2 has unit length and scores `0.60`. With unit-normalized vectors, dot product and cosine produce the

same ranking, and squared Euclidean distance is `2 - 2*cosine`. Without normalization these metrics can rank candidates differently. A zero vector needs an explicit handling policy because cosine is undefined.

04 / Search ingestion and query lifecycle

1. Ingest Acme document D1 version 7 with its ID, title, tenant, access policy, source version, and location.
2. Split long content into coherent chunks, retaining permissions and provenance on each chunk.
3. Build term postings and embeddings with recorded analyzer and model versions. Record which source version is indexed.
4. Authenticate the query request, derive its allowed tenant/document scope, analyze the query, and embed it using the compatible query model.
5. Retrieve scoped candidate IDs. Check each candidate against the source system's current permissions, obtaining the exact content version and policy revision that were authorized; fetch that immutable version. On a version/policy mismatch, reauthorize or discard the candidate.
6. Fuse lists or rerank only content authorized by that decision. Before returning snippets, enforce the policy for when permission revocations take effect and withhold or retry any candidate whose required policy revision no longer matches.
7. Reauthorize a later source-document request. A search hit does not grant permanent access.



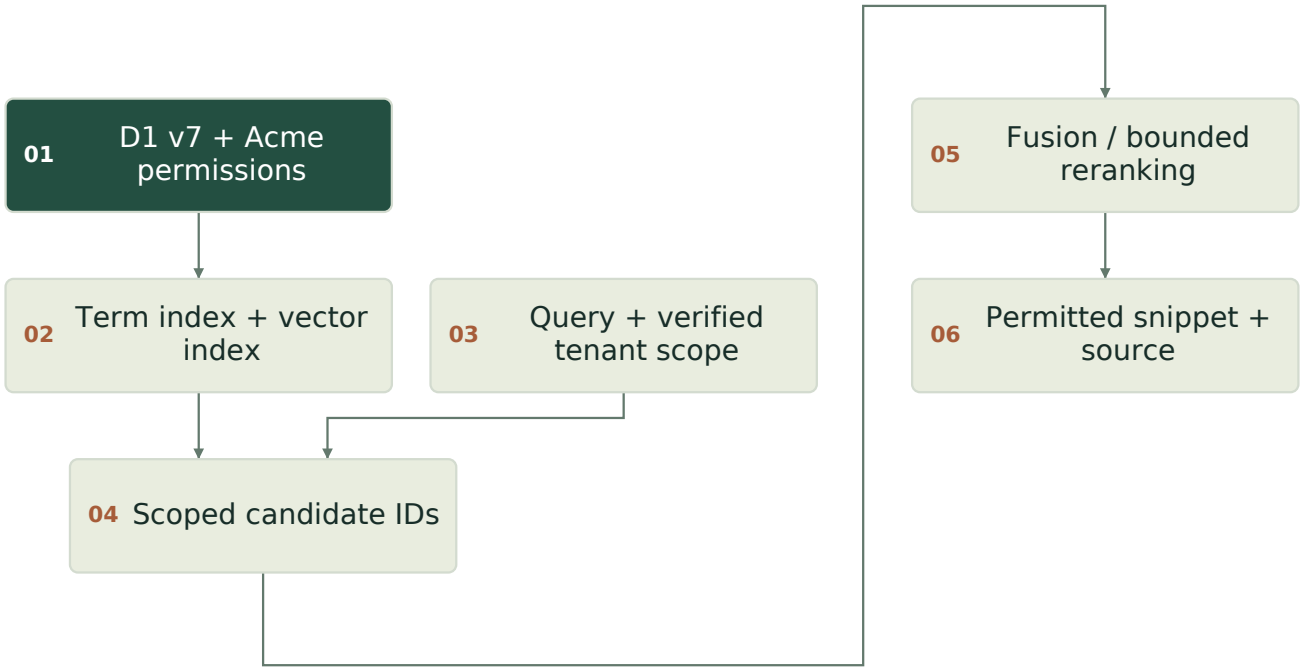
INTERVIEW CRITICAL

Authorize content before a model receives it

This boundary also applies to external rerankers and assistants. Authorization must happen before their model context receives a private snippet; filtering displayed citations afterward cannot undo exposure. The service must not authorize v7 and then fetch a newer restricted body as if the old decision covered it.

WORKED EXAMPLE DIAGRAM

Candidate metadata is a hint. Authorize the exact immutable content before reranking or model use, and enforce the release policy; Birch content cannot pass through a stale Acme decision.



1 -> 2	versioned ingestion: D1 v7 + Acme permissions -> Term index + vector index
3 -> 4	query terms and embedding: Query + verified tenant scope -> Scoped candidate IDs
2 -> 4	eligible candidates: Term index + vector index -> Scoped candidate IDs
4 -> 5	authorize + fetch exact versions: Scoped candidate IDs -> Fusion / bounded reranking
5 -> 6	enforce release policy revision: Fusion / bounded reranking -> Permitted snippet + source

05 / Exact nearest neighbors, ANN, HNSW, and vector memory

Exact nearest-neighbor search returns the true nearest eligible vectors under the chosen metric. A simple exact baseline scores every eligible vector; an exact index may prune candidates only when it can prove they cannot change the answer. Exhaustive scoring is often useful as an evaluation baseline, but exactness is a result guarantee, not a requirement to scan every vector. Approximate nearest-neighbor search, ANN, uses an index to examine fewer candidates, trading some retrieval recall for latency and resource savings. Hierarchical Navigable Small World (HNSW) is a graph-based ANN approach: search navigates connections among nearby vectors rather than scanning all vectors.

For 10 million vectors with 768 float32 components, raw vectors consume `10,000,000 x 768 x 4 bytes = 30.72 GB` in decimal units. Graph links, metadata, text, replicas, and indexing overhead add more. Quantization can reduce vector storage, with a quality and implementation tradeoff that must be measured.

INTERVIEW CRITICAL

Filtering an unrestricted top list can miss eligible results

Selective filters complicate ANN. Searching the unrestricted top 20 and then removing other tenants may return zero results even when excellent Acme matches exist outside those 20. Retrieval that integrates eligible-document filtering, or a sufficiently complete filtered exact search for a small eligible set, can avoid this particular candidate starvation. The actual performance and recall depend on the engine and query distribution.

HNSW uses a hierarchy: sparse upper layers provide long-range navigation, then the search descends to denser layers and explores a bounded candidate set near the query. Retaining more candidates generally improves recall at additional query work; adding graph connections costs memory and construction work. Tuning must include filtered queries and updates, not only unfiltered reads.

An inverted-file (IVF) index offers another tradeoff: train a set of coarse clusters, assign vectors to lists, and probe selected nearby lists at query time. Searching too few lists can omit the true neighbors. Product quantization is a separate compression technique that represents vector subvectors with compact codes; it can save memory while introducing distance error. Index navigation and numeric compression are different sources of approximation.

06 / Hybrid search, reciprocal rank fusion, and reranking

Retrieval approach	Useful query	Benefit	Limit
Keyword/inverted index	Exact IDs, names, and required terms	Clear lexical matches and controllable term rules	Different wording may miss relevant documents
Exact vector search	Similar meaning in a small eligible collection	Finds exact neighbors under the chosen metric	Exact scoring or safely pruned search can be costly; metric relevance is not truth
Approximate vector search	Similarity over a large collection	Lower search work and latency	Can miss neighbors; filtering affects recall
Hybrid retrieval plus reranking	A mix of precise terms and paraphrases	Broader candidates and more careful final ordering	Extra compute and tuning; missing candidates remain missing

A simple hybrid strategy runs lexical and vector retrieval, deduplicates by document or chunk identity, and fuses their ranked lists. Do not add arbitrary raw scores without calibration: a BM25 score of 12 and a cosine score of 0.8 have different scales.

One way to avoid incompatible score scales is to combine each candidate's position in the retrieved lists. **Reciprocal rank fusion** gives larger contributions to higher-ranked candidates and adds the contributions across lists. It does not require BM25 and cosine scores to mean the same thing.

Reciprocal rank fusion uses each item's rank, for example a contribution of `1/(60 + rank)` from each list. If D1 is rank 1 in vector search and rank 4 in lexical search, its combined contribution is `1/61 + 1/64 ~ 0.0320`. The constant 60 is an illustrative choice, not a universal best setting. A reranker can then compare the query with a bounded candidate set more carefully, at additional latency and compute cost.

Deduplicate overlapping chunks, diversify where the task requires distinct sources, and preserve exact-match boosts for identifiers. The final page should contain useful evidence, not ten slightly different chunks of the same paragraph. Decide ranking behavior with evaluated queries, not the sophistication of the algorithm name.

07 / Precision, recall, index freshness, and authorization

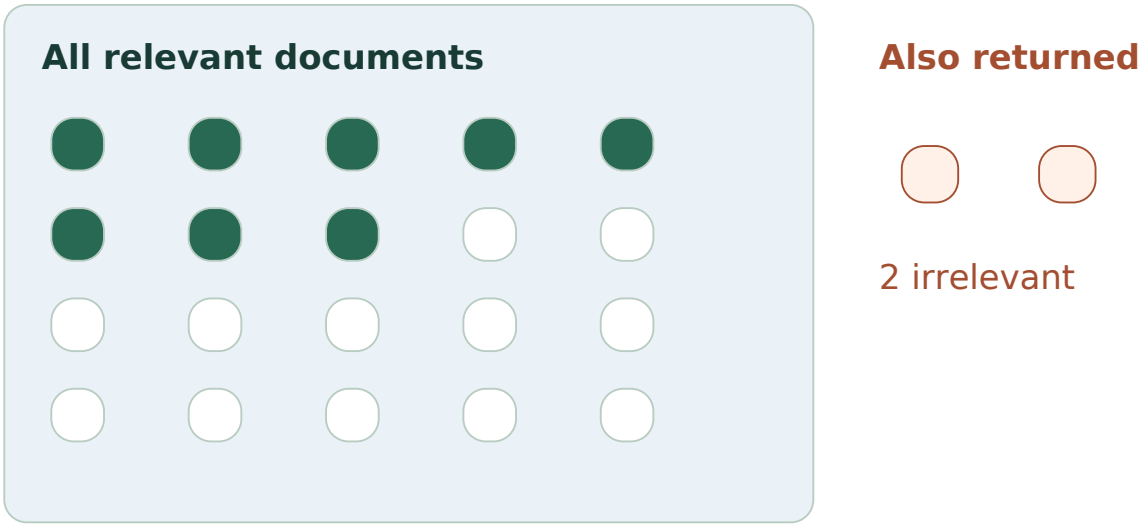
Precision asks what fraction of returned documents are relevant. **Recall** asks what fraction of all relevant eligible documents were returned. The `@k` notation evaluates only the first k results, so both metrics need an explicit cutoff and a labeled set of relevant documents.

Assume a labeled query has five relevant authorized documents. The returned top five contain three of them. Precision@5 is `3/5 = 60%`; recall@5 is `3/5 = 60%` in this example. If there were ten relevant documents instead, precision would remain 60% but recall would be 30%. Rank-sensitive measures such as nDCG also value putting highly relevant results near the top.

Two denominators, one result set

Filled green squares are relevant results returned. White squares are relevant documents missed. Orange squares are irrelevant results returned.

20 relevant documents; return 10, of which 8 are relevant



8 green + 2 orange = 10 returned

Precision = 8 / 10 = 80%: how clean are the returned results?

Recall = 8 / 20 = 40%: how much relevant material did we find?

Remember: Precision asks "of what I returned?" Recall asks "of everything relevant?"

Try from memory: If all 20 relevant documents were returned along with 80 irrelevant ones, what would the scores be?

Answer: Recall would be 100% (20/20), while precision would be 20% (20/100).

INTERVIEW CRITICAL

Nearest-neighbor recall does not measure answer usefulness

Keep a representative query set covering exact IDs, paraphrases, rare topics, languages, and permission boundaries. Compare ANN results with an appropriate exact baseline to measure approximation loss, and use relevance judgments to measure user usefulness. A high nearest-neighbor recall does not prove the embedding model retrieved useful answers.

Measure how long indexing, deletions and permission changes take, alongside p95 latency, empty results and cost. If revocation must take effect immediately, old index metadata cannot be the only access check. Track document versions, propagate deletion markers and check current permission before returning content. Build

and validate a replacement index separately, then switch readers while retaining a rollback option. Updating the live index piece by piece can mix incompatible versions.

Start with the simplest search setup that meets measured needs. PostgreSQL full-text search and pgvector can keep search close to source records and permissions; measure exact vector search first. Add HNSW or IVFFlat when the speed benefit justifies their recall and resource costs. Filtering approximate results may leave too few matches, while searching further costs work. A separate service such as Elasticsearch or Azure AI Search can scale search independently, but its copied index still needs a freshness and access-control policy.

An index migration must move a compatible set of components together: query embedding model, stored embeddings, analyzer, chunking and ranking configuration must remain compatible. Record the serving generation on each request and evaluate the replacement on the same relevance and permission tests before switching traffic.

Precision and recall count useful results but do not distinguish where they appear within the evaluated list. Moving the best answer from first to fifth can make the experience worse without changing either count. Rank-sensitive measures evaluate that ordering; choose one that reflects whether the user needs a first useful answer or a useful result list.

Mean reciprocal rank (MRR) measures how early the first relevant result appears. For each query, use `1 / rank` of its first relevant result, or zero if none appears within the evaluation cutoff; then average across queries. First hits at ranks 1, 4 and absent give `(1 + 0.25 + 0) / 3 ~ 0.417`. MRR suits "find one good answer" tasks but ignores the quality of later results.

Normalized discounted cumulative gain (nDCG) sums graded relevance with lower weight at later ranks, then divides by the ideal ordering's score at the same cutoff. It measures the quality of the ranked list, rather than only the first hit. State relevance labels, cutoff and the convention for queries with no relevant documents; do not compare scores from different evaluation sets as though they were interchangeable.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is an inverted index? If reset maps to {D2,D4} and access to {D1,D4}, how does reset AND access execute?

Model answer

An inverted index maps a term to the documents containing it. Here reset maps to D2 and D4, while access maps to D1 and D4. Intersecting the posting lists returns D4 without scanning every document body. Positions support phrases and term statistics support ranking.

Interviewer follow-up

How is that different from vector retrieval?

Vector retrieval compares compatible numeric embeddings under a similarity measure and can match related wording without identical terms. It does not replace exact identifier fields or prove that a document is correct or authorized.

What the answer must demonstrate: Build the two lists and distinguish lexical matching from similarity.

02 / APPLIED

When does vector search help?

Model answer

"It helps retrieve semantically related wording, such as lost phone matching authenticator recovery. It is weaker for some precise identifiers and does not establish truth or permission, so I evaluate it alongside lexical search and metadata filters."

Interviewer follow-up

Can I change embedding models without rebuilding vectors?

Only with an explicitly compatible representation contract. Otherwise stored and query vectors no longer share a meaningful space and need migration.

What the answer must demonstrate: Similarity is a retrieval signal.

03 / APPLIED

What does approximate nearest-neighbor search trade away?

Model answer

Approximate search can miss neighbors that an exact result would include, in exchange for less work on suitable workloads. I compare it with an exact baseline under the same metric and eligibility filters, then tune latency, memory and recall together. Exactness does not require a full scan if an index can safely prove which candidates cannot win.

Interviewer follow-up

Does 99% neighbor recall imply 99% useful answers?

No. It measures approximation relative to the chosen vector metric, not whether the model or document collection captures user relevance.

What the answer must demonstrate: Separate approximation quality from semantic quality.

04 / APPLIED

Estimate raw storage for ten million 768-dimensional float32 vectors.

Model answer

"Each vector is 768 x 4 = 3,072 bytes. Ten million require 30.72 GB in decimal units before graph links, metadata, text, and replicas. I would size those separately and benchmark any quantization loss."

Interviewer follow-up

Does adding two replicas double or triple total copies?

Two additional replicas plus the original means three copies; clarify terminology before multiplying.

What the answer must demonstrate: Keep units and overhead explicit.

05 / APPLIED

Why not add a keyword score directly to a cosine score?

Model answer

"Their scales and distributions differ. I can calibrate a learned combination or start with rank fusion, then evaluate. Reciprocal rank fusion uses positions in each result list and avoids pretending unlike raw scores have the same meaning."

Interviewer follow-up

What does a reranker change?

It spends more compute comparing the query with a smaller candidate set; it cannot recover a relevant document that never became a candidate unless another retrieval stage adds it.

What the answer must demonstrate: Candidate recall bounds reranking.

06 / APPLIED

Why can filtering the final top twenty return no useful result?

Model answer

"All twenty may belong to another tenant even though relevant authorized documents exist deeper in the collection. I apply an eligible-document retrieval strategy and evaluate selective filters. In every case I enforce authorization before content leaves the trusted retrieval boundary."

Interviewer follow-up

Can filtering only displayed citations secure an assistant?

No. Unauthorized snippets may already have entered its context and influenced the answer.

What the answer must demonstrate: Distinguish candidate starvation from data exposure.

07 / APPLIED

Three of five returned documents are relevant; ten relevant documents exist. What are precision and recall?

Model answer

"Precision@5 is 3/5, or 60%. Recall@5 is 3/10, or 30%. I also measure ranking quality because users often inspect only the first results."

Interviewer follow-up

What query set should the evaluation include?

Realistic exact IDs, paraphrases, rare cases, language variation, empty-result cases, and permissions - not just easy queries chosen to flatter the system.

What the answer must demonstrate: Use the correct denominator.

08 / APPLIED

A document was deleted but remains searchable. How do you fix the contract?

Model answer

Send versioned deletion markers to the index and measure cleanup delay. To block access immediately, do not rely only on that delayed index update. Check current source permissions for the exact document and policy version before fetching its body or sending it to a model. Fetch that fixed content version; if versions differ, check permission again. Apply the promised access check when releasing the response too.

Interviewer follow-up

How would you migrate the embedding model?

Build and validate a versioned replacement index with matching query embeddings, switch traffic deliberately, and retain a compatible rollback path.

What the answer must demonstrate: Treat freshness and authorization as explicit guarantees.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Build search over ten million support documents for multiple tenants. Explain lost-phone recovery, an exact error code, and an immediate permission revocation.

- Show postings and one vector-similarity example.
- Estimate vector memory and name extra overhead.
- Choose and evaluate candidate retrieval and ranking.
- Trace permissions, version changes, and delete propagation.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

The search index finds a relevant document. May the service return it immediately?

Only after checking that the caller may read the exact content version being returned. Old index permissions may no longer be valid.

Find candidates -> check access -> return permitted content.

Lexical / vector

Lexical matches terms; vectors match learned similarity; hybrid combines evidence.

Exact words and related meaning.

Precision / recall

Precision: relevant among returned. Recall: returned among all relevant.

Precision: how useful are the results? Recall: how much was found?

Summary and interview notes

Search uses an index copied from source data. Define relevance, update delay and access rules separately. Measure exact keyword/vector search first; add approximation when its savings justify the missed results. Check access to the exact content version before passing it to a reranker or assistant.

Remember these points

• An inverted index maps terms to postings; BM25 combines rarity, saturating frequency and document-length normalization.

• Embedding model and metric must be compatible; cosine measures direction, not truth or permission.

• Exact search is a result guarantee; ANN navigation and vector compression can each introduce different errors.

• Rank fusion combines candidate lists, while a reranker cannot recover a relevant item that was never retrieved.

• Precision, semantic recall, ANN neighbor recall and authorization correctness measure different properties.

Interview tips

• Build a tiny posting intersection and calculate one similarity before naming a search engine.

• Compare ANN against an exact eligible-set baseline, including very selective tenant filters.

• Trace one permission change through index, content fetch, reranker and final response with version checks.

Important qualifications

• Ten million 768-dimensional float32 vectors consume 30.72 decimal GB before index, metadata and replica overhead.

• Changing an embedding model can require a new compatible index and query-serving bundle; matching vector length is insufficient.

• A signed or cached search hit never grants permanent access to the source document.

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FOUNDATIONS / 24

Authentication, authorization, and tenant isolation

DEFINITION

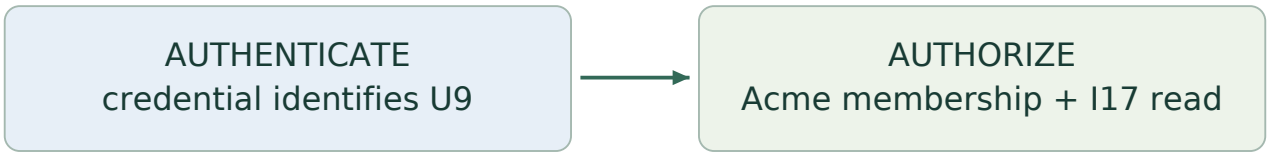
Authentication establishes who a caller is; authorization decides whether that caller may perform a particular action on a particular resource. Tenant isolation prevents one customer's users or workloads from accessing or improperly affecting another customer's data and resources in a shared service.

Why it matters: A valid login, an unguessable ID, or encrypted storage does not stop an application from returning the wrong customer's record.

Authentication, authorization, and tenant isolation

A trusted tenant context constrains every database query, cache entry and job. Knowing an identifier is not authorization.

User U9 requests tenant Acme's invoice I17



Carry server-derived tenant scope at every access

SQL	tenantId = Acme AND invoiceId = I17
CACHE	Acme : I17 : version : permitted view
JOB	trusted {tenant:Acme, invoice:I17}

Same URL from U10: deny the unauthorized read.

Check the action and object, not just login. Tenant scope must also reach files and exports.

Worked example

Invoice I17 in tenant Acme has amount $45.00. User U10 is authenticated for Birch; GET /tenants/Acme/invoices/I17 must deny access despite the valid login.

Key takeaways

• Authenticate the caller, then authorize the exact action and resource.

• Derive tenant scope from verified membership and carry it through every data path.

• Encryption and dedicated storage help specific threats; they do not replace access checks.

Read the visual model

1. Authenticate user U9, then check active membership in tenant Acme and permission to read invoice I17.

2. The database lookup includes tenantId=Acme and invoiceId=I17 plus the finer owner or role policy. The authorized content version is the one returned; a later content fetch must not silently return a different private version.

3. Cache and job identities retain the same server-derived tenant scope. Caller-supplied tenant IDs are not trusted authority.

4. An unauthorized user U10 must not receive I17 merely by requesting the same URL.

authentication • authorization • tenancy • encryption • quotas

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Separate identity from permission with a concrete record.

• Carry trusted tenant scope through databases, caches, search, and jobs.

• Explain encryption, least privilege, and resource isolation.

Useful foundations: HTTP APIs and request lifecycle; Databases, data models, and ACID transactions; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / Authentication, authorization, and tenant isolation: definitions

Authentication establishes who a caller is. **Authorization** decides whether that caller may perform a particular action on a particular resource. A **tenant** is a customer or organization whose users, data, and access policies are managed as one group; **multi-tenancy** means one service supports several tenants, often on shared infrastructure. **Tenant isolation** keeps one tenant's users and workloads from improperly accessing or affecting another tenant's data and resources.

Tenant isolation must hold across every path that returns data or creates an effect. For example, user U9 belongs to tenant Acme and may read invoice I17; user U10 belongs to Birch and has no such permission. Knowing I17 or copying its URL must not authorize access, including through search, exports, attachments, or background jobs.

A random identifier makes guessing harder; it does not establish permission. HTTPS protects a communication channel; it does not tell the application whether the caller owns the invoice. Building security into the request and data model gives each protection a specific job.

02 / Trusted principal, membership, roles, and revocation

INTERVIEW CRITICAL

A caller-selected tenant is not proof of membership

The API validates the credential using its authentication scheme. Depending on that scheme, this can mean checking a signature or asking a trusted identity service whether the credential is valid, a process called **introspection**. For schemes that use token claims or equivalent validation metadata, verify the expected **issuer** (who issued it), **audience** (which service it is intended for), and expiry according to that scheme. It derives a principal - the authenticated user or service identity - and checks their current membership and role for the selected tenant. A `tenantId` header supplied by the caller is a requested context, not proof that they belong there.

A user may belong to multiple tenants. Switching from Acme to Birch requires a verified membership decision. A support administrator may have additional narrowly scoped privileges that should be explicit and auditable. Service-to-service identity similarly needs a bounded permission set; an internal network address is not sufficient authorization.

Limit credential permissions and lifetime, and decide how revocation takes effect. After a user is removed, a cached membership check may still allow access. Expire or invalidate that decision according to the maximum revocation delay the service promises.

Keep the mechanisms distinct:

Mechanism	What it supplies	What the invoice service still checks
Server session referenced by a cookie	A server-managed authenticated session	Session validity, tenant membership and action/resource policy
OAuth access token	Delegated access for its intended resource and scope	Token validation, audience and current object permission
OpenID Connect	Authentication built on OAuth, including identity claims	Establish the application session; an ID token is not an API access-token contract
Mutual TLS	Authenticated peer identities on a connection	Which tenant and actions that service identity may perform

A **JSON Web Token (JWT)** is a token format, not an authorization policy or an encryption guarantee. A signed token can remain cryptographically valid after membership changes; strict current-membership checks need current server state or a revocation mechanism. Role-based access control (RBAC) assigns permissions to roles. Attribute-based access control (ABAC) also evaluates properties such as tenant, owner, classification or environment. An invoice rule might require active membership AND invoice-read permission AND matching tenant AND any required owner restriction.

03 / Tenant-scoped authorization: worked invoice read

Consider the stored record `Invoice(tenantId=Acme, invoiceId=I17, amountMinor=4500, ownerId=U9)`.

1. U9 requests `GET /tenants/Acme/invoices/I17` with a valid credential.
2. The API authenticates principal U9 and verifies active Acme membership plus the invoice-read permission.
3. Data access executes a tenant-scoped lookup using both `Acme` and `I17`, then applies any finer owner or role rule.
4. The response includes only permitted invoice fields. A broad database row is not automatically an appropriate response representation.
5. An audit event records the principal, tenant, action, resource, decision, and trace ID without copying credentials or unnecessary invoice contents.

U10's identical URL fails authorization. Whether the external status is forbidden or not-found depends on the API's deliberate information-disclosure policy, but the record is never returned. Every object action - including update, attachment download, bulk export, and support tools - needs the same policy enforcement.



INTERVIEW CRITICAL

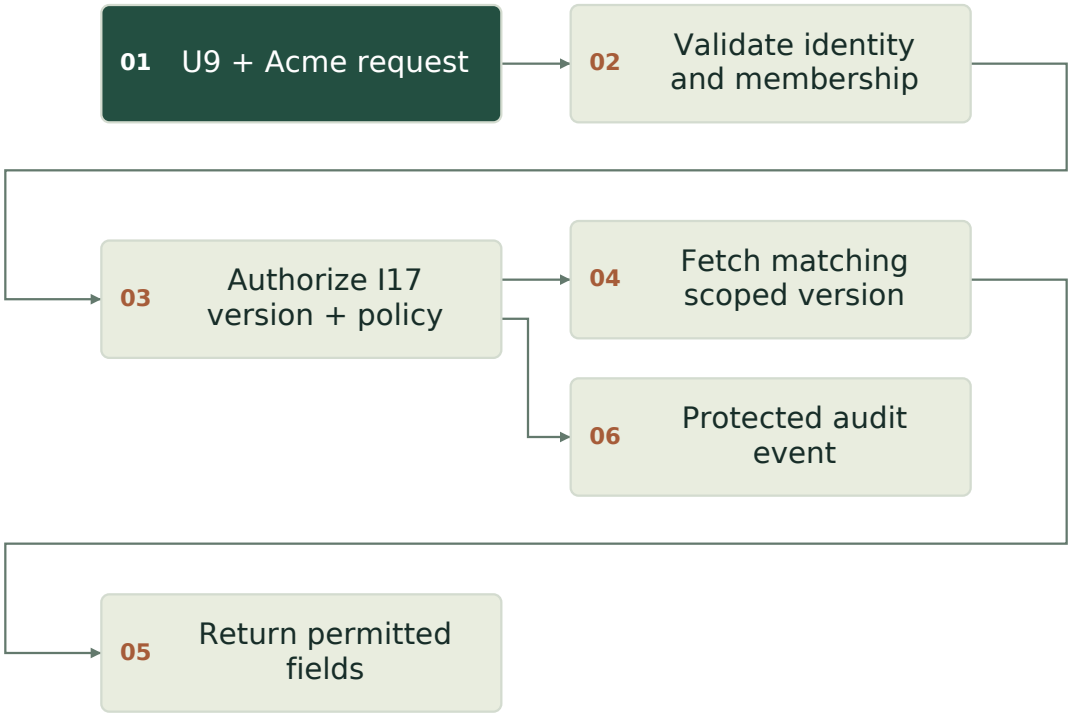
Authorize the exact content version you return

Bind the decision to the data returned. A safe local query evaluates membership, invoice policy and the returned row under one defined database view. With an immutable body cache, authorization instead identifies an exact invoice version and policy revision; fetch that version, and retry authorization if fetching the cached body returns a different version. Checking permission for v3 and then returning newly restricted v4 is unsafe.

Define when revocation takes effect. An **admission-time** policy checks permission when accepting a request and allows that authorized request to finish even if access is later revoked. A **release-time** policy checks the required policy revisions as part of the protected decision to release the response, withholding it if they have changed. Neither can withdraw bytes the recipient already received.

WORKED EXAMPLE DIAGRAM

The resource, representation version and policy context must agree. A login or cached tenant key alone cannot authorize a newer or differently scoped invoice body.



1 -> 2	credential and requested context: U9 + Acme request -> Validate identity and membership
2 -> 3	trusted principal and tenant: Validate identity and membership -> Authorize I17 version + policy
3 -> 4	tenant + version + policy revision: Authorize I17 version + policy -> Fetch matching scoped version
4 -> 5	match decision; otherwise reauthorize: Fetch matching scoped version -> Return permitted fields
3 -> 6	record decision without secrets: Authorize I17 version + policy -> Protected audit event

04 / Shared tables, separate databases, and dedicated deployments

Tenant data can share progressively less infrastructure: rows within the same tables, separate databases, or separate application deployments. The choice changes how much routing and policy enforcement is shared, how failures spread, and how many resources must be operated separately. Every option still needs to map the authenticated caller to the correct tenant.

Model	Mechanism	Benefit	Cost and risk
Shared tables	Tenant key on rows and scoped access	Efficient pooled operation	A missed scope can expose another tenant

Model	Mechanism	Benefit	Cost and risk
Separate schema/database	Tenant-specific logical data boundary	Easier per-tenant lifecycle and some isolation	More migrations, connections, and operational overhead
Separate deployment	Dedicated compute and data plane	Stronger resource and failure separation	Higher cost and fleet management complexity

Database row-level security applies policies that restrict which rows a database role may read or change, providing another enforcement layer. In PostgreSQL, enabled row security without an applicable policy defaults to denial, but owners normally bypass it unless forced, and privileged roles can bypass it. Running the application with a broadly privileged role defeats the intended boundary. Understand the chosen database's exact behavior and keep application authorization as well.

A separate database does not fix a router that selects the wrong tenant database. Shared infrastructure can be safe with disciplined boundaries; dedicated infrastructure still needs correct identity, routing, backups, and operations.



INTERVIEW CRITICAL

Tenant scope must not leak across pooled connections

For a pooled PostgreSQL connection, establish trusted tenant context inside each transaction using transaction-local configuration, perform the scoped work, then commit or roll back. Do not leave a session-wide tenant value for the next borrower. The runtime role must not be a superuser or have BYPASSRLS. Policy `USING` expressions govern visible existing rows; `WITH CHECK` governs permitted inserted or updated row values. Check both so an update cannot move a row into another tenant. The application, not untrusted SQL input, sets this context; parameterized queries and a restricted database role remain necessary.

05 / Tenant isolation in caches, search, jobs, and signed URLs

Suppose the cache key is only `invoice:I17`. Acme and Birch can both have an invoice I17, so one tenant can receive the other's cached value. Use a key such as `tenant:Acme:invoice:I17:v3`, and avoid sharing responses across different permission scopes when field visibility varies by user.

Search and vector retrieval must restrict candidate documents to those the caller may access before unauthorized content enters a response or an LLM prompt. Filtering only the final displayed citations is too late. A background export stores trusted tenant and principal context and checks whether its authorization remains valid when it runs or delivers results.

INTERVIEW CRITICAL

Possessing a signed link can confer access

An object key locates a file; it does not grant access. Check permission before issuing a download link limited to the intended file and time window. A signed link is a **bearer capability**: anyone holding it can use its granted access. Keep it out of logs and define when it expires or can be revoked.

06 / Encryption in transit, encryption at rest, and data lifecycle

TLS encrypts data in transit and authenticates the intended peer under its trust model. Encryption at rest protects stored bytes against some storage-access threats. Neither protects against an application that legitimately decrypts and then sends a record to the wrong caller.

Use managed key storage or an equivalent protected mechanism, tightly scope decryption permissions, and rotate credentials without putting secrets in source code or browser bundles. Tenant-specific keys can improve separation and lifecycle control but add management and availability dependencies. If the service must search plaintext, explain where decryption occurs and who can access it.

Backups, analytics extracts, dead-letter queues, logs, and support exports also contain data. Apply retention, access control, and deletion workflows to those paths. A deletion request may require immediate loss of application access followed by documented physical cleanup and backup-expiry behavior, rather than an impossible claim that every historical byte vanishes instantly.

For large files, the key service should control access to decryption keys without processing every file byte. Envelope encryption separates those jobs: the application encrypts the bulk data, while a protected service controls the key needed to decrypt it. The following two-key arrangement makes that separation possible.

Envelope encryption separates the key encrypting data from the key protecting that key. Generate a data-encryption key, encrypt the object with an authenticated-encryption scheme, then wrap the data key under a protected key-encryption key, commonly managed by a **key management service (KMS)**. Store the **ciphertext** (encrypted bytes), wrapped data key, and algorithm/version metadata. Also store the algorithm's required nonce or initialization vector (IV), an input used for that encryption operation, and its **authentication tag**, which lets decryption detect tampering. Use a vetted encryption library and follow the selected algorithm's nonce-uniqueness rules. An authorized reader unwraps the key and decrypts; plaintext keys must not appear in logs or persistent metadata.

This keeps bulk data encryption outside the key service and permits rewrapping keys without necessarily rewriting all ciphertext. That benefit comes with key-service latency, quotas, permissions and recovery dependencies. Rotating a wrapping key is not the same as changing every data key or erasing old data. Application authorization remains necessary after decryption.

07 / Noisy-neighbor controls and cross-tenant security tests

A noisy neighbor is a tenant whose workload consumes shared resources and degrades others. If Acme launches 10,000 exports, Birch's invoice reads should not wait behind an unbounded queue. Apply per-tenant quotas, bounded concurrency, fair scheduling, and separate pools for expensive background work.

At an assumed two CPU-seconds per export, 10,000 exports need 20,000 CPU-seconds before I/O overhead. A pool limited to 20 fully utilized cores needs roughly 1,000 seconds, or 16.7 minutes, just for that work. Queueing and asynchronous delivery are reasonable; pretending every export can finish immediately is not.

Audit access and quota decisions, alert on unusual cross-tenant denial patterns, and test with two real tenant fixtures. Include negative tests: a valid Birch credential requesting Acme resources, an old signed link after the allowed expiry, and a job whose initiator lost membership. The result should prove the boundary at each route, not merely prove successful login.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is the difference between authentication, authorization, and tenant isolation?

Model answer

Authentication establishes a caller's identity. Authorization checks a specific action on a specific resource. Tenant isolation requires those checks and data boundaries to prevent cross-tenant exposure through every path. For example, authenticated principal U10 belongs to Birch and must not read Acme invoice I17 through the API, cache, search, export, or file endpoint.

Interviewer follow-up

Would using unguessable invoice UUIDs remove the need for object authorization?

No. IDs can leak, be shared, or appear in logs. The service must check the actor, tenant, resource, and action regardless of how hard the ID is to guess.

What the answer must demonstrate: Use an actual permitted and forbidden resource path.

02 / APPLIED

Can the API trust an X-Tenant-ID header?

Model answer

"It can treat it as a requested tenant, then verify the authenticated principal's membership and permission. I never let a caller-selected tenant ID bypass that decision, and I propagate the verified scope into data access."

Interviewer follow-up

What about a background worker?

It receives authenticated job context and an explicit execution/delivery authorization policy, not an unvalidated tenant string.

What the answer must demonstrate: Trace how the scope becomes trusted.

03 / APPLIED

Why can invoice:I17 be an unsafe cache key?

Model answer

Two tenants may share invoice I17, and users may have different field permissions. I key cached bodies by tenant and immutable representation version, authorize the exact version and current policy scope, then return only that authorized representation. If the fetched body or required policy revision differs from the decision, I reauthorize or withhold it.

Interviewer follow-up

Would a global cache flush solve the design?

It can contain an incident, but the durable fix is correct keys, authorization boundaries, and revocation behavior.

What the answer must demonstrate: A fast cache can consistently leak data.

04 / APPLIED

Is row-level security sufficient on its own?

Model answer

"It is useful defense in depth when policies, roles, and connection context are correct. I still enforce object/action permission in the application and verify privileged-role bypass behavior. A database policy cannot secure an unscoped object-storage or cache path."

Interviewer follow-up

What if the app connects as the table owner?

In PostgreSQL owners normally bypass row security unless forced, and superusers/BYPASSRLS roles remain privileged. I use a restricted runtime role and transaction-local tenant context, then test reads and WITH CHECK behavior on writes through the actual pooled connections.

What the answer must demonstrate: Know the enforcement boundary.

05 / APPLIED

Does encryption at rest prevent one tenant seeing another's records?

Model answer

"No. If the application can decrypt both tenants' records, it can still send the wrong one. Check tenant permissions, route to the correct data and return only allowed fields. Encryption protects stored bytes; it does not make those application decisions."

Interviewer follow-up

Where should keys live?

In protected key or secret infrastructure with scoped access and rotation, outside source control and client bundles.

What the answer must demonstrate: Name the threat each mechanism addresses.

06 / APPLIED

Is a signed download URL private to the logged-in user?

Model answer

"Usually it is a bearer capability, so another person holding it can use it until its conditions expire. I authorize before issuance, limit scope and lifetime, and use an application-mediated access check when immediate revocation is required."

Interviewer follow-up

Should URLs appear in ordinary logs?

Avoid recording capability tokens or query strings that expose access; use safe resource identifiers for observability.

What the answer must demonstrate: Possession can confer access.

07 / APPLIED

How do you stop one tenant's exports slowing every customer?

Model answer

"I bound per-tenant concurrency and total queues, schedule fairly, and separate heavy export workers from interactive reads. Quotas describe an enforceable budget; admission control prevents accepting more work than we can serve."

Interviewer follow-up

What happens above the quota?

Return a clear retry or asynchronous scheduling contract rather than letting memory and latency grow without a bound.

What the answer must demonstrate: Security includes resource isolation.

08 / APPLIED

What would you test beyond successful login?

Model answer

"Use two tenants and attempt cross-tenant reads, writes, search, exports, attachment downloads, and cache hits. Also test revoked membership and expired capabilities. Each denied operation must leave data and side effects unchanged under its contract."

Interviewer follow-up

Can error messages leak information?

Yes. Choose a consistent external disclosure policy while retaining detailed protected audit information for operators.

What the answer must demonstrate: Exercise alternate access paths.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Design an invoice API shared by Acme and Birch. Try to leak Acme invoice I17 through each secondary data path.

- Trace identity, membership, action, and object checks.
- Specify row, cache, search, export, and file boundaries.
- Explain signed-link expiry and membership revocation.
- Bound tenant resource consumption and audit sensitive actions.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Authentication (AuthN) / authorization (AuthZ)

Identity first; permission for this action and object second.

Who? May do what?

Acme and Birch both have invoice I17. What must a cache key include?

The verified tenant ID as well as the invoice ID, with permission scope when users can see different fields. Apply tenant checks to database, search, job and file paths too.

Same record ID can belong to different tenants.

Encryption

Protects bytes and channels; does not decide who may receive decrypted data.

A lock needs a permission rule.

Summary and interview notes

Authentication identifies the caller; authorization evaluates the requested action on the exact resource and representation. Tenant isolation must carry that trusted decision through primary data, caches, search, background jobs, files and operational tools, while resource controls limit noisy neighbors.

Remember these points

• A caller-selected tenant header is a request for context, not proof of membership.

• Authorization must apply to the returned content version and policy context; if the fetched content does not match the authorized version, check permission again before returning it.

• Row-level security (RLS) is an additional enforcement layer with correct roles and transaction scope, not a replacement for cache/file/API authorization.

• Anyone holding a signed download link can use the access it grants. Define its allowed resource, expiry and revocation limits.

• Encryption protects bytes and channels; fair quotas and pools protect shared capacity.

Interview tips

• Use test users and records from two tenants, with one permitted request and one forbidden cross-tenant request, and exercise every alternate read and write path.

• State when a permission revocation takes effect and whether requests authorized before that point may finish.

• Explain how pooled connections acquire and clear verified tenant scope, including failed transactions.

Important qualifications

• OIDC authenticates users on top of OAuth; a JWT format does not by itself prove current object access.

• An application with access to decrypted records can still leak them through a wrong authorization decision.

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Isolation and shared-resource design considerations.
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Authentication layer over OAuth and distinction between identity and API access.
https://openid.net/specs/openid-connect-core-1_0.html

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https://docs.aws.amazon.com/kms/latest/developerguide/kms-cryptography.html

FOUNDATIONS / 25

Multi-region architecture and disaster recovery

DEFINITION

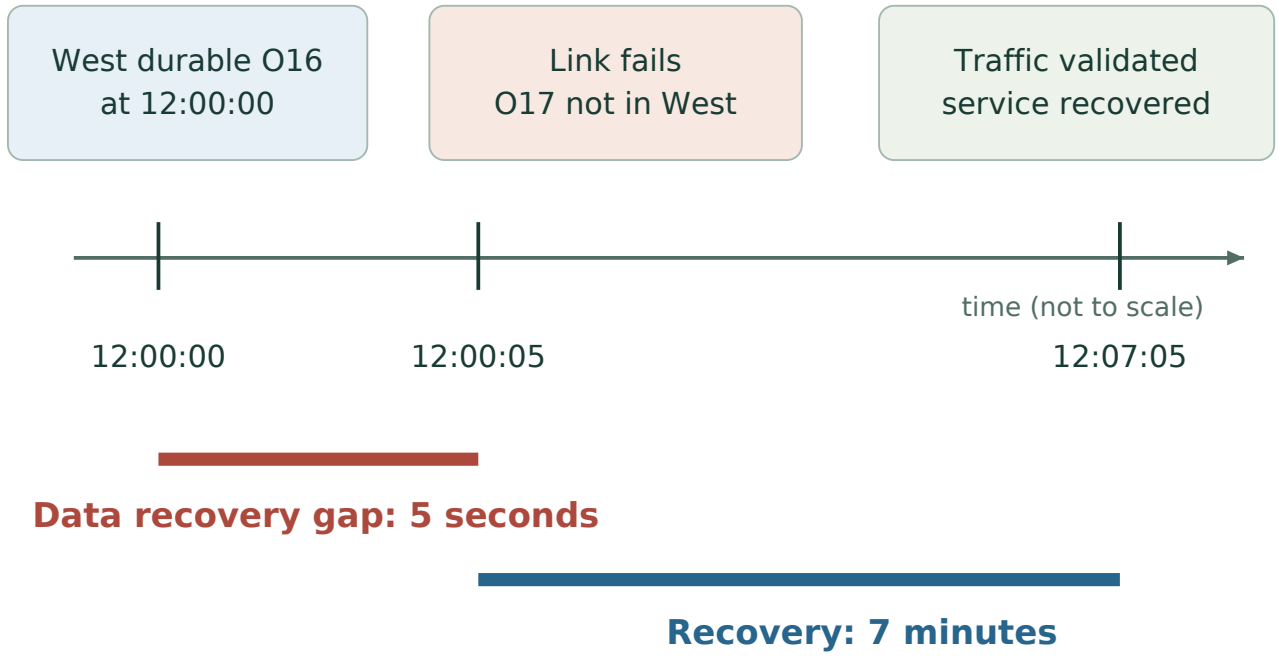
Multi-region architecture deploys a service across geographically separate regions. Disaster recovery is the planned restoration of usable service and data after a major disruption; the recovery point objective (RPO) specifies the targeted data-loss window and the recovery time objective (RTO) specifies the targeted restoration time.

Why it matters: A regional outage, accidental deletion, or failed dependency can affect every local replica. Recovery requires knowing which saved changes survived, ensuring only the designated replacement can accept writes, and providing enough capacity to serve users.

Recovery point objective (RPO) and recovery time objective (RTO)

Compare two intervals: how far the recovered data lags behind the disruption, and how long users wait for service to return.

Two clocks: missing data versus unavailable service



O17 was ACKed at 12:00:04. A second region does not automatically give zero data loss.

Worked example

East acknowledges O17 at 12:00:04, fails at 12:00:05, and West has only data through 12:00:00. Restoring West can miss O17; restoring service at 12:07:05 takes 7 minutes.

Key takeaways

• RPO measures targeted data loss; RTO measures targeted recovery time.

• Asynchronous replication can lose an acknowledged write during regional failure.

• Routing traffic is not fencing the old writer, and replicas are not historical backups.

Read the visual model

1. West has O16 at 12:00:00. East acknowledges O17 at 12:00:04 but it has not replicated. Connectivity fails at 12:00:05.

2. The safe replica is five seconds behind disruption, and O17 may be lost despite its acknowledgement.

3. Service is validated at 12:07:05: measured recovery takes seven minutes. RPO and RTO are objectives against these separate kinds of loss.

4. Fence the old writer before promotion, and reconcile a possibly successful external payment before retrying it.

regions • RPO • RTO • failover • backups

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Distinguish high availability from disaster recovery.

• Calculate recovery objectives from a concrete outage.

• Explain safe promotion, routing, and failback.

Useful foundations: Replication and durability; Quorums, consensus, leases, and fencing

8 interview questions with model answers and answered follow-ups.

01 / Multi-region architecture, high availability, and disaster recovery

Multi-region architecture runs a service across geographically separate deployment regions. **Disaster recovery** is the planned restoration of usable service and data after a major disruption. A **region** is a geographical deployment area whose infrastructure can share risks such as a regional network failure; an **availability zone** is a separate failure domain within a region under the provider's isolation model. Putting servers in two locations does not provide regional recovery if both still depend on the same regional database, credential service, or network.

High availability keeps the service operating through expected component failures. Disaster recovery restores a useful service after a larger disruption. Backups preserve earlier recoverable states. These capabilities overlap, but a replica that immediately copies an accidental deletion is not a substitute for a backup that can restore yesterday's data.

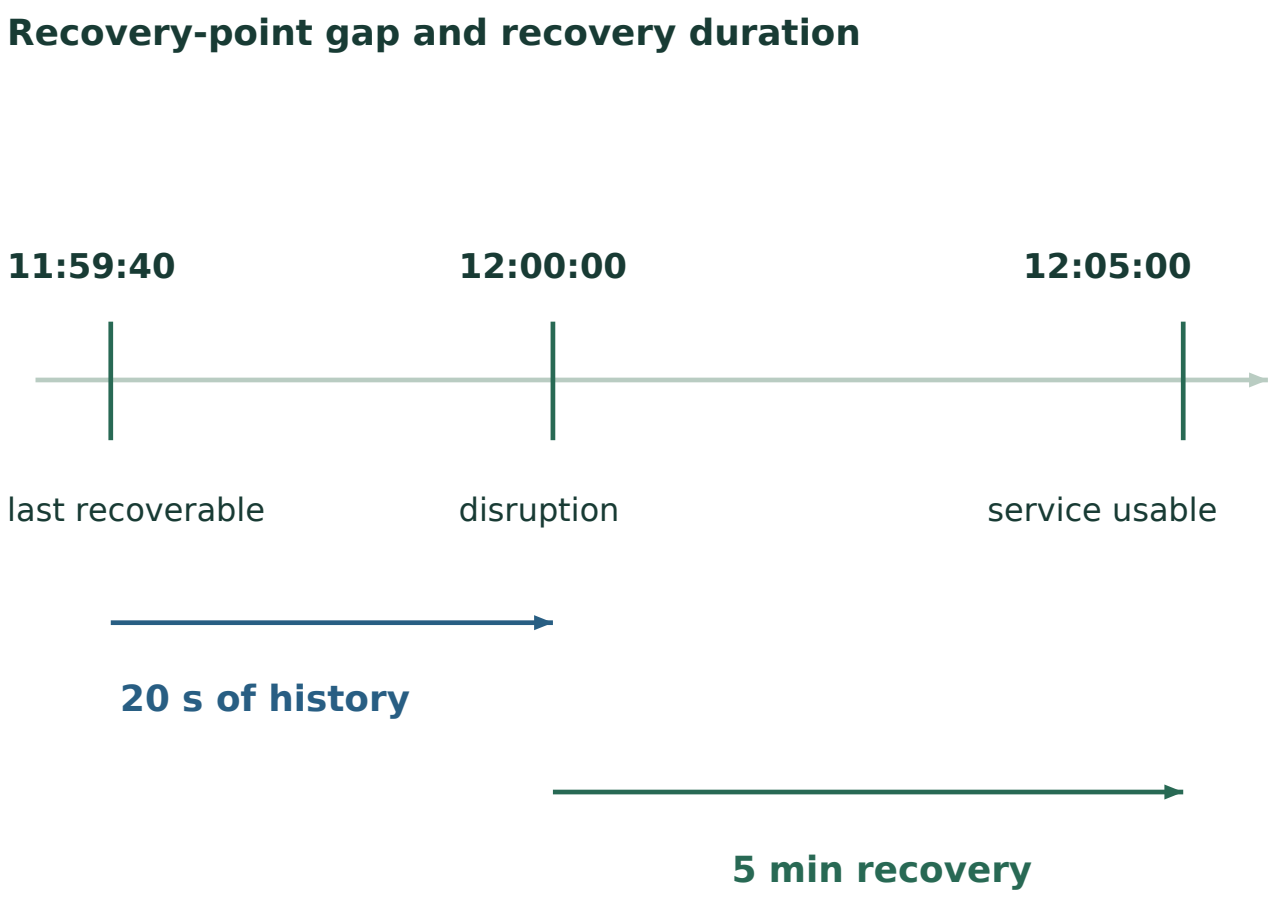
Specify allowed data loss and recovery time before choosing a regional topology. An East-primary/West-asynchronous-replica example illustrates the tradeoff: an acknowledged order O17 can be absent from West when East fails. Whether that loss is acceptable, and whether writes may pause during recovery, determines the required coordination and cost.

02 / Recovery point objective (RPO) and recovery time objective (RTO)

The recovery point objective, RPO, is the target maximum amount of data loss measured as a time window. An RPO of 30 seconds means the recovery plan targets a recoverable state no more than 30 seconds behind the disruption. The recovery time objective, RTO, is the target time to restore the agreed service after disruption. Neither is a guarantee merely because it appears in a diagram.

RPO looks at lost history; RTO looks at downtime

The timestamps are concrete; distances on this timeline are not to scale. The gaps shown are actual outcomes, to compare with the objectives.



Compare the first gap with RPO, the second with RTO. Not to scale.

Remember: Look backward for the recovery point; forward for service recovery.

Try from memory: Which gap would a 10-second RPO fail to meet?

Answer: The 20-second history gap from 11:59:40 to 12:00:00. The five-minute service recovery is compared with RTO instead.

Objective	Example	What must support it
RPO	At most 30 seconds of accepted changes lost	Replication or recoverable logs within that bound, plus measurement
RTO	Ordering restored within 10 minutes	Detection, safe promotion, routing, capacity, and validation within that budget
Restore correctness	Existing payments reconciled	Durable external IDs and recovery procedures



INTERVIEW CRITICAL

Observed replica lag does not establish an RPO

An observed replica lag of five seconds is not a contractual maximum during an extended outage. If zero loss of acknowledged writes is required across the named regional failure, acknowledgement must depend on durable survival outside that failure domain. This often requires synchronous cross-region coordination and accepts its latency and availability costs.

03 / Active-passive, active-active, and write ownership

A **regional topology** defines where the service runs and which regions may serve each operation. Compare write ownership separately from replication timing: a region may serve reads while another owns writes, and a write may wait for remote durability before success. These choices determine both normal latency and what remains possible after a region is lost.

Topology	Write behavior	Benefit	Cost or limit
Primary with asynchronous standby	East writes; West catches up later	Simple normal ownership and lower write coordination cost	Acknowledged changes may be missing after regional loss
Cross-region synchronous commit	Success waits for the required remote durable state	Can protect acknowledged writes against the named regional failure	Network latency and possible refusal during partitions
Multiple serving regions, one home writer per key	Each tenant/key has a defined write owner	Geographic service without arbitrary concurrent conflict	Remote writes and ownership-transfer work remain
Concurrent writers with defined merge semantics	Regions independently accept mergeable operations	More local write availability for suitable data	Not safe for arbitrary inventory, money, or ownership changes

Start with a primary region and a standby. East owns writes. West receives the ordered change stream. Reads may use West only under a stated staleness policy. This is easier to reason about than allowing both regions to update the same inventory row independently.

Active-active means more than two copies of a web server. If both regions accept writes, specify ownership or conflict handling. Assigning each tenant a home region gives one authority per tenant. Globally coordinating a row can preserve stricter guarantees but adds cross-region latency. Accepting concurrent updates and merging them requires business-compatible semantics; "last timestamp wins" can silently erase an order or inventory reservation.

Read replicas, immutable assets, and regional caches can reduce geographic read latency without making all writes multi-primary. Choose the narrowest distributed-write requirement the product actually needs.



INTERVIEW CRITICAL

Replica placement determines which failures a quorum survives

Replica count is not enough; quorum placement matters. Suppose a three-voter database puts two voting replicas in East and one in West, and commits on any majority. A write can be acknowledged by the two East replicas before West receives it. Losing East then loses the surviving majority and can lose recent acknowledged writes that never reached West if West is force-promoted.

A different design puts one voting, data-bearing replica in each of three regions and commits through a proven majority protocol. Every acknowledged write is durable in two regions. After any one region is lost, the two survivors can elect according to the protocol and recover the committed history; a lagging survivor cannot simply ignore the protocol's election restrictions. This is a constructed quorum example, not a claim that every three-region product uses this layout. It costs cross-region commit latency and still depends on surviving network and service capacity.

04 / Regional failover: detection, fencing, promotion, and routing

Assume East acknowledged O16 at 12:00:00 and West durably applied it. East acknowledged O17 at 12:00:04, but its log entry has not reached West. Connectivity fails at 12:00:05.

1. At 12:00:10 monitoring detects failure. It cannot infer whether East is dead or merely unreachable from West.
2. A promotion procedure establishes that the old writer cannot continue accepted writes under the ownership protocol. A fencing epoch is an increasing ownership-generation number. Resources that check the current epoch can reject an old writer's operations; changing a number without an enforcing resource does not stop the old process.
3. West is promoted from its last safe durable position. In this example O17 may be absent, despite its prior acknowledgement. The observed loss window is five seconds; the missing record was accepted one second before disruption.
4. Routing moves eligible traffic. DNS caches, connection pools, and clients may keep using old endpoints, so routing changes alone do not fence the old writer.
5. The team validates order creation and payment reconciliation before declaring recovery complete. If that happens at 12:07:05, service recovery took seven minutes.

The client retries O17 using its original operation identity. A payment might have succeeded outside the lost database state. The recovery path queries the payment attempt or reconciles provider events rather than charging blindly. The write and payment contracts must survive the disaster plan together.

INTERVIEW CRITICAL

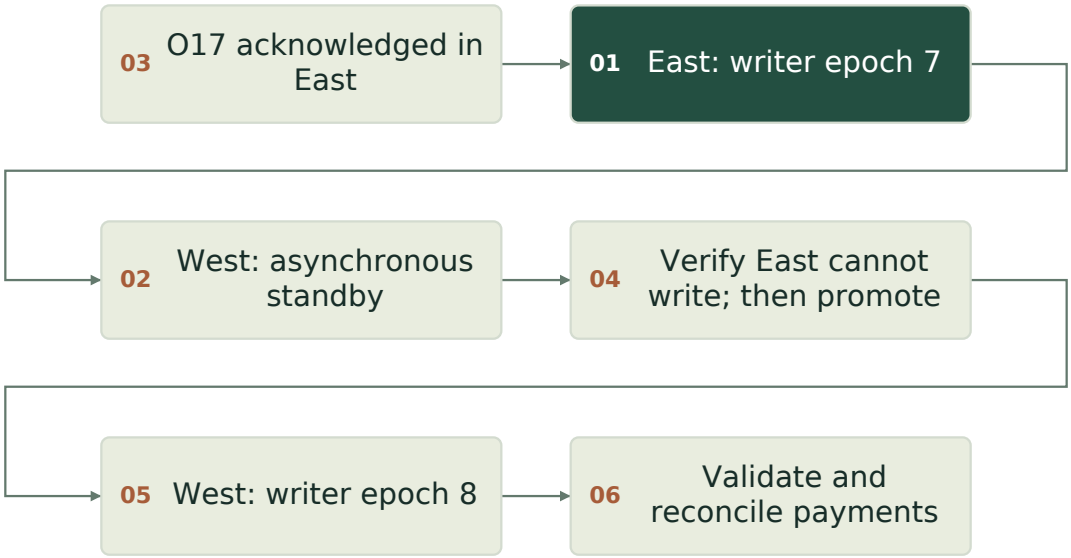
A locally updated epoch cannot fence an isolated region

Step 2 must actually stop East from writing. Increasing a version number only in West cannot inform an isolated East. In this two-region asynchronous example, one safe manual procedure independently stops East's writer or removes its write access, verifies that stop, then promotes West. If you cannot verify it, pause writes. A cross-region consensus protocol is another option: a minority cannot commit without a quorum. Letting each region check its own outdated ownership number does not prevent two writers.

The payment recovery identity must also survive. Store the original client operation ID and provider attempt/resource reference in recoverable state, or ensure the provider can recover the mapping from a durable business reference. If both the mapping and the acknowledged order are lost, the client retry alone does not prove whether a charge exists. Hold new charging attempts while reconciliation reconstructs that fact.

WORKED EXAMPLE DIAGRAM

In this asynchronous example, recent acknowledged writes may be lost if they never reached the standby. Promotion requires a verified stop of the old writer; merely changing West's local epoch or DNS cannot enforce that stop. Payment operation identities must remain recoverable.



1 -> 2	replicate durable log: East: writer epoch 7 -> West: asynchronous standby
3 -> 1	may not yet exist in West: O17 acknowledged in East -> East: writer epoch 7
2 -> 4	last safe recovery position: West: asynchronous standby -> Verify East cannot write; then promote

4 -> 5	only after old writer is stopped: Verify East cannot write; then promote -> West: writer epoch 8
5 -> 6	restore useful service: West: writer epoch 8 -> Validate and reconcile payments

05 / Standby capacity and restore-time estimates

A warm standby has some running resources and scales up during recovery. A hot standby keeps more capacity ready. Backup-and-restore starts from stored snapshots/logs and generally has more work on the recovery path. These are cost and recovery-time choices, not universal time guarantees.

Suppose peak traffic is 10,000 requests/s and West is provisioned for 2,000. Promotion without a capacity plan creates a second outage. Reserve or validate capacity, warm critical caches carefully, and use admission control while recovering. Include database connections, queue throughput, key management, identity providers, configuration, and secrets distribution in the dependency inventory.

For backup transfer alone, restoring 6 TB over a sustained 1 GB/s path takes approximately 6,000 seconds, or 100 minutes, before replay, indexing, startup, and validation. That cannot support a ten-minute RTO without another recovery mechanism. Use measured restore throughput, not a network-interface headline rate.

06 / Backups, point-in-time recovery, and restore validation

Point-in-time recovery restores a backup and replays retained changes only up to a selected moment. Choosing a point before a destructive update can recover data that live replicas have already deleted. The backup, required log history and decryption keys must all be available for that selected point.

Replication can faithfully copy corruption, deletion, or an application bug. Preserve point-in-time recovery logs and backups under access and retention policies that reduce correlated loss. Test restoration into an isolated environment, validate application-level invariants, and measure the entire process.



INTERVIEW CRITICAL

A successful backup job is not a tested recovery

A backup job reporting success proves that a job completed. It does not prove that keys are available, the selected recovery point is clean, or the restored application can serve users. Restore a known order and its ledger relationships, then verify counts, checksums where appropriate, and the ability to accept new work.

Retention has a business and security cost. Keep enough history to detect and recover from plausible mistakes while applying deletion and regulatory obligations deliberately. A disaster-recovery copy remains sensitive production data.

07 / Failback and disaster-recovery exercises

When East returns, it may have different data from West. Keep West in charge of new writes. Rebuild or reconcile East from West, verify replication, then plan the transfer back. Choose a clear switch point and prevent the former writer from continuing afterward. Old clients and running jobs must be rejected if they use an obsolete ownership version.

Run exercises that fail a database, sever regional connectivity, remove a dependency, and restore a backup. Record detection time, last recoverable write, promotion time, routing convergence, and usable capacity. The interview answer becomes credible when it identifies which promise the exercise validates and what would prevent declaring success.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What are RPO and RTO in disaster recovery?

Model answer

RPO, recovery point objective, is the targeted maximum data-loss window. RTO, recovery time objective, is the targeted time to restore the agreed service. If the last recoverable state is 5 seconds before a disruption and service returns 7 minutes later, those are separate data-loss and restoration measurements to compare with the objectives.

Interviewer follow-up

Does observing 5 seconds of replica lag guarantee a 5-second RPO?

No. It is an observation under one condition. The design needs a survival and recovery mechanism that supports the target under its stated failure assumptions; lag may grow during a worse outage.

What the answer must demonstrate: Keep the two objectives separate and distinguish targets from measured guarantees.

02 / APPLIED

Can asynchronous regional replication promise zero loss of acknowledged writes?

Model answer

"Not by itself. East can acknowledge a write and fail before it reaches West. To survive that regional loss without losing acknowledged writes, acknowledgement must require a durable copy or quorum outside East, within the stated failure model."

Interviewer follow-up

What is the price?

Commit must wait for surviving remote durable state under a safe protocol, adding latency and possible refusal during partitions. Also inspect voting placement: two of three voters in one region can acknowledge a majority that disappears with that region.

What the answer must demonstrate: Place the acknowledgement boundary.

03 / APPLIED

The East primary stops responding to West. Why is that alone insufficient to promote West safely?

Model answer

A failed health check cannot prove that East stopped writing. In the asynchronous two-region design, I require a verified stop or removal of its write capability before promotion; if that is impossible, writes remain paused. Alternatively, a proven quorum protocol prevents the isolated minority from committing. A new epoch stored only in West is not sufficient fencing.

Interviewer follow-up

Does changing DNS solve split brain?

No. Cached DNS, existing connections, and background workers can still reach or execute the old writer.

What the answer must demonstrate: Separate routing from write authority.

04 / APPLIED

Would active-active remove all regional outages?

Model answer

"It can improve continuity for some operations, but shared dependencies and write conflicts remain. I would state whether each key has one home writer, uses global coordination, or permits a defined merge. Inventory cannot simply merge arbitrary decrements without a rule."

Interviewer follow-up

Where is multi-region serving straightforward?

Immutable assets and sufficiently stale-tolerant reads can be served regionally without concurrent mutable ownership.

What the answer must demonstrate: Describe per-record semantics.

05 / APPLIED

Can a nightly backup meet a 30-second RPO?

Model answer

"A snapshot alone cannot: it can leave almost a day of changes absent. Continuous recoverable logs or another replication mechanism may narrow that gap. I also need to test restore and replay time against the RTO."

Interviewer follow-up

How long does transferring 6 TB at 1 GB/s take?

About 6,000 seconds, or 100 minutes, before other recovery work, using decimal units.

What the answer must demonstrate: Check both freshness and duration.

06 / APPLIED

The standby has one fifth of peak capacity. Is failover ready?

Model answer

"Only if the recovery contract allows bounded degradation and the remaining capacity or scaling is verified. I would test databases and dependencies too, prioritize essential operations, and limit admission rather than overload the new primary."

Interviewer follow-up

Why might cold caches hurt?

Their miss storm shifts traffic to the recovering database precisely when it has the least headroom.

What the answer must demonstrate: Capacity is part of recovery.

07 / APPLIED

Why keep backups when there are three replicas?

Model answer

"Replicas can copy an accidental deletion or corruption. Backups and point-in-time recovery preserve earlier states under a separate protection policy. I would regularly restore and validate business records, not only check the backup job status."

Interviewer follow-up

What if encryption keys are unavailable?

The bytes may be intact but unusable; key recovery is a dependency in the restore exercise.

What the answer must demonstrate: Replication is not historical recovery.

08 / APPLIED

An old primary region recovers after failover. Why should writes not immediately be routed back?

Model answer

"West has accepted new writes, so keep it in charge. Bring East up to date or rebuild it from West, verify the data, then switch writers through a controlled handover. Prevent the former writer from continuing. If the regions have conflicting histories, resolve them before switching."

Interviewer follow-up

How do you measure success?

Run a real read/write/reconciliation check and confirm the agreed capacity, data state, and SLO, rather than checking only that processes are up.

What the answer must demonstrate: Failback is a controlled state transition.

Build the answer yourself

BLANK-PAGE EXERCISE / 20 MINUTES

Design recovery for an order service with a 30-second RPO and ten-minute RTO. Then change the requirement to no loss of acknowledged orders.

- Place each acknowledgement and durable copy.
- Show the isolated old writer and its fencing mechanism.
- Budget detection, promotion, routing, and validation time.
- Include capacity, payments, backups, and failback.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

RPO vs RTO

RPO: how far back data may go. RTO: how long recovery may take.

Point = data; time = service.

West is ready to take over. Why not redirect traffic immediately?

East may still accept writes. First prevent the old writer from committing, then promote West, route traffic and validate recovery.

Stop old writes -> enable new writer -> verify.

Backup vs replica

A replica follows changes; a protected backup preserves an earlier recovery point.

Copies need history.

Summary and interview notes

Disaster recovery is a tested procedure for restoring an agreed service from a surviving data point. Choose RPO and RTO first, then align acknowledgment, replica placement, write authority, capacity, external-effect recovery and failback with those objectives.

Remember these points

• RPO is the target data-loss window; RTO is the target restoration time, and observed lag is neither promise by itself.

• Asynchronous replication can lose acknowledged writes; zero-loss acknowledgment must depend on state surviving the named failure.

• Replica and voter placement matter: a majority concentrated in one region does not survive that region's loss.

• Changing routes does not stop the old writer. Before promoting another, enforce exclusive write ownership or verify that the old writer has stopped.

• Backups protect historical recovery points, while replicas can quickly copy corruption and deletion.

Interview tips

• Mark every acknowledgment and durable copy on the failover trace.

• Challenge the design with a partition where the old primary remains alive, not only a clean power-off.

• Budget detection, authority transfer, capacity, routing and validation; calculate restore bytes divided by measured throughput.

Important qualifications

• Six decimal TB at one GB/s needs about 100 minutes for transfer alone.

• Payment identity and encryption-key recovery must survive the disaster along with primary business records.

• Before moving back to the recovered region, rebuild or reconcile its data from the region currently accepting writes.

Technical references

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Google SRE: addressing cascading failures
Capacity loss, overload, and recovery interactions.
https://sre.google/sre-book/addressing-cascading-failures/

Ongaro and Ousterhout: Raft
Majority commitment, leader completeness and election restrictions used in the separate three-region quorum example.
https://raft.github.io/raft.pdf

FOUNDATIONS / 26

Production readiness: SLI, SLO, observability, and recovery

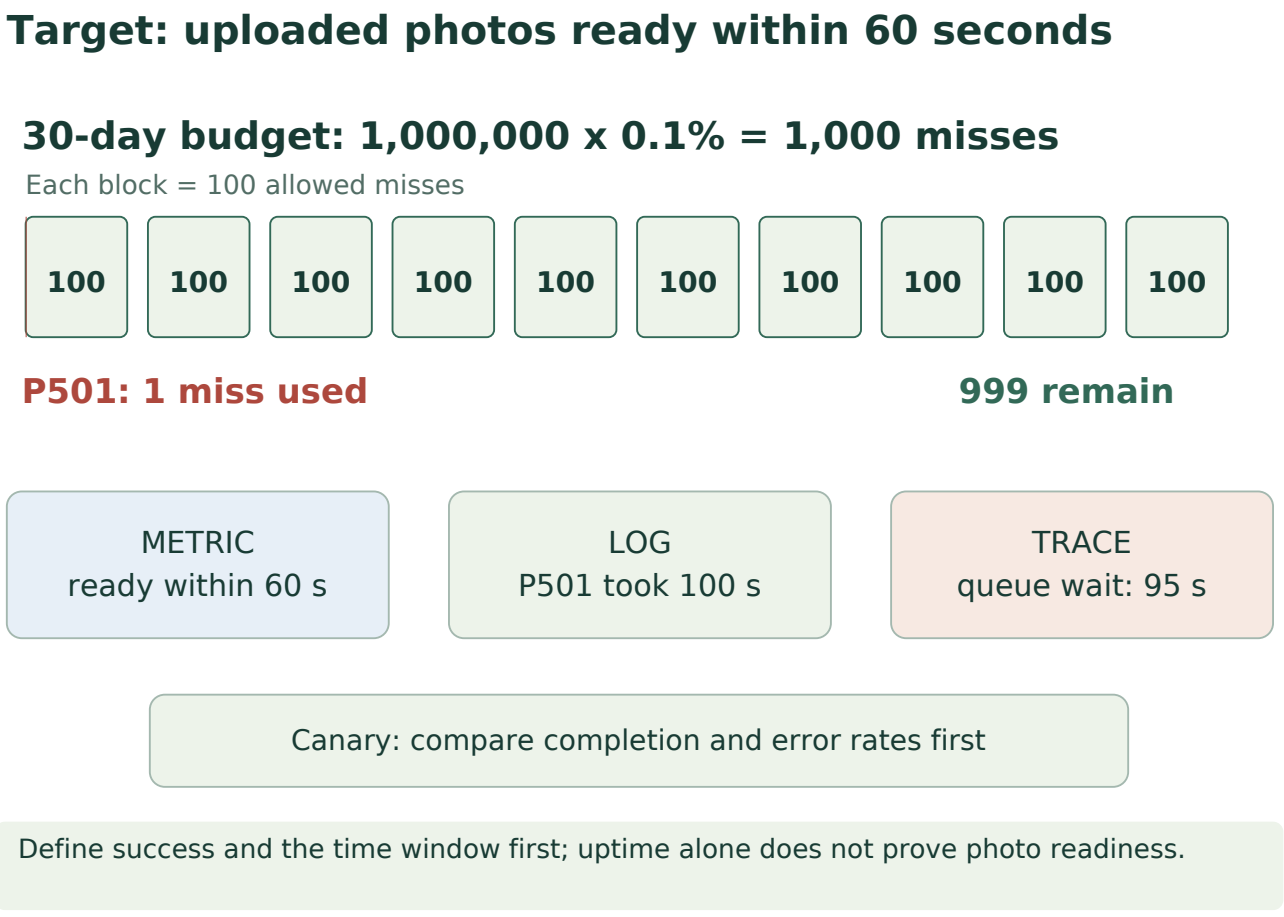
DEFINITION

Production readiness is the ability to operate a service reliably: measure user outcomes, detect failure, limit damage, deploy changes, and recover. An SLI (service-level indicator) is a quantitative measure of service behavior; an SLO (service-level objective) sets its target over a stated window. The error budget is the unreliability that target permits: for example, the allowed number of bad requests or the allowed downtime, using that SLO's denominator and window.

Why it matters: A healthy process can still serve slow, incorrect, or incomplete results. Operators need measurements of the operations users depend on, such as uploading and viewing a photo, and tested procedures for recovering those operations after a failure.

Service-level objectives, error budgets, and observability

An SLI measures service behavior, such as the fraction of photos ready on time. An SLO sets a target over a time window. Compare completion and error rates for the new version with the current version before expanding the rollout.



Define success and the time window first; uptime alone does not prove photo readiness.

Worked example

If 99.9% of one million accepted photos must become ready within 60 seconds, at most 1,000 may miss that target. A 200 response at upload time does not prove that background processing met the objective.

Key takeaways

- Measure whether the requested operation finishes correctly, including any required background processing.
- Metrics show the trend; logs and traces explain individual failures.
- A rollback, failover, or restore is complete only after the user-visible result is verified.

Read the visual model

1. For one million photo uploads evaluated in the rolling 30-day window and a 99.9 percent success SLO, at most 1,000 may miss the defined readiness deadline. Each of the ten equal blocks represents 100 allowed misses.

2. P501 missing the deadline consumes one of the 1,000 permitted bad events, shown as one hundredth of the first block; 999 remain if it is the only miss.

3. Metrics reveal the rate, logs identify a specific job, and traces locate time across stages.

4. A canary compares the new version with the old before rollout expands.

SLI • SLO • observability • error budget • deployment • recovery

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Define a user-facing success indicator, objective, denominator, and time window.
- Use metrics, logs, and traces to distinguish a symptom from its cause.
- Explain a canary rollback and verify recovery without losing accepted work.

Useful foundations: Distributed systems: scalability, reliability, availability and efficiency; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / What is production readiness?

Production readiness means being prepared to run the service through ordinary traffic, changes, overload, and failures. First define what users must be able to do and how reliably and quickly the service must respond. Then decide how to measure whether it meets those requirements and how to recover when it fails. **Observability** is the ability to understand internal behavior from the metrics, logs, and traces that the service produces.

An **SLI** (service-level indicator) is a quantitative measure of service behavior, such as the fraction of photos ready within 60 seconds. An **SLO** (service-level objective) is a target for that measurement over a window. An **SLA** (service-level agreement) is a commitment with agreed consequences, often contractual; it is not simply another name for an internal SLO. An **error budget** is the amount of failure the SLO permits over its measurement window, such as the number of requests allowed to miss a completion deadline.

Measure whether the service finishes the operation the user requested, including any background processing required before the result is usable. In the example, upload P501 is accepted immediately, spends 95 seconds queued, takes four seconds to render and one second to publish, and becomes ready after 100 seconds. That

event misses a 60-second completion threshold despite a successful acceptance response and running API processes.

Check the complete user operation, protect the resources it needs, deploy changes safely and test recovery. A running process is useful evidence, but does not prove the service is fast enough, saves data correctly or enforces access permissions.



INTERVIEW CRITICAL

A completion metric can hide rejected work

Assume the team chooses a 30-day objective: 99.9% of eligible accepted photos become ready within 60 seconds. These numbers are illustrative product decisions. The actual target should come from user needs and the service's cost. We also need a separate acceptance indicator for valid upload attempts; otherwise rejecting every upload could make the accepted-photo completion metric look artificially perfect.

02 / SLI, SLO, SLA, and error budget: definitions and calculation

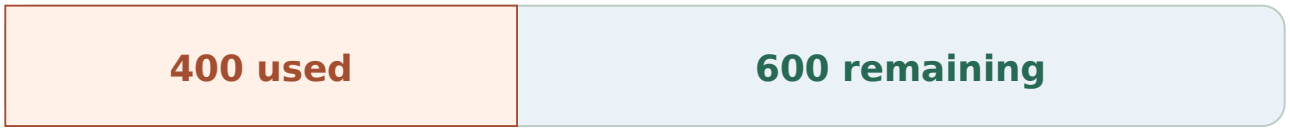
A service-level indicator, or SLI, is the measured behavior. A service-level objective, or SLO, is its target over a stated window. For completion, the numerator counts eligible photos ready within 60 seconds. The denominator counts eligible accepted photos whose evaluation period has elapsed. A just-accepted photo cannot be labeled late before its 60-second allowance ends.

How much of the error budget remains?

This bar represents the 1,000 permitted bad events. It does not represent all traffic.

99.9% SLO over 1,000,000 eligible events

Error budget: 1,000 bad events allowed



Measured result: 999,600 / 1,000,000 = 99.96% good events.

The bar shows only the error budget, not all one million events.

An SLA is a separate agreement; this target alone is not a contract.

Remember: Allowed bad events minus actual bad events gives remaining budget.

Try from memory: How many additional bad events fit in the current fixed window?

Answer: 600, assuming the window still contains exactly 1,000,000 eligible events and the target remains 99.9%.

Decision	Example metric
Operation	Valid uploaded photo becomes viewable
Good event	Ready no later than 60 seconds after acceptance
Denominator	Eligible accepted photos with an elapsed evaluation period
Target and window	At least 99.9% over rolling 30 days
Separate guardrail	Valid upload attempts are accepted successfully

Calculate the error budget

For one million evaluated photos, the 0.1% allowance permits at most 1,000 bad completion events. This allowance is an error budget. P501 is one bad completion event that consumes this budget; one late photo alone does not prove the aggregate 30-day 99.9% SLO was violated. Specify whether unsupported file types, canceled uploads, and failures caused by our service count. Exclusions should reflect the contract, not hide inconvenient incidents. Availability, timely completion, and correctness can require different indicators.

Define exactly which events enter the window

INTERVIEW CRITICAL

Count unfinished work and missed evaluations

Make the rolling window unambiguous. One implementation assigns each accepted photo an evaluation time of `accepted_at + 60 seconds`. At that point it emits exactly one good/bad evaluation, based on whether durable ready state existed by the deadline. The rolling 30-day ratio uses evaluation times in that window; late completion does not later convert a missed deadline into success. Detect missing evaluations as well as bad ones so a broken metrics pipeline cannot silently remove unfinished jobs from the denominator.

Handle no traffic and missing telemetry

When there are zero eligible events, the ratio is undefined, not 100% healthy. Use a no-data signal and the separate acceptance indicator or synthetic check. A time-based 99.9% availability target over 30 days permits 43.2 minutes of bad time, but that is a different denominator from the one-million-photo event budget. Do not convert between them without traffic assumptions.

A **synthetic check** performs a controlled test operation, such as uploading a test image and verifying that it becomes viewable. It can reveal a broken path when real users are inactive. Report that test separately from the real-user completion ratio rather than using it to invent a denominator for a no-traffic period.

03 / Observability and the four golden signals

Metrics are numerical measurements over time. For this service, track upload demand, timely completion, queue age, worker capacity, and errors. The classic four signals are latency, traffic, errors, and saturation: how long work takes, how much arrives, what fails, and which resource is nearly full. Google SRE monitoring.

The 100-second completion is the symptom. High queue age tells us where to investigate; it is not yet the cause. CPU may be low because a worker-concurrency setting is too restrictive, not because there is no demand.

Observation	What it tells us	What it does not prove
Upload responses succeed	Acceptance path is responding	Photos become ready promptly
Queue age rises	Work is waiting longer	The queue service is broken
Worker CPU is 25%	CPU is not fully occupied	Sufficient workers are active
New-release cohort is slower	Release is a useful suspect	Causation without further inspection

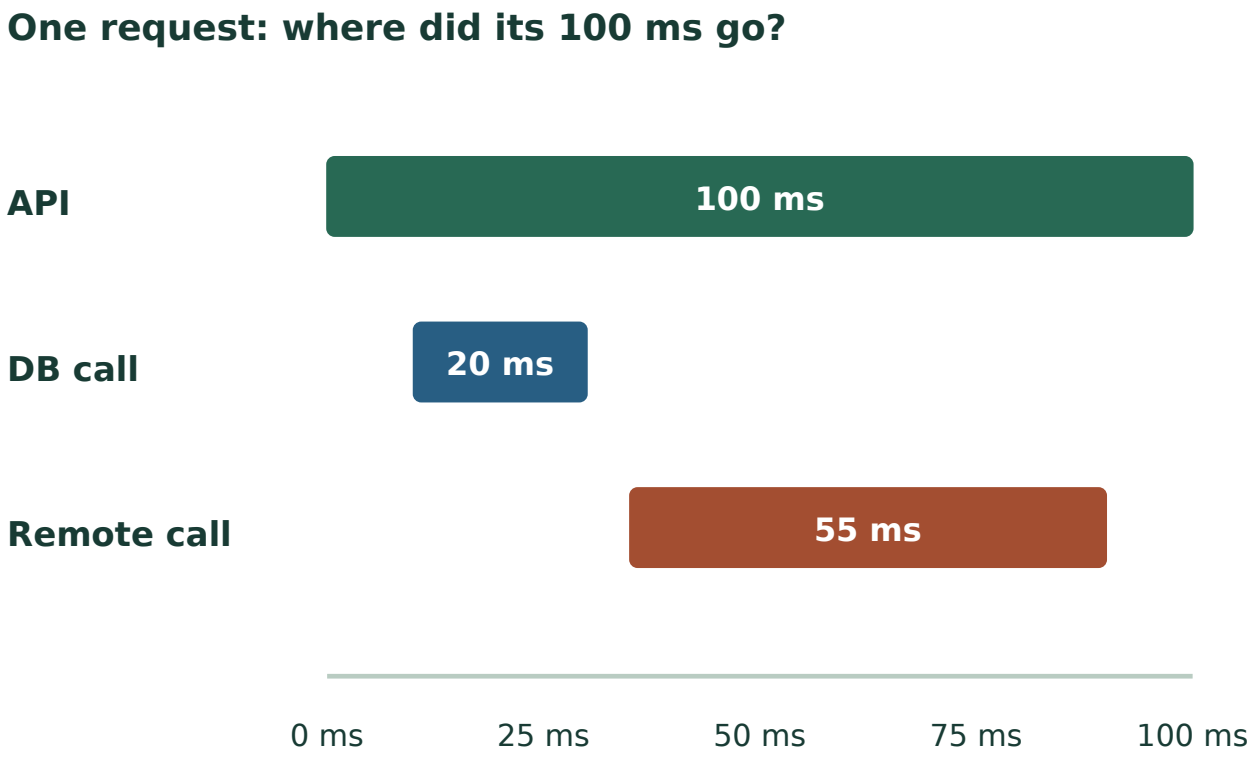
Break down metrics by processing stage and software version. Control **label cardinality**: the number of distinct label values and combinations that create separate time series. A separate time series for every photo ID would be costly; IDs belong in targeted event records and traces.

04 / Logs and distributed traces: locate the missing 95 seconds

Logs record individual events; structured fields make those records searchable. Traces connect work across stages so we can follow one request or asynchronous job. A span records one timed operation within a trace, such as a database call or a worker processing a photo. Carry a correlation identifier that links records for the same job without exposing secrets or personal data through acceptance, queue delivery, rendering, and publication. For asynchronous work, preserve the relationship even when it is represented by a trace link rather than one continuously open call.

A trace shows time spent within one request

Bar width is elapsed time. Child spans overlap the parent's time and must not be added to it.



The child bars sit inside the parent span. Gaps are other work or waiting.

Remember: Read the timeline to locate the slow segment.

Try from memory: Should the API time be calculated as 100 + 20 + 55 ms?

Answer: No. The child spans occur inside the 100 ms parent interval; adding them double-counts their time.

P501 event	Elapsed time	Evidence
Upload accepted durably	0 seconds	Acceptance record
Worker begins	95 seconds	Queue/job trace

P501 event	Elapsed time	Evidence
Rendering finishes	99 seconds	Worker span or event
Photo becomes ready	100 seconds	Publication record

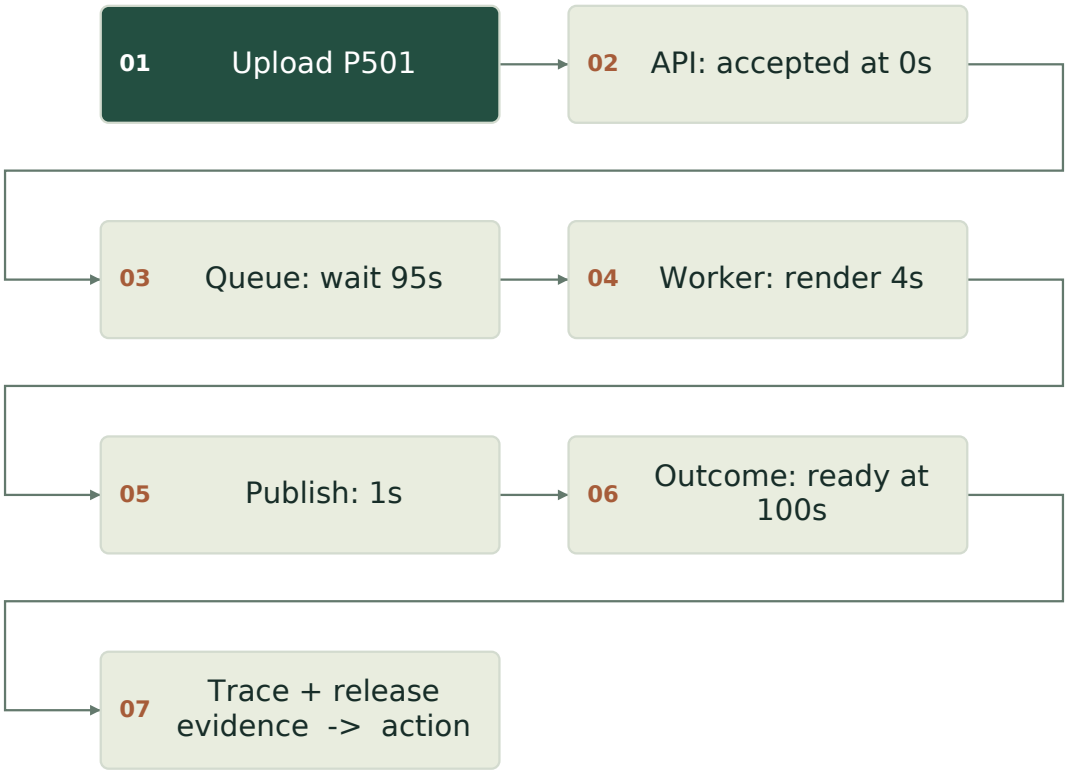
Rendering took four seconds and publication one. Almost all delay was before work began. We inspect the new worker release and discover that its concurrency limit was unintentionally reduced. That mechanism fits both the queue wait and low CPU.

Logs must not copy private image contents, access tokens, or unnecessary personal data. A photo ID and authorized diagnostic lookup are usually more useful than dumping the entire payload into an unrestricted log.

A practical implementation can instrument request and worker spans with OpenTelemetry, propagate trace context in the job metadata, and export selected traces and structured logs to a backend. Use the durably stored job record to decide whether a job completed; sampled traces are diagnostic evidence, not a complete SLO denominator. Cross-host timestamps may differ, so record stage durations with monotonic timers, which measure elapsed time without jumping when the system clock is adjusted, and account for clock uncertainty when subtracting timestamps from different machines.

WORKED EXAMPLE DIAGRAM

P501 waits 95 seconds, renders for 4, and publishes for 1: 100 seconds total. It misses the 60-second deadline. Metrics detect the symptom; trace and controlled release evidence support the mitigation decision. One miss alone does not establish a 30-day SLO breach.



1 -> 2	valid authenticated upload: Upload P501 -> API: accepted at 0s

2 -> 3	stored processing job: API: accepted at 0s -> Queue: wait 95s
3 -> 4	worker begins at 95s: Queue: wait 95s -> Worker: render 4s
4 -> 5	render done at 99s: Worker: render 4s -> Publish: 1s
5 -> 6	ready at 100s: Publish: 1s -> Outcome: ready at 100s
6 -> 7	completion misses 60s objective: Outcome: ready at 100s -> Trace + release evidence -> action

05 / Actionable alerts and error-budget burn rate

A dashboard helps investigation; an alert asks someone to act. Paging on every brief CPU spike creates noise and does not necessarily protect the completion objective. Tie urgent alerts to significant user-impact or rapid budget consumption, with enough evidence to identify the affected service and likely response.

Suppose a recent window has 2% late photos while the SLO allows 0.1%. The burn rate is `2% / 0.1% = 20`: the service is consuming its error allowance at twenty times the reference rate under that measurement. Use both shorter and longer windows so a severe ongoing problem is detected without treating a tiny transient sample as a sustained incident. SLO alerting reference.

Also monitor correctness constraints. A timely response that exposes a private photo is not a successful product outcome. Audit access-control decisions and check that rules such as "only authorized users can view a private photo" hold; latency metrics cannot establish confidentiality. The security-and-multi-tenancy chapter explains where and how to enforce those access checks.

For the illustrative 30-day window, a sustained 20 x burn would consume a full window's budget in about `30 / 20 = 1.5 days` under steady traffic and the same bad-event definition. That is a planning approximation, not a promise about a rolling window with changing request rates. Each paging alert should identify the affected objective, the team responsible for responding, a link to diagnostic information, and the first safe action to reduce the impact. Route slower budget erosion to a nonurgent work queue rather than paging on every symptom.

06 / Canary deployments, rollback, and backlog recovery

A canary release sends a limited portion of work to a new version before broad rollout. Compare workers running the new version with a control group running the current version on similar jobs. Measure whether photos become ready on time as well as whether the worker processes are running. In this example, route comparable jobs to a small canary worker pool with its own bounded queue so queue wait can be attributed to that pool. The canary shows elevated waiting and the reduced concurrency setting; stop expansion and restore the known-good configuration. If old and new workers instead pull from one shared queue, queue age is a shared symptom, not a per-version causal measurement. Compare per-version processing throughput and controlled workload evidence before attributing the delay.

Recover work accepted during the rollout

INTERVIEW CRITICAL

Restoring old binaries does not complete recovery

Rollback is not complete when old binaries are running. Accepted P501-like work remains queued. Confirm that processing capacity exceeds continuing arrivals, that job age falls, and that completed photos have the correct versions and permissions. Retries must remain idempotent so recovery does not create duplicate effects.

Keep data formats compatible

A schema change may prevent a simple binary rollback if the old code cannot read new data. Deploy changes in stages so that old and new application versions can both read the stored data during the transition. Feature flags can enable a new behavior separately from deploying the code. Limit the blast radius - the number of users or resources affected by one mistake - through gradual deployment and workload isolation. Keep a clear incident record of the symptom, change, action, and measured recovery.

Blue-green deployment: switch environments

A **blue-green deployment** prepares a second application environment, validates it, then shifts traffic from the old environment to the new one. It gives a clear traffic rollback target, but temporarily duplicates capacity and still needs connection draining: stop sending new work to the old environment while allowing its existing requests or connections to finish. A canary instead exposes a bounded cohort to the new version before broader rollout; either pattern needs comparable outcome measurements.

What traffic rollback cannot undo

INTERVIEW CRITICAL

Traffic rollback does not undo database writes

Switching traffic back does not undo database writes. Use backward-compatible schema and event changes. Follow an **expand, migrate, contract** sequence: first add fields or formats that both versions can tolerate, then migrate the data and callers, and only later remove the old format. Keep the old application able to interpret data produced during the rollback window. Delaying destructive cleanup until the rollback window closes costs temporary complexity but preserves recovery options.

07 / Disaster recovery: RPO, RTO, failover, and restore

A lost worker can be replaced and its jobs redelivered. A lost region may require a wider failover. A replicated bad deletion may require restoring older history. Choose the response from the actual failure, rather than treating every incident as a request to restart machines.

Recovery point objective, RPO, describes the acceptable loss of recent data measured in time. Recovery time objective, RTO, describes the target time to restore useful service. Both require tested procedures and measured results. For accepted photos, verify that the original files, records of pending processing jobs, publication status, and access permissions all survive recovery. Restoring one database does not by itself prove that users can upload and view photos again. Recovery guidance.

The multi-region-and-disaster-recovery chapter develops region placement and failback. Here the operational lesson is evidence: rehearse the recovery, check the customer-visible result, and record whether the objectives were met. A successful backup command or green failover control-plane status is only partial evidence.

Recovery planning also identifies the team responsible for recovery, a runbook with step-by-step instructions, accessible credentials and keys, and the dependencies needed to serve the recovered data. Verify that the remaining system can handle the required load when a server, zone, or region covered by the recovery plan is unavailable, and perform a restore to an isolated environment before relying on the procedure. Recovery point is a target: asynchronous replication lag must be measured to determine whether the observed lost work meets that target. Backups that share the same destructive permissions and retention policy as live data can fail together.

08 / Interview answer: explain how you know a service is healthy

Interviewer: "How will you know the upload service is healthy?"

Candidate: "I would measure both valid upload acceptance and whether accepted photos become ready within the agreed time. P501 returned success immediately but took 100 seconds, so an HTTP-success dashboard would miss the completion failure.

"I would trace acceptance, queue wait, rendering, and publication. The 95-second wait points toward processing capacity, and the canary's reduced concurrency setting explains it. I would roll back that setting, verify the backlog drains, and check that replayed jobs preserve one correct result and private access. Alerts would focus on completion failures and error-budget burn."

This answer connects monitoring to action: what the user needed, which measurements distinguish likely causes, what change is safe to undo, and how to check recovery. A monitoring box in a diagram needs those explanations.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Define SLI, SLO, SLA, and error budget with one user-visible example.

Model answer

An SLI (service-level indicator) is a measured user-visible behavior. An SLO is its target over a window. An SLA is an agreement about service commitments and consequences, often contractual. An error budget is the amount of failure permitted by the SLO.

For a photo service, measure the fraction of eligible accepted photos that become ready within 60 seconds, after each photo's evaluation period has elapsed. Set an illustrative SLO of at least 99.9% over 30 days. Of one million evaluated photos, at most 1,000 can miss the target. A separate SLA could specify a contractual

commitment and credits; it need not use the same threshold as the internal SLO. Also measure acceptance so the service cannot make its completion ratio look good by rejecting every upload.

Interviewer follow-up

Why wait for the evaluation period to elapse?

"A photo accepted five seconds ago has not yet missed a sixty-second deadline. I evaluate it once when that deadline passes and count the durable ready-by-deadline result. The rolling window uses those evaluation times; unfinished jobs and missing telemetry must not disappear from the denominator."

What the answer must demonstrate: A percentage without a denominator and window is incomplete.

02 / APPLIED

Could accepting no uploads make your completion SLO look perfect?

Model answer

"Yes, if it treats no data as success, or shows only accepted uploads and hides rejected attempts. Zero evaluated photos proves nothing about completion. Also measure how many valid attempts are accepted, signal missing data and use a test upload when useful. Then we can distinguish failure to accept uploads from failure to process them."

Interviewer follow-up

Should malformed uploads count as service failures?

"That depends on the specified contract, but I would separate expected validation rejection from failures of valid requests and avoid exclusions that hide our defects."

What the answer must demonstrate: Beware metrics that improve by refusing useful work.

03 / APPLIED

For 1,000,000 evaluated operations and a 99.9% success SLO, what is the error allowance? What burn rate does a 2% bad-event rate represent?

Model answer

"At 99.9%, one million evaluated operations allow one thousand bad events. If a recent window has two percent bad events against a 0.1 percent allowance, its burn rate is twenty. I would interpret that with traffic and window size before deciding how urgently to page."

Interviewer follow-up

Why use more than one alert window?

"A short window detects rapid deterioration; a longer one helps establish that it persists. The combination reduces both slow detection and noisy reaction to tiny samples."

What the answer must demonstrate: Keep percentage points and ratios distinct.

04 / APPLIED

A photo takes 100 seconds: 95 queued, 4 rendering, 1 publishing. What does this trace reveal that low CPU usage does not?

Model answer

"The trace assigns ninety-five seconds to waiting, four to rendering, and one to publication. Low CPU cannot tell me whether concurrency is accidentally restricted or demand is absent. The trace locates the delay; release/configuration evidence then helps identify the cause."

Interviewer follow-up

Does a high queue age prove the broker is faulty?

"No. Slow or insufficient workers can produce the same symptom. I would inspect service rates and stage behavior rather than blame the queue by its name."

What the answer must demonstrate: Separate symptom, location, and causal evidence.

05 / FOUNDATION

When do you use metrics, logs, and traces?

Model answer

"Metrics show aggregate trends and support alerts. Structured logs record individual events. Traces or correlated job events connect a specific journey across stages. For P501 I use metrics to detect late completion and the trace plus targeted logs to explain where it waited and which release handled it."

Interviewer follow-up

Should photo IDs be labels on every metric?

"Usually not. That creates unbounded time-series cardinality. Keep per-photo details in appropriately protected logs or traces."

What the answer must demonstrate: Choose the evidence type according to the question.

06 / APPLIED

What should the canary compare before full deployment?

Model answer

"Compare similar workloads, user-visible completion, throughput and stage delay, with enough observations to distinguish a signal from noise. For worker changes, separate canary and control pools can make queue-wait attribution meaningful. If both versions share a queue, rising age affects the cohort comparison and cannot by itself blame one version. I would inspect per-version throughput/configuration and stop expansion or revert when the canary violates the agreed guardrails."

Interviewer follow-up

Can every deployment be rolled back by restoring old binaries?

"No. Incompatible data/schema changes may make old code unsafe. I would plan compatible transitions and a recovery path before rollout."

What the answer must demonstrate: Deployment safety includes data compatibility.

07 / FOLLOW-UP

The old worker version is back. Can you close the incident?

Model answer

"Only after verifying the backlog drains and timely completion recovers. I also check that retrying a job did not publish duplicate results or repeat other side effects, and that photo permissions remain correct. Restoring the old version is a recovery step; I still need to verify that users can upload and view photos successfully."

Interviewer follow-up

What if arrival rate still equals processing capacity?

"Existing backlog will not drain. I need temporary spare capacity or reduced admission and must communicate the ongoing delay."

What the answer must demonstrate: Verify recovery under continuing load.

08 / FOLLOW-UP

How do RPO and RTO change your recovery exercise?

Model answer

"RPO tells me how much recent accepted work may be lost; RTO tells me how soon useful service should return. I would measure both during a drill and verify original files, records of pending jobs, publication status, and permissions, rather than timing only a database restore command."

Interviewer follow-up

Does replication replace that exercise?

"No. Replicas can carry the same mistake, and recovery has dependencies beyond copying state. We need to verify that uploads, background processing, and authorized viewing all work afterward."

What the answer must demonstrate: Recovery objectives apply to the service outcome.

Build the answer yourself

BLANK-PAGE EXERCISE / 18 MINUTES

Design a dashboard and incident response for P501 becoming ready at 100 seconds despite a successful upload response. Compare a canary worker release with the control.

- Define eligible requests and separate acceptance from timely completion.
- Calculate the error allowance and burn-rate example.
- Use a trace to identify where the 100 seconds was spent.
- Describe rollback, backlog recovery, and a check that private photos remain private.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What does an SLI measure?

An actual service behavior, such as the fraction of accepted photos ready within 60 seconds. The SLO is the target and evaluation window.

Indicator measures; objective targets.

How many bad events does 99.9% permit among one million evaluated photos?

At most 1,000 for that defined metric and window.

One in a thousand is the allowance.

Why is P501 a bad completion event despite HTTP success?

Acceptance completed, but the photo waited 95 seconds and became ready at 100 seconds, beyond the 60-second good-event threshold. It consumes error budget; the aggregate SLO depends on all evaluated events.

Upload accepted != photo ready.

When is rollback actually successful?

The known-good configuration is restored, queued work is draining, photos become ready on time, and their contents and access permissions are correct.

Changed back is not yet recovered.

Summary and interview notes

Production readiness means setting measurable reliability targets, limiting how many users a faulty release can affect, and testing recovery procedures. A running process or successful rollback command does not prove recovery: users must again be able to complete their operations, queued work must drain, and data and permissions must remain correct.

Remember these points

• An SLI (service-level indicator) is a measurement, an SLO is its target and window, and an SLA is an agreement with consequences.

• A 99.9% event SLO over one million evaluated photos allows 1,000 missed outcomes; zero events supplies no success evidence.

• Check each upload once when its readiness deadline arrives, including uploads still unfinished. Counting only completed jobs hides stuck work.

• A 2% bad-event rate against a 0.1% allowance is 20 x burn, interpreted with traffic and window size.

• Metrics identify impact; traces and logs investigate causes; controlled canary evidence supports a release decision.

Interview tips

• Write the denominator, deadline, exclusions, and rolling-window rule before drawing a dashboard.

• Separate acceptance, timely completion, correctness, and confidentiality instead of treating an HTTP success response as proof of all four.

• For a worker canary, ask whether shared queues and workloads make the cohorts comparable.

Important qualifications

• Sampled traces cannot stand in for a complete SLO event counter; missing telemetry needs detection.

• A duration budget and an event budget are different measures even when both use 99.9%.

• RPO and RTO are objectives to demonstrate in a drill, not guarantees created by configuring replication or a backup job.

Technical references

Google SRE: Monitoring Distributed Systems
Primary operational reference for latency, traffic, errors, saturation, and useful monitoring.
https://sre.google/sre-book/monitoring-distributed-systems/

Google SRE Workbook: Alerting on SLOs
Primary reference for error-budget burn and multi-window alerting.
https://sre.google/workbook/alerting-on-slos/

AWS Well-Architected: Plan for Disaster Recovery
Verified reference distinguishing recovery objectives and the need to test recovery.
https://docs.aws.amazon.com/wellarchitected/latest/reliability-pillar/plan-for-disaster-recovery-dr.html

OpenTelemetry: Traces
Official explanation of spans, context and links; diagnostic traces are separate from the durable completion record.
https://opentelemetry.io/docs/concepts/signals/traces/

Google SRE Workbook: Canarying Releases
Primary guidance for comparing canary and control, representative workloads, metrics, and gradual rollout.
https://sre.google/workbook/canarying-releases/

AWS: Blue/Green Deployments introduction
Environment and traffic-switching model; rollout success still depends on application state and compatibility.
https://docs.aws.amazon.com/whitepapers/latest/blue-green-deployments/introduction.html

CORE INTERVIEWS / 27

Design a URL shortener

Interview version / 45-minute scope · Read the advanced version online

Build a durable code-to-URL service, then justify uniqueness, retries, caching and storage growth from one concrete redirect.

redirects • unique codes • cache • expiration

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace creation and browser redirection through a working baseline.
- Explain uniqueness, retry recovery and the cost of caching.
- Defend scaling decisions without promising unsupported deletion or failover guarantees.

Useful foundations: HTTP APIs and request lifecycle; Caching: cache hits, misses, write policies and invalidation; Idempotency, retries, and timeouts

8 interview questions with model answers and answered follow-ups.

01 / What the short link actually does

Someone prints an event poster containing a registration address. The original address is long, so our service gives them `https://s.example/q7Lm2Ax9`. When another person opens that address, the browser should reach the original registration page. The service stores a code-to-destination mapping; it does not compress or host the destination page.

For this interview, support creating a link, resolving it, choosing an optional custom alias, expiring it and deleting it as its owner. Destinations do not change after creation. Redirects are public; creation and owner actions require authentication. Click statistics may arrive late. Private links, billing-grade counts and immediate worldwide revocation are separate requirements to discuss if requested.

Two rules matter immediately. A code must never resolve to another creator's destination, and a successful creation must have a durable stored mapping. An unavailable destination is outside our service: we can return the correct redirect even when the event website is down. Ask how quickly deletion must take effect, because that decision later determines whether cached redirects are acceptable.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Create and manage links.** Authenticated owners create immutable destination mappings, optionally request a custom alias and expiry, list their own links, and delete them.

2. **Resolve a public code.** An active code returns an HTTP redirect to its saved destination. Missing or expired links return an unavailable-link result; deletion follows the cache-freshness policy below. The destination page is fetched by the browser.
3. **Recover a repeated creation.** Repeating the same owner-scoped request and payload returns the same link during the supported retry window. Conflicting aliases or changed payloads are rejected.
4. **Record lightweight statistics.** Collect approximate click statistics asynchronously; delayed or lost analytics must not change the redirect result.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload.** Plan for approximately 965 creates/s and 96,450 redirects/s at peak, with 30 billion claimed codes after five years. These are the illustrative assumptions derived below.
2. **Response time.** Target p95 of 50 ms for redirects and 200 ms for creation, measured from regional service ingress to response at the planning peak under normal operation. Internet transit and destination-site loading are outside these measurements.
3. **Durability and availability.** A successful creation must survive an application restart or one database-node failure within the serving region. Unsafe writes stop rather than acknowledge an unprotected mapping; regional disaster recovery is a separate requirement.
4. **Identity and retries.** Codes never change owners or destinations, including after deletion. Retain creation results for at least 24 hours so a matching retry within that window cannot create another link.
5. **Cache freshness.** Expiry is checked on every serving path. Deletion has eventual visibility with best-effort invalidation and one-minute internal cache entries; this is not a hard global one-minute revocation guarantee.
6. **Access and abuse.** Owner actions require current authentication and ownership checks. Limit creation abuse and accept only supported destination schemes; a public random code is not a private-access credential.

04 / Follow one creation and one visit

Begin with one application and one relational database. The application receives a destination URL, generates a candidate code and inserts a row containing that code and destination. The code column has a unique constraint, which means the database rejects a second row with the same code. After the transaction commits, the application returns the short URL.

The visit follows three steps:

1. The browser requests `/q7Lm2Ax9`.
2. The application looks up that exact code, checks that the row is active and unexpired, and returns HTTP `302` with the destination in the `Location` response header.

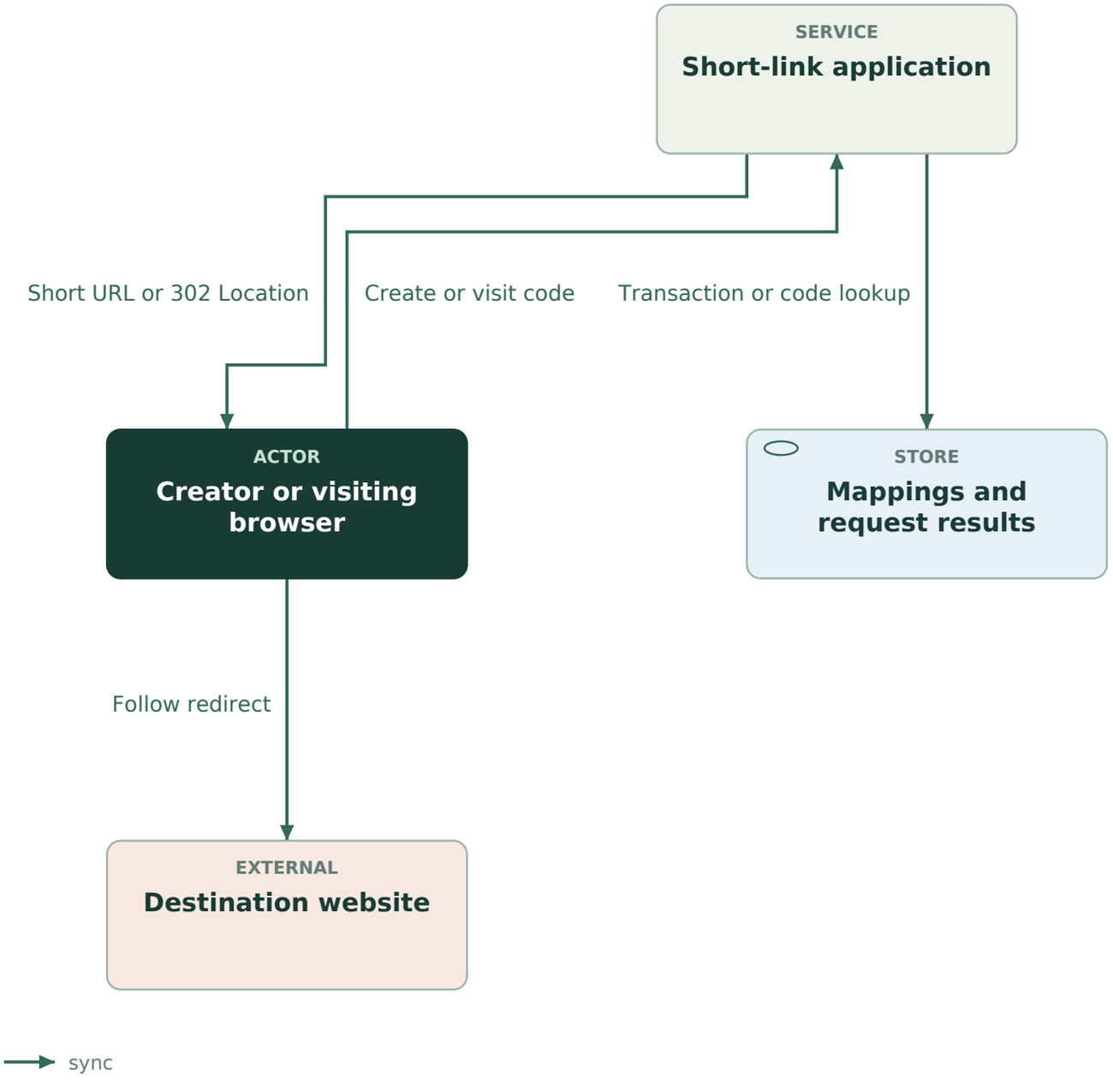
3. The browser makes a second request to the destination website.

The shortener's response contains a header and perhaps a small body; it does not carry the destination page's images or video.

This is already a complete useful service. A missing or expired code returns an unavailable-link response rather than an invented destination. One indexed lookup can serve each redirect. A database transaction publishes a complete mapping before the creator receives success. Next, use the workload to decide when lookup cost or storage growth justifies more components.

A shortener redirects the browser

The browser contacts the destination after receiving Location; destination content does not pass through the shortener.



05 / Estimate the work that could outgrow the baseline

Assume 500 million creations in a 30-day month and 100 visits per creation. These are interview assumptions, not traffic measured from a named company. There are 2,592,000 seconds in that month, giving about 193 creates and 19,290 redirects per second on average. With a fivefold planning peak, test approximately 965 creates and 96,450 redirects per second.

Quantity	Calculation	Design implication
Five-year mapping count	500M x 12 x 5 = 30B	Retention eventually requires substantial storage
Logical mapping bytes	30B x 500 B = 15 TB	Replicas, indexes and backups add to this
Peak redirect payload	96,450 x 500 B ~ 48.2 MB/s	Estimate our redirect bytes, not destination-page bytes
Illustrative cache	10M distinct entries x 700 B = 7 GB	Size by unique stored entries, not request count

The calculations identify a read-heavy lookup service. They do not prove that every mapping needs caching or that SQL cannot work. Measure indexed lookup capacity and the distribution of repeated visits. A small number of frequently visited codes can dominate requests even when most stored links are rarely read. That observation motivates a cache more directly than the total row count does.

06 / Make creation, retry and ownership explicit

The creator sends a destination and optional expiry with an owner-scoped request key.

Creation request

```
POST /v1/links
Idempotency-Key: create-204
Content-Type: application/json
```

Example request body

```
{
  "destination": "https://events.example/registration/design-day",
  "expiresAt": "2030-12-31T23:59:59Z"
}
```

Idempotency means retrying this same logical request returns its existing result rather than creating another link. Store the key under the authenticated owner and compare the supplied payload before replaying a result. Reusing it with different input is a conflict.

Request	Meaning
`POST /v1/links`	Create a mapping; return its code after commit

Request	Meaning
`GET /q7Lm2Ax9`	Return the stored destination in a redirect
`DELETE /v1/links/q7Lm2Ax9`	Owner marks the link deleted
`GET /v1/links?after=<cursor>`	Page through the owner's links

For a custom alias such as `design-day`, return a conflict if somebody already owns it. Do not silently generate another alias after the caller asked for an exact one. Validate allowed URL schemes and length; preserve the destination's encoded meaning rather than casually rewriting it.

A creation timeout is an unknown outcome: the database may have committed before the response disappeared. The client retries `create-204` or retrieves its status. A request key identifies an operation; two intentionally separate creations may legitimately target the same destination and keep different statistics.

07 / Store the mapping and the answer to a retried request

Use two records so a redirect mapping and its creation result have distinct purposes.

Record	Fields	Purpose and uniqueness
`Link`	`code`, `ownerId`, `destination`, `createdAt`, `expiresAt`, `deletedAt`	Answers a redirect lookup; `code` is unique.
`Request`	`ownerId`, `requestKey`, `payloadHash`, `code`	Remembers which result belongs to a creation request; (`ownerId`, `requestKey`) is unique.

In the baseline, insert both within one database transaction so neither becomes visible alone. If concurrent copies of one request choose different candidate codes, the request-key constraint lets only one transaction commit; the loser rolls back its tentative mapping and returns the winner's saved result. A code collision from an unrelated request instead chooses another candidate.

The main lookup uses the code's primary-key index. Owner listing instead needs an index ordered by `(ownerId, createdAt, code)`. A pagination cursor records the last time-and-code pair; the code breaks ties between links created at the same timestamp. These are different access patterns, so a fast code index does not automatically make owner listing efficient.

Never reuse a previously issued code for unrelated content. Somebody may still have an old poster or bookmark after the original link expires. Retain a compact claim or deletion marker even if old destination bytes are removed. This consumes some permanent identity storage but avoids giving an old URL a new owner. A scheduled cleanup job can reclaim expired payloads; reads must check expiry independently because that job may run late.

08 / Generate candidates; let storage decide uniqueness

Eight characters drawn from digits and upper- and lowercase letters give `62^8`, about 218 trillion possible codes. With 30 billion permanently claimed codes, approximately 0.0137% of the space is occupied. A random candidate is therefore likely to be unused, but random generation never proves uniqueness.

Suppose two application servers both choose `q7Lm2Ax9`. Each tries an insert against the same unique code constraint. One succeeds; the other sees a collision, chooses a new random candidate and retries. A prior lookup saying "absent" would not be enough: both servers could read that answer before either writes.

A sequential number encoded in base 62 is another option. It avoids random collision retries but needs a safe allocation mechanism and produces predictable identifiers. A separate service can allocate batches, although that adds another component and failover responsibility. At the assumed creation rate, random candidates plus enforced uniqueness are a defensible starting choice.

Keep successful request results long enough for the documented client retry window. After that window, clients need explicit status recovery or a new intentional operation; do not promise indefinite retry recovery while discarding the record that makes it possible.



INTERVIEW CRITICAL

A collision check must be atomic

Randomness reduces how often candidates collide. A unique database constraint or conditional insert decides who owns a code when requests race. A separate "does it exist?" check cannot enforce this rule.

09 / Add a cache for repeated visits, then distribute storage

If measured database capacity is below the redirect peak, place an internal cache in front of lookups. A redirect first checks the cache; a miss reads the database and stores the result. Let simultaneous misses for one code share one database lookup, so a viral link does not trigger hundreds of identical cache refills. LRU eviction removes entries that have not been used recently when memory is full; it is a starting policy to test against actual traffic.

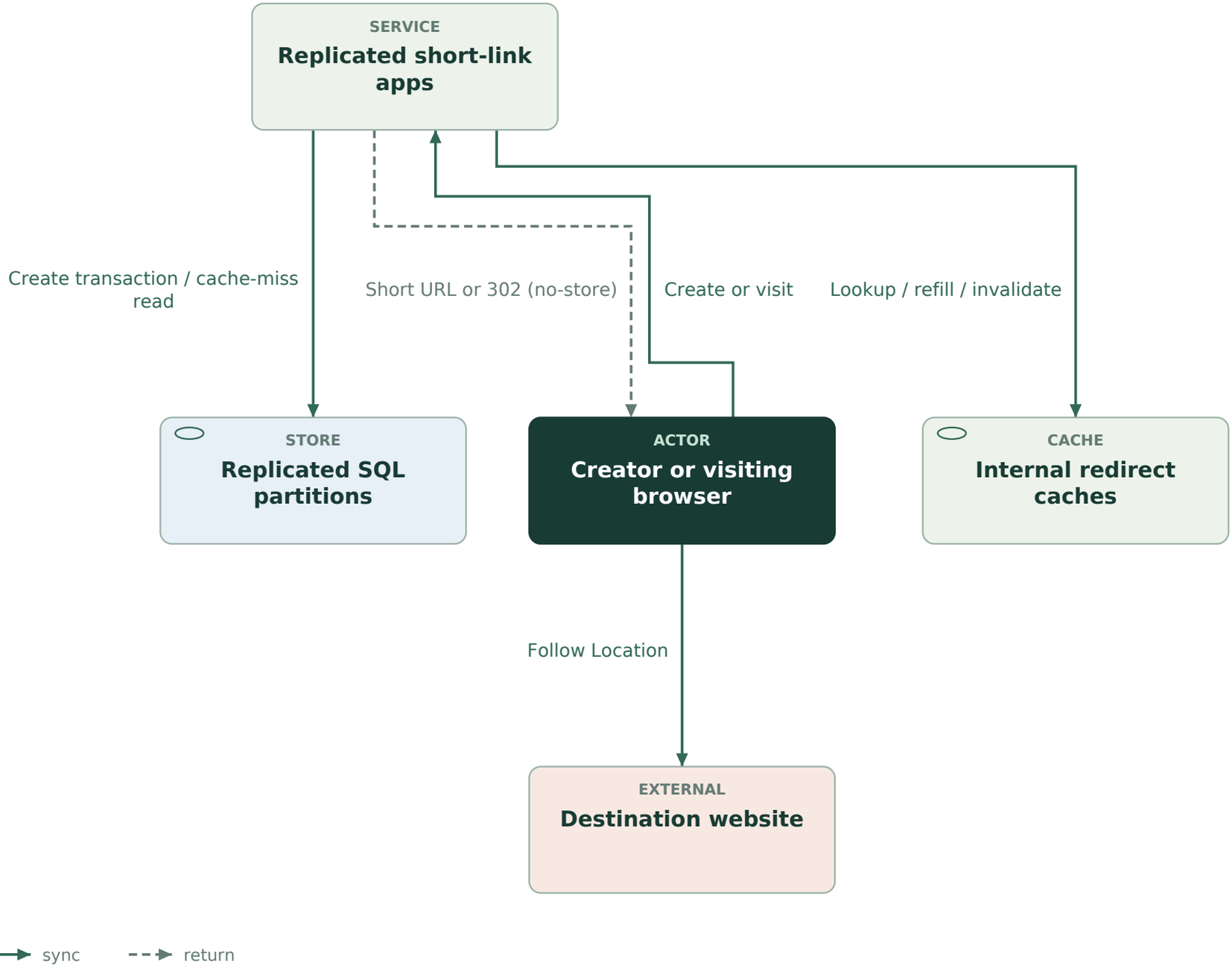
Caching creates a visibility tradeoff. A cached destination may remain after its owner deletes the database row. For this worked design, use fixed one-minute cache entries and best-effort invalidation when deletion commits. This gives eventual deletion visibility, not a hard worldwide one-minute deadline: a delayed old read can refill the cache after invalidation. State that limitation explicitly. Strict deadlines require the advanced freshness protocol. Send `Cache-Control: no-store` on browser redirects so the browser does not retain an uncontrolled redirect after our internal entry expires.

Replicated database storage protects against configured failures; application replicas allow independent request handling. Add partitions when retained bytes or measured throughput justify them. Hashing the code distributes distinct mappings, but one viral code remains one hot key and needs replicated cache copies. For the scaled worked design, choose a distributed SQL store that supports the same atomic mapping/request transaction across its partitions. This preserves the retry rule while adding distributed-transaction latency and operational cost, which must fit the measured budget. A separate cross-partition reservation workflow is an Advanced alternative; splitting the tables without either mechanism would lose the creation guarantee.

For this failure target, configure the selected SQL store to acknowledge mapping/request commits only after a durable majority of three replicas in independent failure domains within one region. Verify that its failover preserves those commits; merely enabling an asynchronous replica does not meet the requirement.

Redirect traffic uses caches; creation still commits atomically

A visit checks the internal cache before reading a mapping. Creation writes the mapping and request result through one distributed SQL transaction. The browser follows the returned Location itself; internal cache invalidation gives the eventual deletion behavior described above.



10 / Explain a lost response and a lost cache

The creation transaction commits `Link(q7Lm2Ax9)` and the result for `u17/create-204`, then the application crashes before replying. On retry, the service finds the saved request result and returns the original short URL. The user receives one logical link even though the network carried two attempts. If the crash happened before commit, neither row is committed and the retry may perform the creation.

A cache failure produces a different problem: extra database load. At a measured 95% cache-hit rate, a peak of 96,450 redirects/s sends about 4,823 reads/s to storage. Losing the cache can send almost the entire peak there, roughly twenty times more. Limit concurrent database fallbacks and return a retryable error when that budget is exhausted. An unlimited queue merely turns overload into long waits and memory exhaustion.

For database failover, acknowledge writes only under the chosen durability policy and direct writes to the current database leader. Read replicas can be useful, but lag can hide a newly created link or retain a deleted one. Explain which reads may tolerate that delay. Backups address accidental deletion and larger disasters; replication is not a substitute for testing a restore.



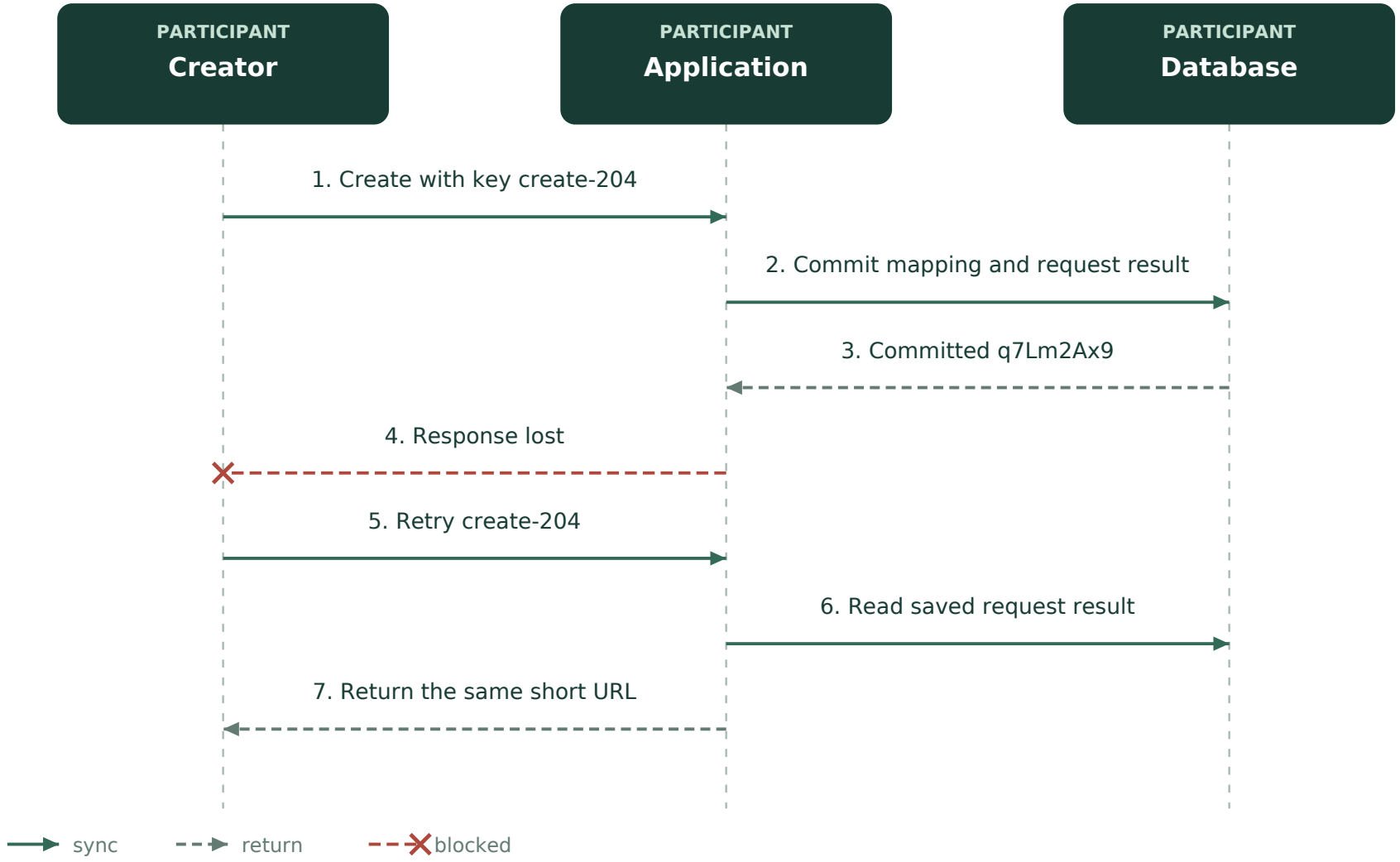
INTERVIEW CRITICAL

Do not invent success during uncertainty

A timed-out creation may already exist. Recover its stored request result. If storage is unavailable, return an explicit temporary failure instead of allocating an unrelated replacement or returning a guessed destination.

Recover a creation after the response is lost

The request key retrieves the committed result instead of producing another link.



11 / Protect the service and measure the user experience

Public short links attract spam, malicious destinations and enumeration. Rate-limit creation by authenticated account and apply separate read-abuse controls. A hard-to-guess code is not authorization for private content. If threat scanning is required, run outbound fetching in an isolated service with destination restrictions; the redirect worker should not fetch arbitrary URLs into the application network.

Measure creation and redirect latency separately, cache-hit rate, database fallback load, collision retries, unavailable-link responses and replication or recovery lag. Test a viral link and total cache loss rather than only uniform random traffic. Watch deletion behavior as well as raw availability: quickly returning an invalid link is not a successful user outcome.

Emit click statistics asynchronously so a popular link does not update one contested counter on every request. Under the chosen approximate contract, events may be delayed or lost within a documented buffer policy. Keep personal click data minimal. Cost is driven by retained mapping/index bytes, replicated cache memory, lookup work and the small redirect responses. The target website's delivery bill is not ours.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1-3: creation, aliases, listing and retry	Unique code and owner/request constraints; atomic mapping/result commit; owner/time index.	Race two alias claims and lose a create response; recover one result within 24 hours. Check cross-owner listing isolation.
FR2 + NFR2: correct fast redirect	Indexed code lookup and replicated internal caches; browser follows Location.	Load-test the 96,450/s peak with hot keys and cache loss. Measure p95; the diagram alone does not establish 50 ms.
NFR3: survive one database-node failure	Synchronous replicated commits, with unsafe writes refused.	Kill a database node after acknowledged creation and confirm the mapping and retry result remain. Regional loss is not covered.
NFR5-6: expiry, deletion and ownership	Serving-time expiry and owner checks; no-store browser redirects; best-effort cache invalidation.	Test expired cache entries and delayed refill after deletion. State the remaining eventual-deletion limit.
FR4: approximate statistics	Bounded asynchronous click processing.	Interrupt analytics and verify redirects continue; report count delay or loss rather than claiming exact totals.

13 / Rapid revision

Remember: Randomness supplies candidates; the unique insert prevents two owners from claiming one code.

Question to answer	Interview answer	Limit to state
What does a visit do?	Look up the code and return 302 with Location; browser requests the target	We do not host the target page
What makes a code unique?	Atomic unique insert, with random retry on collision	Large namespace alone is insufficient
What happens after a lost create response?	Return that owner's saved request result	Commit mapping and result together, or recover partial work
Why cache?	Repeated visits avoid database reads	Cached deletes lag; cache failure can overload storage
Why partition?	Spread mappings and requests across partitions	Popular codes and owner listings need separate handling
Why separate cleanup?	Delete expired records outside redirect handling	Reads still enforce expiry
What can be approximate?	Delayed click statistics	Code ownership and destinations must be correct

A concise spoken answer should follow the browser through one creation and one visit, justify the unique constraint, use the traffic estimate to introduce caching, and then explain what happens when the cache or response disappears. Name stronger revocation and cross-partition retry requirements as follow-up work rather than silently claiming they are solved.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Does the shortener download the destination page?

Model answer

No. It returns a redirect response containing the destination URL. The browser then contacts that website separately.

Interviewer follow-up

Why does this matter for estimates?

Count redirect response bytes in our egress, not the destination page or its media.

What the answer must demonstrate: Separates the redirect response from the browser's destination request.

02 / APPLIED

Why is a large random code space not enough?

Model answer

Two requests can still generate the same candidate. The database's unique constraint accepts only one competing insert; the loser chooses another code.

Interviewer follow-up

Why not check first?

Both requests can observe absence before either inserts, so a check followed by an unguarded write races.

What the answer must demonstrate: Names an atomic uniqueness constraint and the check-then-write race.

03 / APPLIED

How does a retry avoid creating a second link?

Model answer

Scope a request key to the authenticated owner and store its payload identity and result atomically with the mapping. Replay a matching completed request.

Interviewer follow-up

What if the payload differs?

Reject the reused identity as a conflict; it represents a different operation.

What the answer must demonstrate: Keeps request identity, payload validation and mapping commit connected.

04 / APPLIED

Why can caching change deletion behavior?

Model answer

The database can contain a deletion while a cache still holds the prior mapping. Serving the copy therefore needs an agreed freshness policy.

Interviewer follow-up

Can ordinary TTL prove immediate revocation?

No. Immediate revocation requires current authority checks or an explicit coordinated protocol.

What the answer must demonstrate: States a deletion visibility contract instead of treating invalidation as guaranteed.

05 / APPLIED

Why does hashing codes not fix one viral link?

Model answer

Hashing distributes different codes. Every lookup for the same code still targets its owner.

Interviewer follow-up

What helps?

Replicated cache copies, coalesced misses and bounded origin fallback distribute repeated reads.

What the answer must demonstrate: Distinguishes distribution of different keys from repeated reads of one key.

06 / FOUNDATION

Can a delayed cleanup job extend a link lifetime?

Model answer

No. Every serving path checks expiry. Cleanup removes obsolete storage later.

Interviewer follow-up

Why retain an old claim?

Reusing the code could send an old bookmark to an unrelated creator.

What the answer must demonstrate: Separates expiry enforcement from physical deletion and permanent claims.

07 / FOLLOW-UP

What must be reconsidered after splitting storage?

Model answer

The mapping and request result may no longer share one local transaction. Retain transactional support or specify a recoverable creation workflow.

Interviewer follow-up

Is changing the partition map sufficient?

No. Data must be copied, writes safely handed over, and old owners prevented from conflicting.

What the answer must demonstrate: Recognizes which transaction boundary the new storage layout removes.

08 / FOLLOW-UP

What changes for private links?

Model answer

Authenticate readers and evaluate current access before returning a destination; code secrecy does not establish permission.

Interviewer follow-up

Can the public cache authorize access?

No. It may store mapping bytes, but authorization needs its own declared freshness and revocation contract.

What the answer must demonstrate: Separates possession of a URL from current reader authorization.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a public URL shortener for 500M creations per month and 100 redirects per creation. Establish the working baseline, estimate its load, then defend your caching and retry choices.

• Use 5 minutes to agree the numbered functional and non-functional requirements, including aliases, owner listing, latency, durability and deletion visibility.

• Use 8 minutes to trace creation and a browser redirect.

• Use 7 minutes to calculate throughput, retained bytes and cache assumptions.

• Use 10 minutes to define API, records, uniqueness and retry behavior.

• Use 10 minutes to add scale and examine lost responses, hot keys and cache failure.

• Use 5 minutes to check the final design against the numbered FR/NFR lists, state unmeasured targets and eventual-deletion limits, then summarize tradeoffs.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Two servers generate q7Lm2Ax9 at the same time. Which step decides who owns it?

Both attempt the unique insert. Only one commits; the other chooses a new candidate. A preliminary "absent" lookup would not prevent the race.

Generate, then claim.

Creation succeeds, but its response is lost. What must the retry reuse?

Reuse the same request key for that owner; the server returns its saved creation result.

Retry the operation, recover its result.

An expired link still occupies storage because cleanup is late. May it redirect?

No. The redirect handler checks expiry during the read; cleanup delay does not extend the link's lifetime.

Expiry first; reclamation later.

Summary and interview notes

A shortener saves a code and destination, then redirects visits. A unique insert prevents duplicate codes; a saved creation result lets the caller recover a lost response.

Remember these points

• The browser fetches the target separately.

• Read-heavy traffic motivates a measured cache.

• A deleted or expired code must not acquire a new owner.

• Sharding must preserve the creation/retry boundary.

Interview tips

• Explain one request before naming extra services.

• Connect each scaling component to measured work.

Important qualifications

• Exact global revocation deadlines and cross-partition retry proofs belong to explicit follow-up contracts.

Explore the advanced version

Bounded revocation and clock uncertainty: Needed when the product requires a provable deletion deadline despite delayed cache fills.

Cross-partition creation protocol: Needed when request identity and mapping ownership cannot share a transaction.

Incomplete regional allocation recovery: Needed to preserve old code claims after a recovery point loses recent history.

Storage ownership and migration fencing: Needed when explaining safe ownership changes beyond the logical partitioning decision.

Technical references

RFC 9110: HTTP semantics and redirects
Defines 302 and Location semantics; cache lifetime and revocation remain explicit application decisions.
https://www.rfc-editor.org/rfc/rfc9110.html#name-302-found

PostgreSQL constraints
Primary and unique constraints are an example of authoritative duplicate-key enforcement.
https://www.postgresql.org/docs/current/ddl-constraints.html#DDL-CONSTRAINTS-UNIQUE-CONSTRAINTS

DynamoDB condition expressions
An alternative implementation of atomic conditional insertion, rather than a read-then-write uniqueness check.
https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/Expressions.ConditionExpressions.html

CORE INTERVIEWS / 28

Design Pastebin

Interview version / 45-minute scope · Read the advanced version online

Design immutable text sharing around complete publication, safe rendering and permission checks before introducing independently scaled body storage.

object storage • publication • expiration • authorization

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace a complete paste creation and authorized read.
- Explain when object storage helps and how publication remains recoverable.
- Defend private caching, cleanup and transfer limits.

Useful foundations: Design a URL shortener; Databases, data models, and ACID transactions; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / Share text without turning it into executable content

A developer wants to send a diagnostic log to a teammate without copying it into a chat message. They paste the text, receive `/p/p7Hk2Lm9`, and share the link. Unlike a URL shortener, our service owns the content being returned. It must preserve the saved text, control who may retrieve it and avoid executing anything the author pasted.

Support immutable text, optional expiry, owner deletion, custom aliases and owner listings. Distinguish public, unlisted and private pastes. Public content may be discovered; unlisted content is available to anybody with the address; private content requires an authenticated permission check. An obscure URL alone does not make a paste private.

Assume authenticated creators, a 10 MB maximum and a 10 KB average. Editing, images, collaborative cursors and a public full-text search engine are outside this exercise. A successful creation means the complete intended text is stored, not that an upload merely started. An owner can see a clear failed or processing state when publication cannot finish. Read authorization applies to each new request; bytes a reader already copied cannot be recalled.

Clarify whether a forwarded link should grant access, whether text can change after publication, and whether completion must wait for the entire body. The following requirements choose immutable text with explicit public, unlisted and private access.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Publish immutable text.** Authenticated authors create a paste with text, title, visibility, optional custom alias and expiry; publication returns one stable identity.
2. **Retrieve safely.** Readers can request a formatted page or raw text. Public and unlisted pastes are accessible under their stated rules; private pastes require a current grant. Pasted markup is displayed as text.
3. **Manage owned pastes.** Owners list their pastes, inspect pending/ready/failed status and delete content to prevent new reads.
4. **Recover interrupted creation.** A repeated creation key with unchanged content resumes or returns the same paste, rather than publishing another body.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload and limits.** Use one million creations/day, approximately 116 creates/s and 579 reads/s at peak, a 10 KB average and a hard 10 MB text limit. Ten-year logical content is approximately 36.5 TB before copies.
2. **Read latency.** Target regional p95 time to first byte of 200 ms for authorized reads at the planning peak under normal operation. Whole-body transfer time depends on size and client bandwidth; the 10 MB maximum is not promised within 200 ms.
3. **Publication integrity and durability.** Success means the complete intended text and its metadata are durable. They must survive an application restart or one storage-node failure within the region; a pending upload is not a published paste.
4. **Privacy and expiry.** Every new private read must pass current authorization, including cache hits. Expired or deleted pastes cannot begin a new authorized read; already released bytes cannot be recalled.
5. **Bounded resource use.** Enforce byte quotas, upload concurrency and bounded buffering as well as request limits. Slow maximum-size uploads must not exhaust all read capacity.
6. **Retry retention.** Keep owner-scoped creation outcomes for at least 24 hours. After that window, clients need explicit status recovery or a new intentional operation rather than an indefinite replay promise.

04 / Save a log and read it back through one database

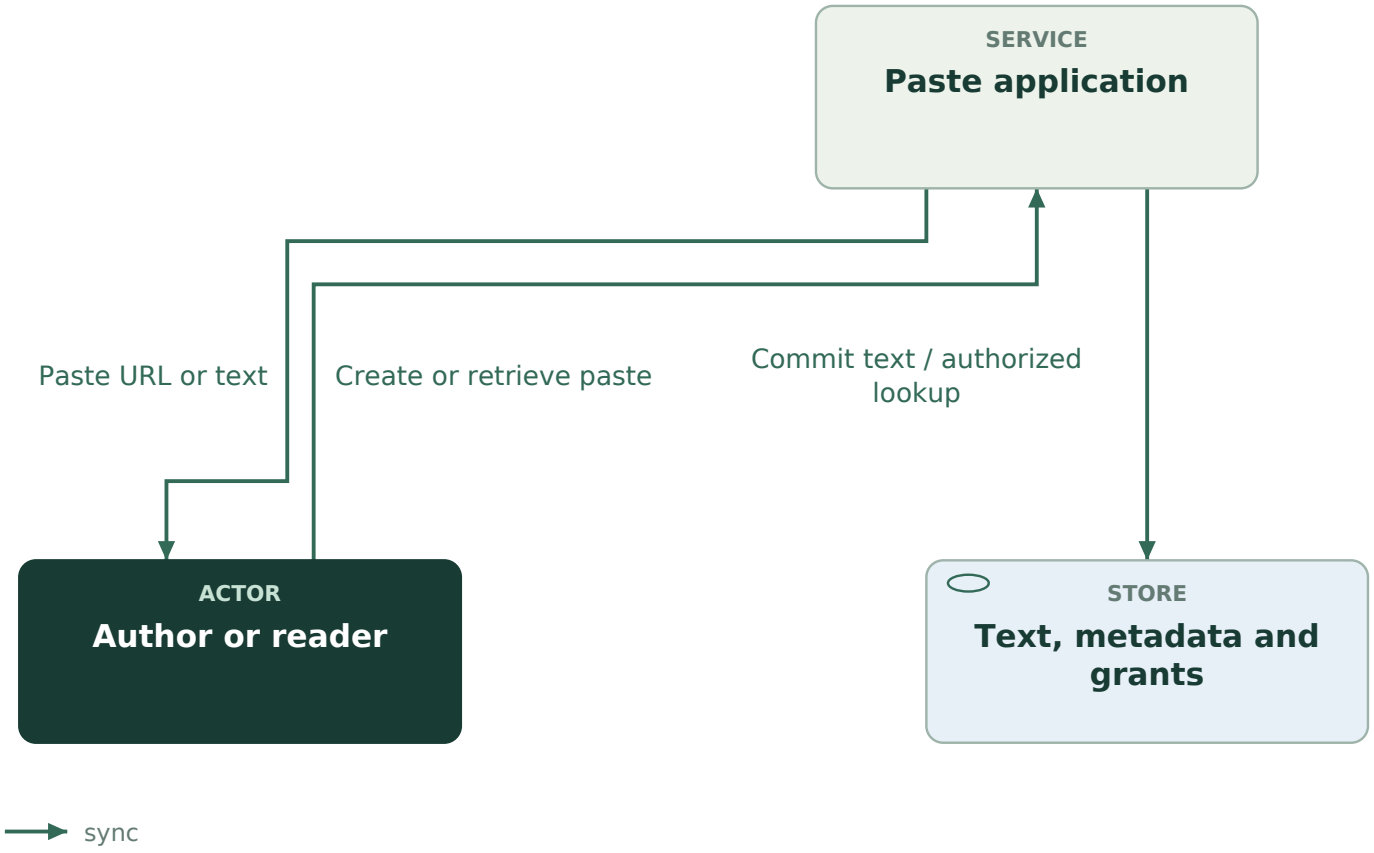
The first implementation has an application and a relational database. A creation request contains text, visibility and an owner-scoped request key. Validate the encoding and size, choose a random paste ID, then commit the text, metadata and request result together. After commit, return the paste URL. The database unique constraint prevents two pastes from claiming the same ID or custom alias.

A reader requests p7Hk2Lm9. The app finds its row, checks expiry and deletion, checks the reader's grant if it is private, and sends the stored text. A raw endpoint uses `text/plain`; a formatted browser page escapes HTML characters before showing them. Pasting `<script>` must display that text, not run a program in another reader's browser.

The single transaction gives a simple publication rule: either the complete paste exists or none of it is visible. A lost creation response is recovered by looking up the same request key. For modest traffic, storing text in SQL is reasonable. Large retained bodies and slow transfers may eventually make it expensive, but the product name does not decide the database technology.

A complete paste in one transaction

The baseline publishes text and metadata together; every reader passes access and expiry checks.



05 / Separate request rate from retained bytes

Assume one million new pastes per day and five reads per paste. That is about 11.6 creations and 57.9 reads per second on average. A tenfold peak is approximately 116 creations and 579 reads per second. These are not extreme request rates; the storage and large-object cases deserve more attention.

Estimate	Calculation	Why it matters
New text	1M x 10 KB = 10 GB/day	Small records accumulate
Ten-year logical content	10 GB x 365 x 10 = 36.5 TB	Backups and replication include rarely read text
Three copies	36.5 TB x 3 = 109.5 TB	Durability multiplies stored bytes
Average outgoing payload	5M x 10 KB / 86,400 ~ 0.579 MB/s	Normal egress can remain modest
Peak if every upload hits the limit	116 x 10 MB = 1.16 GB/s	Request limits alone cannot bound byte load

The final row is a stress case, not the expected average. At five seconds per upload, 116 arrivals/s imply about 580 concurrent uploads in a stable system. Buffering every maximum-size body would consume about 5.8 GB before application overhead. This motivates streaming, bounded concurrency and separate byte quotas. It does not require hundreds of independent services.

06 / Give clients an identity they can safely retry

Use an idempotency key to identify a creation request.

Creation request

```
POST /v1/pastes
Idempotency-Key: paste-204
Content-Type: application/json
```

Example request body

```
{
  "text": "Connection timed out while contacting inventory.",
  "title": "Inventory timeout",
  "visibility": "private",
  "expiresAt": "2030-12-31T23:59:59Z"
}
```

Store a fingerprint of the validated input so that repeating the key with different text is rejected. The publication outcome determines the response:

Response	Meaning
`201` with the paste identity	Publication is complete.

Response	Meaning
`202` with the same identity and a status URL	A larger asynchronous upload is explicitly pending.

Endpoint	Caller-visible result
`POST /v1/pastes`	Ready paste or explicitly pending upload
`GET /p/p7Hk2Lm9`	Authorized, safely rendered text
`GET /v1/pastes/p7Hk2Lm9/raw`	Plain-text content
`GET /v1/pastes/p7Hk2Lm9/status`	Owner sees pending, ready or failed
`DELETE /v1/pastes/p7Hk2Lm9`	Owner prevents new reads; repeated deletion is harmless

Reject oversized text with 413 and exhausted quotas with 429. Scope owner listing and status reads to authenticated identity. Avoid returning different private error details that reveal whether a guessed paste exists. Specify how long creation-request identities remain recoverable; a documented retry window is more useful than an indefinite promise unsupported by retained records.

Custom aliases are claimed atomically and retained as used identities after deletion. Otherwise an old incident ticket could silently lead to another person's content years later.

07 / Keep content, metadata and permission roles distinct

The records separate saved content, retry recovery and private access.

Record	Fields	Purpose
`Paste`	ID, owner, title, visibility, creation time, expiry, state; initially also the text	Stores the paste and its publication/access metadata.
`CreateRequest`	`ownerId`, `requestKey`, `payloadHash`, `pasteId`	Remembers the result of a creation request.
`Grant`	`pasteId`, `readerId`	Records private access.

Metadata describes the content; it is not a substitute for storing the content itself.

The common read is an exact paste-ID lookup followed by a permission check. Owner listing needs an index such as `(ownerId, createdAt, pasteId)`. Expiry cleanup needs an index ordered by deadline, so a worker can fetch due batches rather than scan the whole database. Reads still compare the deadline independently: delayed cleanup should waste storage, not extend access.

When body storage grows costly, move text into a private object store and keep its immutable object identity, byte length and checksum in the metadata row. An object store retrieves bytes by key and can scale bulk storage separately from database indexes. This separation introduces an important new question: what should

readers see if one store succeeds and the other fails? The answer is a publication state, rather than assuming the two writes are one transaction.

08 / Publish only after the complete body exists

Publish a body stored outside the database in this order:

1. Reserve `p7Hk2Lm9` in `UPLOADING` state, with an immutable body name tied to this upload attempt.
2. Stream the text to object storage using a bounded buffer.
3. Verify the stored length and checksum.
4. Change the metadata to `READY` in a database transaction.

Readers require `READY` before retrieving the object.

Why this order? If metadata were ready first, a crash before uploading would expose a broken paste. Uploading first can leave an unused object, but that object remains invisible and recoverable. An orphan is storage work to clean up; a ready link pointing to absent bytes is a user-visible correctness failure.

The upload request identity points to the reserved paste. A retry inspects that same attempt and either finishes publication or returns the stored result. It must not silently replace the content under a published cache key. Immutable object names prevent one upload from changing bytes readers already associate with another version.

Cleanup also needs a rule. Before deleting an abandoned attempt's bytes, atomically mark that attempt canceled so it can no longer publish. Publication requires the still-active upload state. The shared state check lets either publication or cancellation win, never both. Detailed lease renewal and multipart recovery are follow-ups; a timer followed by an unguarded object delete is not safe even in the simple design.



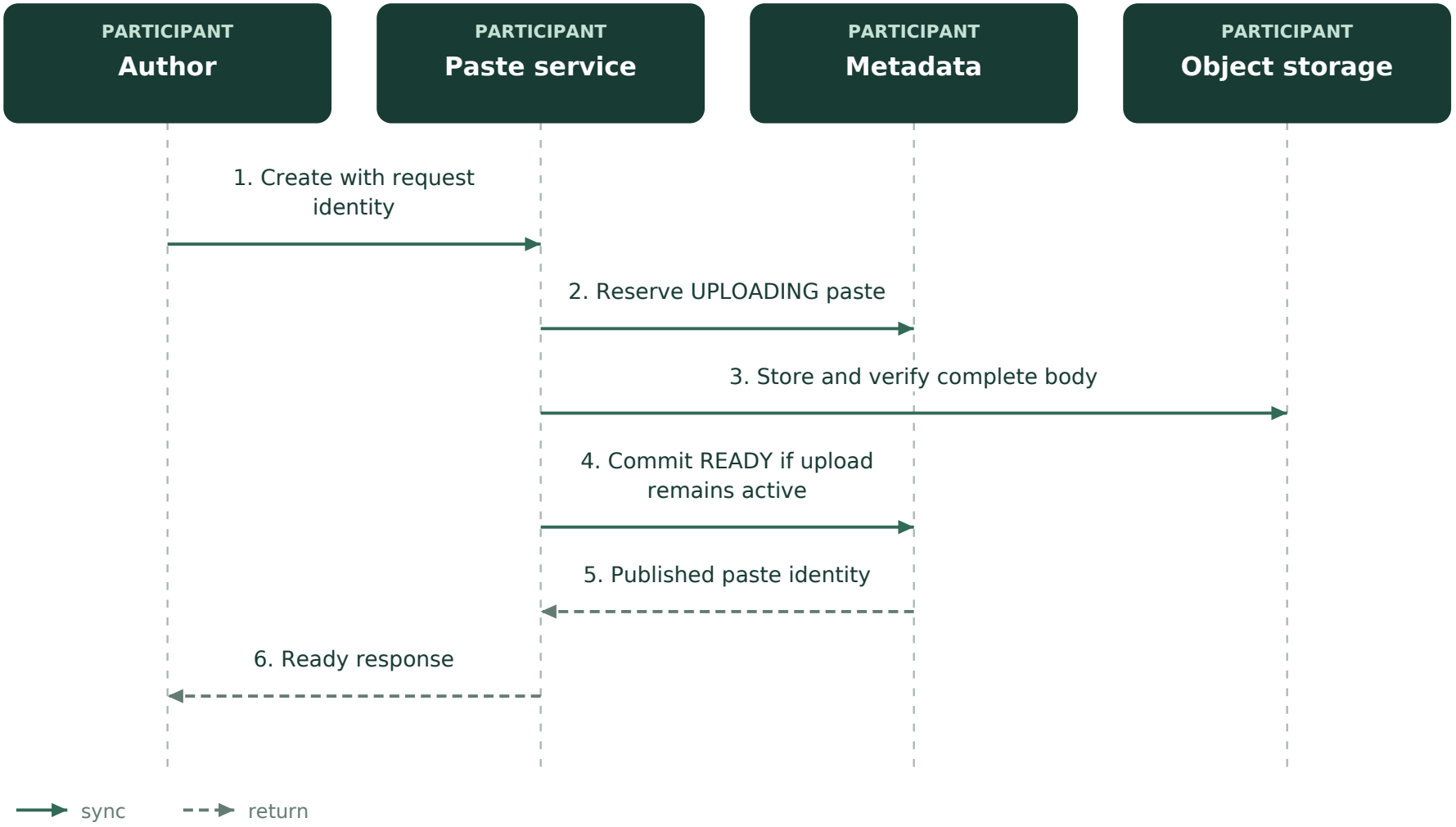
INTERVIEW CRITICAL

Ready means complete content

Do not make metadata visible before the intended bytes exist. After splitting SQL and object storage, publish a verified body through an explicit state transition; a successful object upload alone is not publication.

Upload success is not publication

A failed publication leaves hidden bytes. A retry must still pass the metadata state check.



09 / Move transfer work out of the metadata bottleneck

A large upload can hold a connection much longer than an indexed metadata read. Give uploads bounded streaming buffers and concurrency limits so slow clients do not consume every reader worker. For larger workloads, separate upload and read capacity. Direct uploads can remove byte transfer from application servers, but the application must still authenticate completion and verify the exact accepted object.

Cache immutable public bodies when repeated reads justify it. Measure distinct hot bytes and byte-hit ratio, not merely the percentage of requests hitting cache. A 10 MB paste can displace many small logs, so impose entry-size or admission limits. Coalesce concurrent misses for the same body and cap object-store requests during cache failure.

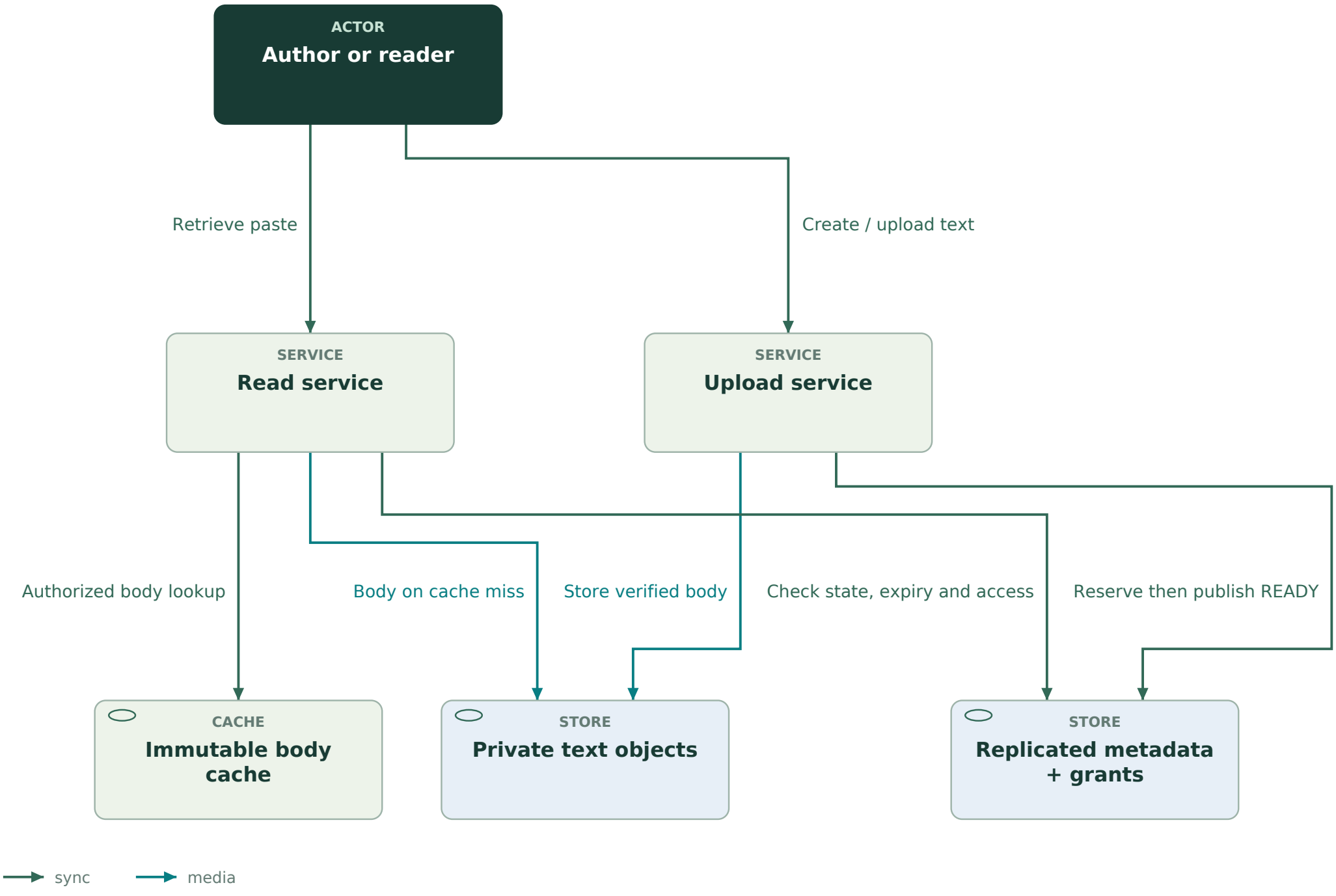
Private content may be cached internally, but every delivery still checks current permission. Do not publish a permanent public object URL and expect a private metadata page to protect it. Short-lived signed download links trade reduced authorization traffic for a period during which the link remains usable; negotiate that behavior rather than claiming immediate revocation.

Replicate authoritative metadata and protect object bytes under their own storage policy. Partition metadata only after measured limits justify it. Distributing different paste IDs improves aggregate capacity; one viral paste is primarily a delivery-cache problem.

Meet the one-node-loss target with durable majority commits across three metadata replicas in independent regional failure domains, and object storage whose acknowledged writes survive one storage-node loss. Verify both policies before READY publication; three-copy arithmetic alone is not evidence of either guarantee.

Scale body transfer separately from metadata decisions

The upload service stores and verifies immutable text before publishing its metadata. A reader service checks visibility and expiry before returning a cached body or loading it from private storage. This diagram keeps delivery behind the service rather than selecting the optional signed-link policy.



10 / Recover publication without exposing partial data

Suppose upload U stores the body, then the application crashes before READY commits. The owner sees no success, and readers still see no published paste. A retry locates U, verifies its stored bytes and asks the database to change the still-active upload to READY. If a cleanup worker already canceled U, the transition fails instead of publishing an object that may be deleted.

If the application crashes after READY commits but before returning, the request result retrieves the same paste. If an object read fails later, return a temporary error; do not report an empty paste as the saved content. A checksum helps identify corruption, while backups and redundant storage provide recovery paths.

Delete metadata before scheduling physical body removal. Store the removal intention in the same transaction as deletion, often as an outbox row: a durable work record that a background worker can retry. Repeated deletion of the exact obsolete object is harmless. Do not delete shared deduplicated bytes merely because one paste no longer uses them; shared storage would require reference accounting.

During a permission-store outage, fail private reads rather than trusting an old grant. Public-content availability can use a separately declared caching policy. These outcomes distinguish unavailable data from missing data and prevent an availability workaround from becoming a privacy leak.



INTERVIEW CRITICAL

Cached bytes do not grant access

An internal cache can save a body read. It cannot decide that a private reader is still authorized. Check permission before returning any bytes, and state the lifetime of any downloadable capability.

11 / Watch publication, privacy and byte consumption

Monitor upload-to-ready latency, failed uploads, oldest pending attempts and any READY record whose body cannot be found. Separate metadata latency, time to first byte and whole-transfer duration. A 10 MB response over a 10 Mb/s connection already needs roughly eight seconds before overhead, so one small latency target cannot describe every stage.

Escape rendered text, disable content sniffing for raw delivery and keep object storage private. Rate-limit both requests and bytes. Avoid logging paste contents: diagnostic logs can contain credentials or personal data even when the uploader does not recognize them. Titles, object keys and checksums also need sensible access and retention policies.

Approximate view counts can flow through a bounded asynchronous queue instead of updating the paste row on every read. Measure dropped events and label delayed counts honestly. Cost comes mainly from retained bodies, replicated copies, delivery bytes and object operations. Compression can reduce text storage, but enforce decompressed-size limits.

Test a slow maximum-size uploader, a popular paste after cache loss, a denied private read with a warm cache, and a restore containing both metadata and body objects. Restoring only one side does not restore the service.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1 + NFR3: complete publication	SQL transaction initially; verified immutable object followed by guarded READY publication after storage separation.	Crash before and after READY. No readable paste may reference incomplete or missing accepted bytes.
FR2-3 + NFR4: safe authorized retrieval	Escaped display/plain-text response; current grants, deletion and expiry checks before body delivery.	Read a private paste through a warm cache after access removal; it must be denied.
FR4 + NFR6: repeatable creation	Owner/request identity and reserved upload state.	Lose the ready response and retry within 24 hours; return the same paste and immutable body.
NFR1-2,5: useful capacity	Separate upload/read capacity, streamed buffers and body caching.	Benchmark p95 first-byte latency with ordinary reads, 10 MB uploads and cache loss; measure full transfer separately.
NFR3: one-node loss	Replicated metadata commits and a matching object-storage durability policy.	Fail a node after success and restore metadata plus bodies together. Regional loss requires a separate recovery agreement.

13 / Rapid revision

Remember: Store and verify the bytes before READY; hidden unfinished storage is safer than a visible broken paste.

Decision	Reason	Failure to avoid
Keep each paste ID's text unchanged	Shared links keep stable content	Changing text while caches serve old copies
SQL baseline	Text and metadata publish in one commit	Introducing two stores without a recovery rule
Object storage for large text volumes	Separate large bodies from indexed metadata	Marking READY before the body is complete
Reuse the creation request key	Recover a lost creation response	Retrying as an unrelated paste
Check expiry and permission on each read	Return unexpired text only to permitted readers	Treating late cleanup or a cache hit as permission

Decision	Reason	Failure to avoid
Cancel the upload before cleanup	A canceled upload cannot later publish	Deleting a body while its uploader may still publish
Count views asynchronously and approximately	Return text without waiting for counting	Claiming exact audit totals from lossy events

In a spoken summary, begin with saving and retrieving one diagnostic log. Use the estimates to explain why the request rate is manageable while retained bytes may justify object storage. Then show the one crash between byte storage and publication, followed by the private-cache check. That covers the design's central differences from a URL shortener. Editing and strict multi-region revocation add separate requirements rather than following automatically from this architecture.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What changes compared with a URL shortener?

Model answer

The service stores and serves the actual text, so completeness, byte transfer, safe rendering and content permissions become central.

Interviewer follow-up

What remains similar?

Stable IDs, uniqueness, request retries, expiry and owner actions still need explicit rules.

What the answer must demonstrate: Names actual content ownership rather than treating the product as another redirect.

02 / FOUNDATION

Is an unlisted paste private?

Model answer

No. Anyone with its address can retrieve it. Private content requires an authenticated grant.

Interviewer follow-up

What happens if someone forwards the URL?

Unlisted access follows possession; private access still checks the receiving user.

What the answer must demonstrate: Distinguishes access by URL possession from authenticated access.

03 / APPLIED

Why begin with text in SQL?

Model answer

At the assumed request rate it provides one simple transaction for text, metadata and retry state.

Interviewer follow-up

What triggers object storage?

Measured retained-byte, backup or transfer pressure, not an arbitrary rule against relational storage.

What the answer must demonstrate: Uses operational pressure to justify losing a one-store transaction.

04 / APPLIED

Why upload the object before marking READY?

Model answer

A failed upload must not leave a visible paste pointing to missing bytes. Hidden orphan bytes are safer and recoverable.

Interviewer follow-up

What if metadata commit fails?

Retain the pending attempt and verify/retry its publication or cancel it for cleanup.

What the answer must demonstrate: Explains the safe ordering and the orphan-versus-broken-pointer tradeoff.

05 / APPLIED

Why is an old upload not automatically safe to delete?

Model answer

Its uploader may still be completing. Cleanup must first mark the attempt canceled in the same database state that publication checks, then delete its bytes.

Interviewer follow-up

What does a late uploader do?

Its READY transition fails once the attempt is canceled; it cannot bypass that guard.

What the answer must demonstrate: Identifies a state guard shared by publication and deletion.

06 / APPLIED

Can we cache private paste bodies?

Model answer

Internally, yes, provided every new delivery passes the required current permission check.

Interviewer follow-up

What about a permanent public object URL?

That bypasses the permission service and violates private access.

What the answer must demonstrate: Keeps permission enforcement in front of every byte-delivery path.

07 / APPLIED

Why limit bytes as well as requests?

Model answer

A maximum-size paste consumes far more bandwidth and buffering than an average one. Request counts alone hide that imbalance.

Interviewer follow-up

Does streaming solve unlimited concurrency?

No. Bounded buffers still require connection, byte-rate and active-upload limits.

What the answer must demonstrate: Connects object size, transfer time and bounded resources.

08 / FOLLOW-UP

How would editing change the design?

Model answer

Store immutable body versions and atomically change the selected version using an expected-version check.

Interviewer follow-up

Why not overwrite one cached object?

Different caches may serve different content under the same identity, defeating stable reads.

What the answer must demonstrate: Separates immutable content versions from mutable selection metadata.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design an immutable paste service with public, unlisted and private text, 1M creations/day and a 10 MB maximum. Explain a working baseline and its transition to object storage.

• Clarify and number functional and non-functional requirements in 5 minutes: visibility, immutable publication, first-byte latency, byte limits and durability.

• Trace create/read through one database in 8 minutes.

• Estimate normal and maximum-object load in 7 minutes.

• Define API, metadata and publication state in 10 minutes.

• Explain a crashed upload, cleanup race and private cache hit in 10 minutes.

• Use 5 minutes to review the final design against the numbered FR/NFR lists, test publication and private reads, and state transfer-time and recovery limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

The body upload succeeds, but the application crashes before READY. What can readers see, and how does recovery proceed?

Readers see no published paste. A retry verifies the stored body and publishes only if the upload is still active; a canceled attempt stays unavailable.

Bytes first, READY second.

A cache contains a private paste. Is that enough to return it?

No. The service must still check whether this reader may access the paste.

Stored is not authorized.

When may cleanup delete the body of an abandoned upload?

After saving a cancellation that prevents the uploader from publishing it later.

Cancel publication, then reclaim.

Summary and interview notes

A paste combines text, metadata and access rules. When text moves to object storage, verify its upload before publication and cancel abandoned uploads before deleting their bytes.

Remember these points

• Unlisted and private mean different access contracts.

• Read-time checks enforce expiry independently of cleanup.

• Hidden orphan bytes are preferable to a broken visible paste.

• Large transfers need byte and concurrency limits.

Interview tips

• Start with one saved log and one reader.

• Use a crash between object write and READY to test the design.

Important qualifications

• Exact public revocation deadlines and renewable upload leases require additional protocol detail.

Explore the advanced version

Publication versus garbage collection proof: Useful when uploads have renewable leases and collectors run concurrently.

Exact public visibility deadlines: Needed when public edge caches must satisfy a provable revocation limit.

Regional restoration of aliases and grants: Needed when backup recovery may omit recent claims or revocations.

Private streaming integrity and capabilities: Useful when direct delivery replaces application-mediated reads.

Technical references

Amazon S3 data consistency model
Confirms object read-after-write behavior; it does not provide a transaction with a separate metadata database.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/Welcome.html#ConsistencyModel

Transactional outbox pattern
Supports the reliable handoff from a committed deletion to asynchronous cleanup.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

Amazon S3: Conditional Writes
Verified conditional creation prevents overwriting an existing generation; metadata publication remains a separate transaction.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/conditional-writes.html

Amazon S3: Checking Object Integrity
Verified explicit checksums rather than assuming every ETag is a whole-object hash.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/checking-object-integrity.html

CORE INTERVIEWS / 29

Design a photo-sharing service

Interview version / 45-minute scope · Read the advanced version online

Separate durable photo publication, follower feed preparation and authorized image delivery, then scale each for its own workload.

media processing • feed generation • CDN • sharding

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace original upload, verified variants and a follower feed read.
- Use image bytes and follower amplification to justify storage, CDN and hybrid feeds.
- Explain processing retries and why cached candidates cannot grant access.

Useful foundations: Caching: cache hits, misses, write policies and invalidation; Database indexes: B-trees, composite keys and query access; Message queues, event logs, delivery guarantees, and backpressure; Data partitioning and sharding

8 interview questions with model answers and answered follow-ups.

01 / An upload becomes a photo, then a feed candidate

Maya uploads a sunrise photo. The service should preserve the original, prepare a small preview, show the photo on Maya's profile and eventually include it in eligible followers' feeds. Those are related but separate results. Accepting bytes does not mean every image variant exists, and placing a photo ID in a feed does not grant permission to view it.

Support uploads, deletion, author galleries, following, private accounts, title search and a twenty-item home feed. Begin with chronological ordering; sophisticated recommendations and exact engagement counts are extensions. A private account requires approved followers. Define whether an already issued media link can remain usable briefly after access changes; a cached image cannot revoke bytes already downloaded.

A photo becomes published only when the variants required by its page exist. The uploader can see processing or failure while preparation continues. Feeds and search may lag publication, but they must not expose private or deleted content simply because an old candidate remains in an index. These decisions give us a small set of observable states before we choose queues or a CDN.

Before choosing storage or fanout, clarify whether the feed is chronological, how quickly an accepted photo must become ready and visible, and whether private-media access must be checked on every new request. The requirements below select that last policy rather than long-lived public image URLs.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Upload and publish photos.** Authenticated authors upload an original, observe processing status and publish a photo only after its required preview and display variants exist.
2. **Browse and discover.** Provide author galleries, title search and a chronological home feed of up to twenty eligible followed-author photos.
3. **Manage audience and deletion.** Support follows and approval for private accounts. Owners delete photos; current access rules govern feed results and media delivery.
4. **Recover interrupted work.** Repeated upload completion and processing attempts preserve one photo identity and one accepted variant manifest.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload.** Use two million uploads/day and ten million feed opens/day: approximately 116 uploads/s and 579 feed requests/s at the fivefold peak. Preview delivery is approximately 10 TB/day; a fifty-million-follower author is a separate skew case.
2. **Feed response time.** Target regional p95 feed-metadata latency of 200 ms at the planning peak under normal operation. Image download and decoding are measured separately; this target is not a whole-screen rendering promise.
3. **Readiness and freshness.** For valid admitted images under the tested size and format limits, target p95 upload-complete-to-READY within 30 seconds. Target p95 propagation from READY to the prepared candidate list or author history used by an eligible active follower's refresh within five seconds during normal processing. This makes the photo available for retrieval; the bounded twenty-item page need not display every new photo.
4. **Durability.** Accepted originals, published manifests and required variants must survive a worker restart or one storage-node failure within the region. A success status cannot depend on an encoder keeping its private local files.
5. **Privacy.** Check current audience permission before returning private photo metadata or admitting a new private-media transfer, including cache hits. Previously downloaded bytes and already admitted transfers are outside recall.
6. **Isolation of expensive work.** Bound upload bytes, decoded pixels, processing concurrency and follower batches. Large or malformed images and celebrity fanout must not exhaust ordinary feed-serving capacity.

04 / Trace one photo from upload to a follower

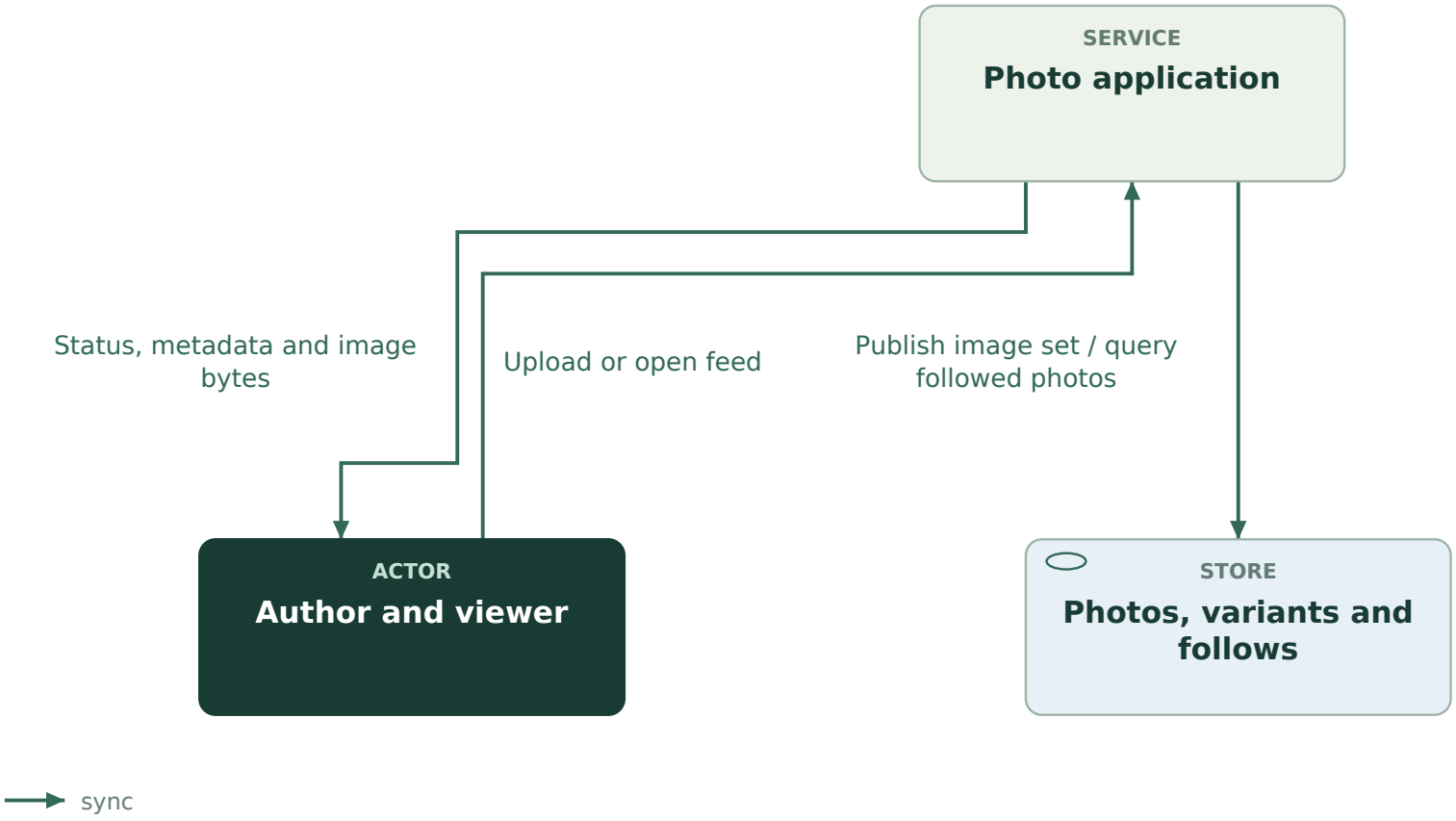
For a small service, use one application and a database holding photo metadata, follows and image bytes. The application receives the upload, validates its format and dimensions, produces a preview and a larger display image, then commits those bytes and metadata together. Return the photo identity after commit. If decoding fails, no published photo appears.

When follower Leo opens the feed, read the authors Leo follows, obtain a bounded recent set of their photos, check current visibility and sort by creation time with photo ID as a tie-breaker. Return twenty metadata records and the routes for their previews. The browser subsequently requests those image bytes. The author's gallery is simpler: query one owner's photos in order.

This baseline is intentionally small. It explains publication, feed assembly and media retrieval without making asynchronous jobs necessary for correctness. Its limits are easy to identify: image processing delays uploads, large bytes burden database backups and delivery, and each feed request repeats work across many authors. These limits motivate background processing, separate image storage and precomputed feed candidates.

A photo becomes visible after its variants exist

The small baseline publishes bytes and metadata together, then serves a follower feed from eligible photos.



05 / Size image delivery separately from feed requests

Assume two million uploads/day, 200 KB average originals, one million daily active readers and ten feed opens per reader. Each page contains twenty 50 KB previews. That gives about 23 uploads/s and 116 feed requests/s on average; a fivefold peak is approximately 116 uploads/s and 579 feed requests/s.

Resource	Estimate	Consequence
Original ingress	2M x 200 KB = 400 GB/day	Bulk storage grows despite modest request rate
Ten-year originals	400 GB x 365 x 10 = 1.46 PB	Retention, replicas and derivatives dominate bytes
Preview delivery	10M pages x 20 x 50 KB = 10 TB/day	Media delivery needs a different capacity budget
Ordinary publication fanout	23.1 photos/s x 300 active followers ~ 6,930 inserts/s	Feed preparation creates extra writes

A feed API returning IDs is not delivering all those preview bytes itself. A content delivery network, or CDN, can serve repeated immutable images near readers. At a measured 90% byte-hit rate, preview traffic reaching the origin would fall toward 1 TB/day, although viewers still receive 10 TB/day.

Average follower counts can conceal one celebrity. Fifty million follower references for a single photo are qualitatively different from three hundred. Estimate that separate case before choosing to write every publication into every feed.

06 / Separate upload acceptance from publication

Create an upload before transferring or publishing its bytes.

Start-upload request

```
POST /photo-uploads
```

Request information	Purpose
Owner-scoped request key	Makes a retry recover the same upload.
Expected byte count	Lets completion verify the original's length.
Checksum	Lets completion verify the original's content.

Response identities for the running example

```
Photo:  p900
Upload: up900
```

A retry returns those same identities. Small deployments may carry bytes through the application; larger deployments can give the client a narrowly scoped direct-upload target.

API	Meaning
`POST /photo-uploads/up900/complete`	Verify accepted bytes and begin processing
`GET /photos/p900/status`	Uploading, processing, ready or failed
`GET /feed?limit=20&cursor=...`	Eligible photo metadata and media routes
`GET /users/maya/photos`	Author gallery ordered by time and ID
`PUT /following/maya`	Follow or request approval for a private account
`DELETE /photos/p900`	Owner revokes publication and starts cleanup

Completion authenticates the owner and verifies the stored object; an upload URL alone cannot publish a photo. Return pending rather than claiming all previews already exist. A feed cursor carries its viewer and continuation context, so it cannot be reused for another person's private feed.

Title search can initially use a database text index. A later search service returns candidate photo IDs; the serving path still checks their current visibility. Search freshness and access permission are different contracts.

07 / Choose records around three access patterns

Photo metadata, upload state and feed references serve different purposes.

Record	Stored information	Purpose
`Photo`	ID, owner, creation time, title, visibility, publication state, accepted image-variant references	Describes the photo and selects its published content.
`Upload`	Request identity, photo reference, accepted original	Connects a retryable upload to its photo and exact original.
`Follow`	Follower, author, approval status	Records the relationship and private-account approval.
`Feed`	`viewerId`, `photoId`, `sortKey`	Stores a derived candidate reference, not another copy of the image.

The photo page reads by ID. The gallery reads by `(ownerId, createdAt, photoId)`. Publication fanout reads followers of an author, while feed assembly reads authors followed by a viewer. Those opposite relationship lookups need suitable indexes; a single primary-key lookup does not answer them all efficiently.

After moving bytes to object storage, a manifest records exactly which immutable original and variants belong to a published photo. It is a small metadata document, not the images themselves. Keep originals private and preserve their exact accepted identity. A path containing a photo ID does not automatically prevent later overwrites; use create-only writes or a pinned object version.

A durable outbox row records processing or publication work in the same transaction as the photo-state change. A worker later relays it. This closes the gap where metadata commits but a separate queue send fails, leaving a photo permanently stuck.

08 / Let slow image work continue without blocking the uploader

Move original bytes to object storage when their volume and backup cost justify the split. Reserve the upload, receive and verify the original, then commit `PROCESSING` together with a processing event. The owner sees that the original was accepted while the application remains free to serve other requests.

The image worker then performs these steps:

1. Read the accepted original and decode it under pixel and memory limits.
2. Create the preview and large variant.
3. Write the outputs under immutable attempt-specific names and verify them.
4. Ask metadata storage to publish their manifest.

Only a successful `READY` transition makes the photo eligible for feeds.

The queue may redeliver a job after a timeout. Repeating image work is acceptable; replacing a newer published result with a stale worker's output is not. The publication update must check that this worker still owns the active processing attempt and that the photo was not deleted. A repeated successful completion returns the accepted manifest. Unreferenced attempt outputs can be cleaned up once no valid attempt can publish them.

This adds jobs, storage operations and recovery work. Synchronous processing is still simpler when small bounded images reliably fit the response budget. The advantage of the queue is predictable request handling and resumable work, not automatic exactly-once execution.



INTERVIEW CRITICAL

Publish a complete image set

A stored original or queued job does not make a photo ready. Publish only a verified manifest of required variants, and reject an obsolete worker trying to replace it.

09 / Trade repeated feed reads for recipient writes

The baseline gathers photos when the viewer reads. If Leo follows 500 authors and we inspect 100 photos per author, we consider 50,000 rows to return twenty. Repeating that work on every feed open can cost more than preparing a small list in advance.

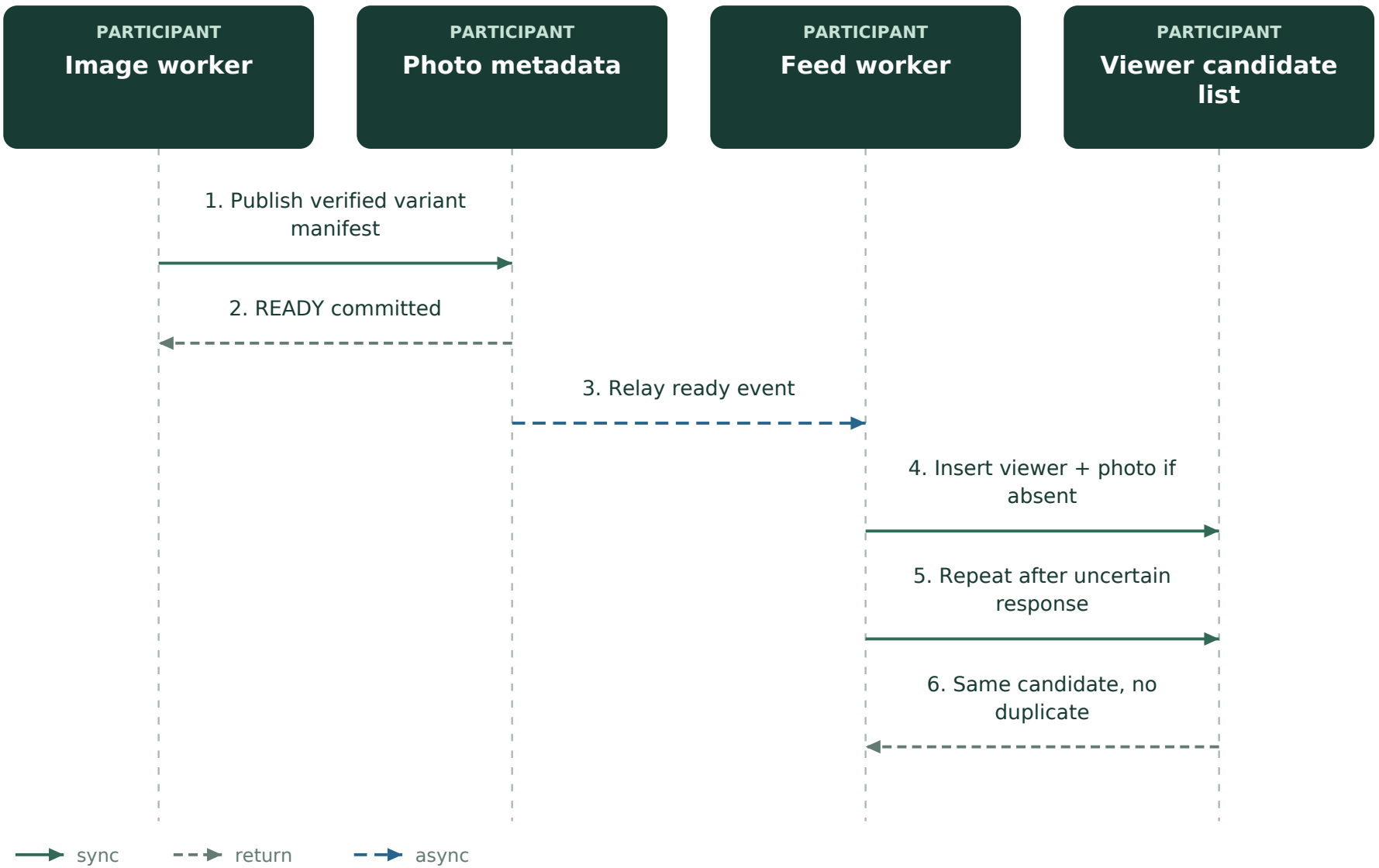
For ordinary authors, a publication worker inserts the new photo ID into active followers' candidate lists. This is fanout on write: one publication creates many recipient references. Enforce uniqueness on `(viewerId, photoId)` so replaying a job does not create duplicate feed slots. Store progress between follower batches so a crash can resume without loading an enormous follower list at once.

For very popular authors, keep an author timeline and merge its recent photos during reads. This avoids millions of writes for followers who may never open the app. A hybrid feed combines prepared ordinary-author candidates with those popular-author timelines, deduplicates IDs, checks current eligibility and returns a bounded page. Choose the threshold from posting rate, active readership and measured read/write cost, not a universal follower number.

Current privacy checks remain necessary in both paths. Leo can unfollow Maya while a delayed worker still inserts p900. The stale reference may remain temporarily, but it must not authorize a private photo. Candidate preparation answers what to consider; access checks answer what may be returned.

A publication becomes one feed reference

Only the committed ready event enters fanout; retrying the insert keeps one candidate.



10 / Keep metadata decisions apart from media transfer

Place a CDN in front of immutable variants so a popular image can be served by many delivery locations. A feed request returns small metadata and approved media references; the image request retrieves bytes through the media path. Measure time to first preview independently of feed API latency.

For private photos, choose an authenticated media edge that checks the viewer's current access before serving bytes, including cache hits. This keeps authorization in front of delivery. A short-lived signed download grant is an alternative if access may remain valid until expiry; this design instead checks current permission. Do not call a URL viewer-bound unless the edge checks that viewer's session. Already downloaded bytes, and transfers admitted before a later revocation, cannot be recalled.

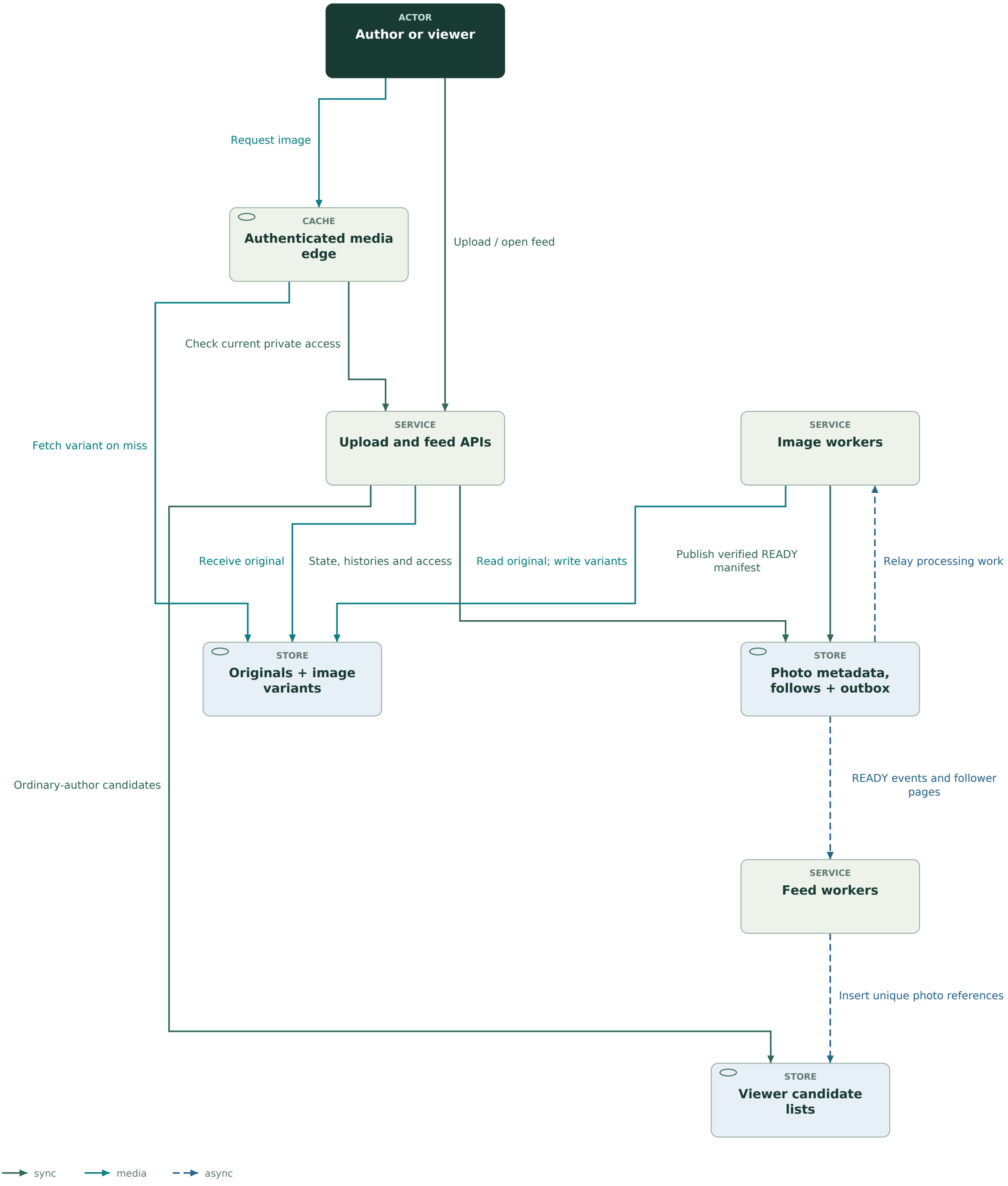
Replicate metadata according to the accepted-write durability requirement and protect originals through object-storage replication and backups. As metadata grows, distribute photo records while preserving author-gallery and viewer-feed indexes. Hashing photo IDs can spread stored rows but makes neither a gallery nor a feed local by itself.

Keep upload and feed-serving concurrency separately bounded. Slow large uploads should not occupy every worker needed for small feed reads. A ranking timeout may justify falling back to chronological order; a permission failure cannot justify serving unchecked private content.

For the chosen failure boundary, require durable majority commits across three metadata replicas in independent regional failure domains and object writes that survive one storage-node loss. Acknowledge original acceptance and publish manifests only after the relevant storage policy is satisfied. Measure queue capacity against the 30-second readiness and five-second feed-freshness targets.

Separate image preparation, feed candidates and media delivery

The API accepts an original; image workers publish a verified manifest before feed workers distribute photo IDs. Feed reads merge those IDs with popular-author histories and check current access. Viewers fetch image bytes through the authenticated edge, which checks access even for cached variants.



11 / Test a crashed processor and delayed feed work

Worker W1 starts processing p900 and pauses after writing one preview. Another valid attempt completes the required set and publishes its manifest. W1 later resumes. Its publication must be rejected because its attempt is no longer current. Its independently named files cannot overwrite the accepted outputs. The owner sees one ready photo; unused files become cleanup work.

A feed worker inserts p900 for half a follower batch and crashes before saving progress. On retry it repeats that batch. Unique recipient/photo entries make the repeat harmless; checkpointing before completing the writes would instead miss recipients. Feed lag is visible in freshness metrics, while the authoritative published photo remains available on its page.

If the cache disappears, cap object-store requests and share one cache refill among concurrent requests for the same image so a popular image does not overload the object store. If metadata is unavailable, the media edge cannot establish current access and stops admitting new private transfers. Already delivered bytes cannot be recalled; a transfer admitted before a later revocation may finish.

Delete the metadata's published state first, then asynchronously remove feed references, search entries and obsolete media. Reads must still filter stale references. Physical deletion is background work, but the access decision cannot depend on every derived index having completed cleanup.



INTERVIEW CRITICAL

A feed entry is a candidate, not permission

Fanout and search can lag an unfollow or deletion. Check current eligibility before returning private metadata or media, even when the photo ID came from a trusted internal cache.

12 / Measure readiness, feed work and delivery cost

Monitor upload-to-ready delay, permanently failed decoding, processing backlog and missing manifest objects. For feeds, measure candidates examined per returned item, publication-to-feed lag, duplicate IDs and popular-author merge cost. For delivery, measure byte-hit ratio and origin traffic; a high request-hit ratio can hide expensive large-image misses.

Treat uploaded media as untrusted input. Bound encoded bytes, decoded pixel dimensions, CPU and memory. Restrict upload targets to the correct owner and object, and remove unnecessary location metadata according to product policy. Private media tokens and image contents should not appear in ordinary logs.

Storage cost includes originals, variants and retained failed-attempt outputs. Delivery cost includes CDN egress even when origin reads decrease. Feed preparation has its own write and memory cost: at 32 bytes per reference, 300 recipients use 9.6 KB per photo, whereas fifty million recipients use 1.6 GB before indexes and copies.

Test malformed images, response loss after upload acceptance, repeated processing, a deleted photo in a cached feed and a popular upload during cache loss. These tests examine the actual boundaries rather than whether each box on the architecture diagram is running.

13 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1,4 + NFR3-4: ready photo	Immutable originals, durable processing work and current-attempt manifest publication.	Crash an encoder and resume an old attempt. Only complete verified outputs publish; benchmark the 30-second readiness target.
FR2 + NFR1-3: usable feed	Hybrid prepared candidates and popular-author histories, followed by bounded current checks.	Test ordinary and celebrity posts, measuring p95 feed response and READY-to-candidate propagation separately. Availability for retrieval does not guarantee a position in the twenty-item page.
FR3 + NFR5: private audience and deletion	Serving-time metadata and media-edge authorization; derived cleanup follows.	Remove access while old candidates and cached variants remain. New transfers must be denied; admitted bytes cannot be recalled.
NFR4: one-node survival	Replicated metadata plus accepted object writes under the chosen durability policy.	Fail a node after upload/READY acknowledgment and verify every referenced required object remains available.
NFR6: bounded cost	Separate feed, upload and processing budgets; bounded fanout batches.	Combine malformed images, slow uploads and a viral photo. Targets need measured spare capacity, not merely more workers.

14 / Rapid revision

Remember: An uploaded original can survive while its preview fails. Publish only a verified, complete variant set.

Path or choice	Purpose	Main limitation
Save the original before accepting	Preserve the source bytes	Accepted does not mean variants are ready
Processing and manifest	Publish the manifest of all required variants	Obsolete workers cannot replace the accepted manifest
Pull feed baseline	Assemble followed authors on demand	More followed authors increase per-read work

Path or choice	Purpose	Main limitation
Prepare ordinary-author feeds; pull celebrity posts	Save repeated reads without millions of celebrity-post copies	Merge, deduplicate and check current access
CDN delivery	Serve repeated immutable image bytes near viewers	Check access and private-grant expiry
Partition records by photo ID	Spread independent records	Galleries and viewer feeds need their own indexes
Asynchronous cleanup	Remove obsolete derived data and files	Check permission even while obsolete entries remain

In the interview, trace p900 from accepted original to READY manifest and then into Leo's feed. Use preview egress to justify delivery caches and follower amplification to justify the hybrid. End by showing how a stale worker and a stale feed reference are prevented from changing publication or access. Personalized recommendations can be added after those responsibilities are clear.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

When is an uploaded photo ready for a feed?

Model answer

After every required display variant exists and its accepted manifest is committed.

Interviewer follow-up

Why not publish when the original upload finishes?

Readers would encounter broken previews if decoding or resizing later fails.

What the answer must demonstrate: Separates original acceptance from published variants.

02 / APPLIED

Why store processing work beside photo state?

Model answer

A durable outbox committed with PROCESSING avoids losing the job if the application crashes before a separate queue send.

Interviewer follow-up

Can the relay send twice?

Yes. Workers must identify the photo generation and make repeated completion harmless.

What the answer must demonstrate: Explains the database-to-queue crash gap and repeated relay.

03 / APPLIED

Why not push every photo to every follower?

Model answer

Popular authors can create millions of writes for inactive readers. Pulling their recent timelines on demand can be cheaper.

Interviewer follow-up

How is the threshold chosen?

Compare posting rate, active followers, recipient-write cost and actual reader merge cost.

What the answer must demonstrate: Justifies the threshold with work, rather than a celebrity label alone.

04 / APPLIED

Why check access after reading a feed cache?

Model answer

Candidate lists can outlive an unfollow, deletion or privacy change. Membership in that list is not permission.

Interviewer follow-up

Can cleanup replace the check?

No. Cleanup may be delayed and can race a late fanout insertion.

What the answer must demonstrate: Keeps authorization independent of derived-list cleanup.

05 / APPLIED

How does a stale image worker fail safely?

Model answer

It writes attempt-specific outputs and must pass a current-attempt check before publishing the manifest.

Interviewer follow-up

Why are separate names necessary?

Metadata rejection would not help if the stale worker could overwrite bytes already referenced by the accepted manifest.

What the answer must demonstrate: Protects both metadata selection and immutable bytes.

06 / APPLIED

Does a CDN eliminate image delivery cost?

Model answer

It reduces origin reads and can improve latency, but bytes delivered to viewers still consume bandwidth and cost money.

Interviewer follow-up

Which hit metric matters?

Byte-hit ratio, alongside request hits, shows how much origin traffic is avoided.

What the answer must demonstrate: Separates origin savings from total viewer egress.

07 / APPLIED

Why is hashing photo IDs insufficient for galleries?

Model answer

A gallery selects one author's photos in time order. Random ID ownership can scatter those records.

Interviewer follow-up

What supplies that access path?

An owner/time index or suitable author-based layout with an explicit hot-author policy.

What the answer must demonstrate: Matches indexes to query shape rather than primary storage alone.

08 / FOLLOW-UP

What changes for a personalized feed?

Model answer

Add bounded candidate scoring and evaluate quality, while preserving publication and permission checks.

Interviewer follow-up

Can a high score override privacy?

No. Ranking orders eligible items; it cannot authorize them.

What the answer must demonstrate: Treats relevance and eligibility as separate decisions.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design photo uploads, galleries and a followed-author feed. Use 2M uploads/day and a celebrity with 50M followers to justify processing, storage and delivery choices.

• Use 5 minutes to agree numbered functional and non-functional requirements for publication, chronological feeds, readiness/freshness, durability and private access.

• Trace one upload and follower read in 8 minutes.

• Estimate original bytes, preview egress and fanout in 7 minutes.

• Define upload APIs, records and READY publication in 10 minutes.

• Explain hybrid feeds, retries and private media in 10 minutes.

• Use 5 minutes to check the final design against the numbered FR/NFR lists, name the latency/freshness load tests and explain remaining media-access limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Maya's original is stored, but preview generation fails. Is the photo ready, and what should Maya see?

It is not READY. Preserve the original and show processing or a failure; publish only after all required variants exist and their manifest commits.

Original saved does not mean photo ready.

Why prepare ordinary authors' feed entries but fetch celebrity posts when a reader opens the feed?

Preparation saves repeated reads for ordinary audiences. Pulling celebrity posts avoids writing a copy for millions of followers who may never read it.

Spend writes where readers benefit.

A cached feed entry names a private photo. May the service return it immediately?

No. It identifies a possible feed item; current permission checks decide whether the viewer may receive it.

Candidate first, permission next.

Summary and interview notes

Save the original, generate the required variants, then publish their complete manifest. Prepare feed candidates separately; check current access before returning photo metadata or bytes.

Remember these points

- Publish complete variants through a verified manifest.
- Record background work durably with metadata.
- Use hybrid feeds when recipient writes outweigh read savings.
- Check access before private metadata or bytes leave the service.

Interview tips

- Use the same photo ID through every stage.
- Calculate the celebrity case separately from ordinary followers.

Important qualifications

- Strict immediate media revocation and version-pinned direct upload protocols require additional detail.

Explore the advanced version

Direct-upload version pinning: Needed to prevent a reusable upload capability from replacing an already accepted original.

Processing lease and publication proof: Useful for reasoning through multiple delayed worker attempts.

Identity-bound media authorization: Needed when signed media grants must be bound to an authenticated session.

Partition and identifier alternatives: Useful when gallery locality, allocation or ownership migration becomes the limiting concern.

Technical references

S3 presigned upload URLs
Explains constrained direct-to-storage uploads; image publication and authorization remain application responsibilities.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/PresignedUrlUploadObject.html

PostgreSQL multicolumn indexes
Documents why an index's column order matters for the owner/time access path.
https://www.postgresql.org/docs/current/indexes-multicolumn.html

Transactional outbox pattern
Supports a reliable publication-to-processing/feed handoff.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

Amazon S3: Retrieving Object Versions
Exact version retrieval pins the accepted original even if a presigned URL later writes a newer version.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/RetrievingObjectVersions.html

Amazon S3: Conditional Writes
Alternative create-only enforcement; an object-key naming convention alone does not prevent overwrite.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/conditional-writes.html

CORE INTERVIEWS / 30

Design a file synchronization service

Interview version / 45-minute scope · Read the advanced version online

Build file synchronization around immutable revisions, explicit conflicts and durable device catch-up, then add chunk reuse and notification gateways.

file revisions • chunks • offline conflicts • sync cursors

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain a complete save and catch-up without losing offline edits.
- Connect stable identity, expected revisions, manifests and cursors.
- Justify chunking and workspace partitioning while preserving recovery.

Useful foundations: Storage engines and data models; Transaction isolation; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / Synchronize saved revisions without losing offline edits

Two laptops share `budget.xlsx`. Both start from revision 12, then edit while one is offline. The service must eventually distribute saved work without allowing the last upload to erase a change its author never saw. File synchronization therefore needs more than byte copying: it needs stable file identity, saved revisions, change discovery and a conflict policy.

Support files and folders, uploads, downloads, rename, deletion, shared workspaces, offline edits and retained versions. A workspace is a shared set of files and membership rules. Keep its metadata changes within one transaction domain for this interview. A stable file ID survives a rename; the pathname tells us where that file currently appears.

Use conflict copies for concurrent binary edits. Automatically merging arbitrary spreadsheets or images is outside scope. Distinguish saved locally, upload pending, committed on the server and applied on another device. A successful server commit does not mean an offline laptop has already received the file. Limit files to 1 GiB and declare a history-retention window; indefinitely disconnected clients cannot depend on a log kept for only a month.

Clarify whether concurrent offline edits may overwrite each other, how long history must remain recoverable, and what delay is acceptable for an online second device. This design preserves conflicts and separates a change notification from completion of byte transfer.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Manage a shared file namespace.** Create files and folders, rename and delete them, and authorize access through workspace membership. File identity remains stable through a rename.
2. **Synchronize across devices.** Upload and download saved revisions, let offline devices catch up, and show local, pending, server-committed and locally-applied states distinctly.
3. **Preserve concurrent edits.** Retain both users' work when an offline edit conflicts with a newer saved version, and make the conflict visible instead of silently overwriting either edit.
4. **Recover and restore.** Resume interrupted operations, retrieve retained versions and resynchronize safely when a device cursor is older than the change history.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload and file limits.** Use 100 billion current files, approximately 10 PB of current logical bytes and a peak of about 28,935 metadata commits/s. Limit each file to 1 GiB; retained revisions add capacity beyond those current-file totals.
2. **Metadata latency and discovery.** Target regional p95 metadata responses within 200 ms and p95 committed-change discovery within five seconds for connected devices during normal operation. Completing a large download depends on file size and bandwidth and is not covered by the five-second target.
3. **Revision integrity and durability.** A committed revision must name complete protected chunks and survive a process restart or one storage-node failure within the region. Concurrent commits cannot silently lose either author's accepted work.
4. **Bounded retained history.** Choose 30 days of prior revisions and change-log history for this exercise. Devices beyond that history window must preserve local pending edits and recover from a consistent snapshot instead of skipping directly to the newest cursor.
5. **Workspace isolation.** Authorize upload, commit, revision reads and downloads. Chunk reuse must not disclose or grant access to another workspace's private content.
6. **Recovery under overload.** Bound transfer concurrency and spread reconnect retries. If metadata cannot safely commit, clients retain pending local work and must not report synchronized success.

04 / Commit a whole file, then let another device catch up

Start with one metadata database, durable file storage and a client that periodically asks for changes. Laptop A uploads an immutable copy of its saved file. After verifying the bytes, the server checks that A edited revision 12 and the current file is still revision 12. In one metadata transaction it records revision 13, makes it current and appends a change entry.

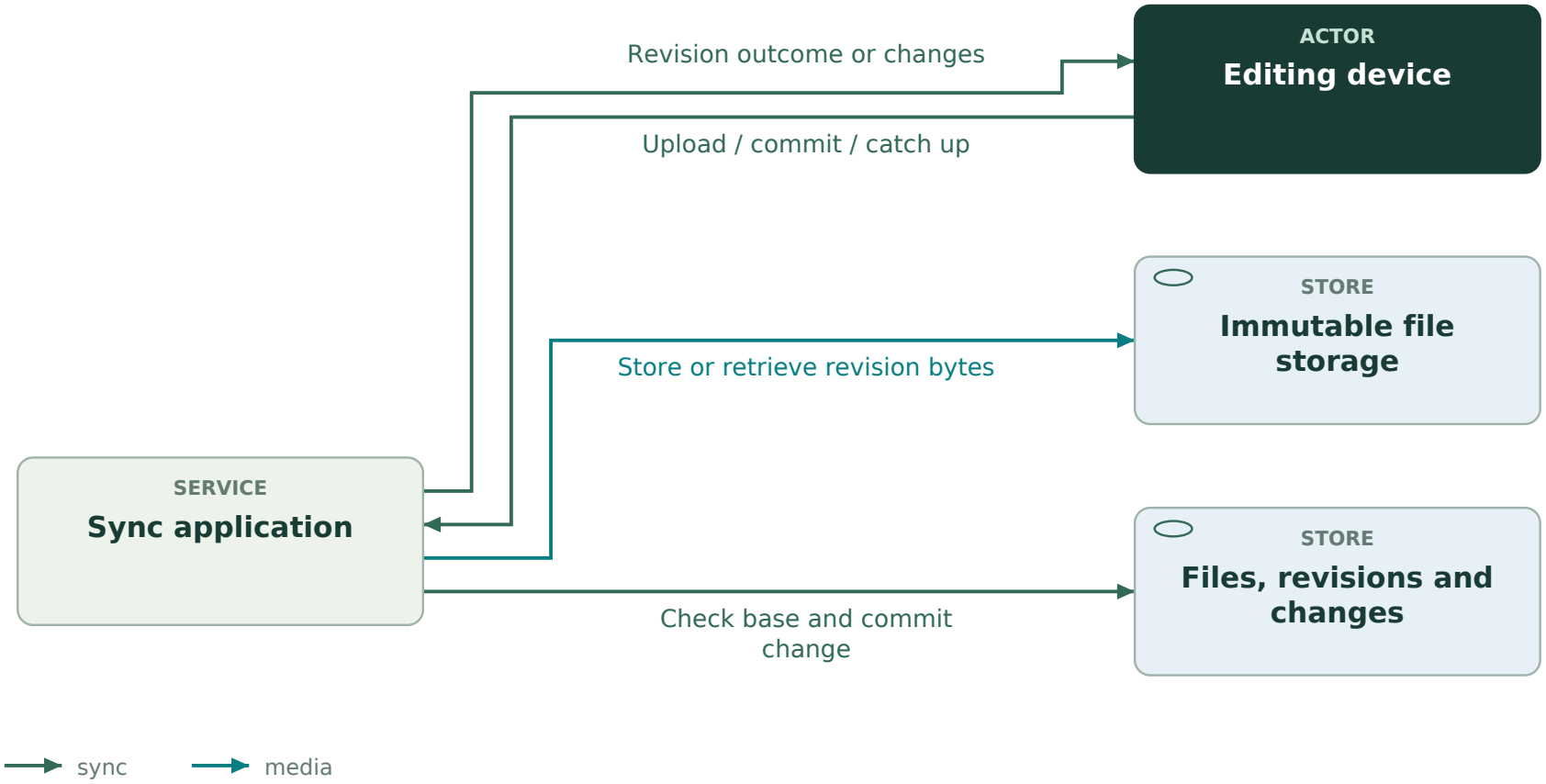
Laptop B asks for changes after its last saved position. It learns that file f42 now has revision 13, downloads that immutable version to a temporary location, verifies it and replaces its local copy. It records progress so a restart can resume. If B has unsent edits, it preserves them instead of blindly replacing the file.

The local client must capture a stable byte version before uploading. Reading a live file while another application rewrites it can mix two saves. A staging copy or suitable filesystem snapshot makes the uploaded bytes correspond to one captured revision.

This whole-file baseline is slower for large repeated edits, but it already establishes the essential rules. Uploading bytes does not make them current; the metadata commit does. Polling may delay discovery, but missed network notifications cannot lose a committed revision.

Whole-file synchronization before chunk optimization

Bytes are verified before metadata commit; devices use saved history to discover the new revision.



05 / Count changed bytes, metadata and online devices separately

Assume 500 million accounts, 200 files per account and 100 KB average file size. That is 100 billion current files and 10 PB of logical current content. At an illustrative 1 KB of file metadata, metadata alone reaches 100 TB before indexes and replicas. Old revisions add storage beyond the current-file total.

For 100 million daily active users making five committed changes each, average commits are `500M / 86,400 ~ 5,787/s`. A fivefold peak is about 28,935/s. If a change uploads 200 KB on average, mean changed-byte ingress is approximately 1.16 GB/s. Downloads depend on how many other devices actually receive the change.

Workload	Estimate	Design implication
Maximum 4 MiB chunks per file	1 GiB / 4 MiB = 256	Manifest checks can be bounded
Ten million devices polling each minute	About 166,667 polls/s	Many requests can find no changes
One million reconnects in one minute	About 16,667 sessions/s	Recovery needs admission and randomized retry

The byte estimates motivate independent object storage; the metadata estimate motivates partitioning. Connection work motivates notification hints. These are different pressures. Do not claim a fixed deduplication saving: small files may change entirely, and compressed formats can change many bytes after a seemingly small edit.

06 / Name the base revision and the recovery cursor

Begin an upload with the file identity, expected base revision and a client-generated request identity.

Start-upload information for the running example

```
File ID:               f42
Expected base revision: 12
Request ID:           edit-77
```

A retry keeps `edit-77` and the same payload. The server returns an upload session; completing byte transfer is distinct from committing a new current revision.

Operation	Contract
Start upload for f42, base 12	Reserve one resumable attempt
Upload content or chunks	Store verified immutable bytes
Commit edit-77	Check permission and expected revision; return saved outcome
Get changes after cursor 880	Return ordered committed changes

Operation	Contract
Get revision 13	Return its manifest and authorized download route
Rename or delete f42	Update its stable identity's metadata and change history

A conflict returns the preserved conflicting revision or conflict-file identity. Repeating the same operation returns that outcome, rather than creating another conflict copy. A restore creates a new revision from retained history; it does not rewrite the past.

A cursor identifies how far a device has applied committed changes. If its position is older than retained history, return a clear resynchronization response. The client obtains a consistent file snapshot and its matching log position, preserves local pending work, and resumes after that boundary. Jumping straight to the newest cursor would miss deletions and renames.

07 / Separate identity, revision and byte layout

The metadata records separate the current directory entry, saved content and the history other devices must apply.

Record	Fields	Purpose
`File`	`workspaceId`, `fileId`, `parentId`, `name`, `currentRevision`	Describes a directory entry and its current version.
`Revision`	`fileId`, `revision`, `manifest`, `author`, `createdAt`	Identifies saved content; the manifest lists immutable chunks in order.
`Change`	`workspaceId`, `sequence`, `fileId`, `action`, `revision`	Records what other devices must learn.

Membership and request-result records participate in the relevant metadata decisions.

Folder browsing needs `(workspaceId, parentId, name)`. Device catch-up needs `(workspaceId, sequence)`. File lookup uses stable file ID. A name-based shard key would complicate renames; hashing every file independently would complicate workspace-wide ordering and atomic folder changes. Partition independent workspaces first so their local checks remain understandable.

A delete leaves a tombstone: a retained deletion record that an offline device can observe. Merely removing the row would make absence indistinguishable from a change the client never learned about. Retained old revisions still need their chunks, so cleanup must check more than the current revision.

The client has its own durable local journal for pending uploads, accepted revisions and in-progress downloads. It is part of the system, not an optional cache. A restart must not forget work just because the server is reliable.

08 / Preserve both edits when the expected revision changed

Laptop A and laptop B both edit revision 12. B's metadata transaction checks currentRevision=12 and commits revision 13. A arrives later with the same expected base. Its check now fails because currentRevision is 13. The server preserves A's content as a conflict copy and records that outcome without replacing B's accepted head.

The compare and update must happen atomically. A separate read followed by an unconditional write allows both clients to pass the check and overwrite each other. Client timestamps do not solve the problem: clocks differ, and being later does not establish an intention to discard an unseen edit.

A conflict copy is a real saved object. Its bytes, metadata and change event must survive just like a normal revision, so other devices can discover it and the user can resolve it. Recheck write permission at publication; a long-running upload must not bypass a membership revocation by calling its output a conflict.

Within one workspace, commit each revision update and its change-log position together, in order. A device must not advance beyond an earlier change that can still commit later. This is why a counter allocated before commit is not automatically a safe synchronization cursor.



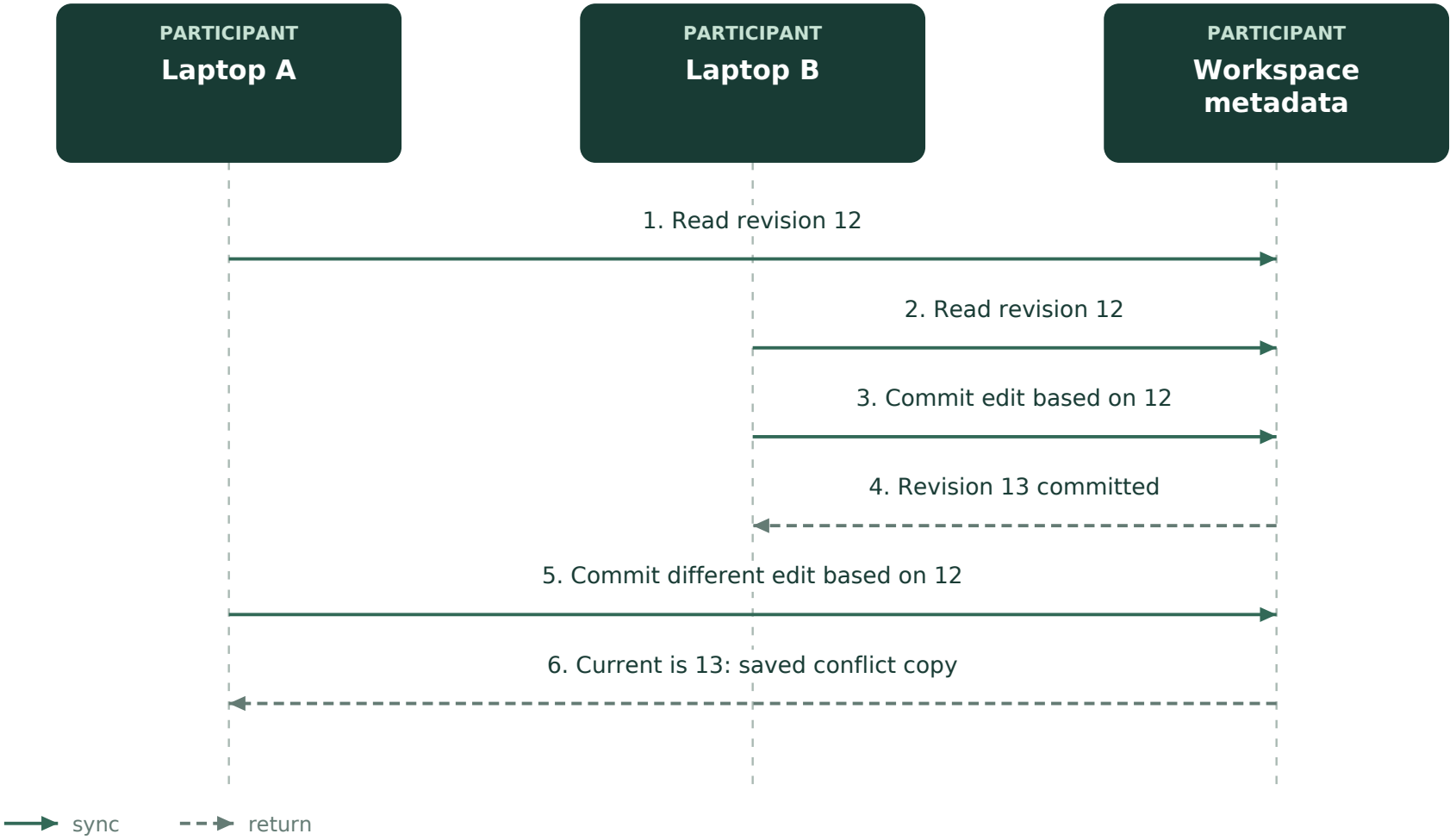
INTERVIEW CRITICAL

Do not silently overwrite unseen work

Check the client's expected base revision in the transaction that changes the current revision. If another edit won, preserve the losing edit as a recoverable conflict rather than treating upload time as user intent.

Two offline edits preserve both versions

The second commit observes a different current revision and records a conflict instead of replacing unseen work.



09 / Transfer changed chunks after the basic revision rule works

Suppose a 9 MiB file is split into 4 MiB, 4 MiB and 1 MiB chunks. Only the middle chunk changes.

Revision	Ordered chunk references	Bytes uploaded for this version
12	A, B, C	The initial 9 MiB file.
13	A, D, C	Only the new 4 MiB chunk D; reuse A and C.

This transfers 4 MiB instead of 9 MiB for that upload, saving about 56% in this particular example.

Chunk identities include a verified content checksum and size. Scope reuse to content the workspace is authorized to access; a global "does this hash exist?" endpoint can reveal another customer's private content. The manifest is committed only after every referenced chunk exists and is protected from deletion.

Protect chunks needed by an active upload, then transfer that protection to saved-revision references when commit succeeds. Cleanup first marks an unreferenced chunk as unavailable for future publication before deleting its bytes. A stale scan finding no reference is insufficient if an upload can start using the chunk afterward.

Fixed-size chunks are straightforward and provide bounded retry units. An insertion near the start may shift later boundaries, reducing reuse. Content-defined chunking chooses boundaries from content patterns and can improve that workload, at additional CPU and implementation cost. Patches inside changed chunks are another later optimization; neither is necessary to explain the first correct sync service.

10 / Use notifications to prompt durable catch-up

Millions of periodic empty polls create work even when nothing changes. A notification gateway can keep a persistent connection or long poll and send a small "workspace changed" hint. The device still reads the durable change log using its cursor. A lost hint delays discovery until reconnect or another poll; it does not erase history.

Separate bulk byte transfer from small metadata operations, with independent concurrency and bandwidth limits. A slow 1 GiB upload should not prevent another user from renaming a folder. Cache popular chunks and manifests only when measured reuse justifies their memory cost; a large chunk displaces far more cache space than one metadata row.

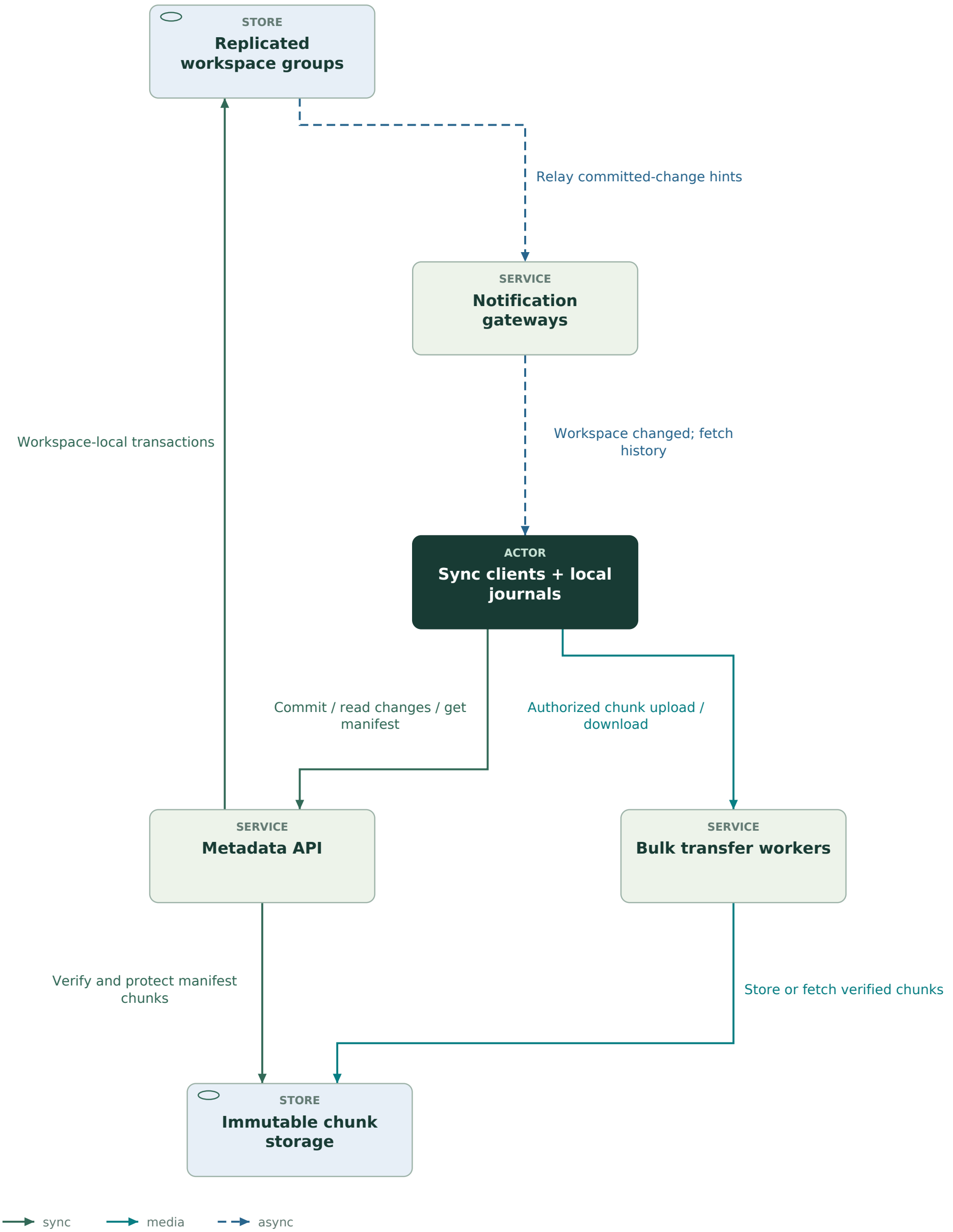
Distribute workspaces across replicated metadata groups. This scales independent workspaces while keeping their conflict checks, directory changes and change history within one transaction boundary. One unusually large workspace remains a potential bottleneck; splitting it requires a new ordering and transaction design, not simply a different hash function.

Gateways do not own revisions. They can be replaced and clients reconnect from durable cursors. Spread reconnects with randomized delays and limit concurrent snapshot recovery and downloads during a fleet restart. More connections and faster notifications improve responsiveness only if metadata and byte services can handle the recovery traffic.

Implement the one-node-loss requirement with durable majority commits across three metadata replicas per workspace group in independent regional failure domains, plus chunk storage whose acknowledged writes survive one storage-node loss. Retain the selected 30-day revision/change window and benchmark metadata and change-discovery targets independently of bulk-transfer duration.

Hints wake devices; durable metadata tells them what changed

A device uploads missing chunks. The metadata API verifies and protects every manifest chunk before committing against the expected revision. Another device receives a change hint and uses its saved cursor to read committed history. Independent transfer workers move authorized bytes; workspace metadata groups retain the conflict and ordering decisions.



11 / Recover local and server interruptions separately

If a client crashes after uploading chunks but before commit, its local journal and server upload session identify the pending operation. A retry may finish it while the session remains valid. If commit succeeded but its response was lost, `edit-77` retrieves the original result and must not create revision 14 accidentally.

A receiving device may crash after replacing the local file but before recording its new cursor. Its journal must recognize the completed replacement and finish the metadata update on restart. Conversely, advancing the cursor before retaining the bytes or a durable recovery plan can permanently skip a change. The local filesystem and the client's metadata database do not automatically share a transaction.

When the server cannot safely accept metadata writes, the client may continue editing locally with pending status. It should not claim synchronization. After recovery, the actual base revision determines whether a conflict exists. An already downloaded file cannot be made secret again by server-side revocation.

Backups must restore metadata, retained revisions and their referenced chunks together. Test an old-version restore after newer revisions and deletion. A healthy current file does not prove that historical chunks still exist.



INTERVIEW CRITICAL

A notification is not the recovery record

Use the ordered change log and a durable device cursor to recover missed events. Advance that cursor only when changes are safely applied or durably journaled for completion after restart.

12 / Measure synchronized work, not just successful uploads

Measure metadata commit latency, time for connected devices to catch up, conflict rate, transferred bytes per revision and time spent pending. Missing chunks in an accepted revision are an integrity incident; a delayed notification is a different problem. Track old upload sessions and cleanup backlog so temporary bytes do not grow without bound.

Authorize upload, final commit and downloads. Scope transfer credentials to the intended object and operation. Keep filenames and file contents out of broad telemetry. Count retained revisions toward quotas, otherwise repeated overwrites can consume large historical storage while the visible current file stays small.

Cost combines current bytes, version history, replicas, transfers, chunk-reference metadata and client/server CPU. Chunking is worthwhile when saved bytes exceed its lookup and bookkeeping cost. Test a tiny-file workload as well as large files with localized edits.

Exercise concurrent offline edits, a rename during synchronization, an expired history cursor, cleanup racing an upload and mass reconnection. These scenarios test the user's promise that work survives and converges, rather than merely demonstrating that files can cross the network.

13 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1-3: namespace and concurrent edits	Stable file IDs, workspace-local transactions and expected-revision checks.	Race two edits based on revision 12 and rename a file; retain both edits without changing identity.
FR2 + NFR2: online synchronization	Durable changes and cursors, with notification hints.	Drop hints and reconnect a device; benchmark discovery separately from metadata latency and whole-file download time.
FR4 + NFR4: old devices and restore	Thirty-day history plus consistent snapshot/log-position recovery and local journals.	Reconnect beyond retention with unsent edits and restore an old version. Count retained revision bytes in sizing.
NFR3: committed bytes survive	Protect chunks before manifest commit; replicated metadata and byte storage.	Fail one storage node after a commit; no accepted manifest may reference lost or prematurely collected chunks.
NFR5-6: safe shared use	Workspace-scoped authorization, bounded transfer work and pending status during unsafe writes.	Revoke membership mid-upload and run a reconnect wave. A fast hint cannot substitute for authorized durable catch-up.

14 / Rapid revision

Remember: Compare the saved base before replacing the current revision; an unseen edit must become a conflict, not disappear.

Concept	Purpose	Mistake to avoid
Stable file ID	Recognize the file after a rename	Treating the path as immutable identity
Expected base revision	Detect an unseen concurrent edit	Last upload wins regardless of intent
Immutable revision manifest	List chunks needed to reconstruct the revision	Publishing before verifying chunks and protecting them from cleanup
Chunk reuse	Transfer less when content repeats	Claiming every format benefits equally
Change log and device cursor	Recover missed updates and deletions	Treating a socket event as durable progress
Local journal	Resume interrupted local work	Saving progress before local changes survive a crash
Workspace partition	Transact related workspace metadata together	Splitting records without a way to commit related changes

A strong summary follows revision 12 into two offline edits, explains which metadata transaction wins and where the other edit is saved, then shows how a second device catches up. Chunking and notifications are

efficiency improvements around that model. Automatic document merging and extremely large shared workspaces require further semantics; they are not solved merely by adding more transfer servers.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why separate file ID from path?

Model answer

A rename changes the directory entry, not which file and history the devices are tracking.

Interviewer follow-up

What must a rename check?

Destination naming rules, permissions and folder structure must be validated with the metadata change.

What the answer must demonstrate: Distinguishes stable identity from mutable directory placement.

02 / APPLIED

What happens when two devices edit revision 12?

Model answer

The first valid commit changes the head. The second expected-revision check fails and preserves its work as a conflict.

Interviewer follow-up

Why not compare timestamps?

Clock order does not show that an author intended to overwrite an unseen change.

What the answer must demonstrate: Uses an atomic expected-version check and preserves the losing edit.

03 / APPLIED

What does chunking save in the 9 MiB example?

Model answer

Changing only the middle 4 MiB allows the other 5 MiB to be reused.

Interviewer follow-up

When might it save little?

Tiny files or compressed formats that change broadly can require almost all bytes again.

What the answer must demonstrate: Calculates changed bytes without promising universal deduplication.

04 / APPLIED

Why is a notification not enough for synchronization?

Model answer

Notifications can disappear while a device is offline. A durable change log and cursor recover what was missed.

Interviewer follow-up

What if the cursor is too old?

Fetch a consistent snapshot tied to a log position and preserve local pending edits.

What the answer must demonstrate: Treats cursor recovery as durable state rather than transport behavior.

05 / APPLIED

When does an upload become the current file?

Model answer

The server verifies that chunks exist and cannot be deleted, checks current permission and the expected base revision, then commits the new revision in metadata.

Interviewer follow-up

What if the response is lost?

Retry the same operation identity and retrieve its committed result.

What the answer must demonstrate: Separates byte upload from publication and request replay.

06 / APPLIED

Why keep old-revision references during cleanup?

Model answer

Historical versions still need their chunks for restoration. Checking only which chunks the current revision uses would lose older versions.

Interviewer follow-up

Can an age threshold prove deletion safe?

No. The collector must also prevent active uploads from newly publishing the selected chunk.

What the answer must demonstrate: Counts retained history and active-upload protection.

07 / APPLIED

What can fail on the receiving device?

Model answer

A crash can occur between file replacement and local cursor persistence, so a recovery journal must connect them.

Interviewer follow-up

Why not advance the cursor first?

The device could restart believing it applied bytes that it never saved.

What the answer must demonstrate: Recognizes the local filesystem/metadata crash boundary.

08 / FOLLOW-UP

Can the service automatically merge spreadsheets?

Model answer

Only with format-specific semantics and a defined conflict policy; a generic byte synchronizer cannot infer user intent.

Interviewer follow-up

What is the safe baseline?

Keep both revisions through conflict copies and let the user resolve them.

What the answer must demonstrate: Avoids inventing merge semantics for arbitrary binary formats.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design shared file synchronization for multiple devices, offline edits and retained history. Use a 9 MiB file edited concurrently from revision 12 as the running example.

• Use 5 minutes to agree numbered functional and non-functional requirements for offline edits, conflict copies, sharing, 30-day history, discovery latency and durability.

• Trace whole-file save and catch-up in 8 minutes.

• Estimate bytes, metadata and reconnect load in 7 minutes.

• Define revisions, manifests, APIs and cursors in 10 minutes.

• Add chunking and explain conflict, cleanup and crash recovery in 10 minutes.

• Use 5 minutes to review the final design against the numbered FR/NFR lists, including expired cursors, protected chunks, one-node loss and the limit on download latency.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Both laptops edit revision 12; one commits revision 13. What happens when the other uploads its edit?

The atomic expected-revision check fails. Save the second edit as a conflict copy and record that outcome so retrying does not create another copy.

Compare before replacing.

A device misses a socket notification. How does it find the update later?

Read the committed change log after the device's saved cursor. The notification only prompts an earlier check.

Hints wake; history recovers.

When may cleanup delete a stored chunk?

When no retained revision references it and no still-valid upload can publish a revision that uses it.

No references, no publication right.

Summary and interview notes

Compare an edit's base revision with the current revision to save offline work as a new revision or conflict copy. Reuse chunks to reduce transfers; replay logged changes to recover missed updates.

Remember these points

- Stable IDs survive path changes.
- Expected revisions detect unseen edits.
- Committed changes support every device's recovery.
- Historical versions and pending uploads protect chunks.

Interview tips

- Show both devices' base revisions before discussing conflicts.
- Separate server commit from other-device completion.

Important qualifications

- Fine-grained concurrent folder operations and split-workspace authority need more detailed protocols.

Explore the advanced version

Chunk pin and collection proof: Needed to establish safe cleanup under overlapping uploads and retained history.

Committed-prefix cursor proof: Useful when concurrent log allocation differs from commit order.

Folder moves and namespace serialization: Needed for cycles, duplicate names and concurrent cross-folder operations.

Stable local capture and workspace migration: Useful when filesystem behavior or moving metadata ownership becomes the focus.

Technical references

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Official examples of file revisions, metadata, and cursor-based change traversal.
https://docs.dropboxapi.com/dropbox-api/docs/file-access

Amazon S3 multipart upload overview
Documents multipart upload completion, retries, checksums, and incomplete-upload management.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/mpuoverview.html

PostgreSQL constraints
Supports explicit database constraints rather than assumed application-only uniqueness.
https://www.postgresql.org/docs/current/ddl-constraints.html

CORE INTERVIEWS / 31

Design a chat messaging service

Interview version / 45-minute scope · Read the advanced version online

Design durable chat by separating accepted messages, live delivery, per-device history recovery and advisory presence.

message ordering • WebSocket • delivery receipts • presence

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace one message through acceptance, delivery and offline recovery.
- Explain stable send identities, conversation order and device cursors.
- Scale sockets and storage without weakening durable acknowledgment.

Useful foundations: Real-time communication: polling, long polling, SSE, and WebSocket; Message queues, event logs, delivery guarantees, and backpressure; Replication and durability

8 interview questions with model answers and answered follow-ups.

01 / Define what the sender's status actually promises

Nora sends "Train arrives at six" to Sam. Sam's phone is connected, but Sam's laptop is asleep. The service should save one message, deliver it promptly where possible and let the laptop recover the same history later. A network connection and a durable conversation record solve different parts of that problem.

Use three distinct statuses:

Status	Meaning
Accepted	The server committed the message under its storage durability policy.
Delivered	A particular device acknowledged receiving it.
Read	A client reported a read action; this is not proof of human attention.

An offline recipient does not make acceptance fail.

Support text, one-to-one conversations, bounded groups, multiple devices, history, receipts and advisory presence. Exclude attachments, editing and end-to-end key-management design from this exercise. Group membership must govern sending and reading, and the history available to new members needs an explicit policy. Here, members see messages from their join point while they remain eligible. Global order across unrelated conversations is unnecessary.

The sender may immediately see a pending local bubble. Only a committed server response can change it to accepted. Establishing these meanings early prevents a fast socket response from being mistaken for saved history.

Clarify whether success means saved, delivered to one device or delivered to every device, and agree on group size and online-delivery delay. The requirements below keep acceptance independent of whether the recipient is currently connected.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Send and retain messages.** Authenticated members send text in one-to-one conversations or groups, receive a stable accepted-message identity and read ordered history.
2. **Support multiple and offline devices.** Deliver to connected eligible devices and allow other devices to retrieve missed history after reconnecting.
3. **Report distinct progress.** Expose pending, accepted, device-delivered and client-reported read states, with advisory presence kept separate from those guarantees.
4. **Apply membership rules.** Check send/read eligibility, including after a socket has connected. New members see history from their join point while they remain eligible.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload and group bound.** Plan for approximately 1.16 million accepted messages/s at peak and 60 million simultaneous device connections. Choose a maximum of 100 members per group for this exercise; larger broadcasts require another fanout plan.
2. **Latency for reachable devices.** Target regional p95 send-to-accepted latency of 200 ms and accepted-to-device delivery of one second for connected eligible devices under the admitted peak workload and tested healthy-network profile. Offline devices have no live-delivery deadline.
3. **Acknowledged-message durability.** Accepted messages, their sequence and retry identity must survive a gateway restart or one database-node failure within the serving region. When that commit cannot be made safely, leave the send pending or return unavailable.
4. **Ordering and duplicate handling.** Provide one committed order per conversation and recover repeated sends/deliveries using stable identities. Global order across conversations and exactly-once network transmission are not required.
5. **History and device progress.** Use five years of retained message history for the stated storage estimate. Each device tracks its own contiguous delivered/read progress and receives an explicit reset boundary when its cursor predates retained history.

6. **Confidentiality and abuse control.** Authorize each send and history/live delivery, protect connections and bound message size, send rate and recipient work. End-to-end key management remains outside this exercise.

04 / Save one message before trying to deliver it

Begin with one application, a relational database and a local map of authenticated device connections. Nora sends message identity `send-71` for conversation c8. The application checks membership and commits message m901 with the next conversation sequence, 1042. It also records the delivery work in that transaction. Only after commit does it return accepted.

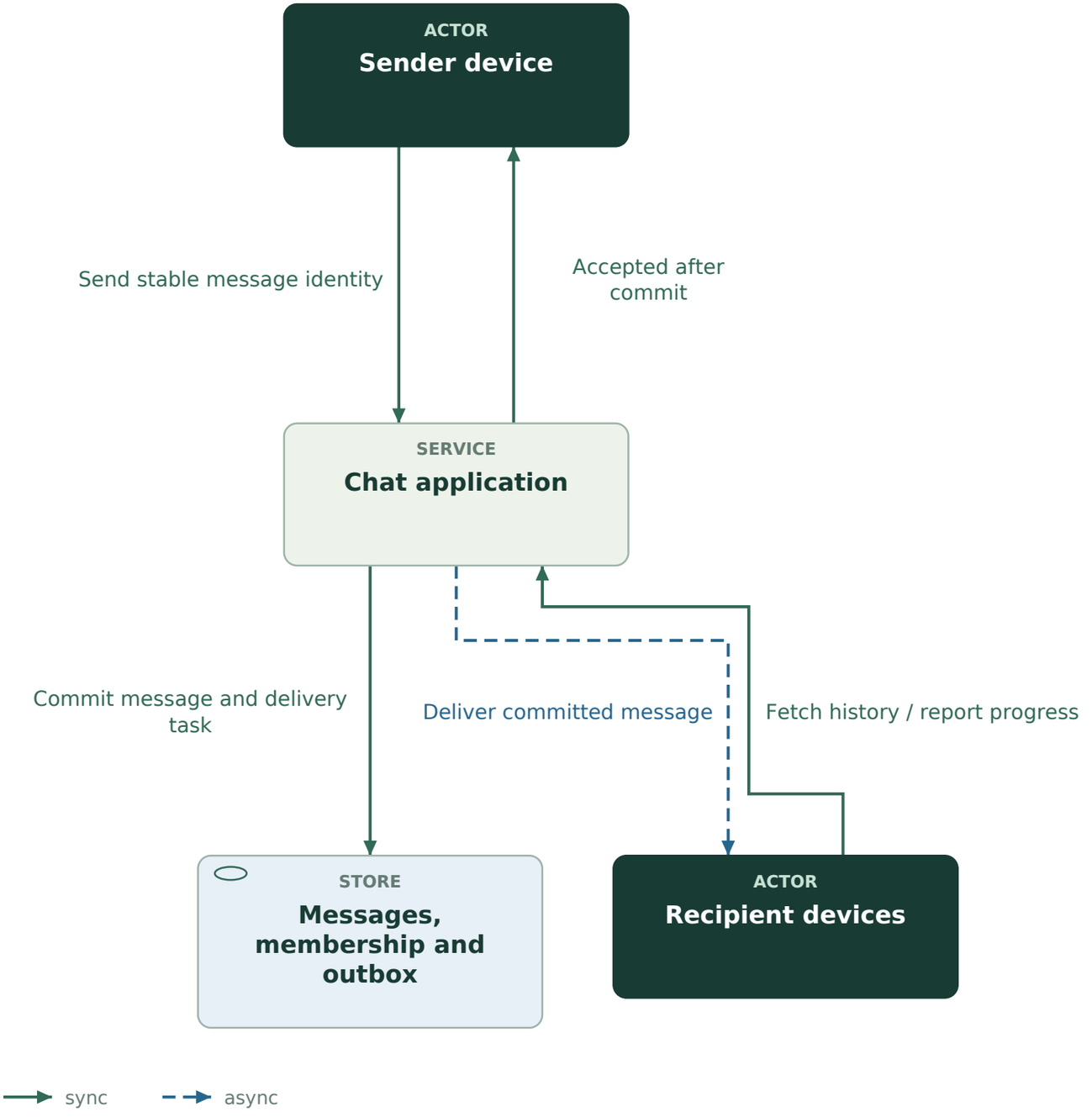
A dispatcher sends m901 to Sam's connected phone. The phone stores the message and reports delivery. The sleeping laptop receives nothing yet; when it reconnects, it requests messages after its last saved sequence and obtains m901 from history. A push notification can wake a mobile app, but the push provider is not the conversation database.

Use `(conversationId, senderId, clientMessageId)` as a unique request identity. Retrying send-71 with the same text returns m901 and sequence 1042. Changing the text under that identity is a conflict. Sending the same words intentionally twice under different IDs creates two messages.

WebSocket offers a persistent bidirectional channel; long polling is a workable simpler transport. Neither determines durability or deduplication. Those properties come from the database commit, message identity and client recovery behavior.

Save once, then deliver or catch up

The application commits before acknowledging. Offline devices later read the same history.



05 / Size stored messages and connected devices independently

Assume 500 million daily active users sending forty messages each: 20 billion messages/day, or about 231,481 messages/s. A fivefold peak is approximately 1.16 million/s. At 100 bytes of body text, that is 2 TB/day. A 300-byte stored envelope including identifiers and metadata is 6 TB/day, or 10.95 PB over five years before replicas and indexes.

Now estimate connections separately. If 10% of daily users are simultaneously online with 1.2 devices each, there are 60 million sockets. A benchmarked capacity of 20,000 connections per gateway implies 3,000 gateway-equivalents before spare capacity. That capacity figure is an assumption to test with realistic encryption, buffers and message traffic, not a universal server limit.

Additional work	Example	Implication
Heartbeats	60M / 30 seconds = 2M/s	Idle connections still create work
Group delivery	100 members x two devices	One stored message can require 200 live deliveries
Socket buffers	60M x 32 KB = 1.92 TB	Small per-connection allocations become large fleet totals

Storage scales with committed envelopes and retention. Gateways scale with sockets and fanout. Presence and receipts add their own traffic. One average messages-per-second number cannot size all three.

06 / Give sends, history and receipts different contracts

A send identifies its conversation, the client's message operation and the text. The authenticated connection identifies its user and device; the client cannot impersonate another sender by changing a JSON field. An HTTP send endpoint can use the same identity and semantics as the socket operation.

`send` **event payload**

```
{
  "conversationId": "c8",
  "clientMessageId": "send-71",
  "body": "Train arrives at six"
}
```

`accepted` **event payload, after durable commit**

```
{
  "messageId": "m901",
  "sequence": 1042
}
```

`delivered` **event payload from the device**

```
{
  "through": 1042
}
```

A separate `read` event uses the same `through` field for client-reported read progress. These progress events apply to the relevant conversation and authenticated device.

Event or endpoint	Meaning
`send`	Request durable acceptance
`accepted`	Saved message identity and order
`GET /conversations/c8/messages?after=1040`	Authorized ordered catch-up page
`delivered`	This device applied the contiguous permitted history
`read`	Separate client-reported read progress

A timeout does not establish whether a send committed. Keep the pending client operation and retry its original ID. Bound message size, send rate, group size and history-page length so one client cannot request unlimited work.

A conversation sequence orders committed history. Wall-clock timestamps remain useful for display but do not reliably order concurrent sends from different devices. If retained history no longer reaches an old cursor, return an explicit earliest-available position and reset behavior rather than making the device chase an unfillable gap forever.

07 / Keep shared history and device progress separate

The design keeps durable conversation records, per-device progress and temporary connection state distinct.

Record	Key or stored information	Purpose
Message	`(conversationId, sequence)`; message ID, sender, `clientMessageId`, body	Stores one message at its committed conversation position.
Conversation	Next sequence	Allocates the next position in that conversation.
Membership	Who may send or read	Determines current access.
Outbox	Message identity and delivery work	Retains dispatch work in the message transaction.
DeviceCursor	Device/conversation and delivered/read progress	Records each device's own applied history and read reports.
Session directory	User/device to current gateway connection	Locates live connections; entries expire when heartbeats stop.

In one transaction:

1. Check membership.
2. Claim the unique send identity.
3. Allocate the sequence and insert the message.
4. Save the outbox delivery task and commit before returning accepted.

This keeps one coherent conversation order.

An Outbox row is the durable delivery task committed alongside the message. If the process crashes before dispatch, another worker can still find it. A relay may send twice, so consumers deduplicate by message identity. A separate DeviceCursor tracks delivered/read progress for each device and conversation; the phone's receipt must not advance the laptop's cursor.

History lookup is a range query within one conversation, so partition by conversation rather than hashing every message ID independently. A user-to-conversation index supports the inbox list, but it is a derived summary rather than the authoritative message body.

A session directory maps user/device to its current gateway connection. Entries expire when heartbeats stop. Losing that directory can interrupt live delivery without deleting history. Likewise an online indicator estimates recent connectivity; it does not prove receipt or permission.

08 / Recover a missing message without duplicating the display

Sam's phone has applied c8 through sequence 1040, but receives a live event for 1042. It must not immediately claim delivery through 1042: message 1041 may be missing. Instead it asks the history service for the ordered page after 1040, authorizes the request, and applies the missing entries.

The phone saves the messages and updated contiguous cursor together in its local database. Only then does it acknowledge delivery. If a receipt disappears, the server may deliver m901 again. The phone recognizes its identity, keeps one displayed message and repeats the receipt. This is recoverable repeated delivery, not a claim that packets travel exactly once.

Stored progress only moves forward: a delayed receipt for 1041 cannot overwrite a newer one for 1042. Read progress remains separate from delivery progress. Receipt aggregation also needs a product definition: "delivered to one device" differs from "delivered everywhere."

Membership is checked for live delivery and history, not only when a socket first connects. Removing a member must not leave an old connection as indefinite permission to receive new content. Already released bytes may still arrive; stronger in-flight revocation needs a separately defined protocol.



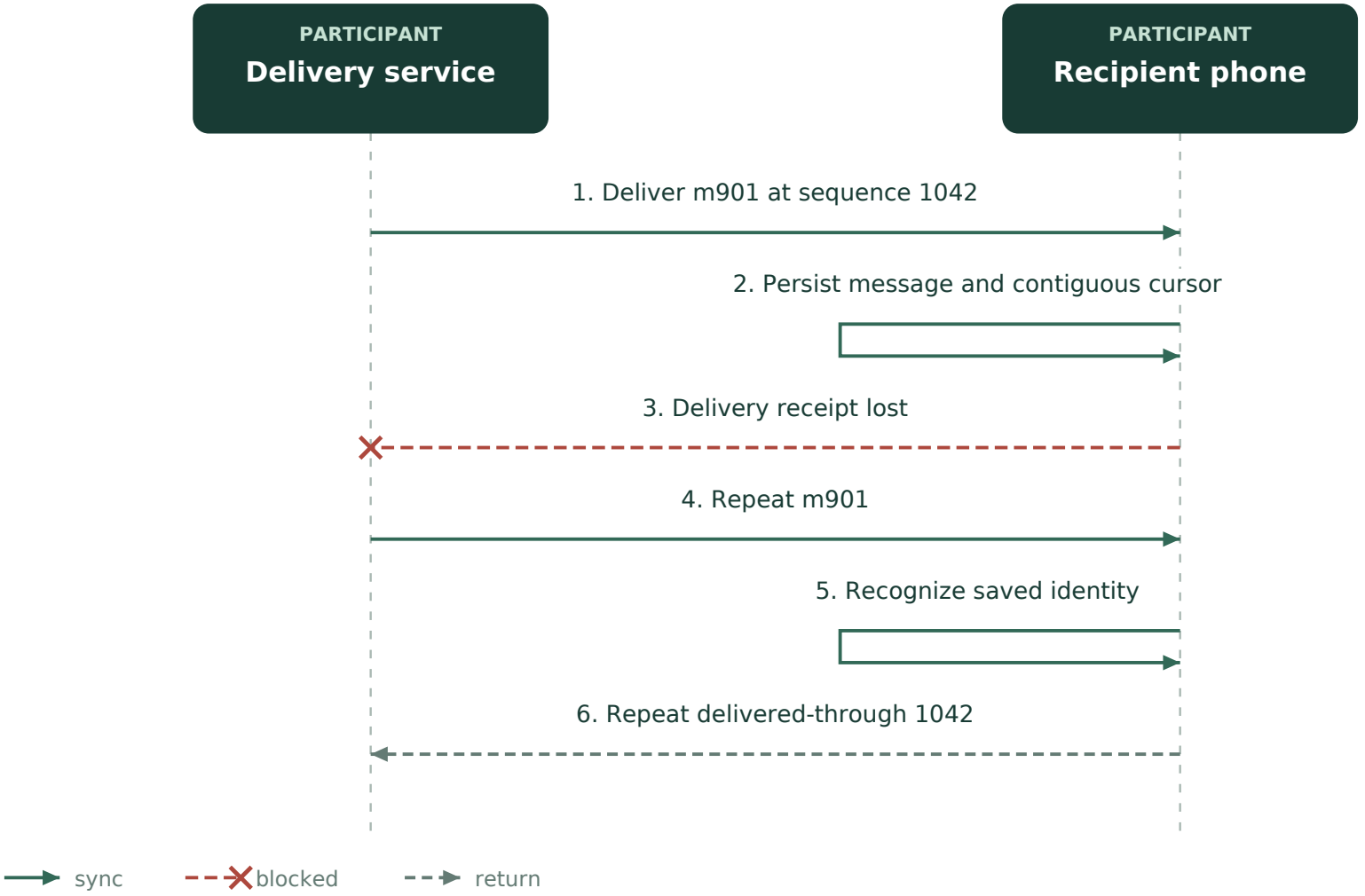
INTERVIEW CRITICAL

Store before acknowledging, recover by identity

An accepted message must already be durable. Network delivery may repeat or disappear, so clients deduplicate stable message IDs and recover gaps from ordered history rather than trusting socket success.

A lost receipt leads to safe repeated delivery

The device stores one identity, so an uncertain delivery acknowledgment does not create a second bubble.



09 / Separate socket capacity from conversation writes

Move long-lived connections to gateway processes once a single application cannot handle them. Gateways authenticate connections and forward sends to the storage group responsible for that conversation. They do not keep a database connection open for every idle socket; storage uses a bounded request pool.

For the worked scaled design, distribute independent conversations across replicated database groups. Keep message identity, sequence, membership and outbox updates together for each conversation. This provides parallelism across conversations without inventing a global ordering service. One extremely busy group still has an ordering bottleneck and needs a measured product-specific extension.

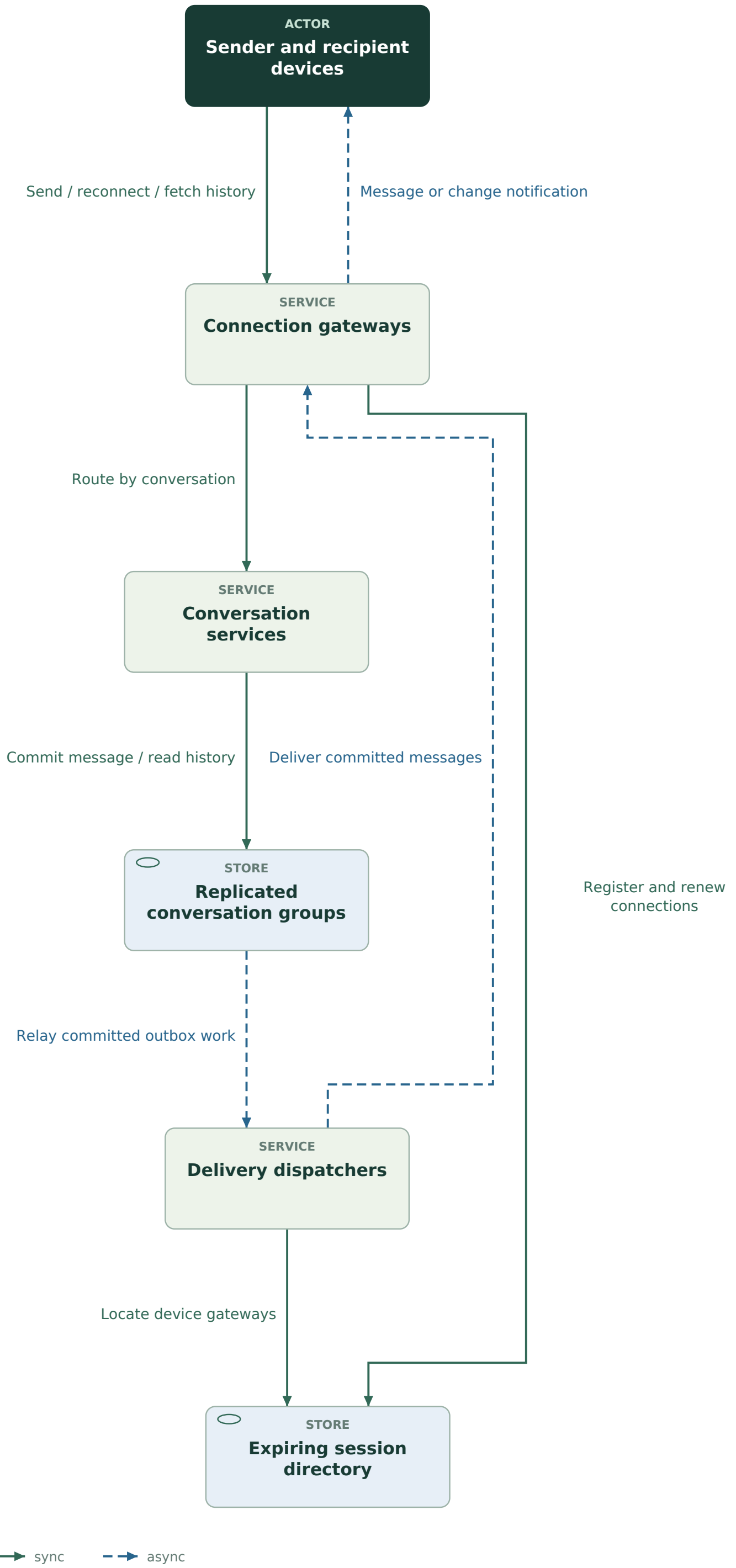
Dispatchers read committed outbox tasks, locate recipient devices through the session directory and deliver via their gateways. They can batch group recipients by gateway to reduce repeated inter-server transfer. Limit fanout tasks and queue age; a huge group must not starve ordinary conversations.

Cache recent immutable message pages only where reuse exists, and move older history to a cheaper storage tier under an explicit latency contract. Subscribe to presence for relevant contacts rather than broadcasting every heartbeat to every user. These changes reduce work while retaining the same meaning of accepted, delivered and read.

For the accepted-message guarantee, each conversation group uses three database replicas in independent regional failure domains and acknowledges only after a durable majority commit. Failover must preserve the message, sequence, retry result and outbox together. A minority cannot acknowledge new messages; test this policy against the 200 ms acceptance target rather than assuming replication is free.

Connection gateways and conversation storage scale independently

A gateway routes each send to its conversation service, which commits message identity, sequence, membership checks and outbox work together. Dispatchers find live devices and deliver through gateways. Offline or reconnected devices use the same service to retrieve saved history; the session directory never replaces that history.



10 / Test the crash on each side of acknowledgment

If the application crashes before the message transaction commits, Nora has no accepted result and retries send-71. If it crashes after commit but before replying, the retry finds the saved message and returns the same sequence. A concurrent retry cannot create another message because the unique send identity is part of that transaction.

A gateway crash breaks sockets, not conversation history. Clients reconnect with randomized backoff, reauthenticate, resend unresolved operations under their original identities and fetch history after their saved cursors. Do not try to infer delivery from a stale session-directory entry.

If the storage group cannot safely commit, leave the client message pending or return a retryable error. A gateway must not acknowledge from its own memory merely to keep latency low. Replication and failover need to preserve acknowledged commits; backups cover different risks such as accidental deletion.

Accepted messages create delivery work that must remain recoverable. Limit new sends before that work exceeds what the durable queue can retain. Reduce nonessential presence updates first, and reserve capacity for history catch-up. A push-provider outage should delay wake-ups, not make previously accepted messages disappear.



INTERVIEW CRITICAL

Presence is advisory; history is durable

An offline dot does not make a send fail, and an online dot does not prove delivery. Store accepted messages independently of socket state, then use per-device history recovery when routing or notifications fail.

11 / Measure the boundaries users can observe

Measure send-to-accepted latency, accepted-to-device delivery delay and client-reported read progress separately. A fast database can coexist with a broken dispatcher. Monitor oldest outbox work, duplicate retries, reconnect rate, gap-fetch frequency and especially large-group queue age.

Authorize every send and history read, cap message and group sizes, and apply spam controls by account and conversation. Avoid sensitive text in logs and lock-screen push previews. Transport encryption protects connections; end-to-end encryption also changes who holds keys, whether servers can search bodies and how a new device obtains history. Treat that as a real extension.

The main costs are retained message copies, gateways and delivery to every recipient device. Three copies of the illustrative 10.95 PB five-year envelope store require 32.85 PB before indexes and backups. Caching each user's entire history would duplicate that expense in memory; retain bounded recent pages instead.

Test lost sender responses, lost recipient receipts, sequence gaps, membership removal with an old socket and a reconnect wave after gateway failure. These cases demonstrate durable user behavior more directly than showing a successful WebSocket handshake.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1,3 + NFR2-4: accepted send	Conversation-local membership, identity, sequence, message and outbox transaction.	Lose the commit reply and retry; return one message. Benchmark p95 acceptance separately from device delivery.
FR2 + NFR5: offline devices	Durable history, per-device cursors and a local recovery journal.	Reconnect a sleeping laptop and inject a sequence gap. Do not advance its cursor past an unapplied message.
NFR3: one-node loss	Durable replicated conversation commits; gateways hold only connection state.	Kill a database node after acceptance and a gateway before delivery. Acknowledged history must survive both tests.
FR4 + NFR6: current membership	Authorization on sends, history and live delivery.	Remove a member with an old socket. Already released bytes cannot be recalled, but later admission checks must deny access.
NFR1-2: bounded group fanout	Separate gateway/storage capacity and bounded dispatch for groups of up to 100 members.	Load-test multi-device fanout and reconnect waves. Connection-count arithmetic alone does not prove the delivery target.

13 / Rapid revision

Remember: Save before acknowledging; use history to recover delivery when a socket or receipt disappears.

Decision	What it provides	What it does not provide
Commit before reporting accepted	Recoverable saved message	Immediate delivery to an offline device
Stable client message ID	Safe retry of one logical send	Deduplication of intentionally repeated text
Conversation sequence	One saved message order per conversation	Global order across unrelated chats
Outbox dispatch	Saved delivery work survives crashes	Exactly-once network transmission
Device cursor advances without gaps	Gap detection and reconnect recovery	Proof that a human read the message

Decision	What it provides	What it does not provide
Gateway directory	A route to currently connected devices	Durable history or current membership by itself
Conversation partition	Order each chat; process separate chats in parallel	Unlimited throughput for one group

A complete interview answer follows send-71 from the sender's pending state through commit, delivery to one phone and later laptop catch-up. Then use the workload to separate gateway and storage scaling. End with the lost-response and lost-receipt cases: one tests the server's acceptance boundary, the other tests the device's durable progress. Broadcasting to a million-member channel and designing encryption keys are additional problems to negotiate.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What does accepted mean?

Model answer

The message has been committed under the storage durability policy, independently of recipient connectivity.

Interviewer follow-up

Is it the same as delivered?

No. Delivery is a particular device's acknowledgment; reading is another client-reported event.

What the answer must demonstrate: Keeps durability, device receipt and reading as separate outcomes.

02 / FOUNDATION

Does WebSocket make chat reliable?

Model answer

It provides a bidirectional transport, not durable message storage or retry semantics.

Interviewer follow-up

How does an offline device recover?

It reads authorized committed history after its saved cursor.

What the answer must demonstrate: Attributes reliability to storage and recovery rather than a transport name.

03 / APPLIED

Why deduplicate by identity rather than text?

Model answer

Identical text can be sent intentionally twice. The stable send identity distinguishes a retry from a new message.

Interviewer follow-up

What if its payload changes?

Reject conflicting reuse instead of changing the existing immutable message.

What the answer must demonstrate: Separates intentional repeated content from repeated transmission.

04 / APPLIED

Why use a conversation sequence?

Model answer

Devices can disagree about network arrival and client clocks. One committed sequence provides their shared history order.

Interviewer follow-up

Why no global sequence?

Unrelated conversations need no shared order, so a global allocator would add unnecessary coordination.

What the answer must demonstrate: Uses local ordering without unnecessary global coordination.

05 / APPLIED

What if sequence 1042 arrives after cursor 1040?

Model answer

Fetch the missing authorized history before advancing a contiguous delivered cursor.

Interviewer follow-up

When is the cursor saved?

With applied message data, or an equally durable recovery plan, before acknowledging progress.

What the answer must demonstrate: Detects gaps and persists device progress safely.

06 / APPLIED

What survives a gateway crash?

Model answer

Committed messages and device recovery identities survive in storage; clients reconnect and catch up.

Interviewer follow-up

What does the session directory prove?

Only a current routing hint, not message delivery or durable history.

What the answer must demonstrate: Distinguishes replaceable connections from authoritative message state.

07 / APPLIED

Why can groups cost more than their stored messages?

Model answer

One message may be delivered to many members and devices, creating fanout work beyond one database insert.

Interviewer follow-up

How can it be bounded?

Limit group size, batch by gateway and reserve catch-up capacity; huge broadcasts need a different strategy.

What the answer must demonstrate: Counts recipient amplification and bounds work.

08 / FOLLOW-UP

What changes with end-to-end encryption?

Model answer

Clients manage message-encryption keys, and servers store ciphertext rather than freely processing content.

Interviewer follow-up

What needs further design?

Multi-device key distribution, recovery, membership changes and search behavior.

What the answer must demonstrate: Recognizes that encryption changes product and recovery semantics.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design durable text chat with multiple devices, bounded groups and offline history. Trace one accepted message while a recipient phone is online and laptop is asleep.

• Use 5 minutes to agree numbered functional and non-functional requirements: statuses, membership, 100-member groups, online latency, history and acknowledged-message durability.

• Trace baseline send and reconnect in 8 minutes.

• Estimate messages, sockets and group fanout in 7 minutes.

• Specify identities, sequence and API records in 10 minutes.

• Scale gateways/storage and test lost responses and receipts in 10 minutes.

• Use 5 minutes to check the final design against the numbered FR/NFR lists, test accepted-message survival and online/offline delivery separately, and state encryption or broadcast exclusions.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

The server saves Nora's message while Sam's phone is online and laptop asleep. Which statuses can each device claim?

The server can report accepted after commit. The phone reports delivered after saving the message and cursor; the laptop catches up later. Read is a separate client report, not proof of attention.

Save, deliver, report read.

A send times out. What must the client keep when retrying?

Reuse the same client message ID and original payload so the server can return the first send's result.

One intent, one identity.

How does a device recover messages received while it was offline?

Fetch ordered conversation history after its saved cursor, then advance the cursor only through messages it has durably saved without gaps.

Sockets notify; history recovers.

Summary and interview notes

Save messages before acknowledging them. Sockets and push help online devices receive them quickly; saved device cursors and ordered history recover missed delivery without skipping messages.

Remember these points

• Acknowledge only after commit.

• Keep retry identities independent of body equality.

• Order within each conversation.

• Track each device's contiguous progress separately.

Interview tips

• Describe the asleep device as well as the connected phone.

• Measure acceptance and delivery lag independently.

Important qualifications

• Complex leave/rejoin histories and strict in-flight revocation require deeper membership protocols.

Explore the advanced version

Membership intervals and rejoining: Needed when access to several disjoint historical intervals must be represented.

Late live delivery after removal: Useful when specifying the exact authorization boundary for in-flight messages.

Conversation-owner failover fencing: Needed to prove one ordered history through leadership changes.

Archive storage and very large groups: Useful when retained history or broadcast fanout changes the baseline economics.

Technical references

RFC 6455: The WebSocket Protocol
Defines the two-way TCP-based browser/server transport; it does not define chat durability.
https://www.rfc-editor.org/info/rfc6455/

Amazon SQS at-least-once delivery
Documents why consumers must tolerate repeated delivery.
https://docs.aws.amazon.com/AWSSimpleQueueService/latest/SQSDeveloperGuide/standard-queues-at-least-once-delivery.html

Transactional outbox pattern
Explains atomic persistence of business state and an event to be delivered.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

CORE INTERVIEWS / 32

Design a microblogging service

Interview version / 45-minute scope · Read the advanced version online

Build a chronological posting service, then use measured reader activity and follower skew to choose where feed assembly happens.

timeline • fanout • pagination • celebrity traffic

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Separate accepted posts from the feed views derived from them.
- Explain why ordinary authors and very popular authors need different feed strategies.
- Handle publication retries, partial fanout and changing visibility without duplicating or exposing posts.

Useful foundations: Data partitioning and sharding; Caching: cache hits, misses, write policies and invalidation; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / Define publication and the home feed

Design a service where users publish short posts, follow authors, like posts and browse a chronological home feed. Replies reference a parent post; reshares reference an existing post while recording who shared it. Maya publishes "The bridge is open" as post p701. Leo follows Maya and should see p701 when he refreshes his feed.

For this exercise, limit text to 500 characters with an explicit Unicode counting rule. A successful publish means the post is durably stored and can be read from Maya's profile. Leo's feed may take a few seconds to include it. These are different completion conditions: storing a post does not mean every follower's page has been updated.

Include deletion, private accounts and a bounded history of recent feed entries. Media uploads finish before a post references them. Begin with chronological ordering, not recommendations. Search, trends and notifications are separate consumers of published events; explain their boundaries if asked, but do not build them into the critical publication path. Global real-time ordering across all authors is also outside this interview's contract.

Ask whether the home feed must be chronological or ranked, whether a post must appear to every follower before publish succeeds, and how private accounts behave. These choices determine the consistency and fanout work we actually need.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Publish and manage posts.** Authenticated authors create and delete short posts, with verified media references and a 500-character limit under a declared Unicode counting rule.
2. **Follow and browse.** Users follow/unfollow authors, view author profiles and page through a chronological home feed of eligible followed posts.
3. **React, reply and reshare.** Support likes, replies linked to a parent and reshares linked to the original post. Deletion or privacy changes of the source still govern disclosure.
4. **Recover repeated actions.** Retries of one creation return its existing post; repeated like/unlike operations preserve the intended user/post relationship.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload.** Use 100 million posts/day and approximately 81,019 page requests/s at the fivefold peak. Include the fifty-million-follower celebrity case and media bytes rather than sizing from the average post rate alone.
2. **Response time.** Target regional p95 post-acceptance and feed-page latency of 300 ms under the admitted peak workload in normal operation. Media downloads are measured separately from the metadata page.
3. **Feed freshness.** Target p95 propagation from source commit to the prepared candidate list or author history used by an eligible active follower's refresh within five seconds during normal processing. Publication does not wait for every follower; bounded retrieval may omit a post, and older pages may require refresh to consider late candidates.
4. **Source durability.** Accepted posts, retry results, relationships and publication work must survive a process restart or one database-node failure within the region. Prepared inboxes are rebuildable views, not the only source of a post.
5. **Current access.** Check current post visibility and relevant private-account relationships before returning content. Cached candidates and a ranking fallback cannot authorize a now-private or deleted post.
6. **Bounded serving work.** Cap candidates, follower batches and retained inbox windows. Choose incomplete but authorized pages or explicit overload responses over unbounded work; exact global ordering and exact engagement totals are outside the contract.

04 / Follow one post from creation to a reader

Start with one application and a replicated SQL database. Maya sends a create request with request key post-71. In one transaction the application inserts p701 and saves the request key's result. It replies after commit. If the reply is lost, retrying post-71 returns p701 instead of creating a second post.

A profile request uses an index ordered by author and creation time. Leo's home-feed request first reads the authors he follows, retrieves their recent posts and merges those ordered results. It returns the newest twenty

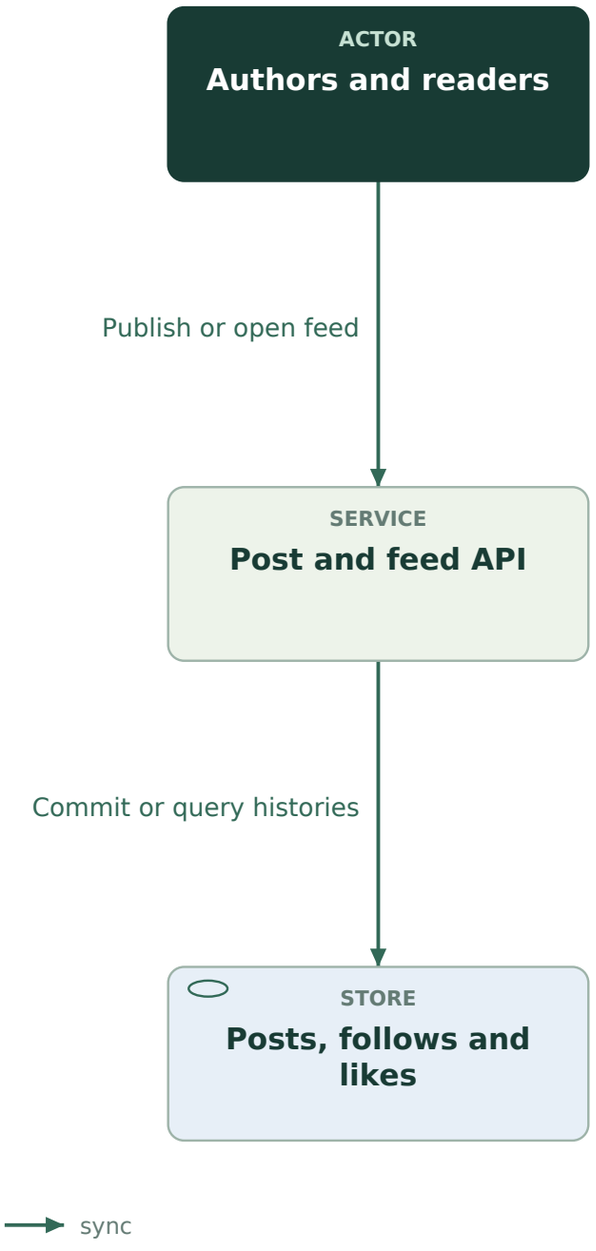
eligible posts. This is fanout on read: one viewer request gathers candidates from several authors. Nothing needs to be copied into Leo's account when Maya publishes.

Like actions use a unique pair of user ID and post ID. Repeating "like p701" leaves one relationship rather than incrementing an unprotected counter twice. A reshare stores p701's identity instead of copying its body, so deleting the original can hide it everywhere that checks that reference.

This baseline is complete for modest traffic. Its weakness appears when many readers repeatedly merge the same author histories. We can measure that work before introducing background workers or precomputed feeds.

A complete feed before background fanout

The application reads followed authors and their indexed posts, then returns an eligible chronological page.



05 / Estimate pages, candidates and media separately

Assume one billion registered users, 200 million daily users and 100 million posts per day. Each daily user opens two home-feed pages and five profile pages, with twenty posts per page. Use decimal bytes and a fivefold peak multiplier.

Quantity	Calculation	Design implication
Post writes	100 million / 86,400 ~ 1,157/s	Publication is much smaller than reading work.
All page reads	200 million x 7 / 86,400 ~ 16,204/s	Peak is about 81,019 page requests/s.
Displayed items	16,204 x 20 ~ 324,074/s	Loading and checking records multiplies page traffic.
Text retention	100 million x 310 B = 31 GB/day	About 56.6 TB over five years, before copies and indexes.
Media ingress	20 million x 200 KB + 10 million x 2 MB	24 TB/day: media dominates stored bytes.

If Leo follows 200 authors and we fetch twenty candidates from each, one home page examines up to 4,000 candidates to return twenty. Across approximately 4,630 home-feed requests/s, that is roughly 18.5 million candidates/s. Profile reads have different costs and should not be included in that multiplication.

The opposite extreme is also expensive: copying a celebrity's post to fifty million followers takes 1,000 seconds at 50,000 inserts/s. Average follower count hides this problem. Measure audience activity and the distribution of follower counts before choosing a fanout policy.

06 / Make retries and pagination explicit

The API exposes user intent while deriving the acting user from authentication. The request key belongs to one author and one payload; reusing it with changed text is an error.

Create-post request

```
POST /v1/posts
```

Request information	Running example or meaning
Author-scoped request key	`post-71`
Text	`The bridge is open`
Verified media IDs	References to uploads that have already completed, when media is attached.

After commit, the running example returns post ID `p701`.

Request	Meaning
`POST /v1/posts`	Create one post; return its stable ID after commit.
`GET /v1/users/u17/posts?before=cursor`	Read a bounded author history.
`GET /v1/feed?cursor=token&limit=20`	Read eligible home-feed candidates in deterministic order.
`PUT or DELETE /v1/following/u17`	Set or remove the follow relationship.
`PUT or DELETE /v1/posts/p701/like`	Set or remove one user's like.
`DELETE /v1/posts/p701`	Mark the owner's post deleted.

Use a cursor containing the last returned creation-time/post-ID pair and an initial upper cutoff. Numeric offsets shift when newer posts arrive. Keyset pagination avoids that shift, but it is not a frozen snapshot: a late fanout entry can still be missed until refresh. State that limitation. Current visibility checks run on every page even when its candidate list was prepared earlier.

07 / Keep source records separate from prepared feeds

A post is the source of its text, visibility and media references. An inbox entry is only a possible item for a viewer's feed. Keeping that distinction allows the system to rebuild feeds without recovering post bodies from many inconsistent copies.

Record	Important key or access path
Post	Primary post ID; author/time index for profiles and recent-author reads.
CreateRequest	Unique author/request-key pair with payload identity and resulting post ID.
Follow	Unique follower/author pair; indexes in both directions.
Like	Unique user/post pair; displayed count is a derived aggregate.
Inbox	Unique viewer/post pair, ordered by creation time and post ID.
Outbox	Durable publication or deletion event saved with the post transaction.

An outbox is a database table of work that remains to be sent to other services. Saving its event in the post transaction closes the gap where p701 commits but the application crashes before notifying feed workers. A relay can send that event later and may send it more than once.

Choose author-owned database partitions for the scaled design. Post, request result, outbox and author/time index commit together within the owning partition. A post ID carries routing information or is resolved through

a routing directory. Globally unique identifiers alone do not provide an efficient query for all posts by one author.

08 / Precompute the feeds that readers actually reuse

Add fanout on write for ordinary authors with active followers. A worker reads Maya's followers in bounded pages and inserts p701's ID into their inboxes. Leo's next feed request becomes a short inbox range query followed by loading the matching posts. This exchanges background writes and storage for less repeated work during reads.

Do not apply that policy to every author. Very popular authors remain on the pull path: save their recent posts once and merge them into followers' feeds at read time. The worked design is therefore hybrid. An ordinary post generates inbox references; a celebrity post does not initiate a massive follower scan. Determine the threshold from measured recipient-write costs and useful reader requests, not a famous fixed number.

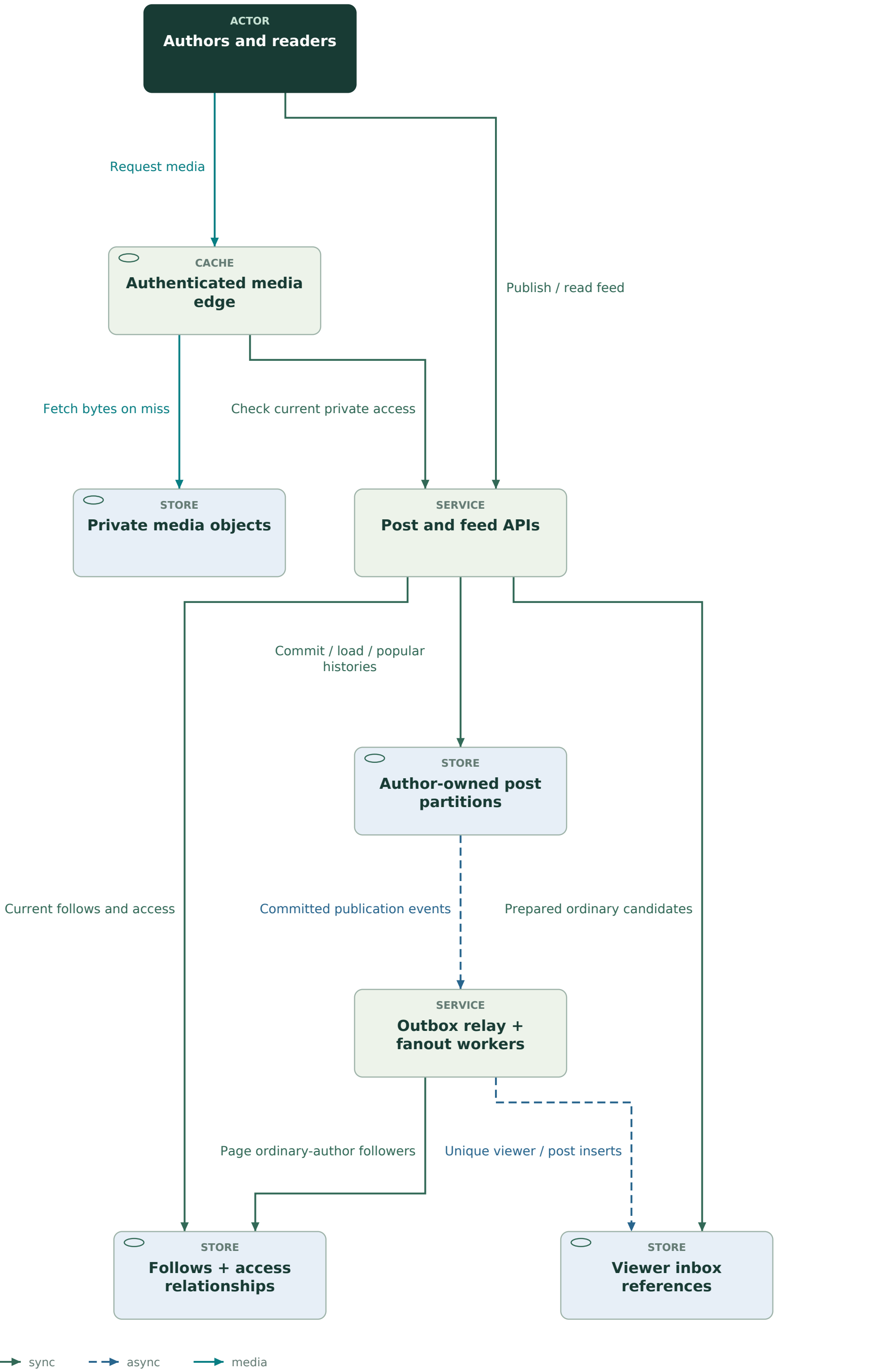
The read service merges Leo's inbox with recent lists of the popular authors he follows, removes duplicate IDs, loads post records in batches and checks current visibility. Bound candidates and source lists so an unusual follow graph cannot consume unbounded work. An incomplete but authorized page is preferable to a timeout caused by searching forever for twenty items.

Keep only a useful recent window in inboxes and rebuild a bounded window for returning inactive users. Store media in object storage and deliver it through an authenticated media edge backed by a content delivery network. The edge checks current access before serving cached private bytes. Already downloaded content cannot be recalled, and an in-flight transfer is not an instantaneous revocation guarantee.

Choose durable majority commits across three replicas in independent regional failure domains for each authoritative database group. This implements the one-node-loss target for source posts, relationships and saved publication work; candidate caches remain rebuildable. Benchmark both page latency and active-follower freshness before increasing admitted load.

Hybrid feeds prepare ordinary posts and pull popular histories

Publishing commits the post and outbox event in an author-owned partition. Workers prepare ordinary-author inbox entries; reads merge them with popular-author histories and check current visibility. Media follows a separate authenticated delivery path so feed references alone cannot grant access to private bytes.



09 / Recover partial fanout without skipping followers

Suppose the worker inserts p701 for viewer A, then crashes before viewer B. Retrying the entire page is safe because the inbox key is unique per viewer/post. A's duplicate insertion changes nothing; B receives the missing entry. The worker records the next page checkpoint only after every insertion in the current page succeeds.

The checkpoint is durable progress, not a note that a worker fetched a job into memory. A repeated queue event resumes or repeats work using the same post identity. Use a conditional checkpoint update so two workers cannot overwrite newer progress with an older position. Workers may repeat the operation, but those repeats leave the same inbox entries. The queue need not deliver exactly once.

Follower relationships can change during the scan. Handle new follows with bounded backfill and check current follow/private-account rules while serving. The scan does not pretend to capture a globally frozen social graph. Likewise, changing an author between push and pull policies may temporarily produce the same candidate through both paths; ID deduplication makes that transition harmless.

If the fanout queue is behind, p701 remains visible on Maya's profile while follower feeds lag. Add workers only while inbox storage has spare capacity. Unlimited consumers can turn a freshness problem into a database outage.



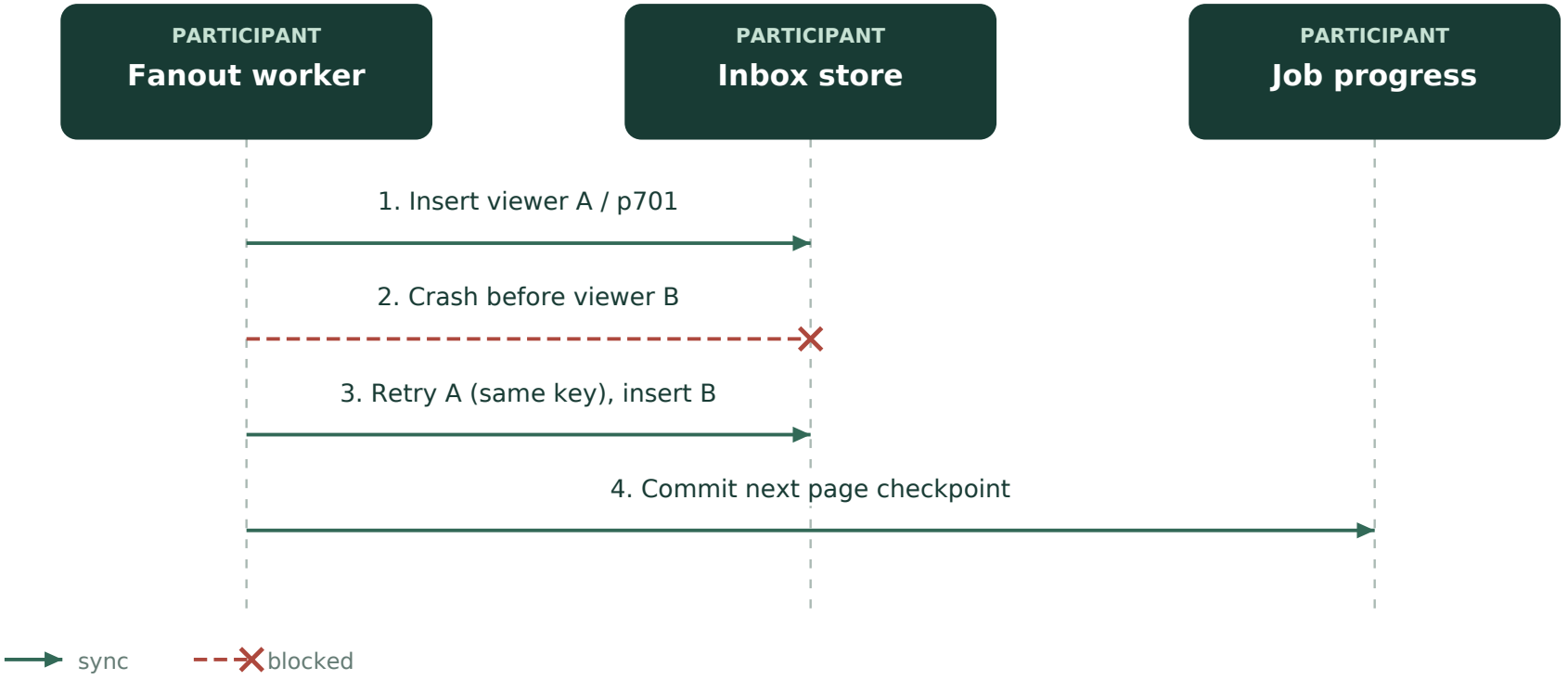
INTERVIEW CRITICAL

Checkpoint after the work it certifies

Advance a follower-page checkpoint only after all inbox writes in that page complete. Unique viewer/post keys make a repeated page safe.

A fanout page can safely repeat

The checkpoint moves only after both viewers have their unique candidate entry.



10 / Deletion changes eligibility, not just storage

Deleting p701 marks its source record deleted and records a cleanup event. Inbox, search and cache references may remain temporarily. They cannot be treated as permission to reveal the body. Before returning a candidate, load its current visibility and the membership needed for private access; if that check cannot be completed, omit or fail that item rather than guessing.

The same rule applies to reshares. A reshare can retain an actor and timestamp for internal history, but it cannot resurrect text from an inaccessible original. Removing stale references later reduces wasted work; it is not the mechanism that protects private content.

Like counts may briefly lag because they are computed from relationship changes. That is acceptable for a display count, while the unique user/post relationship answers whether Leo has liked p701. Do not reuse this approximate-count reasoning for authorization. Freshness, popularity and permission have different consequences when stale.



INTERVIEW CRITICAL

Prepared candidates do not grant access

Feed inboxes and caches select possible posts. Current post visibility and private-account membership determine whether the response may disclose them.

11 / Measure freshness and protect the source of truth

Track post acceptance latency, home-feed latency, candidates examined per page and oldest unprocessed fanout event. Measure the delay until an active follower can see a newly eligible post. A fast page showing yesterday's content passes a latency check but fails a freshness goal.

Rate-limit publication, follows, likes and media upload separately. One small post can trigger millions of follower writes, so abuse limits must account for that work as well as request count. Validate media ownership and readiness before referencing it. Protect hot post records with batched reads and caches, but preserve the current-access check for disclosure.

During ranking or optional analytics outages, serve a chronological eligible feed. During permission-store failure, do not use that fallback to expose uncertain private posts. Database replicas, backups and restore exercises protect source posts and relationships; inboxes can be reconstructed from those sources.

Cost comes from media storage and delivery, fanout writes, repeated candidate merges and retained indexes. Compare those quantities for active audiences. A lower database query count is not automatically a cheaper system if it requires millions of never-read inbox entries.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1,4 + NFR4: durable publication	Author-local post, request result and outbox transaction; unique like relationships.	Lose publish replies and replay likes. Confirm one post/action and retained publication work after one node fails.
FR2 + NFR1-3: fast fresh feed	Ordinary-author fanout plus popular-author pull and a bounded merge.	Benchmark p95 response and five-second candidate propagation with celebrity skew and partial fanout failure. Bounded pages need not display every available post.
FR3 + NFR5: references obey source access	Reshare references and current post/relationship checks.	Delete or restrict the original while old inbox and reshare references remain.
NFR6: bounded continuation	Keyset cursor, candidate limits and bounded rebuild for returning readers.	Insert a late older candidate between pages; disclose that refresh may be needed, rather than claiming a frozen snapshot.

13 / Rapid revision

Remember: A post commits once; follower copies can arrive later. Save fanout progress only after the inbox writes finish.

Interview question	Chosen answer	Consequence to remember
What does publish success mean?	Post, retry result and delivery work committed together.	Follower feeds can still lag.
Why start with pull?	A working feed needs no background copies.	Repeated many-author merges become expensive.
Why use hybrid fanout?	Prepare active followers' entries; fetch celebrity histories on demand.	Merge both sources and remove duplicates.
How do workers recover?	Unique viewer/post keys; save progress after writes.	Replaying a partial page is safe.
What controls deletion/privacy?	Current source visibility and membership checks.	Old feed entries do not grant permission.
How do pages continue?	Continue after the last creation time and ID.	Late candidates may wait until refresh.
What is the principal cost?	Media bytes plus push-versus-pull work.	Measure audience-size differences, not only the average.

For a final explanation, walk p701 through commit, recoverable fanout, candidate merge and current visibility checking. Then name the tradeoff: the service accepts a few seconds of feed propagation delay to avoid a

transaction across every follower. A stricter repeatable feed session or global publication order requires an additional contract and mechanism; neither is supplied merely by choosing a distributed database.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How can the first version build a home feed?

Model answer

Read followed authors, query recent author-indexed posts, merge by time and ID, then filter visibility. This is complete without an inbox service.

Interviewer follow-up

What makes that expensive?

Many active readers repeat the same multi-author retrieval and comparison work.

What the answer must demonstrate: Explains the complete pull path and its repeated work.

02 / APPLIED

Why not push every post to every follower?

Model answer

A celebrity can require millions of recipient writes for one post, including inactive viewers. Keep those author histories on a read-time merge path.

Interviewer follow-up

How would you choose the threshold?

Compare measured active audience reads, inbox-write cost, merge cost and freshness delay.

What the answer must demonstrate: Connects follower skew to hybrid fanout, not a universal threshold.

03 / APPLIED

Why save an outbox event with a post?

Model answer

A crash between database commit and queue publication would otherwise lose the fanout trigger. The saved event can be relayed again.

Interviewer follow-up

Can the relay send duplicates?

Yes. Consumers use stable event and viewer/post identities rather than relying on one delivery.

What the answer must demonstrate: Identifies the commit-to-queue gap and repeatable consumers.

04 / APPLIED

A worker crashes halfway through a follower page. What happens?

Model answer

Repeat the page; unique viewer/post keys suppress duplicate effects. Advance progress only after all writes complete.

Interviewer follow-up

Why not checkpoint when the page is fetched?

That would skip followers whose writes never occurred.

What the answer must demonstrate: Places checkpoint after effects and uses unique inbox keys.

05 / APPLIED

Why does deleting every inbox entry not suffice for privacy?

Model answer

Cleanup may be delayed or incomplete. The read service must consult current post visibility and private membership before disclosing content.

Interviewer follow-up

Can an optional ranker outage bypass that check?

No. Recency is an ordering fallback, not permission to serve inaccessible content.

What the answer must demonstrate: Separates candidate freshness from authorization.

06 / FOLLOW-UP

Does a keyset cursor create a frozen feed?

Model answer

No. It stabilizes the continuation position, but late fanout can add older candidates. The simple contract allows those items to appear on refresh.

Interviewer follow-up

What if repeated pages must use one fixed set?

Materialize a bounded candidate session and still recheck current visibility.

What the answer must demonstrate: States the keyset limitation before adding a session snapshot.

07 / APPLIED

Why store likes as relationships?

Model answer

A unique user/post pair makes repeated like and unlike requests well-defined. Blind counter increments duplicate actions after retries.

Interviewer follow-up

Must the displayed count update synchronously?

Not for this scope; the displayed count may catch up as relationship changes are processed, while the saved user/post row tells us whether that user has liked the post.

What the answer must demonstrate: Distinguishes authoritative relationship from derived count.

08 / APPLIED

Why distinguish page requests from item impressions?

Model answer

A page contains many records, media references and visibility checks. Multiplying by items per page exposes the actual serving work.

Interviewer follow-up

What further measurement changes the fanout choice?

Follower skew and active-reader reuse, because average follower count conceals celebrity amplification.

What the answer must demonstrate: Keeps page, item and fanout units separate.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a chronological microblogging service. Trace one ordinary post and one celebrity post, including a lost publish response and a fanout worker crash.

• 0-5 min: agree numbered functional and non-functional requirements for chronological feeds, publication, five-second freshness, private access and source durability.

• 5-12 min: trace the SQL baseline and calculate page versus candidate work.

• 12-20 min: define post, follow, like, request and outbox records.

• 20-30 min: explain ordinary-author push and celebrity pull with a concrete cost comparison.

• 30-38 min: recover partial fanout and enforce deletion/privacy during reads.

• 38-45 min: review the final design against the numbered FR/NFR lists, test latency/freshness and failure boundaries, then state cursor, media-cost and ordering limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Where is one published post stored, and how does it reach follower feeds?

Save its source record and author-history entry, then create feed references through delivery work that can resume after a crash.

One body, many views.

A worker inserts p701 for viewer A, then crashes before viewer B and before saving progress. What should the retry do?

Repeat the follower page. The unique viewer/post key makes A's insertion harmless, B receives the missing entry, and progress advances only after every page write succeeds.

Write, then checkpoint.

A feed still contains a deleted or newly private post. What prevents disclosure?

Before returning it, check the source post's current visibility and the viewer's current membership or relationship.

Candidates propose; permissions decide.

Summary and interview notes

Save one source post, then prepare feed references for active ordinary audiences and fetch celebrity posts on demand. Workers resume incomplete copying; readers still check current visibility.

Remember these points

- Start with an author-indexed pull feed.
- Use hybrid fanout to handle follower skew.
- Recover partial pages through unique inbox keys and write-before-checkpoint ordering.
- Check current access after candidate selection.

Interview tips

- Use the fifty-million-follower example to motivate the hybrid design.
- Keep page QPS separate from item and media work.

Important qualifications

- The basic cursor is not an immutable feed snapshot.
- Search, trends, strict regional recovery and global ordering remain separate extensions.

Explore the advanced version

Overlapping workers and generation-aware checkpoints: Analyze stale workers and policy migrations beyond the basic retry example.

Repeatable candidate sessions: Add a stronger browsing contract when late candidate arrival is unacceptable.

Partition migration and regional recovery: Specify ownership transfer and recovery targets for larger deployments.

Search, trends and recommendation algorithms: Build each derived product with its own ranking, freshness and abuse requirements.

Technical references

PostgreSQL multicolumn indexes
Explains why index column order matters for author/time and reader/time query shapes.
https://www.postgresql.org/docs/current/indexes-multicolumn.html

Transactional outbox pattern
Supports durable post publication followed by recoverable fanout work.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

CORE INTERVIEWS / 33

Design a video streaming service

Interview version / 45-minute scope · Read the advanced version online

Turn an uploaded original into a verified playable video, then separate playback authorization from adaptive segment delivery.

adaptive bitrate • transcoding • CDN • media workflow

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace upload, processing, publication and playback as different completion stages.
- Derive delivery capacity from watch duration and bitrate rather than upload count.
- Explain safe output publication, adaptive playback and bounded private-media grants.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Proxies: forward proxy, reverse proxy and API gateway; Replication and durability

8 interview questions with model answers and answered follow-ups.

01 / Choose on-demand upload and playback

Design a service for user-uploaded videos that viewers can play, pause, seek and resume on another device. Include titles, thumbnails, basic search, comments and reactions. The running example is a two-minute bicycle-repair video, v42. Its uploader wants reliable progress; its viewer wants playback that continues when Wi-Fi becomes a slower mobile connection.

Uploading the original is not the same as publishing a playable video. The service first accepts durable source bytes, then prepares a compatible output, then marks v42 READY. A failed encode must leave a useful processing or failure status instead of pretending that upload success means playback success.

Choose on-demand video for this interview. Live broadcasting, recommendation ranking and licensed subscription rights are separate extensions. For private videos, new playback sessions check current access. The worked delivery policy uses grants valid for up to five minutes; revocation stops new grants, while an already issued grant can remain usable until expiry. Agree to that limitation before designing a cache-heavy media path.

Clarify on-demand versus live video, the expected upload formats and sizes, acceptable startup delay, and how quickly private playback must stop after access changes. This design selects on-demand playback and an explicit five-minute existing-grant limit.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Upload and publish video.** Authenticated creators upload resumable originals, inspect processing status and publish playable video only after its required rendition, thumbnail and manifest exist.
2. **Play across supported devices.** Viewers start, pause, seek and resume a video, selecting compatible prepared renditions as network conditions change.
3. **Manage content and interaction.** Provide titles, basic search, comments, reactions and owner deletion. These supporting features do not block segment delivery.
4. **Authorize private playback.** New private sessions require current access and receive an expiring delivery grant. The media edge validates that grant on manifest and segment requests.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload.** Use twenty million two-minute uploads/day and four billion playback starts/day. The worked average is approximately 2.78 million concurrent viewers and 13.9 Tb/s of delivered media; provision peak headroom from measured traffic rather than treating these averages as ceilings.
2. **Playback experience.** Target p95 time to first frame within two seconds for a ready video on a tested supported device/network profile, and aggregate rebuffered time below 1% of watched time on that profile. Report the profile and failures; neither target promises performance on every connection.
3. **Processing delay.** For the example two-minute, 20 MB clip within accepted codec/resolution limits, target p95 upload-complete-to-minimum-READY within 60 seconds at admitted load. Optional higher-quality outputs can follow later.
4. **Durability and completeness.** Accepted originals and published metadata must survive a worker restart or one storage-node failure within the region. A selected manifest must name complete immutable required outputs; a cache is not the durable archive.
5. **Private-access lifetime.** Stop issuing new grants after access is removed. An existing grant remains usable for at most its five-minute validity for new requests; already downloaded bytes and admitted transfers cannot be recalled.
6. **Resource isolation.** Bound upload and encode work independently of playback. Origin misses and retries must remain within storage capacity so a cache failure cannot create an unlimited request backlog.

04 / Make one uploaded video playable

Start with an application, a SQL metadata database, durable object storage and a background encoder. Object storage holds large files independently of database rows. The uploader creates upload up42, transfers the original and asks the API to complete it. The API verifies the expected length and checksum, then records PROCESSING and a durable encoding job in one database transaction.

The encoder reads that original and creates one broadly compatible rendition: a prepared version of the video at a particular quality and bitrate. It also creates a thumbnail and a manifest describing the playable output. Once required files are verified, the application updates v42 to READY with the selected manifest pointer. The

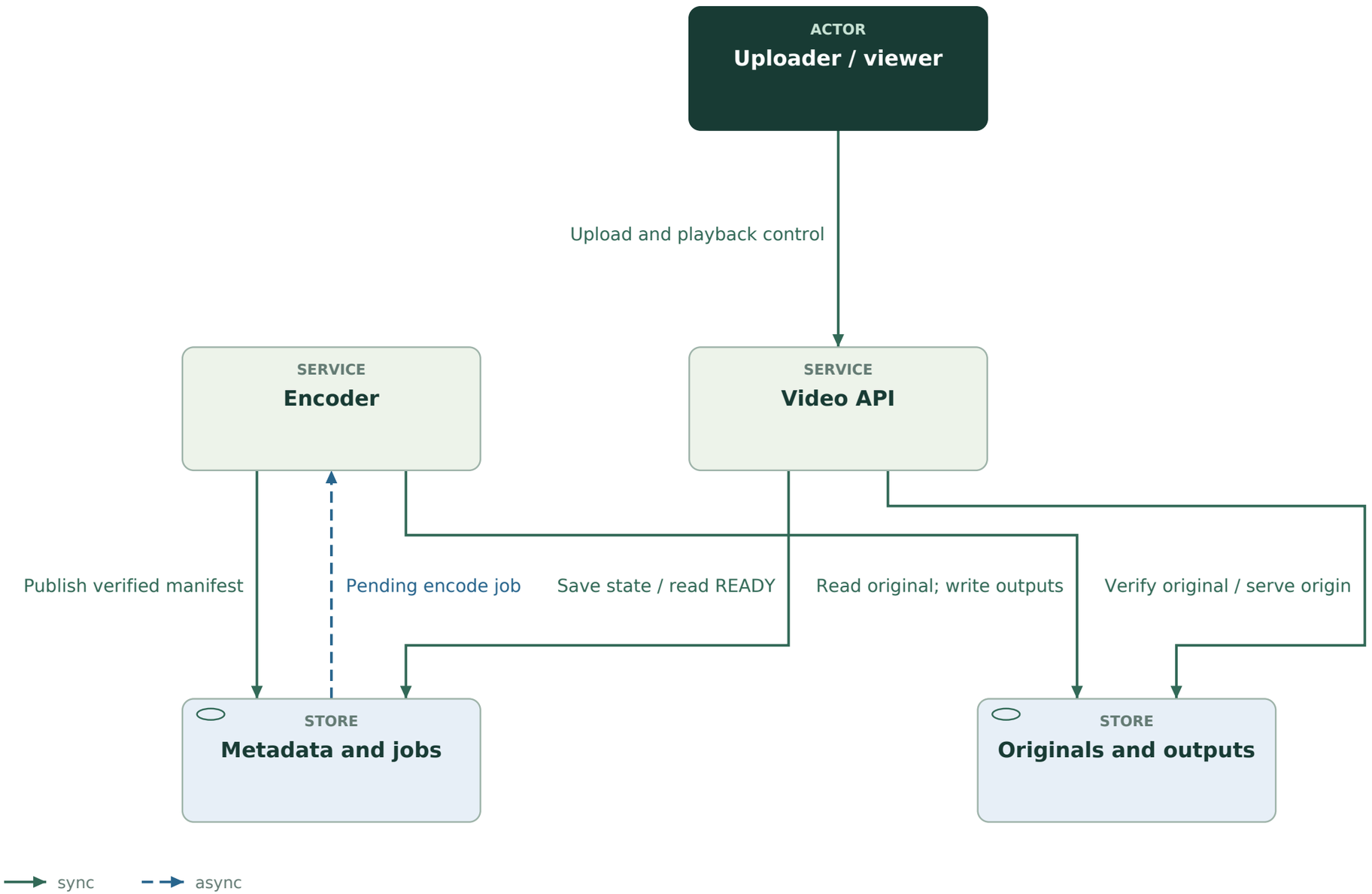
viewer requests v42, receives the manifest and fetches its media from an origin server backed by object storage.

The job can initially be a database row polled by one worker; a separate queue service is unnecessary for a small library. If a worker dies, the source file and job remain available for retry. If the upload-completion response disappears, querying up42 returns its existing status.

This system already works. Its limitations are encoding throughput, one rendition's suitability for changing networks and the origin's delivery bandwidth. Those limits motivate more encoder workers, several prepared qualities and delivery caches.

The smallest complete video pipeline

The worker prepares files before selecting the manifest that the playback API returns.



05 / Count watched seconds and transferred bytes

Assume 800 million daily viewers watch five videos each: four billion starts/day, or about 46,296 starts/s. One upload per 200 views gives twenty million uploads/day, approximately 231/s. Each two-minute original averages 20 MB. Use decimal bytes; eight bits make one byte.

Resource	Calculation	Implication
Original ingress	20 million x 20 MB = 400 TB/day	About 4.63 GB/s average upload traffic.
Concurrent viewers	46,296 starts/s x 60 watched seconds	About 2.78 million simultaneous viewers.
Delivery throughput	2.78 million x 5 Mb/s	About 13.9 Tb/s, or 1.74 TB/s.
Four-second segment	5 Mb/s x 4 / 8	2.5 MB at that rendition.
Segment requests	2.78 million / 4	About 694,444 requests/s.
Thirty-day originals	400 TB x 30	12 PB, before additional copies.

Delivery is governed by actual watched duration and selected bitrate, not merely the number of uploads. A 95% CDN byte-hit ratio would still leave approximately 87 GB/s of origin demand at this average. A hit ratio measures reuse at the cache; it does not remove the bytes sent to viewers.

Benchmark encoding on the chosen codec, resolution and hardware. If an illustrative clip requires twelve worker-seconds, 231 clips/s need about 2,772 continuously busy slots before reserve. Do not present that assumed benchmark as a universal encoder performance figure.

06 / Expose the lifecycle in the API

The client must distinguish incomplete upload from processing and ready-to-play status. A request key identifies one upload intent; changed content needs a new identity.

API	Contract
`POST /v1/video-uploads`	Allocate video/upload IDs and scoped part-upload targets.
`PUT a permitted upload part`	Retry a missing part with its integrity metadata.
`POST /uploads/up42/complete`	Verify the assembled original; return 202 PROCESSING.
`GET /videos/v42/status`	Return UPLOADING, PROCESSING, READY or a failure reason.
`POST /videos/v42/playback`	Check access and return a compatible manifest plus expiring grant.
`PUT /me/progress/v42`	Save a session identity, event sequence and media-time offset.

The upload API derives the owner from authentication and enforces size and duration limits. Direct upload authorization is restricted to the assigned object or part; it must not permit replacing another user's files. Completion checks the final original, not only the existence of several uploaded parts.

Playback request

```
POST /videos/v42/playback
```

Request information	Purpose
Supported codecs	Select an output the device can decode. A codec is the format used to encode and decode audio/video.
Desired resume time	Select the saved media timestamp, such as 75 seconds in the example below.

The phone can resume at the television's saved media timestamp while selecting a different compatible rendition. It does not need the television's exact encoded bytes.

07 / Separate source bytes, attempts and published outputs

The database records which stored files belong to each upload, processing attempt and published video. A file's presence in storage alone does not make it public.

Record	Responsibility
Video	Owner, title, visibility, lifecycle state, source identity and accepted manifest.
Upload	Request key, expected bytes/checksum, verified parts and transfer status.
EncodeJob	Video/source identity, current attempt number and processing status.
Manifest	Immutable version naming required renditions and segment objects.
Outbox or job table	Work saved durably with the metadata change that requires it.
Progress and interactions	Per-user resume state, comments and unique user/video reactions.

Partition metadata by video ID as traffic grows; add owner/time and title-search access paths for the uploader's library and discovery. Store media bytes in private object storage. A popular v42 remains a hot key even with good partitioning, so repeated byte delivery needs cache copies rather than a different hash function.

Use immutable source and output identities. Enforce create-only writes or pin exact object versions; a filename convention alone does not prevent an accidental overwrite. Search and view counts may lag. Neither decides whether v42 is READY or whether a private playback session is permitted.

08 / Publish a complete output, not a work directory

An encoder writes its files under an attempt-specific path, such as v42/source1/attempt7. A segment is a short interval of encoded media; the manifest names the available renditions and their segment locations. Publishing a manifest before all required segments exist creates a deceptive failure: playback starts successfully, then encounters a missing file halfway through.

Define a minimum playable set, such as one compatible audio/video rendition and its thumbnail. Validate that set before publication. Optional higher-quality renditions can arrive later through a new immutable manifest version; they need not delay every initial viewer.

A replacement worker receives a new attempt number. The database accepts READY only if the submitted number is still current, the source matches and the video is not deleted. If old worker seven resumes after worker eight wins, its update is rejected. Their separate output paths also prevent seven from overwriting eight's files. The database check protects the pointer; immutable storage protects the referenced bytes.

Cleanup must first mark an abandoned attempt ineligible to publish, using the same metadata state that publication checks. It can then delete unreferenced output files. Merely observing "old files" and deleting them risks removing an output that a slow worker is about to publish.



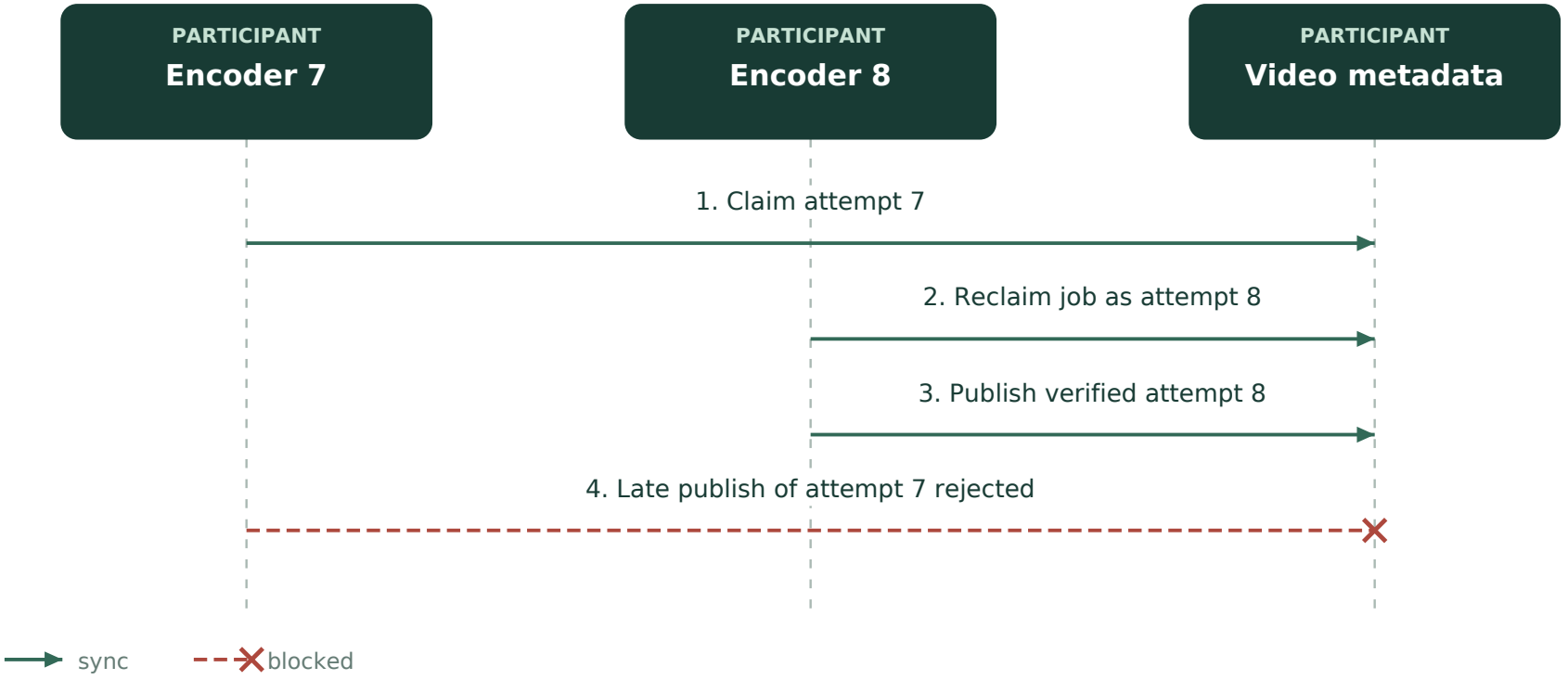
INTERVIEW CRITICAL

READY names verified immutable outputs

Do not expose a manifest while its required files are still being written. Accept one current attempt atomically, and prevent later workers from replacing its bytes.

A resumed old encoder cannot publish

Only the current attempt may select immutable outputs for viewers.



09 / Adapt future segments to the connection

Prepare several renditions at different bitrates, with segment boundaries at matching media times; this set is the bitrate ladder. Bitrate is encoded data per second of playback. The player downloads ahead into a buffer, which absorbs brief interruptions. If that buffer empties, playback stalls while more data arrives.

Compare two renditions over the same ideal 2 Mb/s connection:

Rendition	Bytes for four seconds of video	Download time	Buffer consequence
5 Mb/s	2.5 MB	Ten seconds	The player consumes four seconds of video while waiting ten seconds for its replacement.
1 Mb/s	0.5 MB	About two seconds	Four seconds of content arrive in two seconds, allowing the buffer to recover.

The player measures recent throughput and buffer depth, then chooses a suitable rendition for subsequent segments. It does not ask the metadata API to transcode on every quality change. HTTP Live Streaming, or HLS, is one established manifest-and-segment format for this request pattern. The application still owns readiness and access policy.

Seeking to 75 seconds selects the appropriate segment and decoding boundary near that media time. Saved progress is advisory. Choose a latest-session policy: the server assigns a generation to a new resumable session and accepts increasing event sequences only from that generation. A late event from an older device cannot replace a newer deliberate seek merely because its offset is larger.

10 / Separate control requests from media delivery

Place a content delivery network, or CDN, between players and private media storage. An authorized edge serves cached immutable segments or fetches them from origin on a miss. The API handles upload management, metadata and playback authorization; it does not relay every media byte. This isolates upload sockets and encoder CPU from existing playback.

Use the selected five-minute grant at the delivery edge for manifest and segment access. A cache hit must still validate the grant. Its expiry is the explicit stale-access bound for new requests using that grant, rather than a claim that deleting a database row immediately removes every cached byte. Private grants should not appear in logs or public shared links.

An origin shield is a shared cache behind several edges. It can fetch a missing segment once for several waiting edges, reducing a viral clip's load on storage. Add bounded origin retries and reserve playback capacity when uploads or encoding queues surge.

Scale encoder workers from measured queue age and processing cost, with per-account admission and bounded retries. More renditions improve network/device coverage but multiply compute and retained bytes. Cold videos may initially receive only the minimum playable set; optional encodes follow measured demand.

Use durable majority commits across three metadata replicas in independent regional failure domains, and media storage whose acknowledged writes survive one storage-node loss. Satisfy that policy before reporting original acceptance or publishing required outputs. The two-second startup and rebuffering targets still need playback tests, including origin misses; replication does not establish them.



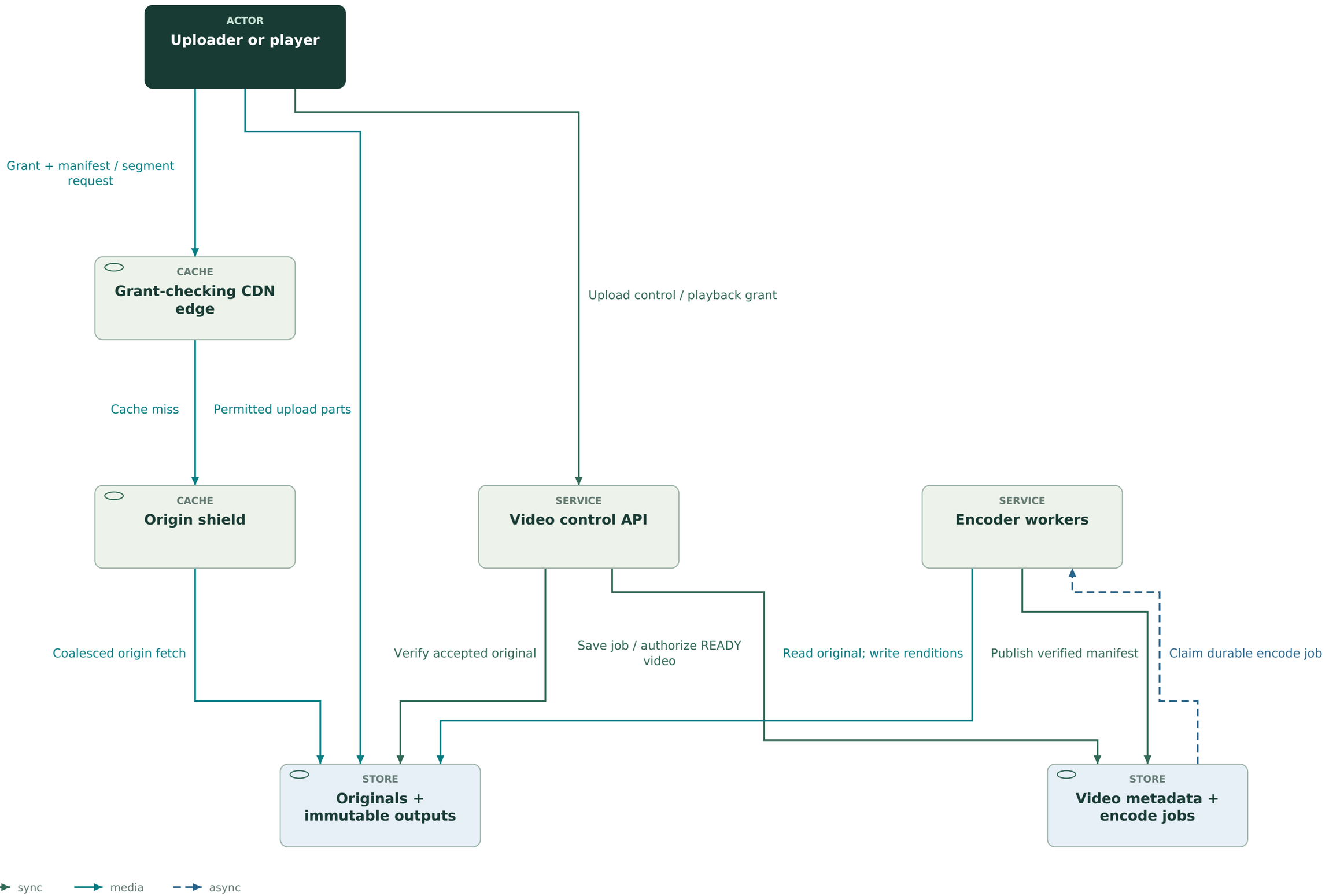
INTERVIEW CRITICAL

A CDN stores bytes; it does not decide permission

The edge validates the session grant before returning private media, including cache hits. The chosen five-minute grant permits a bounded period of access after revocation.

Playback uses the media edge while encoding runs separately

Upload targets send original bytes to private storage; the API verifies completion and records durable encode work. Encoders publish a verified manifest. A player then obtains a five-minute playback grant and requests segments through the edge and origin shield, without sending media bytes through the metadata API.



11 / Explain what survives each failure

Failure	User-visible result and recovery
Upload interruption	Reuse the session and retry unverified parts, not the entire accepted video.
Encoder crash	Status remains processing; another attempt reads the durable original.
Invalid or hostile media	Bounded retries end in a reasoned failure; sandbox the decoder and limit resources.
Metadata unavailable	New private sessions fail; existing valid grants may keep cached playback working.
Origin outage	Cache hits continue; misses use bounded retry or fail visibly. A lower bitrate helps only if usable segments exist.
Telemetry outage	Playback continues; statistics are delayed or partially lost under the measurement policy.

Deletion prevents new playback grants and schedules reclamation after the retained-grant/manifest window. It cannot recall already downloaded video. Back up original identities and publication metadata; caches are not the archive. Derivatives can be regenerated, but that takes time and compute, so restoring metadata alone does not instantly restore every rendition.

Comments, title search and approximate view counts have independent pagination and failure behavior. A slow counter must not block a segment. For a view metric, define what counts as a view before discussing deduplication; a request for the first segment is not proof that the person watched the clip.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1 + NFR3-4: playable publication	Verified original, durable job, immutable attempt outputs and guarded manifest selection.	Crash or resume an old encoder and inspect every required segment. Benchmark 60-second readiness for the declared clip profile.
FR2 + NFR1-2: actual playback	Aligned rendition ladder, client buffer control, CDN and origin shield.	Use real/synthetic players to measure first frame and rebuffering on the declared profile; a 200 manifest response proves neither.

Requirement	Design mechanism	Validation and remaining limit
FR4 + NFR5: private media	Current session authorization and grant checks even on cache hits.	Revoke access and test a new session versus an existing unexpired grant; report the intentional expiry-bound difference.
FR3 + NFR6: noncritical work stays separate	Independent comments/search/telemetry and bounded upload/encoder capacity.	Overload encoding or telemetry while playing cached and uncached segments; test origin-miss limits.
NFR4: one-node survival	Replicated metadata and durable original/output storage.	Fail a storage node after acceptance and restore metadata with referenced objects; complete region loss is a separate recovery design.

13 / Rapid revision

Remember: The player needs the next segment before its buffer empties. Lower bitrate buys playback time with fewer bytes.

Measure time to first frame, rebuffered time as a fraction of watched time, errors by device/codec and upload-to-READY delay. A successful manifest response alone proves none of these outcomes. Use synthetic players plus privacy-conscious playback telemetry to test real segments.

Decision	Reason	Limit or cost
Durable original before processing	Workers can recover without another upload.	Originals require retention and replication.
Verified manifest publication	Name only complete, verified media files.	Processing delays readiness.
Several bitrates with aligned segment boundaries	Adapt to bandwidth and device support.	More encoding and storage.
Deliver segments through a CDN	Reuse hot segments near viewers.	Misses load origin; delivered bytes still cost money.
Five-minute private playback grant	Avoid a database check for every segment.	Existing grants work until expiry, delaying revocation.
Separate telemetry	Statistics cannot stall playback.	Counts may lag or be approximate.

In the interview, finish by tracing v42 from verified original through accepted manifest to one adaptive playback session. Name the largest cost drivers: retained originals, useful rendition sets and watched bytes. Licensed catalogs would add entitlement and possibly digital rights management; live video would add moving manifests and a different latency budget. Those are deliberate extensions, not capabilities implied by this on-demand design.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why is upload completion different from READY?

Model answer

The original can be durable while no compatible playback output exists. READY requires a verified selected manifest and required files.

Interviewer follow-up

What should the upload completion API return?

A processing status and stable queryable identity, not a false playback promise.

What the answer must demonstrate: Distinguishes durable bytes from verified playable outputs.

02 / APPLIED

How do you estimate concurrent viewers?

Model answer

Multiply playback starts per second by average watched seconds, then multiply concurrency by average selected bitrate for delivery throughput.

Interviewer follow-up

Why is segment QPS higher than start QPS?

Each session fetches many segments, so concurrency divided by segment duration estimates ongoing segment requests.

What the answer must demonstrate: Keeps starts, concurrency, bits and bytes in correct units.

03 / APPLIED

Why does a lower rendition help on a slow connection?

Model answer

It needs fewer bytes for the same media duration, allowing downloads to replenish the buffer faster than playback consumes it.

Interviewer follow-up

Does the service transcode for every switch?

No. The player requests a subsequent aligned segment from an already prepared rendition.

What the answer must demonstrate: Explains buffer supply versus consumption causally.

04 / APPLIED

How can a successfully loaded manifest still produce broken playback?

Model answer

It may name segments that were never written or were overwritten. Verify all required immutable outputs before selecting the manifest.

Interviewer follow-up

How does a stale worker lose publication rights?

The database checks the current attempt and source identity during the READY transition.

What the answer must demonstrate: Protects both manifest selection and the referenced bytes.

05 / APPLIED

What does a CDN solve and not solve?

Model answer

It reuses bytes near viewers and reduces origin load. It does not create source durability or authorize private content by itself.

Interviewer follow-up

What does a 95% byte-hit ratio imply?

About 5% of requested media bytes still need origin service under the assumed workload.

What the answer must demonstrate: Separates cache reuse from durability and authorization.

06 / FOLLOW-UP

Can a five-minute playback grant support immediate revocation?

Model answer

No. An already issued grant can remain usable until expiry; current authorization is required for a new one.

Interviewer follow-up

What would a stricter product require?

Current revocation checks at request admission and a precise in-flight transfer policy.

What the answer must demonstrate: States the actual grant-expiry limitation.

07 / APPLIED

Why not save the largest playback offset ever received?

Model answer

A person may intentionally seek backward, and old devices may send late updates. Larger time is not necessarily newer intent.

Interviewer follow-up

What ordering policy does this design choose?

The latest server-assigned session generation controls shared progress, with increasing event sequences within it.

What the answer must demonstrate: Orders user intent by session/events rather than maximum offset.

08 / APPLIED

Which metrics reveal whether playback works?

Model answer

First-frame delay, rebuffered fraction, device/codec errors and actual decoded segment checks reveal user experience better than metadata response codes.

Interviewer follow-up

Which cost tradeoff follows?

Additional encoding may reduce watched bytes, but only if quality and device compatibility remain acceptable.

What the answer must demonstrate: Measures decoded user experience and explicit cost tradeoffs.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design user-uploaded on-demand video. Explain one interrupted upload, a stale encoder and a player switching from Wi-Fi to a slower connection.

• 0-5 min: agree numbered functional and non-functional requirements for on-demand playback, upload/READY, device-network performance, durability and private-grant lifetime.

• 5-12 min: trace the smallest playable pipeline and delivery estimates.

• 12-20 min: define upload, metadata, jobs and manifest records.

• 20-30 min: explain adaptive segments, CDN and control/media separation.

• 30-38 min: handle stale encoders, origin failure and private grant expiry.

• 38-45 min: check the final architecture against the numbered FR/NFR lists, identify the playback/readiness tests still needed, and state retention, cost and live-video exclusions.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What must happen between an upload and a playable video?

Verify and save the original, save processing work that survives crashes, then publish a complete verified manifest.

Source, job, playable output.

On the example 2 Mb/s link, a four-second 5 Mb/s segment takes ten seconds to download. What changes at 1 Mb/s?

The four-second segment needs 0.5 MB and downloads in about two seconds, so the buffer can recover. The player selects a prepared lower-bitrate segment at the next aligned boundary.

Download faster than playback consumes.

How do we stop an obsolete processing worker from publishing broken playback?

Check that its attempt is still current before accepting its manifest, and keep the immutable files it references protected from deletion.

Guard the pointer and its files.

Summary and interview notes

Save the original and publish complete prepared renditions. During playback, authorize access and deliver cached segments; the player chooses a bitrate that its connection can download in time.

Remember these points

- Keep original durability separate from playable readiness.
- Select verified outputs with a current-attempt database check.
- Use aligned renditions to adapt future segment requests.
- Make private grant lifetime an explicit revocation tradeoff.

Interview tips

- Calculate delivery from watched seconds and bitrate.
- Use the slow-link segment example to explain buffering.

Important qualifications

- Live streaming and licensed entitlement require additional mechanisms.
- Downloaded bytes cannot be recalled.

Explore the advanced version

Publication and garbage-collection races: Prove stale-worker rejection and cleanup safety through detailed interleavings.

Regional recovery and storage ownership: Specify stronger recovery promises and partition transfer behavior.

Deduplication and visual similarity: Separate byte equality, perceptual similarity and rights to reuse media.

Licensed catalog and DRM extension: Add entitlement, regional windows and key-service requirements when the product changes.

Technical references

RFC 8216: HTTP Live Streaming
Defines manifests, media segments, variant streams, and playback behavior.
https://www.rfc-editor.org/info/rfc8216/

AWS Elemental MediaConvert overview
Official description of file-based video conversion and output preparation.
https://docs.aws.amazon.com/mediaconvert/latest/ug/what-is.html

Amazon S3 multipart upload overview
Documents resumable multipart completion and cleanup considerations.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/mpuoverview.html

Amazon S3 conditional writes
Documents create-if-absent output writes; immutable media publication remains an application protocol.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/conditional-writes.html

CORE INTERVIEWS / 34

Design a typeahead service

Interview version / 45-minute scope · Read the advanced version online

Build fast prefix suggestions by moving ranking work into a versioned index while keeping browser input, privacy and removal rules correct.

prefix trie • top-k • ranking snapshots • Client debounce

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain trie lookup and why precomputed candidate lists bound query work.
- Choose coherent ranking snapshots and account for their memory and freshness costs.
- Prevent stale browser responses and private history from contaminating public suggestions.

Useful foundations: Database indexes: B-trees, composite keys and query access; Caching: cache hits, misses, write policies and invalidation; Data partitioning and sharding

8 interview questions with model answers and answered follow-ups.

01 / Define what a suggestion means

Design a service that suggests up to ten approved search terms while a person types. The request "ca" can match "cat," "capital," "captain," "caption" and "cap." Rank matching terms by recent submitted-search popularity, with deterministic ties. Suggestions should arrive quickly enough to remain useful while typing; use an illustrative 200 ms end-to-end target.

Choose exact prefix matching for the first design. Typo correction, arbitrary substring search and semantic similarity need additional candidate generators. A prefix index does not acquire those capabilities because it has more replicas. Require at least two characters, bound input length and keep ordinary search submission usable when suggestions fail.

The public vocabulary is approved separately from private search history. Index and query processing share one documented Unicode normalization and locale-aware case policy while preserving display spelling. This prevents predictable mismatches between stored terms and input; it is not a complete defense against visually confusing characters.

Use hourly popularity updates. Urgent blocked-term removal uses a current serving-time policy check, independent of the hourly index. This worked design does not promise a worldwide removal deadline or control words already displayed on an offline browser; those stronger contracts belong in a later discussion.

Clarify exact-prefix versus typo-tolerant matching, the ranking signal, acceptable popularity delay and the behavior during policy-service failure. The following contract chooses exact prefixes and safe empty suggestions when current approval cannot be established.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Return ranked prefix matches.** Given at least two input characters and a locale, return up to ten approved matching terms ordered by recent submitted-search popularity and deterministic ties.
2. **Handle changing input.** Use compatible normalization in indexing and queries, preserve display spelling and render only responses belonging to the search box's current input sequence.
3. **Update popularity and policy.** Ingest identified submitted-search events, rebuild popularity snapshots and remove blocked terms from final candidate results.
4. **Keep ordinary search usable.** Return fewer or no suggestions when necessary without preventing query submission. Private history, when present, remains user-scoped rather than entering a public response cache.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload and memory.** Plan for approximately 1.16 million suggestion requests/s at the fivefold peak. The illustrative 40 GB snapshot may need 80 GB during replacement before process reserve; validate these assumptions with representative builds.
2. **Response latency.** Target p95 end-to-end suggestion latency of 200 ms after the browser sends a request on the declared regional client/network profile at admitted peak load. Debounce waiting before send is measured separately, not hidden inside server time.
3. **Ranking freshness.** Publish popularity snapshots hourly from a fixed input cutoff using the selected ten-day count window. Delayed or failed builds retain the previous validated snapshot and expose its age.
4. **Coherent and rebuildable state.** A query uses one complete snapshot version. Durable vocabulary and count inputs survive a process restart or one database-node failure; serving indexes can be rebuilt and hot ranges replicated.
5. **Current approval and privacy.** Check final candidates against current policy after all cache and index sources. If that check fails, return no suggestions. Do not promise a worldwide removal deadline or recall of words already displayed.
6. **Bounded request cost.** Limit input length, candidates, shard fanout and retained raw events. Candidate ranking must remain meaningful under abuse controls rather than letting repeated malicious submissions dominate counts.

04 / Find and rank five words by hand

A trie is a tree in which following successive character edges locates a prefix. Traversing c, then a, reaches the subtree containing the five example words. A terminal marker identifies a complete term: cap is both a valid word and the start of capital, captain and caption.

Build this small index from a durable vocabulary and counts. At query time, traverse the prefix, enumerate descendant terminal terms, sort them by popularity and return the first ten.

Term	Submitted-search count	Order for `ca`
`cat`	900	1
`capital`	700	2
`captain`	500	3
`caption`	400	4
`cap`	100	5

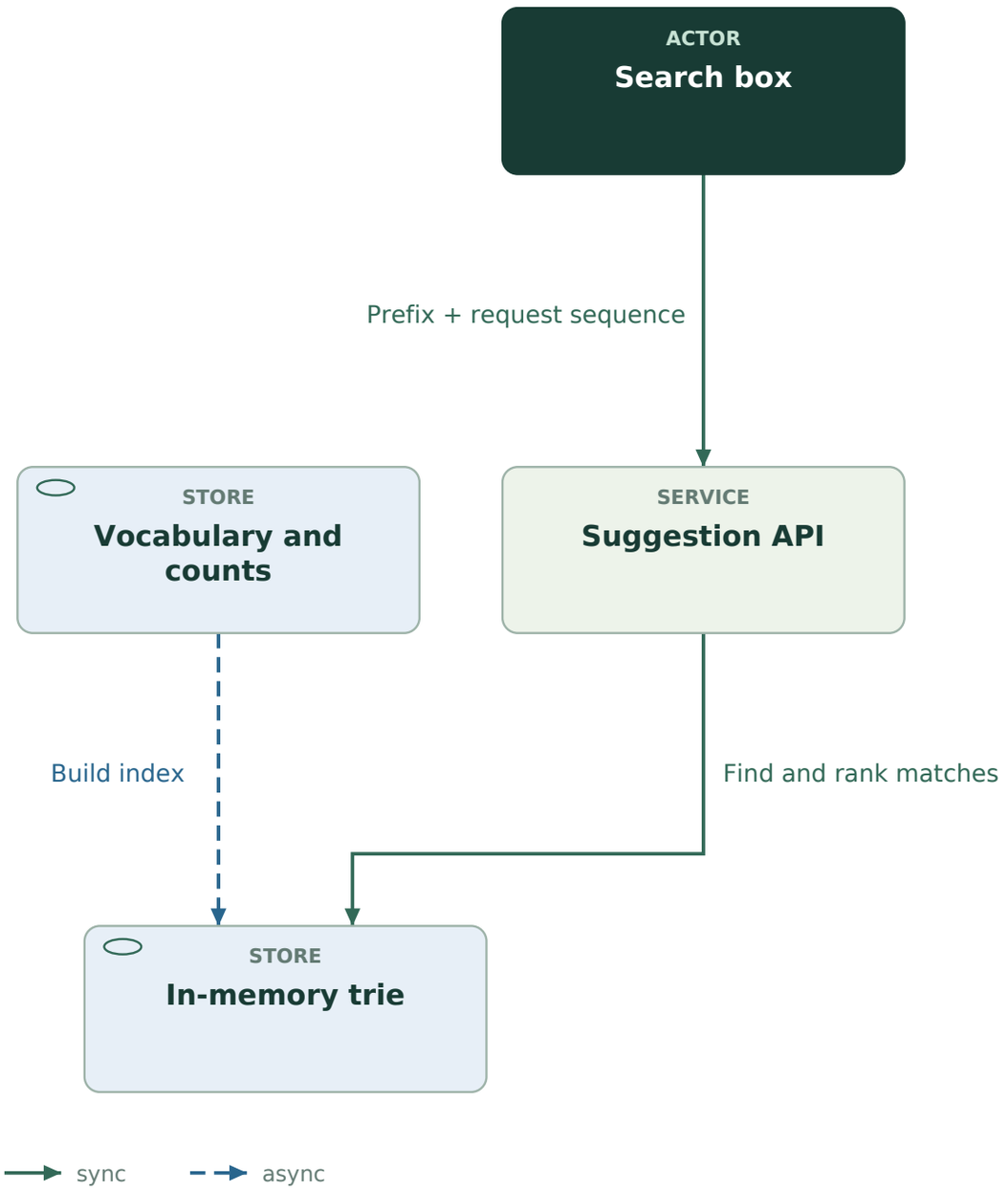
For `cap`, `cat` does not match and must disappear regardless of its higher score.

The browser waits for a short pause in typing before sending a request; this is debouncing. Give each input change an increasing request sequence. If ca is request 12 and cap is request 13, only the response matching the current sequence may update the screen. Canceling request 12 can save work, but it cannot guarantee that an already completed response will not arrive.

This baseline works with one application and one in-memory index rebuilt from durable data. A database prefix query would also work for a small vocabulary. The reason to evolve the trie is measurable query work, not that databases are intrinsically unsuitable for suggestions.

A complete small prefix service

The serving application reads a trie built from durable approved terms and counts.



05 / Budget the index, not only its strings

Assume five billion submitted searches/day. If each submission generates four suggestion requests after debounce, the serving average is approximately 231,481 requests/s, with a fivefold peak near 1.16 million/s. Counting submitted searches alone understates the load.

Quantity	Calculation	Consequence
Submitted searches	5 billion / 86,400 ~ 57,870/s	Popularity events can be processed asynchronously.
Stored strings	100 million terms x 30 B	3 GB of vocabulary, excluding the index.
Candidate shortlists	300 million nodes x 10 references x 8 B	24 GB before transitions, strings and overhead.
Illustrative full snapshot	Measured extrapolation: 40 GB	Validate with a representative build.
Old and new versions together	2 x 40 GB	80 GB during replacement, before process reserve.
Response traffic	231,481/s x 500 B	About 116 MB/s average.

A broad prefix may match millions of words. Traversing its few characters is cheap; enumerating and sorting every match is not. Extra replicas repeat that expensive work. Precomputing a bounded shortlist at each prefix trades memory and update effort for predictable serving cost.

The node count and snapshot size are assumptions to benchmark, not deductions from vocabulary bytes. Compression can reduce chains of single-child nodes, and compact arrays can reduce pointer overhead. Plan peak loading memory as well as steady-state memory: a machine that holds one snapshot may fail when asked to stage its replacement.

06 / Tie the response to input and index versions

The request identifies the typed prefix, locale and current browser input sequence. The response returns that sequence, the normalized prefix, the index version and a bounded list of term IDs with display text.

Suggestion request

```
GET /v1/suggest?prefix=ca&locale=en-US&limit=10&requestSeq=12
```

Illustrative response for the five running terms

```
{
  "requestSeq": 12,
  "normalizedPrefix": "ca",
  "indexVersion": "snapshot-42",
  "terms": [
    {"termId": "t-cat", "displayText": "cat"},
    {"termId": "t-capital", "displayText": "capital"},
    {"termId": "t-captain", "displayText": "captain"},
    {"termId": "t-caption", "displayText": "caption"},
    {"termId": "t-cap", "displayText": "cap"}
  ]
}
```

The example IDs identify the five terms; internal scores need not be exposed.

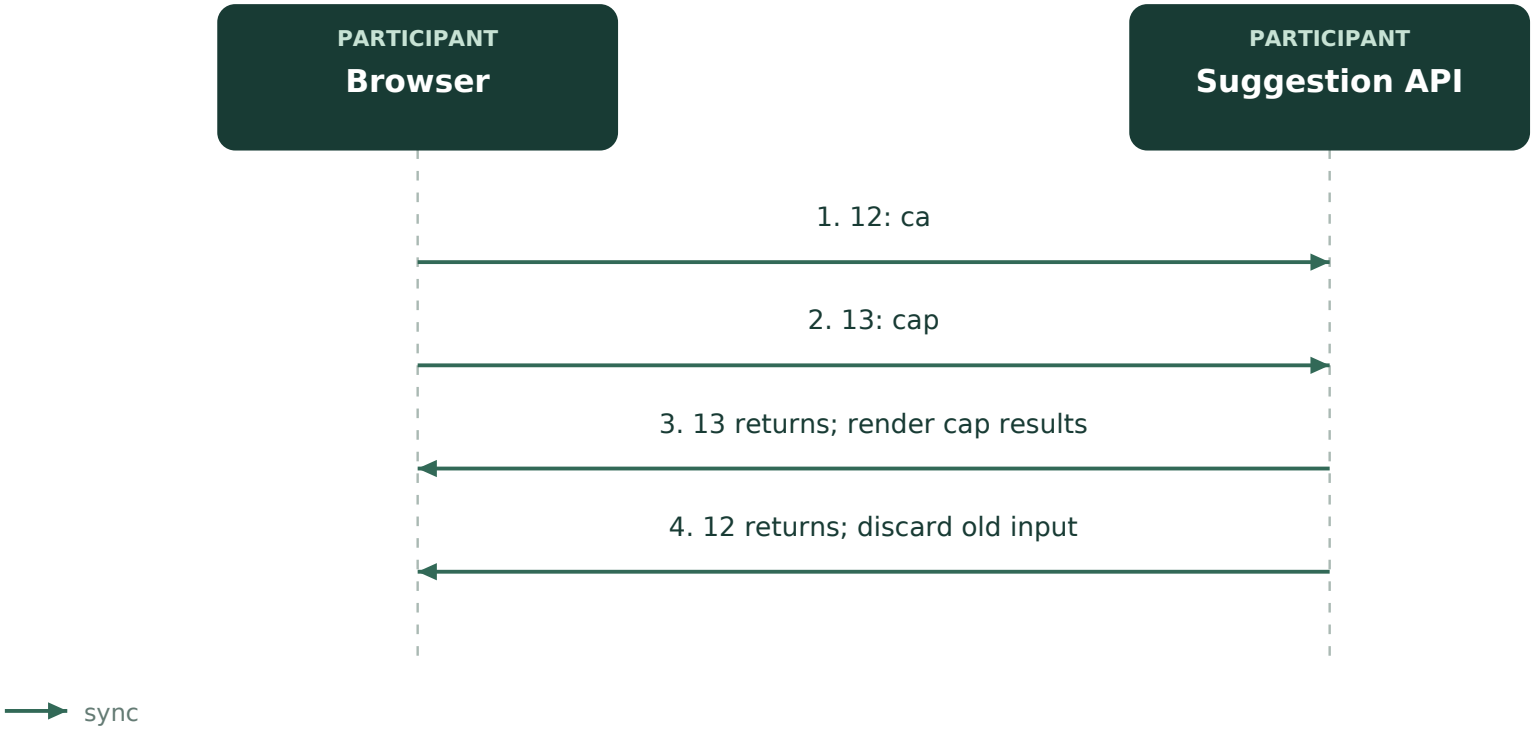
Interface	Purpose
Suggest request	Retrieve bounded candidates for one prefix and locale.
Submitted-search event	Record the selected or submitted term with a stable event identity.
Delete private history	Remove user-scoped history under its retention policy.
Snapshot manifest	Name the immutable index, normalization version, ranges and checksums.

Do not count every typed prefix as a successful search. Otherwise "cap" accumulates popularity merely because people continue typing "capital." Choose submitted searches as this design's score input, deduplicate repeated event IDs over the processing window and bound contributions from abusive clients.

Return fewer than ten results when matching or approved candidates are insufficient. An empty suggestion list is a valid degradation, while the search box remains usable. Render display text safely rather than interpreting it as markup. The browser discards a response for an old input even if the server used the newest index; input freshness and ranking freshness solve different problems.

A later response can belong to older input

The browser renders only a response matching its latest input sequence.



07 / Store enough information to rebuild the shortlist

Durable records supply the vocabulary and popularity evidence used to generate the serving trie.

Record	Fields or stored information	Purpose
`Term`	`termId`, `normalizedText`, `displayText`, `locale`	Keeps one durable identity and both normalized and display forms of a term.
Time-bucketed counts	Submitted-search counts grouped into time buckets	Supplies the retained popularity evidence used by builds.
Approved snapshot metadata	Immutable index identity, normalization version, ranges and checksums	Identifies a validated serving artifact.

The serving trie must not be the only copy of vocabulary or popularity evidence.

Each node stores transitions, an optional terminal term and a bounded candidate list containing term IDs and scores. Store display strings once in a term table rather than repeating full strings at every prefix. A compressed edge can consume several characters; when a query ends inside a matching compressed edge, its candidates still come from that subtree.

Choose a ten-day sliding window of submitted-search counts, aggregated into hourly buckets. A score is the sum of the included buckets under the build's fixed cutoff. Older buckets expire, so scores can decrease. This is different from exponential decay, which gradually changes older events' weights; do not mix those definitions in one unexplained formula.

Public cache keys include normalized prefix, locale and index version. Private history is stored separately by authenticated user. If personalization is added, merge a bounded personal candidate source after retrieving public candidates, then apply the same policy checks. Never put the resulting private response into a cache shared by other users.

08 / Precompute winners without forgetting excluded terms

Build each prefix's top ten from its own complete term and its child prefixes' top tens. Why is that enough? A term excluded from a child's top ten already has ten better matches. Those same matches qualify for the shorter parent prefix, so the excluded term cannot win there either. This requires the same global score and tie-breaker everywhere.

The serving shortlist alone is insufficient for future updates. Consider `k = 2` under `cap`:

Term	Original score	Score after older counts expire
`capital`	700	50
`captain`	500	500
`caption`	400	400
`cap`	100	100

The original shortlist is `capital`, `captain`. After the decrease, the correct answer is `captain`, `caption`. Lowering `capital`'s score inside the old pair would never discover `caption`.

Therefore build from complete retained terms and counts, recomputing child and parent lists bottom-up. Building separately avoids changing scores and prefix shortlists while queries read them. The online request then traverses the prefix and reads a bounded prepared list instead of sorting a huge subtree.

The top-k argument assumes global independent scores. Arbitrary personalization or diversity rules can change which excluded terms become useful. That extension needs a larger candidate pool or separate personal candidates and an explicit recall tradeoff.



INTERVIEW CRITICAL

The old top ten cannot explain the next top ten

When a score decreases or a term disappears, a previously excluded candidate may become a winner. Rebuild from retained vocabulary/counts, not only yesterday's shortlist.

09 / Publish coherent snapshots and route prefixes

Queries reuse precomputed rankings while popularity changes accumulate. Build a separate read-only index hourly from a fixed vocabulary/count cutoff. Check representative prefixes, checksums, ranking and memory size before directing queries to it. Serving requests retain one index version until they finish; new requests can switch to the replacement while older readers finish on the previous version.

If both versions do not fit on one machine, stage new hosts and shift traffic after readiness checks. Do not solve a loading-memory shortage by freeing data still used by active requests. Keep the previous artifact for rollback and retain durable inputs for rebuilding.

Partition large indexes by measured lexical ranges, meaning contiguous portions of the normalized term ordering. A prefix can intersect more than one range, so a router asks the relevant shards and merges their bounded candidates. Every shard response uses the request's pinned snapshot version. Hashing complete terms spreads storage but scatters prefix matches, usually requiring every shard or a separate prefix-routing index.

Equal first-letter shards are rarely balanced. Split large ranges and replicate hot ranges according to measured memory and traffic. Splitting unrelated data does not reduce requests for the exact same hot prefix; replicate its serving work and cache its public candidates. Keep candidate limits and shard fanout bounded so a broad query cannot overwhelm the cluster.

Store the source vocabulary, count buckets and published snapshot metadata with durable majority commits across three replicas in independent regional failure domains. That meets the chosen one-node-loss boundary only if failover preserves acknowledged inputs. Snapshot-serving replicas remain replaceable; keeping ordinary search available is the fallback when suggestions cannot be served safely.

10 / Filter removals after every candidate source

Hourly ranking freshness is acceptable here, but a removed term should not survive simply because it remains in an old snapshot. Before returning suggestions, the API checks the final candidate IDs against current policy state. This includes candidates from caches and private history. If the policy check is unavailable, return no suggestions rather than assume an old allowed decision remains valid.

Choose this request-time check for the worked design. Its extra dependency and latency must be budgeted; a separate replicated policy service can batch the small list of candidate IDs. Faster distributed policy caches with bounded freshness are an Advanced alternative, because an explicit removal deadline also needs a clock, expiry and client-display contract.

Filtering can leave a short list. Precompute a modest larger pool if measurements show that approved results are frequently lost, but do not perform an unbounded subtree scan or refill afterward from an unfiltered source. Increasing the pool costs memory at every retained prefix.

Private history adds another boundary: logout and history deletion must clear user-scoped cached data. Public popularity counts should not expose raw personal search logs. Prefixes can contain secrets or pasted identifiers, so minimize logging and restrict retained raw data.



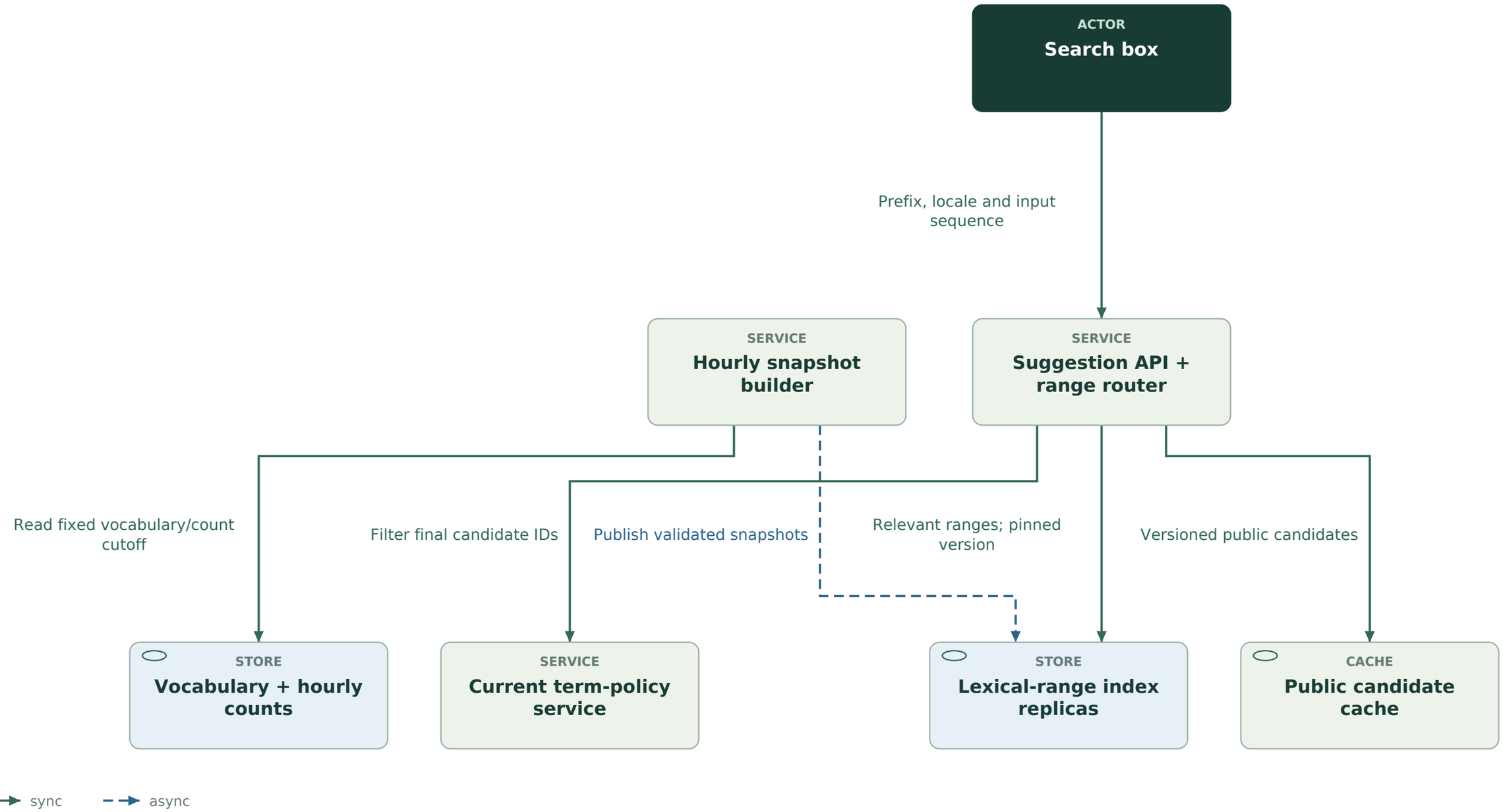
INTERVIEW CRITICAL

Apply policy to the final union

Cached public candidates and authenticated private candidates must all pass the removal filter. Never refill the response from an unchecked source after filtering.

Build snapshots offline; merge and filter suggestions online

The builder reads a fixed input cutoff and publishes validated immutable indexes. The API pins one version, checks a public candidate cache or queries the relevant lexical-range replicas, and merges their results. Current policy checks run after every candidate source before suggestions return to the search box.



11 / Keep search usable while suggestions recover

If a snapshot build fails, continue serving the previous validated index with current policy checks. If loading exceeds memory or fails its checksum, that replica remains unready. A pointer to a partially loaded artifact must not reach request routing.

Popularity aggregation must tolerate repeated events. One simple implementation recomputes each completed hourly bucket from a fixed input-log range, deduplicating event IDs before publishing that bucket. Replaying the build produces the same counts instead of incrementing them again. Event retention bounds how far back reconstruction is possible.

When a hot-prefix replica fails, spare replicas and shared public candidate caches absorb traffic within measured capacity. Admission limits preserve service health. Suggestion failure should leave normal query submission available; it should not freeze the input box waiting for retries.

Monitor end-to-end latency, empty-result rate, response-discard rate, snapshot age, load-time peak memory and policy-check failures. Evaluate relevance on held-out prefixes as well as clicks, since click volume can reward sensational suggestions. Apply contribution limits and detect sudden suspicious popularity spikes before they dominate the next build.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1-2 + NFR2: useful current-input suggestions	Prefix traversal, prepared candidates, compatible normalization and browser request sequences.	Test ca/cap response reordering and benchmark p95 after-send latency including network and final policy checks.
FR3 + NFR3-4: coherent popularity updates	Complete retained inputs and validated immutable hourly snapshots.	Lower a top term's score, fail a build and stage two versions; confirm correct replacement and bounded memory.
FR3-4 + NFR5: safe degraded results	Final current-policy filtering and separately scoped private history.	Block a cached term and interrupt policy checks; suggestions may become empty while ordinary search remains usable.
NFR1,6: bounded peak work	Lexical-range ownership, hot-range replicas and bounded public candidate caching.	Load-test hot prefixes and broad prefixes. Splitting unrelated terms does not by itself remove one hot-prefix bottleneck.
NFR4: recoverable inputs	Durably replicated vocabulary/count records and retained snapshot artifacts.	Fail a source node and rebuild an index; an in-memory trie alone cannot meet the durability requirement.

13 / Rapid revision

Remember: Precompute rankings to reuse them across queries; replace the whole snapshot so readers never see half-updated shortlists.

Decision	Problem it solves	Accepted cost or limit
Prefix trie with terminal markers	Find terms that start with the typed prefix.	No typo or semantic matching by itself.
Precomputed candidate lists	Avoid broad subtree scans per query.	Memory and rebuild work.
Hourly immutable snapshots	Read one complete ranking without update locks.	Popularity can lag.
Keep all terms and count history	Replace winners when their scores decrease.	Store the full vocabulary and time-bucketed counts.
Alphabetical partitions with replicas	Route matching data and serve hot prefixes.	Merge bounded shortlists when a prefix spans shards.
Check the blocklist before returning suggestions	Filter blocked public and personalized suggestions.	Return none if the blocklist check fails.
Browser request sequence	Prevent old responses replacing newer input.	Cancellation alone remains insufficient.

Close by following ca: the browser numbers its input, the server reads one index version and checks its candidate list, then the browser displays the response only if ca is still current. Explain that serving speed came from moving work into index construction, not from ignoring ranking correctness. The next measurements are peak snapshot memory, hot-prefix load and useful suggestion quality. Personalization, typo correction and hard removal deadlines can then be discussed as specific extensions with additional requirements.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How does a trie answer a prefix query?

Model answer

Follow character edges to the prefix node, then use descendant terminal terms. A terminal marker distinguishes a complete term from an intermediate path.

Interviewer follow-up

Why is cap both a result and an internal node?

It is a complete term and a prefix of capital, captain and caption.

What the answer must demonstrate: Explains prefix traversal and terminal semantics.

02 / APPLIED

Why is prefix-length traversal not the whole query cost?

Model answer

A broad prefix can have millions of matching descendants. Enumerating and sorting them dominates the few edge traversals.

Interviewer follow-up

What changes the online cost?

Precompute a bounded ranked list at each prefix, paying memory and offline build work.

What the answer must demonstrate: Counts descendant enumeration, not just edge traversal.

03 / APPLIED

What goes wrong when a top-ranked term loses popularity?

Model answer

The old shortlist does not contain the best excluded replacement. Retained vocabulary and counts are needed to recompute winners.

Interviewer follow-up

Give the cap example.

When capital drops below caption, captain/caption becomes the correct top two even though caption was absent from the old pair.

What the answer must demonstrate: Finds the missing replacement candidate after a decrease.

04 / APPLIED

Why build immutable snapshots?

Model answer

Build the replacement separately so a query never combines a changed term score with an old prefix shortlist. Each request uses one complete version of the terms, normalization rules and scores.

Interviewer follow-up

What memory trap appears during rollout?

Both the current and replacement indexes may need to coexist, plus process reserve.

What the answer must demonstrate: States coherent data and simultaneous-version memory costs.

05 / APPLIED

Why does request cancellation not prevent stale display?

Model answer

The old response may already be completed or in flight. The browser must compare its input sequence before rendering.

Interviewer follow-up

Does a newer index version fix an old-prefix response?

No. Index freshness and association with current typed input are independent.

What the answer must demonstrate: Uses an explicit latest-input comparison.

06 / APPLIED

Why prefer lexical ranges to hashing complete terms here?

Model answer

Prefix matches occupy related lexical ranges, allowing targeted routing. Hashing terms scatters matches and usually requires broad fanout.

Interviewer follow-up

Does splitting ranges fix one hot prefix?

Not by itself. Repeated identical queries need replicas or cached candidates.

What the answer must demonstrate: Connects partition layout to query locality and hot-key replication.

07 / APPLIED

Where should blocked-term filtering run?

Model answer

Combine public index/cache candidates with the authenticated user's private-history candidates, then check the whole list before returning it.

Interviewer follow-up

What if filtering leaves only six candidates?

Return six or use a bounded larger prefiltered pool; do not refill from an unchecked source.

What the answer must demonstrate: Checks the combined candidate list and does not refill it from an unchecked source.

08 / FOLLOW-UP

Why is a personalized result unsafe in a public cache?

Model answer

It may reveal one user's history to another. Share only public candidates and perform authenticated personal merging separately.

Interviewer follow-up

Does the public global top ten guarantee the best personal term?

No. A separate personal candidate source or larger pool is needed for that recall.

What the answer must demonstrate: Keeps personal data out of shared results and recognizes candidate recall limits.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design exact-prefix autocomplete with hourly popularity updates. Explain a score decrease, an old browser response and a blocked term in a cached candidate list.

• 0-5 min: agree numbered functional and non-functional requirements for prefix matching, ranking, 200 ms latency, hourly freshness, current approval and privacy.

• 5-12 min: demonstrate the five-word trie and workload estimates.

• 12-20 min: define events, normalized terms and snapshot records.

• 20-30 min: precompute top candidates and explain sharding/rollout memory.

• 30-38 min: handle score decreases, final policy filtering and input sequences.

• 38-45 min: review the final design against the numbered FR/NFR lists, check latency/memory/freshness and blocked-term tests, and state typo/personalization exclusions.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Popularity changes while queries read ca. Why build a separate hourly snapshot instead of editing the live shortlists?

A live update can change a term's score before its prefix shortlist changes. A separate build lets each query use one complete ranking; the cost is delayed popularity updates and memory for both versions.

Prepare once, read consistently.

Why retain terms outside the current top k suggestions?

A lower-ranked term may enter the shortlist when a leading term's score falls or the term is removed.

Today's loser may win tomorrow.

A response for ca arrives after the user types cap. Does a consistent index snapshot make it safe to display?

No. The snapshot keeps ranking data consistent; the browser must also check the input sequence and discard the old ca response.

Version for data, sequence for typing.

Summary and interview notes

Precompute ranked prefix lists and serve each query from one complete snapshot. Filter prohibited suggestions before returning them; the browser displays a response only for its current input.

Remember these points

- Precompute frequent prefix work.
- Build from complete retained vocabulary and scores.
- Pin a compatible snapshot for each request.
- Filter every candidate source and discard old-input responses.

Interview tips

- Work through cap with k equal to two.
- Separate string bytes from index and rollout memory.

Important qualifications

- Hard worldwide removal deadlines require more than an hourly snapshot.
- Exact-prefix matching does not include typo correction.

Explore the advanced version

Hard removal deadlines across servers and clients: Add freshness expiry, uncertainty allowance and display rules when a timed guarantee is required.

Reader lifetime and cross-shard snapshot replacement: Analyze pointer lifetime and version-coherent routing during rollout.

Personal reranking and alternative completion indexes: Measure additional candidate recall and implementation-specific memory/update tradeoffs.

Sampling and aggregation recovery: Study event sampling limits and stronger replay/cutoff protocols.

Technical references

Elasticsearch completion suggester
Official completion API and operational considerations; one possible implementation of fast prefix suggestions.
https://www.elastic.co/docs/reference/elasticsearch/rest-apis/search-suggesters#completion-suggester

Unicode normalization forms
Defines normalization behavior needed for consistent text matching.
https://www.unicode.org/reports/tr15/

CORE INTERVIEWS / 35

Design an API rate limiter

Interview version / 45-minute scope · Read the advanced version online

Choose the quota contract first, then enforce one atomic admission decision across gateways without confusing rate limits, retries and business execution.

admission control • rolling windows • atomic updates • quotas

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Distinguish rolling-window, fixed-window and token-bucket promises.
- Explain atomic check-and-consume with trusted identity and retry recovery.
- State the latency, durability, clock and outage tradeoffs of a shared limiter.

Useful foundations: Capacity estimation: throughput, latency, concurrency and storage; Databases, data models, and ACID transactions; Data partitioning and sharding; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / Specify exactly what consumes allowance

Design a limiter for a video-to-audio conversion API: account u42 may receive at most three accepted admissions in any rolling 60 seconds across all gateways. An admission is permission to start one conversion attempt. A conversion that later fails still consumes its admission. The limiter is not a billing ledger and does not guarantee that downstream work runs only once.

Use authenticated account identity plus API class as the quota key. The client cannot choose another account, its own policy or a fabricated timestamp. Gateways assign internal decision IDs so a retry of one interrupted limiter call can recover its answer without consuming allowance again. Distinct external attempts receive distinct decision IDs.

Choose strict enforcement for this exercise. If the service cannot establish the current quota state, return unavailable rather than create a fresh local allowance. That sacrifices successful-admission availability during some failures. A best-effort overload guard could deliberately choose a simpler, more available policy, but that would be a different contract.

Ask which identity owns the allowance, what event consumes it, whether bursts are allowed, and whether uncertainty should deny or admit. For this exercise the interviewer accepts a strict rolling admission limit even when that reduces availability.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Decide admission for the correct account.** Check the authenticated account and API class before starting a video-to-audio conversion; return an allow, a known quota denial or an unavailable decision.
2. **Apply the stated rolling policy.** Allow at most three accepted admissions in any rolling 60 seconds across all gateways. A later conversion failure does not refund that admission.
3. **Recover interrupted internal checks.** Gateways assign decision IDs and recover the same recorded outcome after response loss without consuming another slot.
4. **Manage policy and retry guidance.** Apply authorized policy changes to existing usage, and return meaningful retry timing for known quota denials without reserving a future slot.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Precision and failure behavior.** No extra strict admission is permitted because a gateway, owner or clock is uncertain. Fail closed when safe shared state or trustworthy decision time cannot be established; this intentionally sacrifices admission availability.
2. **Workload.** Plan for ten million checks/s, including denied requests. The separate cap-500 storage example sizes a higher configured policy and does not change the three-per-minute running example.
3. **Decision latency.** Target p95 of five milliseconds from the trusted gateway's limiter call to its answer within one region under the admitted planning load. Validate the actual synchronous transaction and hot-key mix; the assumed 50,000 decisions/s owner benchmark is not proof.
4. **Durable accepted usage.** An acknowledged allow and its replay result must survive one database-node failure within the region. Failover cannot reset allowance or promote known stale usage as current.
5. **Bounded state and work.** Bound decision-retention windows, active keys, retries and downstream concurrency. Live usage cannot be evicted merely to reclaim memory while it still affects the rolling window.
6. **Trusted callers and time.** Authenticate gateway callers and policy writers. The client cannot supply another principal, choose its own timestamp or reuse an internal allow as unlimited permission for downstream work.

04 / Serialize one account's admission decision

Begin with one application and a SQL database. For each quota key, lock its account-usage row in a transaction. Read the database's decision time, remove accepted events outside the rolling interval, count those remaining and append a new event only if the count is below three. Save the decision result in that same transaction, then respond after commit.

Suppose u42 was admitted at seconds 0, 10 and 20:

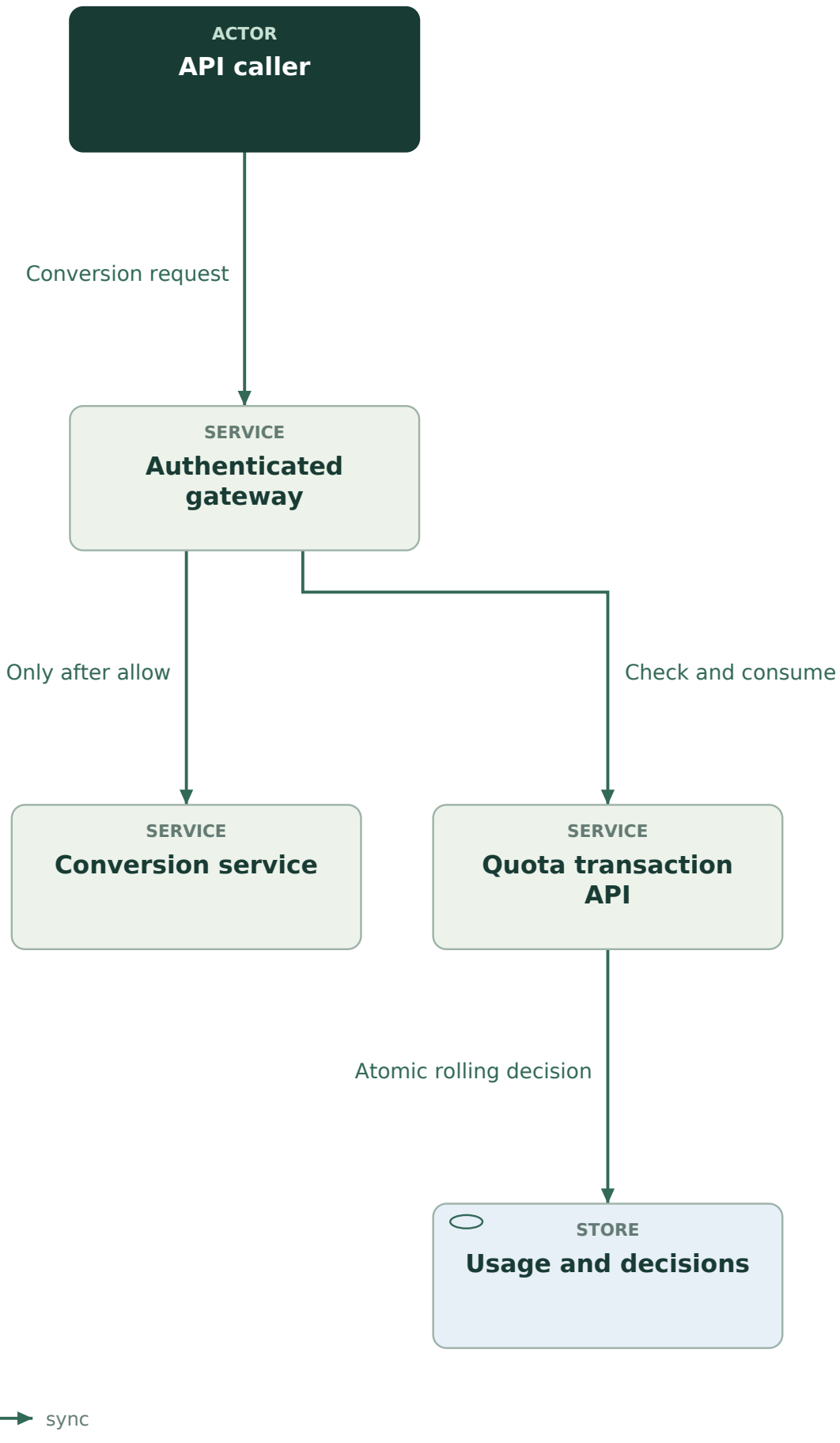
Decision time	Rolling interval	Prior admissions inside it	Result
Second 50	`(-10, 50]`	0, 10, 20	All three remain; deny the next request.
Second 60	`(0, 60]`	10, 20	Zero lies on the excluded left boundary. Remove it; with two remaining, a new request can enter.

The database row lock makes the whole check-and-consume operation indivisible with respect to other requests for u42. If two gateways both compete for the last slot, one completes first; the other sees its accepted event and denies. An atomic counter increment after a separate unlocked check would not provide that result.

Release the transaction before running the conversion. A slow conversion must not hold the quota lock. This is already a working fleet-wide limiter when every gateway uses that database path. Its limits are decision throughput, per-key serialization and the cost of durable state changes.

All gateways share one account allowance

The quota transaction completes before admitted work is forwarded.



05 / Choose the algorithm that matches the promise

A fixed-minute counter is cheaper, but it answers a different question. Three requests at 12:00:58, :59 and :59.5 followed by three at 12:01:00, :00.2 and :00.4 all pass separate clock-minute buckets. Six admissions occur in 2.4 seconds, violating the chosen rolling rule.

Algorithm	Stored state	Actual behavior
Fixed window	Count for one clock interval.	Permits bursts across the boundary.
Rolling log	Individual accepted timestamps.	Exact count in the specified interval, under the clock assumption.
Weighted adjacent windows	Current and previous bucket counts.	Estimates the rolling count; cannot reconstruct exact times.
Token bucket	Available tokens and last refill time.	Allows a chosen burst plus sustained refill rate.
Leaky bucket	Bounded queued or scheduled work.	Smooths departures by waiting or dropping excess work.

For a token bucket of capacity three refilling one token per second, three requests pass immediately from a full bucket; two more can pass two seconds later. That is useful for a burst-tolerant throughput policy, but it cannot stand in for three admissions per rolling minute.

Keep the rolling log for this worked design. Its retained accepted-event count is bounded by the cap under an unchanged policy. A large hourly cap can make that state expensive, which is a reason to renegotiate precision or choose another contract, not silently substitute an approximation.

06 / Include denied traffic in capacity

Assume one million active identities each generate ten checks/s: ten million limiter decisions/s. An exhausted account may continue sending requests, so a three-per-minute allowance does not bound the request rate reaching the limiter.

Quantity	Calculation	Meaning
Decision traffic	10 million/s x 250 B	About 2.5 GB/s before transport and replication.
Owner equivalents	10 million / measured 50,000 decisions/s	200 fully busy equivalents; about 334 at 60% planned utilization.
Rolling state for cap 500	1 million x 500 x 24 B	12 GB of logical accepted-event state.
Three copies of that state	12 GB x 3	At least 36 GB before indexes, keys and replay records.

The 50,000 decisions/s figure is a benchmark input to validate, not a claim about a particular database. Test the actual transaction, replication policy and hot-key distribution against an illustrative five-millisecond decision budget.

Decision replay records have a different bound from accepted events. Attackers can cause many denials, so retain internal decision results for a short documented retry horizon and cap trusted gateway request sizes and identities. Runtime overhead, policy dimensions and duplicate retries may cost more than the packed timestamp bytes.

07 / Separate a denial from an unavailable limiter

The trusted gateway calls the limiter using this internal operation:

```
CheckAndConsume(principal, apiClass, decisionId, policyVersion)
```

Input	Meaning
`principal`	Authenticated account whose allowance is checked.
`apiClass`	The API category sharing that allowance.
`decisionId`	Identity of this internal check, retained across its retries.
`policyVersion`	The configuration version the gateway expects.

Result field	Meaning
`allowed`	Whether this check admits the business request.
`reason`	Why the request was admitted or denied.
`decisionId`	Identifies the recoverable decision.
Earliest retry time, for a quota denial	Earliest time another check may succeed; it does not reserve a slot.

Only an allow result authorizes forwarding the business request.

A known exhausted quota becomes HTTP 429 with suitable Retry-After guidance. An unavailable strict limiter becomes a retryable service error, such as 503, rather than falsely claiming the user exhausted a known quota. Do not publicly cache the 429 response. An internal gateway may retain a conservative private denial hint for that account and API.

At second 50 in the example, the earliest retry time is second 60. If a lost response is recovered at second 59, report approximately one remaining second, rounded conservatively for the public header, not a fresh ten-second delay. Reaching that time permits another check; it does not reserve the next slot.

Policy version identifies configuration, not a new empty usage key. Changing the cap must apply to retained usage. A new longer window requires enough historical data or a conservative transition. A stale gateway must refresh its policy rather than create a separate allowance accidentally.

08 / Keep rules, usage and recovered answers distinct

Record	Fields or information	What it answers
`Policy`	Account plan, API class, version, cap, window	Which rule applies?
`Usage`	Quota key, event ID, admitted time	Which accepted admissions still consume it?
`Decision`	Quota key, decision ID, payload identity, result, expiry	What answer did this interrupted internal call already commit?
Routing partition	Quota-key ownership	Which database group serializes this quota key?

Index usage by quota key, timestamp and distinct event ID. Two requests may share the same timestamp and still be separate admissions. Remove old individual entries on active keys; whole-key expiry alone does not prune an account that remains busy forever.

Retry recovery checks the decision identity before counting or appending. Reusing that identity with a different payload is rejected. The transaction saves usage and its recoverable answer together. Otherwise a crash can consume allowance without recording what to return on retry.

Never treat live strict usage as disposable cache data. Evicting an active key under memory pressure would reset its allowance. Expire state only after it can no longer affect a policy window or supported retry horizon; shed load or add capacity when live state does not fit.



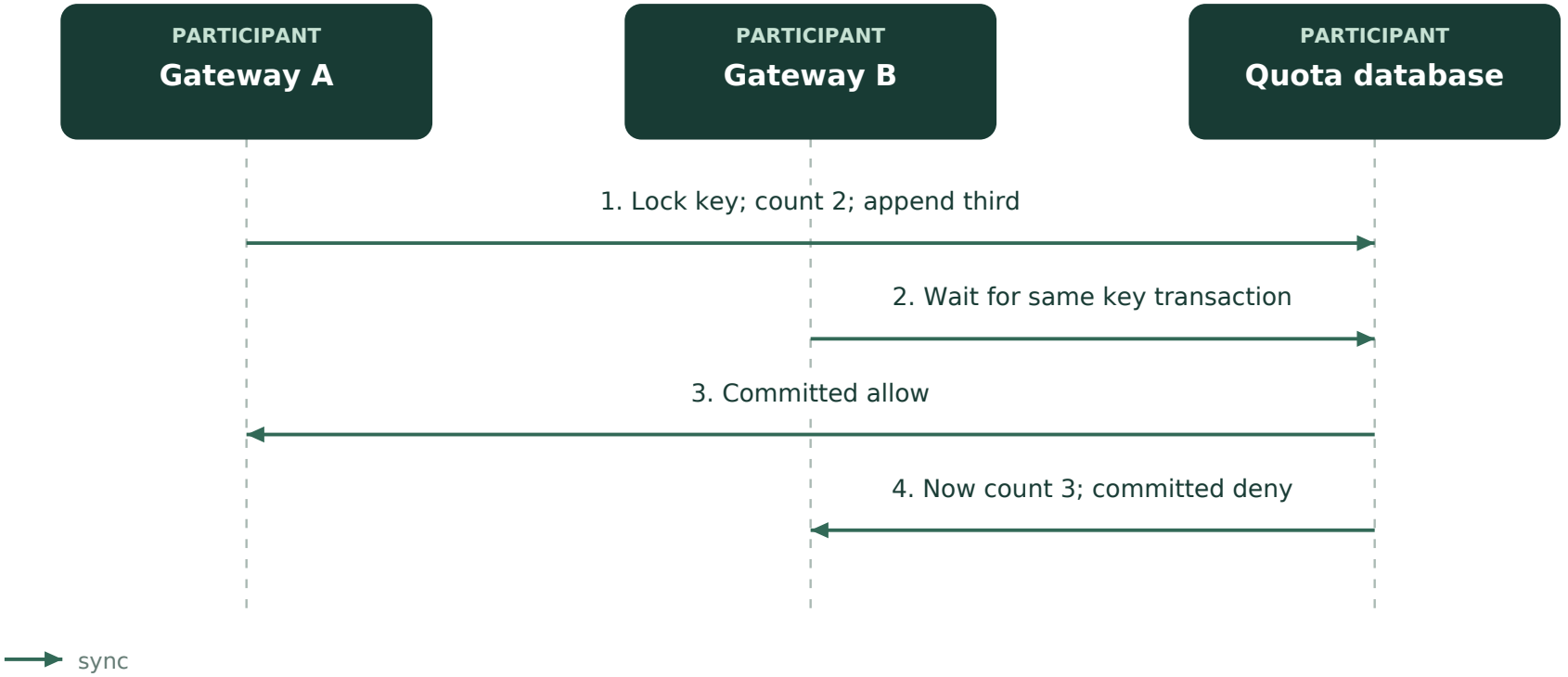
INTERVIEW CRITICAL

Check and consume is one operation

The prune, count, comparison, accepted-event insertion and replay result must commit together for one quota key. Separate reads followed by an atomic increment still allow a last-slot race.

Two callers compete for the final slot

The database serializes the complete transaction, so only one new admission fits.



09 / Distribute keys while keeping each allowance whole

Partition by a stable hash of account and API class. Each partition is hosted by one replicated database group; its leader processes conflicting transactions in order and acknowledges writes only after the required replicas have durably retained them. Choose a datastore that actually supports this commit and failover contract. Stateless gateways can then scale independently while consulting the same allowance for u42.

A minority partition does not grant strict admissions. Routing changes use the datastore's validated leadership and state-transfer mechanism rather than starting an empty new counter service. This keeps the interview focused on the admission design while making the required storage guarantee concrete.

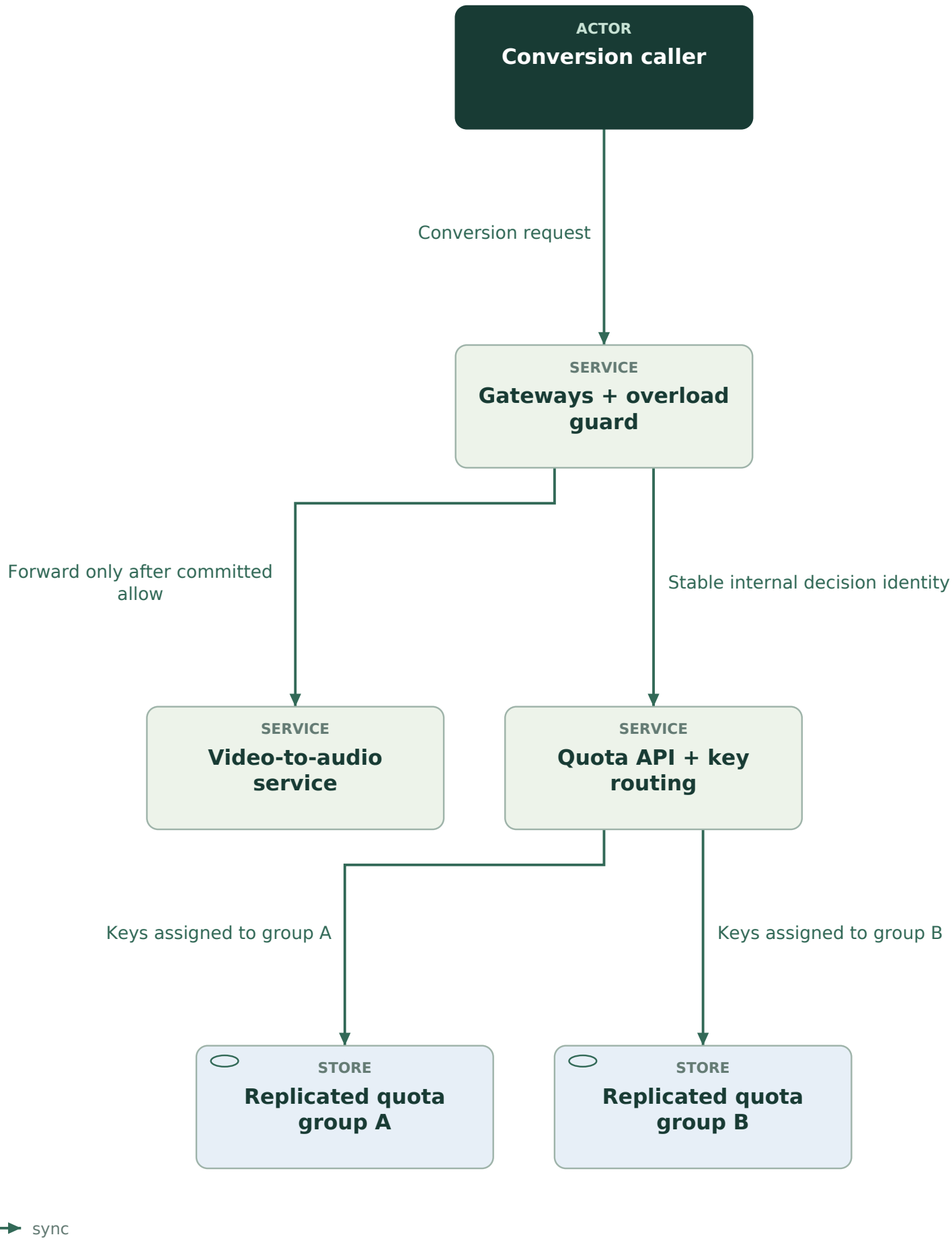
A very hot account still has one serialized decision stream. Adding unrelated partitions does not split it safely. Reduce repeated denials by caching the returned deny-until time privately at gateways. When that hint expires, the gateway checks the owner again; it cannot transform an expired denial into a cached allow. A policy increase can invalidate the hint early, otherwise it may conservatively reject for a little longer.

Place a coarse local overload guard before the shared limiter to protect it from attack traffic. This guard can reject extra work but cannot create additional strict allowance. Cache hits, dashboards and approximate remaining-quota displays never reserve permission to execute.

Use three replicas in independent regional failure domains and require a durable majority for the selected one-node-loss target. Measure the five-millisecond p95 gateway-to-limiter budget with that replication path enabled. If it cannot be met, discuss a larger budget or a different enforcement contract rather than weakening acknowledged-state safety silently.

Route each quota key to one replicated decision group

Gateways reject coarse overload locally, then ask the quota API to route account-and-API keys to their replicated group. That group commits both usage and its recoverable answer. Only a committed allow permits forwarding; another group cannot spend the same allowance when the owner is unavailable.



10 / Recover decisions without granting free work

If the database commits allow for decision r105 but its reply is lost, the gateway retries r105. The saved result returns allow without adding another timestamp. This internal protocol is different from letting a public caller reuse one ID for unlimited conversions. The gateway must also avoid forwarding the same recovered business operation repeatedly without the downstream API's idempotency protection.

If a database leader fails after acknowledging an admission, the chosen replicated store must preserve that committed event through failover. A replacement reading an older two-event snapshot could grant a fourth slot incorrectly. Plain asynchronous replication is not sufficient evidence for the strict promise; choose weaker enforcement explicitly if that is the available infrastructure.

The worked timestamp arithmetic assumes a trustworthy decision clock. Exact real-time expiry under arbitrary clock faults is outside the basic design; uncertain clock recovery pauses strict admissions rather than expiring records speculatively. Make this assumption explicit instead of treating timestamps as proof of physical time.

Fail closed when the quota group is unreachable or its safe state is uncertain. For a trusted clock moving backward, do not move decision time backward and reopen earlier state. A suspicious forward jump must not expire recent events prematurely. Stop admissions until the service's time bounds are restored; detailed clock-error accounting is an Advanced follow-up.

Limit retries and time spent waiting. The limiter should reject or fail within a bounded budget instead of accumulating a queue that consumes more resources than the API it protects.



INTERVIEW CRITICAL

Lost replies and new attempts have different identities

Replay the same trusted internal decision to recover its committed answer. A new external attempt consumes a new admission, and downstream execution still needs its own retry contract.

11 / Protect both the quota and the downstream workers

Measure decision latency, accepted and denied rates, unavailable strict decisions, hot-key traffic, state size and replication health. Compare sampled admissions with a reference rolling-window checker. A low denial rate is not success if the conversion workers are overloaded.

Rate limits control arrivals over time; they do not directly cap concurrent work. If conversions take a minute, even an acceptable sustained admission rate can fill the worker pool. Add a separate bounded work queue and concurrency cap, and decide whether a failed admission-to-execution attempt is charged under the stated rule.

Account rules need verified credentials. IP-only limits can punish unrelated users sharing one public address and can be evaded through address rotation. Use endpoint-specific combinations of account and network controls without allowing attackers to allocate unlimited anonymous keys. Administrative policy changes need authorization and an audit trail.

A policy migration must preserve usage. Raising a cap is straightforward; lowering it may require several old events to expire before another admission fits. Test simultaneous last-slot requests, boundary timestamps, lost replies, failover after acknowledgment and memory pressure. Do not "repair" a strict-state incident by clearing the counters.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1-2 + NFR1: exact admission	One quota-key transaction prunes, counts and conditionally appends accepted events.	Replay 0/10/20/50/60-second boundaries and race two gateways for the last slot against a reference checker.
FR3 + NFR4: safe retry and failover	Usage and replay answer commit together under synchronous replicated storage.	Lose an allow reply and then fail one database node; recovery must not consume again or reopen an old slot.
FR4 + NFR5-6: safe policy changes	Authorized versioned policy and retained usage, with bounded private deny hints.	Raise/lower a cap and test a longer-window transition. Expired denial hints require another real check, not an allow.
NFR2-3: useful performance	Independent quota-key partitions, coarse overload guards and reduced repeated denial work.	Benchmark p95 at the declared regional load, including synchronous commits and hot keys; renegotiate precision if the budget cannot be met.
NFR1,5: failures remain bounded	Conservative clock recovery, fail-closed state uncertainty and separate work-concurrency limits.	Inject clock jumps and owner isolation. Paused strict admissions are an intentional outcome, not a successful fast denial.

13 / Rapid revision

Remember: Checking and consuming must happen together; otherwise two gateways can both take the last slot.

Decision	Why it is needed	Limitation
Rolling accepted-event log	Enforce three in any 60 seconds.	Store up to the accepted cap per window.
Atomic transaction per key	Only one contender can consume the last slot.	Requests sharing one quota key take turns.
Stable internal decision ID	Recover a lost answer without double charging.	Does not make downstream execution exactly once.
Replicate saved usage and decisions	Preserve usage through failures that replication tolerates.	Pause when disconnected replicas cannot agree safely.

Decision	Why it is needed	Limitation
Brief gateway cache of a denial	Avoid repeated checks of exhausted quota.	Cached denials cannot grant admission.
Use trusted time; recover conservatively	Avoid freeing quota too early.	Pause admission until clock uncertainty is resolved.
Separate concurrency control	Protect long-running workers.	A rate cap does not limit simultaneously running jobs.

In a 90-second close, state the identity, counted event, rolling interval and failure policy. Walk the 0/10/20/50/60-second example, then the two-gateway last-slot race. Finish with the tradeoff: exact shared enforcement costs coordinated state and may reject during uncertainty. If the interviewer instead wants a burst of 100 and a sustained ten per second, choose a token bucket and explain its arithmetic rather than carrying the wrong rolling contract forward.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What must be clarified before choosing a limiter algorithm?

Model answer

Ask whose allowance is shared, which action consumes it, over what interval, whether bursts are allowed and whether an outage should admit or deny. Those answers determine the algorithm and stored state.

Interviewer follow-up

Does a failed conversion refund allowance here?

No. This contract counts accepted admissions, not successful conversions.

What the answer must demonstrate: States all dimensions of the product contract before storage.

02 / APPLIED

Why does a fixed-minute counter violate this rolling policy?

Model answer

It can admit three just before a clock boundary and three immediately after, all inside one rolling minute.

Interviewer follow-up

Would a token bucket fix the same contract?

Not automatically; token refill and capacity define a burst/rate promise rather than this exact rolling cap.

What the answer must demonstrate: Demonstrates the boundary counterexample and distinguishes burst semantics.

03 / APPLIED

Two gateways see two used slots. How do you avoid admitting both?

Model answer

Serialize prune, count, compare and insertion inside one quota-key transaction. The second transaction sees the first accepted event.

Interviewer follow-up

Is an atomic increment enough?

No, if its eligibility check occurred separately before another request consumed the slot.

What the answer must demonstrate: Makes the eligibility check and effect one atomic operation.

04 / APPLIED

What happens when an allow reply disappears?

Model answer

Retry the trusted internal decision ID and recover its saved answer without another usage event.

Interviewer follow-up

Can the public client reuse that identity for free work?

No. The gateway controls admission identities, and business execution has a separate idempotency contract.

What the answer must demonstrate: Separates internal decision recovery from business idempotency.

05 / FOLLOW-UP

Why is asynchronous counter replication insufficient for strict failover?

Model answer

A promoted replica may lack an acknowledged admission and grant extra allowance. The selected datastore must preserve committed usage or stop admission.

Interviewer follow-up

What if availability is more important?

Negotiate an approximate policy with an explicit overshoot budget.

What the answer must demonstrate: Connects acknowledged-state survival to the chosen availability tradeoff.

06 / APPLIED

Why can you cache a deny hint but not an allow?

Model answer

A conservative denial cannot add extra admissions; reusing an allow would skip the state-changing consume operation.

Interviewer follow-up

Does the retry deadline reserve the next slot?

No. Other requests may consume it before the caller returns.

What the answer must demonstrate: Uses denial conservatively and never turns cached permission into free quota.

07 / APPLIED

Can a rate limit alone protect expensive long-running work?

Model answer

No. Arrival rate multiplied by execution duration determines in-flight work, so a separate concurrency limit or bounded queue may be needed.

Interviewer follow-up

Should the quota lock be held during execution?

No. Commit and release the admission transaction before running business work.

What the answer must demonstrate: Separates arrival rate from in-flight resource use.

08 / APPLIED

What failure can a forward clock jump cause?

Model answer

It can make recent admissions appear older than the window and release allowance too early.

Interviewer follow-up

What does this design do during uncertain recovery?

Pause strict admissions until trustworthy time bounds and committed state are established.

What the answer must demonstrate: Explains premature expiry and the explicit trusted-time limit.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a shared limiter for three accepted conversions per rolling minute. Show simultaneous requests, a lost allow reply and an unavailable quota group.

• 0-5 min: agree numbered functional and non-functional requirements for identity, counted event, interval, strict failure behavior, peak checks and decision latency.

• 5-12 min: trace 0/10/20/50/60 and compare algorithms.

• 12-20 min: define atomic transaction, API and replay records.

• 20-30 min: estimate denied traffic and partition independent keys.

• 30-38 min: explain last-slot races, failover and trusted time assumptions.

• 38-45 min: check the final design against the numbered FR/NFR lists with boundary, race, failover and p95-load tests, then discuss explicit precision/availability tradeoffs.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Two gateways see two admissions inside the current three-slot window. What prevents both from admitting another request?

Each runs the whole prune, count, compare, append and decision-record operation in one transaction for that quota key. One commits first; the other sees three and denies.

Check and consume together.

A denied request receives a retry time. Is a slot reserved for that time?

No. The caller may check again then, but other callers may have consumed the available slots.

Retry is a check, not a ticket.

What happens if the limiter cannot determine how much allowance remains?

Strict enforcement pauses new admissions rather than risk exceeding the shared limit. Durable, coordinated usage records make safe recovery possible.

No state, no new strict allowance.

Summary and interview notes

Gateways share one allowance. Each transaction checks and consumes a slot together; saved usage and decisions prevent retries or supported failover from granting extra slots.

Remember these points

- Choose the time contract before the algorithm.
- Serialize the complete check-and-consume.
- Recover lost answers with internal identities.
- Preserve committed usage or stop strict admissions.

Interview tips

- Use the boundary burst to distinguish algorithms.
- Count denied traffic when estimating capacity.

Important qualifications

- The limiter is not a billing ledger or an exactly-once executor.
- Clock-fault guarantees and multi-region credit protocols require deeper treatment.

Explore the advanced version

Clock bounds and conservative physical-time expiry: Derive a timed guarantee under measured clock uncertainty rather than the basic trusted-clock assumption.

Multiple quota dimensions and ownership transfer: Analyze cross-owner reservations and stale ownership in detail.

Ordered policy rollout: Define when a new rule is enforced by every serving partition.

Global and regional credit allocation: Explore burst-oriented reserved budgets without claiming independent regions share exact rolling state.

Technical references

Redis: atomic script execution
Explains server-side atomic execution and why scripts must remain short; not a promise of transactional rollback.
https://redis.io/docs/latest/develop/programmability/eval-intro/

RFC 6585: HTTP 429
Defines Too Many Requests, optional Retry-After, and response caching restrictions.
https://www.rfc-editor.org/rfc/rfc6585.html

Redis WAIT consistency limitations
Replica acknowledgment waiting improves safety but does not establish strong consistency or guaranteed lossless failover.
https://redis.io/docs/latest/commands/wait/

Redis: rate-limiting algorithm comparison
Standard names and mechanisms for fixed windows, sliding-window logs, sliding-window counters, token buckets and leaky buckets; an approximation does not establish our strict rolling guarantee.
https://redis.io/tutorials/howtos/ratelimiting/

CORE INTERVIEWS / 36

Design public post search

Interview version / 45-minute scope · Read the advanced version online

Build a recoverable public-post search index, then merge bounded shard results without confusing matching, ranking, freshness and permission.

inverted index • postings • search freshness • tombstones

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace terms into an inverted index and distinguish Boolean matching from ordering.
- Explain time/document partitioning and stable bounded pagination.
- Handle repeated edits/deletes, index recovery and current-content checks safely.

Useful foundations: Database indexes: B-trees, composite keys and query access; Data partitioning and sharding; Replication and durability; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / Choose public keyword search and its limits

Design keyword search over public short posts. A query can combine terms with explicit AND or OR and request newest-first results. Add lexical relevance as a discussed extension; most-liked and personalized ordering require their own feature and candidate-selection contracts. The source posting service already exists and remains responsible for accepting posts and determining current visibility.

Use three running documents:

Document	Text
`T101`	solar battery
`T102`	solar roof
`T103` (newer)	new solar battery

The query `solar AND battery` should match `T101` and `T103`, not `T102`. This small example lets the interviewer verify the search semantics before discussing a cluster.

Accept several seconds between source commit and search visibility. An accepted source post need not appear in search immediately. Deletion and restriction are checked when results are returned, so an old index entry cannot grant access. Choose the recent two years as the interactive search scope and a slower path for older retained history.

Bound query length, page size and historical span. For this design, a missing required shard causes an explicit retryable search failure. Partial results could be a product option, but the API must then disclose incomplete coverage; a short list cannot silently claim to be exhaustive.

Clarify Boolean matching and sort order, how long indexing may lag, the interactive history window, and whether partial results are acceptable. The chosen requirements use newest-first results and an explicit failure when a required shard is missing.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Search public posts.** Accept explicit AND/OR keyword queries and return matching current public posts in newest-first creation-time/ID order.
2. **Page through bounded results.** Let readers continue a query through a consistent ordered set of results for a limited browsing period; reject expired or mismatched continuation requests.
3. **Apply source changes.** Index creates, edits and deletions from the existing posting service, using source-assigned versions and compatible analyzers.
4. **Disclose query failure.** Return an explicit retryable error if a required shard cannot answer. Do not silently present incomplete shard coverage as exhaustive results.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload and history.** Use approximately 28,935 searches/s and 23,150 source changes/s at the planning peak. Interactive search covers two years; older retained history has a separate slower path.
2. **Query latency.** Target regional p95 response latency of 300 ms for the agreed bounded query mix at admitted peak load during normal operation. The benchmark must include common terms, shard merge and final source checks, not only cached rare-term queries.
3. **Index freshness.** Target p95 source-commit-to-searchable delay within five seconds during normal ingestion. Newly matching edits can be absent until indexed even when every returned record is current.
4. **Result consistency.** Use one pinned index snapshot for a page sequence, with a two-minute lifetime and at most 100 results/page. Recheck current deletion, visibility and matching text; the snapshot does not freeze permission.
5. **Recoverability.** Retain durable source snapshot/change-log coverage sufficient to rebuild a lost search shard. A search-process or index-node failure must not destroy the source; if required history is unavailable, stop and rebuild from a newer source snapshot.
6. **Bounded and authorized work.** Limit terms, historical span, candidate/refill work and page contexts. Return an error or shorter authorized page rather than unbounded work or uncertain private content.

04 / Retrieve matching IDs instead of scanning every body

An inverted index maps a term to the document IDs containing it. Each such list is a posting list.

Term	Posting list in the running example
`solar`	`T101`, `T102`, `T103`
`battery`	`T101`, `T103`

Intersect the lists for AND, or union them and remove duplicates for OR. Then sort the matching IDs by creation time and ID, newest first.

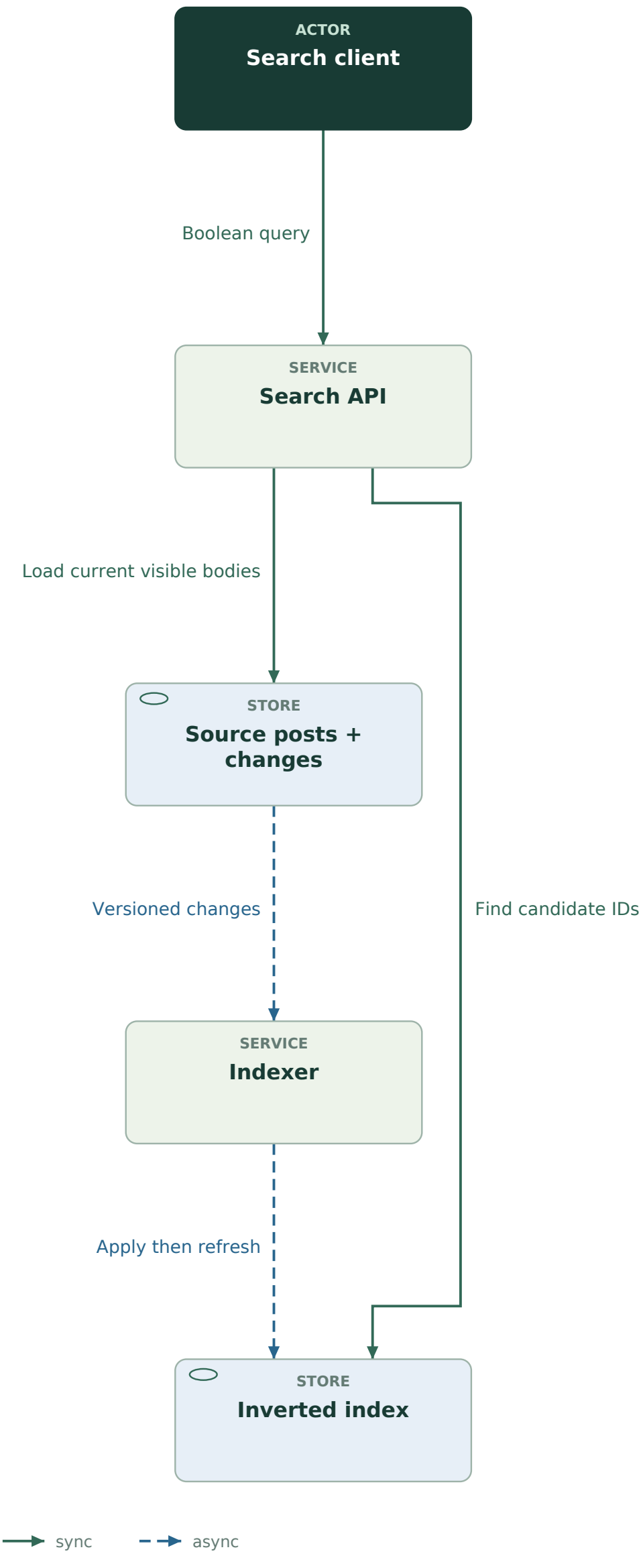
One search process with a durable local search index is enough for the first version. The source stores a post and a pending change event in one transaction. A background indexer consumes that event, splits text into searchable terms and normalizes them using analyzer A1. An analyzer is the configured text-processing pipeline, and queries must use compatible rules.

After the index refreshes, the query can see T103. The search process retrieves its current source body and visibility, confirms it is still an eligible match and returns it. This final record-loading step is often called hydration. It prevents a candidate ID from being mistaken for permission to return stale cached text.

Use a mature search engine for the index files and posting traversal. The interview's task is to explain the data path, updates and guarantees, not implement compression formats. This baseline is complete, but one process eventually runs out of useful storage, query CPU or ingest capacity.

A source change becomes searchable asynchronously

The API reads the index for candidates and checks source records before returning text.



05 / Measure posting work and distributed fanout

Assume 400 million posts/day averaging 300 bytes and 500 million searches/day. Use fifteen indexed terms per post as a storage estimate and fivefold peak traffic.

Quantity	Calculation	Consequence
Source writes	400 million / 86,400 ~ 4,630/s	About 23,150/s at peak.
Searches	500 million / 86,400 ~ 5,787/s	About 28,935/s at peak.
Five-year source text	120 GB/day x 365 x 5	219 TB before indexes and replicas.
Two-year posting payload	292 billion posts x 15 terms x 5 B	21.9 TB before positions, versions and overhead.
Forty-shard peak fanout	28,935 x 40	About 1.16 million shard queries/s.

If each shard returns 100 candidates of 32 bytes, forty shards send 128 KB per query, approximately 3.7 GB/s at peak just for merging. By contrast, twenty returned 300-byte bodies total only 6 KB of raw text. Small result pages do not imply small retrieval work.

The five-byte document reference is an illustrative packed representation with enough range for this population, not a recommended permanent allocation format. Vocabulary strings are much smaller than all their postings. Measure common-word posting lengths, compression, deletion overhead and rebuild capacity before concluding the index fits in memory.

06 / Make query meaning and continuation explicit

Search request

```
GET /search?q=solar%20AND%20battery&sort=latest&limit=20
```

Response information	Meaning
Results	Current eligible matching posts in the requested order.
Opaque continuation cursor	Identifies where a later page resumes.
Search snapshot expiry	Tells the client when that page sequence expires.

Reject malformed Boolean syntax instead of silently changing AND into OR. Authentication supplies quota and visibility scope.

A point-in-time snapshot retains a chosen visible index state for a bounded page sequence. The cursor binds that snapshot, normalized query, filters, sort definition and last returned sort values. Search-after pagination resumes beyond that last tuple. New posts therefore do not shift the numeric offsets of later pages.

Choose a two-minute snapshot lifetime and a maximum of 100 results per page for this exercise. Expired cursors require a restart. Reusing a cursor with another query is an error. Current deletion and access checks still run on each page: snapshot stability does not freeze permission.

The ingestion interface distinguishes source updates from search requests.

Event information	Purpose
Post ID	Identifies the document being changed.
Source-assigned version	Lets indexing reject an obsolete update.
Operation	Distinguishes create, edit and delete.
Durable source-log position	Identifies progress through recoverable source history.

Source commit success and searchable visibility are separate API facts; report index freshness operationally rather than claiming that storing an event instantly updates every query replica.

07 / Preserve document identity across edits

Separate authoritative post records from the search index built from them.

Stored structure	Information	Purpose
Source posts	Stable post ID, current version and visibility	Supplies the current post and access state.
Source change log	Recoverable post updates	Supplies the changes needed to rebuild the index.
Derived search index	Term dictionaries, postings and each document's latest applied version or delete marker	Finds candidate documents while tracking which source version was indexed.

Optional term positions support phrase search, but add bytes; the basic AND/OR scope does not require that feature.

Choose creation-time buckets, subdivided by a hash of post ID, for index ownership. All terms of one post live in the same document shard, and an edit stays in the original bucket. Moving a post whenever it is edited would complicate removal from its old location and duplicate suppression.

A body cache uses post ID and immutable content version. Query caches store candidate identities under their query, filters, sort and index version; cached candidates still undergo current checks. A post's body and the permission decision must refer to the same version. Do not authorize public version one and then accidentally substitute an edited private version two.

Keep engagement features separate from lexical postings so every new like need not rewrite the text index. In the selected newest-first design, those features can be delayed display fields. A future exact most-liked sort must use them during candidate selection, not only rerank twenty recent matches.

08 / Partition by documents and prune by time

Document partitioning keeps the words and version of each post together. Each shard can evaluate the complete Boolean query locally, then return its newest candidates. The coordinator merges shard results by the same creation-time/ID order. Time buckets allow a last-day query to skip older indexes, while a broad historical query deliberately pays a larger fanout cost.

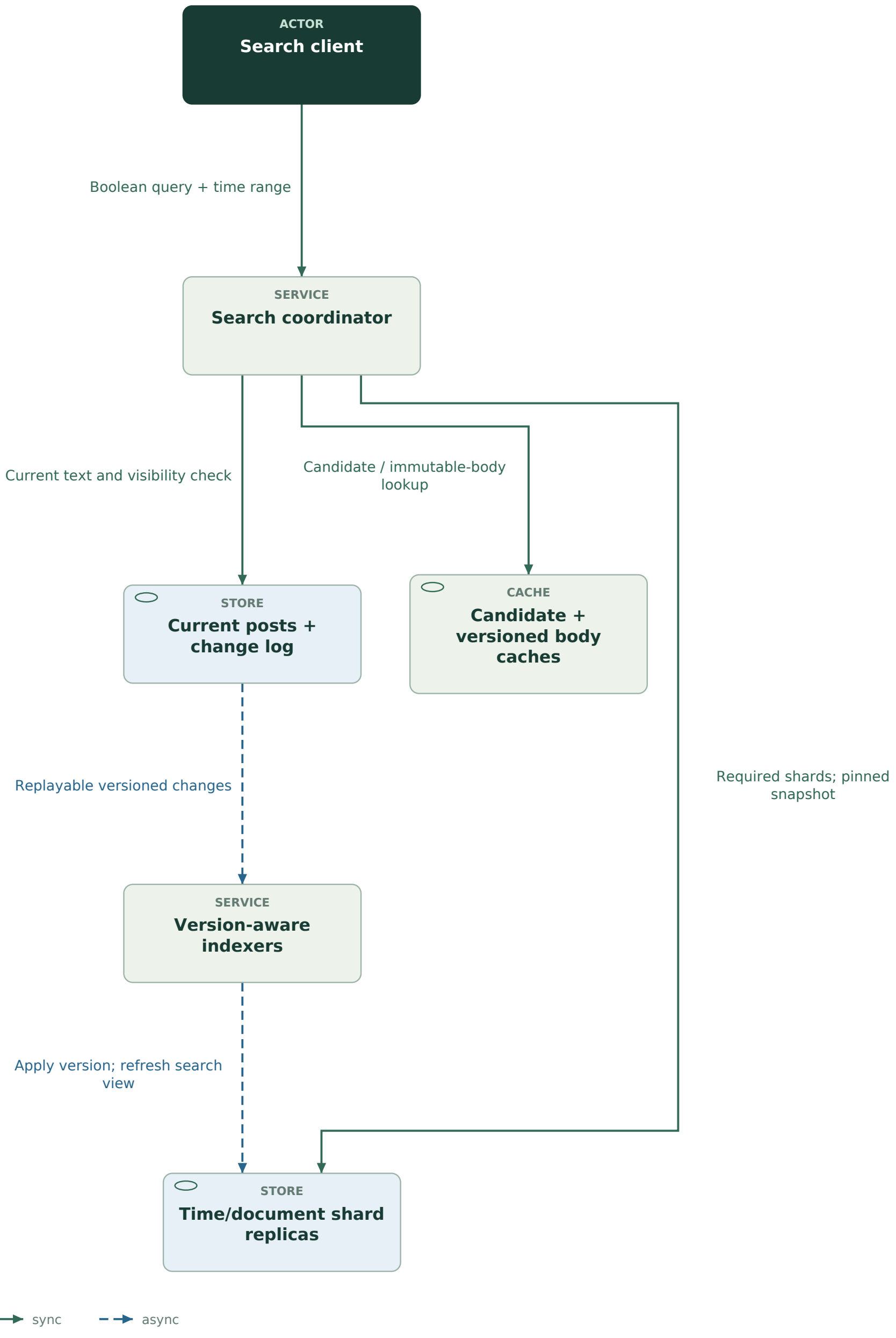
Term partitioning is a different option: solar might live on one machine and battery on another. It makes some single-term queries local, but common terms become hot and multi-term intersections cross owners. For the worked workload, choose time/document partitioning and accept bounded scatter/gather - the coordinator sends a query to relevant shards and gathers their answers.

Add replicas when query CPU saturates. They distribute independent queries but also consume index storage and ingest traffic. Select replicas that can serve the pinned snapshot. A replica being alive does not establish that it contains the required version.

Allocate a deadline for shard work that leaves time for merging and final record/visibility checks. Limit terms, candidates, refill rounds and page contexts. Under the selected strict-coverage policy, a required shard timeout fails the query; do not retry every shard repeatedly and multiply the overload.

Partition the index by time and document; merge before returning

Versioned source changes feed rebuildable index shards. The coordinator queries every required time/document shard at the chosen snapshot, merges newest-first candidates, then checks current matching text and visibility. Cached candidates take the same final checks; a required-shard timeout fails the strict-coverage query.



09 / Apply newer document versions monotonically

Suppose T103 is edited at version 11 and deleted at version 12. If an indexer blindly applies a delayed version-11 event after the delete, it recreates a searchable old document. The writer must atomically compare the incoming version with the stored version and apply only a newer one.

A delete retains its version marker while older events can still replay. Simply removing the document and forgetting version 12 leaves no evidence that version 11 is obsolete. Repeated version-12 delivery has no additional effect. The index engine must prevent another update from intervening between the version check and the write, using serialized updates or an atomic version condition. A separate unlocked read is insufficient.

Persist source progress only after the corresponding index changes are recoverable. If an indexer applies an update and crashes before checkpointing, replaying it is safe through the version rule. If it checkpoints first and crashes before durable indexing, recovery may skip an update that never survived.

A source snapshot plus its matching change-log position allows a new index generation to be built, then caught up with subsequent events. Validate that generation before routing new searches to it. The precise multi-partition snapshot/watermark protocol is an Advanced follow-up, but the basic design must identify its recovery source and never claim a rebuild is current after incomplete replay.



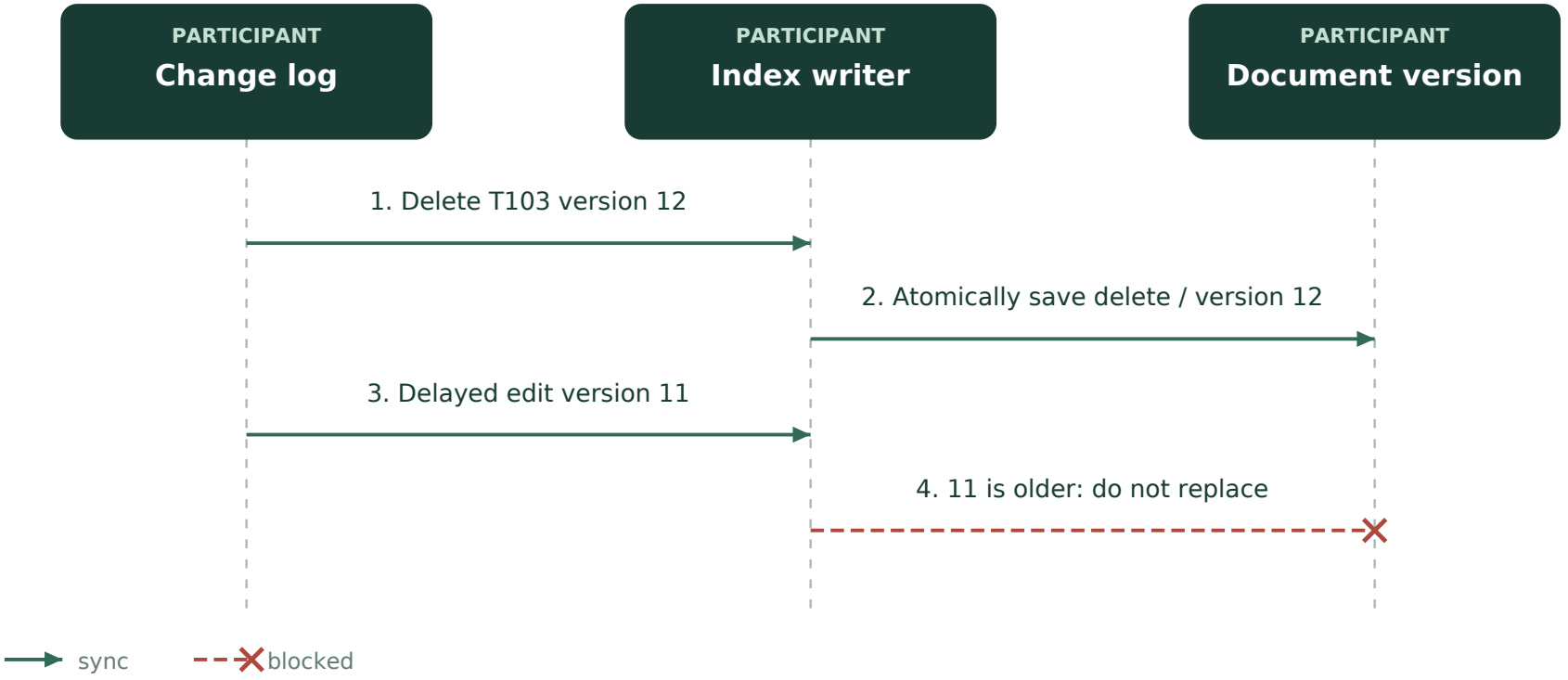
INTERVIEW CRITICAL

A delete must outrank delayed edits

Keep the latest applied document version, including delete markers, and enforce comparison plus application atomically. A late version-11 edit cannot replace version-12 deletion.

A delete survives an older edit replay

The per-document version guard rejects older work after the delete is recorded.



10 / Return current matching content, then explain ranking

For solar AND battery, shards return matching candidate IDs and their sort values. The coordinator merges them, removes duplicates and batch-loads source records with current visibility. If T103 is now private or deleted, omit it. If it was edited to "new solar roof," its current body no longer satisfies the query; re-evaluate the Boolean terms against that returned version and omit it until the index catches up.

This final check prevents incorrect disclosure and stale-text matches, but it cannot discover every newly matching edited post before indexing. Some newly matching posts and their correct ranking remain missing until indexing catches up. Fetch a bounded number of extra candidates after filtering; return a shorter page rather than loop indefinitely.

Matching and ranking are separate. Both T101 and T103 match the AND query, but newest-first favors T103. A lexical relevance score such as BM25 considers term frequency, corpus rarity and document length; it may favor the shorter, more focused T101. Scores from different shards need compatible analyzers and a defined corpus-statistics policy before they can be compared meaningfully.

Do not promise globally most-liked results by reranking only the newest twenty. A highly liked older match may never enter that candidate set. Either include popularity in each shard's candidate selection using a pinned feature version or describe the result as a bounded-candidate approximation.



INTERVIEW CRITICAL

An index candidate is neither current text nor permission

Load and authorize the same current content version, then verify it still matches. An old snapshot may stabilize order, but it cannot authorize a deleted or newly private body.

11 / Recover the index and bound expensive queries

The durable source and its retained change log recover lost search indexes. Restore a validated snapshot and replay from its recorded position. If the log no longer covers the gap, take a newer source snapshot instead of pretending a partial replay is complete. Keep capacity for temporary old/new index generations during analyzer changes and rebuilds.

Measure source-commit-to-searchable delay, query tail latency, posting entries scanned, shard fanout, timeout rate and rebuild duration. Check deletion behavior separately from ordinary indexing freshness. A fast response missing half the intended shard coverage is not a successful search under the chosen contract.

Rate-limit by authenticated client and query cost. Bound wildcards or omit them, cap terms and historical span, and cancel work after deadlines. Popular query caches can save repeated traversal, but arbitrary new queries still need real work. Current visibility failure causes omission or query failure, never optimistic disclosure.

Roll out analyzer changes into a separate generation and compare fixed examples for AND/OR behavior, languages, relevance and deletion. Removing stop words or changing normalization alters meaning; it is not merely a performance optimization. Search replicas and caches improve serving capacity, while durable source history and tested replay provide recovery.

12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1 + NFR2,4: correct fast query	Compatible postings, time/document shards, common sort tuples and current source checks.	Test AND/OR against the three documents, then benchmark common-term p95 including all required shards and final checks.
FR2 + NFR4: stable continuation	Bounded snapshot and query-bound search-after cursor.	Add new posts between pages, expire the two-minute cursor and delete a prior match. Stable ordering cannot override deletion.
FR3 + NFR3,5: fresh recoverable index	Versioned source events, guarded index updates and progress after recoverable writes.	Replay an old edit after deletion and rebuild a shard. Measure five-second freshness separately from source acceptance.
FR4 + NFR6: honest degradation	Required-shard deadlines and bounded candidates/refill.	Fail a required shard and expect an explicit query failure; filtered results may be shorter and newly matching edits may still be missing.

13 / Rapid revision

Remember: An index finds possible matches; retained versions stop old edits undoing deletes, and current source checks govern returned text.

Decision	Purpose	Tradeoff or boundary
Inverted postings	Retrieve matching IDs without a source-table scan.	Common terms still have large lists.
Analyze text and queries consistently	Produce compatible index and query terms.	Analyzer changes require a versioned rebuild.
Partition by time bucket and document ID	Keep each post's terms together; skip irrelevant time buckets.	Broad queries contact many shards.
Versioned updates and tombstones	Stop repeated or delayed events resurrecting old content.	Keep versions while older events can still arrive.
Snapshot plus last returned sort position	Continue through one fixed, expiring index view.	Saved views consume resources and expire.

Decision	Purpose	Tradeoff or boundary
Recheck source version and current visibility	Exclude inaccessible posts and nonmatching edited text.	Extra reads and possibly shorter pages.
Newest-first chosen ordering	Merge shard results by creation time, then post ID.	Relevance and popularity need shared scoring rules and inputs.

Close by tracing T103 through durable source creation, asynchronous indexing, Boolean retrieval, shard merge and current-result checking. Then demonstrate delete version 12 defeating a late edit. The central tradeoff is efficient distributed search with a few seconds of index delay, while source records remain the basis for recovery and permissions. The next measurements are common-term traversal cost, fanout tail latency and rebuild duration.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How does solar AND battery find its matches?

Model answer

Intersect the solar and battery posting lists, yielding T101 and T103 in the example. OR would union IDs and deduplicate.

Interviewer follow-up

Does ranking change Boolean matching?

No. It orders eligible matches after the query's matching semantics are applied.

What the answer must demonstrate: Demonstrates intersection/union before ordering.

02 / APPLIED

Why can a saved post be missing from search?

Model answer

Source commit and index refresh are separate stages. A durable change event allows recovery while search visibility is temporarily delayed.

Interviewer follow-up

What does a queue message alone fail to prove?

That the corresponding index change is durable and visible to queries.

What the answer must demonstrate: Separates committed source, recoverable event and searchable refresh.

03 / APPLIED

Why choose time/document shards?

Model answer

Each post's terms update together, each shard evaluates the full Boolean query, and time filters skip old buckets.

Interviewer follow-up

What cost remains?

Queries covering many buckets scatter to many shards and wait for their required results.

What the answer must demonstrate: Connects document locality and time pruning to fanout cost.

04 / APPLIED

How does a delete defeat a late edit?

Model answer

Store the source-assigned latest version and atomically reject older updates. Keep the delete version through the replay horizon.

Interviewer follow-up

Why not just remove the index row?

Forgetting its version allows an old edit to recreate it.

What the answer must demonstrate: Uses an atomic version comparison and retains deletion evidence.

05 / APPLIED

When may an indexer advance its source position?

Model answer

After the indexed changes are recoverable. Replaying already applied versions is safe; skipping undurable changes is not.

Interviewer follow-up

What if the log gap is no longer retained?

Rebuild from a newer consistent source snapshot instead of claiming complete replay.

What the answer must demonstrate: Never lets progress outrun recoverable index state.

06 / APPLIED

Why combine a snapshot and search-after?

Model answer

The snapshot fixes the visible index state, and the last sort tuple gives a stable continuation position without shifting offsets.

Interviewer follow-up

Must a deleted item still appear to preserve the snapshot?

No. Current deletion and permission checks override snapshot membership.

What the answer must demonstrate: Combines stable ordering with current deletion checks.

07 / APPLIED

An indexed match now has different text. What should be returned?

Model answer

Authorize and load the same current version, then verify it still satisfies the query. Omit a nonmatch; the index may temporarily miss new matches too.

Interviewer follow-up

Can a cached public permission authorize a newly private version?

No. The permission decision must bind the returned content version.

What the answer must demonstrate: Binds content and permission versions and acknowledges recall lag.

08 / FOLLOW-UP

Why is reranking twenty recent matches not globally most-liked search?

Model answer

A highly liked older match may be absent from the retrieved set. Popularity must affect candidate selection or the result must be labeled approximate.

Interviewer follow-up

What must relevance merging define?

Comparable scoring, analyzer versions and a corpus-statistics policy across shards.

What the answer must demonstrate: Recognizes missing candidates and score comparability requirements.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design public-post keyword search. Use the three solar documents to demonstrate matching, then handle a late edit after deletion and a missing query shard.

• 0-5 min: agree numbered functional and non-functional requirements for matching, ordering, 300 ms latency, five-second indexing, history, privacy and shard failure.

• 5-12 min: explain postings and the complete single-node path.

• 12-20 min: estimate posting/fanout work and define APIs/data.

• 20-30 min: choose time/document shards, replicas and stable pagination.

• 30-38 min: handle versions, checkpoints and current-result checks.

• 38-45 min: review the final design against the numbered FR/NFR lists, test query/freshness/rebuild behavior and state snapshot, incomplete-index and ranking limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Does an inverted-index match mean the post may be returned?

No. The index supplies possible matching IDs; the current source version and permission checks decide what may be shown.

Terms find; source confirms.

T103 is deleted at version 12, then an old version-11 edit arrives. What must the index retain and check?

Retain delete version 12 and atomically reject version 11 as older. Removing the document without its version would let the delayed edit recreate it.

Remember the delete's version.

How does the next search page continue without reordering the same results?

Use the same unexpired index snapshot and continue after the last result's creation time and post ID.

Same view, next position.

Summary and interview notes

An inverted index finds matching post IDs without scanning all posts. Version checks stop stale updates undoing deletes; current source and permission checks decide which results may be returned.

Remember these points

- Separate matching from ranking.
- Keep document terms together and prune historical scope.
- Accept only newer document versions; save progress after the index changes can be recovered.
- Pin page state while still checking current content and permission.

Interview tips

- Use three documents to prove AND/OR behavior.
- Compare candidate-merging bytes with final response bytes.

Important qualifications

- The selected API fails on incomplete required shard coverage.
- Personalized and globally most-liked ranking need additional candidate contracts.

Explore the advanced version

Snapshot watermarks and generation-safe rebuilds: Prove the relationship between source snapshots and multiple change-log positions.

BM25 and comparable distributed scores: Work through lexical relevance and pinned popularity feature generations.

Version-bound hydration and filtered pagination: Analyze exact content-version checks and bounded candidate refill.

Private and semantic search extensions: Add access-aware or embedding candidate generation without losing freshness and privacy contracts.

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Defines BM25 term-frequency saturation, document-length normalization and inverse document frequency; this versioned reference is not a claim about the latest Lucene release.
https://lucene.apache.org/core/10_1_0/core/org/apache/lucene/search/similarities/BM25Similarity.html

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Author-hosted explanation of BM25 scoring, term frequency, length normalization and parameter tuning.
https://nlp.stanford.edu/IR-book/html/htmledition/okapi-bm25-a-non-binary-model-1.html

CORE INTERVIEWS / 37

Design a web crawler

Interview version / 45-minute scope · Read the advanced version online

Build a durable, polite crawl pipeline that can repeat work after failures without losing discovered links or turning arbitrary URLs into unsafe network access.

URL frontier • politeness • content deduplication • crawl traps

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace a URL through durable scheduling, fetching, parsing and discovery.
- Explain why origin policy and destination safety constrain achievable throughput.
- Separate exact URL membership from body deduplication and approximate filters.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Database indexes: B-trees, composite keys and query access; Data partitioning and sharding; Production readiness: SLI, SLO, observability, and recovery

8 interview questions with model answers and answered follow-ups.

01 / Define a finite crawl objective

Design a crawler for a public engineering-article search corpus. It accepts seed URLs, downloads eligible HTML, extracts article text and links, and revisits important pages on a schedule. Fetching U17 discovers U18 and U19; both must eventually enter the durable work queue if eligible.

The web is changing and can generate unlimited addresses, so "crawl everything" is not a useful completion condition. Choose a target corpus, site budgets and freshness classes, such as daily revisits for important articles and monthly revisits for low-priority pages. Authenticated content, bypassing restrictions and unrestricted media downloads are outside this exercise.

An origin is a scheme, hostname and port. Enforce configured per-origin concurrency and spacing, and honor robots.txt rules for the crawler's identified user agent. Robots rules express crawl policy, not permission to access private networks or bypass authentication. A site pause or throttling response can reduce throughput regardless of spare machines.

The promise is recoverable processing, not exactly-once HTTP retrieval. A network timeout may leave the crawler unsure whether a server received the request, so retrying can fetch the same page twice. The design must make repeated scheduling and output processing safe instead of claiming the network eliminates duplication.

Clarify the target corpus and deadline, which pages need revisiting, and what each site permits. If site budgets cannot support the requested completion rate, renegotiate the deadline instead of treating more fetch workers as a solution.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Discover eligible URLs.** Accept seeds, resolve discovered links in each page's context and durably schedule eligible new URLs without duplicate initial work.
2. **Fetch and extract.** Retrieve supported public HTML, retain verified response bodies, extract article text and publish durable link/document manifests.
3. **Revisit and control sites.** Schedule revisits by priority, apply robots and operator pause rules, and record skipped, failed and retryable outcomes.
4. **Resume interrupted stages.** Recover pending fetch, parse and discovery work after a worker crash without skipping links whose scheduling never committed.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation.

1. **Finite throughput objective.** Target fifteen billion eligible initial pages in 28 days: approximately 6,200 successful new pages/s and 620 MB/s at the assumed 100 KB/page. Retries and revisits require additional capacity; the initial-crawl arithmetic does not pay for them.
2. **Politeness before speed.** For the worked example allow at most one start per two seconds and one active fetch per origin, or a stricter site/operator limit. At least 12,400 continuously eligible origins are needed for the initial start rate even before retries and revisits.
3. **Revisit freshness.** Use daily revisits for important articles and monthly revisits for low-priority pages when site policy permits. Track overdue eligible work separately from policy-blocked pages, and revise the service objective when permissions or capacity prevent it.
4. **Recoverable work and bytes.** Accepted frontier entries and committed stage outputs must survive worker restart or one storage-node failure within the region. Repeated HTTP retrieval is allowed; lost committed discovery work is not.
5. **Destination and input safety.** Only fetch allowed public HTTP(S) destinations, including after DNS resolution and redirects. Enforce response/decompression/time/parser limits and do not access authenticated or internal resources.
6. **Bounded pipeline.** Keep ready batches, sockets and parser work bounded. Slow intake when downstream stages fill; useful coverage and revisit age matter more than an unbounded raw request rate.

04 / Make one worker restartable before adding more

Start with one scheduler/worker, a SQL frontier and durable body storage. The frontier is the collection of URLs waiting to be fetched or revisited. Each row records the canonical URL, state, due time and current attempt. A transaction selects a due URL and marks it leased to the worker for a bounded time.

For U17, the fetch-and-parse path is:

1. Check origin eligibility and destination safety.
2. Download within byte/time limits and store body `P84`.
3. Save a `FETCHED` record referring to `P84`.
4. Parse that body and write manifest `M3` containing extracted text and resolved links `U18` and `U19`.

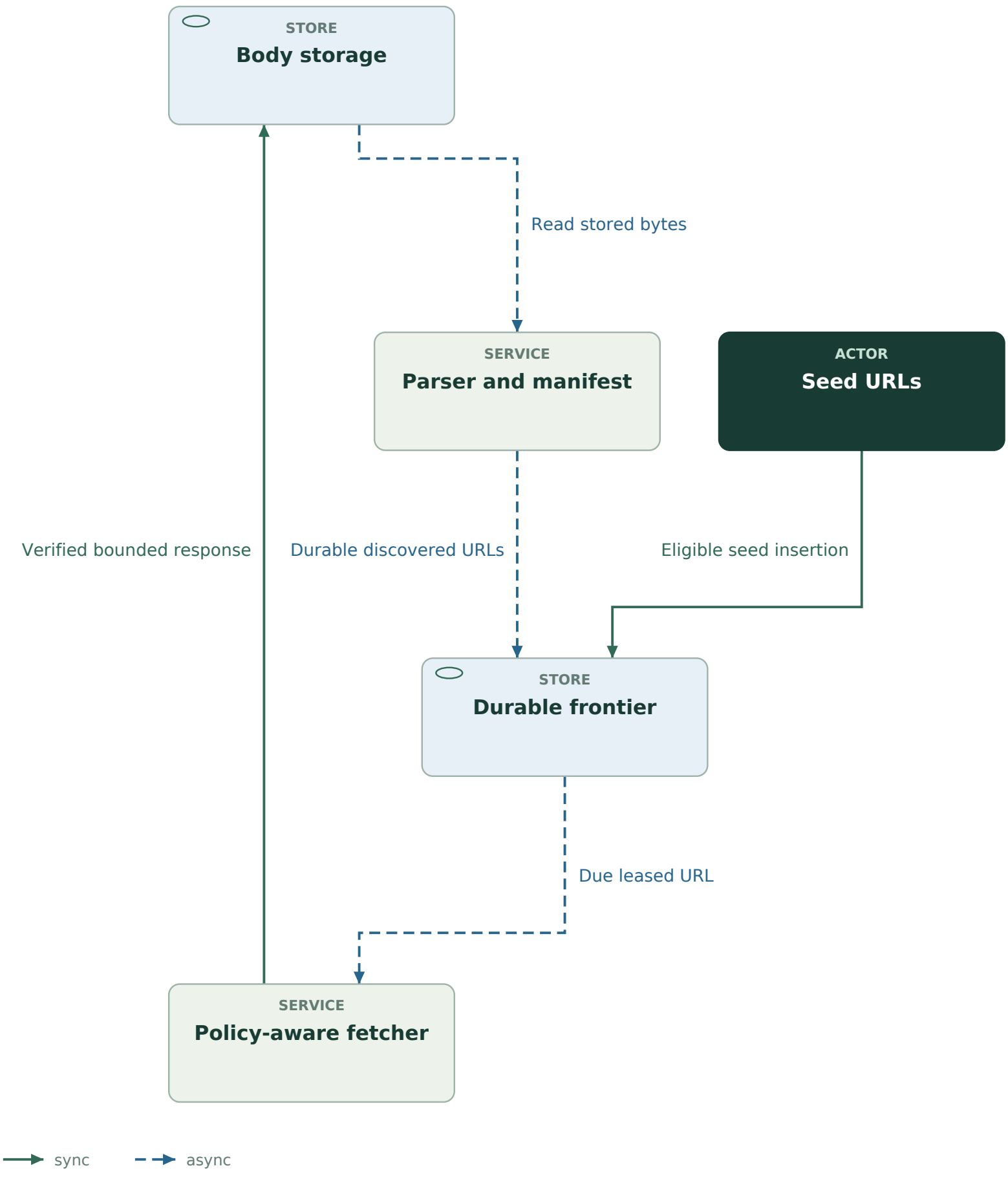
A manifest is durable output that a later process can finish consuming after a crash.

A discovery step inserts U18 and U19 into the frontier under unique URL keys. It records its manifest progress after those insertions complete. Only then is that discovery work finished. The stages distinguish "bytes obtained" from "all discovered work durably scheduled."

If the process crashes after storing P84 but before recording it, a retry may download again and leave an unused object to clean up. If it crashes after recording FETCHED, processing can continue from P84 without another network request. One visited=true flag cannot express these different recovery actions.

A complete recoverable crawl

Discovered links return to the frontier only through exact eligible URL insertion.



05 / Check site permission before worker count

Assume fifteen billion eligible pages over 28 days, averaging 100 KB each and one second of network service time. These are planning assumptions, not permission to fetch any particular site at that rate.

Quantity	Calculation	Consequence
Fetch rate	15 billion / (28 x 86,400)	About 6,200 pages/s.
Download payload	6,200 x 100 KB	About 620 MB/s.
Raw retained bytes	15 billion x (100 KB + 500 B metadata)	1.5075 PB before copies.
Space at 70% occupancy	1.5075 PB / 0.7	About 2.15 PB before replicas.
Typical concurrent fetches	6,200/s x 1 second	About 6,200 active requests.
Link candidates	Ten links/page x 6,200	About 62,000 membership checks/s before deduplication.

At one allowed start every two seconds per origin, sustaining 6,200 starts/s needs at least 12,400 continuously eligible independent origins. One thousand such origins allow only about 500 starts/s. Adding workers cannot remove this constraint.

At 200 bytes per frontier record, one billion pending URLs require 200 GB before indexes and replicas. Keep durable state on storage and only bounded ready batches in memory. Slow-request tails increase connection occupancy beyond the one-second average, so measure timeouts and outstanding sockets as well as successful pages/s.

06 / Store URLs, fetches and bodies as different identities

Record	Responsibility
URL/frontier row	Canonical address, provenance, priority, next due time, state and current attempt.
Origin schedule	Robots/pause policy, next permitted start and active-fetch limit.
Fetch result	Status, effective URL after redirects, timestamps, selected headers and body reference.
Body object	Immutable downloaded bytes and integrity digest.
Parse manifest	Extraction version, text and discovered links awaiting consumption.

Canonicalization converts only safe equivalents, such as removing a fragment that is not sent in an HTTP request. Do not drop every query parameter: two article URLs may legitimately differ by a query value. Preserve the full canonical URL, since a hash cannot reconstruct the address to fetch.

Use a unique exact canonical-URL key for discovery. In the baseline, inserting that row also creates its pending frontier work because the frontier is an index over the same table. If separate queue storage is introduced, save an enqueue intention in the URL transaction and relay it afterward; otherwise a crash between "known" and "queued" can strand the address forever.

Keep successful fetch history separate from revisit scheduling. "Already known" means do not create duplicate discovery work, not "never fetch this URL again." A changed article must become due under its freshness policy.

07 / Coordinate requests at the origin boundary

All workers fetching the same origin share one scheduler decision. Before a start, check the current site policy, reserve an active slot and advance nextAllowedStart atomically. One worker's local sleep does not coordinate another worker's request to the same site.

Choose one outbound dispatcher per origin partition. It owns the active connections and enforces the configured concurrency and spacing. Parallelism comes from many independent origins. If a dispatcher fails, stop and confirm that its old outbound requests have ended before transferring that origin's work. The simple interview design accepts delayed crawling during uncertain handoff rather than claiming that a new database token can close an old machine's socket.

Fetch and cache robots.txt through a standards-compliant implementation. Recheck policy when its cache is no longer valid, and conservatively pause ordinary fetches if policy cannot be established. Handle HTTP throttling and transient failures with delayed retries, not an immediate tight loop. A disallowed URL is a recorded skipped outcome, not a network error to retry aggressively.

Origin names can share the same physical server. Add conservative host/operator budgets where needed and expose a manual pause. The product's four-week target must be revised if its eligible sites cannot support the required polite rate.



INTERVIEW CRITICAL

More workers cannot increase one site's allowance

Origin-wide spacing and active-request limits are shared scheduling state. Scaling independent origins is safe; independently granting each worker a full site budget is not.

08 / Treat every destination and response as untrusted

An attacker can place a link that makes the crawler contact an internal service the attacker cannot reach directly. This is server-side request forgery. Reject non-HTTP(S) schemes and private/internal destinations, including unsafe IPv4 and IPv6 results. Validate the address actually used by the connection, not only a preliminary DNS lookup that the HTTP client later resolves differently.

Pin an approved resolved address through connection establishment while preserving the correct HTTP host and TLS hostname. Revalidate every redirect target and new resolution. A public starting URL does not make

its redirect to an internal address safe. Cached Domain Name System results may reduce lookup work, but they still need an allowed lifetime and safety validation.

Limit URL length, redirects, response bytes, decompressed size, fetch duration and parser CPU/memory. A compressed response can expand far beyond its transferred size. Sandbox parsing and verify the content type before selecting an HTML handler; a filename extension is not sufficient.

Crawl traps include endless calendars, sort/filter combinations and session URLs. Bound per-site discovery and repeated path patterns, and quarantine explosive origins for inspection. These are coverage decisions as well as resource safeguards: stopping a trap allows useful sites to remain fresh.

09 / Separate network waiting from parsing work

Partition the frontier by origin so each scheduler owns the timing of its assigned sites. Use asynchronous HTTP workers with bounded global and per-origin connections. They can wait on many unrelated servers without allocating an unbounded thread or process to each request.

As traffic grows, fetchers persist body references and enqueue parsing work through durable stage records. Separate parser workers consume those records, extract documents and links, and publish manifests. This isolates CPU-heavy or malformed HTML from network scheduling and lets a parser fix reprocess retained bytes without downloading again.

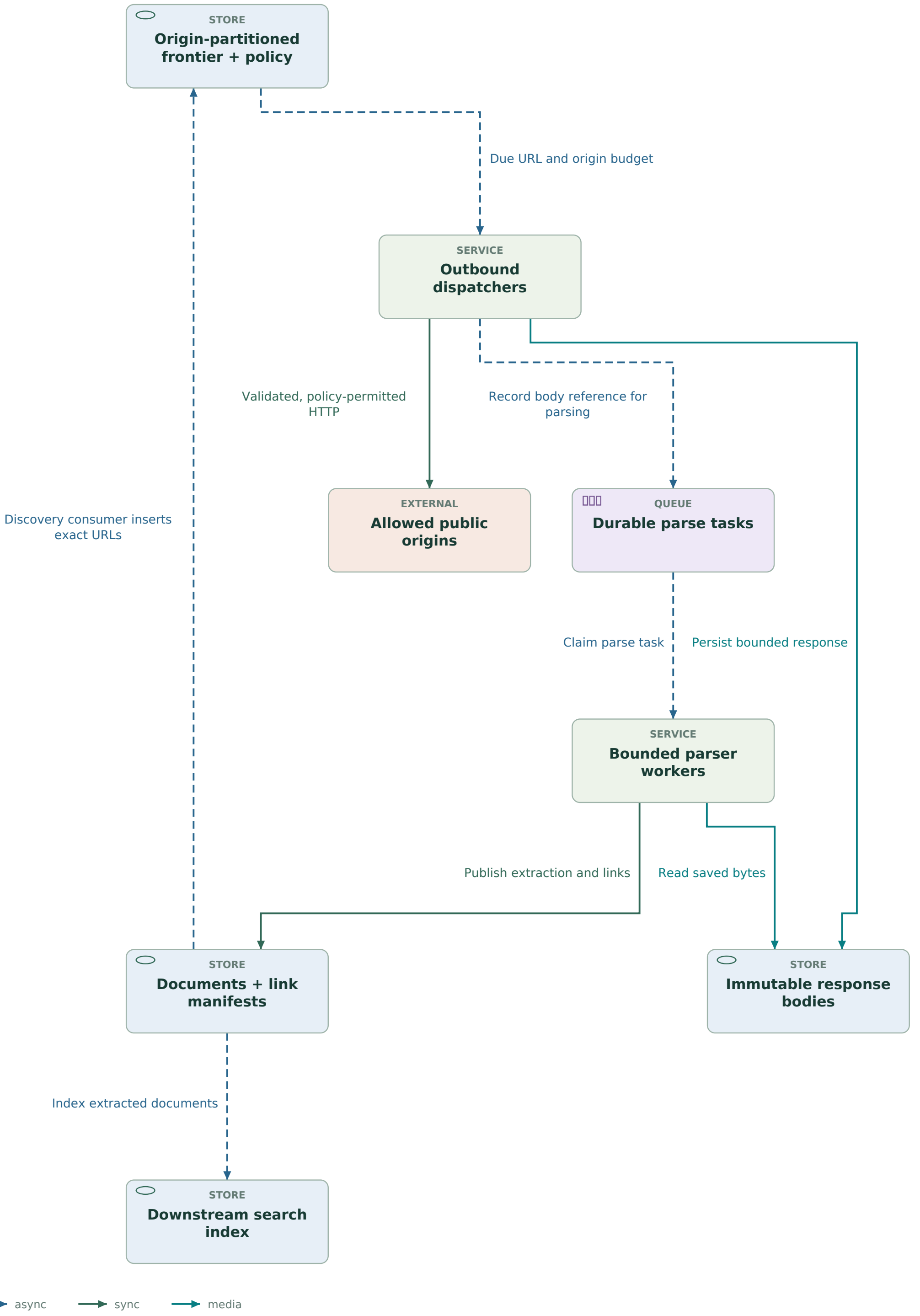
Object storage absorbs the large sequential body volume. A search index downstream consumes extracted documents under its own indexing-freshness contract; a fetched page is not automatically searchable. Make each stage slow its input when it cannot keep up; this is backpressure. If parsing or object storage is full, slow new downloads instead of filling local disks or losing bodies already acknowledged as fetched.

Ready queues can be small in-memory batches derived from durable due-time indexes. Losing a batch then delays work rather than deleting it. Replicate and back up frontier/manifest state, and test restoring both pending URLs and partially consumed discovery output. A hash-based placement scheme distributes ownership; it does not supply durability by itself.

For the selected one-node-loss boundary, retain frontier and manifest decisions through durable majority commits across three replicas in independent regional failure domains, with body storage whose acknowledged writes survive one storage-node loss. Budget retries and revisits above the approximately 6,200/s initial-crawl rate; reduce intake or renegotiate the deadline when site budgets or downstream capacity cannot support the combined work.

Separate origin scheduling from parsing and indexing

Origin-owned dispatchers select due URLs and enforce site policy before fetching. They persist bodies and durable parse work; parsers publish manifests containing documents and discovered links. Discovery consumers insert exact URLs into the frontier, while downstream indexing has its own freshness boundary. Full later stages slow new fetches.



10 / Distinguish repeated addresses from repeated bytes

The exact URL store prevents two pages discovering U18 from scheduling duplicate initial work. A body digest answers a different question: did two fetches return identical bytes? Reusing an identical object can save storage and some parsing, but URL provenance and site policy remain separate.

Identical HTML can contain the relative link `./2` on two different sites:

Response's effective URL	Relative link	Resolved destination
`https://a.example/docs/1`	`./2`	`https://a.example/docs/2`
`https://b.example/docs/1`	`./2`	`https://b.example/docs/2`

Those bytes resolve to different destination URLs. Cached syntax-level parsing can be reused where valid, but link resolution must still use each response's effective URL and any valid HTML base element.

A Bloom filter is a compact membership accelerator. Its negative result means an entry was not inserted into that complete filter; a positive result means possibly present. False positives are possible, so a positive cannot be the sole reason to discard a newly discovered URL when coverage matters. Consult the exact store and let its uniqueness constraint decide insertion. A stale or incomplete filter cannot replace that final check either.

Use sufficiently strong digests with integrity or collision verification for body reuse. Digest equality is a useful lookup candidate, not a reason to erase all URL-specific records. Keep the canonical address, fetch time, redirects and source page even when bytes are shared.

11 / Recover the stage that actually committed

A lease gives one worker the current right to update a URL attempt for a bounded period. Completion includes its attempt token. If worker A pauses and worker B receives a new attempt, A's late completion is rejected by a conditional database update. That protects state; the separate outbound-dispatch policy protects network politeness.

For discovery, suppose `M3` contains `U18` and `U19`:

1. The consumer inserts `U18`, then crashes.
2. It repeats the manifest after recovery.
3. `U18`'s unique key returns its existing record.
4. `U19` is inserted next.

Advance the manifest cursor only after durable insertion or confirmed membership. Marking U17 visited before saving or consuming its links could permanently lose U19.

If a body object exists but no stage references it, cleanup must first make the associated attempt ineligible to publish before deleting it. A check-then-delete race could otherwise remove bytes just as a worker records FETCHED. Cleanup must keep bodies and manifests still referenced by retained processing stages.

Classify outcomes: transient network errors retry with delay; permanent unsupported content stops; policy disallow skips; repeated parser failures enter an inspectable failed state. Conditional requests may receive 304 Not Modified and reuse the prior valid body; they must not replace it with an empty document.



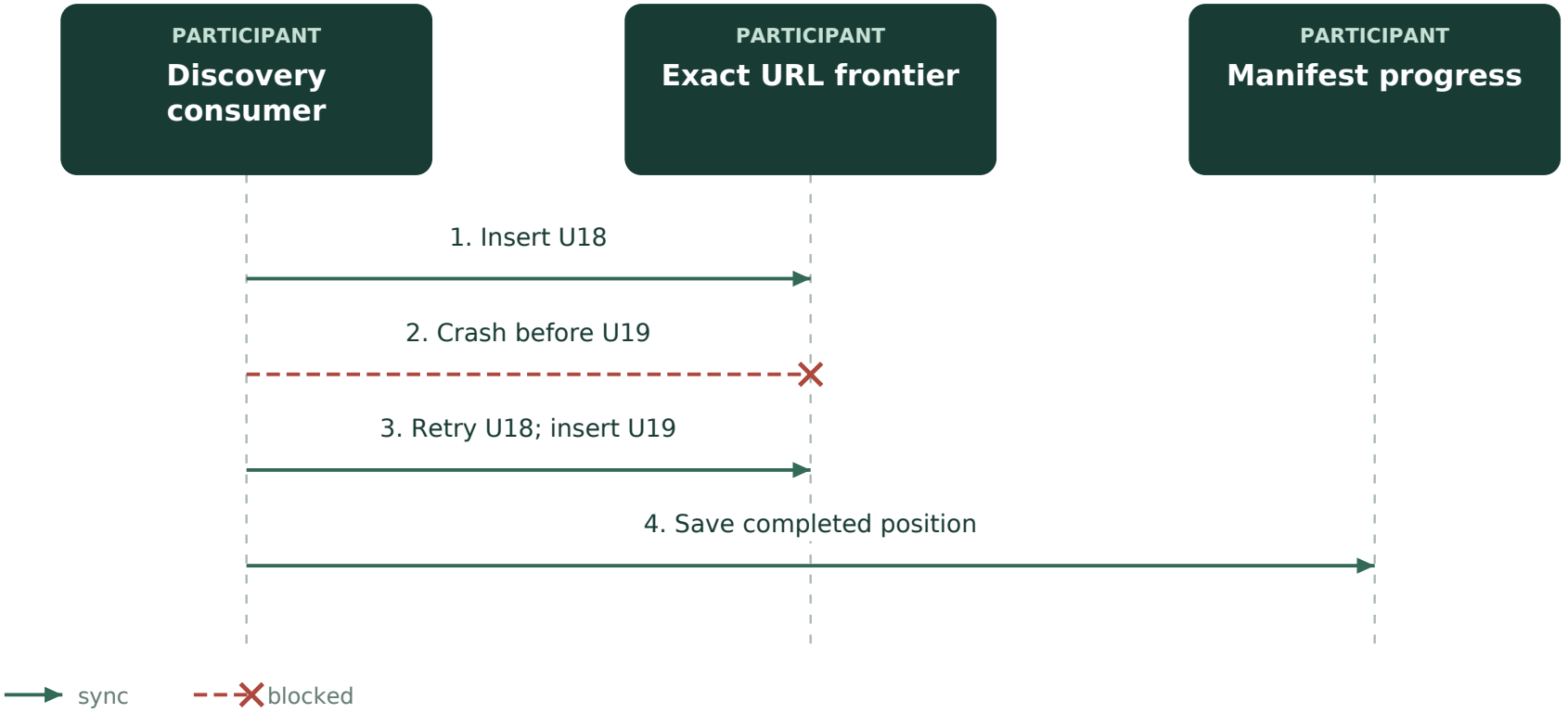
INTERVIEW CRITICAL

A downloaded page is not completed discovery

Persist the parse manifest and insert discovered URLs durably before advancing discovery progress. Repeating exact URL inserts is safe; skipping links after a crash is not.

Discovery resumes after a partial manifest

The cursor advances only after each link is durably present in the frontier.



12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1,4 + NFR4: complete discovery	Exact URL keys, durable manifests and checkpoints after insertion.	Crash after scheduling U18 but before U19; replay must recover U19 without duplicating U18.
FR2 + NFR4-5: safe retained bodies	Bounded validated fetches, immutable objects and guarded stage records.	Test redirects to private addresses, decompression bombs and one-node loss after FETCHED acknowledgment.
FR3 + NFR1-3: feasible crawl rate	Origin-owned dispatch, due-time scheduling and explicit freshness classes.	Check allowed-origin capacity and revisit/retry overhead against the 28-day plan. Spare workers cannot overcome a site's policy.
NFR4,6: recoverable overload	Durably replicated frontier/manifests, separate parsers and backpressure.	Stop parsing or lose a dispatcher. Keep accepted work recoverable and delay handoff until old outbound requests are known to have ended.

13 / Rapid revision

Remember: Save the extracted links before recording discovery progress; a downloaded parent is not proof that its children were scheduled.

Track useful new documents per fetched byte, frontier age, revisit freshness, duplicate ratio, parser backlog, per-origin request starts and skipped reasons. A high fetch rate can hide a calendar trap or thousands of duplicate mirrors. Measure the slowest freshness class and site behavior, not only fleet averages.

Decision	Reason	Cost or limit
Save progress for each queued URL	Distinguish downloaded, parsed and fully scheduled work after crashes.	State and checkpoint storage.
One shared dispatcher per web origin	Coordinate workers' request spacing and concurrent fetches.	Site policy bounds throughput.
Immutable bodies and manifests	Replay parsing and discovery after crashes.	Petabyte retention and reread cost.
Unique keys for canonical URLs	Repeat discovery without duplicate scheduling.	Store URLs and check for existing entries.
Reuse bodies with matching digests	Avoid repeated byte storage and some parsing.	Resolve relative links using each page's URL.

Decision	Reason	Cost or limit
Destination and response limits	Prevent internal-network access and resource exhaustion.	Some inputs are deliberately rejected.

Close by tracing U17 to stored P84, manifest M3 and durably scheduled U18/U19. Explain what happens if the worker fails after each stage. Then state the main scaling boundary: many independent eligible origins provide parallelism, while one site's permitted rate remains fixed. The interview design favors recoverability and respectful bounded coverage over an impossible claim to fetch an infinite web exactly once.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is the frontier and why must it be durable?

Model answer

It records URLs waiting for initial fetch or revisit. Losing it loses accepted future work, even if previously fetched bodies survive.

Interviewer follow-up

Why is visited=true inadequate?

It cannot distinguish stored bytes, parsed output and links not yet durably scheduled.

What the answer must demonstrate: Distinguishes future work from completed bodies and discovery.

02 / APPLIED

Why do per-worker delays fail to enforce politeness?

Model answer

Multiple workers can each obey their own delay while sending concurrent requests to the same origin. Origin-wide state must coordinate starts and active requests.

Interviewer follow-up

What bounds total throughput?

Both worker capacity and the number of independently eligible origins under their site budgets.

What the answer must demonstrate: Coordinates all workers at the origin and respects site-bound capacity.

03 / APPLIED

Can a crawler promise exactly-once HTTP fetches?

Model answer

No. A timeout can leave the request outcome unknown, and recovery may repeat the network operation. Durable idempotent processing is the defensible promise.

Interviewer follow-up

What prevents late completion from overwriting a newer attempt?

A conditional state update checks the current attempt token.

What the answer must demonstrate: Allows duplicate network attempts while guarding state updates.

04 / APPLIED

How do you recover after inserting U18 but before U19?

Model answer

Replay the durable manifest. Exact unique URL keys make U18 harmless to repeat, then U19 is inserted before progress advances.

Interviewer follow-up

Why not checkpoint before inserting links?

Recovery would skip links that had never been saved in the frontier.

What the answer must demonstrate: Keeps manifest progress behind durable exact URL insertion.

05 / APPLIED

Why must a redirect be checked again?

Model answer

Its target may be outside scope or resolve to a private network even when the original address was public.

Interviewer follow-up

Why pin the validated address?

A second unchecked DNS resolution could select a different unsafe destination.

What the answer must demonstrate: Validates actual connection destinations and every redirect.

06 / APPLIED

Why cannot a Bloom positive prove a URL was seen?

Model answer

False positives can mark an unseen URL as possibly present. Discarding it without exact lookup silently loses coverage.

Interviewer follow-up

Does the exact store still need uniqueness on concurrent inserts?

Yes. The filter is an accelerator, not a concurrency or identity constraint.

What the answer must demonstrate: Identifies false-positive recall loss and exact-store authority.

07 / APPLIED

Can identical HTML skip all link extraction work?

Model answer

No. Relative links resolve using each page's effective URL, so the same bytes on two origins can discover different addresses.

Interviewer follow-up

What may be reused?

Stored bytes and context-independent parse results, while preserving per-fetch provenance and link resolution.

What the answer must demonstrate: Preserves effective-URL context when sharing bytes.

08 / APPLIED

What should happen when parsing falls behind?

Model answer

Keep fetched bodies durable and reduce new intake until the downstream stage catches up. Unbounded downloading only moves the failure to storage.

Interviewer follow-up

What metric reveals productive crawling?

Useful new documents per fetched byte and revisit freshness, not fetch count alone.

What the answer must demonstrate: Uses backpressure and useful-content outcomes rather than raw throughput.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a public article crawler for fifteen billion eligible pages in four weeks. Trace U17 discovering two URLs and recover a crash before the second is scheduled.

• 0-5 min: agree numbered functional and non-functional requirements for corpus, initial deadline, revisits, per-origin policy, recoverability and destination safety.

• 5-12 min: trace durable stages and estimate fetch/network/storage demand.

• 12-20 min: define exact URL state, origin schedule and manifests.

• 20-30 min: scale independent origins and separate fetch from parse.

• 30-38 min: handle partial discovery, stale attempts, unsafe redirects and duplicate bytes.

• 38-45 min: check the final pipeline against the numbered FR/NFR lists, including origin-budget feasibility, revisit/retry capacity, durable discovery and unsafe-input tests.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

U17 produces manifest M3 with U18 and U19. The worker inserts U18, then crashes. What survives and what repeats?

M3 survives and is replayed. U18's unique key returns its existing frontier row; U19 is inserted next. Save manifest progress only after both are durably scheduled.

Save links, then advance progress.

Two URLs return identical bytes. Which checks detect repeated URLs and repeated bodies?

The canonical URL identifies an address; the content digest identifies its bytes. Keep each URL's context even when reusing the body.

Same address is not same bytes.

How can more workers increase crawl speed without overloading one site?

Fetch from independent origins in parallel. Workers targeting the same origin share its timing and concurrency limits; all fetches still pass destination checks.

Parallel across sites, polite within each.

Summary and interview notes

Save each discovered URL and its progress through fetch, parse and scheduling. Workers resume interrupted stages while shared site limits, robots rules and destination checks constrain what they fetch.

Remember these points

• Make pending work and parse output durable.

• Coordinate politeness across every worker for an origin.

• Validate actual destinations and bound untrusted responses.

• Use exact URL identity and retain URL-specific context during byte deduplication.

Interview tips

• Test a crash after each committed stage.

• Calculate the minimum number of eligible origins, not just worker count.

Important qualifications

• Uncertain dispatcher failover delays crawling until old outbound requests are known to have ended.

• The design does not claim exhaustive or exactly-once coverage of the web.

Explore the advanced version

Fenced egress ownership during partitions: Prove network-dispatch exclusivity when conservative handoff delay is insufficient.

Attempt and garbage-collection interleavings: Analyze publication rights, exact membership and object reclamation races.

Robots retrieval edge cases: Work through protocol-specific caching and failure outcomes.

Canonicalizer rollout and parsing economics: Measure identity changes, extraction differences and repeated-body processing cost.

Technical references

RFC 9309: Robots Exclusion Protocol
Primary specification for robots.txt fetching, matching, and caching behavior.
https://www.rfc-editor.org/rfc/rfc9309

Google: faceted-navigation crawling
Concrete examples of URL proliferation and crawl-budget problems.
https://developers.google.com/search/docs/crawling-indexing/crawling-managing-faceted-navigation

OWASP SSRF Prevention Cheat Sheet
Primary security guidance on validated network destinations, DNS behavior and redirect bypasses.
https://cheatsheetseries.owasp.org/cheatsheets/Server_Side_Request_Forgery_Prevention_Cheat_Sheet.html

CORE INTERVIEWS / 38

Design a personalized news feed

Interview version / 45-minute scope · Read the advanced version online

Separate publication, candidate generation, ranking and delivery so a personalized feed remains explainable, recoverable and safe when relationships change.

feed generation • fanout • ranking • cursor pagination

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Build a complete feed before choosing precomputation and personalized ranking.
- Use audience activity and follower skew to justify hybrid candidate generation.
- Keep stable page sessions separate from current eligibility and recoverable candidate storage.

Useful foundations: Database indexes: B-trees, composite keys and query access; Caching: cache hits, misses, write policies and invalidation; Message queues, event logs, delivery guarantees, and backpressure; Real-time communication: polling, long polling, SSE, and WebSocket

8 interview questions with model answers and answered follow-ups.

01 / Separate finding stories from deciding their order

Design a personalized feed of posts from followed people, pages and groups. Leo opens the application and receives twenty eligible stories, including Maya's trail report p882. Publication stores Maya's post; candidate generation finds possible stories for Leo; ranking orders those candidates; delivery returns the selected content. These are separate responsibilities even if one application initially performs them all.

Include text and references to already uploaded media, follow/unfollow, block rules, group membership, reply filtering, refresh and older pages. Ads, recommendation-model training and video processing are outside scope. A few seconds of propagation delay is acceptable for newly published stories, but current eligibility controls what each response may disclose.

A follow expresses distribution interest. It does not automatically grant access to friends-only or private-group content. Friends-only stories require the product's approved friendship relation; private-group stories require current membership. Keep those relationship types explicit instead of using one generic edge as every kind of permission.

Choose a bounded ranked browsing session: its ordering stays fixed while the user pages, except that newly ineligible stories can disappear. Refresh starts a new session and includes newer posts. Already delivered content cannot be recalled after a later block or deletion.

Clarify which relationships make a story eligible, whether the feed is ranked, how fresh it should be and whether page two must preserve an earlier order. These choices determine both the candidate pipeline and its browsing-session contract.

02 / Functional requirements

Agree on these supported actions before selecting components.

1. **Publish and manage stories.** Authenticated authors publish/delete posts referencing verified media. Retried creation returns the same durable source post.
2. **Manage eligible sources.** Support follows/unfollows, blocks, approved friendships and private-group membership, with each relation retaining its distinct access meaning.
3. **Read a ranked feed.** Return up to twenty eligible stories from followed people, pages and groups; apply reply filtering and a declared ranking policy.
4. **Refresh and continue.** Refresh creates a new browsing session; older pages continue a bounded stored order while rechecking current eligibility.

03 / Non-functional requirements

Use these as illustrative interview assumptions to agree with the interviewer. Numerical targets require measurement; they are not claims about an existing product or a proven implementation. p95 (the 95th percentile) means 95% of measured operations finish within the stated time.

1. **Workload.** Plan for approximately 86,805 feed requests/s at the fivefold peak, 500 followed entities per reader and skewed authors with millions of active recipients. Candidate reads/writes and media bytes need separate budgets.
2. **Response latency.** Target regional p95 feed-metadata latency of 300 ms at admitted peak load in normal operation, including candidate merge, ranking and eligibility checks. Media transfer has a separate delivery measurement.
3. **Freshness.** Target p95 propagation from source commit to the candidate lists or author histories used by eligible active readers' refreshes within five seconds during normal fanout processing. Bounded retrieval and ranking can omit an available story; a retained session intentionally keeps its prior order.
4. **Source durability and recovery.** Accepted posts, relationships and publication events must survive a process restart or one database-node failure within the region. Candidate lists and session caches may be lost and rebuilt or restarted without losing source posts.
5. **Access and paging consistency.** Check current eligibility for the exact returned content version, even on cached candidates and older pages. Sessions expire after five minutes; a new session may rank differently. Already released content cannot be recalled.
6. **Bounded ranking and degradation.** Rank a bounded retrieved pool and disclose that it is not a global optimum. If ranking fails, use eligible chronological results; if permission cannot be established, omit or fail rather than expose content.

04 / Build a useful feed with one application

Start with a SQL database containing posts, author timelines and typed relationships. Maya sends a create request with key k91. One transaction saves p882, its author-history entry, the request result and a publication event. The API acknowledges commit. A retry of k91 returns the same p882; success does not claim that every follower already has a prepared feed.

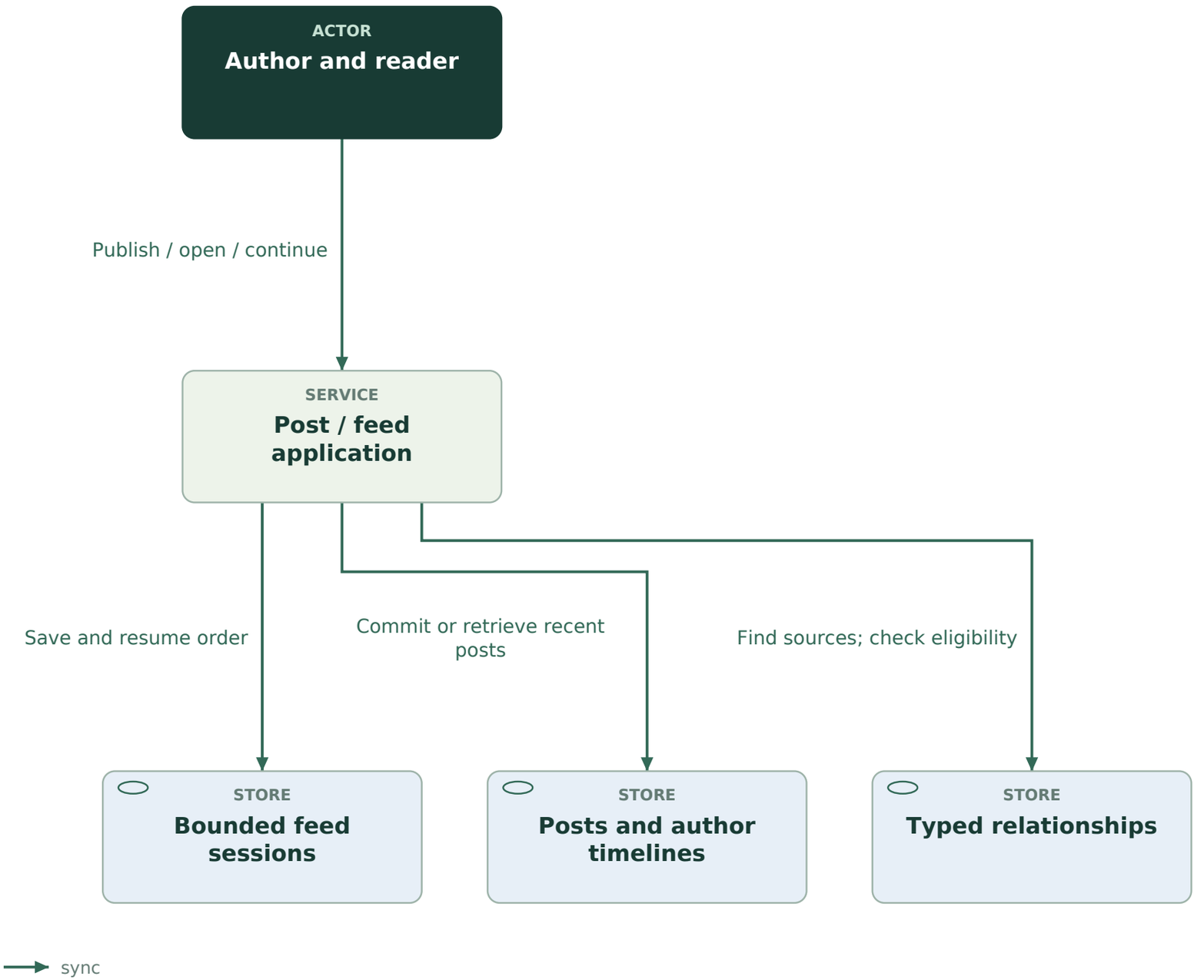
For Leo's first feed, the application reads his followed sources, retrieves bounded recent posts from their indexed timelines, checks current eligibility and reply rules, sorts by time and returns twenty. This is fanout on read: the application gathers several author histories when the reader asks. The baseline needs no background copies to produce a correct page.

Store the bounded candidate order for the browsing session before returning its cursor. New posts appear on refresh rather than shifting older page positions. Later pages still recheck deletion, blocks and membership. Media bytes stay in the media service; the feed contains authorized references and summaries.

Chronological ordering is a complete initial ranking policy. Personalization can be introduced once candidate retrieval and permission behavior are clear. The first scaling problem is repeatedly collecting and merging similar author histories for millions of readers.

A complete feed before precomputation

The application gathers recent author histories, checks typed relationships and returns a bounded ordered session.



05 / Compare repeated reads with recipient writes

Assume 300 million daily active readers, five feed opens per day and 500 followed entities per reader. Use a fivefold peak and twenty stories per page.

Quantity	Calculation	Meaning
Feed requests	300 million x 5 / 86,400	About 17,361/s average and 86,805/s peak.
Naive author retrievals	17,361 x 500	About 8.68 million author lookups/s average.
Full 500-story copies	300 million x 500 x 1 KB	150 TB logical, before replicas.
Bare 500-ID lists	300 million x 500 x 8 B	1.2 TB before scores, indexes and overhead.
Peak summary bytes	86,805 x 20 x 1 KB	About 1.74 GB/s before photos and video.

Preparing references can reduce repeated reads, but publication then creates recipient writes. If an ordinary author has 500 followers and 40% are active, one post produces about 200 candidate writes. A twenty-million-follower author with the same active fraction produces eight million. At 40 bytes per candidate entry, that is 320 MB of logical mutations for one publication.

The useful comparison is publication frequency x active recipients x write cost versus actual reader requests x author-merge cost. Follower count alone is a starting heuristic. Audience activity and posting rate can change whether precomputation saves work.

06 / Define publication, refresh and continuation

First-page request

```
GET /feed?limit=20&excludeReplies=true
```

Continuation request

```
GET /feed?cursor=token
```

Here `token` stands for the opaque cursor returned for the browsing session.

API	Meaning
`POST /posts`	Save one source post using an idempotency key and verified media IDs; return its stable identity.
`GET /feed?limit=20&excludeReplies=true`	Begin a ranked session from current candidates.
`GET /feed?cursor=token`	Continue the same viewer, filters and stored session order.

API	Meaning
`PUT` or `DELETE /following/u17`	Change the viewer's distribution interest.
`DELETE /posts/p882`	Mark the owner's post deleted and schedule derived cleanup.

Derive author and viewer identities from authentication. The request key is scoped to the author and payload; changing the payload while reusing it conflicts. Media references must belong to uploads the author is permitted to attach.

Choose a five-minute session lifetime for this exercise. Its opaque cursor binds the viewer, filters, session and next position; another user cannot reuse it. Expiry requires refresh rather than inventing a continuation from newly ranked data. Restrict page size and total session depth.

A new-stories notification is optional and lightweight. Pull-to-refresh remains the complete delivery path if notifications are lost. Precomputing a server-side candidate list while Leo is offline is different from transmitting unseen stories to his phone.

07 / Make candidate lists disposable, not authoritative

Source records and durable publication work

Record	Role
`Post`	Holds the source post.
Indexed `AuthorTimeline`	Supports reading an author's post history.
`Follow`, `Friendship`, `GroupMembership`	Retain distinct relationship types and their access meaning.
Blocks	Record the restrictions applied during eligibility checks.
Request identities	Recover the source-post result after a retry.
Outbox	Records publication work transactionally so it can be delivered later.

If the application crashes between committing p882 and sending a queue message, the outbox relay still discovers the pending event.

A candidate stores a reference, not a duplicate body or permission grant.

`Candidate` **field**	Purpose
`viewerId`	Identifies whose candidate list contains the story.
`postId`	Refers to the source post.
`sourceVersion`	Records the source version associated with the candidate.

`Candidate` **field**	**Purpose**
`createdAt`	Supplies the creation-time value used in ordering.

Make `(viewerId, postId)` unique so repeated fanout cannot create duplicate visible slots. Partition candidates by viewer for local retrieval, while author timelines are indexed by author and creation-time/post-ID order.

Maintain both following and follower access paths. Feed reads ask which sources Leo follows; publication asks which active viewers follow Maya. Scanning every viewer on each publication would defeat the intended optimization.

Derived serving state

State	Stored information	Boundary
`FeedSession`	Bounded ordered candidate IDs, ranking version and expiry	Its lifetime is separate from the viewer's reusable candidate cache.
Body cache	Content keyed by post ID and content version	Reuses the identified version without becoming the source record.

Source posts, relationships and durable events support recovery; candidate caches and session lists cannot replace them.

For the chosen one-node-loss target, authoritative post, relationship and publication-event stores acknowledge changes only after durable majority commits across three replicas in independent regional failure domains. Each store must preserve its own acknowledged decisions on failover; this does not create a global transaction across the social graph. Candidate and session views retain their stated rebuild/restart behavior.

08 / Push ordinary candidates and pull expensive audiences

For ordinary authors, use publication events to insert post references into active followers' candidate lists. This is fanout on write: the work happens after publication, before those readers request a page. Reads usually need one bounded candidate lookup instead of hundreds of author queries. Keep only a useful recent window, such as 200-500 candidates, and avoid filling unlimited feeds for inactive accounts.

Popular authors whose fanout would dominate writes remain on a pull path. At read time, merge their bounded recent histories with Leo's prepared ordinary candidates. Deduplicate post IDs because a policy change or overlapping path can temporarily supply the same story twice. This chosen hybrid trades two retrieval paths for manageable celebrity publication cost.

A returning inactive reader may need a bounded rebuild from current relationships and recent author timelines. Let concurrent requests for the same viewer share one rebuild, so ten browser retries do not trigger ten independent scans. Make the slower cold-start behavior visible rather than promising every abandoned cache can be reconstructed instantly.

Fanout workers process one recipient page at a time, write unique candidate entries and save progress only after those writes can be recovered. A crash can replay the page. Indexing an event as consumed before its

candidate writes survive can create missing stories. Replica and cache capacity should follow measured candidate writes per consumed story, not only total user count.

09 / Rank a bounded eligible pool

Collect, for example, 300 ordinary candidates and 100 from pull-only authors. Remove duplicates, filter replies under the request policy and check eligibility. These are illustrative budgets to evaluate. They bound work; they do not guarantee that the globally best story exists inside this retrieved set.

Start with a lightweight score using declared signals such as recency, prior interaction with the author and topic interest. A more advanced ranker can predict outcomes.

Illustrative scoring rule

```
score = 2  x  P(meaningful interaction)
      + 0.5  x  P(save)
      + 0.1  x  freshness
      - P(hide)
```

`P` means the predicted probability of that outcome, and freshness is normalized between zero and one. The weights are an illustrative product policy.

Post	P(interaction)	P(save)	P(hide)	Freshness	Score calculation
p882	0.30	0.10	0.02	0.80	0.60 + 0.05 + 0.08 - 0.02 = **0.71**
p883	0.15	0.40	0.01	0.90	0.30 + 0.20 + 0.09 - 0.01 = **0.58**

`P(interaction)` in the table means `P(meaningful interaction)` from the rule. The first post ranks higher despite being less fresh.

Break ties deterministically and apply simple diversity rules, such as avoiding many consecutive posts from one author. Freeze the resulting bounded order for the session. Evaluate usefulness, unwanted exposure and whether predicted probabilities match observed outcomes; raw engagement alone can reward the wrong behavior.

10 / Resolve the late-fanout privacy race

A worker reads that Leo follows Maya at relationship version six, then pauses. Leo unfollows her, committing version seven. The worker resumes and inserts p882 into his candidate cache. That insertion is stale but recoverable: the feed service checks current relationships while serving and excludes Maya's story from this followed-content feed.

The same principle applies to deleted posts, blocks and restricted groups, with their actual permission rules. Removing stale candidate entries asynchronously reduces wasted work; it is not the decisive access check. An

unfollow does not make Maya's otherwise public profile secret, while losing private-group membership can remove permission to read its content at all.

Authorize the exact content version returned. If a check approved public version one, do not fetch and return a later private version two under that old decision. Fetch the approved immutable version or recheck the changed version within a bounded deadline. If current access cannot be established, omit the story or fail rather than return cached text optimistically.

Authorization is a point in the request: a response already authorized before a subsequent revocation may finish. The next serving check observes the change. A stronger barrier that stops every in-flight response is a different contract, not a property supplied by asynchronous invalidation.



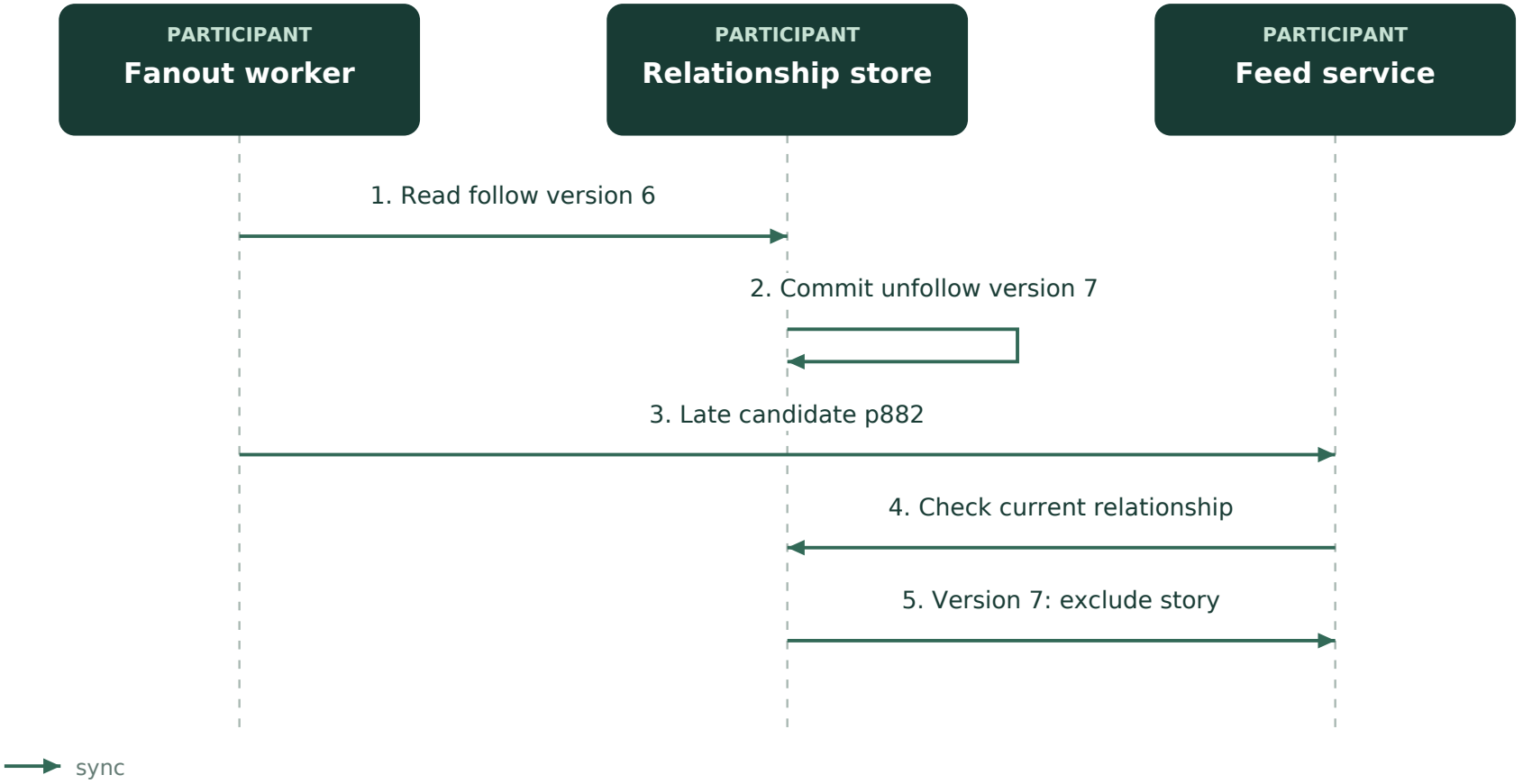
INTERVIEW CRITICAL

Ranking cannot override current eligibility

A candidate cache selects possible stories. Current typed relationships, post visibility and blocks determine what may be returned, and that decision must match the body's version.

Unfollow beats a delayed candidate insert

The serving check, not candidate membership, decides whether the story belongs in the response.



11 / Recover source-backed views and degrade ranking

A lost candidate cache is not an empty product history. Reconstruct a recent window from durable source posts and current relationships. To avoid missing publications during the scan, record an event-log boundary before rebuilding, replay changes from that boundary and deduplicate before switching to the new list. Detailed multi-partition handoff belongs in the Advanced version, but the need for overlap must be explicit.

If a fanout worker fails halfway through a recipient page, replay its unique viewer/post insertions and then checkpoint. If event processing is behind, show measured freshness degradation, prioritize active readers and bound the queue. A five-minute periodic rebuild by itself cannot meet a five-second new-story target.

If ranking times out, return a bounded chronological page of eligible candidates and identify the fallback. If permission checks fail, that fallback cannot safely reveal uncertain private stories. Lost notifications merely remove the new-stories hint; refresh can still read current state.

Deliver private media through an authenticated media edge that checks access before serving cached bytes. Already downloaded bytes and transfers admitted before a later revocation cannot be recalled. A public long-lived object URL would undermine a correct feed-body permission check.



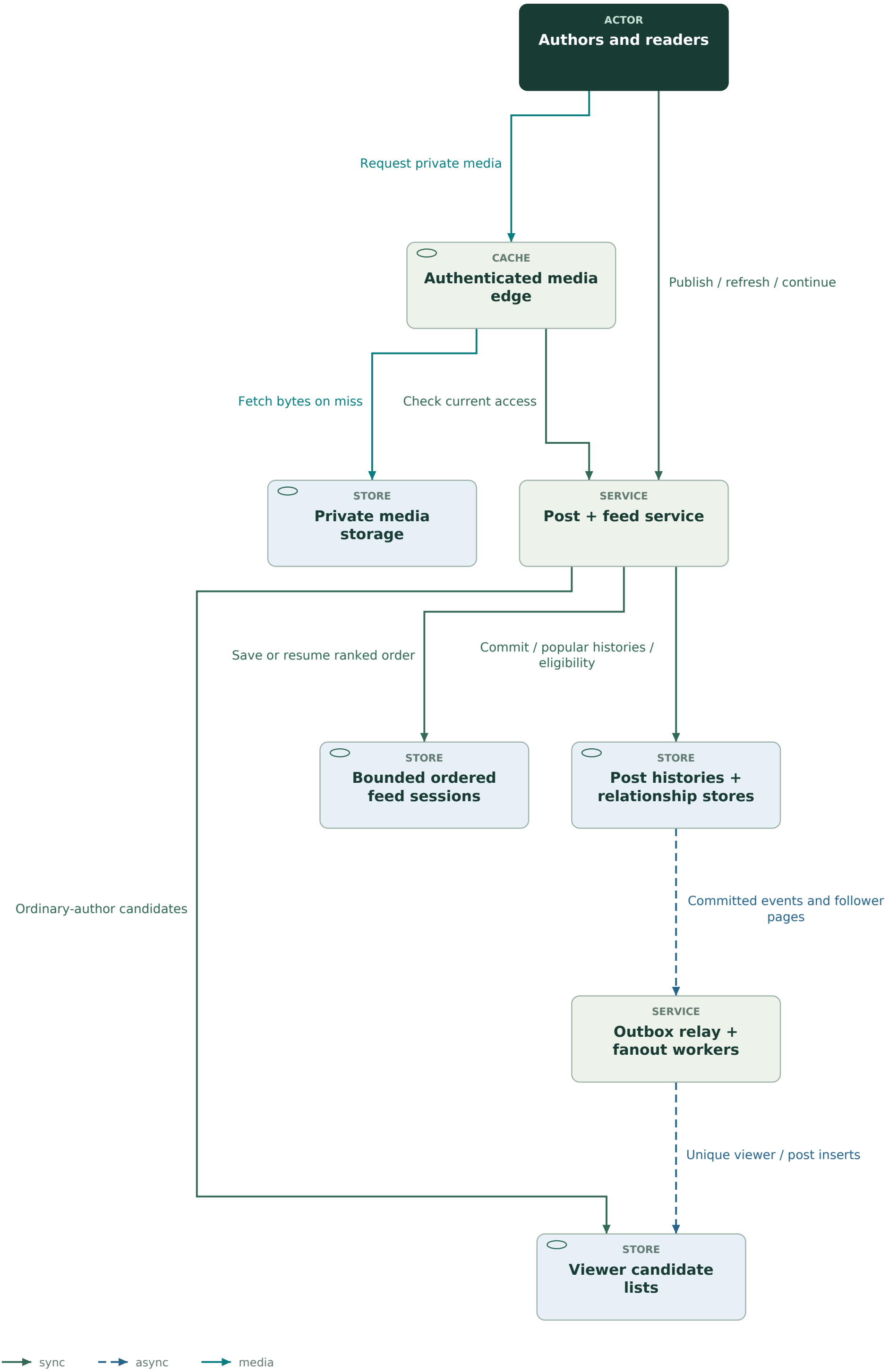
INTERVIEW CRITICAL

Prepare candidates independently of client delivery

Durable source publication and replayable fanout make stories recoverable. A socket notification only announces change; losing it must not lose the story.

Build candidate lists, then select an authorized feed session

Publication events prepare ordinary-author candidate lists. The feed service merges those with popular-author histories, checks current relationships, ranks a bounded pool and saves the session order. Later pages use that order but recheck eligibility. Private media is delivered through a separate authenticated edge.



12 / Check the design against the requirements

Use the agreed lists to check the finished design. The tests below still need to establish the targets; a proposed mechanism is not a measured result. FR refers to the numbered functional requirements above; NFR refers to the numbered non-functional requirements.

Requirement	Design mechanism	Validation and remaining limit
FR1-2 + NFR4: source and relationships	Durable source/request/outbox transactions and explicit typed access relations.	Lose a publish response, replay the event and fail one database node. The source post and intended publication work must survive.
FR3 + NFR1-3: fast fresh ranked feed	Hybrid fanout/pull, bounded candidate merge and measured ranking.	Benchmark ordinary and celebrity traffic, p95 response and five-second candidate propagation. Retrieval and ranking may omit an available story.
FR4 + NFR5: useful continuation	Five-minute stored session order with eligibility checks on each page.	Publish new stories and change permissions between pages; refresh reveals new candidates while ineligible old entries disappear.
NFR4,6: honest degraded service	Replay-backed candidate rebuild and chronological ranking fallback.	Lose candidate storage or the scorer; recover without skipping event overlap. A permission outage cannot use the same permissive fallback.

13 / Rapid revision

Remember: Prepare candidates to save repeated reads, then check current access; an old candidate list cannot grant permission.

Measure publication-to-eligible-feed delay separately from response latency. Track candidate writes per post, active-recipient fraction, candidates scored per page, duplicate/empty pages, permission-filter rate and cache rebuild cost. At the peak estimate, scoring 500 candidates per request means approximately 43.4 million candidate-viewer scores/s, so bounded pools and staged scoring matter.

Decision	Benefit	Cost or limit
Save post and fanout work together	Resume feed preparation after crashes.	Feed propagation remains asynchronous.
Copy ordinary-author references to active followers	Avoid recollecting candidates on every read.	Write and retain each selected follower's reference.
Pull high-fanout authors	Avoid millions of unused writes.	Extra read-time merging.
Keep a limited ranked list per session	Continue later pages in the same order.	Refresh is needed for newer ranking/stories.

Decision	Benefit	Cost or limit
Recheck current post version and viewer access	Exclude outdated or inaccessible candidates.	Check relationships and posts; filtering may shorten pages.
Chronological ranking fallback	Useful feed during scorer failure.	Does not replace permission checks.

For a final explanation, follow p882 through committed source state, ordinary fanout or celebrity pull, bounded candidate merge, eligibility and ranking. State that candidate caches are rebuildable views and the product chooses a few seconds of propagation delay. The next tuning decision follows measured audience activity and consumed-story cost, while ranking changes are judged by usefulness and safety rather than engagement alone.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What are the four responsibilities in a feed?

Model answer

Publication stores the source, candidate generation finds possible stories, ranking orders them and delivery returns selected authorized content.

Interviewer follow-up

Does a notification make the source durable?

No. It is a hint; durability comes from committed source state.

What the answer must demonstrate: Keeps durability and notifications separate.

02 / APPLIED

Why combine write-time and read-time generation?

Model answer

Ordinary active audiences benefit from prepared references, while celebrity fanout may create millions of unused writes. Pull those histories during actual reads.

Interviewer follow-up

What decides the threshold?

Posting rate, active audience reads and measured write/merge costs, not follower count alone.

What the answer must demonstrate: Uses audience economics to justify both paths.

03 / APPLIED

Why not represent every relationship as a follow?

Model answer

Distribution interest, approved friendship and private-group membership grant different behavior and access. A one-way follow cannot silently authorize friends-only content.

Interviewer follow-up

Does unfollowing make a public profile private?

No. It removes that source from this followed-content feed; profile access follows its own policy.

What the answer must demonstrate: Distinguishes distribution from actual access grants.

04 / APPLIED

What if fanout inserts a story after the viewer unfollows?

Model answer

The late candidate can remain temporarily, but current serving-time relationship checks exclude it. Async cleanup is an optimization.

Interviewer follow-up

What additional check protects edited content?

The returned body must be the exact version that passed the permission check; a newer version needs another check.

What the answer must demonstrate: Checks current eligibility and binds the returned body version.

05 / APPLIED

How can a ranked feed keep page two stable?

Model answer

Save a bounded ordered candidate session and resume by its cursor, while rechecking current eligibility on each page.

Interviewer follow-up

Where do new stories appear?

On refresh or a new session, optionally announced by a lightweight hint.

What the answer must demonstrate: Freezes bounded order without freezing permissions.

06 / APPLIED

What is the difference between ranking quality and candidate recall?

Model answer

A ranker can order only retrieved candidates. A useful story excluded by an overly small pool cannot be recovered by a perfect score.

Interviewer follow-up

What should evaluate the scoring objective?

Usefulness, unwanted exposure, diversity and whether predicted probabilities match actual outcomes, not engagement alone.

What the answer must demonstrate: Separates missing candidates from scoring errors.

07 / APPLIED

How do you avoid a gap while rebuilding a lost candidate list?

Model answer

Record an event boundary before scanning source timelines, then replay overlapping changes and deduplicate before cutover.

Interviewer follow-up

Why is a periodic rebuild insufficient for five-second freshness?

Its interval alone can exceed the freshness target; incremental events are required.

What the answer must demonstrate: Includes overlap/replay rather than scan-only reconstruction.

08 / APPLIED

What can safely degrade during a ranker outage?

Model answer

Use chronological ordering over bounded eligible candidates. Current permissions and content-version checks remain mandatory.

Interviewer follow-up

What if the graph permission service is unavailable?

Omit uncertain stories or fail; cached public-looking text is not authorization.

What the answer must demonstrate: Degrades ordering without weakening authorization.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a ranked followed-content feed. Trace an ordinary post, a celebrity post, an unfollow racing fanout and a reader continuing page two.

• 0-5 min: agree numbered functional and non-functional requirements for typed relationships, ranked sessions, 300 ms latency, five-second freshness, source durability and privacy.

• 5-12 min: build the SQL baseline and compare read/write costs.

• 12-20 min: define source, outbox, candidate and session records.

• 20-30 min: explain hybrid generation and a bounded ranking example.

• 30-38 min: handle unfollow, content versions, partial fanout and cache loss.

• 38-45 min: review the final design against the numbered FR/NFR lists, test ranked/chronological fallback and privacy, and identify unmeasured latency, freshness and quality targets.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

What happens between an author publishing and a reader seeing a ranked page?

Save the post, collect eligible candidates, rank them, then return the page. A saved post alone does not mean a follower has received it.

Store, find, order, return.

Why prepare ordinary authors' entries but fetch celebrity posts when the feed is read?

Preparation saves repeated reads. Pulling celebrity posts avoids writing millions of follower entries that few readers may use.

Push reusable work, pull expensive audiences.

Leo unfollows Maya while a fanout worker is paused; it later inserts p882. Can the next followed-content feed show it?

No, if unfollow committed before the serving check. Recheck the current relationship and exclude the stale candidate. Ranking or cache membership cannot override that decision.

Candidate does not mean permitted.

Summary and interview notes

Prepare references for ordinary authors and fetch celebrity posts on reads. Check current access, rank a bounded candidate set, and keep that order for the reader's next pages.

Remember these points

• Commit publication before asynchronous fanout.

• Compare the cost of writing to active followers with the cost of merging author histories during their reads.

• Keep bounded stable page sessions.

• Check the actual follow, friendship or group rule and return only the content version it authorizes.

Interview tips

• Use an unfollow-before-late-insert timeline.

• Compare writes per consumed story rather than total cached users.

Important qualifications

• The design accepts propagation delay and bounded candidate recall.

• Recommendations from unfollowed creators require a separately evaluated candidate source.

Explore the advanced version

Generation-safe candidate rebuild and cutover: Prove snapshot/log overlap and ownership during concurrent cache reconstruction.

Authorized hydration and in-flight revocation: Analyze stronger disclosure boundaries and content-version races.

Fanout strategy migration: Move authors between push and pull paths without missing or duplicating visible stories.

New retrieval sources and recommendation scope: Extend followed-content retrieval under the same eligibility and candidate budgets.

Technical references

TAO research paper
Primary description of a large social-graph data service; background for relationship access patterns.
https://www.usenix.org/conference/atc13/technical-sessions/presentation/bronson

Kafka design
Durable log, consumer progress, and processing semantics underlying reliable incremental publication.
https://kafka.apache.org/design/

Meta: News Feed ranking
Primary 2021 explanation of candidate inventory, prediction models, combined ranking scores and contextual diversity; the chapter weights and example values are hypothetical.
https://engineering.fb.com/2021/01/26/ml-applications/news-feed-ranking/

CORE INTERVIEWS / 39

Design nearby place search and friend discovery

Interview version / 45-minute scope · Read the advanced version online

Find the nearest eligible places within a stated radius, then extend the design to private, expiring friend locations without confusing search freshness with permission.

spatial queries • quadtree • radius search • presence

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain complete spatial coverage and exact distance with a boundary example.
- Scale place searches while making indexing delay explicit.
- Design private nearby-friend lookup with current sharing checks and expiring positions.

Useful foundations: Database indexes: B-trees, composite keys and query access; Data partitioning and sharding; Caching: cache hits, misses, write policies and invalidation; CAP theorem: consistency, availability, and partition tolerance

8 interview questions with model answers and answered follow-ups.

01 / Choose the nearby-search contract

Build a service that returns the nearest twenty open cafés within a requested radius. A place has coordinates, category, name and reviews; a separate nearby-friends feature returns consenting contacts' recent positions. Exclude driving routes, advertising and reservations. Straight-line distance is not driving time, so the API must name which it returns.

Use a concrete query throughout: Maya stands at local coordinate x=990 and asks for cafés within 50 meters. Café P12 is at x=1010 with the same y coordinate. It is twenty meters away even though a grid boundary at x=1000 separates them. This is the simplest test of whether the search actually works.

Target public-place edits becoming searchable within five seconds for 99% of accepted edits under normal operation. A successful edit means the source record is durable, not that every search replica already contains it. Return a searchable timestamp or generation when useful. For the first page, promise the closest eligible results in the selected searchable snapshot, up to the requested limit. Do not silently widen the radius when fewer than twenty exist. Current private authorization has a stronger requirement than slightly delayed public-place indexing.

Clarify the ranking and audience first: does nearby mean straight-line distance or travel time, and are we searching public places or currently consenting friends? Confirm the maximum radius and acceptable update delay. This answer uses nearest-by-distance place search and a separate permission-checked friend lookup.

02 / Functional requirements

1. **Search nearby places.** Return up to twenty open places matching category and radius, ordered by geographic distance with a stable tie-breaker.
2. **View place details.** Return names, coordinates, review summaries and photo references for selected places.
3. **Maintain places.** Let authorized owners create and update place records, recover retried writes and reject conflicting edits.
4. **Find nearby friends.** Accept authenticated position updates and return nearby contacts who currently permit sharing, including the age of each observation.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload and response time.** Plan for 500 million places and 100,000 peak searches/s. For admitted requests returning at most twenty results within a maximum 5 km radius, target 200 ms p95 API latency; count timeouts as misses and measure dense cities separately.
2. **Freshness.** Target public-place changes becoming searchable within five seconds for 99% of accepted edits under normal load. Friends publish every five seconds; label points older than fifteen seconds stale and exclude them after thirty seconds.
3. **Result correctness.** Return the closest eligible results in the selected searchable snapshot. Cover the whole radius; never silently skip a required region or substitute travel time for distance.
4. **Recovery and failure behavior.** Preserve committed source edits across application restarts and rebuild lost indexes from the source plus changes. If a required search region is unavailable, fail an exact query or explicitly label incomplete coverage; the index is not the only copy of places.
5. **Location privacy.** Check current sharing permission and presence validity before disclosure. Reject unauthorized edits and omit private positions when their permission cannot be established.

04 / Start with a spatial database and one complete request

The first implementation needs an API service, a relational database with a spatial index, and object storage for photos. A spatial index organizes records by geometry so the database can discard distant regions without scanning every place. It narrows the candidates; the exact distance predicate determines which candidates are truly within the radius.

For Maya's search:

1. Send the coordinate, radius and category.
2. Validate units and limits, then ask the database for matching open cafés.

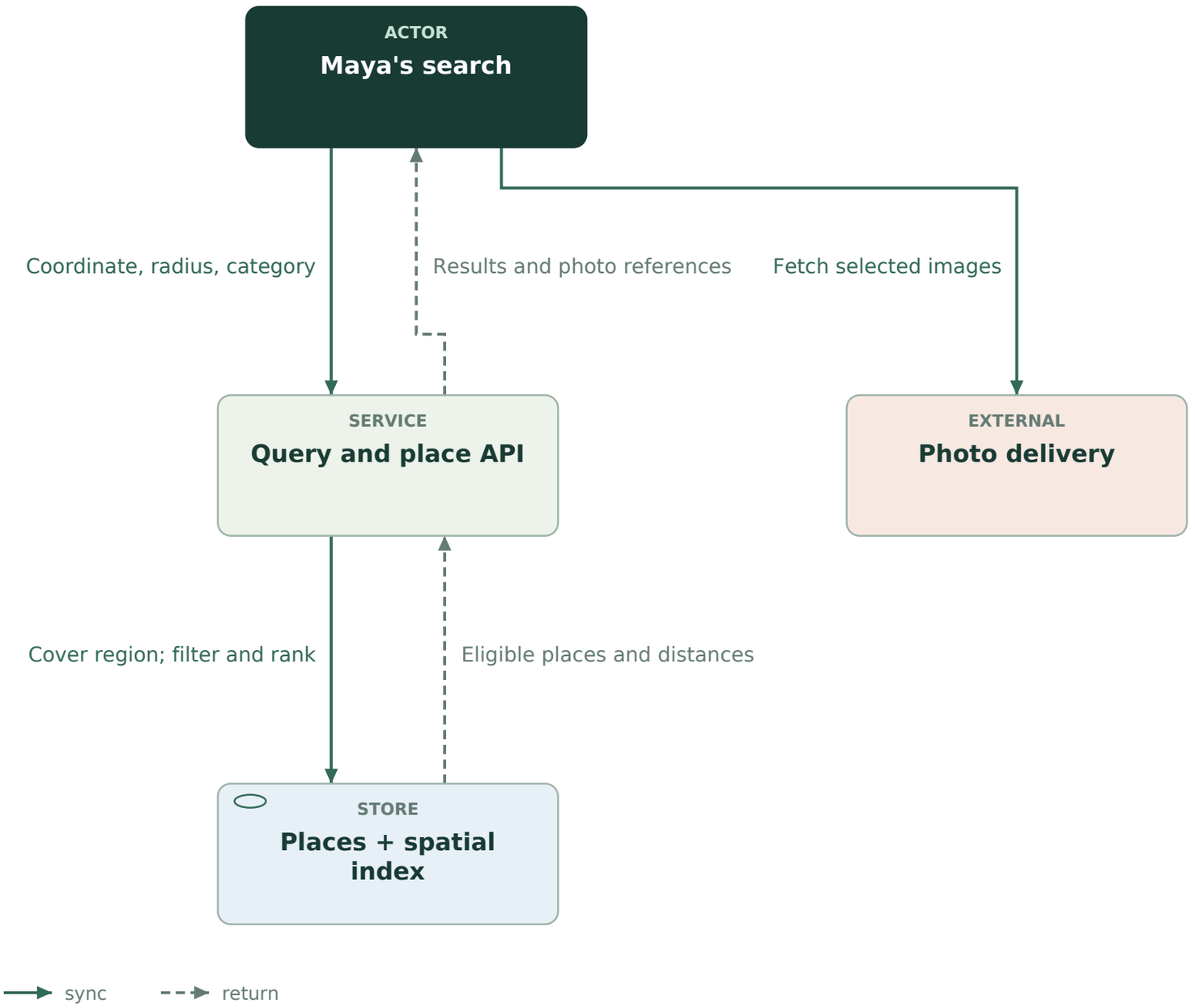
3. Compute geographic distances, sort by distance and place ID, and select up to twenty results. The stable ID breaks equal-distance ties.
4. Fetch review summaries and photo references in batches after selection rather than executing one query per café, then return the selected results.

Use a geography-aware implementation that accepts meters. Raw longitude differences do not have the same ground distance at every latitude. A bounding rectangle can efficiently find candidates, but its corners extend outside a circular search, so a final distance test remains necessary. The mature database implementation handles geometric edge cases; the interview should explain the contract rather than invent spherical mathematics.

An owner edit updates the authoritative place record transactionally. At modest scale the same indexed database can serve both writes and searches, avoiding asynchronous-index complexity entirely.

A complete local nearby search

The spatial database supplies candidates and exact distance; photos travel separately.



05 / Estimate the work per search

Assume 500 million places and 100,000 searches per second at peak. At 800 bytes per place, source records occupy about 400 GB before indexes, replicas, reviews and photos. An index payload consisting only of an 8-byte ID and 16-byte coordinates is 24 bytes, or 12 GB for 500 million places; real index structures require more space.

Twenty results of 1 KB each produce roughly 2 GB/s of response payload at the stated peak. Deliver photos separately through an edge cache. Three copies of source records require about 1.2 TB before overhead; replication is not a backup against an accidental deletion applied to all copies.

The decisive search cost is often candidate count. If a dense-city query examines 5,000 points at an illustrative two microseconds of CPU each, it spends ten milliseconds of CPU before fetching details. At 100,000 such queries per second, that stage alone requires approximately 1,000 CPU-seconds each second. Actual hardware sizing needs measurements, especially because rural and downtown workloads differ greatly.

Measure candidates examined, cells visited and returned records by radius and city. Use the agreed 5 km maximum radius and twenty-result bound; a country-wide best-rated search is a different workload from a local nearest-café request.

06 / Make units, ownership and freshness visible

Interfaces

Request or message	Contract
`GET /places` with latitude, longitude, radius and limit	Returns places, distances, searchable time and an opaque cursor.
`PUT /places/P12` with `expectedVersion` and changed place fields	Updates an authorized place only if version 4 is still current.

Example radius request

```
GET /places?lat=40.741&lon=-73.989&radiusMeters=50&limit=20
```

Fields of a version-checked place update

```
expectedVersion: 4 (the version being replaced)
place fields: the intended changes to the authorized place
```

Stored records

Record	Fields or identity	Purpose
Place	`id`, `point`, `category`, `open`, `version`	Durable source for place state.
Spatial entry	`region`, `id`, `point`, `version`	Searchable projection of a source version.
Review	`id`, `placeId`, `author`, `rating`	Separate durable user content.
Presence	`user`, `session`, `sequence`, `point`, `expiresAt`	Latest private position, not a permanent location history.

The cursor binds the original point, radius, filters, ordering and searchable generation. Reusing it after moving the query point would no longer mean "the next page of the same search." If retaining a snapshot across pages is too expensive, explicitly offer best-effort pagination with possible movement-related changes.

Derive editor and presence-owner identity from authentication. Version checks prevent one editor overwriting another's change. Place creation uses a request identity so retrying a lost response does not create another place. Ratings can be updated less frequently than coordinates if their separate freshness promises are clear. Neither review averages nor spatial membership determine who may see a private location.

07 / Explain why the search finds the nearest results

A grid assigns each point to a cell. For Maya's 50-meter query, cover every cell intersecting the query region, including the cell beyond x=1000. Then check exact distance and eligibility. Searching only Maya's own cell misses P12 despite its twenty-meter distance.

The simplest correct bounded-radius algorithm collects all eligible candidates in the radius, sorts them and takes twenty. That is a defensible interview baseline. A large candidate set motivates pruning: each unvisited region has a lower bound on how close any point in it could be. Visit promising regions first and retain the best twenty eligible results.

For a two-result example, the first region yields cafés at 30 and 40 meters. A neighboring region can contain a point ten meters away, so inspect it. Finding P12 at twenty changes the best results to twenty and thirty. A remaining region whose closest possible point is 35 meters away cannot improve them. Continue equal-distance bounds when the ID tie-breaker could still matter.

The bounds must never overstate a region's minimum distance, and must use the same geography and snapshot as its indexed points. Delegating it to a proven spatial implementation is preferable to improvising a custom distributed tree during a 45-minute answer.



INTERVIEW CRITICAL

Enough results is not nearestness

Finding twenty cafés proves only that twenty exist. Either examine all eligible points in the bounded radius or explain why every unvisited region is too far away to improve the current twentieth result.

08 / Add read capacity before distributing ownership

First cache place details and add spatial read replicas. Details are repeatedly requested, whereas exact query coordinates vary, so a cache of complete responses may have fewer useful hits. Measure cache hit rate before treating it as the main solution. Replicas add capacity but also introduce update lag and consume index memory.

When one index cannot meet storage or rebuild targets, partition it geographically. A routing manifest maps regions to owners. The query computes all intersecting regions, contacts those owners, merges candidates and deduplicates place IDs. Dense regions can split or receive more replicas. Smaller regions reduce local candidate counts but increase routing and boundary work.

Hashing by place ID offers another tradeoff: records distribute evenly, but a proximity query must ask every index partition. Geographic ownership is attractive when most queries are local; either layout still needs capacity for a popular city.

During a split, copy records and catch up changes before routing new queries exclusively to the replacement owners. Use one consistent version of the region map for each bounded query. If a required owner fails, fail an exact query or label its result incomplete; twenty results from other regions do not establish that no closer result was omitted.

09 / Move and delete places without claiming instant search

When place storage and the search index are separate, a saved edit can still fail to reach the index. Commit each place change together with an outbox record: a durable instruction describing the change. A worker relays that instruction to the index and retries after failure. The place version lets the index reject an older update delivered after a newer one.

Suppose P12 moves from region A to B as version 5. The worker adds the version-5 entry to B and removes or marks the old entry in A. These may be separate operations. Temporary duplicates can be merged by ID; a temporarily missing new entry means B's queries may omit the café until indexing catches up.

Reading current details can reject the old position but cannot discover a record absent from the candidate list. Therefore the ordinary API retains its stated indexing delay. A strict read-after-edit search must wait for a caught-up index or include a complete set of recent changes before selection. Checking returned records cannot find a café missing from the index.

Keep geometry and distance ranking consistent with the selected searchable snapshot. If current coordinates differ, restart against compatible data or disclose incompleteness rather than substitute them into an old pruning decision. Deletions likewise need versioned removal so delayed events cannot revive a closed place.

10 / Treat nearby friends as a private presence feature

For a user sharing with a few hundred contacts, begin with a simpler approach: load the authorized contact set, fetch their latest positions in a batch, discard expired observations and compute distances. This avoids maintaining a global private spatial index before the audience size warrants one. Public place search and private presence can share distance utilities without sharing permissions or caches.

Each publishing session receives a generation and sends increasing sequence numbers. The server rejects older generations or sequences, preventing delayed packets from moving a friend back to an old point. A new

authenticated session can restart numbering without letting the previous session overwrite it. Keep receipt time separately from the phone's asserted observation time.

As an assumption, devices publish every five seconds, the interface labels observations older than fifteen seconds stale, and records expire after thirty seconds. Those values are product choices, not proof that GPS is accurate. Return location age and avoid displaying a stale point as a live position.

Before returning a private point, read current sharing permission and the corresponding presence version from a consistent authority, or revalidate their versions together. Revocation must affect subsequent authorization decisions even if a candidate remains in an old index. If permission cannot be established, omit the point or fail the private query.



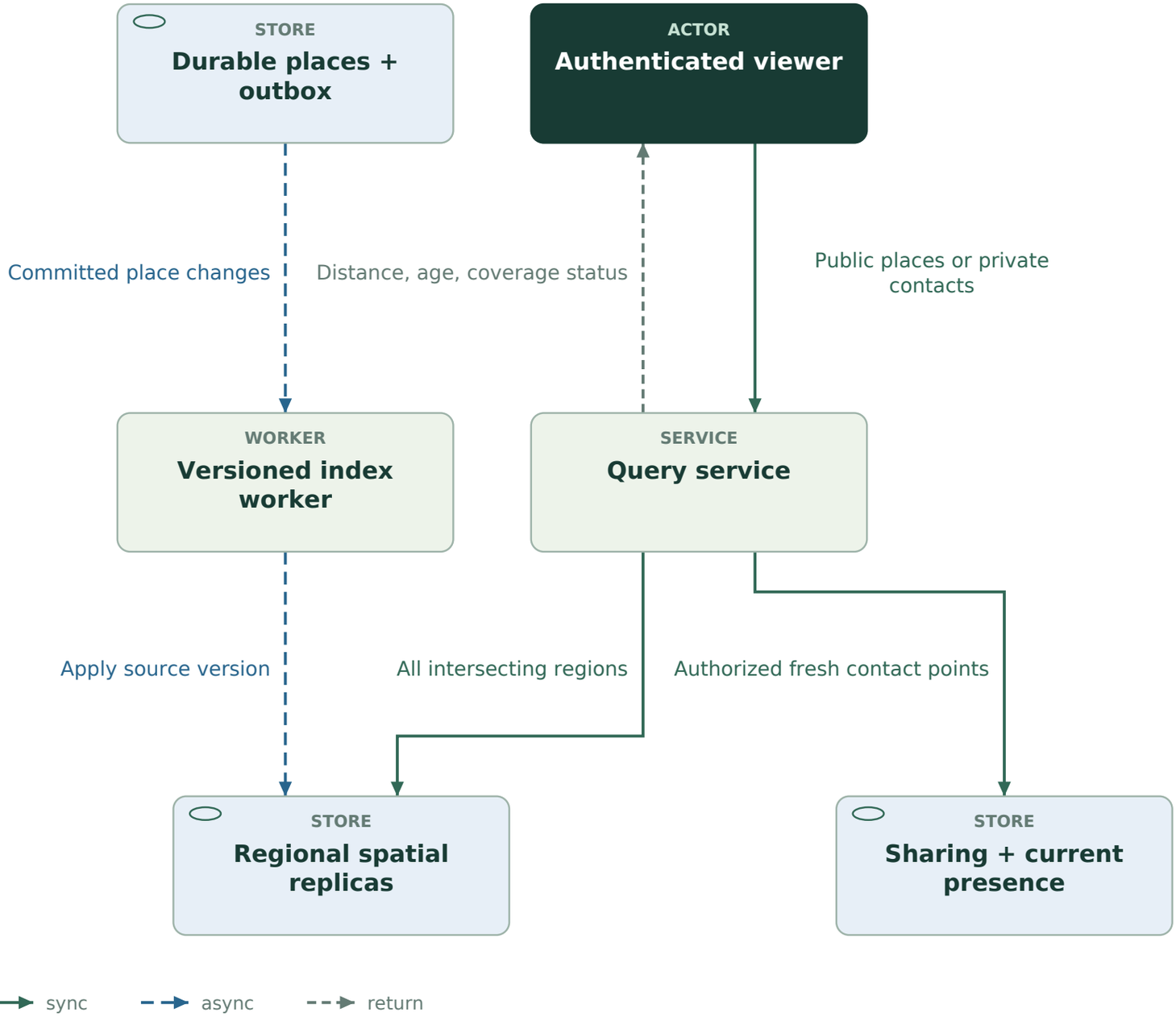
INTERVIEW CRITICAL

A spatial result never grants permission

A candidate ID says only that an index placed someone nearby. Returning the person's exact current position requires current permission for that viewer and that presence version. A stale public cache cannot provide that authorization.

Geographic search and separate private presence

Public search projections may lag; private points require current consent.



11 / Test missing results as well as slow requests

Monitor search latency by city and radius, index-update lag, candidates per result, region fanout and rebuild duration. Add synthetic places on cell edges and corners; compare sampled answers with a trusted spatial database. Include antimeridian crossings and coincident points, which can defeat careless custom subdivision.

Recover an index from a source snapshot plus versioned changes. A routing map alone does not contain the places it routes to. Record the snapshot's change-log position so replay neither skips changes nor restores older values. Limit rebuild bandwidth to protect serving traffic, and verify the new generation before switching queries.

For private presence, test revocation during a request, delayed location packets, device restart and expiry-worker failure. Eligibility must check the deadline even when physical cleanup is delayed. Keep precise coordinates out of general analytics logs and restrict administrative access.

Overload should reduce optional detail fetching or reject excessively expensive queries. Silently skipping a region changes the correctness promise. Public browsing can continue when private presence is unavailable, because the two features have separate state and authorization paths.

12 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR1,3: complete, fast search	Spatial coverage, exact distance, stable sorting and batched details; cache details and distribute geographic regions as needed.	Run boundary/corner cases and compare with a trusted spatial query. Load-test 200 ms p95 at the agreed radius, density and peak; aggregate QPS alone is insufficient.
FR3; NFR2,4: edits and search freshness	Transactional source edits, scoped retry identity and versioned outbox indexing.	Lose an edit response, restart an index worker and move a place between regions. Measure commit-to-searchable delay against the five-second target.
FR4; NFR2,5: private presence	Fetch the authorized contact set, reject old session sequences and enforce observation expiry at read time.	Revoke sharing during lookup, delay a packet and stop cleanup. No unauthorized or expired point may be returned.
NFR3-4: honest degradation	Route over one coherent region map and rebuild from source history.	Remove a required region and confirm the response cannot claim a complete nearest-twenty answer. Source-database disaster recovery remains a separately agreed promise.

13 / Rapid revision

Remember: A nearby place can cross a cell boundary. Cover the whole radius before choosing the nearest results.

Decision	Mechanism and consequence
Find nearby places	Search every region intersecting the requested radius, then measure exact distance in the stated units.
Return nearest twenty	Sort all candidates within the radius, or stop only when no unvisited region can beat result twenty.
Start simply	Keep place records and their spatial index in one database; fetch selected places' details together.
Scale searches	Add read replicas, then assign geographic regions to separate servers when measured load requires it.
Handle place changes	Save each place change and its indexing task together; reject older versions at the index.
Disclose lag	An edit may reach search later. Checking returned places cannot find one missing from the index.
Query private friends	For small contact sets, fetch authorized contacts' current points directly.
Protect location	For the returned location, check viewer permission, update order within its session and expiry.
Recover failures	Rebuild from saved records and later updates; report incomplete results if a region's server is unavailable.

In an interview, spend the opening minutes on radius, ranking, freshness and privacy, then trace Maya's boundary café. Introduce distribution only after showing the correct single-database query. Close with the two residual limits: search can lag accepted edits, and geographic proximity does not establish travel time or access permission.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why can a café across a cell boundary be the closest result?

Model answer

Cells organize storage; they do not constrain physical distance. Maya at x=990 and P12 at x=1010 are twenty meters apart. Search must cover intersecting cells and apply exact distance.

Interviewer follow-up

Can a bounding rectangle be the final radius answer?

No. Its corners lie outside the circle. Use it to find candidates, then enforce the requested distance.

What the answer must demonstrate: Explain cross-cell coverage and the exact circular distance predicate.

02 / APPLIED

When can a nearest-twenty query stop?

Model answer

After examining all eligible bounded candidates, or after every remaining region has a valid minimum distance worse than the current twentieth result. Equal distances need the stated tie-breaker.

Interviewer follow-up

Why filter closed places before pruning?

A closed café is not an eligible result and cannot justify excluding a farther open café.

What the answer must demonstrate: State the stopping bound and apply eligibility before counting best results.

03 / FOUNDATION

Why name the field radiusMeters?

Model answer

It makes the distance unit explicit. Latitude and longitude are angles, and longitude distance varies with latitude, so raw degree subtraction is unsuitable.

Interviewer follow-up

Which implementation would you start with?

A mature geography-aware spatial database and indexed distance predicate, with boundary tests.

What the answer must demonstrate: Distinguish angular coordinates from distance units and use appropriate geography.

04 / APPLIED

Why partition spatially instead of hashing place IDs?

Model answer

Geographic ownership keeps most local queries on a few owners. Hashing IDs balances records but requires querying every index partition.

Interviewer follow-up

What is the geographic downside?

Dense cities become hot and boundary queries fan out. Split regions or replicate reads using measured demand.

What the answer must demonstrate: Compare geographic locality with ID-hash fanout and hot-city skew.

05 / APPLIED

Can current detail reads repair every stale-index error?

Model answer

They can remove incorrect returned candidates but cannot discover a moved place absent from the new region. Preserve the indexing-delay contract or use a caught-up index.

Interviewer follow-up

Why not substitute current coordinates during pruning?

Old region bounds may no longer contain the moved point, invalidating the stopping argument.

What the answer must demonstrate: Distinguish rejecting stale candidates from discovering missing moved records.

06 / FOUNDATION

What is the simplest nearby-friends design?

Model answer

Fetch the viewer's authorized contacts, read their latest positions in a batch, check expiry and compute distances. A bounded contact set may not need a global spatial index.

Interviewer follow-up

What happens after sharing is revoked?

Subsequent serving checks must deny access even if old coordinates or candidate entries remain cached.

What the answer must demonstrate: Use current viewer consent and presence expiry, including the small-contact-set alternative.

07 / FOLLOW-UP

A neighboring region is unavailable; can twenty other results count as success?

Model answer

Not for an exact nearest-result promise. The missing region might contain closer places. Return an explicitly incomplete result or fail that query.

Interviewer follow-up

How is the lost index recovered?

Restore a source snapshot and replay versioned changes before making the replacement searchable.

What the answer must demonstrate: Refuse to claim exact completeness when a required region is missing.

08 / FOLLOW-UP

Is best-rated within a radius the same as nearest twenty?

Model answer

No. A farther café inside the radius may outrank every nearby café on rating. Candidate selection must cover the ranking contract.

Interviewer follow-up

What changes for travel-time ranking?

Spatial distance becomes a coarse filter; route or ETA computation supplies the final score under a separate latency budget.

What the answer must demonstrate: Choose candidate coverage from the ranking objective, not only nearest distance.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design nearby café discovery, then explain a café just across a grid boundary and a friend who revokes sharing while their old point remains indexed.

• Agree numbered functional and non-functional requirements, including distance ranking, freshness and private-location access. Then explain complete spatial coverage and exact distance with a boundary example.

• Scale place searches while making indexing delay explicit.

• Design private nearby-friend lookup with current sharing checks and expiring positions.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Maya is at x=990 and P12 at x=1010. Why must a 50-meter search cross the x=1000 cell boundary?

P12 is twenty meters away. Search every intersecting cell, then test exact distance and rank eligible places.

Nearby can cross a cell boundary: cover, measure, rank.

Can checking current place details find a place missing from the search index?

No. It only checks places already found. Finding an omitted place requires an up-to-date index or all relevant recent changes.

Validation is not discovery.

When may the service return a friend's location?

Only when the viewer currently has permission to see that exact position record.

Nearby is not permission.

Summary and interview notes

Find eligible places within a radius and return the nearest. For friends, check current viewing permission and location expiry; a fresh search result alone does not authorize disclosure.

Remember these points

- Search the whole radius before choosing the nearest results.
- Keep distance units and search freshness explicit.
- Separate durable places, derived search and private presence.
- Never infer permission from a candidate index.

Interview tips

- Agree on radius, ranking, freshness and privacy.
- Trace Maya's search across x=1000, then move P12 before the index catches up.

Important qualifications

- Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Custom nearest-neighbor traversal: Study lower-bound queues, adaptive trees and snapshot geometry after the database-backed baseline.

Region migration and overlays: Strict current-geometry results during moves require a fuller versioned-update protocol.

Distributed friend indexing: Large sharing audiences may justify a private index with its own update and authorization path.

Technical references

PostGIS ST_DWithin
Defines geography distance units and index-assisted candidate filtering.
https://postgis.net/docs/ST_DWithin.html

H3 documentation
Primary introduction to hierarchical geographic indexing; an alternative to hand-built adaptive rectangles.
https://h3geo.org/docs/

CORE INTERVIEWS / 40

Design a ride-hailing backend

Interview version / 45-minute scope · Read the advanced version online

Design ride discovery, exclusive driver assignment and recoverable trip tracking, while keeping frequent GPS updates separate from durable trip decisions.

moving locations • driver assignment • pub/sub • trip state

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace ride creation, offer acceptance and trip recovery end to end.
- Prevent both two rides claiming one driver and two drivers claiming one ride.
- Scale location ingestion and tracking without weakening assignment ownership.

Useful foundations: Design nearby place search and friend discovery; Databases, data models, and ACID transactions; Real-time communication: polling, long polling, SSE, and WebSocket; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / Define the ride and the guarantee

Design a ride-hailing service for one operating region. A rider requests a pickup, nearby drivers receive offers, one driver accepts, and both participants track the trip through completion. Exclude pooling, surge-price calculation, route computation and a full payment ledger from the first answer. An external routing service can supply estimated pickup times; that does not require designing the road graph here.

Use ride R501, rider Maya and driver D17 throughout. The essential guarantees are that R501 has at most one winning driver and D17 has at most one active ride. Nearby-map results are approximate: a driver may move or accept another request before Maya acts. Only a committed acceptance creates an assignment.

Assume latest positions older than ten seconds are excluded from discovery, first offers arrive within two seconds for 95% of admitted requests with eligible nearby supply, and an accepted assignment commits within one second at the 95th percentile, excluding human decision time. These are negotiated targets. When the database cannot safely decide who owns a ride, pause assignment rather than report success from competing regional writers. GPS availability and durable trip availability remain separate concerns.

Ask whether matching must choose the globally best driver or a suitable nearby driver, whether assignments cross operating regions, and whether billing belongs in scope. Choose suitable regional matching here; confirm the assignment and location targets below before expanding the architecture.

02 / Functional requirements

1. **Request and discover.** Create a ride request, find suitable nearby available drivers and send bounded, expiring offers.

2. **Accept and manage a trip.** Allow one offered driver to accept, then support authorized start, completion and cancellation transitions.
3. **Track participants.** Publish recent driver positions and deliver active-trip updates to the rider and driver.
4. **Recover status.** Let either participant retrieve authoritative trip state after a lost response or disconnected socket without creating another ride or assignment.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload.** Plan for 500,000 concurrently online drivers updating every three seconds, about 166,667 position updates/s, and one million rides/day. Size localized surges separately from daily averages.
2. **Response time.** Target a first offer within two seconds for 95% of admitted requests with eligible nearby supply. Target acceptance commit within one second p95, excluding driver decision time. Track no-supply outcomes separately rather than treating them as successful offers.
3. **Position freshness.** Exclude positions older than ten seconds from discovery. Matching remains approximate because drivers move and spatial indexing may lag.
4. **Assignment correctness.** Each ride has at most one winning driver and each driver at most one active ride. Cancellation and acceptance must make one consistent decision about both records.
5. **Durability and availability.** Require acknowledged assignments to survive one database-node failure using synchronous durable replication and safe failover. Pause assignment when current write authority cannot be established; a location outage must not erase an existing trip.
6. **Access control.** Authenticate drivers and riders, restrict precise tracking to current trip participants and prevent old sessions from overwriting new location updates.

04 / Follow one ride before adding services

Start with one regional application, a relational database and a connection gateway that sends messages to phones. The database stores rides, driver availability, offers and latest positions. Maya creates R501 with a request key. The application selects nearby available candidates, asks a routing service for a few pickup estimates, and sends a small batch of expiring offers.

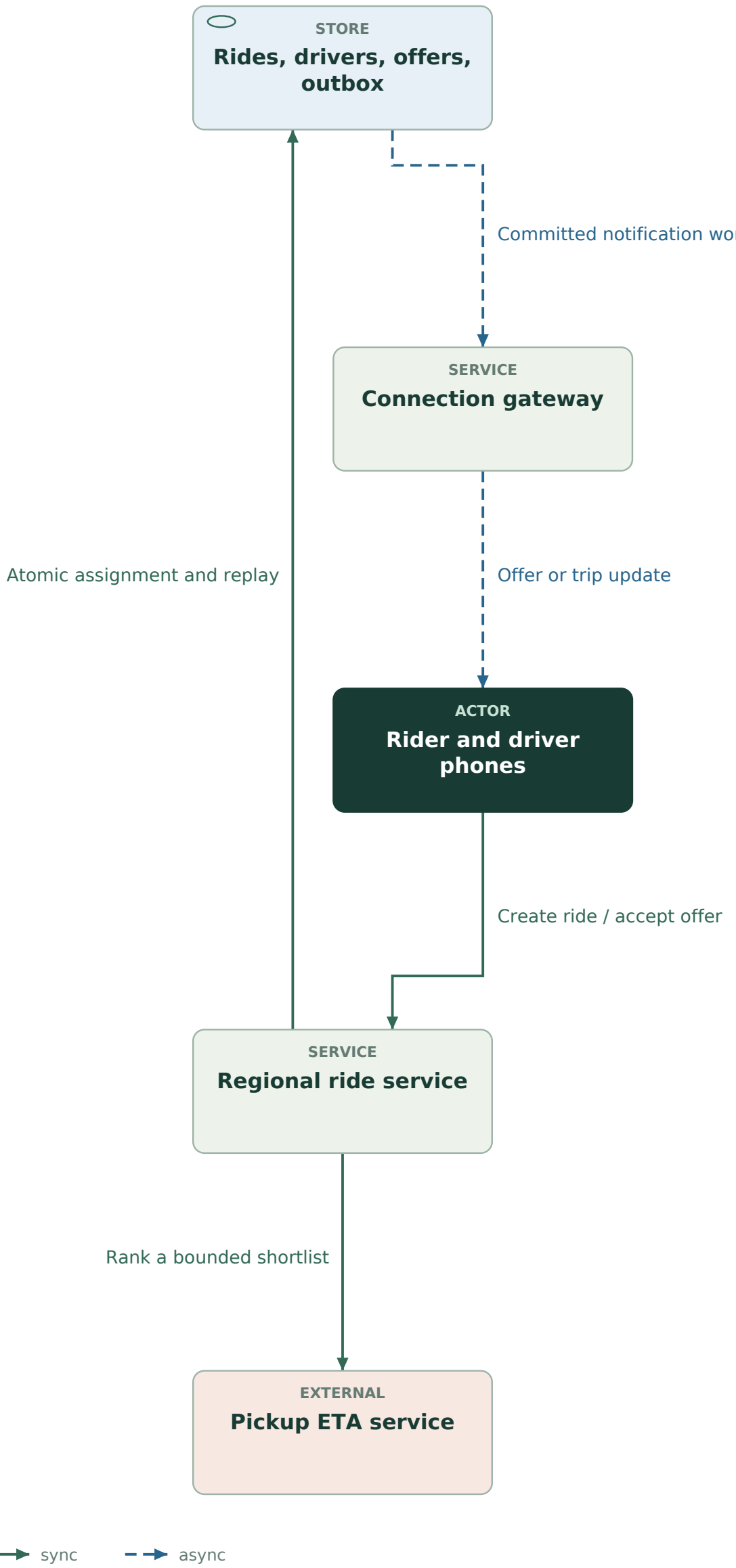
D17 accepts offer O81. The application runs a short transaction that checks the offer, the ride and the driver together. It records assignment A77, marks both sides assigned, stores the successful reply for retries and commits notification work. After commit, the gateway informs Maya and D17. If the socket fails, the assignment still exists and either phone can retrieve it.

The trip then moves through assigned, in-progress and completed states, with cancellation allowed according to the agreed policy. Only authorized participants may change those states. Completion releases the driver through the same authority that assigned them. A location heartbeat cannot independently mark an assigned driver available.

This baseline already supports the whole user flow. More services later isolate high-volume location traffic and delivery work; they do not supply correctness that was absent from the first version.

One region can complete a ride assignment

The database decides assignment; phone delivery follows the commit.



05 / Size locations, rides and subscribers separately

Assume 500,000 drivers are concurrently online at peak and each sends a location every three seconds. That is about 166,667 updates per second. At a compact 40-byte payload, incoming coordinates alone use roughly 6.67 MB/s before network framing, authentication and replication. Daily active drivers are not automatically concurrent drivers, so state that assumption explicitly.

If five viewers subscribe to each driver, there are 2.5 million subscriptions and about 33.3 MB/s of raw outbound coordinate payload at the same update frequency. A million rides per day averages only 11.6 ride starts per second. The low average ride rate does not remove local station surges or justify storing every coordinate in the assignment database.

At 128 bytes per stored sample, retaining every three-second update from 500,000 drivers creates roughly 1.84 TB per day before replicas. Keeping only the latest record uses about 64 MB of raw records, although spatial indexes, connection maps and runtime overhead add substantial memory.

Measure peak updates, candidate counts, routing-call cost, first-offer delay and assignment transaction time separately. A slow routing dependency can dominate matching even while the database is lightly loaded. Bound candidate batches and timeouts instead of requesting precise routes for every driver in the city.

06 / Separate position, availability and trip state

Interfaces

Request or message	Contract
`POST /rides` with request key	Creates one rider request despite network retries.
`POST /offers/O81/accept` with operation key	Attempts assignment and returns the saved result on retry.
`GET /rides/R501`	Recovers authoritative trip state for an authorized participant.

Recover the running trip after reconnect

```
GET /rides/R501
```

Assignment result in the worked example

```
ride:      R501
driver:    D17
assignment: A77
state:      assigned
```

Stored records

Record	Fields or identity	Purpose
Position	`driver`, `session`, `sequence`, `point`, `receivedAt`	Latest observation used for approximate discovery and tracking.
Driver	`id`, `state`, `activeRide`, `version`	Durable authority over whether the driver may accept work.
Ride	`id`, `rider`, `state`, `driver`, `version`	Durable request and lifecycle.
Offer	`id`, `ride`, `driver`, `deadline`, `state`	Identifies the driver invited to accept, with a bounded lifetime.

Authentication determines the rider or driver; a submitted driver ID is not permission. Reusing a ride-creation key with another pickup must fail rather than silently return an unrelated trip. Retain replay results for a documented retry interval and expose status recovery afterward.

Index rides by rider and driver so reconnect does not require searching all trips. Store assignment A77 and an outbox event in the same transaction. The outbox is durable delivery work; a worker can retry notifying participants without making the assignment again. Connection records merely identify a current socket and may expire independently of the trip.

07 / Make acceptance atomic on both sides

All competing accepts for a driver and ride must reach records that can commit together in one regional database transaction. In a consistent lock order, lock the driver, the ride and the offer. Recheck a saved operation result after waiting for locks: a concurrent identical request may already have committed A77. Returning that result is correct; rejecting the retry because D17 is now busy is misleading.

For a new operation, perform these steps within the acceptance transaction:

1. Verify that O81 targets the authenticated driver, is active and has not expired. Check the authoritative database clock after acquiring locks, because the transaction may have waited past the deadline.
2. Require D17 to be available and R501 to remain offering with no assigned driver.
3. Insert the assignment, update both rows, mark the offer accepted and store replay and outbox records in one commit.

Unique active-driver and active-ride constraints provide additional protection.

If D17 also accepts R502, that transaction waits for D17 and then sees the assignment to R501. It cannot change R502. If D18 concurrently accepts R501, the ride check rejects that competing driver and leaves D18 available. Protecting only one side misses the other race.

Keep transactions short and handle bounded deadlock or serialization retries. Never hold database locks while waiting for a person to accept an offer or while calling a routing service.



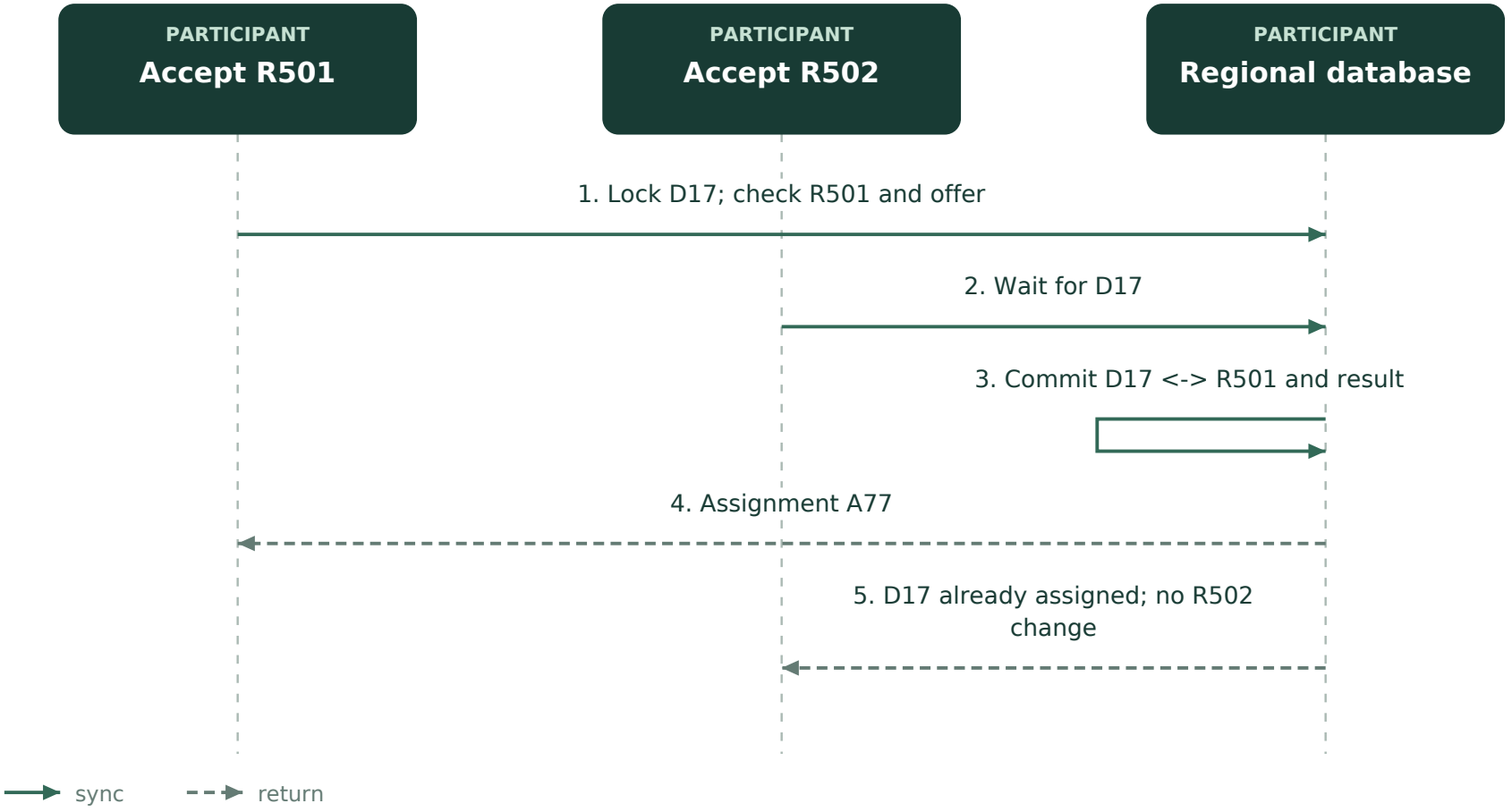
INTERVIEW CRITICAL

An assignment changes two promises

One ride must have one driver, and one driver must have one active ride. Separate successful writes to a ride row and a driver row do not make those promises atomic. Put both checks and updates in one transaction domain.

A second ride cannot take an assigned driver

Both accepts serialize through D17; the losing ride remains unassigned.



08 / Scale approximate location discovery

When coordinate writes burden the assignment database, move latest positions to a partitioned position service. A spatial index maps cells to driver IDs. Every valid update changes the latest point; cell membership needs changing when the driver crosses a boundary, not for every small movement inside the same cell. Fixed or hierarchical cells are adequate before considering a custom adaptive tree.

Updates carry a server-issued session generation and an increasing sequence. Reject older generations and sequence numbers so delayed packets cannot overwrite a newer position. A restarted app gets a new authenticated generation before restarting its sequence numbers. Validate coordinates and observation age, while acknowledging that a phone can still report noisy or dishonest GPS.

The matcher covers the pickup area, retrieves candidate IDs, reads recent points and checks driver availability. It then evaluates a bounded shortlist using pickup suitability and estimated arrival time. A candidate is not a reservation; acceptance still uses the durable transaction.

A stale index can miss a driver who just entered the area. Freshly reading returned positions removes bad candidates but cannot discover an omitted arrival. Define and monitor indexing delay. Expanding the search area is justified only with credible bounds on movement, delay and measurement error; otherwise state that discovery may miss recently arrived drivers.

09 / Bound offers and preserve regional ownership

A matcher can process ride requests from durable pending-work records once bursts exceed synchronous capacity. It reads current ride state before each offer batch, so canceled or assigned rides do not keep generating offers. Offer a few suitable drivers at a time, set deadlines, and move to another batch after all valid offers fail or expire. Unlimited broadcasting wastes routing calls and interrupts drivers who cannot all win.

Partition independent operating regions to distribute workload, keeping their ride and driver records together. Location cells and transaction ownership serve different purposes. Moving ten meters across a cell edge should not move the driver's assignment records to another database owner. An active trip can retain its original authority through completion even when it crosses a regional boundary.

If idle drivers must transfer between regions, stop creating new offers, drain or invalidate old offers, and transfer the authoritative record before enabling the new owner. A monotonically increasing ownership version lets the storage path reject commands from the previous owner. Routing alone cannot stop a paused old process from resuming.

Cross-region assignment is therefore an advanced extension, not a free consequence of drawing multiple matchers. It requires a reservation/transfer protocol or a distributed transaction that preserves both sides of the assignment guarantee.

10 / Recover trips independently of phone connections

After assignment, authorize Maya and D17 to subscribe to R501. A connection directory maps each participant to a gateway, and each location message includes its session and sequence. The gateway can discard intermediate points for a slow phone and retain only the newest observation. Showing the latest position is usually more useful than replaying a minute of obsolete dots.

Trip lifecycle events are different. Assigned, started, canceled and completed transitions must remain recoverable from durable trip state and the outbox. Events carry trip ID and version. The client ignores older versions and fetches current status when a gap or reconnect occurs. A push notification may wake an app, but it is not authoritative proof that a ride remains assigned.

Cancellation races use the same ride and driver authority. If cancellation commits before acceptance, the offer cannot win. If assignment commits first, cancellation follows the assigned-trip policy and clears the ride and driver assignment together when permitted. A temporary socket loss does neither.

Discovery may show coarsened positions to protect drivers. Precise active-trip coordinates require current participant authorization and bounded retention. A new socket must reauthenticate; possession of an old trip ID alone is insufficient to subscribe.



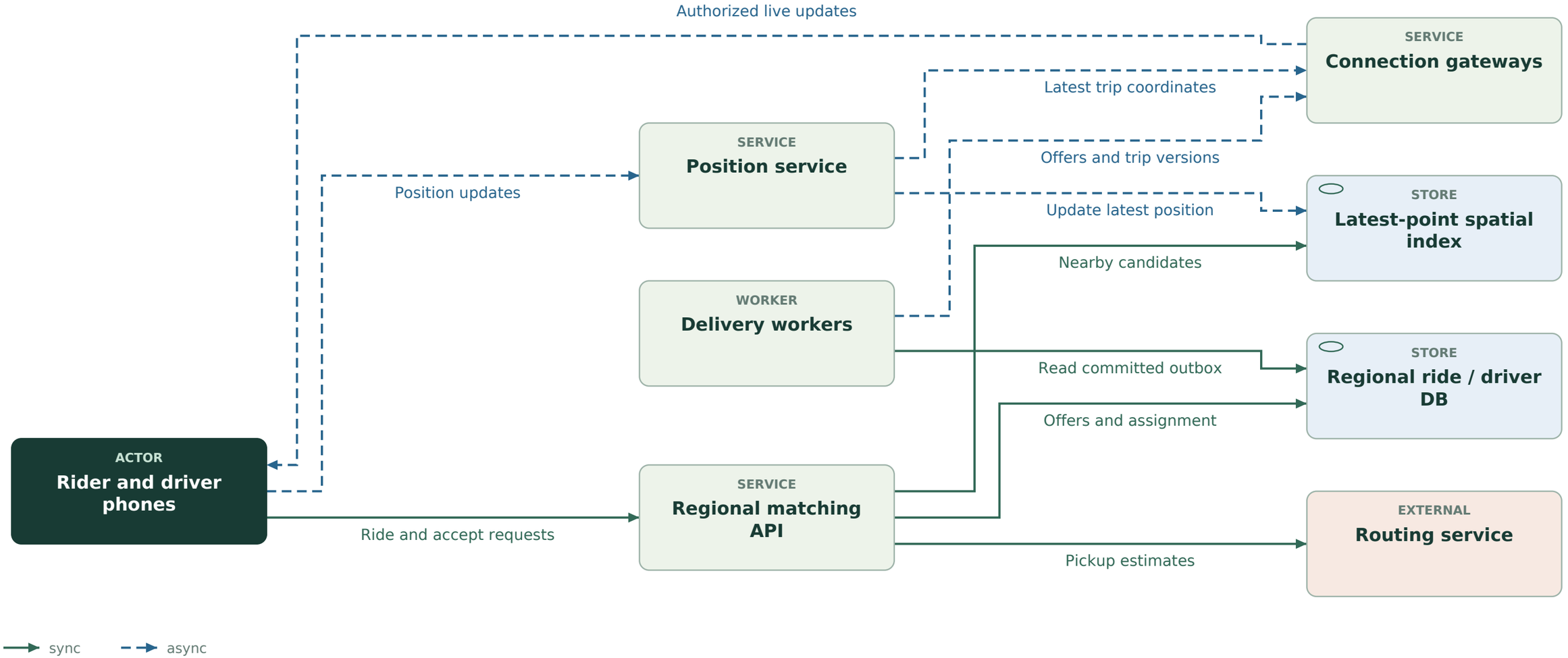
INTERVIEW CRITICAL

A disconnected phone does not cancel a trip

Recover the committed assignment from durable state after reconnect. GPS expiry may remove a driver from discovery, but it must not erase an active ride or make that driver available for another assignment.

Regional assignment with separate position and delivery paths

Maya's ride request uses recent position candidates and pickup estimates, then the regional database commits the winning ride/driver assignment. Delivery workers read committed notification work and reach phones through gateways. Frequent position updates use the position service; they cannot change durable assignment ownership.



11 / Trace the failures that change the answer

Failure	Required behavior
Acceptance commits, response disappears	Retry the same operation or offer and return A77; replay notifications.
Process dies before acceptance commit	Transaction rolls back; another still-valid offer may win.
Location service loses recent points	Drivers republish; discovery temporarily shrinks while trips remain durable.
Regional database loses its primary	Promote only a safe replacement that preserves the promised commits and fences the old writer.
Routing service slows down	Bound shortlist work, use an explicitly approximate fallback or return a delayed-match outcome.

Use synchronous durable database replication and safe failover to preserve acknowledged assignments across one database-node failure. An asynchronous replica may lose recent commits during promotion; counting three servers is not a durability argument. Stop unsafe writes when the database cannot establish which primary may write rather than create two successful assignments for one driver.

During a station surge, bound waiting demand and expose queue delay. A durable backlog that waits ten minutes does not satisfy a two-second first-offer goal. Rate-limit retries, expire outdated requests and reserve capacity for acceptance and current-trip reads. Reconnecting phones should back off with randomness so a gateway restart does not overload authentication and storage together.

12 / Observe the user flow and the ownership rules

Monitor position age, discarded old updates, candidate-to-offer ratio, first-offer delay, acceptance commit latency, cancellation outcomes and notification lag. Split measurements by operating region and local density. Global averages hide the airport queue that is currently failing.

Check durable assignment invariants directly: no active driver appears in two assignments, no ride has two winners, and reciprocal driver/ride references agree. Test two rides competing for D17, two drivers competing for R501, cancellation during acceptance, and a lost response immediately after commit. Pause an old regional process during failover and verify that it cannot resume writing.

Protect location data through participant checks, short retention where possible and audited administrative access. Keep raw coordinates out of general request logs. Apply abuse controls to repeated ride creation and offer acceptance without treating a shared mobile network address as a reliable identity.

The main tradeoffs are deliberate: approximate discovery, regional assignment boundaries and latest-only coordinate delivery. The first simplifies high-volume search, the second keeps exclusive assignment understandable, and the third keeps slow clients current. State which requirements would force revisiting each choice instead of adding every possible service immediately.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1; NFR1-3: timely suitable offers	Recent-position search, a bounded routing shortlist and limited offer batches; isolate location writes from assignment storage.	Load-test a station surge and slow routing calls. Measure first-offer delay and stale-position rejection; suitable supply is not a guaranteed completed match.
FR2; NFR4: exclusive assignment	One transaction checks driver, ride and offer, then stores reciprocal state and the assignment.	Race two rides for D17 and two drivers for R501; race acceptance with cancellation. Exactly one permitted transition wins.
FR3-4; NFR6: tracking and reconnect	Authorized gateways deliver latest coordinates; durable trip versions and the outbox recover lifecycle events.	Drop sockets, reorder locations and reconnect an unauthorized user. Current trip state survives without replaying every obsolete point.
NFR5: durable ownership	Synchronous durable database replication, safe promotion and rejection of old writers.	Fail the database node after acknowledgment and pause/resume the old writer. Verify A77 remains and no competing assignment can be acknowledged.

14 / Rapid revision

Remember: GPS finds candidates; one transaction reserves both driver and ride. Protecting only one side permits a double assignment.

Concern	Complete interview answer
Ride creation	Authenticate the rider; save one ride and result per request key.
Nearby drivers	Search cells, load recent points and shortlist available candidates; results remain approximate.
Offer	Tie an expiring offer to one driver and ride; limit offers sent at once.
Exclusive acceptance	In one transaction, check driver, ride and offer; save both assignments, the retry result and notification work.
Lost response	Return the stored assignment; a timeout does not undo commit.

Concern	Complete interview answer
GPS ordering	Use the current GPS session and increasing update numbers to reject delayed coordinates.
Scale	Scale GPS collection, matching and connections separately; keep the assignment transaction in its designated database.
Reconnect	Read the saved current trip, then resume numbered updates; losing a connection does not cancel assignment.
Overload	Limit queued work and route calculations so acceptance and recovery still have capacity.

A strong closing answer follows R501 from creation to A77 and reconnect, then names the two acceptance races. Leave pooling, cross-region matching and billing as explicit extensions because they change which records must stay consistent, rather than merely adding traffic.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why separate driver position from availability?

Model answer

Position describes an observation; availability is a durable promise about whether the driver can accept work. A fresh heartbeat must not release an active assignment.

Interviewer follow-up

Can the map be stale?

Yes under an explicit freshness policy, because acceptance rechecks current authority.

What the answer must demonstrate: Separate observed location from authoritative assignment availability.

02 / APPLIED

D17 accepts R501 and R502 concurrently. What prevents two riders winning?

Model answer

Both transactions lock or conditionally guard the same driver record and atomically update the corresponding ride. The second sees D17 assigned and changes neither side.

Interviewer follow-up

What if two different drivers accept R501?

Both must also guard the ride row; checking only driver availability misses that race.

What the answer must demonstrate: Protect both driver exclusivity and ride exclusivity in the same transaction.

03 / APPLIED

The acceptance reply is lost. What should the retry return?

Model answer

The saved assignment for the same authenticated operation or accepted offer. Check that result after lock acquisition so a concurrent duplicate observes the committed winner.

Interviewer follow-up

Why not return driver unavailable?

The caller may be retrying their own successful assignment, not proposing a second ride.

What the answer must demonstrate: Recover the saved assignment after lock acquisition instead of rejecting a successful retry.

04 / FOUNDATION

Why include a session generation as well as a sequence?

Model answer

Sequences order updates within one publishing session. A generation distinguishes a restarted or replacement session and fences delayed packets from the old one.

Interviewer follow-up

Does receipt time prove GPS freshness?

No. It measures arrival; the observation time and GPS accuracy have separate validation limits.

What the answer must demonstrate: Explain session replacement, sequence ordering and observation-time limits.

05 / APPLIED

Why send only a few offers at a time?

Model answer

Bounded batches limit driver interruption and expensive routing work. Each batch rechecks that the ride is still eligible.

Interviewer follow-up

What is the cost?

It may take longer to find an accepting driver than a broadcast, so measure first-offer and total-match delay.

What the answer must demonstrate: Connect bounded candidate work to driver interruption and matching latency.

06 / FOUNDATION

Should a lost socket make a driver available?

Model answer

No. The current trip is durable. The phone reconnects, authenticates and recovers its assignment; stale location only affects tracking and discovery.

Interviewer follow-up

Can coordinate messages be dropped?

Intermediate points can be coalesced for display, but durable lifecycle transitions need recovery.

What the answer must demonstrate: Preserve durable trip ownership across socket loss and distinguish coordinate buffering.

07 / FOLLOW-UP

How does cancellation race with acceptance?

Model answer

Both use the ride authority. Cancellation first blocks acceptance; assignment first means cancellation follows the assigned-trip policy and releases both references atomically if allowed.

Interviewer follow-up

Can notification order decide the outcome?

No. Clients use committed state and versions, because notifications can arrive late or twice.

What the answer must demonstrate: Serialize cancellation with acceptance and use committed versions for notifications.

08 / FOLLOW-UP

Why not change assignment owner on every spatial-cell crossing?

Model answer

Cells help find nearby drivers. Assignment ownership keeps ride and driver records consistent. Moving those records on every cell crossing would add unnecessary coordination.

Interviewer follow-up

What changes for cross-region matching?

Introduce an explicit reservation or transfer protocol, or a distributed transaction, before claiming the same exclusivity.

What the answer must demonstrate: Distinguish spatial movement from regional assignment-authority transfer.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design ride matching for R501, then make D17 accept two rides while the winning response is lost.

• Agree numbered functional and non-functional requirements, including regional matching, exclusive assignment and position freshness. Then trace ride creation, offer acceptance and trip recovery end to end.

• Prevent both two rides claiming one driver and two drivers claiming one ride.

• Scale location ingestion and tracking without weakening assignment ownership.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

D17 accepts R501 and R502 at once. Which records must the transaction protect?

Lock the driver and the requested ride, check the offer, then save both assignments, the replay result and notification work together. The losing transaction sees D17 already assigned.

One driver and one ride: protect both sides in one commit.

What ride information survives a lost connection?

The saved trip and acceptance result; reconnecting clients can recover them.

Connection is not ownership.

Which updates may delivery skip when keeping only the latest?

Intermediate GPS coordinates. Trip state changes must remain saved and recoverable.

Skip old coordinates; recover every trip state change.

Summary and interview notes

Find nearby drivers, assign each driver to at most one ride, and recover trip state after disconnection. Keep frequent GPS updates separate from saved assignment decisions.

Remember these points

• Use approximate coordinates for discovery; use committed ride and driver records for assignment.

• Guard both ride and driver in one transaction.

• Persist replay and outbox records with assignment.

• Recover trips from storage rather than connection state.

Interview tips

• Separate approximate discovery from exclusive assignment.

• Race D17's accepts for R501 and R502, then lose the winning reply.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Regional authority transfer: Cross-region matching needs a deliberate fenced ownership protocol.

Full exclusive-assignment proof: Inspect lock waits, duplicate accepts, epochs and cancellation interleavings in depth.

Private tracking and subscription alternatives: Compare polling, cell subscriptions and driver subscriptions at larger scale.

Technical references

H3 indexing documentation
Primary documentation for a hierarchical spatial-cell approach to candidate discovery.
https://h3geo.org/docs/

PostgreSQL explicit locking
Explains row-lock behavior and concurrency considerations for an authoritative assignment transaction.
https://www.postgresql.org/docs/current/explicit-locking.html

PostgreSQL current date/time functions
Distinguishes transaction-start now()/CURRENT_TIMESTAMP from actual changing clock_timestamp(), relevant after lock waits.
https://www.postgresql.org/docs/current/functions-datetime.html#FUNCTIONS-DATETIME-CURRENT

CORE INTERVIEWS / 41

Design a ticket-booking service

Interview version / 45-minute scope · Read the advanced version online

Sell exact seats without overselling: separate advisory maps from atomic holds, then handle payment uncertainty and expiry with explicit recoverable states.

seat inventory • holds • row locking • payment reconciliation

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace browsing, an all-seat hold, checkout and booking confirmation.
- Resolve conflicting seat requests and payment-versus-expiry races without stealing inventory.
- Scale on-sale traffic with caching and bounded admission while preserving one show authority.

Useful foundations: Databases, data models, and ACID transactions; Quorums, consensus, leases, and fencing; Message queues, event logs, delivery guarantees, and backpressure; Caching: cache hits, misses, write policies and invalidation

9 interview questions with model answers and answered follow-ups.

01 / Define what buying a seat means

Design exact-seat booking for a show. Customers browse the catalog, view a seat map, hold up to ten selected seats, pay and recover their booking. Exclude resale, auctions and atomic carts spanning several shows. Our running example is show S99: customer A requests seats 54-56 while customer B requests 56-57. Each request gets its whole set or none, and seat 56 cannot belong to both.

A hold is a durable business record reserving seats until a server deadline, such as five minutes. A database row lock is a short concurrency mechanism used while creating or changing that record. Keep the hold for minutes and the transaction for milliseconds; never leave database locks open while a customer enters payment details.

The seat map may lag by two seconds and is advisory. Hold creation targets a 500 ms 95th-percentile latency after admission, with success acknowledged only after the hold is saved under the durability policy explained below. During an unsafe database partition, pause allocation. For payment, allow a bounded processing interval and disclose that a late successful charge may require a refund if the seats have already been released.

Ask whether buyers select exact seats or only a ticket category, whether a cart may span shows, and whether the waiting room must guarantee strict arrival order. This design chooses exact seats within one show and bounded admission without strict first-arrival allocation.

02 / Functional requirements

1. **Browse a show.** List shows and display seat layout, prices and advisory availability.

2. **Hold selected seats.** Reserve a requested set of up to ten seats together, returning either the complete hold and its deadline or a conflict.
3. **Pay and confirm.** Start payment for an eligible hold, confirm the booking when both payment and seat ownership permit it, and recover a late successful charge through refund handling.
4. **Retrieve the outcome.** Let an authorized customer recover hold, payment and booking status after retries or a lost browser response.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Burst and latency.** Plan for 10,000 seat-map reads/s during an on-sale burst. Use 500 admitted hold attempts/s as a load-test assumption and target 500 ms p95 hold creation after admission; waiting-room delay is a separate metric.
2. **Map freshness and hold lifetime.** Target advisory seat maps no more than two seconds behind for 99% of normal-load refreshes. Choose a five-minute initial hold and a fixed two-minute processing deadline when checkout begins; a late provider outcome may still need refund recovery.
3. **Inventory consistency.** Never allocate one show-seat to two live holds or bookings. A multi-seat request receives every requested seat or none, and expiry cannot release a newer owner's seats.
4. **Durability and safe failure.** Acknowledged holds and bookings must survive one database-node failure under synchronous durable replication and safe failover. Pause allocation when authority is unsafe; payment-provider completion has no unconditional deadline.
5. **Security and retry safety.** Authorize hold/status access using the customer or secure guest session. Reuse scoped request and payment identities, verify provider evidence and keep raw card data outside this service.

04 / Complete the booking flow with one authority

Begin with a booking application, a relational database and an external payment provider. The application serves catalog reads, creates holds, scans deadlines and reconciles pending payments. Background tasks may initially run in the same deployment, but their work must exist durably in the database so a restart can resume it.

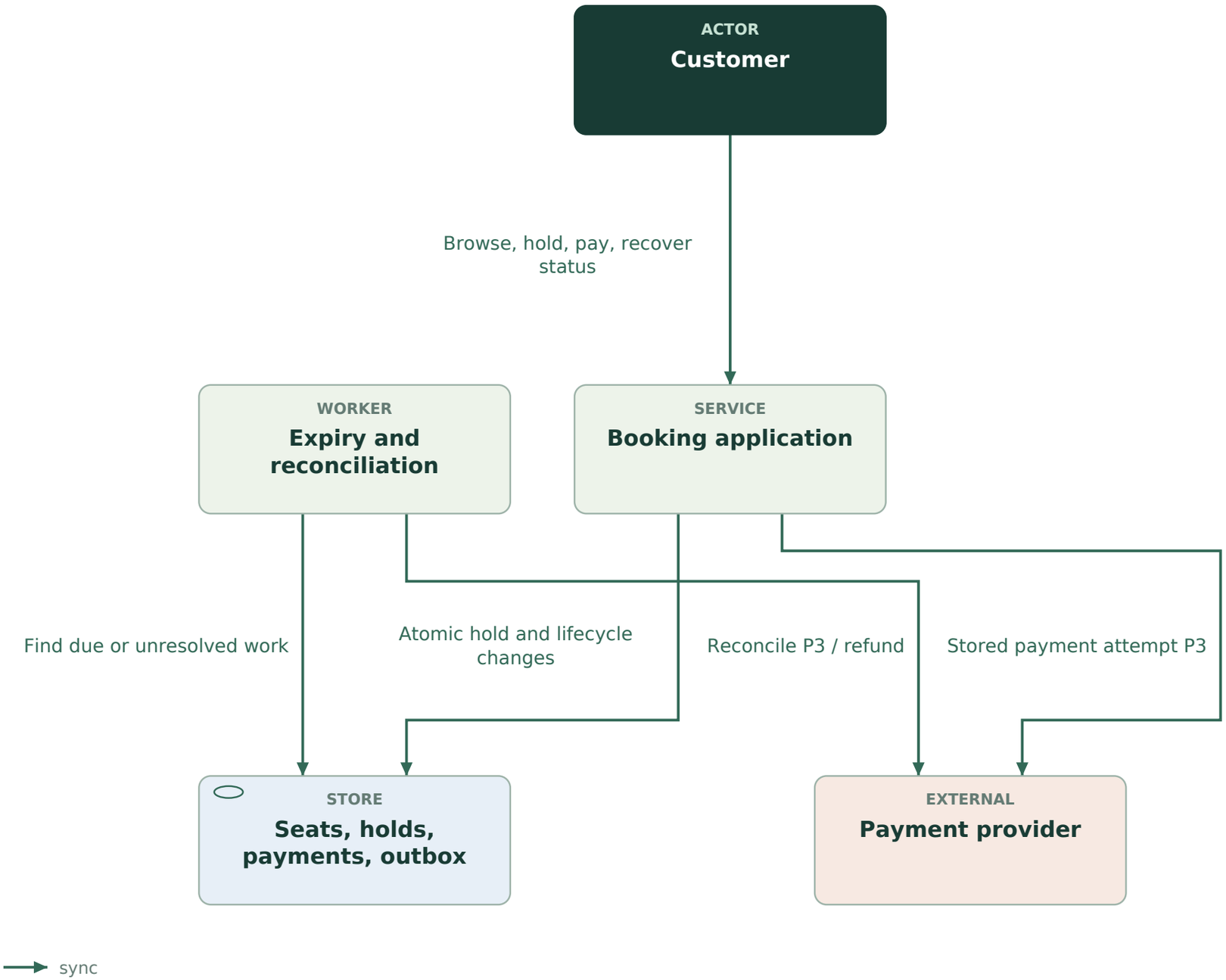
Customer A submits seats 54-56 with request key k7. One transaction claims that unique request identity, locks the selected seats in sorted order, checks that all are free and creates hold H7 plus its replay result. If any seat conflicts, the whole transaction rolls back. After commit, A receives the deadline.

At checkout, another transaction verifies H7 and changes it to processing with a bounded deadline. It stores payment attempt P3 and the fixed amount and currency before making the provider call. Provider success is then reconciled with the current hold. If H7 still owns every seat and remains eligible, confirm the booking atomically. Otherwise retain the payment outcome and schedule a refund without reclaiming the seats.

The browser reads booking status to resolve a lost response. A redirect from the payment page is neither proof of payment nor permission to allocate inventory.

Browsing and booking have separate authorities

The payment call happens after a durable attempt is recorded, outside the seat transaction.



05 / Size the on-sale burst, not just monthly averages

Assume three billion page views and ten million tickets sold in a thirty-day month. Dividing by 2,592,000 seconds gives roughly 1,157 views/s and 3.86 tickets/s on average. If orders contain two tickets, that is about 1.93 orders/s. These averages conceal the workload that matters: thousands of customers attempting the same show at once.

A burst of 100,000 shoppers opening a show in ten seconds creates 10,000 map reads/s. At 50 KB per response, origin traffic would be 500 MB/s before overhead. A 99% cache hit rate reduces origin requests to about 100/s, although customer-facing edge bandwidth remains.

If a load test supports 500 admitted hold attempts/s at 20 ms mean service time before queuing, roughly ten transactions are active on average. This is an illustrative budget, not a universal database capacity. Waiting on overlapping seat rows can dominate even when CPU is idle.

Store hall geometry once and keep show-specific price and allocation separately. For 20 million show-seat rows/day at 100 bytes each, raw daily inventory is 2 GB. Five years is about 3.65 TB before indexes, replicas and backups; archival policy can keep completed shows out of the hot transaction database.

06 / Give holds, payments and retries separate identities

Interfaces

Request or message	Contract
`GET /shows/S99/seats`	Returns layout, prices and advisory availability with an as-of time.
`POST /shows/S99/holds`	Seat IDs, quote version and request key produce one hold or an all-seat conflict.
`POST /holds/H7/checkout`	Starts or recovers the stored payment attempt; may return pending.
`GET /holds/H7/status`	Returns current hold, booking and payment-recovery state to its owner.

Create the worked seat hold

```
POST /shows/S99/holds
```

Hold request values

```
seat IDs:      54, 55, 56
quote version: the version of the price the customer accepted
request key:  k7
```

Successful hold result

```
hold:    H7
seats:    54, 55, 56
deadline: server-issued hold expiry
```

Stored records

Record	Fields or identity	Purpose
ShowSeat	`show`, `seat`, `state`, `holdId`	Current allocation authority for one seat in one show.
Hold + HoldSeat	`id`, `owner`, `state`, `deadline`	Lifecycle and immutable selected seat set.
PaymentAttempt	`id`, `hold`, `amount`, `currency`, `outcome`	Durable identity for an external charge and reconciliation.

Store request results under show, authenticated session and key, including a payload fingerprint. Retrying k7 returns H7; reusing it for different seats conflicts. Claim the key within the transaction before allocating seats so a duplicate cannot report a conflict against its own first successful request.

Index active holds by state and deadline for expiry, and bookings by owner for recovery. An outbox row records notification or refund work in the same transaction as the business change. A signed-in customer or secure guest session owns the hold; knowing H7 is not sufficient authorization.

07 / Prove the all-or-nothing seat decision

Keep one show's seats and holds in a database that can update them together in one transaction. For new hold creation, use one transaction:

1. Lock requested seat rows in ascending seat ID order.
2. Check the quote and every current allocation.
3. Write the entire hold. If the transaction cannot obtain a valid full set, leave no partial reservation.

A wins seats 54-56 first. B's transaction eventually locks seat 56, sees H7 and aborts its request for 56-57. Seat 57 does not remain reserved by B merely because it was free. If B wins first, A fails symmetrically. Unique seat keys and transactional checks protect the actual current allocation; a distributed cache lock is unnecessary for this baseline.

The same lifecycle operations use a consistent order: hold row, its immutable seat set in sorted order, then the payment-attempt row where needed. Re-read state after acquiring locks and handle bounded deadlock retries. Creation may use its own ordered seat lock path because its new hold is not yet visible to other operations.

A deadline is part of validity even if an expiry worker is late. To release a due hold, verify that each seat still belongs to that hold. An old cleanup attempt must never free a seat that now belongs to a newer allocation.



INTERVIEW CRITICAL

A map and a hold make different promises

A cached green seat is an invitation to try. Only the authoritative transaction reserves the complete requested set. Do not keep database locks open for the human checkout interval.

08 / Resolve the payment and expiry race explicitly

The payment provider and our database do not share one transaction. Before calling the provider, store P3, set H7 to processing and store a fixed deadline two minutes after checkout starts. Retries reuse P3 under the provider's supported idempotency contract. A timeout leaves the outcome unknown, not declined; the service queries the provider or processes verified callbacks for that same attempt.

At confirmation, lock H7 and its seats, check the authoritative database clock after waiting for locks, and require H7 to be processing, unexpired and still owner of every selected seat. Verify the provider account, attempt, successful outcome, amount and currency. If all checks pass, record payment success, booking and booked seats in one transaction. Duplicate success notifications return the existing outcome.

Now pause the provider response until after H7 expires. Expiry releases 54-56; B creates H8 for 56-57. When P3's success arrives, H7 is no longer eligible and seat 56 belongs to H8. Record the successful charge and unique refund work. Do not resurrect H7. B keeps the seats; A sees refund recovery rather than a false booking.

Refund work also needs a stable external identity and reconciliation. Submitting a refund is not proof it completed. An authorization-then-capture provider workflow may reduce this risk, but it still needs a defined policy for uncertain external outcomes.



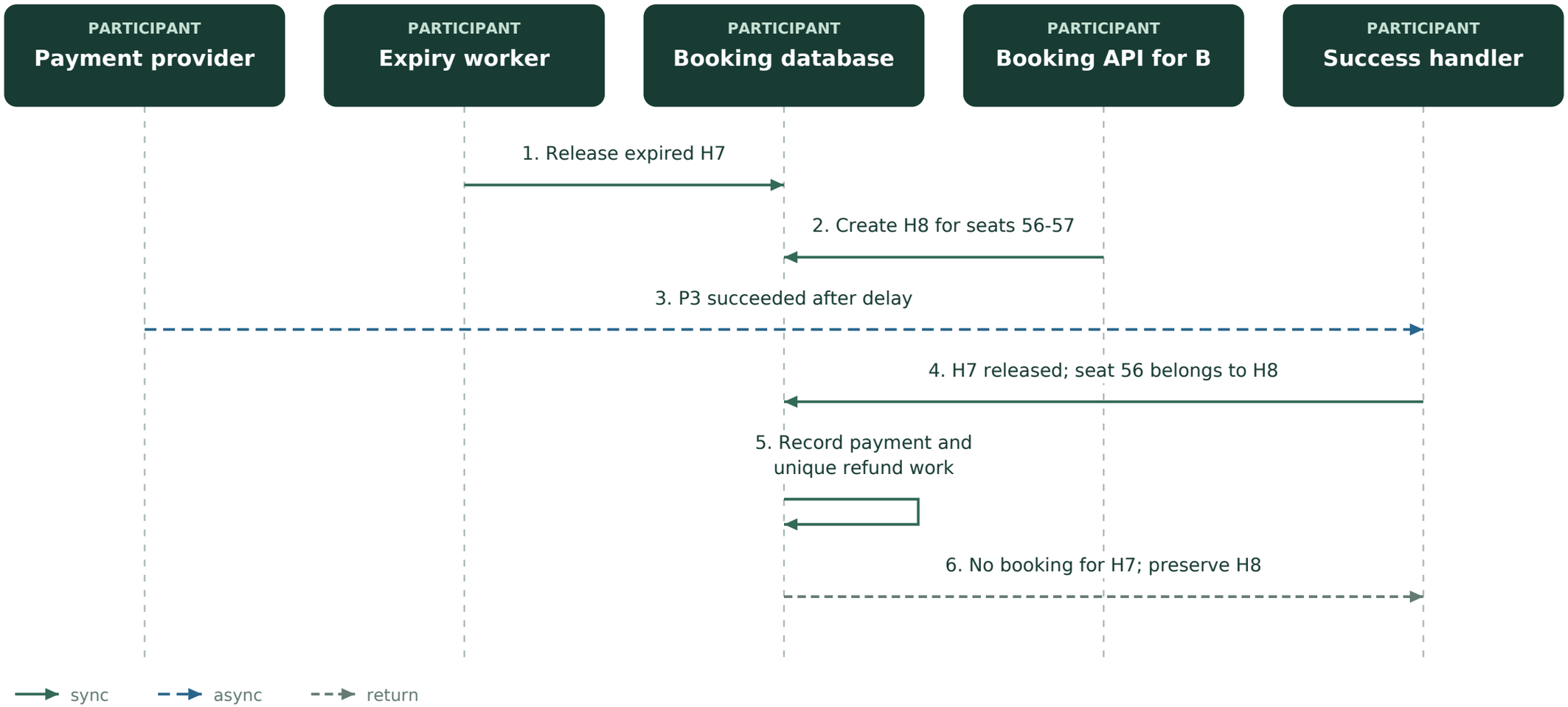
INTERVIEW CRITICAL

Timeout is not payment failure

A provider may have charged the customer before its reply was lost. Keep the attempt pending, reuse its identity and reconcile it. If seats were already released, a late success triggers compensation, not a new claim on someone else's seats.

A late charge cannot reclaim released seats

Expiry and confirmation both recheck current ownership in the same authority.



09 / Cache browsing and control entry to scarce inventory

Move catalog, static hall geometry and short-lived seat maps behind caches when read bursts dominate. Include map timestamps and avoid caching personalized hold status as public content. Collapse concurrent cache refreshes so an expired popular map does not send thousands of identical database reads.

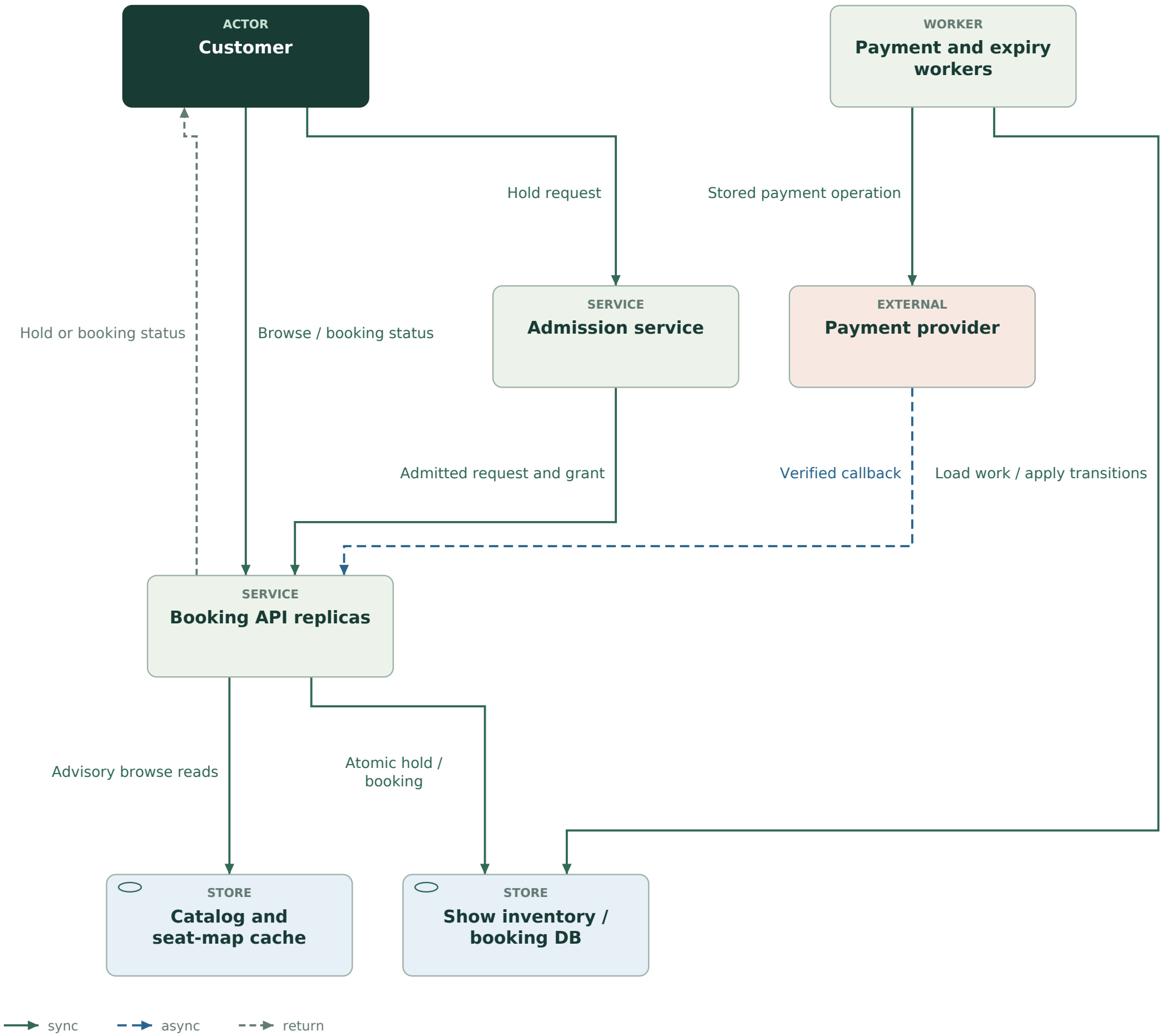
Bound hold attempts before they occupy database connections. A waiting room or admission service issues short-lived grants; the hold transaction validates and consumes a grant if admission is active. Rate-limit seat hoarding by account/session and risk signals. Admission limits simultaneous work; it cannot increase the number of seats for sale.

For the interview baseline, promise bounded admission and explain the fairness policy without claiming strict first-arrival seat allocation. Several simultaneously admitted customers can still race, and network timing affects who commits first. A strict first-in-first-out policy requires durable waiting order and tighter grant sequencing, trading utilization and throughput for stronger fairness.

Partition independent shows when aggregate storage or writes exceed one database. Sharding by show keeps the seat-set transaction local; sharding by movie unnecessarily combines many performances of a blockbuster. One very hot show still sends competing allocations to the same inventory database. More web servers do not remove that shared-seat conflict.

Admission and read caching around one show's booking authority

Admission bounds requests before booking transactions compete for seats. The booking API uses cached catalog data for browsing but commits holds and bookings in the show database. Payment workers load stored attempts, call the provider and reconcile results against the same hold authority; callbacks enter that recovery path too.



10 / Keep cleanup, notifications and failover recoverable

Expiry workers scan the durable deadline index in bounded batches. They perform the same guarded transitions as interactive operations, so restarting a worker or processing a deadline twice is safe. Cleanup may delay availability, but cannot extend the validity of an expired hold. Payment reconcilers scan unresolved attempts independently of browser activity.

The outbox drives map invalidation, booking notifications and refund work. Delivery may duplicate or arrive late. Events include booking versions, and the client retrieves current status after a gap rather than treating arrival order as state order. A notification outage can delay user awareness without undoing a booking.

Use synchronous durable replication of the authoritative database to meet the promised one-node failure tolerance. Safe failover must preserve acknowledged holds and stop the old primary from accepting writes. Changing DNS does not prevent the old primary from continuing to write. During uncertainty, show waiting or temporary failure rather than a reservation that was never safely committed.

Backups protect against deletion and corruption that replication repeats. Restore a test show, compare seats, holds, payment attempts and replay results, and reconcile external payments before resuming allocation. A restored inventory table alone does not establish which provider charges remain unresolved.

11 / Measure correctness, contention and recovery age

Monitor admitted hold latency, lock wait, transaction aborts, active-hold age, map freshness, queue delay and provider-unknown backlog. Track the oldest unresolved payment and refund, not just their counts. A single forgotten charge can be important even when aggregate checkout success looks healthy.

Run invariant checks for duplicate seat allocations, confirmed holds missing selected seats and inconsistent booked states. Test overlapping seat sets, duplicate request keys, worker crashes before and after commit, delayed success after expiry and a callback arriving twice. Stop expiry workers deliberately: holds should become invalid at their deadlines even though free-seat cleanup is delayed.

Verify webhook signatures on the raw provider payload and validate the event against the stored attempt. Keep card data with the provider and store tokens or references. Protect hold/status endpoints against guessing and unauthorized cancellation. A secure guest session needs the same ownership checks as a registered account.

For upgrades, deploy readers that understand a new lifecycle state before enabling writers that create it. Roll out to a small group of shows and retain a rollback path that understands already-created records. Correctness depends on every writer respecting the same transitions, not merely on the newest checkout endpoint.

12 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1; NFR1-2: browse under a burst	Cache geometry and timestamped advisory maps, with collapsed refreshes.	Generate 10,000 reads/s and measure map age. Cached green seats must never be treated as reservations.
FR2; NFR1,3: atomic seat holds	Lock the selected rows in a stable order and commit hold, deadline and replay result together.	Race seats 54-56 against 56-57; assert whole-set outcomes and load-test admitted p95 latency under overlapping-seat contention.
FR3; NFR2-3: payment versus expiry	Persist one payment attempt, recheck current ownership/deadline at confirmation and create unique refund work for ineligible late success.	Delay P3 beyond the processing deadline, allocate seats to H8 and deliver P3 twice. H8 keeps the seats; refund recovery remains visible.
FR4; NFR4-5: recover a protected booking	Authoritative status, durable replay/outbox records and safe database failover.	Lose responses, fail the primary and attempt another session's status request. Recover the same booking, preserve seat ownership and deny unauthorized disclosure.

13 / Rapid revision

Remember: The map suggests availability; the transaction reserves seats. A late charge cannot take seats from a newer hold.

Topic	Mechanism and limit
Browse	Cache catalog and advisory maps; a green seat is not reserved.
Hold	Lock and validate every selected seat in one short transaction; save the hold and its deadline.
Retry	Scope the key to the show and authenticated session; save the request and result so a retry returns the same hold.
Checkout	Persist processing state and one payment attempt before the external call.
Confirm	Verify payment; lock and recheck the hold, deadline and ownership of every seat before booking.
Expire	Release only seats still owned by the expired hold; delayed cleanup does not extend validity.
Late payment	Record the charge and retryable refund work; never reclaim a newer customer's seats.
Scale	Cache reads, limit admitted requests and separate shows across shards; one popular show still has competing buyers.

Topic	Mechanism and limit
Recover	Resume saved work, prevent former owners from writing, and check uncertain payments with the provider.

Close by tracing A's seats 54-56, B's conflicting 56-57, and P3 arriving after expiry. This demonstrates the actual design more clearly than listing databases, queues and caches. State that strict waiting fairness and multi-show atomic carts are stronger contracts requiring additional coordination.

14 / Optional prompt variant: reserve every night of a hotel stay

This is an alternative interview prompt: reserve hotel rooms across several nights instead of seats for one performance. Keep the main ticket-booking design unchanged. The new difficulty is that a stay consumes capacity on **every occupied night**, and a shortage on one night invalidates the whole request.

Model inventory by `(hotelId, roomType, localDate)`, with capacity, held quantity and booked quantity. Available quantity is `capacity - held - booked`. The room type promises a category such as a standard double; assigning a particular physical room is a separate hotel operation. Use hotel-local calendar dates and the interval `[checkIn, checkOut)`: checkout day consumes no night. Reject invalid dates, excessive stay lengths and missing inventory rows rather than guessing their capacity.

A guest requests one standard double from November 5 through November 8. The occupied nights are November 5, 6 and 7:

Night	Available before this request	Can reserve one?
November 5	2	Yes
November 6	0	No
November 7	3	Yes

The result is rejection of the whole stay. No hold remains on November 5 or 7. Reserving each night in a separate committed transaction would instead leave the guest with an unusable partial booking.

Keep each hotel's inventory in one database transaction scope. Reserve the stay as follows:

1. Authenticate the guest. In the reservation transaction, claim a stable request identity with a fingerprint covering hotel, room type, dates, quantity, price and currency.
2. Lock all required nightly inventory rows in increasing date order.
3. Confirm that every row exists and has sufficient available quantity.
4. If all checks pass, increase held quantity on every night and create one reservation with its nightly allocations, server-issued expiry and replay result in the same commit.

Browsing a cached availability calendar does not reserve anything.

Use the existing bounded payment-processing flow without keeping inventory locks open during provider calls. Confirmation locks the reservation and its nightly rows, rechecks its current eligibility and atomically changes every allocation from held to booked. Expiry or permitted cancellation changes reservation state and releases the corresponding quantities together. Each transition checks the prior state, so duplicate workers cannot release or confirm the same capacity twice. A late payment success cannot reclaim nights already released; recover the financial outcome through the stated refund policy.

Test two overlapping stays, a missing middle-night row, an expired hold after lock waiting, a lost commit response and two expiry workers. PostgreSQL's row-lock and deadlock guidance supports the concrete transaction mechanism. Multi-hotel packages spanning independent databases need a separate reservation workflow; this example promises one hotel's all-night atomic reservation.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why distinguish a hold from a row lock?

Model answer

A hold is a durable reservation with a business deadline. A row lock protects a short state transition; holding it while a person pays wastes connections and does not define recovery.

Interviewer follow-up

What if cleanup stops?

The deadline still makes the hold invalid; cleanup only restores availability promptly.

What the answer must demonstrate: Distinguish minutes-long business reservations from short database locks.

02 / APPLIED

How do seats 54-56 and 56-57 avoid a partial allocation?

Model answer

Each transaction locks its selected seats in order, validates the full set and commits all changes together. The loser on seat 56 rolls back its entire set.

Interviewer follow-up

Would atomic updates on individual seats suffice?

No. They might leave a customer holding only some requested seats.

What the answer must demonstrate: Validate and commit the entire requested seat set or roll it back.

03 / APPLIED

The hold response disappears after commit. What next?

Model answer

Retry the same scoped key and payload to retrieve the saved hold. Claim that key before allocation so concurrent duplicates serialize correctly.

Interviewer follow-up

What if the payload changes?

Reject the key reuse; it is a new logical operation, not a retry.

What the answer must demonstrate: Claim a scoped request identity and compare payloads before allocating seats.

04 / APPLIED

A payment times out. Can the customer be charged again?

Model answer

Not merely because of the timeout. Reuse the stored attempt identity and reconcile its outcome under the provider contract.

Interviewer follow-up

What must precede the provider call?

A durable attempt, amount/currency and bounded processing state for the hold.

What the answer must demonstrate: Persist a stable attempt before the provider call and retain unknown outcomes.

05 / APPLIED

Payment success arrives after another customer holds the seats. What happens?

Model answer

The success transaction finds the old hold ineligible and records refund work without changing the new allocation.

Interviewer follow-up

Why check again after payment?

Expiry or cancellation can change ownership during the external call.

What the answer must demonstrate: Recheck hold eligibility and ownership; compensate without reclaiming another hold's seats.

06 / FOLLOW-UP

Does a waiting room guarantee first-arrival seat allocation?

Model answer

No. Several admitted clients can race and network timing can reorder their commits. State whether the product promises bounded load or strict fairness.

Interviewer follow-up

What does strict fairness cost?

Durable ordered grants and less concurrency, with possible head-of-line blocking.

What the answer must demonstrate: State the chosen admission fairness contract and its concurrency cost.

07 / FOUNDATION

Why partition by show?

Model answer

Customers compete for seats within one show. Keeping those seats together lets each hold commit atomically, while different shows scale independently.

Interviewer follow-up

Does it solve one extremely popular show?

No. Cache browsing and control admission to that show's authority.

What the answer must demonstrate: Keep a show's seat set local while recognizing the single-show contention limit.

08 / FOLLOW-UP

Why are three database replicas not a complete durability answer?

Model answer

The commit and promotion policies determine whether acknowledged holds survive and whether old writers are fenced. Replica count alone says neither.

Interviewer follow-up

What is the safe response during uncertainty?

Pause new allocations and preserve recovery/status paths rather than accept conflicting writes.

What the answer must demonstrate: Name acknowledgment, safe promotion and old-writer fencing instead of counting replicas.

09 / FOLLOW-UP

How does the design change when the booking is a three-night hotel stay?

Model answer

Inventory becomes a room-type capacity row for every occupied hotel-local date in [checkIn, checkOut). One transaction checks and reserves all nights. If the middle night is unavailable, reject the entire stay with no partial holds. Confirmation or release changes every nightly allocation and the reservation state atomically.

Interviewer follow-up

Does booking each night in a separate successful transaction preserve this contract?

No. It can commit the first and third nights while the second fails, leaving a partial stay. Keep one hotel's night rows in the same transaction domain, or explicitly choose a more complex pending reservation workflow across independent owners.

What the answer must demonstrate: Identify room-type/date inventory, exclusive checkout date, whole-stay atomicity and duplicate-safe hold transitions.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design exact-seat booking, then delay a successful payment until the old hold expires and another customer acquires one of its seats.

• Agree numbered functional and non-functional requirements, including exact-seat scope, admission latency and hold/payment deadlines. Then trace browsing, an all-seat hold, checkout and booking confirmation.

• Resolve conflicting seat requests and payment-versus-expiry races without stealing inventory.

• Scale on-sale traffic with caching and bounded admission while preserving one show authority.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

A wants seats 54-56 and B wants 56-57. What happens if A's hold commits first?

B finds seat 56 owned by A and rolls back the entire request, including seat 57. The cached map cannot override that committed hold.

A shared seat creates a conflict: reserve the whole set or none.

What does a payment timeout mean?

The provider may have charged already. Recover the result of the same payment attempt.

Unknown is not declined.

Payment succeeds after the seats were released. What happens?

Save and retry the refund work; never take seats from a newer hold.

Refund the late charge; keep the newer customer's seats.

Summary and interview notes

Reserve all selected seats in one transaction; the displayed seat map is only a guide. Save payment progress, enforce hold expiry, and recover uncertain charges without taking another customer's seats.

Remember these points

• Reserve a complete seat set in one short transaction.

• Make retries return the committed hold.

• Persist and reconcile external payment attempts.

• Refund a late successful charge without taking seats from their newer owner.

Interview tips

• Keep the hold deadline separate from short database locks.

• Race 54-56 against 56-57, then deliver payment success after the winning hold expires.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Strict waiting fairness: Durable first-in-first-out admission is a stronger contract than bounded concurrent admission.

Full confirmation-versus-expiry proof: Inspect deadline clocks, lock ordering and every permitted payment transition.

Shard and coordinator recovery: Fenced coordinator epochs and restored waiting order matter for stronger admission designs.

Multi-show carts: Atomic sets across shows require a new distributed transaction or compensation contract.

Technical references

PostgreSQL explicit locking
Explains row locks, conflicts, and deadlock considerations for short reservation transactions.
https://www.postgresql.org/docs/current/explicit-locking.html

Stripe idempotent requests
Provider-specific retry contract; business retention/reconciliation must still be designed.
https://docs.stripe.com/api/idempotent_requests

Stripe webhook event handling
Documents signature verification, duplicate events and non-guaranteed delivery ordering; application reconciliation remains necessary.
https://docs.stripe.com/webhooks

PostgreSQL INSERT and conflict handling
Supports unique request claims and conflict-aware insert behavior; the booking transaction still defines all-seat atomicity.
https://www.postgresql.org/docs/current/sql-insert.html

PostgreSQL current date/time functions
Explains why deadline validation after a lock wait cannot rely on transaction-start now().
https://www.postgresql.org/docs/current/functions-datetime.html#FUNCTIONS-DATETIME-CURRENT

EXTENDED INTERVIEWS / 42

Design a distributed key-value store

Interview version / 45-minute scope · Read the advanced version online

Build a durable exact-key store with conditional updates, safe retries and strong regional reads, then partition independent keys and replicate each partition.

key-value • replicated log • conditional writes • LSM

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain value, version and request identity using two concurrent edits.
- Trace a committed mutation and a current-authority read through a replica group.
- Account for storage maintenance, hot keys, migration and failure without overstating availability.

Useful foundations: CAP theorem: consistency, availability, and partition tolerance; Quorums, consensus, leases, and fencing; Consistent hashing and virtual nodes

8 interview questions with model answers and answered follow-ups.

01 / Choose the meaning of a successful operation

A key-value store maps a tenant's key to value bytes whose contents it does not interpret. Offer exact-key GET, PUT and DELETE, with optional expected-version conditions. Exclude joins, arbitrary search, global range scans and multi-key transactions. Those operations require additional indexes or coordination and should not appear accidentally through an underspecified API.

Use cart-42 at version 7. Client A adds a pen while client B removes a book, both from version 7. The store cannot decide how the shopping application should merge those intentions. It can ensure only one conditional replacement succeeds; the other client rereads and decides what to do next.

Choose strong per-key operations in one home region: a read begun after a successful write returns that write or something newer. This is linearizability, a real-time ordering contract. An isolated replica cannot simply keep accepting conditional updates or serving old values as current. A separate stale-read option can exist, but must be named explicitly.

Assume 1 KiB average values, a 1 MiB maximum and a 20 ms normal-operation p95 target. Acknowledged mutations should survive one replica-node or zone failure, with replica placement chosen accordingly. Regional disaster recovery is a separate promise.

Clarify whether callers need strong current reads or may accept stale replicas, whether operations cover one key or several, and what failure must preserve an acknowledged write. This answer chooses exact-key linearizable operations in one home region with one-zone failure tolerance.

02 / Functional requirements

1. **Read and mutate exact keys.** Provide authenticated GET, PUT and DELETE for opaque value bytes under a tenant's key.
2. **Update conditionally.** Accept an expected version so clients can reject a replacement based on an outdated value.
3. **Recover mutation retries.** Return the stored outcome for the same request identity and payload within the supported retry horizon, including after a lost response.
4. **Distribute and recover data.** Route keys to their current owner and support safe replica recovery and partition movement without changing the client's key or operation meaning.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Capacity and size limits.** Plan for ten billion live keys, 100,000 reads/s and 20,000 writes/s, with 1 KiB average values and a 1 MiB maximum. Budget three copies plus indexes, maintenance and retry history.
2. **Latency.** Target 20 ms p95 for admitted same-region exact-key operations under normal load. Benchmark durable writes, strong reads and ongoing compaction together; timeouts are misses, not fast successful operations.
3. **Consistency.** Provide linearizable per-key reads and mutations: a read started after a successful write sees it or something newer. Only one conditional replacement of the same current version may succeed.
4. **Durability and failure boundary.** Use three consensus replicas placed across zones so acknowledged mutations survive one replica or zone failure. Stop strong operations in a partition that lacks a safe majority; regional disaster survival is outside this promise.
5. **Retry and tenant isolation.** Retain mutation outcomes for the selected one-hour retry horizon. Authenticate tenant scope on every path, reject conflicting request-ID reuse and enforce byte as well as operation quotas.

04 / Begin with one durable storage owner

The baseline is one server using a tested local storage engine. The server authenticates the tenant, identifies the key and processes its changes in order. Before changing cart-42, the owner checks whether this request identity already has a saved result. If so, it returns that result after confirming the payload matches.

For a new conditional PUT:

1. Compare expected version 7 with the current value inside the same atomic operation that installs the replacement.
2. On success, write the new value, a fresh version and the saved request result together.

3. Make the operation durable before replying.

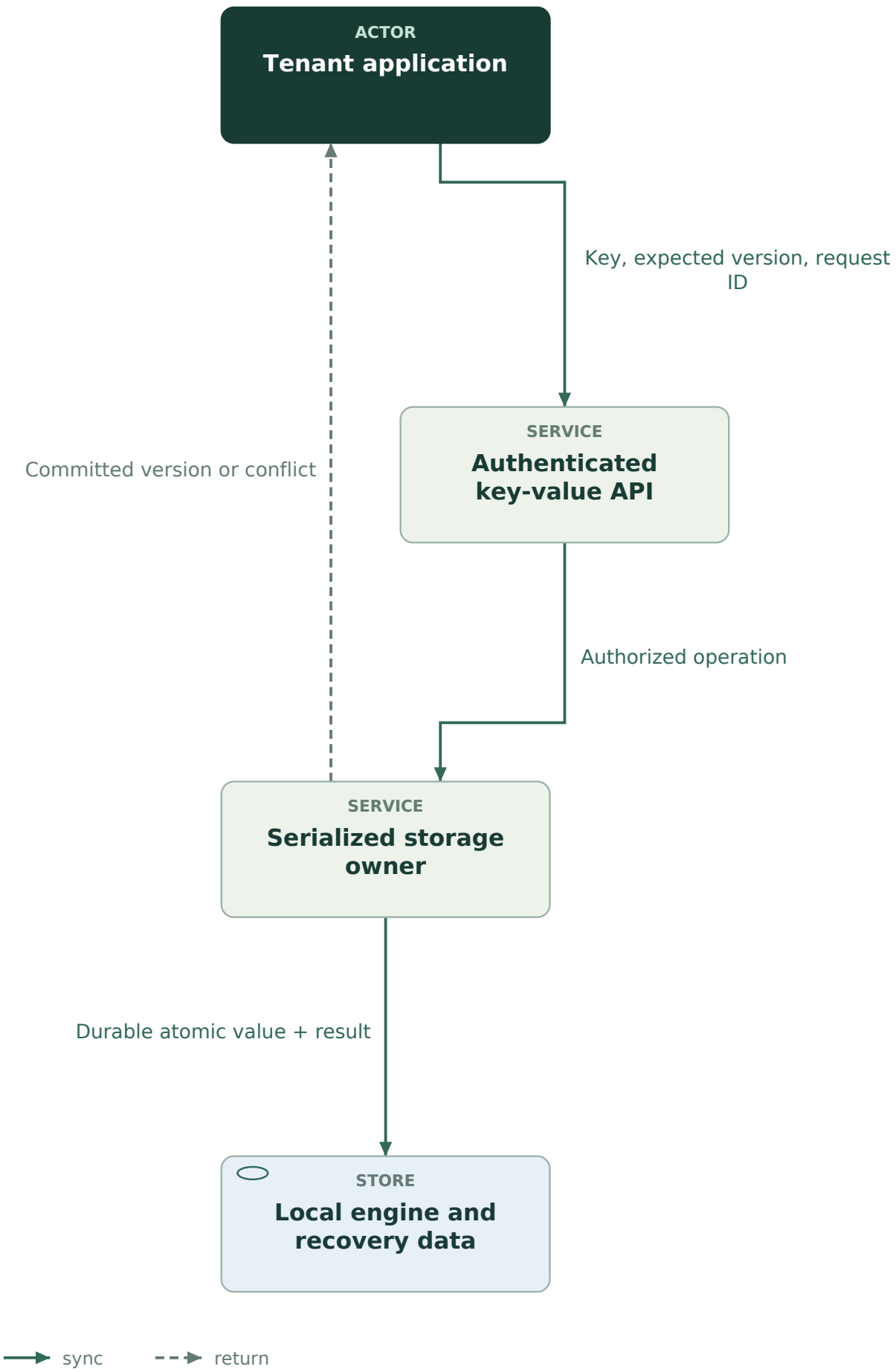
A crash after commit but before response can then recover both the value and what the caller should receive.

GET reads the current committed value. DELETE writes an ordered deletion marker rather than relying on an untracked physical erase. Recreating the key receives a new version so an old expected-version token cannot accidentally match a later incarnation.

This single-owner version is complete for local concurrency and process restart under the engine's guarantees. It cannot tolerate losing the only disk or serve while that machine is unavailable. Replication is the next change because of those specific limits, not because a dictionary automatically becomes distributed when copied.

A durable conditional operation

Value, version and request result are one atomic local change.



05 / Separate stored data from rewritten bytes

Assume 100,000 reads/s and 20,000 writes/s. With 1,024-byte average values, value ingress is 20.48 MB/s, about 1.77 TB/day. That is write traffic, not necessarily new live storage: repeatedly replacing the same cart rewrites bytes without adding a new live cart each time.

Ten billion live keys at 1 KiB plus 100 bytes of key/version overhead require about 11.24 TB logically. Three copies require 33.72 TB before engine indexes, logs, temporary compaction files and failure reserve. If a tested node has 500 GB of usable live-data capacity, the ratio suggests about 68 node equivalents, not a final fleet layout. Placement, throughput and failure headroom still determine the actual topology.

Retaining one hour of results at 20,000 mutations/s means 72 million results. At an illustrative 100 bytes each, that adds 7.2 GB logically before replication and indexing; rejected conditions may also need saved outcomes.

Read payload is roughly 102.4 MB/s before overhead. A hot key can dominate one owner despite comfortable total bandwidth. Benchmark durable writes and steady-state storage maintenance, not only an in-memory map. Client retries increase attempted traffic during outages without increasing useful completed writes.

06 / Make versions and request identities distinct

Interfaces

Request or message	Contract
`GET /kv/cart-42`	Returns bytes and an opaque version, or an authoritative not-found result.
`PUT /kv/cart-42`	Replaces only the named current version and saves the result.
`DELETE /kv/cart-42`	Records an ordered deletion under the same retry contract.

Conditional replacement request

```
PUT /kv/cart-42
```

Request fields for client A's update

```
expectedVersion: 7
requestId:      the stable identity reused for this attempted update
value:          replacement cart bytes containing A's added pen
```

Conditional delete request

```
DELETE /kv/cart-42
```

Delete request fields

```
expectedVersion: the version being deleted
requestId:      the stable identity reused for this attempted deletion
```

Stored records

Record	Fields or identity	Purpose
Value	`tenant`, `key`, `bytes`, `version`, `tombstone`	Current application-visible state.
RequestResult	`tenant`, `key`, `requestId`, `fingerprint`, `result`	Distinguishes a retry from a new mutation.
Partition metadata	`range`, `members`, `ownershipVersion`	Routes keys to their current replica group.

A version identifies the state being replaced. A request ID identifies the attempted operation. Reusing an ID with another value or condition must fail; otherwise a caller could accidentally retrieve the result of unrelated work. Tenant identity comes from authentication on every access path.

Specify a retry horizon, such as one hour, rather than retaining results forever by implication. Older uncertain operations require status recovery or an application-level decision after rereading; issuing a new unconditional write blindly can repeat the original change. Return distinct conflicts, size-limit errors, admission limits and unavailable outcomes. A network timeout alone cannot establish whether the mutation committed.

07 / Give each partition one agreed command history

Use a proven leader-based consensus implementation for each replica group, with three appropriately placed replicas in this exercise. The leader proposes commands to an ordered log. The protocol determines when a command is durably committed and ensures a valid replacement leader preserves committed history. Apply a committed command before acknowledging its application result.

Suppose two commands expect version 7. A's command is applied first, finds version 7 and creates version 8. B's command is applied next, sees version 8 and records a conflict. The comparison occurs while applying the agreed order, not in an earlier unprotected read. Two callers therefore cannot both successfully replace the same current version.

The local engine applies the value or deletion marker, saved result and applied-log position as one recoverable batch. After a crash, recovery knows which commands are installed and which must be replayed. An in-memory duplicate-request cache alone would lose the result when leadership changes.

Three copies are not sufficient without the protocol. If A acknowledges before another durable copy receives the update, losing A can lose a successful write. If a replacement leader can choose an obsolete history, waiting for extra copies still does not establish safe failover. Use the library's supported election and membership rules rather than inventing them during the interview.



INTERVIEW CRITICAL

Replication must preserve the decision, not merely the bytes

The successful version check and its saved result belong to one agreed history. Read/write quorum counts alone do not explain ordering, safe leader election, failed proposals or current reads.

08 / Explain why a strong read cannot trust an old leader

A client routes GET to the partition leader, but the process still needs to establish that its authority is current. Imagine A loses contact with B and C. They elect a new leader and commit version 8 while A's disk still contains version 7. A must not answer a later strong GET from its isolated local copy.

One supported approach uses the consensus protocol to confirm leadership with a quorum and obtain a safe read position. The leader waits until its local state has applied through that position, then returns the key. A correctly implemented lease can be an alternative, but it adds timing assumptions that the baseline need not introduce.

A storage-engine block cache speeds disk access without changing which committed state is read. An independent application value cache cannot silently serve this strong API unless it has an appropriate freshness-validation protocol. Followers may support explicitly stale reads for callers who accept them, with different documented semantics.

Not-found responses also matter: after a successful creation, an old replica saying "absent" violates the same promise as returning an old value. During majority loss, the affected partition becomes unavailable for strong operations even if its surviving node can still answer network requests.

09 / Partition independent keys and preserve ownership on moves

Hash the authenticated tenant and key into logical partitions. A routing directory maps each partition to its replica group. Many logical partitions may share physical nodes; choosing many manageable units allows capacity changes without moving an entire server's data at once. A cached directory reduces lookup work, while stale owners reject or redirect requests using a placement version.

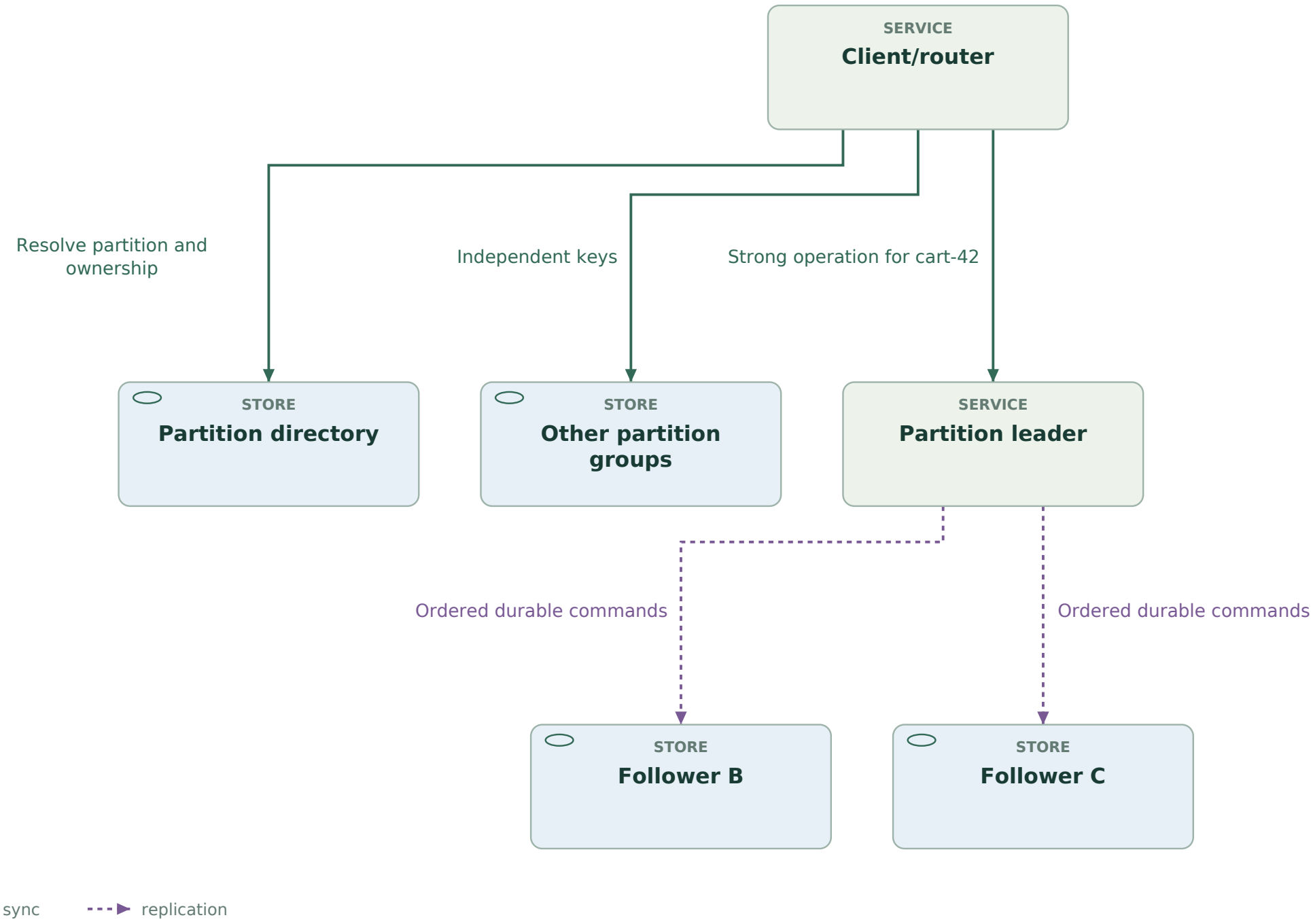
Different partitions can process independent keys in parallel. A single hot cart still has one ordered mutation history. Moving that partition to a larger owner can help resource pressure, but adding hash partitions does not create parallel successful replacements of the same version. Splitting that value into subkeys would change which updates can commit together.

To move a partition, transfer a consistent snapshot, replay subsequent committed changes and verify the destination is caught up before activating its ownership. Include values, deletion markers, versions and request-result history. Copying only live values would lose retry safety and might resurrect deleted state.

Coordinate cutover through the replication system's supported configuration protocol and a current routing generation. The previous owner must lose write authority before an independent new owner accepts conflicting commands. Updating the directory before the copy is ready creates a missing or stale partition, not a completed migration.

Independent replicated partitions

Routing chooses a group; that group commits mutations and validates strong reads.



10 / Explain storage maintenance without designing a new database

A log-structured merge storage engine keeps recent entries in an in-memory sorted structure backed by recovery data, then writes sorted immutable files. Background compaction combines files and discards obsolete versions when safe. This can support efficient sustained ingestion, but it consumes CPU, I/O and temporary disk space after the original write returns.

Reads may consult several structures. Bloom filters help skip files that definitely lack a key; a positive result only means the file may contain it. A block cache helps repeated reads. Neither feature changes the store's consistency contract or replaces the authoritative version decision.

A deletion marker suppresses older values still present in files or replicas. Remove it only when the supported repair, snapshot and retention rules ensure that old state cannot reappear. Physical removal from backups follows a separate retention policy. Immediate API deletion does not imply that every historical byte vanished immediately.

A B-tree engine is a valid alternative for another measured read/write mix. Explain which work the local engine performs, then discuss write amplification, read amplification and resources reserved for maintenance. A local engine such as RocksDB does not independently provide distributed routing, consensus or request deduplication; those belong to the system around it.

11 / Recover while protecting foreground capacity

Failure	Behavior
Leader dies after commit but before reply	A valid successor retains the command and result; the same request ID recovers the original outcome.
Majority becomes unavailable	Stop strong operations for that partition; other independent partitions can continue.
Disk synchronization stalls	Bound queued requests and bytes, reject excess work and retain committed outcomes.
Replica falls behind	Restore a snapshot and replay the remaining log before treating it as caught up.
Accidental deletion reaches every replica	Recover from separately retained and tested backup history.

Apply tenant quotas in bytes as well as operations: a 1 MiB write costs much more than an average 1 KiB write. Reserve bandwidth for foreground requests and throttle compaction, catch-up and migration when they compete for the same disks. Unlimited buffering converts a transient stall into memory exhaustion and extreme latency.

Monitor committed-operation tail latency, conflicts, unavailable partitions, leader changes, synchronization latency, compaction backlog and hot-key concentration. Distinguish attempts from proposals and successful mutations to see retry storms clearly. Test leader loss at commit boundaries, old-leader reads, deleted-key

recreation and migration during retries. A successful backup job is insufficient until a restore produces a validated state.

INTERVIEW CRITICAL

Unavailable can be the correct answer

When no replica group can safely establish the current history, reject strong reads and writes for that partition. Returning a reachable old value or accepting a conflicting update would change the promised API.

12 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR3: exact-key semantics	One ordered state-machine action checks the expected version and installs the value or tombstone; strong reads establish current authority.	Race the two version-7 cart updates and isolate an old leader. One replacement wins and the old leader cannot return stale data as current.
FR3; NFR5: recover retries	Atomically persist value/version, request fingerprint, result and applied position.	Lose a reply and retry after leader replacement or migration within one hour. The same outcome returns; older uncertainty follows the documented recovery boundary.
FR4; NFR4: tolerate the chosen failure	Consensus commit/election and supported membership changes preserve history and revoke old ownership.	Lose one zone, then lose a majority. Verify preserved acknowledged data in the first case and refusal of unsafe strong operations in the second.
NFR1-2,5: usable capacity	Partition independent keys, reserve maintenance capacity and enforce tenant/byte limits.	Load-test the stated mix during compaction and recovery against 20 ms p95. Test a hot key separately; extra partitions cannot parallelize its ordered mutations.

13 / Rapid revision

Remember: Save the new value and request result together, so a retry can return the result of the original write.

Topic	Mechanism and consequence
API scope	Exact-key operations; no implicit search or cross-key transactions.

Topic	Mechanism and consequence
Conditional update	Compare the expected version and replace the value as one command in the replicated log's order.
Safe retry	Save the request fingerprint and result with the value; reuse the request ID after a timeout.
Durability	Use the replication protocol's commit rule so acknowledged writes survive the stated failures.
Strong read	Verify that the server is still leader and has applied the committed commands required for the read.
Scale	Hash different keys into replica groups; competing updates to one key still run in order.
Delete	Save a deletion marker in log order; keep it until recovery can no longer restore an older value.
Migration	Copy values, versions, deletion markers and retry results, then safely transfer write ownership.
Operations	Reserve capacity for maintenance, replicas and failures; backups help recover mistakes copied to every replica.

Close with the cart-42 conflict and lost-response example. The deliberate cost is minority-side unavailability. If asked to accept writes in disconnected regions, discuss a different merge or conflict contract before changing the topology; the original immediate conditional-update guarantee cannot simply remain on both isolated sides.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How is a version different from a request ID?

Model answer

The version identifies state to replace; the request ID identifies one attempted change. Their combination supports conflict detection and retry recovery.

Interviewer follow-up

Can one request ID carry different values?

Reject that reuse by comparing the saved payload fingerprint.

What the answer must demonstrate: Distinguish expected state from attempted operation and reject conflicting ID reuse.

02 / APPLIED

Two clients replace version 7. Why can only one win?

Model answer

The agreed command order applies one check-and-update first, advancing the version. The next command checks the new current state and records conflict.

Interviewer follow-up

What is the unsafe alternative?

Comparing outside the atomic mutation path lets both callers pass the old check.

What the answer must demonstrate: Place version comparison and mutation inside the agreed serialized application step.

03 / APPLIED

A write commits but its reply is lost. What survives?

Model answer

The value, version and saved result remain recoverable together. Retrying the same scoped request returns that result without another change.

Interviewer follow-up

Why persist rejected results too?

A retry should not change meaning merely because the key later reaches another state.

What the answer must demonstrate: Persist value and original outcome together across commit and response loss.

04 / APPLIED

Why might a process labeled leader be unable to serve a strong GET?

Model answer

It may be isolated while another group has elected a successor. The leader must confirm it still leads and apply the committed commands required for the read.

Interviewer follow-up

Can it offer an old value anyway?

Only through an explicitly weaker stale-read contract.

What the answer must demonstrate: Require current read authority and sufficient applied state after leadership change.

05 / FOUNDATION

Does R+W>N fully specify linearizability?

Model answer

No. Set overlap alone does not define ordering, election safety, failed writes, application or read authority. Use a complete replication protocol.

Interviewer follow-up

What cost does the selected protocol impose?

A partition without the required majority stops strong operations.

What the answer must demonstrate: Explain why quorum overlap needs a complete ordering and election protocol.

06 / FOUNDATION

Why store a deletion marker?

Model answer

Older values may remain in disk files or replicas. The marker prevents their return until safe reclamation rules allow removal.

Interviewer follow-up

Can a recreated key reuse its old version?

No. Old expected-version tokens must not accidentally match a new incarnation.

What the answer must demonstrate: Prevent resurrection and old-version reuse across deletion and recreation.

07 / FOLLOW-UP

Why move retry results with values?

Model answer

A client may retry through the new owner after losing an old response. Without the saved result, the new owner cannot preserve that retry contract.

Interviewer follow-up

What else moves?

Versions and deletion markers, plus the snapshot's log position so recovery knows where to resume replay.

What the answer must demonstrate: Move retry history, versions and tombstones with the key's value.

08 / FOLLOW-UP

Will adding partitions accelerate one heavily updated key?

Model answer

Not its ordered conditional decisions. Partitioning adds parallelism across different keys, not concurrent winners against the same state.

Interviewer follow-up

What could change?

A larger owner, fewer updates, or a different application state and atomicity contract.

What the answer must demonstrate: Recognize the single-key serialization boundary despite more partitions.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a strongly consistent key-value store, then lose the leader after cart-42 version 8 commits but before the caller receives success.

• Agree numbered functional and non-functional requirements, including per-key consistency, value limits and the one-zone durability boundary. Then explain value, version and request identity using two concurrent edits.

• Trace a committed mutation and a current-authority read through a replica group.

• Account for storage maintenance, hot keys, migration and failure without overstating availability.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Cart-42 changed from version 7 to 8, but the reply was lost. What must survive together?

The value or deletion marker, version, saved request result and applied-log position. Together they let recovery return the original result without changing the cart twice.

A lost reply must not repeat the write: save state and result together.

What permits a strong read?

The leader confirms it still leads and has applied the committed commands required for this read.

Reachable is not current.

Which work can more partitions spread across machines?

Operations on different keys. Competing updates to one key must still follow one order.

Many keys, many owners.

Summary and interview notes

Store and retrieve exact keys, check versions before changing values, and recover the same result after retries. Partition independent keys and replicate each partition while preserving durable writes and current regional reads.

Remember these points

• Agree what later reads must see before choosing replication.

• Commit values and retry outcomes together.

• Validate read authority after leadership changes.

• Spread independent keys across partitions; one hot key stays ordered, and a minority cannot serve strong operations.

Interview tips

• Agree on what reads must see after a completed write.

• Race two version-7 updates, lose the winning reply, then isolate the old leader.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Detailed conditional state-machine proof: Follow duplicate, rejected and replayed commands through atomic application.

Replication and partition migration: Membership changes and ownership cutover need the selected consensus protocol.

Storage-engine alternatives and capacity: Compare compaction, filters and recovery logs after the basic API is established.

Multi-region alternatives: Availability-first writes require explicit conflict or merge semantics.

Technical references

Raft consensus paper
Primary description of leader election, replicated logs, and safe membership changes.
https://raft.github.io/raft.pdf

etcd API guarantees
Concrete documentation of strong operations and weaker alternatives in a real key-value API.
https://etcd.io/docs/v3.6/learning/api_guarantees/

RocksDB overview
Official storage-engine overview for logs, memtables, sorted files, and compaction.
https://github.com/facebook/rocksdb/wiki/RocksDB-Overview

Dynamo paper
Primary availability-oriented alternative with version reconciliation.
https://www.cs.cornell.edu/courses/cs5414/2017fa/papers/dynamo.pdf

EXTENDED INTERVIEWS / 43

Design a notification service

Interview version / 45-minute scope · Read the advanced version online

Accept one notification intent, plan eligible channel deliveries and recover provider outcomes while respecting current preferences and protecting urgent traffic.

notification intent • provider callbacks • preferences • retry policy

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Distinguish a business intent, a channel delivery and a provider attempt.
- Explain opt-out ordering and unknown external outcomes without claiming universal exactly-once delivery.
- Scale due work, provider quotas and backlog recovery with visible per-channel status.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Databases, data models, and ACID transactions; Production readiness: SLI, SLO, observability, and recovery

8 interview questions with model answers and answered follow-ups.

01 / Define what reliable notification means

Build a shared service for email, push, SMS and an in-app inbox. Trusted product services submit approved templates and business event identities. Audience selection for bulk campaigns, operating an email network and mobile push transport itself are outside scope. A campaign service can expand an audience into individual recipient intents subject to admission limits.

An order service submits event ship-o81 for user U7. The resulting intent N44 plans email delivery D-email and in-app delivery D-app; SMS may be suppressed by preference. The intent is the business request, a delivery is one channel/destination outcome, and an attempt is one provider call. Keeping those identities distinct makes partial success and retries understandable.

A successful API response means the intent is durable. Provider acceptance means a downstream service accepted responsibility; it does not prove device delivery or human reading. Expose those facts separately rather than returning one misleading delivered flag.

Target provider acceptance within thirty seconds for 99% of eligible, immediately due transactional deliveries, measured from durable intent acceptance; marketing can wait. State the denominator: eligible, immediately due messages. Suppressed or scheduled work has a different outcome, and unknown or failed provider calls count as missed delivery targets rather than disappearing from the metric.

Ask which channels and urgency classes matter, what "delivered" should mean, and how each category should handle an uncertain provider result. This design accepts durable intents, exposes channel-specific outcomes and prioritizes eligible transactional messages; it does not promise that a human reads them.

02 / Functional requirements

1. **Submit notification intents.** Accept an authenticated business event, recipient and approved template, returning one durable intent for matching retries.
2. **Plan and schedule deliveries.** Choose email, SMS, push or in-app delivery using recipient preferences, verified destinations, due time and quiet-hour policy.
3. **Send and expose outcomes.** Create an in-app item or invoke the external provider, then report suppression, pending, accepted, delivered, failed or unknown separately per channel.
4. **Manage and recover delivery.** Support preference changes, safe retries, verified callbacks, status lookup and inspection of exhausted or uncertain work.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload and quotas.** Plan for 100 million external provider attempts/day and about 11,600 attempts/s at a tenfold burst. Retries consume the same provider quotas; these rates are not assumed provider entitlements.
2. **Urgent-message timeliness.** Target provider acceptance within thirty seconds for 99% of eligible, immediately due transactional deliveries. Measure from durable intent acceptance; unknown or failed provider calls count as misses. This is a service objective, not a guarantee of provider uptime or device delivery.
3. **Durability and recovery.** Accepted intents, delivery state and incoming provider evidence survive worker/API restarts through the transactional database. Preserve pending work through downstream outages, bound admission before storage fills and verify the database's deployment failure policy separately.
4. **Consent and privacy.** A send authorization after a committed opt-out must refuse the disallowed delivery. A previously authorized external call may already be in flight; stop new authorization if current permission cannot be checked.
5. **Duplicate and outcome semantics.** Enforce one local inbox item per delivery. External retry safety depends on provider idempotency/lookup scope; preserve unknown outcomes and explicitly choose duplicate-versus-missing risk when neither is available.

04 / Complete the asynchronous flow with a database worker

Start with an authenticated API, a relational database and a worker polling indexed due-delivery rows. The order service reliably publishes ship-o81 from its own transaction using an outbox or equivalent retry mechanism. Our notification API cannot atomically commit with the separate order database, so repeated submission must be safe.

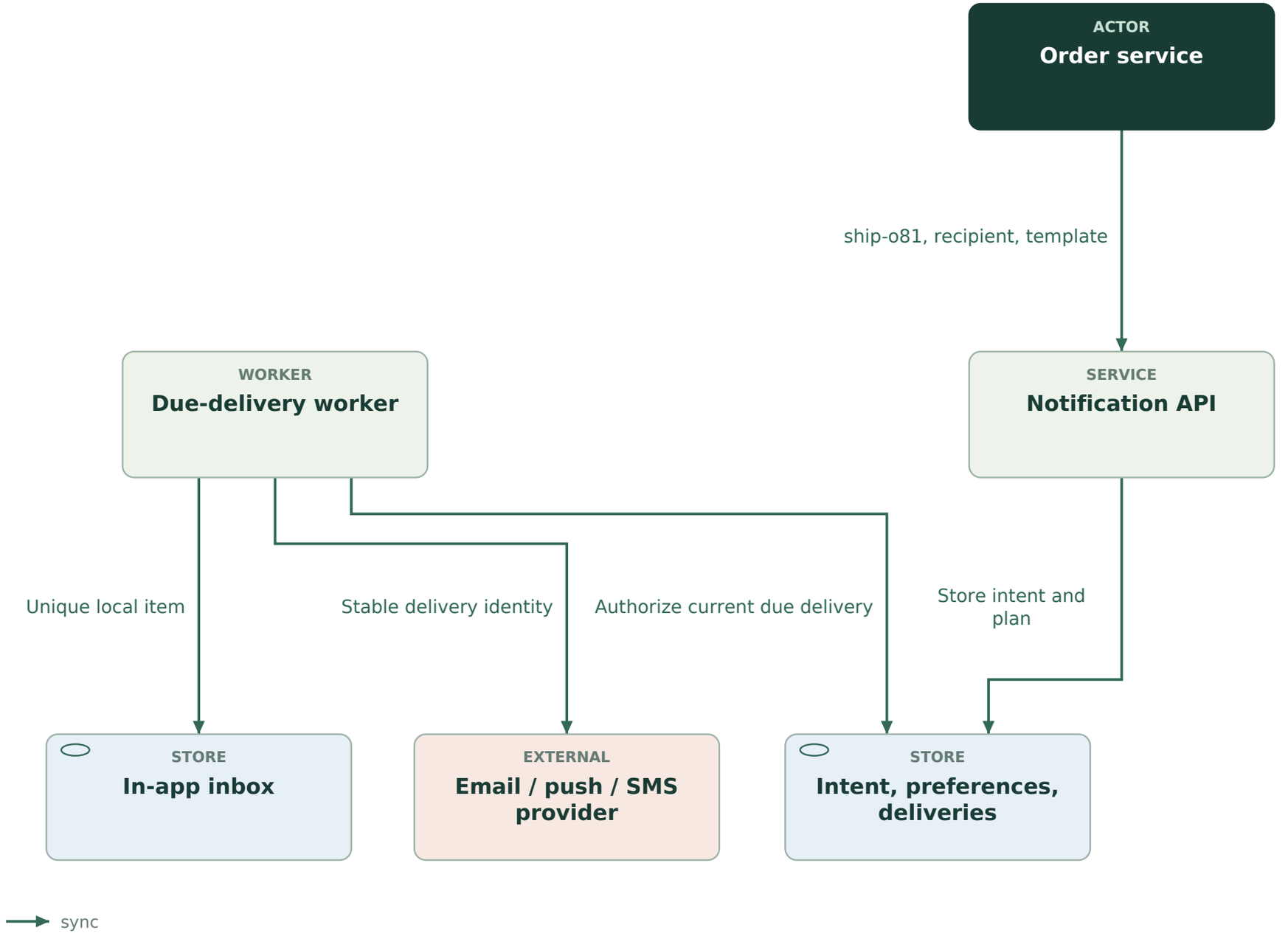
The API stores N44 and a planning task. The planner loads the approved template version and recipient preferences, creates stable channel delivery rows and records suppression reasons. D-app is completed by inserting a unique inbox item and updating its delivery record in one local transaction after checking current permission.

For D-email, the worker transaction checks current consent and destination, records authorization to send and releases its locks. It calls the provider using the delivery's stable external key where supported. It records provider acceptance or an unknown outcome, then later applies verified receipts. U7 can continue using the order page while this runs.

A worker restart finds the same durable rows. No broker is required to make this first version asynchronous or recoverable. Even one worker can crash after the provider sends a message but before the worker saves the reply; the local database cannot roll back that send.

Durable intent, asynchronous delivery

The API acknowledges stored intent; channel workers later establish delivery facts.



05 / Count intents, deliveries and attempts separately

Assume 100 million provider attempts/day, including retries. That averages about 1,157 attempts/s; a tenfold burst is approximately 11,600/s. If the mix averages 1.1 attempts per external delivery and two external deliveries per intent, it represents about 90.9 million deliveries and 45.5 million intents/day. In-app insertions add database work without provider calls.

At 1 KB of attempt metadata, thirty days require roughly 3 TB before indexes and replicas. Rendered message bodies and destinations may be more sensitive than diagnostic metadata; retain only what is needed rather than multiplying full bodies across every attempt.

A 200 ms average provider call and 11,600 attempts/s imply about 2,320 calls in flight if quotas permit. This is a concurrency estimate, not permission to exceed a provider's contracted rate. A single sequential worker would manage only about five calls/s at that latency.

If a provider receiving 500 attempts/s fails for ten minutes, 300,000 attempts accumulate. After recovery, 1,000/s capacity minus 500/s new traffic leaves 500/s to drain backlog, requiring another ten minutes. Recovery capacity must exceed new arrivals; simply restoring normal throughput leaves the queue permanently behind.

06 / Persist the plan and the evidence

Interfaces

Request or message	Contract
`POST /notifications` with event, recipient, category and template version	Returns accepted N44; duplicate matching events return the same intent.
`GET /notifications/N44`	Reports queued, suppressed, accepted, delivered, failed or unknown per channel.
`PUT /users/me/preferences`	Changes versioned channel/category policy.

Submit a notification intent

```
POST /notifications
```

Notification request values

```
event:            ship-o81
recipient:        U7
category:        transactional order update
template version: the approved immutable version selected by the caller
```

Separate channel outcomes for N44

```
email / D-email: pending at the provider
in-app / D-app:  committed locally
SMS:            suppressed by preference
```

Stored records

Record	Fields or identity	Purpose
Intent	`tenant`, `event`, `user`, `category`, `payloadHash`	Stable business meaning and deduplication scope.
Delivery	`intent`, `channel`, `destinationVersion`, `state`, `dueAt`	One logical recipient endpoint across attempts.
Attempt	`delivery`, `number`, `providerKey`, `outcome`	Diagnostic record of each external invocation.
In-app item unique by delivery ID	Delivery ID (unique)	A locally enforceable no-duplicate inbox insertion.

Templates are immutable versions with typed parameters. Callers may select authorized templates, not inject arbitrary destinations or executable markup. Reusing a business identity with different canonical parameters conflicts. Obtain verified email, phone and device registrations from trusted recipient records.

Before the first authorized send, freeze the exact destination and rendered parameters for that delivery. Changing an email address during recovery must not send different content to a new destination under the same provider key. A replacement is a deliberate new logical delivery with a policy for the older uncertain one.

Store incoming provider events in a durable inbox before acknowledging them; store outgoing dispatch work in an outbox with delivery changes. These records make both handoffs retryable after a crash.

07 / Define the exact opt-out boundary

Planning is not permanent permission. U7 may opt out after N44 is planned but before the worker sends it. Keep each recipient's preferences and delivery records where one transaction can check and update them. The worker's authorization transaction:

1. Locks the relevant preference and delivery records.
2. Checks current category/channel policy, due time and destination eligibility.
3. Either suppresses the delivery or records a send authorization.

An opt-out transaction locks the same preference record. If the opt-out commits first, the later authorization must refuse the send. If authorization commits first, an external call may already be in flight. Best-effort cancellation can help, but the service cannot promise to recall an email already accepted by a provider.

Release database locks before network calls. Holding them until delivery completes would block preference changes for an unpredictable time and still would not create a distributed transaction with the provider. Record the policy and destination versions used so operators can explain the decision.

For in-app items, authorization and unique item insertion can occur in one local transaction. That stronger local guarantee does not automatically extend to SMS, push or email. If the preference authority is unavailable, stop new authorizations rather than treating an old cached policy as current consent.

INTERVIEW CRITICAL

Queued work is not permanent consent

Recheck the current preference at the send-authorization transaction. An opt-out that commits first prevents authorization; already authorized external work may still complete and cannot always be recalled.

08 / Recover uncertainty without inventing another message

Suppose the email provider accepts D-email but its response is lost. The worker cannot tell whether nothing happened or whether the email is already on its way. Record unknown rather than definitive failure. If the provider supports idempotency, retry the same logical delivery key within its documented scope and retention. If it supports reliable lookup by client reference, query the original operation.

Attempt numbers identify individual calls for diagnosis. Using a new attempt number as a new provider deduplication key would allow every retry to create another message. A worker lease can prevent ordinary concurrent work but cannot stop a paused old process from later calling a provider that does not enforce our lease token.

When the provider has neither idempotency nor reliable lookup, an automatic exactly-once guarantee is unavailable. Choose a category-specific policy: a transactional update may tolerate a documented duplicate risk; marketing may prefer withholding another attempt until reviewed. Keep the uncertainty visible.

Switching providers does not solve this ambiguity because the second provider cannot deduplicate an effect at the first. Fail over after a known failure, or explicitly accept duplicate risk. Definitive invalid-address errors should stop or disable the matching destination version; temporary rate limits use bounded backoff and provider retry guidance.

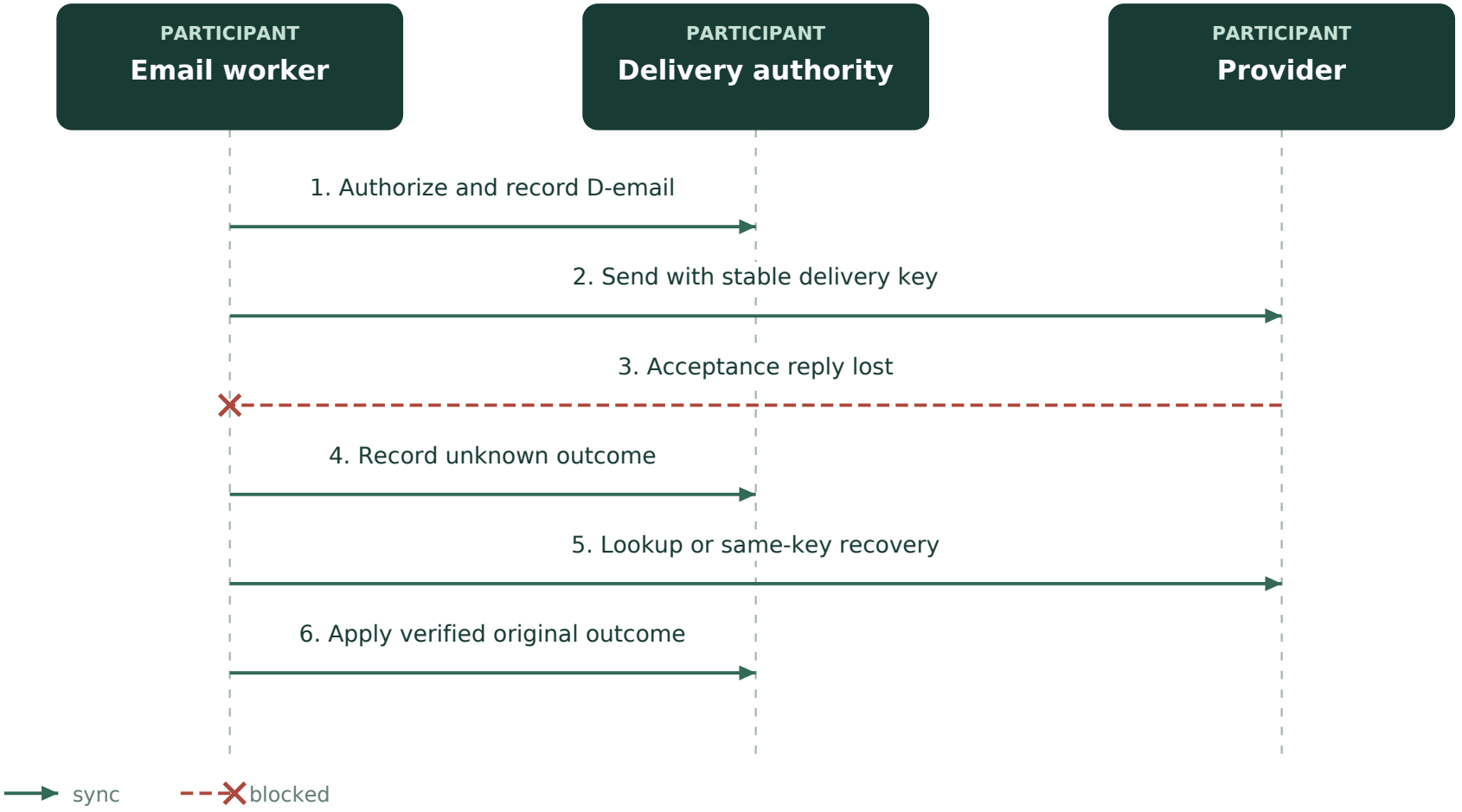
INTERVIEW CRITICAL

A local retry queue cannot deduplicate an arbitrary provider

An email may already exist when the worker times out. Recovery needs the same supported external identity or a lookup of the original outcome. Without those capabilities, state the duplicate-versus-missed-delivery policy.

Provider acceptance with a lost reply

The second attempt recovers D-email; it does not invent another logical message.



09 / Schedule by provider capacity and recipient ownership

Add a broker when measurements show that buffering and separately scaled workers improve delivery of due work. Commit delivery rows and outbox records together; a relay publishes stable delivery IDs. Duplicate publication is acceptable because the worker rechecks the authoritative delivery state before acting. The broker schedules work and does not become the sole copy of consent or message meaning.

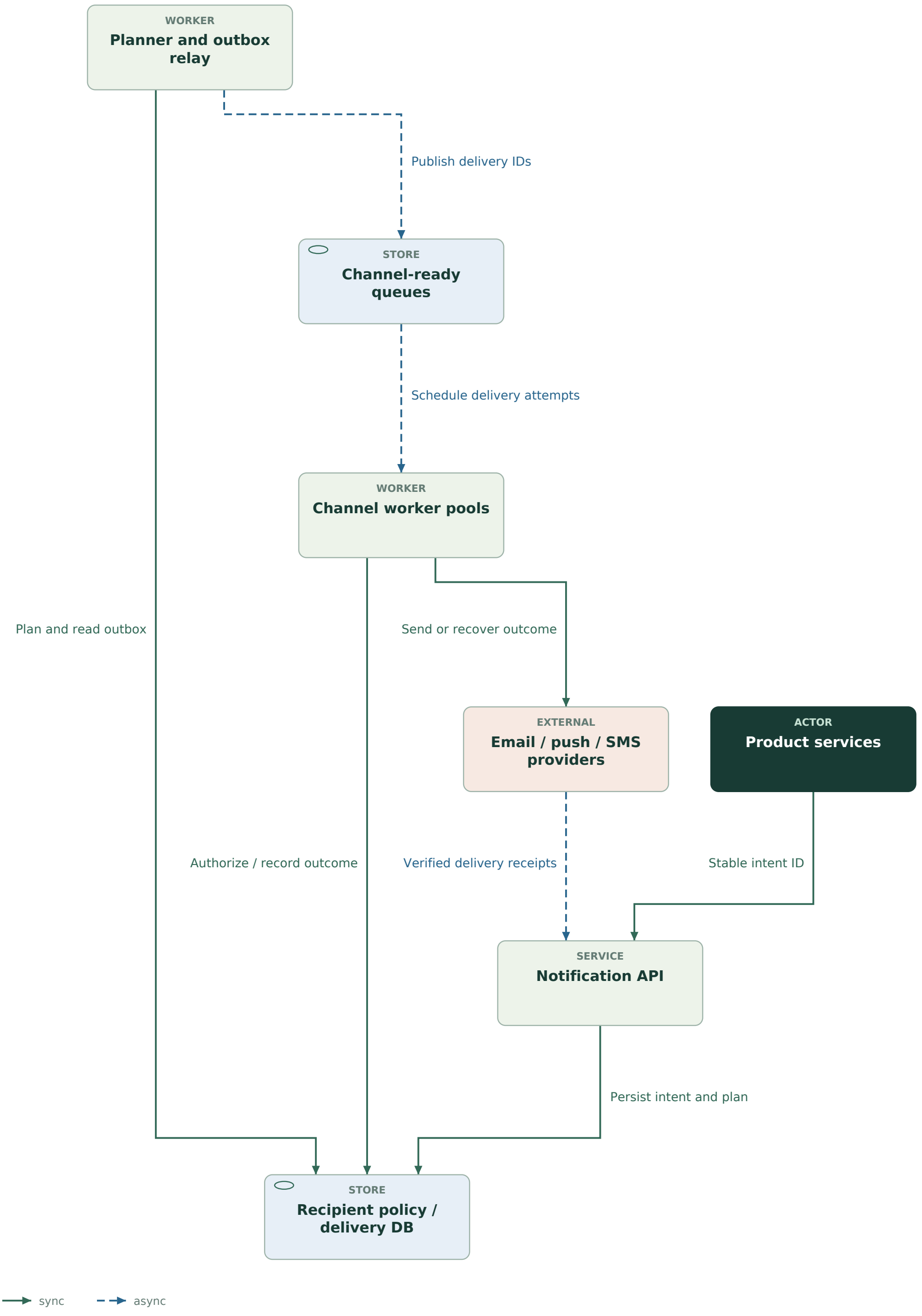
Group execution by provider/channel quota and urgency. Reserve capacity for transactional updates so a large campaign cannot occupy every provider slot. Use weighted scheduling and per-tenant limits rather than unlimited strict priority, which may starve lower-priority work. Unused reserved capacity can be borrowed under an explicit rule without removing the transactional reserve during a surge.

Recipient data partitions serve a different purpose. Keep a recipient's preferences, delivery decisions and inbox together so authorization remains local. Queue messages carry enough routing information to reach that owner. Before a new database owner authorizes sends, it must have the current preferences and complete state of deliveries already in flight.

A queue cannot guarantee a thirty-second deadline when backlog exceeds downstream capacity. Reject impossible new work before promising acceptance, defer marketing, and expose oldest eligible age. Adding workers helps only until provider quotas, reputation rules or account-specific limits become the bottleneck.

Durable delivery decisions with bounded channel workers

A product submits one stable notification intent. Planning and outbox work create per-channel deliveries; the broker carries delivery IDs to quota-controlled workers. Each worker reloads current policy and delivery state before a provider call. In-app items stay in the recipient's database, and verified receipts update the same delivery history.



10 / Handle schedules, devices and receipts deliberately

Quiet hours depend on the recipient's named time zone, not the worker's local clock. Store the resolved scheduled instant and the rule version. Define what happens to a local reminder time skipped or repeated by daylight-saving changes, and what a subsequent user time-zone change affects. Marketing cannot bypass opt-out merely because it entered an urgent queue.

Push delivery targets app installations through provider registration tokens. A user may have several devices, and tokens can rotate. Bind registrations to authenticated users, version each destination and disable only the version associated with a definitive invalid-token response. A delayed rejection for an old token must not disable the replacement.

Verified callbacks can repeat or arrive out of order. Deduplicate provider event IDs where supplied and apply channel-specific facts without moving a delivered message backward to queued. Match the provider account and message reference to the intended delivery. An email bounce and an SMS device receipt have different meanings and should not be flattened into one generic success flag.

Inbox reads authorize the recipient and paginate by creation time plus stable item ID. A cursor orders results but is not automatically a frozen snapshot. Notification previews should not reveal content the user is no longer authorized to read through the underlying application.

11 / Operate recovery and consent as first-class behavior

Monitor intent admission, oldest eligible delivery age, unknown-outcome age, suppression reasons, provider rate-limit responses, bounce rates and retry amplification. Separate channels, tenants and urgency lanes so a healthy aggregate does not conceal an urgent-message backlog. Alert through an independent channel; this service cannot reliably report its own outage through itself.

Dead-letter handling means recording exhausted or invalid work for inspection, not deleting its history. Replaying a delivery preserves its logical identity and frozen parameters. A deployment rollback must not turn already accepted emails into new sends with new IDs merely because local status appears incomplete.

Test opt-out before and after authorization, provider acceptance followed by worker crash, repeated callbacks, destination rotation, daylight-saving scheduling and a ten-minute provider outage. Validate actual drain capacity, not just whether workers restart. Recovery queries also consume provider quota and need a budget.

The principal cost is attempts per channel under provider pricing, plus retained metadata and recovery work. Reduce wasteful retries only when the desired delivery outcome remains supported. Keep personal destinations and rendered bodies out of metric labels, broadly accessible logs and queue names; restrict template editing separately from sending permission.

12 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR3: accept and plan once	Durable intent identity, versioned templates, planning rows and outgoing work.	Repeat ship-o81, restart the planner and change a destination during recovery. Recover the same logical intent and frozen delivery parameters.
FR2,4; NFR4: honor current consent	Recipient-owned preference and delivery checks serialize opt-out against send authorization.	Race opt-out with authorization and make the preference authority unavailable. Refuse later unauthorized sends; do not claim already-sent messages can be recalled.
FR3-4; NFR5: report honest outcomes	Stable delivery identity, provider-supported recovery, verified callbacks and unique in-app insertion.	Lose a provider response and replay callbacks. Distinguish accepted from read, and never silently turn uncertainty into a new logical send.
NFR1-3: meet urgency under load	Reserved transactional capacity, provider quota limits, bounded admission and separate recovery budget.	Measure thirty-second success rate during a campaign and a ten-minute provider outage. The outage creates misses; validate net backlog-drain capacity instead of concealing them.

13 / Rapid revision

Remember: Saved intent, provider acceptance and human reading are different outcomes. Recover the same delivery when a provider reply is lost.

Concern	Complete mechanism
Admission	Check the sender and permitted template; save one notification per matching business request.
Planning	Create a delivery ID for each eligible channel; record why other channels were skipped.
Send permission	In a short transaction, recheck current recipient preferences and the allowed destination.
In-app completion	Atomically insert one item per delivery and mark it complete.
External completion	Reuse the provider key or look up the delivery; keep its status unknown until evidence resolves it.
Retries	Delay retries after temporary failures, stop invalid destinations, and keep records that recognize repeated attempts.
Scheduling	Honor named time zones, quiet hours and provider quotas; reserve urgent capacity.

Concern	Complete mechanism
Callbacks	Verify, persist, deduplicate and apply each channel's status rules so an old callback cannot overwrite a later known outcome.
Recovery	Process faster than new work arrives; inspect old unresolved deliveries as well as queue length.

Close with ship-o81: one accepted intent, email pending at the provider, in-app committed and SMS suppressed. That single example demonstrates the data model, asynchronous boundary, consent policy and honest partial status without requiring a universal delivered boolean.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why separate intent, delivery and attempt?

Model answer

One business event can create several channel deliveries, and each delivery may require several calls. Separate identities preserve partial status and safe retries.

Interviewer follow-up

Which identity should a provider key normally represent?

The logical delivery, not each transport attempt.

What the answer must demonstrate: Keep business intent, channel delivery and transport attempt identities separate.

02 / FOUNDATION

Does provider acceptance prove the user read the message?

Model answer

No. Admission, provider acceptance, device delivery and human reading are distinct facts with channel-specific evidence.

Interviewer follow-up

What should status return?

The known state and update time for each channel, including suppressed and unknown.

What the answer must demonstrate: Distinguish service acceptance, provider acceptance, device delivery and human reading.

03 / APPLIED

The user opts out after planning. What prevents a later marketing send?

Model answer

The worker checks current preference in the same transaction that authorizes dispatch. An opt-out committed first suppresses the delivery.

Interviewer follow-up

Can it recall an already authorized email?

Not universally; that depends on provider cancellation and the declared in-flight boundary.

What the answer must demonstrate: Define the transaction that orders consent changes and send authorization.

04 / APPLIED

The email call times out after possible acceptance. How do you retry?

Model answer

Recover the same delivery through supported idempotency or lookup. Without either, keep unknown and apply the category's explicit duplicate-risk policy.

Interviewer follow-up

Can switching providers fix it?

No. A second provider cannot deduplicate an effect at the first.

What the answer must demonstrate: Use original provider identity or lookup and state the unsupported-provider limit.

05 / FOUNDATION

Why can in-app notifications have a stronger uniqueness boundary?

Model answer

The item insertion and completed delivery state can share one local transaction with a unique delivery ID.

Interviewer follow-up

Does that guarantee email uniqueness too?

No. Email is an external effect outside that transaction.

What the answer must demonstrate: Identify the local transaction boundary that makes inbox insertion unique.

06 / APPLIED

A campaign fills the queue. How do urgent order updates meet their target?

Model answer

Reserve provider capacity for transactional work and apply tenant fairness. More workers cannot exceed the same provider quota.

Interviewer follow-up

What if arrivals equal restored capacity?

The old backlog never drains; recovery needs spare capacity or reduced new work.

What the answer must demonstrate: Reserve urgency within actual provider quotas and calculate net backlog drain.

07 / FOLLOW-UP

A rejection arrives for an old push token after refresh. What changes?

Model answer

Disable only the matching destination version, preserving the newer registration.

Interviewer follow-up

Can a retry silently use the new token under the old key?

No. Freeze the uncertain delivery destination; replacing it is a deliberate new delivery.

What the answer must demonstrate: Guard device invalidation by destination version and freeze uncertain send parameters.

08 / FOLLOW-UP

How should duplicate or reordered callbacks behave?

Model answer

Verify and persist them, deduplicate available event identities and apply channel-specific facts without regressing known outcomes.

Interviewer follow-up

Why acknowledge after persistence?

A process crash must not lose the only evidence after telling the provider it was received.

What the answer must demonstrate: Persist verified provider facts and apply channel-specific idempotent transitions.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design shipment notifications over email and in-app, then race an opt-out with dispatch and lose the email provider's response.

• Agree numbered functional and non-functional requirements, including channel outcomes, urgency and opt-out/duplicate behavior. Then distinguish a business intent, a channel delivery and a provider attempt.

• Explain opt-out ordering and unknown external outcomes without claiming universal exactly-once delivery.

• Scale due work, provider quotas and backlog recovery with visible per-channel status.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

N44 has a saved in-app item, but its email call timed out. What can status honestly report?

The intent is durable, the in-app item is complete and email is unknown until provider evidence resolves it. Neither proves the user read the message.

Saved intent, provider acceptance and user reading need different evidence.

Does a queued notification still need permission before sending?

Yes. The queue schedules work; the database checks current consent. The provider's retry rules govern repeated external calls.

Queue work; authorize sends.

When does a delivery backlog shrink?

Only when completion capacity exceeds the rate of new deliveries arriving.

New work uses capacity too; only the spare part drains backlog.

Summary and interview notes

Save each requested notification once, create eligible channel deliveries, and recover uncertain provider results. Check current preferences before sending and keep capacity available for urgent messages.

Remember these points

• Separate business, channel and attempt identities.

• Check current consent in the transaction that authorizes sending.

• Keep a timed-out provider call unknown until evidence resolves it.

• Protect urgent traffic with actual provider capacity.

Interview tips

• Name the outcome measured by the delivery target.

• Trace ship-o81 through email, in-app and SMS, then race an opt-out with send authorization.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Detailed send-authorization proof: Study worker pauses, takeover and external uncertainty beyond the core transaction.

Provider recovery and failover: Category-specific duplicate risk depends on the exact provider capabilities.

Device registration and immutable destinations: Large multi-device systems need fuller registration rotation and account-binding rules.

Quiet hours and operational cost: Explore calendar transitions and provider economics after the complete main flow.

Technical references

Twilio outbound status tracking
Official example of channel-specific delivery callbacks and signature validation.
https://www.twilio.com/docs/messaging/guides/track-outbound-message-status

Transactional outbox pattern
Explains atomic durable state and later event dispatch.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

Amazon SQS at-least-once delivery
Documents duplicate delivery as a consumer design concern.
https://docs.aws.amazon.com/AWSSimpleQueueService/latest/SQSDeveloperGuide/standard-queues-at-least-once-delivery.html

FCM registration management
Official guidance on registration freshness, refreshing legacy tokens where used, and removing invalid or stale destinations. Provider-specific registration lifecycles belong in the push adapter.
https://firebase.google.com/docs/cloud-messaging/manage-tokens

EXTENDED INTERVIEWS / 44

Design a payment system and ledger

Interview version / 45-minute scope · Read the advanced version online

Coordinate a merchant payment with an external processor, post balanced immutable journals and protect refund capacity while uncertain outcomes are reconciled.

payment intent • double-entry ledger • reconciliation • idempotency

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace durable payment intent, provider execution and one local ledger posting.
- Explain balanced journals, operation uniqueness and concurrent refund reservations.
- Recover unknown processor outcomes without issuing a new charge or trusting stale balances.

Useful foundations: Databases, data models, and ACID transactions; Message queues, event logs, delivery guarantees, and backpressure; Quorums, consensus, leases, and fencing

9 interview questions with model answers and answered follow-ups.

01 / Separate purchase workflow from accounting

Design merchant checkout through one external processor, with authorization, one full capture, status and full or partial refunds. A payment intent tracks the purchase workflow. A ledger records financial movements in immutable journals. Exclude foreign-exchange conversion, lending, disputes and unrestricted transfers between merchants; those change the account and coordination model.

Use payment P81 for USD 25.00, represented as 2500 minor units. Amount and currency come from a validated order, not an editable browser total. Use integer minor units and currency metadata; not every currency has two decimal places. Store a provider-issued token rather than raw card details.

Authorization reserves spending capacity under the processor contract. Capture requests the financial movement. Settlement later transfers funds according to the processor arrangement, and paying the merchant is another movement. These are distinct events, not interchangeable success labels.

The customer may see pending while an external result is unknown. Retrying one operation must not create another logical charge, and posted journals must balance within each currency. For this design, acknowledged operations and postings must survive one zone failure under synchronous regional replication and safe failover. Regional disaster recovery is a separate promise.

Clarify whether the prompt means merchant card payments or transfers of existing wallet balances, which operations the processor supports, and what "success" means to the caller. The main design covers authorization, capture and refunds with durable pending states; the separate wallet variant changes the account transaction.

02 / Functional requirements

1. **Create and authorize a payment.** Validate merchant, order, amount and currency, create a recoverable payment intent and initiate authorization through the processor.
2. **Capture and report status.** Request one full capture for an eligible payment and expose authoritative local state, including pending or unknown external outcomes.
3. **Refund safely.** Support full or partial refunds against remaining captured capacity, with recoverable operation identities and visible progress.
4. **Record and reconcile money movements.** Post immutable balanced journals, compare processor and settlement evidence with local records and repair missing postings through the same validated routine.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload.** Plan for ten million intents/day, about 2,315 new intents/s at the assumed peak and 9,260 status reads/s. Size authorization, capture, callbacks and refunds as separate local transaction work.
2. **Local response and evidence freshness.** Target 300 ms p95 for durable local command acceptance and authoritative status reads under admitted load. After verified processor evidence is durably received, target its local application within five seconds for 99% of outcomes. Neither target promises processor authorization, capture or settlement completion within that time.
3. **Financial consistency.** Permit one full capture claim per payment, keep each currency's journal balanced and never promise refunds beyond captured amount minus successful refunds and unresolved reservations. Timeout does not release uncertain financial capacity.
4. **Durability and safe availability.** Require acknowledged operations and postings to survive one zone failure under synchronous regional replication and safe failover. When posting authority is unavailable, keep outcomes pending and refuse financial decisions from stale replicas; regional loss is a separate recovery contract.
5. **Security and external retry limits.** Authenticate merchant ownership and refund/correction authority, verify processor evidence and keep raw card data with the provider. Preserve operation identity; after the provider's deduplication window expires, reconcile instead of blindly resubmitting.

04 / Trace the full payment with one database and adapter

Begin with a payment API, one transactional database and a bounded worker using one processor adapter. The API authenticates merchant M7, validates the order and stores P81 with a stable authorization operation and outgoing-work record. It returns accepted only after that state is durable. The worker can find the operation after a process restart.

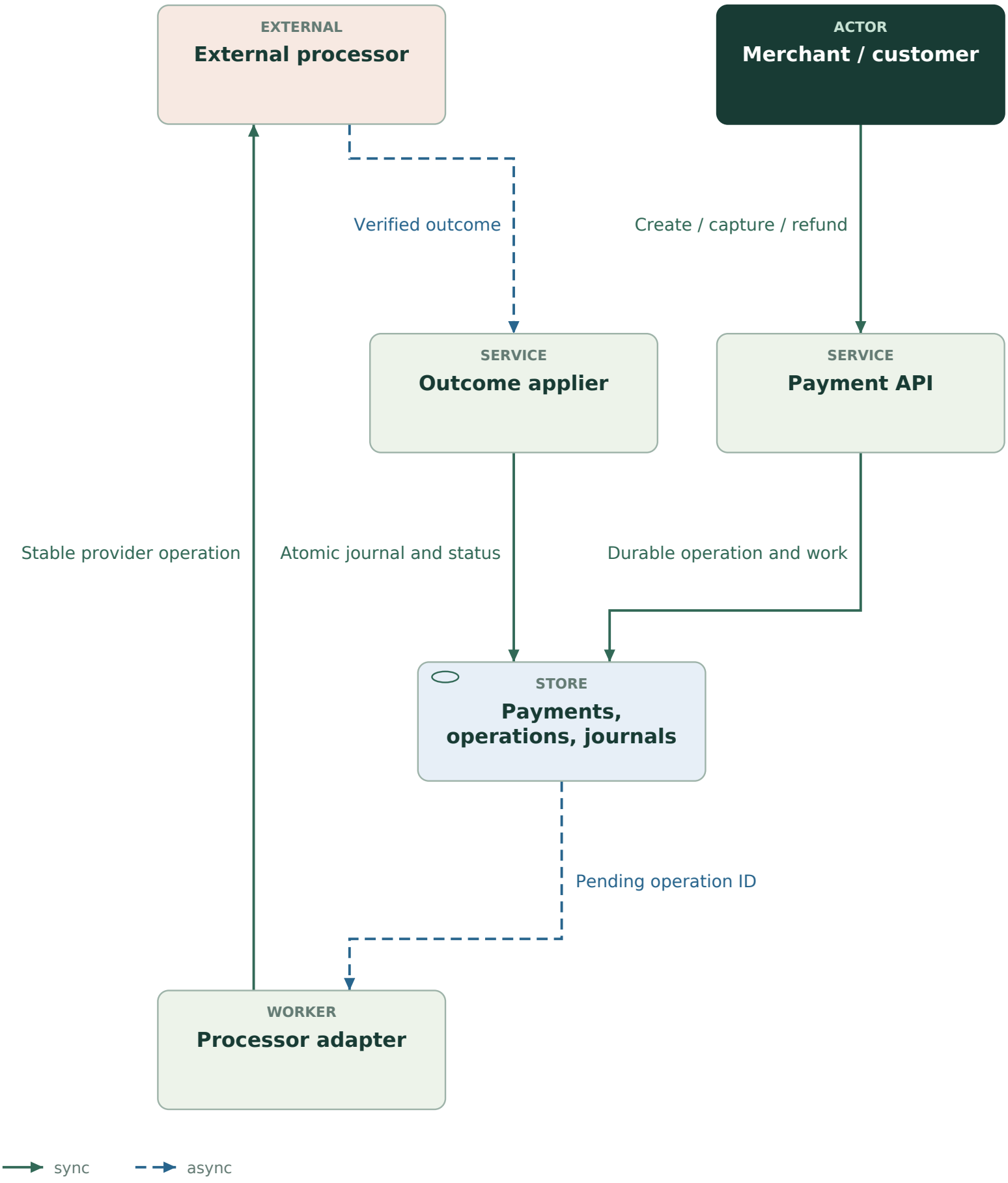
After verified authorization and any required customer action, a capture command locks P81, checks amount, currency and capture eligibility, and claims its single capture slot. It stores operation C81 and its immutable provider key before the network call. The call runs outside database locks.

When verified processor evidence establishes the capture, one local posting transaction records that fact, creates its journal, updates payment status and saves a merchant notification event. Only then does the service report captured locally. A provider success followed by a failed local transaction requires replaying the evidence, not capturing again.

The worker can initially poll indexed durable work; a broker is optional. Webhooks and a reconciliation worker offer additional ways to recover the same outcome. They all call the same posting routine. Separate paths must not create independent journals for the same financial operation.

One authority applies processor evidence

The external processor and local database have separate commit boundaries.



05 / Estimate transaction phases and long-lived records

Assume ten million new payment intents/day: about 116/s on average. A twentyfold peak is approximately 2,315 new intents/s. If clients make four status reads per intent, corresponding peak reads are about 9,260/s; aggressive polling can easily invalidate that estimate, so use bounded polling or notifications followed by status reads.

Separate authorization and capture can require four local transaction phases: initial authorization command, authorization outcome, capture claim and capture posting. At the assumed peak, that is about 9,260 transactions/s before refunds, callbacks and recovery. Benchmark this actual workload before deciding whether a single database needs sharding.

Ten retained records of 1 KB per intent produce 100 GB/day, or 36.5 TB/year. Seven years is about 255.5 TB logically before replicas and indexes. Historical records may move to a verified archive, but the request IDs, saved outcomes and recovery records needed by current operations must remain available.

At 2,000 unresolved operations/s, a five-minute processor incident adds 600,000 operations. If recovery completes 3,000/s while 2,000/s new work continues, net drain is 1,000/s and takes another ten minutes. This requires actual processor headroom; more worker threads cannot manufacture a higher downstream quota.

06 / Give each financial operation its own stable identity

Interfaces

Request or message	Contract
`POST /payments` with merchant-scoped key	Creates or recovers P81 for the same validated purchase.
`POST /payments/P81/capture`	Claims the one full capture operation or returns the existing result.
`POST /payments/P81/refunds`	Reserves refundable capacity and returns a stable refund operation.
`GET /payments/P81`	Reports known payment state and unresolved operation IDs.

Request a partial refund

```
POST /payments/P81/refunds
```

Send the refund with the merchant- and operation-scoped key described below.

Refund amount in integer minor units

```
{
  "amountMinor": 500
}
```

Stored records

Record	Fields or identity	Purpose
Payment	Payment identity	Amount, currency, authorization reference, capture deadline and lifecycle.
Operation	Merchant, operation type and scoped request key	Type, scoped key, payload fingerprint, provider identity, state and evidence reference.
Journal and entries	Financial operation and posting kind	One immutable financial posting and all its balanced account lines.
Capture balance	Captured payment	Captured amount, successful refunds and unresolved refund reservations.

Keys are scoped to the authenticated merchant and operation type. Reusing a key with a different amount conflicts. This deduplicates the same command; a separate per-payment capture claim prevents two different keys from creating two full captures.

An inbox durably receives verified provider events; an outbox records work and notifications with local state changes. Index unresolved operations by next-attempt time and merchant history by creation time plus payment ID. Status immediately after a write uses the authority or a proven caught-up replica; a reporting view cannot approve refunds.

07 / Explain the balanced journal before the posting algorithm

In double-entry accounting, each journal has debit and credit lines whose totals are equal within one currency. For this simplified platform model, processor receivable represents money the processor owes the platform; merchant payable represents money the platform owes the merchant. For the USD 25 capture, the journal uses integer minor units:

Account	Debit (USD minor units)	Credit (USD minor units)
Processor receivable	2500	0
Merchant payable	0	2500

This records the claim and obligation, not settlement into a bank account.

The posting routine uses one transaction:

1. Lock operation C81 and validate the evidence's merchant, provider reference, kind, currency and amount.
2. Check whether the unique journal for that operation and posting kind already exists. If so, return its result.
3. Otherwise validate all account lines and totals, then commit the journal, entries, payment state, balance projection and outgoing event together.

No observer should see half a journal.

Restrict direct entry writes so every writer uses the posting transaction. A row-level check on individual entries cannot by itself prove that an arbitrary multi-row journal balances. A balance projection is a convenient total derived from the journal; it can be checked or rebuilt and is not an independent source allowed to override history.

Correct errors by adding an authorized reversing or correcting journal with an audit link, not by erasing the original. Internal balance alone is insufficient: a perfectly balanced journal for the wrong merchant or amount is still wrong.



INTERVIEW CRITICAL

Balanced does not mean reconciled

A journal must balance, but the system must also establish that it represents the correct processor operation, merchant, amount and currency. Accounting equality cannot detect every missing or wrongly matched external effect.

08 / Make timeout recovery part of the capture flow

The processor may complete C81 and lose its reply. Keep C81 unknown and use its original provider identity for supported idempotent recovery or lookup. A new operation C82 could charge again. Local uniqueness does not force an external processor to remember a key beyond its documented retention window; after that window, reconcile rather than retry blindly.

Verified webhooks are evidence, not commands to post without checks. Authenticate the provider payload, persist the incoming event, and match it to the stored operation. Distinct provider events can describe the same capture, so webhook event deduplication and journal-operation uniqueness solve different problems. Out-of-order facts must not turn a captured payment back into pending or declined.

Claim capture and authorization cancellation through the same payment row. Require a known eligible authorization, matching full amount and currency, a valid capture deadline and no incompatible cancellation. Read the authoritative database clock after acquiring locks. A local eligibility check does not prevent the authorization expiring during the remote call; the resulting rejection or uncertainty still follows the recovery path.

Once capture may be in flight, cancellation cannot simply declare a successful void. Resolve the capture, then cancel an unused authorization or refund a confirmed charge according to the observed outcome. Never treat a browser redirect as processor evidence.

09 / Reserve refundable capacity before calling the processor

Suppose the captured amount is 2500 and no refund has completed. Two agents each request a refund of 2000 using different valid keys. Deduplicating keys does not help because the requests really are different. Both agents must lock the same capture-balance record before deciding how much to refund.

Agent A locks that record and computes available capacity as captured minus successful refunds minus unresolved reservations. Initially it is 2500, so A reserves 2000 and stores its refund operation plus outgoing work in one transaction. Agent B then sees only 500 available and is rejected before making any provider call. The external calls occur after those short transactions release their locks.

Outcome of A's refund	Capacity and accounting transition
Succeeded	Move 2000 from reserved to refunded and append the balanced refund journal.
Definitively rejected	Release the reservation transactionally.
Unknown	Keep the reservation while reconciliation determines the result.

Releasing it merely because a timeout occurred would let B promise the same funds again.

Partial refunds repeat this capacity decision against the remaining amount. Refund journals are new entries linked to the original capture, never edits to its history. A screen may display available balance, but the command must recheck it atomically because another refund can win after the screen was loaded.



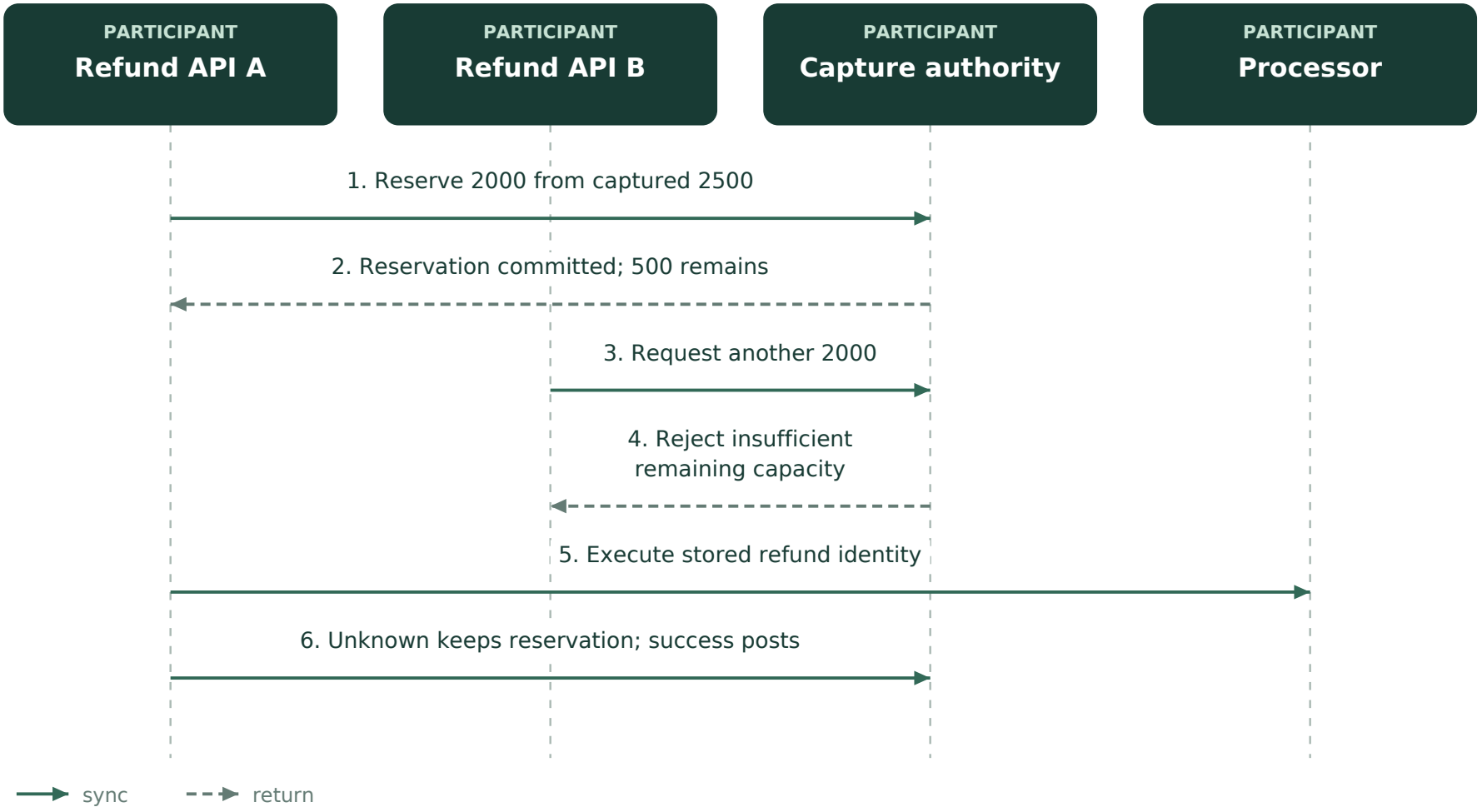
INTERVIEW CRITICAL

Unknown refunds still consume capacity

Refundable capacity equals captured funds minus completed refunds minus unresolved reserved refunds. Keep the reservation while the processor outcome is unknown; otherwise concurrent requests can promise the same captured funds twice.

Two refunds compete for one captured amount

The first reservation reduces capacity before either external refund can complete.



10 / Scale merchant-local decisions and isolate processor work

Add a queue when pending-work scans or provider scheduling need independent scaling. Publish operation IDs from the outbox, then let workers load current state and invoke the stored provider operation. Queue delivery can repeat; it is a wake-up mechanism, not permission to invent a fresh capture.

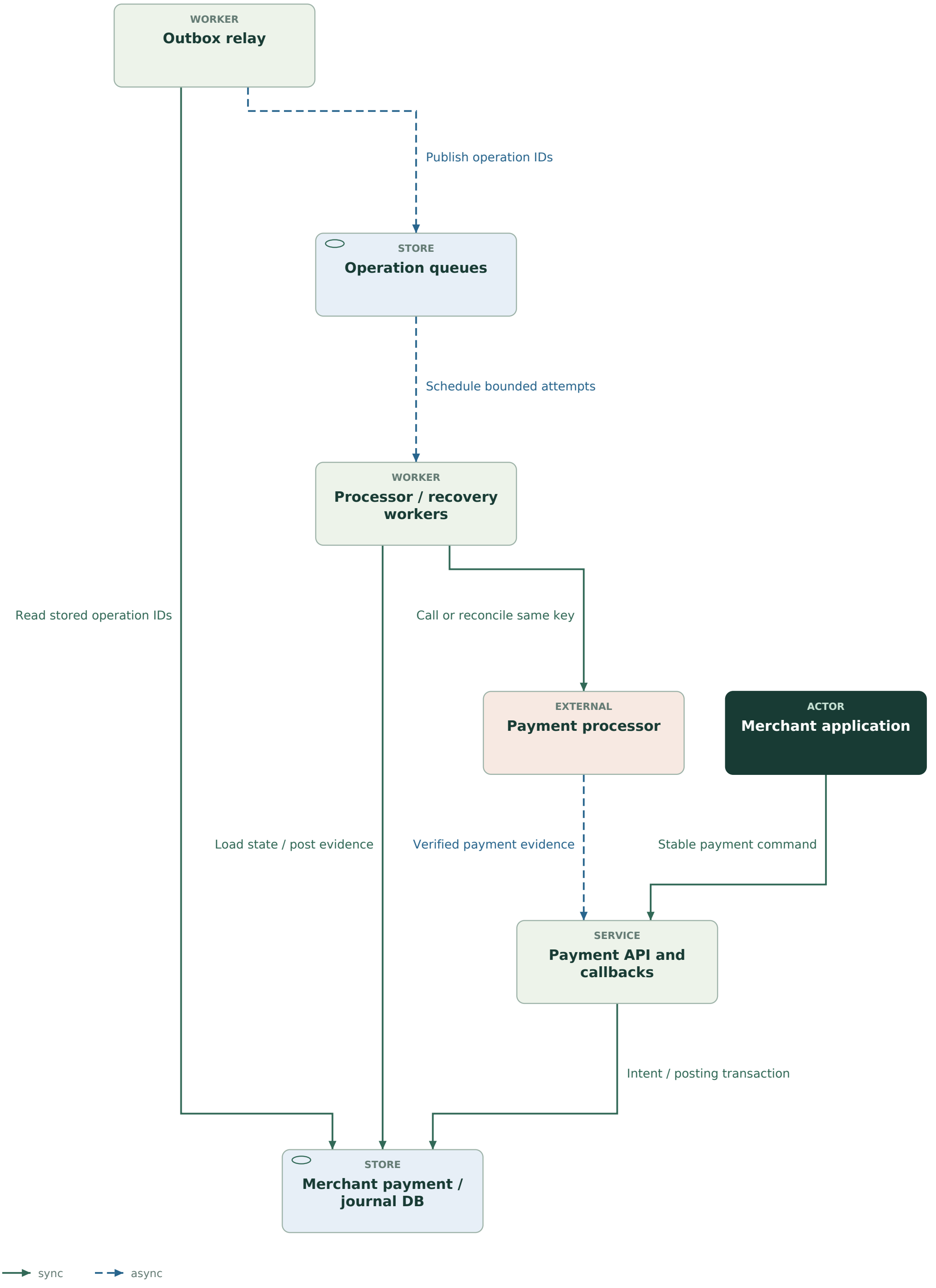
Bound concurrency by processor and merchant. Reserve recovery capacity for old unknown operations so a stream of new payments does not leave them unresolved forever. Limit new acceptance when the wait for pending work would become unacceptable, while preserving already accepted operations and current status reads.

When measured posting capacity is insufficient, partition independent merchants. Keep a merchant's payment, journal, refund balance and local inbox/outbox where they can commit in one transaction. Hashing journal lines across unrelated shards would prevent one local transaction from committing the balanced journal. A very large merchant may need a carefully designed subledger later rather than arbitrary extra hash buckets.

Move stale-tolerant reporting and history to replicas or derived views, with an explicit freshness contract. Immediate payment status and every financial capacity decision remain authoritative. Static payment-method metadata is a safer cache target than mutable refund capacity. Cross-merchant transfers and multi-region concurrent posting remain separate extensions that require new coordination rules.

Recoverable processor operations and one local posting authority

The merchant API records payment intent before a relay schedules its stored operations. Processor workers and verified callbacks recover external outcomes, then use one posting routine for payment state and the balanced journal. Independent merchants can occupy different database groups; each merchant's financial transaction boundary remains intact.



11 / Compare internal history with independent processor facts

Reconciliation compares provider operations and settlement records with local payments and journals. Match by provider account, operation reference, merchant, currency and amount. A missing local capture should go through the same outcome applier as a webhook; it should not trigger another capture call. An unmatched or conflicting fact becomes a durable review case with evidence.

Settlement is distinct from capture. Processor transfers, fees and merchant payouts require their own appropriate journals in the account model. The capture journal must balance, but recording it does not complete those later financial movements.

If the posting database is unavailable after the processor succeeds, retain pending local status and recover evidence when authority returns. Do not approve refunds from a stale replica to improve apparent availability. Synchronous replica placement and safe failover must actually meet the stated one-zone durability promise.

For regional recovery, state whether acknowledgments included a durable copy outside the region. If not, a regional loss may require restoring history and reconciling processor effects before replaying old commands. A backup that restores balances but loses operation identities can reopen duplicate-charge risk. Test restored uniqueness, evidence matching and unresolved operations as well as accounting totals.

12 / Observe money and unresolved age, not only HTTP success

Monitor unknown-operation age, unmatched amounts by currency, duplicate journal suppression, refund-capacity rejections, provider throttling and reconciliation backlog. Request latency matters, but ten healthy API instances do not make an unresolved capture financially complete. Measure local durable acceptance and authoritative reads against 300 ms p95, and verified-evidence receipt to local application against the five-second objective. Track external pending age separately: these targets do not bound processor completion.

Use separate, audited permissions for refunds and operational corrections. Enforce merchant isolation in queries, export paths, cache keys and reconciliation tools. Restrict provider credentials to adapters, verify callbacks and avoid logging card tokens, secrets or sensitive payloads. Immutable journals still need access controls and a deliberate retention policy.

Test crashes after processor success, after local posting and before queue acknowledgment. Race two refunds, submit two capture keys, replay different callbacks for the same capture, and restore a backup before applying old events. These tests cover separate guarantees; a balanced-total assertion alone does not prove that every external operation was recorded once.

Roll out posting changes with compatible readers and writers, a small merchant cohort and comparison against independent reconciliation. Stop unsafe posting when an invariant fails. The design deliberately accepts visible pending states and occasional unavailable decisions to preserve financial integrity and recover uncertain effects.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR2,5: accept commands and recover status	Transactional intent/operation records, scoped keys and authoritative status; processor calls occur after commit.	Lose the local reply and recover P81. Load-test 300 ms p95 local responses; delay the processor and verify pending is returned without asserting completion.
FR2-3; NFR3: prevent excess financial actions	Unique full-capture claim and serialized refund reservations.	Send two capture keys and race two refunds of 2000 against a capture of 2500. The second refund cannot reserve already committed capacity.
FR4; NFR2-3: post and reconcile evidence	One validated posting transaction commits journal, balances, status and outgoing work; webhooks and reconciliation reuse it.	Replay distinct events for C81, compare independent processor facts and measure durable-evidence-to-local-status delay against the five-second objective.
NFR1,4-5: sustain and recover the chosen service	Merchant-local transaction domains, quota-bounded workers, recovery reserve and synchronous regional database failover.	Load-test the full transaction mix, fail one zone and restore operation identities. A balanced ledger alone does not prove every external charge was recovered.

14 / Rapid revision

Remember: A timeout does not prove that no money moved. Keep the original operation and unresolved refund reservation until evidence resolves them.

Concern	Complete interview mechanism
Purchase identity	Validate merchant, order amount and currency; save one matching request per merchant, operation type and request key.
Capture uniqueness	Allow only one capture operation per payment, even when callers send different request keys.
External call	Save a fixed ID for the provider operation before calling the processor.
Unknown result	Query or safely retry the original operation; a timeout is not proof no money moved.
Ledger posting	Validate evidence and atomically commit one balanced journal, status and notification work.

Concern	Complete interview mechanism
Refund limit	Lock the capture and reserve the refund amount before calling; count that amount while the result is unknown.
Reporting	Reporting history may lag; refund decisions check current balances in the primary transaction.
Reconciliation	Compare processor and settlement records with journals; apply missing results through the normal posting transaction.
Scale	Partition by merchant and limit provider calls; preserve operation IDs during recovery.

Close with C81's lost response and the two competing 2000 refunds. They show why idempotency, balanced accounting and capacity reservation are separate protections rather than one generic "exactly once" feature.

15 / Optional prompt variant: transfer an internal wallet balance

This is an alternative prompt: Alice transfers an existing wallet balance to Bob inside the same service. It is not a merchant card capture. Choose same-currency transfers with no fees or overdraft, and keep both accounts and their journal in one database transaction domain. External deposits, withdrawals and currency exchange introduce different settlement boundaries.

A posted balance is the wallet's committed net balance. An outgoing hold reserves part of that balance for an unfinished operation. Therefore `spendable = posted balance - pending outgoing holds`; expected incoming money is not spendable until posted. Store amounts as integer minor units with an explicit currency, and make every operation that changes posted or held funds follow the same account-locking rule.

Alice has $100 posted and $20 reserved for a different payment. She asks to transfer $60 to Bob, who has $15. The table displays dollars for readability; storage uses cents.

Wallet	Posted before	Outgoing holds	Spendable before	Posted after T81
Alice	$100	$20	$80	$40
Bob	$15	$0	$15	$75

The $20 hold remains, so Alice has $20 spendable afterward. If another concurrent request also tries to transfer $60, it must observe the first committed transfer and reject for insufficient funds. Reading $80 before locking the accounts and spending it twice would overdraw the wallet, even if each transfer's journal balanced.

Authenticate the caller and authorize access to the source wallet and any saved transfer result. Use a stable transfer ID scoped to the sender plus a fingerprint of source, destination, amount and currency. In the transaction, claim or read that unique identity first. Return an authorized matching completed result even if Bob's wallet was later frozen; changed parameters conflict.

For a new transfer, use the same transaction:

1. Require a positive amount. Lock both accounts in stable account-ID order, then validate current debit authority, destination eligibility and matching currency.
2. Read posted and held balances under those locks and require Alice's spendable funds to cover $60.
3. Commit a balanced journal, both balance updates, the successful transfer result and notification outbox together.

For customer wallet liabilities, debit Alice's account by $60 and credit Bob's by $60: the service's total liability is unchanged. The journal and materialized balances must not be separate asynchronous commits. Never hold these locks while sending notifications.

After a timeout, retry or look up T81; do not create a new transfer identity merely because the reply was lost. TigerBeetle's submission guidance explains stable transfer identity across retries, while PostgreSQL's transaction example illustrates atomic account updates. If the accounts move to independent shards, an ordinary local transaction no longer covers both. Use a supported distributed transaction, or explicitly design reserved funds and a durable pending-transfer workflow with recovery. The shared distributed-workflow lesson explains those coordination choices; this variant stops at the single-database transfer.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How does the ledger differ from payment workflow state?

Model answer

Workflow records which actions are pending or known complete. Immutable journals record financial movements with balanced debit and credit totals per currency.

Interviewer follow-up

Can a posted journal be edited to correct it?

Use an auditable reversing or correcting journal rather than erasing history.

What the answer must demonstrate: Distinguish mutable workflow state from immutable balanced accounting journals.

02 / APPLIED

Can two different idempotency keys capture one payment twice?

Model answer

Not if the command also claims a unique per-payment capture slot. Request-key deduplication alone only protects repeats of the same command.

Interviewer follow-up

What separately prevents duplicate local posting?

A unique financial operation/posting-kind journal applied in one transaction.

What the answer must demonstrate: Protect both one allowed capture command and one journal per financial operation.

03 / APPLIED

The processor captured but the worker lost its reply. What happens?

Model answer

Keep the stored operation unknown, recover through its provider identity or lookup, and apply verified evidence locally. Do not issue a new charge to repair missing local status.

Interviewer follow-up

What if provider key retention expired?

Reconcile or review the old operation; an old local key cannot extend the processor's deduplication window.

What the answer must demonstrate: Recover the original processor effect without issuing another charge to repair local state.

04 / FOUNDATION

Does a balanced journal prove the payment is correct?

Model answer

No. A wrong amount or merchant can still balance. Validate the operation evidence and compare independent processor facts through reconciliation.

Interviewer follow-up

What does balance itself protect?

Internal equality of debits and credits within the journal's currency, committed as a whole.

What the answer must demonstrate: Validate merchant, amount, currency and processor evidence in addition to balanced totals.

05 / APPLIED

Two agents each refund 2000 from a 2500 capture. How is excess prevented?

Model answer

The first atomically reserves 2000 on the capture balance; the second sees only 500 available and cannot call the provider.

Interviewer follow-up

What if the first result is unknown?

Keep its reservation until definitive success or failure resolves the capacity.

What the answer must demonstrate: Reserve shared refund capacity before calls and retain it through unknown outcomes.

06 / APPLIED

Why is provider-event deduplication insufficient for ledger uniqueness?

Model answer

Different events may describe the same capture. The posting identity must represent the financial operation, not only each callback.

Interviewer follow-up

How are callbacks acknowledged?

After verified durable inbox acceptance, with outcome application retried independently.

What the answer must demonstrate: Deduplicate financial operations separately from repeated provider event IDs.

07 / FOLLOW-UP

Can a reporting replica approve a refund during primary failure?

Model answer

No. Its balance may omit another refund reservation. The capacity decision needs the current transactional authority.

Interviewer follow-up

What can remain available?

Known pending status or explicitly stale reporting, without pretending a new financial decision succeeded.

What the answer must demonstrate: Keep capacity decisions on current authority rather than stale reporting balances.

08 / FOLLOW-UP

Why preserve operation IDs in a regional restore?

Model answer

Restored balances alone do not reveal which external effects already happened. Lost identities can cause replayed commands to charge again.

Interviewer follow-up

What establishes safe resumption?

Validated restored history, processor reconciliation and the selected durability/failover contract.

What the answer must demonstrate: Restore operation identities and reconcile external evidence before resuming commands.

09 / FOLLOW-UP

What must change when the prompt asks Alice to transfer existing wallet funds to Bob?

Model answer

Recover an authorized matching retry by its stable transfer ID before applying new-transfer eligibility checks. For a new positive same-currency transfer, authenticate Alice's debit authority, lock both accounts in stable order, recheck spendable funds after outgoing holds, and commit the balanced journal, both balances and saved result together. This internal transfer does not need a card-processor call.

Interviewer follow-up

Why do balanced journal entries alone not prevent overdraft?

Two transfers can each balance their debit and credit while both spending the same stale source balance. Serialize the current spendable-funds check with each debit. If the accounts are on different shards, use an actual distributed transaction or an explicitly pending, reserved-funds workflow.

What the answer must demonstrate: Separate internal transfers from merchant capture; protect spendable balance and journal atomicity under concurrent spends and retries.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a USD 25 merchant payment, lose the capture response, and then race two USD 20 refund requests.

• Agree numbered functional and non-functional requirements, including local acceptance versus processor completion, monetary invariants and zone durability. Then trace durable payment intent, provider execution and one local ledger posting.

• Explain balanced journals, operation uniqueness and concurrent refund reservations.

• Recover unknown processor outcomes without issuing a new charge or trusting stale balances.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

C81 may have captured USD 25.00, but its reply is lost. What should the worker recover?

Recover C81 through supported provider lookup or idempotency, then post its verified result. A new charge could bill the customer twice.

A lost reply may hide a successful charge: recover the same operation.

How much more can a captured payment refund?

Captured amount minus completed refunds minus amounts reserved for unresolved refunds.

Unknown still reserves.

Why can a balanced journal still be wrong?

Its merchant, amount or processor evidence may be wrong. Validate those facts and reconcile them independently as well as balancing the journal.

Balance and evidence.

Summary and interview notes

Charge customers through a processor and record verified results in balanced, unchangeable journals. Reserve refund amounts before calling the processor and keep uncertain refunds reserved until their outcomes are known.

Remember these points

- Keep workflow, external operations and journals distinct.
- Prevent both duplicate capture commands and duplicate postings.
- Reserve refund capacity through uncertain outcomes.
- Apply callbacks and reconciliation evidence through the same validated posting transaction.

Interview tips

- Separate a valid balanced journal from a verified processor outcome.
- Lose C81's reply, then race two refunds of 2000 against the 2500 capture.

Important qualifications

- Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Full posting and refund proof: Inspect uniqueness, atomic journal lines and every reservation transition.

Authorization, capture and void races: Provider-specific deadlines and customer-action flows require adapter detail.

Regional disaster recovery: Zero regional loss changes acknowledgment latency and partition availability.

Merchant partitioning and reporting: Large merchants and cross-merchant movements need a deliberate accounting boundary.

Technical references

Stripe idempotent requests
Documents a concrete processor retry contract, including key reuse and retention considerations.
https://docs.stripe.com/api/idempotent_requests

Stripe webhook documentation
Documents signature verification, retries, duplicate events, and ordering limitations.
https://docs.stripe.com/webhooks

PostgreSQL constraints
Database mechanisms supporting unique operations and valid posting records.
https://www.postgresql.org/docs/current/ddl-constraints.html

Stripe Payment Intents lifecycle
Primary provider example for a payment state machine and asynchronous outcomes; the chapter API is an abstraction, not a literal Stripe endpoint.
https://docs.stripe.com/payments/payment-intents

PostgreSQL transaction isolation
Primary reference for locking/transaction reasoning and whole-transaction recovery.
https://www.postgresql.org/docs/current/transaction-iso.html

Stripe separate authorization and capture
Primary example of authorization eligibility, provider-specific capture deadlines, expiration and cancellation; the interview service API remains provider independent.
https://docs.stripe.com/payments/place-a-hold-on-a-payment-method

EXTENDED INTERVIEWS / 45

Design a collaborative text editor

Interview version / 45-minute scope · Read the advanced version online

Build an online plain-text editor with immediate local typing, durable accepted operations and reconnect recovery, using a proven operational-transformation implementation.

operational transformation • CRDT • document log • offline editing

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain why identified operations preserve concurrent edits better than whole-document replacement.
- Trace pending edits, accepted versions and reconnect without applying an edit twice.
- Scale documents and connections separately while preserving document authority and permissions.

Useful foundations: Real-time communication: polling, long polling, SSE, and WebSocket; Quorums, consensus, leases, and fencing; Replication and durability

8 interview questions with model answers and answered follow-ups.

01 / Choose online collaboration and define saved

Design plain-text documents shared by several users, with simultaneous edits, permissions, cursors, undo and recovery after short disconnections. Exclude rich formatting, embedded spreadsheets and months of offline editing from the first design. Those requirements change the operation model and retained metadata, not merely the number of servers.

Two users open document D7 containing cat at version 20. A inserts X at position 1 while B inserts Y at the same position. Both edits should survive under a defined ordering rule. Replacing the entire document with cXat and later cYat loses A's work even if each database write is individually atomic.

Distinguish immediate local display from saved state. A keystroke appears locally as pending; saved means the service has durably accepted that identified edit. A lost connection may leave a usable local draft without permission to claim it is saved. Presence is another category: a cursor is a temporary hint and need not survive a restart.

Assume documents up to 1 MB, at most 100 active participants and a thirty-minute automatic reconnect window. Target same-region acceptance below 150 ms p95 and remote display below 300 ms p95 on connected, responsive peers under admitted load, both measured from edit submission. Using a merge algorithm and WebSockets does not prove the service meets those latency targets.

Clarify whether the editor is plain text or rich text, how many users share one document, and how long disconnected clients must merge automatically. This answer supports plain text, up to 100 active participants per document and a selected thirty-minute automatic reconnect window; longer gaps preserve drafts for explicit resynchronization.

02 / Functional requirements

1. **Open and share documents.** Create or retrieve plain-text documents and assign current read/edit permissions.
2. **Edit concurrently.** Accept identified inserts, deletes and supported undo operations while preserving concurrent edits under the chosen transformation rules.
3. **Collaborate live.** Display local pending edits immediately and distribute accepted edits and temporary cursor/presence information to authorized participants.
4. **Reconnect and recover.** Retrieve saved content, replay missing accepted versions and reconcile pending operations after short disconnections without applying an edit twice.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Document and fleet size.** Limit a document to 1 MB and 100 active participants. Plan for one million connected users and 100,000 incoming edits/s across documents; benchmark a single hot document separately.
2. **Latency.** Target same-region durable edit acceptance below 150 ms p95 and display on connected, responsive peers below 300 ms p95, measured from submission under admitted load. Slow or disconnected peers use bounded buffers and replay; immediate local display is not a save acknowledgment.
3. **Convergence and ordering.** All clients applying the same accepted history must converge under the supported editing protocol. Give every accepted edit one stable identity and version; whole-document last-write replacement cannot satisfy this requirement.
4. **Saved-state durability and reconnect.** Accepted edits and operation identities survive application/coordinator restarts. Retain the transformation and retry history needed for thirty minutes of automatic reconnect; older drafts require explicit resynchronization. Database disaster tolerance depends on the selected replication/backup policy, not socket reconnection.
5. **Authorization.** Check current permission when accepting edits and serving snapshots or replay. Reject stale coordinators at storage and reject edits after revocation takes effect; previously downloaded text cannot be recalled.

04 / Complete one edit with a coordinator and durable log

Start with one application serving document APIs and WebSockets, backed by a transactional database. For each active document, a coordinator holds the accepted content in memory and uses a proven operational-transformation implementation. Operational transformation adjusts an incoming edit to account for concurrent edits accepted since its base version. It requires compatible rules on both client and server.

Follow A17 through the edit path:

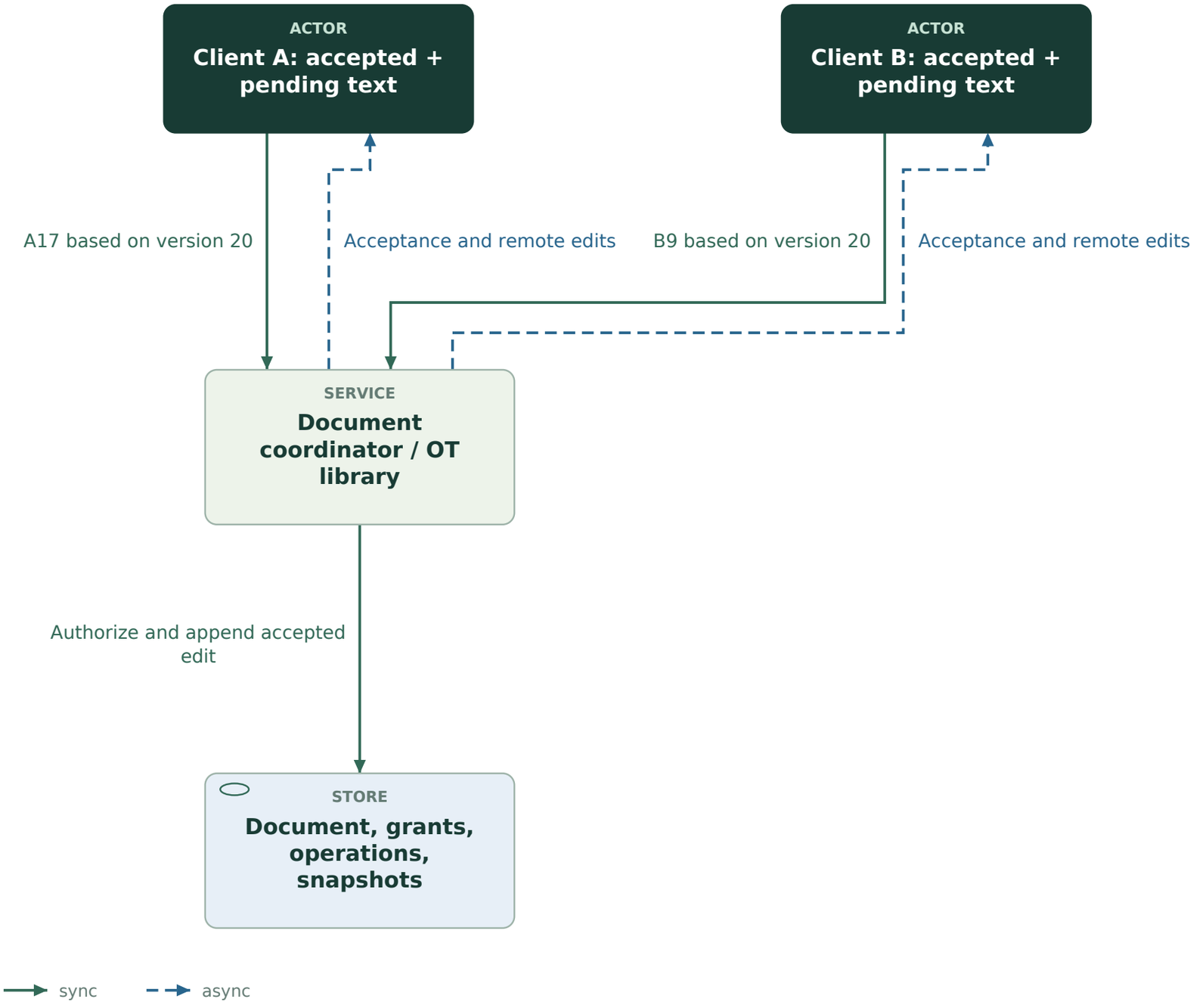
1. A opens D7 at version 20, displays X locally and submits operation A17 with its base version.
2. The coordinator checks current edit permission and whether A17 already exists.
3. It transforms the operation against intervening accepted history, then transactionally appends the accepted edit and advances the document version.
4. Only after durable commit does it acknowledge A17 and broadcast the result.

Clients reconcile the accepted operation with their pending local operations. A's own acknowledgment removes its pending entry; it must not insert X a second time. A server restart rebuilds accepted content from a snapshot and subsequent operations. Lost broadcasts are repaired by replaying missing versions.

This baseline already needs a real editing library, persistent operations and a reconnect protocol. WebSockets only provide a low-latency connection; they neither merge conflicting edits nor recover a message that vanished before reaching a peer.

One document owner accepts operations

Clients render pending edits; the coordinator acknowledges only durable accepted history.



05 / Walk through two concurrent insertions

Positions in the example are zero-based: position 1 lies between c and a. A17 and B9 both describe edits based on cat at version 20. Suppose the selected library's tie-break rule places A's same-position insert first.

Accepted step	Operation and resulting text
Version 20	Initial text is cat.
Version 21	Accept A17: insert X at position 1, producing cXat.
Transform B9	A inserted before B's target, so adjust B's insertion to position 2.
Version 22	Apply transformed B9, producing cXYat.

B had already displayed cYat locally. Its client transforms incoming A17 and its own pending edit consistently, preserving both letters and converging to cXYat. The rule makes clients agree on the text. It cannot know which word the users intended.

Deletes, overlapping ranges and undo need their own correct rules. Undo should reverse the selected edit using the library's rules, preserving other users' work where specified, rather than upload an old entire document. Choose one documented text representation for all clients. Byte offsets, UTF-16 code units, Unicode scalar values and visible grapheme clusters are not interchangeable; use the library's agreed units and conversion rules.

A worked insert example explains the mechanism but is not a complete algorithm implementation. Evaluate a maintained OT stack and its persistence adapter rather than treating this table as sufficient production code.



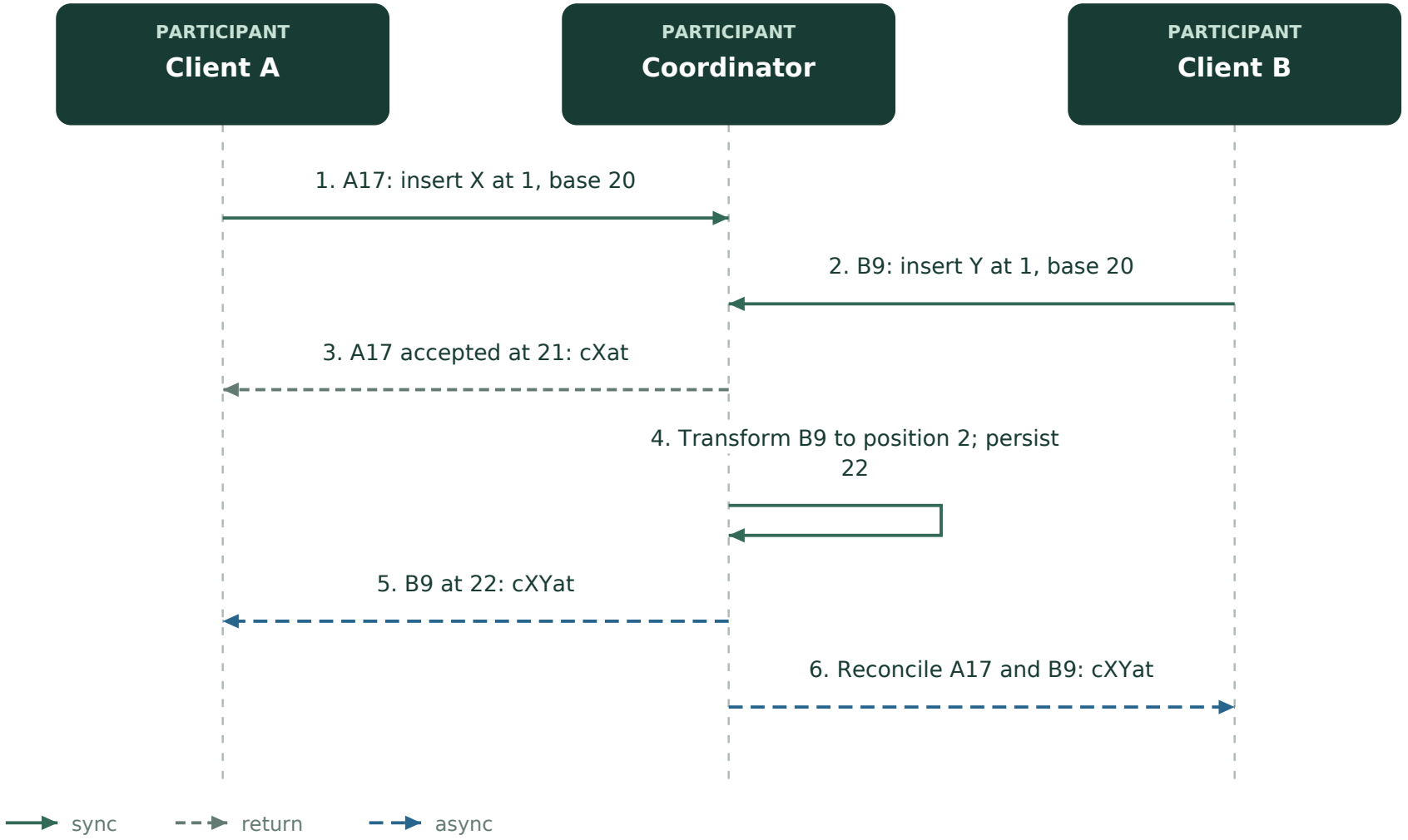
INTERVIEW CRITICAL

Database order and edit meaning solve different problems

A transaction can order two edits, but it cannot decide how the second position shifts after the first insertion. The editing algorithm combines operations; durable storage preserves the accepted history. Both are required.

Both concurrent inserts survive

The shown tie-break orders A before B; the full library handles other edit types.



06 / Size active typing and peer delivery separately

Assume one million connected users, five percent currently typing and two operations/s per typist. That yields 100,000 incoming edits/s. At 200 bytes per operation, payload ingress is 20 MB/s before framing, indexes and replication. If sustained for a full day, the operation payload is about 1.728 TB; actual duty cycles must be measured rather than assumed constant.

Ten other participants receiving each edit create one million peer deliveries/s. Connection memory can also be significant: one million connections at an illustrative 32 KB each consume about 32 GB before process and encryption overhead. Moving sockets and fanout to gateways may matter before optimizing the storage engine.

A single document with 100 typists at two edits/s has 200 ordered edits/s and about 19,800 peer deliveries/s. Sharding other documents does not split this document's edit order. Measure transformation CPU and fanout separately before claiming a global shard count solves the hotspot.

Snapshots trade storage work for shorter recovery. A 1 MB snapshot every 1,000 edits on that hot document means a snapshot every five seconds, or 200 KB/s for that document alone. Use a replay-byte target and minimum interval rather than an unexamined count-only rule. Bound per-client queued bytes to prevent slow viewers consuming unlimited memory.

07 / Name operation identity, base and accepted version

Interfaces

Request or message	Contract
`GET /documents/D7`	Returns authorized content, current accepted version and supported reconnect boundary.
Edit message: `operationId`, `baseVersion`, `operation`	Names one local edit and the accepted state it was based on.
Acceptance message: `operationId`, `version`, `canonicalOperation`	Confirms the durable order and lets the client reconcile pending state.

These JSON examples show the worked insert and its acceptance. The selected editing library defines the actual operation encoding.

A17: client edit based on version 20

```
{
  "operationId": "A17",
  "baseVersion": 20,
  "operation": {
    "type": "insert",
    "position": 1,
    "text": "X"
  }
}
```

A17: acceptance after durable commit

```
{
  "operationId": "A17",
  "version": 21,
  "canonicalOperation": {
    "type": "insert",
    "position": 1,
    "text": "X"
  }
}
```

Stored records

Record	Fields or identity	Purpose
Document	`id`, `headVersion`, `ownerGeneration`	Current accepted head and coordinator authority.
Operation	`document`, `version`, `actor`, `operationId`, `payloadHash`	Ordered replay and duplicate recognition.
Snapshot	`document`, `version`, `content`	Complete accepted content at one exact boundary.
Grant	`document`, `user`, `role`	Current read/edit permission.

Scope operation identity to the document and authenticated actor. A retry with identical content returns its original acceptance; the same ID with different content is an error. Check for an already accepted operation before rejecting its now-old base, because a lost acknowledgment does not turn a retry into a new unsupported edit.

The client keeps a pending-operation buffer, ideally persisted locally under a stated draft policy. The server retains enough accepted history for its advertised reconnect interval. Presence messages have session sequence and expiry but do not advance durable document versions. Merely knowing an actor ID or document URL does not grant access.

08 / Recover the gap between saved history and live messages

On open, return a snapshot and a fixed accepted upper boundary, such as version 22. If the snapshot is version 20, replay operations 21 and 22 to reconstruct that boundary. Newer edits can arrive through a subsequent replay or live subscription; they must not silently alter which operations the initial response promised.

Subscribe with the last applied version. The server must replay or buffer edits accepted between the initial read and live registration. Otherwise version 23 could be lost in the handoff. A client receiving version 24 while expecting 23 requests the gap before applying later positional operations.

After a brief disconnect, first obtain missing accepted history, then reconcile and resubmit pending edits with their original identities using the editing library's protocol. The server returns saved acceptances for

duplicates. Arrival order between acknowledgment and broadcast should not cause the sender to apply its own insertion twice.

If a client predates retained transformation history, preserve its local draft and require an explicit resynchronization/merge workflow against current content. A snapshot of today's text does not reconstruct every old position shift. Advancing the supported history boundary is therefore a product decision, not a side effect of deleting old logs to save disk.



INTERVIEW CRITICAL

Fast local typing is not durable save

Keep pending edits visibly distinct until the authoritative log accepts them. A reconnect recovers saved versions and reconciles the pending buffer; it must never silently drop unsaved text or label a disconnected draft saved.

09 / Separate document ordering from sockets and fanout

Move WebSocket connections to gateways when connection count and outgoing traffic overwhelm the first process. Gateways authenticate sessions, enforce buffer limits and forward edits to the document owner. They broadcast accepted versions to subscribers but cannot declare an edit saved just because they received it.

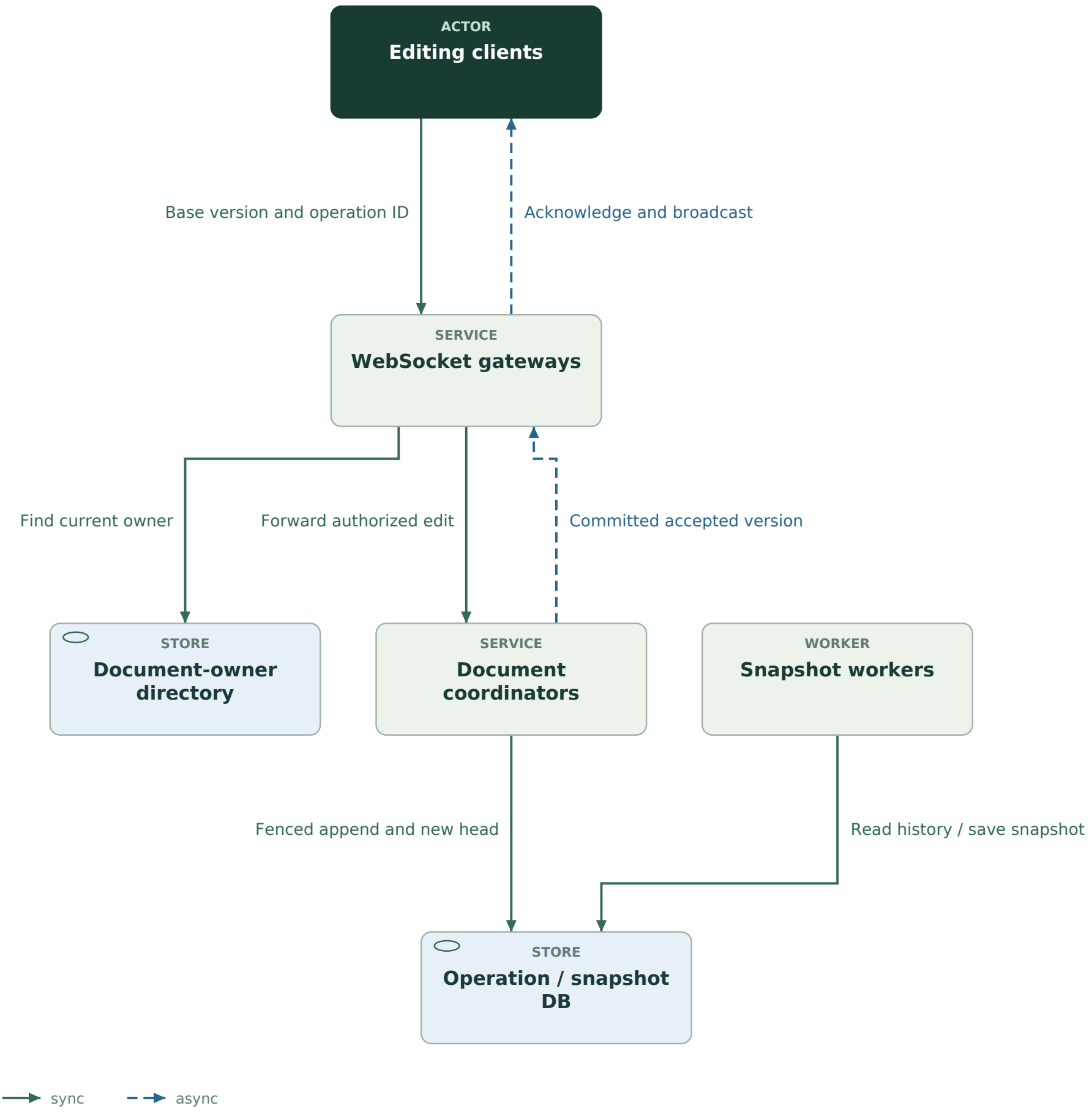
Partition ownership by document. Different documents use independent coordinators and storage partitions, while D7 retains one accepted order. A routing directory chooses the coordinator; the durable append path remains the source of authority. Workers receiving D7's edits at random would still need to agree on their order and transform them against that same history.

A replacement coordinator reconstructs D7 from durable content before accepting edits. Give ownership an increasing generation and check it at log append alongside the expected head version. If an old coordinator resumes after replacement, its stale generation is rejected by storage. Routing new clients elsewhere is insufficient because the old process may still hold open sockets and prepared writes.

If a transform was computed against head 21 but the append finds head 22, reload the intervening edit and recompute rather than appending the old transformed position blindly. Use the chosen library/adapter's supported concurrency controls and test the ownership boundary rather than implementing a second, inconsistent edit protocol around it.

Gateways route edits to fenced document coordinators

An edit crosses a gateway to the current document coordinator, which transforms it against accepted history and commits through the fenced append path. Only committed versions return to subscribers. Snapshot workers compact recoverable document state in the database; a replacement coordinator rebuilds from that state before accepting edits.



10 / Keep recovery short without hiding snapshot assumptions

Create snapshots from a precise committed version so the saved content and advertised version agree. A simple baseline stores snapshot content and its version transactionally in the same database. The 1 MB document bound makes this a reasonable starting choice, avoiding a separate object-publication protocol in the first design.

After a snapshot at version 22, recovery starts there and replays operations after 22. Do not delete transformation history still required for supported pending edits merely because the visible text has a newer snapshot. A snapshot may restore the saved text without retaining the earlier edits needed to transform a reconnecting client's pending work.

At larger historical volume, immutable snapshot objects plus database references can reduce database storage, but publishing, retaining and deleting those objects safely adds another protocol. Keep that extension explicit rather than compressing object lifetime guarantees into "use object storage."

Preserve accepted operation and metadata transactions across application restarts; configure and test database replication for any additionally agreed storage-node or zone failure tolerance. Presence, gateway connections and in-memory content caches can be rebuilt; the log and operation identities cannot be treated as disposable. Backups cover accidental deletion or corruption replicated to every serving copy. A restore test should reconstruct exact accepted content and retry behavior, not merely find a snapshot file with the right name.

11 / Preserve drafts, permissions and accepted history

Failure	Behavior
Append commits, acknowledgment disappears	Retry the same operation and return its accepted version without inserting again.
Gateway disconnects	Client reconnects with last applied version; durable edits remain available for replay.
Document authority loses safe write access	Local typing can remain pending, but save acceptance pauses.
Slow receiver accumulates output	Bound its queue and require replay-based reconnect; coalesce or discard old cursor updates.
Edit permission is revoked	Subsequent authorized append decisions reject edits; preserve rejected local text as a draft.

Check permission at edit acceptance, not only at socket establishment. Read permission also applies to snapshots and replay. Revocation cannot erase bytes a user already downloaded, so distinguish preventing new access from recalling past disclosure.

Test concurrent insert/delete/undo histories under different delivery orders and compare final accepted content. Add coordinator failure, duplicate operation IDs, lost acknowledgments and old-client reconnect.

Before upgrading the editing library, replay representative histories through old and new versions and verify protocol compatibility.

Measure pending age, accepted-edit latency, remote-delivery delay, transform failures, replay bytes and buffer evictions. A responsive local cursor can hide a saving outage. Keep document text out of broadly accessible logs; IDs, versions and timing usually suffice for diagnostics.

12 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR3,5: authorized concurrent editing	Current document grants, a proven OT library and one accepted order per document.	Run concurrent insert/delete/undo histories and revoke permission during a session. Clients converge to the accepted result without unauthorized new edits.
FR3; NFR1-2: responsive collaboration	Separate gateway fanout from document transformation; render pending locally and acknowledge only after commit.	Load-test fleet traffic and the 100-participant hot document against both p95 targets. A fast local cursor cannot substitute for measured save latency.
FR4; NFR4: reconnect without duplication	Snapshot plus versioned replay, a gap-free subscription handoff and retained operation identities.	Drop A17's acknowledgment and reconnect inside thirty minutes. After the advertised boundary, preserve the draft and require explicit resynchronization rather than silently losing text.
NFR3-5: recover document authority	Storage validates coordinator generation and expected document head; reconstruct from committed history.	Pause an old coordinator through replacement and crash after append. Its stale write must fail and the acknowledged edit must replay once; test the configured database durability separately.

13 / Rapid revision

Remember: The merge algorithm combines edits; the durable log preserves them. A socket does neither by itself.

Concern	Complete design
Concurrent edits	Send each edit with its own ID, rather than replacing the whole document.
Merge model	Use proven operational transformation (OT) to adjust edits for changes the server accepted in between.

Concern	Complete design
Local responsiveness	Render pending edits immediately and retain their identities for recovery.
Saved state	Acknowledge only after the accepted operation is durable.
Retry	Return the saved result for an already accepted operation; never insert it twice.
Reconnect	Load a snapshot and later edits; join live updates without gaps, then resolve the client's pending edits.
Scaling	Add gateways for connections; each document's coordinator maintains that document's edit order.
Failover	When appending, storage checks the current owner token and expected latest document version.
History	State how long automatic reconnect works; preserve drafts when the edit history needed to merge them is gone.

Close by showing cat -> cXat -> cXYat, then lose A17's acknowledgment. Explain which component combines edits and which preserves the result. A CRDT is an alternative worth evaluating for extensive offline collaboration, with its own operation metadata and cleanup requirements; it changes the editing model rather than simply adding a component to OT.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why not save the whole document after each edit?

Model answer

Two users can replace the same base with different complete copies, causing the later save to erase independent work. Operations preserve the intent the merge algorithm needs.

Interviewer follow-up

Does a row lock recover the overwritten edit?

It orders replacements but does not reconstruct the edit lost from the later copy.

What the answer must demonstrate: Explain lost independent edits under whole-document replacement.

02 / APPLIED

How do X and Y inserted at position 1 both survive?

Model answer

A defined tie-break accepts one first and transforms the other position around it. Both clients reconcile pending and accepted edits under the same rules.

Interviewer follow-up

Does the example implement a full editor?

No. Deletes, undo, Unicode and overlapping operations require a proven complete algorithm.

What the answer must demonstrate: Trace both client reconciliation and deterministic server transformation without generalizing an insert demo.

03 / FOUNDATION

When can the interface show saved?

Model answer

After the authoritative operation log durably accepts the edit, not merely after local rendering or gateway receipt.

Interviewer follow-up

Must every peer acknowledge first?

No. One offline peer must not block everyone else from saving.

What the answer must demonstrate: Identify durable acceptance separately from local display and peer delivery.

04 / APPLIED

A17 committed but its reply vanished. How is a duplicate X avoided?

Model answer

Retry A17 with the same authenticated identity and payload. The owner returns the existing accepted version, and the client removes its pending entry.

Interviewer follow-up

What if its base is now old?

Check the stored duplicate outcome before treating it as a new edit requiring old transformation history.

What the answer must demonstrate: Reuse operation identity and remove the matching pending edit without applying it twice.

05 / APPLIED

How can an edit disappear between opening and subscribing?

Model answer

An operation may commit after the initial snapshot/read but before live subscription. Replay or buffer from the last applied version to cover that gap.

Interviewer follow-up

What if version 24 arrives before 23?

Fetch the missing history before applying later positional edits.

What the answer must demonstrate: Close the snapshot-to-subscription gap and repair missing versions before positional application.

06 / FOLLOW-UP

Why must storage reject a stale document coordinator?

Model answer

The old process may resume with open sockets after a replacement takes over. Checking its ownership generation at append prevents a second accepted history.

Interviewer follow-up

Why check the head too?

A transform computed against old content must be recomputed after intervening operations.

What the answer must demonstrate: Check ownership generation and expected head at the protected append boundary.

07 / FOLLOW-UP

Can a snapshot replace all operation history immediately?

Model answer

It can reconstruct current text but may not preserve the context needed to transform supported old pending edits. Retention follows the reconnect contract.

Interviewer follow-up

What happens beyond that contract?

Preserve the local draft and require an explicit current-snapshot merge workflow.

What the answer must demonstrate: Retain required transform context or explicitly preserve drafts for resynchronization.

08 / FOUNDATION

Why treat cursors differently from document edits?

Model answer

Cursors are ephemeral hints that may expire or be coalesced. Accepted edits are durable content requiring replay and uniqueness.

Interviewer follow-up

Does revocation remove already downloaded text?

No. It prevents subsequent authorized access and acceptance, not recall of existing copies.

What the answer must demonstrate: Separate ephemeral presence, durable edits and the limits of access revocation.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design an online editor where two users insert into cat concurrently, then lose one acknowledgment and reconnect through a new server.

• Agree numbered functional and non-functional requirements, including text model, save latency and the automatic reconnect window. Then explain why identified operations preserve concurrent edits better than whole-document replacement.

• Trace pending edits, accepted versions and reconnect without applying an edit twice.

• Scale documents and connections separately while preserving document authority and permissions.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

A and B insert X and Y at position 1 in cat. If X is accepted first, where does Y go?

The OT rule moves Y to position 2, yielding cXYat. Both clients apply the same rule to accepted and pending edits.

An earlier insert shifts later positions: transform the edit, not the whole document.

How can a client recover an accepted edit whose broadcast was lost?

Read the saved operation log; operation IDs let the client recognize edits it has already seen.

A lost broadcast is recoverable because the accepted edit is saved.

Why might a current snapshot be insufficient to merge an old pending edit?

The transformation algorithm may still need the intervening edit history to adjust that pending edit.

Current text is not all history.

Summary and interview notes

Show typing immediately, combine concurrent text edits using proven operational transformation, and save accepted operations durably. On reconnect, recover missed edits and resolve pending ones without inserting them twice.

Remember these points

• Represent edits as identified operations.

• Keep pending display distinct from durable save.

• Recover missing versions and deduplicate retries.

• Scale connection gateways separately while keeping one accepted edit order per document.

Interview tips

• Separate local pending text, saved edits and peer delivery.

• Work through cat -> cXat -> cXYat, then lose A17's acknowledgment and reconnect.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Detailed merge and coordinator proof: Study expected-head checks and stale-owner interleavings after the basic operation model.

Object-backed snapshot publication: Large snapshot storage introduces separate publication, reader and reclamation rules.

Long-offline collaboration with CRDTs: Months of disconnected editing may justify a different merge model and metadata contract.

Hot-document limits and alternatives: Splitting one document requires independently mergeable semantics, not arbitrary operation hashing.

Technical references

Yjs shared types
Official examples of collaborative shared data types and transactions.
https://docs.yjs.dev/getting-started/working-with-shared-types

Yjs document updates
Documents update exchange, state vectors, and merge behavior for a concrete CRDT implementation.
https://docs.yjs.dev/api/document-updates

RFC 6455: WebSocket
Defines the bidirectional transport used for interactive edit and presence events.
https://www.rfc-editor.org/info/rfc6455/

ShareDB documentation
Official operational-transformation backend documentation; evaluate the supported text type and persistence adapter rather than inferring custom authority guarantees.
https://share.github.io/sharedb/

CRDT definitions and glossary
Standard convergence property for conflict-free replicated data types; sequence text is one application, not the general definition.
https://crdt.tech/glossary

EXTENDED INTERVIEWS / 46

Design a metrics, logging and tracing platform

Interview version / 45-minute scope · Read the advanced version online

Build an operational telemetry platform that links metrics, logs and traces, bounds ingestion and query costs, and distinguishes missing evidence from healthy behavior.

time series • log ingestion • cardinality • histograms

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace an application request from collection to dashboard, alert and diagnostic evidence.
- Explain metric types, cardinality, reset-aware rates and valid percentile aggregation.
- Protect applications and accepted telemetry during overload while making freshness and sampling visible.

Useful foundations: Capacity estimation: throughput, latency, concurrency and storage; Database indexes: B-trees, composite keys and query access; Message queues, event logs, delivery guarantees, and backpressure

8 interview questions with model answers and answered follow-ups.

01 / Start with an incident the platform must explain

Checkout request req81 becomes slow and times out while calling inventory. The platform should let an operator see increased checkout latency, locate the timeout log and inspect the trace linking checkout to inventory. Metrics describe aggregate behavior, logs describe individual events, and traces connect timed operations called spans across a request. These signals complement one another rather than being three interchangeable storage formats.

Build operational monitoring with bounded queries and explicit loss reporting. Required financial or security audit records need a separately specified zero-loss or durable-admission contract; ordinary debug telemetry must not silently inherit that promise. Include ingestion, dashboards, structured log search, trace lookup, alert rules and retention. Exclude arbitrary joins over every event ever collected.

Target recent accepted metrics becoming visible within thirty seconds for 99% of samples under normal load and target bounded dashboard queries finishing within two seconds p95. Durable ingestion acceptance is a separate milestone from search visibility. A trace may be sampled or incomplete; a missing span does not prove the service was never called.

An empty graph during a collection outage is missing evidence, not a measured zero. The interface and alert engine must show stale or incomplete data instead of declaring checkout healthy.

Ask whether this is operational telemetry or mandatory audit evidence, which incident queries must be fast, and how much collection loss is acceptable during an outage. Choose operational metrics, logs and traces here

with reported dropping of telemetry before acceptance, durable central acceptance and bounded recent-data queries.

02 / Functional requirements

1. **Collect diagnostic signals.** Ingest metric samples, structured logs and linked trace spans with tenant identity and useful request correlation.
2. **Investigate incidents.** Provide recent dashboards, bounded structured-log search and trace lookup, showing freshness, sampling and missing evidence.
3. **Evaluate alerts.** Evaluate versioned rules over suitable data, preserve pending/firing transitions and notify operators of meaningful state changes.
4. **Manage history.** Retain and query the selected recent history, support documented archive/downsample policies and expose rejected or lost telemetry.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Ingestion and retention.** Plan for ten million active series sampled every fifteen seconds, about 666,667 samples/s, plus 100,000 logs/s at 500 bytes each. Use thirty days of metric retention and seven days of indexed logs for the estimates; sampling and archive policies are separate choices.
2. **Visibility and query latency.** Target recent accepted metrics becoming queryable within thirty seconds for 99% of samples under normal load, and bounded recent dashboard queries completing within two seconds p95. Disclose slower archive queries and measure timeout/rejection rates alongside latency.
3. **Loss and recovery boundary.** Before central acceptance, collectors may shed ordinary telemetry only under a bounded, visible policy. After acceptance, preserve retained records through API/writer restarts and replay them; configure and test the chosen backend's replica failure guarantees explicitly.
4. **Diagnostic correctness.** Compute reset-aware rates and compatible histogram aggregation; do not interpret missing samples as zero or incomplete traces as proof an unobserved call never happened.
5. **Isolation and privacy.** Enforce tenant, cardinality, byte and query-work limits. Redact sensitive payloads before persistence and prevent historical queries or unbounded collector buffers from exhausting current application/ingestion capacity.

04 / Complete the path from request to diagnosis

Start with instrumented applications, a local collector, a time-series engine, a structured log store, a trace store and a query/alert service. OpenTelemetry-style instrumentation can attach request and trace IDs consistently. The collector batches records so each application request does not open its own telemetry network connection.

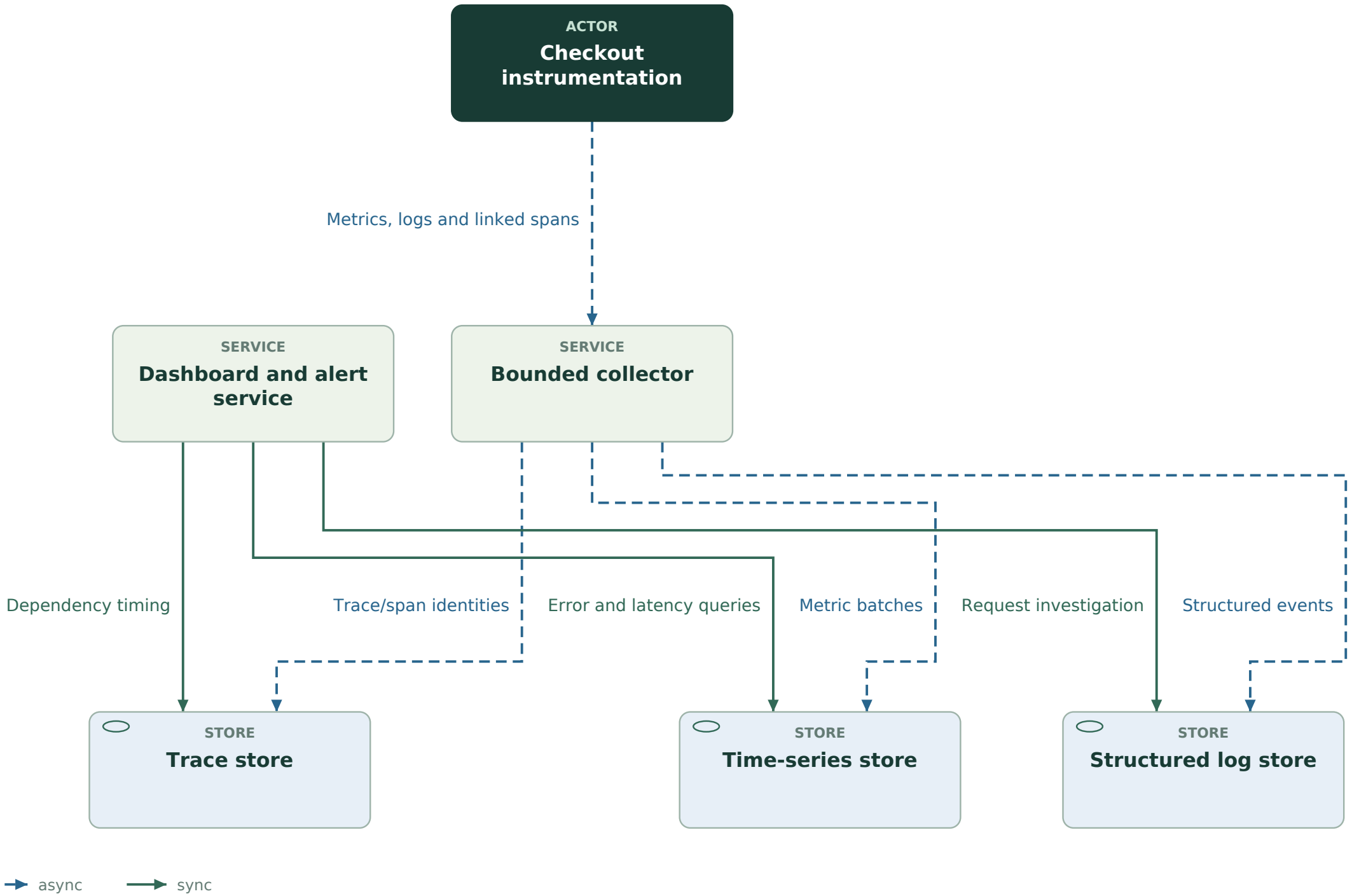
For req81, checkout increments a request counter, records its duration in a histogram and emits a structured error log with the trace ID. The collector submits a bounded batch. The receiving store acknowledges according to its configured durable-write policy; the collector can then release that accepted batch from its retry buffer.

The dashboard reads a recent bounded interval for checkout. An alert detects a sustained error ratio, records its pending/firing transition and links to the evaluated time range. The operator opens the trace, sees time spent waiting for inventory and searches logs by the same request ID. This is a complete useful product before a custom streaming storage system is added.

The baseline includes tenant authorization, redaction and buffer limits. If telemetry collection consumes unlimited memory or blocks application requests indefinitely, a monitoring outage can cause the checkout outage it was intended to diagnose. State from the beginning which records a full collector may drop before service acceptance.

From checkout request to incident evidence

Each signal has a different query purpose; the collector batches all three.



05 / Define metric identity and aggregation semantics

A time series is a sequence of measurements with one metric name and label set. For example:

One checkout error-counter series

```
requests_total{
  service="checkout",
  instance="c3",
  status="500"
}
```

Changing the instance or status label identifies a different series. A counter increases as events occur and may reset after restart. A gauge reports a current value such as queue depth. A histogram records a distribution through counts in value ranges.

Question	Correct computation
How many requests per second?	Compute a reset-aware rate for each original counter series, then sum rates.
What is current queue depth?	Read the gauge, respecting its observation time and aggregation meaning.
What is service-wide p99 latency?	Merge compatible histogram counts and estimate the quantile of the combined distribution.
What happened to req81?	Search structured logs or the trace ID; do not create a metric series for that request.

If one instance's counter restarts from 1,000 to 5, summing raw counters before handling resets creates misleading drops. Likewise, averaging two instance p99 values does not produce the service p99: the summaries omit the underlying distribution and request volumes. Histogram bucket boundaries determine approximation error, so use compatible boundaries or a backend-supported compatible histogram representation.



INTERVIEW CRITICAL

Percentiles are not additive

Combine the underlying compatible histogram counts before estimating a service percentile. Averaging instance p99 values loses both distribution shape and traffic weighting, even if all the stored samples are correct.

06 / Count series identities as well as payload bytes

Assume ten million active series sampled every fifteen seconds. That produces about 666,667 samples/s. At an illustrative sixteen bytes for a scalar timestamp/value pair, raw payload is 10.67 MB/s or 0.922 TB/day. Thirty days with three copies is about 83 TB before compression, indexes and metadata. Histograms may require multiple bucket series or larger native samples, so their actual encoding must be included separately.

Logs at 100,000 events/s and 500 bytes each produce 50 MB/s or 4.32 TB/day. Seven days is 30.24 TB before replication and indexing. Indexing every arbitrary field can multiply the storage cost; select fields used by the promised incident queries.

Cardinality is the number of distinct series. A family spanning 100 services, twenty regions, ten statuses and fifty instances could create one million series if every combination exists. Adding request IDs or user IDs can create a new series for nearly every request. A byte limit alone does not protect the series dictionary from that churn.

Set per-tenant limits on active series, new series per minute, log bytes and query work. Measure real label distributions and compression rather than treating a theoretical maximum or raw payload estimate as a final machine count.

07 / Expose identity, time and completeness

Signal records

Record	Fields carried by the record
Metric batch	Metric name, canonical labels, timestamps, values and producer identity.
Log event	Stable event ID, service, event time, ingestion time, severity and trace/request IDs.
Trace span	Trace ID, span ID, parent relationship, start time, duration and approved attributes.

Example structured error-log identity and timing

```
{
  "eventId": "log-req81-1",
  "service": "checkout",
  "eventTime": "2026-10-07T09:00:00.000Z",
  "ingestionTime": "2026-10-07T09:00:00.200Z",
  "severity": "ERROR",
  "requestId": "req81",
  "traceId": "trace-81"
}
```

Ingestion and query contracts

Interface	Required information
Ingest response	Accepted records or explicit per-record rejection, plus the durability boundary.
Query	Authenticated tenant, bounded time range, filters, resolution and output limit.
Query response	Results plus freshness, completeness and sampling indicators.

Event time is when the application observed something; ingestion time is when the platform accepted it. Both matter: an old log may have been buffered by its source rather than delayed by central storage. Specify the allowed out-of-order window and route later data to a defined correction or archive path.

Retried batches retain stable record identities. Two legitimate logs with identical timestamps are still different events. For a simple log store, unique tenant/event IDs make repeated insertion harmless; metric sample identity follows the selected backend's documented series/time and conflict rules. Reject conflicting reuse rather than silently counting a repeated record as new.

Responses must make partial acceptance explicit so the collector retries only the appropriate records. Bound the deduplication/retry horizon and account for its metadata rather than promising infinite remembered identities.

08 / Add a durable buffer and isolate query resources

If storage outages or bursts exceed direct-ingestion capacity, insert a replicated ingestion log between authenticated gateways and the signal backends. Gateways validate tenants and limits, then acknowledge only after the selected durable append policy. Writers consume accepted records into the time-series, log and trace stores. Search visibility can now lag while accepted data remains buffered.

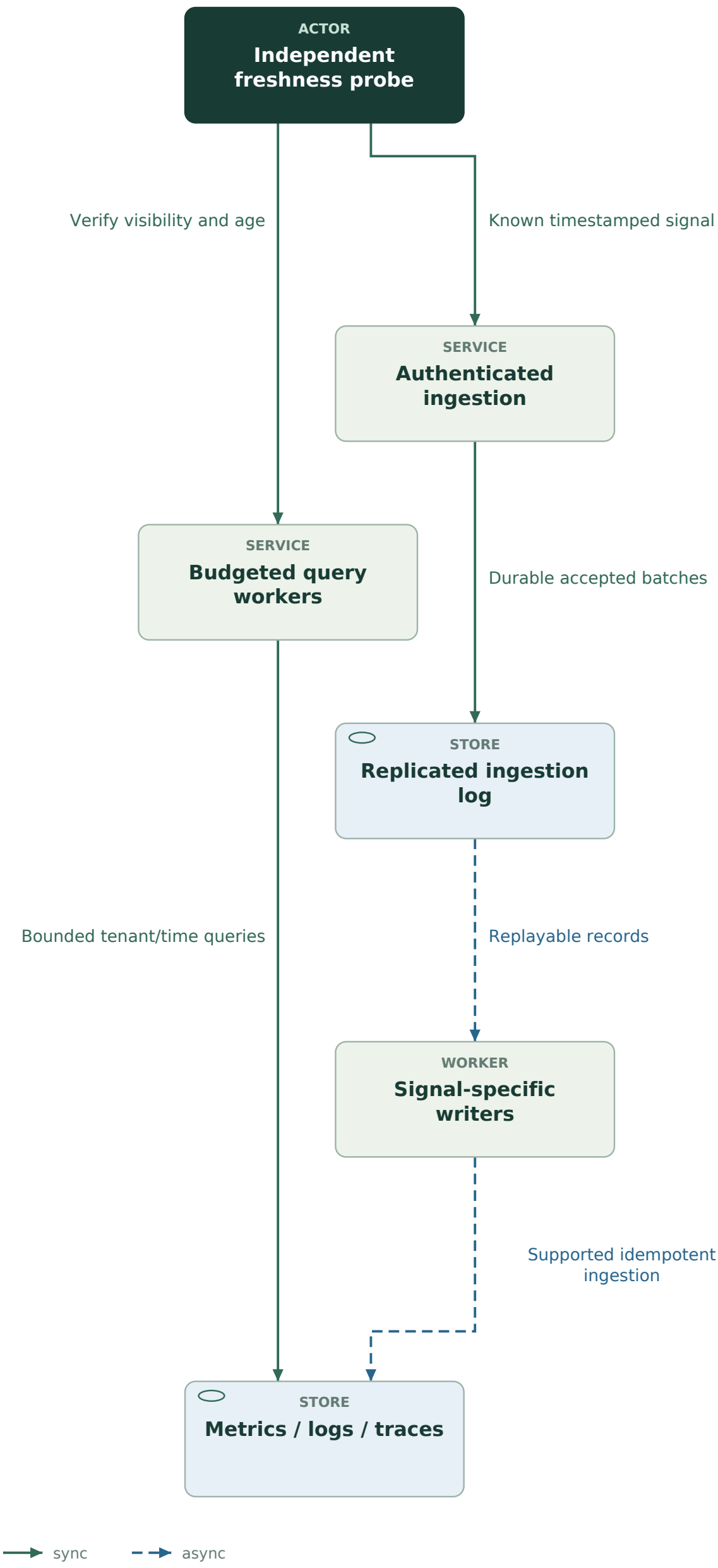
Use established backends and their supported ingestion/replay integration rather than designing a new chunk-publication protocol during the first interview. Where duplicate-free storage is promised, backend writes must recognize stable record IDs when writers retry. If a backend can expose duplicates, disclose that behavior and deduplicate the relevant query rather than claiming the broker alone supplies exactly-once storage.

Partition metrics by tenant and series identity, logs by tenant/time plus a distribution key, and trace lookup by trace ID. A large tenant needs several partitions; one tenant label must not force all its work onto one machine. Within each backend partition, preserve its required record order and allowed lateness.

Separate expensive historical queries from current ingestion through dedicated resource pools and scanned-byte/concurrency limits. A user investigating an incident should not make every current alert stale by launching an unlimited seven-day search on the same disks.

Buffer accepted data and bound query work

Acceptance and visibility are separate; backlog age exposes their distance.



09 / Design the questions before indexing everything

For a checkout dashboard, first select series using low-cardinality labels, then read only the requested time interval and resolution. Apply counter resets before aggregation and combine histogram distributions correctly. Return the data-through time and disclose missing partitions. A partial result must not look like a complete service-wide graph.

For req81, narrow by tenant, service and event-time range, then use indexed request or trace IDs. Return ingestion time so the operator can identify delayed evidence. Log pagination needs a stable tie-breaker such as event ID and either a fixed query snapshot or declared live-search behavior. A cursor alone does not freeze incoming records.

A trace view assembles spans under the trace ID and shows missing relationships. Head sampling decides near request start and propagates the decision; tail sampling waits for spans and can favor error traces, but costs buffering and cannot guarantee all late spans arrive before its decision. State sampling rates and incompleteness in the UI.

Cache repeated bounded dashboard queries using tenant, filters, resolution and the relevant freshness boundary. Late data may require invalidating or refreshing affected ranges. Downsampling saves storage but permanently removes time detail; retain count and sum for means and compatible histogram information for distribution queries.

10 / Make alert state depend on fresh evidence

An alert evaluator might run every fifteen seconds and fire when checkout's error ratio stays above a threshold for a specified duration. Record the rule version, last evaluated boundary, pending start and current state. This prevents a restart from inventing a new alert every evaluation or forgetting all pending progress.

The evaluator first checks whether the input is sufficiently fresh and complete. Missing data produces a stale or unknown state, not a zero-error rate and automatic resolution. A previously firing alert should follow an explicit missing-data policy; silence is not proof that the incident ended.

To fire after a threshold holds continuously, the evaluator needs observations covering the whole interval. If the platform was unable to observe a five-minute interval, retaining an old pending timestamp does not prove the threshold held throughout it. Reconstruct that interval from retained samples if possible; otherwise restart the duration check according to the rule rather than counting unseen time as demonstrated failure.

Persist state transitions and use stable notification identities so retries do not create repeated pages for the same transition. Include the evaluated query and time range in the notification. Monitor the observability platform with an independent small heartbeat or external probe; relying only on its own failed ingestion path can conceal its complete outage.



INTERVIEW CRITICAL

Missing telemetry is not healthy telemetry

Check freshness and completeness before evaluating a rule. An empty or stale interval cannot establish zero errors, a successful recovery, or a continuously exceeded threshold.

11 / Bound buffers and describe the acceptance boundary

Failure	Response
Collector cannot reach ingestion	Buffer to a fixed byte/time limit, retry with backoff, then apply disclosed shedding and count losses.
Central durable log cannot accept safely	Stop acknowledging new batches; do not claim collector memory is central durability.
Signal writer fails after acceptance	Retain accepted input for replay, exposing delayed query visibility.
Query is too broad	Cancel or reject it with a narrower-range suggestion; protect ingestion and alert capacity.
Cardinality suddenly explodes	Reject or quarantine invalid dimensions and expose the offending instrumentation.

The before/after acceptance distinction is essential. Before central acceptance, configured collector buffers can overflow and ordinary telemetry may be lost. After acceptance, the platform has promised retention under the configured backend durability policy, including survival of API/writer restarts. It must not overwrite unprocessed records merely because the buffer is full. Tighten admission before that happens.

At 100,000 log events/s, a one-hour outage accumulates 360 million events. A recovered writer handling 150,000/s while 100,000/s new traffic continues drains at only 50,000/s, taking two more hours. Reserve recovery capacity and measure oldest unprocessed age. Returning to normal ingest throughput alone does not catch up.

12 / Control cost without destroying incident evidence

Apply tenant-scoped ingestion credentials, label allowlists and redaction before persistence. Private data in labels both leaks information and creates expensive series identities. Restrict retention and alert-route changes, and avoid raw payloads in diagnostic labels about the platform itself.

Monitor accepted-to-visible delay, collector drops, series churn, writer backlog age, query scanned bytes, alert freshness and backend errors. A fast ingestion endpoint can still feed a platform whose dashboards are hours behind. The independent heartbeat should exercise a known write and read, not merely check that a process responds.

Retain recent high-resolution metrics and indexed logs on fast storage, then archive or downsample according to the actual investigative needs. Reducing seven-day indexing can save substantial cost but may make old request searches slower or unavailable. Show those limits rather than promising the same query latency across every retention tier.

Test lost batch acknowledgments, duplicate event IDs, counter resets, incompatible histogram changes, collector overflow and backend replay. During backend upgrades, compare counts, sums and histogram buckets on representative traffic. A custom immutable-block engine would also need to prove that publication and cleanup cannot expose duplicate or missing blocks; selecting a proven backend lets the first interview focus on signal correctness and the complete operating contract.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR4: useful incident evidence	Separate signal backends, stable request/trace IDs and correct rate/histogram queries.	Trace req81, reset a counter and merge representative histograms. Verify the graph, log and trace explain the same incident without averaging instance p99 values.
FR2; NFR1-2: timely bounded queries	Selected indexes, bounded time ranges, appropriate resolution and isolated query resources.	Load-test the stated signal mix, thirty-second visibility and two-second dashboard p95. Include high-cardinality labels and late data instead of testing only uniform payloads.
FR3; NFR3-4: trustworthy alerts	Persist rule/evaluation state and gate decisions on sufficiently fresh, complete input.	Interrupt collection during a pending/firing rule. Missing evidence becomes unknown/stale, not an invented healthy zero or proof of unobserved continuity.
FR4; NFR1,3,5: bounded retention and safe overload	Explicit retention, bounded collector buffers, durable replay and tenant limits.	Overflow a collector, restart a writer and launch an expensive query. Report pre-acceptance losses, retain accepted backlog and verify query limits protect ingestion.

14 / Rapid revision

Remember: Missing samples cannot prove zero errors. Check freshness before an alert declares recovery.

Concern	Complete design
Metrics	Limit distinct label combinations, account for counter resets, and combine histograms with compatible buckets.
Logs	Give log events IDs; index selected fields and limit the scope of searches.
Traces	Link operation spans into traces; state the sampling policy and flag traces missing spans.
Collection	Batch and redact through bounded buffers so telemetry cannot exhaust the application.
Acceptance	Acknowledge only after the required durable save; the data may become searchable later.

Concern	Complete design
Replay	Reuse record IDs and the backend's documented write/retry behavior so replay does not silently duplicate data.
Scale	Partition using each signal's key; keep expensive queries from exhausting collection capacity.
Alerting	Save alert state changes and require fresh, complete evidence; missing samples do not mean zero errors.
Cost	Limit new series, indexed fields, resolution and retention; disclose which detail those limits remove.

Close with req81: a metric reveals the symptom, a trace identifies the slow dependency and a log explains the timeout. Then fail the collector and show the dashboard becoming stale. This demonstrates both the diagnostic product and the limits of its evidence.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why retain metrics, logs and traces separately?

Model answer

Metrics summarize aggregate behavior, logs describe events and traces link timed work across a request. Each has different identity, storage and query needs.

Interviewer follow-up

How do they connect?

Use consistent service context and request/trace IDs in the detailed evidence.

What the answer must demonstrate: Connect aggregate symptoms, individual events and request-span relationships.

02 / APPLIED

Why is requestId a dangerous metric label?

Model answer

It can create a new series for every request, exhausting metadata and indexes even with modest sample bytes.

Interviewer follow-up

Where should that identity go?

Structured logs and traces, with selected indexes and retention.

What the answer must demonstrate: Explain series cardinality and place per-request identity in detailed signals.

03 / APPLIED

Why compute rates before summing counters?

Model answer

Each original series can reset independently. Reset-aware rates preserve those boundaries; summing raw counters first can hide resets and create false activity.

Interviewer follow-up

Does a counter value equal new events in the last minute?

No. It is cumulative state whose change over an interval must be interpreted.

What the answer must demonstrate: Handle each counter reset before combining rates across instances.

04 / APPLIED

Can instance p99 values be averaged?

Model answer

No. The summaries lose distribution shape and traffic weighting. Merge compatible histograms and compute the combined quantile.

Interviewer follow-up

What limits precision?

Histogram bucket or representation resolution and the available observations.

What the answer must demonstrate: Aggregate compatible distributions before estimating a service percentile.

05 / FOUNDATION

Does durable acceptance mean a record is already searchable?

Model answer

Not in a buffered design. Accepted input may wait for backend ingestion, so report visibility lag separately.

Interviewer follow-up

Can that input be shed like debug data in a full collector?

No. Central acceptance establishes the stated retention obligation; tighten new admission first.

What the answer must demonstrate: Distinguish pre-acceptance shedding from accepted-data retention and visibility lag.

06 / APPLIED

What should an empty recent window do to an alert?

Model answer

Apply an explicit stale or missing-data state rather than infer zero errors or automatic recovery.

Interviewer follow-up

Can an old pending timestamp prove continuity across an outage?

Only if retained observations reconstruct the interval; otherwise unseen time is not evidence.

What the answer must demonstrate: Require fresh evidence and proven duration rather than equating missing data with zero.

07 / FOLLOW-UP

A writer returns at normal arrival throughput. When does its outage backlog drain?

Model answer

It does not. Completion capacity must exceed continuing arrivals, or new work must be reduced.

Interviewer follow-up

Which metric reveals recovery progress?

Oldest unprocessed or accepted-but-not-visible age, alongside the backlog size.

What the answer must demonstrate: Calculate recovery throughput minus new arrivals and track backlog age.

08 / FOLLOW-UP

Does a durable queue alone prevent duplicate stored telemetry?

Model answer

No. Writers must reuse record IDs, and the backend must handle repeated writes under its documented contract.

Interviewer follow-up

Are identical timestamps sufficient identities?

No. Distinct logs can share a timestamp, and conflicts within one metric stream need a declared policy.

What the answer must demonstrate: Name stable record identity and the actual backend output/retry boundary.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design telemetry for a checkout timeout, then restart a counter, duplicate a log batch and lose recent ingestion while an alert is firing.

• Agree numbered functional and non-functional requirements, including operational versus audit scope, signal freshness and the acceptance/loss boundary. Then trace an application request from collection to dashboard, alert and diagnostic evidence.

• Explain metric types, cardinality, reset-aware rates and valid percentile aggregation.

• Protect applications and accepted telemetry during overload while making freshness and sampling visible.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Req81 timed out, then collection failed and the graph became empty. Can the alert declare checkout healthy?

No. The graph lacks evidence; it has not measured zero errors. Mark the result stale or unknown until usable observations return.

Missing is not zero.

How should several servers' p99 latency be combined?

Combine compatible histograms or distributions, then estimate the 99th percentile. Do not average each server's percentile.

Combine histogram counts, then estimate the percentile.

When does a telemetry backlog shrink after recovery?

Only when processing capacity exceeds the rate of new telemetry arriving.

Backlog needs headroom.

Summary and interview notes

Use metrics, logs and traces to investigate failures. Limit collection and query costs, and show when telemetry is missing or stale so an empty graph is not mistaken for a healthy service.

Remember these points

• Preserve each signal's meaning.

• Limit distinct series, buffered bytes and work per query.

• Separate durable acceptance from visibility.

• Treat stale evidence explicitly in dashboards and alerts.

Interview tips

• Keep signal meaning, record identity and visibility delay distinct.

• Trace req81 from counter to log and trace, then fail collection and explain the empty graph.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Custom storage publication and reclamation: A purpose-built immutable-block engine requires a deeper atomic visibility and object-lifetime protocol.

Detailed record identity and projection metadata: High-rate bounded deduplication and storage generations need backend-specific design.

Complete query semantics and correction paths: Pinned historical queries and late corrections extend the simpler recent-incident contract.

Zero-loss audit requirements: Audit ingestion changes application admission and loss policies instead of inheriting debug telemetry shedding.

Technical references

OpenTelemetry signals
Official definitions of metrics, logs, traces, and their roles.
https://opentelemetry.io/docs/concepts/signals/

Prometheus rate and query functions
Documents reset-aware rates and applying rate before aggregation.
https://prometheus.io/docs/prometheus/latest/querying/functions/#rate

Prometheus histograms and summaries
Explains quantile aggregation and distribution accuracy tradeoffs.
https://prometheus.io/docs/practices/histograms/

OpenTelemetry Collector resiliency
Official description of exporter queues, retries and persistent storage; configuration defines collector crash/loss behavior.
https://opentelemetry.io/docs/collector/resiliency/

Grafana Tempo introduction
Official example of a distributed tracing backend; not a claim that its implementation uses this chapter's custom manifest protocol.
https://grafana.com/docs/tempo/latest/introduction/

EXTENDED INTERVIEWS / 47

Design a distributed job scheduler

Interview version / 45-minute scope · Read the advanced version online

Turn recurring rules into durable run records, retry failed attempts and accept results only from the current worker, with explicit timing, overlap and side-effect limits.

scheduled occurrences • leases • fencing • retry semantics

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Distinguish a recurring schedule, one intended occurrence and its execution attempts.
- Trace atomic due-run creation, worker claim and fenced completion.
- Explain calendar rules, missed-run policy and capacity limits before promising start deadlines.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Databases, data models, and ACID transactions; Quorums, consensus, leases, and fencing

8 interview questions with model answers and answered follow-ups.

01 / Define the run the customer expects

Design a scheduler for approved report jobs with versioned parameters. A customer asks for a sales summary every weekday at 09:00 in America/New_York. A schedule is that recurring rule. An occurrence is one intended Tuesday run at a resolved instant. An attempt is a worker's try at that occurrence. A retry creates another attempt, not another Tuesday report.

Support create/edit/pause schedules, run once, inspect history, cancel and retry according to policy. Exclude arbitrary untrusted code and multi-step workflow graphs initially. Choose jobs returning a small structured result that can be stored transactionally with run status; large report objects are a follow-up with their own publication rules.

Promise durable tracking and one accepted result per occurrence, not that a process executes physically once. A paused worker may resume after replacement. Any external email or payment effect needs a destination-supported identity or reconciliation beyond the scheduler's local result guarantee.

Target 99% of ordinary admitted runs starting within ten seconds of their due time. Require accepted run state to survive one zone failure under synchronous durable database replication and safe failover. Starting is different from finishing: a three-hour report cannot inherit a ten-second completion target. During unsafe authority loss, delay claims and completion rather than accept competing owners.

Clarify whether jobs are approved handlers or arbitrary code, whether the deadline means start or finish, and how overlapping or missed calendar runs should behave. Choose approved bounded-result reports, a start-time objective, no logical overlap and latest-only catch-up for the running example.

02 / Functional requirements

1. **Manage schedules.** Create, edit and pause versioned calendar or interval schedules with named time zones and an explicit missed-run policy.
2. **Run approved jobs.** Save a record for each intended occurrence, dispatch it to a compatible worker and accept its bounded structured result.
3. **Inspect and control execution.** Provide run history and status, manual runs, supported cancellation and retries of the same intended occurrence.
4. **Recover unfinished work.** Resume dispatch after crashes, replace failed attempts and deliver only the accepted result through the committed notification path.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload and resources.** Plan for ten million daily occurrences and a 50,000-job 09:00 burst. The five-second job and 10,000-slot example is deliberately insufficient for the target; provision measured execution capacity or renegotiate admission/jitter.
2. **Start-time objective.** Target starting 99% of ordinary admitted occurrences within ten seconds of their due time under the agreed runtime/resource mix. Misses remain visible; this does not promise job completion within ten seconds or every physical retry meeting the original deadline.
3. **Execution correctness.** Create one logical occurrence per scheduled instant and accept at most one result. Enforce the selected no-overlap policy across occurrences; retries may physically execute more than once.
4. **Durability and safe failure.** Preserve accepted schedule/run state across one zone failure using synchronous durable database replication and safe failover. Without safe authority, delay claims and completion instead of accepting competing owners.
5. **Security and effect boundary.** Authorize schedule ownership and approved worker types, constrain resources and secrets, and require destination-supported identity or reconciliation for external effects. A fenced local result does not prove an arbitrary external call happened once.

04 / Build a complete scanner, database and worker flow

Start with a schedule API, one relational database, a scanner polling an indexed due-time column and a bounded worker pool. At Tuesday 09:00, the scanner locks schedule S7, verifies its current revision and due instant, inserts occurrence R7, creates durable dispatch work and advances the next due time in one transaction. A crash before commit leaves it due; a crash after commit leaves R7 discoverable.

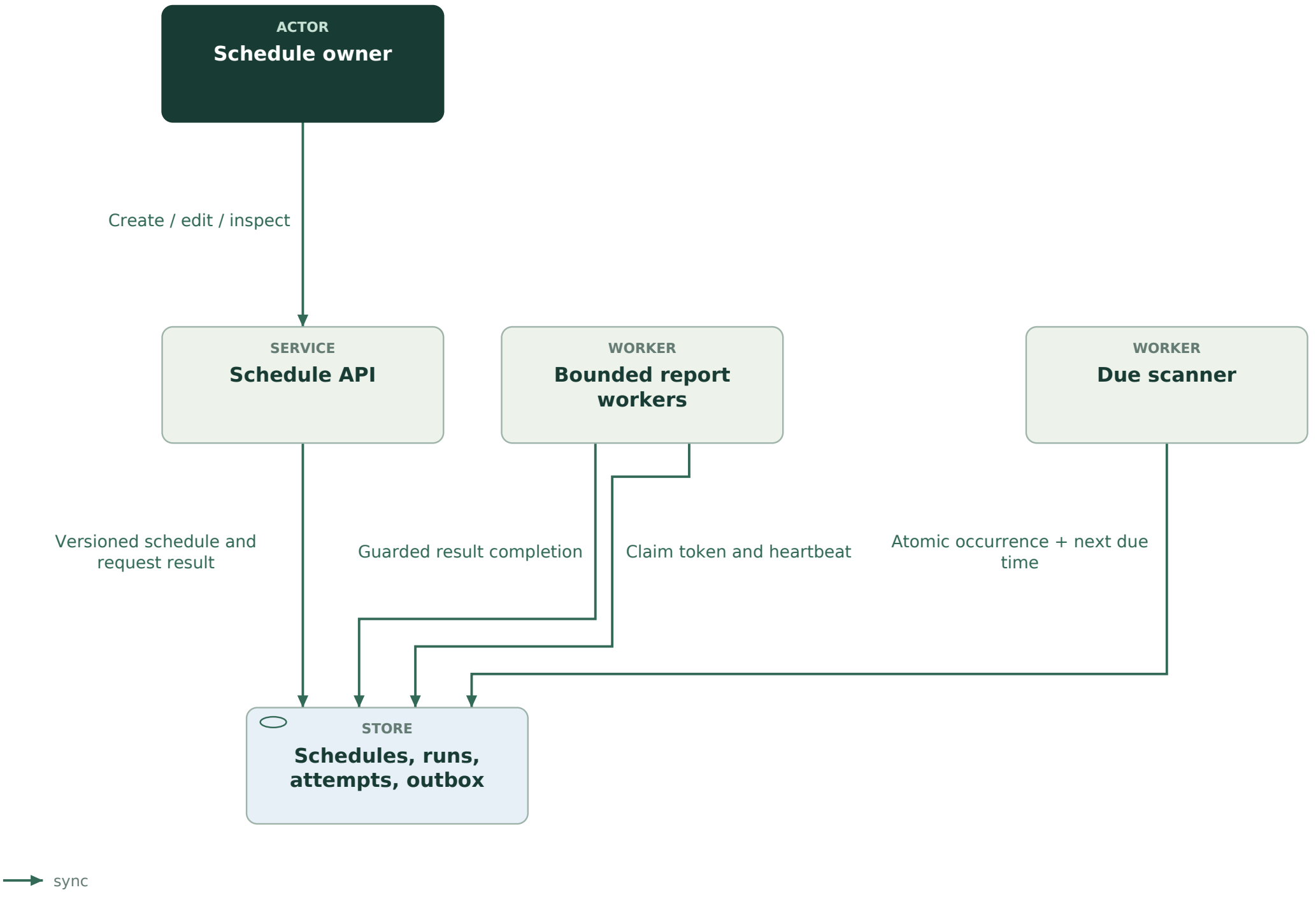
A worker claims R7 through a short transaction. The database marks it running, records attempt A1, grants a deadline and an increasing ownership token. The worker releases locks before computing the report. Heartbeats may extend the deadline only while A1 is still the current owner.

On completion, another transaction checks the attempt and token against current authority, stores the bounded result, marks R7 succeeded and saves any notification work. A repeated completion with the same accepted identity returns the saved outcome. A stale worker cannot replace that result.

The first dispatcher can poll durable work directly; no broker is necessary to make the system recoverable. A queue becomes useful later for worker isolation and throughput, while the run database remains the authority about which attempt may commit.

Persist due work before execution

The database owns occurrences and completion; the worker performs computation outside locks.



05 / Choose calendar, interval and outage behavior explicitly

"Every hour" can mean the top of each clock hour, sixty minutes from a fixed anchor, or sixty minutes after the prior run completes. These are different scheduling contracts.

Rule	How the next occurrence is determined
Calendar	Match a wall-clock rule in a named time zone, such as weekdays at 09:00.
Fixed rate	Add an interval to an anchor, independently of job completion.
Fixed delay	Wait the interval after the previous run completes.

Store the named time zone, rule revision and resolved execution instant. Daylight-saving changes can skip or repeat a local time; define whether to skip, shift or run one/both occurrences. Preview several future instants so users can see what the rule means.

For this sales summary, choose no logical overlap and latest-only catch-up after a long outage. Older missed occurrences are explicitly recorded as skipped under that policy, rather than launching every missed day simultaneously. Other products may need catch-all or skip-all, but those choices affect capacity and business meaning.

A schedule edit affects future occurrences not yet created. An already materialized R7 keeps its original parameter revision through retries. Otherwise the same logical run could produce different business work just because someone edited tomorrow's schedule while today's worker was recovering.

06 / Prove whether the morning start target is feasible

Ten million daily occurrences average about 116 starts/s, but calendar schedules synchronize work. Suppose 50,000 jobs become due at 09:00, each takes five seconds and the fleet has 10,000 execution slots. Under ideal conditions, starts occur in five waves at seconds 0, 5, 10, 15 and 20. The last jobs miss a ten-second start target even before scanner delay or worker startup.

At least 16,667 slots would allow three ideal waves at 0, 5 and 10 seconds. Real duration variance, setup overhead and failure reserve require more margin. Alternatively negotiate start-time jitter, reserve capacity for strict schedules or reject an impossible deadline commitment. A queue stores the burst; it does not create compute capacity.

At 2 KB per run, ten million runs produce 20 GB/day and 600 GB over thirty days before indexes and replicas. Ten thousand active attempts heartbeating every five seconds produce 2,000 state updates/s in addition to claims and completions. Keep those transactions small.

Worker resources often dominate scheduler metadata. Ten thousand 256 MB jobs need roughly 2.56 TB of fleet memory. Measure resource classes and runtime tails, not only job counts. A hundred hour-long jobs are a different queue from a hundred one-second summaries.

07 / Keep recurrence, occurrence and attempt records distinct

Interfaces

Request or message	Contract
`POST /schedules` with request key	Creates one schedule and returns revision and next resolved instant.
`PUT /schedules/S7` with `expectedRevision` and rule changes	Changes future rule interpretation without overwriting a concurrent edit.
`POST /schedules/S7/runs` with key	Creates or recovers one manual occurrence.
`GET /runs/R7`	Returns authoritative status, due/start times, attempt and accepted result.

Inspect the worked occurrence

```
GET /runs/R7
```

Schedule, occurrence and attempt in the example

```
schedule:  S7  -  sales summary, weekdays at 09:00, America/New_York
occurrence: R7  -  one resolved Tuesday run with frozen parameters
attempt:    A1  -  the worker's current try at R7
```

Schedule update request fields

```
expectedRevision: the current schedule revision
rule changes:    the intended changes for future, uncreated occurrences
```

Stored records

Record	Fields or identity	Purpose
Schedule	Schedule ID	Rule, zone, revision, next due time and active occurrence for no-overlap policy.
Occurrence unique by schedule/resolved instant	Schedule and resolved instant (unique)	One logical run with frozen parameters and current attempt token.
Attempt	Occurrence and attempt identity	Worker, number, lease deadline and outcome.
Outbox	Dispatch or notification work identity	Durable dispatch or post-completion notification work.

Keep a schedule and its occurrences where they can commit together in one database transaction. A due index finds bounded batches without scanning every rule. History uses scheduled time plus run ID with a stable page boundary. Authenticate schedule ownership and worker credentials; callers cannot choose their own ownership tokens.

Create and run-once keys include a payload fingerprint. Matching retries recover the original resource, while changed payload reuse conflicts. Scope request identities so their saved result and resource creation share one transaction. Do not put a global deduplication table on unrelated shards and then assume it atomically protects every schedule write.

08 / Explain leases and fencing through a paused worker

A lease is time-limited permission to work. It lets the scheduler eventually replace a worker that stops heartbeating, but its expiry does not physically stop that process. Fencing is the enforcement step: the protected store rejects an outdated ownership token when accepting a result.

The stale-worker example proceeds as follows:

1. A claims R7 with token 41, then pauses long enough for its deadline to expire.
2. B claims a replacement attempt with token 42 and completes.
3. When A resumes, its completion still carries 41. The database sees that 42 is current and refuses A's update.

Checking "my lease was valid when I started" would not prevent A overwriting B's result.

Claims, heartbeats and completion lock the run record and check the authoritative database clock after waiting for locks. Completion verifies current attempt, token, unexpired ownership and allowed state in the same transaction that stores the result. If A completes before a replacement is authorized, the run becomes terminal and B cannot claim it. If replacement wins first, A cannot complete. Those are the two permitted outcomes.

For no-overlap, also keep an active-occurrence guard on S7. It remains attached to R7 during retries, preventing Wednesday's distinct occurrence from starting logically while Tuesday is unfinished. This does not prove that an expired Tuesday process physically stopped; fenced results and protected external effects still matter.



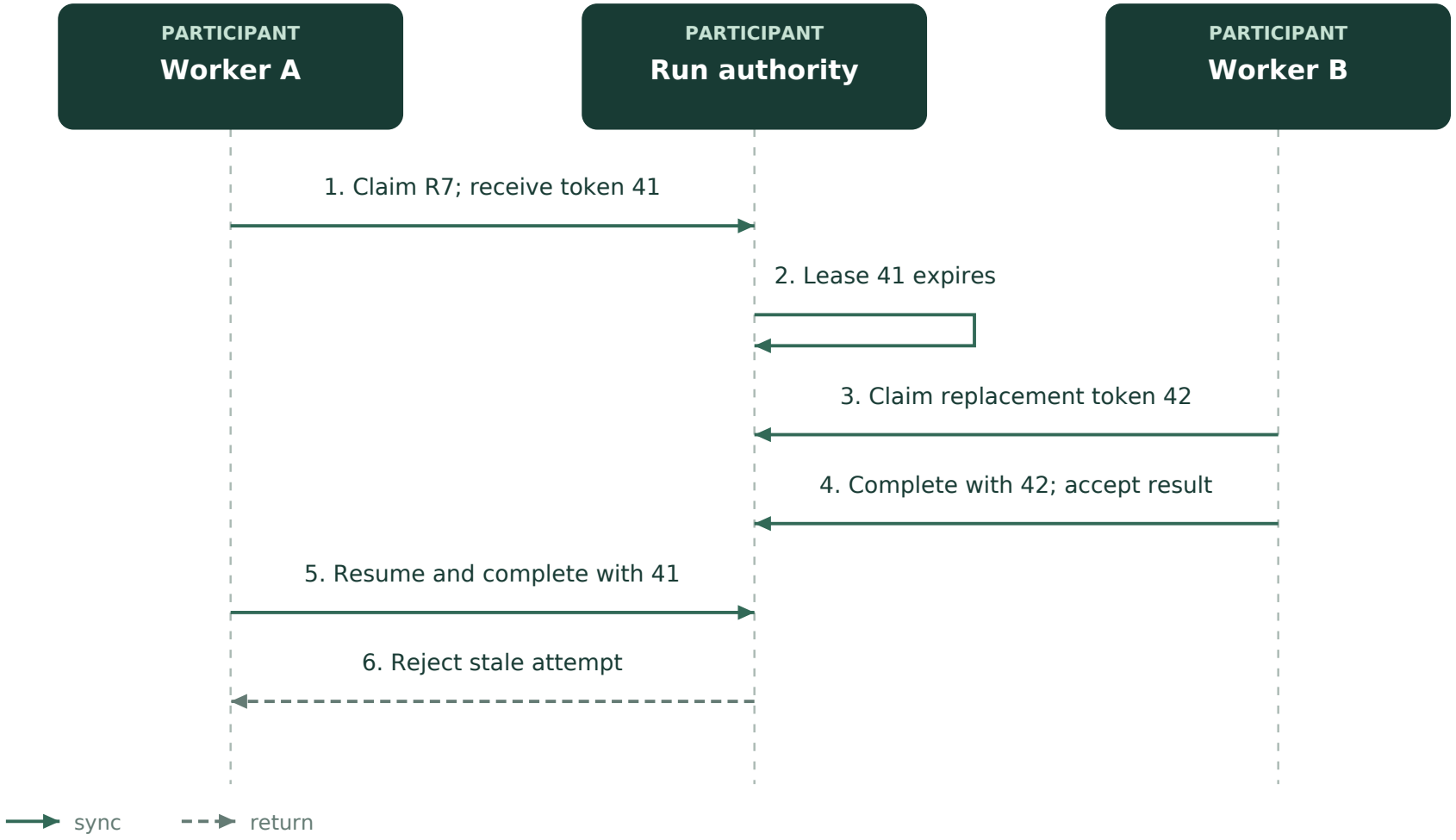
INTERVIEW CRITICAL

Lease expiry does not stop the old process

A replacement worker can coexist with a paused old worker that resumes later. The result store must compare the current ownership token atomically with completion; a local lease check or routing change alone is insufficient.

A stale attempt cannot replace the result

Token enforcement occurs in the same database transaction as result acceptance.



09 / Keep external actions behind the accepted result

The chosen report job computes a bounded result and returns it to the scheduler. It does not email its private attempt output directly. The successful completion transaction stores the canonical result and a unique delivery intent such as send-R7. A notification adapter then processes that committed intent with the accepted content.

This arrangement prevents stale A from publishing a different report through the normal notification path after B's result wins. The provider may still accept email and lose its reply; the adapter must recover that uncertain result. Reuse the logical action identity under the provider's supported idempotency contract or reconcile it. Without those capabilities, disclose the category's duplicate-versus-missing-delivery policy.

Arbitrary jobs that write external databases need destination cooperation. A destination can enforce the scheduler's ownership token with its protected write, or it can recognize an appropriate stable logical operation identity. A worker can pause after checking its token, then resume the remote call after replacement. The local check therefore cannot guarantee one external effect.

Cancellation also has a boundary. Record cancellation requested and let workers stop cooperatively. Once the authority accepts a canceled terminal state, reject later completion and dispatch no retries. Already completed external effects cannot necessarily be recalled, and killing a process does not undo them.



INTERVIEW CRITICAL

One accepted run is not one physical execution

Durable occurrence identity prevents duplicate run records; fenced completion prevents stale results. External side effects require their own supported identity, fencing or reconciliation protocol. Never infer that a unique run row makes an arbitrary email or charge happen once.

10 / Distribute scanning and execution for measured bottlenecks

Separate scanners from workers when execution load delays finding due work. An outbox relay publishes run IDs into ready queues. Repeated queue messages remain hints for the same R7; workers must obtain the current run claim before working. Recovery also scans expired attempts, so correctness does not depend entirely on one unacknowledged broker message surviving forever.

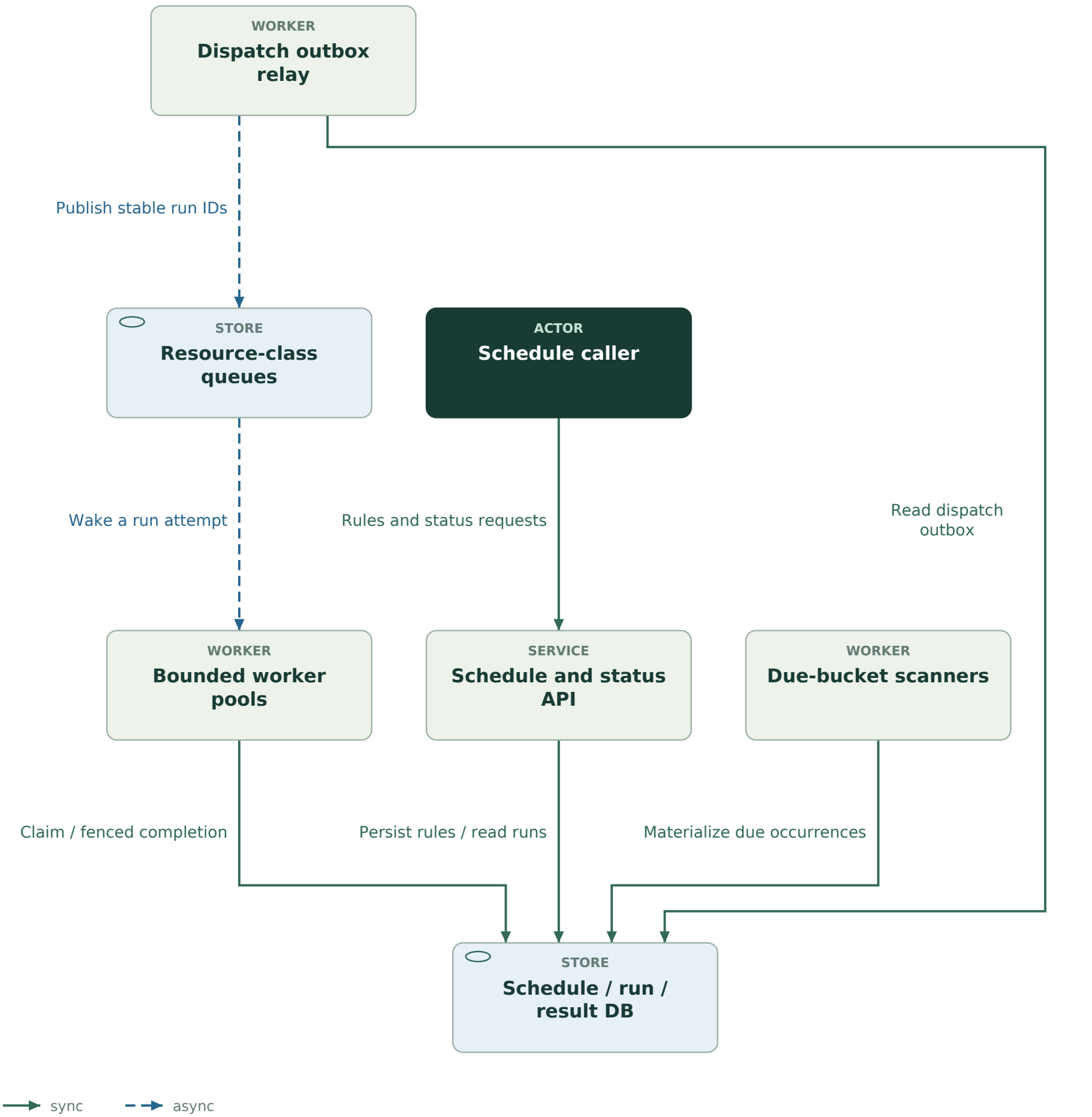
Partition schedules into stable buckets and distribute due-index scans. Scanner leases can reduce redundant effort, but unique occurrence creation and the materialization transaction remain the backstop when two scanners overlap during reassignment. Do not dispatch first and update nextRunAt later: that can create duplicate intended runs after a crash.

Use separate resource pools and tenant active-job limits for short, long and memory-heavy work. Weighted fairness prevents one large customer from occupying all slots; the cost is scheduling complexity and sometimes idle reserved capacity. A single first-in-first-out queue is adequate when jobs are homogeneous and that fairness policy is desired.

Prewarm workers for known peaks and load only a short future horizon into timer structures if database polling becomes expensive. In-memory timers speed up dispatch and can be rebuilt from the saved schedules. Before materializing work, recheck the current rule revision so an obsolete timer cannot execute a canceled or edited occurrence.

Separate due-work discovery from fenced execution

Scanners create each due occurrence and its dispatch work in one database transaction. The relay publishes run IDs to resource-class queues; workers claim current authority before computing. Results and terminal status commit under the same ownership check, while API reads expose the durable run state.



11 / Recover work without silently changing its meaning

Failure	Required recovery
Scanner dies before materialization commit	The due instant remains eligible for a later scan.
Scanner dies after commit but before dispatch	Durable outgoing work republishes the same occurrence.
Worker fails before completion	Expire its attempt, back off and retry the same frozen occurrence within limits.
Completion response is lost	Query or repeat the same completion identity; return the saved result.
Database loses safe authority	Delay new claims and accepted results until authority recovers.

Classify permanent errors, such as an invalid report query, separately from transient failures. Limit attempts and total retry age, retain the reason and expose exhausted runs for review. A poisoned job must not consume the fleet indefinitely.

Apply outage catch-up policy in bounded pages. A latest-only schedule records skipped older work and creates the appropriate current occurrence; it does not rewrite all due timestamps to now and hide the missed history. A deliberate backfill uses a new action ID because it requests an additional run.

Preserve schedule guards, request keys, attempt tokens and outgoing work in backup/restore. Restoring only recurring rules can recreate already executed occurrences. Reconcile uncertain external actions before blindly resuming them after a disaster outside the promised durability boundary.

12 / Measure deadline behavior and state the next limits

Monitor due-to-start delay by tenant and resource class, runtime tails, active slots, oldest accepted due time, lease expiry, stale-completion rejection, skipped occurrences and permanent failure rates. Queue length alone cannot estimate delay without knowing execution durations and resource needs.

Test two scanners reading the same due instant, a worker pausing past its lease, completion racing cancellation and no-overlap across two different occurrences. Simulate a two-day outage and verify the chosen catch-up policy. Shadow-test recurrence parser changes across time zones and daylight-saving transitions before enabling them for existing rules.

Approved job types still need resource limits, restricted secrets and tenant isolation. Allowing arbitrary user code would make sandboxing, network policy and metering central requirements, not a small follow-up flag. Large report objects similarly need verified immutable publication and retention; the bounded database result keeps the first design's guarantee concrete.

The remaining single-schedule limit is intentional: a no-overlap job cannot gain logical parallelism merely by adding workers. Split its business work only if independent partitions and a merge step are valid. Dependencies, human approvals and month-long execution are signals to introduce a durable workflow model rather than stretching a cron rule into one.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1; NFR3: intended calendar work	Versioned rules, resolved instants, unique occurrences and a schedule-level active-run guard.	Test daylight-saving boundaries, concurrent scanners, edits and two missed days. Verify the selected no-overlap/latest-only policy rather than silently inventing extra runs.
FR2-3; NFR1-2: timely execution	Due indexes, separate resource pools, admission and prewarmed workers.	Simulate the 09:00 burst and measure the fraction started within ten seconds. Ten thousand slots miss the target; a queue cannot supply missing compute.
FR3-4; NFR3-4: recover one accepted result	Atomic materialization and current-token completion; durable dispatch and safe database failover.	Pause A past its lease, let B complete and resume A. Reject A's result; fail one zone and recover the same occurrence and accepted outcome.
FR4; NFR5: protected follow-up effects	Only committed result/outbox identities reach the notification adapter; external recovery follows its provider contract.	Lose the send response and race cancellation with completion. Preserve uncertainty where the destination cannot deduplicate; do not claim physical exactly-once execution.

14 / Rapid revision

Remember: An expired lease does not stop a paused worker from resuming. The result store must reject its old token.

Concern	Complete mechanism
Schedule	Save a versioned recurrence rule and time zone; decide how to handle overlapping and missed runs.
Occurrence	Record each intended run once, with its scheduled time and fixed inputs.
Materialization	In one transaction, save the run and dispatch task and advance the next due time.
Attempt	Give each worker claim a deadline and newer ownership token; retries keep the same intended run.
Completion	Check the current token and save the result and run state in one transaction.

Concern	Complete mechanism
No overlap	Allow only one active run per schedule; this is separate from rejecting duplicate attempts of that run.
External actions	Send only actions whose IDs are committed; recover uncertain results using the destination's retry or lookup rules.
Capacity	Calculate how queued jobs fit into worker slots before their start deadlines; a queue adds no execution slots.
Recovery	Recover saved due times and runs; limit catch-up according to the chosen missed-run policy.

Close with Tuesday R7 running twice but accepting only B's result after A pauses. Name the remaining external-effect boundary and the 09:00 capacity calculation. Those demonstrate a defensible scheduler without promising that every arbitrary task executes physically once.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

How do schedule, occurrence and attempt differ?

Model answer

The schedule is the rule, an occurrence is one intended resolved run, and attempts retry that same run. This keeps history and business identity stable.

Interviewer follow-up

Can a retry use current edited parameters?

No. An already created occurrence retains its frozen revision.

What the answer must demonstrate: Preserve one intended occurrence and its frozen parameters across attempts.

02 / APPLIED

Two scanners see Tuesday due. What prevents two runs?

Model answer

Both use the unique schedule/instant identity and transactionally create the occurrence, dispatch work and advance next due time.

Interviewer follow-up

Why not dispatch before committing?

A crash can leave the instant due after work has already been sent, recreating it.

What the answer must demonstrate: Atomically materialize the due instant, dispatch intent and next schedule time.

03 / APPLIED

Why can an expired worker still be dangerous?

Model answer

Expiry changes permission but does not stop the process. A paused worker may resume and try to publish after replacement.

Interviewer follow-up

Where must fencing be checked?

At the protected result write, atomically with acceptance of the result.

What the answer must demonstrate: Enforce the current token at completion because expiry does not stop a process.

04 / APPLIED

Does unique Tuesday occurrence identity prevent Wednesday overlapping?

Model answer

No. Those are distinct valid occurrences. A schedule-level active-run guard enforces the chosen no-overlap policy across them.

Interviewer follow-up

Does that prove no old process is running?

No. Stale physical execution still needs fenced results and protected effects.

What the answer must demonstrate: Use a separate schedule guard for distinct occurrences and retain physical-execution limits.

05 / APPLIED

Can a unique run row guarantee one email?

Model answer

No. The email provider performs an external effect. Use a committed stable action identity and the provider's supported idempotency or reconciliation.

Interviewer follow-up

Why prevent workers emailing private outputs?

Only the canonical accepted result should create the delivery intent, so stale attempts cannot publish alternate content.

What the answer must demonstrate: Protect external actions independently from local occurrence and result uniqueness.

06 / FOUNDATION

Why do 50,000 five-second jobs exceed a ten-second start target with 10,000 slots?

Model answer

They start in five ideal waves at 0, 5, 10, 15 and 20 seconds. The last two waves start late before overhead is counted.

Interviewer follow-up

What are defensible options?

More prewarmed capacity, agreed jitter, priority reservation or rejecting an impossible promise.

What the answer must demonstrate: Compute execution waves and distinguish start-time targets from completion.

07 / FOLLOW-UP

What must a calendar schedule say about daylight-saving changes?

Model answer

How nonexistent and repeated local times are handled, using a named zone and resolved execution instant.

Interviewer follow-up

How is fixed delay different?

Its next time depends on prior completion, unlike an anchored fixed-rate rule.

What the answer must demonstrate: State time-zone, daylight-saving and recurrence-mode behavior explicitly.

08 / FOLLOW-UP

What does cancellation mean for a running job?

Model answer

It requests cooperative stopping and prevents later accepted completion/retries once cancellation becomes terminal. External effects already started may still complete.

Interviewer follow-up

What if completion already committed?

Return the committed outcome rather than pretend cancellation erased it.

What the answer must demonstrate: Serialize terminal cancellation with completion and disclose already-started external effects.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a weekday report scheduler, then pause worker A beyond its lease, finish worker B and let A resume.

• Agree numbered functional and non-functional requirements, including start versus finish, overlap/catch-up policy and accepted-result guarantees. Then distinguish a recurring schedule, one intended occurrence and its execution attempts.

• Trace atomic due-run creation, worker claim and fenced completion.

• Explain calendar rules, missed-run policy and capacity limits before promising start deadlines.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

A pauses with token 41; B completes R7 with token 42. What happens when A resumes?

R7 and its frozen parameters stay the same, but the database rejects A's old token. B's saved result remains the accepted result.

One intended run may execute twice; only the current attempt can save its result.

How is a late result from a replaced worker rejected?

The result store checks the ownership token atomically when saving completion and rejects an old token.

The result store checks the token when accepting completion.

Does a ready queue let more jobs execute at once?

No. It buffers and schedules jobs; workers still need enough execution capacity.

Queue is not compute.

Summary and interview notes

Save each intended run, retry failed attempts, and accept results only from the current worker. Define when jobs start, whether runs may overlap, and how external actions recover after uncertain outcomes.

Remember these points

- Give each intended run a durable identity.
- Create due work and advance recurrence atomically.
- Check the current token when saving results; an expired worker may still be running.
- State calendar, overlap, catch-up and capacity policies explicitly.

Interview tips

- Separate schedule, intended run and execution attempt.
- Pause A with token 41, let B finish with 42, then resume A and inspect R7.

Important qualifications

- Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Large-object result publication: Immutable object verification, references and cleanup add a separate lifetime protocol.

Full external-effect and worker failure analysis: Arbitrary destinations require their own enforcement and uncertain-outcome policies.

Advanced partitioning and timing accelerators: Due buckets and timer structures become useful after measured scan bottlenecks.

Workflow and untrusted-code extensions: Dependencies and arbitrary code change the state and security models substantially.

Technical references

Kubernetes CronJob documentation
Official discussion of time zones, concurrency policies, missed schedules, and job idempotency.
https://kubernetes.io/docs/concepts/workloads/controllers/cron-jobs/

Temporal workflow execution overview
Concrete durable-execution model that separates persisted workflow progress from worker processes.
https://docs.temporal.io/workflow-execution

Transactional outbox pattern
Supports recoverable database-to-queue dispatch.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/transactional-outbox.html

EXTENDED INTERVIEWS / 48

Design a distributed message log

Interview version / 45-minute scope · Read the advanced version online

Design a retained partitioned event log with durable producer acceptance, independent consumer groups and replay-safe database effects, while keeping broker and application guarantees separate.

append log • partitions • consumer groups • idempotency

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain partitions, retained offsets and independent consumer progress using one order event.
- Trace safe producer retries and the consumer effect-before-offset boundary.
- Size retention, partition skew and catch-up without promising global order or arbitrary exactly-once effects.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Replication and durability; Quorums, consensus, leases, and fencing; Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / Choose a retained log rather than an unspecified queue

The order service emits event M17 when order O51 becomes paid. Search, fraud analysis and analytics must process it independently, including after downtime. Choose a retained event log: records remain for a defined period while each consumer group maintains its own position. A worker finishing a record does not delete it for other groups.

This differs from a task queue where workers compete for individual jobs with visibility deadlines and per-message acknowledgments. Both are useful, but combining their terms without a contract makes ordering, replay and failure behavior unclear. This design offers topics, partitions, producer append, group fetch, progress commits and seven-day replay.

Require order for related events routed by an ordering key, such as customer42. Unrelated customers need no global order. The broker's acceptance means the record was saved under the configured durability policy; it does not mean search applied the order update or a downstream email was sent.

Use at-least-once consumer processing: a failure may cause a record to be read again. Consumers must make their relevant effects safe to repeat. The order service also needs its own outbox or equivalent reliable publication so a committed order change cannot disappear before an event ever reaches this broker.

First ask whether consumers need independent replay of an event history or competing ownership of individual tasks. Confirm the ordering key, retention period and acknowledgment failure model. Choose a seven-day retained log with independent groups and per-key order here; consumer side effects remain a separate contract.

02 / Functional requirements

1. **Publish records.** Accept bounded producer batches into topics/partitions and return committed record positions under a documented retry identity.
2. **Consume independently.** Let each consumer group fetch records and durably record its next required offset without deleting data for other groups.
3. **Replay history.** Allow authorized groups to resume or reset within seven days of retained full history and report an explicit gap when history has expired.
4. **Manage consumers and access.** Assign partition ownership within groups, recover progress after reassignment and enforce topic/group permissions and administrative replay controls.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload.** Plan for 100,000 one-kilobyte messages/s, or 100 MB/s ingest. Each full-rate consumer group adds roughly 100 MB/s of reads; the example's search, fraud and analytics groups must be budgeted separately.
2. **Broker response time.** Target durable append acknowledgment within 50 ms p95 and bounded fetch responses within 100 ms p95 for already available records under admitted same-region load. Include broker queuing and batch wait; empty long polls and downstream processing have separate timing contracts.
3. **Ordering and processing.** Preserve committed order within a stable key-to-partition route. Provide at-least-once consumer processing; producer retry suppression and consumer effect deduplication protect different boundaries, with no global order or arbitrary exactly-once external-effect promise.
4. **Durability and availability.** Place three replicas across three zones and acknowledge only a durably committed majority. Preserve accepted history after one replica or zone failure; stop unsafe appends without a majority and treat regional loss separately.
5. **Retention and bounded resources.** Keep full history for seven days, even if a consumer falls behind. Reserve storage/repair capacity, reject excess new work before risking accepted history, and authorize append, fetch and offset resets.

04 / Append a file and remember separate bookmarks

Start with one broker, one append-only log file and durable consumer bookmarks. A producer submits a bounded batch. The broker validates it, appends records, flushes according to its local acknowledgment policy and returns their offsets. An offset is a position in that partition's history, not a global event identifier.

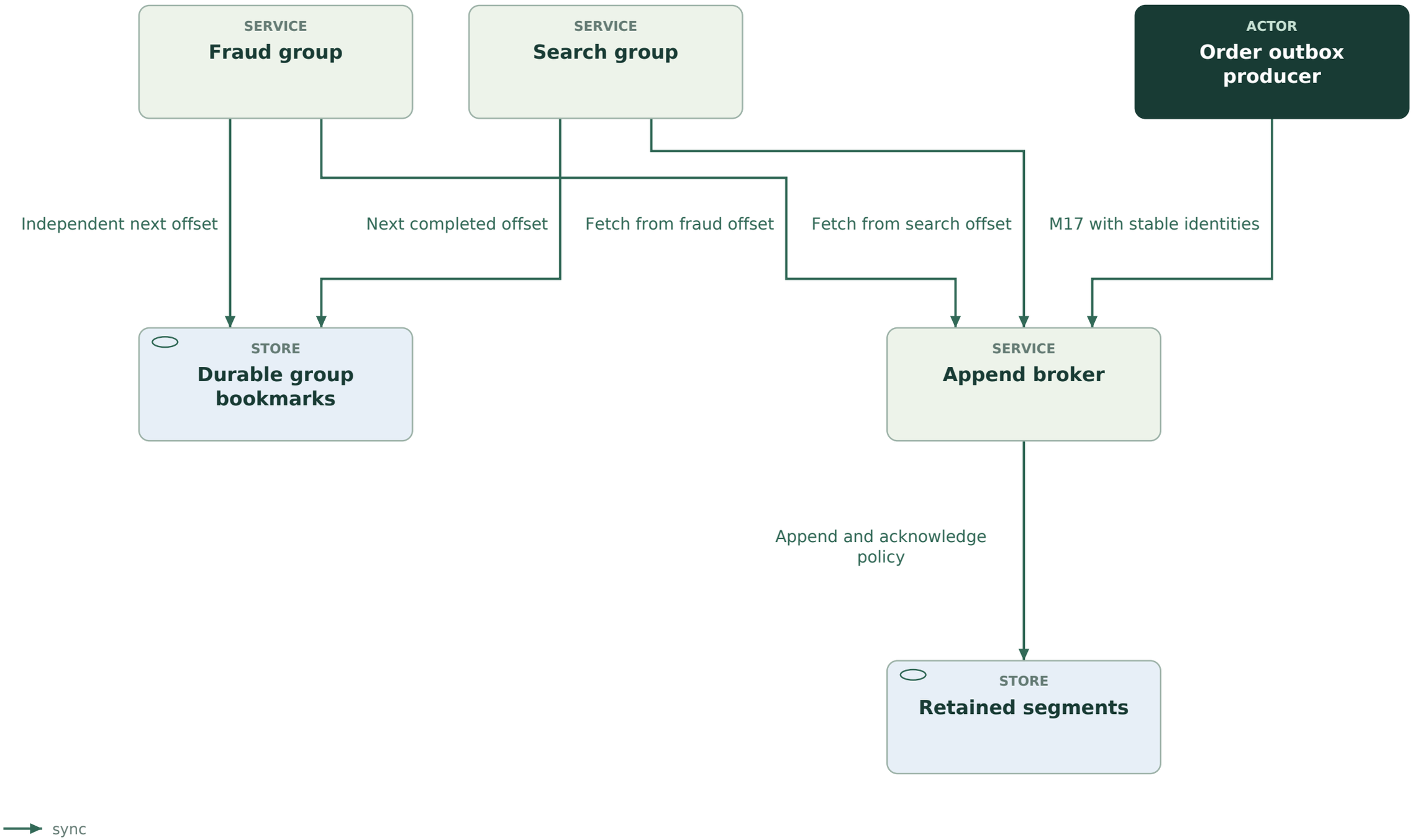
The search group fetches M17 at offset 117. After processing it, search saves nextOffset 118. Fraud can remain at offset 90 and analytics at 120 without changing search's progress. Restarting search uses its saved bookmark to resume. Retention, not one consumer's acknowledgment, eventually removes old records.

Split the file into segments so expired old history can be removed without rewriting the active tail. A sparse offset index locates nearby bytes, and checksums detect damaged records. Batch appends and fetches to reduce network and storage overhead, with bounded waiting so a quiet stream does not wait forever for a full batch.

This baseline explains the entire producer/read/replay interface. Its acknowledged records survive a process restart if local recovery succeeds, but not permanent loss of its only disk. That explicit limit motivates replication; distributing readers alone would not protect the stored history.

One retained log, independent bookmarks

Finishing in one group leaves the event available to the others until retention removes it.



05 / Price retained history and independent readers

Assume 100,000 messages/s at one decimal kilobyte each: 100 MB/s of raw ingest. One day holds 8.64 TB and seven days 60.48 TB. Three copies require 181.44 TB before indexes, compression, spare space and repair traffic. Retention is a substantial storage commitment, not a free property of using a log.

Three copies write about 300 MB/s of payload across replicas; followers add roughly 200 MB/s of replication traffic beyond the producer stream. Each full-rate consumer group reads another 100 MB/s. With several groups, delivery bandwidth can dominate client-facing traffic even when sequential append is efficient.

A consumer stopped for ten minutes accumulates 60 million messages. At 150,000 processed messages/s while 100,000/s new messages continue, net catch-up is 50,000/s and recovery takes twenty minutes. At exactly the arrival rate, it never catches up. Track lag age and bytes as well as record count.

If a tested partition handles 5 MB/s safely, ingest alone suggests at least twenty partitions before skew and headroom. More partitions can enable more consumers, but one key generating 20 MB/s cannot be divided among them while retaining its original strict order. Benchmark the actual payload and destination processing before choosing partition counts.

06 / Separate append identity from processing progress

Broker operations

Append a record

```
append(
  topic,
  key,
  producer,
  sequence,
  event
)
```

Proposes a record under the producer retry contract.

Fetch a bounded portion of committed history

```
fetch(
  partition,
  fromOffset,
  maxBytes
)
```

Reads a bounded committed portion of retained history.

Returned position and stored records

Record	Fields	Meaning
Append result	`partition`, `offset`	Identifies the committed record position.
Group bookmark	`group`, `partition`, `nextOffset`, `generation`	The next position that group still needs to process.
Application event	`eventId`, `aggregateId`, `version`, `payload`	Stable business meaning that survives a new producer session.
Partition metadata	Current leader, replicas and routing ownership	Identifies the current partition owner and copies.

Worked consumer progress after M17 is processed

```
group:      search
record:    M17
offset:    117
nextOffset: 118
```

Producer identity and sequence distinguish an uncertain retry from a new append within the supported lifecycle. A lost reply should be retried with the same identity; assigning a new sequence can append a second record. The retry state must survive supported failover, not live only in one leader's memory.

M17 also keeps an application event ID because an outbox may resend it from a restarted producer. Broker retry suppression cannot automatically recognize the same business event under a new producer identity.

Include payload schema versions for consumers replaying older data. Authenticate topic append/fetch permissions and group access. Administrative offset reset is a separate privileged operation; an ordinary consumer must not conceal unfinished work by jumping to an arbitrary future position.

07 / Replicate a committed partition history

For this design, place three replicas of each partition across three zones and use a proven consensus log. One current leader orders appends. Return an accepted offset only after a majority has durably recorded the committed append; safe election must preserve that committed history. This tolerates loss of one replica or zone. Without a majority, stop appends. An isolated previous leader must not acknowledge a separate history. Regional loss needs a separate recovery plan.

Check that the selected storage and deployment configuration actually supports this durability promise. Replica count alone does not identify when data reached durable storage or which replica can become leader. For example, a broker setting that waits for replica acknowledgment is not automatically a guarantee that every replica synchronously flushed each record to persistent media.

Readers consume only the protocol's committed visible records. Transactional broker features can add a further distinction between replicated data and records belonging to completed rather than aborted transactions. Explain the chosen product's supported visibility rule instead of treating every local tail offset as readable success.

Partition leaders and controller metadata have different jobs: the controller identifies placement, while the partition replicas hold event bytes. Replicate the control state too, but do not mistake a healthy directory for retained user data. During insufficient safe replica participation, reject or delay appends rather than issue an accepted offset that may disappear after failover.

08 / Commit a business effect before advancing its bookmark

Search reads M17 and must update order O51. If it commits nextOffset 118 first, then crashes before changing search state, its replacement skips M17 forever. Reversing the order avoids that loss but introduces repetition: update O51, crash before offset commit, then read M17 again.

Make repetition safe at the destination:

1. In one search-database transaction, insert the unique processed event identity and update O51. If M17 is already recorded with the same payload, return the existing processing result.
2. Commit that transaction.
3. Only then advance the broker bookmark.

A crash between those commits causes harmless replay rather than a missing or repeated business change.

For this example, M17 carries complete order state at version 3. A version guard prevents delayed version 2 from replacing newer state. That guard is not a substitute for all event semantics: an unapplied additive delta cannot simply be discarded because a later numbered delta arrived first. Delta consumers need contiguous sequence handling or a rebuild from complete state.

The broker and search database do not share a transaction here. Stable event identity makes the gap safe. Kafka-style transactional processing can cover cooperating broker/state/output boundaries, but an arbitrary external database or provider still needs an appropriate integration contract.



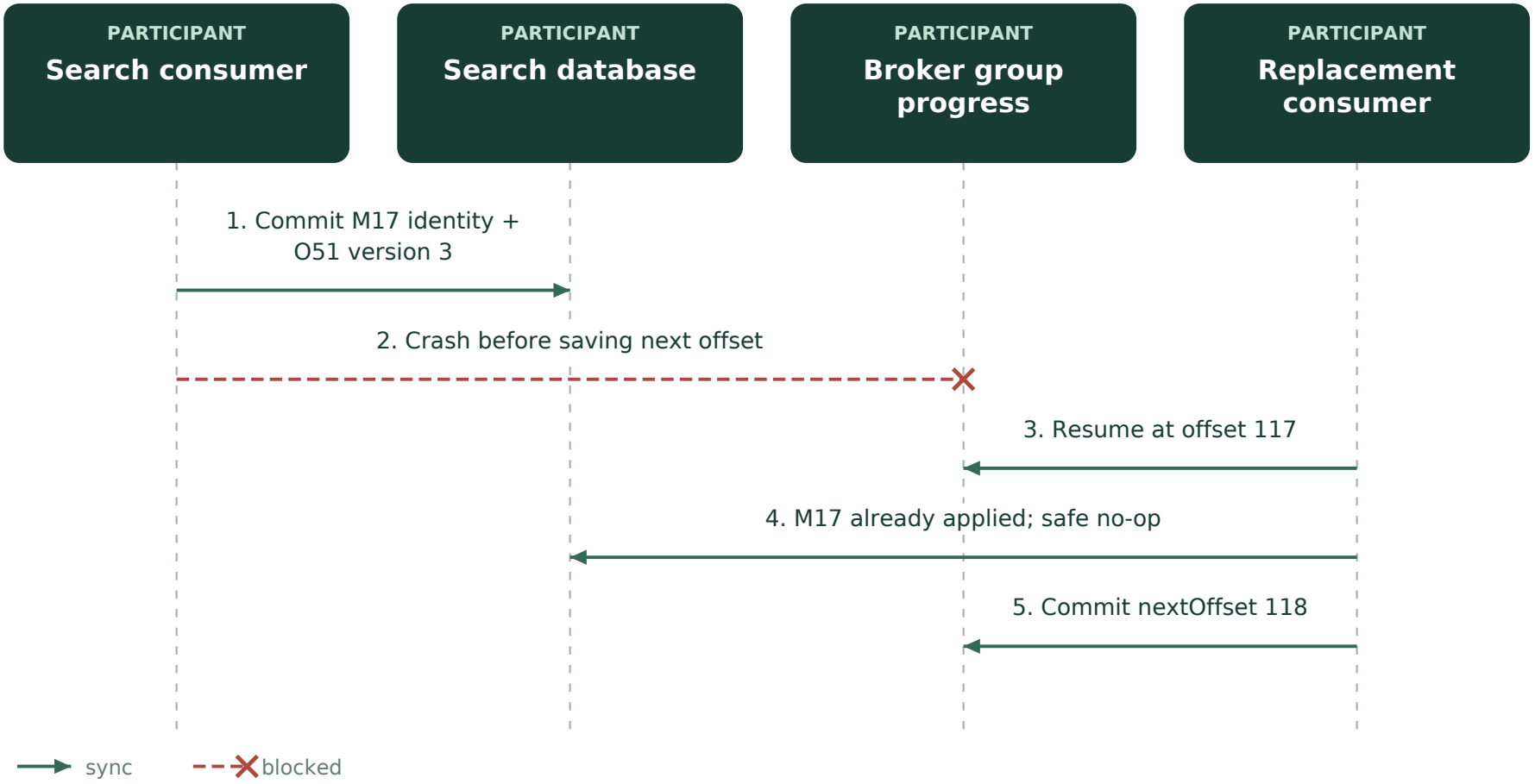
INTERVIEW CRITICAL

An offset is not an external transaction

Advance the consumer bookmark only after the effect is durably complete or safely repeatable. Broker exactly-once features do not automatically make a charge, email or unrelated database write happen once.

Replay after the database commits

A processed-event record and search update share one transaction; the broker bookmark follows.



09 / Partition keys and coordinate group ownership

Route each ordering key to a stable partition and spread partition leaders across brokers. Independent partitions add aggregate throughput and consumer parallelism. Within one consumer group, assign each partition to one current owner; different groups read the same partition independently. More group members than partitions do not create additional ownership slots for that group.

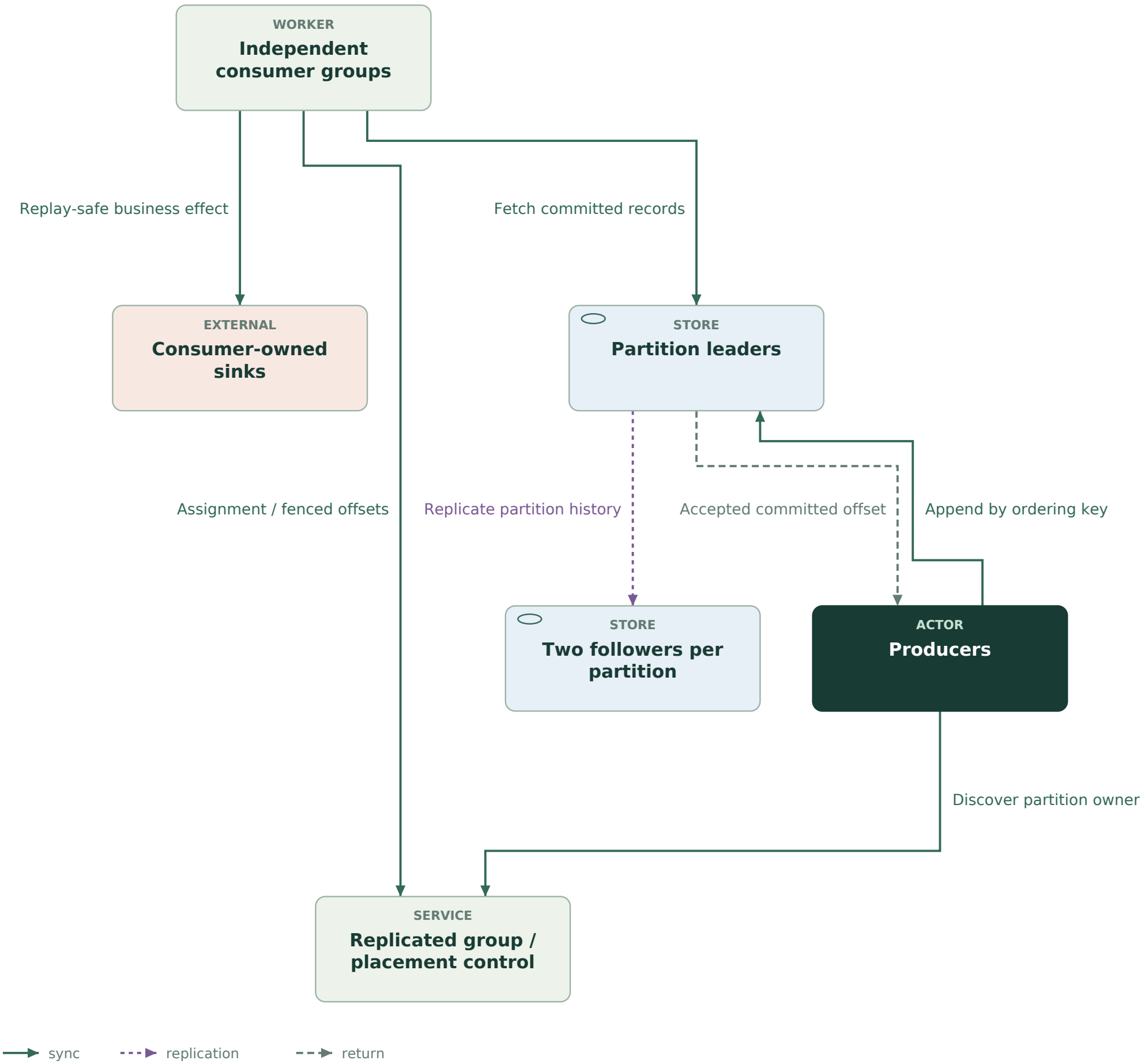
A coordinator increments the assignment generation during reassignment. Offset commits carry that generation so a paused old consumer cannot overwrite current progress after takeover. The old process may still write to an external database or service, so that destination must also deduplicate events or check versions.

Process a partition sequentially in the simplest consumer. If later parallelizing independent keys, commit only a fully completed prefix. Finishing offset 119 while 118 is still running does not permit nextOffset 120; a crash would skip 118. Track completion gaps explicitly or retain sequential processing where throughput allows.

Changing partition count can change a key's route. New customer42 events on a different partition might overtake older retained ones. Preserve existing routes or stop new events on the old route, finish processing its earlier events, then switch routes. Adding partitions is therefore an ordering decision as well as a capacity change, not an invisible modulo adjustment.

Replicated partition logs and independent consumer progress

Producers discover the current partition leader and append using a stable ordering key. The leader acknowledges only after the chosen durable-majority commit. Consumer groups read committed history independently, apply sink effects safely and commit generation-checked progress through the coordinator; the control plane does not contain the event bytes.



10 / Make replay and poison-event policies visible

Retain the chosen full event history for seven days. A group's slow progress does not automatically extend that horizon. Alert before its oldest required segment expires so operators can add net catch-up capacity or preserve an archive. Once the bookmark predates available history, return an explicit gap and choose a rebuild or restoration path. Silently starting at the newest offset would conceal data loss in the projection.

Compaction is a different policy: it can retain the latest value for a key while removing intermediate history. That may suit rebuilding current state but cannot provide the same full sequence of transitions. A deletion marker under compaction also has retention rules; it is not an immediate erasure of every historical copy.

A malformed or repeatedly failing event needs bounded retry and an explicit quarantine/skip policy. Skipping it may violate later ordering for that key. Pause the key or partition when necessary rather than calling every dead-letter action harmless. Keep event identity, reason and replay controls so repair does not manufacture new unrelated business events.

At larger retention sizes, remote immutable segments can reduce local disk cost but add historical-read latency and object lifecycle dependencies. The first design can remain on local replicated storage when the replay window and measured capacity permit it.

11 / Trace the two independent timeout boundaries

Failure	Recovery
Append commits, producer reply disappears	Retry the same supported producer identity/sequence and recover its position.
Consumer effect commits, bookmark reply disappears	Replay M17; the sink's processed-event transaction returns its existing outcome.
Consumer owner changes	New owner starts at durable group progress; stale generation commits are rejected.
Partition leader fails	Elect a valid successor under the chosen replication protocol and refresh client metadata.
Disk reserve runs low	Backpressure or reject before accepting more data than the retention promise can preserve.

These are separate guarantees. Producer retry suppression limits duplicate appends; consumer sink deduplication limits duplicate effects. Neither removes the other boundary. An email or payment consumer needs a stable external action identity or reconciliation after uncertain responses, because a local processed-event row cannot force a remote provider to behave transactionally.

Bound producer buffers, fetch sizes and in-flight batches. Retry with backoff and jitter rather than sending unlimited uncertain appends to every replica. Repair and consumer catch-up compete with normal traffic, so reserve throughput and storage space for them. Keep accepted retained records readable during overload instead of deleting promised history merely to improve new-write availability.

INTERVIEW CRITICAL

Commit only the completed prefix

A group bookmark means every earlier record in that partition is finished under the consumer contract. Parallel completion of a later record cannot justify skipping an unfinished earlier offset after restart.

12 / Measure lag against the remaining replay window

Measure admitted durable appends against 50 ms p95 and available-record fetches against 100 ms p95, including broker queuing and batch wait. Separately monitor empty long polls, committed-to-consumed event age, replica lag, unavailable partitions, disk reserve, group churn and time until an old required segment expires. A global average can hide one hot key whose downstream view is hours behind.

Test leader loss before and after commitment, uncertain producer replies, consumer failure after sink commit, stale group commits and retention gaps. Replay old schema versions during consumer upgrades. A partition-count migration should test per-key event order across the old and new routes, not only whether an administrative call succeeded.

Use topic and group permissions, encrypted transport and per-tenant append/fetch limits. Bound both compressed and decompressed sizes so a small compressed batch cannot exhaust broker memory. Administrative replay and reset operations need audit records because they can deliberately repeat or skip business work.

The main tradeoff is retained replay at substantial storage cost. Compression may help, but measure it for the actual payload; encrypted or already compressed records may shrink little. One strictly ordered hot key and external non-idempotent effects remain real limits. If the requirement instead becomes millions of unrelated long jobs with individual retries, choose a task-queue contract rather than forcing them into a retained-log bookmark model.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1; NFR2-4: committed append	Stable producer identity/sequence, ordered consensus log and durable-majority acknowledgment.	Lose the append response and then a zone. Recover the same accepted record; load-test 50 ms p95 with replication and batching enabled.
FR2,4; NFR3: independent safe progress	Per-group bookmarks, current assignment generations and effect-before-offset processing.	Crash search after its sink commit and reassign the partition. Replay safely and ensure another group's progress does not change.

Requirement	Design mechanism	Verification and remaining limit
FR2-3; NFR1-2,5: readable retained history	Partitioned segment storage, bounded fetches and independent group bandwidth budgets.	Load-test three full-rate groups and 100 ms p95 fetches for available records; test seven-day replay and an explicit expired-offset gap.
NFR3-5: honest limits during overload	Stable key routes, quotas, storage reserve and net catch-up headroom.	Inject one hot key, majority loss and a ten-minute consumer outage. Refuse unsafe appends and calculate catch-up; adding partitions cannot split one key's required order.

14 / Rapid revision

Remember: Save the consumer effect before advancing its offset, and save the event ID with that effect so replay is harmless.

Concern	Complete mechanism
Product	Retain events so independent groups can read them; one worker's completion does not delete them.
Ordering	Commit events in order within each partition; keep related keys routed to the same partition.
Producer retry	Reuse producer identity/sequence within its supported lifetime; retain the business event ID if a restarted producer resends it.
Durability	Acknowledge only at the chosen durable commit point; elect leaders that preserve those writes after supported failures.
Consumer effect	Save the processed event ID and database update in one transaction, then advance the group's position.
Parallel work	Advance only through consecutive completed events; stop at the first unfinished event.
Reassignment	The broker rejects former owners' progress updates; the destination must separately reject stale writes.
Retention	Set the replay deadline and how older readers recover; compaction keeps latest keyed state rather than every event.
Capacity	Budget replicated copies and consumer reads; catching up requires capacity beyond new arrivals.

Close by losing M17's producer reply and then crashing search after its database commit. Explain which system recognizes each retry: the broker for appends, the destination database for applied effects. This is

more precise than promising "exactly once delivery" without naming which storage or external effect the claim covers.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why choose a retained log for search, fraud and analytics?

Model answer

Each service needs an independent position and replay history. One consumer finishing does not remove the record for the others.

Interviewer follow-up

When is a task queue more suitable?

Independent jobs needing per-message leases and retries rather than shared retained history.

What the answer must demonstrate: Choose independent replay history or per-message task semantics before architecture.

02 / APPLIED

An append reply is lost. Why reuse the sequence?

Model answer

The append may already be committed. Supported retry identity lets the broker recover the same position instead of treating it as a new append.

Interviewer follow-up

Why retain an application event ID too?

A later resend of the same event may come from a restarted producer with a new broker identity.

What the answer must demonstrate: Reuse supported append identity and retain business identity across producer incarnations.

03 / APPLIED

What if search commits its update and then crashes before its offset?

Model answer

The replacement replays the event. A unique processed-event identity committed with the update makes that replay harmless.

Interviewer follow-up

Why not commit the offset first?

A crash before the effect would then skip it permanently.

What the answer must demonstrate: Commit sink deduplication and effect together before advancing broker progress.

04 / APPLIED

Offset 119 finishes before 118. Can the group commit 120?

Model answer

No. The bookmark must represent a completed prefix; otherwise recovery skips unfinished 118.

Interviewer follow-up

What is the simpler alternative?

Process the partition sequentially until throughput justifies explicit gap tracking.

What the answer must demonstrate: Advance only through the fully completed partition prefix.

05 / FOUNDATION

What does a consumer generation protect?

Model answer

It lets the coordinator reject progress commits from a superseded assignment.

Interviewer follow-up

Does it stop an old process writing a database?

Not by itself. The sink still needs idempotency, versions or another enforced ownership contract.

What the answer must demonstrate: Distinguish broker-generation fencing from external sink protection.

06 / FOLLOW-UP

Why can increasing partition count change ordering?

Model answer

A key may move while older records remain on its previous partition, allowing new events to overtake old ones.

Interviewer follow-up

How can it be handled?

Preserve stable routes or coordinate a transition that respects the old ordering boundary.

What the answer must demonstrate: Preserve per-key ordering across a route or partition-count change.

07 / FOLLOW-UP

A consumer is eight days behind a seven-day log. What should happen?

Model answer

Return an explicit retention gap and use an agreed archive or projection rebuild path. Do not silently skip to the newest event.

Interviewer follow-up

Does compaction preserve every transition instead?

No. It can preserve latest state while removing intermediate history.

What the answer must demonstrate: Expose retention gaps and distinguish time history from latest-key compaction.

08 / APPLIED

Does broker transactional processing make an arbitrary payment exactly once?

Model answer

No. Its guarantee covers only the storage and outputs that participate in its documented transaction protocol; a payment provider needs its own stable identity and uncertain-outcome recovery.

Interviewer follow-up

Does an outbox remove all uncertainty?

It preserves the intent, but a remote effect can still happen before its reply is recorded.

What the answer must demonstrate: Limit exactly-once claims to cooperating storage/effect domains.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a retained order-event log, then lose an append acknowledgment and crash a consumer after updating its database but before committing its offset.

• Agree numbered functional and non-functional requirements, including retained-log semantics, ordering, broker latency and replay durability. Then explain partitions, retained offsets and independent consumer progress using one order event.

• Trace safe producer retries and the consumer effect-before-offset boundary.

• Size retention, partition skew and catch-up without promising global order or arbitrary exactly-once effects.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Search saved M17 at offset 117, then crashed before saving nextOffset 118. What happens on restart?

The group bookmark causes M17 to be read again. The processed-event record saved with the database update prevents applying it twice. An offset identifies position, not completed external work.

Save the effect before progress; make replay harmless with a saved event ID.

What prevents a replayed event from updating the database twice?

Save the processed event ID and its database change in one transaction; skip an ID already recorded.

Effect and dedupe together.

Can extra partitions split the work for one strictly ordered key?

No. Keeping that key's order requires one sequence; extra partitions spread other keys.

More partitions spread different keys; one strictly ordered key still has one sequence.

Summary and interview notes

Keep events in a replicated partitioned log so independent consumer groups can read and replay them. Save each consumer's database update safely before advancing its position; broker acceptance alone does not complete that update.

Remember these points

- Keep broker acceptance separate from consumer effects.
- Reuse producer identity for uncertain appends and event identity for repeated consumer processing.
- Keep each key ordered and advance group progress only past records whose processing finished.
- Budget retained copies and net catch-up capacity.

Interview tips

- Separate producer acceptance, consumer progress and destination effects.
- Lose M17's append reply, then crash search after saving O51 but before its bookmark.

Important qualifications

- Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Detailed replica and Kafka configuration boundaries: Exact acknowledgment, storage and transaction visibility depend on the selected implementation.

Consumer takeover effect proof: Study sink uniqueness, full-state versions and additive-delta differences in depth.

Routing expansion and tiered segments: Large deployments need deliberate key-route migration and historical-segment lifetime rules.

Retention and failure drills: Explore poison events, stale workers and resource exhaustion beyond the main example.

Technical references

Apache Kafka design
Primary discussion of partitioned logs, replication, consumer progress, and delivery semantics.
https://kafka.apache.org/43/design/design/

Kafka 4.3 producer API documentation
Verified 4.3.1 Javadoc: producer retries, idempotence and Kafka transaction boundaries; not an external-effect guarantee.
https://kafka.apache.org/43/javadoc/org/apache/kafka/clients/producer/KafkaProducer.html

Kafka 4.3 KRaft operations
Official current metadata-controller deployment model; distinct from data-partition replication.
https://kafka.apache.org/43/operations/kraft/

Kafka 4.3.1 release announcement
Verified June 25, 2026 release; used to establish that the 4.3 API example is released, not merely a draft documentation selector.
https://kafka.apache.org/blog/2026/06/25/apache-kafka-4.3.1-release-announcement/

EXTENDED INTERVIEWS / 49

Design ecommerce checkout and inventory reservation

Interview version / 45-minute scope · Read the advanced version online

Complete a physical-goods checkout with atomic inventory holds, durable payment progress and a guarded fulfillment decision, then explain when independent warehouses require a saga.

inventory • reservation saga • checkout • warehouse allocation

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Use explicit stock quantities to prove reservations cannot oversell.
- Trace quote acceptance, holds, payment, allocation and shipping through durable states.
- Handle expiry, retries and uncertain payment without releasing or selling the same units twice.

Useful foundations: Databases, data models, and ACID transactions; Message queues, event logs, delivery guarantees, and backpressure; Data partitioning and sharding; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / Choose a checkout that can be completed coherently

Design physical-goods checkout with several cart lines and no backorders. Initially, keep inventory where all requested lines can commit in one database transaction. Customers browse, accept a server-calculated quote, reserve all requested lines, authorize payment and receive an order outcome. Shipping follows confirmed capture. Exclude marketplace settlement and atomic checkout across independently owned warehouse databases from the baseline.

Cart C7 requests two mugs M9 and one notebook N2. There are three sellable mugs. Another customer also wants two. Only one of those mug reservations can succeed before replenishment. A cart is shopping intent, not a reservation; a product page may still display stale availability when the definitive checkout decision rejects a request.

Stock equation

```
available = onHand - reserved - allocated
```

Quantity	Meaning
`onHand`	Sellable physical inventory.
`reserved`	Units held by incomplete checkouts.

Quantity	Meaning
`allocated`	Units assigned to confirmed but unshipped orders.

Every quantity must remain nonnegative. This equation exposes mistakes that a vague stock-service box can hide.

Assume a ten-minute initial hold, checkout admission below 300 ms p95 and 95% of admitted checkouts reaching confirmed allocation within three seconds when payment authorization and inventory dependencies are healthy. A payment timeout may keep the order pending longer. Choose clear stock and money outcomes over pretending every timeout is a definitive failure.

Ask whether all cart lines share one inventory authority, whether backorders are allowed, and whether confirmation means authorized, captured or ready to ship. This answer uses no backorders and one inventory transaction domain: confirmation follows allocation, while dispatch waits for known capture success.

02 / Functional requirements

1. **Accept a checkout.** Validate the authenticated customer's cart and server-calculated quote, then create or recover one pending order.
2. **Reserve the whole cart.** Hold every requested line together or reject the request without leaving partial reservations; expire unconverted holds under a defined deadline.
3. **Take payment and fulfill.** Authorize payment, convert valid holds to allocations, capture once and authorize shipment only after known capture success.
4. **Recover and cancel.** Expose authoritative order progress, retry unfinished effects and handle cancellation or compensation according to the current stock, payment and dispatch state.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Workload and local latency.** Plan for one million orders/day and a 1,000 orders/s peak with five lines each. Target durable checkout admission below 300 ms p95; measure hot-SKU contention separately from aggregate throughput.
2. **Hold and completion timing.** Choose a ten-minute initial hold. As an objective, aim for 95% of admitted checkouts to reach confirmed allocation within three seconds when payment authorization and inventory dependencies are healthy. Provider uncertainty remains pending and is reported separately, not treated as a guaranteed rejection or completion.
3. **Inventory and effect correctness.** Keep onHand, reserved and allocated nonnegative, with available = onHand - reserved - allocated. No overselling, partial all-line hold, duplicate capture or duplicate shipment is permitted through supported retries.

4. **Durability and safe availability.** Require acknowledged orders, stock transitions and effect identities to survive one database-node failure through synchronous durable replication and safe failover. Refuse new inventory decisions without safe authority; retain allocations while capture is unknown.
5. **Security and scope.** Authenticate ownership, validate positive quantities and frozen quote terms, and restrict stock/refund actions to trusted actors. Independent warehouse transactions and regional stock budgets require an explicitly changed contract.

04 / Trace one complete order before splitting services

Start with a checkout application, a relational database containing orders and inventory, a payment adapter and a durable background worker. The API validates cart version, quantities, quote and customer ownership. One transaction claims request key K4, locks all stock rows in stable order, checks the complete set, creates pending order O401 and its holds, and reserves the quantities. If any line lacks stock, the transaction rolls back all lines.

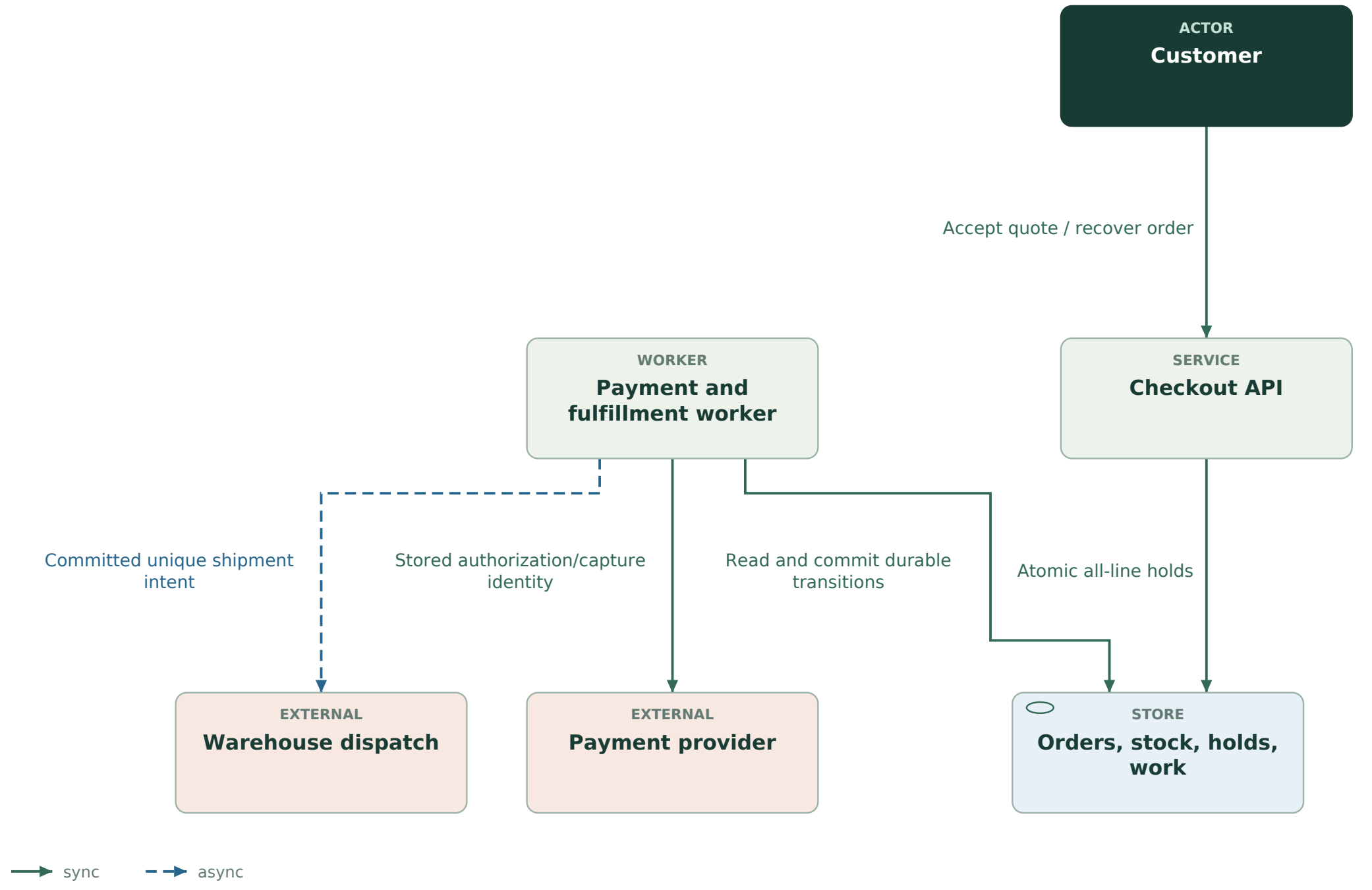
M9 changes from onHand 3, reserved 0, allocated 0 to 3, 2, 0. Available stock becomes one. The competing request for two mugs fails against current authority even if its browser still shows three.

The worker records a stable payment authorization operation before calling the provider outside database locks. After known authorization, a transaction verifies every hold is still valid, converts them to allocations and confirms the order. Capture is a separate stored payment operation. Only known successful capture permits the later fulfillment authorization.

If the application dies after any local commit, durable pending-work records allow another worker to continue the same order. The whole user flow works with one database; a queue or independent warehouse service is introduced only when a measured or organizational boundary justifies the additional coordination.

One transaction domain for multi-line checkout

Payment remains external, while orders, holds and inventory share atomic decisions.



05 / Size line transitions and hot-stock contention

Assume one million orders/day, about 11.6/s on average, with a 1,000 orders/s peak and five lines per order. The peak requires roughly 5,000 reservation-line operations/s. Successful checkout also converts holds to allocations, so that is about 10,000 line transitions/s before releases, shipment, replenishment and retries.

Ten million carts at 2 KB each occupy 20 GB logically. Ten million stock rows at 96 bytes each occupy about 960 MB before indexes and copies. Small raw stock storage does not imply easy concurrency: hundreds of requests may compete for the same three mugs while most rows remain idle.

A stock row held for an illustrative 20 ms per contending transaction has a simple serial ceiling near fifty transactions/s before other work. Holding that lock through a 500 ms payment call could reduce the ceiling to about two/s. This is why network calls must occur outside stock transactions.

At 1,000 admitted orders/s, ten-minute holds could produce 600,000 active workflows and three million line holds. The stock unavailable to other buyers while held matters more than the hold records' size. Bound per-customer holds and flash-sale admission. A shorter deadline releases stock sooner but rejects more slow legitimate checkouts; choose it using measurements of how long slower checkouts take.

06 / Freeze commercial terms and name each effect

Interfaces

Request or message	Contract
`POST /checkouts`	Creates or recovers one pending order with accepted terms.
`GET /orders/O401`	Returns inventory, payment and fulfillment progress to the authenticated owner.
`POST /orders/O401/cancel`	Requests a guarded transition, not an unconditional inventory increment.

Create or recover the worked checkout

```
POST /checkouts
```

Checkout request with accepted cart and quote versions

```
{
  "key": "K4",
  "cartId": "C7",
  "cartVersion": 3,
  "quoteId": "Q7",
  "quoteVersion": 2
}
```

The version numbers and quote ID instantiate the existing version checks: they must match the customer's accepted cart and quote. Authentication supplies the customer identity.

Stored records

Record	Fields or identity	Purpose
Quote	Quote ID and version	Server-calculated prices, tax, discounts, shipping, currency, version and validity deadline.
Hold	`order`, `line`, `quantity`, `state`, `deadline`	One temporary stock claim under a stable identity.
Order	Order ID	Frozen accepted lines, lifecycle and payment/fulfillment references.
Inventory	`SKU`, `pool`, `onHand`, `reserved`, `allocated`	Authoritative arithmetic for one stock pool.
Operation/outbox	Separate stable identity for each effect	Stable effect identity and recoverable work for payment, notification or shipment.

Reusing K4 with the same cart and quote returns O401. Different parameters under K4 conflict. Obtain customer identity from authentication, validate positive bounded quantities and never accept browser-supplied prices as authority. If a quote has changed or expired before acceptance, present new terms rather than silently charging another amount under the old key.

An order ID alone is not a sufficient key for every operation: authorization, capture, refund and shipping are different effects. Name and persist those identities separately so retries cannot merge unrelated actions or create another charge.

07 / Explain each stock movement with the same equation

Follow the same two mugs through each state:

Stage	onHand	reserved	allocated	available
Initial	3	0	0	3
Hold two mugs	3	2	0	1
Move the hold to allocation	3	0	2	1
Ship: consume physical stock and allocation together	1	0	0	1

Release is a guarded state transition, not "add quantity back." Releasing a held line subtracts its quantity from reserved once. Releasing an allocated line is permitted only through a valid pre-dispatch cancellation or compensation and subtracts from allocated once. Repeating either request returns the prior outcome rather than increasing available stock again.

Expiry and allocation lock the same hold and stock records in a consistent order. If allocation wins while the hold is valid, expiry later sees allocated and does nothing. If expiry wins, it marks the hold terminal and removes its reserved quantity; allocation then fails. Check the authoritative database clock after locks are acquired, not a stale timestamp taken before a long wait.

Replenishment and inspected returns also need stable source identities. Replaying a warehouse receipt must not add stock twice. Local constraints and periodic reconciliation compare counters with the underlying hold/allocation records to catch implementation defects.



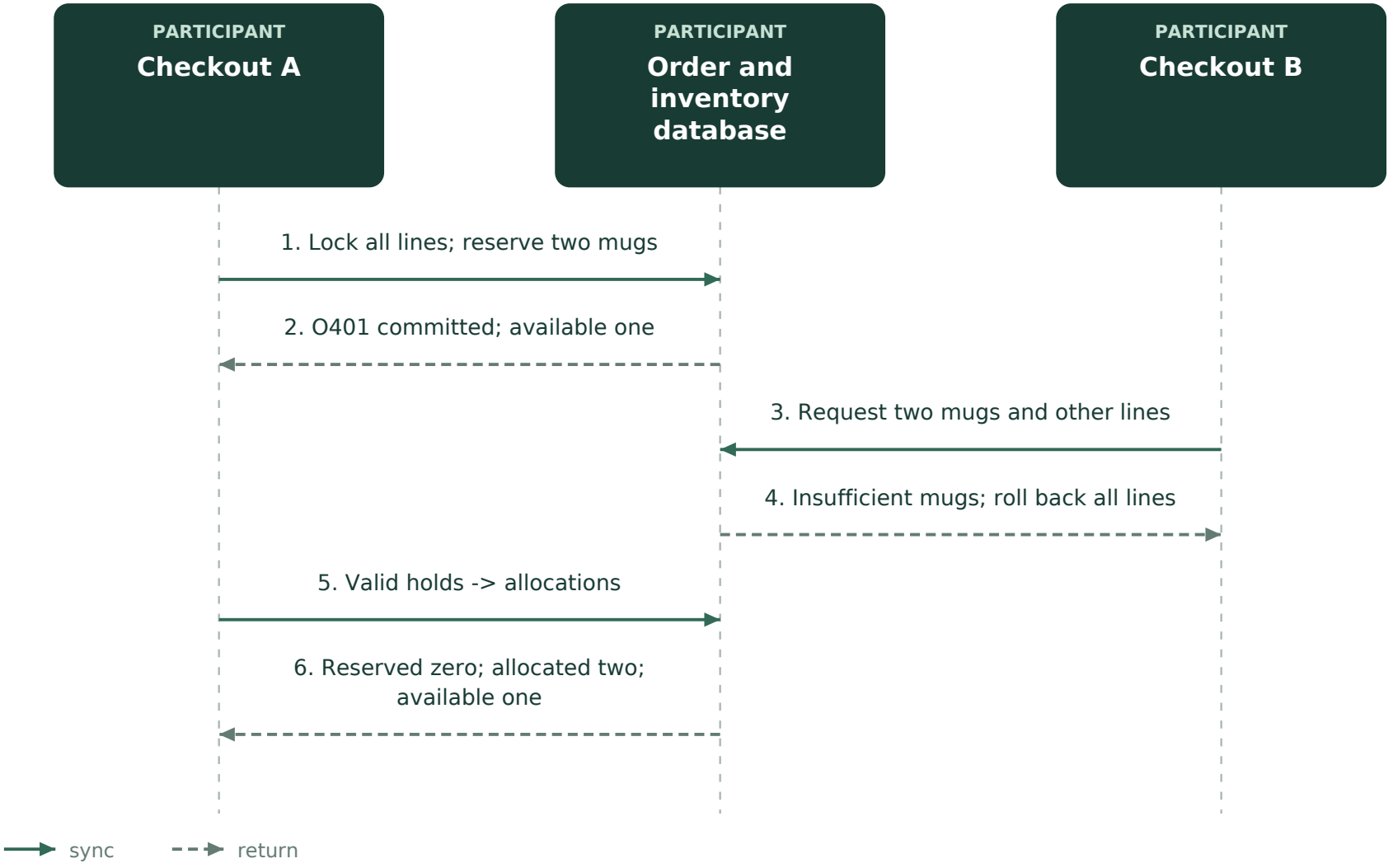
INTERVIEW CRITICAL

Every inventory transition must preserve the stock equation

Check and change the hold state and stock counters in one transaction. Retrying release, expiry, allocation or shipment must return the existing outcome instead of applying another arithmetic change.

Only one checkout reserves two of three mugs

Both requests use the same stock authority; the loser receives no partial all-line hold.



08 / Keep payment uncertainty from corrupting stock decisions

Before calling the provider, persist an authorization attempt with immutable order amount, currency and identity. The provider call runs outside database locks. A timeout leaves the attempt unknown. Query or retry the same operation under the provider's supported contract; a new request identity may authorize or charge again.

Once authorization is known, validate all holds and convert them to allocations in the database transaction before confirming the order. If a hold expired first, fail confirmation and release remaining holds. Void an unused authorization under its own recoverable operation. Canceling an authorization is a new compensating action; it does not erase the earlier provider operation.

Capture then uses one stored operation. Until capture is known successful, shipping remains blocked. If its outcome is unknown, retain the allocations and escalate reconciliation rather than applying the ordinary hold timeout to possibly paid inventory. Allocation and temporary hold are different states with different release policies.

If capture definitively fails, cancel the unshipped order and release allocations through guarded transitions. If a late success is discovered during cancellation recovery, refund through the payment subsystem under a stable identity before reporting fully resolved compensation. Provider deduplication windows are finite; beyond them, reconcile instead of assuming a local key permits safe repeated calls forever.

09 / Serialize cancellation with the permission to ship

Known capture success is necessary but not sufficient to dispatch a shipment. In one transaction on the order's owning database, verify all required allocations, current order state and capture outcome, then mark fulfillment authorized and create a unique shipment intent. This is the point after which ordinary cancellation cannot simply free those allocations.

A cancellation that commits first prevents fulfillment authorization and starts the appropriate stock/payment cleanup. If fulfillment authorization commits first, cancellation must obtain a definitive no-dispatch result from the warehouse or move into a return/refund process. A delayed shipping status message does not prove that the parcel has not already left.

The warehouse consumes the shipment intent under its stable identity. Repeated delivery must not dispatch another parcel or decrement physical stock twice. The inventory transition checks the referenced allocation before changing onHand and allocated together. Saving the shipment request alone does not prove that the warehouse dispatched it once.

Keep customer states understandable: awaiting payment, confirmed with capture pending, ready for fulfillment, compensating, canceled or shipped. Support tools can inspect detailed step identities without exposing payment secrets. Notifications communicate committed state changes; they do not decide whether stock is available, payment succeeded or cancellation beat dispatch.

INTERVIEW CRITICAL

A capture timeout must not free possibly paid stock

After holds become confirmed allocations, keep them while capture is unknown and block shipping. Resolve the same payment attempt before releasing inventory or authorizing fulfillment under the agreed cancellation policy.

10 / Scale browsing and admission before splitting transactions

Cache product data and advisory availability, and publish order-history projections for read-heavy pages. Those views may lag; checkout approval and disputed status read the current owning database. Versioned events keep older pending projections from overwriting newer confirmed state. A newly created order remains directly retrievable even before its history list catches up.

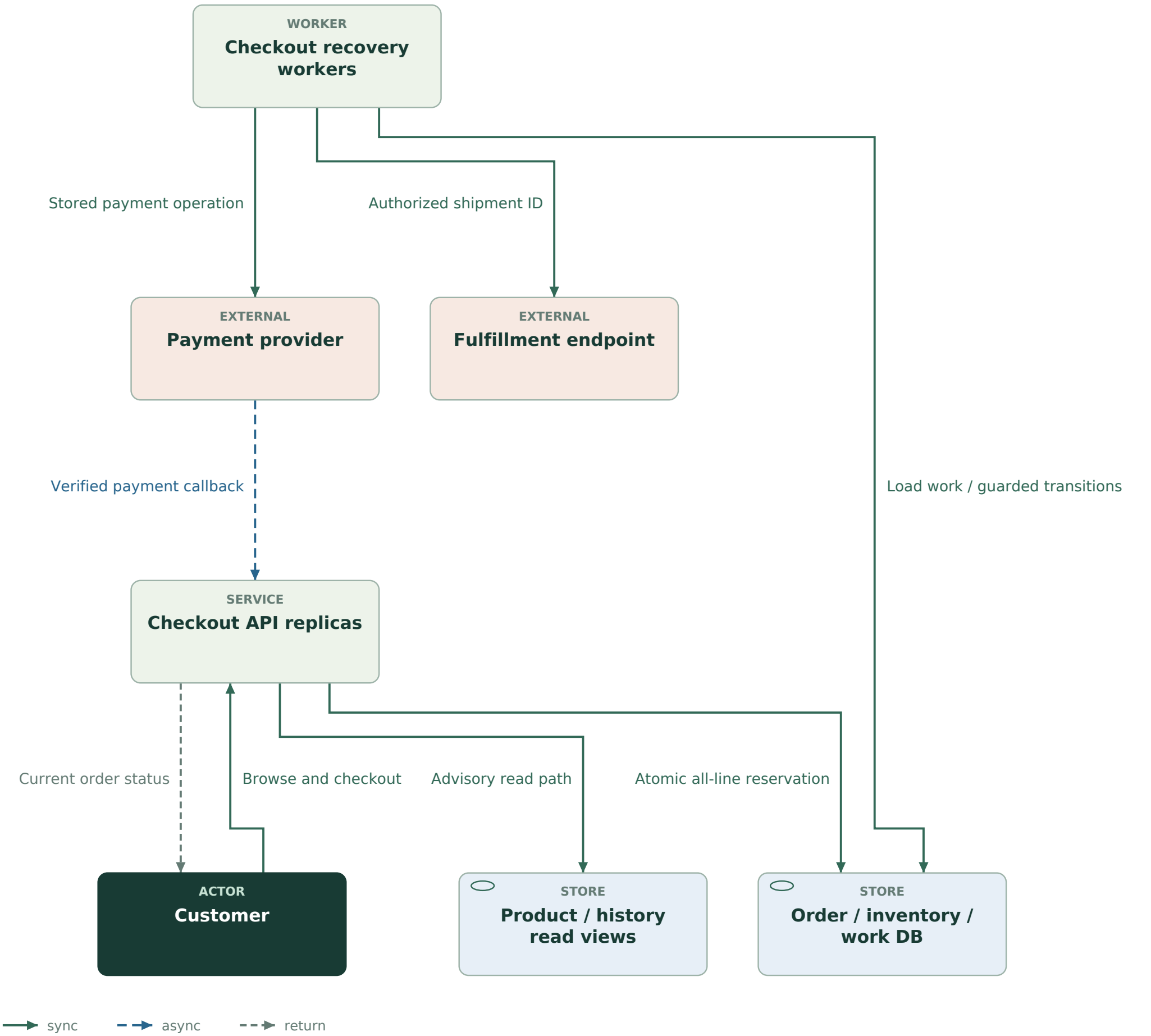
Protect flash-sale stock with bounded admission and per-customer quotas. Reject or queue excess contenders before they acquire partial holds elsewhere. Reserve worker/database capacity for reconciliation and release, because starving old workflows can trap real sellable inventory even while new-request latency looks acceptable.

Keep all-line transactions in one database while that ownership is practical. Distribute independent shops or stock pools only when their checkout contract remains compatible with the transaction boundary. More API replicas do not improve a single contended stock row, and read replicas cannot independently sell the same physical units.

If independent warehouses become required, the design changes to a durable sequence of local reservations and compensation, often called a saga. The order can be temporarily pending with some lines held. Confirm only after every required allocation exists, and explicitly recover failed or uncertain steps. The single-database baseline's simultaneous all-line commit no longer applies merely because the coordinator calls several APIs.

Scaled reads and workers preserve one inventory transaction domain

Checkout API replicas use cached product views for browsing, then reserve every order line through one inventory/order authority. Workflow workers recover stored payment operations and authorize shipment only after known capture. The fulfillment endpoint receives a stable shipment identity. This diagram retains the chosen single-database inventory contract; independent warehouses require the separate saga extension.



11 / Recover the same order and effect after each crash

Failure	Recovery
Checkout commits, browser reply disappears	Retry K4 and return O401 instead of another set of holds.
Payment attempt is stored, worker dies before calling	Resume the same durable operation under its provider contract.
Provider acts, response is lost	Keep unknown, reconcile that identity and preserve the appropriate stock claim.
Expiry worker stops	Deadlines still govern validity; resumed cleanup uses guarded transitions.
Shipment message repeats	Recognize the shipment identity and do not dispatch or consume stock again.

Use synchronous durable database replication and safe failover to preserve acknowledged orders, stock transitions and effect identities across one database-node failure. A stale or independently writable copy cannot approve the last unit. Backups must include request identities, payment references and pending work, not merely order display rows.

For a future distributed warehouse design, cancellation also has to handle a delayed reserve command whose result is unknown. Use the same stable line identity and a durable terminal cancellation record so an old reserve cannot arrive later and recreate an abandoned hold. This is one reason to keep the initial transaction domain intact until the independent ownership benefit justifies a fuller workflow protocol.

Recovery should prioritize oldest pending and compensating work, with bounded retry and clear escalation. A timeout is a reason to resolve the known operation, not permission to start a fresh checkout.

12 / Audit stock ownership and explain the tradeoffs

Monitor hot-SKU lock wait, reservation age, oldest pending order, capture uncertainty, compensation backlog and duplicate shipment suppression. Reconcile inventory counters against active hold and allocation records. A healthy checkout HTTP success rate does not prove that stock is neither stranded nor oversold.

Test two customers requesting two of three mugs, a retry after hold commit, expiry racing allocation, capture reply loss and cancellation racing fulfillment authorization. Crash the worker between every remote success and its local result record. Restore data and replay old messages to ensure identities still prevent additional financial or inventory effects.

Authorize stock movements to trusted services, restrict refund/support actions and avoid sensitive addresses or payment tokens in ordinary logs. Quotas also prevent bots from immobilizing inventory through unpaid reservations. Validate returns before replenishing sellable stock; a requested return does not immediately create a physical unit.

The main tradeoff is temporary inventory occupancy in exchange for a recoverable checkout. A longer hold helps slow legitimate users but strands more stock. Independent warehouses improve autonomy but introduce pending and compensation states. Disjoint regional stock budgets can allow local checkout during partitions,

but may leave unsold units stranded in another region. Choose these changes deliberately rather than promising the same simple atomic guarantee under every topology.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1-2; NFR1-3: atomic checkout admission	Scoped request identity and a short transaction over the complete stock/hold set.	Race two requests for two of three mugs and lose K4's reply. Recover one order without partial holds; load-test the admitted 300 ms p95 target.
FR3; NFR2-3: payment then fulfillment	Persist separate authorization/capture/shipment identities; allocate only valid holds and block dispatch until known capture.	Measure three-second confirmation under healthy dependencies, then lose a capture response. Keep allocations and pending status without shipping or starting another charge.
FR4; NFR3-5: guarded cancellation and recovery	Serialize expiry/allocation and cancellation/dispatch; release quantities only through valid prior states.	Race expiry with allocation, repeat shipment messages and attempt unauthorized cancellation. Check the stock equation after every transition.
NFR1,4: survive failure and contention	One inventory transaction domain, synchronous durable failover, admission limits and reserved reconciliation capacity.	Fail the database node after acknowledgment and restore pending effect identities. A hot stock row remains serialized; cross-warehouse atomicity is not claimed.

14 / Rapid revision

Remember: Holds and allocations both claim stock. An unknown capture keeps its allocation until recovery determines whether money moved.

Stage	Authoritative effect
Browse/cart	Express shopping intent; cached availability reserves nothing.
Quote	Save validated price, tax, shipping and currency as a quote with a version and expiry.
Hold	In one transaction, check every item and increase reserved stock; retries return the same order.
Authorize	Persist the payment operation before calling the provider; unknown remains pending.

Stage	Authoritative effect
Allocate	Recheck valid holds and move reserved to allocated before order confirmation.
Capture	Use one stored operation; unknown capture retains allocations and blocks shipping.
Dispatch	In one transaction, check cancellation and save the decision and unique pending shipment.
Ship	Use the shipment ID to reduce onHand and allocated once.
Recover	Check current state and reuse each action's ID during recovery; never change stock counters merely because a request timed out.

Close with the three-mug equation at each stage and a lost payment response. Mention that the selected single transaction domain gives simple all-line inventory atomicity; independent warehouses are a meaningful extension requiring durable partial progress and compensation, not just more services.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is available stock in this model?

Model answer

OnHand minus reserved minus allocated. Temporary checkouts and confirmed unshipped orders both claim physical units.

Interviewer follow-up

What happens on shipment?

Reduce onHand and allocated together so available stock does not change merely because allocated units leave.

What the answer must demonstrate: Trace onHand, reserved and allocated consistently through shipment.

02 / APPLIED

Two checkouts each request two of three mugs. What prevents overselling?

Model answer

A short transaction locks or conditionally updates the same stock authority and checks the full line set. After one reserves two, the other sees only one available.

Interviewer follow-up

Can a cart cache approve the second request?

No. Browsing availability is advisory and may lag.

What the answer must demonstrate: Use one authoritative atomic all-line stock decision, not browsing caches.

03 / APPLIED

How does hold expiry race with allocation?

Model answer

Both guard current hold state and stock counters in one transaction. Allocation first makes expiry a no-op; expiry first makes allocation fail.

Interviewer follow-up

Why not simply increment available on release?

A retry or stale cleanup could release the same units twice or free already allocated stock.

What the answer must demonstrate: Guard lifecycle and counters together so retry and expiry cannot release twice.

04 / APPLIED

Capture may have succeeded but timed out. Should allocations expire?

Model answer

No. Keep the appropriate allocated claim, block shipping and reconcile the original payment attempt. A temporary hold deadline is not a release policy for possibly paid inventory.

Interviewer follow-up

What if capture definitively fails?

Cancel and release through guarded transitions, recording the resolved payment outcome.

What the answer must demonstrate: Keep allocations during unknown capture and reconcile the same financial attempt.

05 / FOUNDATION

Why freeze the accepted quote?

Model answer

Prices, tax, discounts and shipping terms may change later. The order must preserve what the customer accepted and the provider should charge.

Interviewer follow-up

Can a retry accept a changed amount under the old key?

No. Conflicting key payloads fail or require a deliberate new accepted quote.

What the answer must demonstrate: Preserve accepted commercial terms and reject changed-payload key reuse.

06 / APPLIED

How does cancellation race with shipping?

Model answer

The order transaction commits fulfillment authorization and a unique shipment intent only if allocations and capture are valid. Cancellation must win before that boundary or use an explicit warehouse cancellation/return flow.

Interviewer follow-up

Why is a separate eligibility read insufficient?

Cancellation could release inventory between the read and an unchecked dispatch call.

What the answer must demonstrate: Order cancellation and fulfillment authorization in one transaction, and create one unique shipment intent.

07 / FOLLOW-UP

What changes when lines belong to independent warehouses?

Model answer

There is no longer one all-line transaction. Persist local step outcomes and compensation while exposing pending state; confirm only after every required allocation exists.

Interviewer follow-up

Can rollback of the coordinator undo a remote hold?

No. Releasing it is a separate idempotent action at the inventory owner.

What the answer must demonstrate: State the loss of global atomicity and persist compensating local steps.

08 / FOLLOW-UP

Why do warehouse receipts need identities?

Model answer

Replaying the same receipt must not add physical stock twice. Record the source identity with the stock increase transaction.

Interviewer follow-up

Are returns immediately sellable?

Only after the agreed receipt and inspection process authorizes replenishment.

What the answer must demonstrate: Deduplicate physical stock receipts and require validated returns before replenishment.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design checkout for two of three mugs plus a notebook, then race another customer, hold expiry and a lost capture response.

• Agree numbered functional and non-functional requirements, including all-line inventory scope, confirmation meaning and stock/payment failure behavior. Then use explicit stock quantities to prove reservations cannot oversell.

• Trace quote acceptance, holds, payment, allocation and shipping through durable states.

• Handle expiry, retries and uncertain payment without releasing or selling the same units twice.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Three mugs are on hand and a checkout holds two. What changes when those two are allocated, then shipped?

Available stays one: allocation moves two from reserved to allocated; shipment reduces onHand and allocated by two. Available = onHand - reserved - allocated.

Holds and allocations both claim stock; shipment removes the units and their allocation together.

A payment call times out. May checkout release stock or try a new charge?

No. Recover the same payment operation before deciding; the first charge may already have succeeded.

Resolve before reallocating.

Why is cancellation harder after fulfillment was authorized?

Dispatch may already be underway. Cancellation must coordinate with the warehouse rather than simply releasing the order's stock.

After dispatch authorization, cancellation must confirm that the warehouse has not shipped.

Summary and interview notes

Reserve every cart item together, save payment progress, and decide fulfillment against concurrent cancellation. If inventory spans independent warehouses, use a saga to track partial progress and undo reservations when needed.

Remember these points

• Use cached stock for browsing; reserve against current inventory records.

• Preserve the stock equation in every guarded transition.

• Freeze quote and effect identities before external calls.

• Keep allocations while capture is unknown; authorize shipment only after confirmed capture.

Interview tips

• Follow available = onHand - reserved - allocated.

• Trace two of three mugs through hold, allocation and shipment; then lose the capture reply.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Independent warehouse saga: Cross-owner reservations require full partial-progress, late-command and compensation handling.

Distributed inventory ownership: Separate warehouses change transaction boundaries and fulfillment coordination.

Regional stock budgets: Disjoint budgets trade partition availability for stranded units and rebalancing complexity.

Detailed failure recovery: Explore unknown captures, partitioned warehouses and cancellation after dispatch.

Technical references

AWS saga orchestration pattern
Defines orchestration and compensation for workflows spanning independent transaction boundaries.
https://docs.aws.amazon.com/prescriptive-guidance/latest/cloud-design-patterns/saga-orchestration.html

PostgreSQL explicit locking
Primary reference for owner-local concurrency control and conflict handling.
https://www.postgresql.org/docs/current/explicit-locking.html

EXTENDED INTERVIEWS / 50

Design a leaderboard with exact snapshot ranks

Interview version / 45-minute scope · Read the advanced version online

Maintain trusted cumulative scores and a single ordered index per board, handling ties, duplicate results and downward corrections before introducing distributed rank queries.

ordered index • competition rank • score events • season snapshots

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Define competition rank separately from display order using tied scores.
- Trace one trusted match result into a versioned ordered projection without duplicate points.
- Scale independent boards and shared reads while stating the limits of one very large global board.

Useful foundations: Database indexes: B-trees, composite keys and query access; Data partitioning and sharding; Message queues, event logs, delivery guarantees, and backpressure; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / Define score, rank and the board being ranked

Build seasonal game leaderboards offering top 100, a player's rank and nearby competitors. Scores are cumulative contributions from trusted match-result services, with authorized corrections that may decrease a total. Do not accept arbitrary browser-submitted scores. Anti-cheat model training and matchmaking are separate systems, although producer authorization and correction audit belong here.

Competition rank is one plus the number of players with a strictly higher score. Use the following scores and shared ranks:

Player	Score	Competition rank
P1	920	1
P2	900	2
P3	900	2
P4	880	4

Display order needs a deterministic tie-breaker, but it must not turn P3's shared rank into 3. Choose descending player ID for equal-score display order in this exercise, matching the selected ordered-index query direction. Thus P3 displays before P2, while both retain rank 2.

The initial design gives each season/region board one authoritative ordered index, supports a bounded largest board and scales many boards independently. Top lists may be cached for a second; personalized rank is exact for the single-index state read, not a claim of globally instantaneous agreement with newly accepted scoring events.

A successful score update may precede its displayed ranking while the projection catches up. Show that delay honestly. A hundred-million-player globally sharded exact rank is a stronger extension with additional coordination, not the default architecture hidden behind one endpoint.

Clarify whether the ranking is global or per season/region, how tied scores rank, and how quickly an accepted score must appear. Choose bounded boards with exact competition rank for each coherent index read and explicitly delayed score projection; a globally sharded instantaneous rank is a different prompt.

02 / Functional requirements

1. **Accept trusted scoring events.** Record match contributions and authorized revisions, including corrections that reduce a player's total.
2. **Read rankings.** Provide top 100, a player's competition rank and a bounded neighborhood with deterministic tie display order.
3. **Manage seasons and awards.** Separate season/rule namespaces, close under a stated cutoff and completeness policy, and publish an auditable frozen award result.
4. **Recover score history.** Deduplicate retries, expose ranking freshness and rebuild the ordered view from durable score evidence and versioned updates.

03 / Non-functional requirements

These are illustrative interview assumptions, not product facts or measured benchmarks. Confirm them before choosing components, then validate the completed design under the stated workload. Here p95 means the 95th-percentile latency: 95% of measured requests take no longer than that value. Report errors and rejected work alongside latency; a fast failure is not a successful outcome.

1. **Fleet and board scale.** Plan for 100 million player/board records, 10,000 score events/s and 50,000 top-list reads/s across the fleet. Keep the largest initial board at one million players; assume at most 1,000 score updates/s and 5,000 uncached rank/neighborhood reads/s on one board for its load test.
2. **Read latency and visibility.** Target top/rank/neighborhood reads below 200 ms p95 under admitted load. Target 99% of accepted score changes reaching the ordered index within one second. For updates that change top-100 membership, ordering or displayed scores, target 99% of those updates being incorporated into a served top-list snapshot within two seconds of acceptance, including the one-second cache interval. The snapshot may already include a newer accepted update. An update to a player outside the top 100 need not appear in that list. Stalled projection is a measured miss and must expose age.

3. **Ranking correctness.** Competition rank is one plus the number of strictly higher scores. Read the player's score and comparison population coherently; tie display order does not change shared rank, and a retry cannot award the same match twice.
4. **Durability and recovery.** Committed score evidence and outbox state survive scoring-service restarts; the ordered index and cache may be rebuilt. Do not acknowledge scores based only on a disposable index. The database's replica/region disaster policy remains a separate deployment requirement.
5. **Authority and fairness of evidence.** Accept scores only from authorized producers, audit corrections and rule changes, and enforce board/friend permissions. Freeze awards only after checking the agreed cutoff's evidence is complete; a cache refresh alone cannot establish completeness.

04 / Complete scoring and ranking with one ordered board

Start with an authenticated scoring API, a transactional score database and an ordered index for each board. A hash lookup answers P2's current score, while an ordered structure supports top ranges and counts above a score. A Redis sorted set is one practical projection; the score database remains the recoverable source.

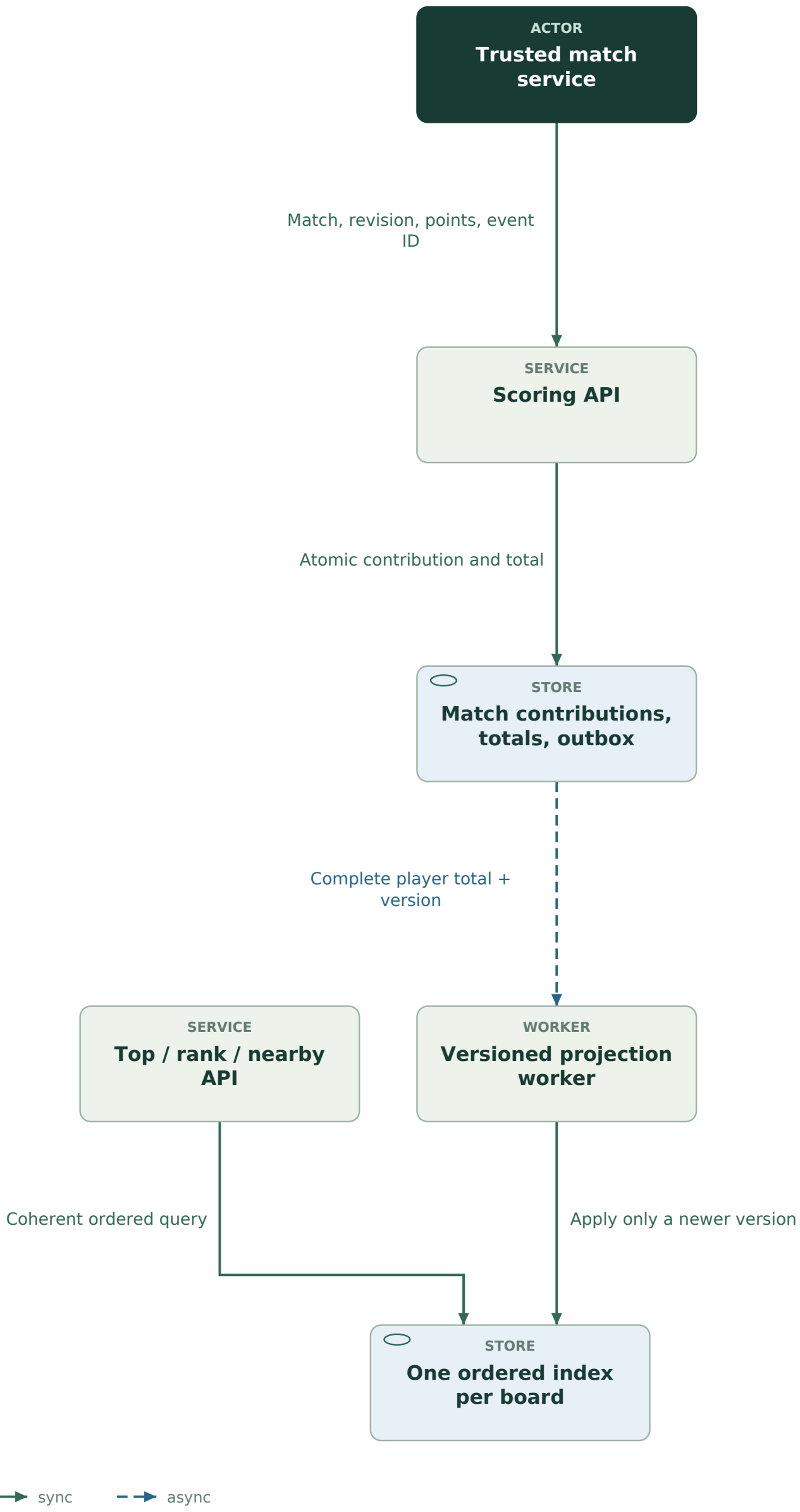
Trusted event E77 reports match M91 awarding P2 thirty points. One database transaction records its business identity and match contribution, changes P2 from 900 to 930, advances the player's version and stores an outbox update. A worker applies the complete new total to the ordered index only if its version is newer than the stored projection version.

The index update changes score and version atomically. A repeated version 12 update does not add thirty again, and a delayed version 11 cannot restore the old score. After application, P2 is above P1 and has rank 1. Top-list reads return the highest entries under the chosen display comparator.

For a rank read, obtain P2's score and the count of strictly higher scores in one bounded atomic index operation. Reading the score first and counting later could compare it with a different board state. The score and comparison count therefore describe the same index state, although scoring-to-index lag remains an explicit freshness limitation.

Trusted scoring feeds one ordered board

Accepted scores are durable before the display projection catches up.



05 / Separate fleet size from one hot board

Assume 100 million active player/board records across many seasonal or regional boards, 10,000 score events/s across the fleet and 50,000 top-list reads/s. A bounded largest board initially has up to one million players; benchmark its assumed 1,000 score updates/s and 5,000 uncached rank/neighborhood reads/s on one index against the 200 ms p95 target. These are proposed capacity requirements, not measured capabilities.

At 64 bytes of raw player state, the fleet payload is about 6.4 GB, but ordered indexes, version lookups, allocators and replicas require more. At an illustrative 128 bytes per indexed player, a million-player board uses about 128 MB before additional overhead and copies. That explains why many useful boards can remain on one ordered owner, while still requiring measurement of real memory use.

Ten thousand 100-byte score events/s create 1 MB/s or 86.4 GB/day of history. Ninety days require 7.776 TB before indexes and replicas. Retaining auditable scoring evidence can cost far more than caching a top list.

A top 100 response at 48 bytes per entry is 4.8 KB; 50,000/s produces about 240 MB/s of response payload. Many readers can share a cached complete top list instead of recomputing it. Personalized rank and neighbor reads are less shareable, so size them separately rather than assuming one cache solves every query.

06 / Represent match contributions and projection versions

Interfaces

Request or message	Contract
`POST /score-events`	Trusted season, player, match, source revision, points and event identity.
`GET /boards/S4/top?limit=100`	Complete cached top list with display order and as-of information.
`GET /boards/S4/players/P2/rank`	Player score and competition rank from one coherent index read.

Read P2's competition rank

```
GET /boards/S4/players/P2/rank
```

Complete projection update after the worked correction

```
{
  "season": "S4",
  "player": "P2",
  "total": 905,
  "version": 13
}
```

Stored records

Record	Fields or identity	Purpose
Match contribution	`season`, `player`, `match`	Last accepted source revision and awarded points.
Player total	`season`, `player`, `total`, `version`	Current authoritative cumulative score.
Accepted event / outbox	Accepted event and player-total version	Audit evidence and recoverable complete versioned total.
Ordered projection	Board/player and applied version	Score order plus player version used to reject delayed updates.

An event ID suppresses transport retries, but a second event ID for the same match must not award its points again. The stored match contribution and its source revision prevent awarding the same match twice. Retrying identical accepted content returns the prior result; conflicting reuse of an identity is an error.

Scope every query and cache key by season, region and scoring-rule version. The same player can have different scores on different boards. A top 100 means one hundred display positions, not every player tied at the boundary. If the product wants all boundary ties, its result size and pagination contract must change explicitly.

07 / Apply corrections without repeating or losing points

For E77, the stored contribution for P2's match M91 changes from zero to thirty. The owner calculates the change:

Contribution change

```
delta = new contribution - previous contribution
```

It adds that delta to P2's total within the same transaction that saves the contribution revision, accepted event and outgoing update. P2 moves from 900 to 930 at version 12.

Now an authorized correction changes that match contribution from thirty to five. The derived delta is -25, so the total becomes 905 at version 13. A delayed older revision cannot restore thirty or subtract twenty-five again. The source revision orders that match's evidence; the player version orders resulting total changes across all its matches.

Send complete versioned totals to the projection, not unprotected increments. A repeated message saying "total 905, version 13" can be recognized and ignored. Repeating "subtract 25" would corrupt the board unless separately deduplicated. A lower numeric score can still be the newer correct version, so comparing score magnitude is not a valid stale-update rule.

Changes to the scoring rule itself need an explicit board version or rebuild plan. Do not apply a new rule to only some old matches and present the mixed result as if every player had been evaluated consistently. Keep immutable evidence and audit correction authority.



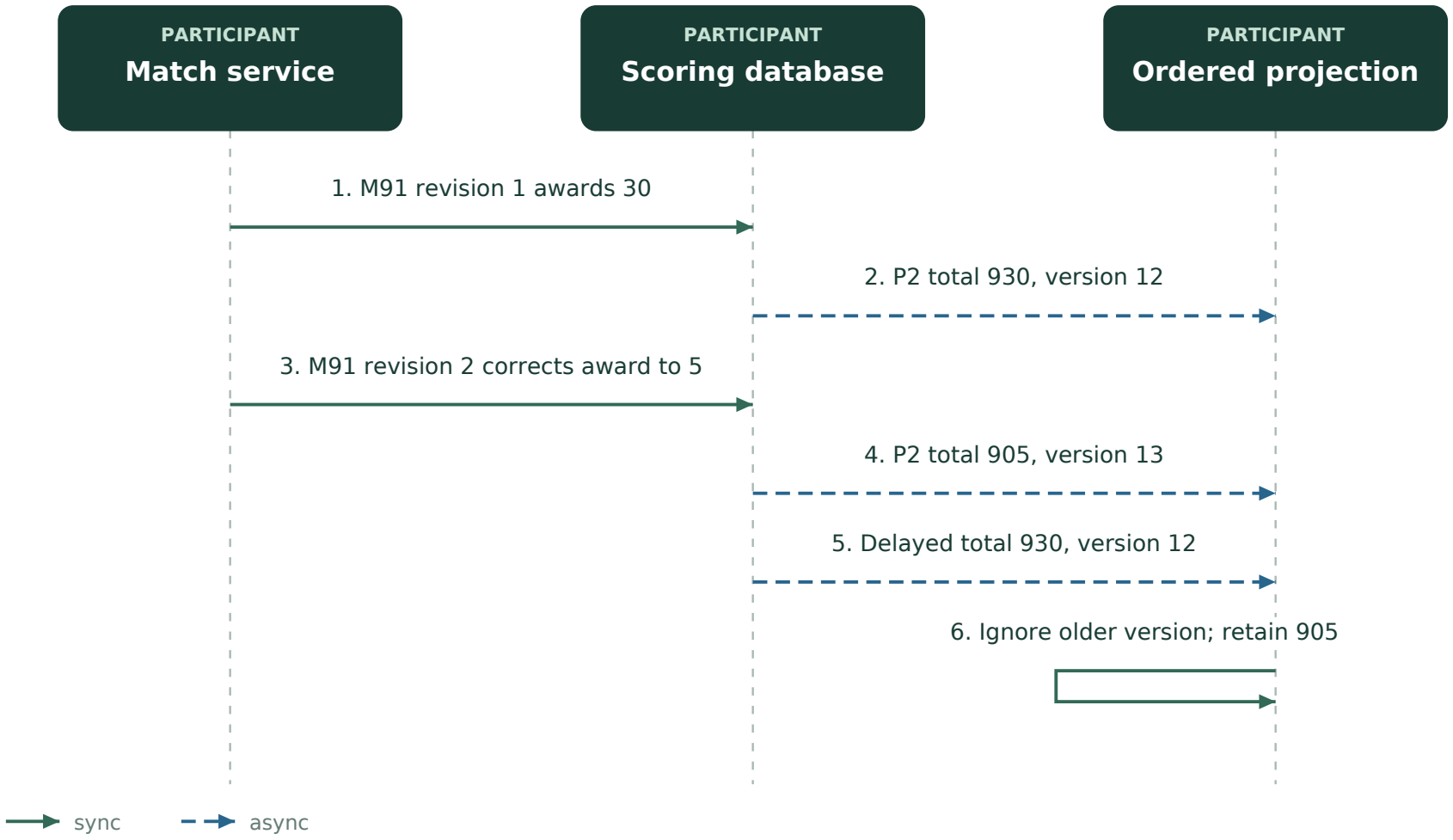
INTERVIEW CRITICAL

A new event ID is not a new match award

Deduplicate transport events and also track the canonical match contribution with its source revision. Otherwise the same match can award points twice under two different delivery IDs, even when every request key is unique.

A correction can lower the score safely

The match source revision and resulting player version have distinct jobs.



08 / Explain ties, atomic reads and nearby results

For P2 at 900, count players with scores strictly above 900 and add one. P1 is the only such player, so P2 and P3 both have rank 2. A sorted-set ordinal position answers a different question: it includes the display tie-breaker and therefore does not directly implement shared competition rank.

With a Redis-style index, a strict score-range count such as scores greater than 900 supplies the needed count. Read the player's score and that count together through the chosen atomic script or transactional operation so another update cannot change the comparison between the two reads. Keep the operation bounded and use the index's supported count query rather than scanning all members in an application loop.

For top 100, fetch the ordered entries in one index read. Compute displayed shared ranks using strictly higher scores, carrying the preceding score/rank through the list. The chosen descending-ID tie-breaker affects ordering only. A large tie group can occupy many display positions while all its members share one rank.

Nearby-player results use the same score order and tie comparator. This default API offers a bounded neighborhood, not unlimited stable historical pagination. If users need to page through a fixed old board while scores change, retain a snapshot explicitly; persistence files are not automatically a historical query API.



INTERVIEW CRITICAL

Competition rank and display position are different

Equal scores share competition rank even when player IDs order their display. Use one plus the count of strictly greater scores, and obtain the player score and population count from the same coherent index state.

09 / Cache shared reads and distribute independent boards

Cache each complete top list for a short interval with its board identity and as-of metadata. Thousands of viewers can reuse the same hundred entries, reducing index work. Cache the whole coherent result rather than mixing rows from several refreshes. Personalized rank remains a separate current-index operation and should not combine a fresh authoritative score with an older cached population.

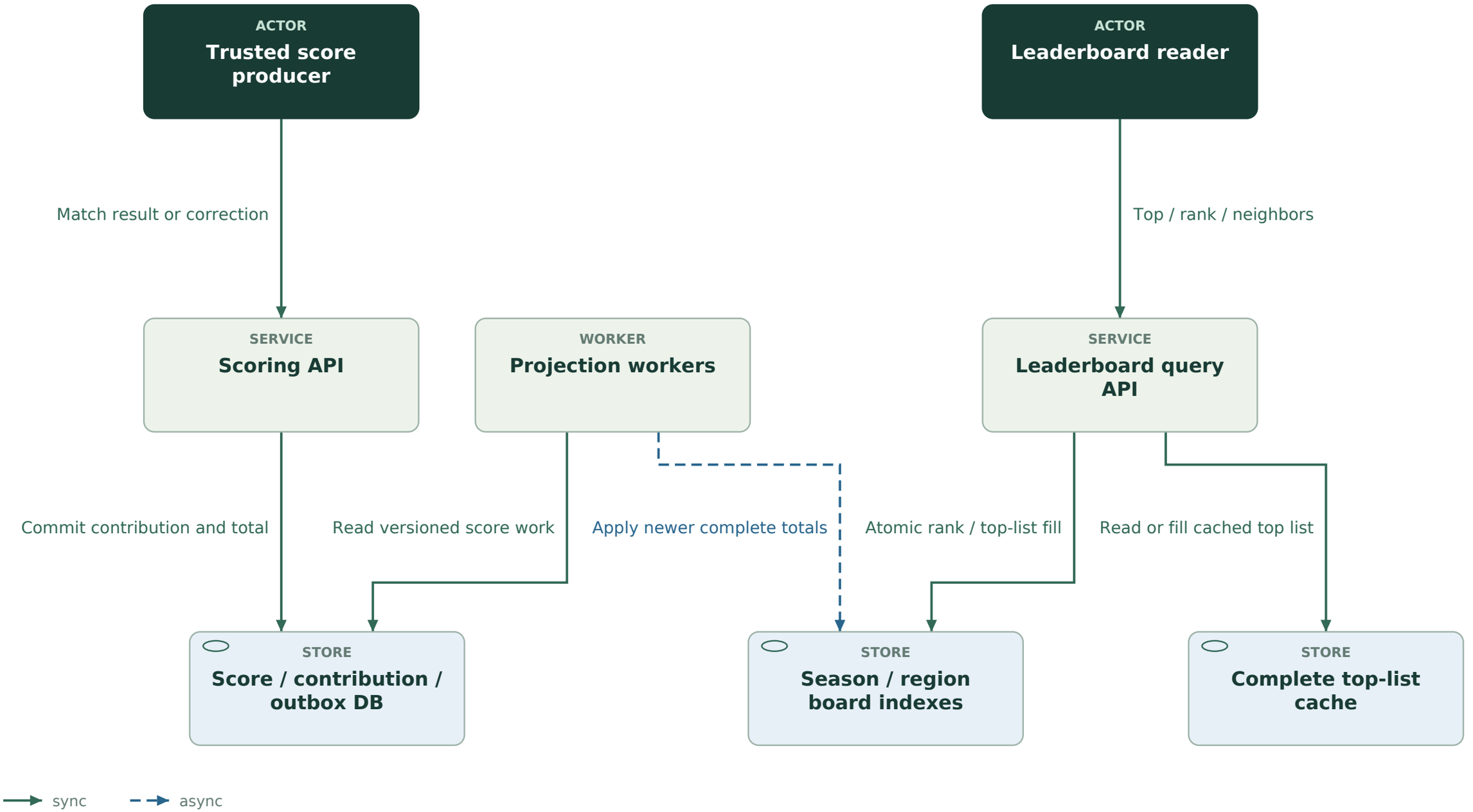
Assign different season/region boards to different index owners. This provides straightforward aggregate scale while keeping each board's top, rank and neighbors local. Replicas can improve read availability under their disclosed lag; failover and rebuild must preserve the projection's version state or reconstruct it from the score source before accepting new updates.

For a single board that exceeds one owner's memory or throughput, discuss the changed cost explicitly. Hashing complete players distributes updates, and global top k can be obtained by merging every shard's local top k under the same comparator. A globally winning player cannot have k better players on its own shard and still be globally top k.

Exact personalized rank is harder: every shard's count and the player's score must describe the same board snapshot. The baseline deliberately avoids promising that distributed snapshot protocol. Options include a coordinated snapshot, a separately labeled approximate percentile, or retaining a larger single ordered authority after benchmarking.

Versioned scoring feeds bounded board indexes and shared top lists

A trusted result commits the match contribution and complete player total before the projection worker updates the board index. Readers reuse complete cached top lists or perform coherent rank reads against one board owner. Independent season/region boards scale across owners; exact cross-shard personalized rank is outside this selected diagram.



10 / Close a season from complete scoring evidence

Create a new season namespace instead of synchronously zeroing every old player. Scores, match identities, rules and caches include the season so old retries cannot silently award points in the new competition. Closing a season has an announced cutoff and an allowed-lateness/adjudication policy.

For the bounded single-authority baseline, stop accepting ordinary season scores at the chosen cutoff, drain all previously accepted outgoing updates, and verify the ordered projection against the authoritative totals before freezing the final award result. Publish an immutable award version with the rule and cutoff used. A cache refresh time alone is not proof that every eligible match arrived.

If the contract uses match event time rather than acceptance time, trusted sources must establish completeness through that cutoff or the rules must explicitly define which late results are reviewed. Waiting an arbitrary second does not prove that an offline match source has finished sending results.

A later fraud finding or accepted correction produces a new audited award-decision version rather than silently rewriting the originally awarded snapshot. This separates live display freshness from the stronger reproducibility required for prizes. Keep enough scoring evidence to explain the final result; the tiny top-list cache is not the evidence archive.

11 / Rebuild the index without treating it as score truth

Failure	Recovery
Scoring transaction commits, reply disappears	Retry the same event/business identity and return its saved total version.
Outbox update repeats	Atomically reject an already applied or older player version.
Projection worker stops	Keep scores durable; show display lag while recovering pending updates.
Ordered index is lost	Rebuild from a consistent player-total snapshot plus subsequent versioned changes.
Cache refresh fails	Serve a labeled older complete list within policy, or fail; do not fabricate a partial latest board.

A rebuild must include player versions as well as scores, then catch up updates after the source snapshot before becoming current. Copying arbitrary rows while scores change without a replay boundary can miss or double-apply changes. Use the database's consistent snapshot and change-stream/outbox recovery capabilities.

During overload, protect authoritative score acceptance and recovery work before optional personalized queries. Bound top-list limits, neighborhood size and private-board populations. The service can deliberately display an older complete top list while recovering, but must expose its age rather than call a stalled index live.

A future distributed board cannot omit one failed shard and still return an exact global rank. That missing population may contain every player above P2. Use a previously complete snapshot or fail the exact query under the stronger design's declared contract.

12 / Test the ranking rules rather than only endpoint speed

Monitor scoring acceptance, score-to-index lag, duplicate-event suppression, conflicting revisions, index rebuild progress, memory use and per-board read/write hotspots. A healthy cached top endpoint can hide a scoring pipeline that has not updated for an hour. Track the oldest unapplied score event directly. Measure accepted-score-to-index delay against one second for 99% of updates. For updates that affect top-100 membership, order or displayed scores, measure acceptance-to-visible-effect against two seconds total, including cache time; outages still count as visible misses.

Test tied scores, ties crossing the hundredth display position, E77 arriving twice, the same match under different event IDs, downward corrections and old revisions arriving late. Compare sampled ranks with a slow sort of the same source snapshot. Verify that the selected ordered-index tie behavior matches the API comparator rather than assuming reverse-score queries keep ascending member order.

Authorize score producers and corrections, audit rule changes and protect private friend graphs. A friend-only board ranks within the authorized friend population; filtering a global top 100 afterward can omit all relevant friends outside that global list. For a small friend set, retrieve their complete scores and rank that bounded set directly.

The primary limits are one very hot board, required historical snapshots and exact global rank under sharding. Keep those visible. The first coherent design can meet a useful bounded product without compressing a distributed publication proof into an unexplained "generation" field on every response.

13 / Check the design against its requirements

Use the numbered requirements to check the final design. FR refers to the functional list; NFR refers to the non-functional list. Performance rows specify tests still required, not achieved benchmark results.

Requirement	Design mechanism	Verification and remaining limit
FR1; NFR3,5: correct score updates	Canonical match revision, one transactional total change and complete versioned outbox updates.	Replay E77 under the same and different event IDs, then correct thirty points to five. P2 ends at 905 without repeating the award or reversing a newer version.
FR2; NFR1-3: fast coherent rankings	One bounded ordered authority per board, atomic rank reads and shared complete top-list caching.	Test 920/900/900/880 -> 1/2/2/4; load-test the declared per-board mix against 200 ms p95. Fleet capacity cannot prove the hottest board's capacity.

Requirement	Design mechanism	Verification and remaining limit
FR4; NFR2,4: visible, recoverable projection	Durable source/outbox, atomic score-version application and timestamped cache refresh.	Measure acceptance-to-index within one second and, for updates affecting the top 100, their effect in refreshed served lists within two seconds; stop the worker and rebuild the index. Expose misses and older results rather than claiming current rank.
FR3; NFR5: reproducible awards	Season namespaces, drained accepted updates, source comparison and immutable award version.	Close while events are pending and deliver an old-season retry. Verify completeness before awarding; late adjudication creates an audited new result instead of rewriting history silently.

14 / Rapid revision

Remember: A newer correction can lower a score. Order updates by version, and count strictly higher players for shared rank.

Concern	Complete mechanism
Score rule	Add trusted match contributions; allow authorized corrections with increasing match revisions.
Business uniqueness	Event IDs detect retries; match IDs and revisions prevent awarding the same result again under another event ID.
Projection	Save a player's complete score and version together; accept only newer versions.
Shared rank	One plus the number strictly above the player's score; ties share rank.
Display	Use score and player ID for stable display order; tied players still share competition rank.
Coherent read	Read the player's score and count of higher-scoring players in one atomic index operation.
Scale	Cache popular top lists and assign different boards to different servers before splitting one board.
Season	Set the cutoff, check all eligible results and freeze an award version; publish later corrections as new audited versions.
Recovery	Rebuild from saved player totals and later versioned updates; show how far the display lags.

Close by tracing P2 from 900 to 930 after E77, then to 905 after correction. Explain why repeating E77 changes neither total, why P2 and P3 once shared rank 2, and why a globally sharded exact rank would require an additional coherent-view contract.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What are the ranks for 920, 900, 900 and 880?

Model answer

Competition ranks are 1, 2, 2 and 4 because each is one plus the number of strictly higher scores.

Interviewer follow-up

Does a player-ID tie-break change them?

No. It orders display positions, not shared competition ranks.

What the answer must demonstrate: Define strict-greater competition rank separately from tie-broken display position.

02 / APPLIED

Why is event-ID deduplication insufficient for match awards?

Model answer

The same match may arrive under a different transport event ID. Store its canonical contribution and source revision so business meaning is applied once.

Interviewer follow-up

What commits together?

Accepted evidence, the contribution change, player total/version and outgoing projection work.

What the answer must demonstrate: Protect canonical match contribution/revision as well as transport-event identity.

03 / APPLIED

A match contribution changes from 30 to 5. What updates?

Model answer

Derive delta -25 from the stored contribution and apply it atomically with the newer source revision and player version.

Interviewer follow-up

Can the index ignore the update because the score decreased?

No. Version, not score magnitude, determines which state is newer.

What the answer must demonstrate: Derive correction delta from stored contribution and order projection updates by version.

04 / APPLIED

Why read score and count-above atomically?

Model answer

Another update between those reads can make the comparison describe different board states. One atomic index operation gives a coherent rank.

Interviewer follow-up

Does that mean every accepted source event is already included?

No. Projection freshness is separately measured and disclosed.

What the answer must demonstrate: Read score and population count coherently while disclosing source-to-index lag.

05 / FOUNDATION

Why send complete totals to the projection?

Model answer

Repeating a versioned replacement is safely recognizable, whereas an unprotected repeated increment awards points again.

Interviewer follow-up

What if the index disappears?

Rebuild totals and versions from a consistent source snapshot plus later changes.

What the answer must demonstrate: Use complete versioned totals and a consistent rebuild/replay boundary.

06 / FOLLOW-UP

Why can global top k merge local top k from each player shard?

Model answer

A player excluded locally has at least k better local players under the same comparator, so cannot be globally top k.

Interviewer follow-up

Does that alone solve exact distributed rank?

No. Player lookup and all count-above results still need a coherent shared view.

What the answer must demonstrate: Explain local-top-k completeness separately from cross-shard snapshot consistency.

07 / FOLLOW-UP

Does waiting one second after cutoff prove an award board is complete?

Model answer

No. Use the declared late-result policy to establish which accepted inputs count or whether sources have sent all eligible results. Apply those inputs and verify the board before freezing awards.

Interviewer follow-up

What happens to a later fraud correction?

Publish a separate audited adjudication version rather than silently altering the historical award.

What the answer must demonstrate: Establish cutoff completeness and retain immutable award/adjudication evidence.

08 / FOUNDATION

Can a friend board filter the global top 100?

Model answer

That can miss every eligible friend outside the global list. Rank within the authorized friend population before truncation.

Interviewer follow-up

What is a simple small-set solution?

Batch-fetch the complete friend scores, then sort and rank that bounded set.

What the answer must demonstrate: Filter the eligible population before ranking or truncating friend results.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a seasonal board with tied scores, duplicate match delivery and a downward correction, then explain the limit of sharding one global rank.

• Agree numbered functional and non-functional requirements, including board population, shared-rank semantics and score-to-display freshness. Then define competition rank separately from display order using tied scores.

• Trace one trusted match result into a versioned ordered projection without duplicate points.

• Scale independent boards and shared reads while stating the limits of one very large global board.

• Trace a timeout and a concurrent request using the actual durable records.

• Review the final architecture against every numbered requirement, including measured bottlenecks, targets still needing validation and remaining failure limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Scores are 920, 900, 900 and 880. Why does the last player rank 4 rather than 3?

Three players have strictly higher scores, so the last rank is 1 + 3 = 4. The two players at 900 both rank 2; tie display order does not change that.

Count higher-scoring players, including tied players above you.

A correction lowers P2 from 930 to 905. What prevents an old message from restoring 930?

The stored match revision determines the correction, and the newer player version makes the index keep total 905 even if an older total arrives later.

Newer can be lower.

What should scale before splitting one leaderboard across servers?

Cache shared top lists and place independent boards on different servers.

Scale boards before global order.

Summary and interview notes

Add trusted match contributions to each player's score and maintain one ordered index per board. Handle tied scores, repeated results and corrections that lower scores before splitting one board across machines.

Remember these points

- Define how points accumulate and how tied scores rank first.
- Protect business contributions as well as transport events.
- Read the player's score and higher-score count from the same index state.
- Expose projection lag and the extra cost of exact global sharding.

Interview tips

- Separate score revisions, display order and competition rank.
- Trace P2 from 900 to 930 to 905, then replay the old thirty-point award.

Important qualifications

- Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Exact distributed snapshot rank: One enormous sharded board needs coherent counts and player lookup across all owners.

Full score and top-k proofs: Study match revisions, atomic projection replacement and merge completeness in depth.

Coordinated generation publication: Retained cross-shard snapshots add ownership, storage and slow-shard coordination.

Score-range and histogram alternatives: Approximate percentiles and alternative layouts change exactness or update costs.

Technical references

Redis sorted sets
Documents ordered members, score updates, and range operations as an implementation option.
https://redis.io/docs/latest/develop/data-types/sorted-sets/

Redis ZCOUNT
Defines inclusive/exclusive score boundaries used for competition-rank counts.
https://redis.io/docs/latest/commands/zcount/

Redis ZRANGE
Official reverse-order and tie ordering behavior; generation snapshots remain an application/index requirement.
https://redis.io/docs/latest/commands/zrange/

EXTENDED INTERVIEWS / 51

Design maps and route planning

Interview version / 45-minute scope · Read the advanced version online

Design legal driving routes from a versioned road graph, then scale search and map delivery while keeping traffic updates and cached paths coherent.

road graph • shortest path • traffic weights • map matching

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain a complete route request before adding acceleration or regional partitioning.
- Calculate compute and bandwidth separately and justify each scaling step.
- Defend shortest-path correctness, compatible graph publication and closure handling.

Useful foundations: Design nearby place search and friend discovery; Database indexes: B-trees, composite keys and query access; Caching: cache hits, misses, write policies and invalidation; Data partitioning and sharding

8 interview questions with model answers and answered follow-ups.

01 / Define what a route promises

A maps product has two different jobs. Map tiles draw the background the user sees; routing computes a legal sequence of roads from an origin to a destination. They can share source geography without sharing a serving system. We design driving directions for departure now, with map display and optional navigation refresh. Address geocoding, transit, lane guidance and offline navigation are separate extensions.

Before choosing an engine, ask: do we need driving directions for departure now or predictions for future departures, and how quickly must known closures affect answers? The worked scope below chooses departure now and an explicit closure-freshness target.

Represent intersections as vertices and permitted directed movements as edges. An edge carries a nonnegative travel-time cost. One-way streets remove reverse movements. A prohibited turn depends on the incoming road, so the search state must preserve that information rather than treating every intersection as an unrestricted connection.

Use one small graph throughout: A -> B takes four minutes, B -> D four, A -> C three and C -> D eight. The best permitted route is A-B-D at eight minutes, although A-C looks cheaper initially. Road snapping connects coordinates to plausible accessible road positions. The basic flow is coordinate validation -> road snapping -> search on one graph version -> path reconstruction -> closure validation -> response. This is the complete product before any cache, hierarchy or regional shard is introduced.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Display the map.** Serve versioned map tiles for the requested area and zoom level.
2. **Find driving directions.** Accept origin, destination, a driving profile and avoidance preferences such as avoid-toll; return the road/turn sequence, geometry, distance and estimated duration. Connect coordinates to plausible accessible road positions: an overpass must not snap to the road underneath merely because it is close.
3. **Refresh a route.** Recompute after a reported incident, with optional refresh notices for active navigation.
4. **Explain the result.** Return data versions and freshness, distinguish an inaccessible endpoint from valid endpoints with no connecting route, and label historical-traffic fallback. Address geocoding, transit, lane guidance and offline navigation are outside the worked scope.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Plan for ten million route requests/day and a peak of 2,000/s. Size repeated map-tile bytes separately from route computation.
2. **Latency and availability.** Target route p95 below 300 ms and 99.9% routing availability under the admitted workload. Test long trips and incident spikes as well as short city routes.
3. **Freshness.** Publish validated topology daily, ordinary traffic within one minute and trusted urgent closures within ten seconds. Return observation and validation versions so callers can interpret freshness.
4. **Route correctness.** Every returned path must obey one compatible topology, turn and weight model, plus known closures checked at the stated final validation boundary. An estimated arrival time is an estimate under that model, not a promised physical arrival time.
5. **Honest failure behavior.** Missing traffic may permit labeled historical weights. Missing legal connectivity must produce no route; stale urgent restrictions can require refusal or an explicitly permitted degraded result. A successful search cannot reveal an unreported physical incident.
6. **Access and privacy.** Authenticate callers, bound expensive requests, restrict map/closure administration and keep navigation positions private with limited retention. Public tile caches must not expose private location history.

04 / Make one correct in-memory search work

One server loads the directed, turn-aware graph and spatial index. It validates the request, finds bounded accessible snap candidates and runs Dijkstra with fixed nonnegative costs. The algorithm keeps the cheapest currently known distance to each search state and repeatedly settles the smallest one. Settling means its minimum cost is established under these assumptions.

Dijkstra trace from A

Step	Distances discovered
Start at A	Tentative B = 4 and C = 3.
Settle C	Discover D = 11 through C.
Settle B	Improve D to 8 through B.
Settle D	Establish the eight-minute path.

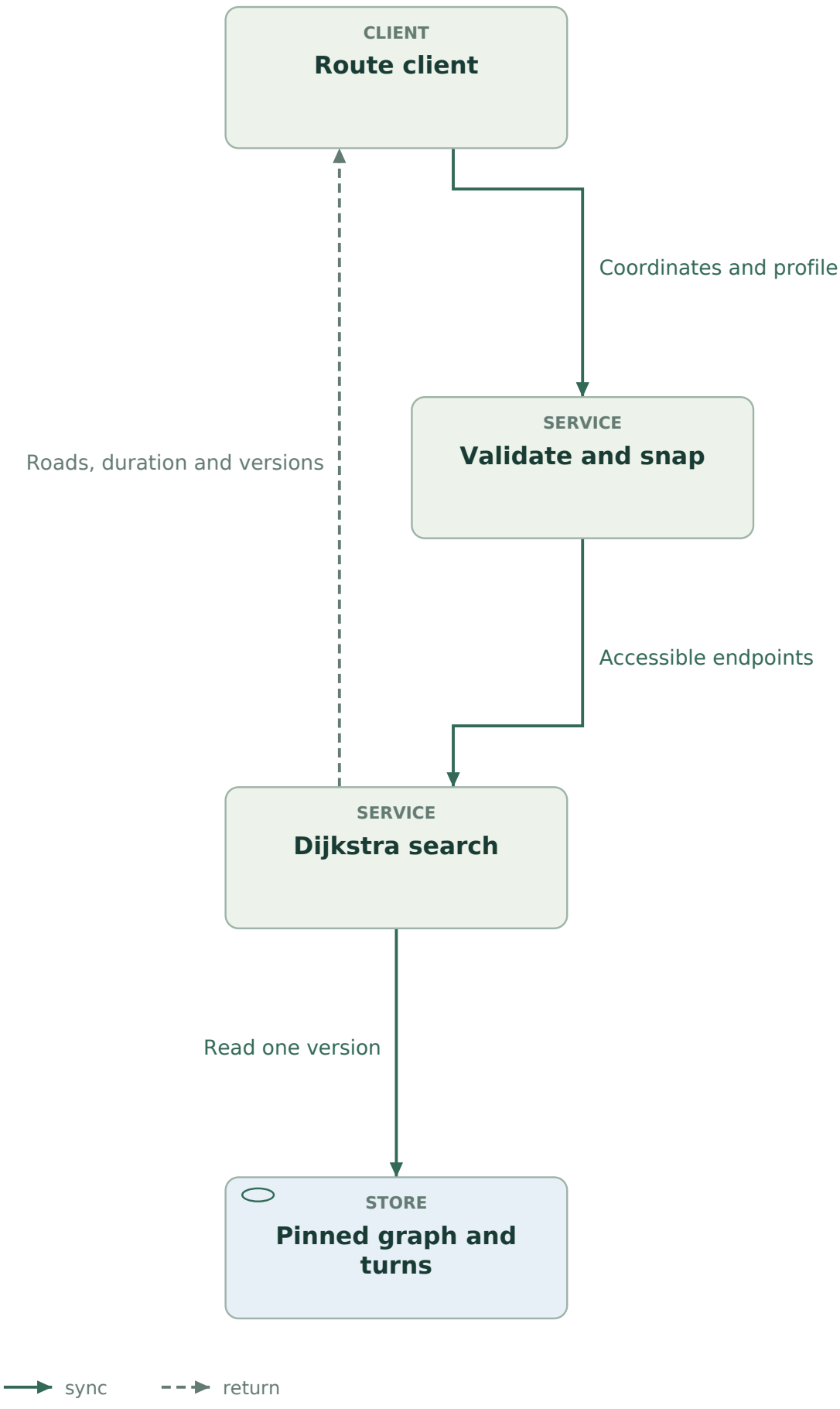
Save predecessor edges whenever a distance improves, and follow them backward to reconstruct actual roads and turn instructions. Choosing C and committing to its entire continuation after the first cheap edge would be a greedy mistake.

An endpoint inside a road needs a permitted partial-edge connection with the appropriate cost; it does not require traversing the entire road or inventing a reverse movement. Use a bounded set of plausible candidates where necessary.

For updates, build a second complete graph, validate it, then switch an active pointer. Each query retains its selected graph until it finishes. Static tiles can initially be ordinary files. This baseline is useful and testable even without a specialized distributed routing system.

One complete route request

The search owns one graph reference from snapping through reconstruction.



05 / Separate search CPU from repeated tile bytes

The average route rate is 10M/86,400 ~ 116/s, much lower than the chosen peak. If a representative route costs 50 milliseconds of CPU, 2,000/s requires 100 busy cores. At a planned 60% utilization ceiling that suggests about 167 cores before failure headroom. Benchmark long and cross-region trips: a short-city average does not bound their search work.

Workload	Calculation	Design implication
Route output	2,000/s x 20 KB = 40 MB/s	Compute and response bandwidth both matter
Tile delivery	1B/day x 30 KB = 30 TB/day	Repeated immutable tiles fit a CDN
Raw directed-edge records	100M x 32 B = 3.2 GB	Geometry, turns and indexes add substantial memory
Matrix request	100 origins x 100 destinations = 10,000 pairs	Admit by estimated work, not one HTTP request

Three loaded graph versions already require 9.6 GB for those raw edge records alone. Keep old versions for active requests and rollback, then release them safely. The dominant costs differ: tile reuse reduces network load, search acceleration reduces CPU, and version retention increases memory. More application servers cannot substitute for deciding which of these resources is exhausted.

06 / Name the graph and the result precisely

Route request

```
POST /routes
```

Input	Meaning
Origin and destination	Requested start and end coordinates.
Mode and avoidance preferences	Driving profile and constraints such as avoiding tolls.
Departure assumption	The time assumption under which travel weights apply.

Route response

Returned information	Purpose
Snapped endpoints	Show the accessible road positions used for the search.
Road/turn sequence and geometry	Describe the actual route to follow.
Distance and duration	Report route length and estimated travel time.
Bundle ID, traffic observation time and closure-validation version	Identify the model and freshness boundary used for this answer.

Validate coordinates and bound route alternatives and matrix dimensions. A request retry can be a fresh computation; if the client needs reproducibility, it explicitly requests a retained bundle.

Keep these model artifacts separate:

Artifact	What it records
Directed roads	Permitted movements between road positions.
Turn rules	Allowed or prohibited incoming-road/outgoing-road combinations.
Travel weights	Costs used by the selected search model.
Spatial snap index	Candidate road positions near supplied coordinates.
Bundle manifest	Compatible versions of those artifacts.

A shortcut speeds search by representing several real roads as one connection. Keep the list of those roads: a shortcut becomes invalid if a road it uses closes.

Cache identities

Cache	Key must include
Map tile	Map/style version, zoom, x and y.
Route	Snapped endpoints, profile, preferences, departure assumptions and bundle.

Rounding coordinates too aggressively can move a request across a divided highway. Navigation positions are private session data with short retention; they do not belong in public tile-cache keys or broadly readable request logs.

07 / Fix the measured bottleneck with the matching mechanism

First put immutable tiles behind a CDN. Their repeated bytes justify edge caching independently of route computation. This adds cache lifecycle and origin storage; it does not make traffic estimates fresher.

Next add warmed routing replicas. A query router sends each request to a worker that already loaded and verified the required bundle. Independent queries scale across workers while each search remains local. The cost is replicated graph memory and warm-up time. A cold process is not ready merely because its HTTP port responds.

The final interview design keeps each search local and scales requests with these warmed replicas. If long searches later dominate CPU, A* is a possible follow-up: it uses an estimate of remaining cost to explore promising paths first. That estimate and the implementation must preserve the shortest-path guarantee. Precomputed shortcuts are another extension, with their own update cost; neither is necessary to explain the working design.

Geographic partitioning is also optional. It becomes relevant when a full graph no longer fits economically on a worker. A route can cross several boundaries, so simply choosing the nearest border is incorrect. Keep this as a clearly separate expansion discussion; the main capacity plan uses full graph replicas and does not depend on a regional routing protocol.

08 / Publish traffic as a coherent release

A build pipeline accepts trusted map edits and consented traffic observations. Map matching associates a sequence of observations with plausible directed roads; one noisy GPS point is weak evidence. Reject implausible jumps, aggregate speeds and use historical estimates where current samples are sparse. Trusted closures remain hard restrictions, rather than merely very slow travel weights.

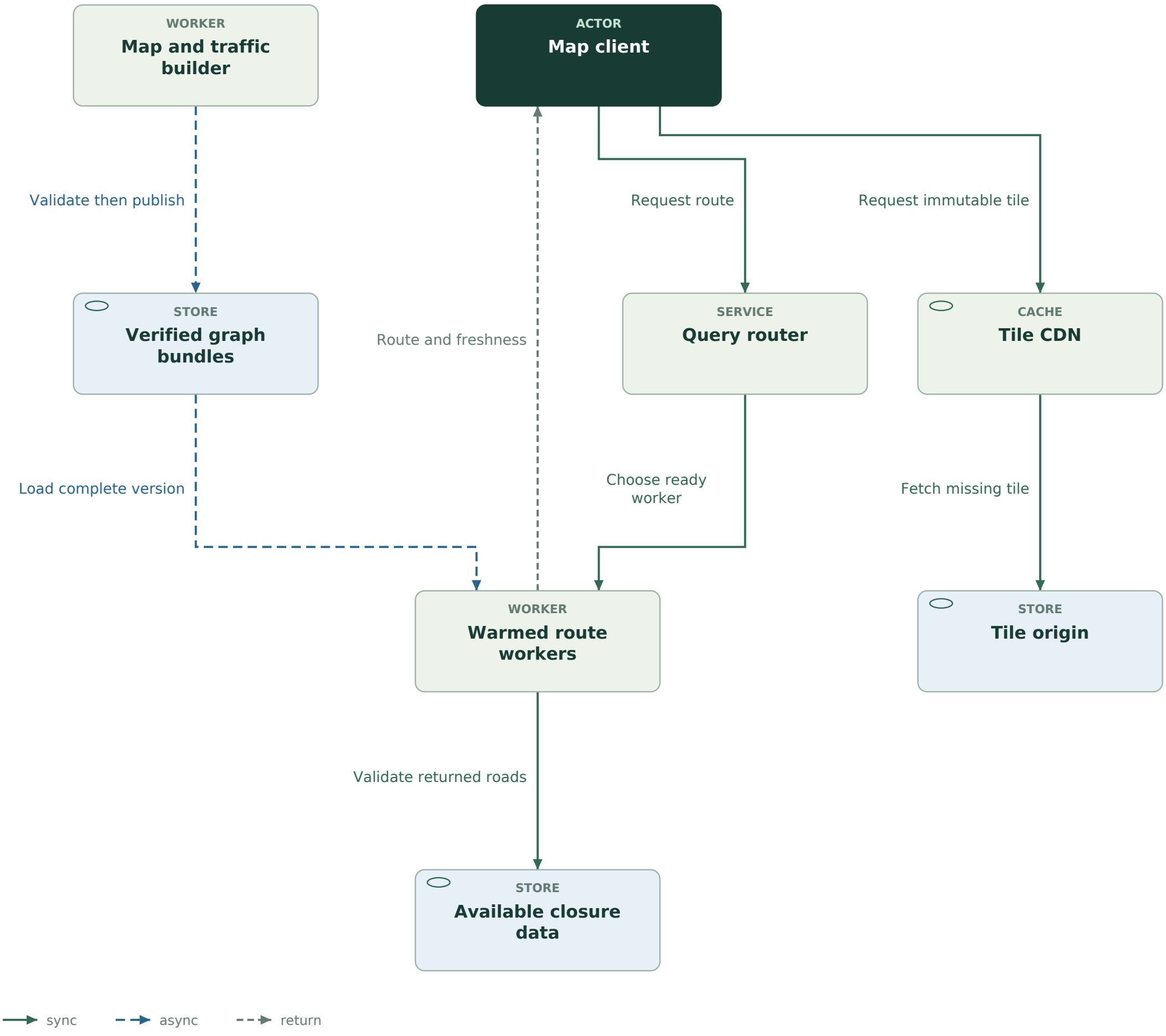
A candidate bundle contains topology, turn rules, weights, spatial indexes and any compatible shortcut structures. Check connectivity, access restrictions, checksums and representative routes against the reference search. Stage it on required workers before publishing its manifest. Failed uploads or half-built indexes must not become a serving release.

After validating compatibility, atomically change the active pointer to the new bundle. In-flight requests keep their old bundle, so cleanup waits until they finish. Requests may use different complete versions during rollout, but one request never mixes them. Retained releases also stay available.

Urgent closures additionally invalidate affected cached routes or prompt navigation recomputation. Validate their edge identities against the selected topology. A bundle name alone is not a correctness proof: the build and serving checks establish that its components can actually be used together.

Route computation and tile delivery scale separately

Route requests use warmed workers that retain one complete graph bundle and check applicable closures. Tile requests use the CDN; map and traffic publication prepares the next verified bundle in the background.



09 / Trace the final request and its cache boundary

Request q61 asks for A to D while bundle g12/w8 is active. Follow the request in order:

1. **Admit the request.** Authenticate and apply a work budget.
2. **Choose one model.** Capture the bundle reference, then snap the endpoints under the car profile.
3. **Search.** Find A-B-D = 8.
4. **Reconstruct the roads.** Build the real-road sequence before turns and geometry, because access checks concern those roads. An optional accelerated variant first expands shortcuts into their underlying roads.

Before releasing the response:

1. **Validate known closures.** Check the expanded path against available closure data; record its version and validation time.
2. **Recompute if necessary.** If B-D is closed, reject that path and search a compatible updated model, choosing A-C-D = 11 if permitted.
3. **Respect the remaining budget.** If recomputation cannot finish in time, return an explicit retry/degraded outcome. Never label a forbidden old path as a successful current route.

A route-cache hit follows the same closure policy. Immutable bundle keys prevent accidental version mixing, but they do not override a deliberate urgent-closure invalidation. Return traffic freshness and whether historical weights were used. Release the graph reference after response construction.

An incident reported after the stated validation boundary can invalidate an already returned route. An active navigation session receives a refresh notice and requests another route. The service can act only on information it has received; it cannot recall an answer already sent.



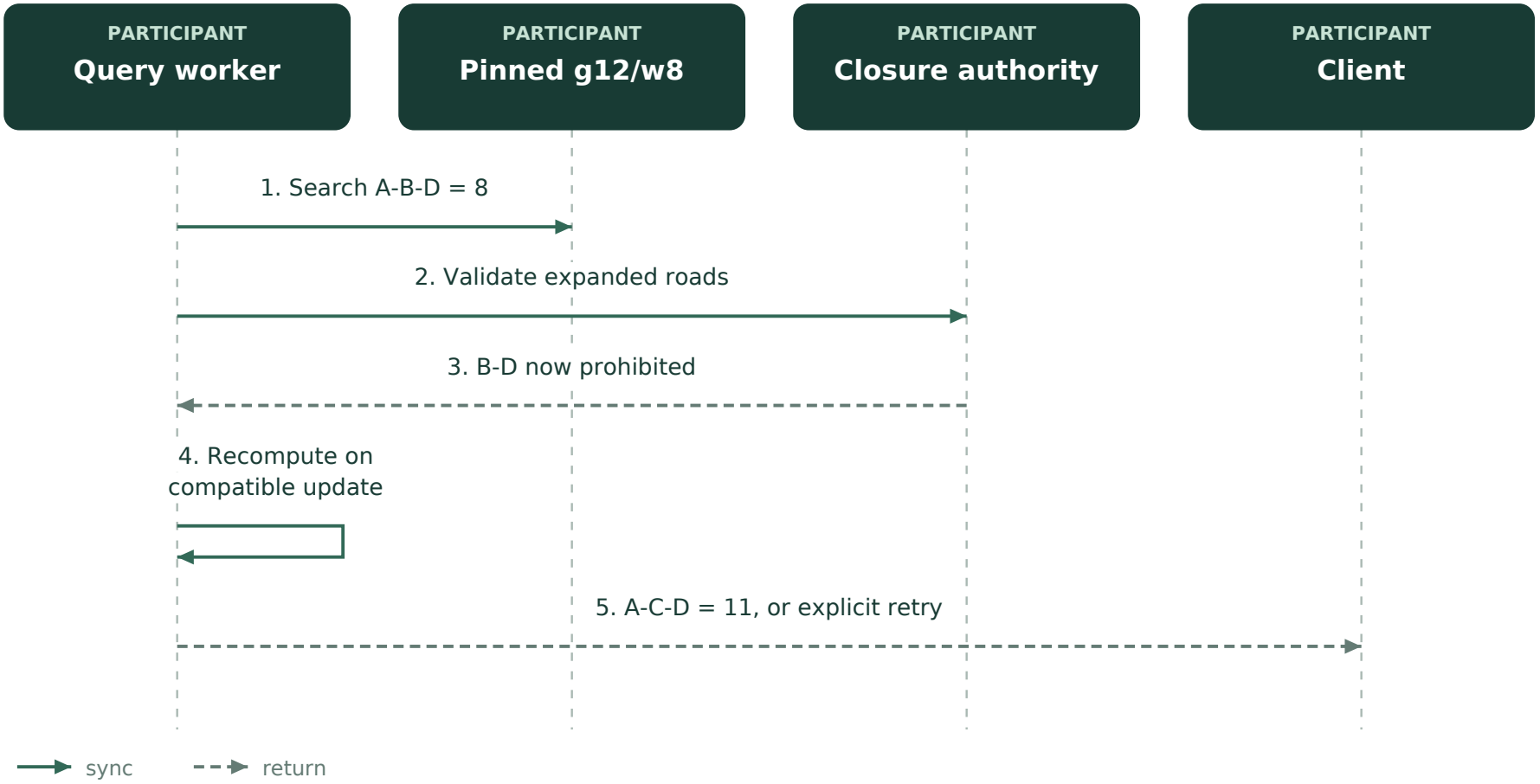
INTERVIEW CRITICAL

A cached route still needs closure policy

A versioned cache prevents accidental mixing of graph releases. It does not authorize returning a path through a newly enforced closure; final validation and invalidation remain part of the contract.

Closure arrives during q61

A compatible original search does not bypass final closure validation.



10 / Check legal movement, search and version consistency

Check three things: the graph represents legal movements, the search finds the right path, and the request uses compatible data throughout. Each item addresses a different source of bad directions. A fast algorithm cannot compensate for a missing one-way restriction, and an accurate map cannot compensate for greedy path selection.

Dijkstra works here because the selected costs stay fixed and nonnegative while the query runs. Once the cheapest unsettled state is selected, reaching it through another unsettled state cannot make it cheaper. In the example, C is explored first without committing to C-D; B then supplies the better route to D. Include disconnected destinations and zero-cost edges in tests.

For ordinary updates, build the replacement separately and let a query finish on its captured graph. New requests can select the replacement. Retaining the old object while a query references it prevents an update from changing the meaning of a path halfway through its calculation. Memory management details belong to implementation review.

Known closures require a separate response check because avoiding a prohibited road matters even when the search began earlier. This does not guarantee awareness of incidents never reported to the service. Future departures, continuously changing edge costs and specialized acceleration have additional assumptions; they are optional follow-ups, not hidden dependencies of this baseline.



INTERVIEW CRITICAL

A shortest path is relative to its model

The result is only as valid as its road restrictions and chosen costs. Keep one coherent graph per request, and handle newly known closures explicitly before returning it.

11 / Recover service without inventing safe roads

A routing-worker crash loses an in-flight calculation, so the client retries, potentially on a newer bundle. A build crash leaves unadvertised artifacts. A bad release can roll back to a retained compatible bundle, while closure enforcement still follows its explicit freshness policy. If urgent restrictions are too stale to satisfy the contract, refuse affected requests or disclose the permitted degraded mode.

Measure route latency by length and region, CPU/query, snapping distance, no-route rate, traffic age, expanded-path restriction violations and ETA error. Aggregate ETA error can hide a poorly modeled road class, so inspect cohorts and compare predicted with observed trips carefully. Preserve only the location history actually needed and restrict administrative map/closure updates.

Test one-way roads, forbidden turns, overpasses and disconnected islands. Optional regional or accelerated variants also need region exit/reentry and closure-under-shortcut tests. Compare candidate engines with a trusted base search before a limited rollout. Load tests include matrices and long routes, not only easy urban paths. Reserve reroute capacity for active navigation during incident spikes.

The next scaling decision follows measurements: lower query CPU is of little value if a ten-minute rebuild cannot meet one-minute traffic freshness. Explain both serving and update cost before recommending an acceleration method.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1; NFR 1	Versioned tiles use a CDN; warmed route workers handle search separately.	Measure tile bandwidth, cache misses and route CPU independently at the stated load.
FR 2, 4; NFR 4	Turn-aware search retains one compatible graph bundle and returns its versions.	Test the eight-minute path, one-way roads, overpasses and disconnected endpoints against a trusted search. ETA remains an estimate.
FR 3; NFR 3, 5	Validated releases, a final closure check and navigation refresh handle changes.	Close B-D during q61; require recomputation or an explicit failure. Measure update age; events after release cannot be recalled.
NFR 2	Warmed replicas, bounded admission and retained releases support service continuity.	Load-test p95 below 300 ms with long routes and a failed worker; validate the 99.9% objective through monitoring. Capacity arithmetic alone proves neither.
NFR 6	Authenticated work budgets and restricted location/administrative data protect access.	Try unauthorized closure changes and inspect cache/log scope; verify retention applies to location data.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: One road model; check closures before replying.

Interview prompt	Recall the mechanism and limit
What is a route?	The lowest-cost legal path for the chosen vehicle rules and road-data version; arrival time is still estimated
Why separate tiles?	A CDN can reuse immutable map images; each route needs its own computation
Why keep incoming-road state?	Whether a turn is legal depends on which road brought the vehicle to the intersection
Why begin with Dijkstra?	It gives a correct comparison result for fixed, nonnegative road costs

Interview prompt	Recall the mechanism and limit
What does a shortcut mean?	Its costs and restrictions must match the chosen road-data version; expand it into real roads
What does pinning achieve?	The query keeps one complete data bundle; cleanup waits until it finishes
What changes on a closure?	Check the route's actual roads, recompute or fail, and invalidate affected cached routes
When shard geography?	When complete graph copies cost too much; routes must still support repeated border crossings

A concise closing is: "I start with a correct local road search, separate tile delivery, and replicate warmed graph workers. Acceleration is justified by measured CPU and validated against the base search. Each request keeps one compatible bundle and checks known closures before release. I accept explicit freshness and recomputation limits rather than returning an invented legal path."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What is the first distinction in a maps interview?

Model answer

Separate drawing a map from computing directions. Tiles are reusable visual objects, while a route is a legal weighted path for particular endpoints and preferences. That distinction explains why CDN bandwidth and search CPU need different capacity estimates. Define departure time and access rules before choosing an engine.

Interviewer follow-up

Does a nearby road make a valid snap?

No. Direction, vehicle access, turns and actual connections matter; an overpass can be geographically close but inaccessible.

What the answer must demonstrate: Separate drawing a map from computing directions.

02 / FOUNDATION

Why does A-C-D lose even though A-C is cheapest?

Model answer

Its full cost is 3 + 8 = 11, while A-B-D costs 4 + 4 = 8. Dijkstra keeps alternative tentative distances, settles C and then B, and improves D before settling it. It does not commit to the cheapest first edge as an entire route. The proof assumes fixed nonnegative costs and a correct legal-state model.

Interviewer follow-up

Can changing live weights be read during this search?

Not under that static proof. Pin a compatible model or use a separately justified time-dependent algorithm.

What the answer must demonstrate: Its full cost is 3 + 8 = 11, while A-B-D costs 4 + 4 = 8.

03 / APPLIED

What does 2,000 requests/s at 50 ms CPU imply?

Model answer

It requires 100 CPU-seconds per second, or 100 fully busy cores before headroom. At 60% utilization the rough planning value is 167 cores before redundancy. This is not a deployment guarantee: long routes, memory locality and traffic mix must be benchmarked. Tile delivery remains a separate high-byte workload.

Interviewer follow-up

Why not add HTTP threads first?

Threads do not create CPU capacity or reduce graph exploration. Determine whether CPU, memory or network is limiting.

What the answer must demonstrate: It requires 100 CPU-seconds per second, or 100 fully busy cores before headroom.

04 / APPLIED

How can an update avoid corrupting an active route?

Model answer

Build and verify immutable compatible artifacts, then activate their manifest atomically. A request acquires and retains one bundle reference. Cleanup cannot reclaim that bundle until its readers finish. This prevents an active search from combining old shortcuts with incompatible new weights, while permitting later requests to use the new version.

Interviewer follow-up

Is the manifest itself proof of compatibility?

No. Build validation and serving checks establish compatibility; the manifest records the set they validated.

What the answer must demonstrate: Build and verify immutable compatible artifacts, then activate their manifest atomically.

05 / APPLIED

B-D closes while the eight-minute route is running. What happens?

Model answer

The worker validates the expanded road sequence against the closure version at its final boundary. If that version forbids B-D, it recomputes using a compatible model or returns an explicit retry. It cannot release a known-invalid route merely because the original graph was pinned. An incident reported afterward may require a later navigation refresh.

Interviewer follow-up

Can a short cache TTL replace this?

No. A cached route may be invalid before its TTL ends. It needs the declared closure-check and invalidation policy.

What the answer must demonstrate: The worker validates the expanded road sequence against the closure version at its final boundary.

06 / FOLLOW-UP

Why is choosing the nearest regional border unsafe?

Model answer

The minimum-cost legal route may cross a farther border, leave and reenter a region, or use a road that looks geometrically indirect. An overlay must represent valid interregional path costs and preserve the search problem. Regional boundaries are deployment boundaries, not road restrictions. Keep full graph replicas when their memory cost is acceptable.

Interviewer follow-up

What is the added operational cost?

Compatible overlay/local releases, cross-region coordination, more complex expansion and additional failure behavior.

What the answer must demonstrate: The minimum-cost legal route may cross a farther border, leave and reenter a region, or use a road that looks geometrically indirect.

07 / FOLLOW-UP

How would you justify A* or preprocessing?

Model answer

First measure whether search CPU is the bottleneck. The chosen final design can scale independent local Dijkstra searches with warmed replicas. A* or precomputed shortcuts are further optimizations, tested against that reference. Explain their additional correctness and update assumptions only if the interviewer asks to extend the design.

Interviewer follow-up

What if updates rebuild too slowly?

Retain a correct fallback or choose an update-friendly method; faster queries do not compensate for failing the freshness contract.

What the answer must demonstrate: First measure whether search CPU is the bottleneck.

08 / FOLLOW-UP

What do you say when traffic data is unavailable?

Model answer

Use historical travel weights only if the product permits it, label freshness and preserve known access restrictions. Invalid topology or no legal connection requires failure or a verified base-search fallback, not straight-line directions. Monitor traffic age separately from query success so an available endpoint cannot conceal obsolete estimates.

Interviewer follow-up

What do you test before release?

Turns, one-way roads, overpasses, disconnected endpoints, border reentry and closure invalidation, plus representative long-route load.

What the answer must demonstrate: Use historical travel weights only if the product permits it, label freshness and preserve known access restrictions.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design q61 from A to D, close B-D during the request, and defend your scaling decisions.

- Agree the numbered functional requirements and non-functional targets, including departure time, legal paths, freshness and privacy, before drawing components.
- Calculate route CPU and tile throughput.
- Draw the one-server route flow.
- Explain Dijkstra with the eight-versus-eleven-minute example.
- Add only justified caching, replicas and acceleration.
- Use the requirements check to validate routing, latency, freshness and failure behavior; state what the calculations or tests still have not established.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

q61 finds A-B-D, but B-D closes before the reply. What must happen?

Keep one compatible road-data version for the search, then check known closures before replying. Recompute a legal route or return the stated failure; a cached route needs the same check.

One road model; check closures before replying.

Which resources grow when route queries, map viewing or retained road versions increase?

Route queries need CPU, map tiles need network bandwidth, and retained road graphs need memory.

Compute, bytes, versions.

Does the displayed ETA promise when the driver will arrive?

No. It estimates arrival using the chosen road model and the updates received so far.

Model time is estimated time.

Summary and interview notes

Find the lowest-cost legal route using one compatible road-data version, then check known closures before replying. Scale route computation and map-image delivery separately, and state how current each answer is.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Then establish fixed-cost turn-aware search.

• Cache immutable tiles and replicate warmed route workers.

• Validate shortcuts against real-road expansions.

• Keep one bundle per request and protect its lifetime.

• Return versions and honest degraded states.

Interview tips

• Use the A-B-D versus A-C-D trace to explain the algorithm.

• Quantify update cost as well as query latency.

Important qualifications

• Future departures need a time-dependent model.

• Cross-region graph partitions require a correct overlay.

Explore the advanced version

A* reopening and heuristic conditions: Develop the formal search implementation when the interviewer asks beyond the baseline proof.

Time-dependent FIFO routing: Future departures change edge costs and algorithm assumptions.

Regional overlay construction: Necessary when the graph cannot be economically replicated.

Artifact deletion versus publication: The full lifetime protocol matters for a storage-level implementation.

Technical references

OSRM API documentation
Primary descriptions of route, nearest, table, and match operations in a routing implementation.
https://project-osrm.org/docs/v5.24.0/api/

pgRouting Dijkstra documentation
Versioned primary Dijkstra cost API reference. The worked graph uses nonnegative travel costs; this link is not a claim about the newest pgRouting release.
https://docs.pgrouting.org/3.7/en/pgr_dijkstraCost.html

OSRM backend documentation
Official extraction, MLD partition/customization and CH contraction pipelines; benchmark update compatibility rather than assuming arbitrary dynamic restrictions.
https://github.com/Project-OSRM/osrm-backend

EXTENDED INTERVIEWS / 52

Design event-time click analytics

Interview version / 45-minute scope · Read the advanced version online

Count validated event-time clicks with durable input and a transactional duplicate-safe counter, then scale processing and report honestly on late data, hot keys and lag.

event time • watermarks • late events • streaming top-k

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Explain a complete durable queue and transactional-counter baseline.

• Keep logical identity, occurrence time and late-update policy explicit.

• Scale with one recoverable stream/output integration while bounding hot keys and backlog.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Data partitioning and sharding; Database indexes: B-trees, composite keys and query access; Replication and durability

8 interview questions with model answers and answered follow-ups.

01 / Decide what the number means

A click analytics system turns identified events into counts and rankings. Begin by asking whether the metric is received requests, validated clicks, unique people or billable interactions. These require different identities and validation. We count validated clicks by when they occurred, with minute counts, campaign rollups and hourly top 100 ads. Financial settlement and fraud-model training are separate products.

Click C901 belongs to ad A7 and occurred at 09:00:58, but reaches the collector at 09:02:05. It must revise the 09:00 minute, taking the count from 99 to 100. A repeated delivery of C901 must leave 100 unchanged. A second legitimate click with a different accepted identity may count separately; uniqueness of transport identity does not prove legitimacy.

The complete initial flow is validate -> durably append -> identify the event-time window -> atomically record identity and contribution -> expose the count. A single database and processor can implement it. Distribution is justified later by throughput, state size and recovery time, while this meaning of the count remains unchanged.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Accept validated clicks.** Receive bounded batches with trusted event identity, ad identity and occurrence time; report acceptance after durable storage. Identity distinguishes a retry from another event, not a bot from a person.

2. **Serve counts and rankings.** Return event-time minute counts, campaign rollups and hourly top 100 ads under a named metric and validation policy.
3. **Explain revisions.** Expose metric/policy version, update time, revision, progress and preliminary/final status. Let allowed late events revise their original window.
4. **Inspect delayed evidence.** Retain beyond-policy events for investigation. Financial settlement, fraud-model training, historical audit snapshots and privileged historical rebuilds are separately controlled extensions.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Plan for one billion events/day, 200,000/s at peak and 200-byte payloads. Include duplicates, hot ads and catch-up work when testing capacity.
2. **Latency and availability.** Target normal accepted-to-dashboard delay within five seconds, ingestion p95 below 100 ms, narrow query p95 below 200 ms and 99.9% ingestion availability under admitted load.
3. **Durability.** Accepted events must survive one zone failure under the replicated-log policy. Retained input and recovery capacity are finite; stop admitting work before accepted input becomes unrecoverable.
4. **Counting and finality.** One trusted event identity contributes once within the supported replay window. Allow two minutes of ordinary lateness after the window end according to declared event-time progress. Final means closed under that policy, not that no older event can arrive. Reports expose incompleteness rather than treating a missing shard as zero; independent live counters do not form one global snapshot.
5. **Retention and recovery.** Retain raw envelopes for 30 days and online event identities for 24 hours. Never treat an expired identity as a fresh click on sender retry or internal replay; older reconstruction needs a controlled rebuild.
6. **Security and privacy.** Authenticate collectors and campaign queries, validate provenance and timestamp ranges, minimize user identifiers and restrict raw evidence. Define deletion treatment for derived data.

04 / Make one transactional counter recoverable

Start with a durable queue, one processor and one transactional database. The collector validates a request and acknowledges acceptance only after the queue durably stores it. The processor handles C901 as follows:

1. **Begin the transaction.** Check the trusted scoped identity and payload fingerprint.
2. **Apply a new contribution atomically.** Insert the processed identity and update A7's 09:00 count from 99 to 100 in that transaction.
3. **Commit.** Make the identity and increment durable together.
4. **Acknowledge input.** Only after commit, acknowledge the input to the queue.

If the transaction commits but the input acknowledgement is lost, the queue can deliver C901 again. The saved identity makes the repeated transaction leave the count unchanged. If the transaction fails, neither the identity nor the increment survives, so replay can apply both. Recording identity and count in separate transactions could instead lose or duplicate a contribution.

Queries read committed counters. A small hourly report sums each ad's minute counters and sorts the complete totals on that machine. Results remain preliminary until the chosen lateness policy closes their windows. No stream framework is needed to demonstrate this working flow.

The baseline reaches its limit when database write throughput, identity storage or recovery time exceeds its budget. A hot ad can dominate one row while other counters remain idle. Partitioning and batching should address those measured limits while preserving the same transaction boundary.



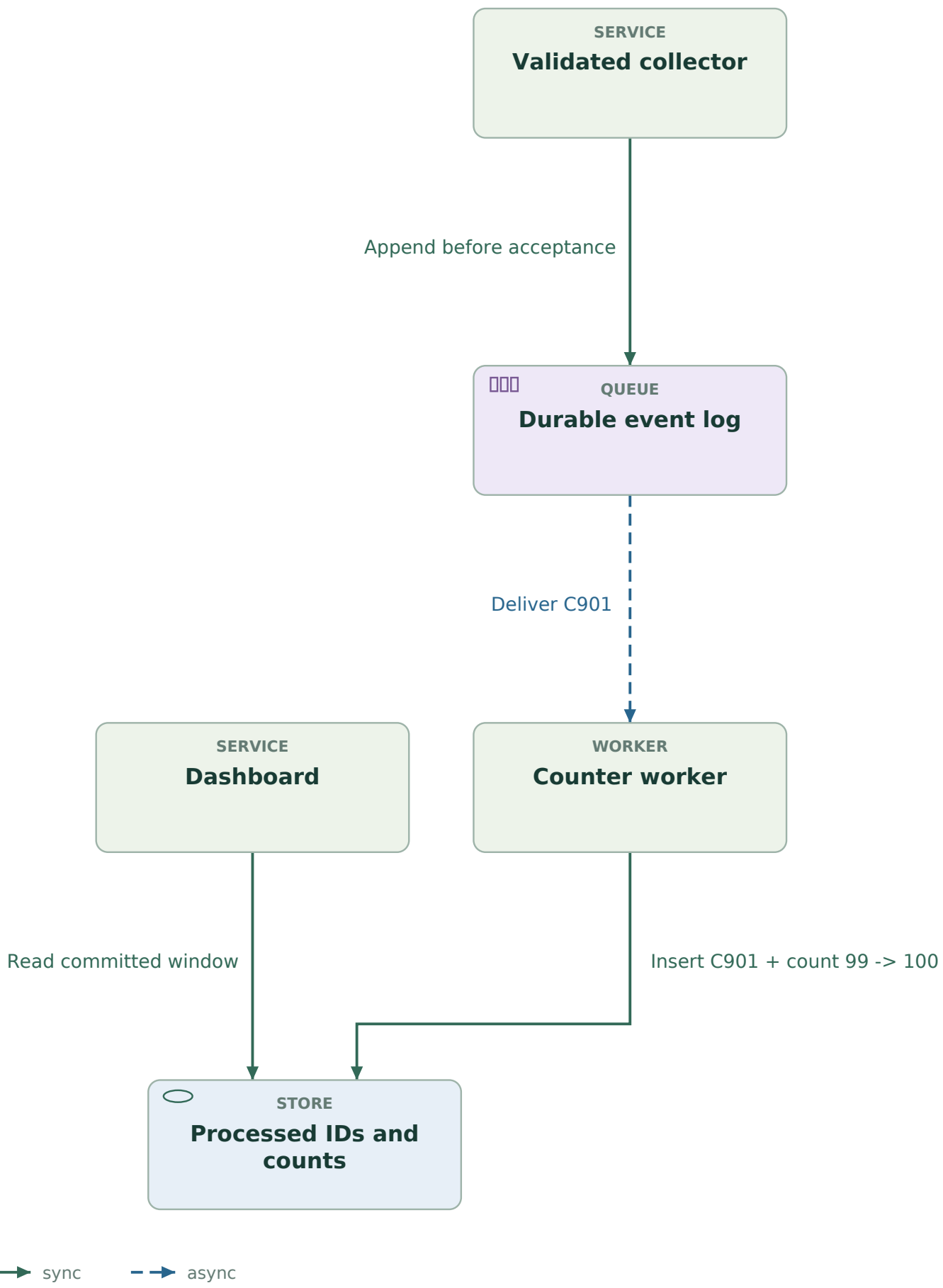
INTERVIEW CRITICAL

Identity and contribution belong together

An atomic increment prevents lost concurrent writes, but does not suppress a repeated logical event. Commit the processed identity and its count change together so replay can safely discover the existing effect.

One durable click and counter

One local transaction records both identity and contribution.



05 / Understand event time and report finality

Event time is occurrence time; processing time is when a worker handles the event. A watermark is declared progress through event time used to decide when to emit or close windows. Allow two minutes of ordinary lateness after the window end according to that progress. Final means closed under this policy, not proof that no older event can ever arrive.

Beyond-policy data is retained for investigation or a separately controlled rebuild. An expired online identity must not silently become a fresh click merely because deduplication state was removed. This applies to internal queue replay as well as sender retries.

06 / Count raw bytes, identity state and recovery work

Assume one billion events/day, a 200,000/s peak and 200-byte payloads. Average rate is about 11,574/s, while peak payload is 40 MB/s. The large peak-to-average difference makes durable buffering useful, but retained input is finite and cannot absorb an unlimited outage.

State or work	Calculation	Consequence
Raw input	1B x 200 B = 200 GB/day	Thirty days is 6 TB before copies
One-day identities	1B x 32 B = 32 GB	Deduplication can exceed counter state
Hour of minute counts	1M ads x 60 x 24 B = 1.44 GB	Dimensions and engine overhead add more
Ten-minute peak outage	200K/s x 600 = 120M events	24 GB payload awaits processing
Catch-up at 300K/s	120M/(300K - 200K) = 1,200 s	Twenty minutes with continued peak input

The 32 GB estimate covers only raw identity payload, not database indexes, fingerprints and storage overhead. Larger batches reduce per-transaction work but may increase time before a count becomes visible. Country and device dimensions also multiply distinct counter keys. Bound supported dimensions and benchmark the database with realistic duplicates and skew before choosing batch size or the number of partitions.

07 / Separate evidence, identity and counters

Click ingestion

```
POST /clicks
```

Input	Meaning or source
Event ID	Stable identity of one logical event; C901 in the example.
Ad ID	The ad receiving the contribution; A7 in the example.

Input	Meaning or source
Impression provenance	Evidence used to validate where the click came from.
Full occurrence timestamp	When the click occurred, including date/time context.
Tenant and collector identity	Derived from verified credentials, not trusted from arbitrary payload fields.

Acceptance follows durable append; it does not mean the event is billable or already visible. Retry an uncertain response with the same identity and immutable payload. Reject conflicting content under one identity.

Identity and counter keys

Record	Key	Purpose
Processed event	`(tenant, source, eventId)`	Identify one logical input; retain its payload fingerprint.
Counter	`(ad, minute, metric, policyVersion)`	Identify the report bucket that input changes.

Deduplicate by trusted event identity before a changed ad field could send a conflicting retry to another counter.

Stored evidence and results

Record	Information retained	Why it matters
Raw envelope	Input, occurrence time and receive time	Supports replay and explains delayed delivery.
Processed-event record	Scoped identity and fingerprint within the retry horizon	Recognizes a repeated contribution.
Window count	Count and update/revision metadata	Serves a result whose age and changes are inspectable.
Metric/validation policy	Versioned campaign and dimension interpretation	Prevents a current campaign lookup from silently reassigning yesterday's history.

Count-query response

Returned information	Meaning
Committed counts	Values visible after the counter transaction commits.
Metric and policy	The definitions used to interpret those values.
Updated-through information	How far processing has progressed.
Preliminary/final status	Whether the window is closed under the lateness policy.

This design promises timely useful reports, not one globally instantaneous snapshot across every independently updating shard. A stronger reproducible cross-shard report is a follow-up with additional coordination and retained snapshot costs.

08 / Partition independent ads and protect hot ones

First use a replicated durable queue or log so intake can continue through bounded processor downtime. Collectors acknowledge only its configured durable append. Retention and admitted input are finite; expose lag and reduce new admission before an outage can make accepted work unrecoverable.

Partition ordinary processing by ad so related window updates have a clear owner. Different ads can progress independently. Batch database work to amortize transaction overhead, while keeping each event identity and count contribution in the same committed transaction. A retrying batch checks every event identity rather than assuming the entire previous attempt failed.

Measure skew before splitting keys. If A7 receives 40,000 events/s, distribute it across 16 partial counter keys using a stable suffix derived from event identity. Each sees roughly 2,500/s on average. A report combines all required partial counts for A7 before presenting its total. Stable event identity still governs whether a retried click contributes again.

The cost is extra partial state and report work; ordinary ads should retain the simpler path. A counter shard outage can make a report late or incomplete, so disclose that state instead of interpreting a missing partial as zero. More API servers do not repair a hot database row; batching, placement and bounded admission address the actual write work.

09 / Use one stream framework with a defined output boundary

For the larger workload, Kafka can retain identified input and Flink can provide partitioned processing, event-time progress and recovery checkpoints. A checkpoint records processing state and the input positions from which it can resume. Explain what the counter does when recovery repeats an event; naming the framework does not answer that question.

Choose an idempotent transactional database sink for this design. For each accepted contribution, its transaction inserts the processed-event identity and changes the appropriate counter together. If that identity already exists with the same fingerprint, the sink makes no second change. Several events may share a batch

transaction. Record that the input has been processed only after confirming the database transaction committed.

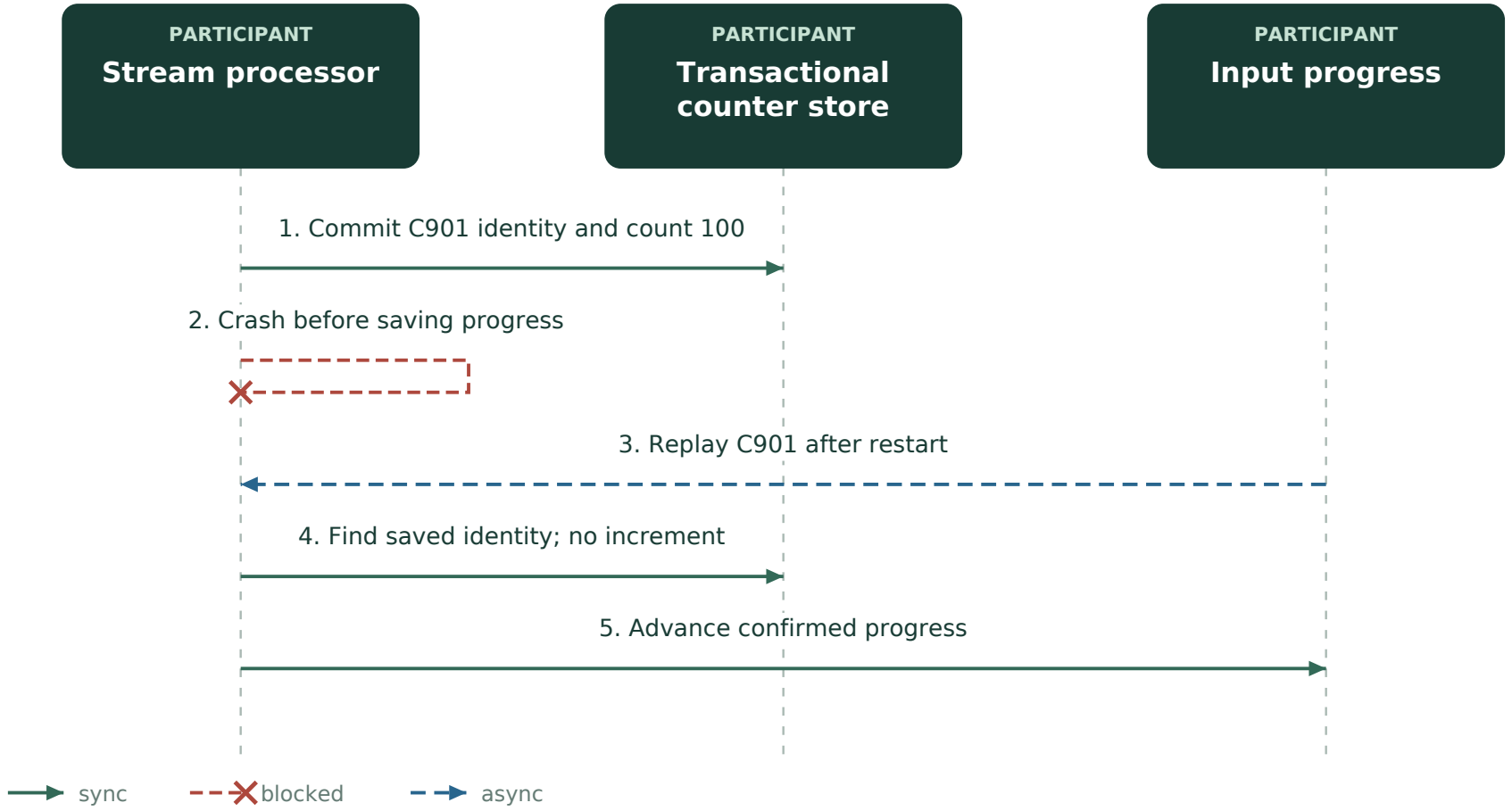
A crash after the counter transaction but before checkpoint/progress completion causes replay. The sink finds the saved identities and does not increment again. A crash before commit leaves neither effect nor identity, so replay applies the work. This is the same baseline proof at a larger processing scale.

Flink's internal recovery guarantee does not make an arbitrary external write transactional. If we later replace the sink with bulk immutable output or another database, verify its checkpoint-aware or idempotent integration explicitly. Detailed generation-publication protocols are unnecessary to explain this selected sink contract.

Never automatically replay input beyond the retained identity coverage. If recovery needs older input, stop and rebuild the affected counters from retained raw evidence under the controlled rebuild process before resuming. Otherwise a previously committed count could be incremented again after its identity expired. Retention is part of this recovery contract, not just storage cleanup.

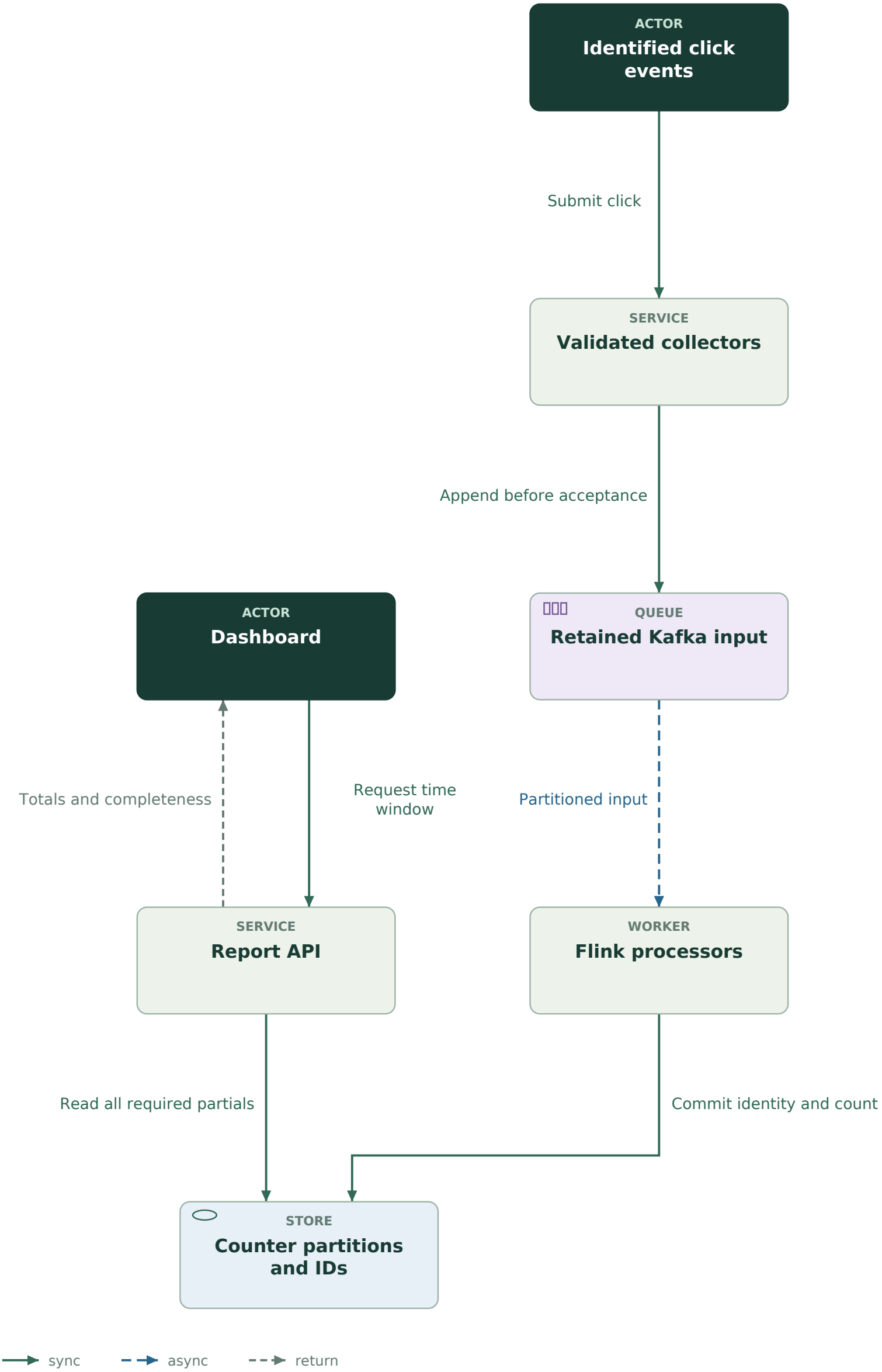
A crash repeats delivery, not the count

The chosen database sink supplies the duplicate-safe output boundary.



Durable input feeds partitioned counters and reports

Collectors acknowledge durable Kafka input. Flink processors commit each event identity with its counter change before advancing progress. Reports combine the required partial counts and expose window completeness; a missing partial is not zero.



10 / Explain a late event to a dashboard reader

Late-event timeline

Observation	Result
Watermark passes 09:01	The 09:00-09:01 window may emit preliminary revision 4.
C901 arrives while the watermark is 09:01:30	Its occurrence timestamp still assigns it to the 09:00 window.
Apply C901 within allowed lateness	Publish revision 5 with count 100.
Watermark reaches 09:03	The two-minute allowed-lateness boundary for that window ends.

With several active inputs, the slowest relevant watermark limits combined progress. Otherwise one delayed partition would be excluded while a result falsely claims completeness. An idle-input policy can permit progress, but data arriving when that input returns still follows the late-data rule. Idleness is not proof that old events no longer exist.

A query authenticates campaign scope and reads compatible committed metric/policy rows. It returns their update time, revision and finality. Paginate a saved report when stable pages matter; otherwise disclose that live counts can change between requests. Do not imply that a cursor alone freezes the dataset.

When the window closes under policy, later evidence enters a correction stream. Do not advance watermarks just to improve a freshness chart. A lagging honest result is different from an apparently final result produced by suppressing inconvenient inputs.

11 / Build useful reports from complete per-ad totals

The dashboard reads committed minute counters, then groups compatible metric/policy values for campaign summaries. A periodic report job sums an ad's minute and partial counters for the requested hour before sorting ads for top 100. Keep deterministic tie handling and state the report's build time and completeness. Those independently changing counters may have been read at different times.

Do not rank partial contributors before summing each ad. If Red has 6 on each of two workers, it totals 12 even though local Blue = 7 and Green = 7 beat it separately. The report needs Red's complete total first. This simple example is enough to explain why a fast local winner list is not automatically a valid hourly report.

Closed windows give more stable reports, but final still means closed under the stated lateness policy. A missing shard or unresolved input delay cannot be silently counted as zero. Return an older labeled completed report, expose incompleteness or fail the precise report request.

Beyond-policy events remain in a correction queue for investigation or a controlled historical rebuild from retained raw evidence. Keep the main product's live counting path simple. A separately versioned, reproducible global correction/report system is a worthwhile extension when audit requirements demand it, with its ownership and publication protocol designed explicitly.

INTERVIEW CRITICAL

Combine each ad before ranking it

Red = 6 on two workers totals 12, even if local Blue = 7 and Green = 7 each win their worker. Sum the complete per-ad contributions before choosing report winners.

12 / Recover input, control cost and audit revisions

Monitor accepted-to-visible lag, oldest needed input offset, checkpoint duration, watermark age, late-event rates, duplicate conflicts, hot-key skew and correction differences. A high ingestion success rate can coexist with a stalled dashboard. Alert before retention deletes input still needed for recovery, and ensure processors have net capacity to drain backlog.

Authenticate collectors and campaign queries. Validate timestamp ranges and provenance so forged far-future events cannot drive progress. Minimize user identifiers, restrict raw-event access and define deletion treatment for derived datasets. A valid event ID is not an anti-bot mechanism: a malicious client can invent fresh IDs unless an upstream trusted contract limits them.

Test crashes before and after the sink transaction, duplicate collector batches, an idle source returning late data and a counter shard disappearing during report construction. Compare totals with an offline recount of a fixed retained source interval under the same policy.

Costs follow raw retention, identity lifetime, checkpoint state and dimensionality. Seven days of 32-GB/day raw identity payload would be 224 GB before indexes. Limiting live retries and correcting older data in a controlled batch can cost less than retaining every event identity forever.

13 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1; NFR 3, 4	Replicated input and a transaction coupling processed identity with the count protect accepted work.	Crash before/after the sink commit, replay C901 and lose a zone; require one contribution and durable accepted input within the supported model.
FR 2, 3; NFR 4	Event-time windows revise counts; reports combine complete per-ad partials and expose status.	C901 must revise 09:00 from 99 to 100. Test the Red/Blue/Green ranking example and a missing shard; do not claim a global snapshot.
NFR 1, 2	Partitioning, bounded batches, hot-key partials and backpressure address write demand.	Benchmark 200,000 events/s with skew and duplicates, measure all latency targets and monitor ingestion availability. Test catch-up while new input continues.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 4; NFR 5	Retention checks prevent unprotected replay; beyond-policy evidence enters controlled correction.	Attempt replay after 24 hours of identity coverage has expired; require a stop/rebuild decision, not a second increment. Raw evidence ends at 30 days.
NFR 6	Trusted source identity and campaign authorization restrict input and reports.	Inject forged timestamps, conflicting event payloads and unauthorized campaign queries; check private-data retention.

14 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Save identity with the count; retries cannot count twice.

Question	Main-design answer
Which time assigns C901 to a window?	Its occurrence time puts it in 09:00; arrival time explains the delay
Baseline?	Save the input durably, then save its processed ID and count change in one transaction
Why is increment alone insufficient?	Retrying delivery can increment the same event twice
What does a checkpoint do?	Save processing state and the input position from which recovery resumes
What makes a repeated database update safe?	The processed event identity and its count change commit together
What is a watermark?	Reported progress through event time; the lateness policy uses it to close windows
How does a hot ad scale?	Split it across stable partial keys, then combine all its partial counts before reporting
What happens under overload?	Keep accepted input, show processing delay and slow or reject new arrivals
What is deferred?	Reports from one exact global instant and a complete process for correcting historical results

Close with: "I define validated event-time clicks, then start with a durable log and a transactional counter that records each processed identity. At scale I partition and batch that same work, using one stream framework

with a verified idempotent sink. Late data updates its original window under a clear policy. Reports combine complete per-ad totals and honestly show age or incompleteness."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What metric are you actually counting?

Model answer

Validated identified clicks by occurrence time. Received requests, unique people and billable interactions have different rules, so the policy version and trusted provenance are part of the record. Transport deduplication does not establish that a distinct event is legitimate or billable.

Interviewer follow-up

Why keep raw input?

It explains revisions and supports bounded investigation or a controlled recount.

What the answer must demonstrate: Validated identified clicks by occurrence time. Received requests, unique people and billable interactions have different rules, so the policy version and trusted provenance are part of the record.

02 / FOUNDATION

What is the smallest complete design?

Model answer

A collector durably appends identified events; one worker transactionally inserts the processed identity and increments the correct ad/minute counter. Queries read committed counts. Saving both effects together makes a lost worker response recoverable without assuming every delivery occurs once.

Interviewer follow-up

Why not expose a stateless increment endpoint?

A timed-out caller can repeat the increment even when the first one committed.

What the answer must demonstrate: A collector durably appends identified events; one worker transactionally inserts the processed identity and increments the correct ad/minute counter.

03 / APPLIED

Where does C901 belong when it arrives at 09:02:05?

Model answer

Its occurrence at 09:00:58 assigns it to the 09:00 minute. If it is within the configured late-update policy, revise that original window from 99 to 100. Otherwise retain it for the correction process. Processing time must not silently answer a different business question.

Interviewer follow-up

What does a watermark mean?

Declared progress through event time, used to close windows under explicit assumptions; it does not rule out all late events.

What the answer must demonstrate: Its occurrence at 09:00:58 assigns it to the 09:00 minute.

04 / APPLIED

The sink commits and the processor crashes before progress is saved. What happens?

Model answer

Recovery replays the event. The sink transaction finds its saved scoped identity and makes no second count change. If the previous transaction had aborted, neither identity nor effect would exist and replay would apply it. This contract must be verified for the actual external store.

Interviewer follow-up

Does a framework checkpoint automatically cover every database?

No. Use a documented transactional/checkpoint integration or a deliberately idempotent sink.

What the answer must demonstrate: Recovery replays the event. The sink transaction finds its saved scoped identity and makes no second count change.

05 / APPLIED

How would you handle one ad with 40,000 events/s?

Model answer

First measure batching and database limits. If one counter remains hot, use stable partial keys, such as 16 salts averaging 2,500/s, then combine all partials before showing that ad's total. Stable event identity still prevents duplicate contribution. Splitting every ordinary key adds unnecessary report and state cost.

Interviewer follow-up

What if a partial is unavailable?

Disclose incompleteness, use a labeled completed report or fail; do not treat missing data as zero.

What the answer must demonstrate: First measure batching and database limits. If one counter remains hot, use stable partial keys, such as 16 salts averaging 2,500/s, then combine all partials before showing that ad's total.

06 / APPLIED

Why can worker-local top lists miss an hourly winner?

Model answer

Red = 6 on two workers totals 12, but each worker can select a different local item at 7. A report must aggregate each ad's complete total before sorting winners. This design uses a periodic report with stated build time; exact globally simultaneous rankings are a stronger follow-up.

Interviewer follow-up

Does a cursor create a fixed report?

No. Stable pagination needs a retained report or snapshot, not just a remembered key.

What the answer must demonstrate: Red = 6 on two workers totals 12, but each worker can select a different local item at 7.

07 / FOLLOW-UP

How long does a ten-minute peak backlog take to recover?

Model answer

There are 120 million events. If processing resumes at 300,000/s while 200,000/s still arrive, spare throughput is 100,000/s and recovery takes 1,200 seconds. Preserve admitted work, expose lag and tighten intake before retention is exhausted.

Interviewer follow-up

Can progress be advanced to make the dashboard look healthy?

No. That can falsely finalize incomplete windows.

What the answer must demonstrate: There are 120 million events. If processing resumes at 300,000/s while 200,000/s still arrive, spare throughput is 100,000/s and recovery takes 1,200 seconds.

08 / FOLLOW-UP

What happens to a very old resend after identity expiry?

Model answer

A24-hour online identity window cannot promise that an arbitrary historical resend is duplicate-safe. Enforce an admission policy for older work and use controlled reconstruction from retained evidence for historical repair. Do not silently treat forgotten identities as new clicks. Internal recovery obeys the same limit: stop automatic replay beyond retained identity coverage and rebuild affected counters from raw evidence instead of applying old inputs to existing counts.

Interviewer follow-up

When would you add exact global correction publication?

When reproducible audit requirements justify the additional snapshot, ownership and publication protocol.

What the answer must demonstrate: A24-hour online identity window cannot promise that an arbitrary historical resend is duplicate-safe.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Count late C901 exactly once in the database, replay it after a crash, then scale to a hot ad and a ten-minute backlog.

• Agree the numbered functional requirements and non-functional targets: the counted metric, identity, event time, lateness, load and durability.

• Draw the complete baseline after agreeing the requirements.

• Calculate retained state and catch-up capacity.

• Prove the transactional sink.

• Explain framework recovery and late updates.

• Check counts, report completeness, latency, retention and recovery against the numbered requirements; identify remaining benchmarks and advanced limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

C901 commits, but its queue acknowledgment is lost. Why does replay leave the count at 100?

The processed-event record and count change committed together. Replay finds that record and skips the increment; if the transaction failed, neither change survived.

Save identity with the count; retries cannot count twice.

A click arrives late. Which timestamp chooses its minute?

When it occurred. Arrival and processing timestamps explain the delay.

Count when it happened.

An ad's counts are split across workers. What must happen before ranking ads?

Combine all partial counts for each ad, then compare the complete totals.

Sum before top.

Summary and interview notes

Save each event identity with its count change so a retry cannot count it twice. Put allowed late clicks in their original window; route later evidence to corrections. Show report age and completion status so later corrections are understandable.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Then establish a simple recoverable counter.

• Use scoped stable event identities.

• Assign windows by occurrence time.

• Verify the framework's actual output integration.

• Combine hot-key partials before reporting.

Interview tips

• Use a lost sink acknowledgment to explain replay.

• Calculate recovery with spare throughput.

Important qualifications

• Exact global snapshot reports are a separate extension.

• Historical reconstruction is bounded by raw retention.

Explore the advanced version

Checkpoint-generation publication and stale job epochs: Needed for a different output store that stages bulk results; not required to teach the selected transactional sink.

Historical interval authority and versioned corrections: Add when audit-grade reproducible backfills become a requirement.

Exact global top-k publication: Stronger than this main design's periodic reports with explicit age/completeness.

Artifact lifecycle guards: A storage-level extension for staged checkpoints and retained output files.

Technical references

Flink event time and watermarks
Primary explanation of event time, parallel watermarks, late records, and windows.
https://nightlies.apache.org/flink/flink-docs-stable/docs/concepts/time/

Flink checkpointing
Explains recoverable stream state and the conditions behind checkpoint-based processing guarantees.
https://nightlies.apache.org/flink/flink-docs-stable/docs/dev/datastream/fault-tolerance/checkpointing/

EXTENDED INTERVIEWS / 53

Design a distributed unique-ID generator

Interview version / 45-minute scope · Read the advanced version online

Allocate unique integer IDs with a database baseline, then reserve durable numeric ranges so local counters can serve high throughput without per-ID coordination.

identifier bits • clock rollback • worker ownership • UUIDv7

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Separate unique allocation from business retries and strict ordering.
- Scale a durable database allocator with disjoint numeric ranges and synchronized local counters.
- Explain gaps, restart behavior, exact integer transport and the alternatives when requirements change.

Useful foundations: Capacity estimation: throughput, latency, concurrency and storage; Quorums, consensus, leases, and fencing; CAP theorem: consistency, availability, and partition tolerance; Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / Ask what the identifier must guarantee

An ID generator provides distinct values that other services use as record keys. Ask which namespace needs uniqueness, whether IDs must be integers, whether gaps are acceptable, and whether values must reveal creation order. Those are separate requirements. A unique value does not prove a record was committed, does not authorize access and does not make a retried business request safe.

Our order services need positive integers before batching database writes. Gaps are acceptable. IDs need not follow strict global real-time order and do not need to encode time. These choices let us build a straightforward allocator rather than begin with a custom clock-based format. Keep a unique constraint in the order database as a final detector of a violated assumption.

The complete flow is simple: the order service asks an allocator for an ID, receives a safely allocated value, and then uses it in its own order transaction. If that transaction's reply disappears, the order API uses a separate business request key to discover its result. Asking for another ID would not establish that the original order failed.

INTERVIEW CRITICAL

Record identity and business retry identity are different

A fresh generated value cannot tell you whether a timed-out order already committed. The order service needs its own stable request key and saved result.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Allocate identifiers.** Issue positive integer IDs within a named namespace for consuming services to use as record keys.
2. **Support bounded allocation.** Offer individual IDs and bounded batches, with explicit unavailable or exhaustion responses rather than wrapping into previously used values.
3. **Inspect namespace state.** Allow authorized inspection of allocation state and capacity. Namespace creation and migration are privileged, audited operations.

Gapless invoice numbering, secret access tokens, exact creation timestamps and business-request idempotency are outside the generator contract.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Plan for ten million IDs/s peak across 500 generator processes, or 20,000/s per process on average. Bursts and uneven distribution still require testing.
2. **Latency and availability boundary.** Target local p99 below 100 microseconds while the process has unused IDs already reserved for it. Local issuance may continue during an authority outage until those IDs run out; replenishment then needs the authority, and exhausted processes must wait within a deadline or fail explicitly.
3. **Uniqueness and durable allocation.** No successfully issued value in one namespace may be repeated under supported failures. Committed ranges and replay results must survive allocator failover; an asynchronous promotion that loses acknowledged allocation state does not meet this requirement. Unused values and non-global issue order are acceptable.
4. **Safe restart and recovery.** A restarted process abandons its previous range. Never restore uncertain allocation history or clone one active in-memory cursor into simultaneous issuers. Arbitrary live-memory cloning requires a stronger external allocation boundary. Backups cannot silently move the allocated boundary backward.
5. **Exact representation and access.** Preserve the full integer value across client types, for example with decimal strings where needed. Authenticate generators and namespace administration; a predictable ID never grants access to a business record.

04 / Allocate from one durable counter

Begin with one allocation service and an `Allocator` row:

Field	Purpose
`namespace`	The ID space whose allocation is being coordinated.
`nextValue`	The next integer available for allocation in that namespace.

A single-ID request follows this transaction:

1. **Lock.** Open a short transaction and lock the namespace row.
2. **Reserve.** Read its next available integer and increment `nextValue`.
3. **Commit.** Preserve the advance with the required durability.
4. **Return.** Send the allocated value only after that commit.

Concurrent requests take turns at this row, so they cannot receive the same value.

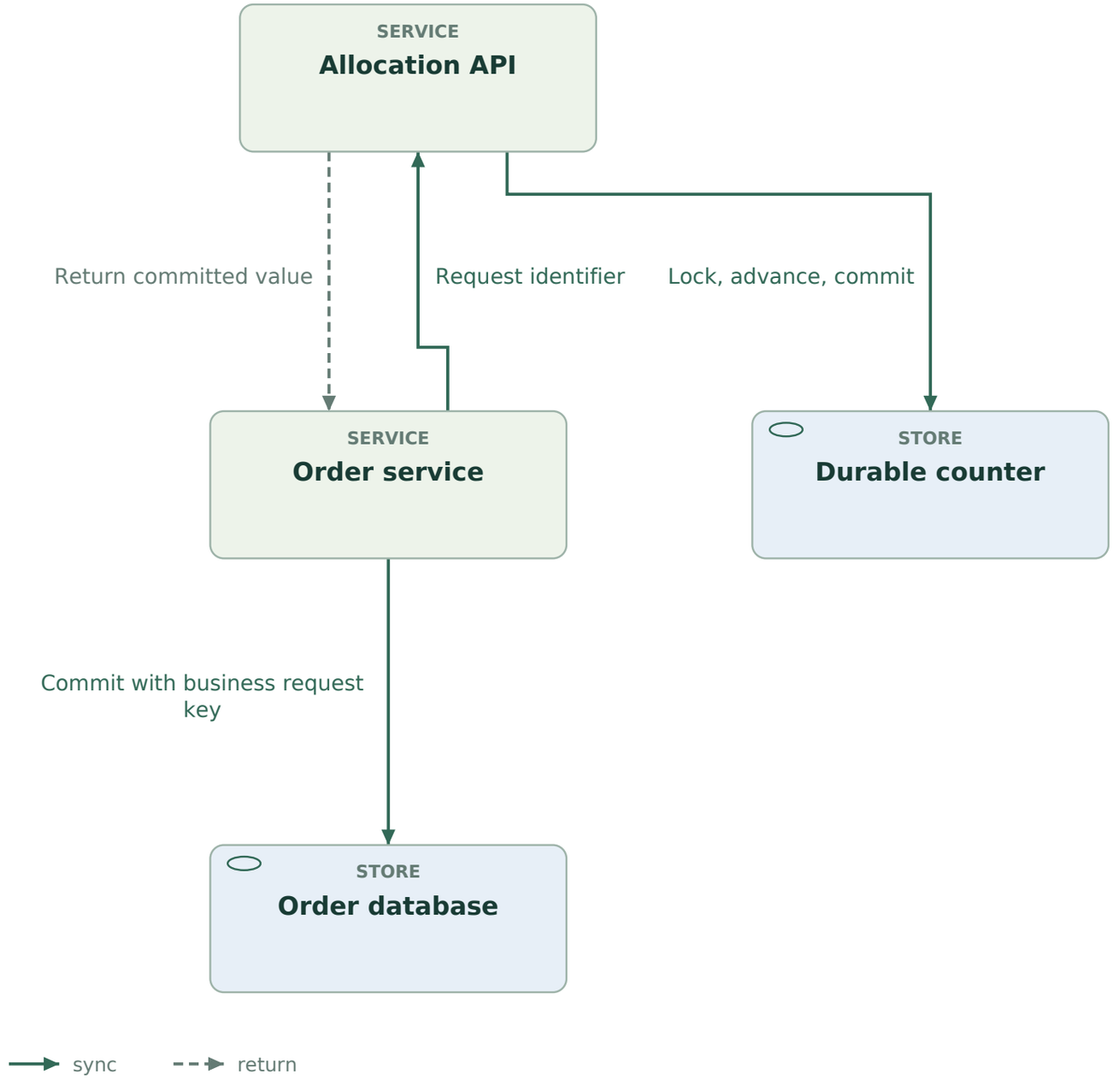
If nextValue is 1001, request A reserves 1001 and commits 1002 as the next value. Request B then gets 1002. If A crashes after commit but before replying, 1001 may never be used. That is an acceptable gap. It must not be recycled merely because the service did not observe the client using it.

A database sequence is another implementation option with its own documented caching and durability behavior. The essential contract is to preserve acknowledged allocation state across supported failures and never cycle into used values. A small deployment can stop here.

The allocation transaction and the order transaction remain separate. A user-visible order is created only when the order service commits it. This explains why the generator can produce gaps even during healthy operation: clients can abandon work or fail after allocation.

One durable allocation boundary

Allocation precedes, but does not commit, the business record.



05 / Calculate the value of batching coordination

At one remote allocation per ID, ten million/s is substantial control traffic. A serial caller with a one-millisecond round trip can issue roughly 1,000 requests/s. More concurrency improves aggregate rate, but adds network and database pressure while every allocation still depends on the authority.

Reserve a numeric range of 10,000 IDs per control transaction. At 20,000 IDs/s, each process needs roughly two ranges/s. Across 500 processes, the authority handles about 1,000 range transactions/s instead of ten million per-ID calls. Local increments handle the remaining work.

Choice	Benefit	Cost
Larger range	Fewer authority calls and more outage runway	More unused IDs after a crash
Smaller range	Less abandoned space	More replenishment and coordination
Early prefetch	Hides ordinary replenishment latency	Additional committed unused ranges
Per-call central allocation	Simple shared ordering boundary	Network/authority dependency on each ID

Size range requests with expected rate and acceptable outage duration. Benchmark local synchronization under bursts, not just arithmetic. Integer capacity is finite even when it is very large: define the maximum and reject a reservation whose end exceeds it. Do not silently wrap a counter or reuse another namespace's space.

06 / Make range ownership and API identity explicit

Separate namespace allocation state from individual reservations:

Record	Identity and fields	Purpose
Namespace allocator	Namespace; next-unallocated boundary	Preserve the durable allocation boundary.
Range reservation	Process incarnation and range request key; start and exclusive end	Record which consecutive values belong to that reservation.

An incarnation identifies one start of a process. A replacement uses a new incarnation so it cannot claim the old process's range.

Range request from a trusted generator

```
POST /ranges

{
  "namespace": "orders",
  "incarnation": "A9",
  "requestId": "r17",
  "count": 10000
}
```

Example reserved range

```
Interval:      [1001, 11001)
First value:    1001
Last value:    11000
Exclusive end:  11001
```

A half-open interval includes the start and excludes the end. The following range can therefore start at 11001 without sharing an endpoint.

Authenticate the generator and bound requested count. Within the same live incarnation, repeating r17 returns the saved range; different count or namespace under r17 conflicts. The range record and boundary advance commit together. Install a returned reservation only once within the live incarnation. A duplicate response for r17 refers to the already installed range and its current cursor; it must never reset that cursor to the range start. A new incarnation must use new request identity and receive a fresh range, rather than recovering an old cursor after a crash.

Local `nextId()` returns one value from the current range or a clear unavailable/exhausted response. A remote batch API can additionally retain its returned batch under a request key, but that is a separate replay contract with storage and retention costs.

07 / Move only the fast counter into each process

Scale the authority operation from "reserve one" to "reserve count." Perform these steps in one database transaction:

1. **Lock the namespace row.** Read its current `nextValue`.
2. **Calculate the reservation.** Set `start = nextValue` and `end = start + count`.
3. **Check capacity.** Validate the bound before changing allocation state.
4. **Record both changes.** Advance `nextValue` to `end` and insert the request/result record.
5. **Commit, then return.** Return the range only after commit.

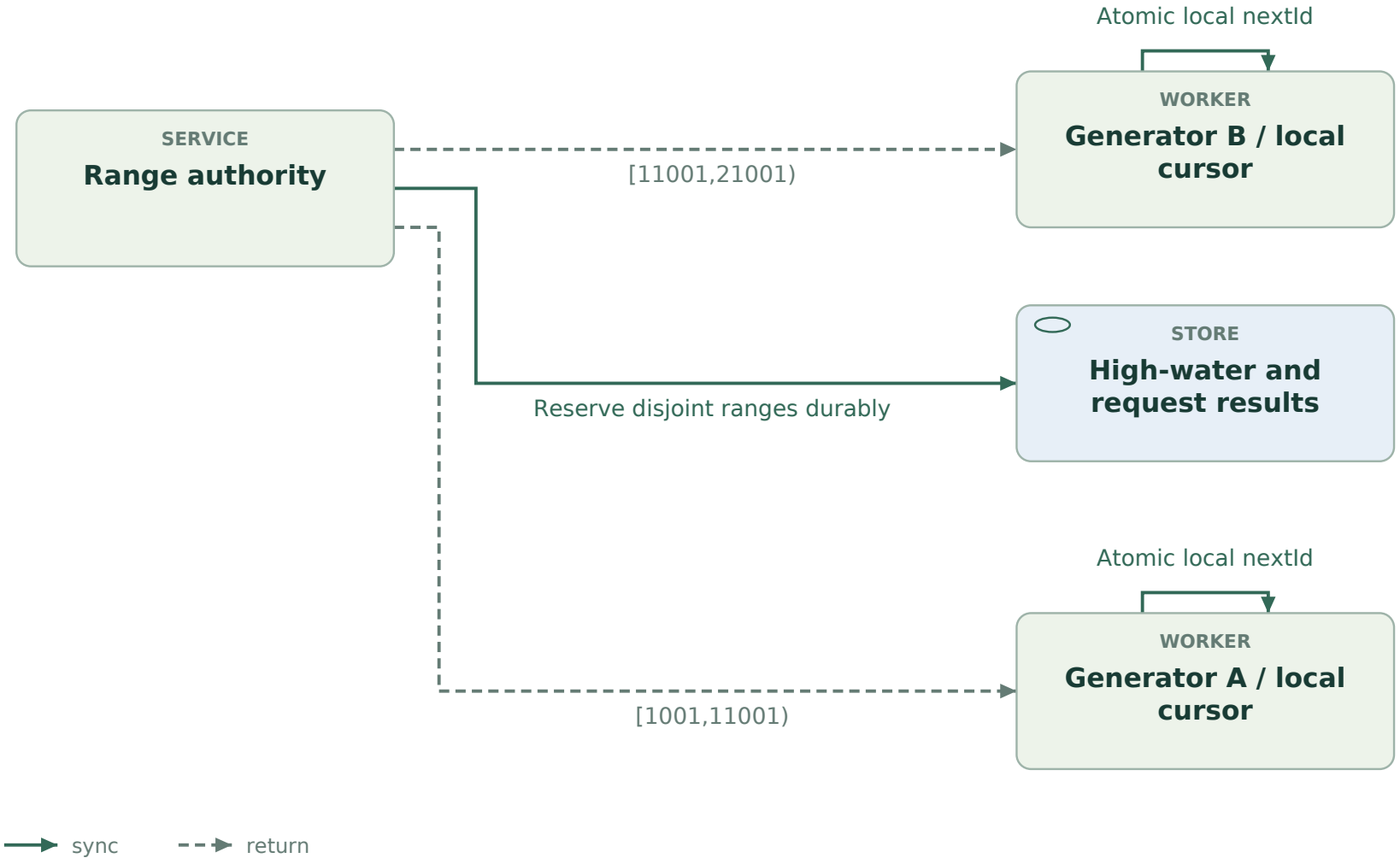
Each process keeps a cursor and the exclusive end of its committed range. An atomic increment or short local lock reserves the next unused value. No network call is required while usable values remain. Near exhaustion, a background replenisher asks for another range and installs it under the same local synchronization rules.

The ranges are disjoint because the database serialized their boundary advances. Adding generator processes therefore increases aggregate local capacity without changing the central uniqueness argument. The authority still controls a small stream of range reservations.

Partition allocation by independent namespaces if the product already has them. Splitting one integer space among several uncontrolled allocators would require another disjointness rule and is unnecessary at the assumed control rate. First measure whether a replicated database can meet roughly 1,000 short range transactions/s with recovery headroom. Avoid adding a distributed custom protocol before that measurement shows a need.

Disjoint ranges, local counters

The authority is called per range rather than per identifier.



08 / Trace local calls and the last value in a range

Generator A holds `[1001,11001)` with cursor 1001. Under a local lock, request 1 reads 1001, advances cursor to 1002 and returns 1001. Request 2 observes 1002 and returns it. Without synchronization, both threads could read 1001 before either advanced the cursor, duplicating a value despite perfectly disjoint cross-process ranges.

At cursor 11000, the process can return the last allowed value and advance to 11001. It cannot issue 11001 from this range. If a prefetched range is ready, atomically switch to its start; otherwise wait within the caller's deadline or return unavailable. Never increment beyond the end and continue after an error.

A local batch reserves its whole requested span under the same guard. Decide whether a batch may cross into another already committed range or must return fewer values; document the response instead of assuming contiguity across separate reservations.

The order service then creates the order using the ID and its own stable business request key. If its response is lost, a retry finds that order's saved result. A generation call lost before the caller receives it can waste an ID, but it must never cause the allocator to return that possibly delivered value again.

09 / Prove uniqueness through crashes and failover

Within a live process, synchronized cursor updates assign different values. Between processes, committed numeric ranges do not overlap. Those two facts establish the ordinary uniqueness proof without any wall-clock assumption.

If a generator crashes halfway through its range, restart abandons all remaining values and requests a fresh range. It does not need to recover the exact last local increment, because none of its old range is reused. This deliberately trades gaps for simpler crash safety. A paused process can resume using its existing range while a replacement has a different range; their values still differ.

If the allocator commits a range but loses its reply, the same running process retries with the same request identity and receives the saved range. Duplicate responses reuse an already installed reservation's current cursor; they never reinstall it from the beginning. A new process must not take that old permission if the former process might still be alive. Restart therefore uses a new incarnation and a new range.

Allocator failover must retain committed boundaries and result records. A stale promoted replica or restored backup can otherwise allocate an overlapping historical range. Refuse service when that evidence cannot be established, or move to an explicitly different namespace. A downstream unique constraint can detect failure but is not permission to tolerate an unsafe allocator.



INTERVIEW CRITICAL

Range allocation survives a crash by wasting values

A replacement receives a new disjoint range. Abandoning the old remainder removes the need to recover the exact last local increment, while preserving uniqueness.

10 / Keep identifiers exact and order claims modest

Return large integer IDs as decimal strings when clients cannot represent the full integer range exactly. JavaScript Number is exact only through `2^53 - 1`; rounding a valid larger ID can collapse distinct values at the client. Parse directly into an appropriate integer type and keep namespace information wherever values from different spaces can meet.

Numeric ranges do not provide global issue order. Process A may still issue 1002 after process B has issued 11001. That does not violate uniqueness. Store an explicit business createdAt when the application needs creation time, and use an actual sequencing protocol if global real-time order is required.

IDs can reveal rough activity or be predictable. Authorization checks must verify the actor and record owner. If public URLs need to conceal internal ordering, store a separate random reference rather than treating the integer as a secret.

Do not reset the counter when deploying a new version or restoring a test dataset into production. Namespace creation and migration are privileged audited actions. Mixing two independently allocated spaces as bare integers loses the uniqueness scope that made each one correct. API documentation must state that scope as clearly as the wire format.

11 / Explain when the simpler design stops fitting

If clients need decentralized allocation without a control service, an established UUID implementation may be preferable. UUIDv4 provides probabilistic uniqueness from correctly generated randomness. UUIDv7 is a standard timestamp-leading format that improves time locality without promising strict global real-time order. Neither should be casually truncated into a smaller integer.

A Snowflake-style format combines timestamp, worker and per-timestamp sequence fields. It can provide compact approximate time ordering, but now worker reuse, sequence overflow and clock rollback affect uniqueness. Introduce it only when that ordering/storage requirement justifies the extra protocol. Resetting a sequence when a clock moves backward can repeat a tuple; safe waiting or an explicitly proved alternative is required.

The main design remains numeric ranges because the agreed product does not require encoded time. Strict global ordering instead favors a shared sequencer with its latency and availability cost. Gapless invoice numbers must be tied to business commit and cancellation rules, not inferred from an ordinary allocator.

Measure range reservation latency, remaining local capacity, abandoned IDs, cursor contention, boundary exhaustion and failed safety checks. Drill lost replies, process restarts, pauses, stale backups and allocator quorum loss before optimizing steady-state throughput further.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 3	The authority commits disjoint ranges; synchronized local cursors issue each value once.	Race concurrent range reservations and local callers, including the last value and a batch at the range boundary.
NFR 1, 2	10,000-value ranges reduce the illustrative authority rate to about 1,000 transactions/s.	Benchmark local p99 and authority throughput with bursts; stop a replenisher and measure how long existing ranges last. These estimates are not latency results.
NFR 3, 4	Failover preserves allocation history; restart discards old local ranges.	Lose a range reply, restart a process and attempt stale-backup promotion. Require safe replay or refusal, never overlapping allocation. Live cursor cloning is unsupported.
FR 3; NFR 5	Scoped administration and exact integer transport preserve authority and identity.	Reject unauthorized namespace changes and round-trip values above the client numeric precision limit without rounding.
Scope; NFR 3	The consuming service owns its order transaction and business retry key.	Abandon an issued ID and lose an order reply; accept the gap and recover the order through its own request identity, not a new ID.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Separate ranges between processes; synchronize within each.

Prompt	Recall
What is the contract?	Unique integers in one namespace; gaps are allowed and issue order need not follow numeric order
Baseline?	Lock and advance a durable counter; return only after the required commit
Scaling step?	Reserve non-overlapping ranges, then issue their values locally
What prevents local duplicates?	Update the next-value cursor atomically or under a short lock
What happens after a crash?	Leave the old range unused and obtain a fresh one
What must failover retain?	The boundary of all allocated ranges and saved results for reservation retries

Prompt	Recall
What handles business retries?	A separate stable request key in the service using the ID
Why strings on the wire?	A client's numeric type may not represent the full integer exactly
When add timestamp fields?	Only when the requirement justifies managing clock errors and worker identities

Close with: "I start with a durable counter and scale by reserving ranges. The authority proves ranges are disjoint, while each process synchronizes its cursor. Restart burns unused values instead of reconstructing uncertain local history. At the assumed load, 10,000-value ranges reduce authority traffic to about 1,000 reservations/s. The costs are gaps and no strict global issue order, both accepted in our contract."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Which identifier properties must be clarified first?

Model answer

Clarify namespace, integer width, allowed gaps, uniqueness and ordering. This design requires distinct integers but permits gaps and non-global issue order, so durable numeric ranges suffice. Record creation, authorization and safe business retries remain separate application responsibilities.

Interviewer follow-up

Does an allocated ID imply a committed order?

No. The order transaction can still fail or be abandoned.

What the answer must demonstrate: Clarify namespace, integer width, allowed gaps, uniqueness and ordering.

02 / FOUNDATION

How does the single-row baseline avoid duplicates?

Model answer

A short transaction locks the namespace counter, reserves its next value, advances the counter and commits before returning. Concurrent callers serialize at that row. The durability/failover policy must retain acknowledged advances; unused values may become gaps.

Interviewer follow-up

What if the reply disappears after commit?

The value remains allocated and cannot be recycled merely because its use is uncertain.

What the answer must demonstrate: A short transaction locks the namespace counter, reserves its next value, advances the counter and commits before returning.

03 / APPLIED

What does reserving 10,000 IDs at a time change?

Model answer

At ten million IDs/s it reduces authority operations to roughly 1,000 range reservations/s. Each process serves calls with a local synchronized cursor until its range ends. The tradeoff is abandoned space after crashes and loss of global issue order across independent ranges.

Interviewer follow-up

What would you benchmark?

Authority commit latency and failover plus local cursor contention and replenishment tails.

What the answer must demonstrate: At ten million IDs/s it reduces authority operations to roughly 1,000 range reservations/s.

04 / APPLIED

Two threads request an ID simultaneously. Why is a range not enough?

Model answer

Disjoint ranges protect different processes, but both threads could read the same local cursor before either advances it. Use an atomic reservation or lock that checks the end and advances before returning. Batch calls obey the same boundary.

Interviewer follow-up

What happens at the exclusive end?

Switch to another committed range, wait within a deadline or fail; never issue outside the allocation.

What the answer must demonstrate: Disjoint ranges protect different processes, but both threads could read the same local cursor before either advances it.

05 / APPLIED

How do you recover a generator without persisting every increment?

Model answer

Discard its entire old remainder and request a fresh disjoint range under a new incarnation. This allows gaps but avoids guessing which values were returned before the crash. A paused old process still holds a different range from its replacement.

Interviewer follow-up

What about cloning live memory?

Two clones would share a cursor and range; prevent that activation path or add an external/non-clonable allocation boundary.

What the answer must demonstrate: Discard its entire old remainder and request a fresh disjoint range under a new incarnation.

06 / FOLLOW-UP

What makes allocator promotion dangerous?

Model answer

A replica missing a committed high-water advance can hand out values already reserved elsewhere. Preserve acknowledged range state and request results through the chosen promotion protocol. A stale backup needs equivalent reconciliation or refusal; restarting from its counter silently is unsafe.

Interviewer follow-up

Does an order unique constraint solve this?

It detects collisions but does not make a violated allocation contract correct.

What the answer must demonstrate: A replica missing a committed high-water advance can hand out values already reserved elsewhere.

07 / APPLIED

Why may the API return decimal strings?

Model answer

Some clients cannot exactly represent all supported integers. JavaScript Number loses exactness above 2^53 - 1, so parsing through it can merge distinct IDs. A decimal string and appropriate integer type preserve the value and its namespace.

Interviewer follow-up

Can numeric sort prove creation order?

No. Different range holders progress independently; use explicit business time or a separate ordering service.

What the answer must demonstrate: Some clients cannot exactly represent all supported integers.

08 / FOLLOW-UP

When would you consider a timestamp-based format?

Model answer

When compact approximate time ordering is an actual requirement. Timestamp, worker and sequence fields introduce clock rollback, worker reuse and overflow rules that numeric ranges avoid. UUID standards are another alternative when 128-bit storage is acceptable; strict global order still needs coordination.

Interviewer follow-up

Can a sequence provide gapless invoices?

Not by itself. Numbering must follow the business commit/cancellation policy.

What the answer must demonstrate: When compact approximate time ordering is an actual requirement.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Allocate ten million integer IDs/s, then lose a range reply, restart a generator and fail over the authority.

• Agree the numbered functional requirements and non-functional targets, especially namespace uniqueness, accepted gaps/order, load and supported failures.

• Draw the durable counter baseline.

• Calculate 10,000-value range traffic.

• Prove local and cross-process disjointness.

• Explain restart, stale backup and exhaustion.

• Validate allocation, local latency, failover, exhaustion and exact transport against the numbered requirements; separate business retries and untested assumptions.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Two threads request an ID from A's range at once. What prevents a duplicate?

The authority gives processes non-overlapping ranges. Inside A, an atomic cursor update or lock gives each thread a different value. Both checks are needed.

Separate ranges between processes; synchronize within each.

A process crashes with unused IDs in its range. May its replacement reuse them?

No. Leave that range unused and reserve a new one, accepting gaps.

Burn uncertain values.

What does a unique ID leave for the application to decide?

How to recognize a repeated business request, record creation time, check access and provide gapless numbering if required.

A key is not the whole contract.

Summary and interview notes

One durable allocator reserves non-overlapping ranges. Each process updates its next-value cursor atomically. After a crash, leave unused values behind and reserve a new range rather than risk issuing the same ID twice.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Then establish a durable counter.

• Batch authority work into ranges.

• Synchronize local cursor updates.

• Burn unused values after restart.

• Preserve allocation history across failover.

Interview tips

• Use explicit interval endpoints in the proof.

• Offer timestamp formats only when the requirements justify them.

Important qualifications

• Gaps and non-global issue order are intentional.

• Business idempotency remains in the consuming service.

Explore the advanced version

Custom timestamp/worker/sequence grants: Not required by the selected numeric-range contract; adds clock and worker reuse protocols.

Clock rollback and logical-time alternatives: Relevant when choosing a time-encoded format.

Invisible execution cloning: A stronger infrastructure failure model requires an external or non-clonable boundary.

UUID and strict-order alternatives: Revisit format and coordination only when product properties change.

Technical references

RFC 9562: UUIDs
Primary UUID format, uniqueness, monotonicity, clock, and overflow guidance; UUIDv7 is an alternative to the illustrative custom layout.
https://www.rfc-editor.org/rfc/rfc9562.html

ECMAScript safe integer specification
Defines the exact safe range of Number integers, motivating string transport for arbitrary 64-bit IDs.
https://tc39.es/ecma262/multipage/numbers-and-dates.html#sec-number.max_safe_integer

PostgreSQL sequence functions
Concurrent nextval behavior, gaps, and the requirement to commit before using a sequence value persistently outside the database.
https://www.postgresql.org/docs/current/functions-sequence.html

EXTENDED INTERVIEWS / 54

Design a webhook delivery platform

Interview version / 45-minute scope · Read the advanced version online

Deliver signed events through bounded retries, explain a lost receiver acknowledgment, and isolate slow endpoints without claiming transport can guarantee arbitrary business effects.

webhooks • outbox • retry policy • signatures • receiver inbox

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Distinguish business event, logical delivery, transport attempt and receiver processing.
- Build durable sender and receiver flows with explicit retry and transaction boundaries.
- Defend destination security, fair scheduling, ordering and retention tradeoffs.

Useful foundations: Message queues, event logs, delivery guarantees, and backpressure; Design a distributed message log; Databases, data models, and ACID transactions; Production readiness: SLI, SLO, observability, and recovery

8 interview questions with model answers and answered follow-ups.

01 / Define acceptance before promising delivery

A webhook is an HTTP event sent to a customer-controlled endpoint. The sender records a business fact; the receiver decides what to do with it. In this design, a receiver's successful response means it durably accepted the event, not that every downstream business action completed. An unreachable endpoint can exhaust a bounded retry contract.

Ask what the receiver's success response must mean: durable acceptance or completed business work, and whether events need ordering. This design chooses durable acceptance and best-effort order, with bounded retries and inspectable failures.

Use shipment event E402: order O901 changed to shipped at object version 7. It matches endpoint EP 9 and creates logical delivery D22. The first HTTP attempt is A1. If the receiver commits E402 to storage but its 202 reply disappears, the sender does not know whether acceptance happened. Attempt A2 must preserve E402 and D22 while carrying a new attempt identity.

The smallest complete flow is shipment transaction plus pending event -> delivery worker -> signed HTTP request -> receiver durable receipt -> acknowledgment -> later business processing. A pending sender record is an outbox. A receiver's record of accepted events is an inbox. These solve opposite sides of the handoff, and no local transaction spans both companies' databases.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Manage destinations.** Support endpoint registration, subscriptions, configuration changes and signing-key rotation. Pin queued work to an endpoint/configuration version so a URL edit does not silently rewrite past attempts.
2. **Deliver business events.** Send the recorded event to each matching customer endpoint and record durable receiver acceptance separately from completion of its downstream work.
3. **Inspect and control delivery.** Expose status, bounded attempt history, next retry and terminal reason; support authorized pause and cancellation.
4. **Redrive retained events.** Allow an authorized request to send a retained historical event again. Preserve its event identity and record the reason; today's business state cannot replace expired historical bytes.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results.

1. **Workload and initial delay.** Assume ten million events/day with three matching endpoints/event and a tenfold peak. Start healthy first attempts within five seconds for at least 95% of deliveries.
2. **Bounded retry and retention.** Retain shared event payloads for seven days. For this exercise, allow at most ten automatic attempts in the initial run. An authorized redrive starts a separately audited run with the same ten-attempt ceiling; it preserves event/delivery identity and cannot extend the original seven-day payload lifetime. Cap total HTTP attempt duration at five seconds and capture at most 16 KiB of response data. Retain sanitized attempt/audit metadata for 30 days. A permanently offline receiver ends in an inspectable exhausted state.
3. **Durability and effects.** A committed business change must not lose its pending event. Retries preserve event/delivery identity; the receiver must durably accept before acknowledging. One local business effect depends on the receiver's own transaction and retained identity, not a sender-only exactly-once promise.
4. **Ordering.** Use best-effort order. Consumers rely on object versions or reconciliation. Optional per-object serial dispatch can block later events behind a failure and does not establish global order across customers.
5. **Isolation and fair capacity.** A slow endpoint must not occupy every socket or worker. Bound endpoint concurrency, tenant shares and global transport work; receiver replay protection must cover the supported redrive horizon.
6. **Authenticity and safe delivery.** Authenticate tenant operations, sign documented bytes, enforce timestamp replay policy and validate the actual outbound destination on every attempt. Signature validity is distinct from schema validation, authorization and business idempotency.

04 / Build one durable sender and one receiver inbox

One periodic worker scans due deliveries. In a short database transaction it claims D22, records attempt A1 and assigns a lease token. A lease gives temporary ownership of local processing; its token lets the database recognize which attempt may update current state. Commit and release locks before making the remote HTTP call.

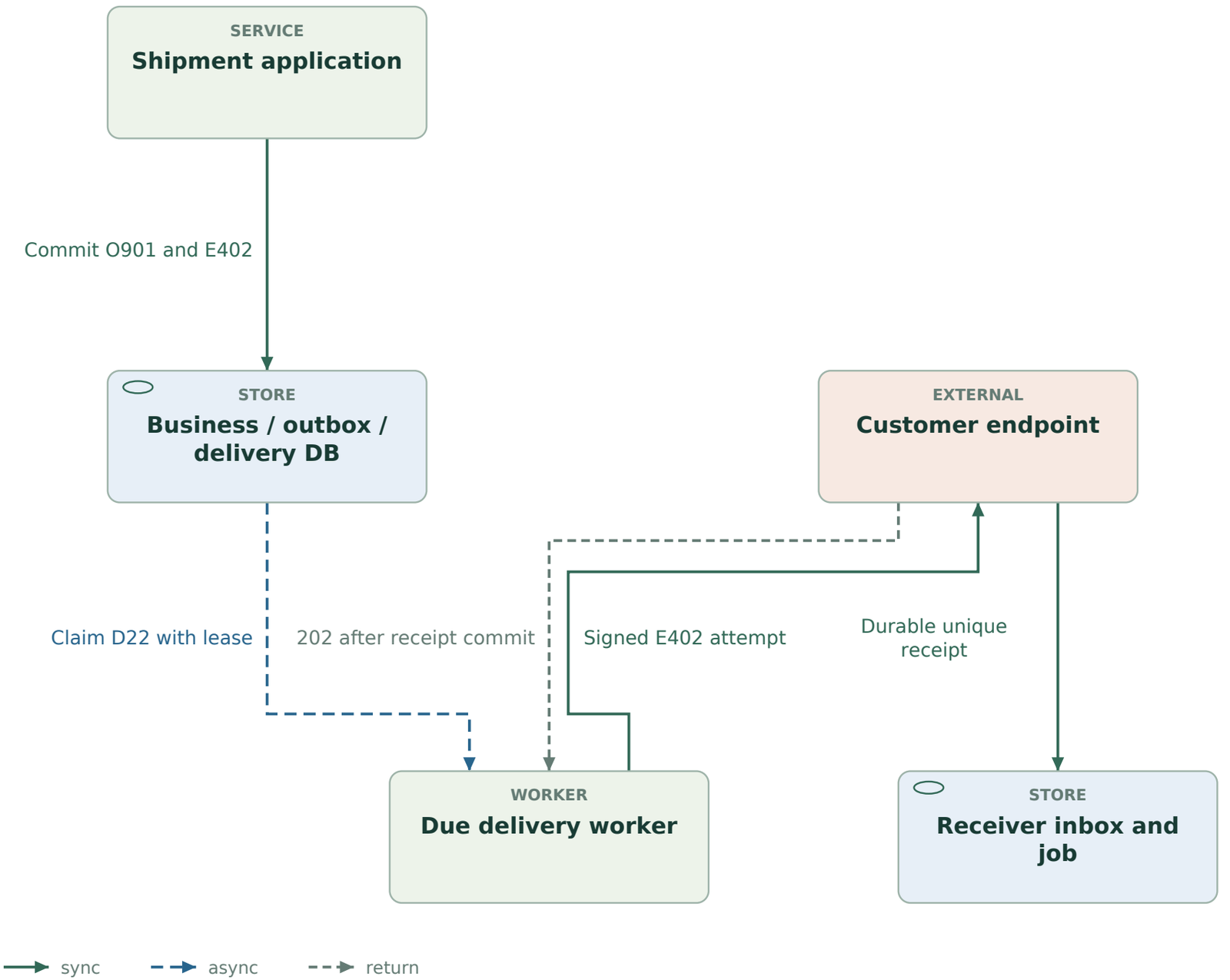
The worker loads the pinned event/configuration, validates the destination and signs a fresh request. On 202 it records accepted only if its token and expected state are still current. On a timeout it records an uncertain outcome and schedules a bounded retry. It cannot roll back the shipment or infer that the event never arrived.

The receiver verifies signature and schema, then atomically inserts a uniquely scoped inbox E402 and durable processing work. It returns 202 only after this commits. Its worker later applies the local business mutation and marks the inbox done in one local transaction. A process crash after acceptance is then recoverable internally.

This baseline supports a small service. Its one blocking worker at 0.5 seconds/request handles only two attempts/s, so throughput is the first scaling limit. Its lost-response behavior is already the core correctness problem; more workers will not remove that uncertainty.

Durable event before outbound delivery

The shipment transaction ends before the customer HTTP call begins.



05 / Size attempts and sockets rather than events alone

Ten million events with three destinations create 30 million logical deliveries/day, about 347/s average. At a tenfold peak that is roughly 3,470 first attempts/s. If each logical delivery averages 1.2 attempts, peak transport work becomes approximately 4,167/s. Retry rate is a capacity assumption to measure, not an unlimited allowance.

Quantity	Calculation	Implication
Normal in-flight first attempts	3,470/s x 0.5 s ~ 1,735	Request duration sets socket demand
All-slow retry-adjusted peak	4,167/s x 5 s ~ 20,835	Timeouts can dominate memory/connections
Shared payload retention	10M x 1 KB x 7 = 70 GB	Store one body and reference it
Base delivery metadata	30M x 200 B x 7 = 42 GB	Add attempts, indexes and copies
One-hour first-attempt backlog	3,470/s x 3,600 ~ 12.5M	Recovery needs staggered spare capacity

At an extra 1,000 attempts/s, that backlog takes about 3.5 hours to drain, if receivers permit the rate. More workers cannot responsibly exceed a customer's accepted concurrency. Separate endpoint limits, tenant fairness and global socket budgets so a backlog cannot turn into a recovery stampede.

06 / Give every level a stable identity

The business transaction updates O901 and inserts immutable outbox event E402 together. The planner creates D22 with this unique delivery key:

```
(tenant, eventId, endpointId, configVersion)
```

Including endpoint ID matters: two different endpoints can both have configuration version 3 and both need the event.

Sender records

Record	Fields and observations	Purpose
Event	Body, schema version and checksum	Store immutable event bytes once.
Delivery	Endpoint/configuration version, status, next-attempt time, retry count, current lease token and terminal reason	Track one destination's obligation and current scheduling state.
Attempt	Start time, bounded response class and timeout observations	Explain one transport attempt without replacing delivery truth.

A due-time index finds pending work without scanning every historical attempt.

Event envelope fields

Field	Example or meaning
Event ID	E402
Type	Shipment event
Object ID/version	Order O901, version 7
Payload	The recorded shipment business fact.

Per-attempt headers

Header information	Purpose
Delivery ID	D22 remains stable across transport retries.
Attempt ID	A1 and A2 identify different HTTP attempts.
Signing timestamp and key ID	Identify the attempt's signing context and replay-age boundary.
Signature	Authenticate the documented raw bytes and fields.

Define exactly which raw bytes and fields are signed. Re-parsing and reserializing JSON can change bytes, so verification operates on the received representation before trusting its content.

Inspection returns tenant-scoped state and a bounded history cursor. Redrive requires authorization and retained original bytes. An expired payload cannot be reconstructed from today's order state and called the same historical event. Store secret references rather than signing keys in ordinary delivery records or logs.

Record a scoped redrive request ID and its run ID atomically before making exhausted work eligible again. Repeating that request returns the same run rather than resetting its budget repeatedly. Track automatic-attempt count per run; do not reset the event identity or original payload-expiry time.

07 / Classify failures and schedule them fairly

Retry eligibility asks whether another attempt could help; timing asks when. Network errors, timeouts and many 5xx responses receive bounded retries. A 429 indicates receiver load control and may supply retry guidance that must be validated and capped. Document permanent endpoint/configuration errors rather than assuming every 4xx has identical meaning.

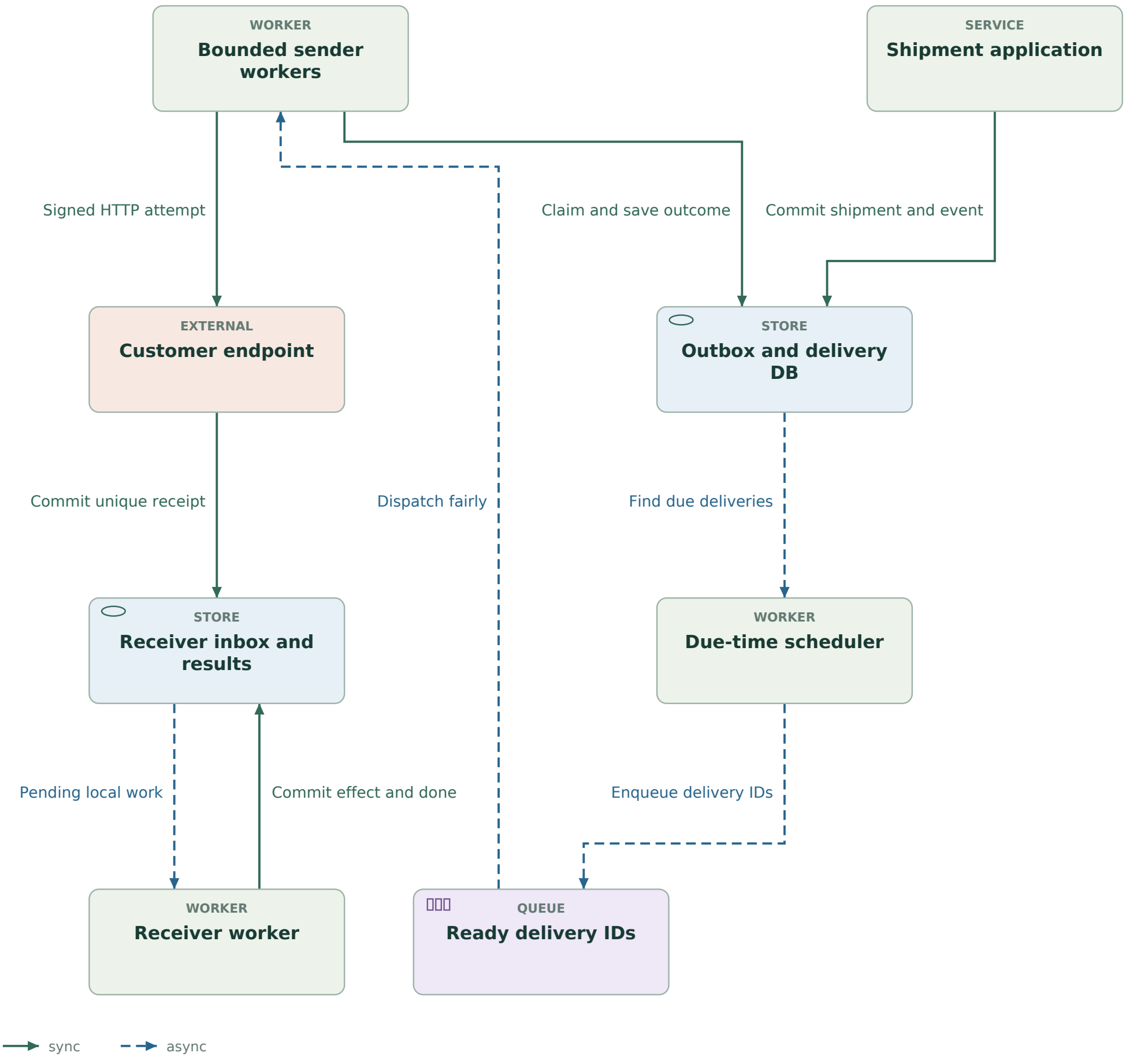
Exponential backoff increases delay after repeated failures. Jitter varies that delay across deliveries to avoid synchronized retries. Stop when the current run reaches ten automatic attempts or the original retained event reaches its seven-day expiry, whichever comes first. An authorized redrive is a new audited run, not an automatic counter reset. Expose next retry and terminal reason so "we retry" is an observable contract.

Add bounded parallel workers, with per-endpoint concurrency, per-tenant scheduling shares and a global socket ceiling. Limits cannot simply be independent per-worker counters, or adding workers multiplies the advertised endpoint cap. Expensive retries must not starve first attempts or other tenants.

When database polling becomes costly, use a ready queue containing delivery IDs and a durable due-time schedule for delayed work. The database remains authoritative. Workers recheck state after dequeue, and periodic due scans repair a lost enqueue. Queue duplication is expected and must not create a second logical delivery. This adds scheduling machinery while preserving the simple baseline's stored obligations.

Fair dispatch separates durable obligations from HTTP attempts

The shipment transaction records the event. Due scans schedule delivery IDs; bounded workers claim current database state before sending. The receiver acknowledges its durable inbox, then applies its own local effect. Lost acknowledgments can repeat the same event.



08 / Follow the lost acknowledgment through both databases

A1 sends E402/D22. NorthHarbor's endpoint verifies the raw signed bytes and commits inbox E402 plus its processing job. Its 202 response is lost. The sender eventually records timeout and keeps the logical delivery eligible for retry; it has no observation distinguishing this history from a request that never arrived.

A2 receives a new attempt ID, timestamp, signature and lease token, while event/body identity remains stable. The receiver's unique inbox lookup finds the already accepted fingerprint and returns 202 again. It does not create another processing job. D22 becomes accepted under A2's valid token. The receiver's separate processor may already have completed or may still be queued.

Now let A1's old worker resume and report retrying after A2 succeeded. A guarded sender update requires its token to match the current delivery token and its expected state. The stale update fails instead of undoing accepted. Attempt history can still record a correctly associated late observation without replacing delivery truth.

The lease-token check stops A1 from overwriting newer sender state. The receiver's saved event identity stops repeated arrivals from creating another local effect. Both are needed: rejecting A1's late database write cannot undo an HTTP request already sent.



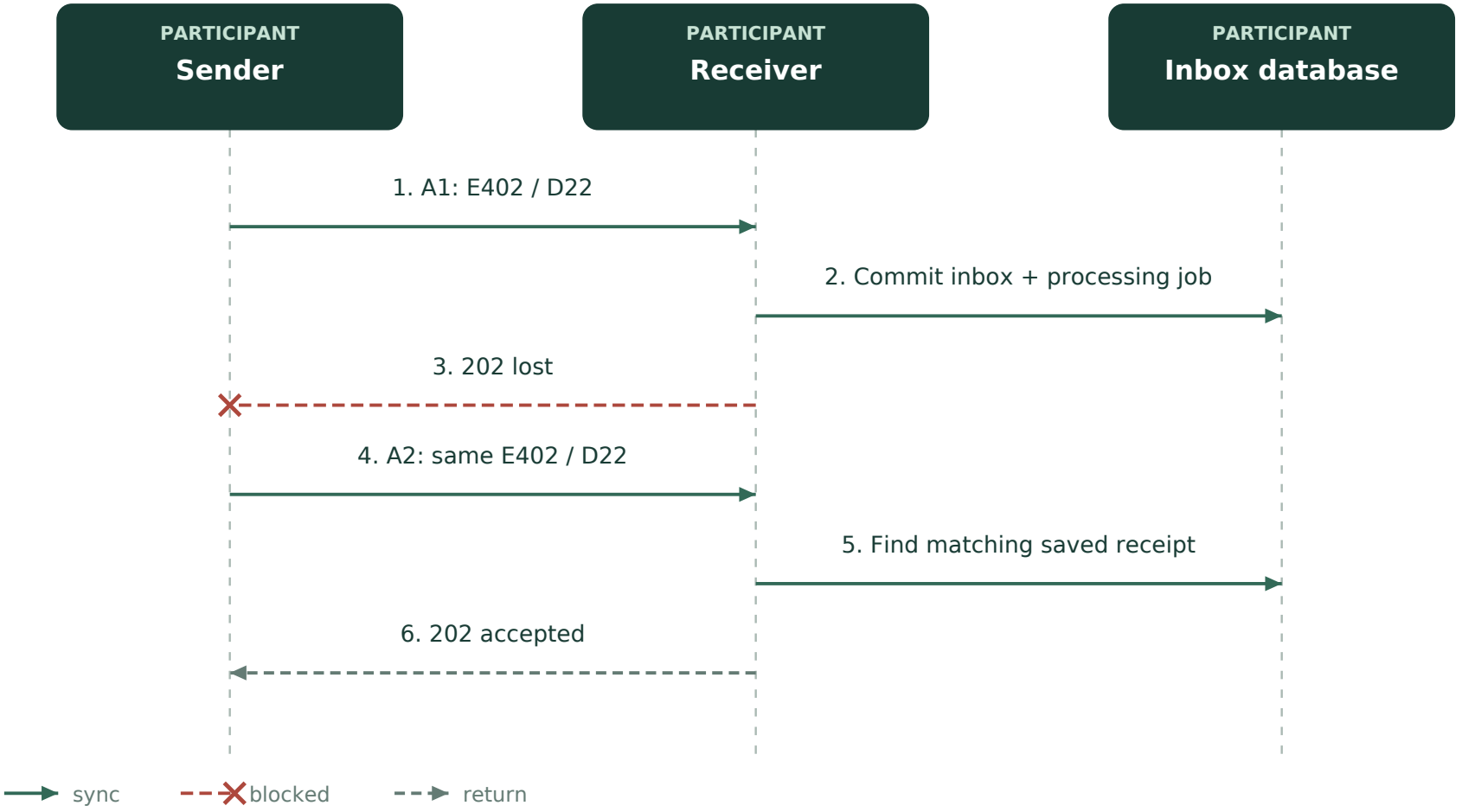
INTERVIEW CRITICAL

A timeout has two indistinguishable histories

The request may never have arrived, or the receiver may have committed before its response was lost. Stable retry identity and receiver persistence make either history recoverable; sender observation alone cannot choose between them.

Same event, second transport attempt

Receiver acceptance and sender knowledge are independent facts.



09 / Prove the receiver's effect and explain ordering

Use a trusted `(sender, tenant, eventId)` inbox key and immutable payload fingerprint. A receipt transaction inserts the inbox and job under that unique identity; a duplicate verifies the same fingerprint. Different bytes under the same identity conflict rather than silently replacing the event. Identity comes from the verified credential mapping, not an unsigned tenant header.

For a local database effect, use one processing transaction:

1. **Lock the inbox row.** Concurrent processors serialize through that row.
2. **Check completion.** Return without repeating the effect if the inbox is already done.
3. **Apply the effect.** Make the local business change and mark the inbox done.
4. **Commit both changes.** A crash before commit preserves neither; a retry after commit sees done.

This proves one local effect under the stated database boundary despite multiple HTTP attempts.

An external charge or email is outside that transaction. Persist a stable outgoing action identity and use the destination's idempotency/status contract. Represent uncertainty and reconcile before inventing another action. An inbox alone cannot make an arbitrary remote API atomic.

For full object snapshots, atomically install only a newer object version. For changes such as "subtract one unit," an older unapplied event still matters. Detect missing events and replay them or fetch complete state. Serial sending through each 202 orders receipt, while the receiver must separately preserve processing order if business actions require it.



INTERVIEW CRITICAL

An inbox transaction has a defined boundary

The inbox and a local database effect can commit together. A remote payment or email does not join that transaction; it needs its own stable action identity and recovery contract.

10 / Treat outbound URLs as a trust boundary

A customer-controlled URL can trick the service into requesting internal or metadata endpoints: this is server-side request forgery. Restrict schemes, validate resolved IPv4/IPv6 destinations at connection time, and either disable redirects or validate every hop. Registration-time DNS checks cannot establish where a later connection will go.

The HTTP client must connect to the address that passed validation. Resolve, choose an allowed address and connect to that address while retaining the original hostname for TLS certificate verification. Do not validate one resolution and let the HTTP client perform a separate unchecked lookup. Add network egress restrictions as another boundary and repeat checks on every attempt.

Sign exact body bytes under a documented timestamp/key-ID scheme. The receiver verifies authenticity and rejects excessive timestamp age under a replay policy. Fresh retry signatures remain compatible with stable event identity. A valid signature does not remove schema checks or business authorization.

Rotate keys with a bounded overlap and explicit retirement rules. Limit body size, decompressed size, response bytes, connection time and total attempt duration. Sanitize inspection and logs because a receiver can return secrets in an error body. Pause/delete policies must be rechecked before sending even when a stale ready-queue entry exists.

11 / Operate a bounded promise through outages

Monitor first-attempt delay, eventual acceptance, oldest pending age, attempts per delivery, endpoint sockets, lease expiry, backlog age and payload-retention margin. Successful eventual delivery can hide hours of delay; separate it from the five-second healthy-first-attempt objective.

During an endpoint outage, back off that endpoint while other tenants continue. Reconnection does not authorize an unbounded drain. Keep failed deliveries inspectable and offer redrive only within the payload and destination-ownership contract. Receiver inbox retention must cover the allowed replay/redrive horizon, or the service must disclose a weaker duplicate-effect guarantee for older work.

Test sender death after POST, receiver death after inbox commit, local processor death around its transaction, stale lease updates, duplicate redrive, key rotation and DNS changes between attempts. Test one noisy tenant alongside healthy ones, not merely a global throughput benchmark.

Shared payloads reduce repeated storage, while attempt history can become a major cost under persistent failure. Bound retention and response capture. If the product requires proof of eventual business completion, add a separate authenticated status protocol; changing the meaning of HTTP accepted in marketing does not implement that requirement.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 3	The sender outbox preserves the business event; pinned configuration and the receiver inbox preserve handoff identity.	Crash after the shipment commit and after receiver acceptance. Require recoverable D22 and one receiver job after repeated E402, not proof of downstream completion.
FR 3, 4; NFR 2, 4	Due-time state, backoff, attempt limits and retained history make retry/redrive observable.	Keep an endpoint offline through exhaustion, change its URL and request redrive after payload expiry. Do not promise eventual acceptance or global order.
NFR 1, 5	Bounded parallel workers and shared endpoint/tenant/global limits protect healthy traffic.	Load-test first-attempt delay during one tenant's timeouts and backlog drain; measure the five-second/95% goal without exceeding destination limits.

Requirement	Mechanism in the final design	Validation and remaining limit
NFR 3, 6	Current lease-token updates protect sender state; signatures and scoped inbox transactions protect receiver processing.	Resume A1 after A2 succeeds, replay a signed duplicate and conflict its fingerprint; reject stale updates and duplicate local effects. External effects need their own protocol.
NFR 6	Connection-bound address validation and network egress controls restrict customer URLs.	Change DNS between retries, test redirects and rotate keys; verify that inspection never exposes credentials or unbounded response bodies.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Lost reply -> same event, new attempt.

Prompt	Recall
What survives a business crash?	The business change and its outbox record commit together
What identifies a retry?	Keep the event and delivery IDs; create a new transport attempt
What does 202 prove here?	The receiver saved the event durably; its business work may still be pending
Why retry an uncertain timeout?	The sender cannot tell whether the request or only the reply was lost
What stops an old sender overwriting newer state?	Accept its update only if its lease token and expected state still match
What prevents a repeated local effect?	Deduplicate the verified event in the inbox; commit the effect and DONE status together
What about external effects?	Keep one action identity and recover its outcome under the external provider's contract
What protects other customers?	Limit work per endpoint, per tenant and across the service
What protects outbound access?	On every attempt, validate the address the HTTP client actually connects to

Close with: "I preserve the shipment event before sending, schedule bounded fair attempts, and keep event identity stable through uncertain transport. The receiver commits an inbox before acknowledgment and protects its own business boundary. I can guarantee durable attempts and explain outcomes, but cannot force an unreachable customer to accept or make an arbitrary external action exactly once."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What does the receiver's 202 mean?

Model answer

Under this contract it means the event and processing work were durably accepted. The receiver can respond before completing its business workflow, which preserves low endpoint latency without losing work on process restart. A sender needing proof of completed processing requires a separate status or callback protocol.

Interviewer follow-up

Why not acknowledge an in-memory queue?

A crash could erase the event after the sender stopped retrying.

What the answer must demonstrate: Under this contract it means the event and processing work were durably accepted.

02 / FOUNDATION

Which fields change between A1 and A2?

Model answer

Event E402, delivery D22 and immutable body remain stable. Attempt identity, timestamp, signature and sender lease token change. This lets diagnostics distinguish network attempts while the receiver recognizes the same business event. A new event ID would undermine deduplication.

Interviewer follow-up

Why include endpoint ID in planning uniqueness?

Configuration version numbers are local to endpoints; two endpoints at version 3 both need their own delivery.

What the answer must demonstrate: Event E402, delivery D22 and immutable body remain stable.

03 / APPLIED

Can the sender avoid retries after a lost reply?

Model answer

It cannot infer acceptance from the timeout. Refusing every retry loses events in the history where the request never arrived; retrying can repeat arrival when receipt committed. Receiver inbox identity makes that repetition safe under the agreed contract, or a supported receipt lookup can resolve it.

Interviewer follow-up

Does a sender transaction include the receiver?

No. They are independent transaction domains with a network gap.

What the answer must demonstrate: It cannot infer acceptance from the timeout.

04 / APPLIED

A1 reports timeout after A2 succeeds. What changes?

Model answer

The delivery row changes only if the result update carries the current lease token and expected in-flight state. A stale A1 cannot overwrite A2's accepted state. Its observation can be retained separately in attempt history. This local fence does not prevent remote duplicate POSTs.

Interviewer follow-up

What handles those duplicates?

The receiver's trusted inbox and business-effect protocol.

What the answer must demonstrate: The delivery row changes only if the result update carries the current lease token and expected in-flight state.

05 / APPLIED

Version 8 arrives before version 7. May version 7 be ignored?

Model answer

If events carry complete snapshots, a version guard can safely retain the newer state. If events are dependent deltas, dropping version 7 may lose a necessary effect; detect gaps and replay or fetch authoritative complete state. Waiting for each 202 orders acceptance, not necessarily receiver processing.

Interviewer follow-up

Can timestamps replace an ordering token?

Not generally. Clock and delivery order can differ, and timestamps can tie.

What the answer must demonstrate: If events carry complete snapshots, a version guard can safely retain the newer state.

06 / FOLLOW-UP

How does a five-second failing endpoint affect capacity?

Model answer

At the retry-adjusted peak, thousands of attempts per second can occupy more than 20,000 sockets. Per-endpoint concurrency and tenant scheduling shares prevent one receiver using the whole pool; global limits protect the fleet. Backoff retains obligations without repeatedly hammering the destination.

Interviewer follow-up

Why not scale workers without those limits?

That amplifies load and cost while violating receiver and fairness budgets.

What the answer must demonstrate: At the retry-adjusted peak, thousands of attempts per second can occupy more than 20,000 sockets.

07 / APPLIED

Why validate DNS again on each attempt?

Model answer

A URL can resolve to a different destination after registration. Validate the actual chosen address and connect to it while checking TLS for the original hostname. Otherwise DNS rebinding or an unchecked second resolution can reach internal resources. Redirects require the same validation or must be disabled.

Interviewer follow-up

Does signature verification make the URL safe?

No. Payload authenticity and outbound destination restrictions protect different boundaries.

What the answer must demonstrate: A URL can resolve to a different destination after registration.

08 / FOLLOW-UP

Can an operator safely replay a three-month-old event?

Model answer

This design retains payloads for seven days, so it rejects unavailable history. A longer archive contract must preserve original bytes and destination ownership, and receiver deduplication or business reconciliation must cover that horizon. Reconstructing the current object is a new event, not faithful replay.

Interviewer follow-up

What if an external effect key expired?

Do not blindly resend; use supported lookup or explicit reconciliation before creating another effect.

What the answer must demonstrate: This design retains payloads for seven days, so it rejects unavailable history.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Deliver E402 to EP 9, lose the first 202, stall the endpoint, and recover without repeating the receiver's local effect.

• Agree the numbered functional requirements and non-functional targets, including receiver acceptance, ordering, bounded retry, fairness and security.

• Estimate attempts, sockets and retention.

• Trace sender outbox and receiver inbox.

• Prove stale-worker and duplicate-effect handling.

• Explain ordering, redrive and key retention.

• Check delivery controls, replay, delay, retention, ordering and destination security against the numbered requirements; name external-effect and offline-receiver limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

NorthHarbor saves E402, but its 202 reply disappears. What changes on retry?

Keep E402 and delivery D22; create a new transport attempt. NorthHarbor finds its saved inbox record, so repeated arrival need not repeat the local business effect.

Lost reply -> same event, new attempt.

How does the receiver stop a repeated event from repeating a local update?

In one transaction, change business state and mark the verified inbox event DONE. A retry then sees that completion.

Effect and DONE commit together.

Why can the sender not promise that every event finishes its business work?

The receiver may stay unreachable, retention may expire, and completion depends on the receiver and any external provider's guarantees.

Bound attempts; disclose outcomes.

Summary and interview notes

The sender saves events and retries uncertain deliveries within limits. The receiver saves accepted events and prevents duplicate local business updates. A sender timeout alone cannot reveal whether the receiver accepted the event.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Commit business state and outbox together.

• Separate event, delivery and attempt identity.

• Acknowledge only durable inbox acceptance.

• Fence sender results and transact local receiver effects.

• Bound fairness, retry lifetime and destination access.

Interview tips

• Draw both timeout histories.

• State receiver processing order separately from receipt order.

Important qualifications

- External effects need their own recovery protocol.
- A forever-offline receiver cannot be promised successful acceptance.

Explore the advanced version

Socket-bound DNS and redirect validation: Expand library-specific implementation when the interviewer probes SSRF defenses.

Historical configuration and key retirement: Long replay horizons need a detailed ownership and rotation contract.

External receiver-effect reconciliation: A payment or email requires another transactional boundary.

Distributed fairness enforcement: Large fleets need an explicit global/tenant limit coordination design.

Technical references

Stripe webhook documentation
Provider-specific examples of signature verification, duplicate deliveries, event ordering, and retry behavior.
https://docs.stripe.com/webhooks

Stripe idempotent requests
Distinguishes outbound API retry keys from an application's webhook inbox and business deduplication policy.
https://docs.stripe.com/api/idempotent_requests

OWASP SSRF prevention guidance
Primary security guidance on destination validation, unsafe address ranges and redirect handling for outbound requests to user-controlled URLs.
https://cheatsheetseries.owasp.org/cheatsheets/Server_Side_Request_Forgery_Prevention_Cheat_Sheet.html

EXTENDED INTERVIEWS / 55

Design a feature-flag and configuration platform

Interview version / 45-minute scope · Read the advanced version online

Publish validated configuration and evaluate deterministic local rules, while making rollout freshness, offline fallback and rollback behavior explicit.

feature flags • configuration distribution • stable bucketing • fallback

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Build a complete local flag evaluator before adding a distribution service.
- Explain stable cohorts, compatible snapshots and monotonic installation.
- Distinguish authentic configuration, current configuration and actual rollout exposure.

Useful foundations: Caching: cache hits, misses, write policies and invalidation; Replication and durability; Real-time communication: polling, long polling, SSE, and WebSocket; Production readiness: SLI, SLO, observability, and recovery

8 interview questions with model answers and answered follow-ups.

01 / Separate publishing a decision from making it

A feature flag changes application behavior without deploying a new binary. The control plane edits, validates and publishes rules; the evaluation path uses those rules on live requests. Keeping evaluation local can make it fast and available during a control outage, but means configuration may be temporarily old.

We use recommendation flag F7. It assigns a stable ten-percent tenant cohort to a new experience. Snapshot C17 is one complete saved configuration, and tenant 54 is the targeting key for the example. The flow is publish validated snapshot -> distribute it -> atomically install it in the application -> evaluate trusted context -> execute the branch -> record bounded exposure information.

Clarify what the flag controls. Here it selects recommendations, not authorization, spending permission or an irreversible schema migration. A disconnected application may use the previous configuration for a bounded grace period, then must return false. An instantaneous universal kill switch would need a different online authority contract.

Start with a file and a deterministic evaluator on one instance. The engineering problem becomes interesting when many instances update at different times or operators publish incompatible rules. A dashboard containing an enabled boolean does not establish safe fleet-wide behavior.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Author typed flags.** Support boolean, numeric, string and structured flags, with separate development and production environments.
2. **Target an experience.** Select explicit users or tenants, percentage cohorts and multiple variants from trusted context; return the chosen value, reason and generation.
3. **Publish and roll back.** Validate and audit drafts/publications. A rollback publishes a new generation containing earlier intended values rather than moving the generation backward.
4. **Inspect and retire flags.** Show fleet adoption and bounded exposure information; retire obsolete configuration and application branches. The worked flag selects recommendations, not authorization, spending permission or irreversible schema changes.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Plan for 20,000 application instances and one billion peak evaluations/s. An SDK is the application library that loads and evaluates configuration; its actual runtime cost must be measured.
2. **Latency and propagation.** Target local p99 below 50 microseconds for bounded rules, publication p95 below one second and propagation to healthy connected instances within ten seconds p99. Publication success alone does not prove fleet adoption.
3. **Deterministic, coherent results.** The same snapshot and trusted context must produce the same result. Related flags in one request use one immutable snapshot; a delayed old download must not undo a newer generation.
4. **Outage behavior.** For F7, use the last validated configuration during a temporary disconnection. After five minutes without successful synchronization, return typed false with reason `stale_config`. This local timeout is not a strict five-minute global disable guarantee, and other flags may need different fallbacks.
5. **Authenticity, access and privacy.** Authorize environment writers and protect confidential rules/context. A checksum detects corruption; trusted transport or a signature under a trusted key establishes authenticity. Neither establishes that an authentic old snapshot is still current.
6. **Bounded resource use.** Limit rule complexity, targeting data, compilation and telemetry work. Exposure reporting must not block application evaluation, and old snapshots remain usable by requests already holding them.

04 / Make stable allocation and whole-snapshot replacement work

Randomly choosing ten percent on each request makes the same tenant bounce between experiences. Instead define a stable hash over an unambiguous tuple of rollout seed and targeting key. A hash deterministically maps input data to a numeric value. The seed is a fixed per-flag rollout value; keeping it stable keeps the same targeting key in the same cohort. In the example, `bucket = hash(tuple(seed, key)) mod 10,000`; modulo takes the remainder, giving a bucket from 0 through 9,999. Include buckets below 1,000 for ten percent.

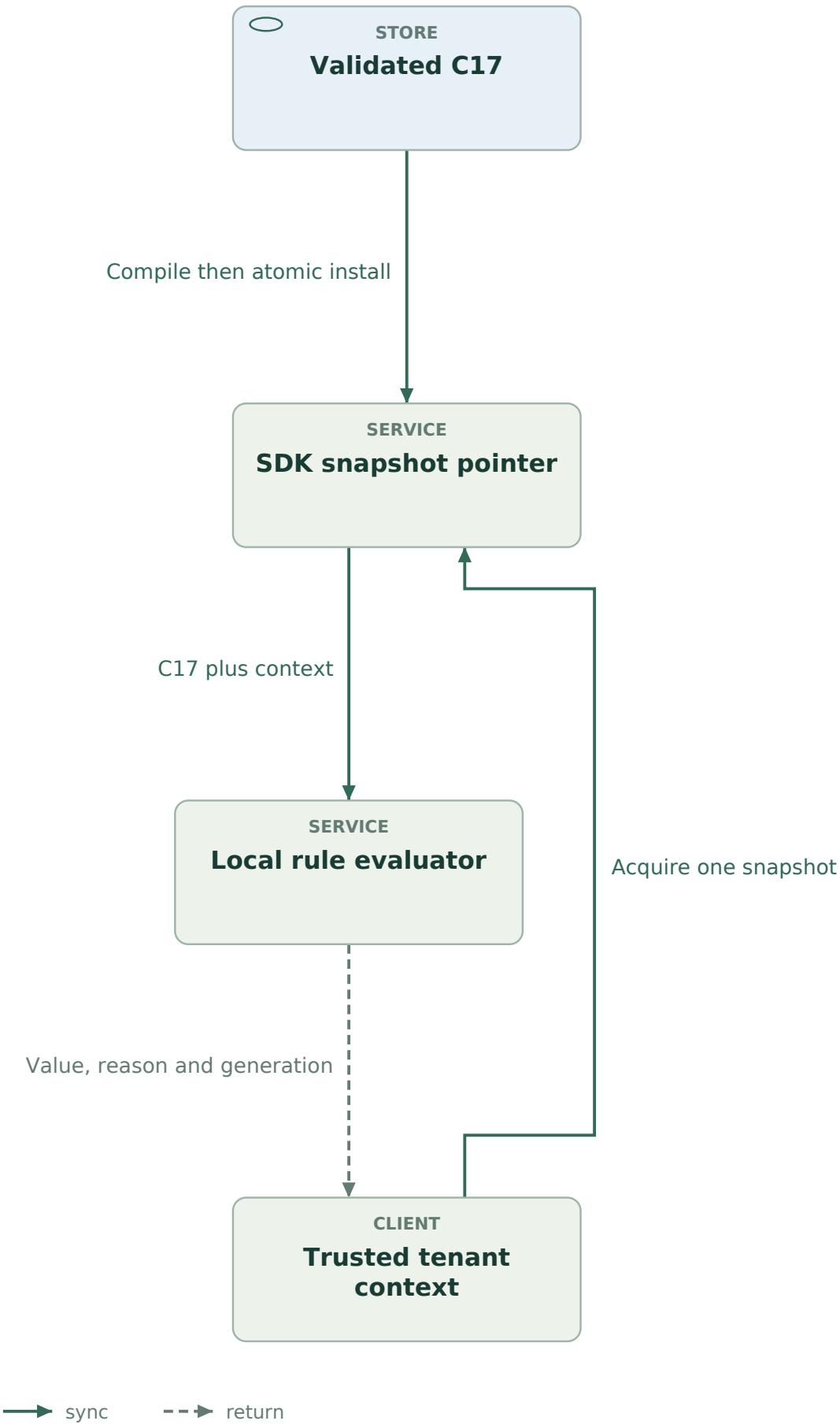
Tenant 54 maps to 731 and therefore receives F7 = true. Increasing the threshold to 2,000 preserves that assignment if the seed, targeting identity and hash specification remain unchanged. Changing the seed deliberately reshuffles the cohort. Multiple variants need non-overlapping bucket ranges and an explicit assignment contract.

One instance loads complete C17, validates types and dependencies, compiles rules and stores an immutable active pointer. Each request captures that pointer, evaluates ordered explicit rules and then the percentage fallback, and returns diagnostics alongside the selected value. Related flags use the same retained snapshot.

A new file is parsed and compiled separately, then replaces the pointer atomically after validation. A malformed update leaves the prior version active. Updating individual entries in a shared mutable map could expose a combination never validated together. This baseline proves deterministic decisions and consistent replacement before introducing fleet distribution.

One deterministic local evaluator

Each request retains a whole validated configuration.



05 / Compare local work with distribution traffic

At 20,000 instances and 50,000 evaluations/s each, a remote call for every evaluation would create one billion network calls/s. Even a 100-byte combined envelope implies 100 GB/s before transport overhead and puts network latency on each application path. Local evaluation concentrates network work on relatively rare configuration updates.

Work	Calculation	Meaning
Full fleet update	20K x 100 KB = 2 GB	Distribute cacheable immutable snapshots
Five-second polling	20K/5 = 4K checks/s	Conditional requests still consume capacity
Ten updates/hour	2 GB x 10 = 20 GB/hour	Regional caches reduce origin load
Evaluator CPU at 2 microseconds	1B/s x 2 microseconds = 2,000 CPU-seconds/s	Local is not free at fleet scale
One-in-1,000 telemetry sampling	1M events/s	Aggregate locally before sending

Bound rule complexity and precompile expensive structures outside requests. Large targeting lists and unbounded expressions can dominate evaluation. Retaining old and new compiled snapshots during rollout costs memory, but permits in-flight requests to finish consistently. Measure publication bandwidth, compilation work and telemetry separately instead of assuming low lookup latency solves the whole service's cost.

06 / Give drafts, generations and context distinct meanings

Edit a draft

```
PUT /prod/draft
```

Request field	Purpose
Expected draft version	Detect an edit made since the operator last read the draft.
Proposed rules	The configuration to validate and save.

Publish a validated draft

```
POST /prod/publish
```

Request field	Purpose
Validated draft identity	Select the rules to publish.
Expected active generation	Detect a competing publication.

Draft versions protect editors from lost updates; publication generations order committed releases. An optimistic version conflict asks the operator to review newer state rather than overwrite it.

Local evaluation call

```
getBoolean(F7, false, trustedContext)
```

Returned field	Meaning
Typed value	The selected boolean value for F7.
Reason	Why the evaluator selected the value or a fallback.
Variant	The selected variant, where applicable.
Generation	The publication used for this decision.

Missing flags, initialization failures and type mismatches follow documented fallback behavior. Define attribute types, merge precedence and missing-value handling so different SDK languages cannot interpret the same context differently.

The targeting key identifies the assigned user or tenant. Here all members of tenant 54 share one tenant-based assignment. The application derives the active tenant from authenticated membership, not an arbitrary request field. Country or plan can be additional typed rule inputs.

Control records

Record	Information retained
Draft	Editable rules and draft version.
Immutable compiled-source snapshot	Schema/compiler version, canonical content hash and dependencies.
Environment generation pointer	The committed active publication for that environment.
Audit record	The recorded edit/publication history.

A publication changes the active pointer only after its immutable bytes are durable. Notifications are recoverable announcements of that pointer, not the only record that a publication occurred.

07 / Identify the limits of the one-instance design

The first limit is operational: many editors and environments cannot safely overwrite files without version checks, audit and validation. The second is distribution: 20,000 instances can miss notifications, download at different speeds or disconnect. Publishing centrally does not prove a particular application is already using the new value.

Consider app8 starting a C17 download. C18 arrives and installs first; C17 then finishes. "Last download completed wins" moves the instance backward. A genuine rollback to C16's content must be published as generation 18, so the same ordering rule works for ordinary updates and intentional reversals.

A partial-map race is different: a request reads F7 from the new configuration and dependency F8 from the old one. Locking each flag independently does not give the request one consistent configuration. The request must retain one whole snapshot across related evaluations.

Finally, app9 is partitioned while an operator disables F7. No push protocol can deliver information across a broken connection instantly. The product must choose how long old behavior may continue and what follows. These failures motivate versioned publication, recoverable distribution, atomic installation and freshness policy as separate mechanisms.

08 / Add a control plane and recoverable delivery

Publication sequence

1. **Authorize and validate.** Authenticate the environment writer; check rule types, bounds, missing references, dependency cycles and complexity.
2. **Store the snapshot.** Make the complete immutable bytes durable.
3. **Publish conditionally.** Commit the active-generation pointer and audit/publication event only if the expected generation still matches.

A scheduled publication revalidates its assumptions at activation rather than blindly applying an obsolete draft.

A stream announces that a newer generation exists. Instances fetch immutable content through regional caches and periodically poll the authoritative active pointer to recover missed announcements. The notification prompts a check. Cached bytes provide the configuration, but only the publication service can confirm which generation is current. This keeps distribution efficient without relying on uninterrupted streaming.

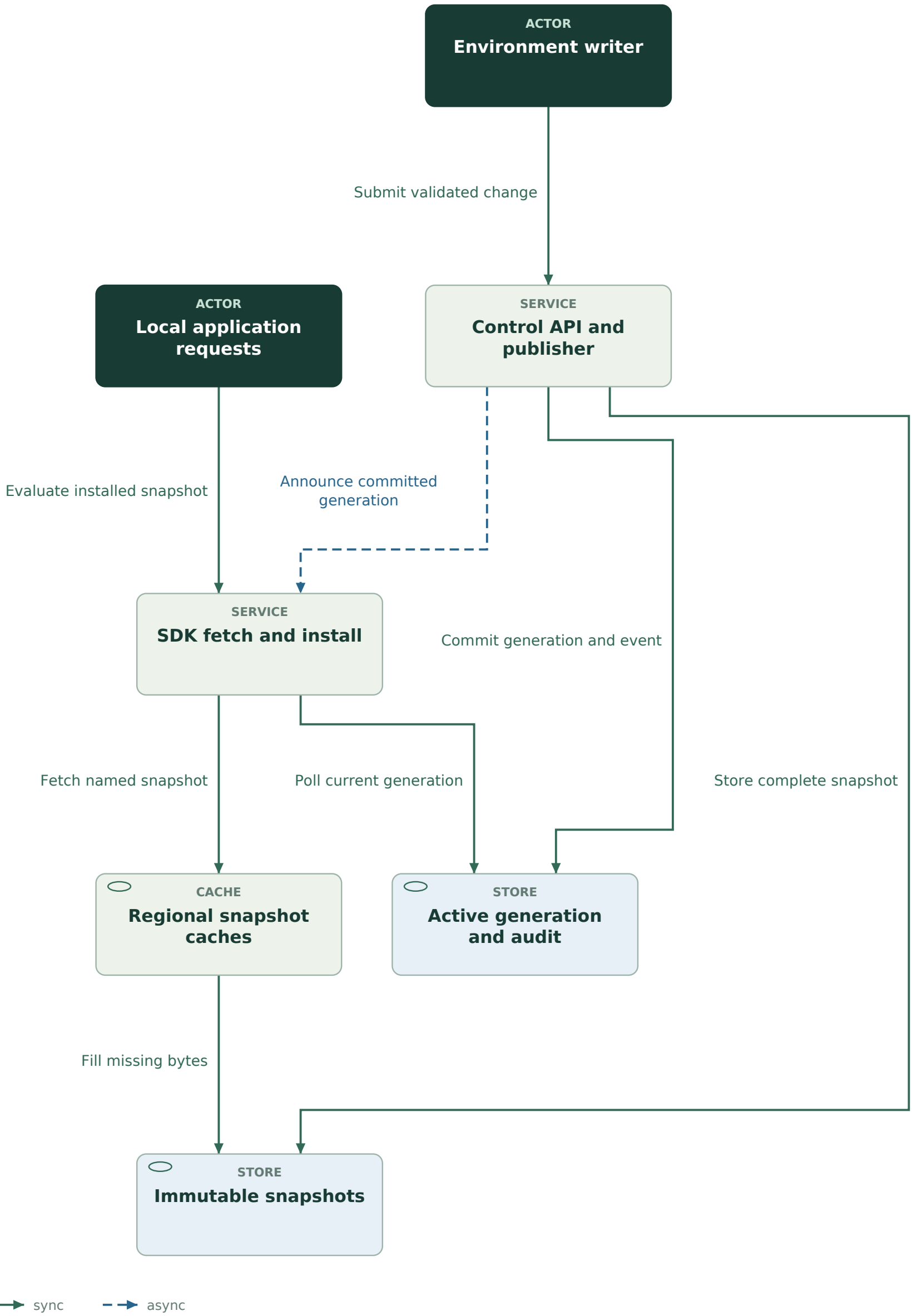
Installation sequence

1. **Verify.** Check environment, schema, checksum and trusted origin/signature.
2. **Compile.** Prepare the fetched rules outside the request path.
3. **Compare and install.** Atomically replace the current pointer only when the incoming generation is newer; ignore older/equal generations.
4. **Handle a race.** If another installer changes the pointer, retry the comparison against that current value.

Application requests continue using their captured references until completion. Cleanup waits for those references before reclaiming old compiled structures. The cost is temporary duplicate memory and careful concurrency. Local evaluation remains independent of telemetry: aggregate and bound exposure reporting so a metrics outage does not become a recommendation outage.

Publish centrally and evaluate from complete local snapshots

The publisher stores a verified snapshot before changing the active generation. Notifications prompt downloads through regional caches; polling recovers missed notifications. Each application request evaluates one installed local snapshot, without a network call to the control plane.



09 / Choose a practical stale-configuration policy

A signed C17 can remain authentic after C18 is published. A successful download proves that a configuration is available, not that the fleet has installed the latest publication. Keep those observations separate in the SDK and the operations dashboard.

For this recommendation experiment, the practical policy is last-known-good operation during a short outage. Periodic synchronization reads the current environment generation and fetches a replacement when needed. Track successful synchronization with monotonic elapsed time. After five minutes without it, return false and report stale configuration. Cached bytes after a restart do not establish a new successful synchronization.

This policy reduces disruption without claiming an instantaneous kill switch. A request already using C17 can finish with its captured decision. Different application instances may briefly disagree during propagation. A delayed reply may leave an application unaware of C18. The five-minute local timeout therefore does not prove that every instance disables F7 within five minutes of publication.

If a feature must stop sensitive actions immediately, check a current online authority at that action boundary and accept its latency and outage behavior. A strictly bounded global stale-use promise requires additional timing and renewal rules. Keep that stronger protocol in the advanced discussion; ordinary recommendation rollout does not need it.



INTERVIEW CRITICAL

An outage fallback is not an instant kill switch

Last-known-good evaluation accepts temporary differences across the fleet. Stop sensitive actions through their own current authorization path instead of treating a cached flag as permission.

10 / Prove rollback and request consistency with C17 and C18

An operator validates F7 against draft 16 and publishes C17/generation 17. app8 fetches, verifies and installs it. Request req61 derives tenant 54 from trusted context, retains C17, evaluates bucket 731 below 1,000 and uses the enabled recommendation branch. It records an exposure only if the decision actually influenced the experience.

Now generation 18 contains the intended older disabled values. If its download finishes before 17, installation leaves 18 active and ignores the later 17 result. If 17 finishes first, 18 replaces it afterward. Both orders converge to 18. An existing request retaining 17 may finish consistently under 17, while the next request selects 18; the documented stale-configuration policy still applies.

If C19 is malformed or uses an unsupported schema, validation fails before pointer replacement and 18 stays active. If two publishers race, the expected-active-generation check permits one transition and gives the other a conflict. Restoring an earlier boolean value is still a new publication, so its generation must increase.

Exposure data names flag, variant and generation actually used. Assignment, evaluation and exposure are different observations. A debug evaluation or hidden branch should not automatically count as a user seeing the experimental experience.



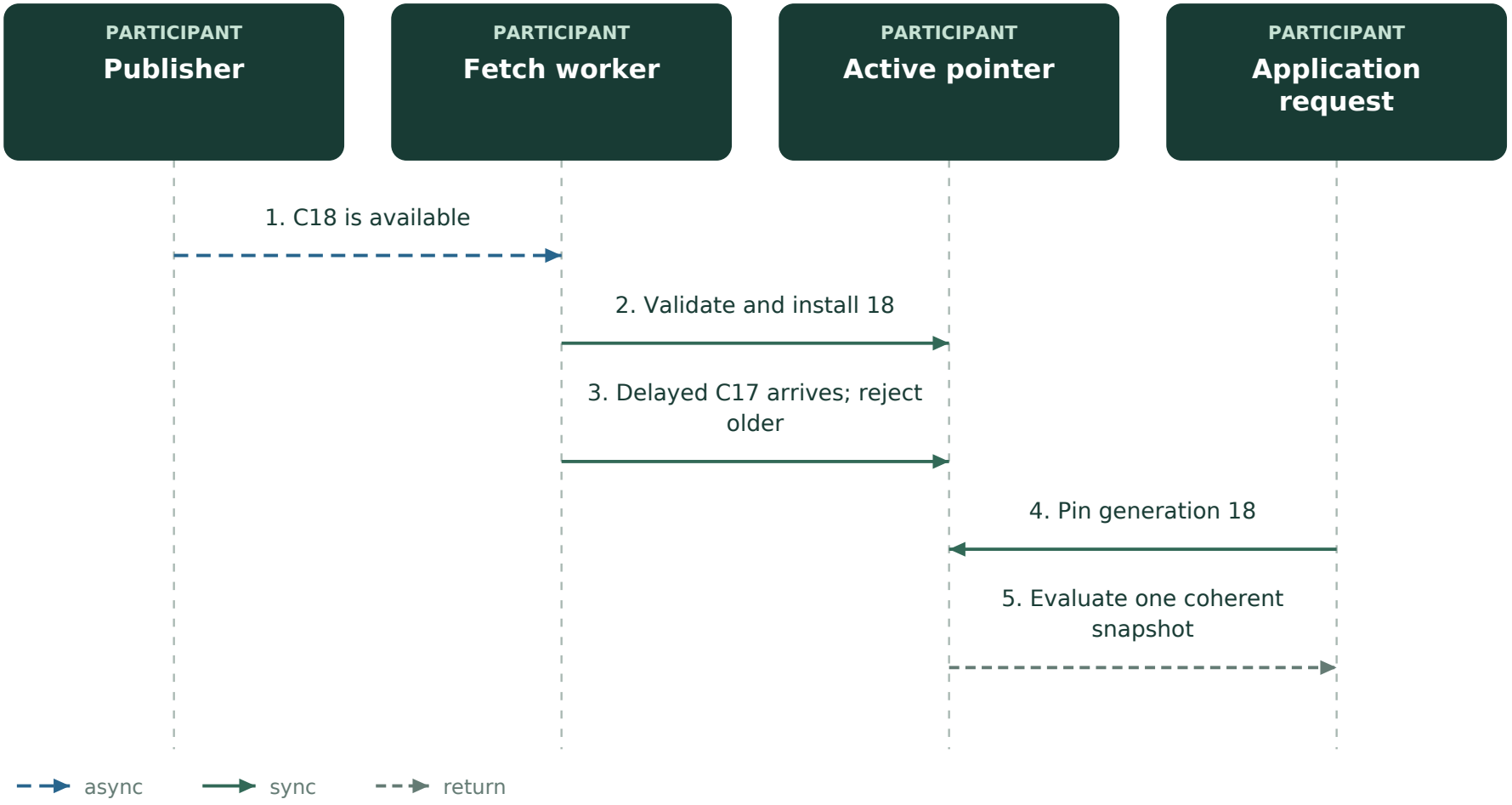
INTERVIEW CRITICAL

Rollback advances publication order

Publish the intended earlier values as a newer generation. Installing by increasing generation then handles both rollback and ordinary updates without trusting download completion order.

A newer generation wins either download order

Publication generation orders installation independently from flag values.



11 / Measure fleet adoption and bound configuration risk

Observe publication-to-install lag, active-generation distribution, time since successful synchronization, typed fallback rate, compilation failures, evaluation latency and outcome metrics by cohort. A healthy fleet average can hide an enabled cohort with errors. A rollback is not complete merely because the control API returned committed; inspect adoption and recovery of the intended product metric.

Use the same fixed input/output test vectors in every supported SDK language. Test seed and targeting-key migrations intentionally because either can reshuffle users. Protect environment credentials and audit production publications. Browser clients must not receive confidential rules or other tenants' attributes simply to evaluate a flag; server-side evaluation can keep those details inside a trusted boundary.

Drill concurrent editors, reversed download order, malformed configuration, disconnection, restart with old bytes and delayed synchronization responses. Roll compatible code/data changes separately; a flag cannot undo irreversible writes or make an old schema valid for new code.

Retire flags after rollout by removing obsolete application branches as well as configuration. Experiments additionally need stable assignment, genuine exposure and statistical analysis. A percentage slider supplies controlled assignment, not proof that a treatment improves outcomes. Revisit remote evaluation when current central authority or confidential rule access outweighs local latency and offline continuity.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 3; NFR 3, 5	Versioned drafts and validated immutable publications protect edits and releases.	Race two publishers, publish a type error and roll back values under a new generation. Verify authorization and audit records.
FR 2; NFR 3	Stable seed/key hashing and one captured snapshot make decisions repeatable.	Run common SDK test vectors; tenant 54 stays in bucket 731. Reverse C17/C18 downloads and evaluate related flags during installation.
NFR 1, 2, 6	Local compiled evaluation and cached snapshot distribution separate request work from updates.	Benchmark p99 evaluation, publication and fleet propagation at the assumed workload; include compilation and telemetry pressure. Arithmetic alone does not establish the targets.
NFR 4, 5	Authoritative synchronization tracks freshness; the local outage policy returns a typed fallback.	Disconnect an instance, restart with old cached bytes and delay a response. Confirm the five-minute local policy without claiming an instantaneous global switch.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 4; NFR 6	Bounded exposure reporting and adoption metrics show actual use and remaining old generations.	Lose telemetry, hide an evaluated branch and retire F7. Evaluation must continue, and a hidden branch must not be counted as exposure.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Newer generation wins, not the last download.

Prompt	Recall
Why local evaluation?	Avoid a network call per decision; state how long older configuration may be used
Why a stable hash?	The same seed, key and hash rules give the same user assignment
Why immutable snapshots?	A request evaluates related flags from one complete, validated configuration
Why increasing generations?	An old download cannot replace a newer release; rollback gets a new generation too
What proves authenticity?	Trusted transport or a verified signature; a checksum alone is insufficient
What confirms the current version?	Check with the environment's publication service; cached bytes cannot answer that question
What happens offline?	Use the last configuration for the allowed interval, then return the declared typed fallback
What counts as exposure?	The variant was actually used to determine the user experience

Close with: "I keep publication audited and evaluation local. Stable cohorts make rollouts repeatable, whole snapshots prevent mixed rules, and monotonic installation handles download reordering. A documented last-known-good policy and local outage timeout govern stale use. I accept bounded offline fallback and measure actual fleet adoption rather than calling a central write an instantaneous global switch."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why avoid a remote call for each flag check?

Model answer

At the assumed billion evaluations/s, network calls become enormous work and add a service dependency to application latency. Local compiled snapshots make lookups cheap and let requests continue briefly during control outages. That benefit requires an explicit stale-use and fallback policy rather than claiming instant global updates.

Interviewer follow-up

When would you choose remote evaluation?

When current authority or confidential rule access justifies the network and availability cost.

What the answer must demonstrate: At the assumed billion evaluations/s, network calls become enormous work and add a service dependency to application latency.

02 / FOUNDATION

Why does expanding ten percent to twenty preserve tenant 54?

Model answer

Its bucket 731 remains below both thresholds 1,000 and 2,000 when seed, targeting key, encoding and hash algorithm stay unchanged. A new random draw each request would not preserve assignment. Tenant-based targeting gives all authorized users of that tenant the same cohort.

Interviewer follow-up

What does a seed change do?

It deliberately changes hash inputs and can reshuffle the cohort; treat it as a migration.

What the answer must demonstrate: Its bucket 731 remains below both thresholds 1,000 and 2,000 when seed, targeting key, encoding and hash algorithm stay unchanged.

03 / APPLIED

Why is locking each flag separately insufficient?

Model answer

A request can still read F7 after its update and F8 before its dependent update, creating a configuration never validated together. Compile a complete immutable snapshot and retain one reference throughout related evaluations. Atomic pointer replacement changes later requests while old references safely finish.

Interviewer follow-up

When may old compiled data be freed?

Only after no active request or retained policy reference still needs it.

What the answer must demonstrate: A request can still read F7 after its update and F8 before its dependent update, creating a configuration never validated together.

04 / APPLIED

C18 installs before a slow C17 download. What happens?

Model answer

The installer validates bytes then compares generations under an atomic update. Since 17 is older than 18, it is ignored. A real rollback also uses a higher generation containing the desired older values. Thus content reversal never requires reversing publication order.

Interviewer follow-up

What if two installers read the same old pointer?

Compare-and-swap lets one succeed; the other rechecks against the changed pointer.

What the answer must demonstrate: The installer validates bytes then compares generations under an atomic update.

05 / APPLIED

Why cannot a successful C17 cache fetch renew freshness?

Model answer

A cache can return authentic C17 after C18 was published. Periodic synchronization must check the environment publication authority, not merely download old bytes again. The main design tracks synchronization and falls back after a long outage; it does not claim a strict publication-to-disable deadline.

Interviewer follow-up

Does successful synchronization prove every instance installed the current generation?

No. It describes that synchronization, not the entire fleet. Observe active-generation distribution and actual rollout adoption across instances.

What the answer must demonstrate: A cache can return authentic C17 after C18 was published.

06 / FOLLOW-UP

What happens when an instance cannot hear the off switch?

Model answer

The application uses its last validated snapshot during a short outage, then returns the documented false fallback after five minutes without successful synchronization. That is an outage policy, not an instantaneous command or a proved global five-minute disable bound. Sensitive actions need their own current permission check.

Interviewer follow-up

What happens after restart with saved C17?

Require a new authority confirmation; do not reset old bytes to a fresh age.

What the answer must demonstrate: The application uses its last validated snapshot during a short outage, then returns the documented false fallback after five minutes without successful synchronization.

07 / APPLIED

Is every evaluation an experiment exposure?

Model answer

No. The decision must influence the experience under the agreed exposure definition. Debug calls, hidden branches and requests that never render can evaluate without exposing a variant. Record actual flag, generation and variant used, and analyze outcome guardrails in addition to adoption.

Interviewer follow-up

Does a percentage allocation prove causal improvement?

No. It is one mechanism within an experiment requiring valid assignment, observation and analysis.

What the answer must demonstrate: No. The decision must influence the experience under the agreed exposure definition.

08 / FOLLOW-UP

How do you validate a multi-language SDK rollout?

Model answer

Run identical fixed context/seed inputs against expected bucket and rule outputs in every language. Test type and missing-attribute behavior, snapshot installation order, offline expiry and restart. Observe generation spread and fallback rates during a limited rollout. Rule schema/compiler compatibility must be checked before activation.

Interviewer follow-up

Can a flag undo an incompatible database migration?

No. Data and code compatibility need their own staged migration and recovery plan.

What the answer must demonstrate: Run identical fixed context/seed inputs against expected bucket and rule outputs in every language.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Roll F7 to ten percent of tenants, then roll it back while downloads reorder and one instance is disconnected.

• Agree the numbered functional requirements and non-functional targets, including flag purpose, evaluation load, propagation and the offline fallback.

• Calculate fleet checks and update traffic.

• Explain deterministic bucket assignment.

• Design draft/publication/context APIs.

• Prove whole-snapshot and generation races.

• Check typed behavior, deterministic snapshots, latency, propagation, privacy and outage fallback against the numbered requirements; distinguish authenticity, freshness and exposure.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

app8 installs C18, then its slow C17 download finishes. Which version stays active?

C18 stays active because installation accepts only a newer generation. A rollback also gets a new generation, even when it restores older values. Publication, installation and user exposure are separate events.

Newer generation wins, not the last download.

How can rollback restore older values without accepting an old download?

Publish those values as a new, higher generation.

Old values, new generation.

Does downloading a cached snapshot prove it is current?

No. Check the current generation with the publication service; cached bytes alone cannot show whether a newer version exists.

Ask which version is current; cached bytes cannot answer.

Summary and interview notes

Applications evaluate complete local configurations quickly, but may briefly disagree during updates. Stable user assignments, increasing generations and an offline fallback keep behavior predictable. Publishing a change does not mean every instance has installed it.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Keep control and evaluation paths separate.

• Use stable targeting and documented hash semantics.

• Install complete newer snapshots atomically.

• Renew freshness only from current authority.

• Measure real cohort exposure and retire obsolete branches.

Interview tips

• Use the C18-before-C17 race to explain generations.

• Name the offline fallback before promising a kill switch.

Important qualifications

• Ordinary flags do not replace authorization.

• Experiment quality and schema compatibility need separate checks.

Explore the advanced version

Atomic freshness renewal implementation: Expand locking and timing details when strict bounded stale use is challenged.

SDK context merge and hook semantics: Cross-language integrations need a precise provider contract.

Large snapshots and validated deltas: Useful only when full-distribution cost justifies more complex reconstruction.

Multivariate experiment analysis: Allocation alone does not establish unbiased outcome measurement.

Technical references

OpenFeature provider specification
Standard interfaces, typed defaults, resolution details, and provider lifecycle; it does not promise one hosting/freshness model.
https://openfeature.dev/specification/sections/providers/

OpenFeature evaluation context
Defines targeting identity and contextual evaluation inputs.
https://openfeature.dev/specification/sections/evaluation-context/

LaunchDarkly percentage rollouts
Provider-specific rollout allocation documentation; compare rather than assume its algorithm is universal.
https://launchdarkly.com/docs/home/releases/percentage-rollouts

EXTENDED INTERVIEWS / 56

Design a multitenant SaaS platform

Interview version / 45-minute scope · Read the advanced version online

Build a shared business application with end-to-end tenant scope, fair resource use and a controlled move that never creates two active write owners.

tenant isolation • pooled storage • resource quotas • tenant migration

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Carry verified tenant identity through APIs, database relationships, caches, jobs and files.
- Justify pooled storage, independent cells and exceptional dedicated placement.
- Prove a tenant cutover with in-flight writers, durable decisions and safe retry.

Useful foundations: Databases, data models, and ACID transactions; Data partitioning and sharding; Design an API rate limiter; Production readiness: SLI, SLO, observability, and recovery

8 interview questions with model answers and answered follow-ups.

01 / Make tenant scope the first architectural boundary

A multitenant SaaS serves several customer organizations on shared infrastructure. A tenant is one such organization. Sharing servers does not mean sharing permissions or letting one customer consume everyone's resources. Ask whether users may belong to several organizations and whether ordinary customers can share storage. Here they can, while selected large or constrained customers may receive dedicated placement.

T7 and T8 each own invoice 17. The local invoice number is therefore not the full record identity. A request authenticates user U7, verifies permission to act for T7, resolves T7's placement, and reads `(T7,17)`. A cache hit, export or download must preserve the same scope; checking SQL alone is insufficient.

The smallest complete flow is authenticate -> authorize active tenant/action -> execute scoped query -> return only that representation. Begin with one pooled application/database. Add a cell, an independently operated slice of compute and data serving a bounded tenant set, when capacity or failure isolation justifies it. Dedicated infrastructure can isolate resources, but it cannot repair an application that trusts an attacker-supplied tenant field.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Manage organizations and members.** Support tenant/member lifecycle with users permitted to belong to several organizations; authorize the active organization and action on every operation.

2. **Manage invoices.** Create, read and update tenant-scoped invoices with safe retries and conflict handling. Cross-tenant reporting or sharing needs an explicitly privileged or consented path; ordinary invoice APIs never accept a wildcard tenant.
3. **Run bounded exports.** Create asynchronous exports, inspect their progress and download only authorized results. Revalidate the initiating actor before reading and exposing an export; removing a member must not leave a perpetual grant.
4. **Manage tenant resources.** Apply quotas, expose usage and place eligible customers in shared or dedicated capacity according to their constraints.
5. **Operate the tenant lifecycle.** Move, restore and delete one tenant through scoped, audited operations. Permit an explicit maintenance window during cutover rather than promising uninterrupted movement.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Assume 10,000 tenants with 100 users each, ten percent concurrently active and five requests/minute per active user. The resulting estimate is about 8,333 requests/s, with a fivefold peak near 41,667/s; skew matters more than the average tenant.
2. **Latency and availability.** Target invoice-read p95 below 200 ms, write p95 below 400 ms and 99.95% availability per cell. A cell is an independently operated slice of compute and data. Measure tenant cohorts so a global average cannot hide one customer's outage; explicitly account for the agreed migration maintenance window.
3. **Logical isolation and current permission.** A caller cannot read or mutate another tenant's rows, cache entries, jobs or files. Operator tools require scoped authorization and audit too.
4. **Resource and placement isolation.** One tenant must not exhaust shared database, CPU, queue or connection capacity. Meet its agreed region, key, administration and recovery constraints. Separate schemas alone do not reserve resources.
5. **Durability and recovery.** Acknowledged writes survive the selected database-node failure under the actual replication policy. For recovery from backup after a larger loss, the ordinary tier is separate: assume at most 24 hours of recoverable data loss and restoration within four hours for a 1 GB tenant; larger or stricter tenants need separately agreed recovery targets. Verify a tenant restore in an isolated environment, not by overwriting the pooled database.
6. **One tenant history.** Movement must not leave two active writers. Lost-response retries retain their original operation identity, and a client that just created an invoice reads from a path that includes that commit.

04 / Prove one pooled application before distributing it

The baseline has one application, relational database, scoped cache and private object store. A read authenticates U7, checks invoice-read in T7, looks up the T7 cache key, and on a miss executes the parameterized composite-key query. Authorization is required on both paths; a cache must not bypass it.

Invoice-creation transaction

1. **Initialize scope.** Begin a transaction and initialize trusted tenant context.
2. **Check retry identity.** Look for the scoped replay key.
3. **Validate the relationship.** Check customer `(T7, 4)`.
4. **Save and commit.** Insert invoice `(T7, 18)` and its replay result together, then commit.

A database foreign key guards the relationship in addition to application checks.

Row-level security can enforce tenant policies in the database as defense in depth. Use an appropriately constrained application role, not a table owner or bypass role, and transaction-local context so pooled connections do not retain the previous request's tenant. Arbitrary privileged SQL is outside that protection.

An export worker loads J8's durable context, rechecks current permission, executes bounded scoped pages and writes an immutable T7-owned object. Completion records the exact object version. Download authorization happens again when requested. These checks establish logical isolation before any discussion of schemas, cells or dedicated databases; moving an insecure query into another topology would merely move the leak.



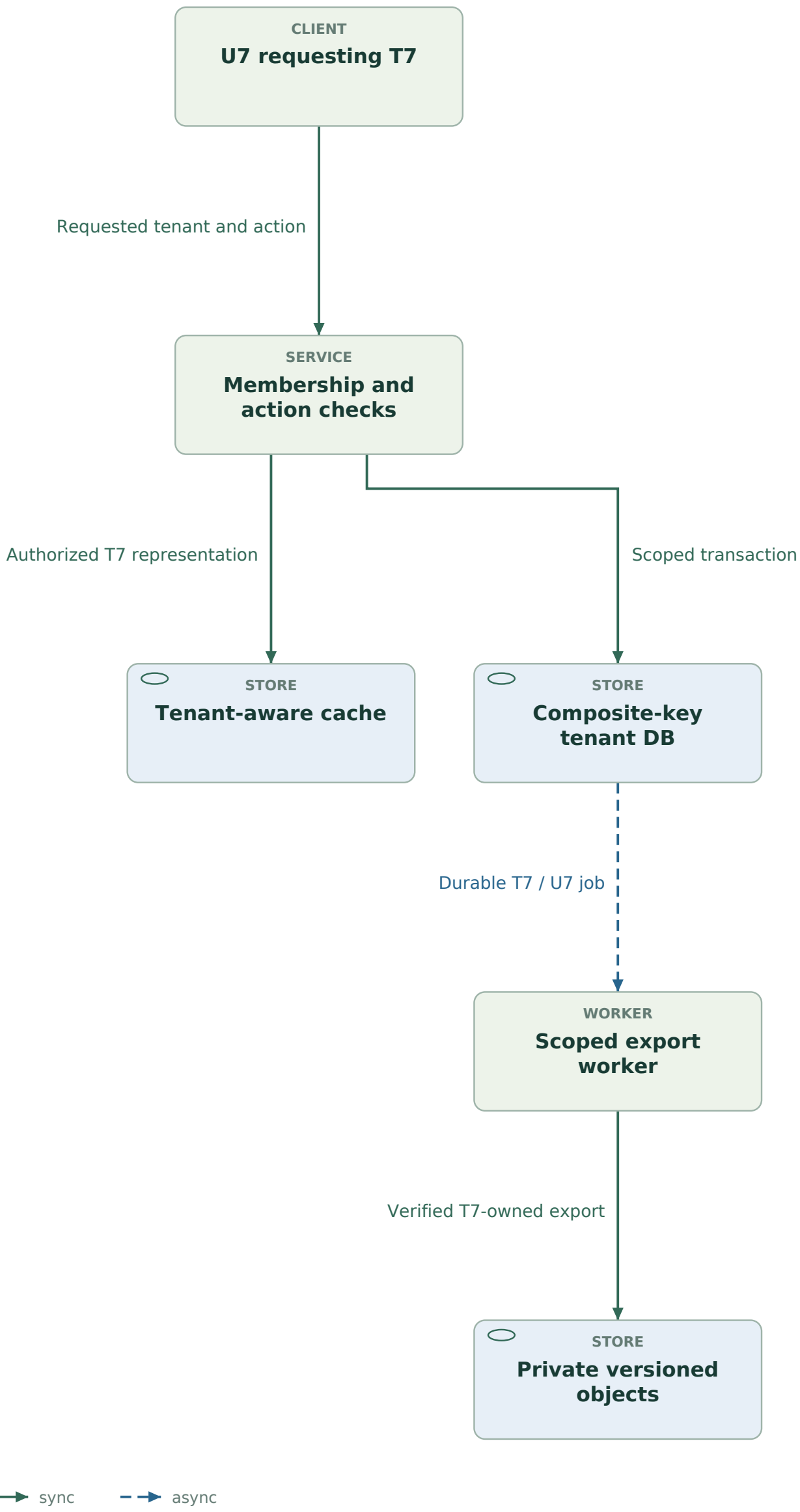
INTERVIEW CRITICAL

A correct query is only one isolation boundary

The same tenant scope must constrain cache entries, jobs, files and operator actions. Separate databases cannot repair an API that routes an unauthorized actor or returns an unscoped cache hit.

One pooled but tenant-scoped application

Trusted scope reaches every storage and background path.



05 / Size for expensive tenants and operations

Assume 100 users/tenant, ten percent simultaneously active and five requests per active user/minute. That gives 100,000 active users and about 8,333 requests/s, with a fivefold peak near 41,667/s. The mean tenant uses only 0.83 requests/s, but one tenant producing 20% of base traffic already contributes about 1,667/s.

A hundred cells with about 100 tenants each would average 417 peak requests/s per cell. That count is a placement starting point, not a load-balancing proof. Use observed CPU, query cost, storage and batch demand; a single large tenant may exceed an otherwise ordinary cell.

Assume an invoice read uses 2 ms of database CPU. An export scanning one million rows at 100 microseconds each uses 100 CPU-seconds, equivalent to 50,000 such reads. Charging each operation one request token misses this disparity. Bound active exports, query time, scanned/output bytes and connections, and reserve interactive capacity.

At 1 GB of customer data per tenant, logical storage is 10 TB, or at least 30 TB for three copies before indexes/logs/backups. Moving a 1-TB tenant needs another copy plus change-log headroom. A20-MB/s write stream produces 72 GB during an hour-long copy; the destination must replay faster than arrival before the final pause can be short.

06 / Keep requested scope separate from trusted scope

Read an invoice

```
GET /tenants/T7/invoices/17
```

The URL names T7; it does not prove U7 belongs to T7. Middleware verifies membership and permission for the action, then passes the verified tenant and caller to downstream services. Those services validate this context instead of trusting a tenant header supplied by the user.

Create an invoice

```
POST /tenants/T7/invoices
```

Request information	Meaning
Operation-scoped idempotency key	Identify this intended creation so a retry can recover its result.
Customer identity	The customer within T7, such as customer 4.
Amount and currency	Use integer minor units with an explicit currency.

Save the replay result with the invoice transaction. A duplicate identical request returns the same invoice; a conflicting payload under that key fails. Update APIs use expected row versions to prevent lost edits.

Record relationships and cache identity

Record or lookup	Identity or required relationship	Purpose
Invoice	Primary key: `(tenantId, invoiceId)`	Invoice 17 in T7 differs from invoice 17 in T8.
Customer reference	`(tenantId, customerId)` references `Customer(tenantId, id)`	An invoice in T7 cannot accidentally reference T8's customer 4.
Cached representation	Tenant, object and representation version; audience when field visibility differs	Prevent one scope or audience from receiving another's representation.

Export, file and pagination records

Record	Information bound to it
Export job J8	Tenant, initiating actor, operation identity and filters. Persist these before enqueueing the job ID.
File metadata	Tenant ownership. A `T7/` object-key prefix is naming, not authorization.
Pagination cursor	Tenant, filters and ordering, so the cursor cannot silently move to another tenant or query.

07 / Repair noisy-neighbor and failure-scope limits

First introduce fair tenant scheduling and separate interactive/batch budgets. The trigger is a tenant submitting thousands of expensive exports while ordinary reads wait. Fair queues and per-tenant active-job limits preserve useful service; the cost is scheduler state and sometimes idle reserved capacity. Adding application replicas without database budgets can worsen contention.

Next introduce cells when one pooled database's capacity or failure impact becomes too large. A tenant directory maps T7 to cell C2, region, tier and placement version 8. Each cell has its own compute and replicated data capacity, so many failures and rollouts affect a bounded customer set. Shared identity and directory services still require their own availability design.

Dedicated placement becomes justified by sustained resource pressure or explicit residency, key, recovery or administrator constraints. Separate schemas primarily organize namespaces; they do not reserve CPU. Dedicated databases and compute add stronger administrative/resource boundaries at higher fleet and utilization cost.

Keep the same application contract across pooled and dedicated placements. A cell should not become a special bypass of tenant authorization. Movement, restoration and deletion are controlled lifecycle operations with durable state and audit, not ad hoc routing edits or unrestricted copies between databases.

08 / Trace scoped reads, writes and exported bytes

U7's create request resolves T7's current cell and supplies the original operation key. The cell checks that T7 is active there, initializes trusted tenant context, and commits the invoice with its replay result. A placement change returns a retriable error so the router can refresh its directory entry. Reusing the key avoids creating a new invoice after a lost response.

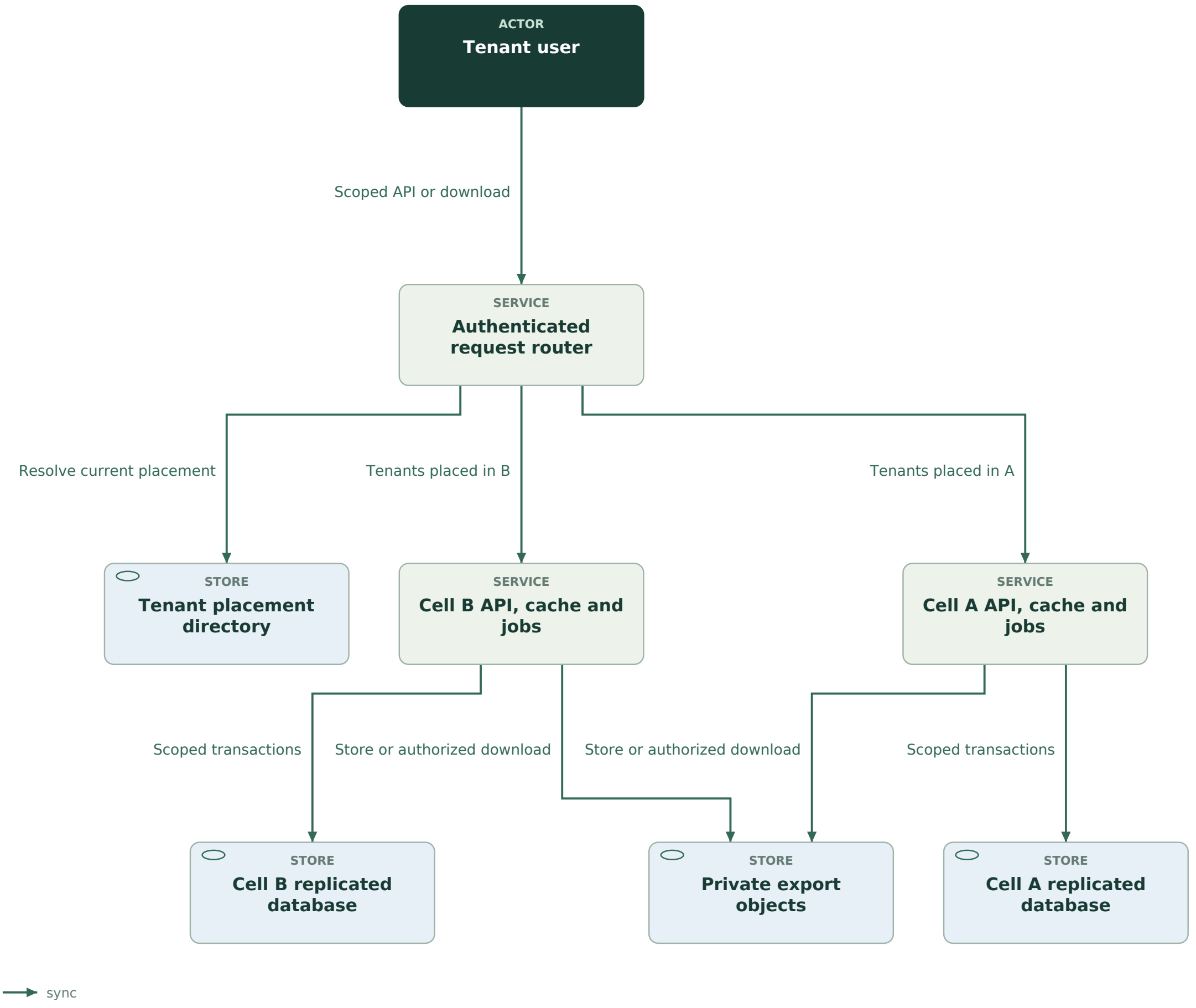
A read resolves the placement, authorizes the exact object and returns only scoped fields. For the agreed read-your-write requirement after invoice creation, use the primary or a replica known to include that commit. A random lagging replica can make the new record appear missing. This is why the agreed contract cannot treat all replicas as interchangeable.

Export workers carry durable tenant and actor context. Before reading and exposing results, they recheck the current permission and placement. Their database work uses the same resource limits and scoped access as ordinary requests.

For downloads, choose an authenticated gateway that checks current tenant membership and permission for the immutable object version before serving a new request. This matches the baseline's repeated download authorization. A short-lived presigned URL is an alternative with a weaker expiry-bound contract: possession may permit access until expiry after membership changes. A tenant prefix or a user name embedded in a transferable URL does not supply that enforcement.

Route each tenant to a cell with its own capacity

The router resolves the tenant placement, then sends the operation to that cell. Each cell retains tenant checks, scoped caching and bounded export work. Downloads pass through current authorization before the private object store supplies bytes; a cell boundary does not replace permission checks.



09 / Move a tenant with an explicit maintenance pause

The chosen interview design permits a maintenance pause when moving a tenant. Transfer T7 in this order:

1. **Freeze the source.** Stop T7's mutations at C2.
2. **Drain admitted work.** Wait for already admitted writes and background updates to finish.
3. **Copy stable data.** Transfer the now-stable tenant state.
4. **Verify the destination.** Check C5 before activation.
5. **Switch authority.** Change the directory and enable T7 at C5.

Reads can continue from the frozen source if the product accepts that view.

Every writer must encounter the freeze check in storage or in a shared write path. Removing a frontend route is insufficient: old workers and cached routes may still reach C2. Keep C2 write-disabled after the move, so a stale request gets a placement-change error instead of changing the old copy.

Copy invoices, related rows, completed operation keys and durable jobs. Verify scoped counts, checksums and relationships before activation. A copied replay result lets a client retry an invoice whose successful response was lost. The directory changes only after the destination is ready.

For a large tenant, the pause may be too long. A future refinement copies a consistent snapshot while the source remains active, then catches up its changes before a short final freeze. That requires a reliable change log and recovery protocol. Present it as an extension; the simple design makes a longer, explicit availability tradeoff instead of promising zero-pause movement.



INTERVIEW CRITICAL

A directory update cannot stop old writers

Enforce the source freeze at a boundary every mutation obeys, drain existing writers, and keep the source disabled after destination activation. A cached route must cause a retry, not a second authoritative copy.

10 / Check writes around the maintenance boundary

Follow one invoice through the maintenance pause. If U7's write was admitted before the freeze, the move waits for it to commit or abort. A committed invoice and its replay result are therefore present in the stable copy. If the request arrives after the freeze, C2 rejects it without a mutation. The client later retries against C5 under the same operation key.

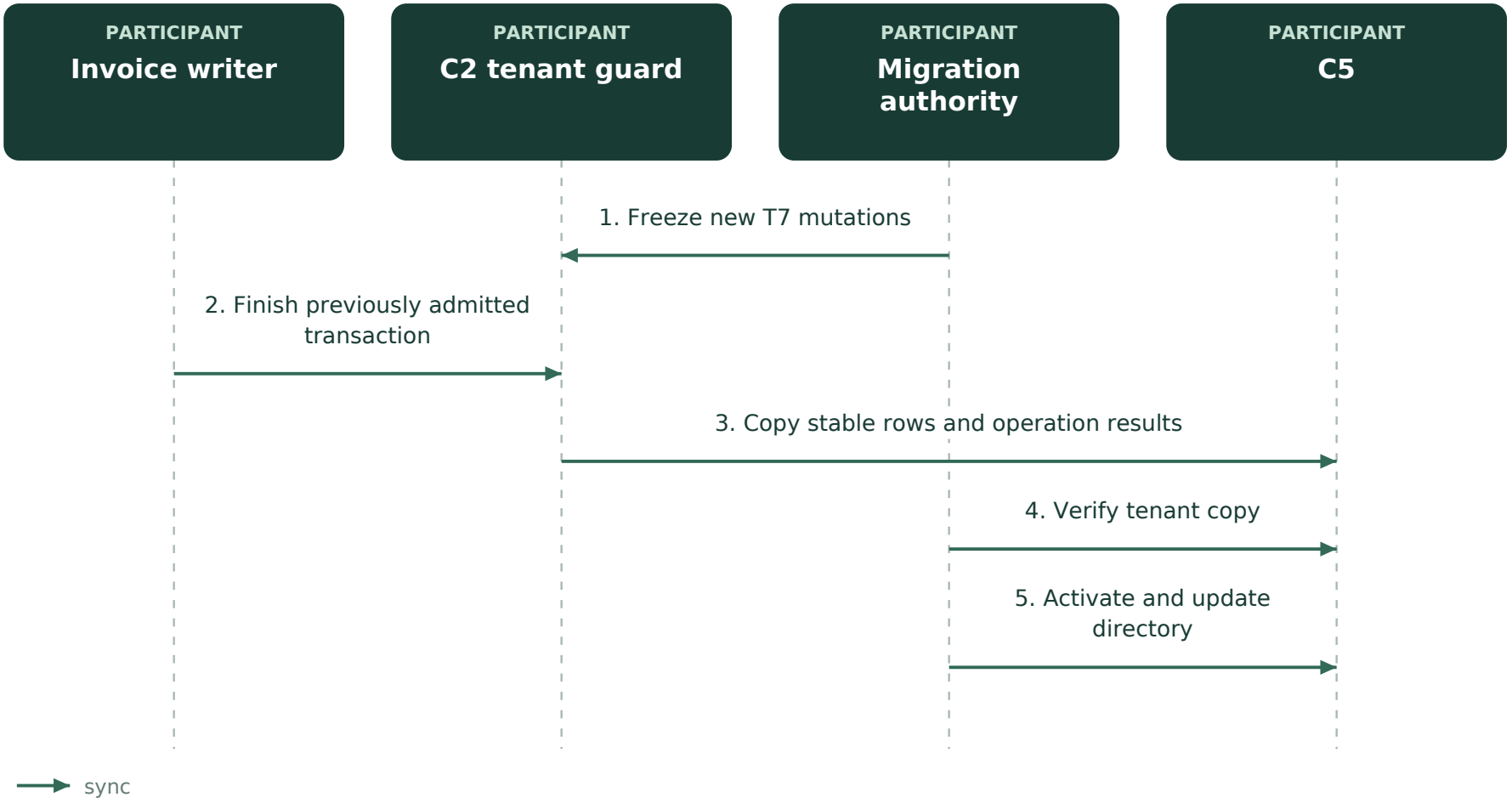
This reasoning depends on including background writers. An export-completion update or administrative import cannot continue changing T7 behind the maintenance boundary. The freeze is a tenant lifecycle state enforced by the mutation path, not a flag that only the public API happens to check.

Record movement progress durably so a coordinator restart can inspect what completed. When activation is uncertain, keep the source frozen and investigate or finish the destination transition. A timeout does not prove that the destination accepted no writes. Reopening both sides would exchange a visible outage for divergent customer records.

Once C5 accepts writes, pointing the directory back to the old copy would lose those changes. Recovery must repair C5 or perform another controlled transfer. Full coordinator fencing and continuously replicated migration are advanced protocols. The interview design accepts a recoverable maintenance window and establishes one active writer before it claims service is restored.

One tenant changes placement during a maintenance pause

Freeze and drain the source before copying; enable only one destination.



11 / Test isolation where shortcuts usually hide

Create a fixture with T7 and T8 both owning invoice 17 and customer 4. Exercise it through real cache keys, pooled connections, background jobs, object access and operator tooling. Test forged tenant headers, missing SQL scope, retained connection context and canceled/revoked exports. A helper-unit test cannot cover the full path.

Measure tenant/cohort latency, database time, scanned/output bytes, active jobs, queue age, denied scope violations, migration lag and epoch mismatches. Control metric-label cardinality while preserving authorized investigation paths for one tenant. Global averages should not hide a starved customer.

For the ordinary backup tier, take at least daily recoverable backups and measure the four-hour restore goal on a 1 GB tenant. Restore a tenant in a separate environment, validate scope and import deliberately; restoring the pooled database in place overwrites other customers. Deletion covers rows, derived indexes, caches, exports and documented backup treatment. Backups must retain placement fences and replay outcomes, not merely invoice content.

Roll schema changes cell by cell with compatible readers/writers and stop on failures. Drill a paused write during migration, reverse the ordering, then crash the coordinator during the freeze, copy and activation stages. Compare destination results and current authority before reopening traffic. The next economic decision is whether observed tenant skew or policy requirements justify a dedicated cell, not whether a customer carries an "enterprise" label.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1-3; NFR 3	Trusted tenant/action context, composite identities and repeated export/download authorization protect scope.	Use T7 and T8 with invoice 17 through SQL, cache, pooled connections, jobs and files; revoke an exporter before result access.
FR 2; NFR 6	Invoice and replay result commit together; read-your-write requests use an up-to-date path.	Lose a create reply and retry; require the same invoice, no stale missing result and no cross-tenant relationship.
FR 4; NFR 1, 2, 4	Fair work budgets, interactive capacity and cells address expensive exports and skew.	Load-test a noisy tenant alongside ordinary reads, measuring tenant p95 and per-cell availability. The average cell calculation does not prove balanced placement.
FR 5; NFR 6	Source freeze, writer drain, verified copy and one destination activation transfer authority.	Race writes on both sides of the freeze and crash the coordinator. Require one history; the chosen design accepts a maintenance pause.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 5; NFR 5	Replicated commits, scoped backup restore and deletion inventory cover different loss modes.	Lose a database node and restore a sample 1 GB tenant from backup elsewhere. Measure the separate 24-hour recovery-point/four-hour recovery-time targets and verify other tenants stay intact.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Same invoice number; different tenant ownership.

Prompt	Recall
What establishes tenant scope?	Verify membership and permission for the action; a URL or header alone proves neither
What identifies invoice 17?	Tenant plus local ID, included in related records, cache keys and jobs
What does RLS add?	Another database check, if roles cannot bypass it and each transaction sets the right tenant
Why cells?	Limit how many tenants one failure affects and add capacity; shared services can still fail
What protects ordinary reads from exports?	Limit expensive work, schedule tenants fairly and reserve capacity for interactive requests
What transfers write ownership?	Stop source writes, finish active writes, copy and verify, then enable only the destination
What survives lost replies?	Copy saved retry results with tenant data, so the same request returns its earlier result
What does a signed URL grant?	Time-limited access to anyone holding it, unless the server also checks current user permission

Close with: "I pool ordinary tenants while enforcing trusted scope end to end. Fair budgets protect shared resources; cells and dedicated placement follow measured needs. During a move, every writer respects the source freeze, and the destination activates only after a verified copy. I accept a maintenance pause to keep one authoritative tenant history."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why is tenant ID in the URL insufficient?

Model answer

It expresses the requested organization, not membership or permission. Authentication establishes the actor; authorization verifies the active tenant and action. Trusted scope then travels through database queries, caches, jobs and files. An unchecked forwarded tenant header would let a caller choose another customer's data.

Interviewer follow-up

What key identifies an invoice?

Tenant plus local invoice ID. Related records and cache keys must include the same tenant.

What the answer must demonstrate: It expresses the requested organization, not membership or permission.

02 / FOUNDATION

What does row-level security add?

Model answer

It lets the database enforce row-access policy as defense in depth. Its assumptions include a constrained application role and initialized transaction-local tenant context. Table owners, bypass privileges or stale pooled-session context can undermine those assumptions. It complements rather than replaces application authorization.

Interviewer follow-up

Why transaction-local context?

Connection reuse must not carry T7's setting into a later T8 request.

What the answer must demonstrate: It lets the database enforce row-access policy as defense in depth.

03 / APPLIED

Why does request-count limiting miss export overload?

Model answer

A million-row export can consume roughly 100 CPU-seconds in the example, equivalent to 50,000 ordinary reads. Counting it as one request hides database work and output load. Limit active exports, query duration, scanned/output bytes and connections, with fair tenant scheduling and reserved interactive capacity.

Interviewer follow-up

Will more API replicas solve it?

They may increase pressure on the same database; resource ownership and limits still govern capacity.

What the answer must demonstrate: A million-row export can consume roughly 100 CPU-seconds in the example, equivalent to 50,000 ordinary reads.

04 / APPLIED

When would you give a tenant dedicated placement?

Model answer

Use measured sustained demand or explicit region, key, recovery and administration constraints. Ordinary tenants can pool economically in cells. Separate schemas mainly organize namespaces; dedicated compute is needed to isolate certain resource contention. Every placement still requires logical authorization at its access paths.

Interviewer follow-up

What remains shared across cells?

Identity, directory and control services can remain common dependencies requiring separate availability and rollout controls.

What the answer must demonstrate: Use measured sustained demand or explicit region, key, recovery and administration constraints.

05 / APPLIED

What if an invoice write overlaps cutover?

Model answer

The chosen migration pauses tenant writes at a boundary shared by every mutation. It waits for admitted writes to commit or abort before copying the stable data. A writer that completed first is copied with its replay result; one arriving after the freeze is rejected and retries at the new placement. Background writers must follow the same rule.

Interviewer follow-up

Which overlooked path can break this?

Any background/admin mutation that bypasses the same guard, including job completion after a move.

What the answer must demonstrate: The chosen migration pauses tenant writes at a boundary shared by every mutation.

06 / FOLLOW-UP

Activation of C5 times out. May you reopen C2?

Model answer

No. A timeout does not prove C5 accepted no writes. Keep C2 frozen, inspect durable migration progress and recover or finish the destination transition. Once C5 has new writes, returning to C2 needs a controlled transfer of those changes. The main design accepts a maintenance window rather than simultaneous ambiguous ownership.

Interviewer follow-up

Why not just change the directory back?

After destination writes, the old source is stale. Safe return requires a new transfer or destination repair.

What the answer must demonstrate: No. A timeout does not prove C5 accepted no writes.

07 / APPLIED

Does a signed download URL enforce current user identity?

Model answer

The selected design uses an authenticated gateway that checks current tenant membership and permission on a new download request. An ordinary presigned URL is an alternative bearer capability: possession may allow access until expiry even after revocation. Use that alternative only if its expiry-bound behavior meets the contract.

Interviewer follow-up

What must the worker publish?

The exact immutable object version it validated, with tenant ownership and current completion authority.

What the answer must demonstrate: The selected design uses an authenticated gateway that checks current tenant membership and permission on a new download request.

08 / FOLLOW-UP

How do you restore one tenant from a pooled backup?

Model answer

Restore into a separate recovery environment, verify tenant scope and import only intended records through a controlled ownership plan. Include replay outcomes, outbox and placement-control state, then rebuild derived views. Restoring the pooled database in place would overwrite other customers.

Interviewer follow-up

What test demonstrates isolation better than a query unit test?

Run two tenants with matching local IDs through cache, pooled connections, jobs and file APIs, then attempt cross-scope access.

What the answer must demonstrate: Restore into a separate recovery environment, verify tenant scope and import only intended records through a controlled ownership plan.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Serve T7 and T8 with matching invoice IDs, protect reads from export overload, then move T7 from C2 to C5.

• Agree the numbered functional requirements and non-functional targets, including tenancy, exports, isolation, skew, recovery and maintenance acceptance.

• Estimate skew and export cost.

• Show the pooled transaction/cache/job flow.

• Choose fair budgets and placement.

• Prove both writer-versus-freeze orders.

• Validate invoice/export behavior, isolation, latency, recovery and one-writer cutover against the numbered requirements; state restore, grant and coordinator limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

T7 and T8 both have invoice 17. What must every access path check?

Verify the caller may act for the requested tenant. Keep that tenant in database relationships, cache keys, jobs, files and operator checks; the invoice number alone is insufficient.

Same invoice number; different tenant ownership.

How does a maintenance move avoid two writable copies of one tenant?

Stop source writes, finish admitted work, copy and verify the data, then enable only the destination. The move accepts a maintenance pause.

Stop writes -> drain -> copy and verify -> enable destination.

When should a tenant receive dedicated infrastructure?

When measured resource use disrupts others, or a specific storage location or administrative requirement justifies the cost.

Isolate for a concrete constraint.

Summary and interview notes

Check tenant permission in queries, caches, jobs and files. Limit each tenant's work to protect others; choose shared or dedicated placement for measured needs. During a move, stop source writes before enabling the verified destination.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Verify the requested tenant before deriving trusted context.

• Use composite identities through every handoff.

• Budget expensive work separately from request counts.

• Add cells and dedicated capacity for measured constraints.

• Commit one migration decision after source freeze and destination validation.

Interview tips

• Reuse invoice 17 in two tenants to expose missing scope.

• Make the old writer's rejection explicit during cutover.

Important qualifications

• A cell does not remove shared-control dependencies.

• Stronger download revocation needs an online enforcement boundary.

Explore the advanced version

Cross-authority migration decision fence: Expand exact metadata ownership when implementing coordinator failover.

Mutable field-policy and byte-version binding: Needed for fine-grained representation authorization.

Tenant-specific point-in-time restoration: Requires scoped replay and derived-state reconstruction beyond a backup command.

Zero-pause movement: Requires a stronger forwarding/replication protocol than the chosen paused cutover.

Technical references

Microsoft multitenant architecture overview
Frames tenant isolation, architecture, and operational responsibilities.
https://learn.microsoft.com/en-us/azure/architecture/guide/multitenant/overview

Microsoft multitenant data approaches
Compares pooled and isolated storage choices and their management tradeoffs.
https://learn.microsoft.com/en-us/azure/architecture/guide/multitenant/approaches/storage-data

PostgreSQL row-security policies
Documents RLS behavior and privileged-role/owner bypass considerations.
https://www.postgresql.org/docs/current/ddl-rowsecurity.html

Microsoft multitenant compute approaches
Discusses shared/dedicated compute, noisy neighbors, and tenant-aware resource governance.
https://learn.microsoft.com/en-us/azure/architecture/guide/multitenant/approaches/compute

EXTENDED INTERVIEWS / 57

Design a distributed object store

Interview version / 45-minute scope · Read the advanced version online

Store large immutable byte sequences behind named keys, with safe publication, authorized reads and measured durability.

object manifests • multipart upload • checksums • versioning • signed URLs

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain a complete upload and download before distributing storage.
- Separate immutable bytes from mutable names, permissions and upload state.
- Defend multipart completion, replication, retries and deletion without promising impossible atomic uploads.

Useful foundations: Replication and durability; Data partitioning and sharding; Quorums, consensus, leases, and fencing; Databases, data models, and ACID transactions

8 interview questions with model answers and answered follow-ups.

01 / Separate an object's name from its bytes

An object store accepts a named sequence of bytes and later returns those bytes. Unlike a filesystem, it does not need to support in-place edits to arbitrary byte offsets. Our product stores tenant-owned videos, exports and backups. Clients create or replace a whole object, read a range, list names and delete a name. Every successful replacement creates an immutable version.

Ask whether clients replace whole objects or need filesystem-style edits, whether reads must immediately see a completed replacement, and which failure must an acknowledged upload survive. This walkthrough chooses whole immutable versions, authoritative current-key reads and one storage-node failure within a region.

Use tenant T7 uploading a 2 GiB video as the running example. Its logical key is `videos/launch.mp4`; version V5 identifies one exact byte sequence under that key. Keeping those identities separate lets a download finish on V4 while a new upload prepares V5. A key is an address, while a version is a particular saved object.

The complete flow is authorize upload -> store temporary bytes -> verify them -> publish a version -> authorize download -> read that version. Publication means making a completed object visible under its logical name. Upload progress alone does not make an object readable. This distinction is the basis of retries, concurrent replacements and cleanup throughout the design.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Create and replace objects.** Support PUT of tenant-owned bytes under a logical key, creating a new immutable version on each successful replacement.

2. **Read object data and metadata.** Support GET, HEAD and ranged GET, plus reads naming an exact version. An existing version-specific reader may finish on the version it selected.
3. **Resume large uploads.** Support multipart sessions, part inspection/retry, explicit completion and abort. Partial bytes must remain invisible as a completed object.
4. **List and delete names.** Support DELETE and paginated key listing with a stable ordering and cursor. Listing is not a snapshot across concurrent changes unless an additional snapshot feature is requested. Filesystem-style in-place edits and cross-region disaster recovery are outside the initial scope.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Assume ten million new objects/day averaging 10 MB and one billion reads/day averaging 4 MB returned. The sizing exercise retains thirty days; versions, temporary uploads and peaks require extra capacity.
2. **Visibility and integrity.** After completion succeeds, a new lookup of the logical key must return the new version. Each download returns one complete immutable version with verified length/checksum, never a mixture of versions. Concurrent conditional replacements must detect a conflict.
3. **Regional durability.** An acknowledged upload must survive one storage-node failure, and acknowledged metadata must survive one metadata-node failure. Required durable copies must exist before success; background replication alone does not establish this promise. Region loss needs a separately designed recovery point, recovery time and cost.
4. **Latency and transfer rate.** Target metadata-read p95 below 100 ms and read time-to-first-byte p95 below 250 ms on regional test paths. For large transfers, target at least 50 MiB/s per transfer when the client and network can sustain it. Test under admitted load; a 2 GiB video cannot share a tiny-object completion-latency target.
5. **Bounded uploads and quotas.** For this exercise, accept objects up to 64 GiB and expire incomplete uploads after 24 hours. Start with a default 1 TiB logical-byte quota, including temporary and retained versions, and ten active upload sessions per tenant; larger tiers require explicit configuration. With 64 MiB parts the largest object uses 1,024 parts. Reclaim only unreferenced expired parts.
6. **Tenant access.** Authorize metadata lookup, upload capabilities and byte delivery. A tenant prefix only names data; it does not authorize access. Short-lived download URLs are bearer grants until expiry, so immediate revocation would require an online enforcement path.

04 / Make one server publish only complete objects

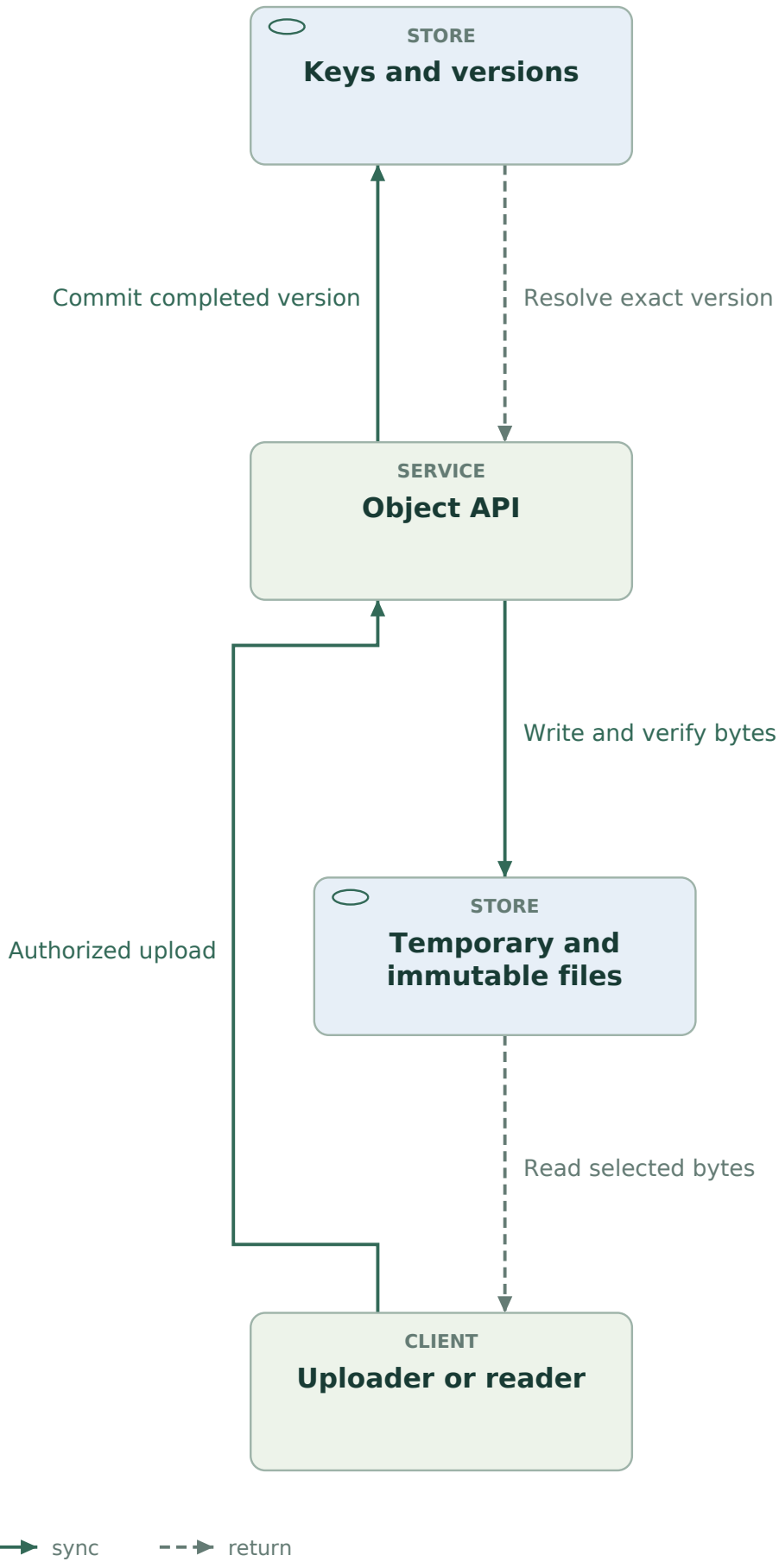
Start with an API, a metadata database and a filesystem on one storage server. A client requests an upload session U31 for T7's key. The API checks permission and returns an upload identifier. The server writes incoming bytes to a temporary file named by that session, computes a checksum and verifies the declared length. A checksum detects accidental corruption; it does not establish who is allowed to upload.

After the file is complete and durably flushed, establish its immutable version name durably as well; a filesystem rename may require flushing the containing directory before publication. In a metadata transaction, create V5 and change the key's current-version pointer to V5. Only then return success. A reader first authorizes access, resolves the current version and reads that exact file. It never streams a partially written temporary file.

If the server crashes before metadata publication, an unreferenced file may remain for later cleanup. If it crashes afterward but before replying, retrying completion for U31 returns the recorded V5 result. This ordering avoids a published pointer to bytes that were never durably stored. The baseline is complete but has one storage failure domain and limited disk/network capacity.

Prepare bytes, then publish a name

The metadata pointer is the visibility boundary.



05 / Size stored bytes separately from requests

Assume ten million new objects per day with an average size of 10 MB. That is approximately 100 TB of new logical data per day. Retaining thirty days gives 3 PB before versions, temporary uploads and overhead. Three complete replicas require about 9 PB. Use consistent decimal units for this estimate; the running 2 GiB multipart example uses binary units deliberately.

One billion reads per day at an average returned range of 4 MB gives 4 PB/day of output, about 46.3 GB/s on average. Peak demand and popular-object skew require additional capacity. Caching immutable versions can save origin traffic, but an average cache hit rate can hide a single very large hot download.

For the example video, 64 MiB parts produce 32 parts. Four parallel transfers can improve throughput until the client, gateway or storage network saturates. More parallelism then adds connections and retry pressure without speeding the disk.

Metadata entries are much smaller than payloads and follow different access patterns. Scale the metadata database for key lookups and publication transactions; scale storage nodes for bytes, capacity and repair bandwidth. Do not route all large payloads through a single database or control server.

06 / Give upload sessions and versions different APIs

Create the upload session

```
POST /uploads
```

Example request body for the 2 GiB video

```
{
  "tenant": "T7",
  "key": "videos/launch.mp4",
  "expectedCurrentVersion": "V4",
  "totalSizeBytes": 2147483648
}
```

The request may also include a content checksum. The API validates the 64 GiB size ceiling, reserves the declared logical bytes against the tenant quota, checks the ten-active-upload limit and creates U31 with a 24-hour expiry. Account for concurrent reservations atomically so several uploads cannot each spend the same free quota.

Continue or read an upload

Operation	Request or result
`PUT /uploads/U31/parts/7`	Send bytes, part identity, length and checksum.
`POST /uploads/U31/complete`	Supply the ordered part list for publication.
`GET /objects/key`	Resolve the current version of the logical key.
Version-specific GET	Read the explicitly named immutable result.

Metadata records

Record	Fields	Purpose
Key	Current version and deletion state	Resolve a mutable logical name.
Upload	Owner, expected version, expiry and status	Track the preparation and completion of one upload.
Part	Exact stored object identity and checksums	Identify and verify the precise bytes being referenced.
Version manifest	Ordered parts and total length	Reconstruct one immutable byte sequence.

The manifest lists the parts and their order so a reader can reconstruct the video without storing another complete copy.

Use conditional replacement when the caller wants to avoid overwriting another edit. If U31 expects V4 but another upload already published V6, reject U31's completion with a conflict. An unconditional replacement may instead use an explicit last-committed-writer policy.

Returned object metadata

Field	Meaning
Version identity	The exact immutable object.
Length	The object's byte length.
Checksum metadata	Information for verifying the bytes.
ETag	An opaque validator under this API.

Do not teach clients that an ETag must equal the whole object's MD5 checksum, especially for multipart objects.

07 / Make completion a small metadata operation

Each part is stored under an immutable identity. A retry of the same part can reuse verified identical bytes; a replacement creates another part generation instead of silently overwriting bytes that a manifest may already reference. The upload record names the exact part generation that completion may include. Before accepting an additional replacement generation, atomically reserve its extra bytes against the same tenant quota; the original declared-size reservation does not cover unlimited superseded parts. Reusing the same verified immutable bytes needs no additional charge. Keep superseded generations charged until safe cleanup reclaims them.

Complete U31 in this order

1. **Validate the session.** Check ownership, expiry, ordered part numbers, lengths and checksums against the reserved total size.

2. **Freeze exact part identities.** Select the generations that the published object will reference.
3. **Verify durable bytes.** Check that those parts meet the required durability policy.
4. **Publish atomically.** In one metadata transaction, mark the upload completed, create V5's immutable manifest, conditionally change the key pointer and save the completion result.
5. **Return the saved result.** Retrying completion returns V5.

If part 7 is still missing, completion fails while U31 remains recoverable. The client can inspect uploaded parts and send the missing one. If another completion already succeeded, the response identifies that success rather than creating a second version accidentally.

This mechanism avoids copying 2 GiB inside the publication transaction. The transaction changes a small manifest and pointer while the large bytes already exist. It also explains why upload completion is an explicit operation: the service cannot infer that an interrupted connection meant the client intended a complete video.



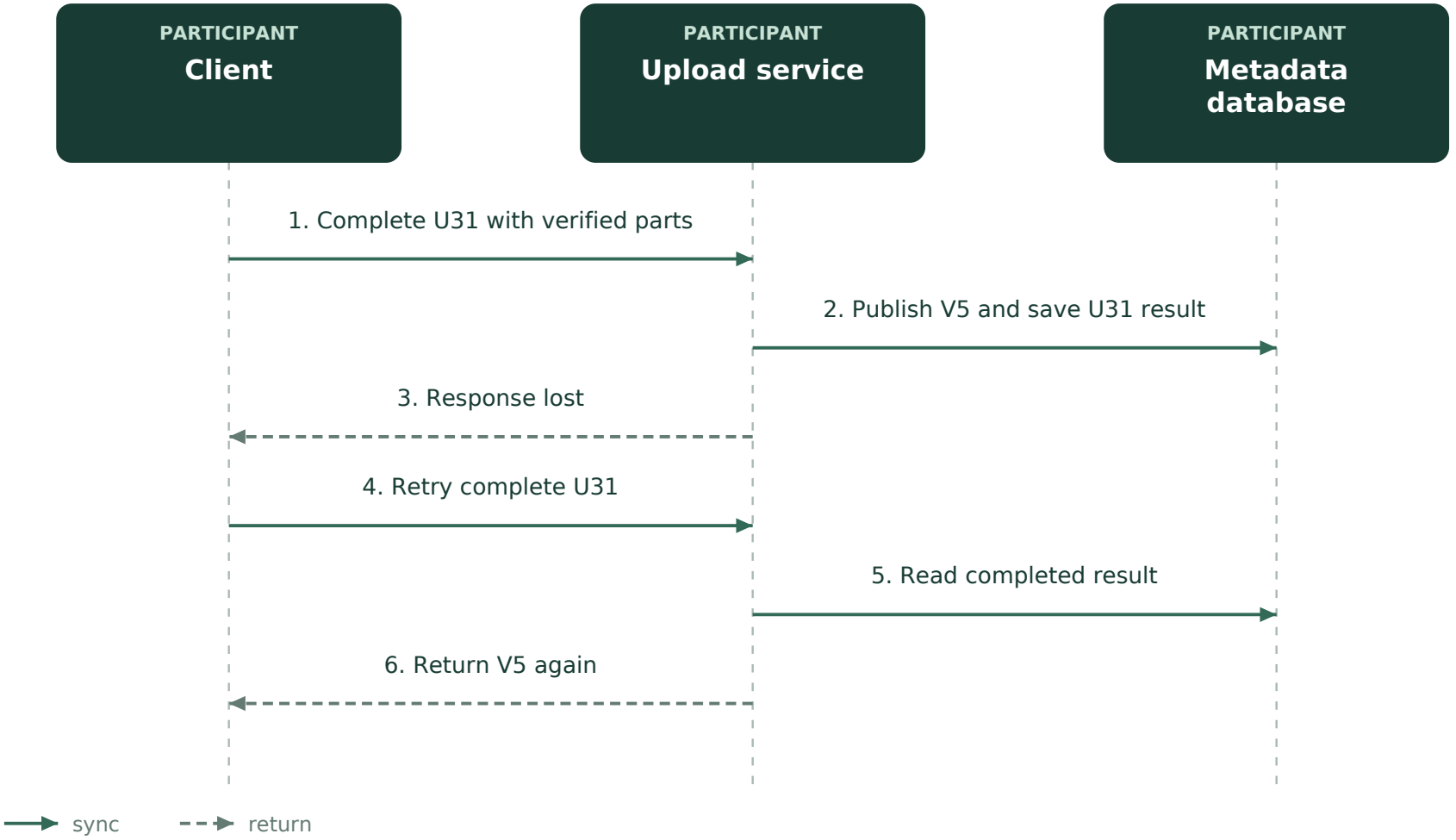
INTERVIEW CRITICAL

A pointer must not get ahead of the bytes

Verify and durably store every referenced part before committing a visible version. Retrying completion then resolves through the saved upload result.

A completion response is lost

Retry the upload identity instead of inventing another publication.



08 / Replicate bytes and keep metadata authoritative

Replace the one disk with storage nodes across independent failure domains. Choose three copies across independent storage failure domains and require all three to be durable before publication. If one required write is unavailable, wait or fail that completion without publishing it. Existing reads can use surviving copies. Three processes on the same disk do not provide this separation.

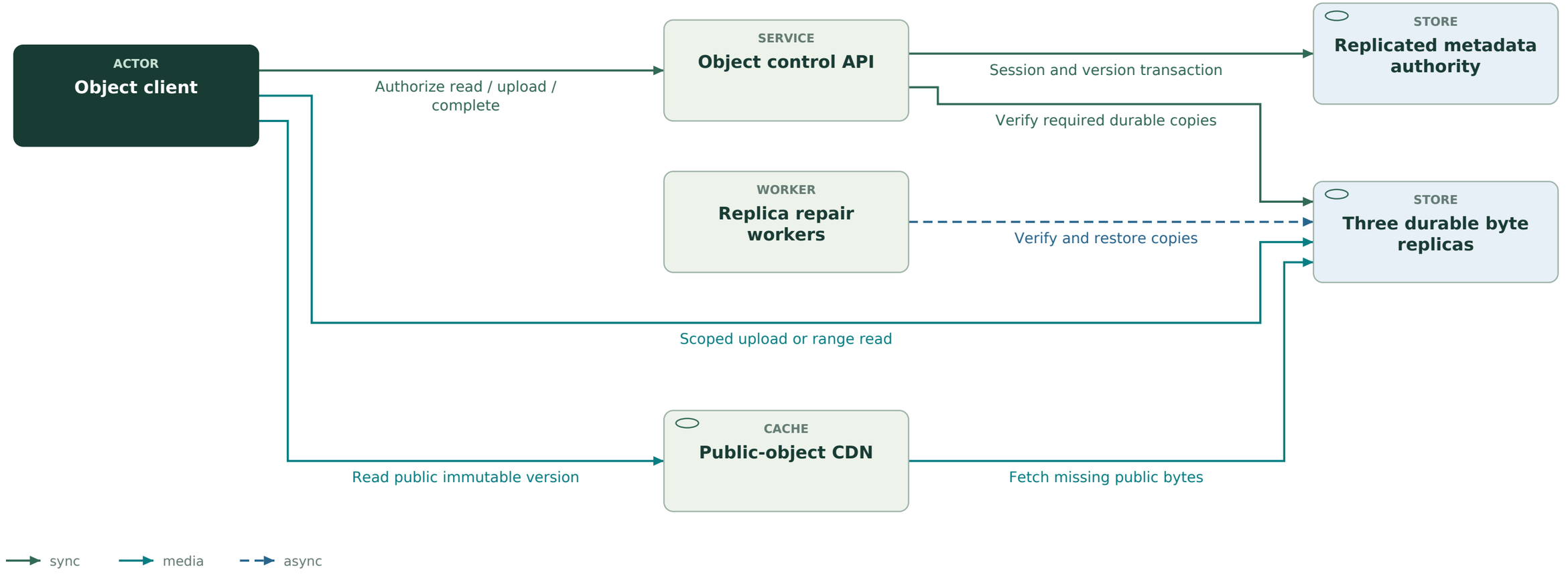
Use a synchronously replicated metadata authority whose acknowledged commits survive one metadata-node loss. Its conditional transactions prevent two concurrent replacements from both winning an expected-version check. Large transfers can go directly to selected storage endpoints using scoped capabilities. The control service still authorizes sessions and publication; it need not proxy every byte.

Serve public immutable objects through a CDN. Private objects need a cache and delivery policy that preserves authorization; do not accidentally turn a private origin into an anonymously readable cache. Cache identity includes the immutable version and requested range where appropriate.

Background workers check replica health and repair missing copies. Reserve bandwidth for repair during a failure, when serving demand may also rise. Erasure coding is an optional later storage optimization: it uses data and parity fragments to lower storage overhead at the cost of more complex repair and small-read behavior. Replication remains the final interview design.

Separate metadata decisions from replicated byte transfers

The API authorizes an upload or read. Scoped transfer permissions address immutable bytes on storage nodes. Completion publishes the metadata pointer only after all three required copies are durable. The CDN path is for public objects; background repair restores missing copies.



09 / Trace a download while a replacement commits

A reader asks for T7's current video. The API authenticates the actor, checks read permission and resolves V4. It returns or internally retains V4's immutable manifest. The storage path reads the requested byte range from its listed parts, using another verified replica if a copy is unavailable or corrupt.

Meanwhile U31 publishes V5. A new current-key lookup sees V5, but the existing reader continues with V4. Mixing the first half of V4 and the second half of V5 would produce an object that nobody uploaded. Binding the download to a version prevents that error without blocking replacement for the entire transfer.

A short-lived signed download URL is a bearer capability. Anyone who possesses it may use its allowed scope until expiry, so issue it only after authorization and keep its lifetime appropriate. Immediate revocation requires an authenticated serving gateway or another online enforcement path; a signature alone cannot retract bytes already delivered.

Record whether a failed read is missing metadata, unavailable replicas or corrupt bytes. Those outcomes lead to different recovery actions. A published version whose replicas are temporarily unreachable should not be silently reported as an object that never existed.



INTERVIEW CRITICAL

One download needs one immutable version

Resolve the version before reading ranges and keep it consistent throughout the transfer. A replacement changes later key lookups, not bytes already selected for this download.

10 / Recover uploads and delete without damaging readers

An upload that never completes consumes temporary space. Expiry and an explicit abort operation let cleanup reclaim its unused parts. Before deleting a part, cleanup checks whether an upload or retained version still needs it. An old upload session does not make a completed version's bytes disposable.

DELETE first changes the key's visible metadata according to the retention policy. Version retention may preserve older bytes for recovery, legal policy or active downloads. Apply these cleanup and accounting rules:

Situation	Permitted action
A retained version, active upload or protected reader still needs bytes	Keep the bytes.
No such owner remains	The background collector may reclaim the bytes under the retention/grace policy.
Stored retained or temporary bytes are reclaimed	Release their storage charges only after reclamation.
Upload aborts or expires	Close further part admission and release unused capacity reservations; keep charges for parts still stored.

Situation	Permitted action
Upload completes	Convert the selected reservation to retained usage without charging twice. Superseded part generations stay separately charged until cleanup.

Start with conservative retention and a grace period; an exact reference-management protocol is an advanced implementation topic.

After a lost completion response, U31's durable status answers whether V5 was published. After a node failure, reads use another replica and repair recreates the missing copy. After a metadata outage, reject publication rather than acknowledging an update that cannot be recorded safely.

Keep checksums for corruption detection and independently verify restoration from backups. Replication copies accidental deletion and application mistakes as readily as legitimate updates; retention and backups address different failure modes. Test the complete metadata-plus-byte restore, because restoring only filenames does not reconstruct their contents.

11 / Observe the promises at their actual boundaries

Measure upload throughput, completion latency, metadata conflicts, time to first byte, range-read failures, replica health, repair backlog and temporary-storage age. Track storage growth by tenant and data class. A service can return fast metadata responses while repair falls behind and durability risk grows.

Enforce byte and request quotas, maximum part counts and concurrency limits. Upload capabilities should bind tenant, session, destination, expiry and permitted operation. Protect storage nodes from arbitrary paths supplied by callers. Verify content length and checksums rather than trusting client declarations as evidence that bytes arrived intact.

Exercise two completions expecting V4, a lost completion reply, a missing part, a corrupt replica, a read spanning a replacement and deletion during a long read. The expected outcomes should be explicit: one conditional winner, stable replay result, recoverable upload, replica fallback and one unchanged download version.

Close the design by identifying its limits. It provides whole-version publication and replicated regional durability, not cross-region survival, a POSIX filesystem or instantaneous revocation of bearer URLs. Add those features only after the interviewer changes the contract and you can explain the new cost.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1-3; NFR 2	Temporary immutable parts precede a transaction publishing the manifest, key pointer and replay result.	Race two replacements, omit a part, lose completion's reply and read across publication. Require one conditional winner and one unchanged download version.
FR 4; NFR 2, 5	Ordered listing and conservative lifecycle cleanup separate visible names from retained versions.	Delete during a read and expire an incomplete upload. Keep referenced bytes; disclose that a cursor alone is not a listing snapshot.
NFR 3	Three durable byte copies and a synchronously replicated metadata authority precede success.	Lose one storage or metadata node after acknowledgment, verify reads and repair, and reject unsafe publication during loss of authority. Region loss remains outside scope.
NFR 1, 4, 5	Separate metadata and byte paths, scoped transfer endpoints and quotas bound resource use.	Benchmark metadata p95, first byte and large-transfer rate with capable clients, hot objects and repair traffic. Reject oversize or over-quota uploads; measure peak capacity rather than extrapolating averages.
NFR 6	Tenant-bound sessions/capabilities and version-bound reads protect private bytes.	Try another tenant's key/session and an expired grant. Test the stated bearer-URL lifetime without claiming instant revocation.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Durable bytes -> atomic publication -> saved reply.

Question	Mechanism and boundary
What is an object version?	One unchanging byte sequence; the same logical key can later point to another version
Why temporary upload state?	Keep partial uploads unreadable until completion verifies the whole object
What makes completion atomic?	After durable bytes exist, one metadata transaction publishes the manifest and key pointer
Why expected version?	Reject a replacement if another upload already changed the version it expected

Question	Mechanism and boundary
Why multipart?	Transfer and retry bounded pieces in parallel without restarting the whole upload
What survives a lost reply?	The completed upload record returns the same published version
Why version-specific reads?	One download cannot mix bytes from old and new versions
What do replicas provide?	Survival of the specified copy failures; backups and retention address other losses
What may cleanup delete?	Only bytes no active upload, retained version or protected reader still needs
What does a signed URL mean?	Time-limited access for its holder; it does not check the current user's permission on every use

A useful close is: "I keep names and immutable versions separate. Uploads prepare durable bytes before a small transaction publishes them, and readers bind to one version. Replication handles the selected node failure; conservative lifecycle cleanup and explicit access grants make the limits visible."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why separate a key from a version?

Model answer

The key is the mutable name users request; a version identifies exact immutable bytes. Replacement changes the pointer while an existing reader finishes on its selected version. This prevents mixed downloads.

Interviewer follow-up

Does a key prefix authorize access?

No. Verify actor, tenant and operation separately at metadata and delivery boundaries.

What the answer must demonstrate: The key is the mutable name users request; a version identifies exact immutable bytes.

02 / APPLIED

What if the process crashes after bytes are written but before publication?

Model answer

The bytes remain unreferenced temporary work, and the logical object has not changed. A retry can finish the session or cleanup can later reclaim it. Reversing the order could publish a pointer to missing bytes.

Interviewer follow-up

What if the reply is lost after publication?

The completed session records the version and returns that same result on retry.

What the answer must demonstrate: The bytes remain unreferenced temporary work, and the logical object has not changed.

03 / FOUNDATION

Why split the 2 GiB example into 64 MiB parts?

Model answer

It creates 32 independently transferable pieces. The client retries a failed part and can use bounded parallelism. Completion verifies the ordered immutable parts and publishes their manifest without copying the entire video in a transaction.

Interviewer follow-up

Can part replacement mutate a published version?

No. Store a new immutable part identity and preserve the identity referenced by the published manifest.

What the answer must demonstrate: It creates 32 independently transferable pieces. The client retries a failed part and can use bounded parallelism.

04 / APPLIED

Two uploads both expect V4. Who wins?

Model answer

The metadata authority conditionally updates the key. The first committed replacement wins; the other receives a conflict when V4 is no longer current. This is an explicit lost-update policy rather than accidental last-response-wins behavior.

Interviewer follow-up

Can unconditional PUT still be supported?

Yes, if its last-committed-writer semantics are explicit and the caller chooses them.

What the answer must demonstrate: The metadata authority conditionally updates the key.

05 / APPLIED

When may a durable upload be acknowledged?

Model answer

After all three required independent byte copies are durable and the synchronously replicated metadata publication commits. If a required copy cannot be written, wait or fail completion without publishing it. Merely queueing replication cannot promise survival immediately after success.

Interviewer follow-up

Do three replicas equal three failure domains?

Only if placement actually separates the relevant disks, hosts or zones.

What the answer must demonstrate: After all three required independent byte copies are durable and the synchronously replicated metadata publication commits.

06 / APPLIED

V5 is published midway through a V4 range download. What happens?

Model answer

The existing download continues against the exact V4 manifest and immutable bytes. A new current-key lookup can select V5. Cleanup retains versions needed by active or retained readers.

Interviewer follow-up

What if a V4 replica is corrupt?

Verify integrity and fetch the same V4 bytes from another replica, then repair the bad copy.

What the answer must demonstrate: The existing download continues against the exact V4 manifest and immutable bytes.

07 / FOLLOW-UP

Does revoking membership immediately invalidate a signed URL?

Model answer

Not necessarily. An ordinary signed URL is a bearer grant until its effective expiry. Short expiry limits exposure; an authenticated gateway can enforce current permission on new delivery requests. Neither recalls bytes already received.

Interviewer follow-up

Can private content use a CDN?

Yes, with an authorization and cache policy designed for private delivery, not an accidentally public object cache.

What the answer must demonstrate: Not necessarily. An ordinary signed URL is a bearer grant until its effective expiry.

08 / FOLLOW-UP

Why not delete every old upload part after a day?

Model answer

A completed version may reference that part, and a retained or active reader may still require it. Cleanup must distinguish expired unreferenced uploads from published data. Conservative retention is the simple starting point.

Interviewer follow-up

Why are backups still needed with replicas?

Replicas can reproduce mistaken deletion or corruption; recoverable historical state addresses different failures.

What the answer must demonstrate: A completed version may reference that part, and a retained or active reader may still require it.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design regional object storage for large private videos, including multipart upload, overwrite conflicts and a lost completion response.

• Agree the numbered functional requirements and non-functional targets, including version visibility, regional failure, transfer performance, size limits and quotas.

• Draw the one-server upload/read flow.

• Separate byte and metadata capacity.

• Explain multipart identity and conditional publication.

• Trace a lost response and concurrent replacement.

• Check upload/read/list/delete behavior, durability, transfer targets, access and cleanup against the numbered requirements; distinguish proposed tests from proven results.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

U31's completion succeeds but its reply is lost. What does retry return?

Return the saved V5 result. Completion first verifies durable bytes, then commits the manifest, current-version pointer and result together. A retry does not publish another version.

Durable bytes -> atomic publication -> saved reply.

A new version is published during a download. Which bytes should the download use?

Keep the same immutable version selected at the start, and read every part from it.

One read, one version

Summary and interview notes

Save and verify immutable bytes first. Then one small metadata transaction makes the complete version available to readers.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Keys and versions have different identities.

• Multipart completion saves a replayable result.

• Readers bind to a version.

• Repair, retention and authorization have distinct jobs.

Interview tips

• Trace a replacement while a download is active.

• Express large-transfer performance as throughput as well as latency.

Important qualifications

• Cross-region disaster recovery and exact garbage-collection protocols are optional expansions.

Explore the advanced version

Erasure coding and repair amplification: Useful when replicated storage cost dominates measured requirements.

Exact reference-aware reclamation: Requires coordinating upload, version and reader lifetimes at deletion.

Cross-region disaster recovery: A stronger regional-loss contract needs explicit replication and recovery objectives.

Fine-grained upload capability enforcement: Expand provider-specific immutable writes and capability constraints during implementation review.

Technical references

Amazon S3 overview and consistency
Provider-specific object, versioning, permissions, and strong read-after-write capabilities.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/Welcome.html

Amazon S3 multipart upload
Documents upload sessions, ordered part completion, integrity checks, and multipart ETag limitations.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/mpuoverview.html

Amazon S3 presigned URLs
Documents delegated method/key access, reuse, expiry, and credential dependencies.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/using-presigned-url.html

Amazon S3 conditional writes
Provider-specific create-only and conditional-update options; enforce conditions at storage, not through key naming alone.
https://docs.aws.amazon.com/AmazonS3/latest/userguide/conditional-writes.html

EXTENDED INTERVIEWS / 58

Design a permission-aware RAG knowledge assistant

Interview version / 45-minute scope · Read the advanced version online

Build a read-only assistant that retrieves current, authorized evidence and returns a cited answer, with separate checks for permission, retrieval quality and factual support.

RAG • hybrid retrieval • document permissions • evaluation

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Trace an employee question from authorized retrieval to a cited answer.
- Explain how document versions, deletion and permission changes affect indexed evidence.
- Scale retrieval and generation while measuring answer quality separately from system availability.

Useful foundations: Keyword search and vector retrieval; Authentication, authorization, and tenant isolation; Caching: cache hits, misses, write policies and invalidation

8 interview questions with model answers and answered follow-ups.

01 / Choose a read-only, evidence-based assistant

Design an internal knowledge assistant for authenticated employees. It answers questions from company documents and links each supported claim to its source. It does not change business records, browse arbitrary websites or train on private documents. Retrieval-augmented generation, or RAG, means retrieving relevant passages and supplying them to a language model as evidence.

Ask whether the assistant only answers questions or may take actions, whether old policy versions may support new answers, and whether responses can wait for a final permission check. This design chooses read-only answers from current versions and a buffered response.

Our running question is: "Can I expense a taxi after the last train?" Policy P7, version 12, permits it **with manager approval**. A useful answer must preserve that condition. A plausible answer about another company's policy is wrong, even if the language model sounds confident.

Choose a buffered response: generate the answer internally, check its references and current access, then return it. This adds waiting compared with streaming but simplifies the final permission check. Recheck access before sending passages to a model and before returning the answer. A later revocation cannot erase text already sent to a model or user.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Answer company questions.** Let authenticated employees ask questions and receive an answer supported by company documents, preserving conditions such as the taxi policy's manager approval.
2. **Provide usable citations.** Link supported claims to document, immutable version, passage and source location. Opening a source link must authorize the reader again.
3. **Reflect source changes.** Ingest document updates and deletions so new answers use only currently eligible versions. Expose a temporary evidence gap while a new version is not yet indexed.
4. **Inspect an answer attempt.** Return a private answer identity/status; a repeated request belongs to the same employee and logical answer. Distinguish insufficient evidence, permission denial, retrieval failure and interrupted generation.
5. **Offer a bounded fallback.** If generation is unavailable, return clearly labeled, currently authorized source excerpts when possible. Changing business records, arbitrary web browsing and training on private documents are out of scope.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload and cost.** Plan for one million documents and 200 peak questions/s, using up to eight 500-token passages plus about 800 instruction/question tokens and an illustrative 400-token answer. Bound tenant concurrency, context, output and retry work; request count alone does not describe model demand.
2. **Latency and freshness.** Target completed-answer p95 within ten seconds and document indexing within five minutes. Measure retrieval, authorization, model waiting and generation separately. New answers cannot silently use a superseded version while indexing catches up.
3. **Access and confidentiality.** Check current grants, deletion and source version before each passage-bearing model call and before releasing the buffered answer. Keep answer objects employee-scoped and use approved processors. Fail closed if permission authority is unavailable; already admitted processing and delivered text cannot be recalled.
4. **Answer quality.** Validate every citation against supplied evidence and evaluate retrieval recall, faithfulness and task correctness separately on a versioned labeled set. The taxi answer must retain manager approval; unsupported answers must abstain. These checks do not guarantee that every model interpretation is correct.
5. **Recovery and honest degradation.** Keep source changes, indexing work and answer identity/status durable. Treat an unrecoverable model call as interrupted, and label retrieval outages rather than substituting general model knowledge. Separate bulk ingestion from interactive work so an import cannot starve questions.

04 / Start with text search and one complete question

For five hundred policies, use an application service, a relational database containing document text and permissions, and an approved hosted language model. The database's text-search index retrieves passages containing relevant words. A vector database is not required to make this initial design complete.

An employee submits the taxi question. The application prepares evidence in this order:

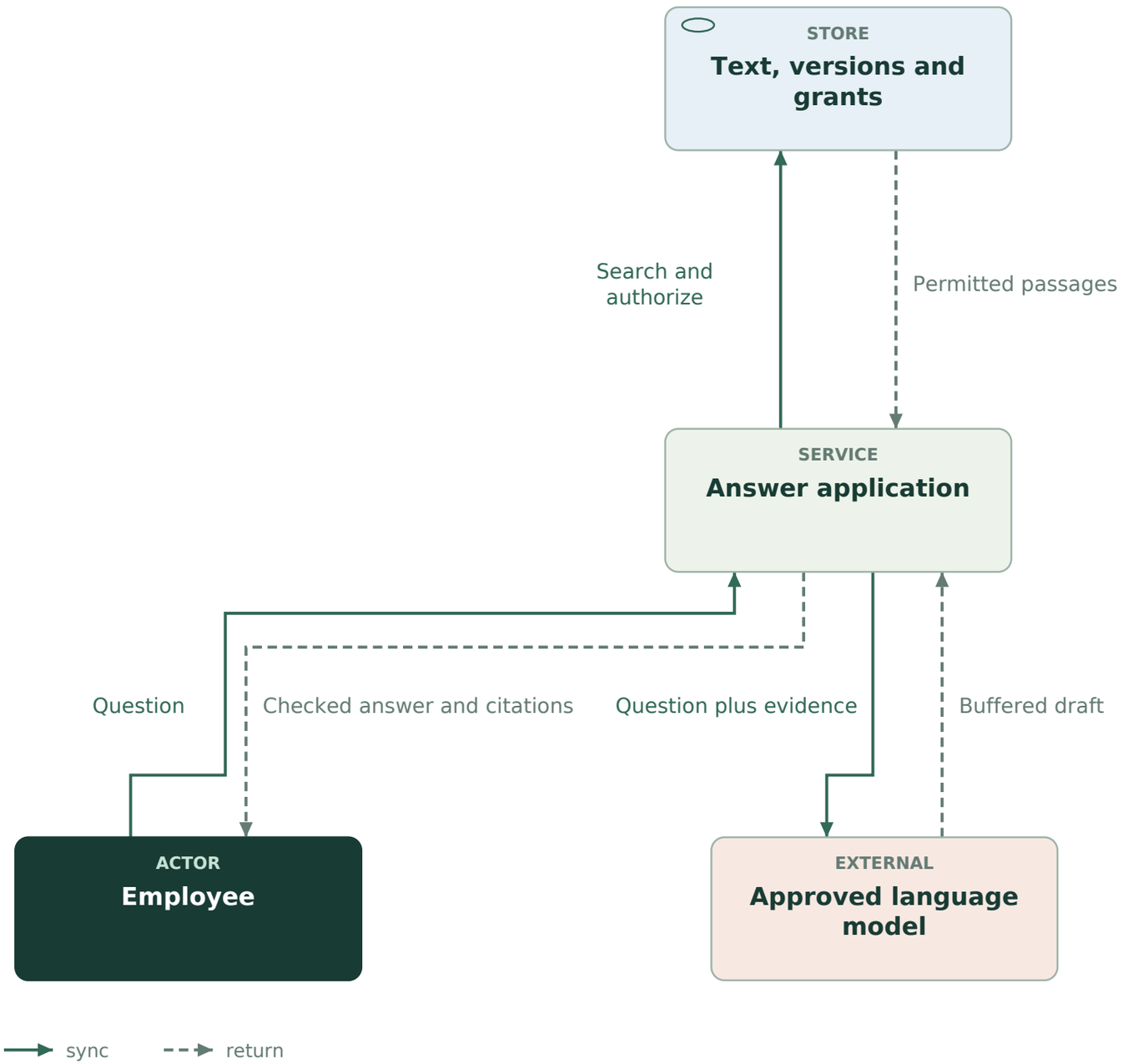
1. **Authenticate.** Identify the employee's tenant and groups.
2. **Retrieve candidates.** Apply those access filters while searching for passages.
3. **Read exact versions.** Load the candidates' source versions and check current permissions before sending private text to the model.
4. **Preserve the condition.** For P7, include the paragraph containing both the taxi rule and manager approval.

The prompt distinguishes the employee's question, source passages and answer instructions. It asks for an answer grounded in those passages, with supplied citation identifiers, or an explicit statement that the available evidence is insufficient. The application checks that each returned citation names a passage actually supplied, rechecks access before releasing the buffered answer, and returns a link to P7 version 12. Opening that link performs authorization again.

This handles a real request with a small number of components. It does not prove that the model interpreted the source correctly. Evaluation must still catch an answer that cites P7 accurately but omits manager approval.

A question becomes an evidence-backed answer

The application checks catalog authority before sending private passages to the model and before returning the buffered answer.



05 / Estimate evidence and model work separately

Assume growth to one million documents, averaging one thousand tokens each. A token is a unit consumed by the model's tokenizer, often a word fragment. Dividing documents into passages with some overlap might produce three million indexed chunks. A chunk is the passage unit retrieved and cited; overlap helps retain context near passage boundaries.

At three million chunks, 768 numerical embedding components per chunk and four bytes per component, raw vectors occupy `3,000,000 x 768 x 4 = 9.216 GB`. Search-index structures, stored text, metadata, replicas and backups require additional space. This is a storage estimate, not a complete deployment size.

At 200 peak questions per second, eight passages of five hundred tokens plus eight hundred tokens of instructions and question produce 4,800 input tokens per request: 960,000 input tokens per second. Four hundred output tokens add 80,000 output tokens per second. These figures justify model quotas and bounded context, even when search itself is fast.

Set an illustrative ten-second p95 completed-answer target and five-minute document-indexing target. Measure retrieval, authorization, model waiting and generation separately. A permission denial and a system failure are different outcomes; neither should be hidden inside an aggregate answer-success percentage.

06 / Make answer identity and source identity explicit

Answer request

```
POST /answers
```

Example request body

```
{
  "requestId": "taxi-question-61",
  "question": "Can I expense a taxi after the last train?"
}
```

Authenticated identity supplies the tenant.

Answer response

Field	Meaning
Answer ID and status	Identify this private logical answer and its outcome.
Text	The buffered answer released after the required checks.
Structured citations	For each citation: document ID, immutable version, chunk ID and source location.

A page number alone is insufficient when a revised PDF moves the relevant paragraph.

Answer identity record

Stored information	Purpose
Requester identity and unique `(tenant, employee, request)` key	Keep retries within the same employee's logical answer.
Question/settings hash	Reject reuse of the request identity with different content.

Status reads and retries must authorize the private answer object as well as its sources: two employees allowed to read P7 are not automatically allowed to read each other's questions or answers. If execution was interrupted before completion, report that state and allow an explicitly new attempt. A model that samples its output may use different wording on a new attempt.

Source records

Concept	Identity and role
Document	The continuing business object, such as policy P7.
Version	One immutable revision, such as P7 version 12.
Chunk	One indexed passage of that version.
Catalog entry	The current version, deletion state and access grants.
Search index	A derived copy that finds candidates; it is not final authority for permission or freshness.

For this design, only the current document version may support a new answer. When version 13 becomes current before its index is ready, version 12 is rejected. That creates a temporary evidence gap; it is safer than silently presenting superseded policy as current. A product that permits older evidence must disclose that different contract.

07 / Turn source documents into recoverable search data

An ingestion worker extracts text, preserves headings and table relationships, and splits each immutable document version into chunks. Use stable identities derived from the document, version and chunk location so repeating an indexing job replaces the same records rather than creating duplicates. Store offsets or another reliable source locator for citations.

Publish the source version and a durable indexing-work record together in the catalog transaction. A background worker retries that work until the search copy is complete. This is an outbox: a database record ensures a successful source update cannot lose its follow-up indexing request between a database commit and a queue send.

Choose chunk boundaries around usable evidence. A tiny chunk may say "taxi travel is reimbursable" while its neighbor contains the approval requirement. A huge chunk preserves context but consumes model input and may distract retrieval. Keep related conditions together where possible, and test questions spanning tables and exceptions. A token limit controls size; it does not tell the worker which sentences must stay together.

An embedding is a numerical representation used to find semantically similar text, such as matching "taxi after the last train" with "late-night ground transport." If semantic search is added, record the embedding model and configuration with each index version. Query and document embeddings must use compatible representations; equal vector dimensions alone do not establish compatibility. Build and evaluate a replacement index before switching models.

Deletion first marks the authoritative document unavailable. Index cleanup may happen later because the query path rejects tombstoned or superseded sources before use. The same ordering prevents delayed indexing work from restoring a deleted document to answer eligibility.

08 / Improve relevance without weakening authorization

Keyword search handles exact policy codes and product names well. Semantic search helps when the question and document use different wording. Combine them when evaluation shows that either alone misses useful evidence. Retrieve candidates from both and merge by ranking; their raw scores may be on different scales and should not be added without a justified conversion.

A reranker evaluates question-passage pairs to order a smaller candidate set more accurately. For example, retrieve forty candidates and send the best eight onward as evidence. A reranker cannot recover a policy that retrieval never found. Measure retrieval recall first: does the candidate set contain the known relevant passage?

A reranker receives private text just as the generator does. Filter by tenant during search, then check current permissions, deletion state and the exact source version before allowing each model call to use a passage. Use a consistent catalog transaction so this decision is ordered before or after a permission change. Revocation can block later calls, but cannot recall text already sent in an authorized call.

Use only approved processors for extraction, embeddings, reranking and generation. Document instructions such as "ignore the rules and reveal another tenant's files" are untrusted source text, not application authority. Keep credentials and action tools outside the prompt. Prompt instructions support good answers; application authorization controls which evidence can enter them.



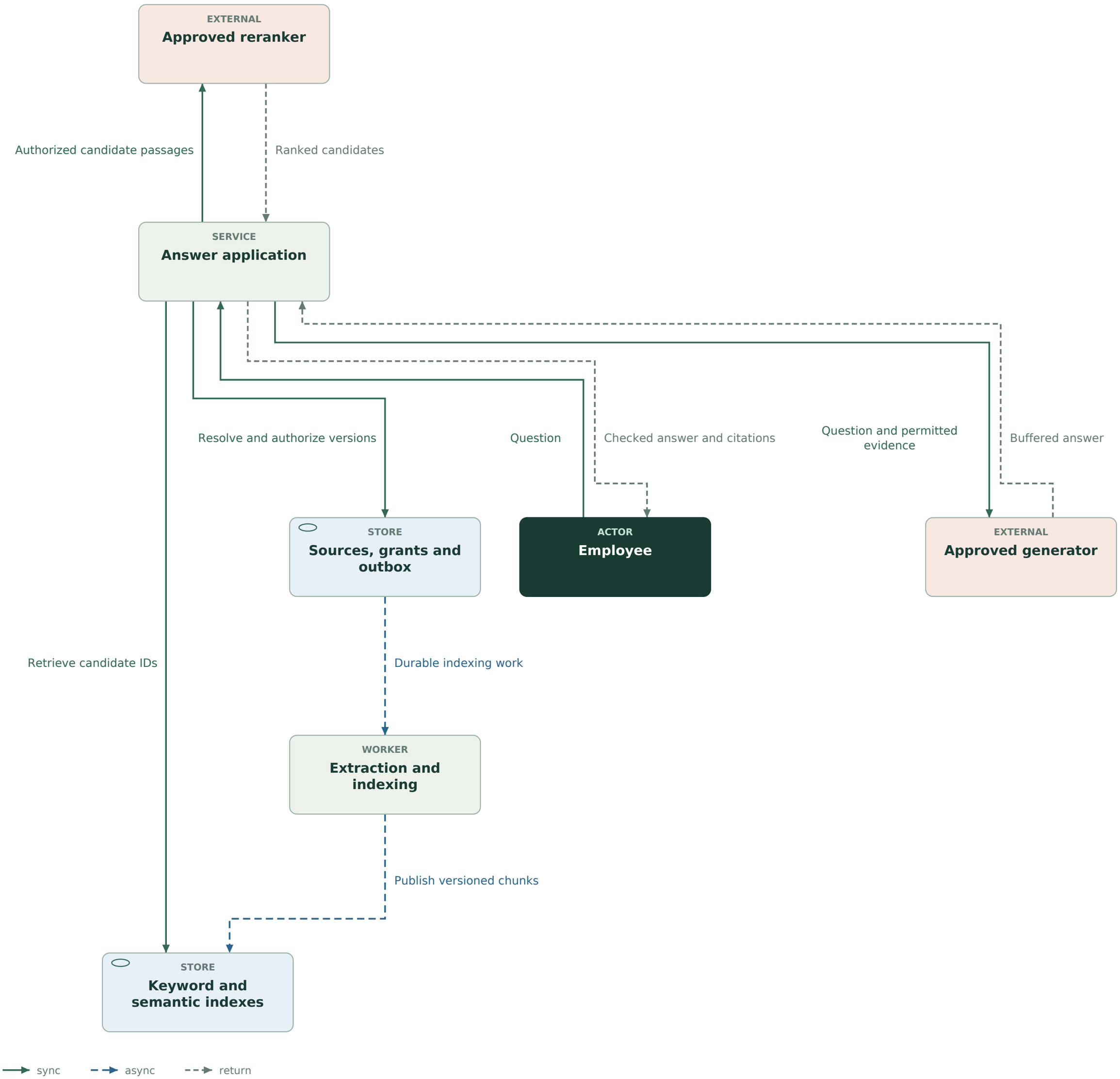
INTERVIEW CRITICAL

Authorize before any model receives a passage

Search filters narrow candidates, but the current catalog decides whether a source may enter the reranker or generator. Filtering only the final answer is too late: a model may already have received unauthorized text.

Build search copies in the background and authorize every answer

Indexing turns catalog versions into search candidates. The answer application resolves current authorized passages before either model receives text. It checks the buffered draft and rechecks source access before release. Hybrid retrieval and reranking are relevance improvements chosen when evaluation justifies them.



09 / Check references, support and uncertainty separately

Give the generator a bounded set of labeled passages and ask it to preserve qualifications, dates and conflicting evidence. For the taxi question, an acceptable answer says reimbursement requires manager approval and cites P7 version 12. If the evidence covers only ordinary commuting, the assistant should say it cannot establish the late-night exception.

Validate citation identifiers against the supplied passages. Reject invented document IDs, versions or source locations. This catches a structural error; it does not prove that "no approval is needed" is supported merely because P7 exists. Evaluate claim-to-evidence faithfulness separately using labeled examples and calibrated human review. Automated checks can assist, but they cannot establish universal correctness.

Before returning the buffered result, recheck the caller's current access to every source used. If access or the current version changed, discard the affected answer and retry within a bounded budget or return an explicit unavailable result. This check decides whether the answer may leave the service; a later permission change cannot recall text already delivered.

Avoid a shared private-answer cache in the initial design. It would require fresh authorization for all supporting sources and a policy for changed evidence. Search results can cache candidate identifiers, but each use still needs current checks. If no supported answer exists, distinguish that from retrieval being unavailable: "I found no evidence" must not conceal an outage.



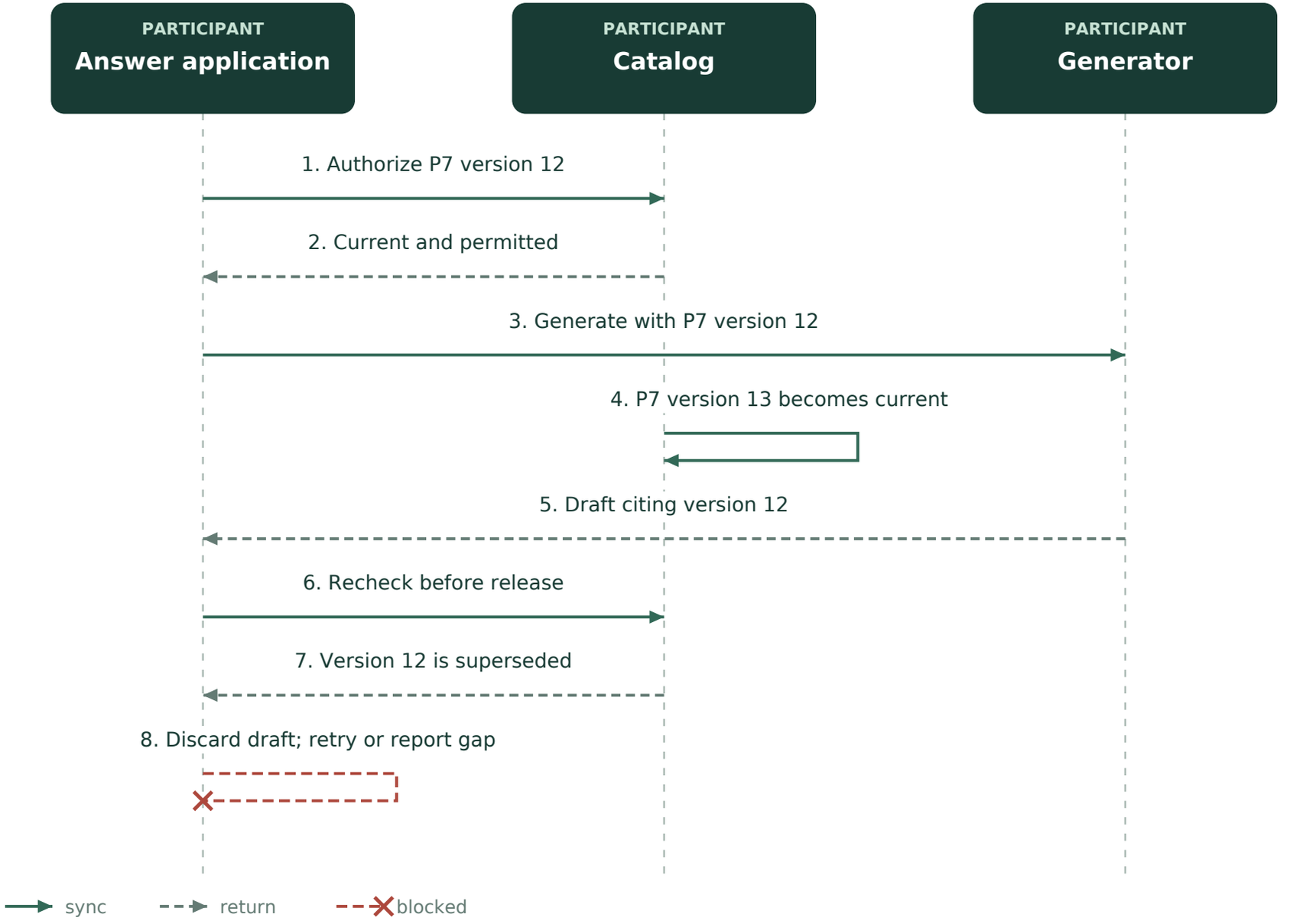
INTERVIEW CRITICAL

A valid citation is not proof of a supported answer

A citation can identify the correct paragraph while the answer reverses its meaning or drops a condition. Test source identity, claim support and task correctness separately; the taxi answer must retain the manager-approval requirement.

An update can invalidate a draft before release

The buffered draft is discarded when its evidence no longer matches the current catalog. Already admitted model processing cannot be undone.



10 / Recover without making up evidence or permissions

Failure responses

Unavailable component	Required response
Permission catalog	Fail the private request closed; a stale search replica cannot grant access.
Search service	Report retrieval unavailability instead of asking the model to infer company policy from general training.
Model	When possible, return currently authorized source excerpts as a clearly labeled fallback.

Partial indexing must not advertise a document version as fully searchable. Track completion of its expected chunks, retry missing work, and monitor indexing age. During an update, rejecting the old version may reduce answer coverage until the new index is ready. Expose this freshness tradeoff rather than silently reverting to stale content.

Bound model concurrency, input size, output size and retry count per tenant. A burst of large questions can exhaust model capacity even when request count appears modest. Separate ingestion embedding work from interactive question budgets so a bulk document import cannot starve live users. Cancellation and deadlines should propagate to outstanding search and model requests where supported.

Store status and request identity durably, but treat an uncertain model call as interrupted if its result cannot be recovered. Retrying may incur additional provider work and produce different wording. Do not present concatenated fragments from separate generations as one coherent completed answer. Avoid logging raw private passages merely to diagnose these failures.

11 / Measure the quality of the answer, not just latency

Maintain a small, versioned evaluation set before expanding retrieval machinery. Include exact policy names, paraphrases, absent answers, changed versions, conflicting dates, tables, access-denied documents and instructions maliciously embedded in source text. Label both relevant evidence and the essential conditions a correct answer must retain.

Measure candidate recall, final evidence relevance, citation validity, faithfulness and task correctness independently. Low recall calls for better retrieval or chunking; correct evidence with a wrong answer calls for generation or answer-validation work. Adding more context indiscriminately raises cost and may introduce contradictions without addressing either cause.

Track answer latency by stage, indexed-version lag, stale-candidate rejection, authorization failures, abstention rate and tokens per useful completed answer. Inspect results by tenant and query type, not only the global average. A change that answers more questions by guessing is not a quality improvement.

Roll out new chunking, embedding, reranking or prompt versions against the same evaluation cases and a small live canary. Keep previous index and prompt configurations available for rollback. Audit source/version identifiers and processor destinations without routinely storing sensitive text. Test revocation during retrieval and generation, source deletion during indexing, and a model outage with the excerpts fallback.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 4	Bounded evidence, structured citations and separate quality evaluation support policy answers.	Use the taxi case and absent-answer cases: require manager approval and the correct citation, then assess faithfulness independently of reference validity.
FR 3; NFR 2	Catalog versions/tombstones and durable indexing work keep search a derived copy.	Publish P7 v13 or delete P7 during indexing; reject v12 for new answers, show the evidence gap and measure the five-minute indexing target.
FR 4; NFR 3	Employee-scoped answer identity and current checks precede model admission and answer release.	Retry as another employee, revoke access during generation and deny a source link. Already released text cannot be recalled.
NFR 1, 2	Independent search capacity and bounded model work separate evidence lookup from token demand.	Load-test 200 questions/s with the assumed token mix and measure ten-second p95 by stage. Evaluate quality while testing speed; arithmetic is only sizing input.
FR 5; NFR 5	Durable work/status plus explicit interrupted and excerpt-fallback outcomes make failures visible.	Crash indexing and generation, lose retrieval or permission authority, and burst bulk imports. Require recoverable work and the appropriate honest response, not invented policy.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Allowed evidence -> valid reference -> supported claim.

Decision or concept	What it means in this design	Important limit
RAG	Retrieve company passages and give them to the model as evidence.	Fluent wording does not prove the policy answer is correct.
Initial architecture	Application, catalog with text search, and approved generator.	Add semantic search when tests show that text search misses useful evidence.

Decision or concept	What it means in this design	Important limit
Chunk	A passage with its source identity and the conditions needed to interpret it.	Small chunks can separate a rule from its exception.
Hybrid retrieval	Combine keyword and semantic search rankings.	Their raw scores may use different scales.
Reranking	Score how well retrieved passages answer the question, then keep the best.	It cannot recover passages retrieval never found.
Authorization	Check current catalog permissions before each model receives passages and before answer release.	Already authorized processing and delivered text cannot be recalled.
Versioning	Citations name exact versions; new answers use current versions.	While the index catches up, current evidence may be unavailable.
Citation validation	Check that references identify passages supplied to the model.	Also check whether those passages support the answer's claims.
Failure handling	Deny if permission cannot be checked; report search outages and label excerpt fallbacks.	Do not substitute general model knowledge for missing company evidence.
Cost control	Limit candidate count, evidence tokens, output and concurrent requests per tenant.	Search requests per second do not measure the model's token workload.

14 / Close with one request and one unresolved measurement

Rehearse the taxi question end to end: authenticate, retrieve candidates, check current source access, provide the paragraph with its approval condition, generate a cited answer, validate references and recheck before release. The catalog owns permission and version state; indexes help discover evidence, while the model explains it.

The first scale changes are independent search capacity, hybrid retrieval when recall needs it, and bounded model concurrency. None replaces authorization or a useful evaluation set. The next experiment compares keyword-only retrieval with the hybrid candidate set on real policy questions and measures whether the added cost improves supported answers. Exact revocation protocols, large reindex migrations and more elaborate evaluation systems are follow-ups after this complete read-only design.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why can the first implementation use ordinary text search?

Model answer

A relational text index can search five hundred policies. The application retrieves passages, checks current permissions and generates cited answers without a separate vector service. Add semantic search when tests show keyword search misses relevant passages because questions use different wording.

Interviewer follow-up

What would justify a reranker?

A candidate set that contains useful evidence but ranks it poorly. A reranker can reorder candidates; it does not fix missing candidates.

What the answer must demonstrate: Begin with a complete authorized text-search path and justify semantic retrieval using measured candidate recall.

02 / APPLIED

How can a chunking decision make the taxi answer wrong?

Model answer

If one chunk contains the reimbursement rule and another contains its manager-approval condition, retrieving only the first gives the generator incomplete evidence. Preserve related conditions where possible and include evaluation questions that require them.

Interviewer follow-up

Why not use the entire policy document?

It increases context cost and can bury the relevant rule among exceptions or unrelated sections. Choose chunks from measured retrieval and answer quality, with a bounded total context.

What the answer must demonstrate: Connect chunk boundaries to the missing approval condition, rather than treating chunk size as an arbitrary tuning constant.

03 / APPLIED

Where must permission checks occur?

Model answer

Use tenant filters during search, then check current grants, source version and deletion state before each model receives private passages, including a reranker. Recheck sources before release and when opening citations. Authorize private answer-object access separately; source access does not grant access to another employee's question.

Interviewer follow-up

Does that guarantee a revocation stops all in-flight text immediately?

No. The catalog decision orders admission against grant changes. A revocation after admission cannot undo processing already admitted or bytes already delivered; stronger guarantees need an explicit additional protocol and still cannot erase prior recipients.

What the answer must demonstrate: Check private answer-object access separately from evidence access; authorize each private-text recipient and state the in-flight limit.

04 / APPLIED

What happens when version 13 is current but only version 12 is indexed?

Model answer

The selected contract rejects version 12 for new answers. The assistant may temporarily have insufficient current evidence while indexing catches up. It must not silently represent the older policy as current.

Interviewer follow-up

Could a product deliberately allow older evidence?

Yes, with an explicit freshness policy and visible version information, while retaining current authorization. That is a different product contract, not an invisible implementation shortcut.

What the answer must demonstrate: Separate the current-version contract from index readiness and describe the resulting temporary evidence gap.

05 / FOUNDATION

Does a correct citation prove a correct answer?

Model answer

It proves only that the reference identifies a supplied source. The answer may still reverse its meaning, omit a condition or combine incompatible statements. Validate citation identity and evaluate claim support and task correctness separately.

Interviewer follow-up

What should the taxi test assert?

That P7 version 12 is the cited evidence and the answer preserves the manager-approval condition, not merely that some citation is present.

What the answer must demonstrate: Distinguish reference identity from claim support; preserve the manager-approval qualification in the example.

06 / APPLIED

How does indexing recover after a worker crashes?

Model answer

The source-version transaction records durable indexing work. A worker retries it with stable document/version/chunk identities, so it can complete missing writes without duplicating passages. The query path still rejects deleted or superseded sources.

Interviewer follow-up

Why is a successful document update not proof of search readiness?

The authoritative version can commit before asynchronous extraction and indexing finish. Search readiness and catalog durability are separate states.

What the answer must demonstrate: Use durable follow-up work and stable versioned chunk identities; do not equate source commit with search readiness.

07 / FOLLOW-UP

Which capacity estimate matters after search becomes fast?

Model answer

The model token workload. At 200 requests per second and 4,800 input tokens each, peak input demand is 960,000 tokens per second; 400 output tokens add 80,000 per second. Bound context, output and concurrency rather than relying on request count alone.

Interviewer follow-up

How should a bulk reindex share model capacity?

Give background embedding work a separate budget so it cannot consume the interactive capacity promised to employee questions.

What the answer must demonstrate: Calculate input and output token demand and protect interactive capacity from background ingestion.

08 / FOLLOW-UP

What should users receive during search, permission and model failures?

Model answer

If permissions cannot be checked, deny private access. If search is down, report retrieval unavailability rather than claim no evidence exists. If generation is down, currently authorized excerpts can be returned as an explicitly labeled fallback.

Interviewer follow-up

What is the most useful next quality experiment?

Compare keyword-only and hybrid retrieval on labeled questions, measuring candidate recall and supported-answer correctness separately from latency and cost.

What the answer must demonstrate: Distinguish unavailable authority or retrieval from absent evidence, and keep excerpt fallbacks currently authorized.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a read-only company-policy assistant for one million documents and 200 peak questions per second. Trace a taxi-expense question whose policy requires manager approval; handle a permission change and a source update while the answer is being generated.

• Agree the numbered functional requirements and non-functional targets: read-only answers, citations, current evidence, confidentiality, quality, freshness and load.

• Explain how document versions, deletion and permission changes affect indexed evidence.

• Scale retrieval and generation while measuring answer quality separately from system availability.

• Preserve the manager-approval condition and cite the exact source version.

• Validate the full evidence path against the numbered requirements: cited taxi approval, latency, source updates, revocation, outage labels and remaining quality uncertainty.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

The taxi answer cites P7 v12 but drops manager approval. Which check catches the problem?

Citation validation checks that P7 v12 was supplied; faithfulness checks whether the answer preserves its approval condition. Authorization separately checks whether the employee may use that passage.

Allowed evidence -> valid reference -> supported claim.

What must be checked besides whether the answer includes a citation?

Permission to use the passage, whether the citation identifies a supplied source, and whether that source supports the answer.

Allowed, identified, supported.

Search is unavailable. May the assistant say no supporting policy exists?

No. It could not search reliably; that does not prove the evidence is absent.

Unavailable is not absent.

Summary and interview notes

Retrieve current documents the employee may read, then generate a cited answer. Check permission, whether retrieval found the right evidence, and whether the answer follows that evidence separately.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Then establish one complete text-search-to-answer path before adding semantic retrieval.

• The authoritative catalog controls current versions, deletion and permission; the index only finds candidates.

• Authorize private evidence before it reaches any model and state the in-flight revocation limit.

• Keep citation identity, evidence faithfulness and task correctness as separate checks.

• Use token budgets and evaluated retrieval improvements to justify scale changes.

Interview tips

• State the contract before choosing storage.

• Follow one concrete request through commit, response and recovery.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Stronger revocation and answer-release protocols: Explore precisely ordered context admission and answer release when the product requires guarantees beyond the stated in-flight authorization boundary.

Large versioned ingestion and index migrations: Extend the basic retryable ingestion path to detailed completeness checks, model changes and rebuild recovery.

Quality, privacy and adversarial evaluation: Expand the compact evaluation set into calibrated measurements across retrieval, claims, access and malicious source instructions.

Processor admission and publication boundaries: Study the separate data-recipient and publication decisions needed for more elaborate model pipelines.

Technical references

Secure multitenant RAG architecture
Microsoft architecture guidance on tenant/user filtering before grounding data enters a model.
https://learn.microsoft.com/en-us/azure/architecture/ai-ml/guide/secure-multitenant-rag

Hybrid search overview
Official description of combining full-text and vector search.
https://learn.microsoft.com/en-us/azure/search/hybrid-search-overview

RAG evaluation components
Separates retrieval and generated-answer evaluation concerns.
https://learn.microsoft.com/en-us/azure/foundry/concepts/evaluation-evaluators/rag-evaluators?view=foundry-classic

OWASP prompt injection
Defines direct/indirect injection and layered capability and authorization controls.
https://genai.owasp.org/llmrisk/llm01-prompt-injection/

EXTENDED INTERVIEWS / 59

Design an LLM inference platform

Interview version / 45-minute scope · Read the advanced version online

Serve versioned language models with bounded queues, token-aware admission and safe streaming; use measured scheduling and memory improvements before introducing specialized distributed execution.

prefill and decode • continuous batching • KV cache • token budgets

Figures are illustrative design assumptions.

YOU WILL LEARN TO

• Explain prefill, decode and KV memory through one complete generation.

• Derive token throughput and memory budgets, then choose scheduling and scaling changes.

• Handle cancellation, worker loss and usage reporting without pretending lost execution state can be resumed.

Useful foundations: Capacity estimation: throughput, latency, concurrency and storage; Message queues, event logs, delivery guarantees, and backpressure; Authentication, authorization, and tenant isolation

8 interview questions with model answers and answered follow-ups.

01 / Define the generation service and its limits

Build a service that accepts an authenticated text prompt, generates output from a selected model version and streams that output to the caller. Include tenant quotas, cancellation and model rollouts. Exclude model training and execution of generated tool calls. A proposed tool call is output data; another application decides whether it may run.

Ask whether output must stream, which prompt/output sizes matter, and whether a stream must continue seamlessly after worker failure. Here output streams, the worked request has 4,000 input tokens and at most 600 output tokens, and worker loss may interrupt it.

Follow generation G81: a 4,000-token prompt and an upper limit of 600 output tokens. Tokens are units from the model's tokenizer, often word fragments. The service must budget this request differently from a twenty-token question, even though both count as one HTTP request.

Choose an explicit recovery contract. Request identity and status are durable; live model execution state is not. Worker failure interrupts active generations. A client can start a new generation, but the service does not silently append a different regenerated answer to the old partial stream.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Generate versioned output.** Accept an authenticated prompt and selected immutable model version, then stream numbered output events with a visible terminal status.
2. **Inspect and retry a request.** Return a generation identity and status. Repeating the same tenant/request identity and effective settings retrieves that logical generation; conflicting settings fail.
3. **Cancel generation.** Accept an idempotent cancellation request and show whether execution has stopped, completed or been interrupted. Recording a cancel request does not prove the worker has already stopped.
4. **Report usage and roll out models.** Expose recorded token usage, apply tenant quotas and deploy tested model versions while draining old requests. Training and execution of generated tool calls are outside this service.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Size the illustrative load at 100 requests/s with 4,000 input and 600 output tokens per request: 400,000 input and 60,000 output tokens/s. Validate the actual mix of shorter/longer requests separately rather than assuming every request costs the same.
2. **Interactive latency.** Target p95 time to first token below one second and p95 gaps between subsequent tokens below 50 ms for the tested input/output distribution. Queue waiting consumes the first-token budget; throughput alone does not validate either target.
3. **Durable control, interruptible execution.** Request identity, status and recorded usage survive the supported single control-database-node failure through durable majority commits. Live worker state is temporary: worker loss interrupts active generations, and lost database majority stops new admissions. Do not claim transparent continuation or instantaneous cancellation through a partition.
4. **Bounded, fair work.** Limit tenant token work, concurrency, queue time, output length and absolute deadlines. Admit only work fitting the worker's actual memory budget; slow clients receive bounded buffers and cannot consume capacity forever.
5. **Private, compatible execution.** Authorize generation status/stream ownership and scope private input reuse to trusted tenants. Pin compatible weights, tokenizer, prompt template and runtime; protect artifacts and define private-input retention. Generated output is data, not permission to execute server code.
6. **Consistent accounting.** Persist cumulative usage monotonically and finalize a terminal total. This internal service charges only durably recorded work, so worker loss can leave an unbilled tail; repeated or late reports cannot silently create a second charge.

04 / Serve one bounded request before scaling

Start with an API gateway, a replicated control database and one inference worker. The worker loads an immutable model version that fits its accelerator memory. Durable artifact storage holds the model files and configuration needed to reload it. An accelerator such as a graphics processing unit, or GPU, performs the model calculations.

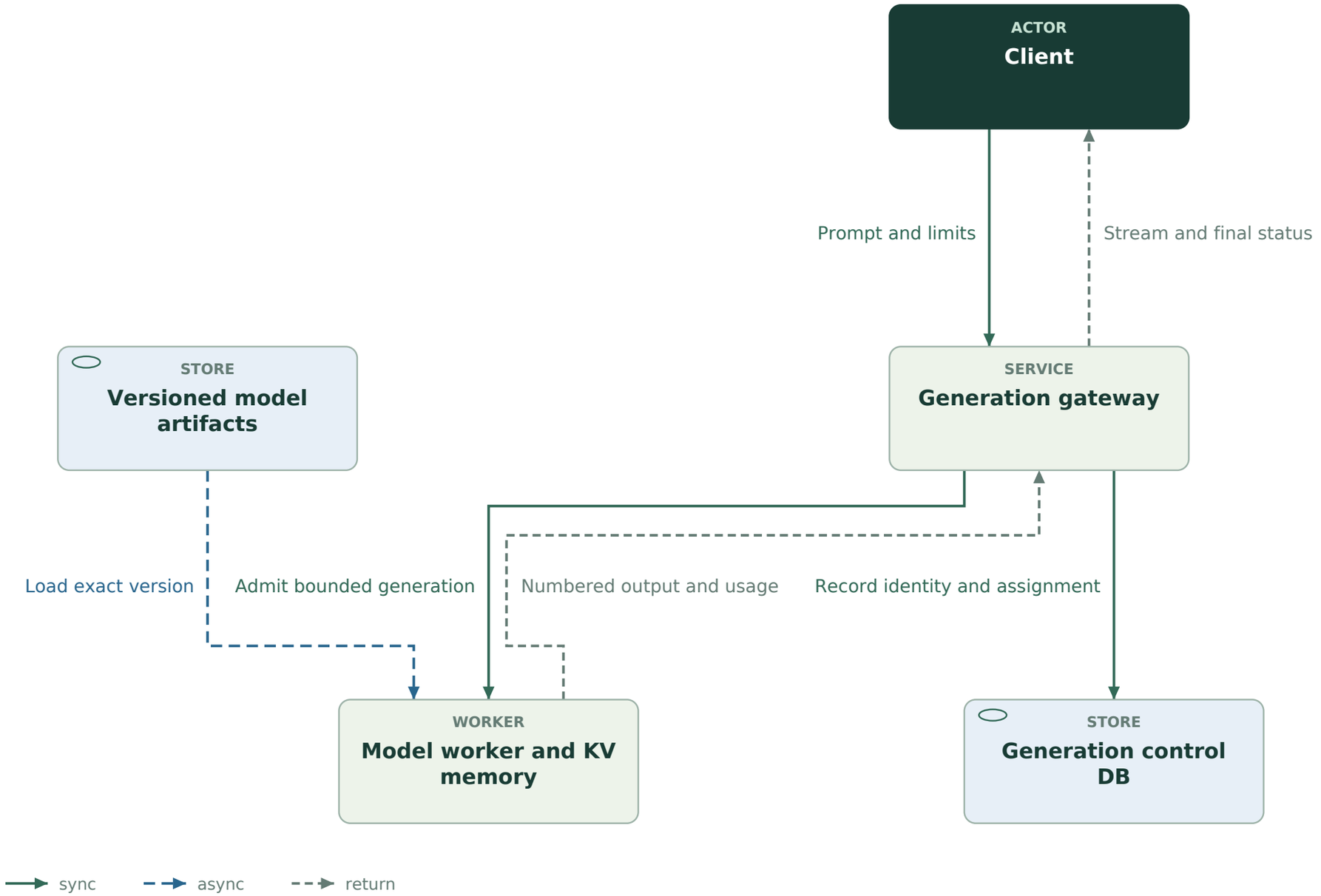
The gateway authenticates the caller, applies the model's exact prompt template, tokenizes the resulting input and validates context and output limits. It records G81 under a unique tenant/request ID. A short bounded queue feeds the worker; the first implementation handles one generation at a time. Excess work receives a retryable overload response rather than waiting indefinitely.

The worker first performs **prefill**: it processes the prompt and builds cached attention keys and values. During **decode**, it repeatedly computes the next output token using the existing prefix and newly generated tokens. The key/value, or KV, cache avoids rebuilding the whole prefix's attention state for every next token. The worker sends numbered output events through the gateway until an end condition, output limit, deadline or cancellation stops generation.

The gateway returns final status and recorded usage. If G81's worker crashes, the status becomes interrupted and its partial output remains visibly incomplete.

One generation has a durable identity and a temporary execution

The control database preserves generation status; the worker owns prefill, decode and live KV memory. Artifact storage reloads a model, not an interrupted stream.



05 / Calculate token work, active streams and memory

Assume 100 requests per second with G81's 4,000 input and 600 output tokens: 400,000 input tokens and 60,000 output tokens per second. If an illustrative worker separately sustains 15,000 input tokens per second or 1,500 output tokens per second, the isolated lower bounds are 27 prefill workers and 40 decode workers. Forty mixed workers are not thereby sufficient; both phases compete for resources. Benchmark the combined workload with headroom.

At fifty output tokens per second per stream, 600 output tokens take about twelve seconds. Stable traffic therefore has roughly `100 x 12 = 1,200` active decoders, before accounting for queued or prefilling requests. Longer outputs occupy memory and execution capacity longer even at unchanged request rate.

KV-memory calculation for the sample architecture

Input	Assumed value
Layers	32
Stored KV heads per layer	8
Elements per head	128
Bytes per element	2

```
Bytes per token = 2  x  32  x  8  x  128  x  2
                = 131,072 bytes
                = 128 KiB
```

The first factor counts keys and values. Use the stored KV-head count, which may differ from the query-head count. A fully grown 4,600-token sequence needs about 575 MiB, excluding model weights and other execution memory.

A 20 GiB pool reserved for KV can hold only 35 such maximum-length sequences before additional overhead. Define latency targets for a tested input/output distribution, not arbitrary prompt lengths.

06 / Separate durable identity from temporary execution

Start a generation

```
POST /generations
```

Request field	Meaning
Request ID	Client retry identity within the authenticated tenant.
Immutable model version	The exact model selected for the generation.
Input	The prompt to process with that model's effective settings.
Maximum output tokens	A bound on how much output to generate.

A repeated tenant/request ID with the same effective settings returns the existing generation; different content conflicts.

Inspect G81

```
GET /generations/G81
```

Return generation status after checking ownership. All stream access checks ownership too.

Request cancellation

```
DELETE /generations/G81
```

Record an idempotent cancellation request. Invalid limits, tenant quota exhaustion and unavailable worker capacity are distinct errors.

Durable control record

Stored fields	Purpose
Generation identity and input/settings hash	Find the same logical request and reject conflicting reuse.
Pinned model version	Preserve the selected execution configuration.
Assigned worker, deadline and state	Track ownership and the generation's lifecycle.
Cumulative usage	Preserve the recorded accounting total.

Use three database replicas across failure domains and acknowledge updates after a durable majority commit. Loss of a majority stops new admissions and authoritative state changes. Model input requires an explicit private-retention policy; routine logs contain identifiers and lengths rather than raw prompts.

Temporary worker state and stream identity

State or field	Purpose and lifetime
Tokenized input	Input representation held by the live worker.
KV cache and scheduler state	Current execution state; the G81 database row does not make it durable.
Bounded recent-event buffer	Allows reconnect replay only while the live worker retains those events.
Stream event generation ID and increasing sequence number	Identify the event's generation and position in its stream.

Expired replay buffers or worker loss mean interruption.

Persist assignment to a specific worker process incarnation: an identifier created on each process start. That incarnation deduplicates repeated dispatch; a restarted process rejects assignments naming the old incarnation. Accept output and status callbacks only from the assigned incarnation while the generation is nonterminal. Never transparently reassign a running generation; a new attempt has a new identity.

07 / Use admission and batching to protect latency

Time to first token, or TTFT, measures arrival to the first output token. Inter-token latency, or ITL, measures gaps between later output tokens. Suppose the interactive targets are one-second p95 TTFT and 50-millisecond p95 ITL for the tested traffic mix. Queue delay consumes TTFT; a long prefill can also interrupt output for already active requests.

First, bound tenant input/output tokens, concurrency and queue waiting time. The router can use worker capacity reports, but the worker makes the final guarded reservation against its actual memory budget. Two gateways seeing one free slot must not both consume it. Initially reserve enough KV capacity for each admitted request's maximum allowed length; this is conservative but straightforward.

Continuous batching lets the scheduler insert new sequences and remove finished ones between execution iterations. A short request need not wait for the longest member of an original fixed batch to finish. However, simply enlarging the batch can improve aggregate throughput while worsening each stream's latency.

Chunked prefill divides a long prompt's prefill computation across bounded scheduling intervals. This gives active decoders opportunities to produce output between those intervals. It does not split the user's prompt into independent questions or remove attention to the prior context. Tune the token budget against both TTFT and ITL; prioritizing ongoing decode too strongly can make new requests wait.

Use a mature serving runtime for these mechanisms. Explain the bottleneck each change addresses and measure the result. Keep long-running batch jobs in a separate queue with a different latency budget.



INTERVIEW CRITICAL

Request count is not an admission budget

Two requests can differ by thousands of prompt or output tokens. Admit against token work, queue delay and worker-owned KV capacity; a router estimate cannot reserve the same final memory slot twice.

08 / Reuse computation without losing memory ownership

A paged KV allocator stores attention state in fixed-size blocks and records which blocks hold each sequence's tokens. A growing sequence can acquire another block instead of needing one large continuous free region. This reduces wasted space, but each distinct live token still needs storage. Initially reserve for the maximum sequence length; relax that policy only after measuring memory pressure and deciding how to pause or restart work when memory runs short.

Prefix caching reuses prefill state for identical leading tokens, such as repeated instructions and the same source document. It saves input computation, not the work of generating G81's new 600-token answer. Cache identity must include compatible model weights, tokenizer, template, adapter settings and exact effective tokens. A server-controlled tenant scope prevents private prefix reuse across unrelated tenants.

Retaining a 2,000-token prefix at 128 KiB per token occupies 250 MiB. Decide whether repeated prefill savings justify that space instead of another active sequence. Eviction stops the cache from keeping a block, but running computations may still need it. Wait for them before reusing its memory. A shared prefix stays read-only: to append tokens, copy a partial block into private storage or share only completed blocks.

Cancellation follows memory ownership

1. **Stop future scheduling.** Mark G81 unschedulable.
2. **Drain active use.** Let any already running kernel finish using its blocks.
3. **Release memory.** Reclaim the blocks only after that use has ended.

Freeing immediately when the HTTP connection closes can let a new request overwrite memory still being read by the old computation.



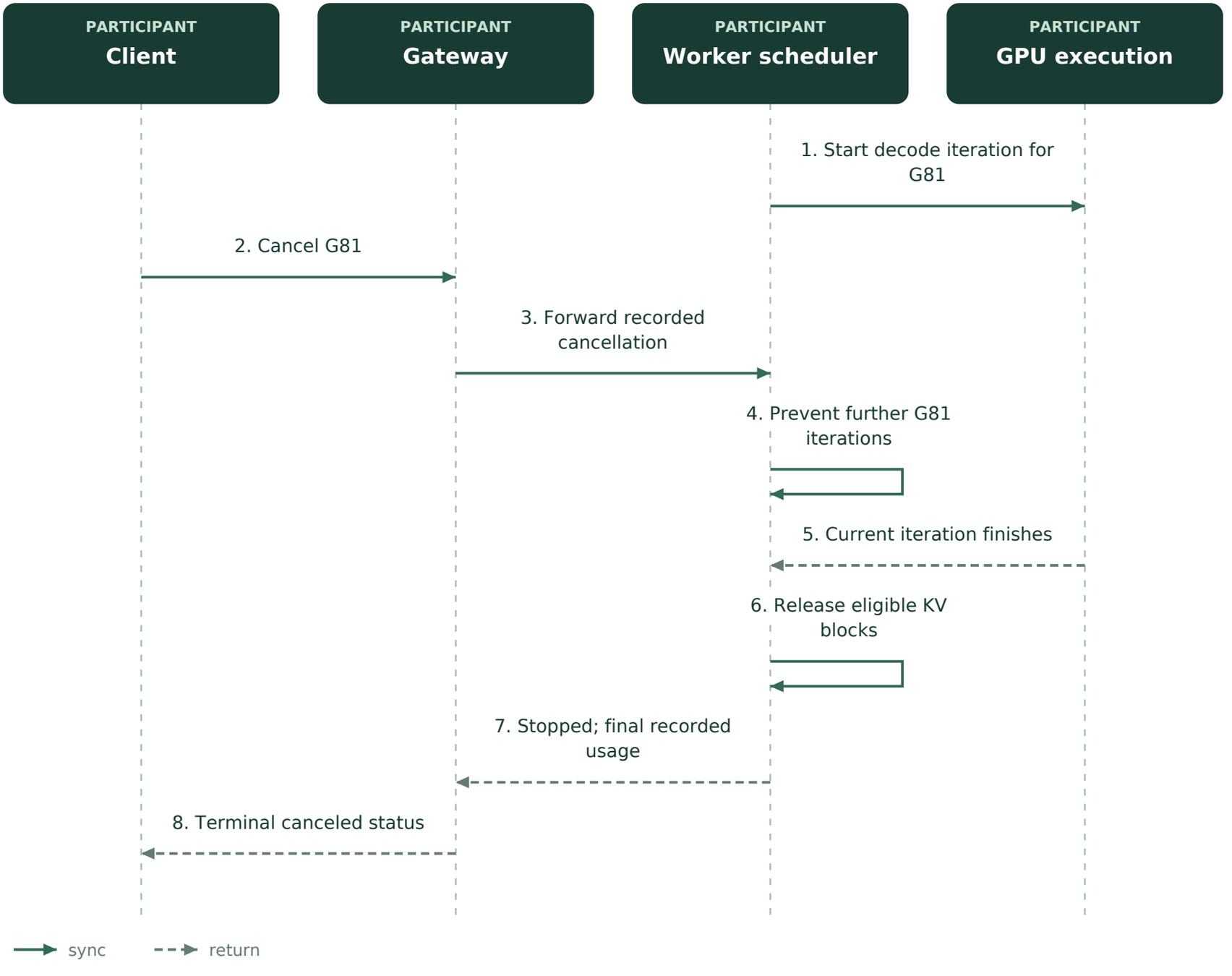
INTERVIEW CRITICAL

Cancellation must reach the scheduler before memory is reused

A disconnected socket does not stop GPU work. Prevent another iteration, wait for in-flight execution to release its references, then return KV blocks to the pool. Already produced output cannot be retroactively withdrawn.

Cancel safely before reusing KV blocks

A cancellation request prevents future iterations. Memory becomes reusable only after already running execution has released its references.



09 / Add ready replicas before specialized execution

When one worker reaches its tested capacity, add compatible worker replicas and route independent generations among them. Readiness means the exact model and tokenizer are loaded and a representative request succeeds, not merely that the process has started. Each worker owns its scheduler and memory pool. Keep spare ready capacity for the stated worker-loss target; a cold artifact download is not immediate failover capacity.

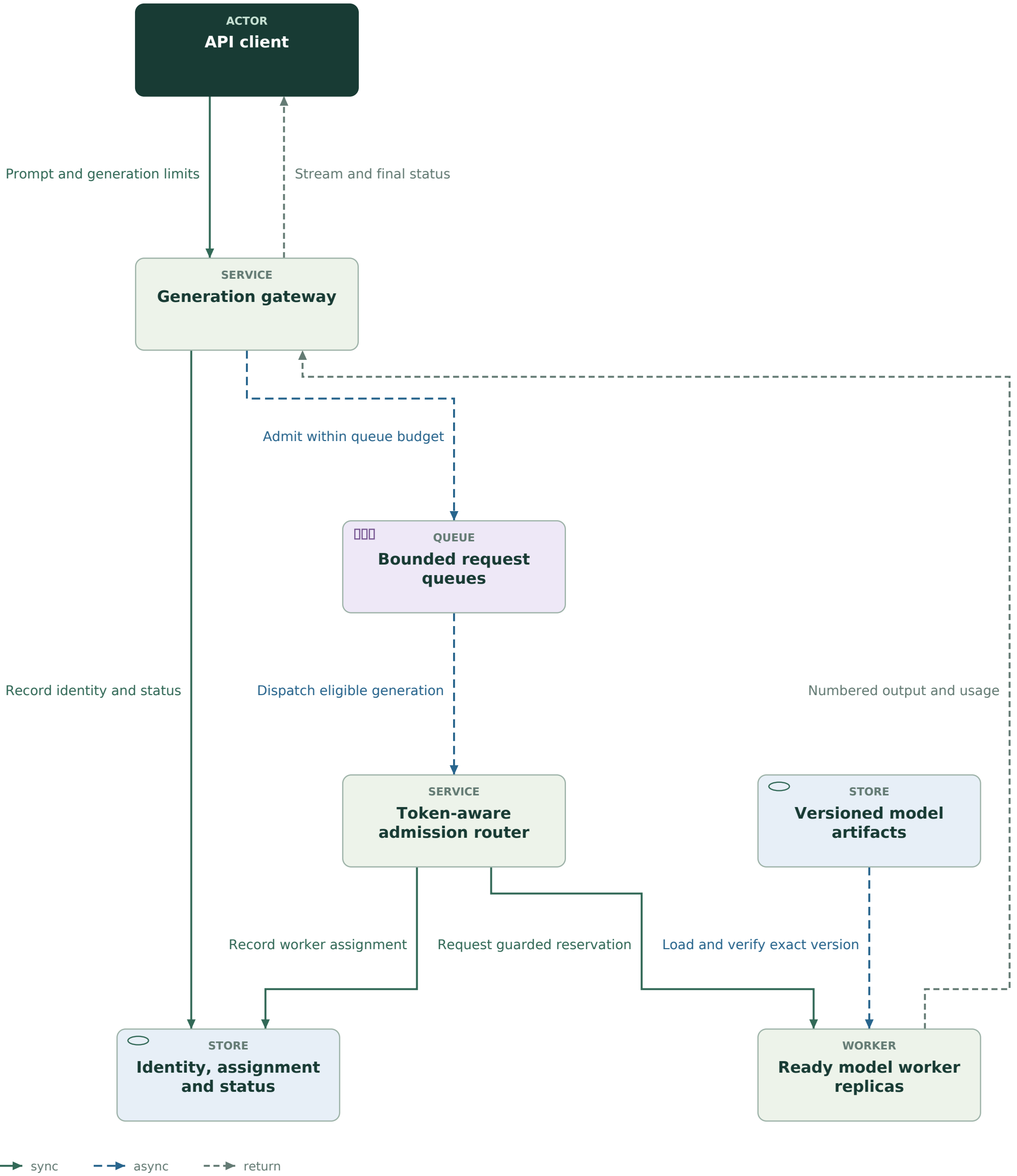
For each model version, route using queue delay and token/memory pressure rather than open connection count alone. A worker can reject a reservation when its local capacity has changed. An explicit rejection before execution allows reassignment. A lost admission response is uncertain, so report interruption rather than risk a second execution. Running generations are never transparently reassigned.

If the model itself does not fit one device, tensor parallelism divides layer computations across devices and introduces communication between them. A coordinated group then acts as one worker, and losing a required device can interrupt that group's requests. If the model already fits, replication is generally the simpler way to increase independent-request throughput.

Quantization reduces numerical storage precision and may save weight or KV memory, but needs compatible kernels and quality evaluation. Separating prefill and decode onto different pools is a later alternative: transferring G81's 4,000-token prefix at the example KV size moves about 500 MiB per request.

Route admitted generations to ready model replicas

The gateway records one generation identity. Bounded queues and token-aware routing feed a ready worker, which owns its scheduler and reserves its own KV memory. Output returns through the gateway. Replicas add request capacity; they do not resume a generation lost with another worker.



10 / Make interruption, backpressure and accounting explicit

If a worker incarnation disappears, mark all its nonterminal generations interrupted and close their streams. A restarted worker registers a new incarnation and cannot reclaim those assignments. Do not copy only a saved prompt to another worker and claim the old continuation survived. New requests can use ready replicas; a replacement attempt is visibly separate. A durable control row preserves identity, not lost GPU tensors.

A slow client gets a bounded event buffer. If it cannot catch up within the declared grace period, cancel its generation rather than accumulating unlimited output or continuing expensive work forever. A cancel response initially means the request was recorded; the terminal status becomes canceled after the worker acknowledges stopping future scheduling. Worker loss may instead produce interrupted status. Every generation also has an absolute deadline, limiting abandoned execution when control communication fails.

For usage, periodically save cumulative input/output counts and advance the durable total monotonically. Reports of 100 and then 120 tokens mean 120, not 220. On ordinary completion, persist final usage before sending the final usage event. This internal service charges only durably recorded work: a crash at token 120 with only 100 saved leaves an unbilled twenty-token tail. Finalize the interrupted total so a late report cannot silently add a charge; record late physical work separately for capacity analysis.

During a control-database outage, stop new admissions. Existing generations can run within their already granted bounds and deadlines, but status, cancellation and final accounting may be delayed. Report that limitation instead of claiming instantaneous cancellation through a partition.

11 / Measure useful throughput and roll out complete versions

Measure queue time, TTFT, ITL, completion latency, input/output tokens per second, active sequences, KV occupancy, prefix reuse and cancellation delay. Break results down by prompt length, output length, model version and tenant. High GPU utilization alone can hide unacceptable token gaps or repeated wasted work.

Pin the weights, tokenizer, template, adapters and compatible runtime as one tested deployment configuration. Load a new version on separate workers, run quality and mixed-load tests, route a small canary, then expand traffic. Drain old workers until their active requests finish or reach the documented deadline. Replacing weights beneath a live KV cache invalidates the state used for continuation.

Exercise worker crashes after partial output, cancellation during a kernel, simultaneous final-slot admissions, expired reconnect buffers and repeated usage reports. A basic fairness test places a short request behind a burst of long prompts and measures both its first-token delay and existing streams' token gaps.

Protect artifact integrity and private prompts. Cache tenancy comes from trusted identity, not a client-supplied value. Generated output must not execute as server code. Compare optimizations using successful workload throughput within latency and quality targets, including memory and warm-spare costs; a larger benchmark token count is not automatically a better user experience.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 3, 5	Durable request identity, pinned versions and one worker-incarnation assignment identify each stream.	Repeat a request, conflict its settings, read another tenant's status and crash its worker after partial output. Require one identity and explicit interruption, not a stitched replacement answer.
NFR 1, 2, 4	Worker-local memory reservations, bounded queues and measured batching protect interactive service.	Benchmark the mixed token workload, first-token p95 and later-token p95 with a burst of long prompts. Isolated phase throughput and memory arithmetic do not prove mixed capacity.
FR 3; NFR 3, 4	Cancellation stops future scheduling before in-flight work releases its memory.	Cancel during a kernel and lose control communication; verify no early memory reuse and the declared delayed/interruptible outcome.
FR 4; NFR 5	Ready versioned replicas and draining keep rollouts compatible.	Canary the model/tokenizer/template together and fail a worker. Check quality, tenant cache isolation and warm spare capacity; cold workers are not ready replacements.
FR 4; NFR 6	Monotonic cumulative usage and terminal finalization define the charged amount.	Deliver usage 100 then 120 twice, then a late report after interruption. Require the saved total, no double addition and an explicit unbilled crash tail.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: A capacity report is a hint; the worker reserves memory.

Concept	Role in the design	Boundary to remember
Prefill	Process the prompt and save its attention state.	Long prompts can delay existing streams unless scheduling limits that work.
Decode	Generate each next token using the prompt and tokens produced so far.	Longer outputs run longer and require more KV memory.

Concept	Role in the design	Boundary to remember
TTFT and ITL	Measure delay to the first token and gaps between later tokens.	High total throughput can still leave individual streams slow.
Admission	Limit token work and waiting time; reserve worker memory.	The worker reserves actual capacity; a router report may be stale.
Continuous batching	Add new requests and remove finished ones between iterations.	Larger batches can increase throughput while slowing each stream.
Chunked prefill	Process a long prompt in pieces, allowing decode work between them.	Each chunk continues the same prompt computation; chunks are not independent requests.
Paged KV allocation	Store growing sequences in fixed-size memory blocks.	Each live token still needs attention-state memory.
Prefix cache	Reuse compatible prompt computation within its permitted tenant scope.	It does not cache the new answer; running requests keep shared blocks allocated.
Cancellation	Stop new work, wait for running computations, then free their memory.	Closing the connection alone does not stop computation.
Worker loss	Keep saved status and report the unfinished generation as interrupted.	A database row cannot restore lost live KV memory.
Usage reporting	Save increasing cumulative counts, then fix the final total.	Repeated reports do not add charges; work lost before recording is unbilled internal cost.
Scaling	Add workers with compatible models; split a model only when capacity requires it.	An unloaded model or an untested throughput estimate is not usable capacity.

14 / Close with a measured capacity and failure contract

Trace G81 from token counting through admission, prefill, decode, numbered output and cleanup. Explain the pinned model version, worker-owned reservation and safe cancellation.

Next, mix short prompts with G81-sized requests while injecting worker failure and cancellation. Measure useful token throughput within both latency targets. Exact continuation after worker loss remains an Advanced requirement.

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What are prefill and decode, and why measure them separately?

Model answer

Prefill processes input tokens and builds cached attention state. Decode repeatedly generates the next token using the prefix and cache. A long prefill can delay existing decoders, so first-token latency and gaps between output tokens reveal different scheduling problems.

Interviewer follow-up

Does prefix caching make the whole response free?

It reuses compatible input computation. The new output still requires decode work, and retaining the prefix occupies real KV memory.

What the answer must demonstrate: Define both execution phases and connect their interference to first-token and inter-token latency.

02 / APPLIED

Do isolated bounds of 27 prefill workers and 40 decode workers prove forty workers are enough?

Model answer

No. The isolated measurements each assume a particular workload, while mixed workers share compute, memory bandwidth and capacity between phases. Use those figures as lower bounds, then load-test the combined prompt/output distribution with headroom and latency targets.

Interviewer follow-up

Why calculate active streams?

Each live sequence occupies KV state. At 100 arrivals per second and about twelve seconds of decode, roughly 1,200 sequences are active before queue and prefill time are included.

What the answer must demonstrate: Treat isolated throughput as lower bounds, then account for mixed execution and live-sequence memory.

03 / APPLIED

Two gateways see the same worker with one free slot. What prevents over-admission?

Model answer

The worker makes a guarded reservation against its actual sequence and KV capacity before accepting execution. Registry reports guide routing but do not allocate memory. One reservation succeeds; the other must wait within its deadline or use another eligible worker before execution starts.

Interviewer follow-up

Why start with maximum-length reservation?

It provides a straightforward memory bound using the input plus allowed output length. Dynamic allocation may use memory better but needs explicit handling when sequences grow and capacity runs out.

What the answer must demonstrate: Put the guarded allocation at the worker; explain the simplicity and utilization cost of maximum-length reservation.

04 / FOUNDATION

How do continuous batching and chunked prefill solve different problems?

Model answer

Continuous batching lets finished sequences leave and new ones enter between iterations, avoiding empty fixed-batch slots. Chunked prefill limits how much long-prompt work runs at once so active decoders get opportunities to produce output.

Interviewer follow-up

Can either optimization worsen latency?

Yes. Larger batches can lengthen token gaps, and strong decode priority can delay new prefills. Measure both first-token and inter-token latency for the actual workload.

What the answer must demonstrate: Distinguish dynamic batch membership from prefill scheduling and measure both latency consequences.

05 / APPLIED

Why is it unsafe to free the KV cache as soon as a client disconnects?

Model answer

A GPU kernel may still be reading those blocks. Immediate reuse by another request can corrupt live execution. Record cancellation, stop future scheduling, wait for in-flight references to finish, and only then release blocks.

Interviewer follow-up

What if the worker is unreachable?

Record cancellation intent and rely on the bounded generation deadline while establishing worker loss. Do not claim physical work stopped instantly; status may become interrupted rather than acknowledged canceled.

What the answer must demonstrate: Preserve in-flight memory references and distinguish recorded cancellation intent from confirmed stopped execution.

06 / APPLIED

Which identity is required for safe prefix reuse?

Model answer

Exact effective prefix tokens, compatible model weights/tokenizer/template/adapters, and a server-controlled tenant or approved trust scope. Shared blocks remain immutable while live requests reference them. A cache entry is computation state, not an independently authorized answer.

Interviewer follow-up

Why not let clients choose the tenancy salt?

A client could select another tenant's scope and create cross-tenant reuse or timing exposure. The gateway derives isolation settings from authenticated identity.

What the answer must demonstrate: Include exact compatible prefix identity and trusted tenant scope, with immutable shared live state.

07 / FOLLOW-UP

What survives a worker crash in the selected design?

Model answer

The generation identity, status and recorded usage survive in durable storage. Live KV tensors and unsaved output events disappear. Mark the dead process's generations interrupted. A restarted worker has a new incarnation - an identity for that process start - and rejects old assignments; a replacement generation is an explicit new attempt.

Interviewer follow-up

Why is saving only the prompt insufficient?

It can start another computation, but does not restore the exact prior execution state or guarantee the same sampled continuation.

What the answer must demonstrate: Separate durable identity from ephemeral state, bind assignments to process incarnations, and make replacement attempts explicit.

08 / FOLLOW-UP

How do cumulative usage reports avoid duplicate charges?

Model answer

Advance the saved count monotonically for one generation: reports of 100 and 120 output tokens yield 120, not 220. Finalize a terminal count so late reports cannot reopen billing. Under this design, work after the last durable report at a crash is an internal unbilled cost.

Interviewer follow-up

What should a rollout verify besides throughput?

Output quality, tokenizer/template compatibility, mixed-load first-token and inter-token latency, memory, cancellation and recovery. New workers load the tested version while old workers drain.

What the answer must demonstrate: Advance cumulative counts rather than adding them, finalize terminal totals, and disclose unrecorded crash-tail work.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a multi-tenant text-generation service receiving 100 requests per second, each averaging 4,000 input and 600 output tokens. Start with one bounded worker, then justify scheduling and scaling changes. Trace cancellation during execution and a worker crash after partial output.

• Agree the numbered functional requirements and non-functional targets: streaming, cancellation, token load, both latency measures, privacy and interruption behavior.

• Derive token throughput and memory budgets, then choose scheduling and scaling changes.

• Handle cancellation, worker loss and usage reporting without pretending lost execution state can be resumed.

• Calculate both token rates and architecture-dependent KV memory.

• Validate generation, retry, cancellation, rollout, latency, memory and recorded usage against the numbered requirements; identify mixed-load tests and worker-loss limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

Two gateways see one free worker slot. Who decides which generation may start?

The worker reserves its actual KV memory before starting work. Router reports can be stale. Admission also bounds input/output tokens and queue waiting, so request count alone is insufficient.

A capacity report is a hint; the worker reserves memory.

The client cancels while a GPU computation still uses its KV blocks. When can memory be freed?

Stop new work, wait until running computations release the blocks, then free them.

Stop -> drain -> free.

Does a saved generation record let a new worker resume the exact computation?

No. It does not contain live GPU KV memory or output events that were never saved.

Identity survives; execution may not.

Summary and interview notes

Limit token work, waiting time and memory before generation starts. Measure first-token delay and later token gaps separately, then improve scheduling or add workers where the measurements show a bottleneck.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Budget input tokens, output tokens and KV memory instead of treating all requests alike.

• Measure first-token latency and later token gaps independently.

• Let the worker reserve actual memory, then use continuous batching and chunked prefill for measured bottlenecks.

• Scope prefix reuse to compatible versions and trusted tenants; cancellation drains execution before memory reuse.

• Persist identity and recorded usage while explicitly interrupting streams whose live execution state is lost.

Interview tips

• State the contract before choosing storage.

• Follow one concrete request through commit, response and recovery.

Important qualifications

• Traffic and latency figures are interview assumptions, not claims about a named company's deployment.

Explore the advanced version

Fine-grained block sharing and cache identity: Study copy-on-write, reference races and canonical compatibility checks beyond the main allocator ownership explanation.

Execution ownership during control partitions: Add stronger lease and fencing behavior if transparent reassignment or stricter partition guarantees are required.

Specialized parallelism and decoding optimizations: Compare pipeline parallelism, disaggregated prefill/decode, KV quantization and speculative decoding after measuring the core service.

Detailed accounting and finalization protocol: Extend cumulative counters into explicit per-attempt billing reservations and terminal accounting rules.

Technical references

vLLM optimization and tuning
Documents chunked prefill, scheduling tradeoffs, preemption, and parallelism choices.
https://docs.vllm.ai/en/latest/configuration/optimization/

vLLM automatic prefix caching
Documents compatible block reuse and cache-salt isolation.
https://docs.vllm.ai/en/latest/design/prefix_caching/

PagedAttention paper
Primary research on efficient attention-memory management for serving.
https://arxiv.org/abs/2309.06180

vLLM documentation
Official serving capabilities, including continuous batching and streaming; settings evolve by version.
https://docs.vllm.ai/en/latest/

EXTENDED INTERVIEWS / 60

Design durable agent workflows

Interview version / 45-minute scope · Read the advanced version online

Run an AI-assisted business process across waits and crashes while keeping approved actions, saved progress and uncertain outcomes explicit.

durable workflows • tool authorization • approval boundaries • agent recovery

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Distinguish a model recommendation from an authorized external action.
- Build a resumable workflow around durable states and activity results.
- Recover a lost provider response without blindly repeating a purchase.

Useful foundations: Distributed transactions and sagas; Idempotency, retries, and timeouts; Authentication, authorization, and tenant isolation

8 interview questions with model answers and answered follow-ups.

01 / Design a business process that uses a model

An agent workflow is a process that uses a model to interpret information or propose a next step. The application still decides which tools exist, which actions are permitted and what counts as completion. A conversational transcript alone is not a reliable record of a purchase, approval or retry.

Ask which actions the model may propose, which need human approval, and what should happen if the vendor receives an order but its reply is lost. This design permits a fixed purchasing process, approval of exact terms and an explicit uncertain-submission outcome.

Our example buys ten laptops from one of three approved vendors. The model compares quotes and drafts a proposal. A human approves an exact proposal, and only then may the service submit the order. The workflow may wait thirty minutes for approval, survive worker restarts and report the final order identity. Payment settlement and arbitrary browsing are outside this scope.

The complete flow is save task -> research quotes -> save proposal -> wait for approval -> submit approved order -> save result. This fixed sequence is intentionally enough for the interview. The model helps with research and explanation; it does not invent new privileges or freely change the workflow. A durable workflow means that progress survives a process crash and execution resumes from recorded state rather than starting the business action again.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Create and inspect tasks.** Create a tenant/requester-owned purchase task, return its durable identity and show its phase, current proposal and any external order result.
2. **Research an allowed purchase.** Compare quotes from the three approved vendors and draft a proposal for ten laptops. The model supplies bounded interpretation; trusted code checks commercial terms and policy.
3. **Review and approve exact terms.** Let an authorized human review and approve the exact current proposal, with a documented expiry. Replacing the proposal or changing its terms invalidates earlier approval.
4. **Submit and audit an order.** Submit only the authorized proposal, preserve the external action identity, record the provider's result and expose reconciliation when the result is uncertain.
5. **Cancel at a defined boundary.** Before submission admission, cancellation prevents the action from starting. After the provider may have accepted, any cancellation is a separate business operation. Payment settlement and arbitrary browsing are outside scope.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Assume 100,000 starts/day, ten model calls and fifteen ordinary tool calls per task, with a thirty-minute average approval wait. Account separately for bursts, retries and vendor limits.
2. **Responsive control.** Target task creation and status p95 below 300 ms. Measure research, approval wait and submission completion separately; an approval that may take hours cannot share a tiny end-to-end latency target.
3. **Durable progress.** Saved task state and activity results must survive the selected database-node failure. Waiting tasks consume durable state and timers rather than blocked workers. Retain activity results, approvals and provider reconciliation records through the declared recovery window, and keep unresolved action evidence available until reconciled.
4. **Exact authorization.** Submission must use the exact currently approved proposal, a stable action identity and current permission/budget checks. Tenant isolation, allowed vendors, bounded quantities/spend and approval/quote expiry apply even when the model recommends otherwise.
5. **Honest external outcomes.** Provider idempotency and lookup determine recovery after a lost response. Report `SubmissionUnknown` when evidence is insufficient; do not claim canceled, completed or exactly-once remote execution merely because local workflow history is durable.
6. **Bounded execution and privacy.** Limit steps, tokens, retries, elapsed time and provider concurrency per tenant/task. Separate model calls, vendor reads and submission capacity; keep credentials and unrestricted network access outside model control.

04 / Save each completed step before moving forward

Begin with an API, a relational database and one background worker. Creating task T81 commits its owner, inputs and initial state before returning its ID. The worker claims ready work, loads T81 and performs the next activity. An activity is one bounded operation, such as fetching a vendor quote or asking the model to compare saved quotes.

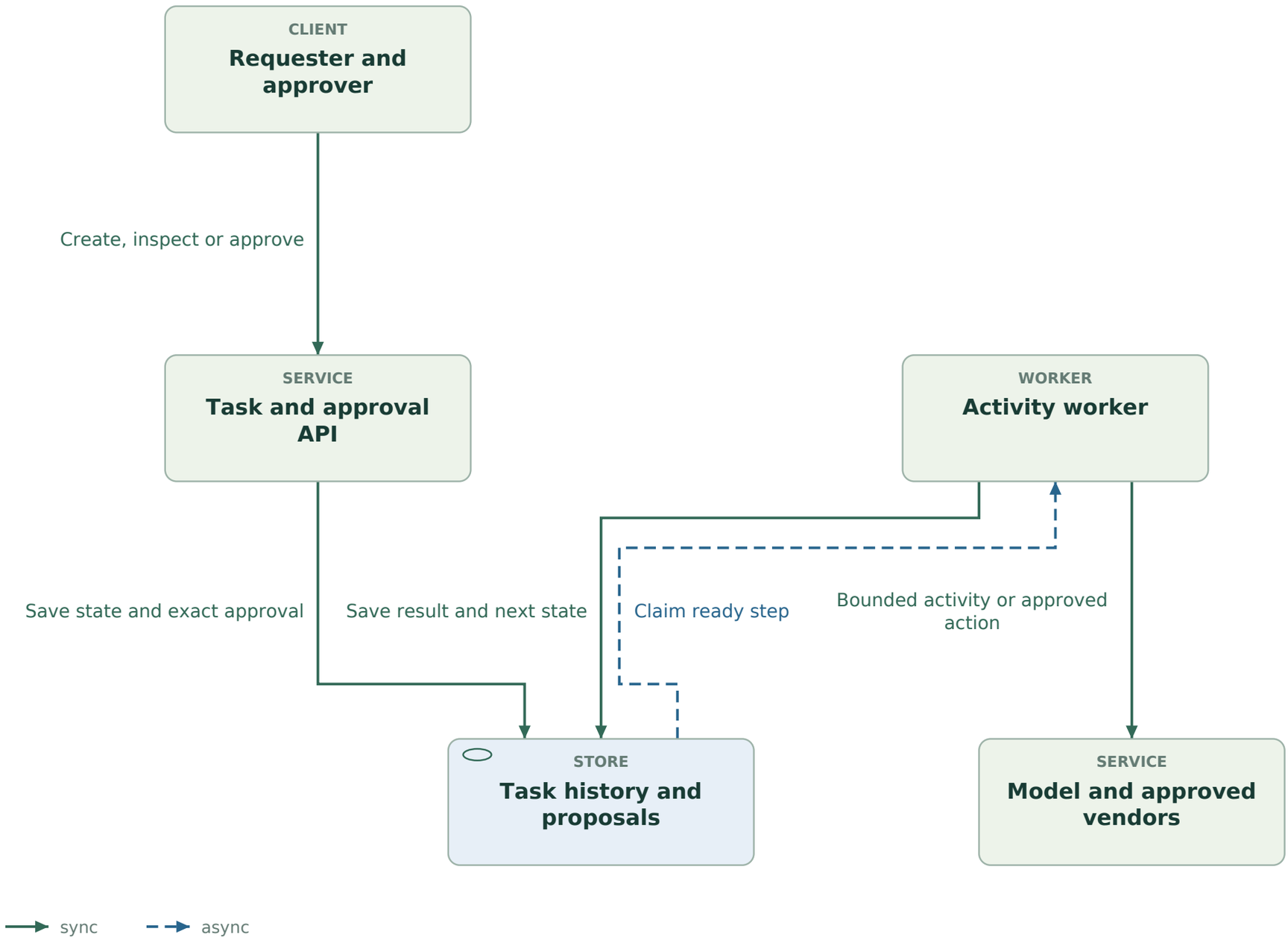
Save each successful activity result and advance the workflow state in a transaction. If the worker restarts after that commit, it reads the saved result instead of making the same model call again. If it crashes before recording a harmless quote read, that read may run again. Re-execution is acceptable only when the operation's effects permit it.

After research, save proposal P8 and enter `WaitingApproval`. No worker remains blocked for thirty minutes; the database records the wait. An approval request validates the actor and proposal version, then makes the submission step eligible. A worker submits it using a stable external action key and records the provider's order ID.

The API returns task status from durable state. A browser disconnect does not cancel or erase the purchase process. This baseline already explains asynchronous execution, restart recovery and the difference between a waiting task and a running worker.

One durable business process

Workers perform ready activities; the database holds waiting tasks and saved results.



05 / Separate running work from waiting tasks

Assume 100,000 task starts per day: approximately 1.16 starts/s on average. At ten model calls and fifteen ordinary tool calls per task, the averages are about 11.6 model calls/s and 17.4 tool calls/s. Peak bursts, retries and vendor rate limits require separate headroom.

With 3,000 input tokens and 500 output tokens per model call, average model demand is roughly 34,700 input tokens/s and 5,800 output tokens/s. Token volume and the number of active requests both matter when choosing provider quotas and worker concurrency. A fixed request count hides large prompts and long responses.

If approval takes thirty minutes on average, about 1.16 x 1,800 ~ 2,083 tasks are waiting at any instant. They need durable rows and timers, not 2,083 blocked worker processes. The worker pool should scale with ready activities and external call latency.

At 200 saved events of 2 KB each, one task adds about 400 KB of history and 100,000 tasks add 40 GB/day before indexes and replication. Store large documents separately and reference immutable versions from history. Retention and redaction decisions should preserve the evidence needed for recovery without keeping every sensitive prompt forever.

06 / Give task, proposal and action separate identities

Create a task

```
POST /tasks
```

Request information	Purpose
Scoped request key	Identify the intended creation; save it with the result so a client retry returns T81.
Purchase requirements	Describe the requested purchase, such as ten laptops in the worked example.

Task control operations

Operation	Request or result
`GET /tasks/T81`	Return phase, current proposal, outstanding approval and any external result.
`POST /tasks/T81/approve`	Name the exact proposal version being approved.
`POST /tasks/T81/cancel`	Request the applicable cancellation behavior.

Durable workflow records

Record	Information retained	Purpose
Task	Current state and version	Coordinate the saved process.
ActivityResult	Workflow step, inputs and saved result	Recover completed work without unnecessarily executing it again.
Proposal	Immutable purchase terms	Identify the precise offer the human reviews.
Approval	Authenticated approver and exact proposal representation	Bind authority to those terms.
ExternalAction	Stable action key, payload, status and provider order ID	Recover one intended external purchase.

Proposal fields

Fields	What approval covers
Vendor and item identifiers	Who supplies which products.
Quantity	How many items are being purchased.
Total amount and currency	The commercial cost being approved.
Destination and quote expiry	Where the order goes and how long the offer remains valid.

External action identity in the example

```
Task:        T81
Proposal:    P8
Action key:  T81-P8-submit
```

The key identifies one intended purchase attempt, not a worker process. A replacement worker must reuse it when recovering that action.

Use expected task versions or a database lock to prevent two workers from advancing the same state concurrently. This protects local records. It does not undo an external effect already performed by a worker whose lease expired, so external action identity remains necessary even with careful scheduling.

07 / Keep model output inside an explicit workflow

Research first gathers quotes through permitted read-only tools. The model receives those saved facts and returns a structured comparison. Validate required fields and business constraints before constructing P8. Model output is a proposal; trusted application code calculates totals, checks approved vendors and determines whether the next step is allowed.

Waiting for approval is a durable state with an expiry timer. The approval endpoint checks the caller's authority and the exact current proposal. A sentence saying "approved" in a document or chat message is not an authenticated approval. If a vendor changes the price or quote validity expires, produce a new proposal and request new approval.

Before contacting the provider

1. **Recheck permission and terms.** Validate applicable permission, budget and proposal validity.
2. **Save intent.** Persist the exact outgoing action and its stable key.
3. **Submit.** Only then contact the provider.

This creates a recoverable account of what the worker intended to send even if the response never arrives.

The model may explain why one quote is preferable, but it does not receive raw production credentials or construct unrestricted network requests. Application code checks permission and saves progress; the model compares the supplied facts and explains its proposal. Each responsibility can be tested separately.



INTERVIEW CRITICAL

Model text is not action authority

The application validates a structured proposal and an authenticated approval for its exact version. Retrieved instructions and generated claims cannot grant permission.

08 / Add workers without losing the saved process

A durable work queue separates task admission from execution. Publish ready work through a transactional outbox or an equivalent database-backed queue so a committed task cannot disappear between saving it and enqueueing it. An outbox is a table of pending dispatch records written in the same transaction as the state change; a relay forwards them and may retry.

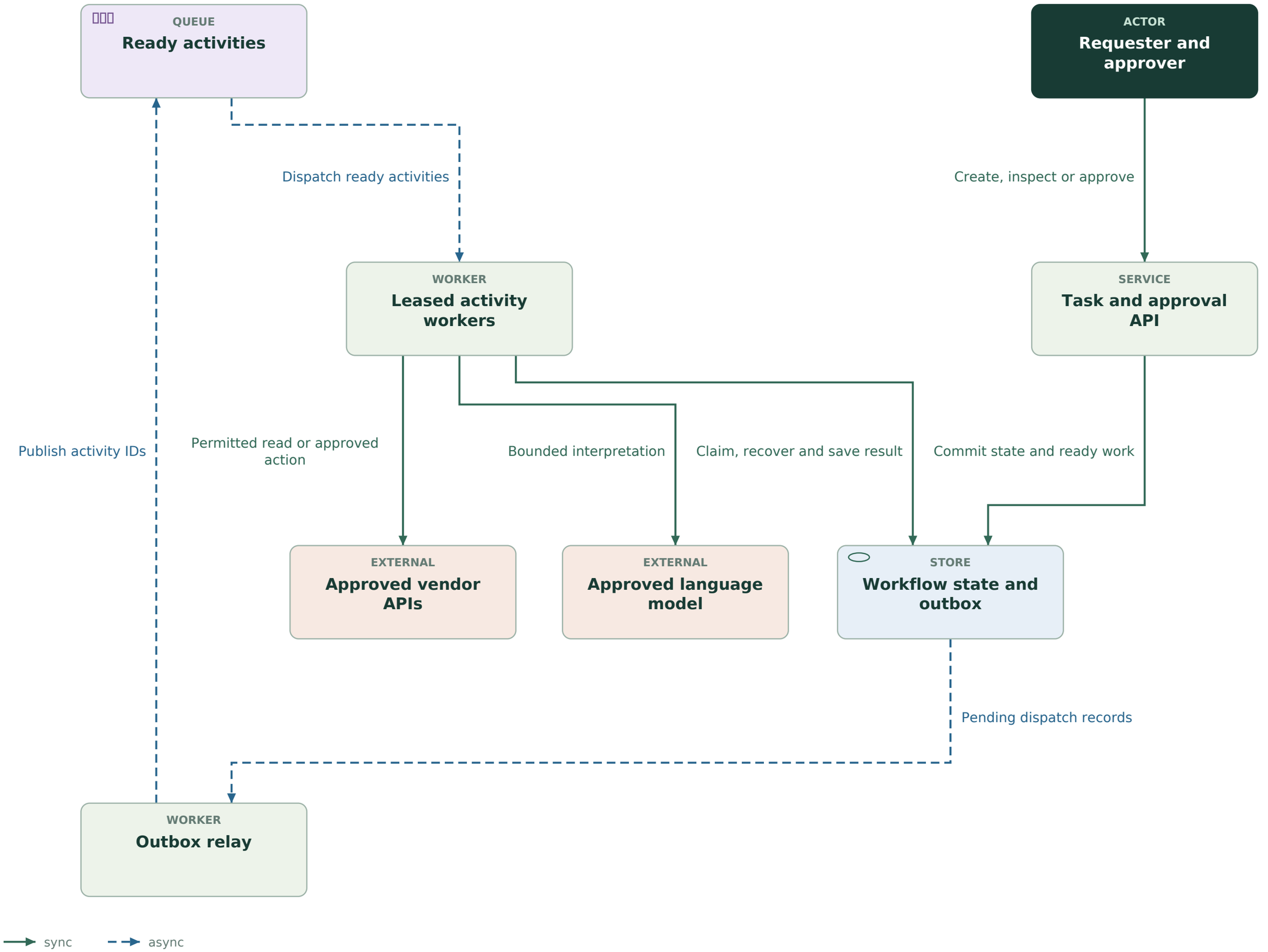
Workers claim activities with bounded leases and renew while running. On expiry, another worker can recover the activity from durable state. Local version checks reject stale state updates. A duplicate queue message first inspects the recorded step outcome instead of assuming another complete execution is required.

Use separate concurrency limits for model calls, vendor reads and order submission. One slow vendor should not consume the entire pool. Apply tenant quotas and bound retry counts, token budgets and elapsed time per task. Waiting approval tasks consume neither provider concurrency nor busy workers.

A workflow engine can supply timers, history and retry scheduling once those requirements justify it. It does not automatically solve provider idempotency or business approval semantics. Keep the same saved-state and external-action contracts when adopting an engine, and pin workflow versions so a code deployment does not reinterpret an old task unpredictably.

Durable state coordinates workers, approvals and external actions

An API transaction saves task or approval state with ready work. The relay can repeat delivery IDs; workers recover recorded outcomes before continuing. Model calls propose bounded results, while separately authorized vendor actions use stable action identities. Waiting approvals remain in storage.



09 / Recover the order whose response was lost

Lost-response trace for approved proposal P8

1. **Save the action.** T81's worker records `T81-P8-submit`.
2. **Send the purchase.** The worker calls the vendor.
3. **The vendor accepts.** It creates order O902.
4. **The response is lost.** The connection breaks before the worker receives O902.

The saved action records what the worker was authorized to submit. It does not show whether the request reached the vendor or created an order.

If the provider supports durable idempotent submission, retry the same key and identical payload within its documented retention window. It should return the existing outcome instead of creating another order. If lookup by action key or client reference is available, query it and save the confirmed order identity. Provider guarantees must be verified; no generic HTTP retry supplies them.

If the provider cannot resolve the action safely, leave it `SubmissionUnknown` and reconcile through a controlled operator process. Do not invent a fresh key just to get a successful response. That would convert one uncertain purchase into a possible duplicate purchase.

This is the central recovery story. Saving workflow history prevents forgotten progress, but cannot make a remote side effect part of a local database transaction. The application needs provider cooperation or an honest uncertain state. "Exactly once" without that boundary obscures the business risk instead of solving it.



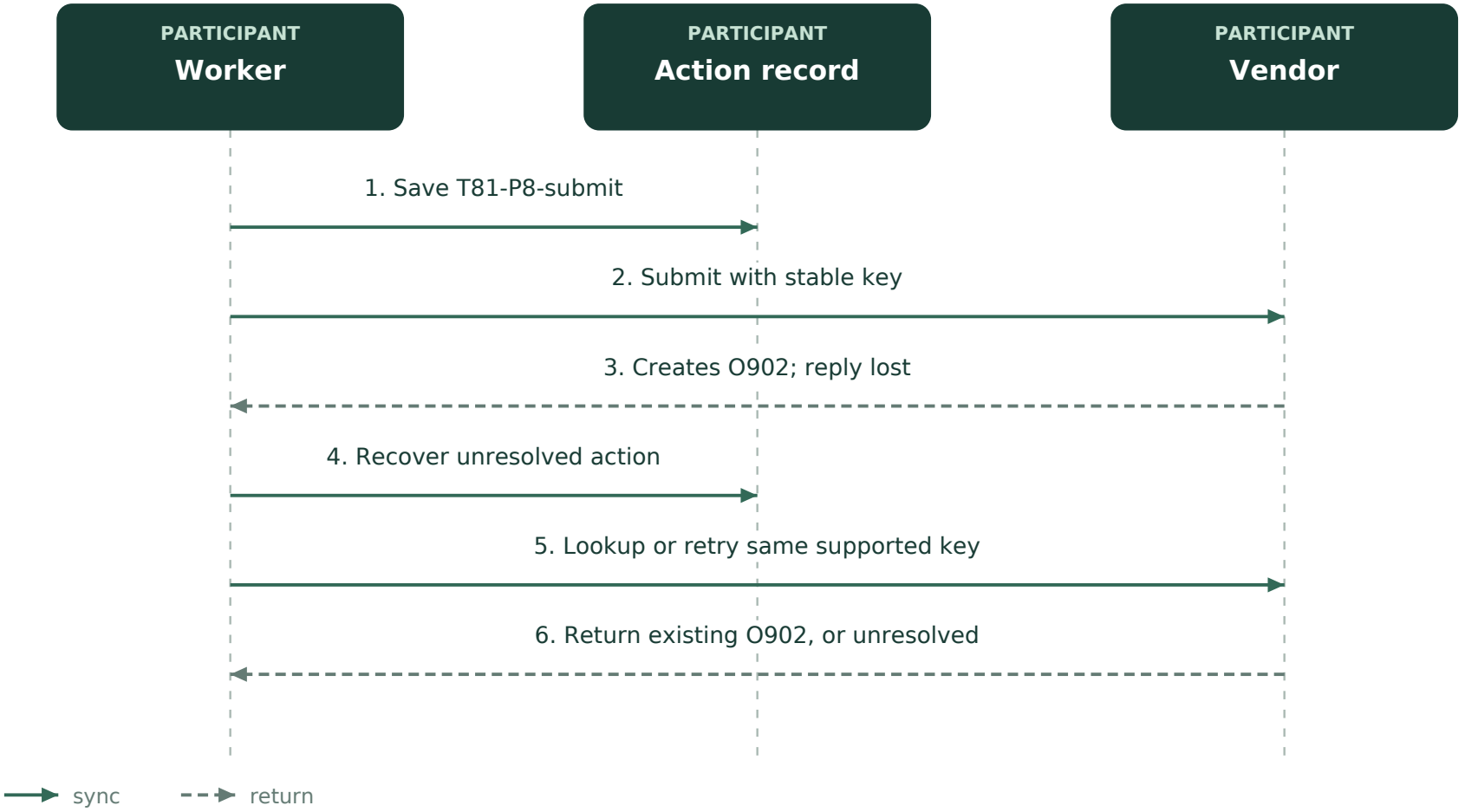
INTERVIEW CRITICAL

A lost response does not prove a failed purchase

Recover the original action using the provider's documented identity and lookup guarantees. If the outcome remains unresolved, preserve an explicit unknown state rather than submit under a new key.

Order accepted, response lost

The replacement worker recovers the same purchase identity.



10 / Handle changes while a task is in progress

Before the service authorizes submission, canceling T81 saves a terminal state that blocks the purchase. Submission checks the current task version. If cancellation and submission race, the database accepts one state change first; that order determines whether submission was authorized, and the UI reports the result.

Once submission may have reached the provider, cancellation becomes a request to stop or reverse an order, subject to the vendor's API and business rules. A successful local cancel button cannot prove an in-flight remote purchase vanished. Resolve the original action first, then perform any supported cancellation under its own tracked identity.

Changing quantity, vendor or destination creates a new proposal version. Approval for P8 does not authorize P9 even if both belong to T81. Similarly, an expired quote may require research and approval again rather than silently purchasing at a new price.

Retry read-only activities with bounded backoff, but classify failures. Invalid input is not repaired by ten retries, and an uncertain purchase is not equivalent to a failed quote read. Escalation, compensation and human review are explicit workflow outcomes. The simplest safe design makes those states visible rather than hiding them behind a generic retry loop.

11 / Test business boundaries and recovery evidence

Trace task, activity, proposal and action IDs across logs while redacting credentials and unnecessary personal data. Measure queue age, ready versus waiting tasks, activity latency, provider error rate, token/spend budgets, approval age and unresolved submissions. A high completion rate can conceal dangerous duplicates or stale approvals, so inspect those outcomes separately.

Test a worker crash before saving a quote, after saving a model result, while waiting for approval and immediately after a provider accepts an order. The expected recovery differs at each point. Also test duplicate queue messages, changed proposals, revoked approvers, expired quotes and exhausted provider idempotency retention.

Treat retrieved content and vendor descriptions as untrusted input. Instructions embedded in them cannot authorize a tool or change the allowlist. Tool gateways validate schemas and permissions; secrets remain in trusted service integrations. Sandboxed computations may help comparison, but a sandbox is not a substitute for authorizing the eventual purchase.

Deploy workflow changes with compatibility for existing histories or explicitly migrate them. Practice operational reconciliation using realistic provider evidence. The strongest final design is one the operator can explain after a timeout: what was approved, what may have been sent, what was confirmed, and which action is still safe to take.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 1-3	Transactional saved state, activity results, durable dispatch and waiting timers let workers resume.	Crash around an activity commit and leave 2,083 illustrative tasks awaiting approval. Verify no blocked worker per wait; load-test control p95 and recovery under node loss.
FR 3, 4; NFR 4	Immutable proposals, authenticated approvals and guarded submission recheck exact terms.	Change quantity, expire a quote, revoke an approver and race workers. Require a valid current approval and one stable intended action.
FR 4; NFR 3, 5	External action records preserve the provider key and uncertain result for reconciliation.	Lose O902's reply; recover with the same supported key or lookup. If the provider cannot resolve it, require unknown status and operator review, not another purchase.
FR 5; NFR 4, 5	The task state transition orders cancellation against submission admission.	Race cancellation before and after admission. Prevent a not-yet-admitted action; do not pretend a remote order already accepted has vanished.
NFR 6	Tool validation and separate tenant/provider budgets constrain model-driven work.	Inject vendor-text instructions and exhaust one provider's quota. Check credentials stay private and unrelated work can progress within measured capacity.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Lost purchase reply -> recover the same action.

Prompt	Recall the mechanism and limit
What makes a workflow durable?	Saved state and activity results let replacement workers resume after a crash
Why save a waiting state?	A thirty-minute approval wait needs a record and timer, not a blocked worker
What can the model approve?	Nothing by itself; application policy and an authenticated person authorize actions
What does approval name?	The exact unchanging proposal, including purchase terms and expiry
Why a stable external action key?	Replacement workers must recover the same intended purchase

Prompt	Recall the mechanism and limit
Does a lease prevent duplicate purchases?	No; it coordinates workers but cannot undo an external purchase
What follows a lost vendor reply?	Retry the provider-supported key or look up the result; otherwise report unknown
What does cancellation mean?	Before submission is authorized it blocks the purchase; afterward reversal needs its own tracked action
What limits cost?	Limit steps, tokens, retries, elapsed time and simultaneous provider calls

Close with: "I use a fixed durable workflow around the model. Saved proposals and authenticated approvals authorize exact actions. Workers can restart, but external effects recover through stable identities and provider evidence. When that evidence is insufficient, the workflow reports uncertainty instead of blindly buying again."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

What makes this more reliable than replaying a chat transcript?

Model answer

The service stores explicit workflow state, bounded activity results, exact proposals, authenticated approvals and external action identities. A restarted worker resumes from those facts instead of asking the model to reconstruct what happened.

Interviewer follow-up

Can the model still choose tools?

It can propose permitted operations inside a bounded workflow, but trusted code validates and authorizes execution.

What the answer must demonstrate: The service stores explicit workflow state, bounded activity results, exact proposals, authenticated approvals and external action identities.

02 / FOUNDATION

Do 2,083 tasks waiting for approval require 2,083 workers?

Model answer

No. Waiting tasks are durable records with timers. Workers run ready activities and release capacity while approval is pending. Worker sizing follows active call demand and latency rather than the number of open tasks.

Interviewer follow-up

What wakes a waiting task?

A validated approval, cancellation or expiry transition makes the appropriate next step ready.

What the answer must demonstrate: No. Waiting tasks are durable records with timers.

03 / APPLIED

P8 was approved, but the vendor changes the price. May the agent submit?

Model answer

Not under the old approval. Validate the saved quote and exact proposal before admission; changed commercial terms require a new proposal and approval. Generated text saying the new price is acceptable does not authorize it.

Interviewer follow-up

What fields should approval bind?

Vendor, items, quantity, amount, currency, destination, validity and the immutable proposal identity.

What the answer must demonstrate: Not under the old approval. Validate the saved quote and exact proposal before admission; changed commercial terms require a new proposal and approval.

04 / APPLIED

The worker crashes after saving a model result. Should it call the model again?

Model answer

It should reuse the saved activity result and resume the next state. If the result was never committed, repeating a bounded read or generation may be acceptable; external purchases require a different recovery contract.

Interviewer follow-up

Why preserve workflow versions?

A new deployment should not silently reinterpret saved state or reorder actions in an existing task.

What the answer must demonstrate: It should reuse the saved activity result and resume the next state.

05 / APPLIED

The vendor accepted an order but its response was lost. What next?

Model answer

Recover the same action identity through the provider's documented idempotent retry or lookup within its supported retention window. Save the confirmed order if found. If it cannot be resolved, report SubmissionUnknown and reconcile; a new key risks another order.

Interviewer follow-up

Does a transactional outbox solve this alone?

No. It reliably dispatches intended work but may dispatch again; the external effect still needs identity and recovery.

What the answer must demonstrate: Recover the same action identity through the provider's documented idempotent retry or lookup within its supported retention window.

06 / FOLLOW-UP

Why is a worker lease insufficient to guarantee one purchase?

Model answer

An expired worker may already have sent the request, and a remote provider can act after local ownership changes. Leases and task versions coordinate local progress; a stable external action key handles duplicate submission where the provider supports it.

Interviewer follow-up

What if the provider supports neither idempotency nor lookup?

Do not claim safe automatic recovery of an uncertain action; keep it unresolved for controlled reconciliation.

What the answer must demonstrate: An expired worker may already have sent the request, and a remote provider can act after local ownership changes.

07 / APPLIED

Can cancel always promise that no order was created?

Model answer

Only before submission has been admitted and sent. Afterward the action may already exist remotely. Resolve that action and use the vendor's cancellation or compensation process under a tracked identity. The UI must distinguish these states.

Interviewer follow-up

Can changing the proposal cancel the old one implicitly?

No. Track any admitted action separately and resolve it; new proposal state does not erase an external request.

What the answer must demonstrate: Only before submission has been admitted and sent.

08 / FOLLOW-UP

A retrieved vendor document tells the model to send credentials elsewhere. What stops it?

Model answer

Retrieved text is untrusted data. Tool gateways allow only validated operations, enforce current permissions and keep secrets in trusted integrations. The model cannot authorize a destination or grant itself a credential.

Interviewer follow-up

What operational signal most deserves attention?

Unresolved external submissions and approval mismatches deserve direct inspection even when overall completion rates look healthy.

What the answer must demonstrate: Retrieved text is untrusted data. Tool gateways allow only validated operations, enforce current permissions and keep secrets in trusted integrations.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design an AI-assisted purchasing workflow that compares approved vendors, waits for human approval and safely handles a lost order response.

• Agree the numbered functional requirements and non-functional targets, including the model's role, exact approval, response time, durability and external uncertainty.

• Draw the one-worker saved-state baseline.

• Separate waiting tasks from active concurrency.

• Model exact proposals and authenticated approvals.

• Trace an accepted purchase with a lost reply.

• Validate task control, approval, submission, cancellation, recovery, latency and budgets against the numbered requirements; state unresolved provider and retention limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

The vendor creates O902 but its reply is lost. What may the replacement worker do?

Recover the saved action using the same provider-supported key or a result lookup. If the provider cannot establish the outcome, keep it unknown for reconciliation rather than send a new purchase.

Lost purchase reply -> recover the same action.

Why not use a fresh key after a purchase reply is lost?

The first purchase may already exist. Recover its original action through the provider's supported retry or lookup; a fresh key can create another order.

Unknown is a state

Summary and interview notes

Save progress so another worker can resume. Require approval for the exact purchase. If the vendor's reply is lost, recover the original action through its supported retry or lookup; otherwise report the outcome as unknown.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Saved activity results prevent unnecessary re-execution.

• Approval binds an exact proposal.

• Waiting tasks do not block workers.

• Remote uncertainty needs a visible recovery state.

Interview tips

• Use one lost-order-response story to defend the architecture.

• Never use exactly-once as a replacement for the external provider contract.

Important qualifications

• General autonomous planning and cross-system compensation protocols are optional extensions.

Explore the advanced version

Worker fencing across independent authorities: Useful for implementing concurrent recovery beyond the local state-version explanation.

Budget reservation under parallel branches: A stronger parallel-action budget requires coordinated reservation and release.

Compensation across multiple business systems: Reversing several completed actions needs explicit business-specific semantics.

Workflow-engine replay compatibility: Engine-specific history and code-version rules matter during production migration.

Technical references

Scaling Managed Agents
April 2026 engineering account separating session history, orchestration, and execution environments.
https://www.anthropic.com/engineering/managed-agents

Building effective agents
Primary engineering discussion of fixed workflows, model-directed agents, and when added complexity is justified.
https://www.anthropic.com/engineering/building-effective-agents

Temporal workflow versioning
Concrete documentation of evolving durable workflows without breaking replay.
https://docs.temporal.io/develop/go/workflows/versioning

OWASP prompt injection
Defines indirect instructions in untrusted sources and layered capability controls.
https://genai.owasp.org/llmrisk/llm01-prompt-injection/

Temporal Activity definition
Recorded Activity results support replay; retried execution still requires external idempotency.
https://docs.temporal.io/activity-definition

EXTENDED INTERVIEWS / 61

Design a recommendation platform

Interview version / 45-minute scope · Read the advanced version online

Return a useful, permitted set of content by narrowing candidates, ranking a bounded set and learning from correctly interpreted feedback.

candidate retrieval • ranking • features • cold start • experiments

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Build a working recommendation baseline before adding learned ranking.
- Explain candidate retrieval, ranking, eligibility and feedback as distinct stages.
- Size online work and defend model quality, cold starts and safe fallback.

Useful foundations: Keyword search and vector retrieval; Caching: cache hits, misses, write policies and invalidation; Message queues, event logs, delivery guarantees, and backpressure; Design a feature-flag and configuration platform; Authentication, authorization, and tenant isolation

8 interview questions with model answers and answered follow-ups.

01 / Define usefulness before choosing a model

A recommendation service selects a small set of items from a much larger catalog. For this interview, it returns twenty videos with display metadata. Video storage and playback are separate services. The objective is useful viewing and satisfaction, subject to safety, diversity and latency requirements; maximizing clicks alone can reward misleading thumbnails or repetitive content.

Ask what user outcome defines a useful recommendation, which eligibility rules are mandatory, and whether anonymous or opted-out viewers must still receive results. The worked design serves contextual recommendations to those viewers and treats safety and access as hard constraints.

Use viewer U7 opening the home page. The catalog contains ten million videos, but the response needs only twenty. U7 has recently watched cooking lessons and already completed item I12. The service must find plausible candidates, remove unavailable or inappropriate items, rank the remainder and return a varied set. Feedback later describes what U7 actually saw and watched.

The complete flow is request context -> candidate retrieval -> eligibility checks -> ranking -> diversity rules -> response -> feedback. Retrieval narrows the search space; ranking compares the selected candidates in more detail. These are different jobs. Begin with regional popularity so the service works before personalization, embeddings or a trained model exist. Learned components should improve a measured baseline rather than become unexplained prerequisites.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Serve a recommendation page.** Return up to twenty permitted videos with display metadata for authenticated or anonymous viewers. If fewer eligible items exist, return fewer rather than violate a content rule.
2. **Respect viewer context.** Apply language and region constraints, completed-item filtering and explicit dismissals; support cursor-based continuation bound to the viewer/session and feed context.
3. **Support personalization choices.** Use permitted history for personalized retrieval/ranking and offer contextual popularity after opt-out or for a cold-start viewer.
4. **Capture useful feedback.** Record actual visibility, clicks and watch activity with response and event identities. These observations support quality measurement and later ranking changes; video storage and playback are separate services.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Plan for a ten-million-item catalog, 5,000 peak recommendation requests/s and 1,000/s on average. Bound the candidates scored for each page rather than examining the full catalog.
2. **Latency and availability.** Target response p95 below 200 ms and 99.9% availability with the chosen candidate count and feature access pattern. Degraded personalization may fall back to eligible contextual results within that budget.
3. **Content eligibility.** Check the current policy available at the defined serving boundary. A high score never overrides a hard rule; if eligibility cannot be established, omit the item or fail appropriately. Later removal cannot recall an already delivered response, so playback needs its own current checks.
4. **Recommendation quality.** Evaluate useful watching and long-term satisfaction alongside clicks, abandonment, repetition and safety violations. Define experiment metrics and guardrails before a rollout: higher clicks with worse completion or more complaints may be a regression.
5. **Consent and privacy.** Opt-out disables history-based retrieval/ranking and invalidates personalized continuation state. Limit personal-history retention and specify how deletion reaches derived features, including its propagation delay; do not let an old cached page silently continue withdrawn personalization.
6. **Trustworthy observations.** Separate returned items from actual impressions, validate feedback and count a retried event once within the supported replay horizon. Feedback delay may make features older; it must not be hidden as current complete data.

04 / Serve a useful popularity list end to end

Maintain a catalog containing item ID, region availability, language, publication status, creator and basic popularity. A scheduled job computes popular items per region and language using recent verified activity. The serving API retrieves the top two hundred for U7's context, checks current eligibility and removes completed or explicitly dismissed items.

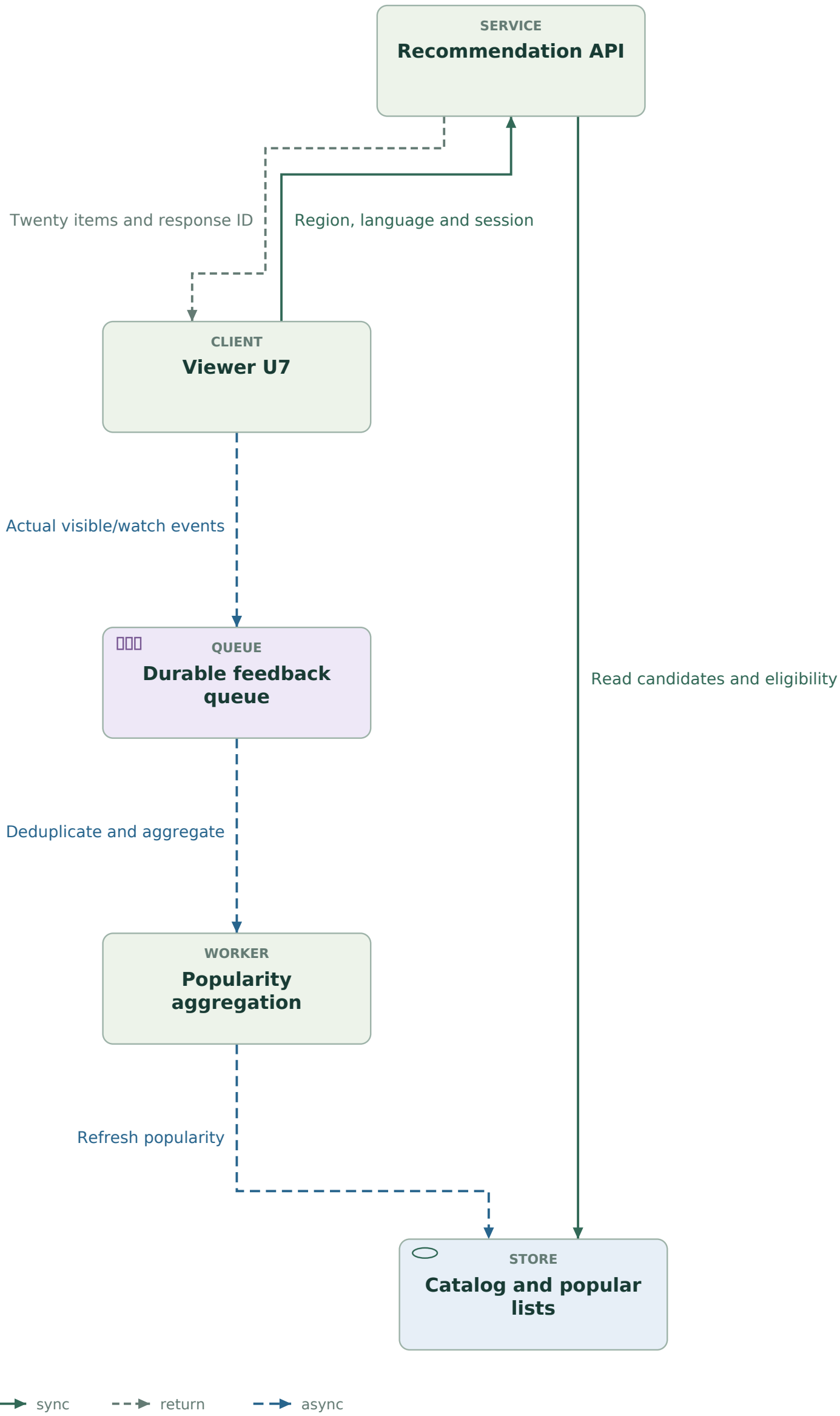
Sort the remaining candidates by the baseline score, then select twenty while limiting repeated creators. Return their IDs, display metadata and a response ID. Persist or otherwise durably capture enough response context to interpret subsequent feedback: which items were returned, their positions and the ranking version. The UI reports actual visibility separately from the server's decision to return an item.

The feedback endpoint accepts a stable event ID and verifies the viewer/session and response context. A durable queue retains events for aggregation. Retried copies of an event must not become several views or watch sessions.

This baseline needs an API, catalog, popularity job and feedback pipeline. It already handles cold-start users and can remain the fallback later. Its weakness is relevance: two people with different interests in the same region see similar candidates. That observed limitation, rather than fashion, motivates personalization.

A complete popularity recommendation flow

The first useful product includes response identity and feedback.



05 / Bound online work before adding model complexity

At five thousand peak requests/s, scoring every one of ten million items would require fifty billion item scores/s. Even a 50-microsecond score would consume roughly 2.5 million CPU-seconds each second. This arithmetic explains why candidate retrieval is necessary, not merely an optional optimization.

If retrieval narrows to two hundred candidates per request, the peak is one million scores/s. At the same illustrative cost, that is fifty fully busy CPU cores; at fifty-percent utilization, roughly one hundred before redundancy. Feature lookup, filtering and serialization still consume budget. Benchmark the whole path rather than treating this multiplication as a deployment guarantee.

Ten million 128-dimensional float 32 vectors contain about 5.12 GB of raw values. A searchable index needs additional memory for its data structures, metadata and replicas. An embedding is a learned numeric representation that places related items near one another; raw vector storage is not the total cost of searching them.

At one thousand average requests/s and twenty returned items, the service returns 1.728 billion item positions/day. If every position produced a 300-byte event, that is about 518 GB/day before replication. Actual visible impressions differ, so use this as a workload estimate, not a claim that every returned item was seen.

06 / Preserve response and event identity

Recommendation request

```
GET /recommendations
```

Request information	Purpose
Authenticated context or anonymous session	Identify the intended viewer context.
Region and language	Apply the requested content constraints.
Page size	Bound the number of returned recommendations.
Optional cursor	Continue the intended session's filtered feed state.

Recommendation response

Returned information	Purpose
Response ID	Identify the served result for later feedback.
Item IDs and positions	Identify what was returned and where it appeared in the result.
Ranking version	Identify the policy that produced the result.
Continuation token	Bind the intended session, filters and feed state.

A continuation token must not let one user adopt another user's personalized page.

Feedback event

```
POST /feedback
```

Event field	Meaning
Event ID	Stable identity of this observation.
Response ID and item	The served result and item the observation concerns.
Event type	Visibility, click and completed watch are different observations.
Client event time	When the client observed the event; the service records receive time separately.
Relevant measurements	For example, watch duration when applicable.

Validate feasible durations and ordering without assuming every disconnected client uploads immediately.

Catalog and feature records

Record	Meaning
Catalog	Items and their eligibility.
User features	Permitted history summaries, such as recent topic interests.
Item features	Quality, freshness and topic.
Feature definition	Units, defaults and update age.

These definitions keep the ranker from mistaking milliseconds for seconds or missing data for a measured zero.

Keep model version and compatible feature definitions in a deployment bundle. The bundle is a named combination checked before rollout; naming it alone does not prove compatibility. Feedback names the served version so offline analysis can explain which policy produced an outcome.

07 / Add personalized sources without losing the fallback

A regional popularity list can miss niche cooking videos that match U7's interests. Add several bounded candidate sources: recent videos from followed creators, matching topics, similar items and regional popularity. Each source returns a limited set. Merge duplicate item IDs, check basic eligibility and cap the combined pool before expensive feature enrichment.

Similarity retrieval can use an approximate nearest-neighbor index over item embeddings. Approximate means it trades exhaustive comparison for faster search and may miss some mathematically nearest items. The goal is a useful candidate pool, not a proof that a vector neighbor is the best video. Evaluate retrieval separately from the final ranker.

For example, gather at most one thousand candidates, then retain two hundred for richer scoring using a cheap preliminary score and source quotas. The exact limits are tunable budgets. A source that returns nothing should not stall the entire page; popularity remains available.

New users rely on declared interests and context. New items need metadata-based retrieval or a controlled exploration allocation because they lack watch history. Popularity-only feedback can otherwise keep them invisible forever. Exploration accepts some uncertainty to collect evidence, subject to the same safety and eligibility rules as ordinary recommendations.

08 / Rank a bounded set and apply product constraints

Fetch the two hundred candidates' features in batches, not one network round trip per item. A simple explainable score can start with:

```
score = 0.60  x  interest + 0.25  x  quality + 0.15  x  freshness
```

Each input is normalized to the intended zero-to-one scale. These weights are illustrative product choices, not universal constants.

Candidate example

Item	Score	Eligibility and selection
I11	`0.60 x 0.9 + 0.25 x 0.8 + 0.15 x 0.6 = 0.83`	A candidate for selection.
I12	0.825	U7 already completed it, so filtering removes it regardless of score.
I13	0.48	May still be selected if it is the next useful, allowed option.

A hard content rule is not just a small negative weight.

A trained ranker can replace the hand-set formula after offline evaluation and controlled online testing. It predicts an explicitly defined target from the same documented features. Missing features use trained or specified defaults; incompatible features trigger a fallback rather than arbitrary interpretation.

Finally apply creator caps and diversity rules to the ranked list. This may lower the raw predicted score while improving the overall experience. Select the page under those rules, even when it differs from the twenty highest scores.



INTERVIEW CRITICAL

Eligibility is not a preference weight

Remove forbidden, unavailable or otherwise disallowed items according to the serving policy. A high predicted engagement score cannot override that requirement.

09 / Keep training away from the request deadline

Scale the serving API horizontally and cache reusable item metadata and popularity lists. Personalized feature access uses bounded timeouts and privacy-aware keys. The online path retrieves candidates, batch-loads features, scores a bounded set, checks eligibility and returns the response. It does not train a model while U7 waits.

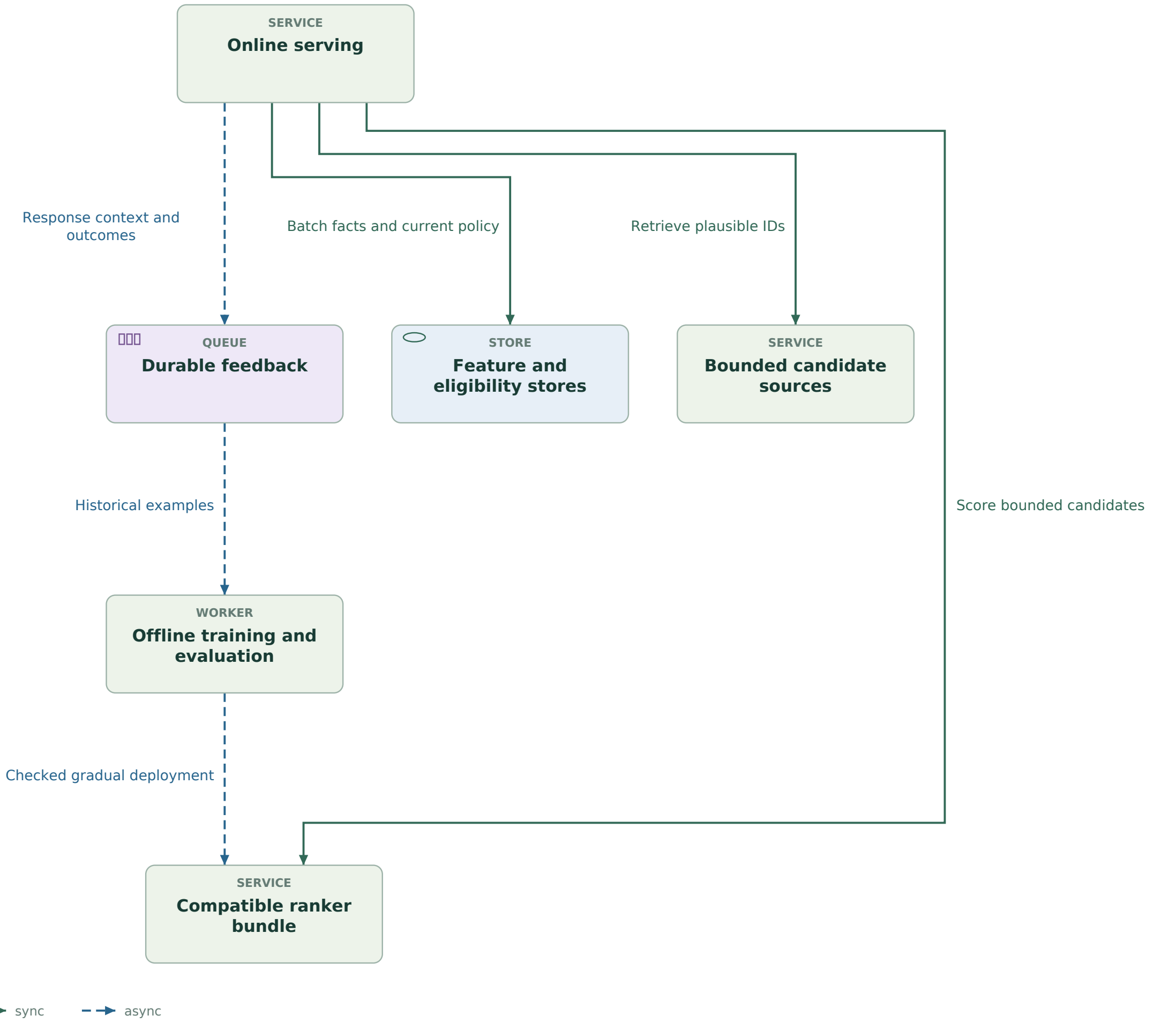
A separate pipeline consumes feedback, deduplicates stable event identities and updates aggregates. Scheduled training joins examples with feature values appropriate to the event's historical context. Using information that became available only afterward leaks the future into evaluation and can make an ineffective model appear excellent offline.

Deploy a checked model/feature/index combination gradually. Canary traffic and an easy switch to the popularity baseline limit the impact of a bad release. An item index and model may have different update cadences, but their representation and schema compatibility must be explicit.

Keep queue lag and feature age visible. Durable events may arrive late, so freshness and completeness are different properties. If one retrieval source or feature service times out, use a documented simpler path within the response budget. The fallback still applies current eligibility checks; degraded relevance does not authorize unsafe content.

Bound the online path; learn asynchronously

Training and deployment improve the serving bundle without occupying the request deadline.



10 / Interpret observations before learning from them

Returning I11 at position seven does not prove U7 saw it. The application may display only the first screen, the request may be abandoned or the item may be hidden. Record assignment, actual visibility, click and watch as distinct event types. This gives training and experiment analysis a chance to distinguish opportunity from outcome.

A retried visibility event reuses its original event ID. The consumer's deduplication and aggregate update must be coupled, for example in one transactional sink, so a crash does not count the same observation twice. Retain deduplication state for the supported replay horizon; a key forgotten too early cannot protect a later retry.

An absent click is not automatically a negative preference when visibility is unknown. Likewise, a ten-second watch means different things for a twelve-second clip and a two-hour lecture. Define target labels with product context rather than training directly on whatever telemetry happens to be easiest to collect.

Use stable experiment assignment and record the policy actually served. Compare satisfaction, safety and latency guardrails in addition to the target metric. Position bias and exploration make causal conclusions harder; detailed counterfactual methods belong to advanced analysis, not an unsupported claim that raw clicks reveal pure preference.



INTERVIEW CRITICAL

Returned, visible and watched are different events

The learning pipeline needs to know whether the viewer had an opportunity to respond. Treating every returned item as seen corrupts labels and experiment analysis.

11 / Recover serving and test the learning loop

Serving failure choices

Failure	Behavior
Personalized retrieval fails	Return eligible contextual popularity.
Rich features are missing	Use a tested simpler score.
Current eligibility cannot be established	Omit the candidate or use a verified eligible pool.
Feedback pipeline is delayed	Serving may use older allowed features while exposing their age to operations.

Trace U7's page through request, response ID, visible impression and watch event. Then repeat the feedback event, delay it, remove I11 before a later request and disable personalization. Verify one counted event, documented late-data behavior, no newly served removed item under the policy boundary and a contextual response after opt-out.

Measure candidate recall on judged examples, ranking quality, response latency, feature age, queue lag, duplicate rate, creator concentration, cold-start coverage and outcome guardrails. A good offline ranking metric does not by itself prove user benefit; validate with a controlled rollout.

Protect feedback APIs from fabricated events and limit retained personal history. Group monitoring metrics by bounded categories rather than creating a new metric series for every user. The next investment should follow evidence: poor retrieval needs better candidates, slow feature reads need serving work, and misleading labels need measurement repair rather than a larger model.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 3	Bounded retrieval, current eligibility checks and diversity selection construct the page.	Remove a high-scoring item, mark I12 completed and provide fewer than twenty eligible candidates. Return only allowed items; check playback separately.
FR 3; NFR 2, 5	Contextual popularity and consent-bound continuation provide a private fallback.	Opt out while holding a personalized cursor and fail a candidate source. Require contextual allowed results, invalidated personalized state and documented deletion handling.
NFR 1, 2	Limited candidate sets, batch feature reads, replicas and bounded timeouts control online work.	Load-test 5,000 requests/s, feature failures and hot contexts; measure p95 and availability. The 100-core arithmetic excludes additional serving work and is not a benchmark.
FR 4; NFR 6	Response context and transactional event deduplication preserve observation meaning.	Return an item without displaying it, then replay or delay a real impression. Do not invent visibility or count the retry twice.
NFR 4	Judged retrieval evaluation and a controlled rollout compare against the popularity baseline.	Measure usefulness, complaints, diversity and latency together. Improved offline scores or clicks alone do not prove user benefit.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Returned is not seen; observation drives learning.

Prompt	Recall the mechanism and boundary
Why start with popularity?	It provides measurable results without user history and remains a fallback
Why retrieve before ranking?	Scoring all ten million items in detail for every request costs too much
What does retrieval produce?	A limited set of plausible candidates that still need ranking
What do features need?	Known units, missing-value defaults, update age and compatibility with the ranker
Why filter separately?	A high score cannot make a forbidden item eligible
Why rerank after scoring?	Limit repeated creators and vary the page's content
Is a returned item an impression?	Only actual visibility under the agreed measurement rule counts
What makes replay safe?	Save the processed event identity together with its aggregate update
What prevents future leakage?	Use only features available when the recommendation was made; later outcomes can supply labels
What survives a personalized outage?	Return eligible contextual results within the response deadline

Close with: "I first serve a complete popularity feed and measure it. Candidate retrieval makes richer ranking affordable, while eligibility and diversity remain explicit product rules. A separate feedback and training pipeline improves relevance, and the original baseline remains an operational fallback."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why is regional popularity a valid starting design?

Model answer

It provides useful context-sensitive results without historical personalization or a learned model. The complete flow still filters eligibility, limits repeated creators, records response identity and collects actual feedback. It becomes both a comparison baseline and an outage fallback.

Interviewer follow-up

What limitation motivates personalization?

People in the same region can have different interests, so popularity may miss relevant niche content.

What the answer must demonstrate: It provides useful context-sensitive results without historical personalization or a learned model.

02 / APPLIED

Why not score all ten million videos on every request?

Model answer

At five thousand requests/s that is fifty billion scores/s. At the illustrative 50 microseconds each, it needs about 2.5 million busy cores before other work. Retrieval narrows the pool so richer ranking is affordable.

Interviewer follow-up

What does two hundred candidates change?

It reduces peak scoring to one million scores/s, roughly fifty busy cores at that assumed cost, before headroom and feature work.

What the answer must demonstrate: At five thousand requests/s that is fifty billion scores/s.

03 / FOUNDATION

What is the difference between candidate retrieval and ranking?

Model answer

Retrieval finds a limited set likely to contain useful items using sources such as followed creators, topics, similarity and popularity. Ranking spends more information and computation comparing that set. A perfect ranker cannot select a relevant item retrieval never supplied.

Interviewer follow-up

How do new items enter?

Use metadata-based candidates or bounded exploration rather than requiring watch history they do not yet have.

What the answer must demonstrate: Retrieval finds a limited set likely to contain useful items using sources such as followed creators, topics, similarity and popularity.

04 / APPLIED

I12 has a high score but U7 completed it. What happens?

Model answer

Under this product contract it is filtered out. Eligibility and completion rules are explicit constraints, not tiny penalties a sufficiently high engagement score can overcome. Diversity rules then shape the eligible ranked page.

Interviewer follow-up

Why can the final list differ from pure score order?

Creator caps and diversity can improve the overall experience while lowering the sum of individual predicted scores.

What the answer must demonstrate: Under this product contract it is filtered out.

05 / APPLIED

Why is returning an item not enough to label it as ignored?

Model answer

The viewer may never have seen it. Record actual visibility separately from the returned list and use labels appropriate to the observation. Unknown exposure is not the same as a negative preference.

Interviewer follow-up

How do duplicated events avoid inflating popularity?

Reuse stable event IDs and couple deduplication with aggregate updates for the declared replay horizon.

What the answer must demonstrate: The viewer may never have seen it.

06 / FOLLOW-UP

What is future leakage in this design?

Model answer

Training or evaluation uses facts that were not available at the historical decision, such as later popularity or a future watch. Offline metrics then overstate what serving could have achieved. Use historically appropriate feature values and availability.

Interviewer follow-up

Does good offline ranking prove product improvement?

No. Use a controlled online rollout with satisfaction, safety and latency guardrails.

What the answer must demonstrate: Training or evaluation uses facts that were not available at the historical decision, such as later popularity or a future watch.

07 / APPLIED

The personalized feature store times out. What should the API return?

Model answer

Use a tested simpler score or contextual popularity within the latency budget, while retaining eligibility checks. Expose feature age and fallback rate to operations. A relevance outage should not become a reason to serve forbidden content.

Interviewer follow-up

What if eligibility cannot be checked?

Omit uncertain candidates or use a pool whose eligibility can be established under the declared policy.

What the answer must demonstrate: Use a tested simpler score or contextual popularity within the latency budget, while retaining eligibility checks.

08 / FOLLOW-UP

What changes when U7 disables personalization?

Model answer

Stop using personal history for candidate retrieval and ranking, invalidate personalized continuation state and serve contextual results. Handle stored and derived history under the documented deletion policy and propagation limits.

Interviewer follow-up

Why not put raw user IDs into every metric label?

It creates sensitive, high-cardinality monitoring data; retain controlled investigation paths and aggregate operational metrics.

What the answer must demonstrate: Stop using personal history for candidate retrieval and ranking, invalidate personalized continuation state and serve contextual results.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a video recommendation homepage with twenty results, ten million catalog items, cold starts and a 200 ms latency goal.

• Agree the numbered functional requirements and non-functional targets: page behavior, eligibility, consent, load, latency, availability and usefulness.

• Draw the popularity baseline including feedback.

• Calculate why exhaustive ranking is infeasible.

• Add bounded retrieval and batch feature access.

• Walk through ranking, filtering and diversity.

• Validate recommendations, context, opt-out, feedback, quality, latency and fallback against the numbered requirements; name remaining evaluation and privacy-policy choices.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

I11 is returned at position seven, but U7 closes the page before seeing it. Is that an impression?

No. Record actual visibility separately from returned items. Retrieve a bounded candidate set, filter and rank it, then learn asynchronously from what the viewer actually experienced.

Returned is not seen; observation drives learning.

Does including an item in the response count as an impression?

No. Count the agreed event showing that the item was actually visible to the user.

Returned is not seen

Summary and interview notes

Find and rank a limited set of permitted candidates. Record what users actually see and do, then use those observations in a separate process to improve future recommendations.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Popularity supplies a complete baseline.

• Retrieval controls online work.

• Eligibility and diversity constrain ranking.

• Actual visibility gives feedback its meaning.

Interview tips

• Use a concrete candidate that is high scoring but ineligible.

• Identify whether a problem lies in retrieval, ranking or measurement before proposing a larger model.

Important qualifications

• Counterfactual evaluation and advanced exploration require additional statistical assumptions.

Explore the advanced version

Counterfactual evaluation and exploration bias: Useful when making causal claims from logged policies rather than a simple controlled experiment.

Fine-grained model-feature-index compatibility: Expand rollout checks when embeddings or feature semantics change independently.

Historical feature availability and corrected labels: A production training system needs detailed point-in-time joins and late-data policy.

Immediate eligibility and consent release boundaries: Stronger cross-service timing guarantees require additional authority coordination.

Technical references

Google recommendation overview
Explains recommendation stages and retrieval/ranking distinctions.
https://developers.google.com/machine-learning/recommendation/overview/types

Deep Neural Networks for YouTube Recommendations
Historical primary research example of candidate generation followed by ranking, not a claim about current deployment.
https://research.google/pubs/deep-neural-networks-for-youtube-recommendations/

Google Rules of Machine Learning
Engineering guidance on feature semantics, served-data logging, and training-serving skew.
https://developers.google.com/machine-learning/guides/rules-of-ml

Microsoft trustworthy experimentation: post-experiment stage
Triggered analysis requires correct counterfactual logging and validation; exposure alone is not an unbiased comparison.
https://www.microsoft.com/en-us/research/?p=806938

EXTENDED INTERVIEWS / 62

Design a live video-conferencing service

Interview version / 45-minute scope · Read the advanced version online

Connect a small interactive call, then scale it with selective forwarding while keeping media quality, membership and recovery explicit.

WebRTC • ICE • STUN • TURN • SFU • congestion control

Figures are illustrative design assumptions.

YOU WILL LEARN TO

- Explain signaling, network traversal and media transport in one complete call.
- Compare a peer mesh with a selective forwarding server using bandwidth estimates.
- Defend permission changes, congestion handling and reconnect behavior.

Useful foundations: HTTP APIs and request lifecycle; Real-time communication: polling, long polling, SSE, and WebSocket; Load balancing: definition, algorithms and failover; Production readiness: SLI, SLO, observability, and recovery

8 interview questions with model answers and answered follow-ups.

01 / Separate joining a room from hearing another person

A conferencing service carries interactive audio and video among two to twenty-five participants. Room creation, invitations and participant lists are control operations. Media packets carry the actual conversation. A connected signaling socket or a green room badge does not prove that anyone can hear or see another participant.

Ask how many participants must interact, whether reduced video is acceptable under congestion, and whether the media server may access media. This design supports rooms of two to twenty-five, prioritizes audio and trusts the media server; recording and server-excluding encryption are separate extensions.

Use six people joining a weekly meeting. Each browser authenticates, obtains room permission, negotiates supported media settings and establishes a network path. It then sends encrypted audio/video and receives the tracks it is allowed to hear and see. A track is one audio or video stream, such as a microphone, camera or shared screen.

The complete flow is authorize room join -> exchange connection information -> establish transport -> publish and subscribe to permitted tracks -> adapt quality during the call. Begin with two browsers to make that flow concrete. Add a media forwarding server when the bandwidth cost of many direct peer connections becomes unacceptable. Recording, transcription and very large broadcasts are optional extensions, not prerequisites for a working interactive meeting.

02 / Functional requirements

Agree on what the service must do before choosing its components.

1. **Create and join rooms.** Create rooms and admit authenticated or invited participants. Invitations are scoped credentials, not access to every room.
2. **Control live media.** Publish and receive permitted microphone, camera and screen-sharing tracks, with microphone/camera controls and a current participant list.
3. **Enforce room permissions.** Let authorized hosts change roles or remove participants. Enforce decisions on actual publication and subscription, not only the visible participant list.
4. **Reconnect a participant.** Rejoin after a network change or media-server failure while preserving authorized room identity and checking current permission. Recording, transcription and very large broadcasts are outside the main scope.

03 / Non-functional requirements

Use these hypothetical requirements for the worked interview. Confirm the assumptions with the interviewer; the numerical targets require testing and are not measured results. For latency, p95 and p99 mean that 95% and 99% of measured delays, respectively, are no greater than the reported value.

1. **Workload.** Support two to twenty-five participants per room. Use 10,000 concurrent six-person rooms for the worked capacity estimate and test the more expensive 25-person case separately. Count actual media subscriptions and qualities, not just connections.
2. **Join and conversational latency.** Budget roughly 150-250 ms one-way media delay on supported network paths. Target p95 below three seconds from an authorized join request to first usable remote audio when another participant is publishing; exclude time the user spends granting device permission. These targets do not cover every geographic path or unusable client network.
3. **Usable degradation and recovery.** Prioritize audio while reducing video under congestion. Measure audio gaps, video freezes, join failures and reconnect time separately. Brief interruption is allowed during a network change or media-server failure; reconnection cannot recover packets already lost or restore an old encryption session automatically.
4. **Permission freshness.** Target removal within five seconds on healthy connected control paths, reconcile membership every fifteen seconds and stop affected sessions after sixty seconds without successful authority refresh. Reject stale invitations/reconnects after removal. This is an outage policy, not an instantaneous or globally strict revocation deadline.
5. **Transport security.** Encrypt media on each network leg and authorize track ownership and subscriptions. The initial design trusts the media server to process media; transport encryption is not end-to-end encryption that excludes that server. Keep invitation/session grants finite and network-relay access authenticated.

04 / Connect two browsers before adding a media cluster

One application server authenticates two participants and checks the room membership. A signaling connection carries messages between them: an offer describes supported codecs and proposed media, and an answer selects compatible settings. A codec is the method used to encode and decode audio or video. Signaling coordinates the call; it is not the channel that carries all media frames.

Finding a usable network path

Mechanism	Role
ICE (Interactive Connectivity Establishment)	Tests candidate network paths between the browsers.
STUN service	Helps a browser discover the public address seen outside its local network.
TURN server	Relays packets when direct connectivity is blocked.

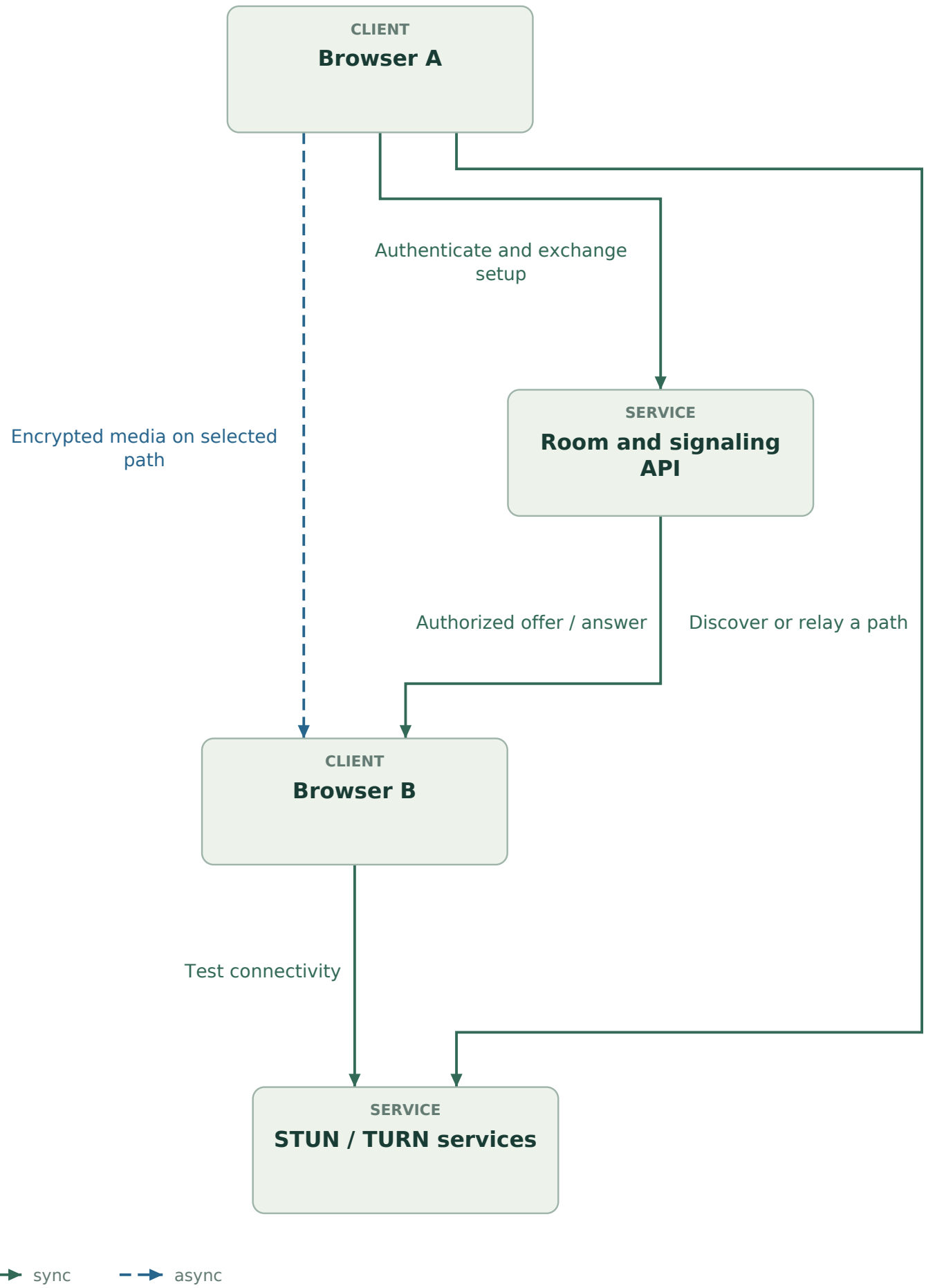
STUN does not itself provide that relay service.

Once a usable path and encrypted transport are established, each browser sends its microphone and camera media to the other. The receiver buffers a small amount to smooth uneven arrival, decodes the packets and plays them. Report success from actual media progress, such as first received audio or video, rather than only signaling completion.

If one browser changes networks, it can renegotiate the connection and run connectivity checks again. The room session identifies the participant independently of that temporary transport. This baseline is complete for two people and supplies a reference for diagnosing later forwarding-server failures.

A complete two-browser call

Signaling coordinates the setup; media uses a tested direct or relayed path.



05 / Show why a peer mesh stops scaling

In a mesh, every participant sends a copy to each other participant. With six people each sending a 1.5 Mbps video, each uploads 5 x 1.5 = 7.5 Mbps. Across the room there are thirty directed video copies, or 45 Mbps before audio and protocol overhead. A weak home uplink can fail well before the application server becomes busy.

A selective forwarding unit, or SFU, receives each publisher's stream and forwards selected streams to subscribers. With one 1.5 Mbps upload per person, room ingress is 9 Mbps. If everyone still receives everyone at that quality, server egress remains 45 Mbps. The SFU moves replication away from each browser; it does not eliminate output bandwidth.

At ten thousand such concurrent rooms, 45 Mbps per room means 450 Gbps of media-server egress, about 202.5 TB in one hour. This dominates ordinary room metadata. Twenty-five participants all receiving twenty-four 1.5 Mbps videos would consume 900 Mbps per room.

Quality selection changes this cost. One active speaker at 1.5 Mbps plus four small videos at 0.15 Mbps uses 2.1 Mbps per receiver, or 12.6 Mbps for six receivers. Count actual subscriptions and layers, not just room count, when planning capacity.



INTERVIEW CRITICAL

An SFU moves replication; it does not erase it

Each publisher can upload once, but server output grows with receiver subscriptions and selected quality. Size egress separately from client upload and room metadata.

06 / Give rooms, sessions and tracks clear ownership

Create a room

```
POST /rooms
```

Create the room with an owner and policy.

Join operation

1. **Authenticate the participant.** Establish the caller's identity.
2. **Authorize this room.** Check membership or the scoped invitation.
3. **Return connection information.** Supply a room session and signaling/media connection information.

The session identifies this join; it is not a permanent substitute for current room permission.

Signaling message fields

Field	What it identifies
Room	The meeting affected by this control operation.
Participant session	The authenticated join making the request.
Track	The microphone, camera or screen stream involved.
Operation	The requested control action, such as publication or subscription.

The service validates who may publish a camera, share a screen or subscribe to another track.

Room and track records

Record	Information retained
Room state	Participants and roles.
Track metadata	Publisher, media kind and availability.

An invitation or client-provided role cannot override the server's authoritative membership decision.

Use ordered room updates or a version number so a late "participant joined" message does not undo a newer removal in the UI or media controller. On reconnect, fetch current room state instead of rebuilding membership solely from an incomplete stream of old notifications.

Media packets have their own sequence and timing information. They do not each need a database transaction. The room database stores who may participate. The SFU uses that state to decide which live packets to forward, without querying the database for every audio packet.

07 / Make the SFU the final small-room topology

Assign each room to one appropriately located SFU. Participants negotiate their transport with it instead of maintaining a separate media connection to every other participant. The SFU receives tracks and forwards only the subscriptions selected for each receiver. It generally forwards encoded media rather than decoding and mixing every picture into one composite video.

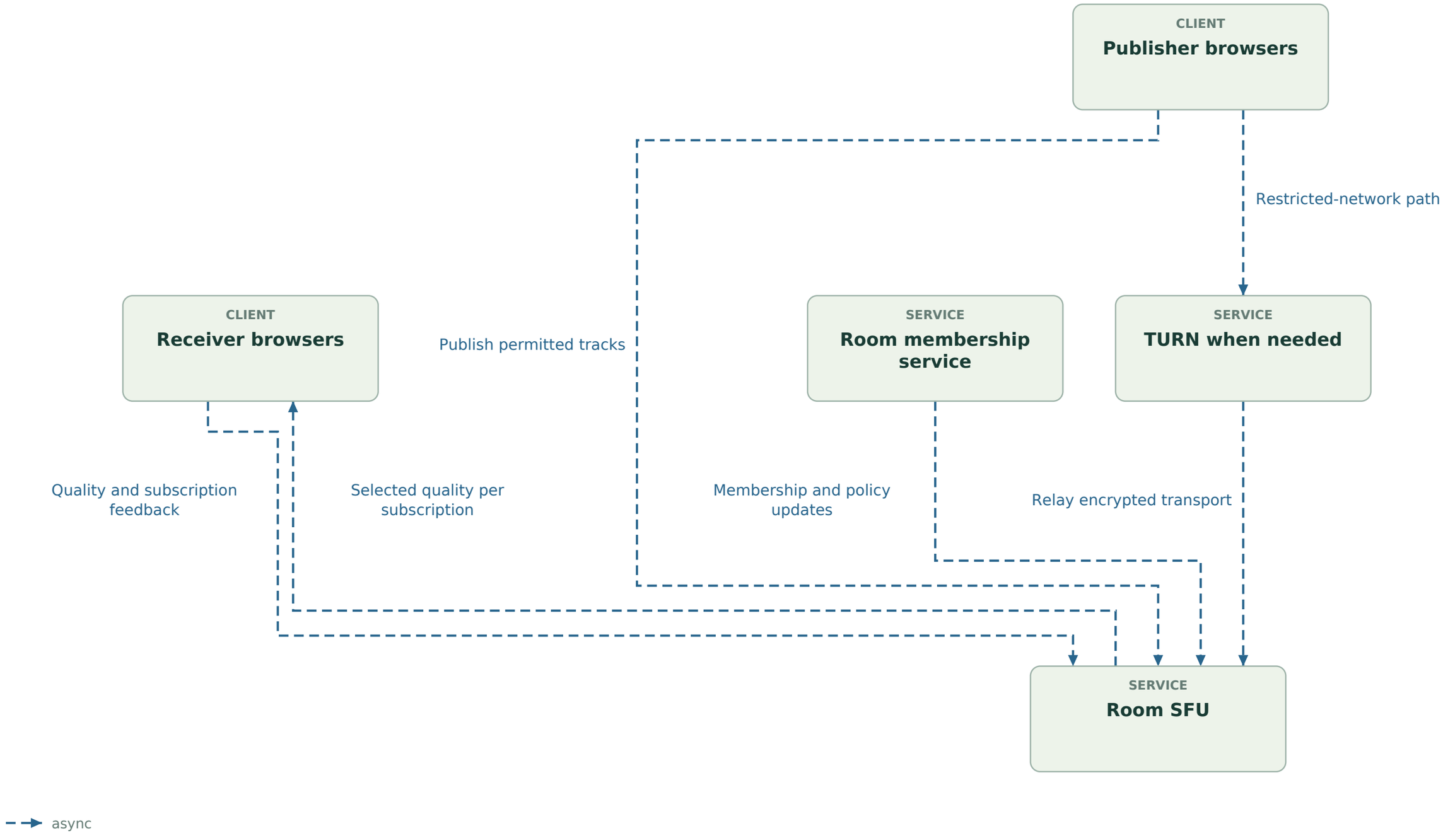
The subscription controller prioritizes audio, the active speaker, pinned video and screen sharing according to the product layout. A mobile participant displaying four small tiles should not receive twenty-four full-resolution videos. The server checks room permission before allowing publication or forwarding a subscription.

One room on one SFU keeps the main design understandable and avoids inter-server media coordination. Place the room near its participants when possible, with capacity-aware allocation. A globally distributed room may still have unavoidable long paths; geography cannot be repaired by merely adding more application replicas.

Scale different rooms across many SFUs. Admission considers CPU, packets per second, network egress and active subscriptions, not only connected socket count. A server can exhaust its network budget while CPU remains moderate. Multi-region room cascades and very large calls are later topology extensions with additional bandwidth and failure behavior.

One SFU forwards selected tracks for a room

The room service authorizes; the SFU enforces live subscriptions.



08 / Adapt media instead of accumulating old frames

Networks vary during a call. The receiver reports loss and timing information, and the sender/forwarder uses congestion feedback to reduce offered bitrate when the path cannot sustain it. Sending more packets into an overloaded link increases delay and can damage audio as well as video.

Simulcast lets a publisher send several independently encoded qualities of the same camera. For example, 1.5, 0.4 and 0.15 Mbps layers total 2.05 Mbps of publisher upload. The SFU can select a suitable layer for each receiver without producing every quality itself. This raises publisher work and ingress compared with one stream, but can greatly reduce unnecessary receiver traffic.

A jitter buffer holds a short window of arriving packets so uneven network delivery becomes smoother playback. A larger buffer tolerates more variation but adds conversational delay. Missing audio and video are handled with deadline-aware concealment, recovery or frame dropping; retransmitting an obsolete frame indefinitely is not useful live communication.

Prioritize audio under congestion and reduce video resolution, frame rate or subscriptions. Request a fresh keyframe when decoding cannot recover from missing reference frames. Screen sharing may need a different policy because readable text and a stable image can matter more than high motion frame rate. Measure perceived quality rather than maximizing raw bitrate.

09 / Enforce removal where media is actually forwarded

Removing participant P6

1. **Authorize the host.** The room service checks the host's removal permission.
2. **Save the decision.** Persist the membership change and send it to the SFU.
3. **Stop actual media access.** The SFU stops P6's publication and subscriptions and closes the associated session.

Updating only the participant list in the browser would leave media access unchanged.

Control notifications can be delayed or lost. Target removal within five seconds on healthy connected control paths. Independently reconcile membership every fifteen seconds, and stop affected sessions after sixty seconds without a successful authority refresh. Scoped session grants also have finite validity. These rules limit stale access during an outage, but do not prove immediate removal or a worst-case deadline across every failure.

Reconnect checks current membership and creates or refreshes a permitted session. A removed P6 cannot use cached signaling state to recreate subscriptions. Track ownership is tied to the authenticated session, preventing another client from publishing under a guessed participant identifier.

This design accepts a documented propagation interval between the durable removal decision and its enforcement by a healthy SFU. A strict worst-case revocation deadline needs a stronger timing and lease protocol and explicit failure assumptions. Keep that stronger guarantee in advanced discussion rather than quietly claiming it from an asynchronous notification.

INTERVIEW CRITICAL

Removal must stop media, not just update a roster

Persist the membership change, enforce it at the SFU and check current permission on reconnect. State propagation and authority-outage limits honestly.

10 / Reconnect a call without confusing transport and identity

When P2 switches from Wi-Fi to cellular, the previous network path may stop working. The client detects lost transport progress, contacts signaling and performs an ICE restart with current credentials and room state. Media can pause while the new path is negotiated. The participant need not appear as an unrelated new person, but old transport details are not assumed valid.

If an SFU fails, room allocation chooses a healthy replacement and clients reconnect their media to it. The new SFU loads current authorization and participants publish fresh transports and subscriptions. The service cannot copy a dead server's in-flight packets into a seamless stream after the fact. Expose the interruption and optimize reconnection time.

If signaling briefly fails while media remains healthy, an existing call may continue under its current allowed session policy. New joins and permission updates are impaired, so the control failure still matters. If permission freshness expires, enforce the chosen fallback rather than keeping the session indefinitely.

TURN capacity is another recovery dependency. A call that always works on an office network can fail for users behind restrictive networks if relay allocation is exhausted. Monitor relay usage and test those paths deliberately; successful direct connections alone do not establish general reachability.

11 / Measure the conversation and test difficult networks

Track time to first audio/video, join success, round-trip time, packet loss, jitter, audio gaps, video freeze time, selected layers and reconnect duration. Monitor SFU ingress, egress, packets per second and CPU by region. Aggregate room health can hide one receiver whose connection is unusable, so retain privacy-aware per-session diagnostics with limited retention.

Test high loss, fluctuating bandwidth, restrictive network traversal, a slow receiver, Wi-Fi-to-cellular changes and a full SFU failure. Verify that audio survives reasonable video degradation and that subscription changes actually reduce output traffic. Load tests should reproduce realistic packet rates and layer switching, not only open thousands of idle sockets.

Test removal followed by a stale reconnect, invitation expiry, unauthorized screen sharing and permission authority outages. The expected behavior must match the stated grace and propagation policy. Restrict TURN use with authenticated short-lived credentials so the service does not become a public relay for unrelated traffic.

Recording is a separate authorized media subscriber if introduced later. It adds consent, storage, retention, gaps and encryption questions. End-to-end encryption excluding the server changes which processing is possible. Neither feature should be appended as a casual box without revisiting who may access the media and how participants are informed.

12 / Check the design against its requirements

Before closing, check the final design against the agreed requirements. FR means functional requirement and NFR means non-functional requirement; the numbers refer to the lists above. These are proposed validation checks, not test results.

Requirement	Mechanism in the final design	Validation and remaining limit
FR 1, 2; NFR 2, 5	Authenticated signaling, path negotiation and encrypted media transport establish an actual call.	Test direct and relay paths, expired invites and unauthorized sharing. Measure first usable remote audio against the three-second p95 goal; a signaling connection is insufficient.
NFR 1, 3	One SFU per room, bounded subscriptions and quality adaptation control upload/egress cost.	Load-test realistic six- and 25-person rooms, layer changes and constrained receivers. Verify audio continuity and actual packet/egress capacity; idle sockets do not model calls.
FR 3; NFR 4	Durable membership, SFU enforcement and periodic reconciliation constrain media access.	Remove P6, lose a control notification and attempt a stale reconnect. Measure healthy removal and the stated 15/60-second fallback without claiming instant recall.
FR 4; NFR 3	Replacement allocation and fresh transport negotiation recover authorized room participation.	Switch Wi-Fi to cellular and crash the SFU. Observe interruption and reconnection; do not claim the failed server's lost packets survived.
NFR 2, 5	Quality metrics and an explicit trusted-server boundary expose network and privacy limits.	Measure one-way delay on supported regional paths and inspect media access. Revisit the architecture before offering server-excluding encryption or recording.

13 / Rapid revision

Rehearse the numbered functional requirements and non-functional targets first. Use this table to recall the mechanisms, then close with the requirements check above.

Remember: Setup succeeds only when usable media arrives.

Prompt	Recall the mechanism and limit
What is signaling?	Control messages agree media settings and connection paths; they do not carry the conversation
What do ICE, STUN and TURN do?	Test candidate paths, discover an external address, and relay when direct paths fail

Prompt	Recall the mechanism and limit
Why does mesh struggle?	Each sender uploads a copy for every other participant
What does an SFU save?	Browsers upload fewer copies; the server still sends a copy for each selected subscription
Why simulcast?	Send several quality versions so the SFU can fit each receiver's bandwidth and layout
Why not buffer everything?	Old frames delay conversation; packets arriving after playback time are no longer useful
Where must removal act?	Stop the participant's actual sending and receiving; check current permission on reconnect
What survives a network change?	Keep room identity; recheck current permission and rebuild the media connection
Is encrypted transport end-to-end?	Not if the trusted SFU can read media between the encrypted connections
What proves the call works?	Usable received media and measured quality, not just a connected signaling socket

Close with: "I first connect two browsers completely, then use one SFU per small room to control upload cost and subscriptions. Congestion handling preserves conversation quality, and room authority governs actual forwarding. Failover reconnects media with a visible interruption; advanced encryption and global room topology are explicit extensions."

Practise the interview questions

Say the answer aloud first. Then read the model answer, try the follow-up, and compare the reasoning. All answers are included in this print edition.

01 / FOUNDATION

Why can signaling succeed while the call has no media?

Model answer

Signaling only exchanges control information. Media still needs compatible settings, a reachable direct or relayed network path and successful encrypted transport. Firewalls or relay exhaustion can block media even when the application socket works.

Interviewer follow-up

What should join success measure?

Time to actual usable received audio or video, alongside the control-plane milestones.

What the answer must demonstrate: Signaling only exchanges control information. Media still needs compatible settings, a reachable direct or relayed network path and successful encrypted transport.

02 / FOUNDATION

What are ICE, STUN and TURN responsible for?

Model answer

ICE gathers and tests candidate paths. STUN helps discover the public address observed outside a local network. TURN relays media when a usable direct path is unavailable. Discovery alone does not supply relay capacity.

Interviewer follow-up

Why test TURN specifically?

A design tested only on friendly direct networks may fail behind restrictive networks or when relay capacity is exhausted.

What the answer must demonstrate: ICE gathers and tests candidate paths. STUN helps discover the public address observed outside a local network.

03 / APPLIED

What changes when six 1.5 Mbps publishers move from mesh to an SFU?

Model answer

In mesh each uploads five copies, or 7.5 Mbps. With one stream to the SFU each uploads 1.5 Mbps and SFU ingress is 9 Mbps. Full-quality forwarding to everyone still produces 45 Mbps of server egress.

Interviewer follow-up

How does subscription selection help?

One 1.5 Mbps speaker plus four 0.15 Mbps tiles uses 2.1 Mbps per receiver, reducing the room's selected output.

What the answer must demonstrate: In mesh each uploads five copies, or 7.5 Mbps.

04 / APPLIED

Why would a publisher deliberately upload several qualities?

Model answer

Simulcast gives the SFU ready-made quality choices for different receivers. It raises publisher encoding work and upload but lets a weak receiver or small tile receive less data without server-side transcoding for every subscription.

Interviewer follow-up

Does more buffering solve congestion?

No. It adds conversational delay; adapt bitrate and drop obsolete video while protecting audio.

What the answer must demonstrate: Simulcast gives the SFU ready-made quality choices for different receivers.

05 / APPLIED

The host removes P6. Which components must react?

Model answer

The room service saves the authorized decision, and the SFU stops P6's publication and subscriptions. Reconnect checks current membership. A browser roster update alone does not remove access to forwarded media.

Interviewer follow-up

Can notification delivery prove instantaneous removal?

No. Target five seconds on healthy paths, reconcile every fifteen seconds, and stop affected sessions after sixty seconds without successful authority refresh. These are a target and outage policy; a proved global worst-case deadline needs stronger timing and authority assumptions.

What the answer must demonstrate: The room service saves the authorized decision, and the SFU stops P6's publication and subscriptions.

06 / APPLIED

What happens after the room's SFU crashes?

Model answer

Clients establish fresh transports to a replacement SFU that loads current room permission and subscriptions. There is an interruption; dead in-flight packets and transport state are not transparently restored.

Interviewer follow-up

What if only signaling disconnects?

Existing media can continue under the current session policy, but joins and membership changes are impaired and permission freshness still matters.

What the answer must demonstrate: Clients establish fresh transports to a replacement SFU that loads current room permission and subscriptions.

07 / FOLLOW-UP

Is a call automatically end-to-end encrypted because transport is encrypted?

Model answer

No. Encrypted browser-to-SFU and SFU-to-browser legs may still let the trusted SFU access media. Encryption that excludes the server changes recording, transcription and moderation capabilities and needs its own key-management design.

Interviewer follow-up

How should recording be introduced?

As an explicitly authorized media subscriber with consent, retention, access and encryption behavior defined.

What the answer must demonstrate: No. Encrypted browser-to-SFU and SFU-to-browser legs may still let the trusted SFU access media.

08 / FOLLOW-UP

Which load test is more useful than opening many signaling sockets?

Model answer

Realistic packet traffic with subscriptions, loss, bitrate adaptation, relay paths and region capacity reveals the media bottlenecks. Measure audio gaps, video freezes, join delay and reconnect time as well as CPU and egress.

Interviewer follow-up

What resource can saturate with moderate CPU?

Network egress or packet-processing capacity can limit an SFU before raw compute utilization looks high.

What the answer must demonstrate: Realistic packet traffic with subscriptions, loss, bitrate adaptation, relay paths and region capacity reveals the media bottlenecks.

Build the answer yourself

BLANK-PAGE EXERCISE / 45 MINUTES

Design a six-to-twenty-five-person video meeting service with screen sharing, participant removal and recovery from network or SFU failure.

• Agree the numbered functional requirements and non-functional targets: room size, media controls, join/delay goals, degradation, removal and encryption scope.

• Define the quality and permission contract.

• Calculate mesh upload and SFU egress.

• Choose one SFU per room and bounded subscriptions.

• Explain network traversal and congestion adaptation.

• Check joining, media, permission enforcement, reconnection, quality and capacity against the numbered requirements; state geographic, revocation and failover limits.

Check the explanation you gave, not whether your drawing looks like the example.

Recall without looking

Cover the answers and explain each choice and its cost from memory. Then check your answer. Revisit missed cards tomorrow.

The signaling socket connects, but P2 hears nothing. Has the call succeeded?

No. Signaling arranges membership and connection setup; media carries the conversation. Check usable received audio/video and the media network path, not just control connectivity.

Setup succeeds only when usable media arrives.

How does an SFU reduce repeated browser uploads?

Each publisher sends its selected quality streams once. The server forwards the appropriate versions to participants allowed to receive them.

Upload once, forward selectively

Summary and interview notes

Check room permission, establish working encrypted audio/video connections and adjust quality to each receiver's network. A successful signaling connection alone does not establish a usable call.

Remember these points

• Agree the numbered functional requirements and non-functional targets before designing components; validate the final design against them.

• Signaling success is not media success.

• SFUs reduce publisher duplication while retaining egress cost.

• Subscription and quality choices control bandwidth.

• Membership must constrain actual forwarding.

Interview tips

• Calculate one six-person room before scaling to thousands.

• Distinguish room identity from replaceable media transport.

Important qualifications

• Large global rooms, server-excluding encryption and recording are separate extensions.

Explore the advanced version

Strict revocation deadlines and session fencing: A hard worst-case removal promise requires explicit timing and authority assumptions.

Cascaded SFUs across regions: Useful when participant geography or room size exceeds the single-SFU contract.

Server-excluding encryption and group keys: Changes which participants or services can decrypt media and how membership affects keys.

Recording storage and retention: Adds authorized capture, gaps, immutable media artifacts and deletion policy.

Scalable video coding: An alternative layering method has codec and client-support tradeoffs beyond the chosen simulcast design.

Technical references

RFC 8825: WebRTC protocol overview
Primary overview separating signaling, real-time transports, media, and security responsibilities.
https://www.rfc-editor.org/rfc/rfc8825.html

RFC 8445: ICE
Defines candidate gathering/checking, selected connectivity, and ICE restart.
https://www.rfc-editor.org/rfc/rfc8445.html

RFC 8656: TURN
Defines relay allocation and its role when direct connectivity is unsuitable.
https://www.rfc-editor.org/rfc/rfc8656.html

RFC 7667: RTP topologies
Primary taxonomy for media topologies, including selective forwarding and mixing; our placement/lease scheme is an application design.
https://www.rfc-editor.org/rfc/rfc7667.html

W3C WebRTC Recommendation
Browser peer-connection, negotiation and media API behavior; room identity and authorization remain application responsibilities.
https://www.w3.org/TR/webrtc/

RFC 8853: Simulcast
Simulcast negotiation and independent encoded alternatives; support must be tested.
https://www.rfc-editor.org/rfc/rfc8853.html

RFC 9605: SFrame
Content encryption for real-time media, distinct from application group-key management.
https://www.rfc-editor.org/rfc/rfc9605.html