Distributed Systems

Lec 16: Agreement in Distributed Systems: Two-phase Commit Problems, Three-phase Commit

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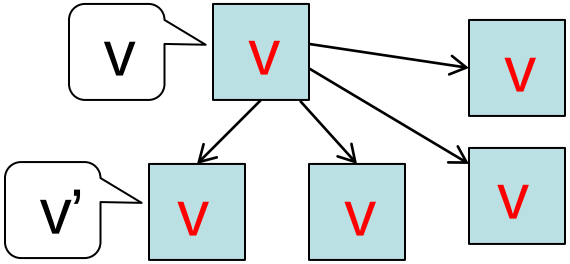
(~~http://news.cs.nyu.edu/~jinyang/fa10/notes/ds-paxos.ppt~~, ~~http://the-paper-trail.org/blog/~~)

Agreement in Distributed Systems

- The crown problem of distributed systems
  - A.k.a. consensus
- Despite having different views of the world, all nodes in a distributed system must act in concert, e.g.:
  - All replicas that store the same object O must apply all updates to O in the same order (consistency)
  - All nodes involved in a transaction must either commit or abort their portion of the transaction (atomicity)
- All that, despite FAILURES
  - Nodes can restart, die, be slow
  - Networks can be slow, as well (but we assume they're reliable here, i.e., all network messages are eventually received)

The Agreement Problem

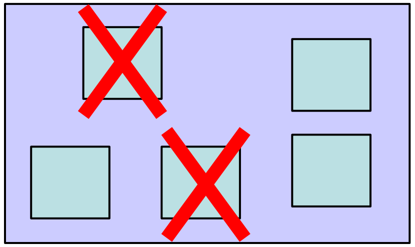
- Some nodes *propose* values (or actions) by sending them to the others
- All nodes must *decide* whether to accept or reject those values



- Examples of values to agree on:
  - Whether or not to commit a transaction to a DB
  - The value of the clock
  - The leader that will coordinate some higher-level protocol
  - Who has a lock in a distributed lock service among multiple clients that request it almost simultaneously
  - Whether to move to the next stage of a distributed alg. (a barrier)

Agreement Requirements

- Safety (correctness)
  - All nodes agree on the same value
  - The agreed value X has been proposed by some node
- Liveness (fault tolerance, availability)
  - If less than some fraction of nodes crash, the rest should still reach agreement
- I.e., agreement aims to give the behavior of a single machine with the fault-tolerance of multiple machines



Failure Models

- For these classes, we define agreement in the context of two failure models:
- Synchronous systems: machines and networks can only be delayed by a bounded time
  - I.e., using a sufficiently large timeout, you can tell with certainty whether the machine crashed or it or the network is just slow
- Asynchronous systems: machines and networks can be arbitrarily delayed ← more general
  - There's no way you can tell whether a machine has crashed or is just slow
- We'll see that different safety/liveness properties are possible under different models

What We've Learned So Far

- We've already been discussing about agreement, e.g.:
  - Logical clocks are a form of agreement (what's the time?)
  - Distributed mutex algos (who has lock?)
  - Two-phase commit (commit or abort?)
- However, none of the algorithms thus far are particularly fault-tolerant (or live during failures)
  - Distributed mutex algo block when any node crashes
  - Two-phase commit (2PC) blocks when TC crashes (we'll see example today)
- Last time, we talked about fault recovery
  - Recovering 2PC (will finish today)

Today

- Fault recovery is important, but is insufficient, because recovery can be very slow
  - E.g., the 2PC coordinator may be down for a long time before it reboots, you don't want the whole protocol to wait for it
- You want fault tolerance
  - I.e., high availability despite concurrent faults
  - (The ability to recover from faults is still important, so that a failed replica can re-join the group after reboot as seamlessly as possible)
- Today's (and next time's) plan:
  - Finish discussion about recovery-enabled 2PC
  - Talk about the fault-tolerance limitations of 2PC
  - Introduce 3 phase commit (3PC)
  - Introduce Paxos

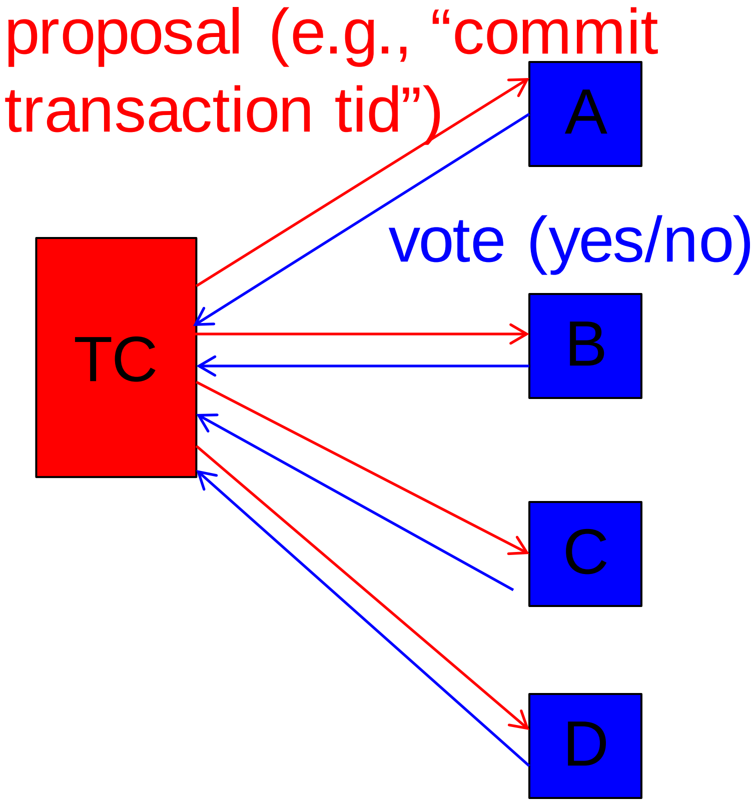
Recovery-enabled
Two-Phase Commit

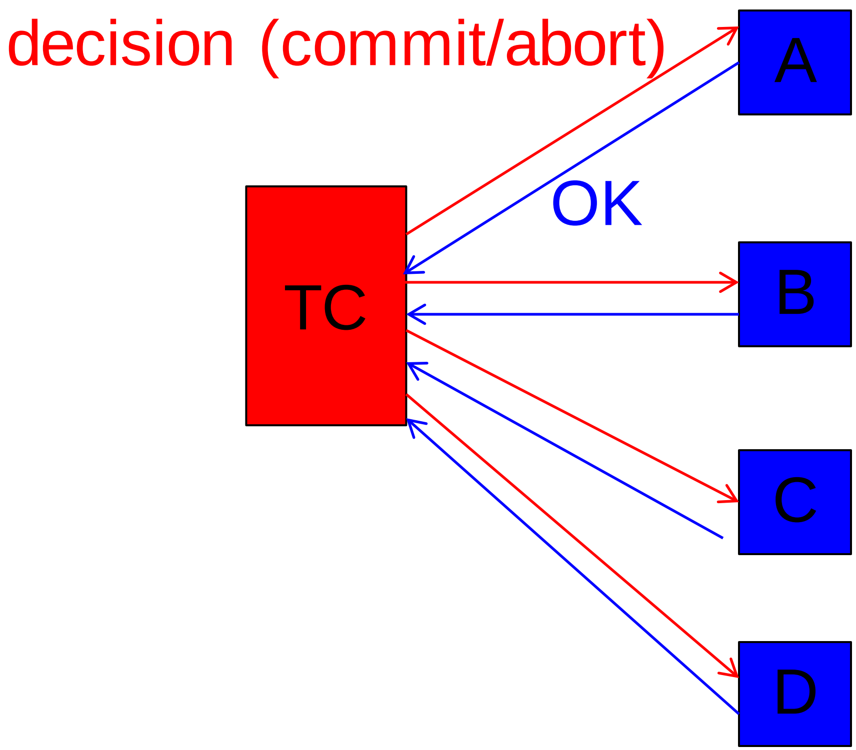
(repeat from last time’s slides, as we left them uncovered)

2PC (with consensus terminology)

Phase 1: proposal

Phase 2: decision





Recovery in Two-Phase Commit

- Easy: just log the state-changes
  - Participants: prepared, uncertain, committed/aborted
  - Coordinator: prepared, committed/aborted, done
  - The messages are idempotent!
    - In recovery, resend whatever message was next
    - If coordinator and uncommitted: abort

- Two cases:
  - Recovery after timeouts
  - Recovery after crashes and reboots
  - (Note: you can't differentiate between the above in a realistic, asynchronous network!)

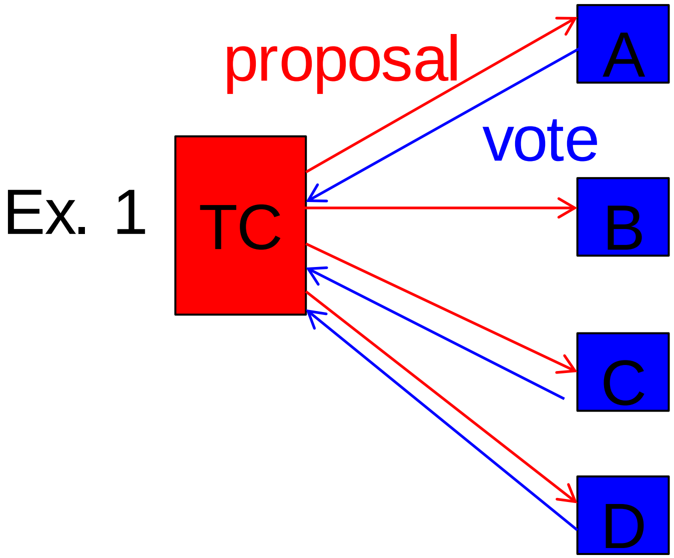
Handling Timeouts

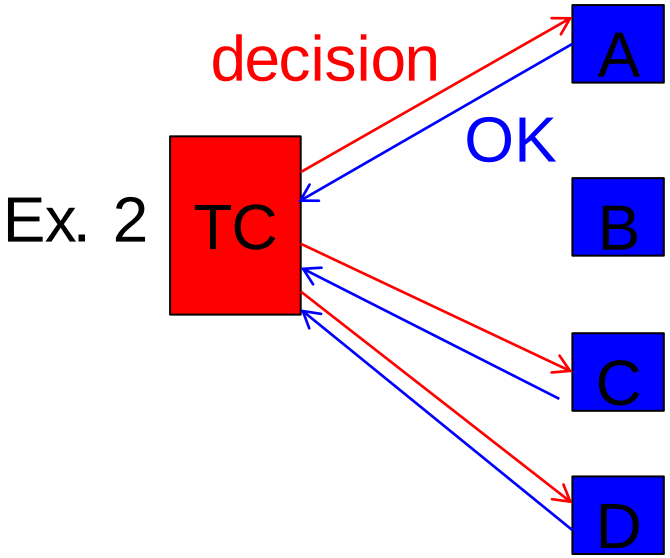
- Examples:

  Ex. 1: TC times out waiting for B's vote

  Ex. 2: B times out waiting for TC's decision message

- Btw, timeouts aren't necessarily due to network
  – They could due to slow, overloaded hosts

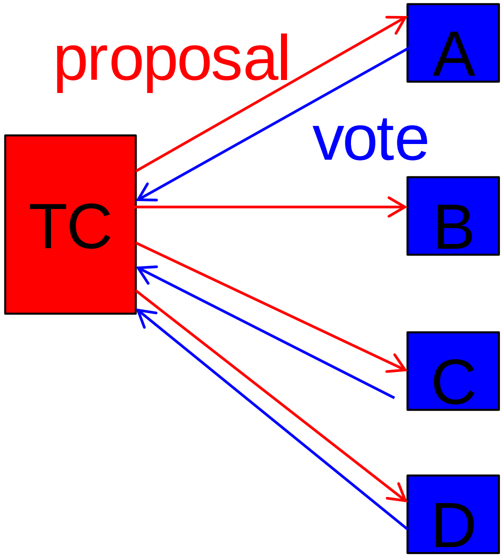




Handling Timeouts on A/B/C/D

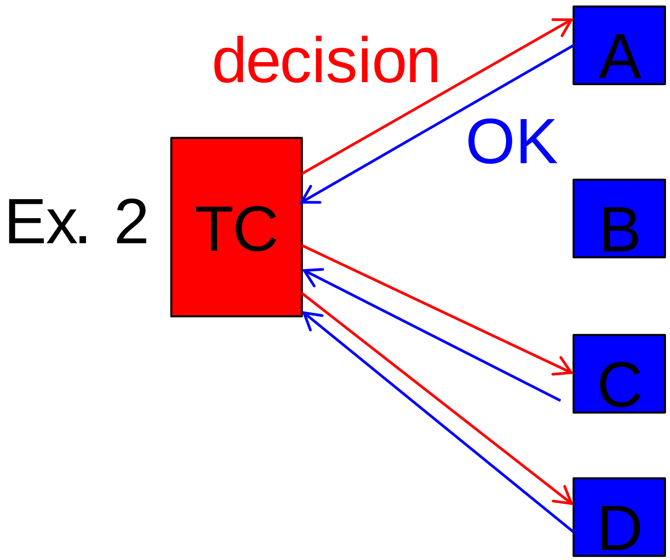
- TC times out waiting for B (or A/C/D)'s vote
- Can TC unilaterally decide to commit?
- Can TC unilaterally decide to abort?

Ex. 1



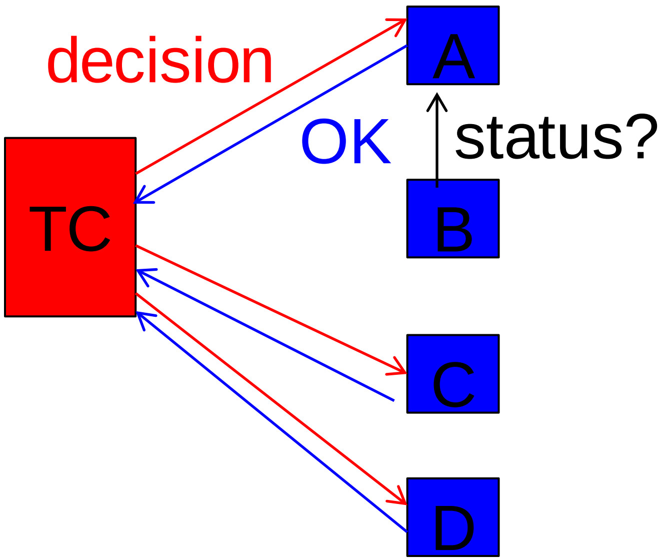
Handling Timeout on TC

- B times out waiting for TC's decision
- If B voted "no" …
  - Can it unilaterally abort?
- If B responded with "yes" …
  - Can it unilaterally abort?
  - Can it unilaterally commit?



Termination Protocol

- If B times out on TC and has voted "yes", then execute termination protocol:
- B sends "status" message to A
  - If A has received "commit"/"abort" from TC, …
  - If A has not responded to TC, …
  - If A has responded with "no", …
  - If A has responded with "yes", …



Handling Crash and Reboot

- Nodes cannot back out if commit is decided

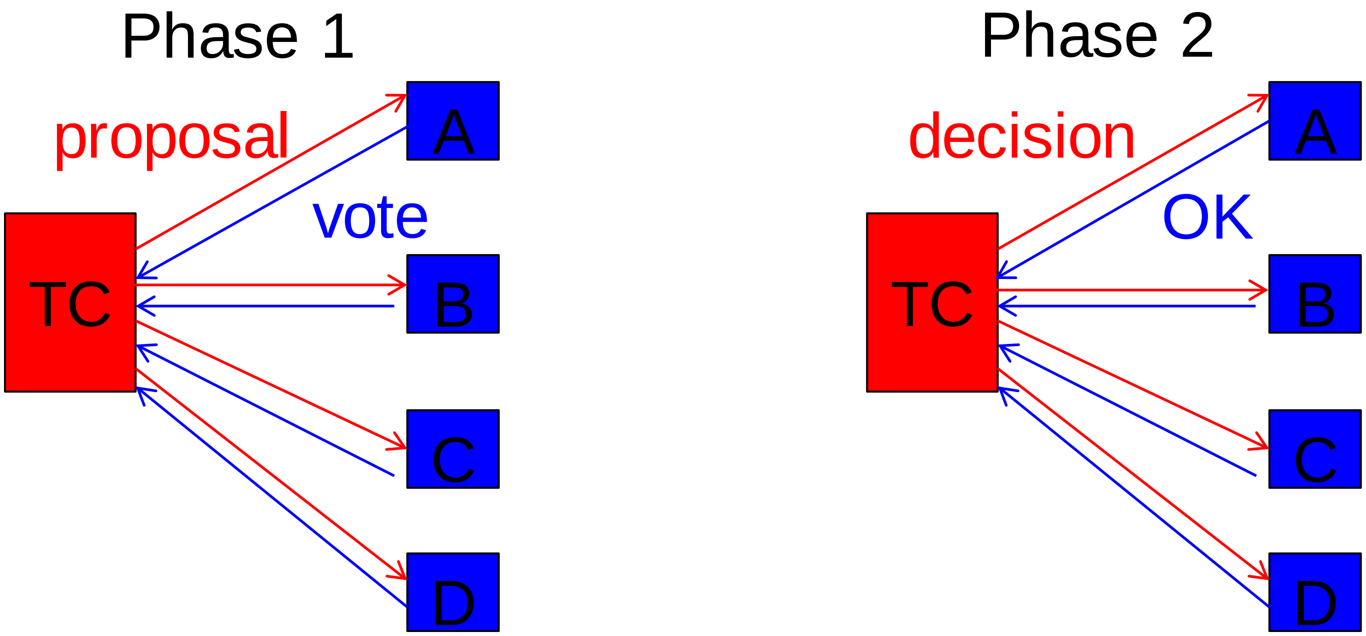
Examples:

- Ex 3: TC crashes just after deciding “commit”
  - Cannot forget about its decision after reboot

- Ex 4: A/B/C/D crashes after sending “yes”
  - Cannot forget about their response after reboot

Handling Crash and Reboot

- All nodes must log protocol progress
- What and when does TC log to disk?
- What and when does A/B/C/D log to disk?



Recovery Upon Reboot

- Ex 3: TC crashes:
  - If TC finds no “commit” on disk, abort
  - If TC finds “commit”, commit
- Ex 4: A/B/C/D crash:
  - If A/B/C/D finds no “yes” on disk, abort
  - If A/B/C/D finds “yes”, run termination protocol to decide

Fault-Tolerance Limitations of Recovery-enabled 2PC

- Even with recovery enabled, 2PC isn't really fault-tolerant (or live), because it can block even when one (or a few) machines fail
  - Blocking means that it doesn't make progress during the failure

- Can you think of an example fault scenario?

Example Blocking Failure for 2PC

- Scenario:
  - TC sends commit outcome to A, A gets it and commits, and then both TC and A die
  - B, C, D have already also replied Yes, have locked their mutexes, and now need to wait for TC or A to reappear
    - They cannot recover the decision with certainty until TC or A are online
  - If that takes a long time (e.g., a human needs to replace a hardware component), then the protocol is stuck and availability goes down
  - 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
  - Btw, the original, non-recovery-enabled protocol blocked even more frequently, but we've fixed some of the obvious glitches

- In context of consensus requirements: 2PC is safe, but not live

Fixing Two-Phase Commit

- Surprisingly enough, there's no simple fix!
  - Creating a protocol that's both correct and available is tough!
  - In fact, as we'll see at the end of the class, it's impossible in the general sense (and it can be proven so!!)
  - But it's tough to even get close to that

- It took 25 years to come up with safe protocol
  - 2PC appeared in 1979 (Gray)
  - In 1981, a basic, unsafe 3PC was proposed (Stonebraker)
  - In 1998, the safe, mostly live Paxos appeared (Lamport)
  - Why so difficult? Well, we'll see later…

Next Time

- Three Phase Commit
- Paxos
- Usage of them

Extra Readings

- Two-phase commit:
  - http://the-paper-trail.org/blog/consensus-protocols-two-phase-commit/
- Three-phase commit:
  - http://the-paper-trail.org/blog/consensus-protocols-three-phase-commit
- Paxos:
  - http://the-paper-trail.org/blog/consensus-protocols-paxos/
- FLP impossibility result in distributed systems:
  - http://betathoughts.blogspot.com/2007/06/brief-history-of-consensus-2pc-and.html