View Change Protocols and Consensus

COS 418/518: Distributed Systems
Lecture 12

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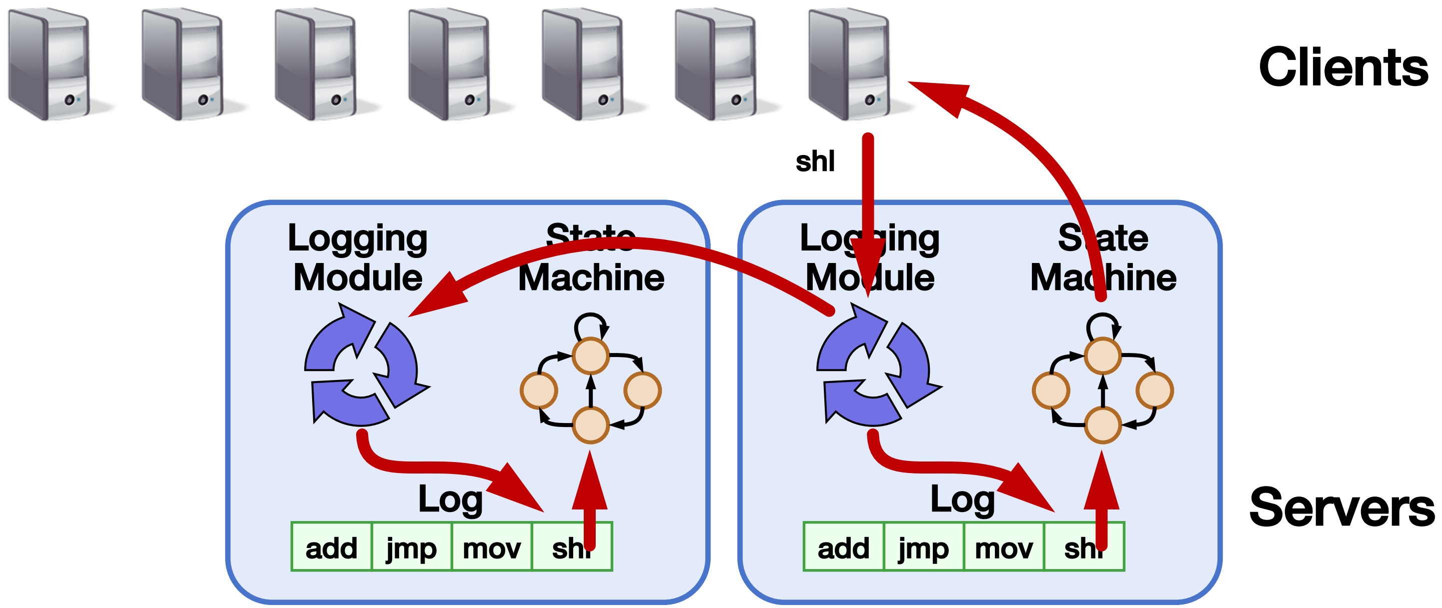
Today

1. From primary-backup to viewstamped replication

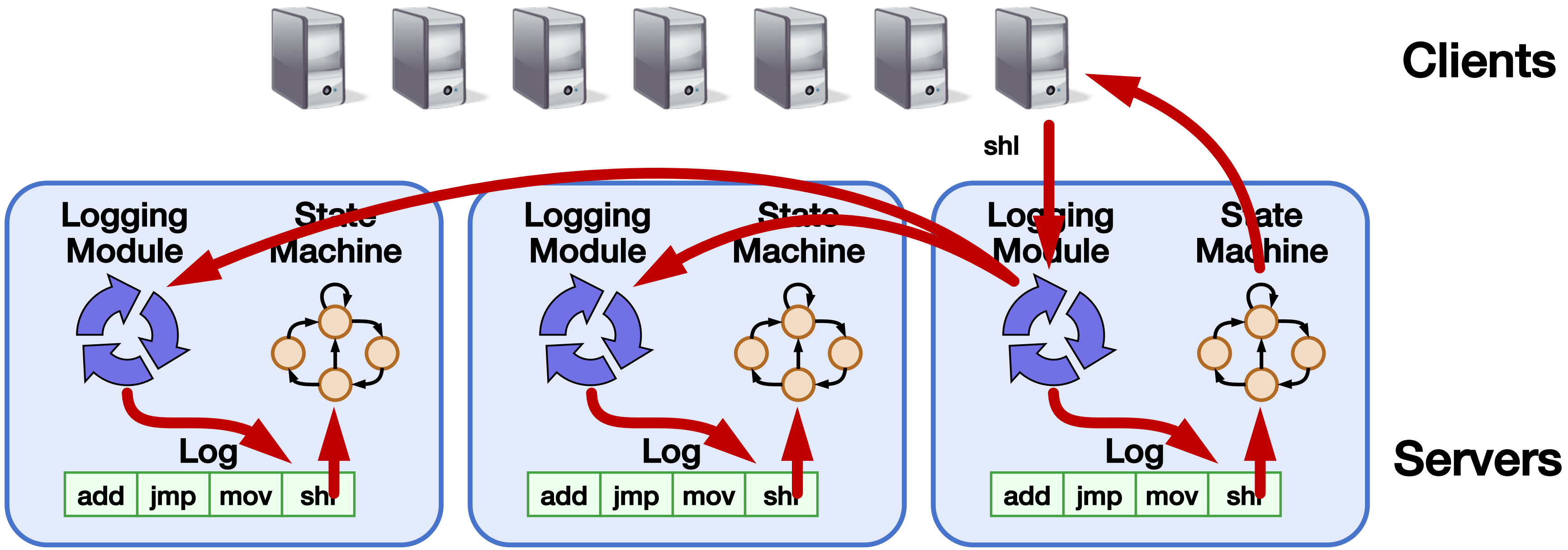
2. Consensus

Review: Primary-Backup Replication



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

From Two to Many Replicas



- Primary-backup with many replicas
  - Primary waits for acknowledgement from **all** backups
  - All updates to set of replicas needs to update shared disk

What else can we do with more replicas?

- Viewstamped Replication:
  - State Machine Replication for any number of replicas
  - Replica group: Group of $2f + 1$ replicas
    - Protocol can tolerate f replica crashes

- Differences with primary-backup
  - No shared disk (no reliable failure detection)
  - Don't need to wait for **all** replicas to reply
  - Need more replicas to handle f failures ($2f+1$ vs $f+1$)

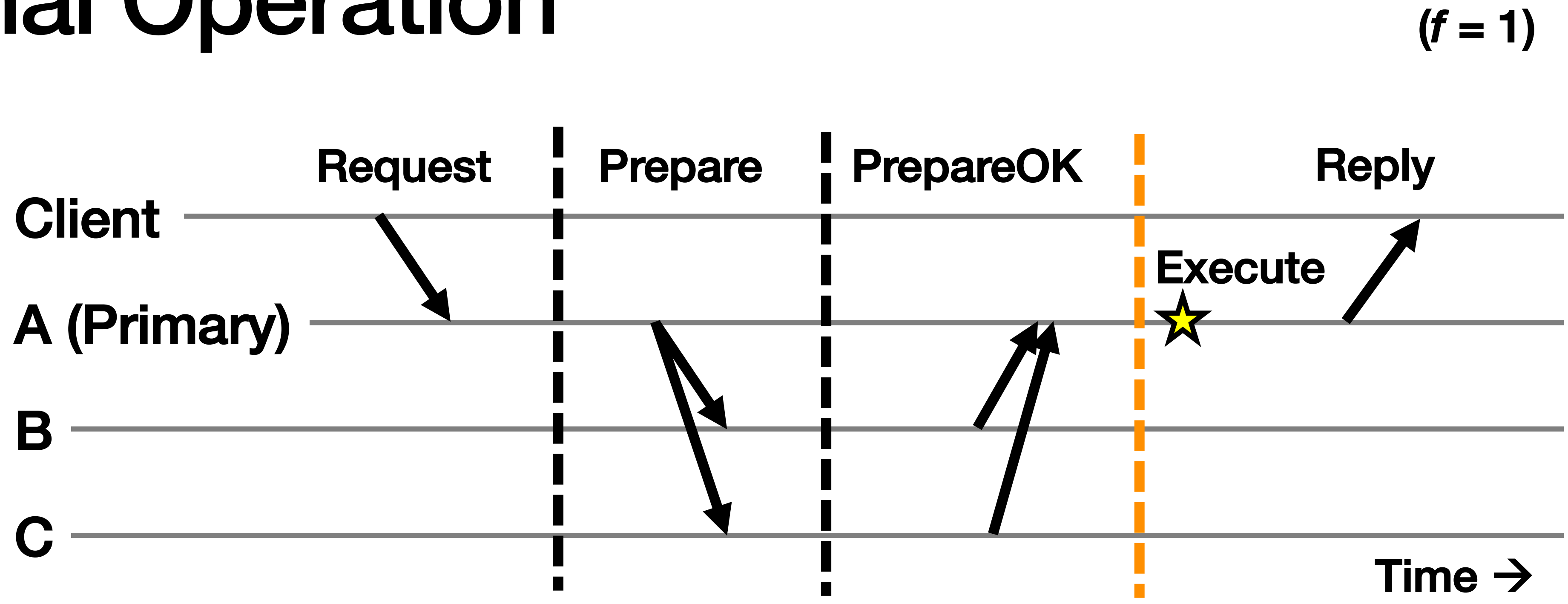
Replica State

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⟩

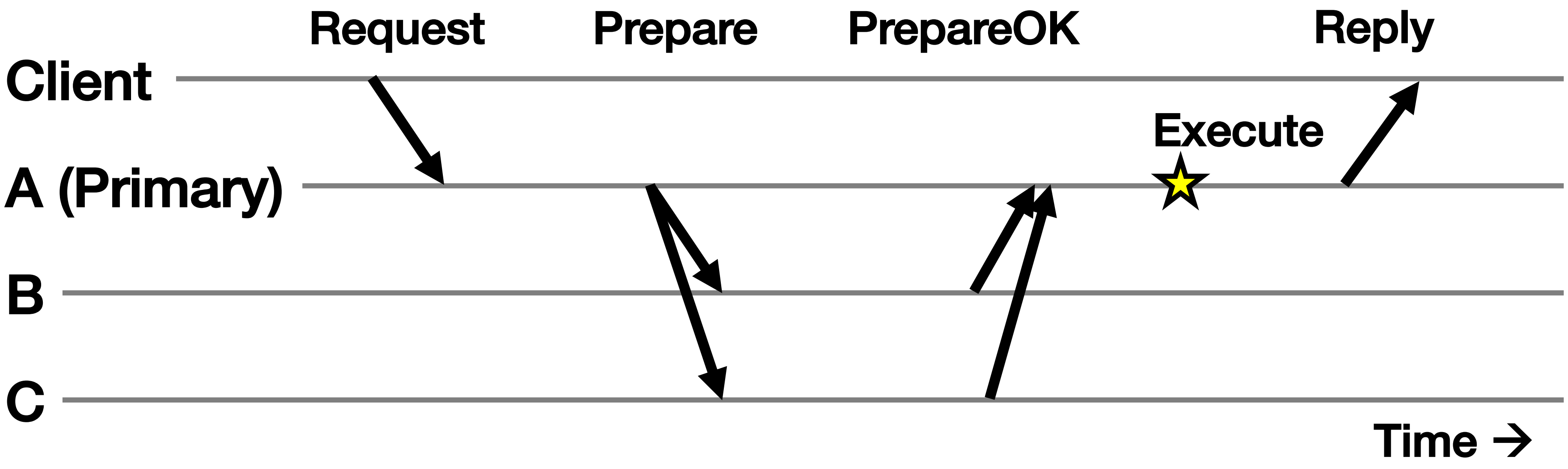
Normal Operation



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

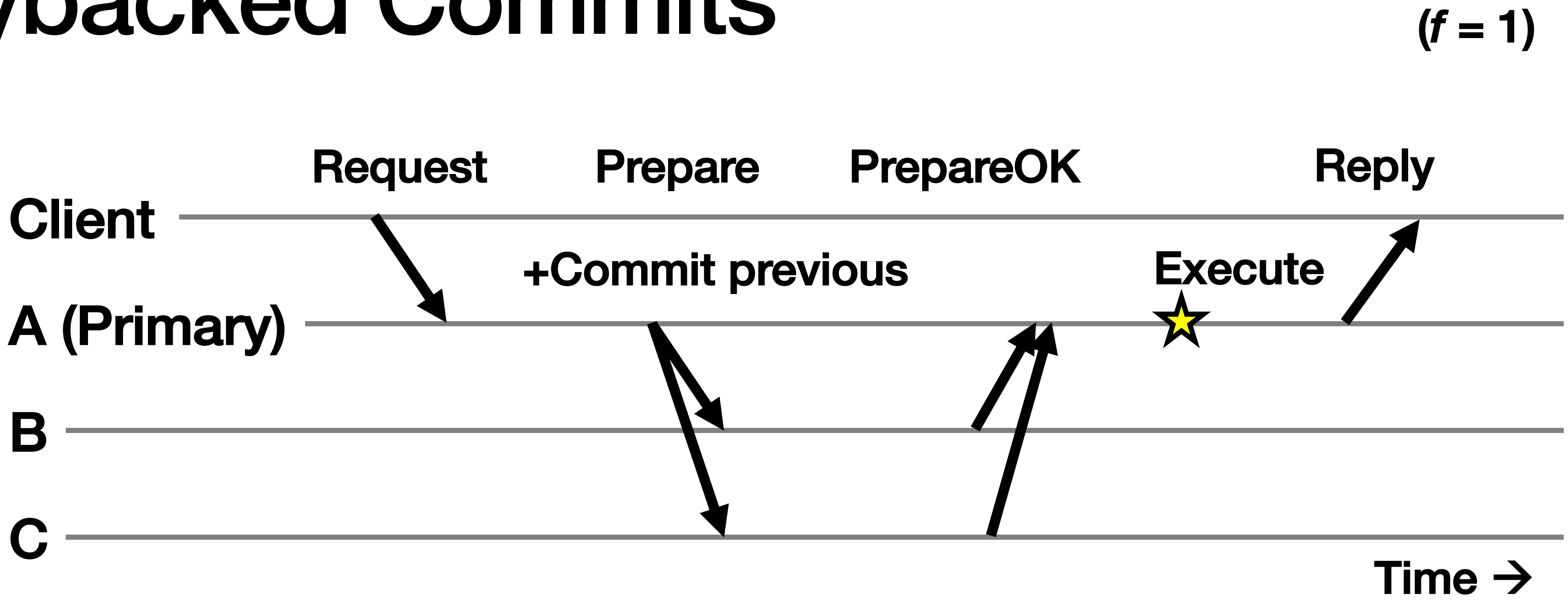
Normal Operation: Key Points

(*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

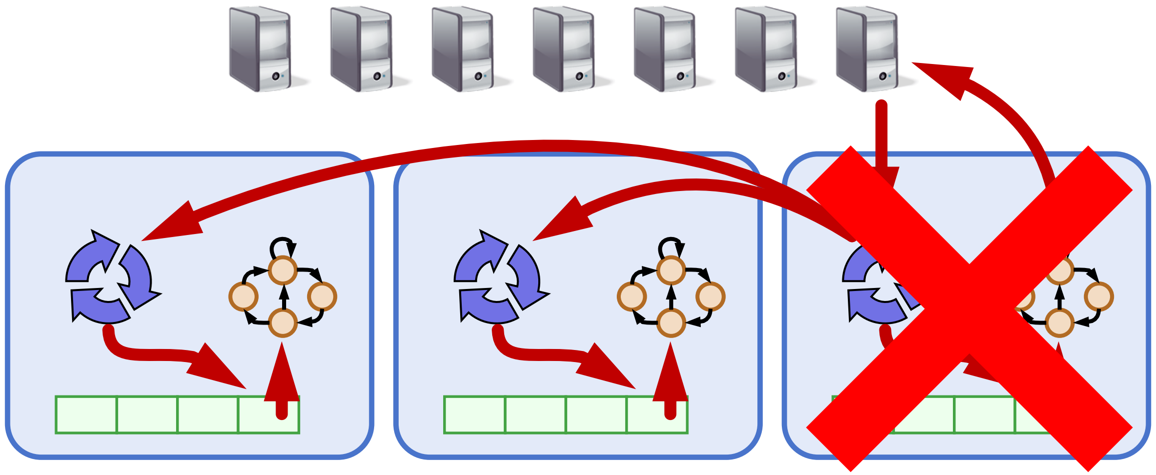
Piggybacked Commits



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

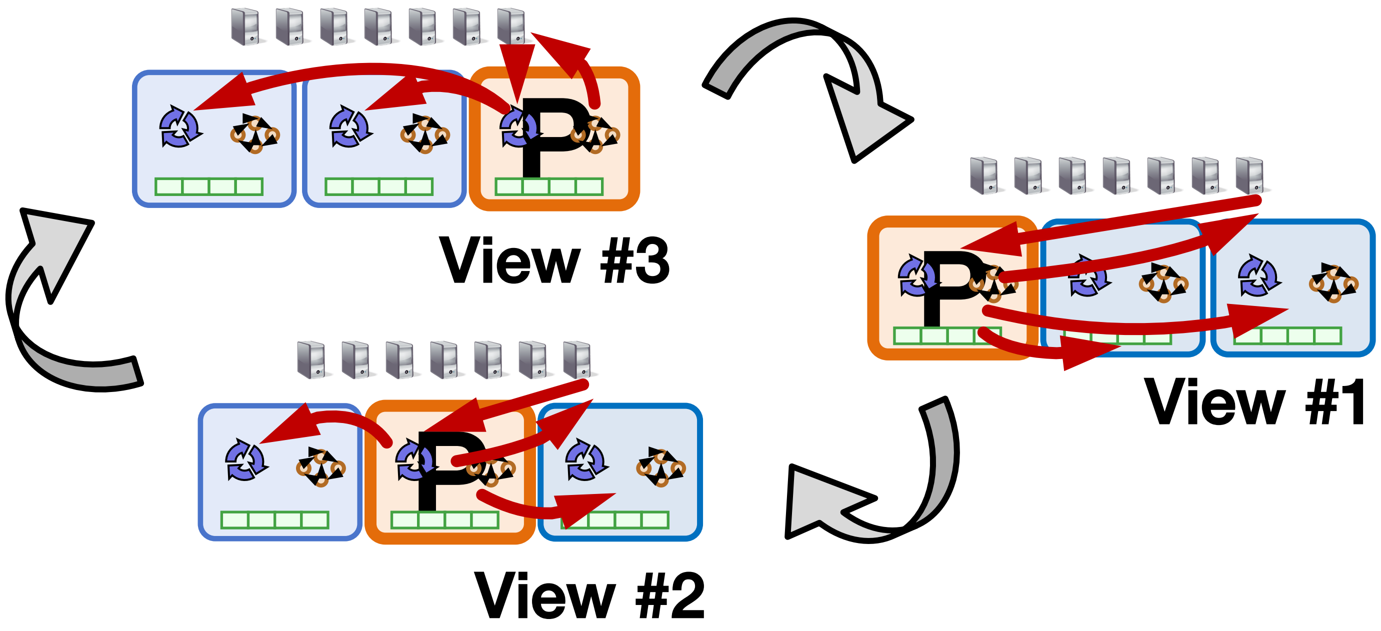
The Need For a View Change

- 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



Views

- Let different replicas assume role of primary over time
- System moves through a sequence of views
  - View = (view number, primary id, backup id, ...)



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

How do replicas agree to move to a new view?

How do replicas agree on what was executed (and in what order) in the old view?

Consensus

- Definition:

1. A general agreement about something
2. An idea or opinion that is shared by all the people in a group

Consensus Used in Systems

Group of servers want to:

- Make sure all servers in group receive the same updates in the same order as each other
- Maintain own lists (views) on who is a current member of the group, and update lists when somebody leaves/fails
- Elect a leader in group, and inform everybody
- Ensure mutually exclusive (one process at a time only) access to a critical resource like a file

Consensus

Given a set of processors, each with an initial value:

- **Termination:** All non-faulty processes eventually decide on a value
- **Agreement:** All processes that decide do so on the same value
- **Validity:** Value decided must have proposed by some process

Safety vs. Liveness Properties

- Safety (bad things never happen)

- Liveness (good things eventually happen)

Paxos

- Safety (bad things never happen)
  - **Agreement:** All processes that decide do so on the same value
  - **Validity:** Value decided must have proposed by some process
- Liveness (good things eventually happen)
  - **Termination:** All non-faulty processes eventually decide on a value

Paxos's Safety and Liveness

- Paxos is always safe
- Paxos is very often live (but not always, more later)
- Also true for Viewstamped Replication, RAFT, and other similar protocols

Roles of a Process in Paxos

- Three conceptual roles
  - Proposers propose values
  - Acceptors accept values, where value is chosen if majority accept
  - Learners learn the outcome (chosen value)

- In reality, a process can play any/all roles

Strawmen

- 3 proposers, 1 acceptor
  - Acceptor accepts first value received
  - No liveness with single failure

- 3 proposers, 3 acceptors
  - Accept first value received, learners choose common value known by majority
  - But no such majority is guaranteed

Paxos

- Each acceptor accepts multiple proposals
  - Hopefully one of multiple accepted proposals will have a majority vote (and we determine that)
  - If not, rinse and repeat (more on this)

- How do we select among multiple proposals?
  - Ordering: proposal is tuple (proposal #, value) = (n, v)
  - Proposal # strictly increasing, globally unique
  - Globally unique?
    - Trick: set low-order bits to proposer's ID

Paxos Protocol Overview

- Proposers:
  1. Choose a proposal number n
  2. Ask acceptors if any accepted proposals with $n_a < n$
  3. If existing proposal v_a returned, propose same value (n, v_a)
  4. Otherwise, propose own value (n, v)

  Note altruism: goal is to reach consensus, not “win”

- Accepters try to accept value with highest proposal n
- Learners are passive and wait for the outcome

Paxos Phase 1

- Proposer:
  - Choose proposal n, send <prepare, n> to acceptors

- Acceptors:
  - If $n > n_h$
    - $n_h = n$ ← promise not to accept any new proposals $n' < n$
    - If no prior proposal accepted
      - Reply < promise, n, Ø >
    - Else
      - Reply < promise, n, (n_a , v_a) >
  - Else
    - Reply < prepare-failed >

Paxos Phase 2

- Proposer:
  - If receive promise from majority of acceptors,
    - Determine v_a returned with highest n_a, if exists
    - Send <accept, (n, v_a || v)> to acceptors

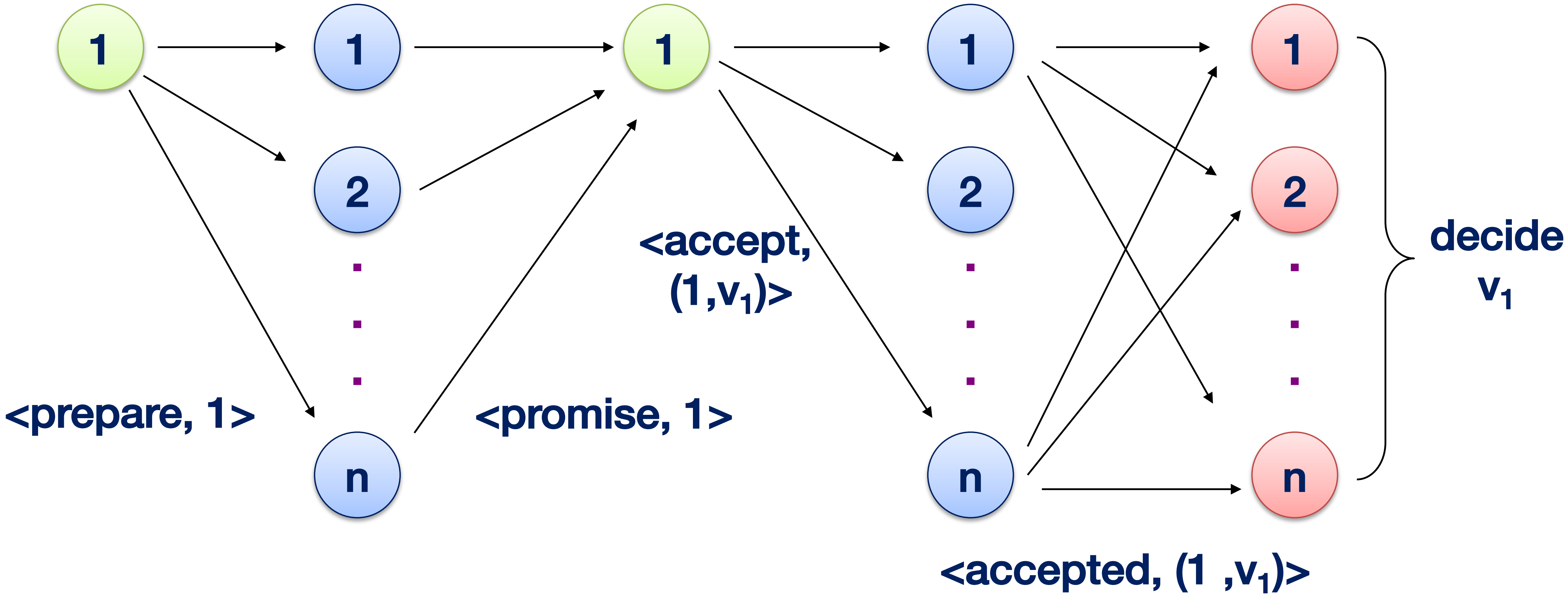
- Acceptors:
  - Upon receiving (n, v), if $n \geq n_h$,
    - Accept proposal and notify learner(s)

$$n_a = n_h = n$$
$$v_a = v$$

Paxos Phase 3

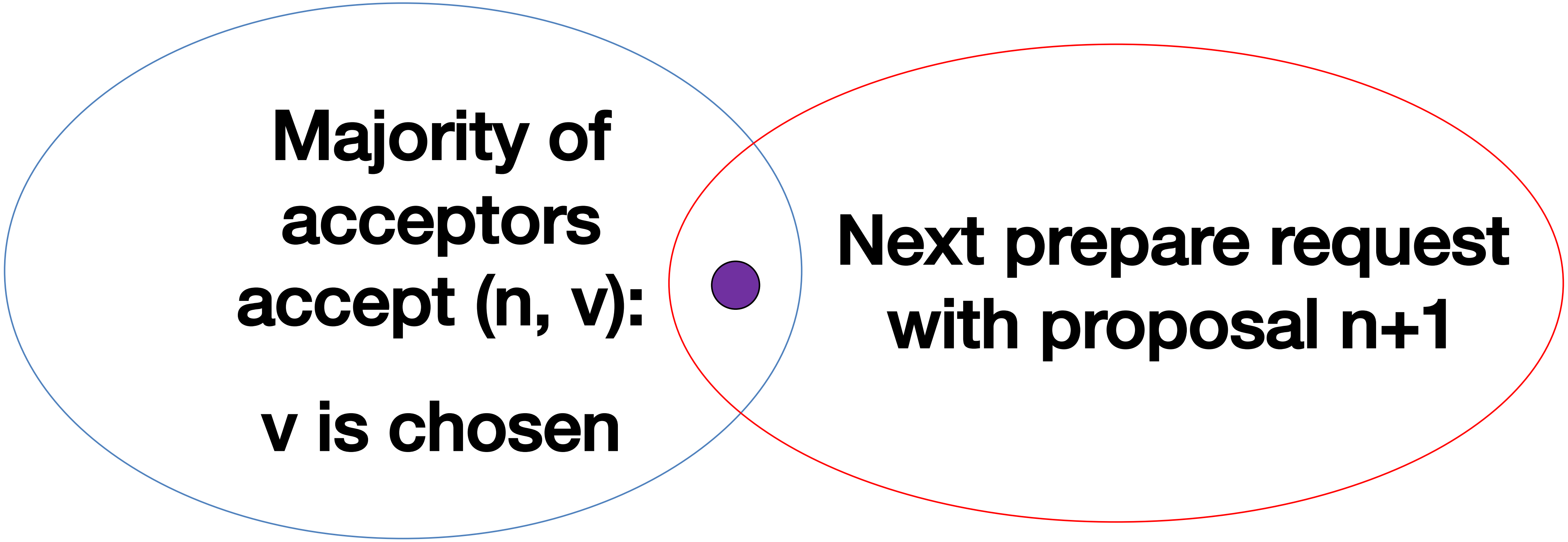
- Learners need to know which value chosen
- Approach #1
  - Each acceptor notifies all learners
  - More expensive
- Approach #2
  - Elect a “distinguished learner”
  - Acceptors notify elected learner, which informs others
  - Failure-prone

Paxos: Well-behaved Run



Paxos is Safe

- Intuition: if proposal with value v chosen, then every higher-numbered proposal issued by any proposer has value v.



Often, but not always, live

Process 0

Process 1

Completes phase 1 with proposal n0

Starts and completes phase 1 with proposal n1 > n0

Performs phase 2, acceptors reject

Restarts and completes phase 1 with proposal n2 > n1

Performs phase 2, acceptors reject

… can go on indefinitely …

Paxos Summary

- Described for a single round of consensus
- Proposer, Acceptors, Learners
  - Often implemented with nodes playing all roles
- Always safe: Quorum intersection
- Very often live
- Acceptors accept multiple values
  - But only one value is ultimately chosen
- Once a value is accepted by a majority it is chosen

Flavors of Paxos

- Terminology is a mess
- Paxos loosely and confusingly defined…

- We'll stick with
  - Basic Paxos
  - Multi-Paxos

Flavors of Paxos: Basic Paxos

- Run the full protocol each time
  - e.g., for each slot in the command log

- Takes 2 rounds until a value is chosen

Flavors of Paxos: Multi-Paxos

- Elect a leader and have them run 2nd phase directly
  - e.g., for each slot in the command log
  - Leader election uses Basic Paxos
- Takes 1 round until a value is chosen
  - Faster than Basic Paxos
- Used extensively in practice!
  - RAFT is similar to Multi Paxos