Primary-backup Replication

Feb 25, 2021

CPSC 416

How'd we get here?

- Failures & single systems; fault tolerance techniques added redundancy (ECC memory, RAID, etc.)
- Conceptually, ECC & RAID both put a "master" in front of the redundancy to mask it from clients -- ECC handled by memory controller, RAID looks like a very reliable hard drive behind a (special) controller

Simpler examples...

- Replicated web sites
- e.g., Yahoo! or Amazon:
  - DNS-based load balancing (DNS returns multiple IP addresses for each name)
  - Hardware load balancers put multiple machines behind each IP address

Read-only content

- Easy to replicate - just make multiple copies of it.
  - Performance boost 1: Get to use multiple servers to handle the load (scalability!)
  - Perf boost 2: Locality. As with CDNs, can often direct a client to a replica *near* it
  - Availability boost: Can fail-over, e.g., at the DNS level (though slower, because clients cache DNS answers)

But for read-write data...

- Must implement write replication, typically with some degree of consistency

What consistency model?

- Just like in distributed filesystems, must consider consistency model you supply
- R/L example: Google mail (mix of consistency models)
  - *Sending mail* is replicated to ~2 physically separated datacenters (users hate it when they think they sent mail and it got lost); mail will pause while doing this replication.
  - *Marking mail read* is only replicated in the background - you can mark it read, the replication can fail, and you'll have no clue (re-reading a read email once in a while is no big deal)
- Weaker consistency is cheaper if you can get away with it.

Goal

- Provide a service
- Survive the failure of up to f replicas
- Provide identical service as a non-replicated version (except more reliable, and perhaps different performance)

- Also known as the "replicated state machine" (**RSM**) abstraction
  - As with other abstractions (e.g., RPC), there are many ways to achieve/implement a RSM

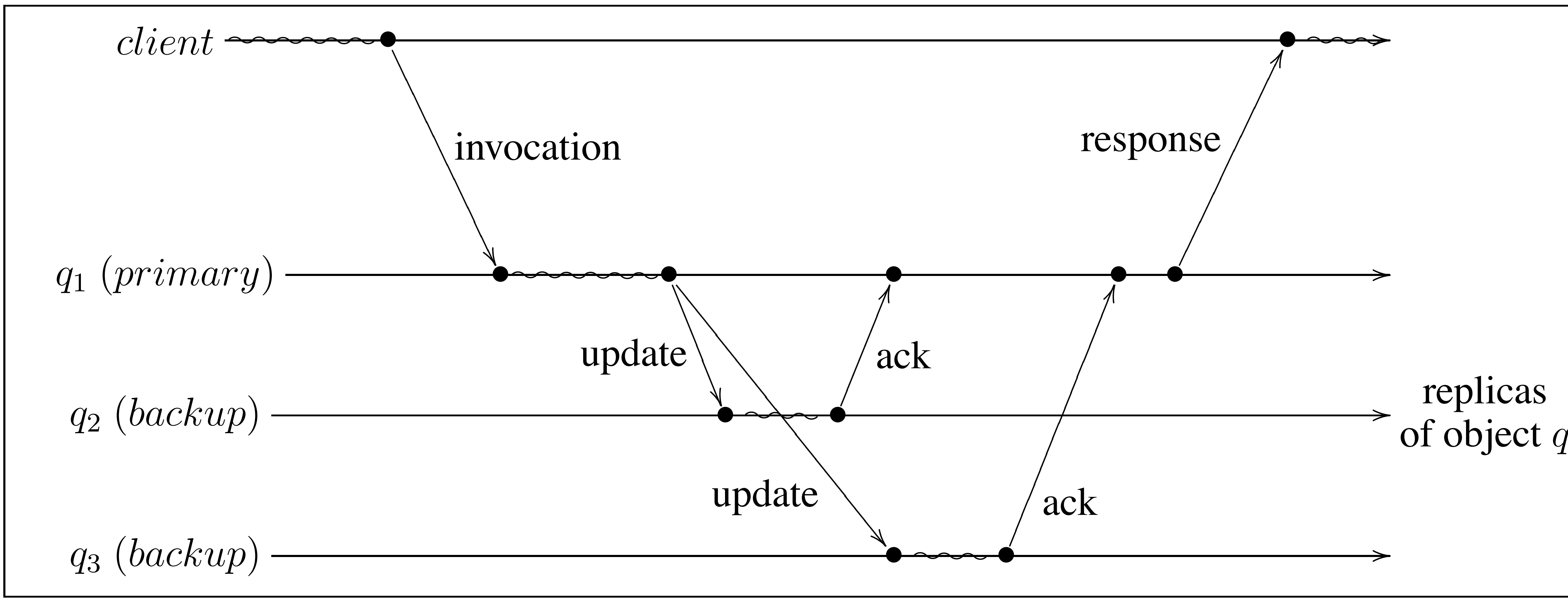
We'll cover

- Primary-backup replication
  - Operations handled by primary, it streams updated state to backup(s)
  - Replicas are "passive"
  - Good: Simple protocol. Tolerates N-1 failures
  - Bad: Clients must participate in recovery.
- Quorum consensus using Paxos or Raft (later in the course)
  - Designed to have fast response time even under failures
  - Replicas are "active" - participate in protocol; there is no master, per se.
  - Good: Clients don't even see the failures. Bad: More complex.

primary-backup

- Clients talk to a primary
- The primary handles requests, atomically and idempotently
- Executes them
- Sends the new state (side effects) to the backups
- Backups reply, “OK”
- Primary ACKs to the client

primary-backup



implementing primary-backup

- Remember logging (if you've taken databases); we'll review next week (transactions)
- Common technique for replication in databases and filesystem-like things: Stream the log to the backup. *They don't have to actually apply the changes before replying, just make the log durable (i.e., on disk).*
- You have to replay the log before you can be online again, but it's pretty cheap.

Optimized primary-backup

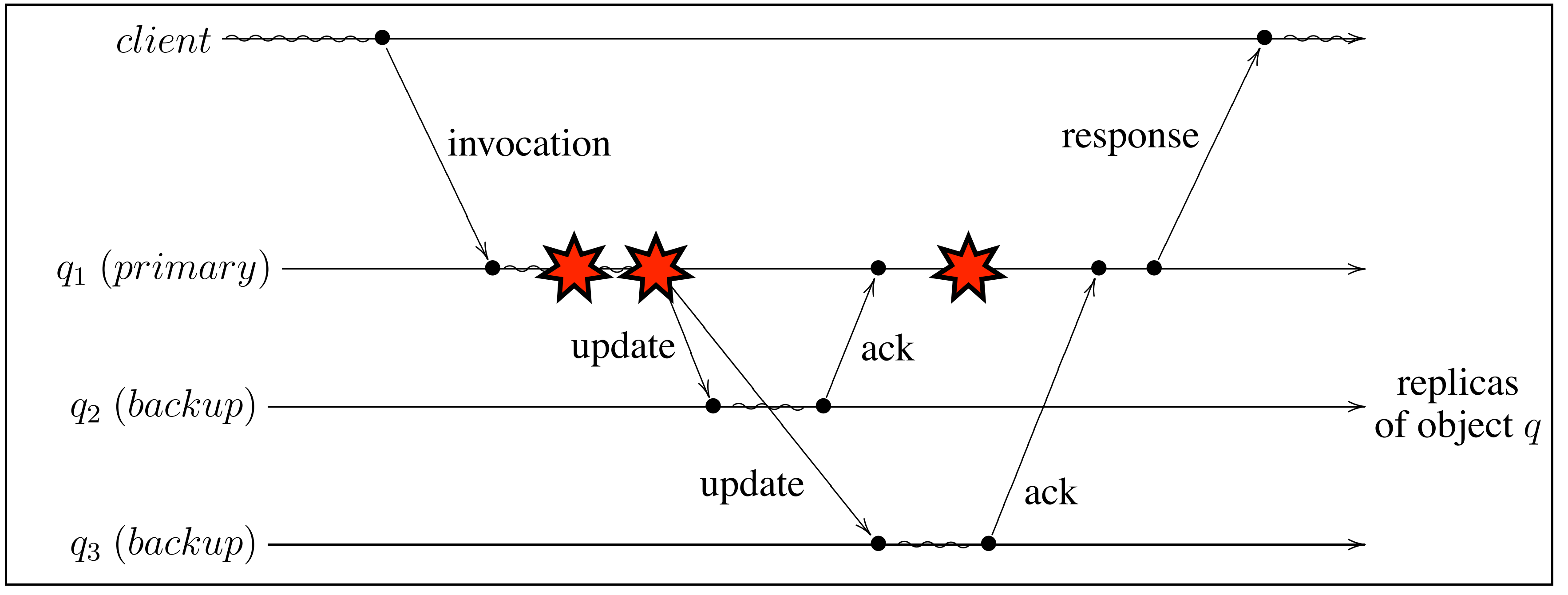
- Note: If you don't care about strong consistency (e.g., the "mail read" flag), you can reply to client *before* reaching agreement with backups (sometimes called "asynchronous replication").
- This looks cool. What's the problem?
- This is OK for some services, not OK for others

Optimized primary-backup

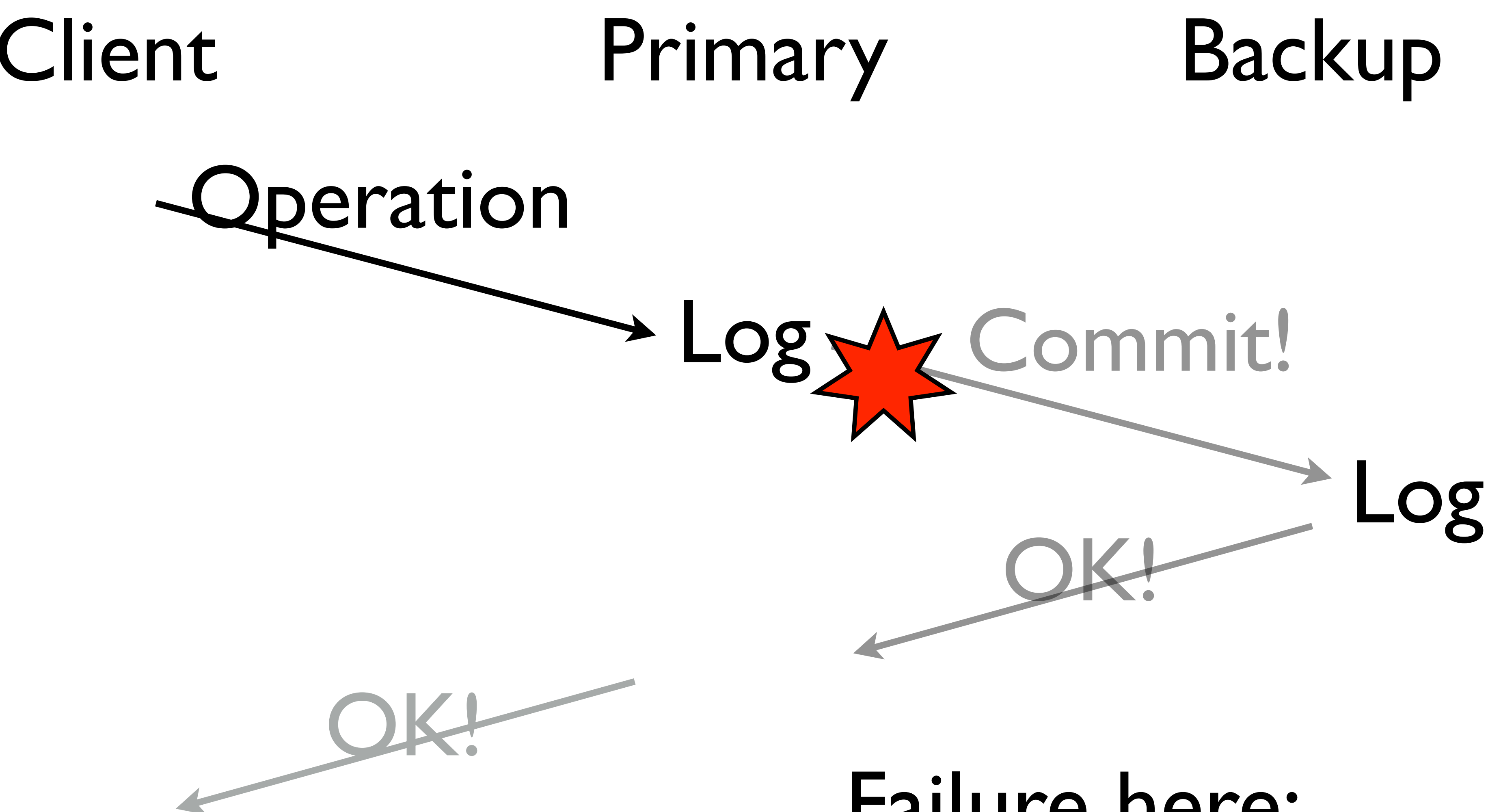
- Note: If you don't care about strong consistency (e.g., the "mail read" flag), you can reply to client *before* reaching agreement with backups (sometimes called "asynchronous replication").
- This looks cool. What's the problem?
  - What do we do if a primary has failed?
  - Can't use a backup immediately since it may be out date
  - So, we wait... how long? Until primary is marked dead.
  - Dependency on the failure detector/timeouts
- This is OK for some services, not OK for others

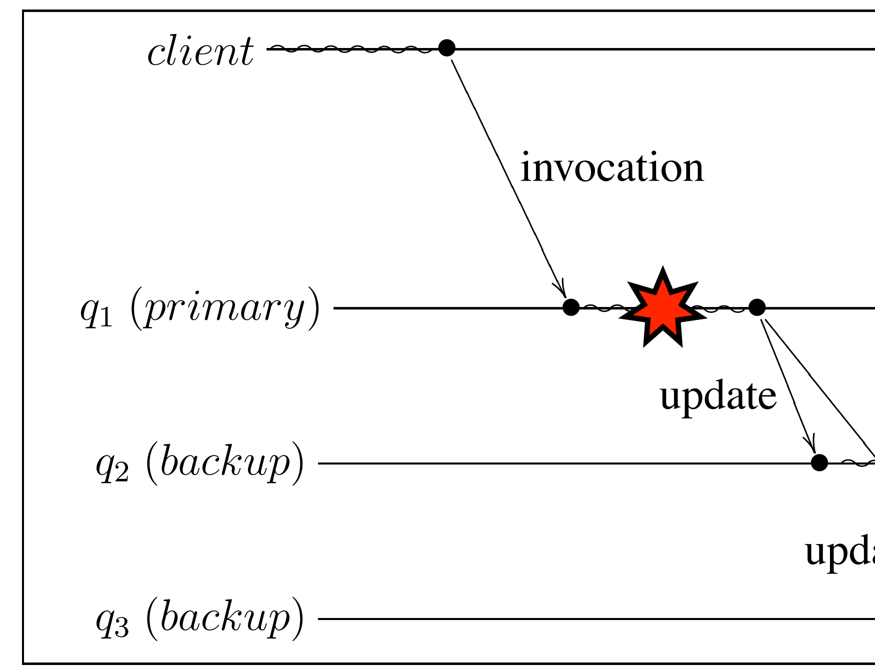
Failures in p-b

- Use timeout-based failure detector for detection
- Backup failures: timeout and remove from set (later add new backups)
- Primary failures: complex because unclear when the primary failed (before/after replicating)
- Handling primary failures requires client participation



p-b: Did it happen?



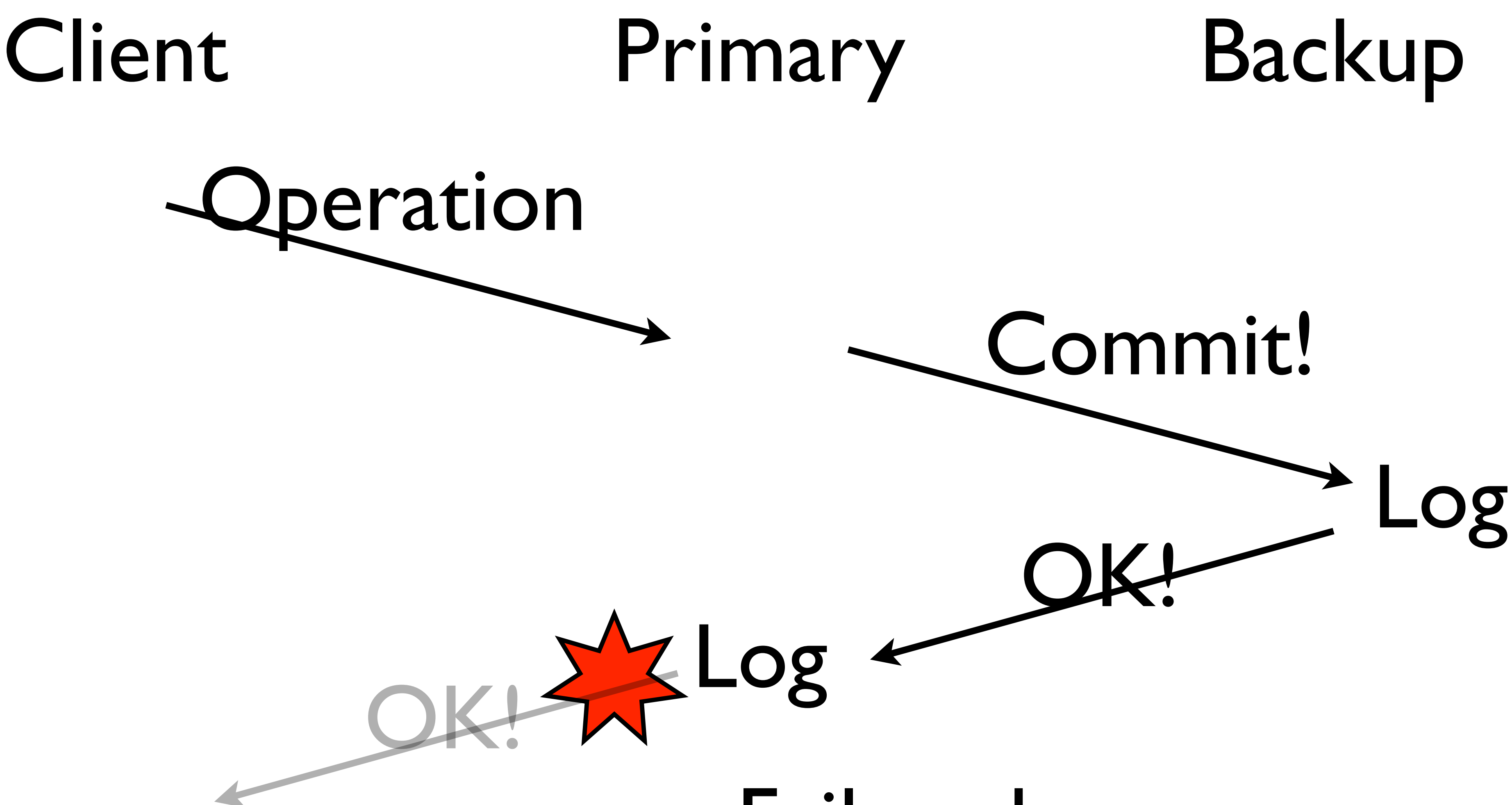


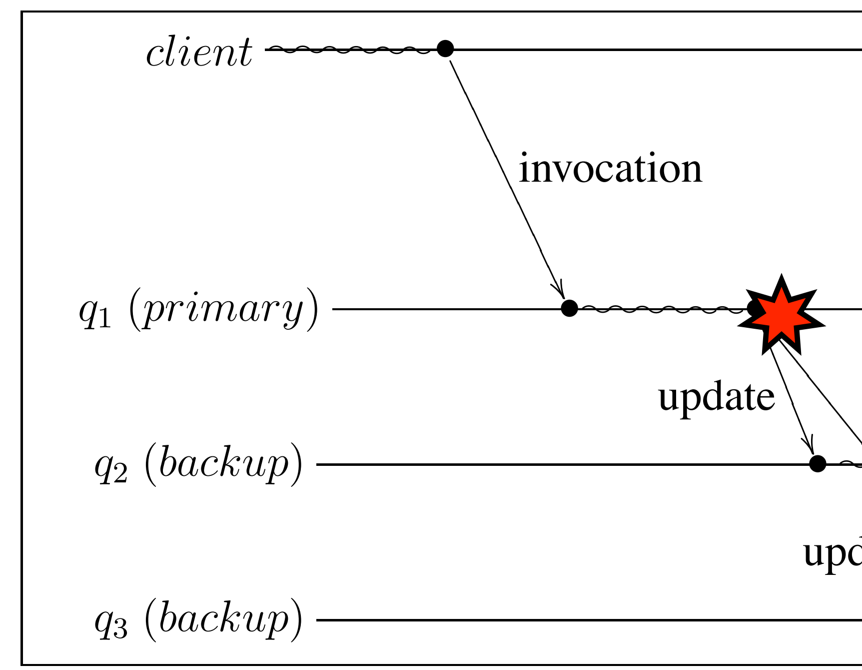
Failure here:

Commit logged only at primary

Primary dies? **Client** must re-send to backup or to newly selected primary (idempotency important)

p-b: Happened twice





Failure here:

Commit logged at backup

Primary dies? **Client** must check with backup

(Seems like at-most-once / at-least-once... :)

Problems with p-b

- Not a great solution if you want very tight response time even when something has failed: Must wait for failure detector
- For that, *quorum* based schemes are used
  - As name implies, different result:
  - To handle f failures, must have $2f + 1$ replicas. Why?

Problems with p-b

- Not a great solution if you want very tight response time even when something has failed: Must wait for failure detector
- For that, *quorum* based schemes are used
  - As name implies, different result:
  - To handle *f* failures, must have 2*f* + 1 replicas. Why? so that a majority (f+1) is still alive after (f) failures

Problems with p-b

- Client must be involved in resubmitting an operation (best case) or helping with recovery (worst case)
- Requires client state (at least operation + id)
- If client helps with recovery, then must be aware of backups (violates RSM abstraction)
- Bringing up a new primary is complicated
  - All clients must sign off on their outstanding ops
  - Vote a new backup to become primary?
  - Download all state to new primary?