Primary-backup replication

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Some slides adapted from 6.824 notes

Fault tolerance via replication

- To tolerate machine failure, one must replicate data on >1 servers.
- Particularly important at scale.
  - Suppose a typical server crashes every month
  - How often some server crashes in a 10,000-server cluster?
    - 30*24*60/10000 = 4.3 minutes

Consistency: Correctness of replication

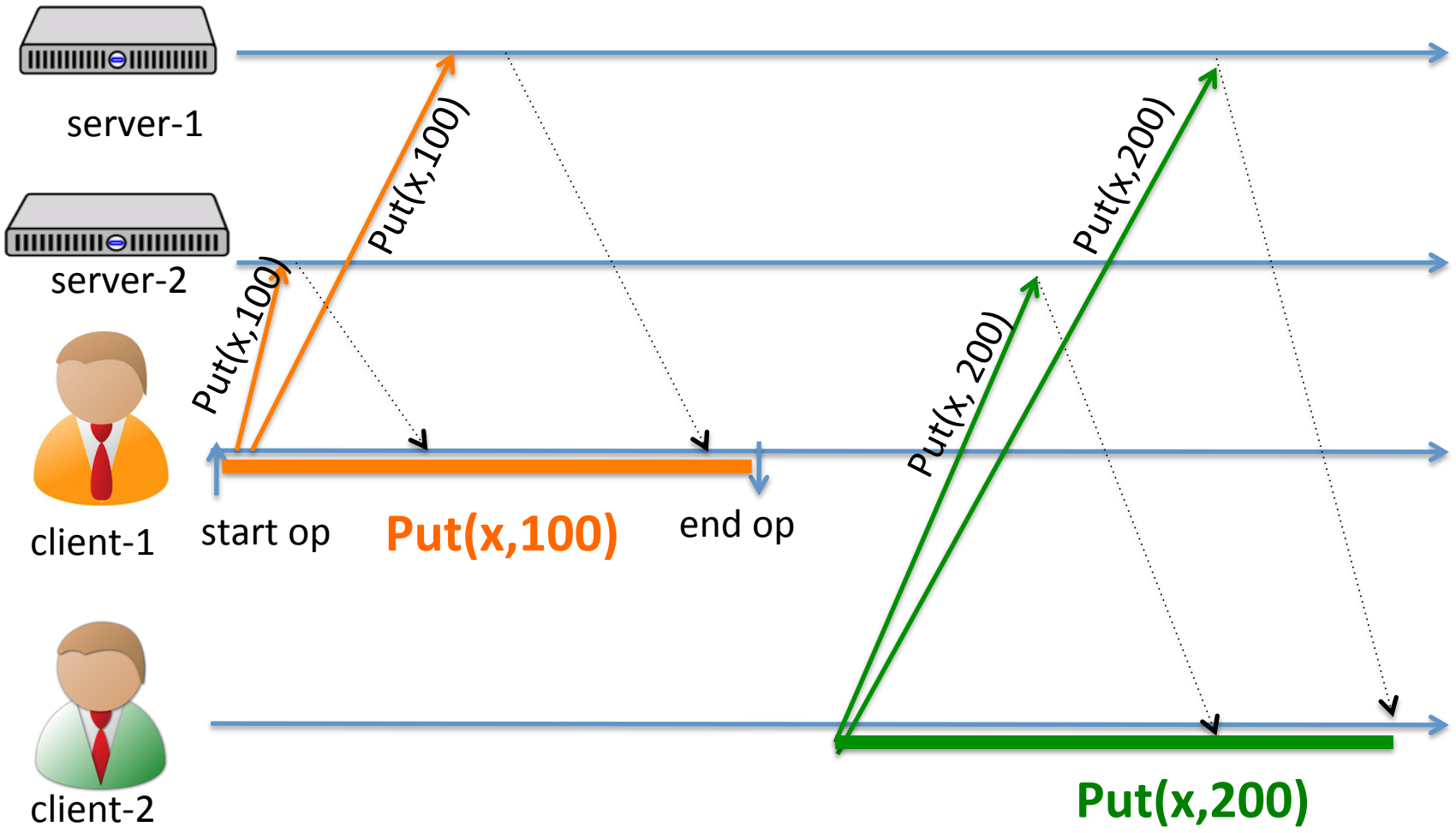
- How to replicate data “correctly”?
- Some informal notion of correctness:
  - copies of the same data should (eventually) be the same
  - replicated system should “behave similarly” to its un-replicated system
  - (we’ll discuss formal correctness notion in Lec 3)

Challenges in achieving correctness

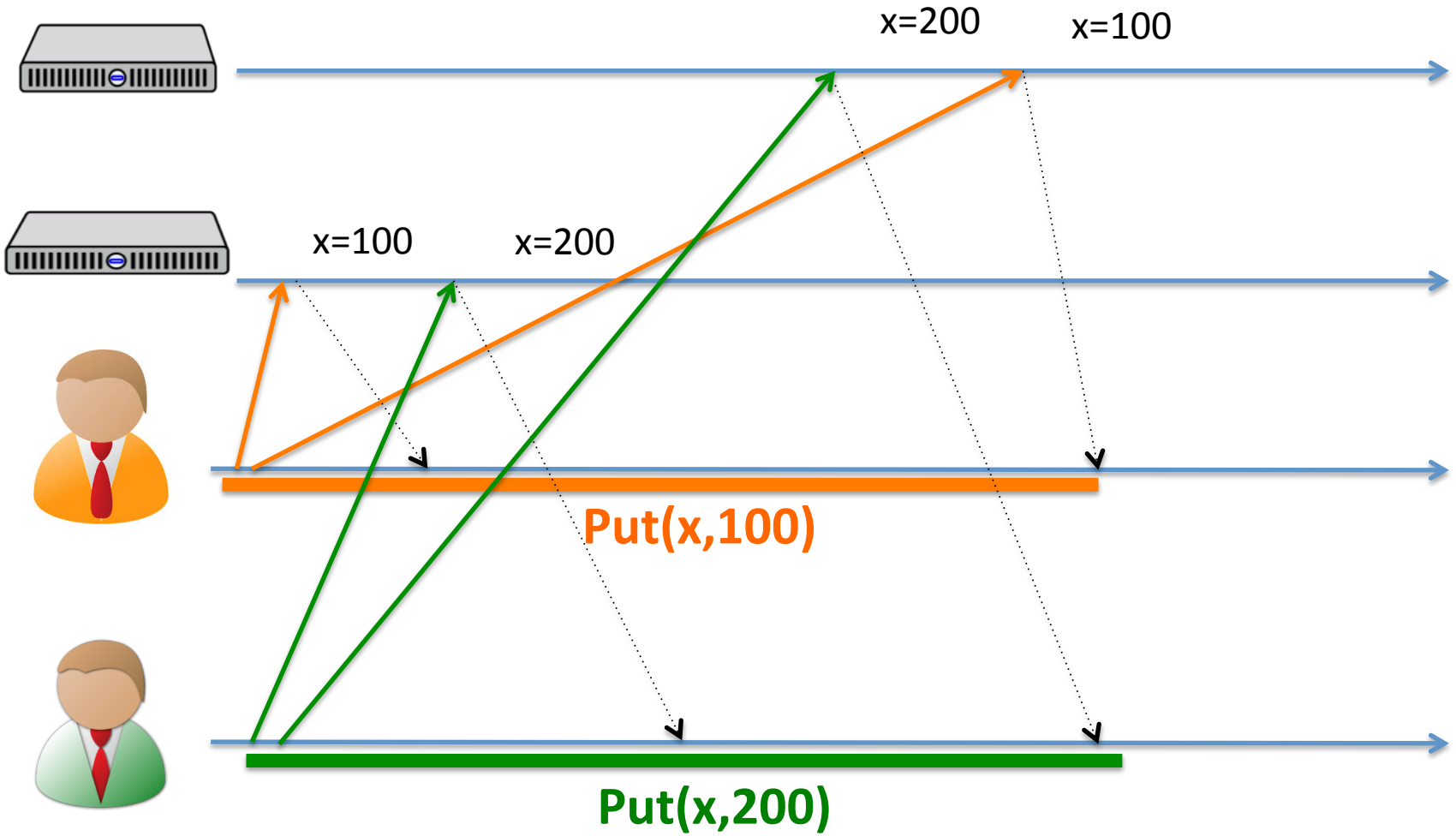
1. Concurrency
2. Machine failure
3. Network failure (e.g. network partition)

- Particularly tricky because
  - one might mistake “slowness” for “failure”
  - one cannot tell 2 from 3.

Replication: a strawman



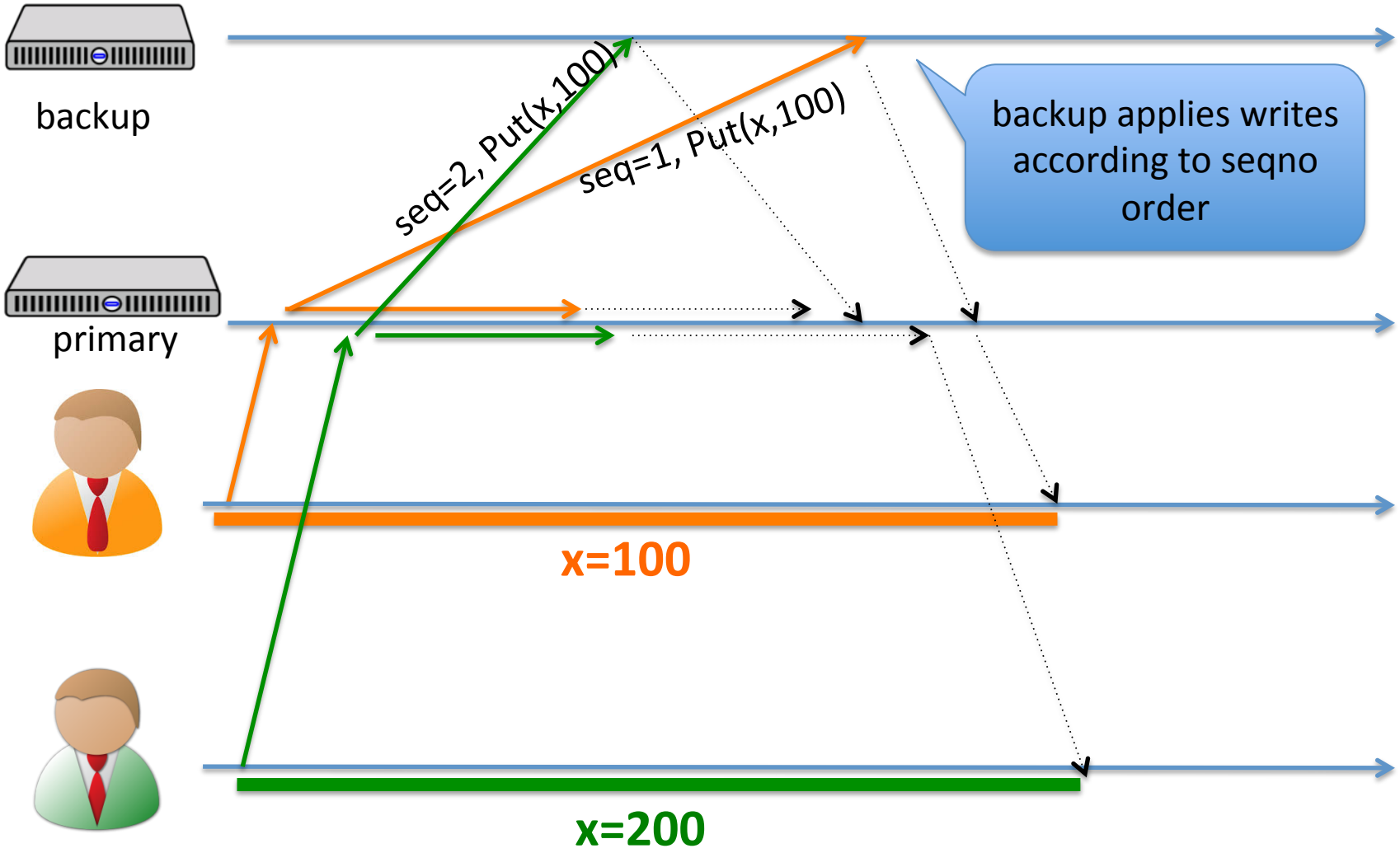
Strawman fails under concurrency



Order updates via primary

- To keep replica in sync, writes must be done in the same order
- Idea: use a designated server (primary) to determine the order of updates, others follow order

Primary determines order of updates



Challenges in handling failure

- What if a backup timed out in acknowledging the replication?
  - Primary re-tries (works only if backup failure is transient)
  - Ignore the fact that a backup might not have processed the op.
    - How many is it safe to ignore?
    - How to make a backup catch up?

Challenges in handling failure

- What if the primary fails? Switch to another primary?
  - Could there be accidentally two “valid” primaries?
  - If an op is done before the switch, how to ensure it’s not “lost” after the switch?
- What to re-integrate a recovered server?

Failure handling: the stone age

- For a long time, people do it manually (with no guaranteed correctness)
  - One primary, one backup. Primary ignores temporary replication failure of a backup.
  - If primary crashes, human operator re-configures the system to use the former backup as new primary
  - some ops done by primary might be “lost” at new primary

Viewstamp replication

- Original paper Oki and Liskov, 1988
- Viewstamp revisited: Liskov and Cowling, 2012
- A landmark work: The first (together with Paxos) to handle failure correctly.

VR overview: state machine replication

- Servers replicate a log of operations (instead of directly modifying state in-place)
  - Efficient for: comparing state among servers, sync-ing out-of-date servers
  - General: A log of operations may be
    - [key=x, data="..."] [key=x, data="..."] ...
    - [create /jinyang/x] [mv /jinyang/x, /jinyang/y]....
    - [update T set grade=10 where uid=123] [insert into T values ...] ...
- Correctness←→ servers execute the same sequence of log
  - Operations must be deterministic

VR overview: primary-backup

- VR assumes a static configuration of servers, e.g. S0, S1, S2
- To handle primary failure, VR moves through a sequence of "views"
  - 0, 1, 2, 3, ...
  - Deterministic mapping from view-number to primary: primary = view-number % total_servers
  - e.g., 0→S0, 1→S1, 2→S2, 3→S0, ...

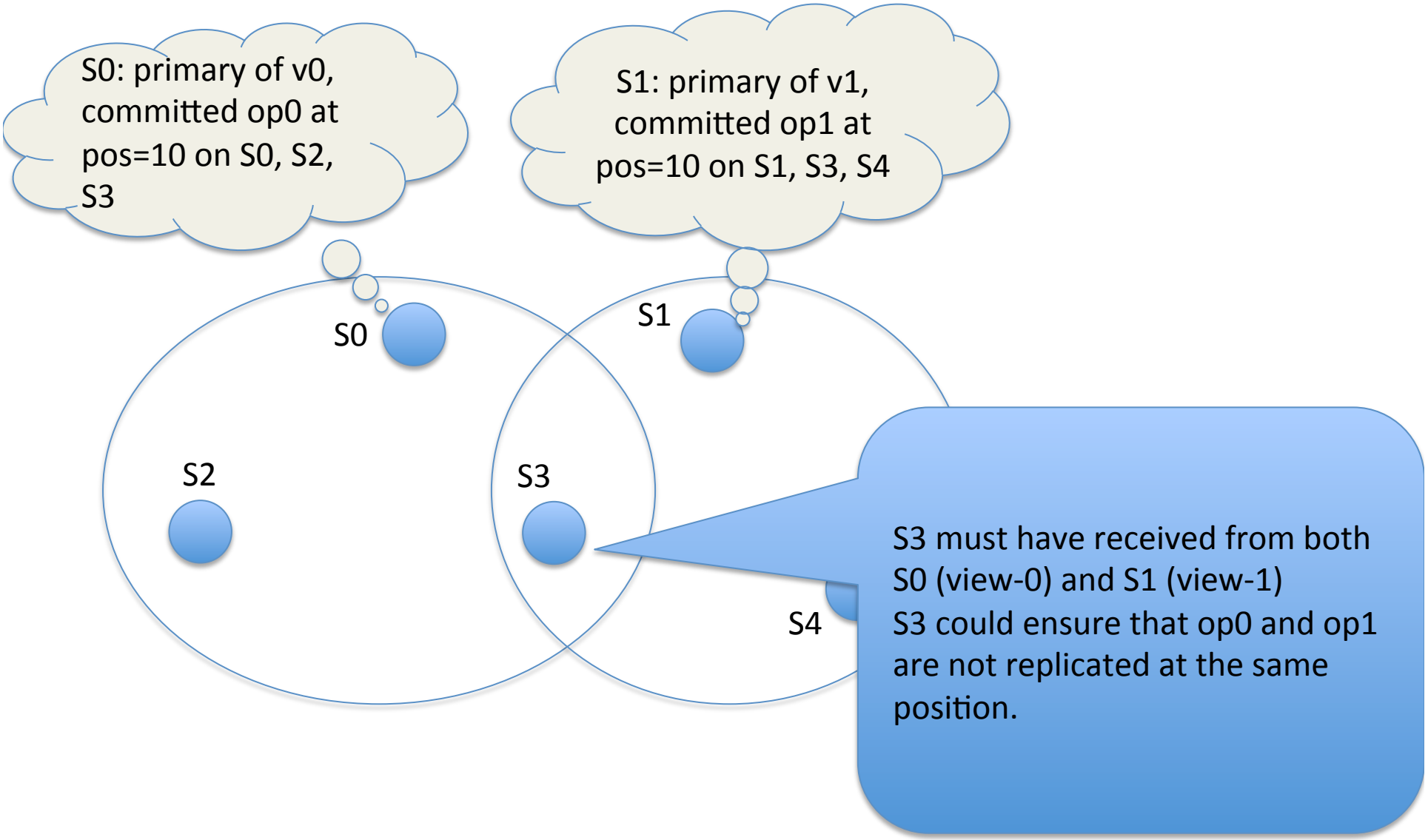
VR correctness conditions

- An op is “committed” if it is replicated by a threshold number of servers
  - Once committed, an op’s position in log is fixed
- Correctness→
  - No two different ops are committed at the same log position

Key mechanism for correctness: quorum intersection

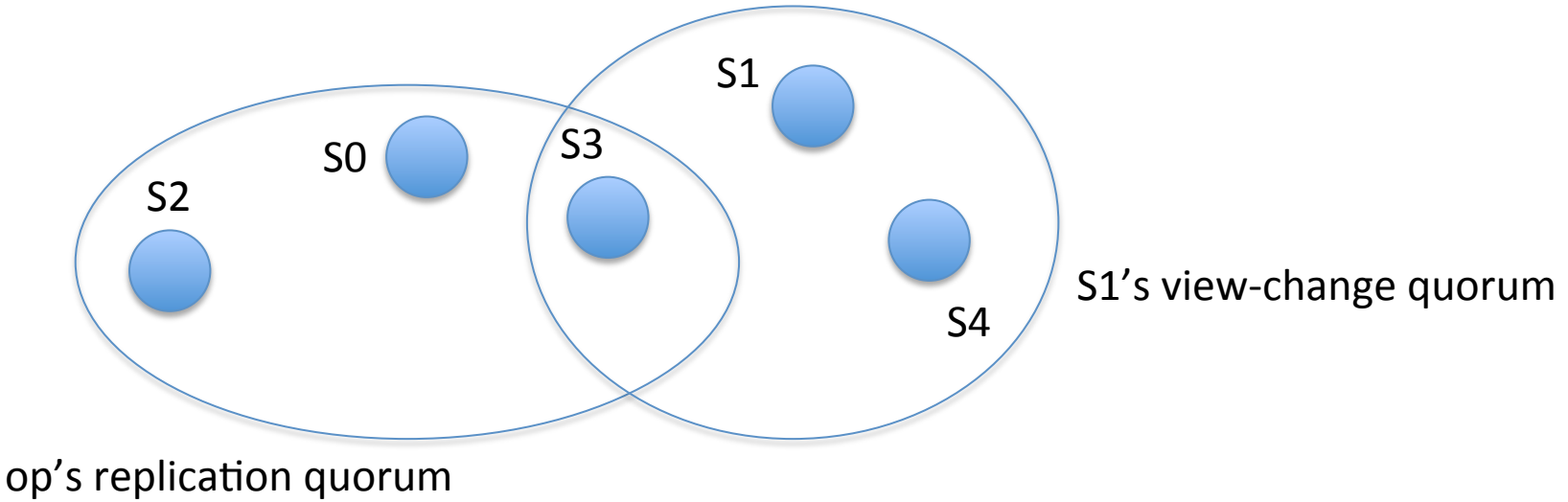
- Primary waits for quorum = majority servers (including self) before considering an op committed
- If backup is slow (or temporarily crashed), the primary can still commit as usual.
- Can two primaries commit different ops at same position?

Key mechanism for correctness: quorum intersection



Key mechanism for correctness: quorum intersection

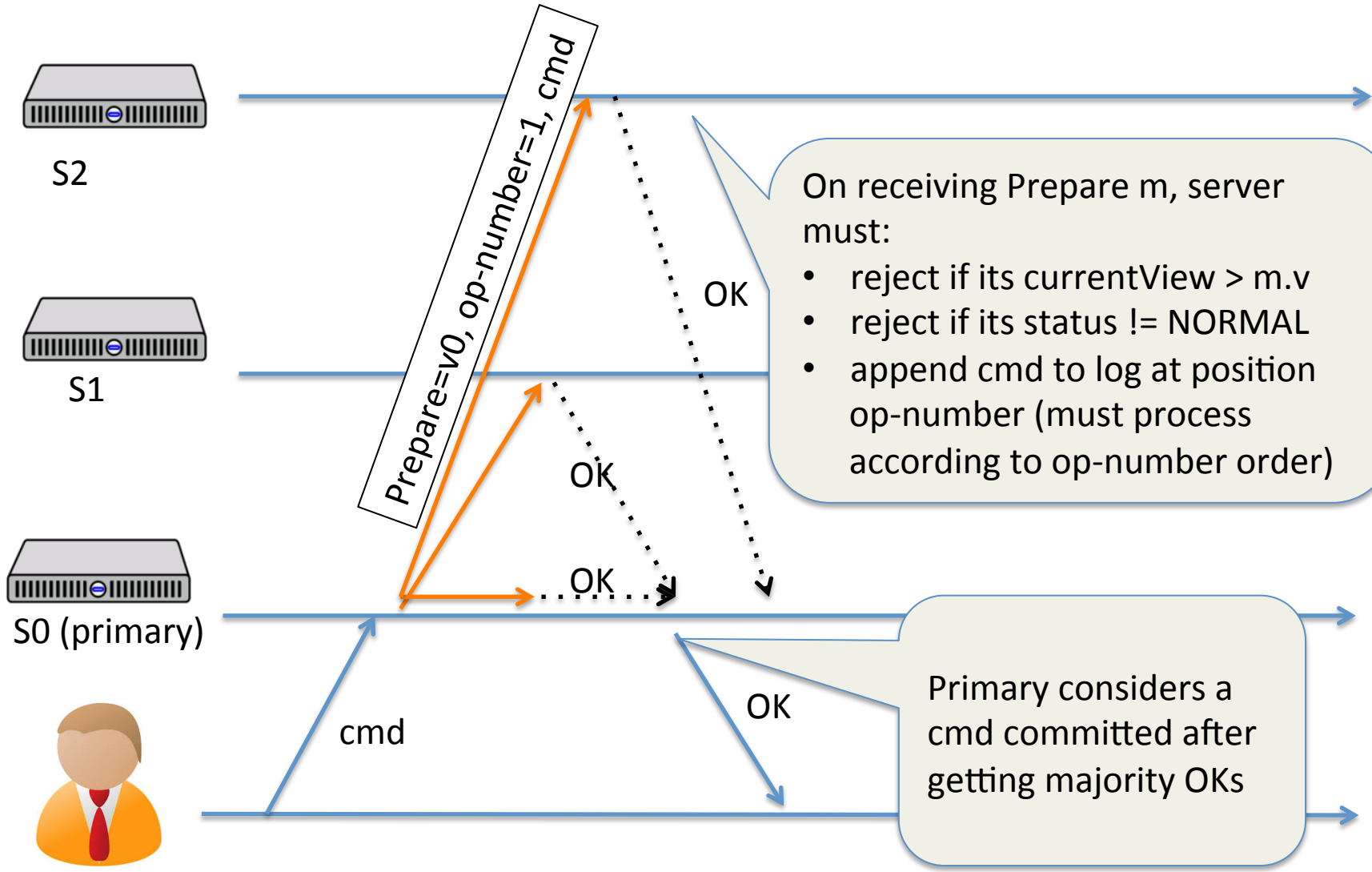
- Correctness condition: all committed ops in view v-1 must be known to primary in view v.
- How?
  - View v is only active after v's primary has learned the log state of majority of nodes (at earlier views)



Basic VR protocol

- Server state:
  - currentViewNumber
  - lastNormalViewNumber
  - status (NORMAL, VIEW-CHANGE, or RECOVERING)
  - op-number
  - commit-number
  - log

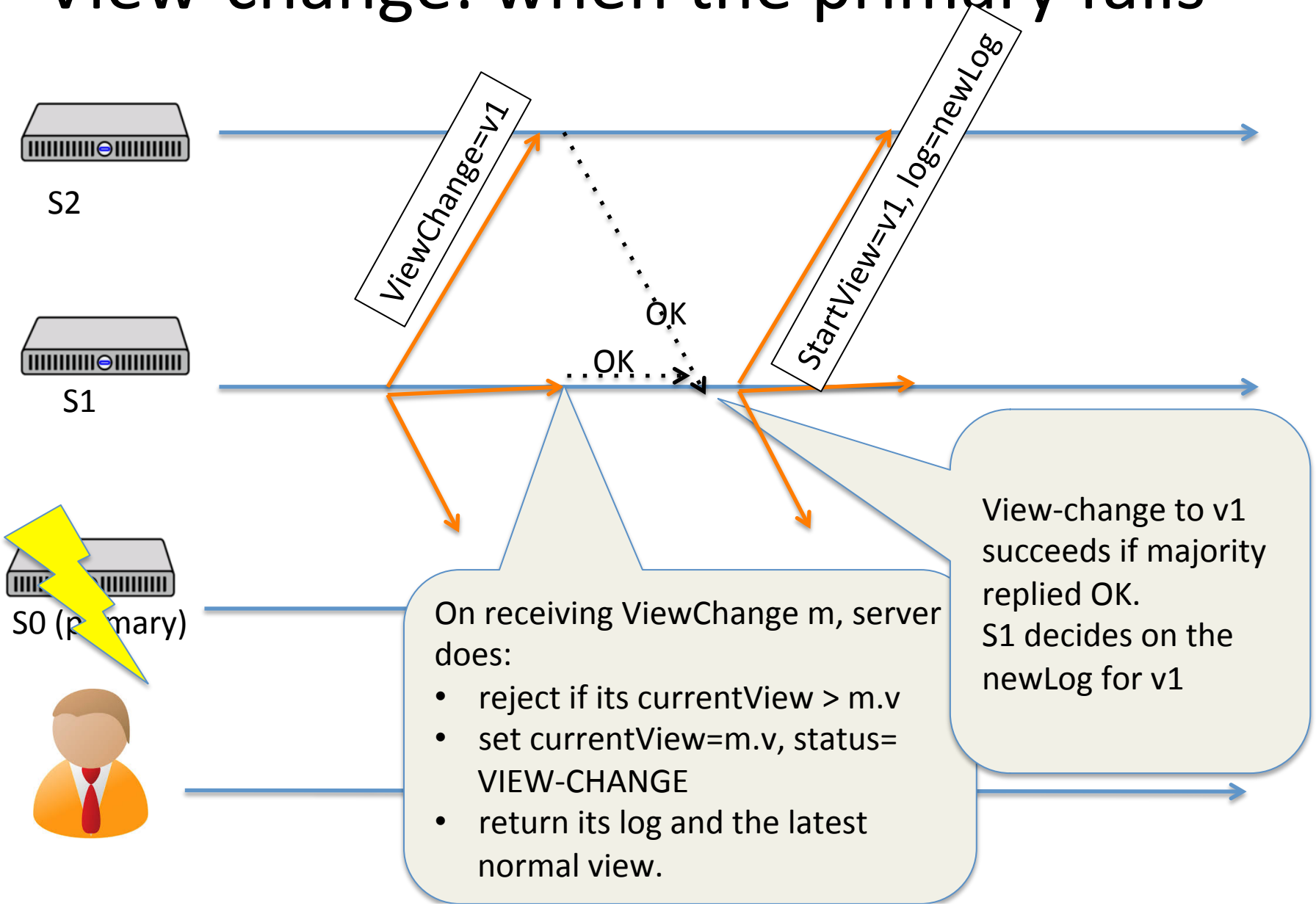
VR normal case processing



VR normal case processing

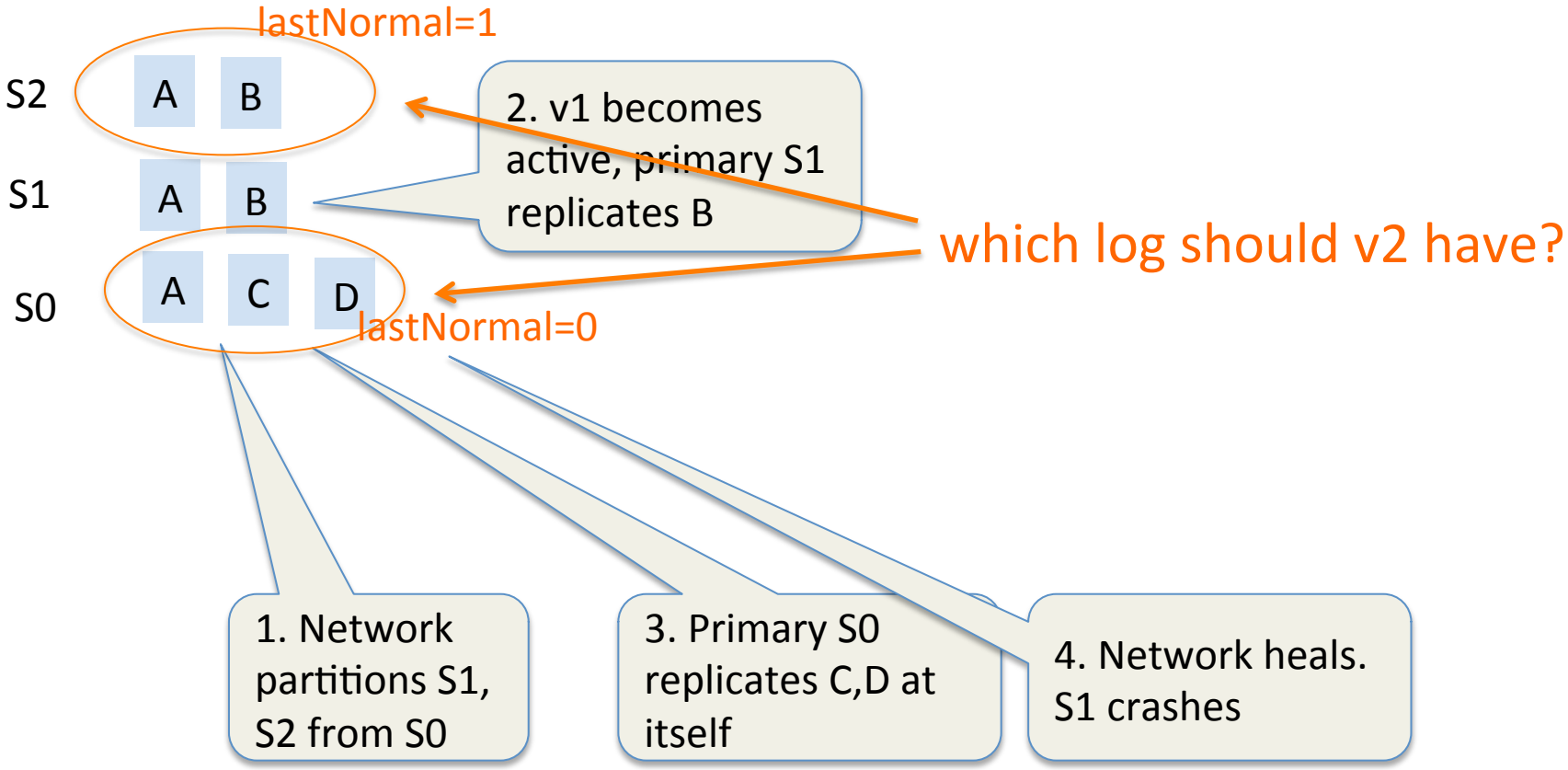
- What's the latency of committing a command?
  - from the primary's perspective
  - from the client's perspective
- How does a backup learn a command's commit status?
  - Primary piggybacks "commit-number" in its Prepare msg.

View-change: when the primary fails



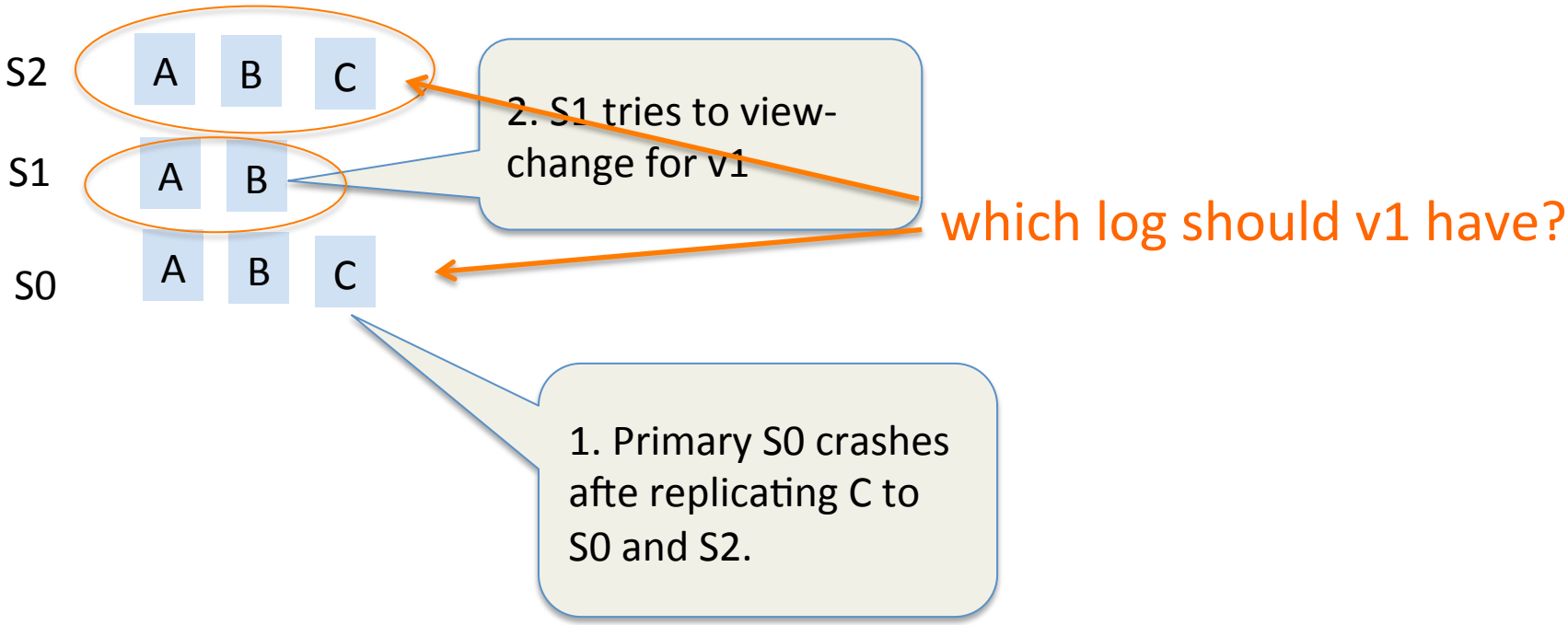
View-change: what log for new view?

- Rule 1: Pick the log w/ biggest latestNormalView



View-change: what log for new view?

- Rule 2: if >1 logs exist in rule-1, pick the longest one



Other details

- A recovered server might be out of sync with primary.
  - To recover, it transfers primary's log
- How to transfer logs efficiently?
  - checkpointing etc.