Distributed Systems

Lec 17: Agreement in Distributed Systems: Three-phase Commit, Paxos

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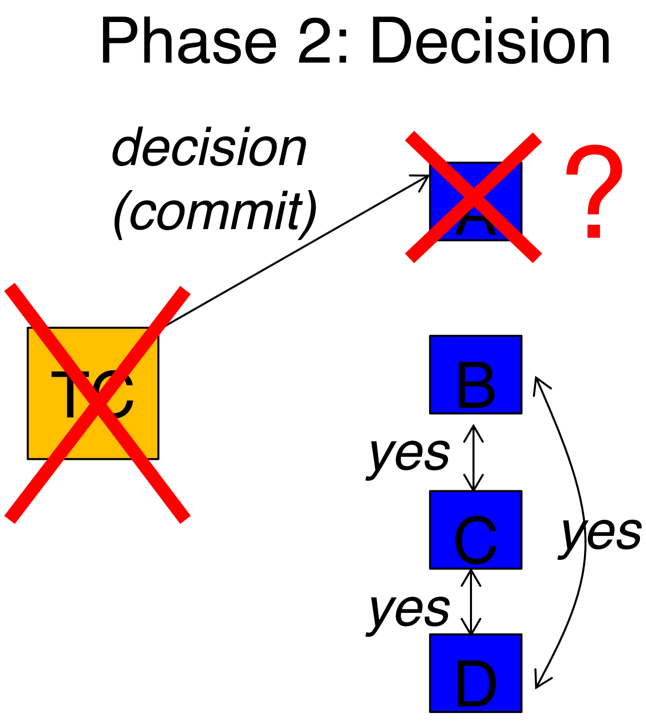
(http://news.cs.nyu.edu/~jinyang/fa10/notes/ds-paxos.ppt, http://the-paper-trail.org/blog/)

Example Blocking Failure for 2PC

- Scenario:
  - TC sends commit decision to A, A gets it and commits, and then both TC and A crash
  - B, C, D, who voted Yes, now need to wait for TC or A to reappear (w/ mutexes locked)
    - They can't commit or abort, as they don't know what A responded
  - If that takes a long time (e.g., a human must replace hardware), then availability suffers
  - If TC is also participant, as it typically is, then this protocol is vulnerable to a single-node failure (the TC's failure)!



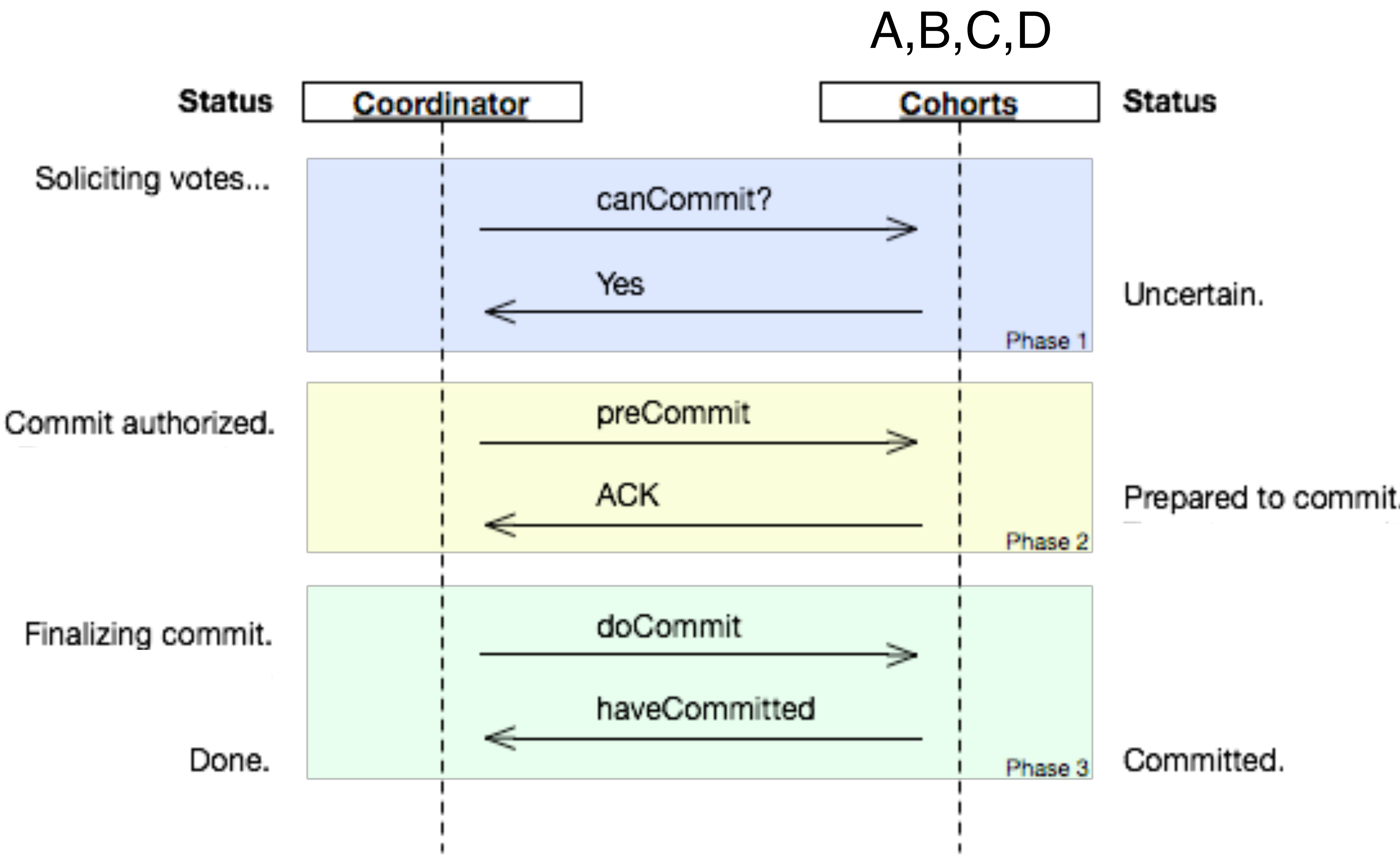
- This is why 2 phase commit is called a blocking protocol
- In context of consensus requirements: 2PC is safe, but not live

Three-Phase Commit
(the original protocol)

3PC: Goal and Idea

- Goal: Turn 2PC into a live (non-blocking) protocol
  - 3PC should never block on node failures as 2PC did
- Insight: 2PC suffers from allowing nodes to irreversibly commit an outcome before ensuring that the others know the outcome, too
- Idea in 3PC: split “commit/abort” phase into two phases
  - First communicate the outcome to everyone
  - Let them commit only after everyone knows the outcome

3PC

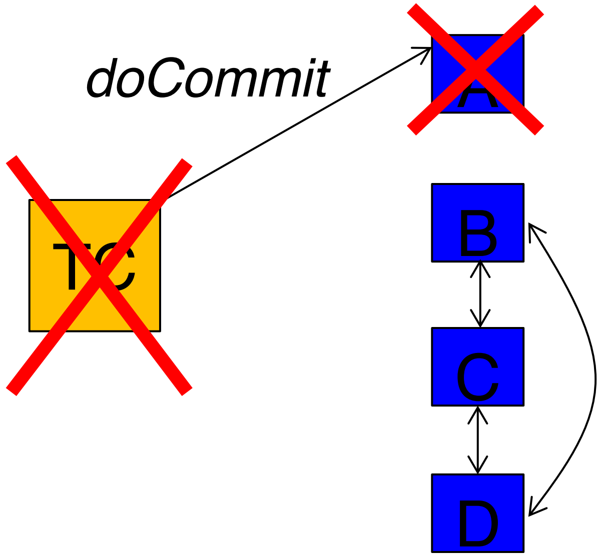


Img source: wikipedia

Can 3PC Solve Blocking 2PC Ex.?

- Assuming same scenario as before (TC, A crash), can B/C/D reach a safe decision when they time out?
  1. If one of them has received preCommit, …
  2. If none of them has received preCommit, …

Phase 3: Commit

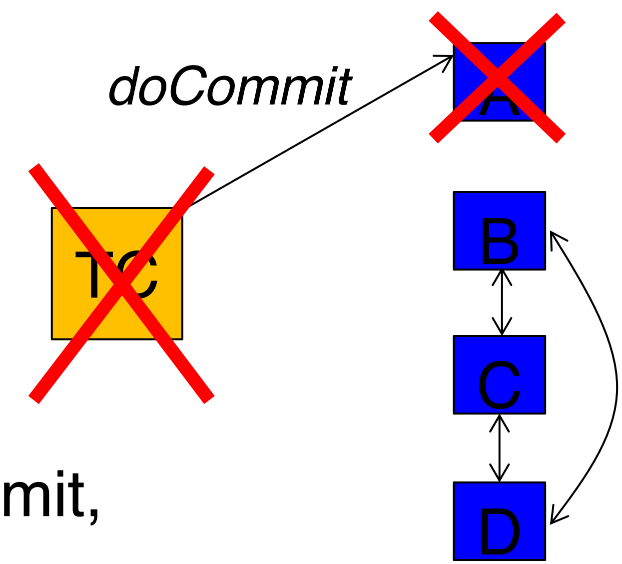


Can 3PC Solve Blocking 2PC Ex.?

- Assuming same scenario as before (TC, A crash), can B/C/D reach a safe decision when they time out?

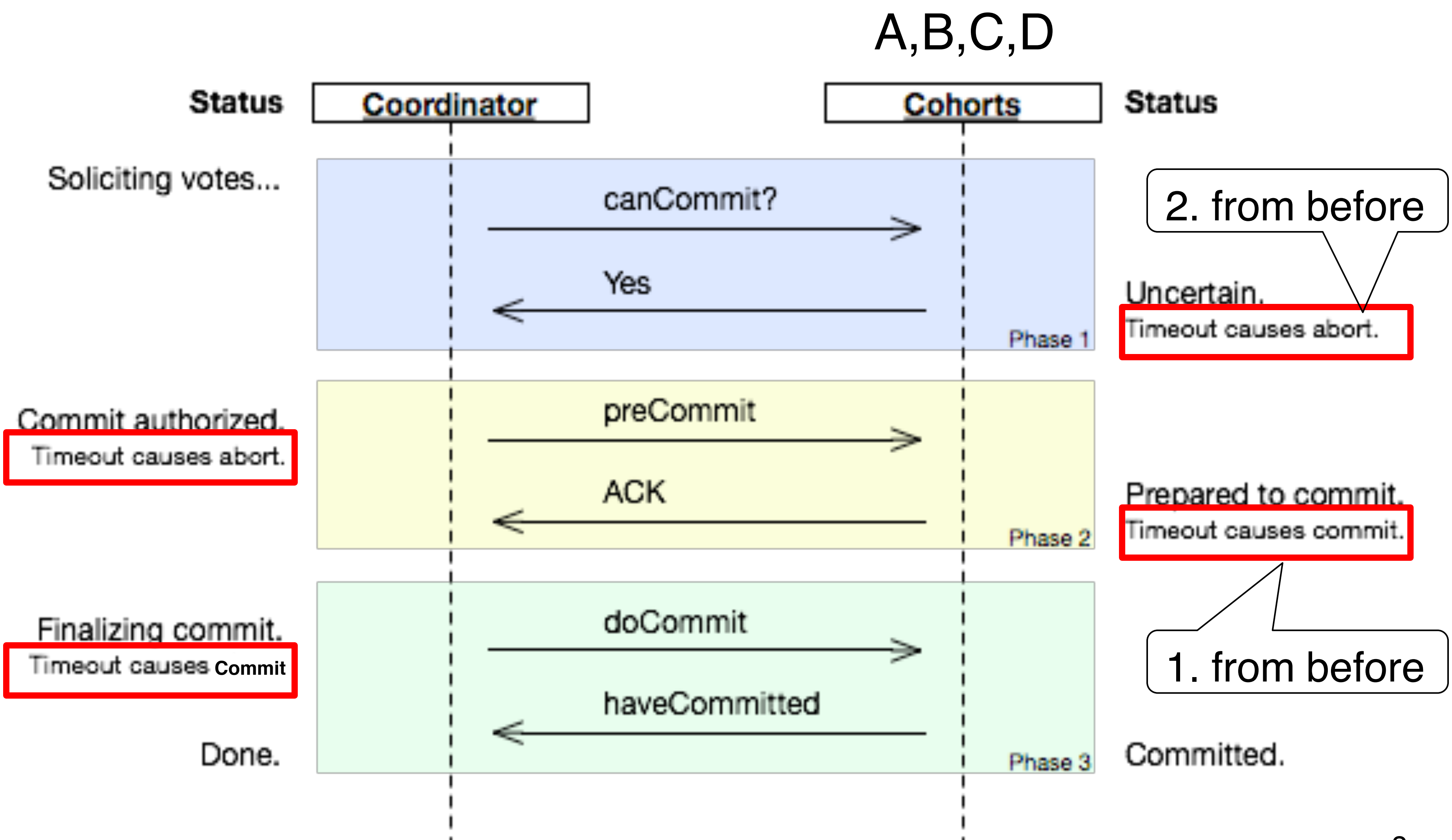
1. If one of them has received preCommit, they can all commit
   - This is safe if we assume that A is DEAD and after coming back it runs a recovery protocol in which it requires input from B/C/D to complete an uncommitted transaction
   - This conclusion was impossible to reach for 2PC b/c A might have already committed and exposed outcome of transaction to world
2. If none of them has received preCommit, they can all abort
   - This is safe, b/c we know A couldn't have received a doCommit, so it couldn't have committed

Phase 3: Commit



3PC is safe for node crashes (including TC+participant)

3PC: Timeout Handling Specs (trouble begins)



Img source: wikipedia

But Does 3PC Achieve Consensus?

- Liveness (availability): Yep
  - Doesn't block, it always makes progress by timing out

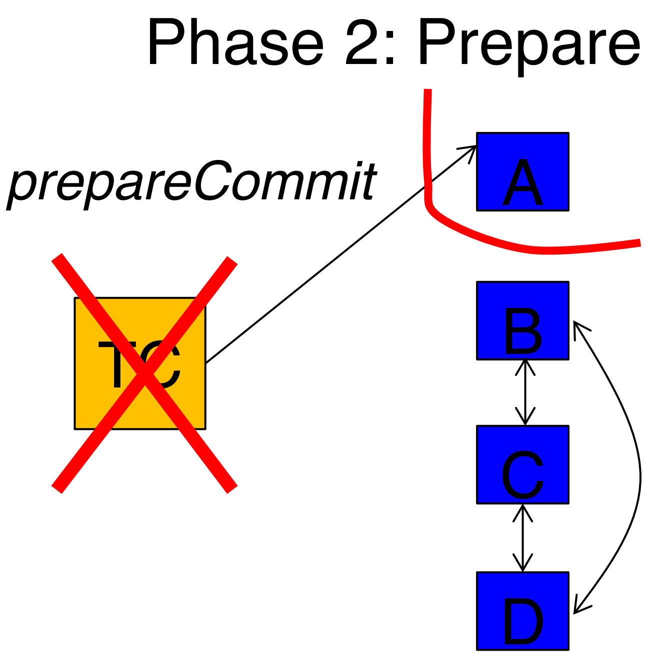
- Safety (correctness): Nope
  - Can you think of scenarios in which original 3PC would result in inconsistent states between the replicas?

- Two examples of unsafety in 3PC:
  - A hasn't crashed, it's just offline
  - TC hasn't crashed, it's just offline

Network partitions

3PC with Network Partitions

- One example scenario:
  - A receives prepareCommit from TC
  - Then, A gets partitioned from B/C/D and TC crashes
  - None of B/C/D have received prepareCommit, hence they all abort upon timeout
  - A is prepared to commit, hence, according to protocol, after it times out, it unilaterally decides to commit



- Similar scenario with partitioned, not crashed, TC

Safety vs. Liveness

- So, 3PC is doomed for network partitions
  - The way to think about it is that this protocol's design trades safety for liveness
- Remember that 2PC traded liveness for safety

- Can we design a protocol that's both safe and live?

- Well, it turns out that it's impossible in the most general case!

Fischer-Lynch-Paterson [FLP'85] Impossibility Result

- It is impossible for a set of processors in an asynchronous system to agree on a binary value, even if only a single process is subject to an unannounced failure
  - We won't show any proof here – it's too complicated
- The core of the problem is asynchrony
  - It makes it impossible to tell whether or not a machine has crashed (and therefore it will launch recovery and coordinate with you safely) or you just can't reach it now (and therefore it's running separately from you, potentially doing stuff in disagreement with you)
- For synchronous systems, 3PC can be made to guarantee both safety and liveness!
  - When you know the upper bound of message delays, you can infer when something has crashed with certainty

FLP – Translation

- What FLP says: you can't guarantee both safety and progress when there is even a single fault at an inopportune moment

- What FLP doesn't say: in practice, how close can you get to the ideal (always safe and live)?

- Next: Paxos algorithm, which in practice gets close