Consensus and Paxos

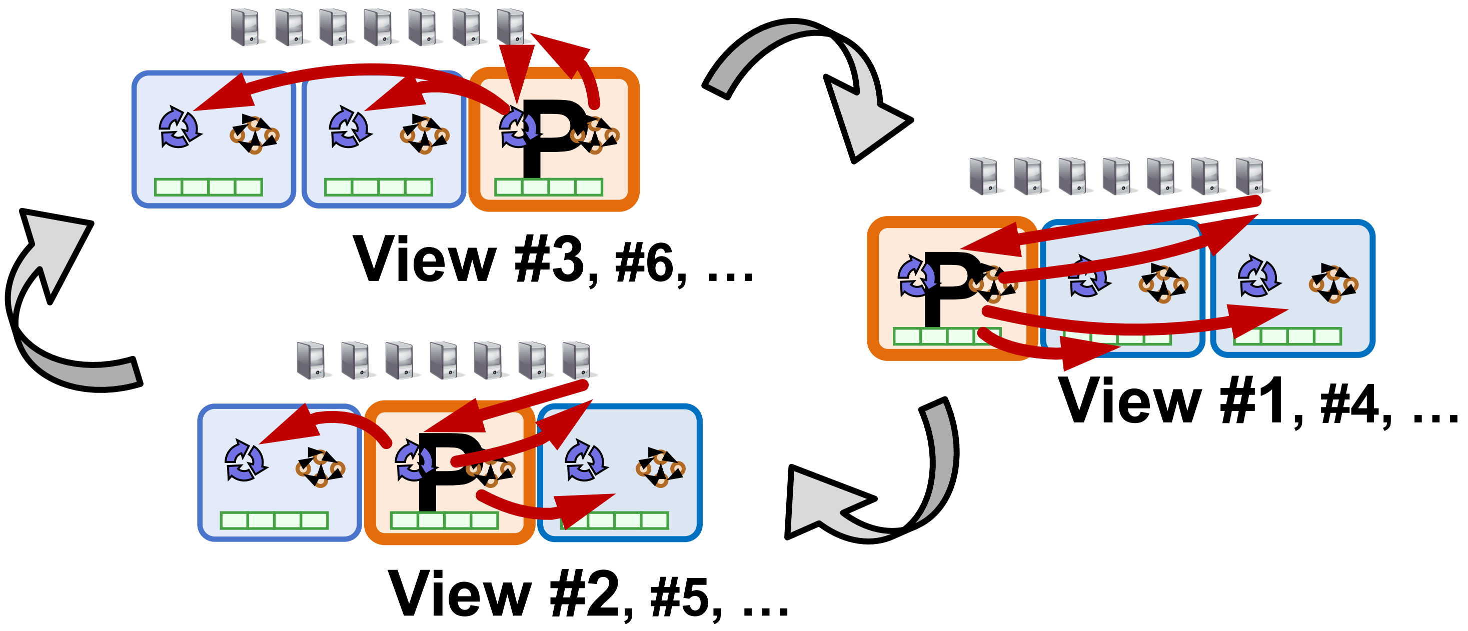
جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

CS 240: Computing Systems and Concurrency
Lecture 13

Marco Canini

Recall the use of Views

- Let different replicas assume role of primary over time
- **How do the nodes agree on view / primary?**
- **What if both backup nodes attempt to become the new primary simultaneously?**



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 attempting:

- 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 processes, 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:** The value that has been decided must have been proposed by some process

Recall: Safety vs liveness properties

Safety (bad things never happen)

Liveness (good things eventually happen)

Consensus

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

- **Termination:** All non-faulty processes eventually decide on a value ← Good thing that eventually should happen

- **Agreement:** All processes that decide do so on the same value ← Bad thing that should never happen

- **Validity:** The value that has been decided must have been proposed by some process ← Bad thing that should never happen

Paxos properties

Safety

- Only a single value is chosen ← **agreement**
- Only chosen values are learned by processes
- Only a proposed value can be chosen ← **validity**

Liveness

- Some proposed value eventually chosen if fewer than half of processes fail
- If value is chosen, a process eventually learns it

termination

Paxos' safety and liveness

- Paxos is always safe

- Paxos is very often live
  - But not always, more later

Roles of a process

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

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

Strawman

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

- 3 proposals, 3 acceptors
  - Accept first value received, acceptors 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”

- Acceptors try to accept value with highest proposal n

- Learners are passive and wait for the outcome

Paxos Phase 1

- Proposer:
  - Choose proposal number 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 <accept, (n, v)>, if $n \geq n_h$,
    - Accept proposal and notify learner(s)

      $n_a = n_h = n$

      $v_a = v$

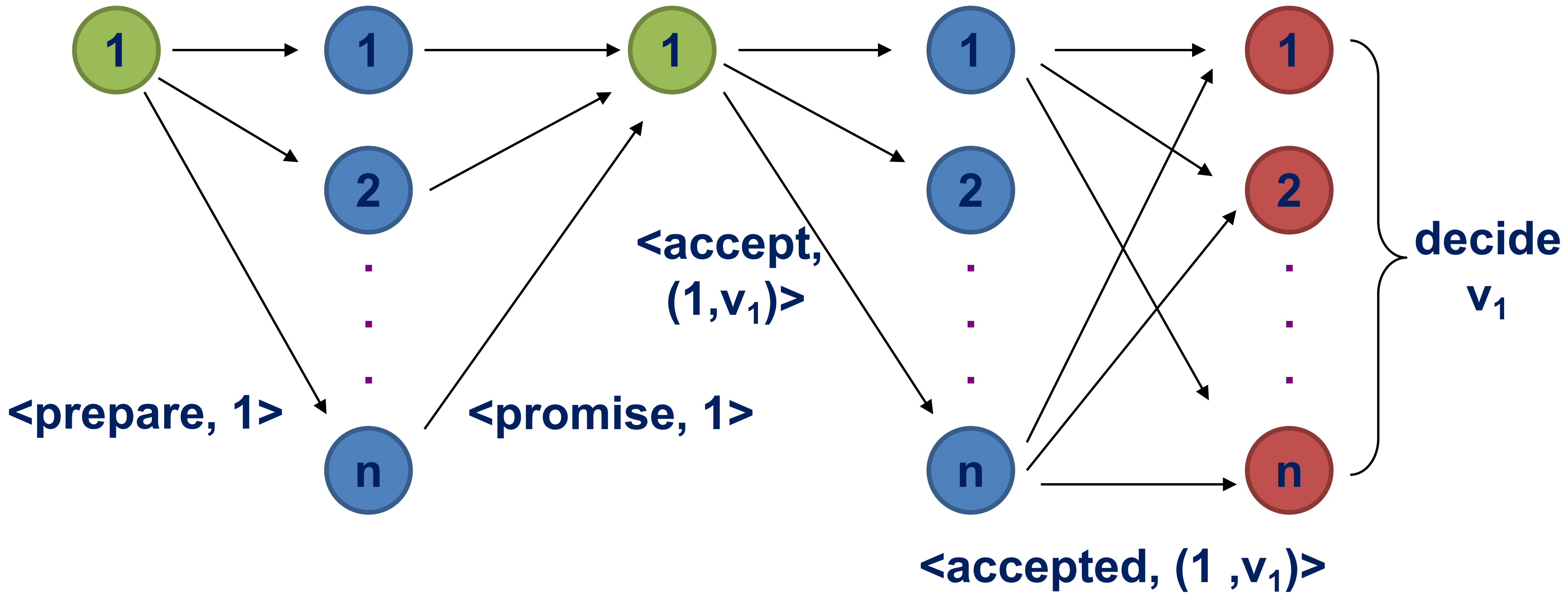
Paxos Phase 3

- Learners need to know which value chosen

- Approach #1
  - Each acceptor notifies all learners
  - More expensive

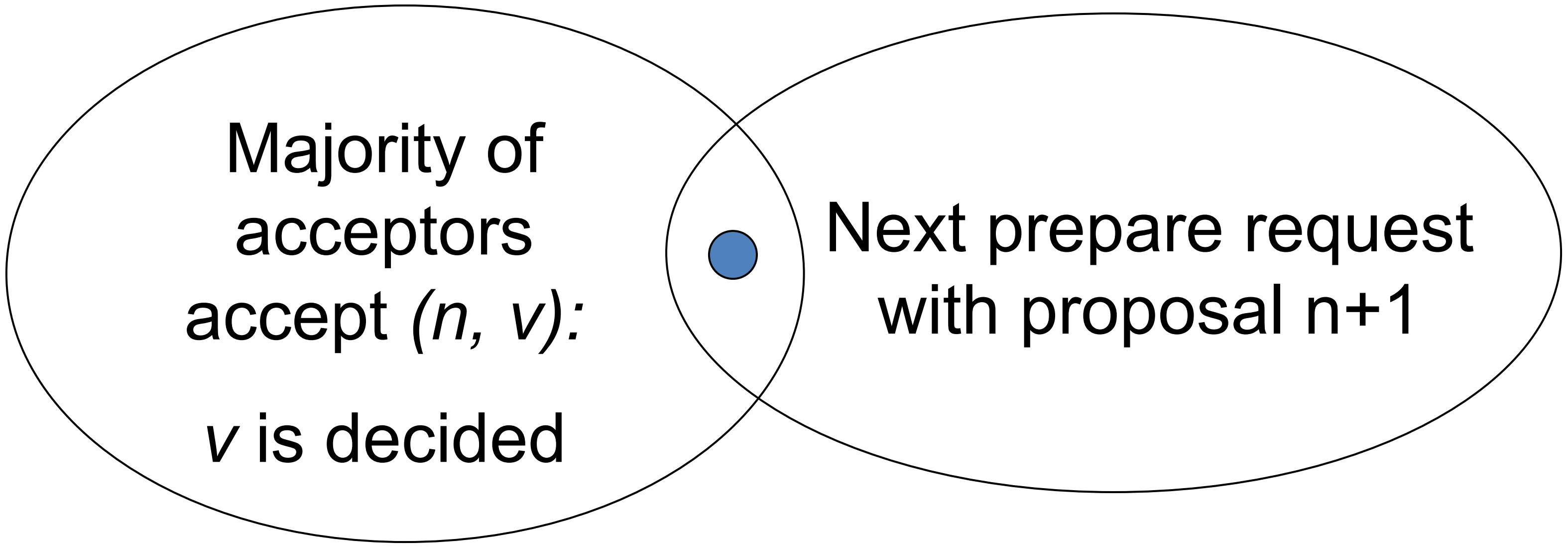
- Approach #2
  - Elect a “distinguished learner”
  - Acceptors notify elected learner, which informs others
  - Failure-prone

Paxos: Well-behaved Run

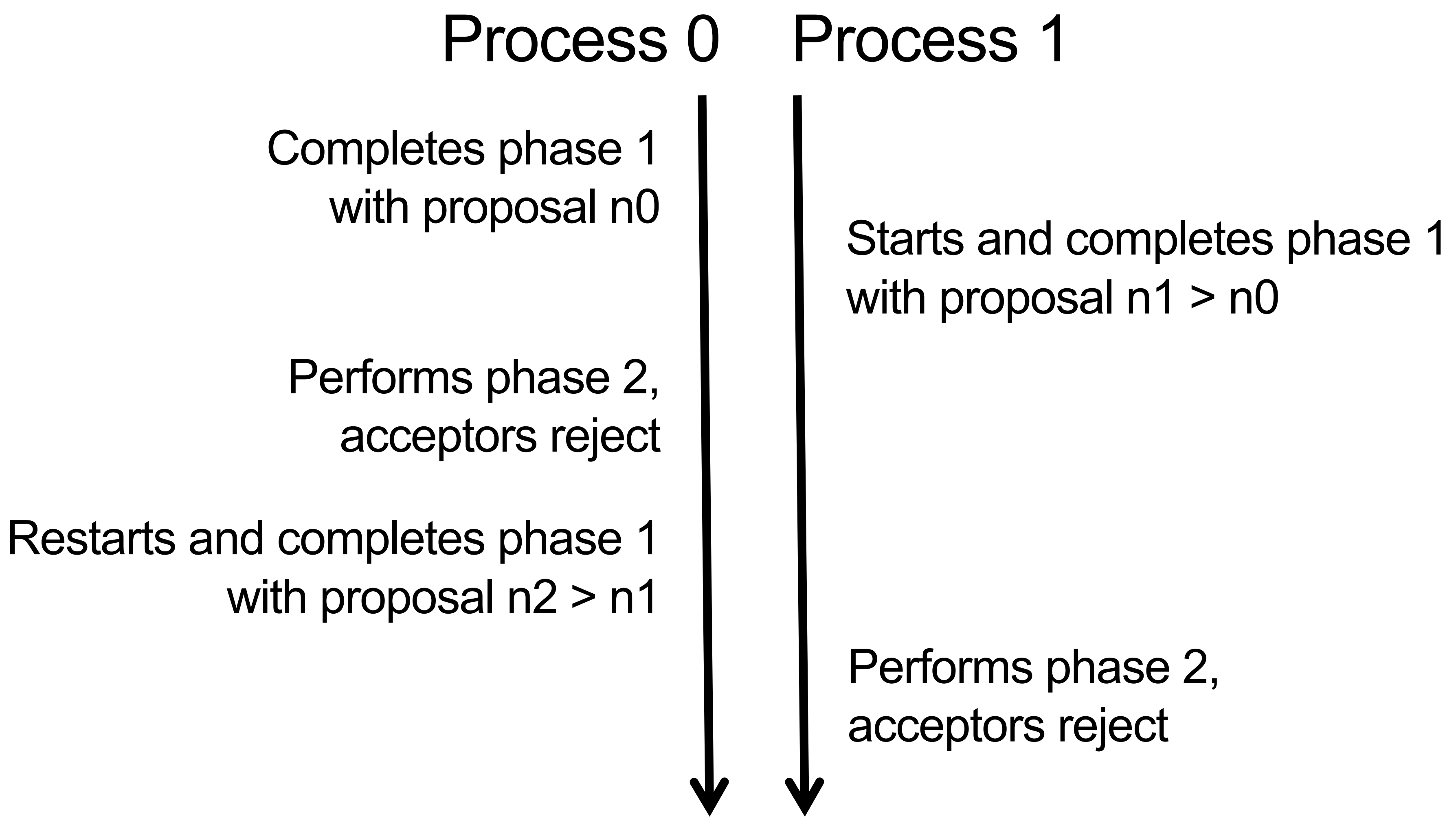


Paxos is safe

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


Majority of acceptors accept *(n, v):*
v is decided
Next prepare request with proposal n+1

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
- Can tolerate failures $f < N / 2$ (aka, 2f+1 nodes)

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 it run the 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