CS 425 / ECE 428
Distributed Systems
Fall 2020

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Lecture 13-B: Paxos

Exercises

1. Why does Paxos provide safety?
2. Why does Paxos not provide liveness?
3. Someone implements Paxos but it has a bug – everywhere there was a quorum (>N/2), the new implementation only requires > N/3 processes. Is this new algorithm safe?
4. Paxos appears to be structured in “rounds”, which appears to indicate that it is intended for synchronous systems. Why does Paxos still work in an asynchronous system?
5. Assuming no failures, what is the point of no return in Paxos?
6. What could go wrong in Paxos?

What is Consensus?

Formal problem statement

- N processes
- Each process p has

  input variable xp : initially either 0 or 1

  output variable yp : initially b (can be changed only once)

- Consensus problem: design a protocol so that at the end, either:

  1. All processes set their output variables to 0 (all-0's)
  2. Or All processes set their output variables to 1 (all-1's)

What is Consensus? (2)

- Every process contributes a value
- *Goal is to have all processes decide same (some) value*
  - Decision once made can't be changed
- There might be other constraints
  - Validity = if everyone proposes same value, then that's what's decided
  - Integrity = decided value must have been proposed by some process
  - Non-triviality = there is at least one initial system state that leads to each of the all-0's or all-1's outcomes

Why is it Important?

- Many problems in distributed systems are equivalent to *(or harder than)* consensus!
  - Perfect Failure Detection
  - Leader election (select exactly one leader, and every alive process knows about it)
  - Agreement (harder than consensus)

- So consensus is a very important problem, and solving it would be really useful!

- Consensus is
  - Possible to solve in synchronous systems
  - Impossible to solve in asynchronous systems

Can’t we just solve Consensus?

- Yes, we can!
- (Whut?)

Yes we Can!

- Paxos algorithm
  - Most popular “consensus-solving” algorithm
  - Does not solve consensus problem (which would be impossible, because we already proved that)
  - But provides <u>safety</u> and <u>eventual liveness</u>
  - A lot of systems use it
    - Zookeeper (Yahoo!), Google Chubby, and many other companies

- Paxos invented by? (take a guess)

Yes we Can!

- Paxos invented by Leslie Lamport

- Paxos provides <u>safety</u> and <u>eventual liveness</u>
  - <u>Safety</u>: Consensus is not violated
  - <u>Eventual Liveness</u>: If things go well sometime in the future (messages, failures, etc.), there is a good chance consensus will be reached. But there is no guarantee.

- FLP result still applies: Paxos is not *guaranteed* to reach Consensus (ever, or within any bounded time)

Political Science 101, i.e., Paxos Groked

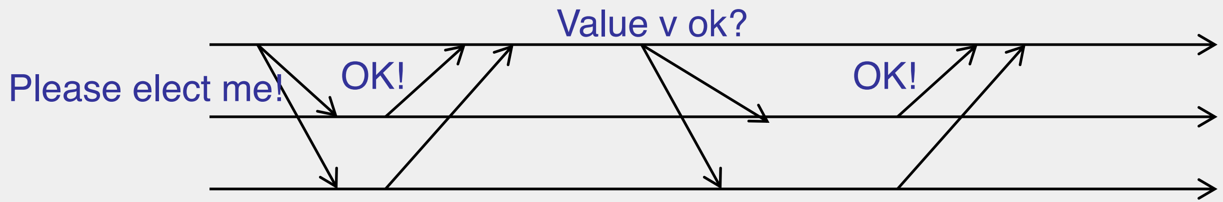
- Paxos has rounds; each round has a unique ballot id
- Rounds are asynchronous
  - Time synchronization not required
  - If you're in round j and hear a message from round $j+1$, abort everything and move over to round $j+1$
  - Use timeouts; may be pessimistic
- Each round itself broken into phases (which are also asynchronous)
  - Phase 1: A leader is elected (Election)
  - Phase 2: Leader proposes a value, processes ack (Bill)
  - Phase 3: Leader multicasts final value (Law)

Phase 1 – election

- Potential leader chooses a unique ballot id, higher than seen anything so far
- Sends to all processes
- Processes wait, respond once to highest ballot id
  - If potential leader sees a higher ballot id, it can't be a leader
  - Paxos tolerant to multiple leaders, but we'll only discuss 1 leader case
  - Processes also log received ballot ID on disk
- If a process has in a previous round decided on a value v', it includes value v' in its response
- If majority (i.e., quorum) respond OK then you are the leader
  - If no one has majority, start new round
- (If things go right) A round cannot have two leaders (why?)

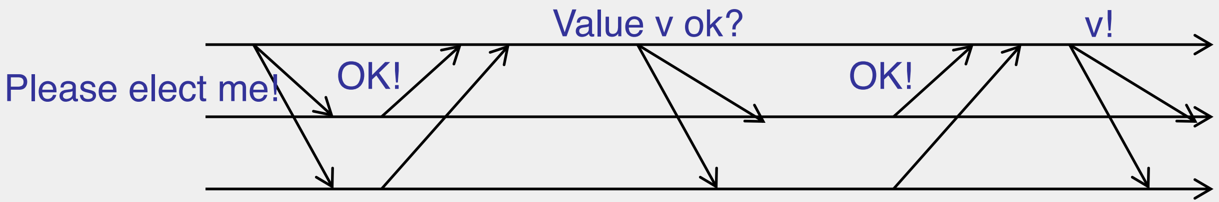
Phase 2 – Proposal (Bill)

- Leader sends proposed value v to all
  - use v=v' if some process already decided in a previous round and sent you its decided value v'
  - If multiple such v' received, use latest one
- Recipient logs on disk; responds OK



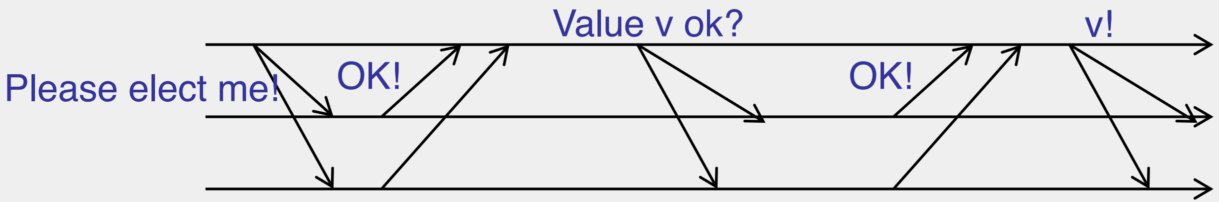
Phase 3 – Decision (Law)

- If leader hears a majority of OKs, it lets everyone know of the decision
- Recipients receive decision, log it on disk



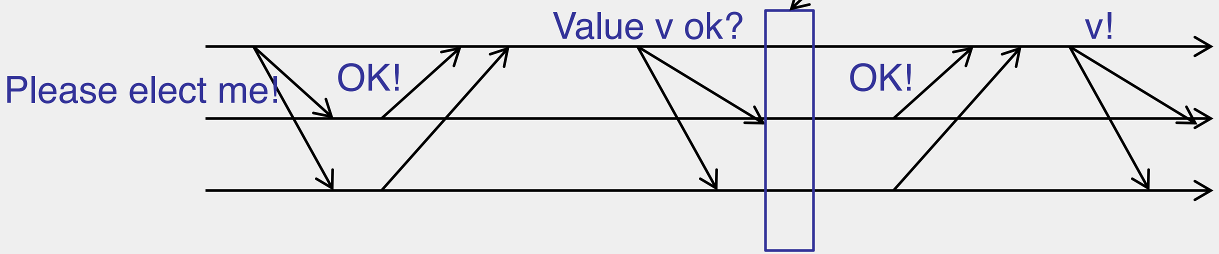
Which is the point of No-Return?

- That is, when is consensus reached in the system



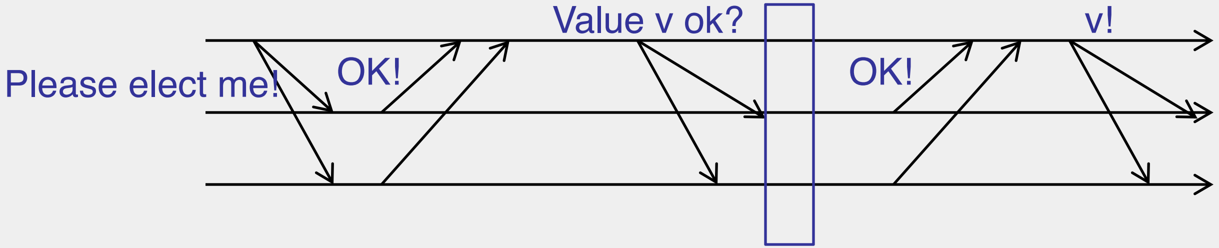
Which is the point of No-Return?

- If/when a majority of processes hear proposed value and accept it (i.e., are about to/have respond(ed) with an OK!)
- Processes *may not know it yet*, but a decision has been made for the group
  - Even leader does not know it yet
- What if leader fails after that?
  - Keep having rounds until some round completes



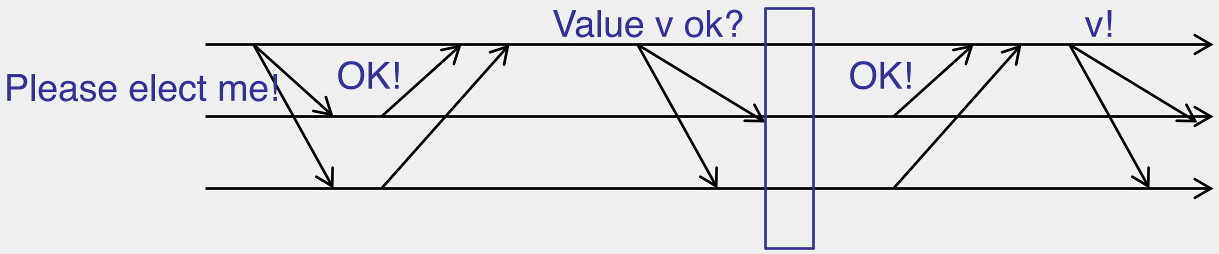
Safety

- If some round has a majority (i.e., quorum) hearing proposed value v' and accepting it, then subsequently at each round either: 1) the round chooses v' as decision or 2) the round fails
- Proof:
  - Potential leader waits for majority of OKs in Phase 1
  - At least one will contain v' (because two majorities or quorums always intersect)
  - It will choose to send out v' in Phase 2
- Success requires a majority, and any two majority sets intersect



What could go Wrong?

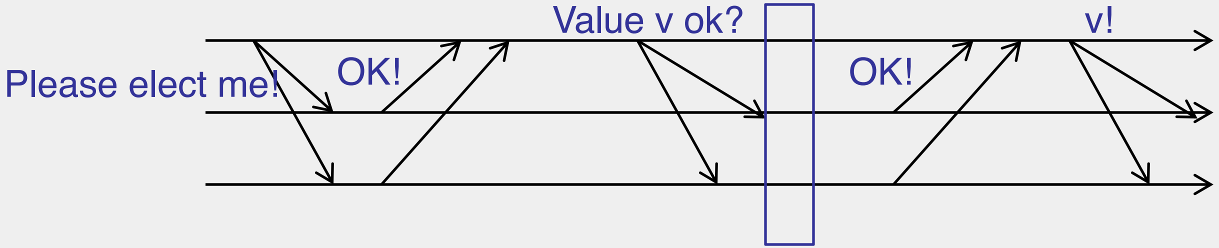
- Process fails
  - Majority does not include it
  - When process restarts, it uses log to retrieve a past decision (if any) and past-seen ballot ids. Tries to know of past decisions.
- Leader fails
  - Start another round
- Messages dropped
  - If too flaky, just start another round
- Note that anyone can start a round any time
- Protocol may never end – tough luck, buddy!
  - Impossibility result not violated
  - If things go well sometime in the future, consensus reached



What could go Wrong?

- A lot more!

- This is a highly simplified view of Paxos.
- See Lamport's original paper: http://research.microsoft.com/en-us/um/people/lamport/pubs/paxos-simple.pdf



Summary

- Paxos protocol: widely used implementation of a safe, eventually-live consensus protocol for asynchronous systems
  - Paxos (or variants) used in Apache Zookeeper, Google's Chubby system, Active Disk Paxos, and many other cloud computing systems