Distributed Systems: Paxos

Burcu Canakci & Matt Burke

Outline

1. Consensus
2. The Part-Time Parliament
3. Single-Decree Paxos
4. Liveness
5. Multi-Decree Paxos
6. Paxos Variants
7. Conclusion

Outline

1. **Consensus**
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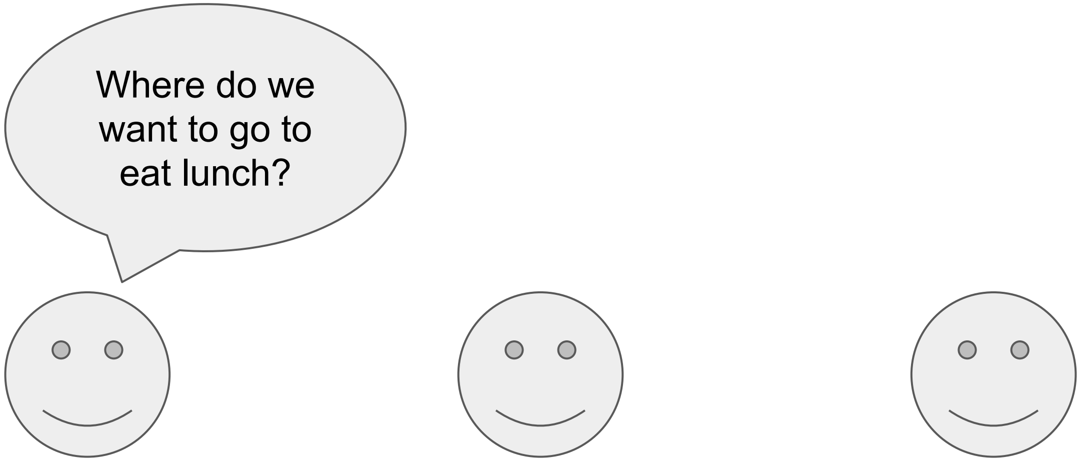
What is consensus?



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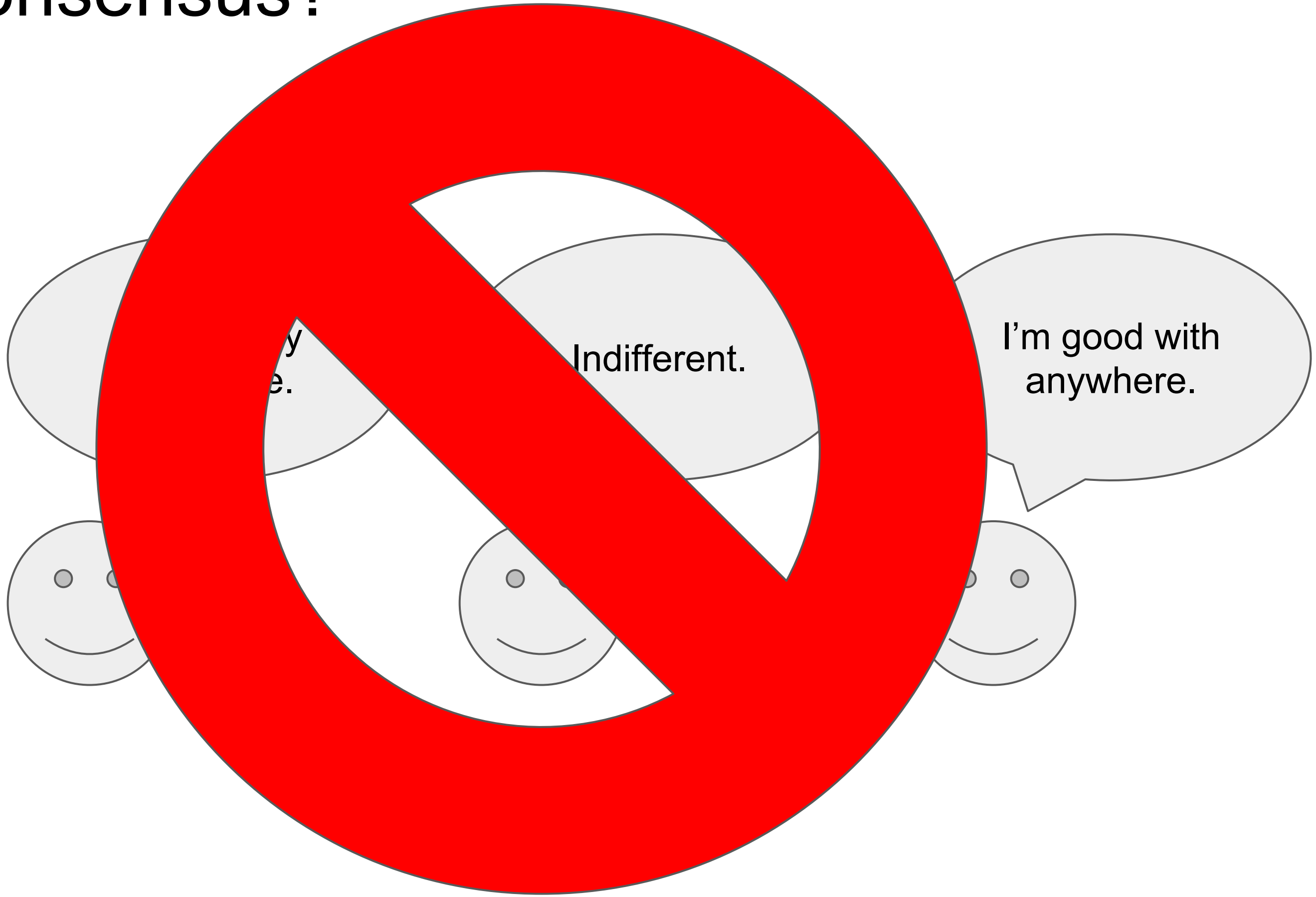

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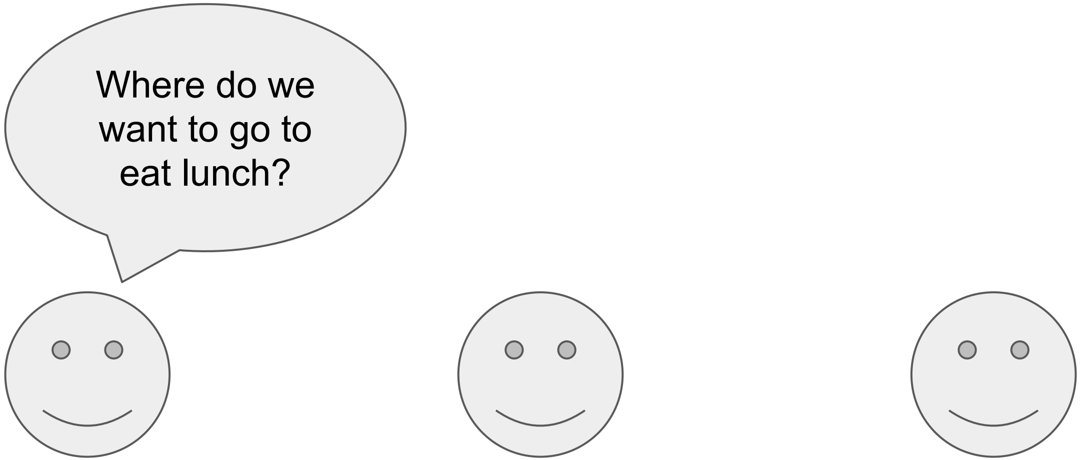

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Consensus is the problem of getting a set of processors to agree on some value.

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More formally, *consensus* is the problem of satisfying the following properties:

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- Agreement
- Integrity
- Termination

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Termination: Every correct learning process eventually learns some decided value

Assumption about our model

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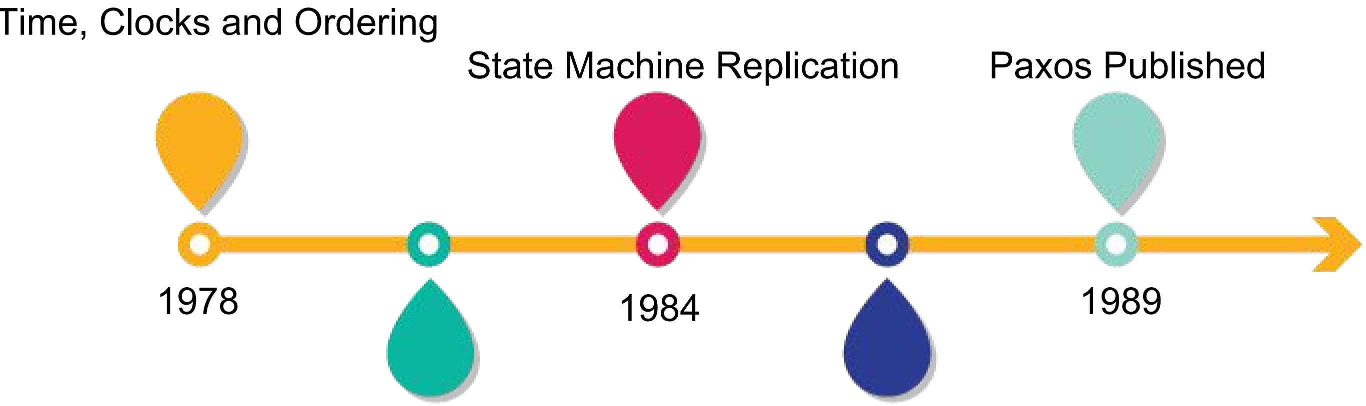
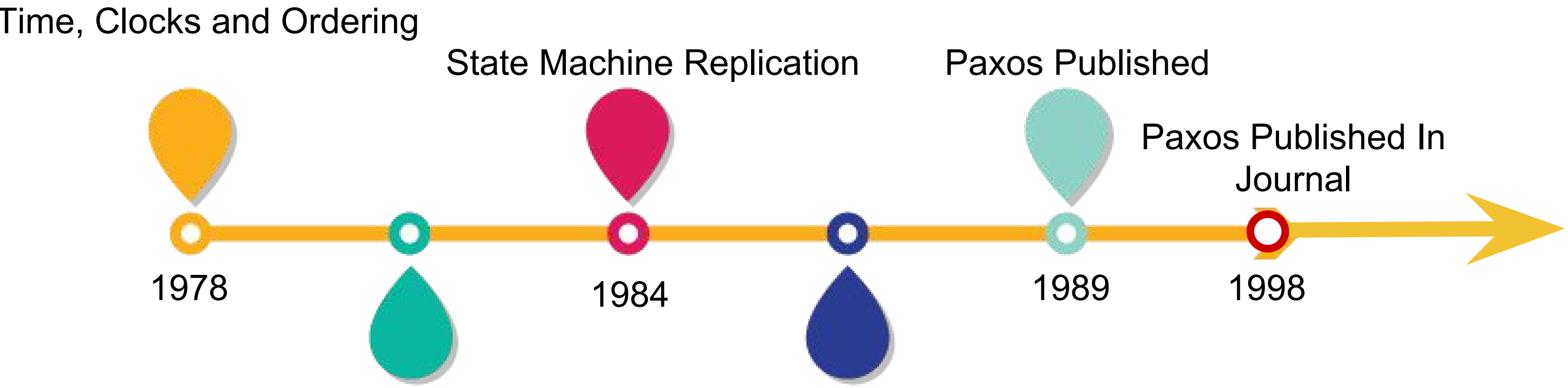
- Processes can only fail by **crashing**
  - No indication of failure; simply stops responding to messages
  - Failed processes cannot arbitrarily transition or send arbitrary messages

Timeline


Time, Clocks and Ordering
State Machine Replication
Paxos Published
1978
1984
1989

Timeline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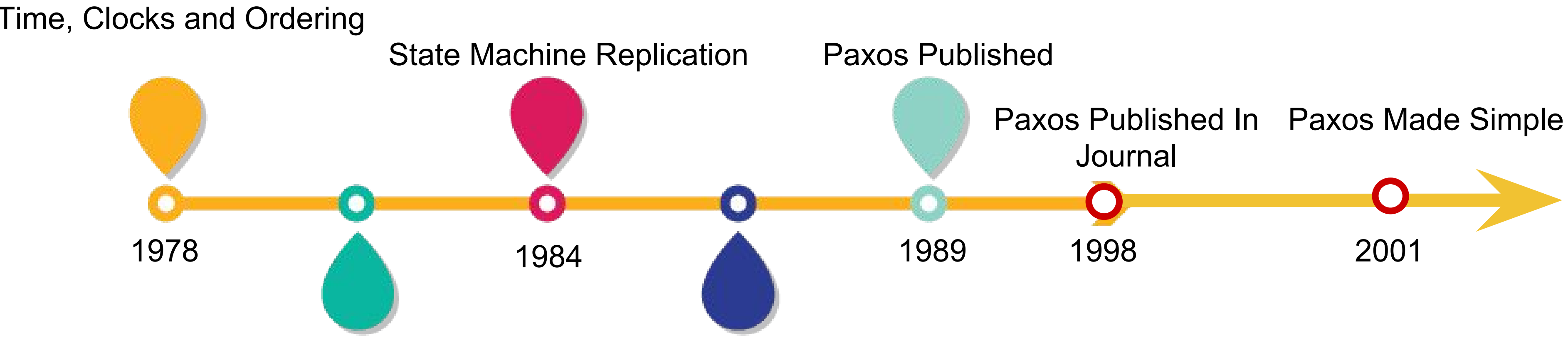
Time, Clocks and Ordering
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Paxos Made Simple
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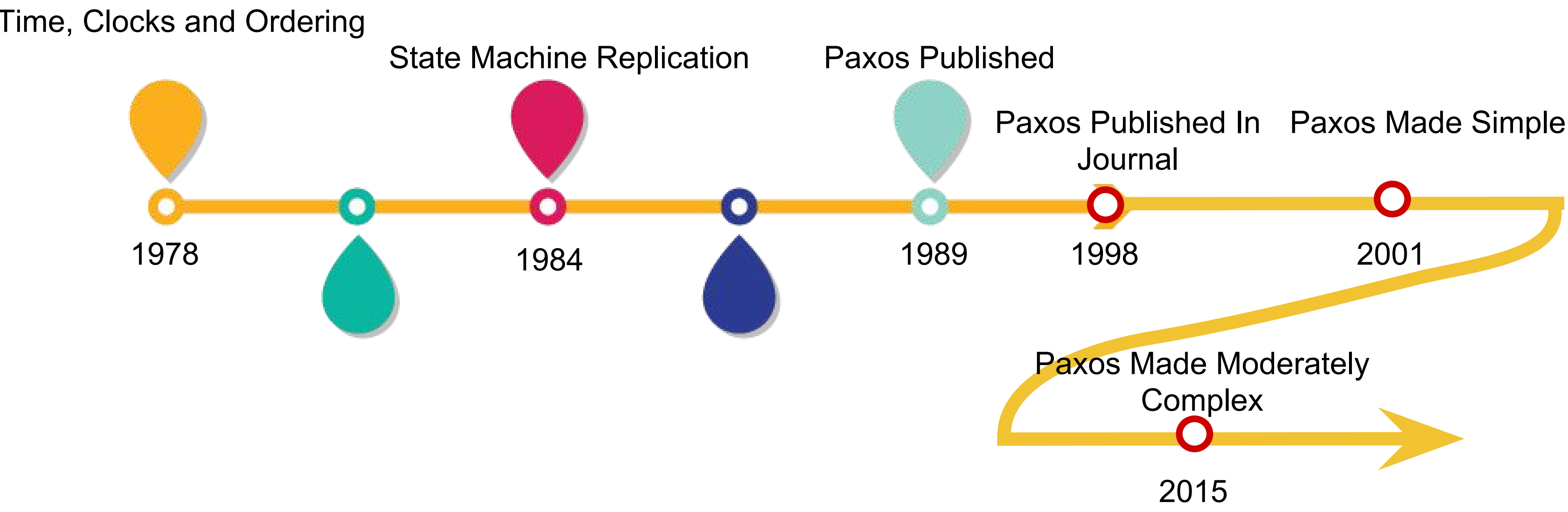
Timeline



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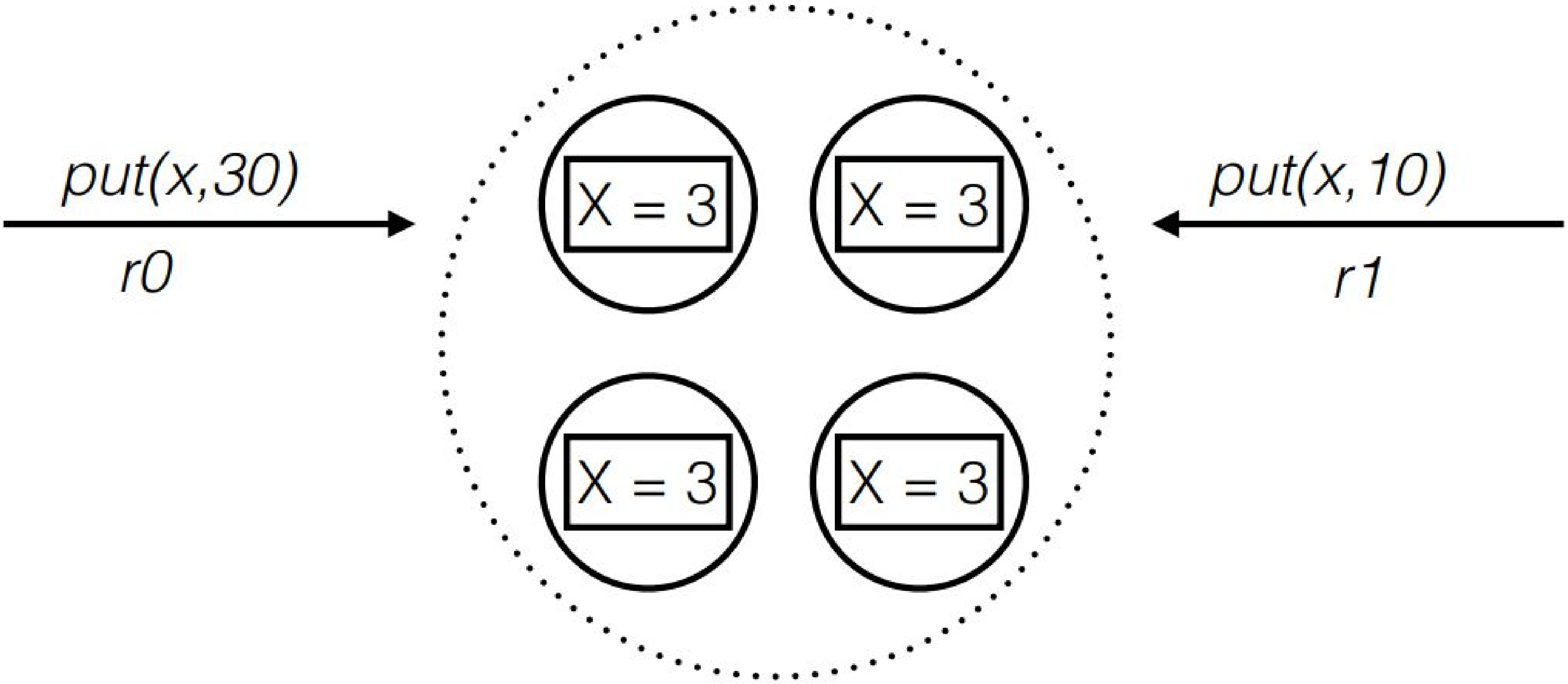
2001
Paxos Made Moderately Complex
2015

Recall the Consensus Problem in the State Machine Approach



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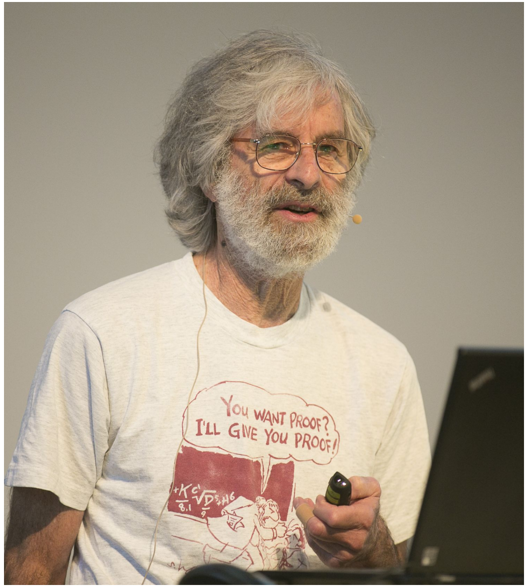
The Part-Time Parliament

- The Part-Time Parliament (1998)

  Recent archaeological discoveries on the island of Paxos reveal that the parliament functioned despite the peripatetic propensity of its part-time legislators. The legislators maintained consistent copies of the parliamentary record, despite their frequent forays from the chamber and the forgetfulness of their messengers. The Paxon parliament's protocol provides a new way of implementing the state machine approach to the design of distributed systems.



Leslie Lamport

The Part-Time Parliament

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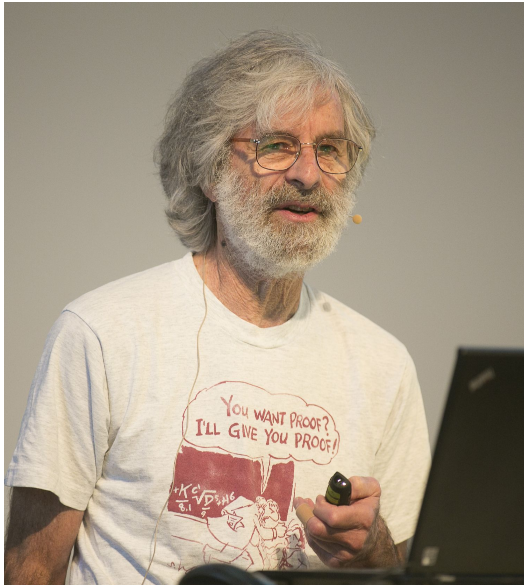
- Paxos Made Simple (2001)

  The Paxos algorithm, when presented in plain English, is very simple.



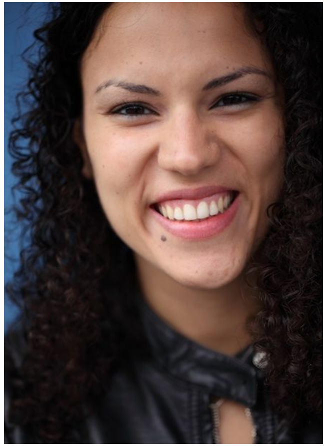
Leslie Lamport

Paxos Made Moderately Complex

- Paxos Made Moderately Complex (2015)

  This article explains the full reconfigurable multidecree Paxos (or multi-Paxos) protocol. Paxos is by no means a simple protocol, even though it is based on relatively simple invariants. We provide pseudocode and explain it guided by invariants.

Robbert Van Renesse



Deniz Altinbuken

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Roles in Protocol

- Validity
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- Agreement
  - If a correct deciding process decides v, then all correct deciding processes eventually decide v
- Integrity
  - Every correct deciding process decides at most one value, and if it decides v, then some process must have proposed v
- Termination
  - Every correct learning process eventually learns some decided value

Roles in Protocol

Proposers

Acceptors

Learners

- Validity
  - If all processes that **propose** a value **propose** v, then all correct **deciding** processes eventually **decide** v
- Agreement
  - If a correct **deciding** process **decide**s v, then all correct **deciding** processes eventually **decide** v
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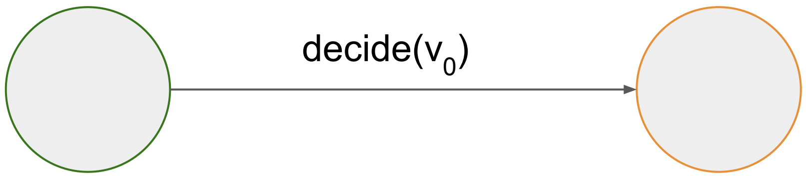
  - ery correct **deciding** proces **es** at most one value, and if **es** v, then some process must have **propose**d v
- Termination
  - Every correct **learning** process eventually **learn**s some **decided** value

Constructing a Protocol

Proposer	Acceptor
Do nothing	Let $v_{decided} = v_0$ and send decide(v_0) to learners

Constructing a Protocol

Integrity: Every correct deciding process decides at most one value, and if it decides v, then some process must have proposed v



Constructing a Protocol

Proposer

When have value v to propose

- Send propose(v) to acceptors

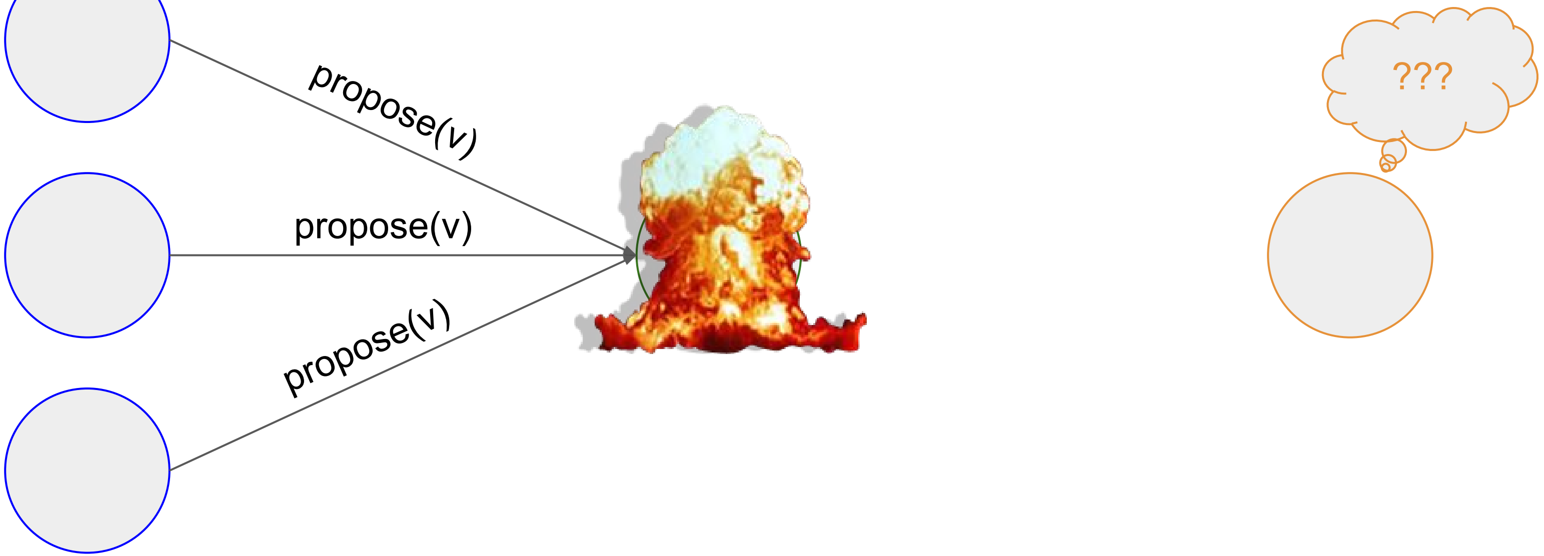
Acceptor

On receive propose(v)

- If not yet decided, let $v_{decided}$ = v and send decide(v) to learners

Constructing a Protocol

Termination: Every correct learning process eventually learns some decided value



Constructing a Protocol

Proposer

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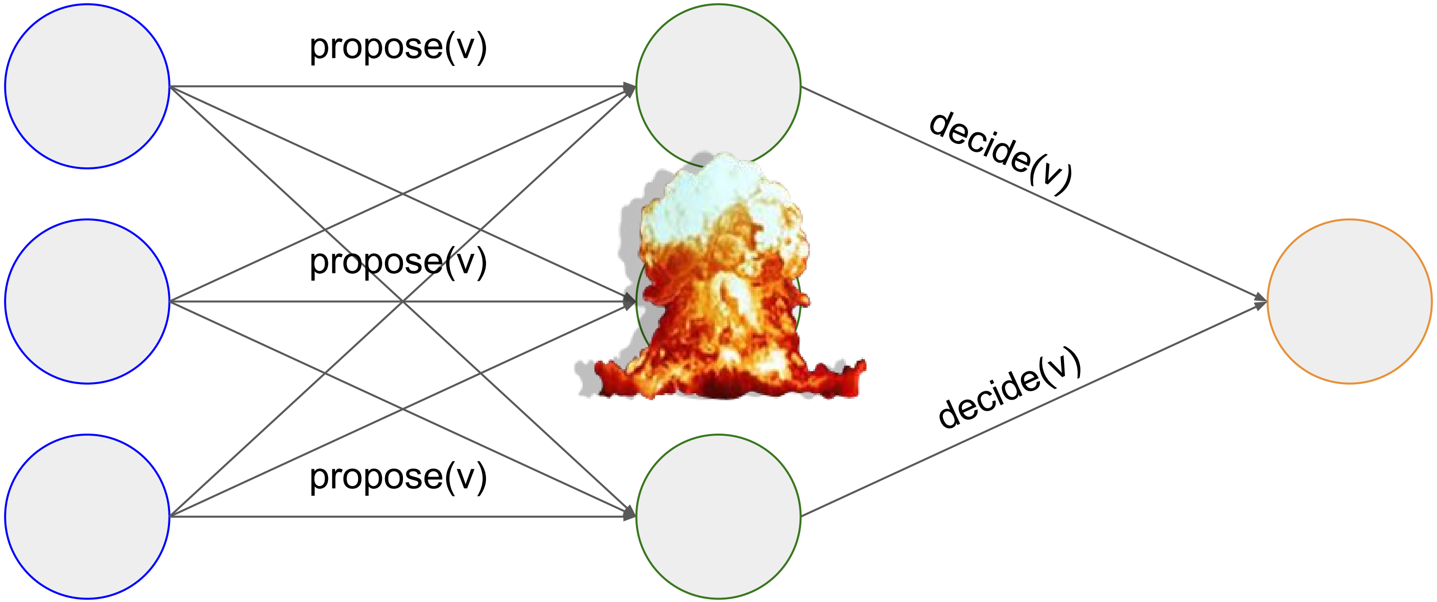
When majority of correct acceptors have decided v

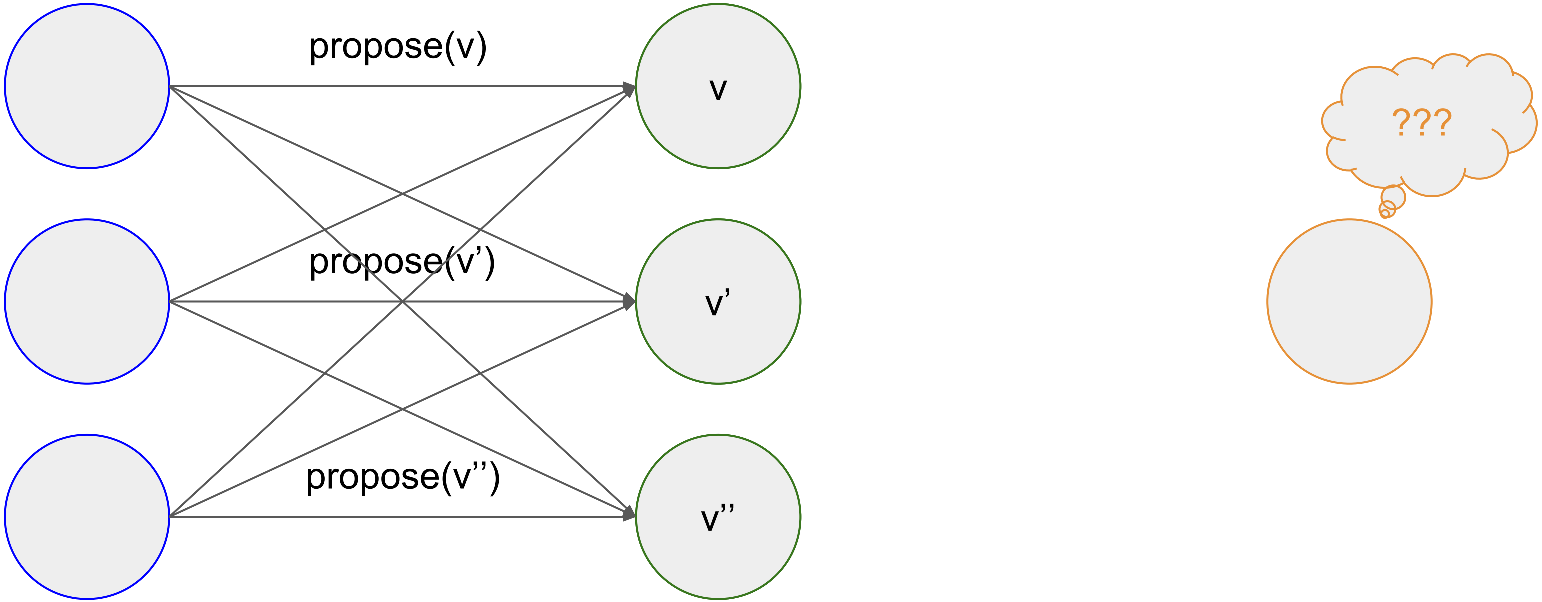
- Send decide(v) to learners

Constructing a Protocol



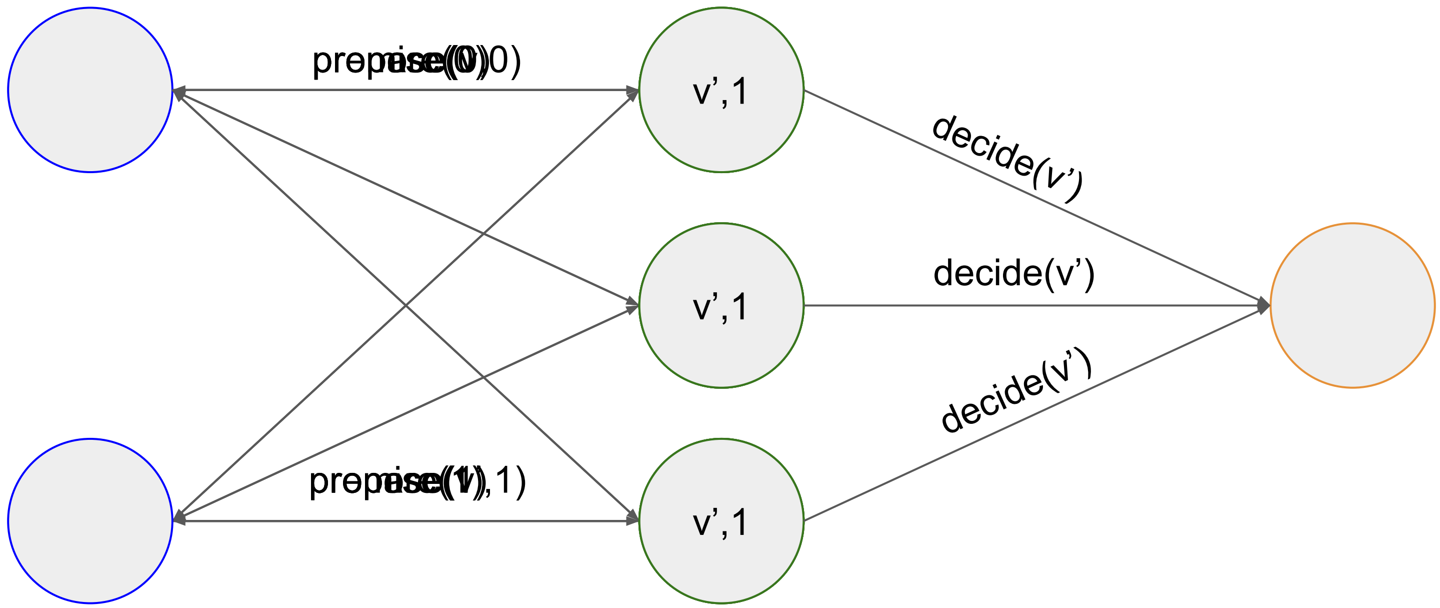
Constructing a Protocol

Agreement: If a correct deciding process decides v, then all correct deciding processes eventually decide v



Constructing a Protocol

Ballot number: unique natural number associated with each proposal made by any proposer



Constructing a Protocol

Proposer

When have value v to propose

- Send prepare(b) to acceptors, where b is the highest ballot number not yet used that is known to the proposer

When have majority of acceptors' promises for proposal b

- Send propose(v,b) to acceptors

Acceptor

On receive prepare(b)

- If $b > b_{promised}$, let $b_{promised} = b$ and respond with promise(b)

On receive propose(v,b)

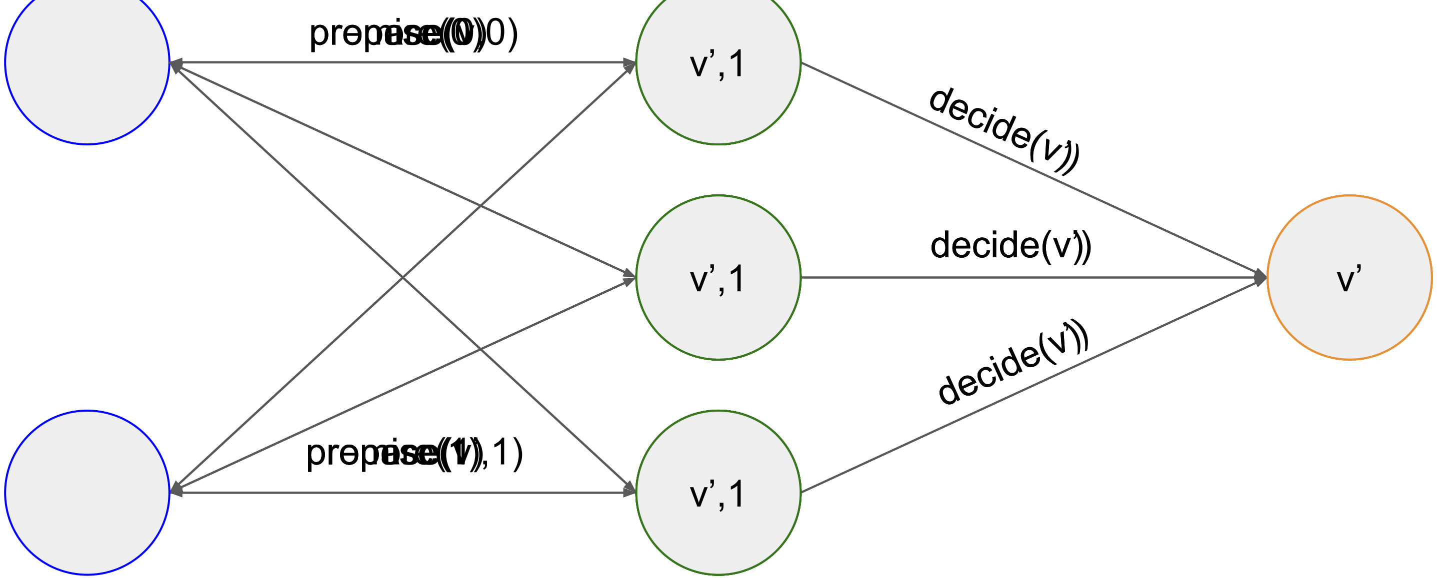
- If $b = b_{promised}$, let $v_{decided} = v$

When majority of correct acceptors have decided v

- Send decide(v) to learners

Constructing a Protocol

Integrity: Every correct deciding process decides at most one value, and if it decides v, then some process must have proposed v



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- Send propose(v,b) to acceptors, where v is the value of the highest accepted proposal, or any value if no proposal accepted

Acceptor

On receive prepare(b)

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Constructing ~~a Protocol~~ Paxos

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When majority of correct acceptors have decided v

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Liveness

- Something good eventually happens
    - Progress is made
        - An action is always eventually executed

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Does Paxos guarantee liveness?

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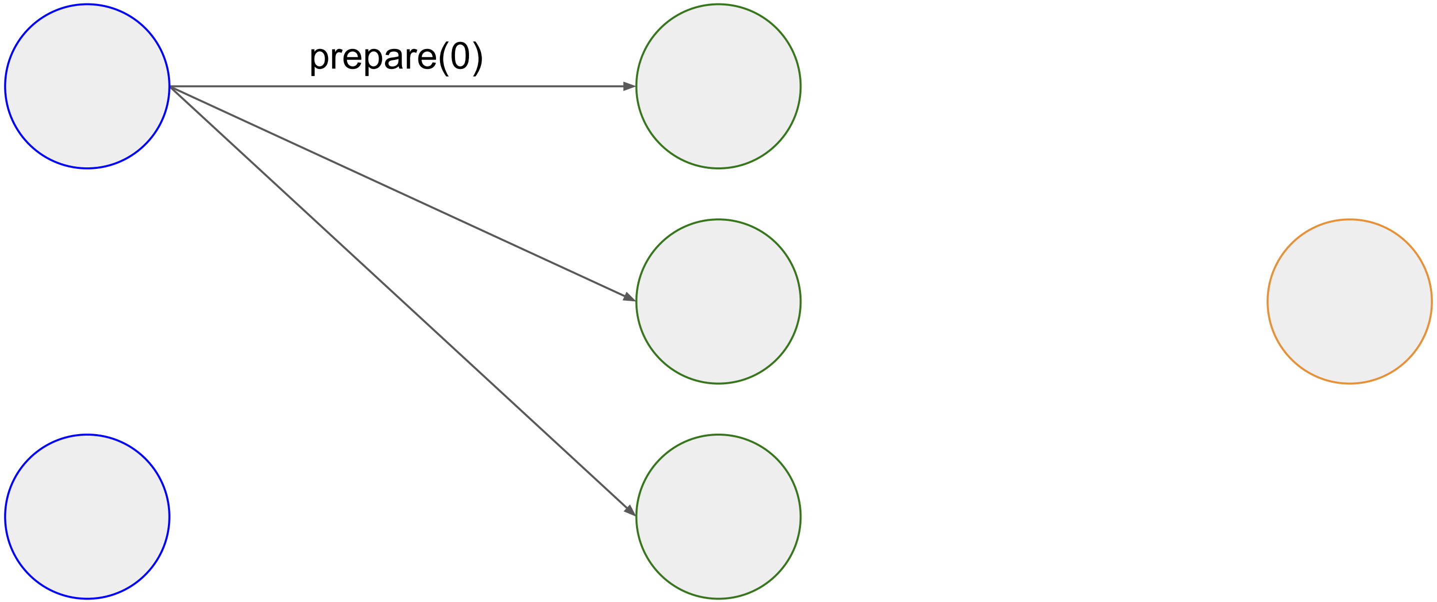

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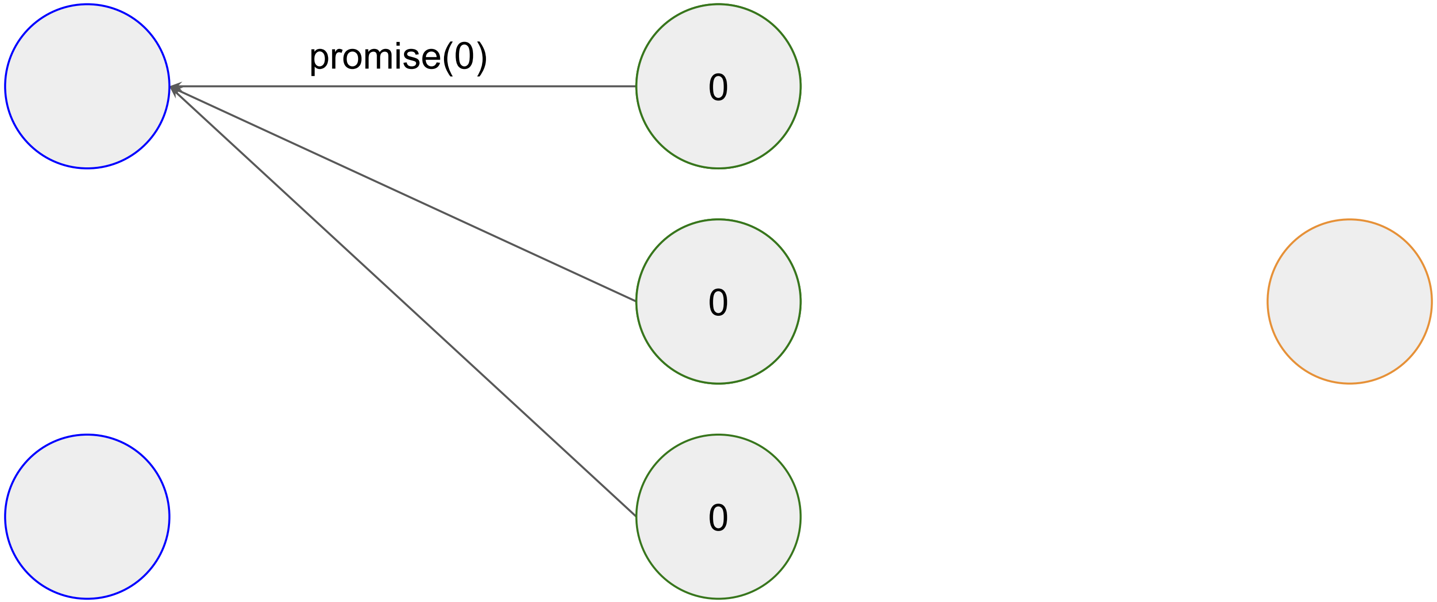

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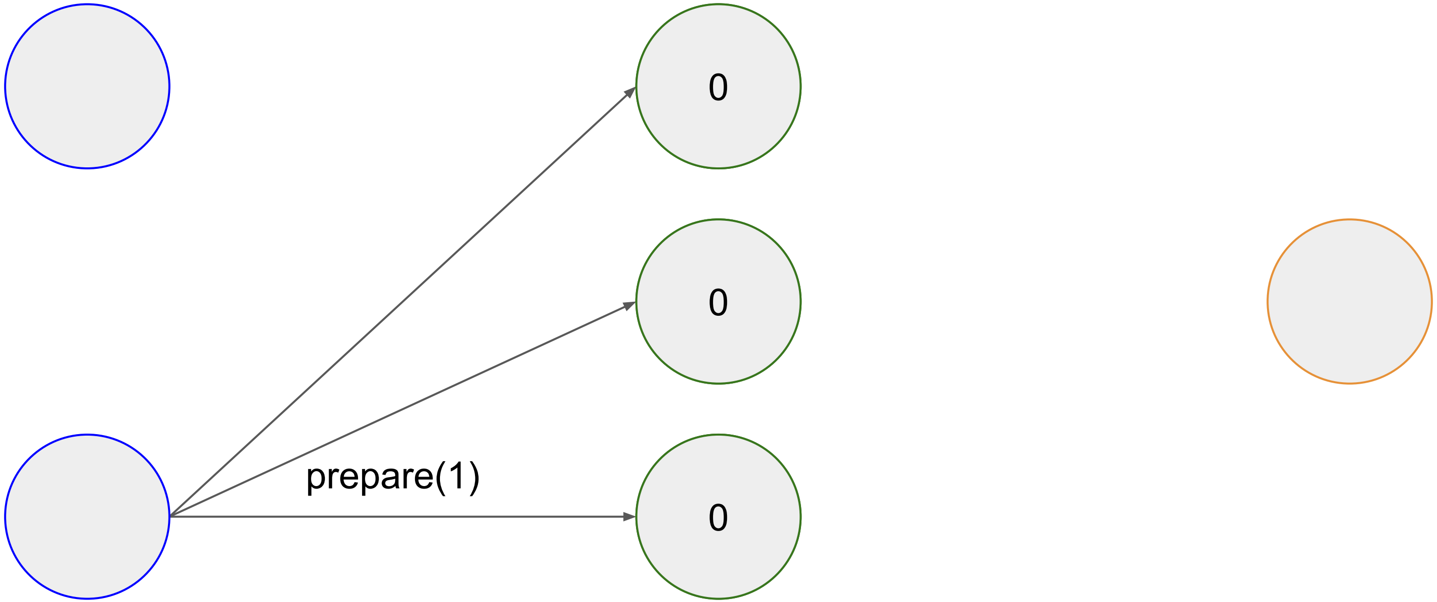

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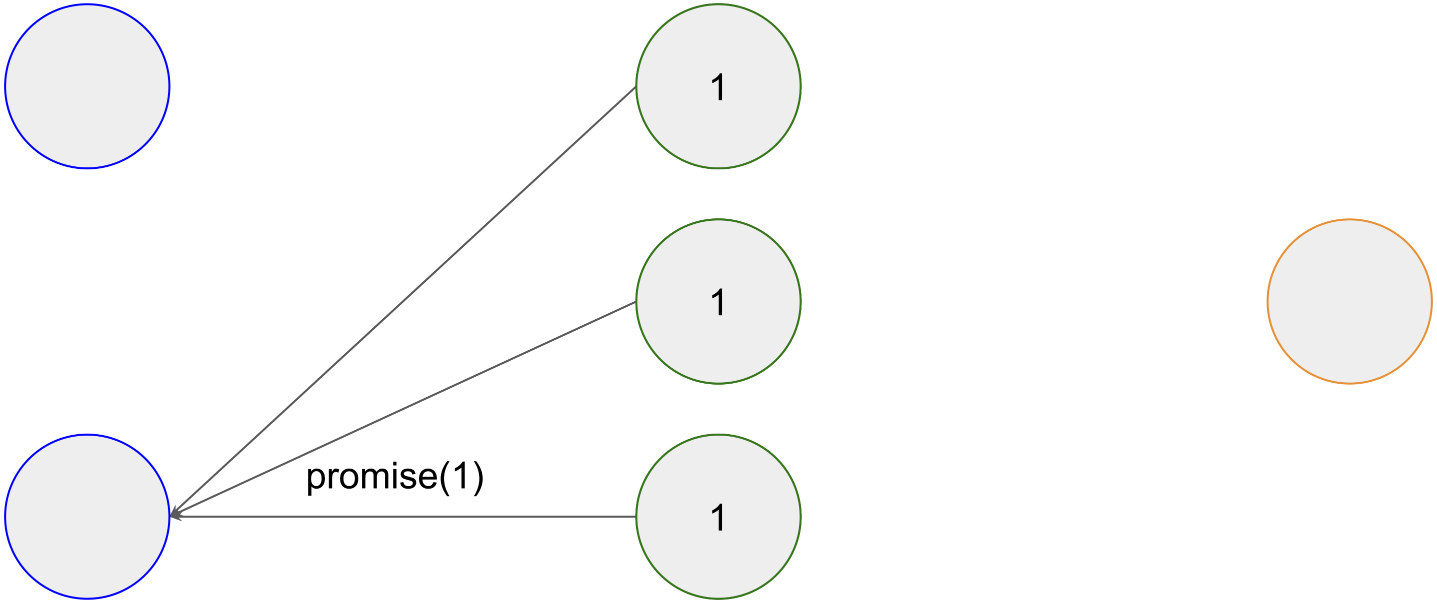

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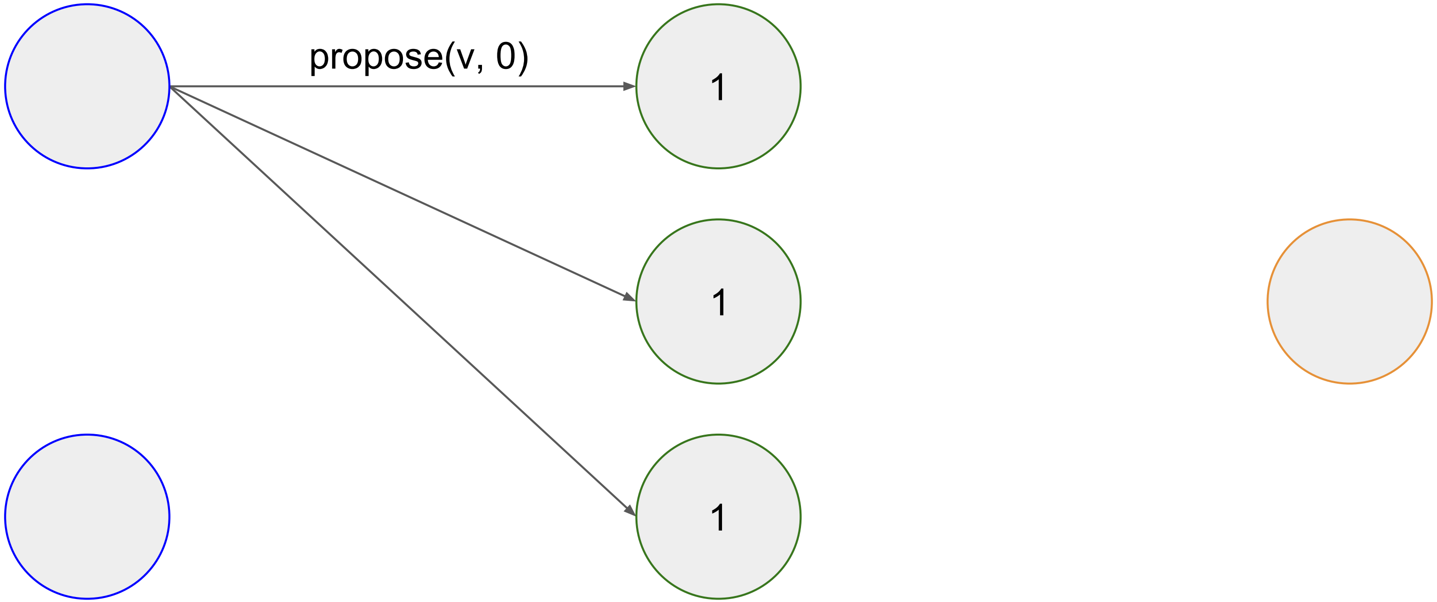

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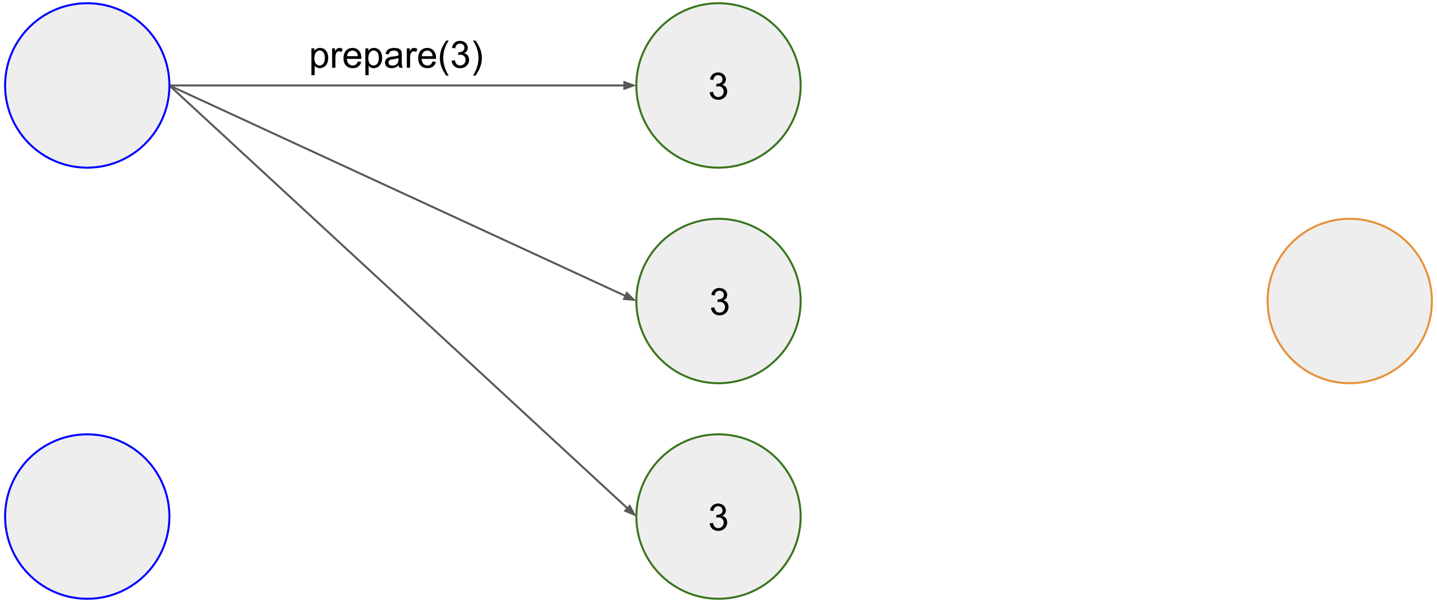

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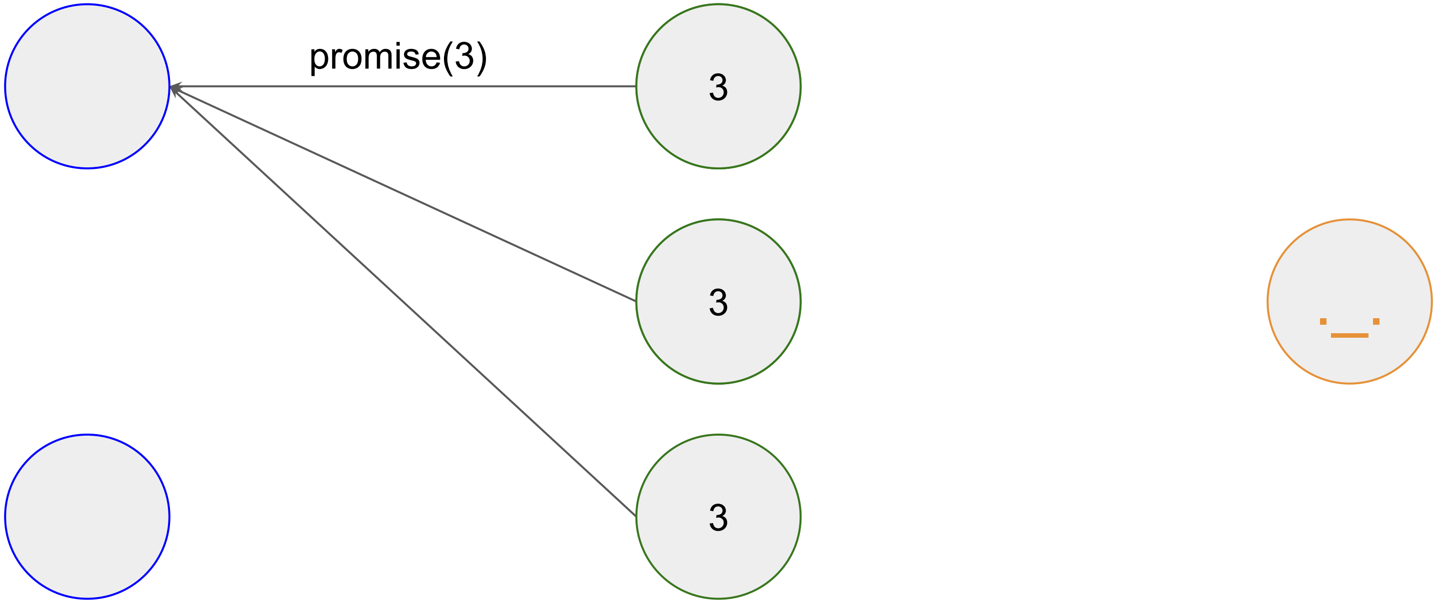

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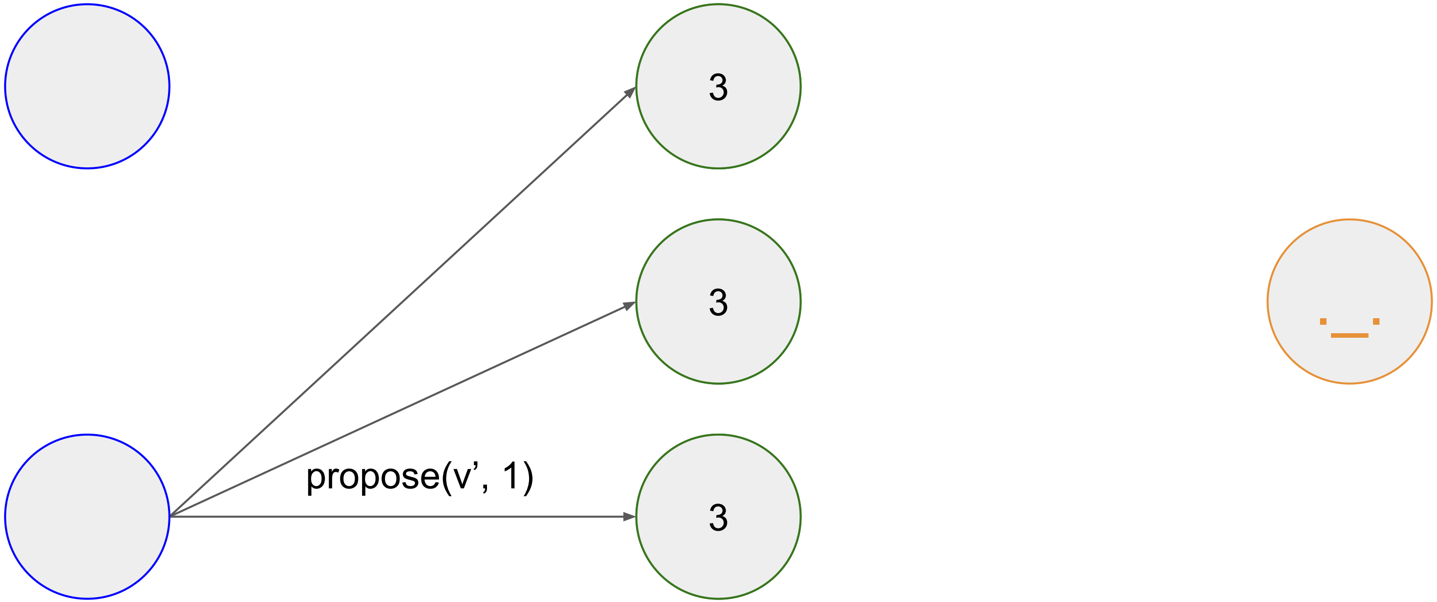

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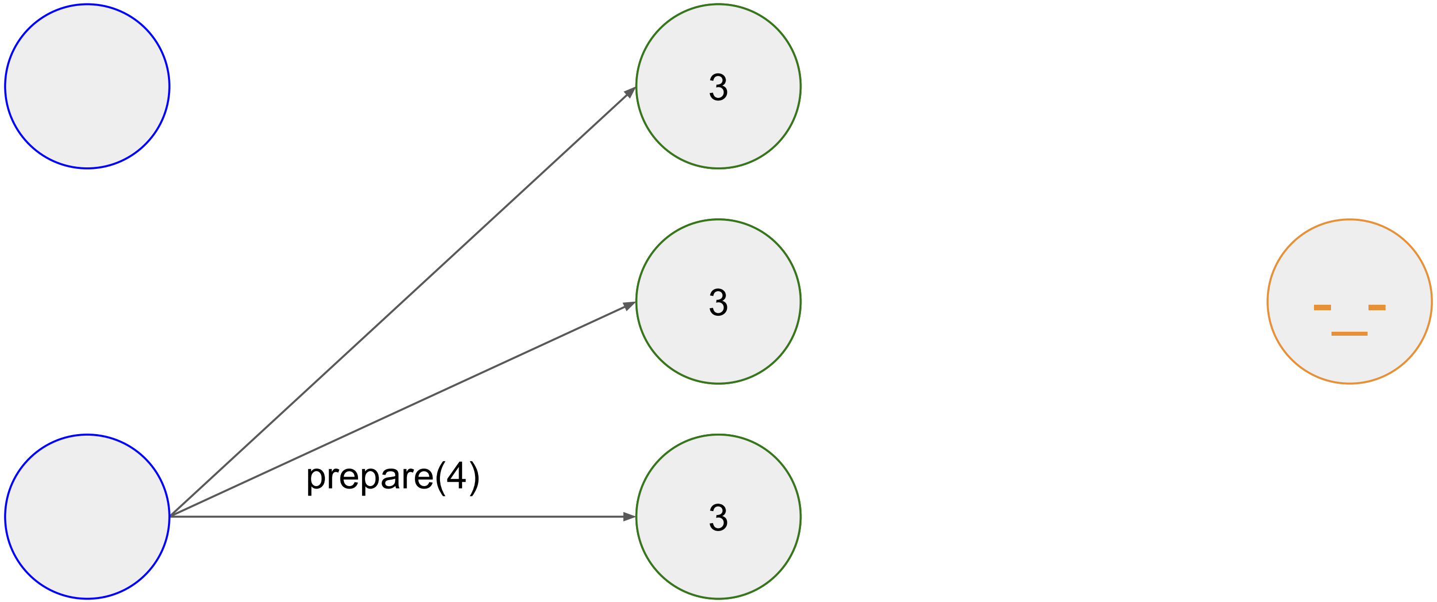

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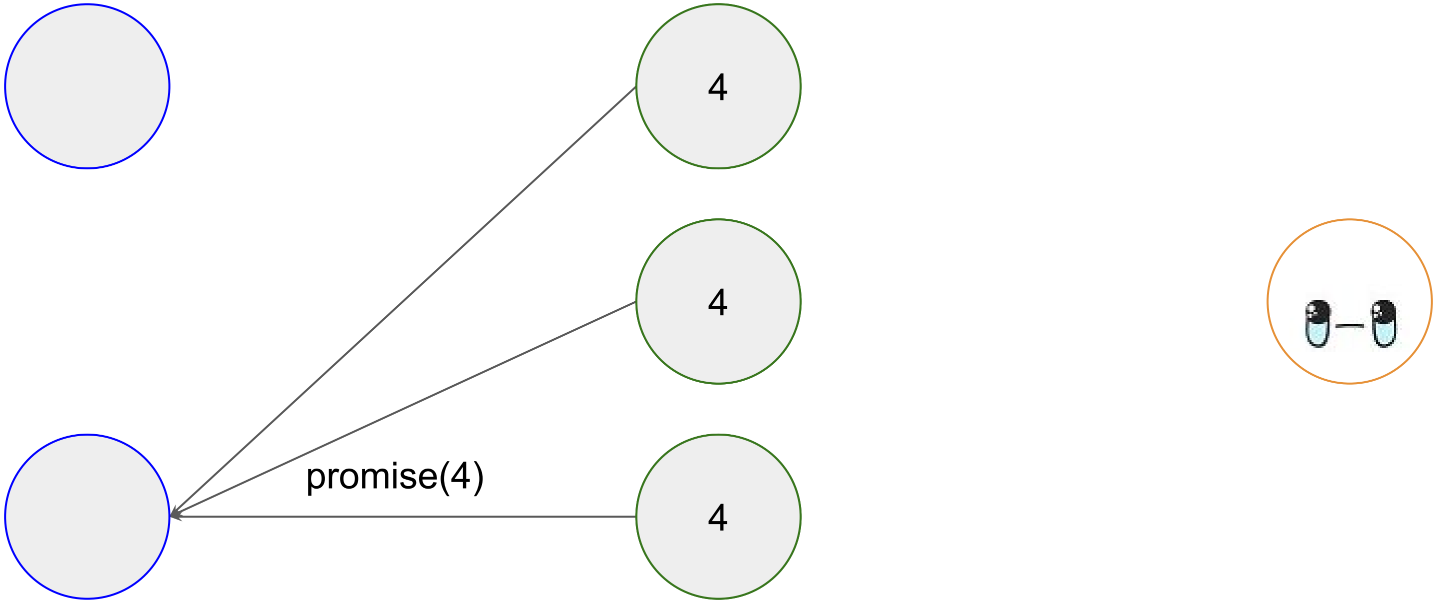

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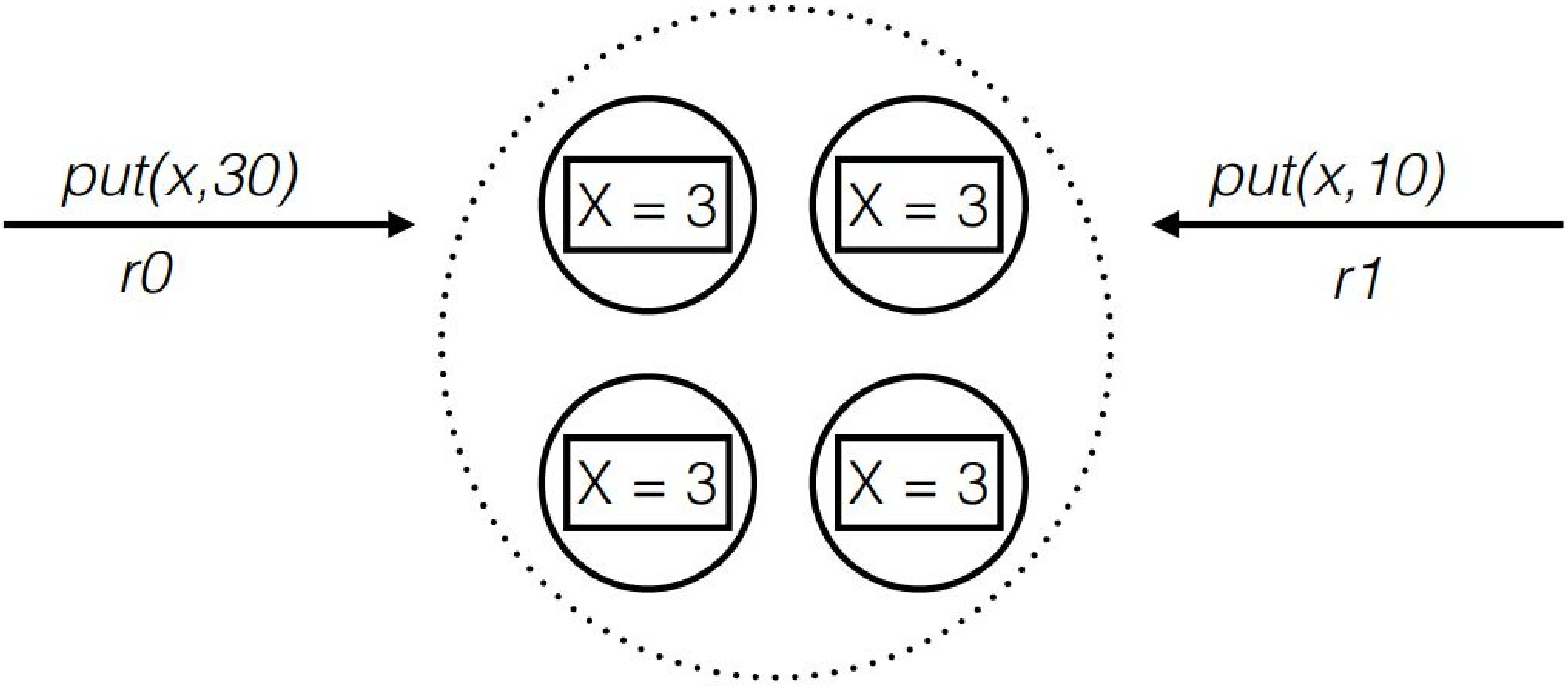
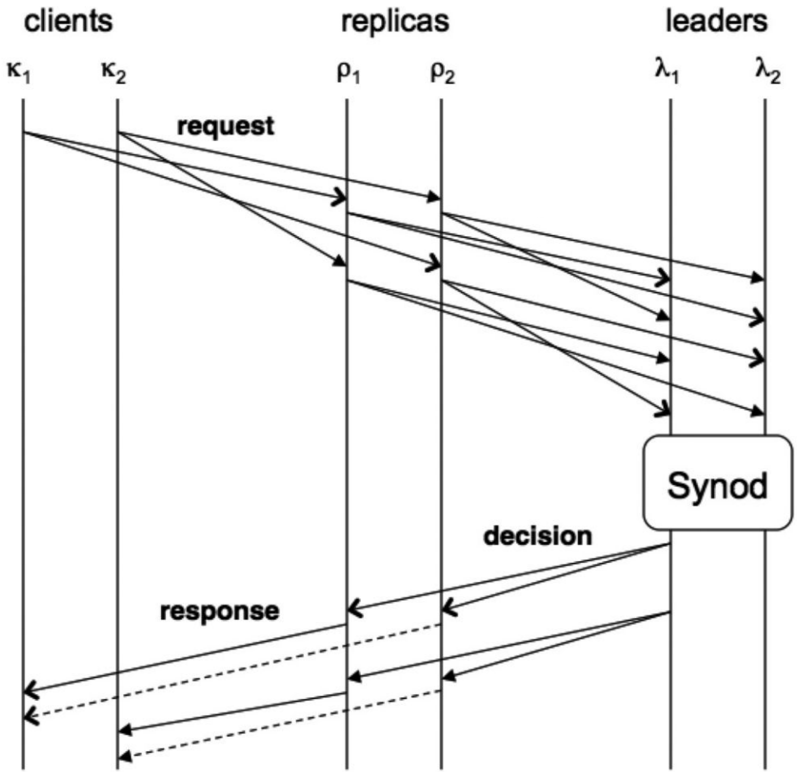
Consider Input Ordering in SMR



Paxos Made Moderately Complex



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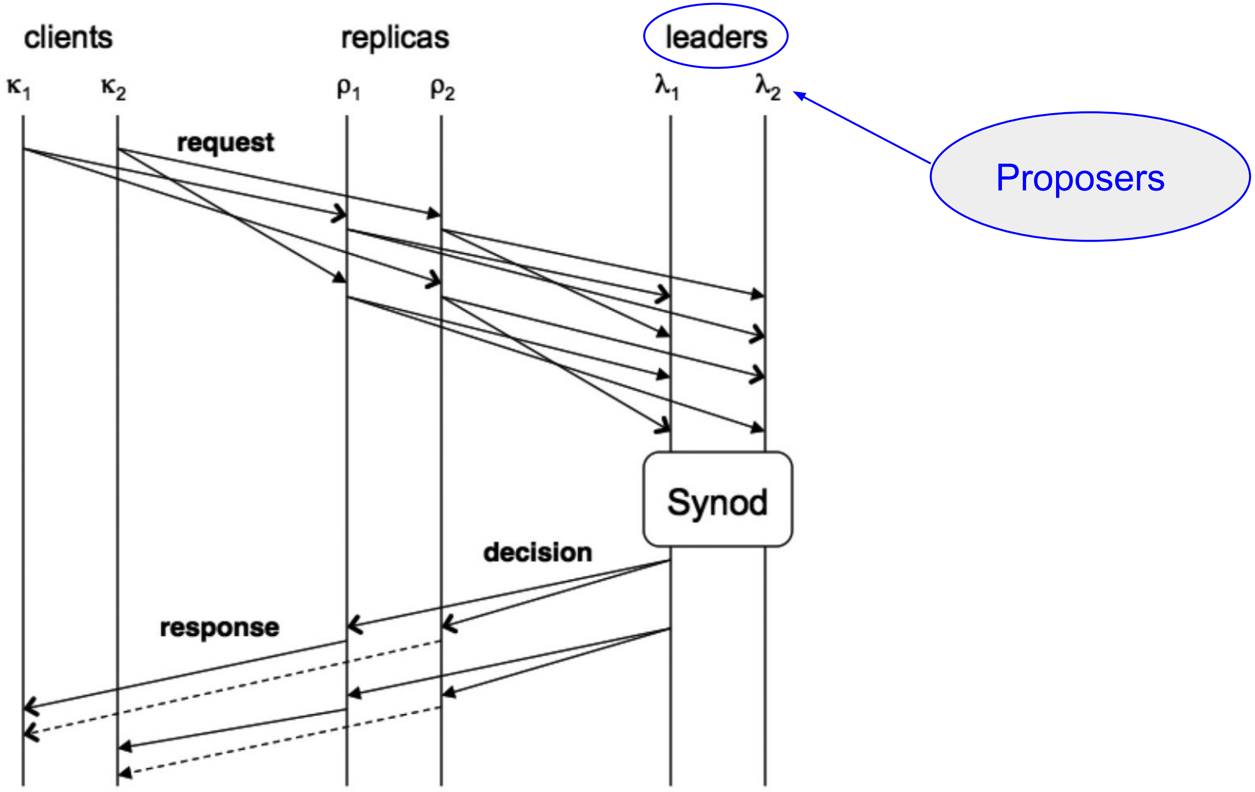

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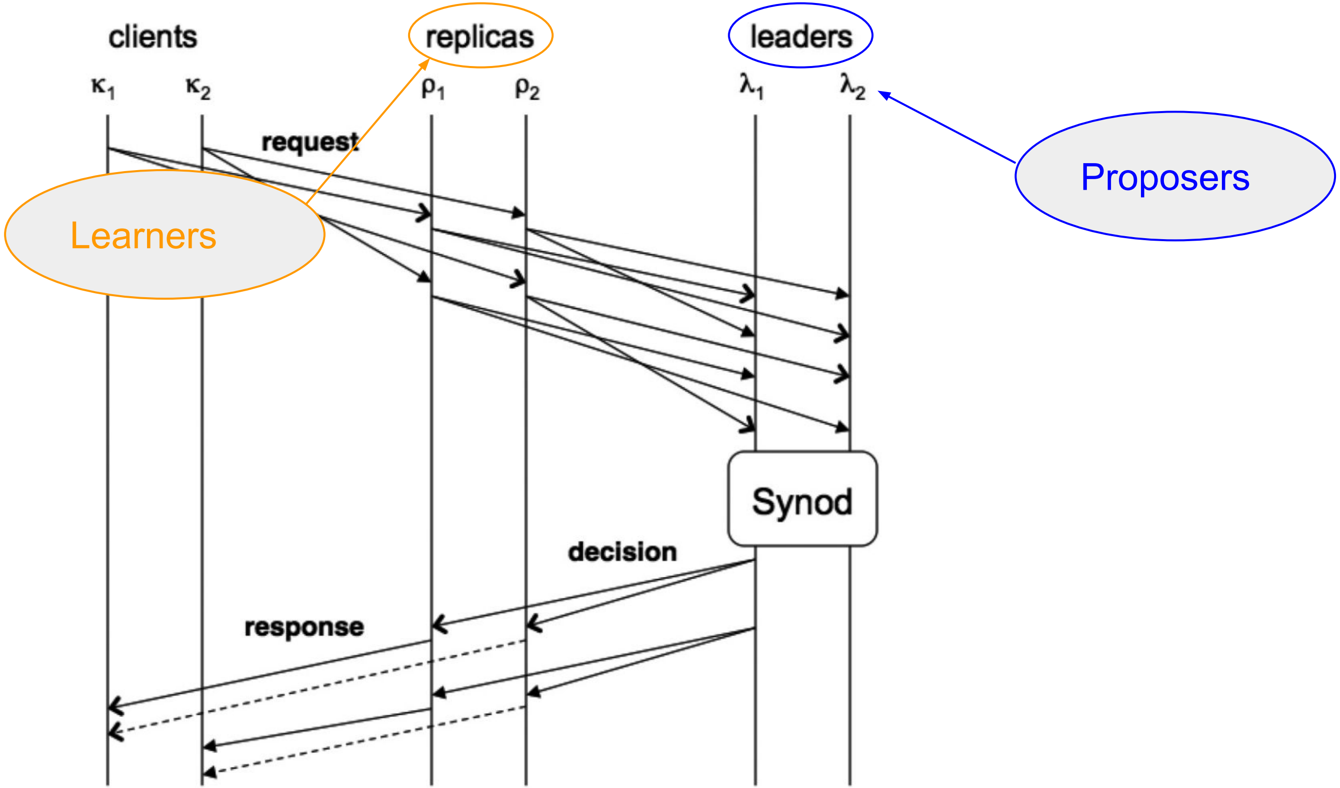

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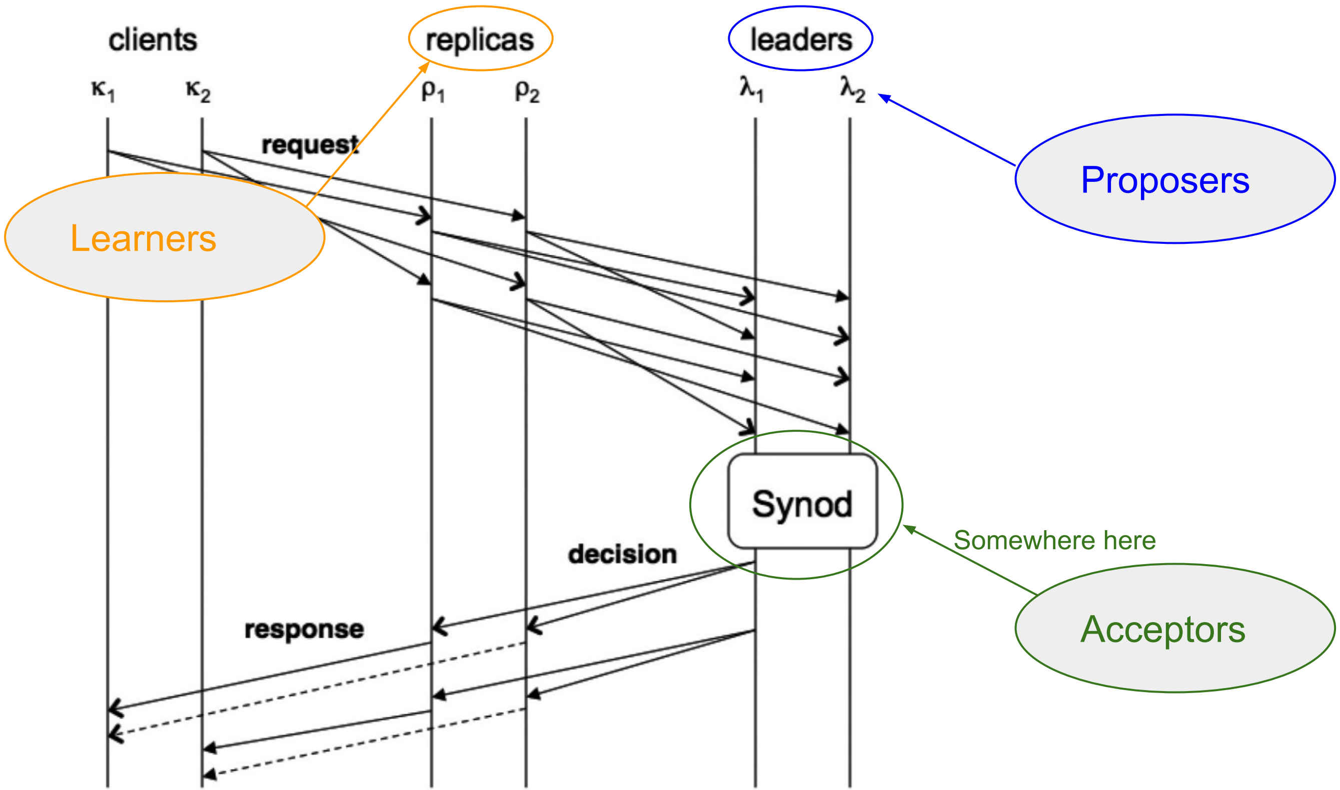

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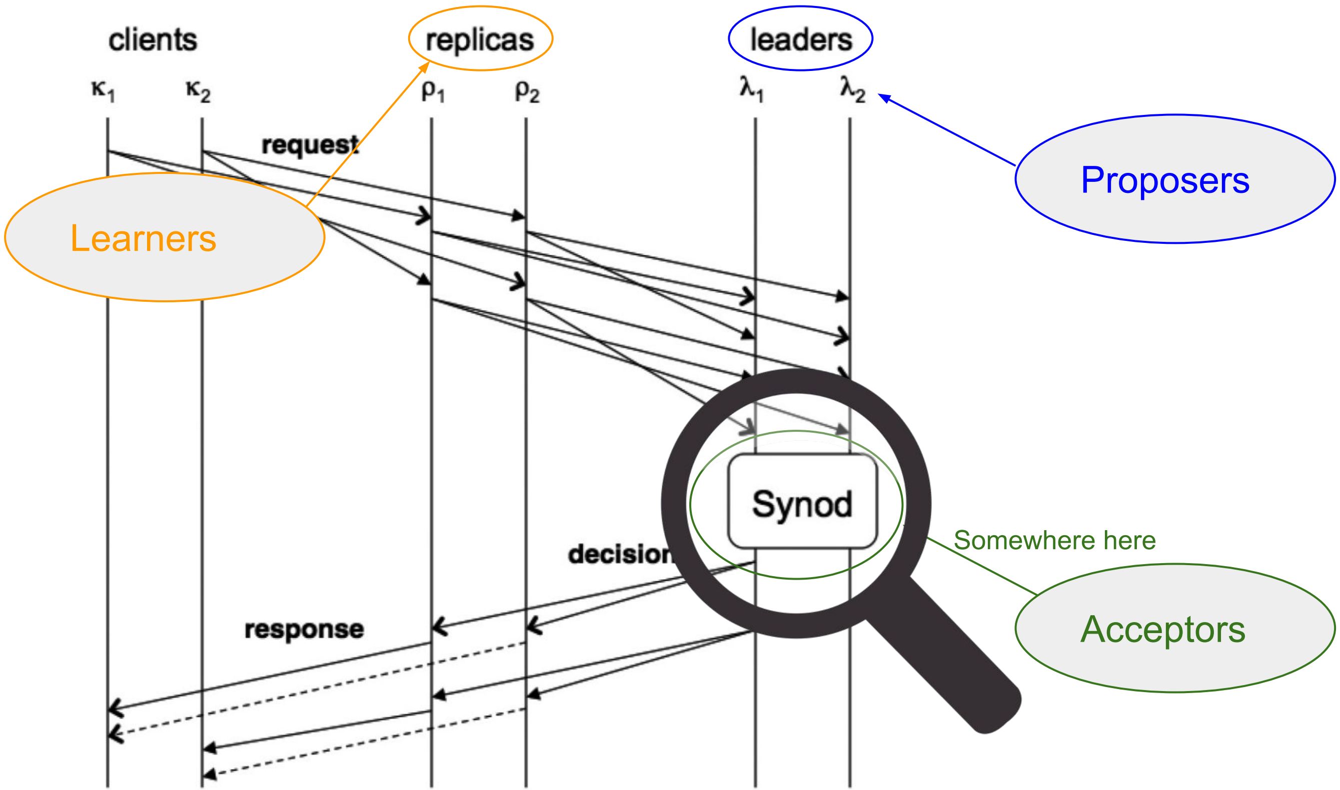

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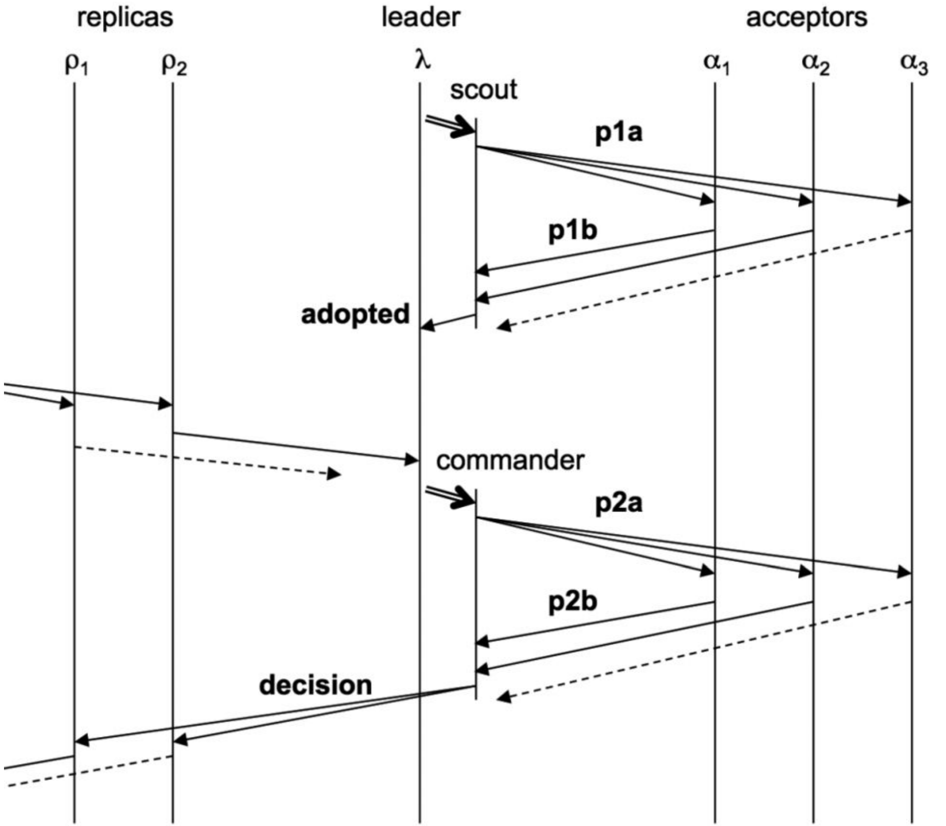

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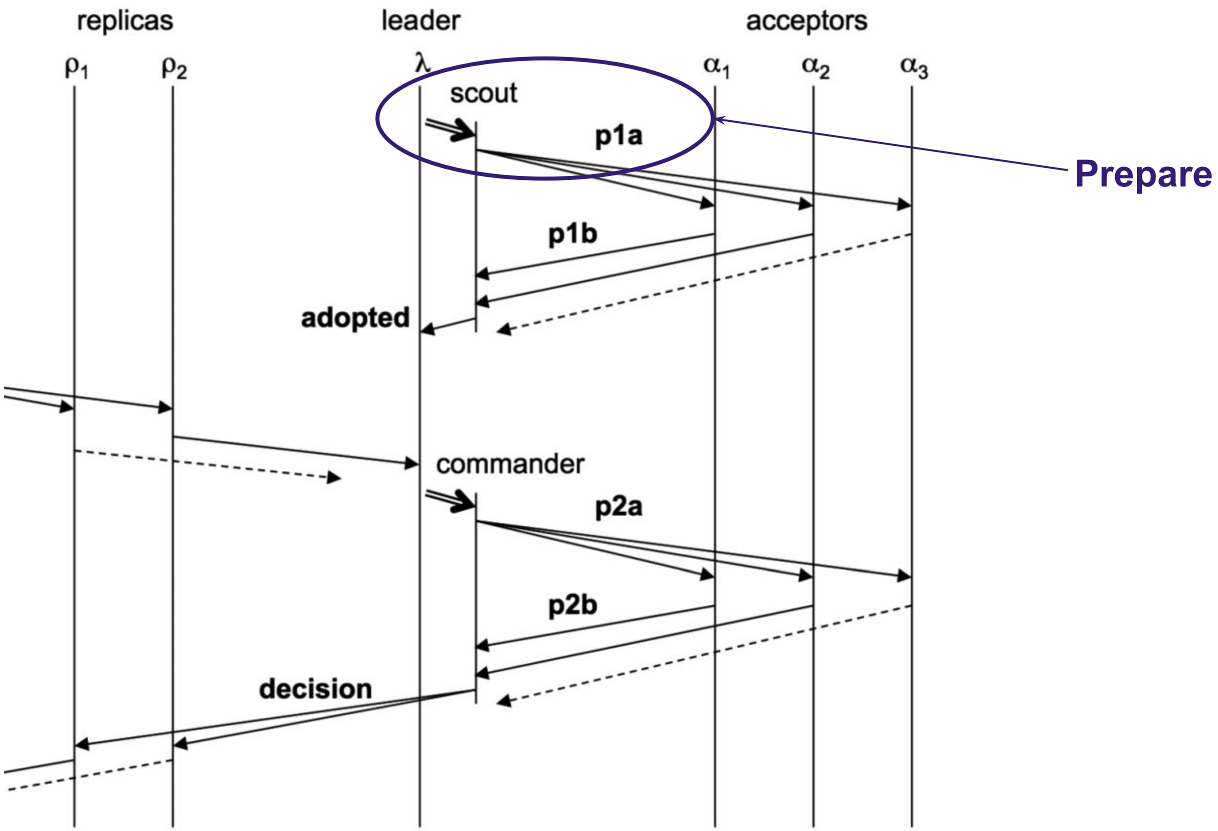

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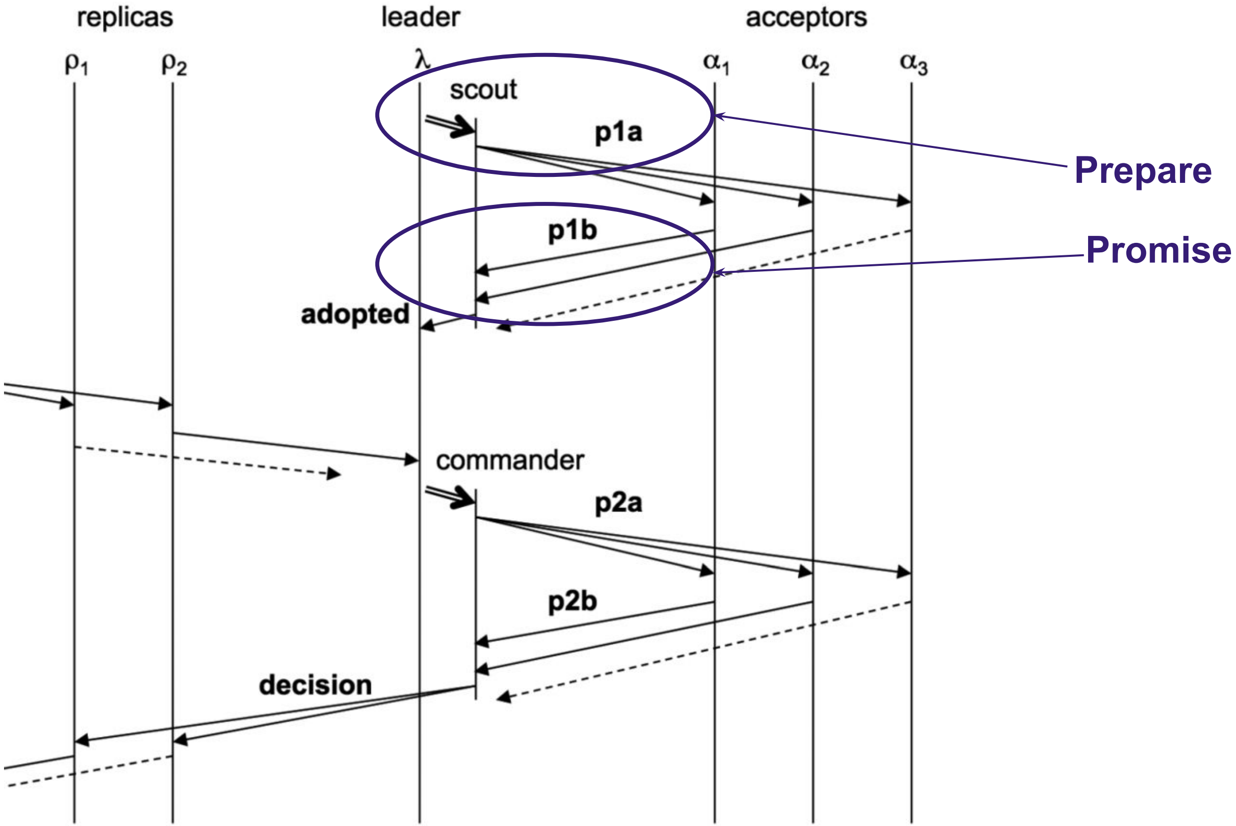

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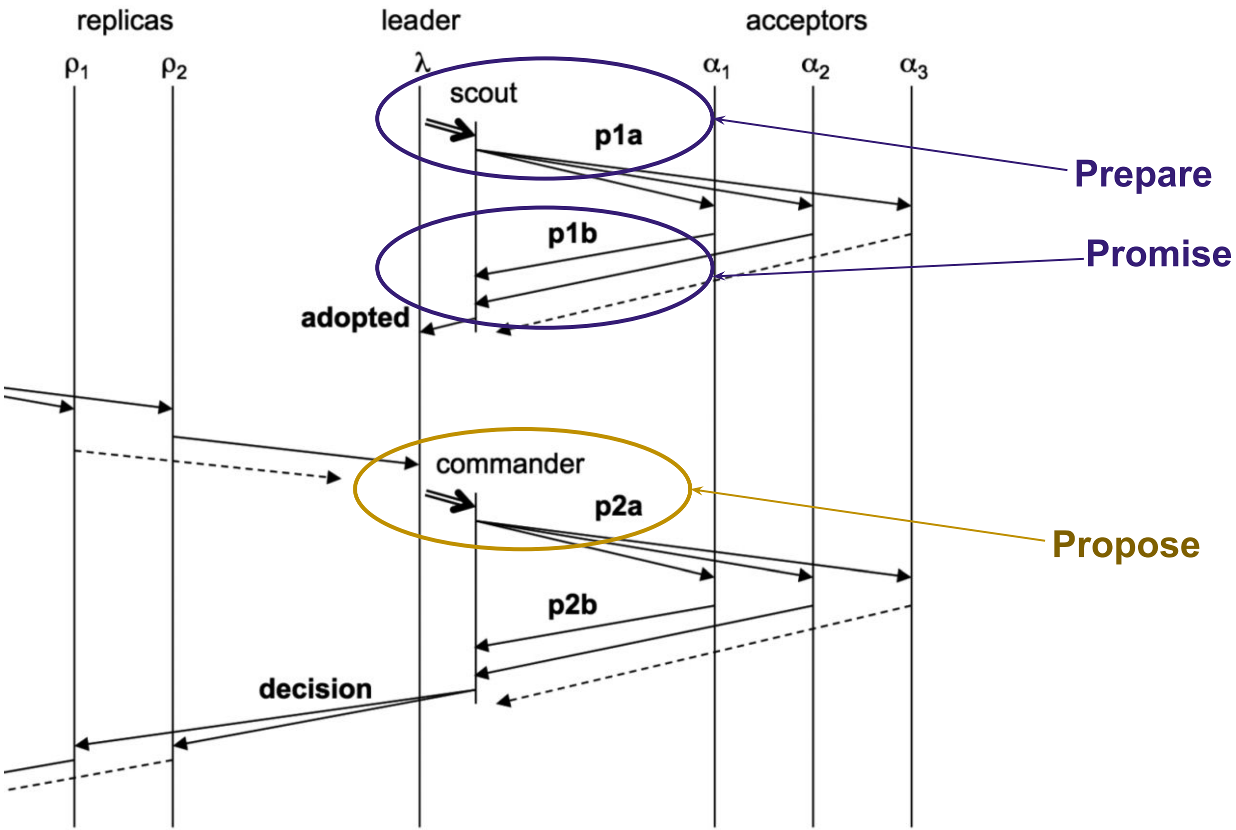

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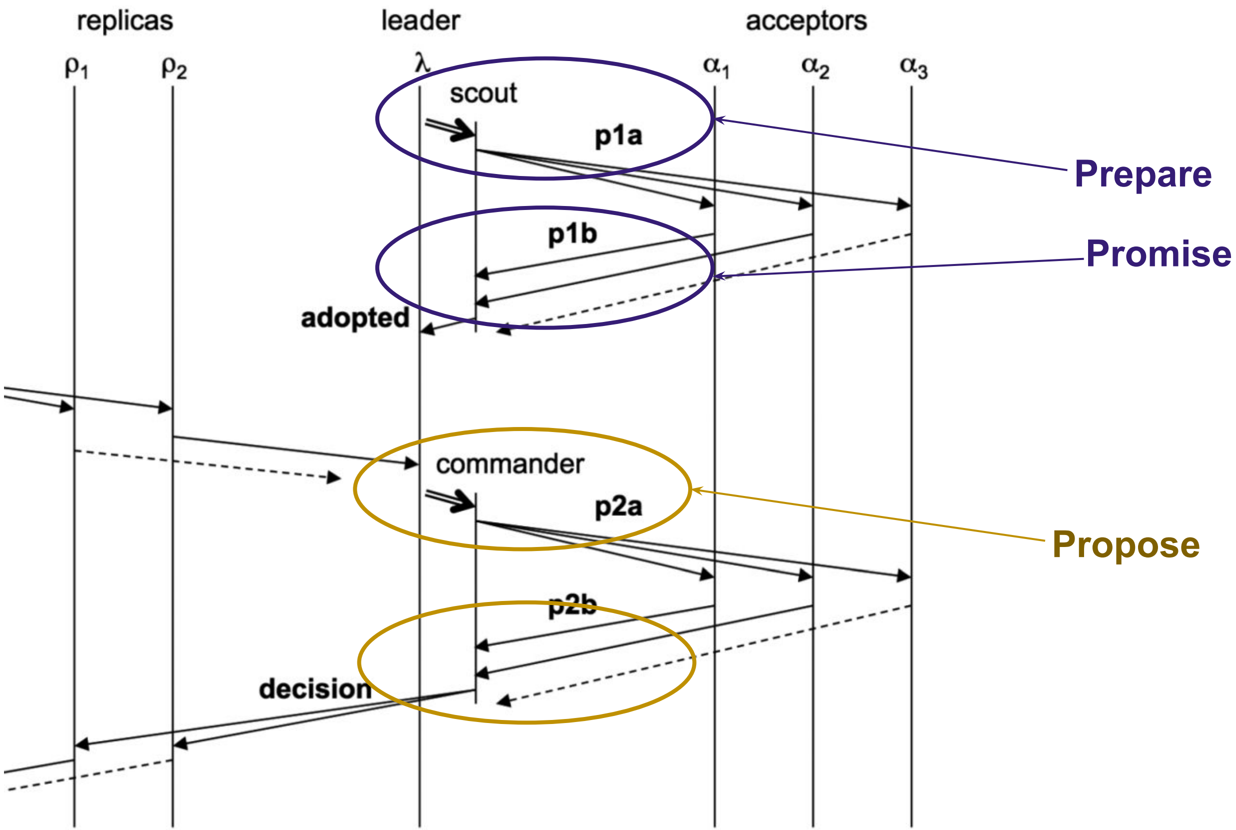

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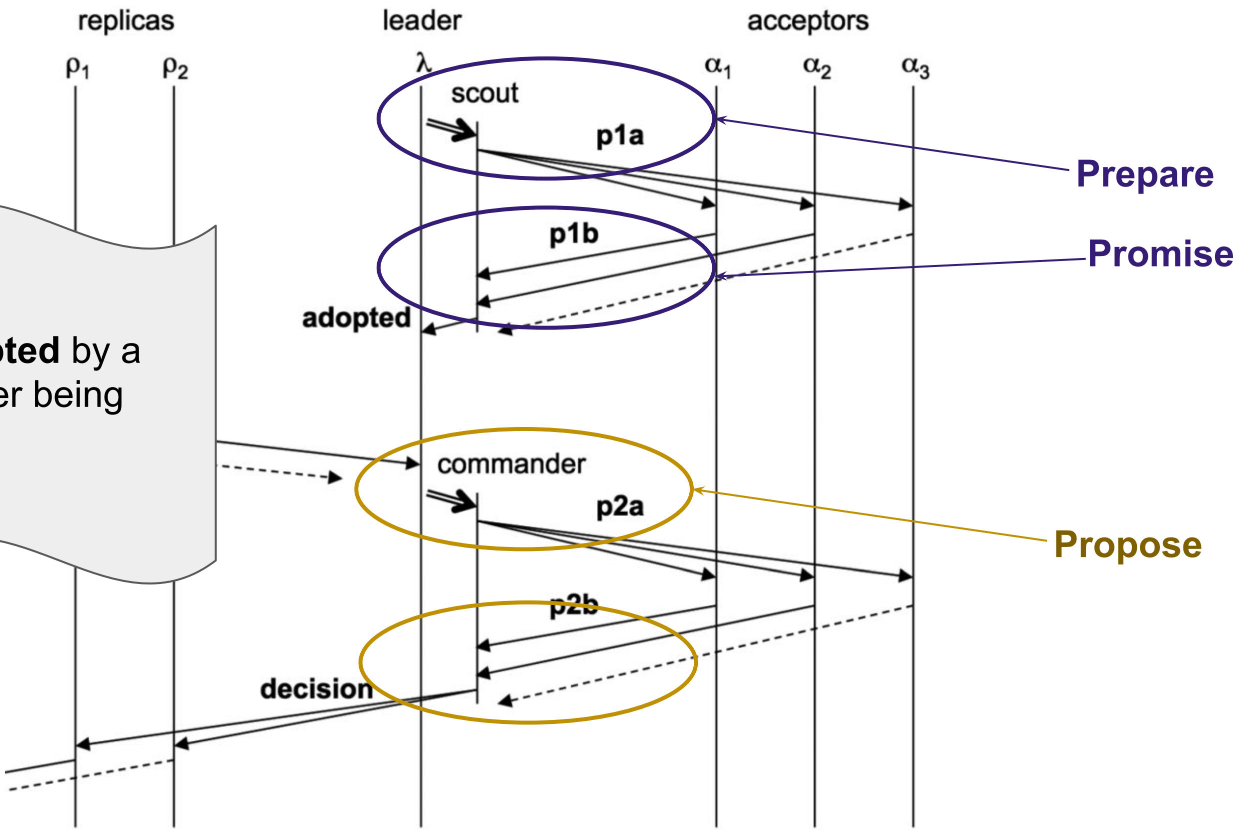

can both be **preempted** by a higher ballot number being reported

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Paxos Variants

- Fast Paxos
- Generalized Paxos
- Disk Paxos
- Cheap Paxos
- Vertical Paxos
- Egalitarian Paxos
- Mencius
- Stoppable Paxos

Paxos in Real Systems

- Chubby
- Google Spanner
- Megastore
- OpenReplica
- Bing
- WANDisco
- XtreemFS
- Doozerd
- Ceph
- Clustrix
- Neo4j

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Conclusion

- **Paxos** is a protocol for solving the **consensus problem** in an *asynchronous* distributed environment with processors that can fail by *crashing*
- A **replicated state machine** can be built by maintaining a **distributed command log** where the command at each position in the log is decided by solving *consensus*
- **Correctly** and **efficiently** implementing a replicated state machine using Paxos is notoriously **difficult**