View Change Protocols and Reconfiguration

COS 418: Distributed Systems
Lecture 9

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Housekeeping

- Midterm finally scheduled
  - 10/24, 7-9pm, Computer Science 104
  - Talk to me after if you have a conflict
- Final also scheduled
  - 1/23, 730pm, Friend Center 101
- Assignment 2 due Thursday
- Where I was last week
  - Global tables in DynamoDB!

Today

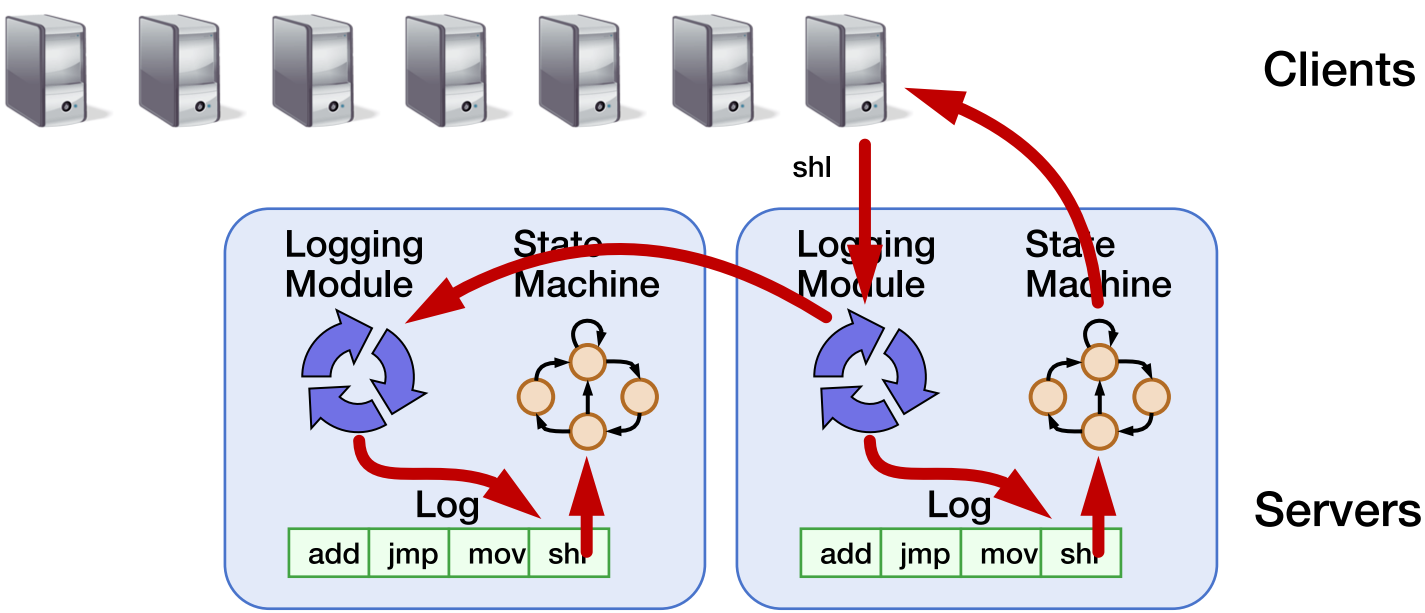
1. More primary-backup replication

2. View changes

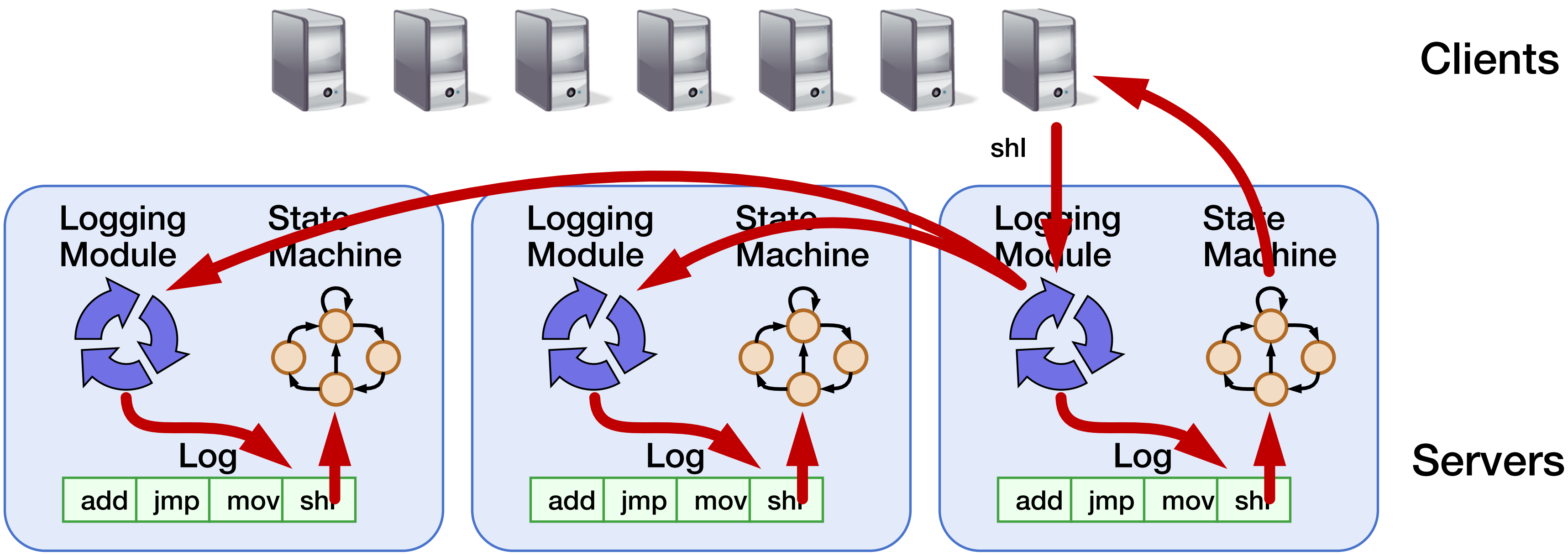
3. Reconfiguration

Review: Primary-Backup Replication

- Nominate one replica primary
  - Clients send all requests to primary
  - Primary orders clients' requests



From Two to Many Replicas



- Last time: Primary-Backup case study
- Today: State Machine Replication with **many** replicas
  - Survive more failures

Intro to "Viewstamped Replication"

- State Machine Replication for any number of replicas

- Replica group: Group of $2f + 1$ replicas
  - Protocol can tolerate f replica crashes

Viewstamped Replication Assumptions:

1. Handles crash failures only
   - Replicas fail only by completely stopping

2. Unreliable network: Messages might be lost, duplicated, delayed, or delivered out-of-order

Replica State

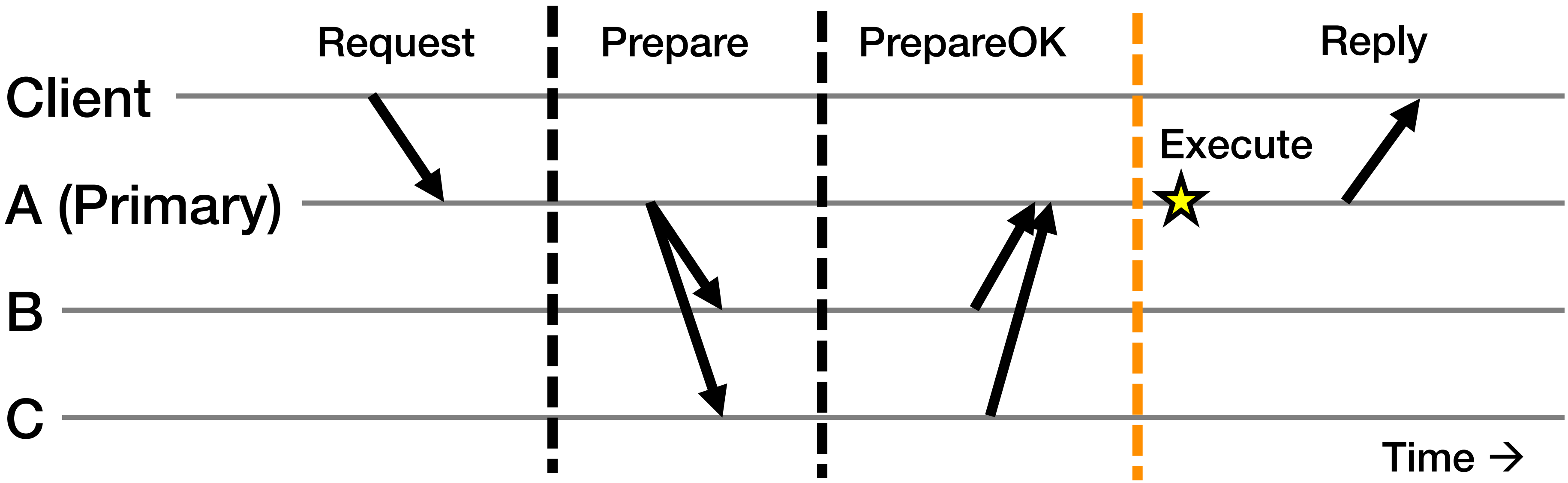
1. configuration: identities of all 2f + 1 replicas

2. In-memory log with clients' requests in assigned order

⟨op1, args1⟩	⟨op2, args2⟩	⟨op3, args3⟩	⟨op4, args4⟩	. . .

Normal Operation

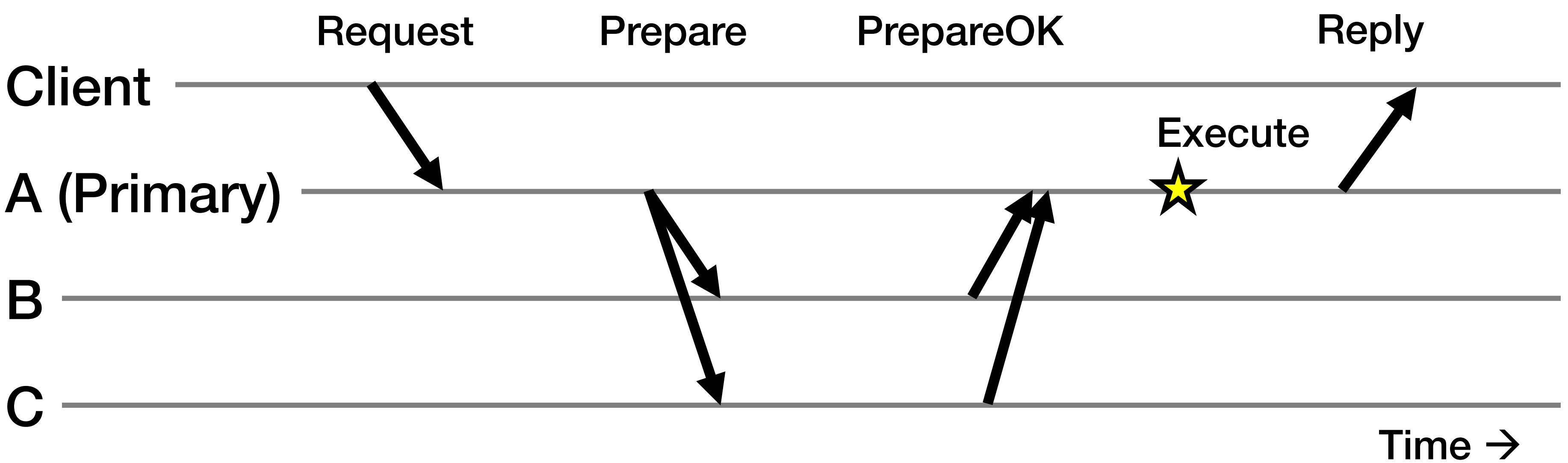
(*f* = 1)



1. Primary adds request to end of its log
2. Replicas add requests to their logs in primary's log order
3. Primary waits for f PrepareOKs → request is committed

Normal Operation: Key Points

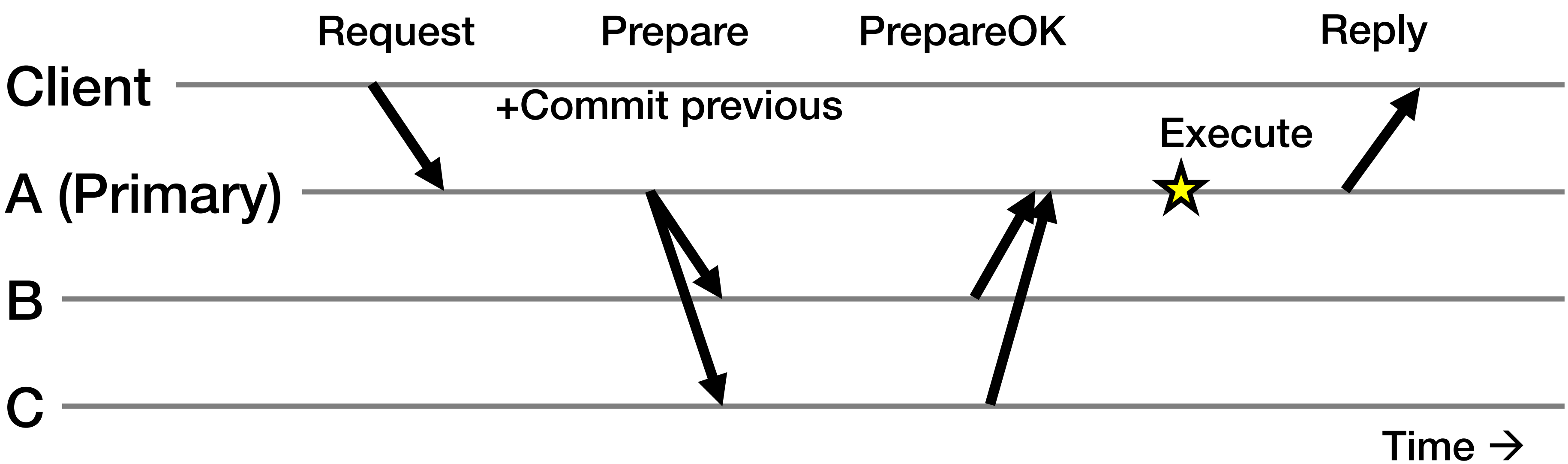
(*f* = 1)



- Protocol provides state machine replication
- On execute, primary knows request in $f + 1 = 2$ nodes' logs
  - Even if $f = 1$ then crash, ≥ 1 retains request in log

Piggybacked Commits

(*f* = 1)

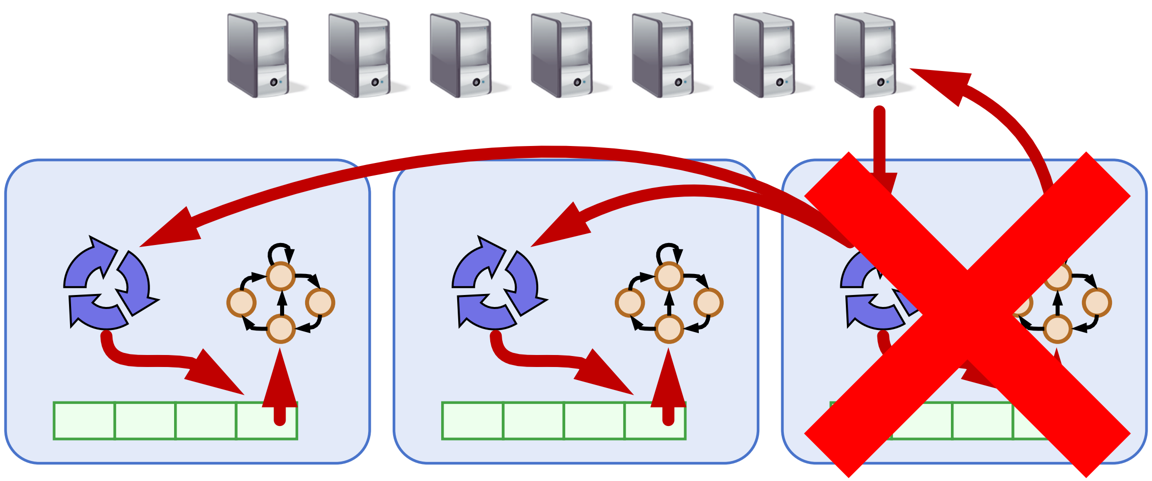


- Previous Request's commit piggybacked on current Prepare
- No client Request after a timeout period?
  - Primary sends Commit message to all backups

The Need For a View Change

- So far: Works for *f* failed backup replicas

- But what if the *f* failures include a failed primary?
  - All clients' requests go to the failed primary
  - System halts despite merely *f* failures



Today

1. More primary-backup replication

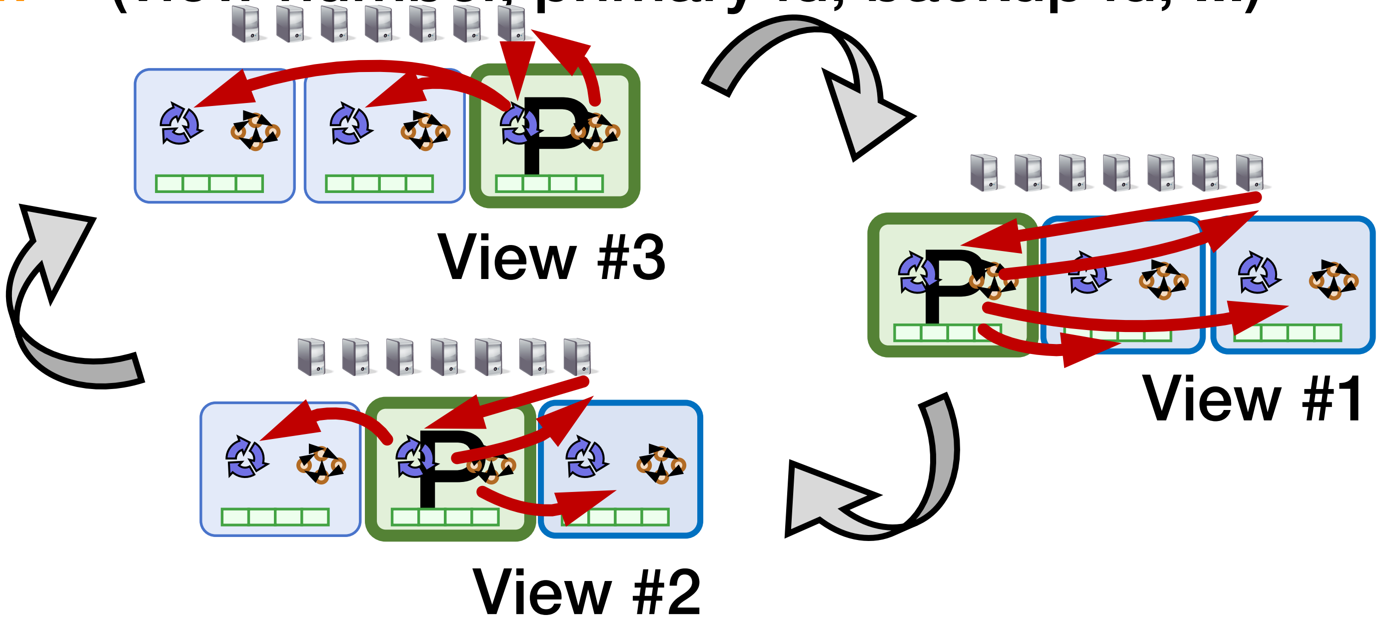
2. View changes
    - With Viewstamped Replication
    - Using a View Server

3. Reconfiguration

Views

- Let different replicas assume role of primary over time

- System moves through a sequence of views
  - View = (view number, primary id, backup id, ...)



View Change Protocol

- Backup replicas monitor primary
- If primary seems faulty (no Prepare/Commit):
  - Backups execute the view change protocol to select new primary
    - View changes execute automatically, rapidly
- Need to keep clients and replicas in sync: same local state of the current view
  - Same current view at replicas
  - Same current view at clients

Correctly Changing Views

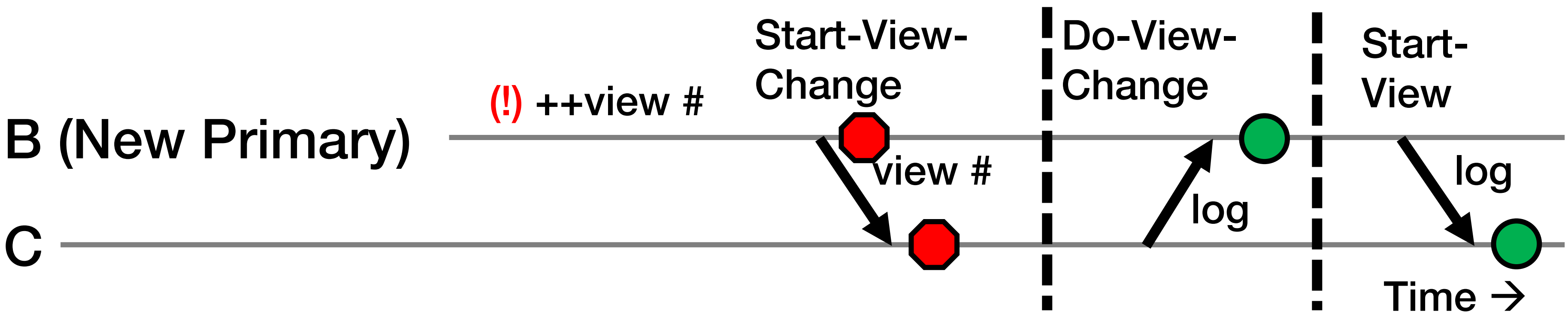
- View changes happen locally at each replica
- Old primary executes requests in the old view, new primary executes requests in the new view
- Want to ensure state machine replication
- So correctness condition: Executed requests
    1. Survive in the new view
    2. Retain the same order in the new view

Replica State (for View Change)

1. configuration: sorted identities of all 2f + 1 replicas
2. In-memory log with clients' requests in assigned order
3. view-number: identifies primary in configuration list
4. status: normal or in a view-change

View Change Protocol

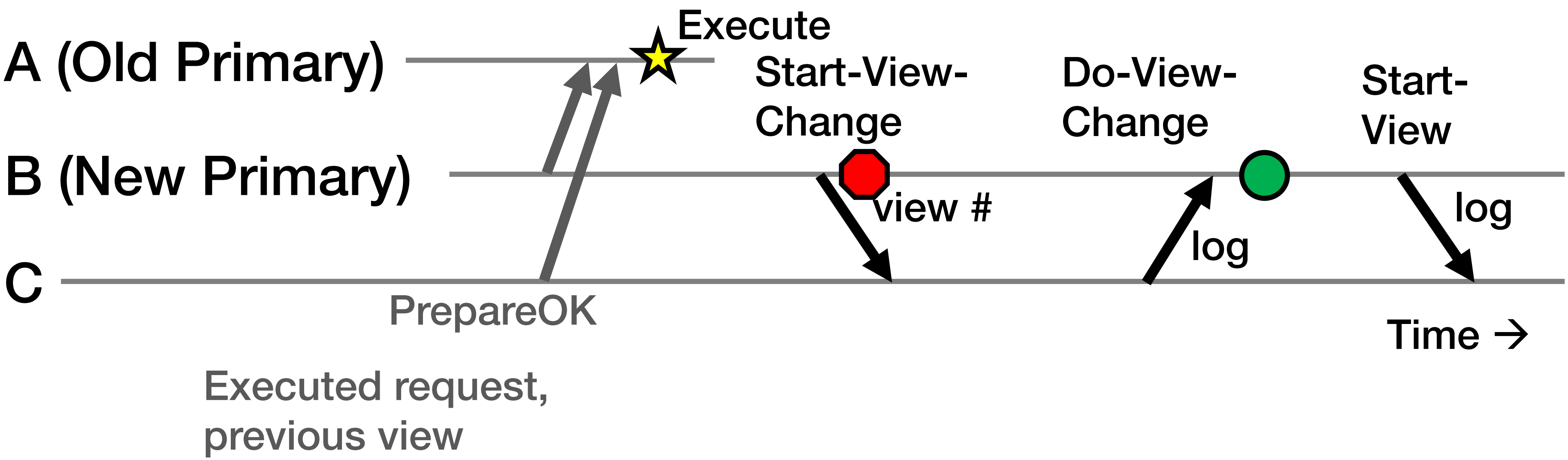
(*f* = 1)



1. B notices A has failed, sends **Start-View-Change**
2. C replies **Do-View-Change** to new primary, with its log
3. B waits for *f* replies, then sends **Start-View**
4. On receipt of Start-View, C replays log, accepts new ops

View Change Protocol: Correctness

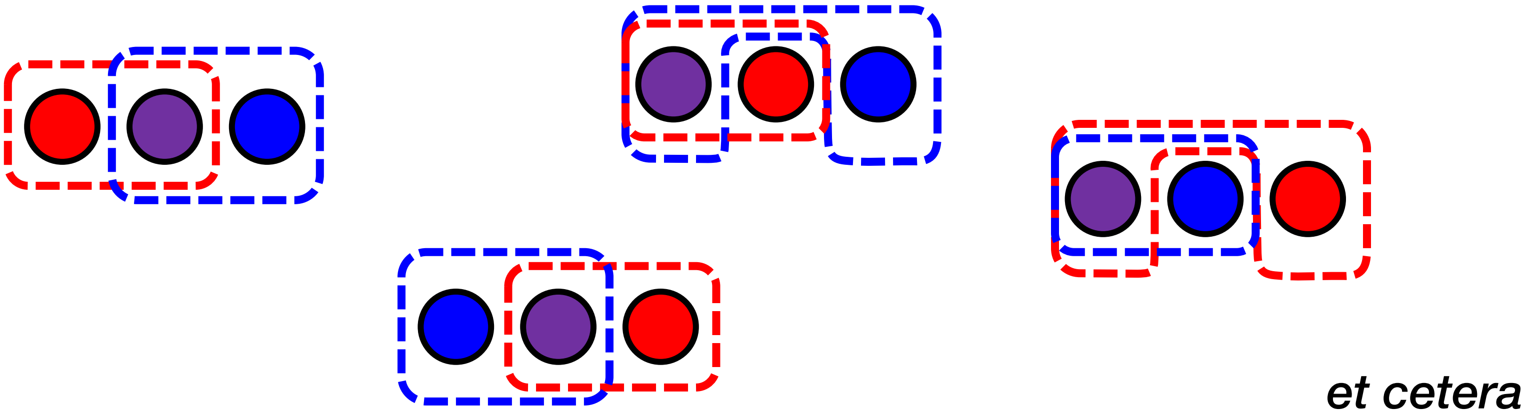
($f = 1$)



- Old primary A must have received one or two PrepareOK replies for that request (*why?*)
- Request is in B’s or C’s log (or both): so it will survive into new view

Principle: Quorums

(*f* = 1)



- Any group of f + 1 replicas is called a quorum
- Quorum intersection property: Two quorums in 2f + 1 replicas must intersect in at least one replica

Applying the Quorum Principle

Normal Operation:

- Quorum that processes one request: Q1
  - ...and 2nd request: Q2
- Q1 ∩ Q2 has at least one replica →
  - Second request reads first request's effects

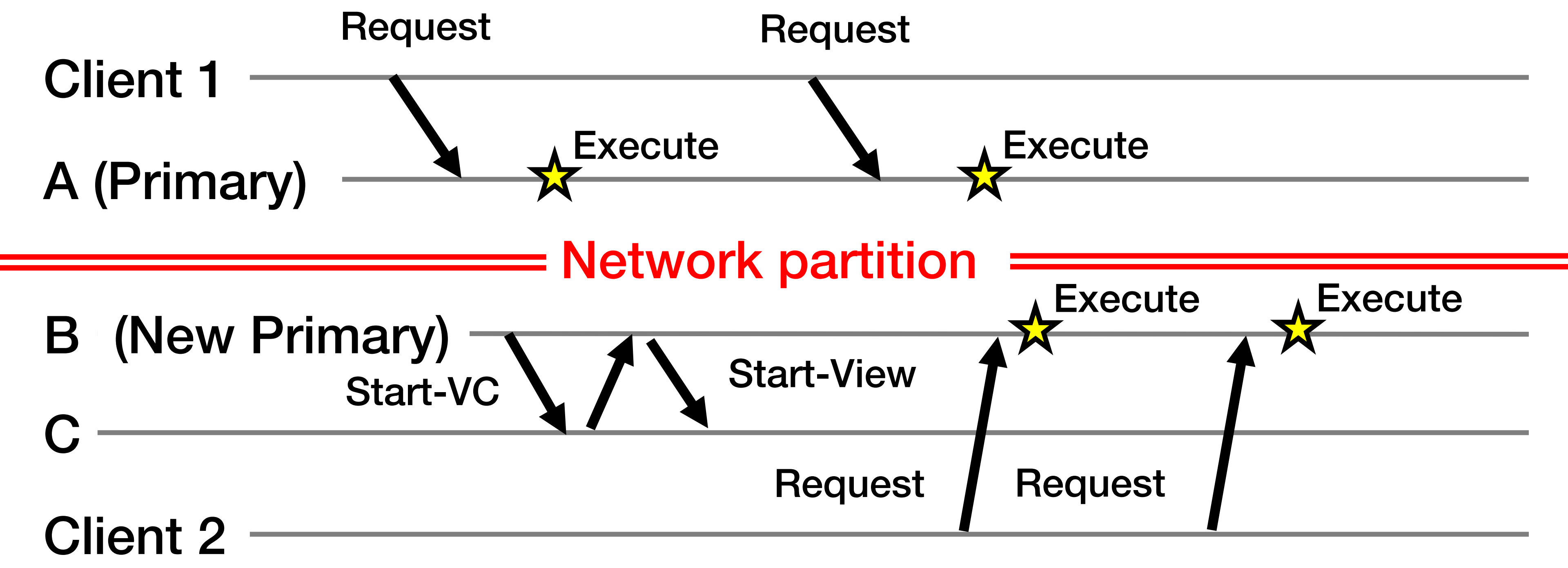
Applying the Quorum Principle

View Change:

- Quorum processes previous (committed) request: Q1
  - ...and that processes Start-View-Change: Q2
- Q1 ∩ Q2 has at least one replica →
  - View Change contains committed request

Split Brain

(not all protocol messages shown)



- What's undesirable about this sequence of events?
- Why won't this ever happen? What happens instead?

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   - Using a View Server

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Would Centralization Simplify Design?

- A single View Server could decide who is primary
  - Clients and servers depend on view server
    - Don't decide on their own (might not agree)

- Goal in designing the View Server:
  - Only one primary at a time for correct state machine replication

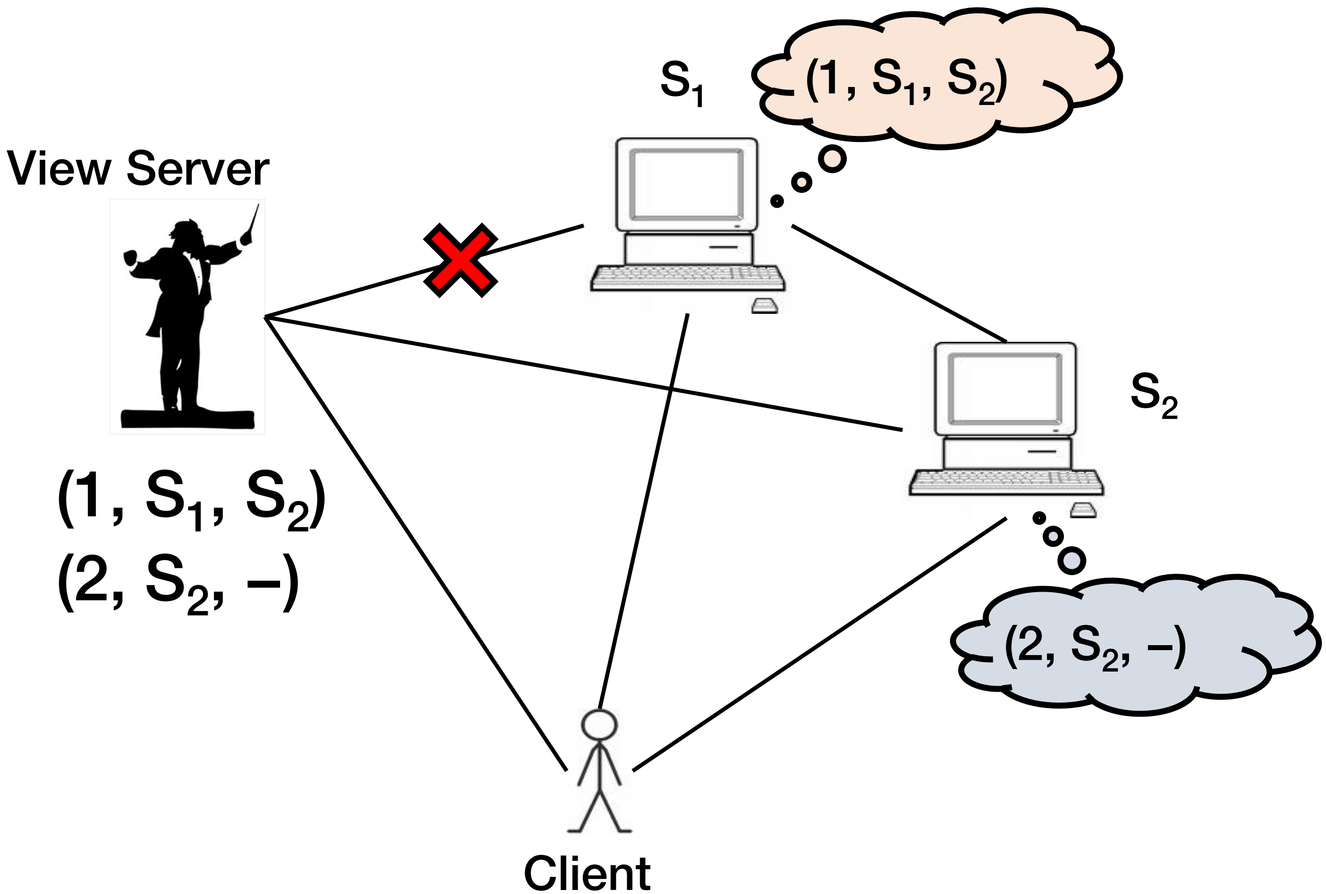
View Server Protocol Operation

- For now, assume View Server never fails

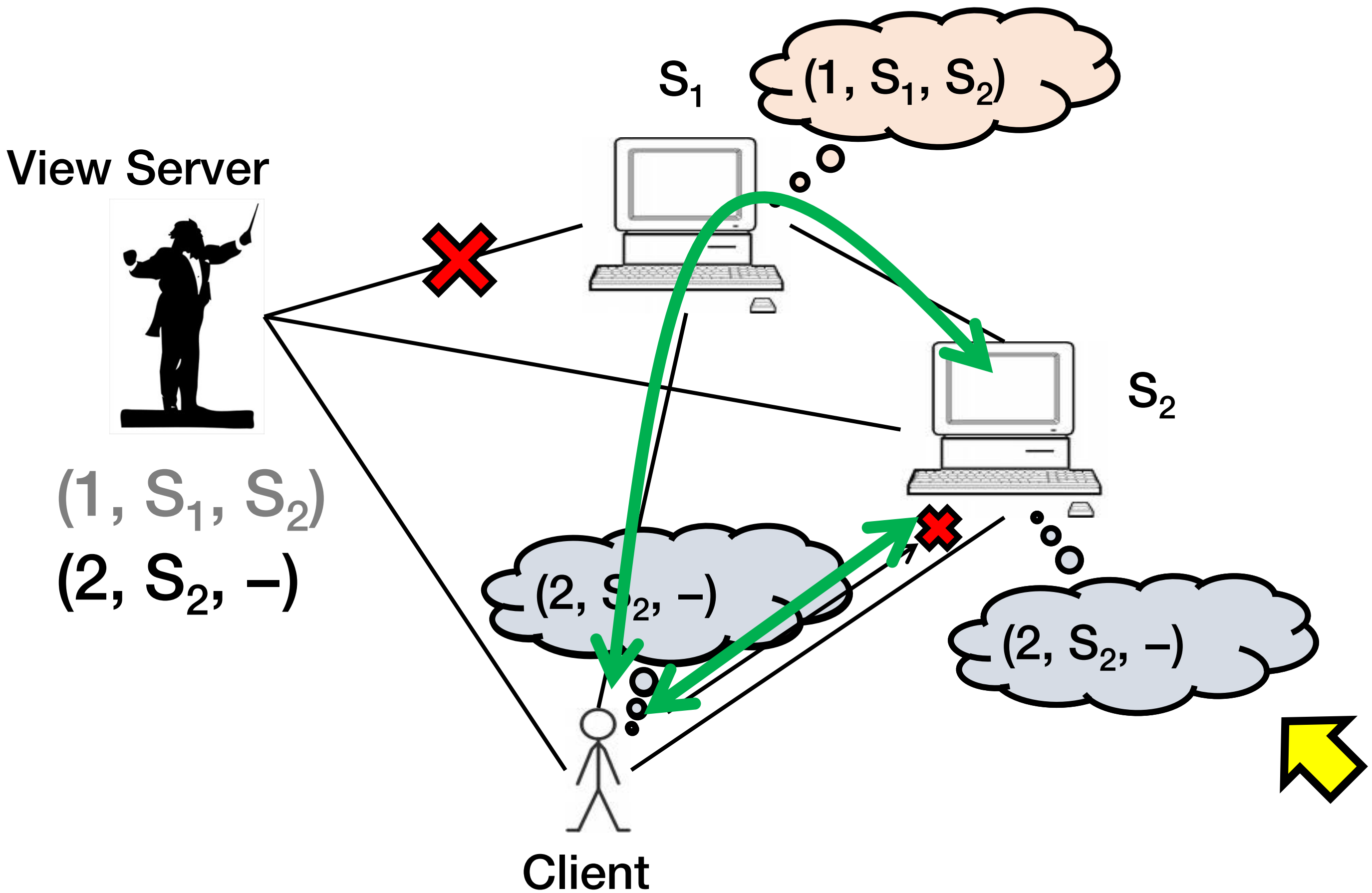
- Each replica periodically pings the View Server
  - VS declares replica dead if missed N pings in a row
  - VS considers replica alive after a single ping received

- Problem: Replica can be alive but because of network connectivity, be declared "dead"

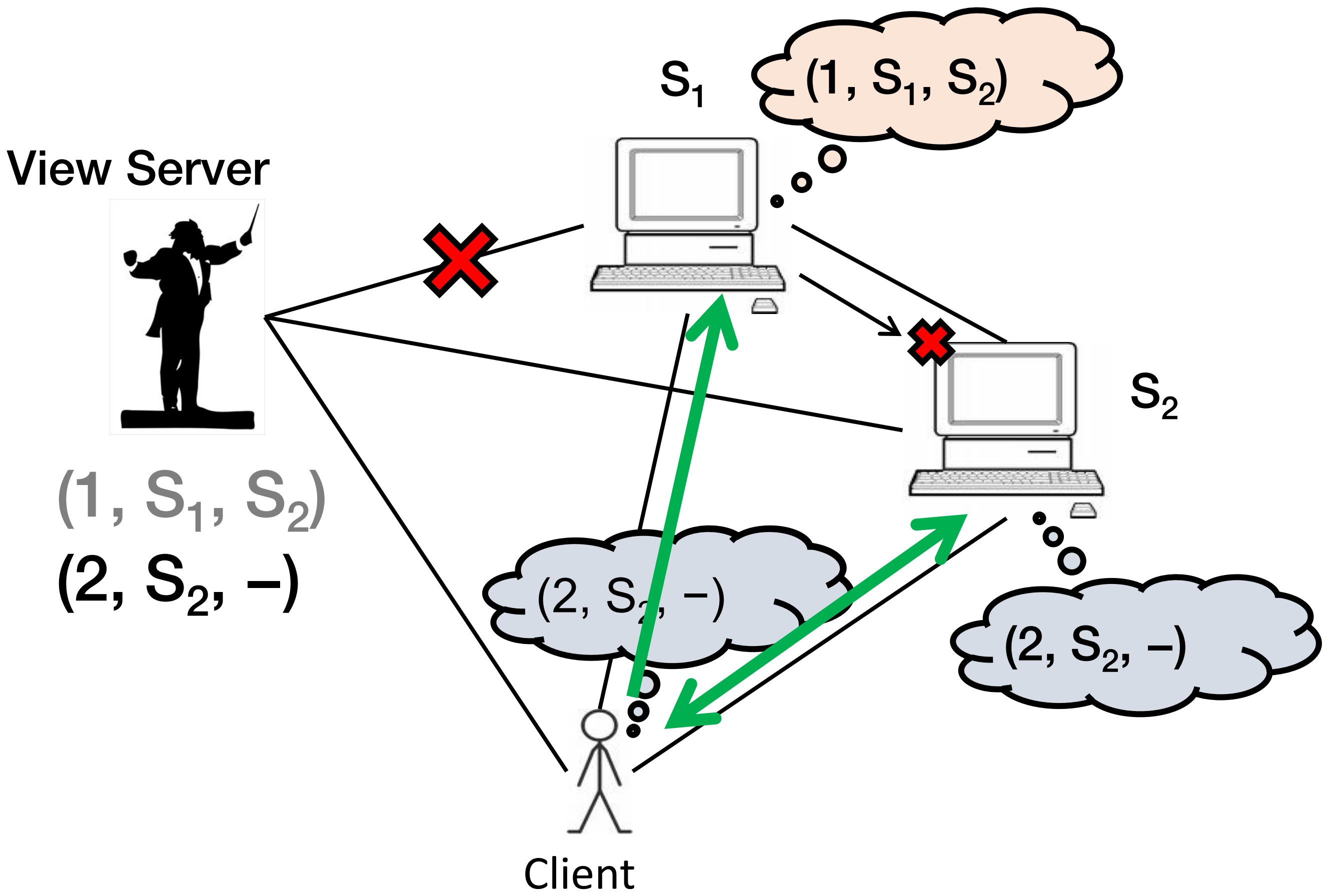
View Server: Split Brain



One Possibility: S_2 in Old View



Also Possible: S_2 in New View



Split Brain and View Changes

Take-away points:

- Split Brain problem can be avoided both:
  - In a decentralized design (Viewstamped Replication)
  - With centralized control (View Server)
- But protocol must be designed carefully so that replica state does not diverge

Today

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The Need for Reconfiguration

- What if we want to replace a faulty replica with a different machine?
  - For example, one of the backups may fail permanently

- What if we want to change the replica group size?
  - Decommission a replica
  - Add another replica (increase f, possibly)

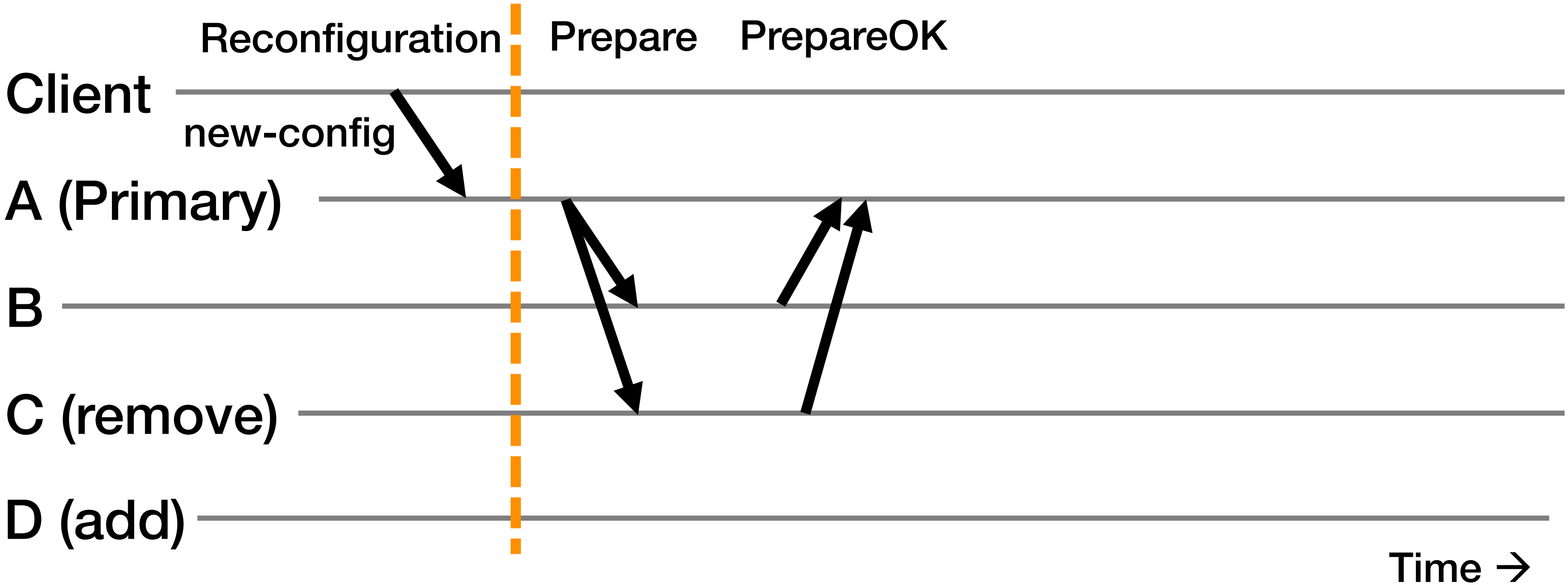
- Protocol that handles these possibilities is called the reconfiguration protocol

Replica State (for Reconfiguration)

1. configuration: sorted identities of all 2f + 1 replicas
2. In-memory log with clients’ requests in assigned order
3. view-number: identifies primary in configuration list
4. status: normal or in a view-change
5. epoch-number: indexes configurations

Reconfiguration (1)

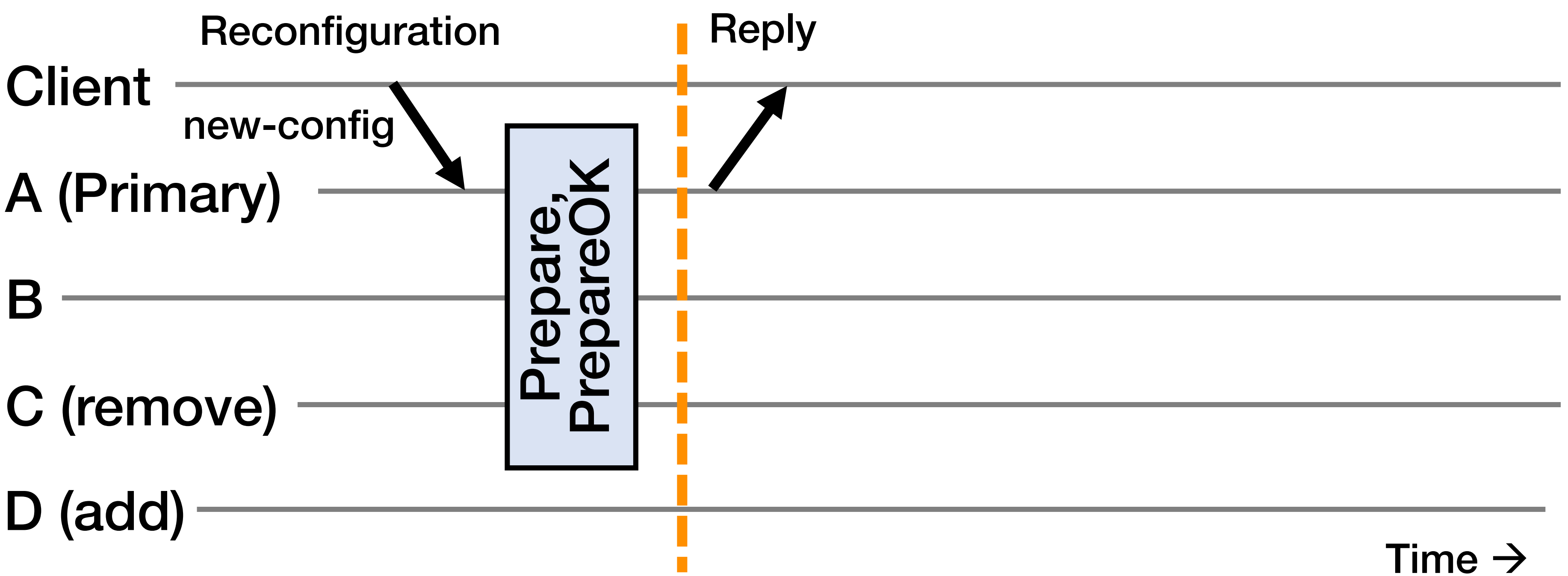
(*f* = 1)



- Primary immediately stops accepting new requests

Reconfiguration (2)

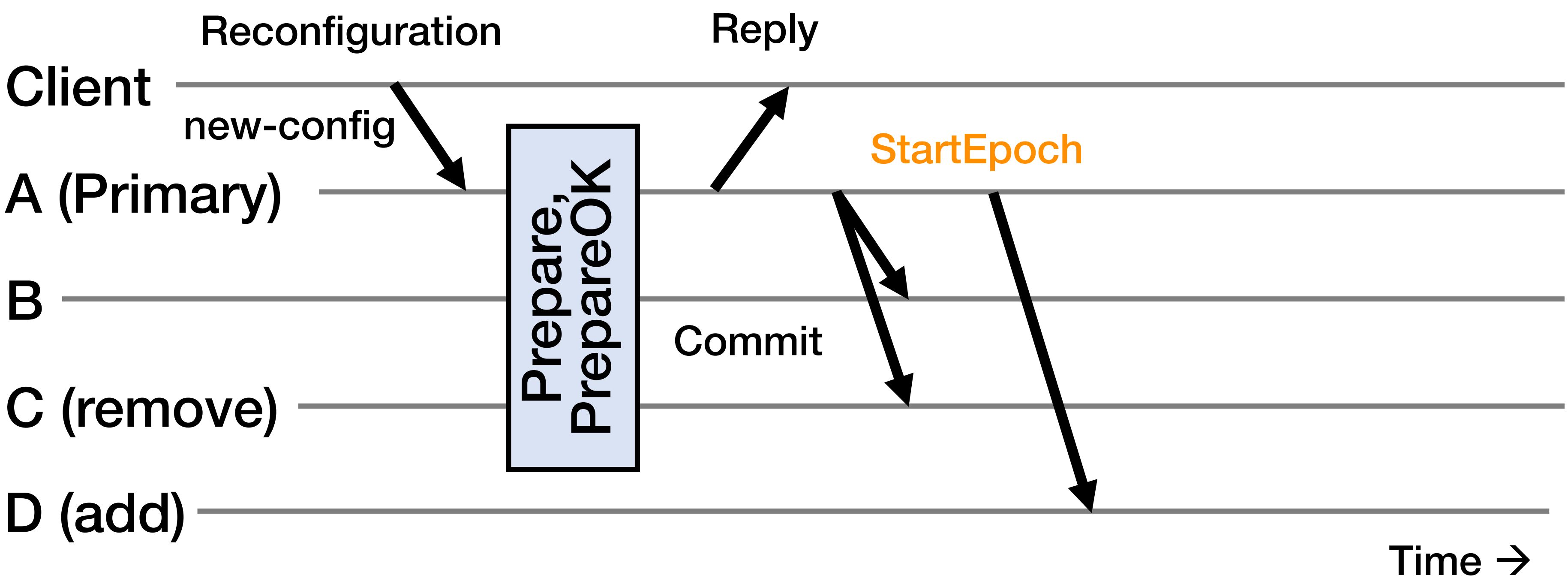
(*f* = 1)



- Primary immediately stops accepting new requests
- No up-call to RSM for executing this request

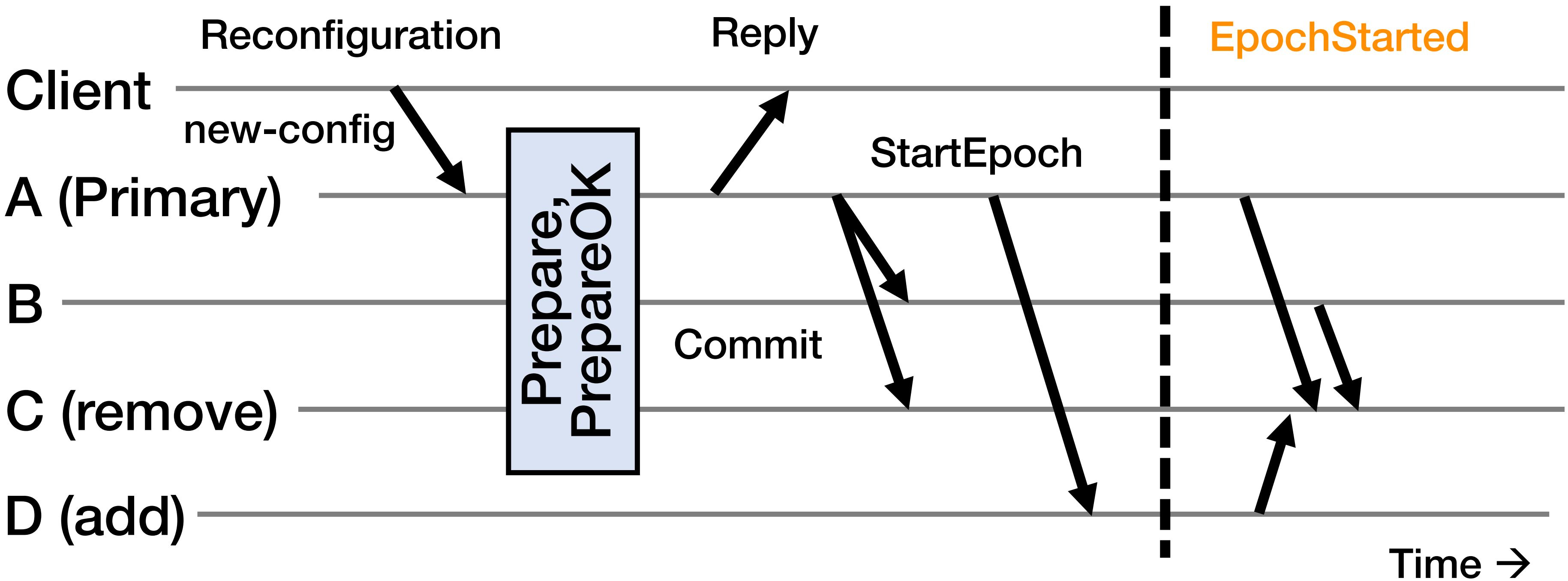
Reconfiguration (3)

(*f* = 1)



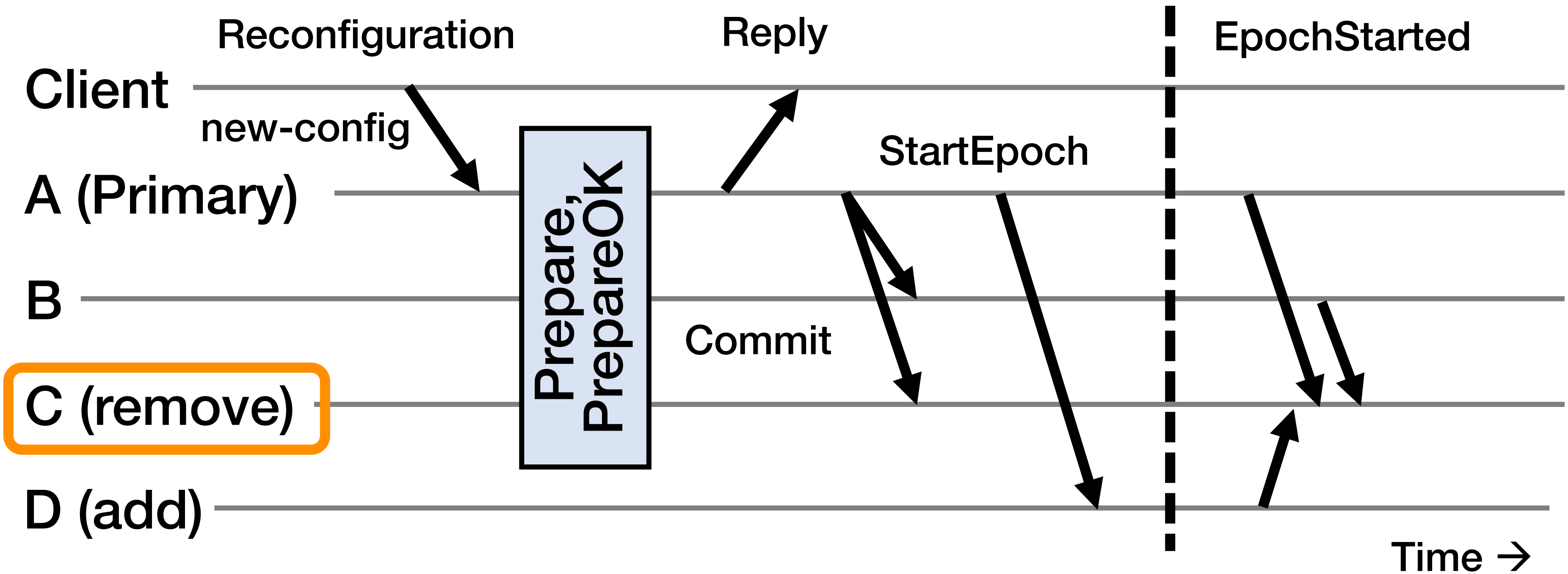
- Primary sends Commit messages to old replicas
- Primary sends StartEpoch message to new replica(s)

Reconfiguration in New Group {A, B, D}



1. Update state with new epoch-number
2. Fetch state from old replicas, update log
3. Send EpochStarted msgs to replicas being removed

Reconfiguration at Replaced Replica {C}



1. Respond to state transfer requests from others
   - Waits until it receives f' + 1 EpochStarteds, f' is fault tolerance of new epoch

2. Send StartEpoch messages to new replicas if they don't hear EpochStarted (not shown above)

Shutting Down Old Replicas

- If admin doesn't wait for reconfiguration to complete and decommissions old nodes, may cause > f failures in old group
  - Can't shut down replicas on receiving Reply at client
- Must ensure committed requests survive reconfiguration!
- Fix: A new type of request CheckEpoch reports the current epoch
  - Goes thru normal request processing (again no upcall)
  - Return indicates reconfiguration is complete
  - Q: Why not have reconfigure wait for this to complete?

Conclusion: What's Useful When

- Backups fail or has network connectivity problems?
- Minority partitioned from primary?

→ Quorums allow primary to continue

- Primary fails or has network connectivity problems?
- Majority partitioned from primary?

→ Rapidly execute view change

- Replica permanently fails or is removed?
- Replica added?

→ Administrator initiates reconfiguration protocol