View Change Protocols and Consensus

COS 418/518: Distributed Systems
Lecture 12

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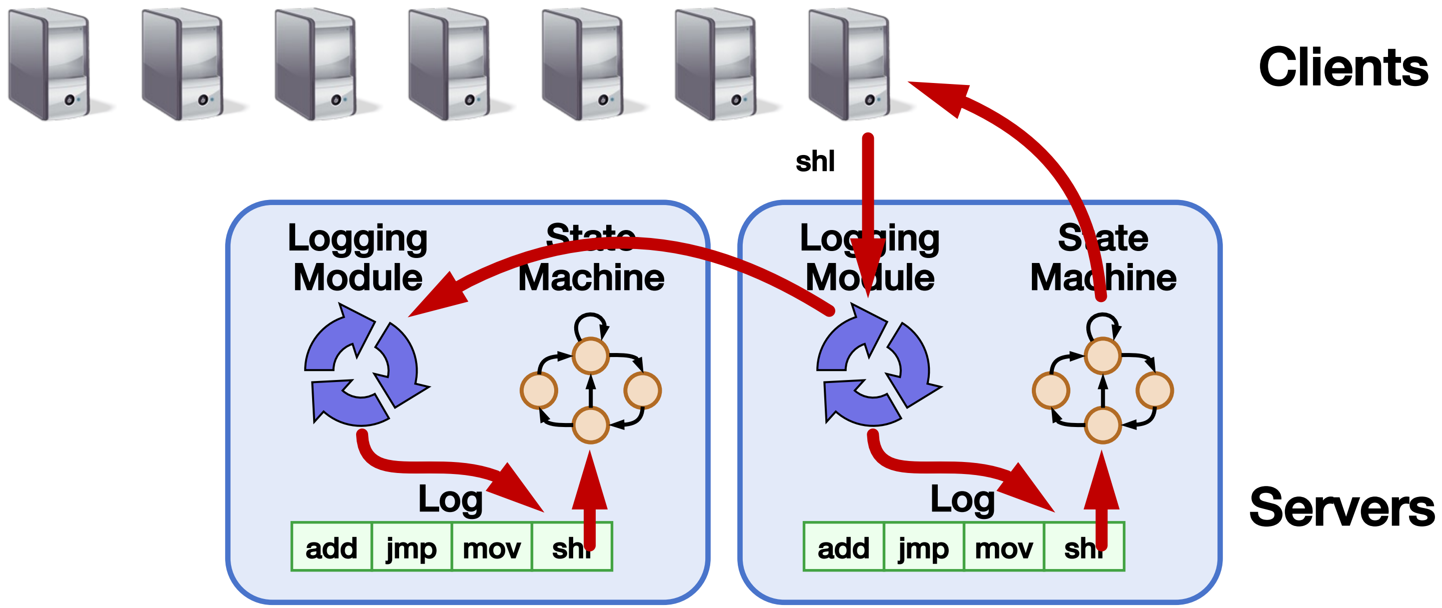
Today

1. From primary-backup to viewstamped replication

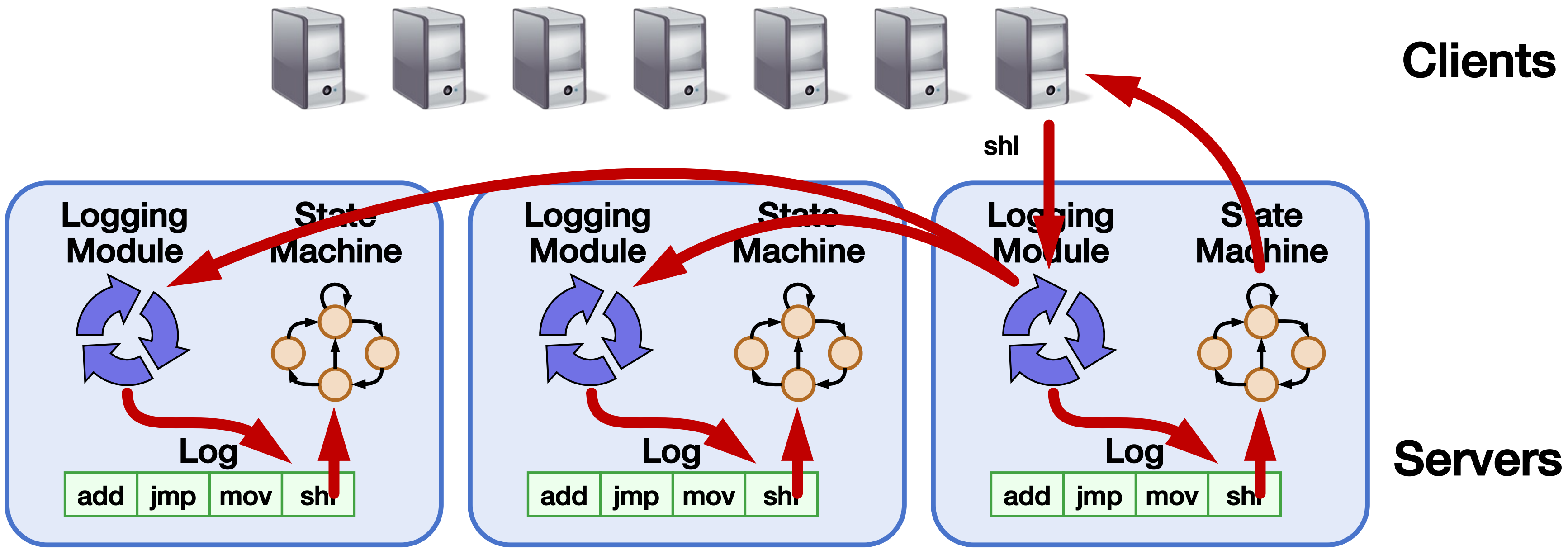
2. Consensus

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

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
  - Don’t need to wait for **all** replicas to reply

Replica State

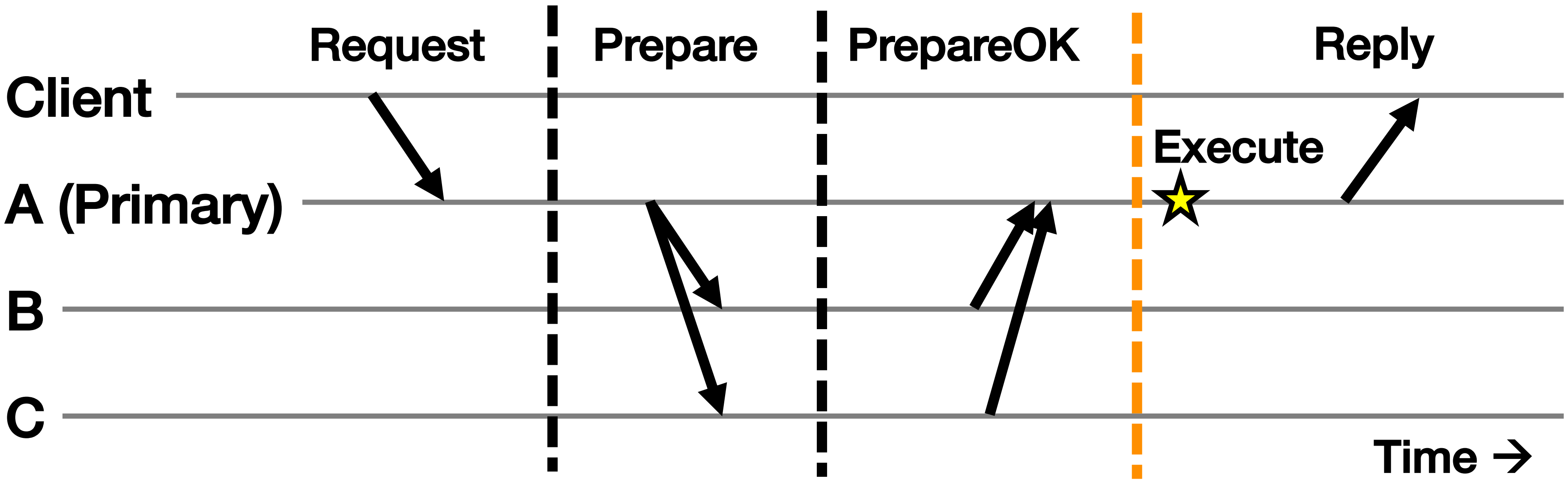
1. Configuration: identities of all 2f + 1 replicas

2. Log with clients' requests in assigned order

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

Normal Operation

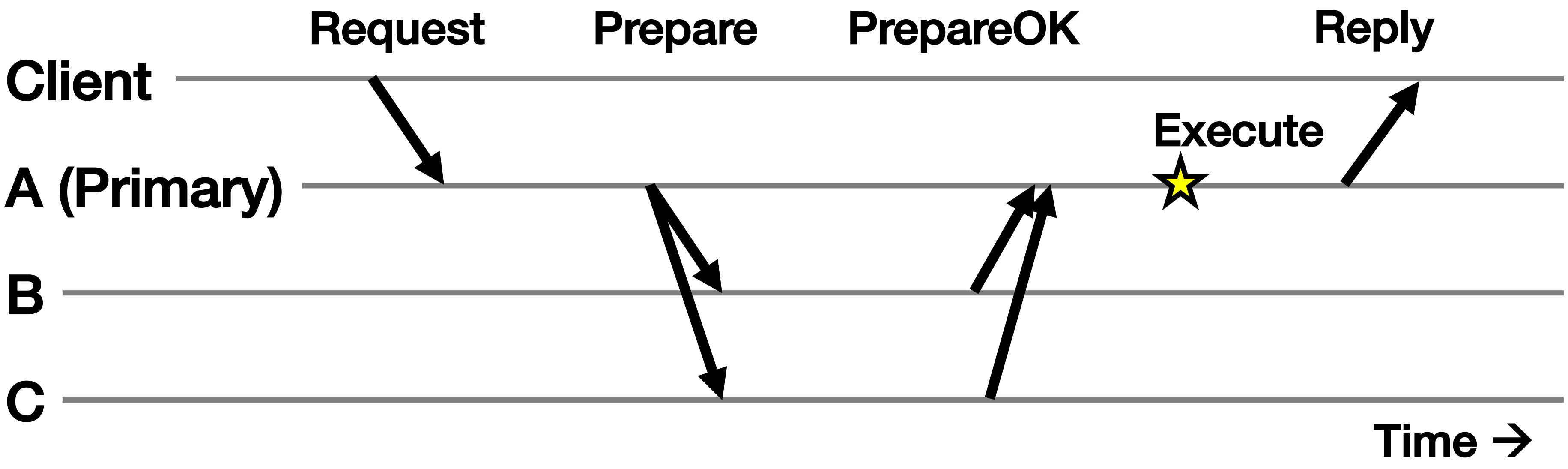
(f = 1)



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

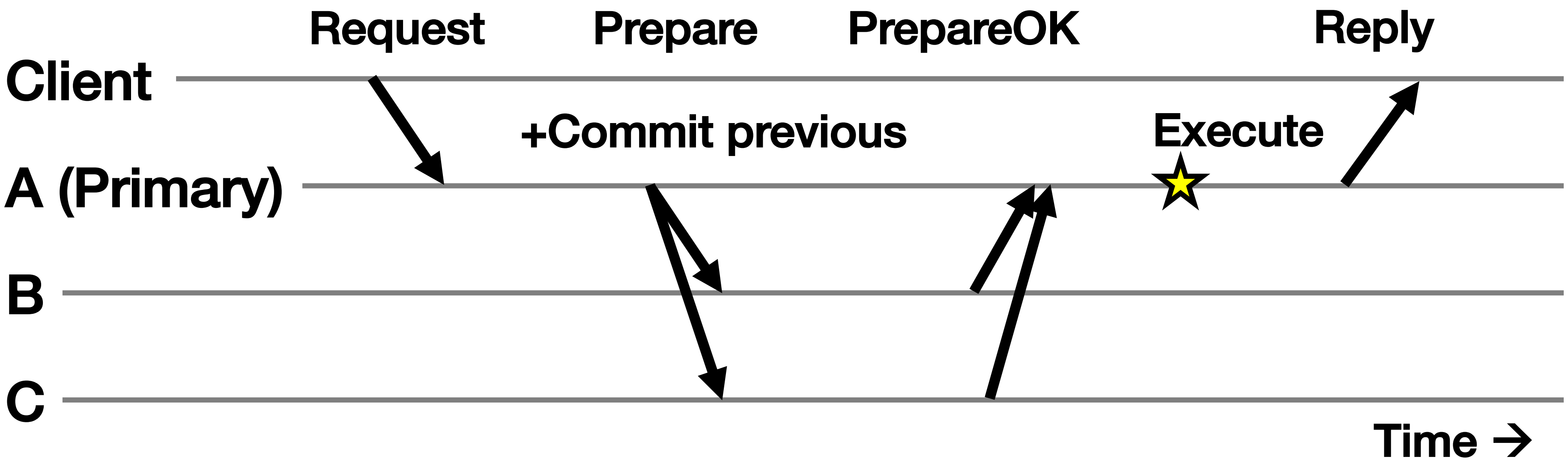
(f = 1)



- 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

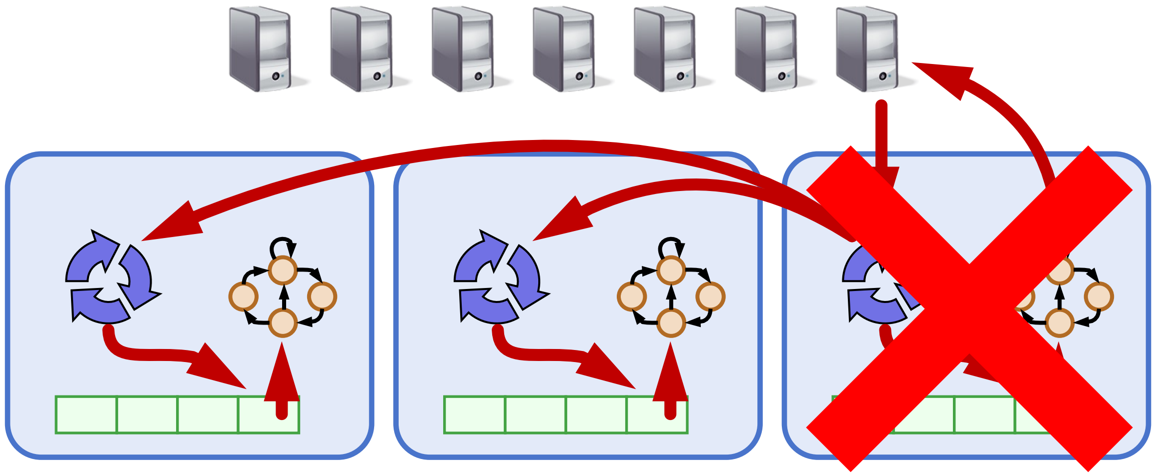
(f = 1)



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

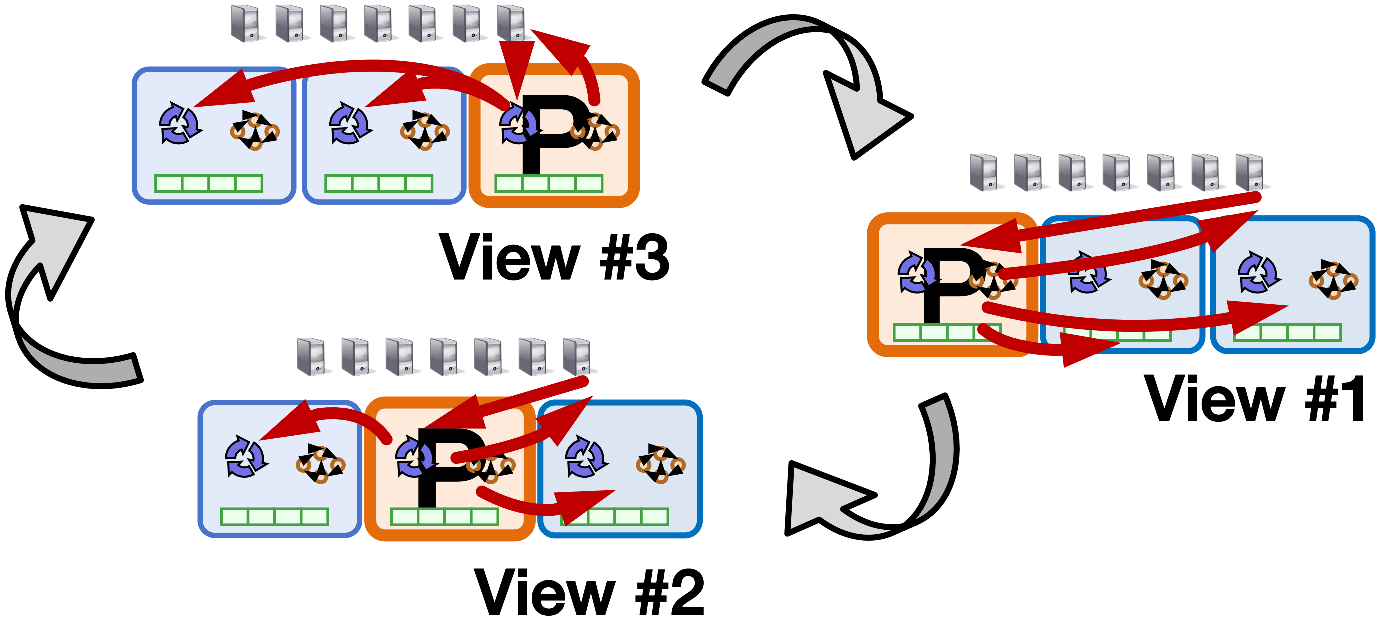
The Need For a View Change

- 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



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

- 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

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

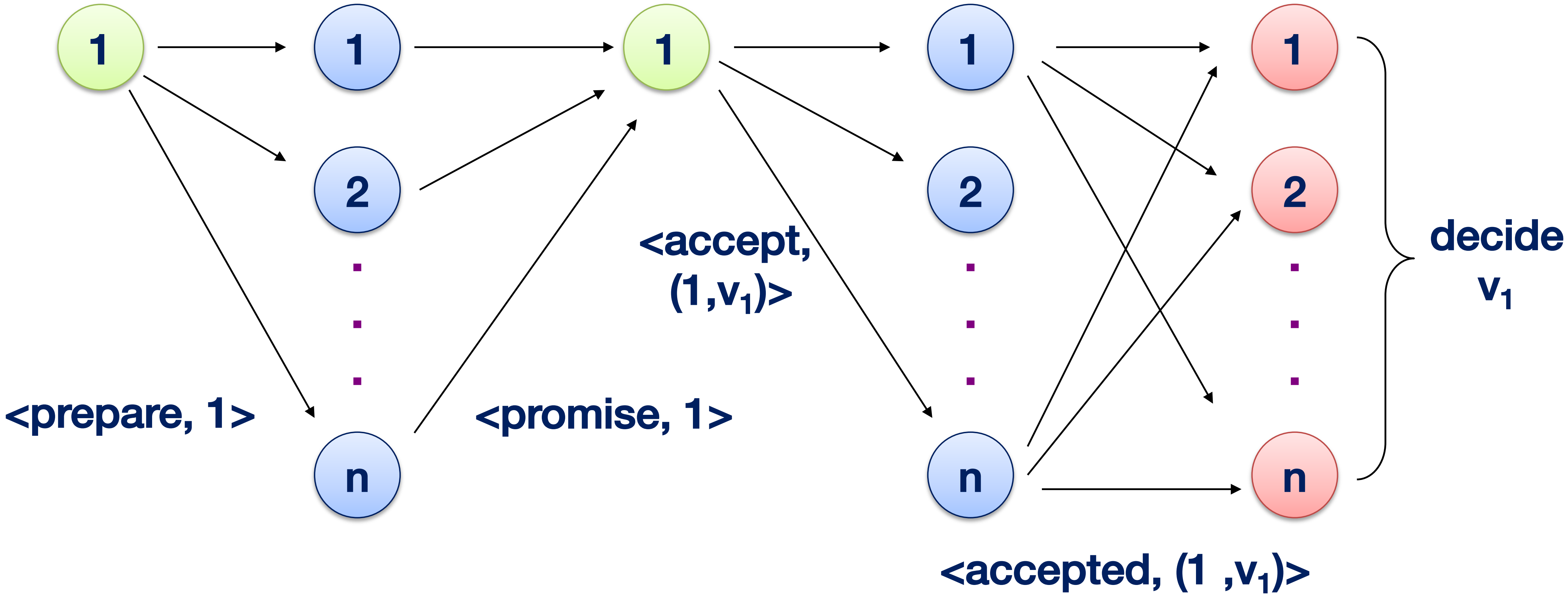
- Proposer:
  - If receive promise from majority of acceptors,
    - Determine v_a returned with highest n_a, if exists
    - Send <accept, (n, v_a || v)> to acceptors

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

Paxos Phase 3

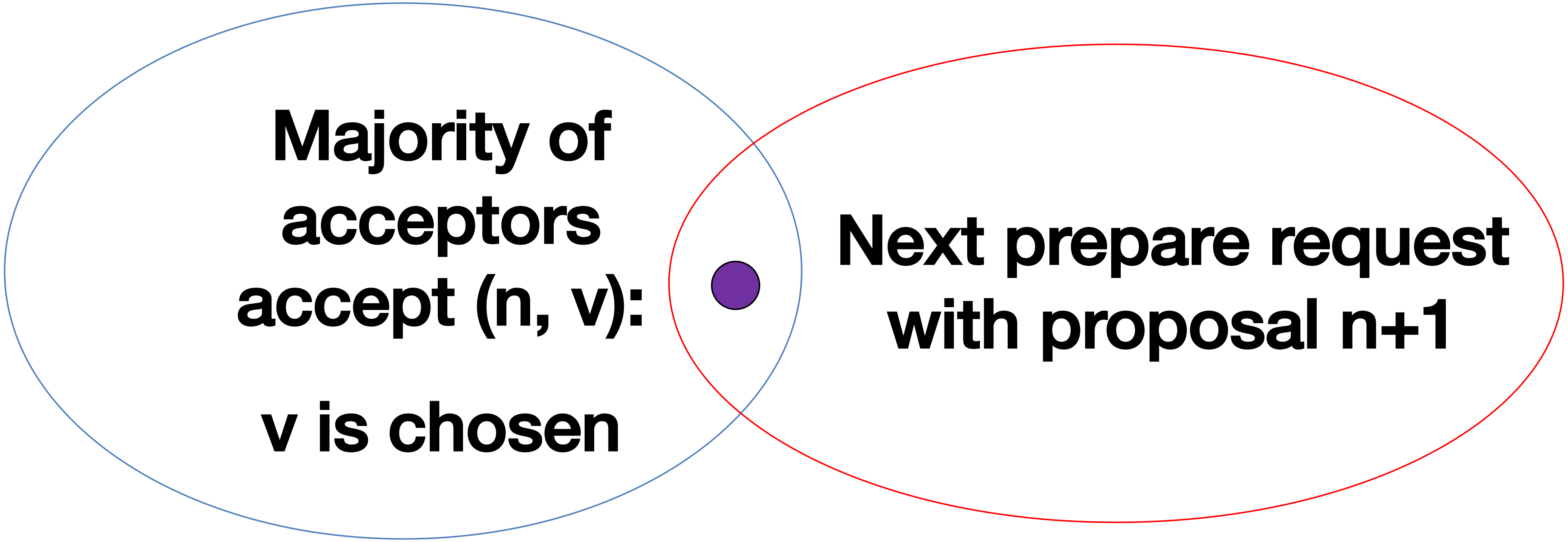
- Learners need to know which value chosen
- Approach #1
  - Each acceptor notifies all learners
  - More expensive
- Approach #2
  - Elect a "distinguished learner"
  - Acceptors notify elected learner, which informs others
  - Failure-prone

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

Completes phase 1 with proposal n0

Performs phase 2, acceptors reject

Restarts and completes phase 1 with proposal n2 > n1

Process 1

Starts and completes phase 1 with proposal n1 > n0

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