Distributed Consensus
Paxos

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CS6410

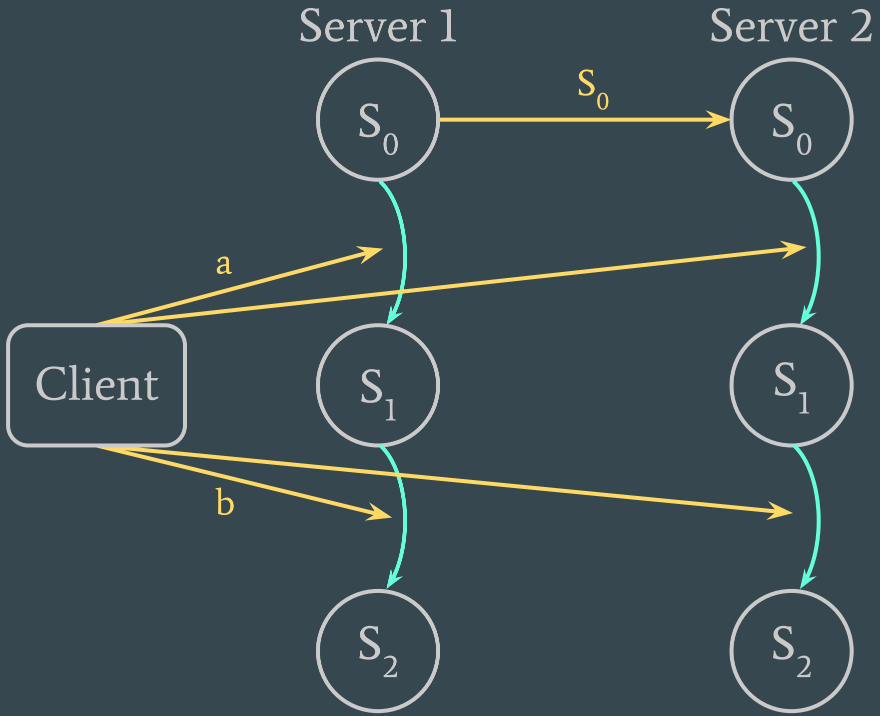
Some structure taken from Robert Burgess's 2009 slides on this topic

State Machine Replication (SMR)

View a server as a state machine.

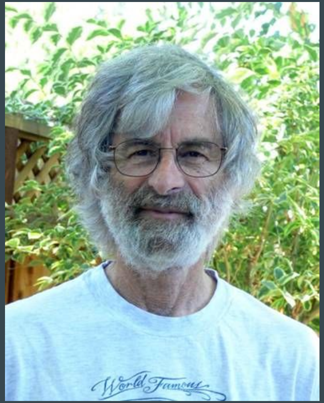
To replicate the server:

1. Replicate the initial state
2. Replicate each transition



Paxos: Fault-Tolerant SMR

- Devised by Leslie Lamport, originally in 1989
- Written as "The Part-Time Parliament"
  - Abstract: *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.*
- Rejected as unimportant and too confusing

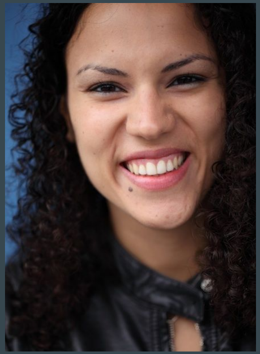


Paxos: The Lost Manuscript

- Finally published in 1998 after it was put into use
- Published as a "lost manuscript" with notes from Keith Marzullo
  - *"This submission was recently discovered behind a filing cabinet in the TOCS editorial office. Despite its age, the editor-in-chief felt that it was worth publishing. Because the author is currently doing field work in the Greek isles and cannot be reached, I was asked to prepare it for publication."*
- "Paxos Made Simple" simplified the explanation...a bit too much
  - Abstract: *The Paxos algorithm, when presented in plain English, is very simple.*

Paxos Made Moderately Complex

Robbert van Renesse and Deniz Altinbuken (Cornell University)
ACM Computing Surveys, 2015



“The Part-Time Parliament” was too confusing
“Paxos Made Simple” was overly simplified
Better to make it moderately complex!
    Much easier to understand

Paxos Structure

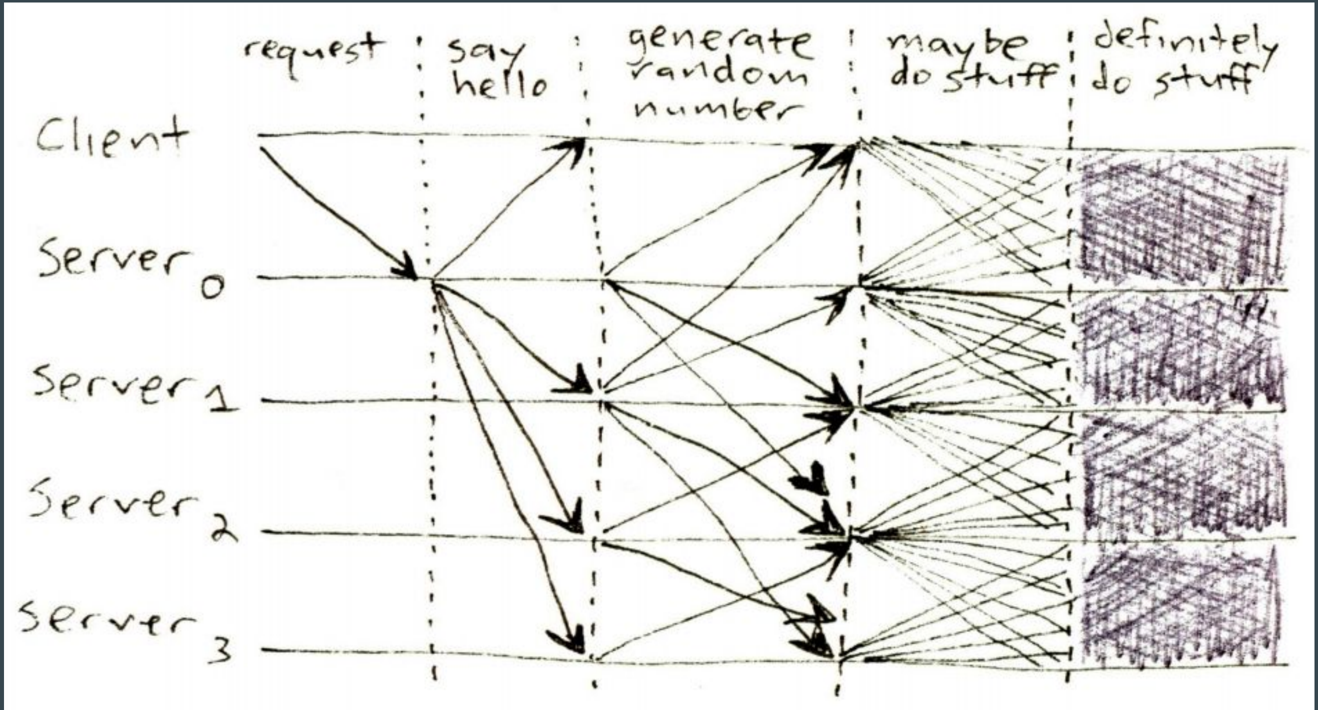
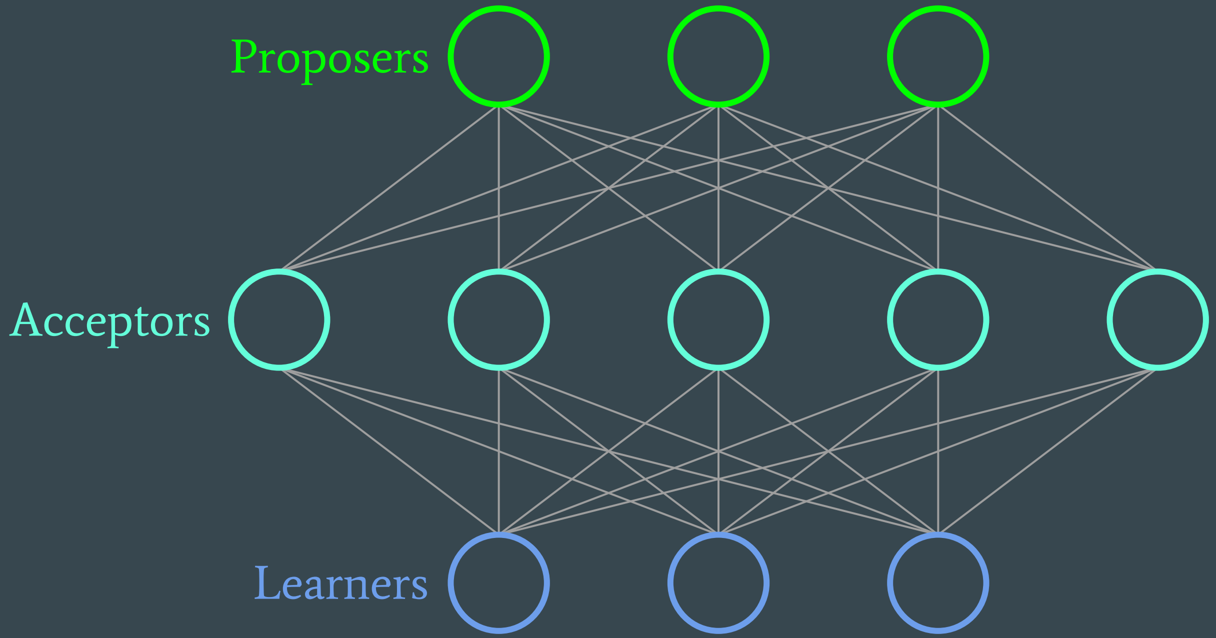


Figure from James Mickens. ;login: logout. *The Saddest Moment.* May 2013

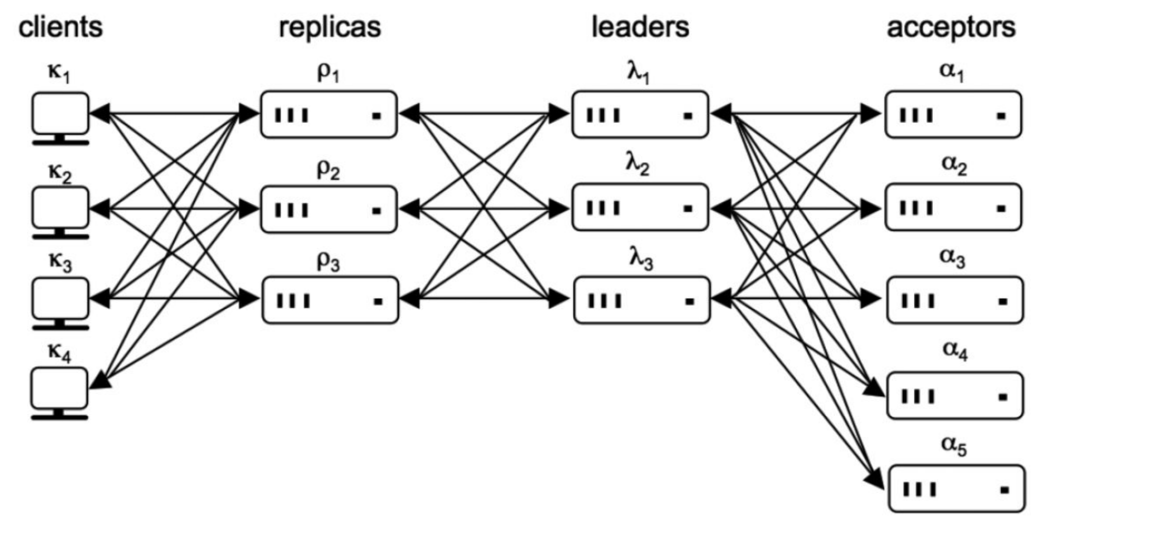
Paxos Structure



Moderate Complexity: Notation

Store data and propose to proposers

Function as proposers and learners without persistent storage



Communication pattern between types of processes in a setting where $f = 2$.

Figure from van Renesse and Altinbuken 2015

Single-Decree Synod

Decides on one command

System is divided into *proposers* and *acceptors*

The protocol executes in phases:

1a. Proposer proposes a ballot b

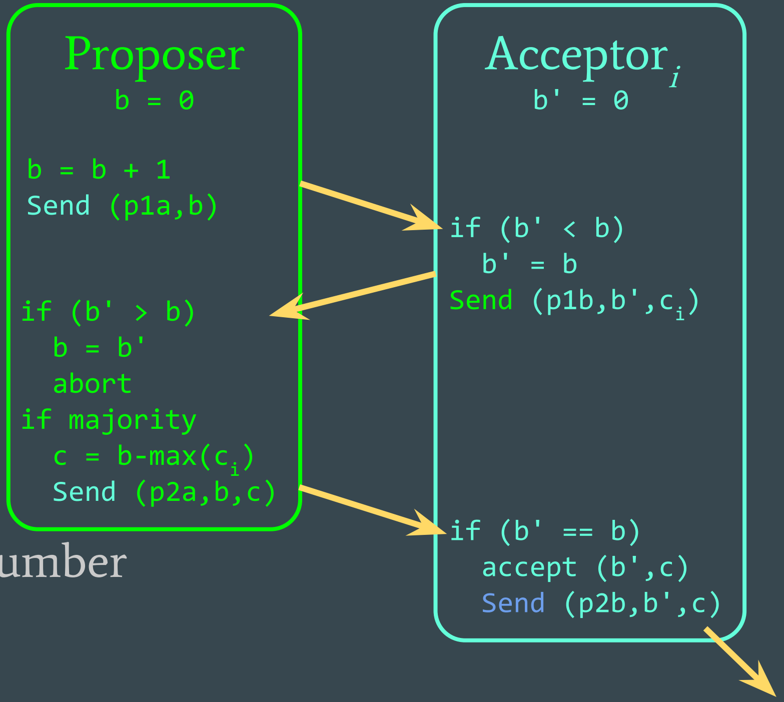
1b. Acceptor_i responds with (b', c_i)

2a. If $b' > b$, update b and abort

Else wait for majority of acceptors

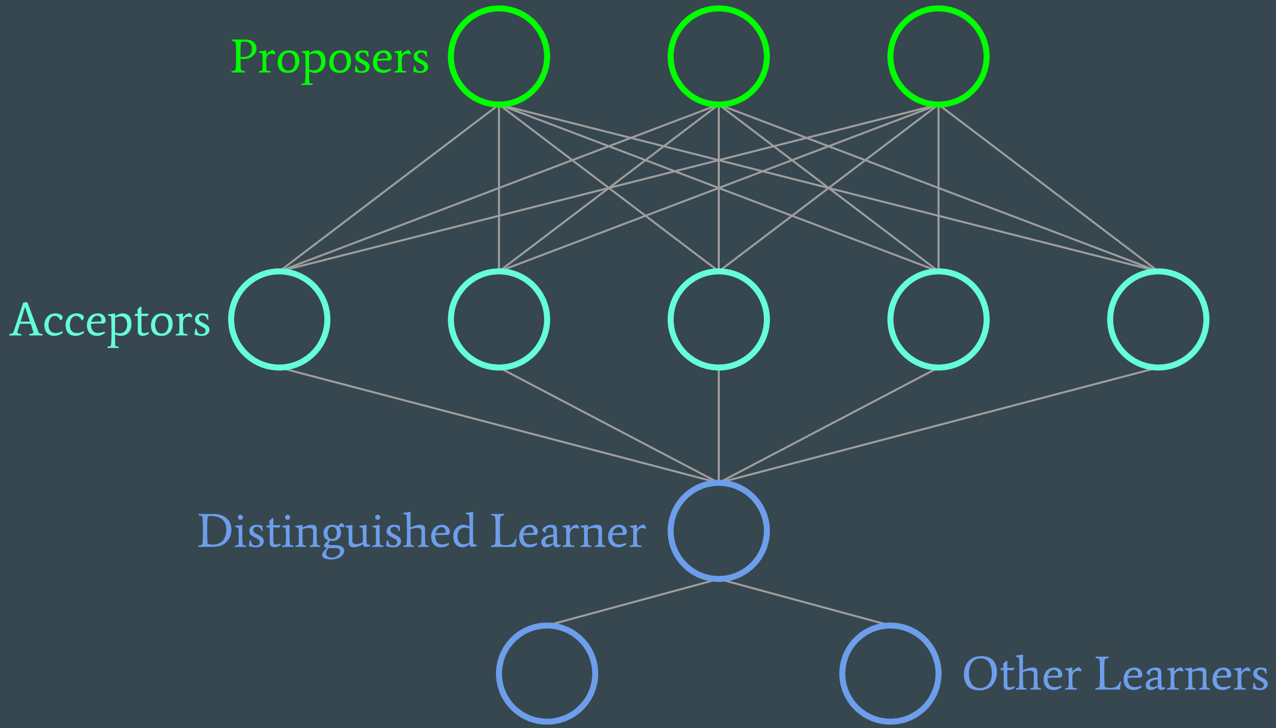
Request received c_i with highest ballot number

2b. If b' has not changed, accept

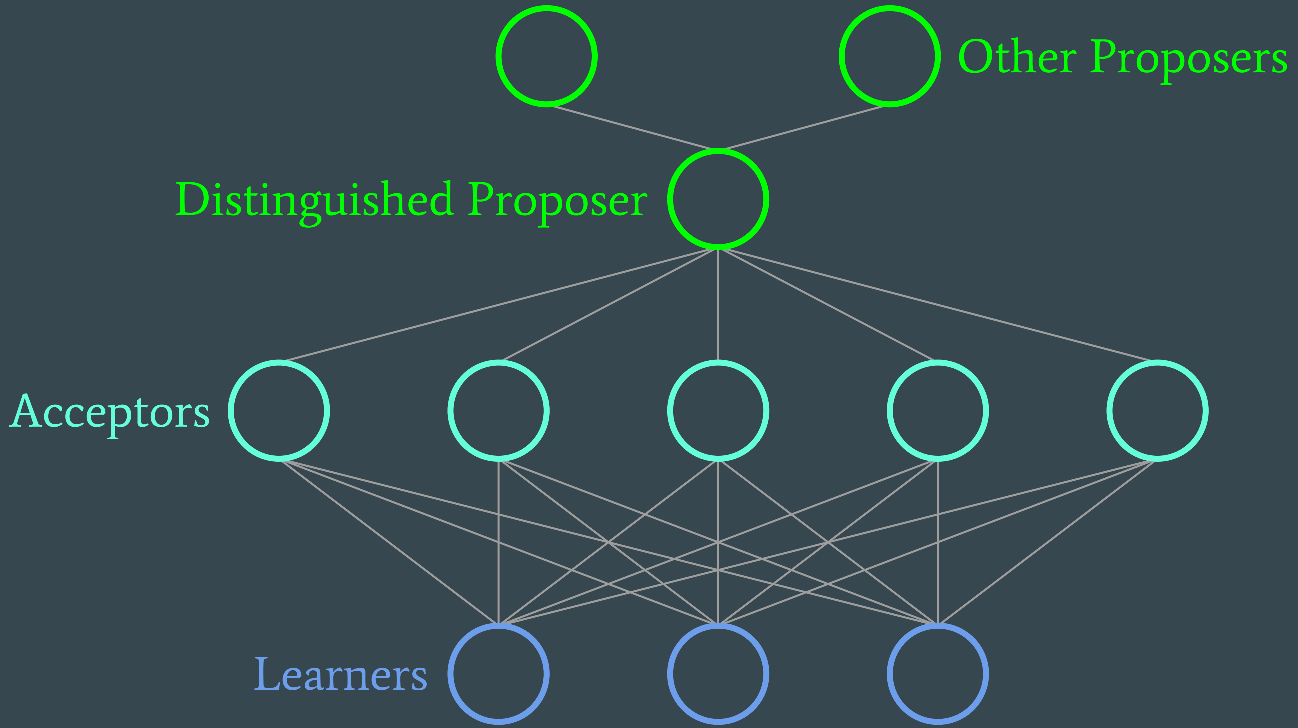


A *learner* learns *c* if it receives the same (p2b, b',c) from a majority of acceptors

Optimizations: Distinguished Learner



Optimizations: Distinguished Proposer



What can go wrong?

- A bunch of preemption
  - If two proposers keep preempting each other, no decision will be made
- Too many faults
  - Liveness requirements
    - majority of acceptors
    - one proposer
    - one learner
  - Correctness requires one learner

Deciding on Multiple Commands

Run Synod protocol for multiple slots

Sequential separate runs

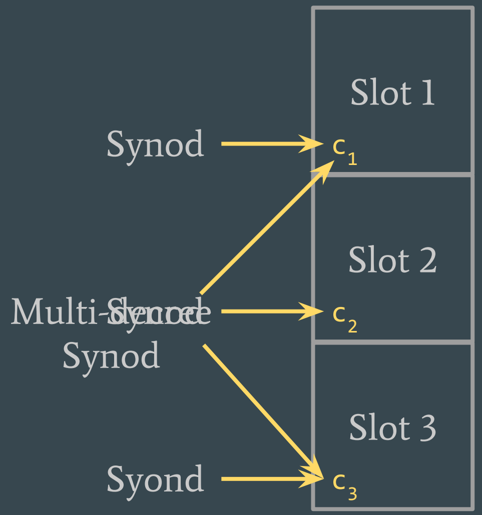
- Slow

Parallel separate runs

- Broken (no ordering)

One run with multiple slots

- Multi-decree Synod!



Paxos with Multi-Decree Synod

- Like single-decree Synod with one key difference:
  Every proposal contains a both a ballot and slot number
- Each slot is decided independently
- On preemption (`if (b' > b) {b = b'; abort;}`),
  proposer aborts active proposals for all slots

Moderate Complexity: Leaders

Leader functionality is split into pieces

- Scouts – perform proposal function for a ballot number
  - While a scout is outstanding, do nothing
- Commanders – perform commit requests
  - If a majority of acceptors accept, the commander reports a decision
- Both can be preempted by a higher ballot number
  - Causes all commanders and scouts to shut down and spawn a new scout

Moderate Complexity: Optimizations

- Distinguished Leader
  - Provides both distinguished proposer and distinguished learner
- Garbage Collection
  - Each acceptor has to store every previous decision
  - Once $f + 1$ have all decisions up to slot s, no need to store s or earlier

Paxos Questions?

CORFU: A Distributed Shared Log

Mahesh Balakrishnan[†], Dahlia Malkhi[†], John Davis[†], Vijayan Prabhakaran[†], Michael Wei[‡], and Ted Wobber[†]
[†]Microsoft Research, [‡]University of California, San Diego
TOCS 2013

Distributed log designed for high throughput and strong consistency.

- Breaks log across multiple servers
- “Write once” semantics ensure serializability of writes

CORFU: Conflicts

What happens on concurrent writes?

- The first write wins and the rest must retry
  - Retrying repeatedly is very slow.
- Use sequencer to get write locations first

CORFU: Holes and *fill*

What if a writer fails between getting a location and writing?

- Hole in the log!
  - Can block applications which require complete logs (e.g. SMR)
- Provide a *fill* command to fill holes with junk
  - Anyone can call *fill*
  - If a writer was just slow, it will have to retry

CORFU: Replication

- Shards can be replicated however we want
  - Chain replication is good for low replication factors (2-5)
- On failure, replacement server can take writes immediately
  - Copying over the old log can happen in the background.

Thank You!