CS 425 / ECE 428
Distributed Systems
Fall 2015

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Lecture 19: 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.

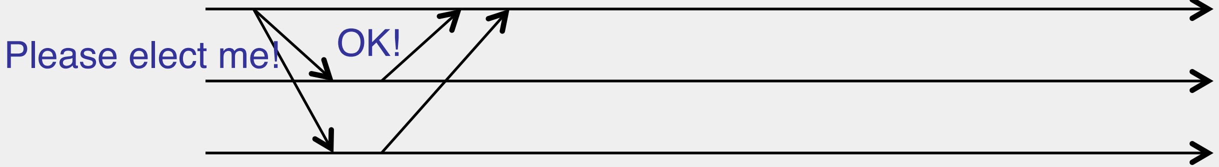
- FLP result still applies: Paxos is not *guaranteed* to reach Consensus (ever, or within any bounded time)

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)

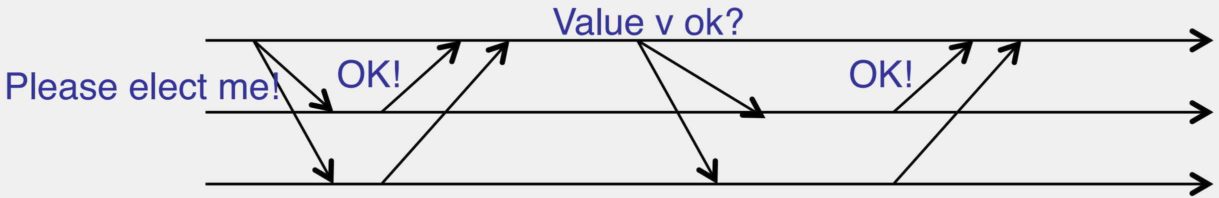
PHASE 1 – ELECTION

- 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?)



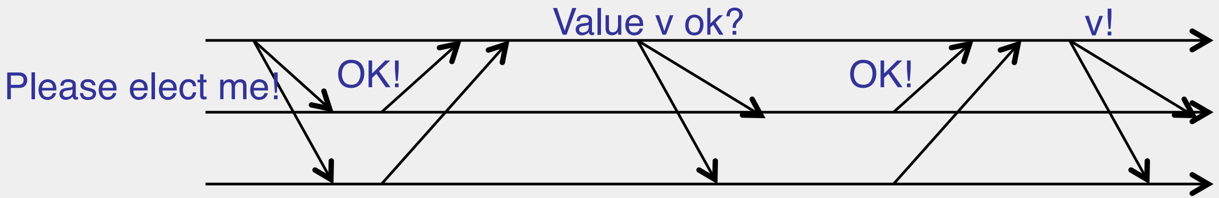
Phase 2 – Proposal (Bill)

- 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



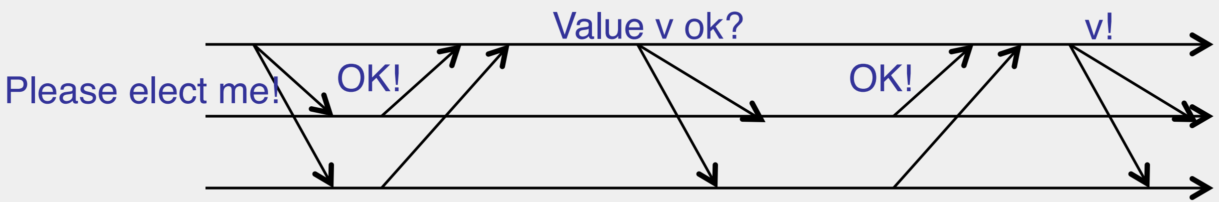
Phase 3 – Decision (Law)

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



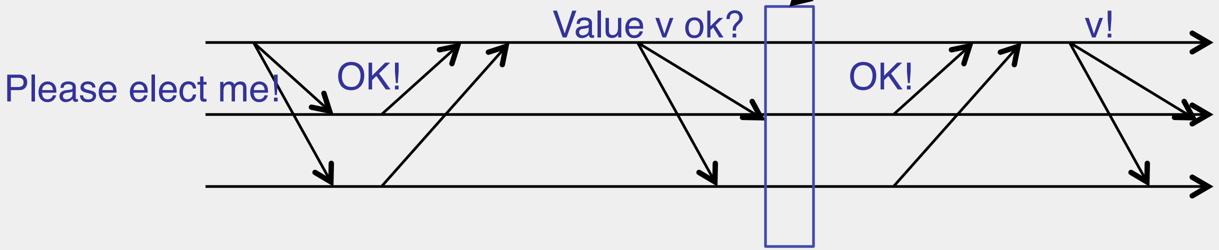
Which is the point of No-Return?

- That is, when is consensus reached in the system



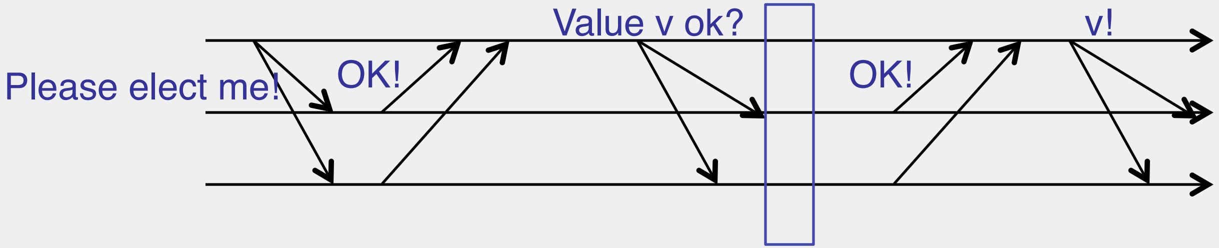
Which is the point of No-Return?

- 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



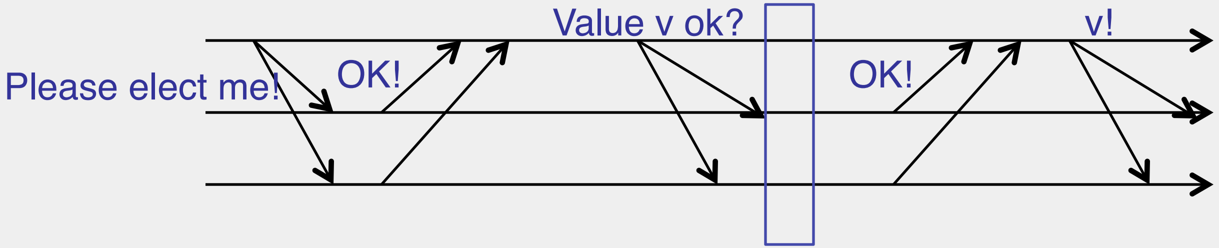
SAFETY

- 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?

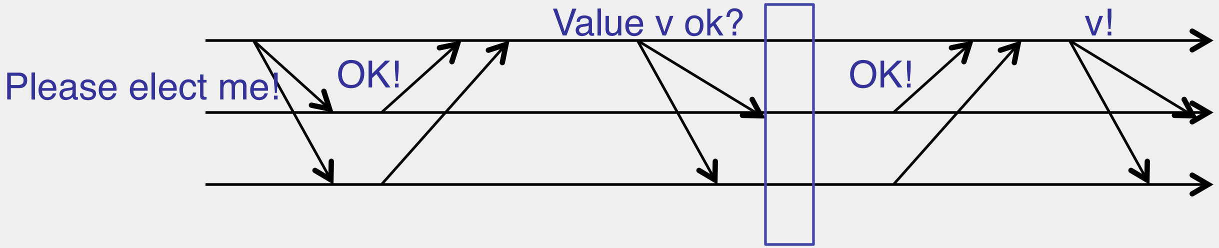
- Process fails
  - Majority does not include it
  - When process restarts, it uses log to retrieve a past decision (if any) and past-seen ballot ids. Tries to know of past decisions.
- Leader fails
  - Start another round
- Messages dropped
  - If too flaky, just start another round
- Note that anyone 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/enus/um/people/lamport/pubs/paxossimple.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