Distributed Transactions

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Transaction Models

ACID vs. BASE

- ACID: Atomicity, Consistency, Isolation, Durability
  - Provides a consistent system
  - Sacrifices high performance for ease of programming
- BASE: Basically-Available, Soft-state, Eventually consistent
  - Provides high availability
  - Ensuring consistency is up to application programmers

CAP theorem: It is impossible to achieve both consistency and availability in a partition tolerant distributed system

ACID vs. BASE

```
// ACID transfer transaction
begin transaction
  Select bal into @bal from accnts where id = sndr
  if (@bal >= amt)
    Update accnts set bal −= amt where id = sndr
    Update accnts set bal += amt where id = rcvr
commit

// ACID total−balance transaction
begin transaction
  Select sum(bal) from accnts
commit
```

(a) The ACID approach.

```
// transfer using the BASE approach
begin local−transaction
  Select bal into @bal from accnts where id = sndr
  if (@bal >= amt)
    Update accnts set bal −= amt where id = sndr
    // To enforce atomicity, we use queues to communicate
    // between partitions
    Queue message(sndr, rcvr, amt) for partition(accnts, rcvr)
end local−transaction

// Background thread to transfer messages to other partitions
begin transaction // distributed transaction to transfer queued msgs
  <transfer messages to rcvr>
end transaction

// A background thread at each partition processes
// the received messages
begin local−transaction
  Dequeue message(sndr, rcvr, amt)
  Select id into @id from accnts where id = rcvr
  if (@id ≠ ∅) // if rcvr's account exists in database
    Update accnts set bal += amt where id = rcvr
  else // rollback by sending the amt back to the original sender
    Queue message(rcvr, sndr, amt) for partition(accnts, sndr)
end local−transaction

// total−balance using the BASE approach
// The following two lines are needed to ensure correctness of
// the total−balance ACID transaction
<notify all partitions to stop accepting new transfers>
<wait for existing transfers to complete>
begin transaction
  Select sum(bal) from accnts
end transaction
<notify all partitions to resume accepting new transfers>
```

(b) The BASE approach.

When applications need higher performance than ACID provides, it's often because of the needs of just a few transactions

Salt: Best of ACID and BASE

How can we use both ACID and BASE in the same application?

- Use BASE transactions for certain performance-critical transactions
- Keep ACID transaction for the majority

New Terms

- **ACID transactions:** The standard ACID transactions
- **BASE transactions:** Retain atomicity for transactions, but allow isolation to be specified at finer granularity (**salt isolation**)
- **Alkaline sub-transactions:** BASE transactions are composed of a sequence of alkaline sub-transactions

Salt isolation: A property that allows BASE transactions to achieve high concurrency by observing each other's internal states

- Does not affect the isolation guarantees of ACID transactions.

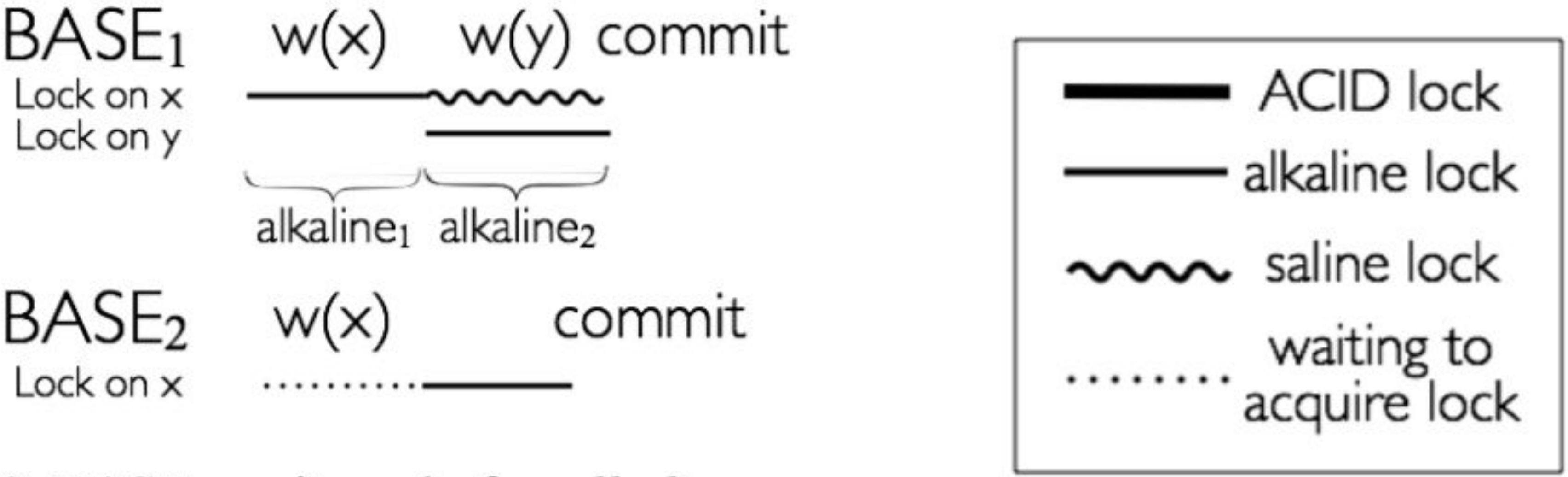
Types of Locks

- **ACID locks:** Writes conflict with reads and writes, reads do not conflict with each other
- **Alkaline locks:** Conflict with all other transactions except read-read, long-term locks only held until transaction completes
- **Saline locks:** Isolate ACID transactions from BASE transactions, conflict with ACID for non-read but never conflict with other saline/alkaline locks

ACID Locks

(a) *BASE* waits until *ACID* commits.

Alkaline/Saline Locks



(b) $BASE_2$ waits only for $alkaline_1 \ldots$

Saline Locks

(c) …but *ACID* must wait all of *BASE* out.

Problem: Indirect Dirty Reads

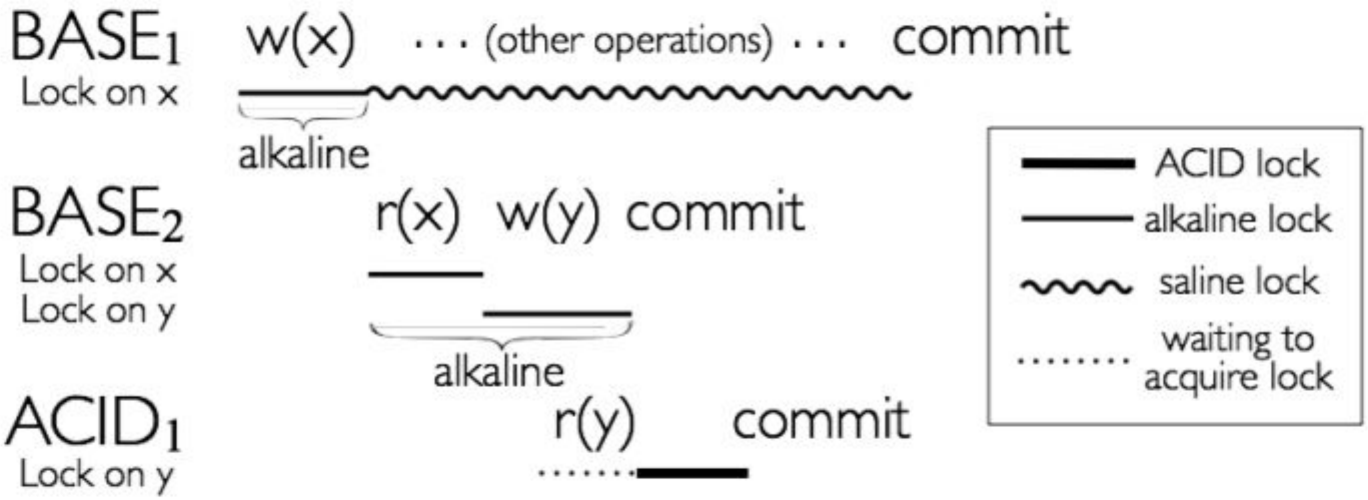
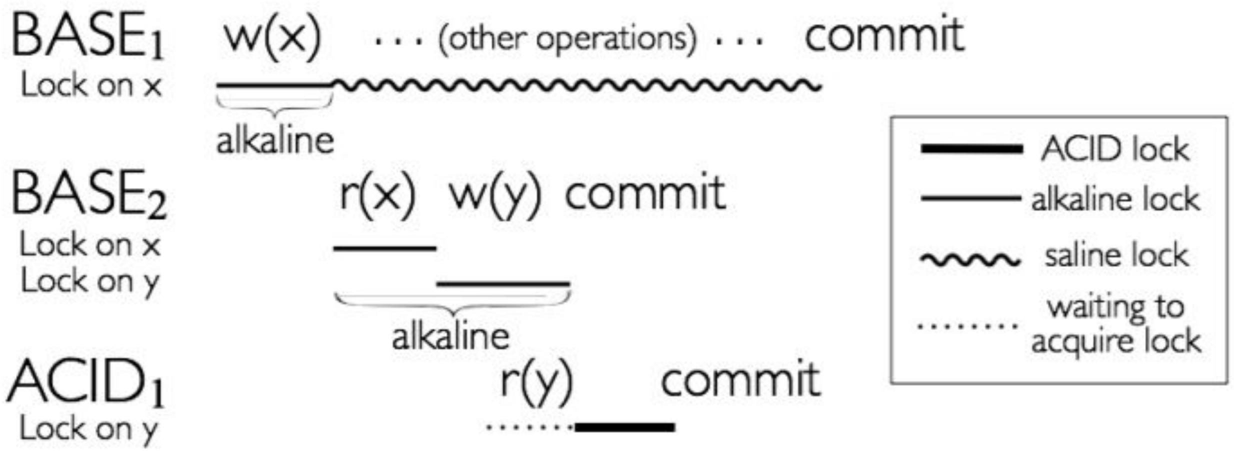


Fig. 4: $ACID_1$ indirectly reads the uncommitted value of x.

Discussion

Indirect dirty reads are possible through naive usage of our locking mechanism.

- What could we have done to prevent the indirect dirty read in the previous example?



Solution: Saline Locks

Fig. 5: How Salt prevents indirect dirty reads.

Locking Rules: Saline Locks

Read-after-write across transactions: A BASE transaction B_1 that reads a value x, which has been written by another BASE transaction B_2, cannot release its saline lock on x until B_2 has released its own saline lock on x.

Write-after-read within a transaction: An operation that writes a value x cannot release its saline lock on x until all previous read operations within the same BASE transaction have released their saline locks on their respective objects.

Salt Performance: Latency

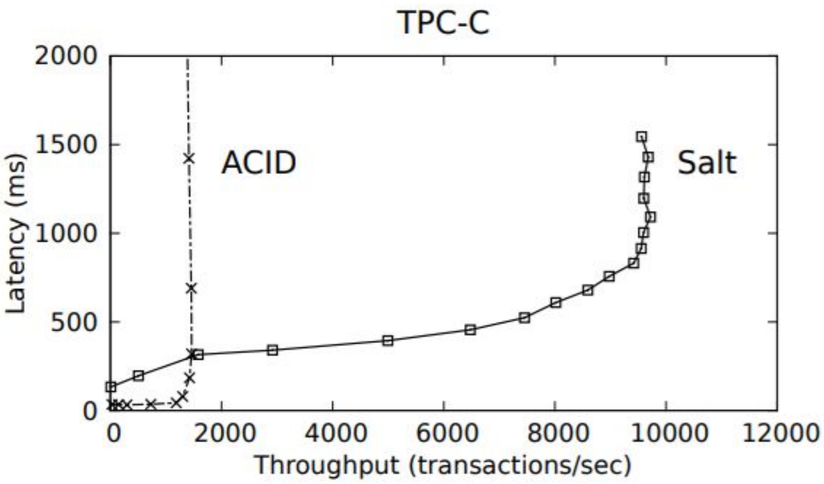


Fig. 7: Performance of ACID and Salt for TPC-C.

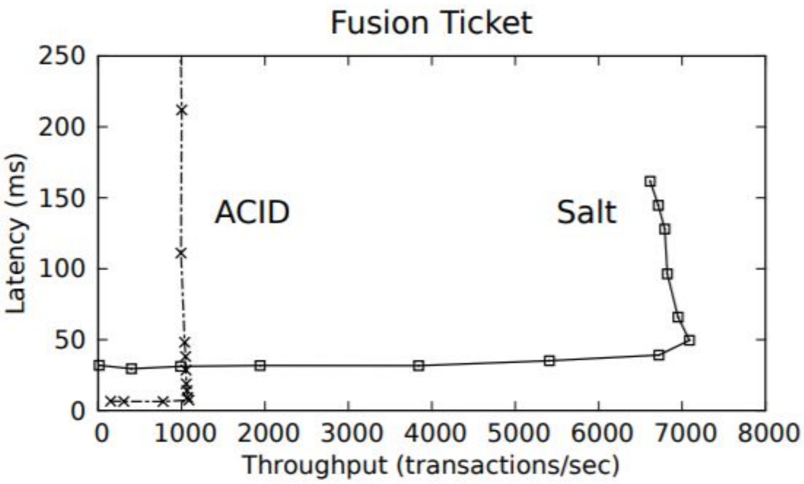


Fig. 8: Performance of ACID and Salt for Fusion Ticket.

Salt Performance: Throughput

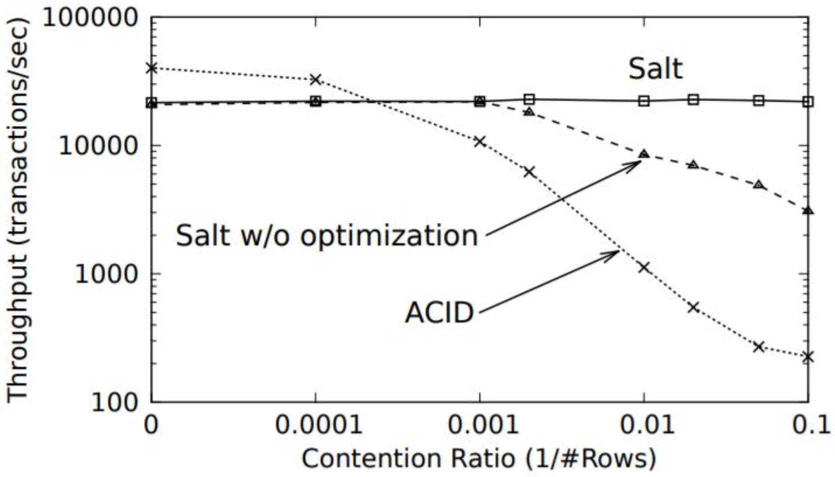


Fig. 11: Effect of contention ratio on throughput.

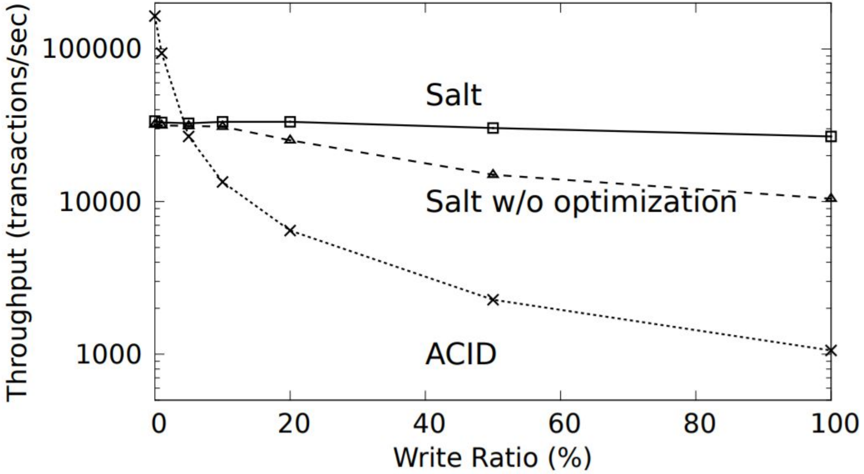


Fig. 13: Effect of read-write ratio on throughput.

Real-World Database Transactions

ACID (SQL databases):

- MySQL
- SQLite
- Microsoft SQL
- Oracle

BASE (NoSQL databases):

- MongoDB
- Cassandra
- Redis

https://tinyurl.com/cse550transactions

Discussion Questions

Salt has demonstrated much lower latency than ACID and much higher throughput in certain cases.

- What other metrics/features of Salt would you want to know about if choosing to use it?
- Why isn’t Salt more widely adopted?
- Are there situations where Salt performance would not be as high as expected?

```
// BASE transaction: transfer
begin BASE transaction
  try
    begin alkaline−subtransaction
      Select bal into @bal from accnts where id = sndr
      if (@bal >= amt)
        Update accnts set bal −= amt where id = sndr
    end alkaline−subtransaction
  catch (Exception e) return // do nothing
  if (@bal < amt) return // constraint violation
  try
    begin alkaline−subtransaction
      Update accnts set bal += amt where id = rcvr
    end alkaline−subtransaction
  catch (Exception e) //rollback if rcvr not found or timeout occurs
    begin alkaline−subtransaction
      Update accnts set bal += amt where id = sndr
    end alkaline−subtransaction
end BASE transaction

// ACID transaction: total−balance (unmodified)
begin transaction
  Select sum(bal) from accnts
commit
```

Fig. 2: A Salt implementation of the simple banking applicatic

```
// transfer using the BASE approach
begin local−transaction
  Select bal into @bal from accnts where id = sndr
  if (@bal >= amt)
    Update accnts set bal −= amt where id = sndr
    // To enforce atomicity, we use queues to communicate
    // between partitions
    Queue message(sndr, rcvr, amt) for partition(accnts, rcvr)
end local−transaction

// Background thread to transfer messages to other partitions
begin transaction // distributed transaction to transfer queued msgs
  <transfer messages to rcvr>
end transaction

// A background thread at each partition processes
// the received messages
begin local−transaction
  Dequeue message(sndr, rcvr, amt)
  Select id into @id from accnts where id = rcvr
  if (@id ≠ ∅) // if rcvr's account exists in database
    Update accnts set bal += amt where id = rcvr
  else // rollback by sending the amt back to the original sender
    Queue message(rcvr, sndr, amt) for partition(accnts, sndr)
end local−transaction

// total−balance using the BASE approach
// The following two lines are needed to ensure correctness of
// the total−balance ACID transaction
<notify all partitions to stop accepting new transfers>
<wait for existing transfers to complete>
begin transaction
  Select sum(bal) from accnts
end transaction
<notify all partitions to resume accepting new transfers>
```

(b) The BASE approach.

Distributed Transactions

Quick Recap

- Distributed vs Centralized Systems
  - Reliability
- How can we provide atomic transactions in a distributed system?
  - Atomic Commitment Protocols

Goals of an ACP

Every operation ends in either *Commit*, or *Abort*

1. All processes that reach a decision reach the same one
2. Decisions cannot be reversed
3. *Commit* can only be reached if all processes agree
4. If there are no failures and all processes agree, then there will be a *commit*
5. The protocol will always advance when it can (no blocking)

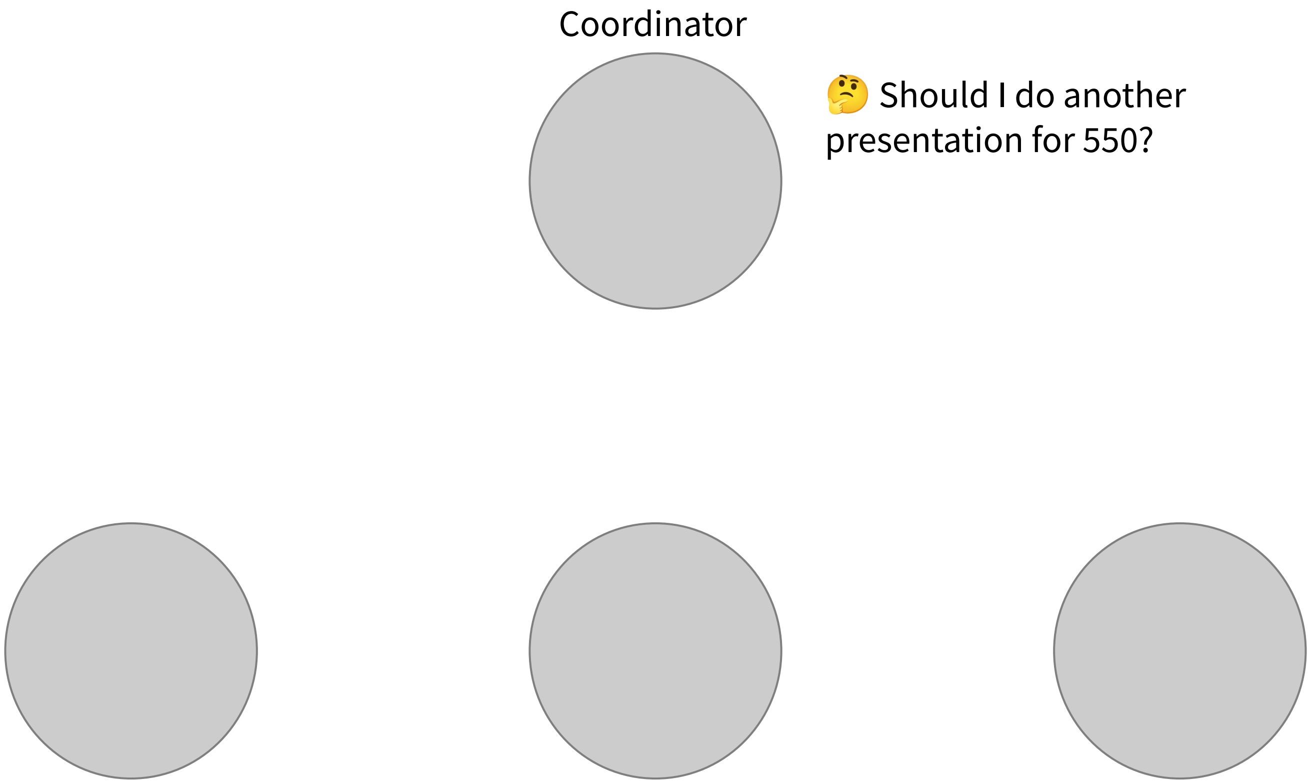
Assumptions

- No data replication
- Fail-stop
- Dropped Messages

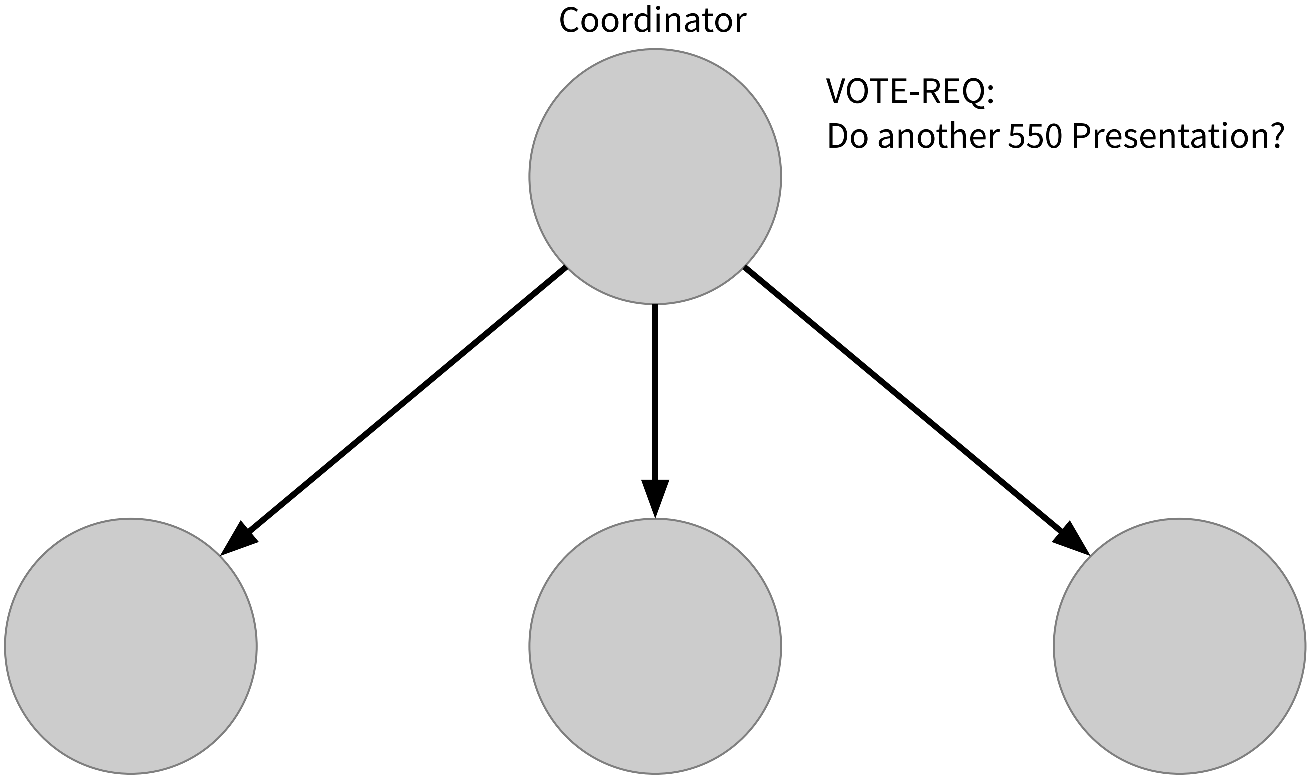
2PC - Rules

1. Phase 1 - Vote
   a. Coordinator sends out a VOTE-REQ to all participants
   b. Participants vote YES or NO to the coordinator’s suggestion
2. Phase 2 - Commit
   a. If all participants vote YES, coordinator sends COMMIT to participants
   b. Participants receive COMMIT and act accordingly

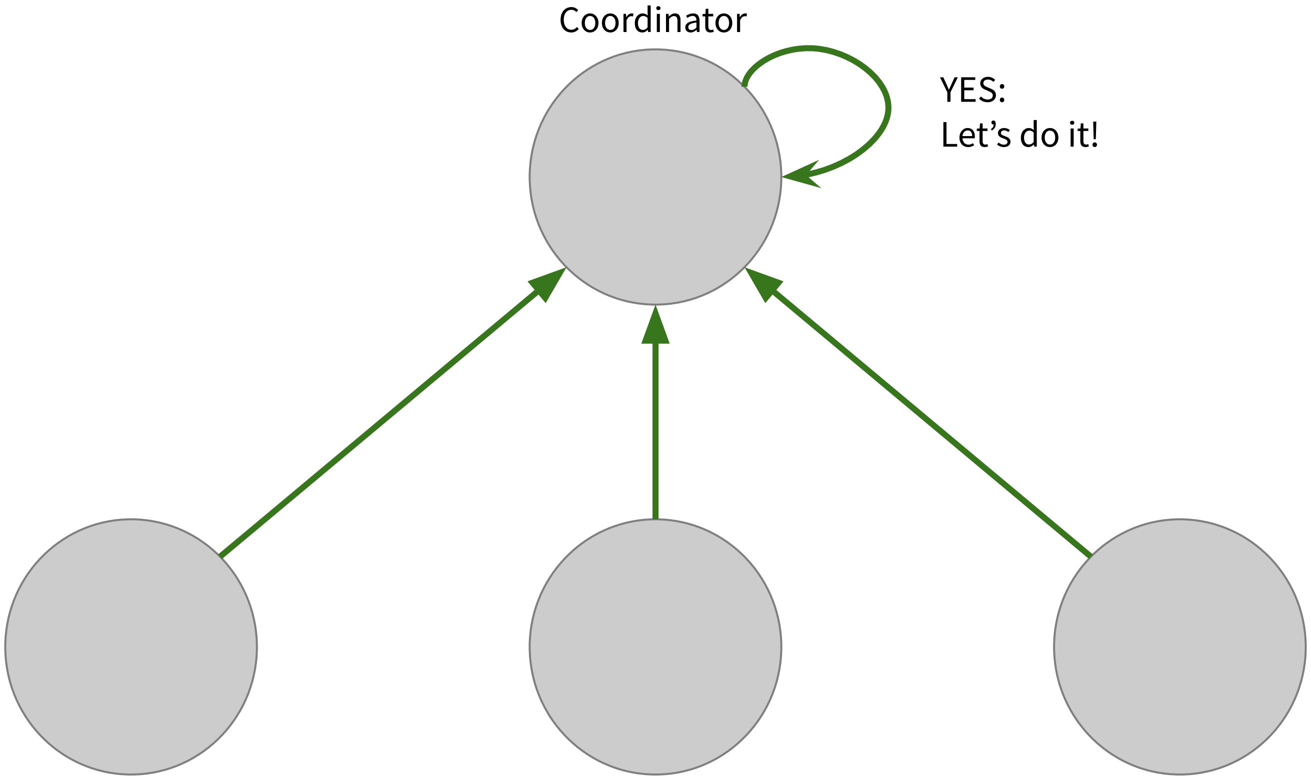
2PC



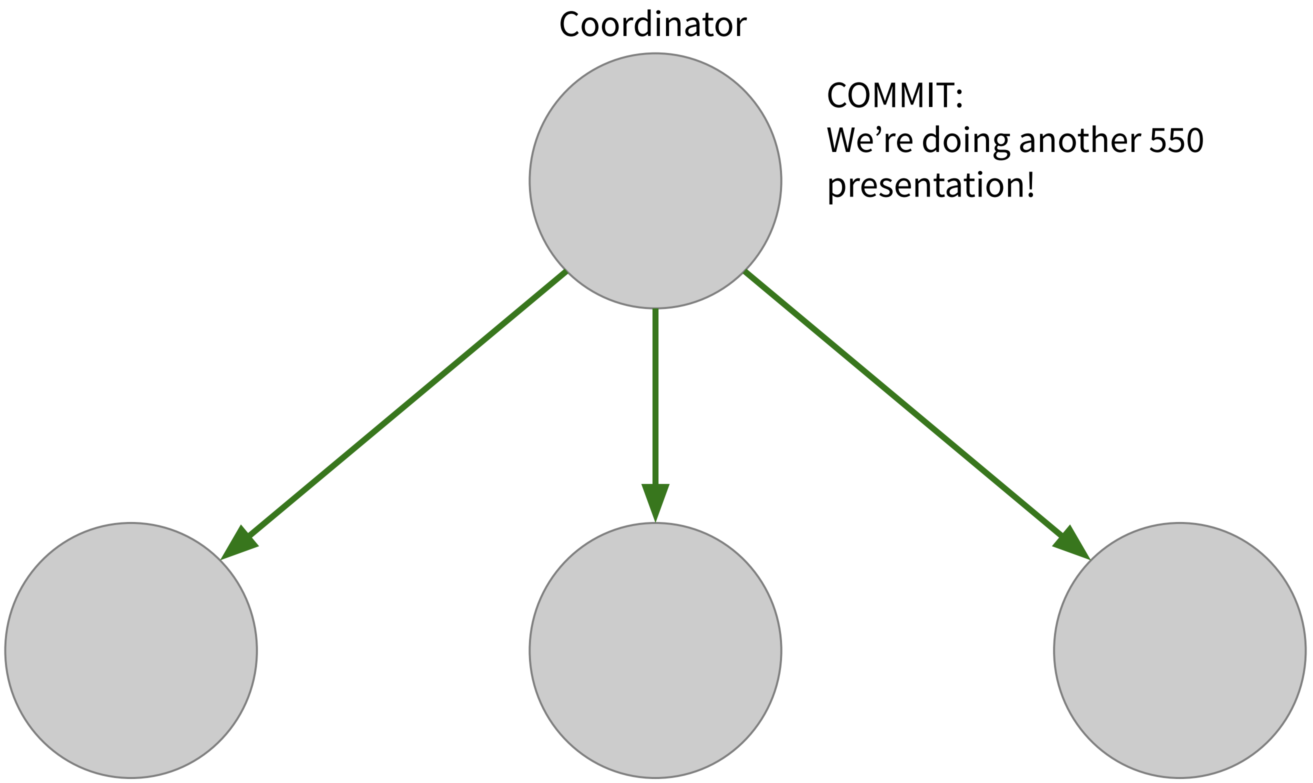
2PC



2PC



2PC



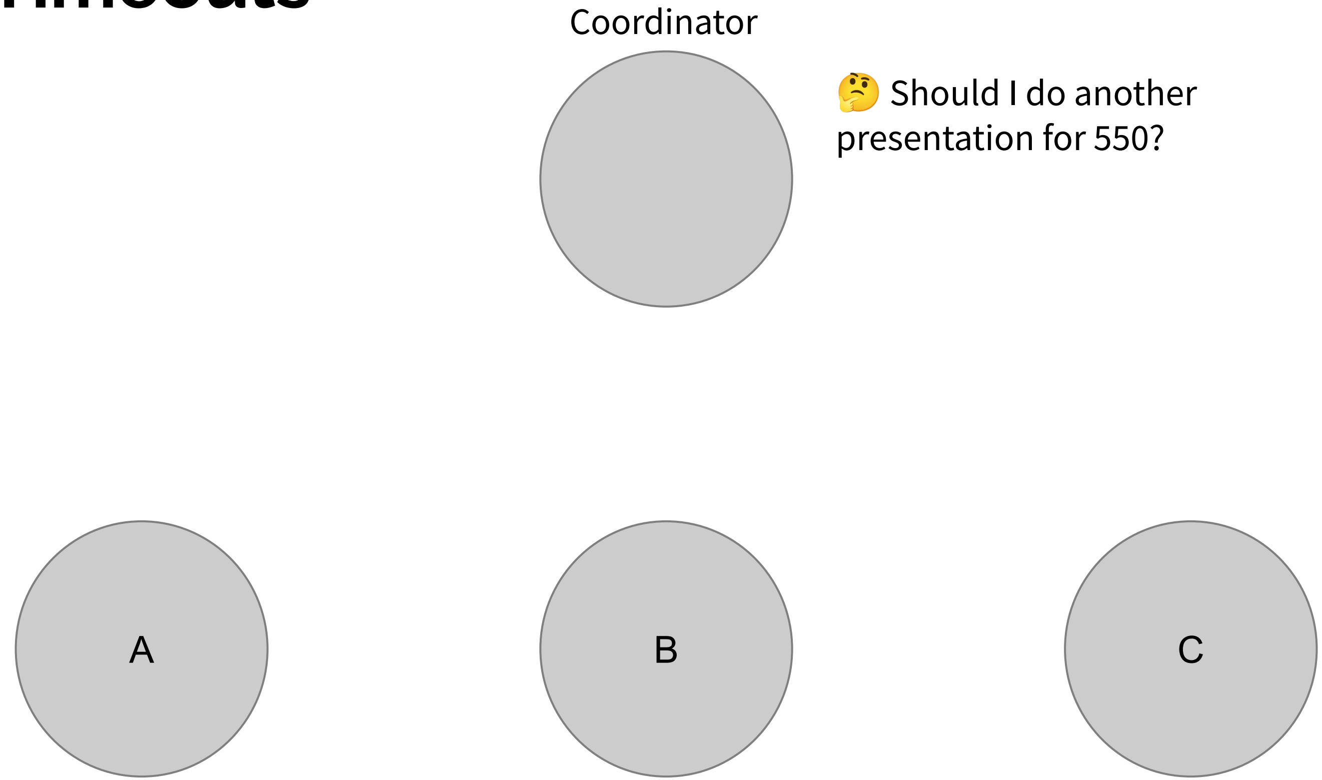
2PC Blocking

1. Waiting on Messages
    - Network Failure
2. Recovery
    - Node Failure

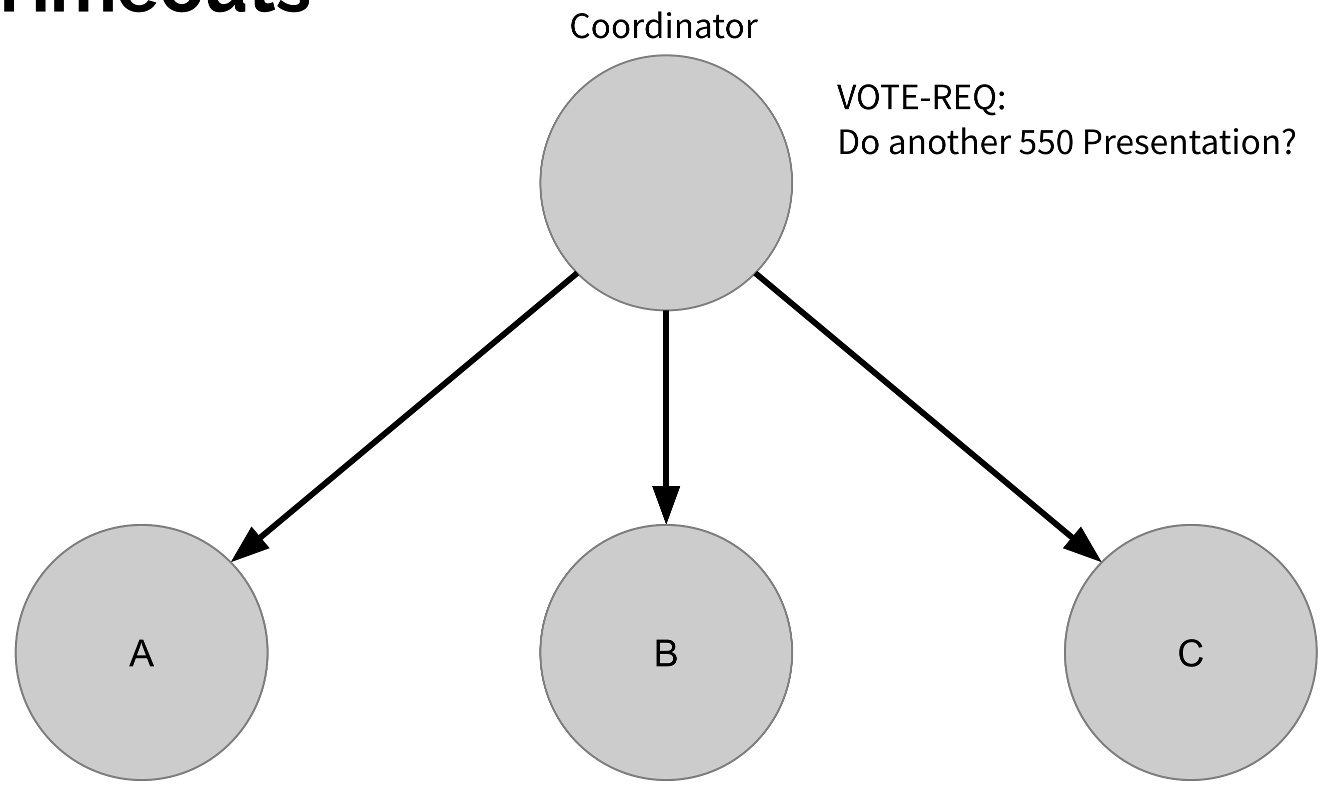
2PC - Timeouts

- 2PC runs in lock-step
  - Nodes have to wait for messages from other nodes
  - Can assume that each node knows how to contact with their peers
- On a timeout, nodes try to find out what the coordinator’s decision was from peers

2PC - Timeouts



2PC - Timeouts



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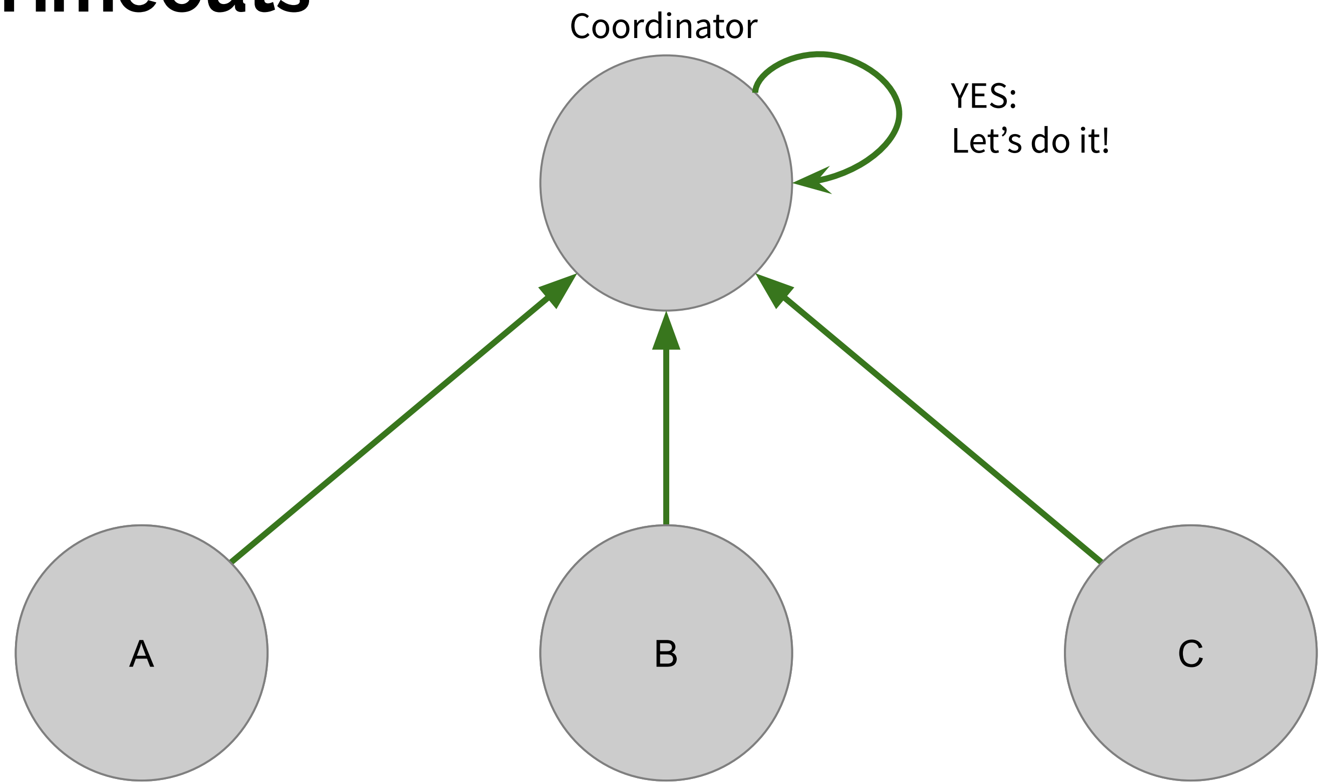

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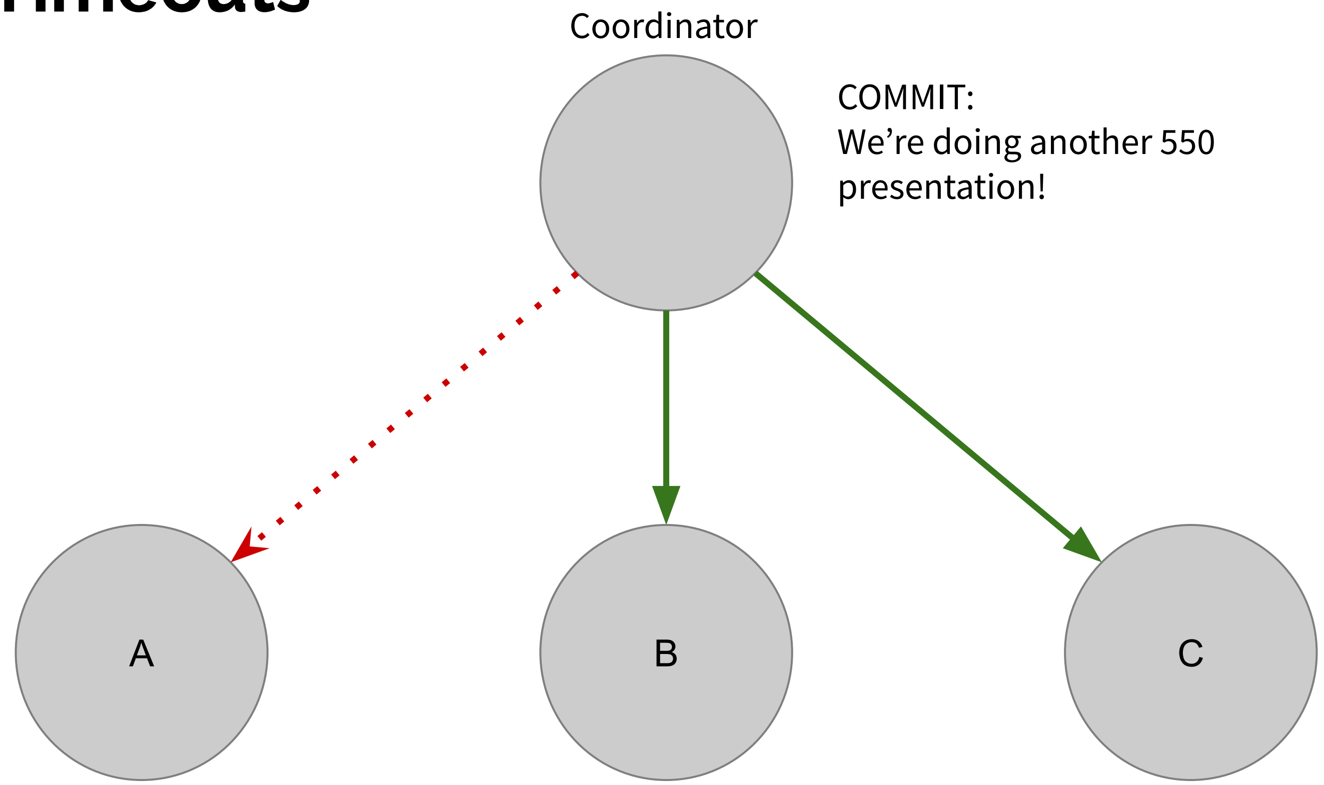

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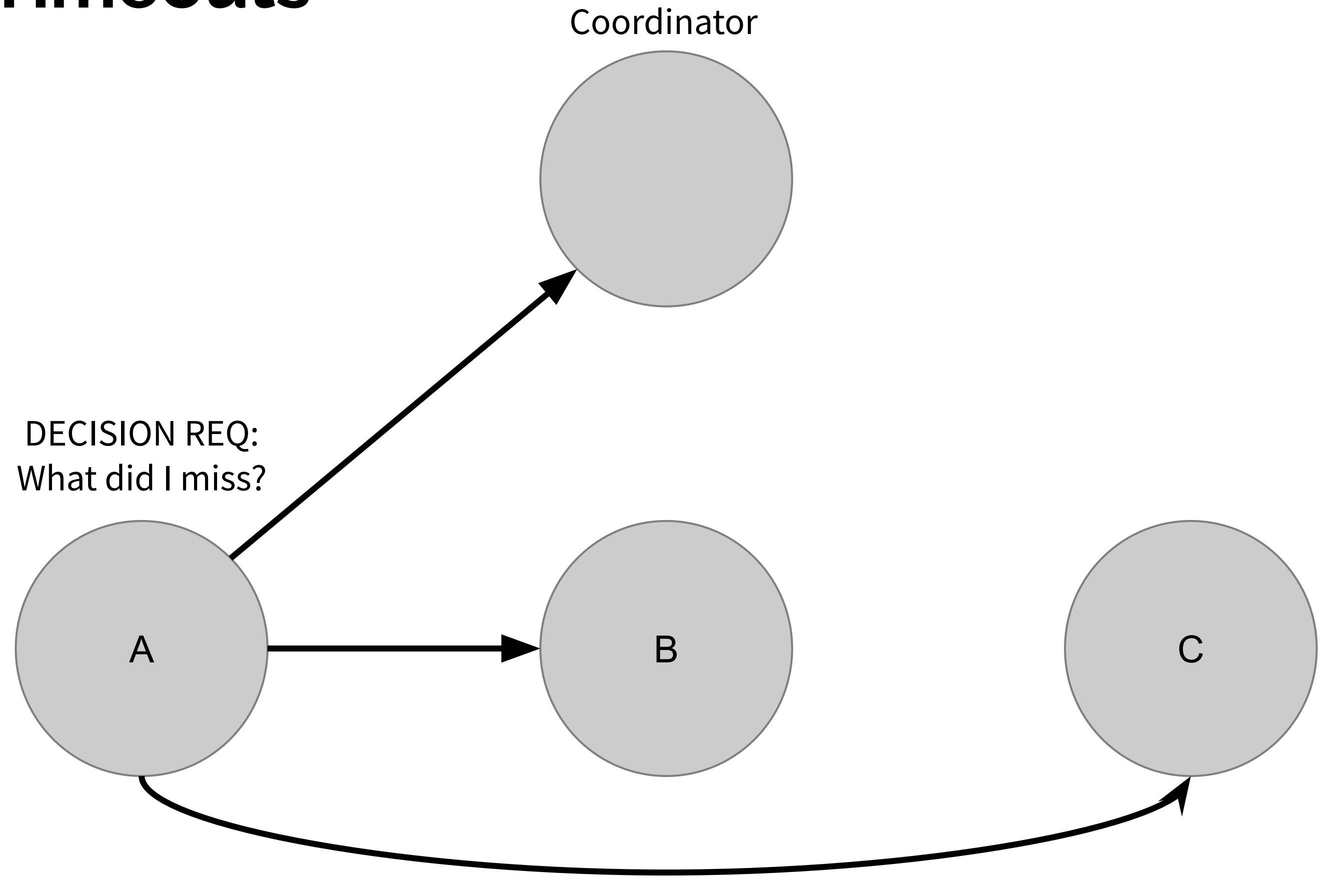

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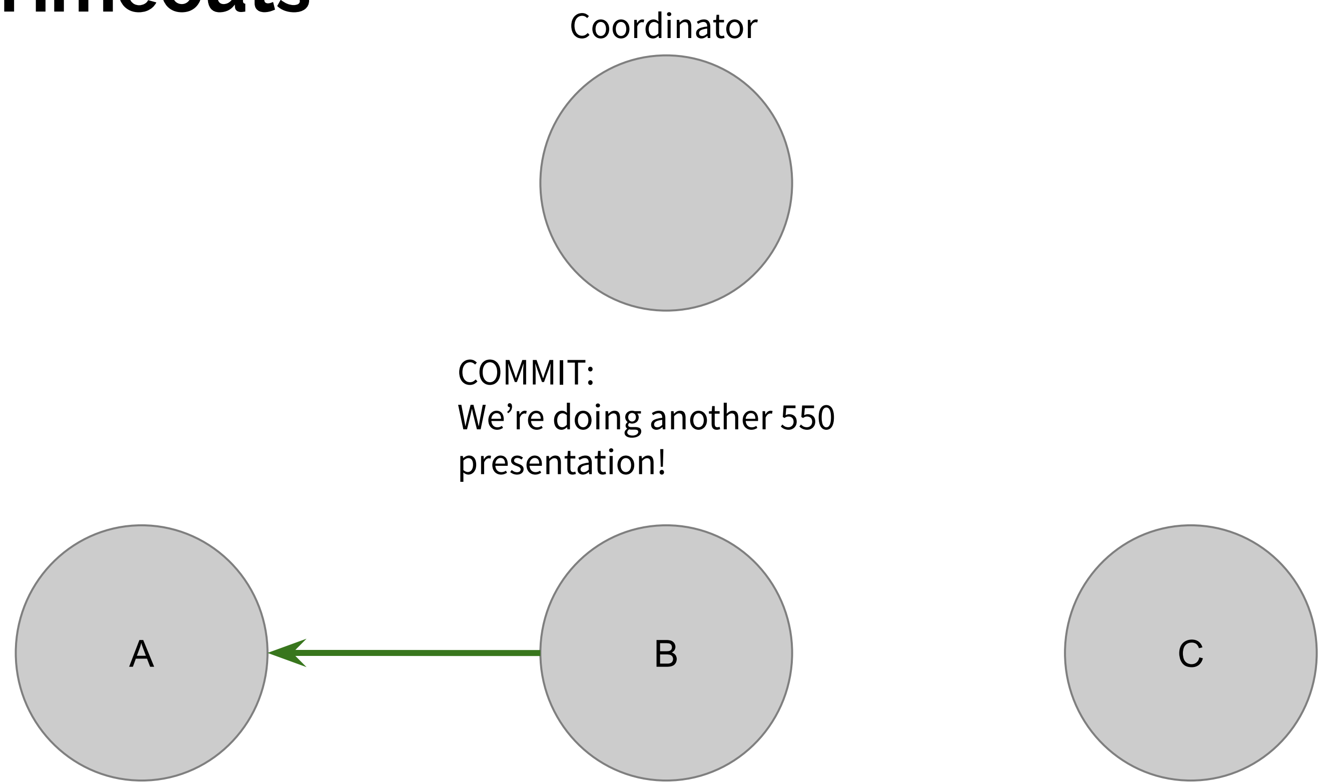

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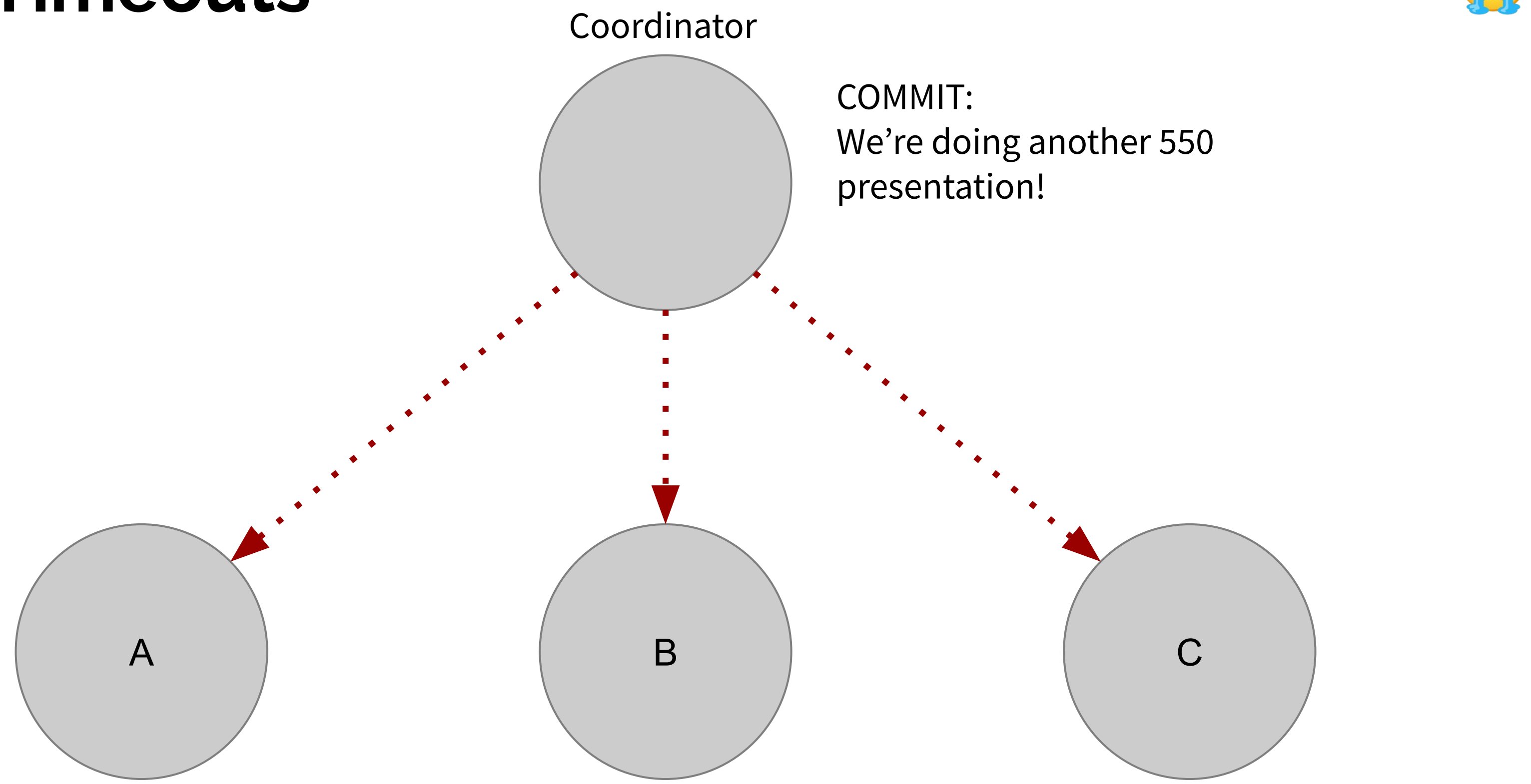

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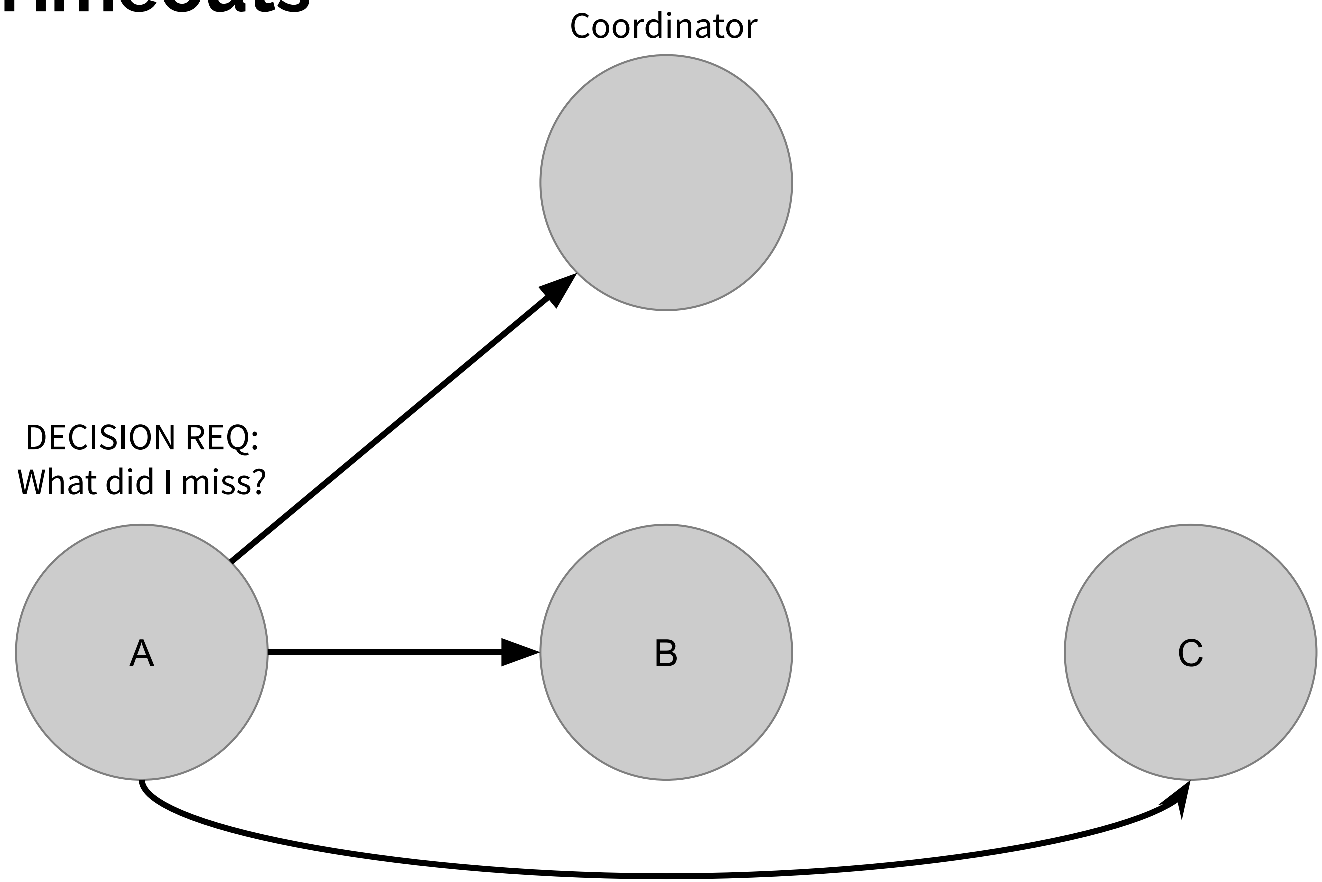
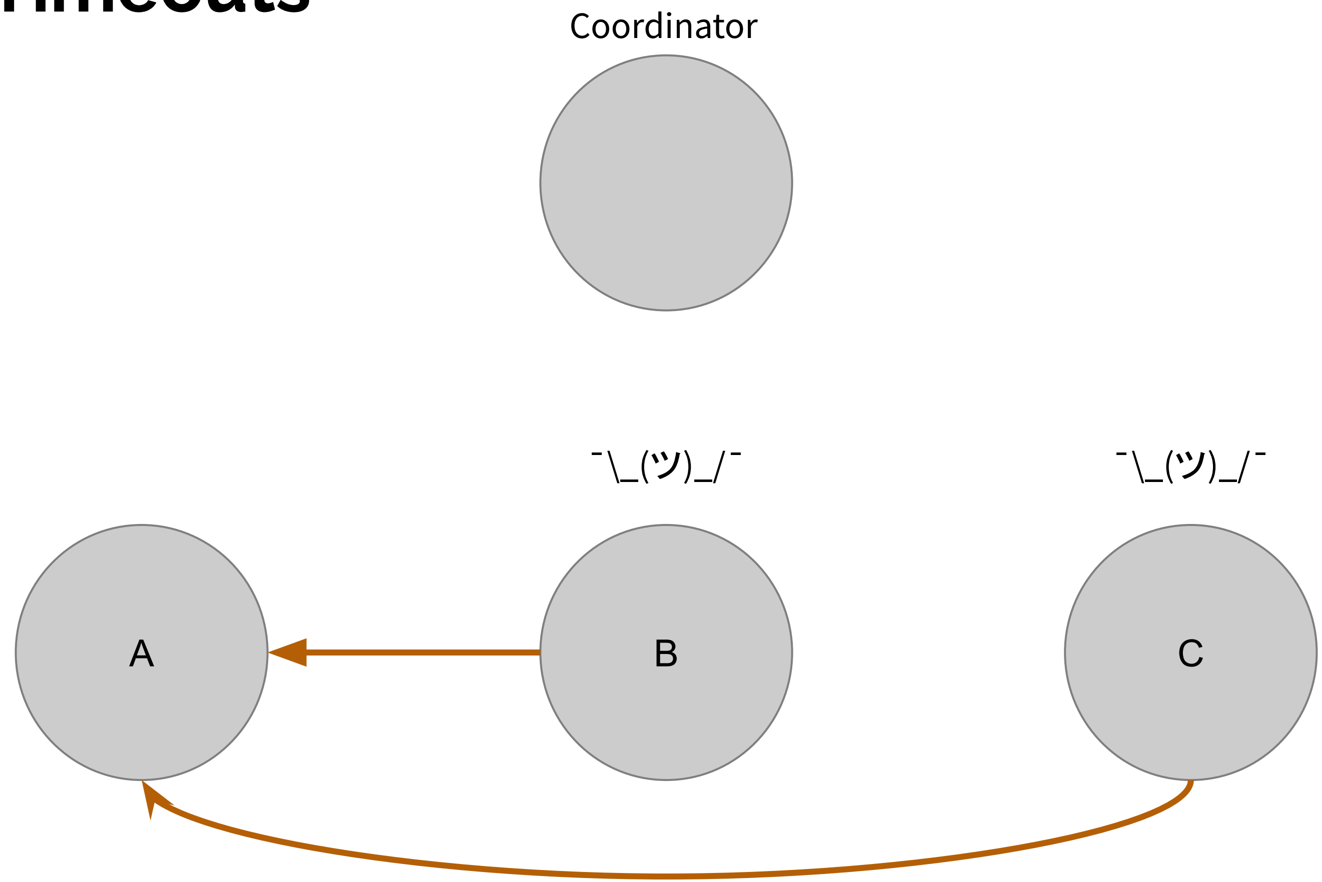


2PC - Timeouts



2PC - Recovery

- If a node fails, it will stop
    - When it turns on, what happens?
    - 2PC requires *all* nodes to participate - can only be at most one step behind
- Nodes keep a log of everything they've seen
    - If they use the log to restore their state, we're looking at the same situation as a timeout!

2PC - Reflection

- Pros
  - Provides Consistency!
  - “Resilient” to “failures”
- Cons
  - Susceptible to blocking
- Variants
  - Decentralized 2PC
    - Everyone broadcasts to everyone all the time
    - More messages, less time
  - Linear 2PC
    - Pass along decisions like a fire line
    - Less Messages, more time

3PC

- 2PC has a lot of blocking 😔
  - Can we do better?
- 2 Flavors of 3 Phase Commit
  - Non Blocking - assume no network failures
  - Some Blocking - assume network failures can happen

3PC - Some Blocking

0. Leader Election

1. Voting Phase
   a. Coordinator sends VOTE-REQ to all participants
   b. Participants vote YES or NO, send vote back to coordinator
2. Pre-Commit Phase
   a. Coordinator collects all votes, if there is any NO vote, coordinator sends ABORT. Otherwise sends PRE-COMMIT
   b. Participants receive PRE-COMMIT, respond with an ACK
3. Commit Phase
   a. Coordinator waits for a *majority* of ACKs, and then sends COMMIT
   b. Participant receive COMMIT, update accordingly

3PC High Level Idea

- Extra phase adds to shared knowledge
- PRE-COMMIT phase allows for recovery during the COMMIT phase
  - When a participant wants to COMMIT, it knows all other participants agreed to the PRE-COMMIT

3PC - Reflection

- Pros
  - Also provides consistency
  - Resilient to failures
  - Blocks less!
- Cons
  - A lot more overhead
    - 3RTTs
    - 6n messages
    - Is the time saved from less blocking worth the extra overhead?

In most practical applications, the circumstances under which 2PC causes blocking are sufficiently rare that blocking is usually not considered a big problem. Consequently, almost all systems we know of that employ atomic commitment protocols use some version of 2PC.[6]

https://tinyurl.com/cse550transactions

Discussion

1. We've talked a lot about fail-stop semantics and why they don't apply generally - what are cases where it might be *okay* to look for fail-stop semantics?
   - How deep should protocol designers try to think about failures?

2. 2PC and 3PC are both ways to build up a consistent, distributed log.
   Paxos is another way to build up a consistent, distributed log.
   - How do these technologies compare to each other? Is one strictly better than the rest?

3. Variants of 2PC are used by popular DBMS's today, and there hasn't been much success in moving away from it. Why do you think 2PC is still used, and do you think it will be replaced? Do you think it should be replaced?