THE UNIVERSITY *of* EDINBURGH

Advanced Database Systems

Spring 2024

Lecture #27:

Distributed Transactions

R&G: Chapter 22

Parallel / Distributed DBMSs

Why do we need parallel / distributed DBMSs?

- Increased performance (throughput and latency)
- Increased availability

Database is spread out across multiple resources to improve parallelism

Appears as a single database instance to the application

- SQL query on a single-node DBMS must generate same result on a parallel or dist. DBMS
- Due to principle of **data independence**

Parallel vs. Distributed DBMSs

Parallel DBMSs

- Nodes are physically close to each other
- Nodes connected with high speed LAN
- Communication cost is assumed to be small

Distributed DBMSs

- Nodes can be far from each other
- Nodes connected using public network
- Communication cost and problems cannot be ignored

OBSERVATION

A distributed transaction can access data located on multiple nodes

- The DBMS must guarantee the ACID properties

We have not discussed how to ensure that all nodes agree to commit a transaction and then to make sure it does commit if we decide that it should

- What happens if a node fails?
- What happens if our messages show up late?
- What happens if we don't wait for every node to agree?

Outline

Distributed Locking

Distributed Deadlock Detection

Distributed Two-Phase Commit (2PC)

Recovery and 2PC

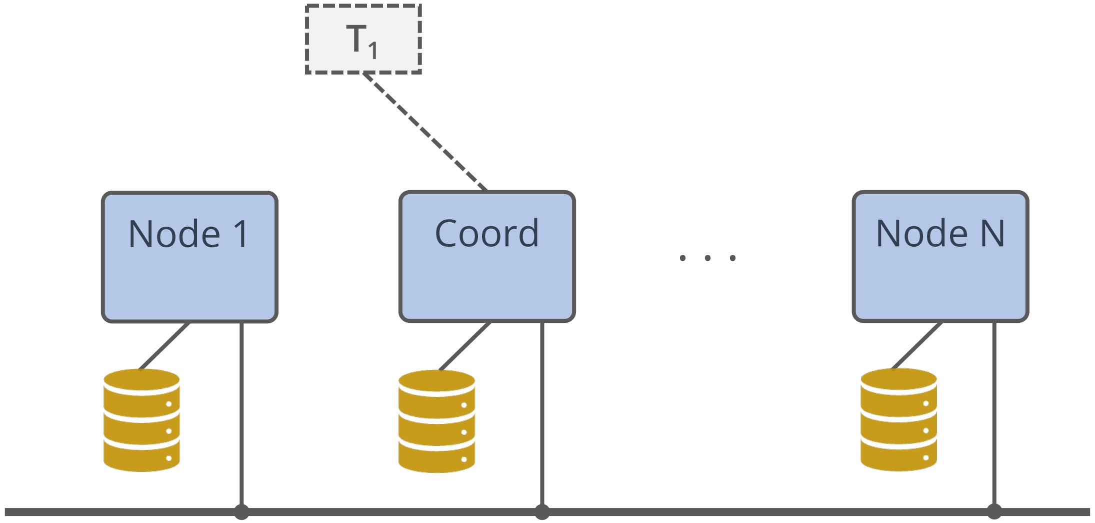
Distributed Concurrency Control

Consider a shared-nothing distributed DBMS

For today, assume partitioning but no replication of data

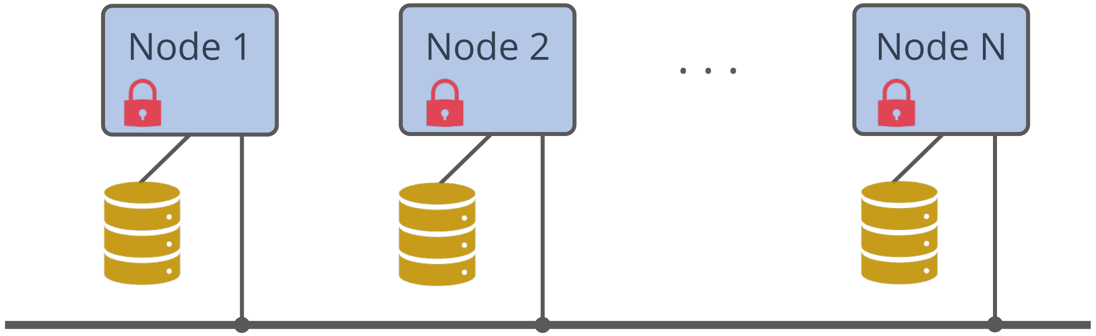
Each transaction arrives at some node:

- The "coordinator" for the transaction



Where is the Lock Table?

- Typical design: Locks partitioned with the data
  - Independent: each node manages “its own” lock table
  - Works for objects that fit on one node (pages, tuples)
- For coarser-grained locks, assign a “home” node
  - Object being locked (table, DB) exists across nodes



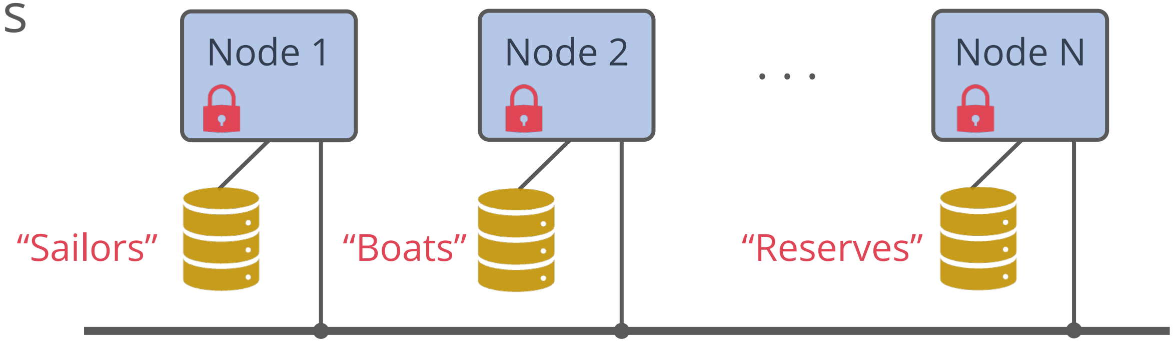
Where is the Lock Table?, Part 2

Typical design: Locks partitioned with the data

- Independent: each node manages “its own” lock table
- Works for objects that fit on one node (pages, tuples)

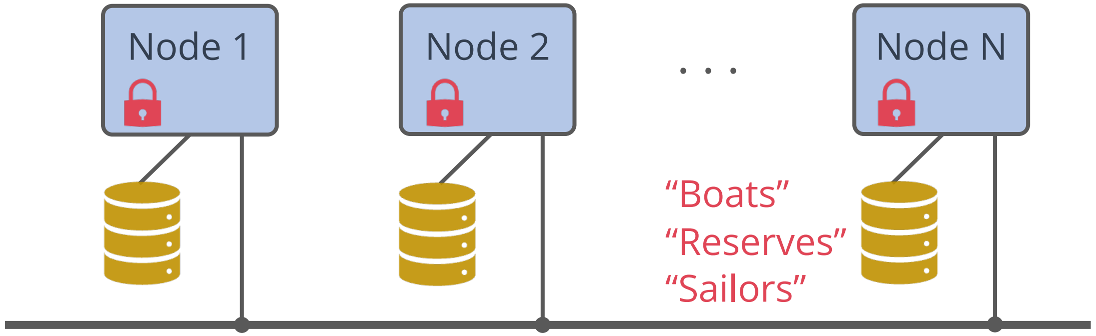
For coarser-grained locks, assign a “home” node

- Object being locked (table, DB) exists across nodes
- These locks can be partitioned across nodes



Where is the Lock Table?, Part 3

- Typical design: Locks partitioned with the data
  - Independent: each node manages "its own" lock table
  - Works for objects that fit on one node (pages, tuples)
- For coarser-grained locks, assign a "home" node
  - Object being locked (table, DB) exists across nodes
  - These locks can be partitioned across nodes
  - Or centralized at one node



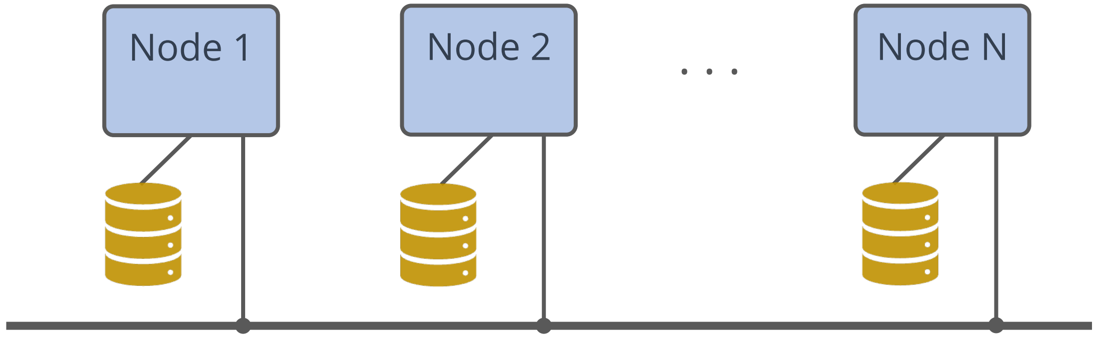
Ignore Global Locks For a Moment…

Every node does its own locking

Clean and efficient

"Global" issues remain:

- Deadlock
- Commit/Abort



Outline

Distributed Locking

Distributed Deadlock Detection

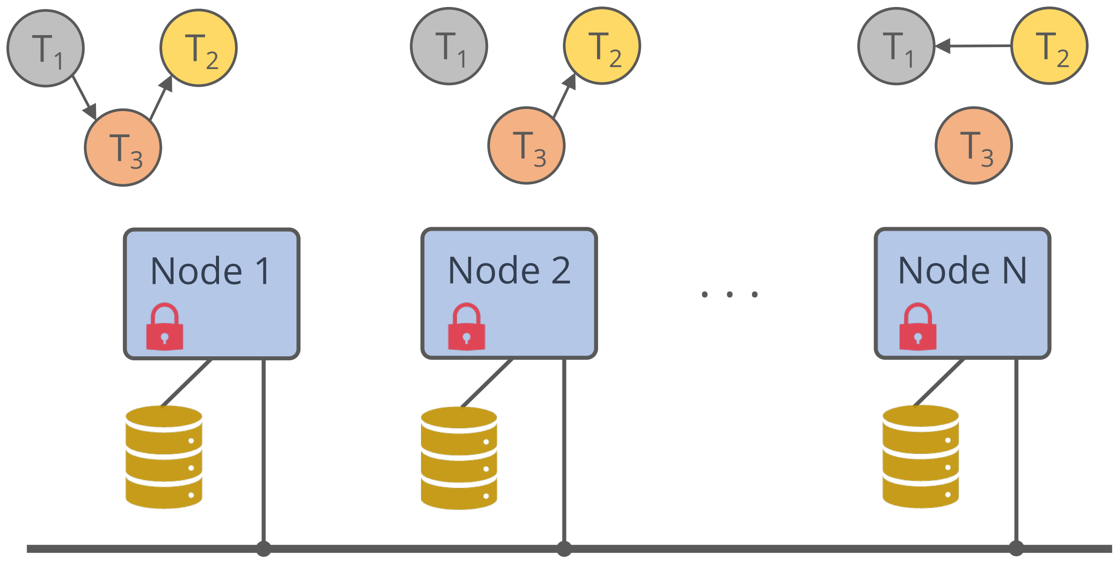
Distributed Two-Phase Commit (2PC)

Recovery and 2PC

What Could Go Wrong? #1

Deadlock detection

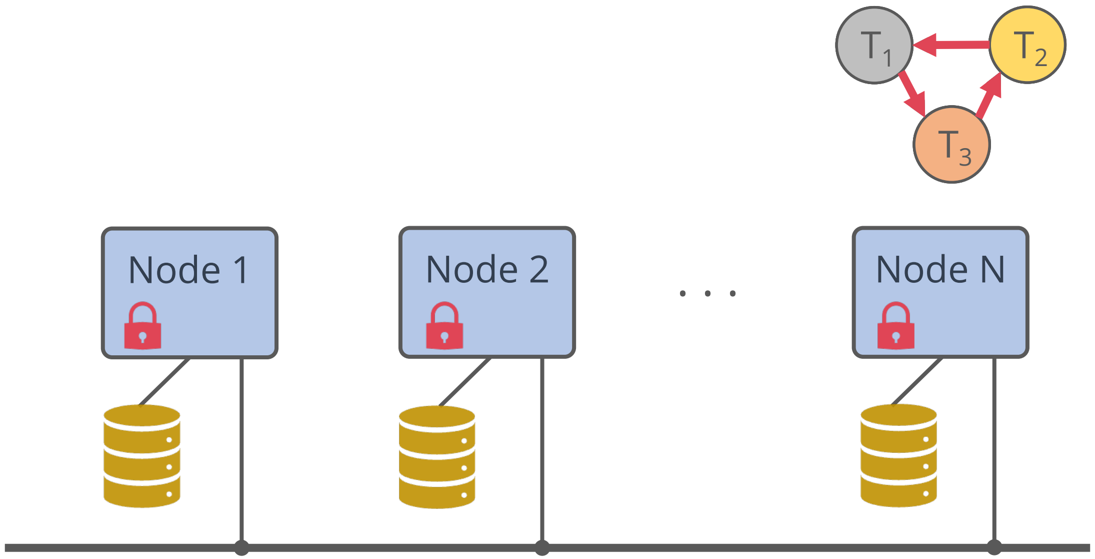
No cycles in local waits-for graphs, but there's a cycle in global waits-for graph



What Could Go Wrong? #1, Part 2

Deadlock detection

Easy fix: periodically union at designated node. If a cycle is detected, abort one txn



OUTLINE

Distributed Locking

Distributed Deadlock Detection

Distributed Two-Phase Commit (2PC)

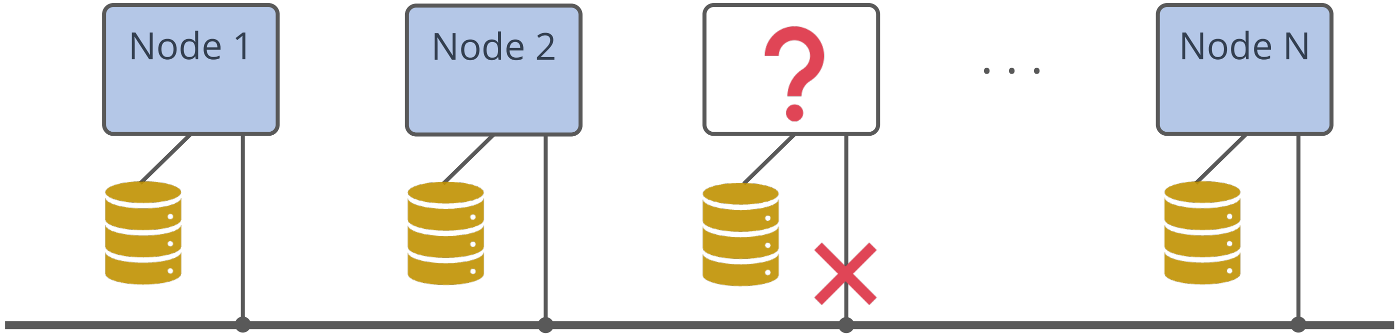
Recovery and 2PC

What Could Go Wrong? #2

Failures/Delays: Nodes

Commit? Abort?

When the node comes back, how does it recover in a world that moved forward?

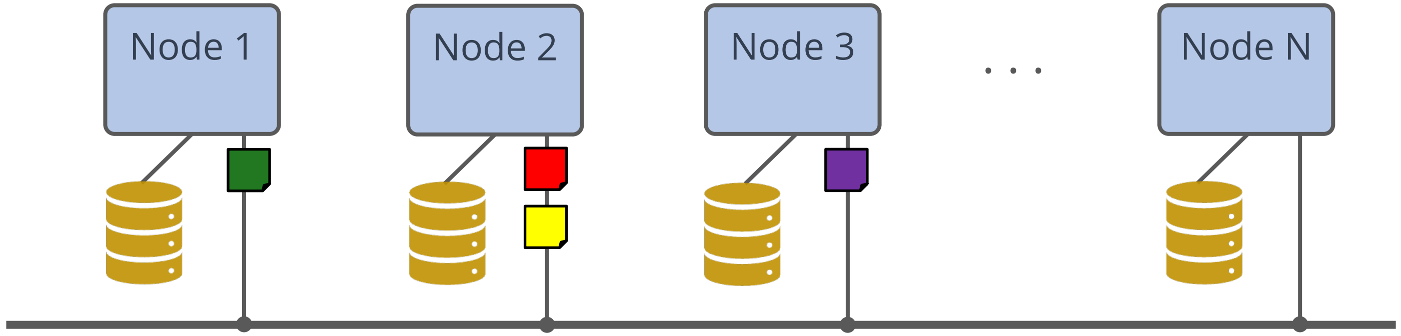


What Could Go Wrong? #2, Part 2

Failures/Delays: Nodes

Failures/Delays: Messages

- Non-deterministic reordering per channel, interleaving across channels
- “Lost” (very delayed) messages



What Could Go Wrong? #2, Part 3

Failures/Delays: Nodes

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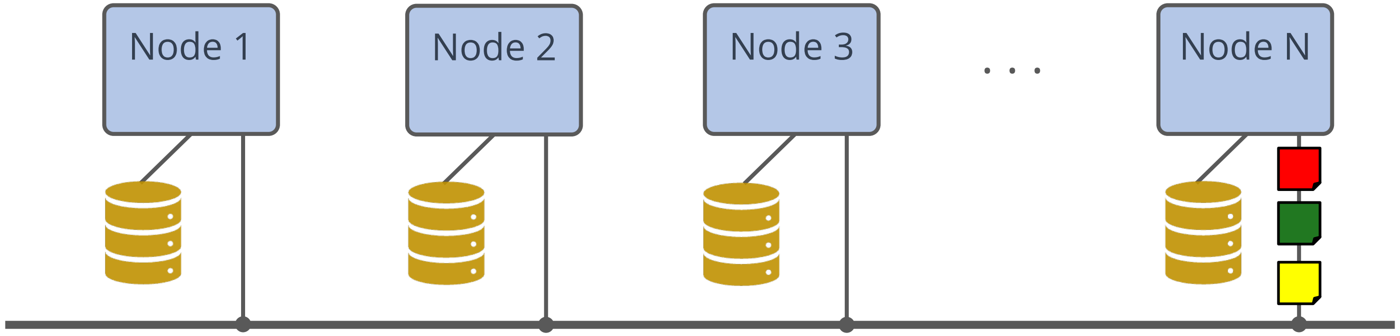


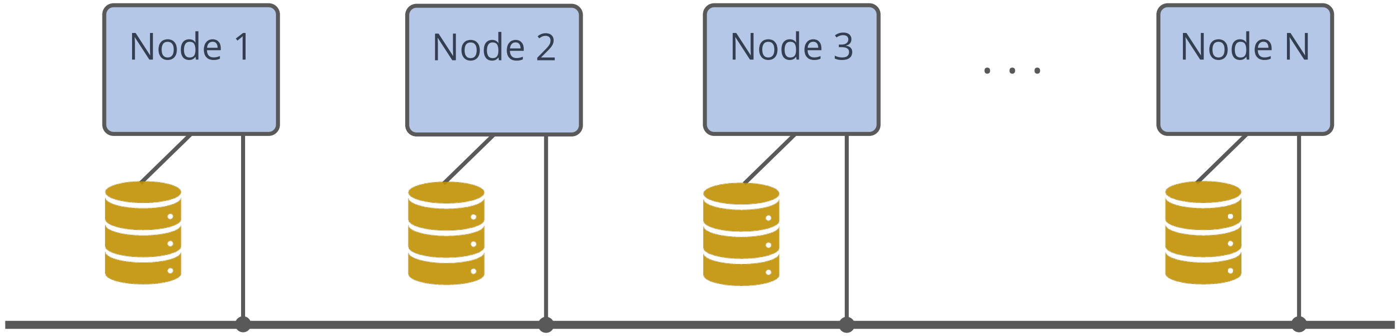
What Could Go Wrong? #2, Part 4

Failures/Delays: Nodes

Failures/Delays: Messages

- Non-deterministic reordering per channel, interleaving across channels
- “Lost” (very delayed) messages

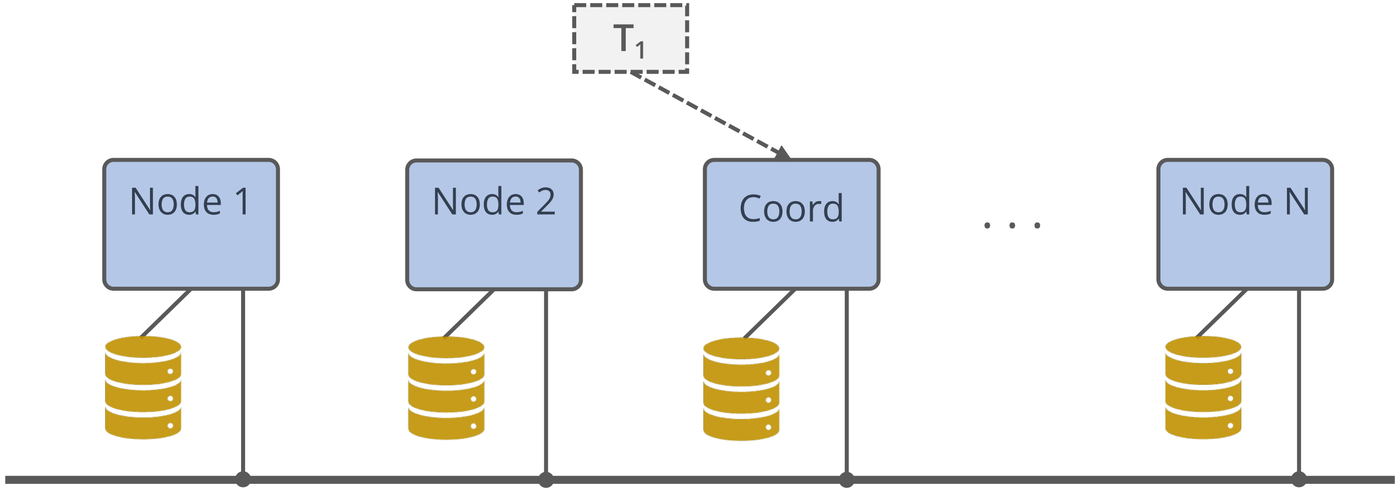
How do all nodes agree on Commit vs. Abort?



Basic Idea: Distributed Voting

Vote for commitment

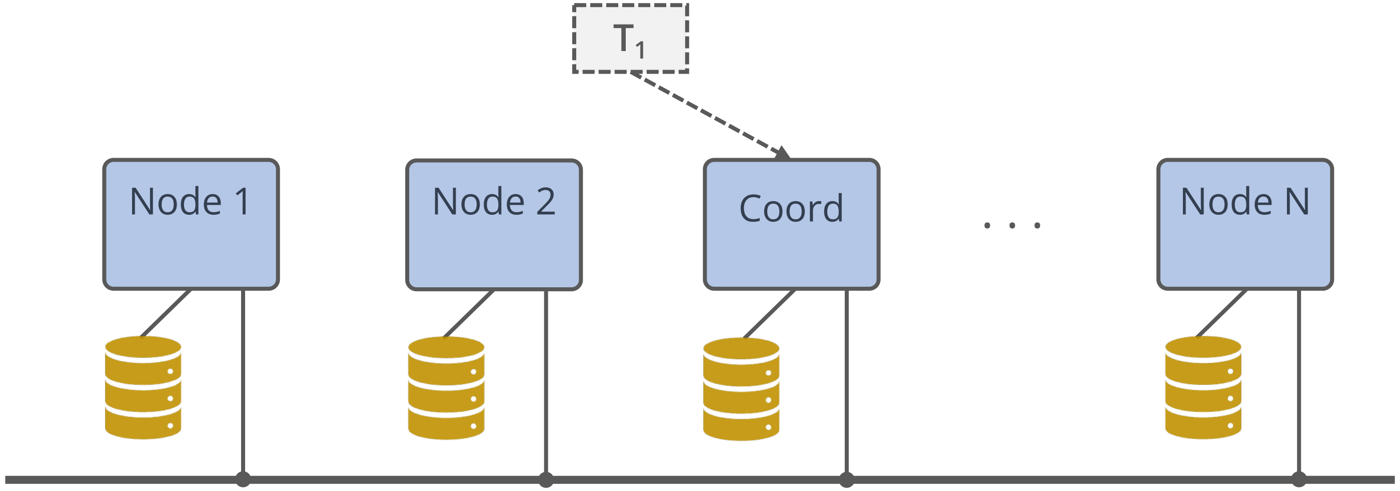
- How many votes does a commit need to win?
- Any single node could observe a problem (e.g., deadlock, constraint violation)
- Hence must be unanimous



Distributed voting? How?

How do we implement distributed voting?!

In the face of message/node failure/delay?



2-Phase Commit

A.k.a. 2PC. (Not to be confused with 2PL!)

Phase 1: Voting phase

- Coordinator tells participants to "prepare"
- Participants respond with yes/no votes
  - Unanimity required for yes!

Phase 2: Commit phase

- Coordinator disseminates result of the vote

Need to do some logging for failure handling....

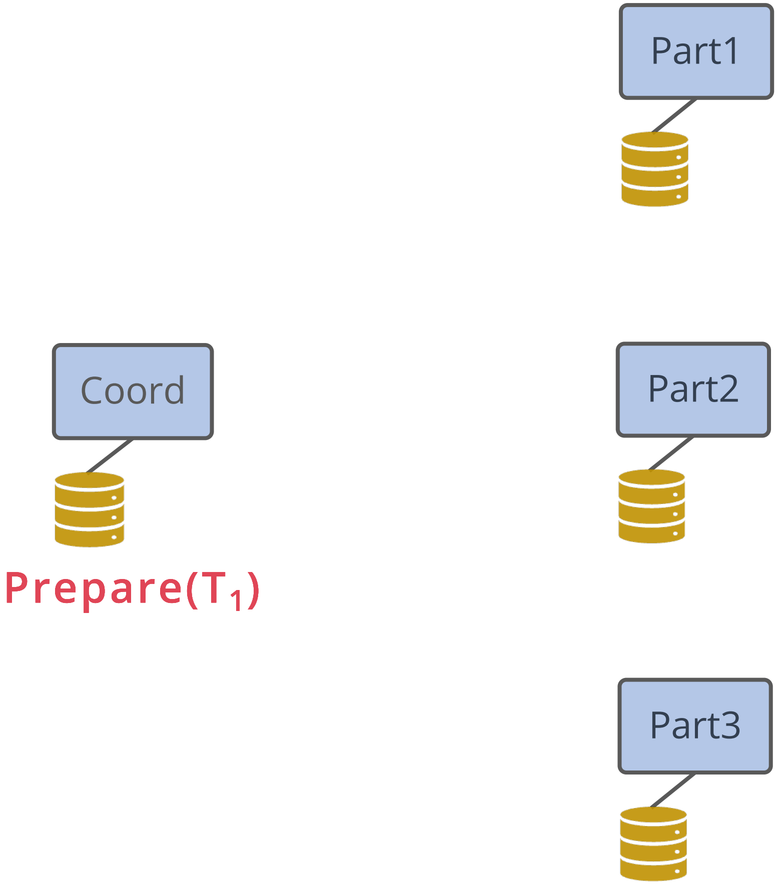
2-Phase Commit, Part 1

Phase 1:

- Coordinator tells participants to "prepare"
- Participants respond with yes/no votes
    - Unanimity required for commit!

Phase 2:

- Coordinator disseminates result of the vote
- Participants respond with Ack



2-Phase Commit, Part 2

Phase 1:

Coordinator tells participants to "prepare"

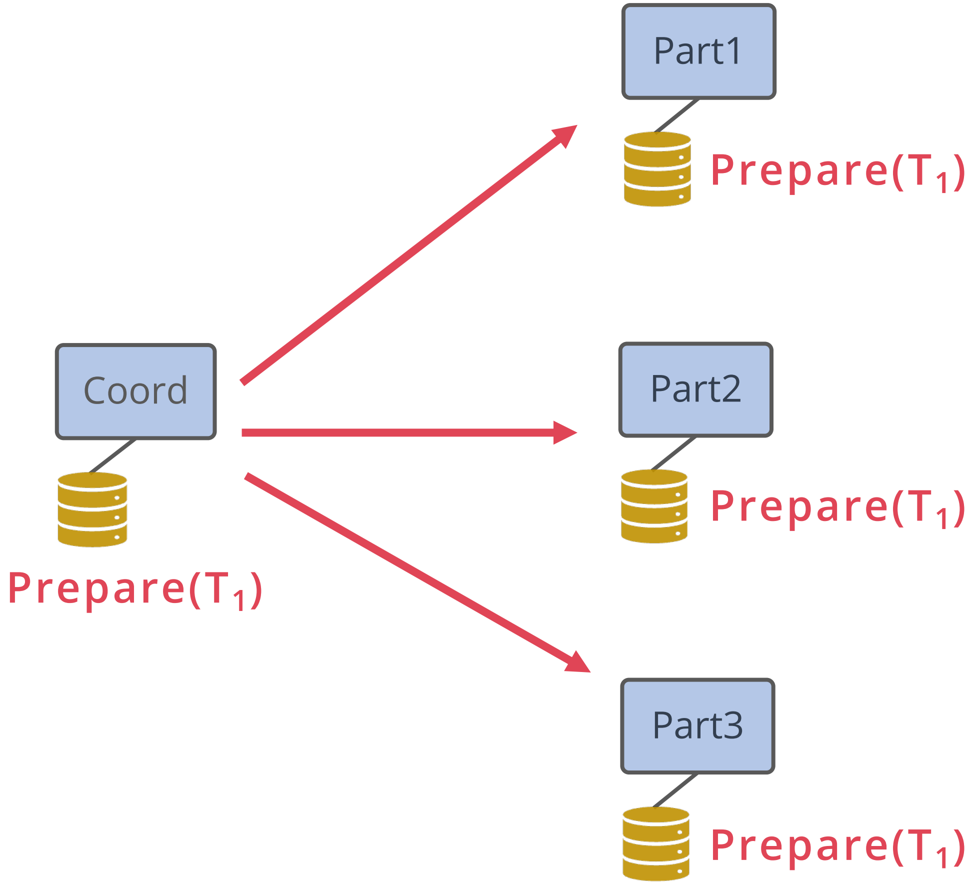
Participants respond with yes/no votes

Unanimity required for commit!

Phase 2:

Coordinator disseminates result of the vote

Participants respond with Ack



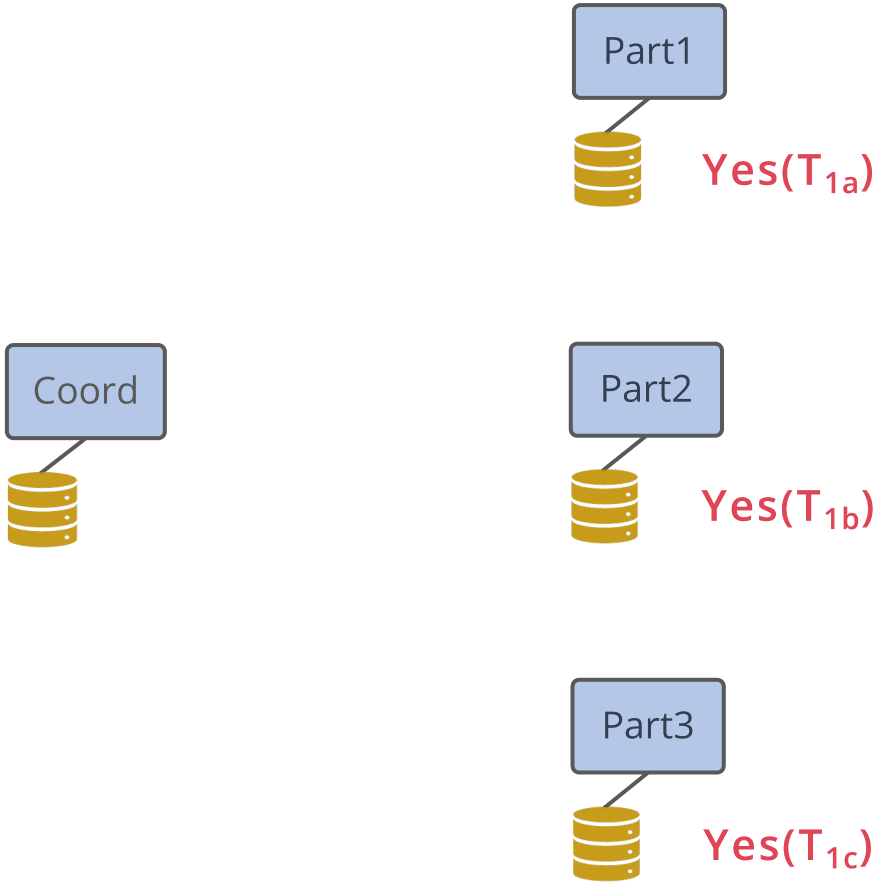
2-Phase Commit, Part 3

Phase 1:

- Coordinator tells participants to “prepare”
- **Participants respond with yes/no votes**
  - **Unanimity required for commit!**

Phase 2:

- Coordinator disseminates result of the vote
- Participants respond with Ack



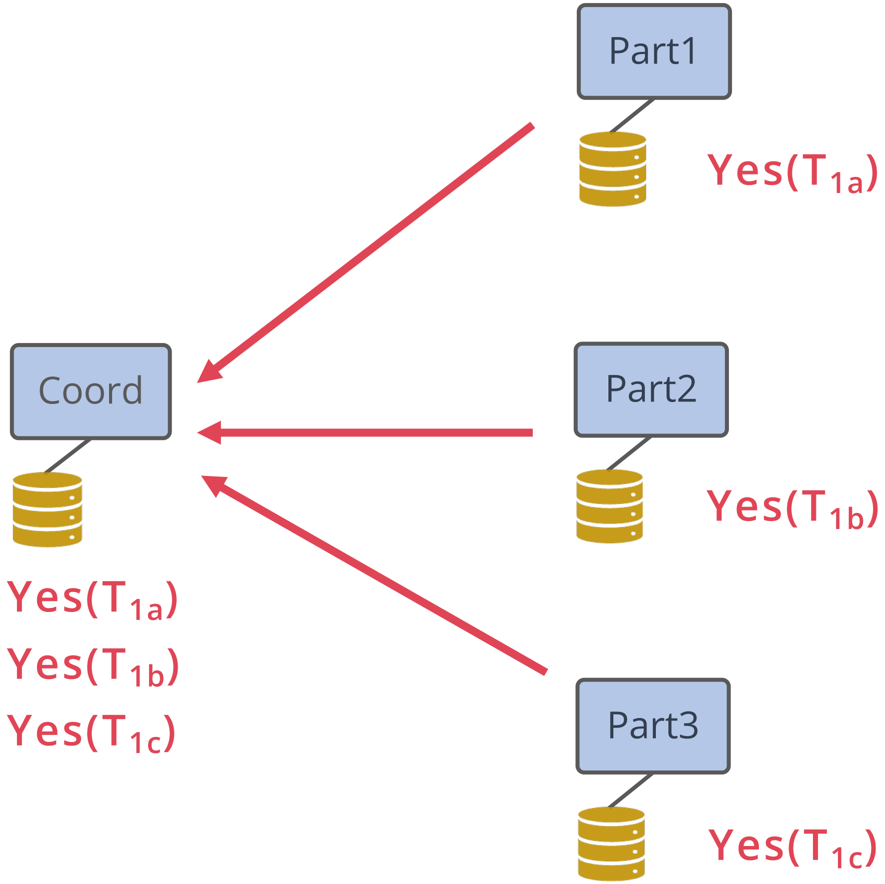
2-Phase Commit, Part 4

Phase 1:

- Coordinator tells participants to “prepare”
- Participants respond with yes/no votes
  - Unanimity required for commit!

Phase 2:

- Coordinator disseminates result of the vote
- Participants respond with Ack



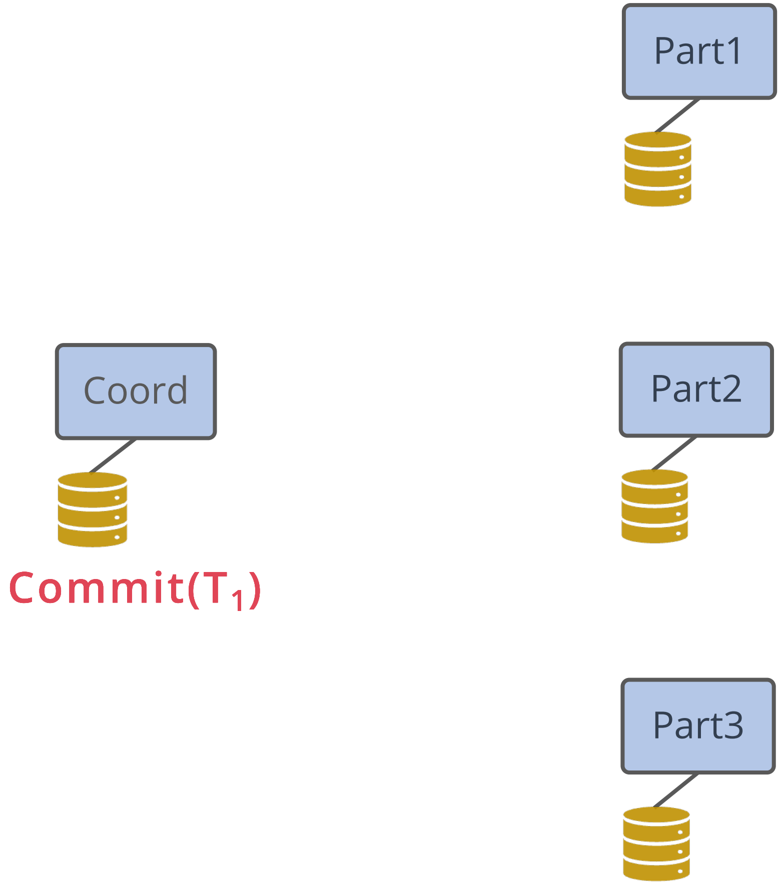
2-Phase Commit, Part 5

Phase 1:

- Coordinator tells participants to “prepare”
- Participants respond with yes/no votes
  - Unanimity required for commit!

Phase 2:

- Coordinator disseminates result of the vote
- Participants respond with Ack



2-Phase Commit, Part 6

Phase 1:

Coordinator tells participants to “prepare”

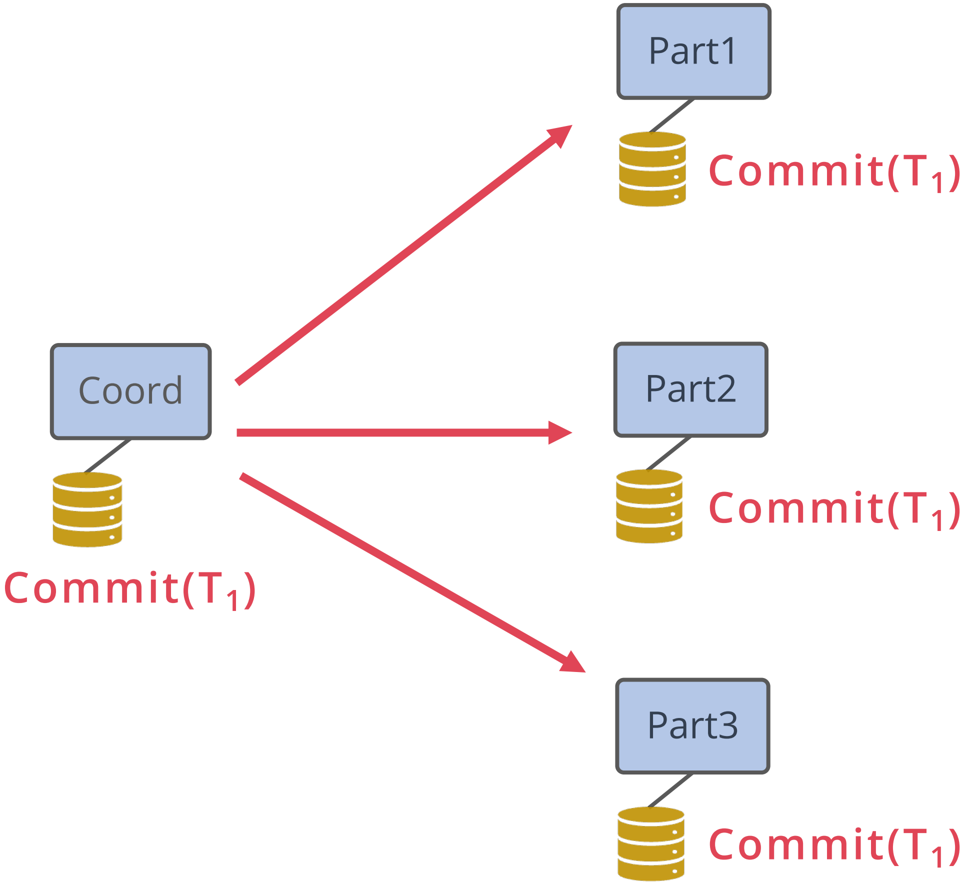
Participants respond with yes/no votes

Unanimity required for commit!

Phase 2:

Coordinator disseminates result of the vote

Participants respond with Ack



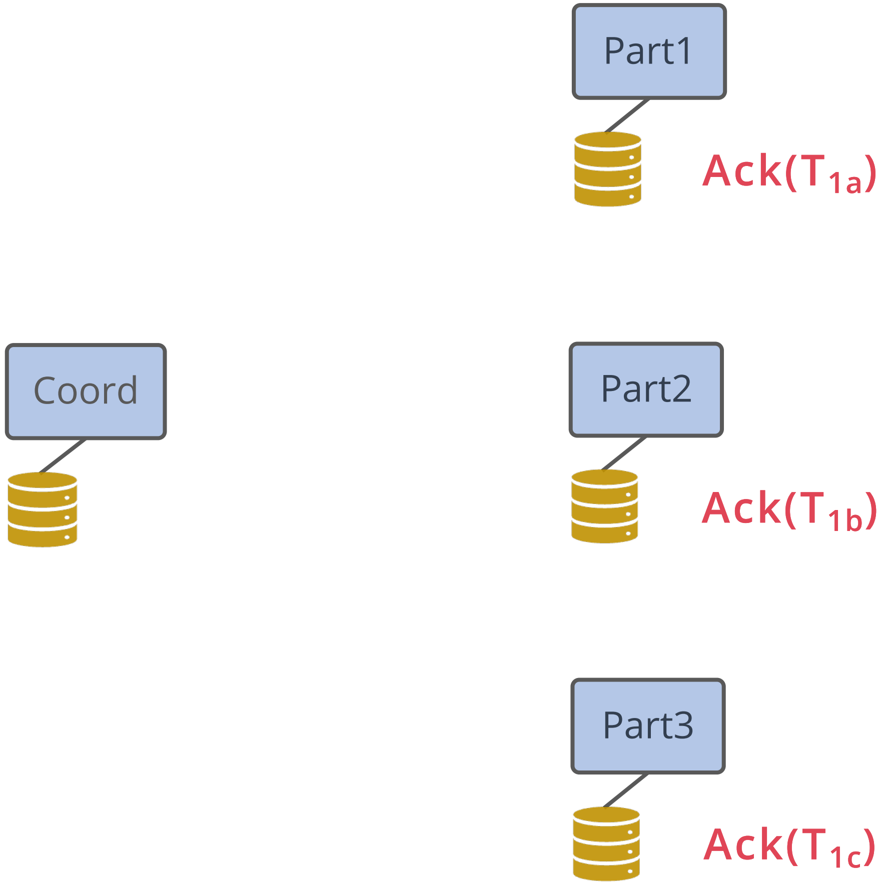
2-Phase Commit, Part 7

Phase 1:

- Coordinator tells participants to “prepare”
- Participants respond with yes/no votes
  - Unanimity required for commit!

Phase 2:

- Coordinator disseminates result of the vote
- Participants respond with Ack



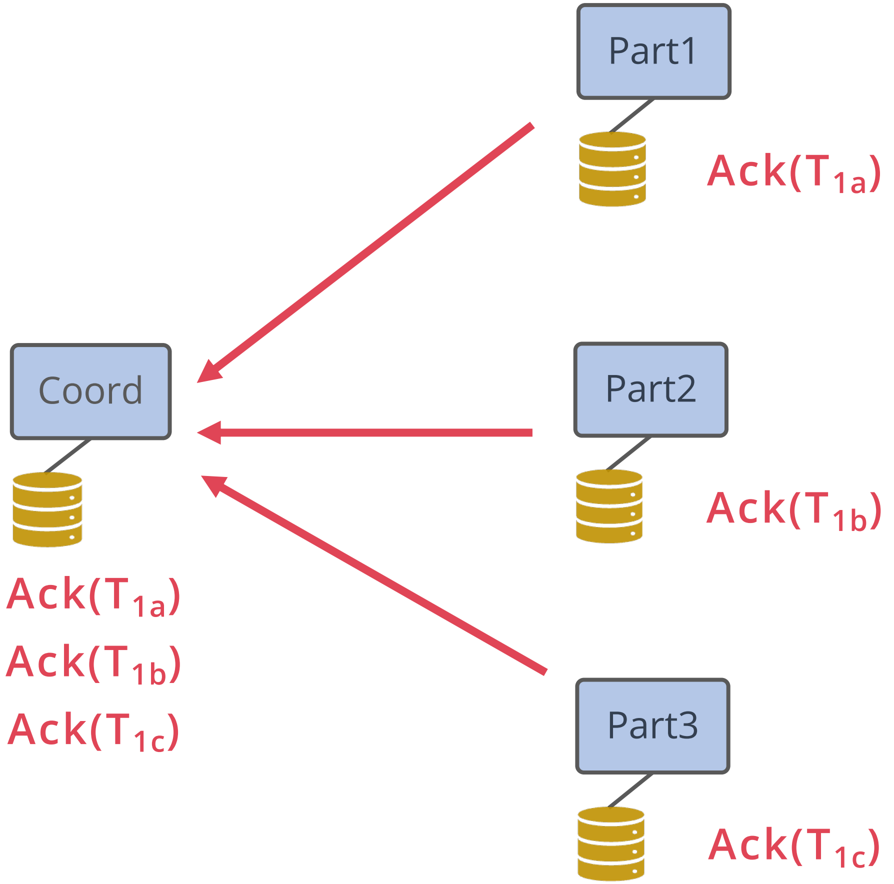
2-Phase Commit, Part 8

Phase 1:

- Coordinator tells participants to “prepare”
- Participants respond with yes/no votes
  - Unanimity required for commit!

Phase 2:

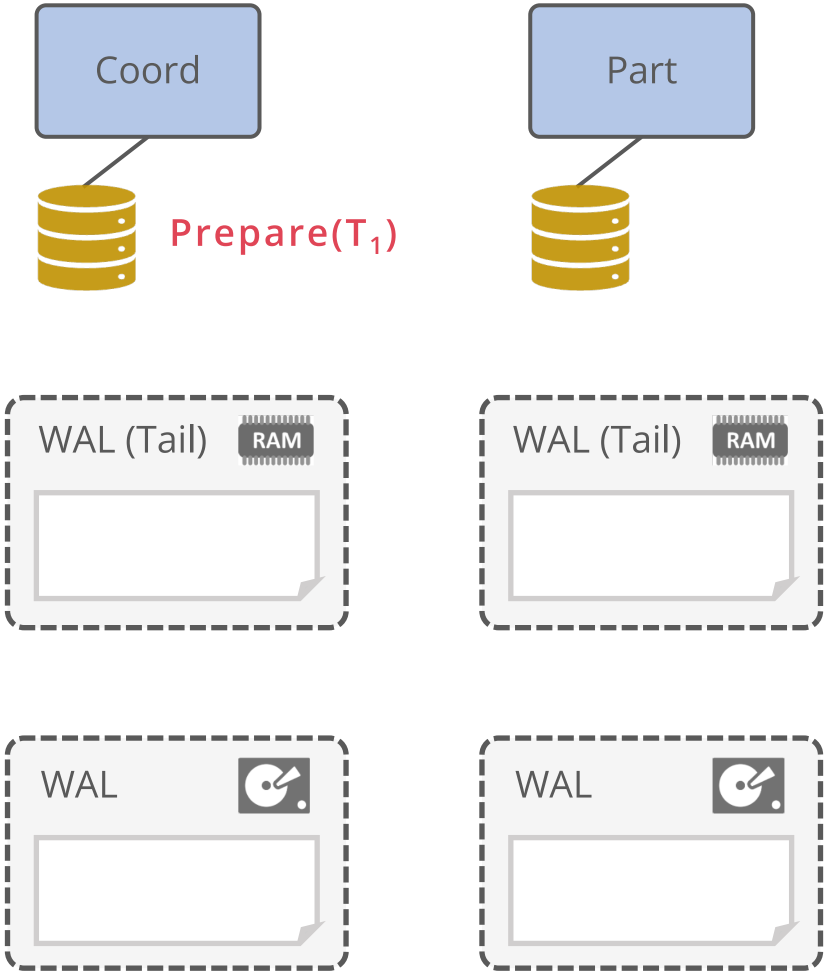
- Coordinator disseminates result of the vote
- **Participants respond with Ack**



One More Time, with Logging

Phase 1:

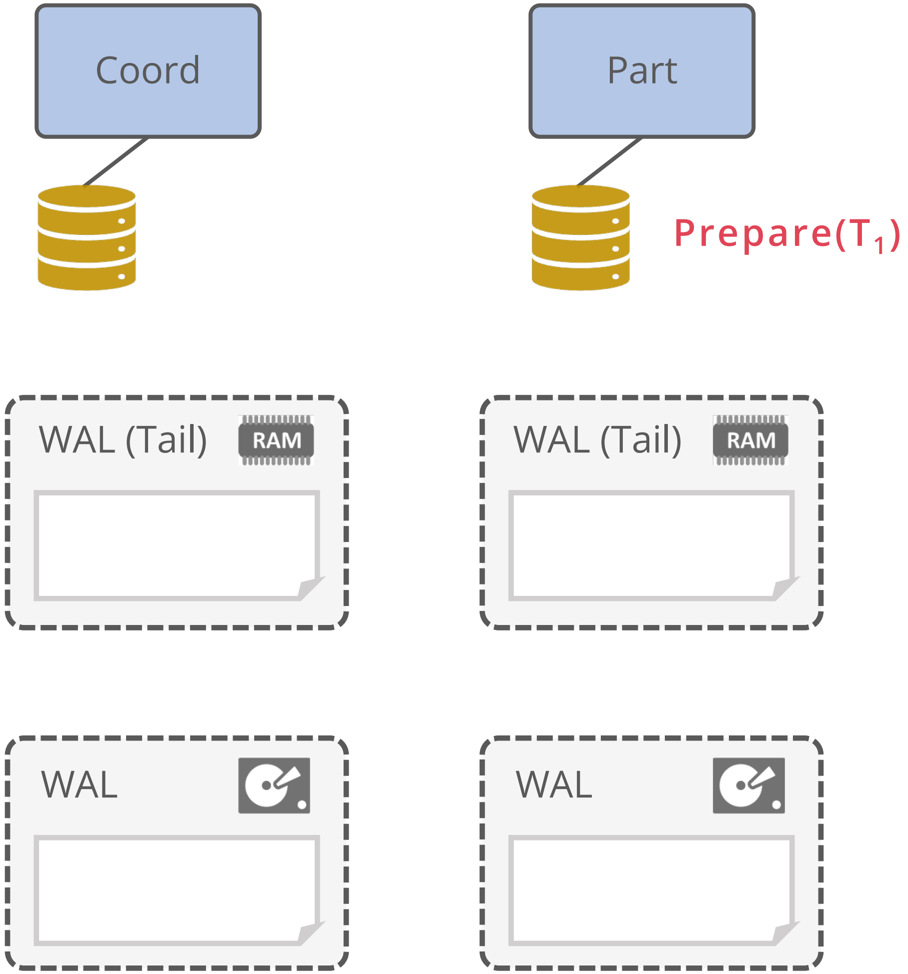
- Coordinator tells participants to "prepare"
- Participants generate prepare/abort record
- Participants flush prepare/abort record
- Participants respond with yes/no votes
- Coordinator generates commit record
- Coordinator flushes commit record



One More Time, with Logging, Part 2

Phase 1:

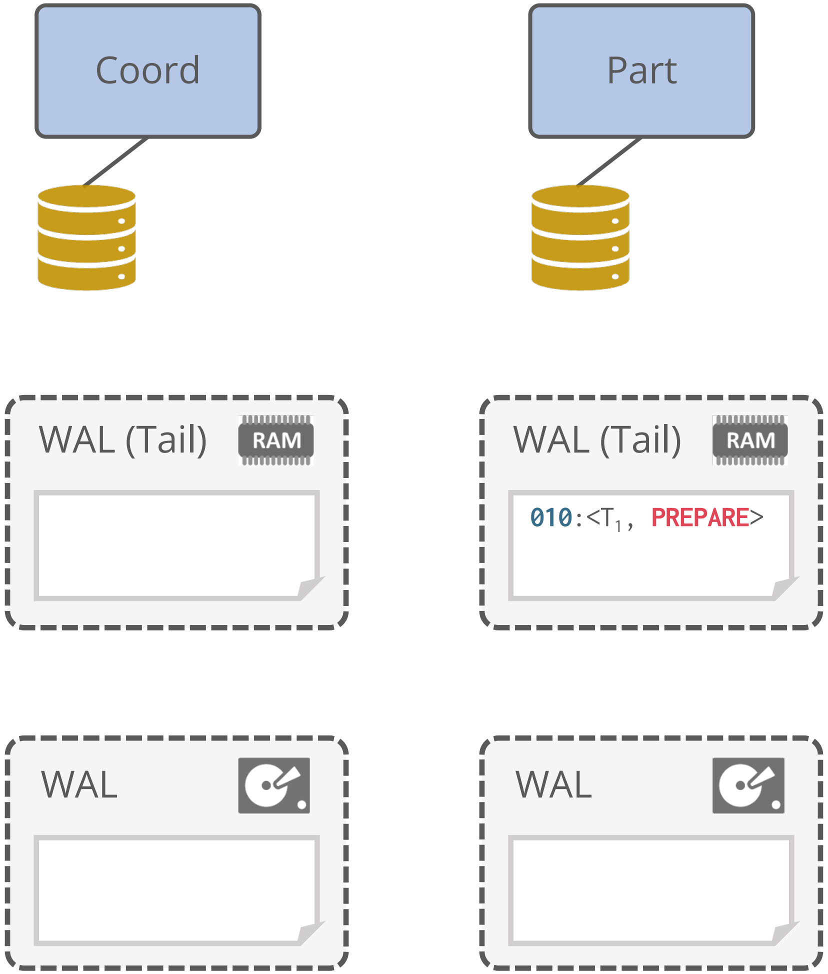
- Coordinator tells participants to "prepare"
- Participants generate prepare/abort record
- Participants flush prepare/abort record
- Participants respond with yes/no votes
- Coordinator generates commit record
- Coordinator flushes commit record



One More Time, with Logging, Part 3

Phase 1:

- Coordinator tells participants to “prepare”
- Participants generate prepare/abort record
- Participants flush prepare/abort record
- Participants respond with yes/no votes
- Coordinator generates commit record
- Coordinator flushes commit record



One More Time, with Logging, Part 4

Phase 1:

Coordinator tells participants to “prepare”

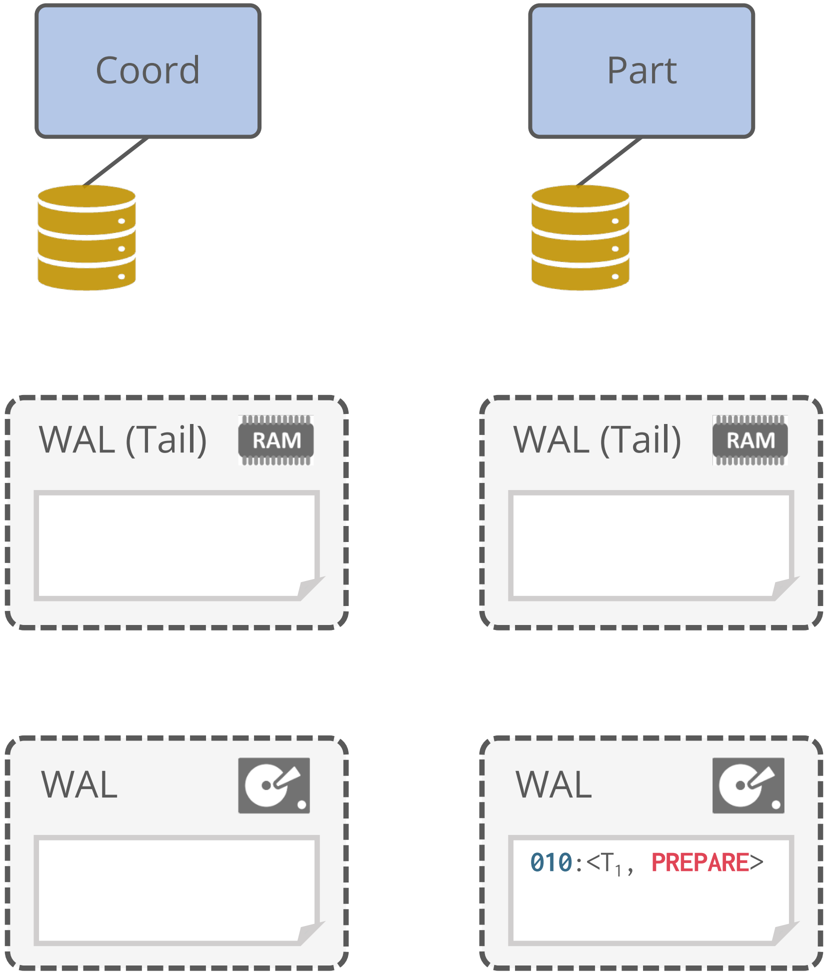
Participants generate prepare/abort record

Participants flush prepare/abort record

Participants respond with yes/no votes

Coordinator generates commit record

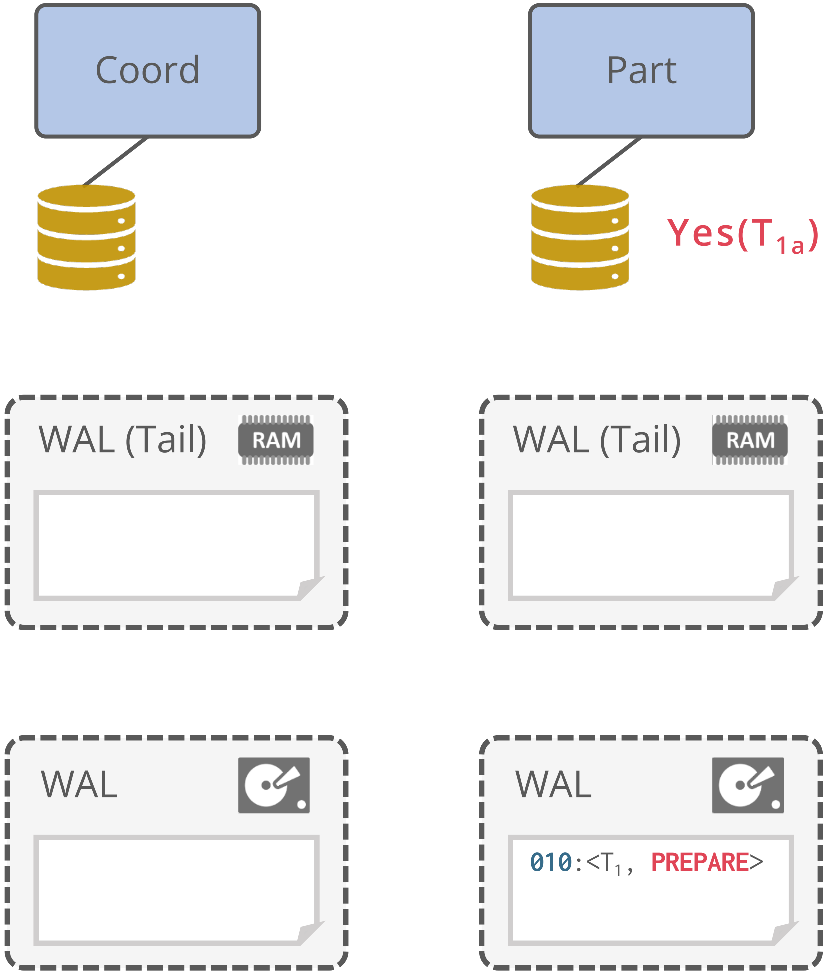
Coordinator flushes commit record



One More Time, with Logging, Part 5

Phase 1:

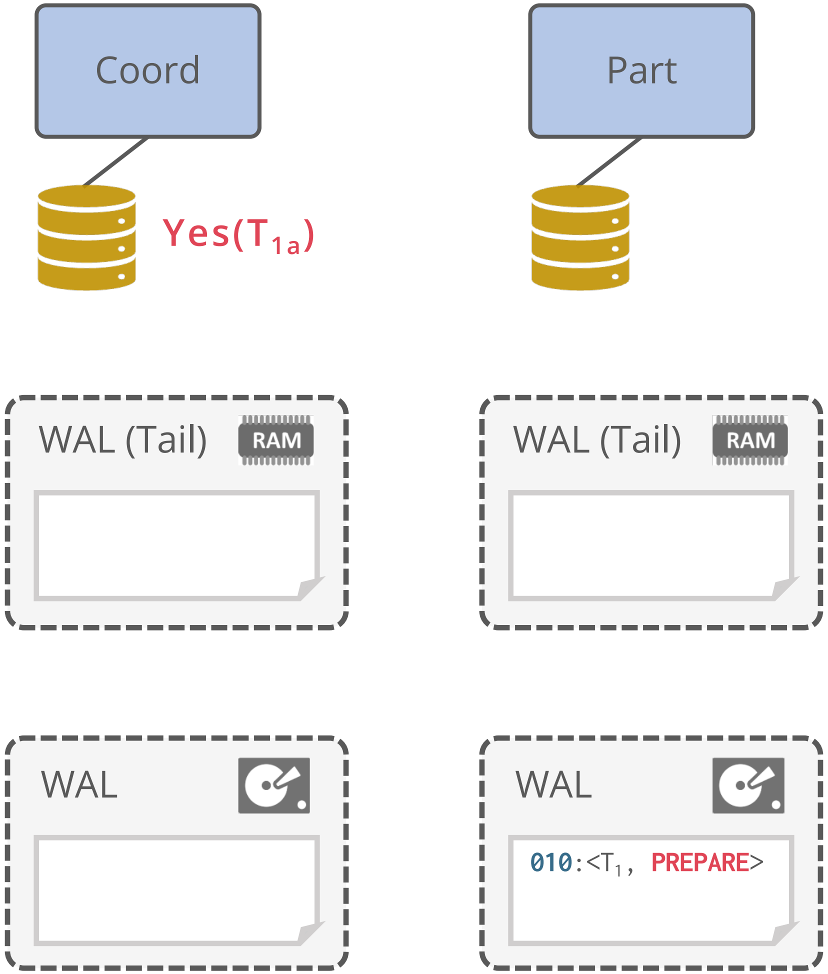
- Coordinator tells participants to “prepare”
- Participants generate prepare/abort record
- Participants flush prepare/abort record
- **Participants respond with yes/no votes**
- Coordinator generates commit record
- Coordinator flushes commit record



One More Time, with Logging, Part 6

Phase 1:

- Coordinator tells participants to “prepare”
- Participants generate prepare/abort record
- Participants flush prepare/abort record
- **Participants respond with yes/no votes**
- Coordinator generates commit record
- Coordinator flushes commit record



One More Time, with Logging, Part 7

Phase 1:

Coordinator tells participants to “prepare”

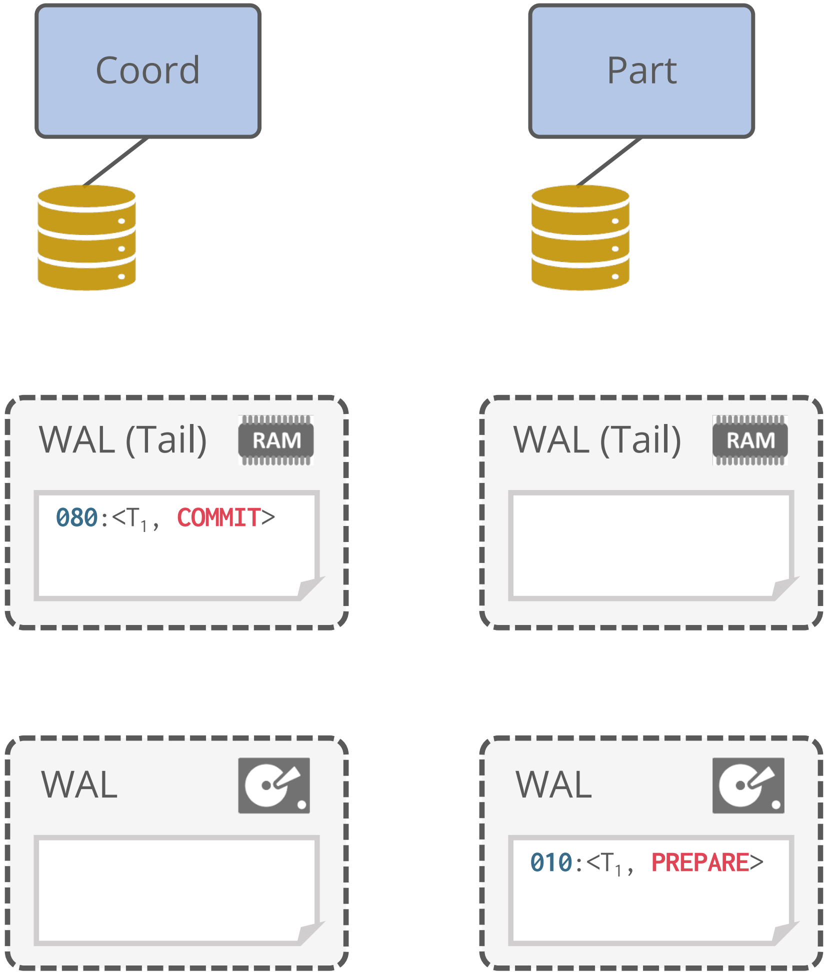
Participants generate prepare/abort record

Participants flush prepare/abort record

Participants respond with yes/no votes

Coordinator generates commit record

Coordinator flushes commit record



One More Time, with Logging, Part 8

Phase 1:

Coordinator tells participants to "prepare"

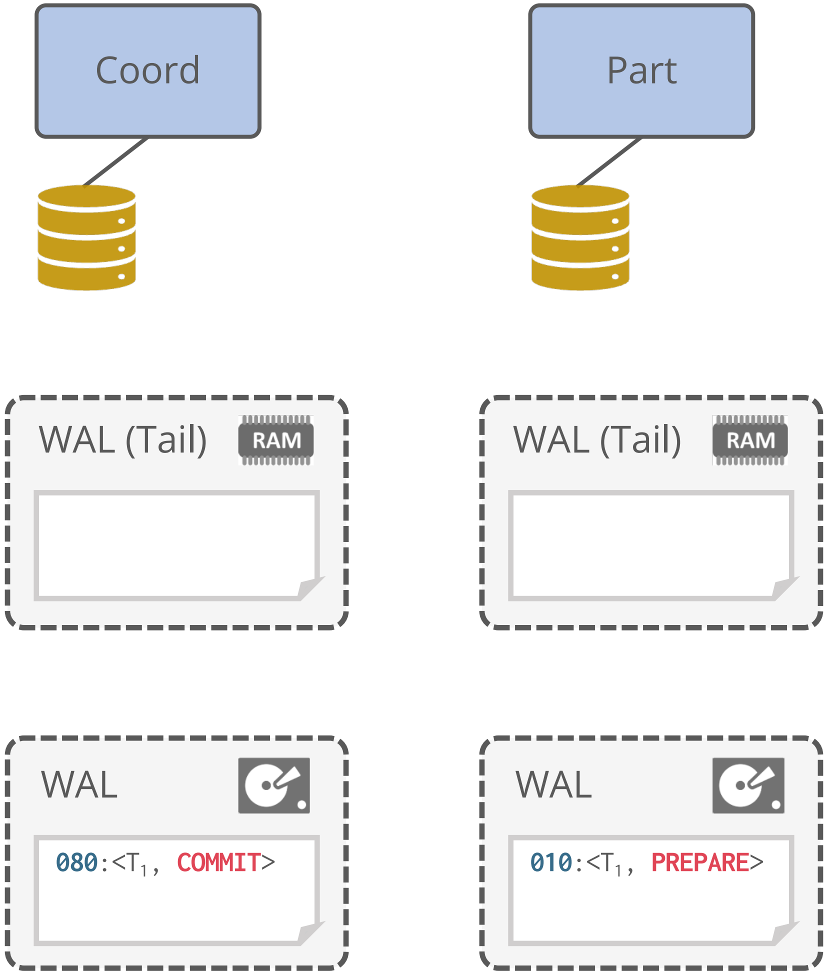
Participants generate prepare/abort record

Participants flush prepare/abort record

Participants respond with yes/no votes

Coordinator generates commit record

Coordinator flushes commit record



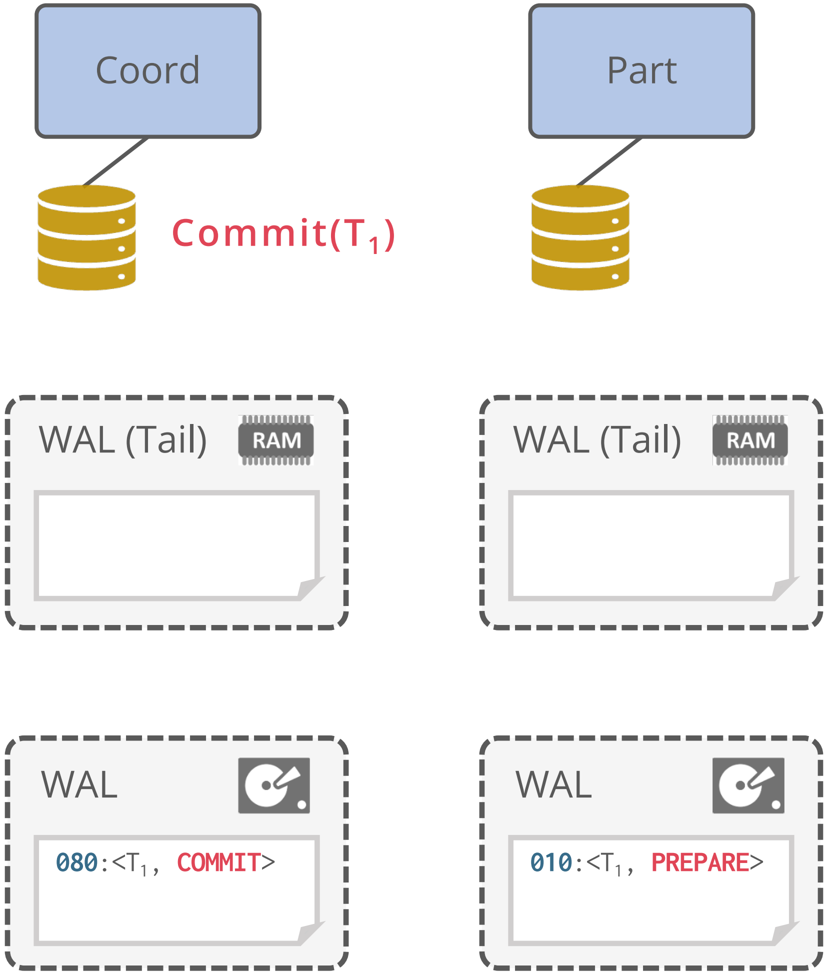
080:<T_1, COMMIT>

010:<T_1, PREPARE>

One More Time, with Logging, Part 9

Phase 2:

- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



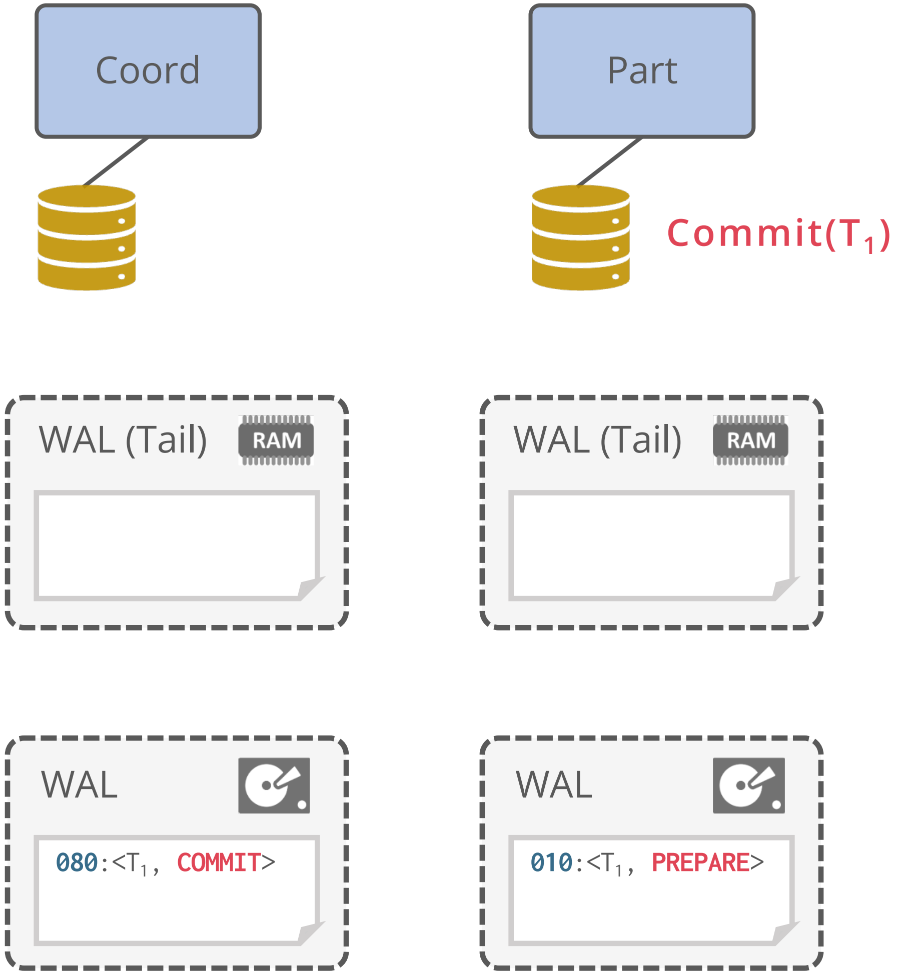
```
080:<T1, COMMIT>
```

```
010:<T1, PREPARE>
```

One More Time, with Logging, Part 10

Phase 2:

- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



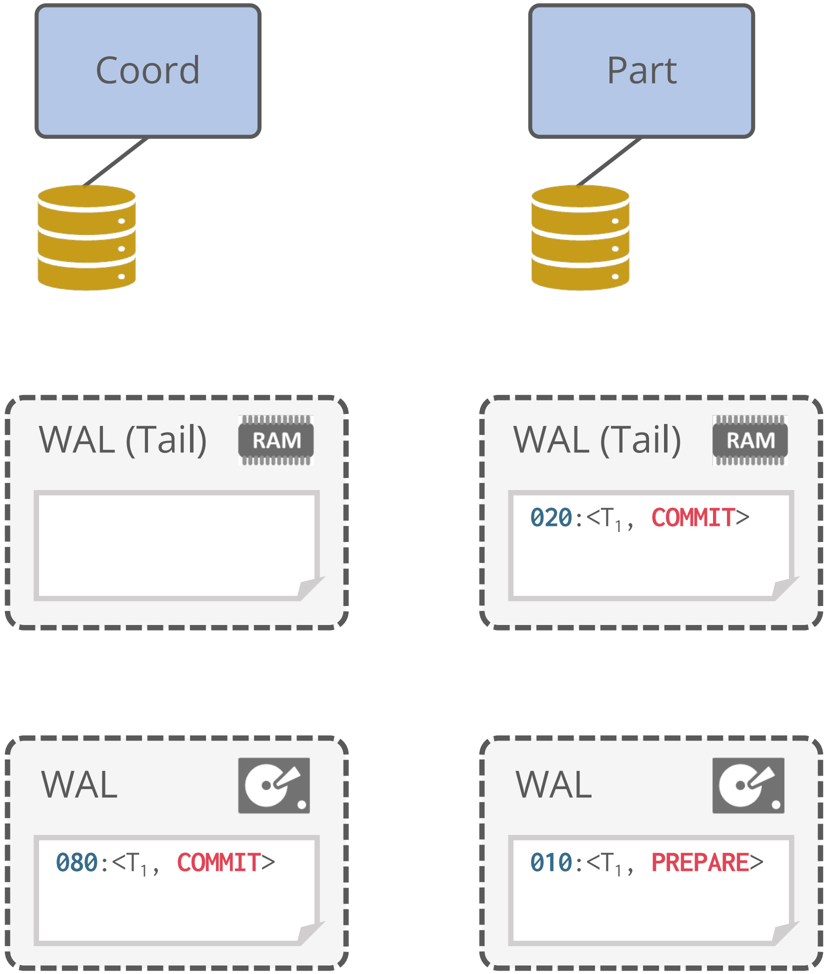
080:<T_1, COMMIT>

010:<T_1, PREPARE>

One More Time, with Logging, Part 11

Phase 2:

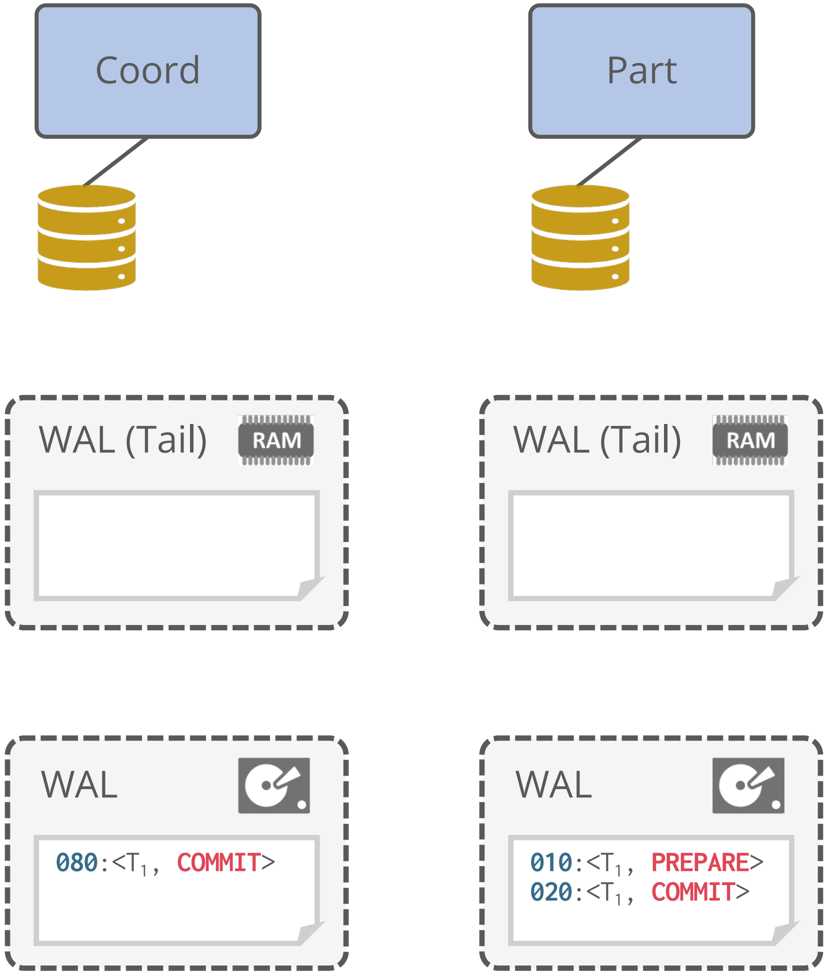
- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



One More Time, with Logging, Part 12

Phase 2:

- Coordinator broadcasts result of vote
- Participants make commit/abort record
- **Participants flush commit/abort record**
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



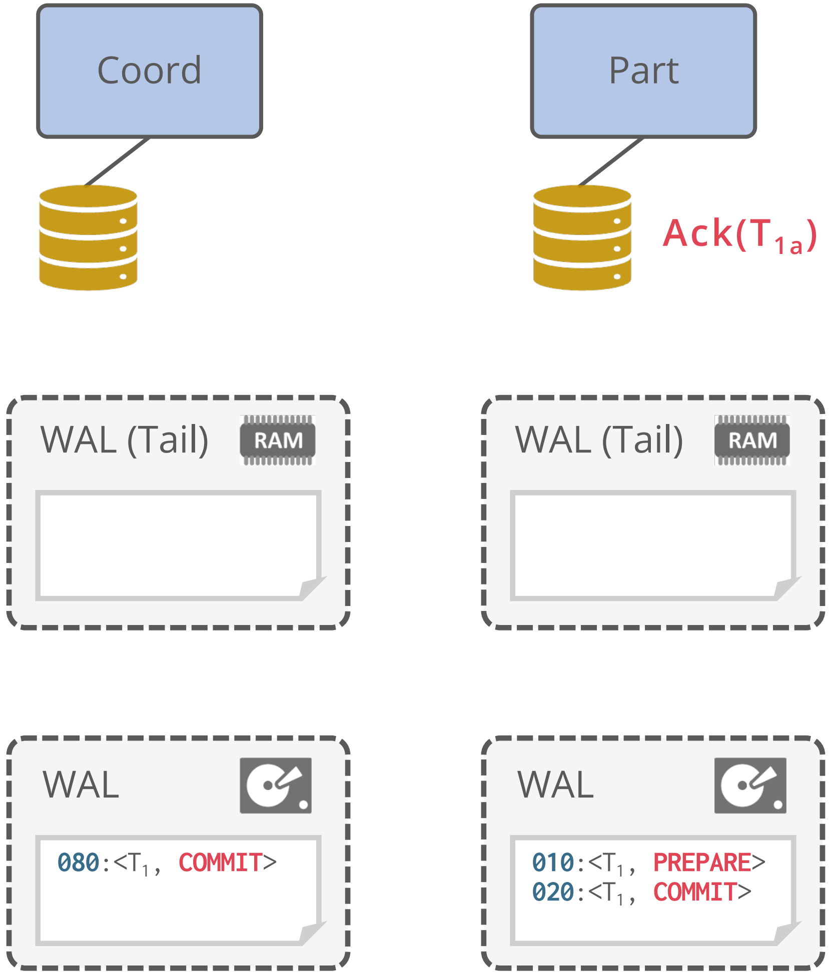
```
080:<T1, COMMIT>
```

```
010:<T1, PREPARE>
020:<T1, COMMIT>
```

One More Time, with Logging, Part 13

Phase 2:

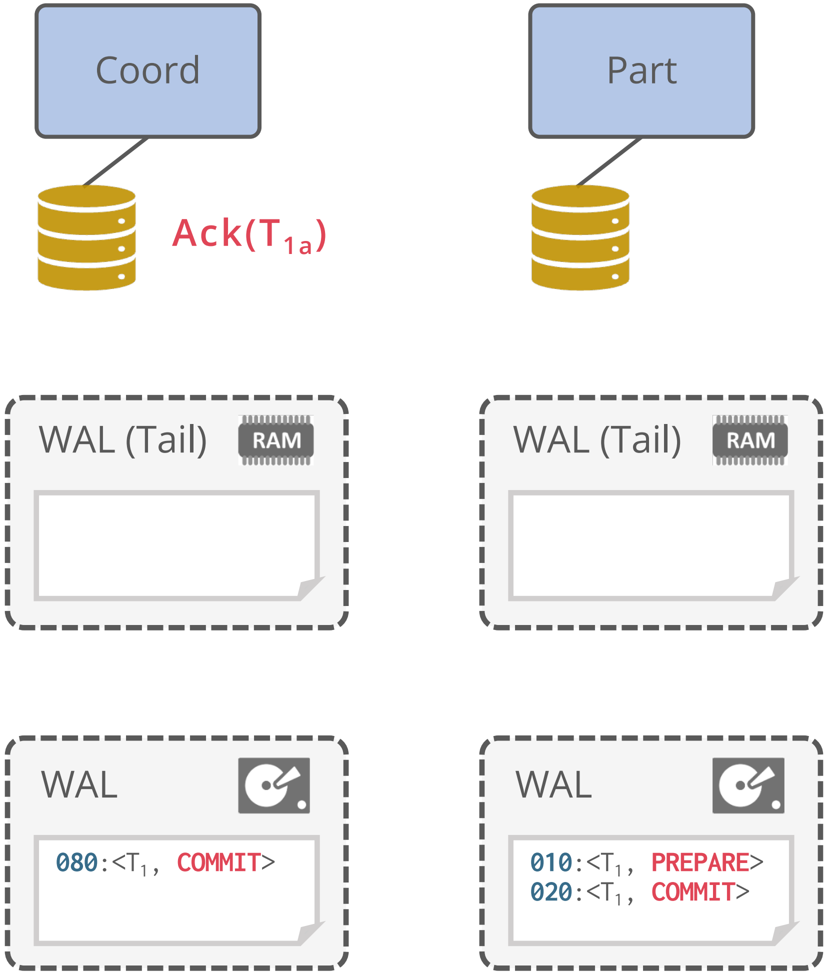
- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- **Participants respond with Ack**
- Coordinator generates end record
- Coordinator flushes end record



One More Time, with Logging, Part 14

Phase 2:

- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- **Participants respond with Ack**
- Coordinator generates end record
- Coordinator flushes end record



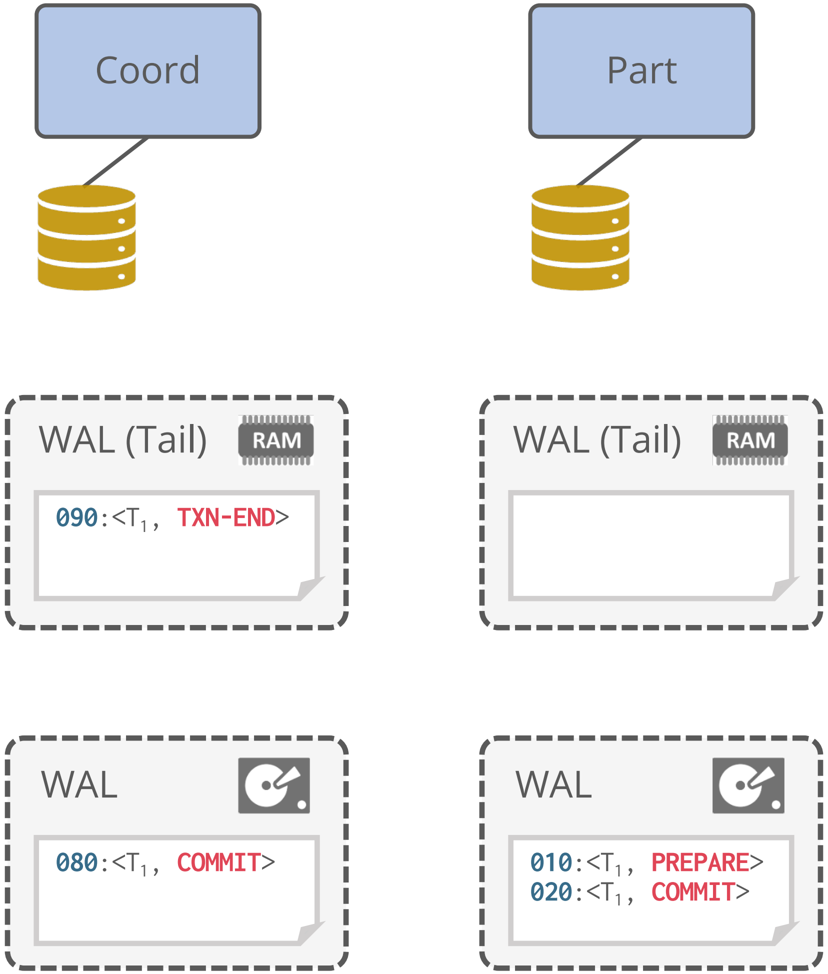
```
080:<T1, COMMIT>
```

```
010:<T1, PREPARE>
020:<T1, COMMIT>
```

One More Time, with Logging, Part 15

Phase 2:

- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



```
090:<T1, TXN-END>
```

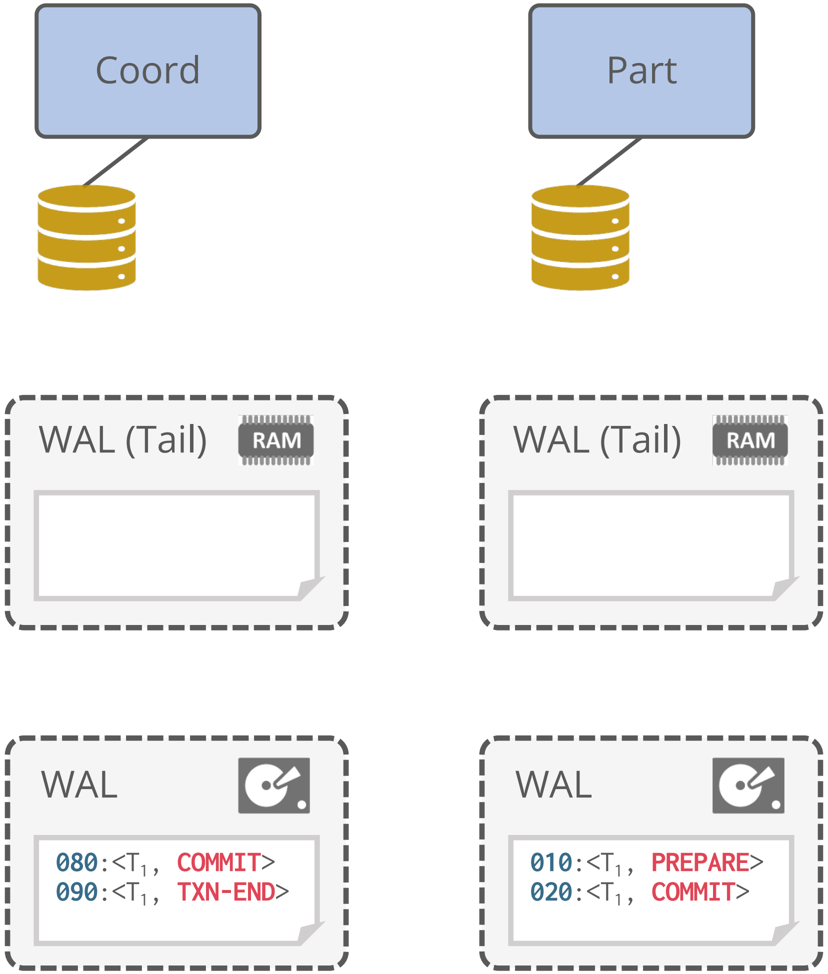
```
080:<T1, COMMIT>
```

```
010:<T1, PREPARE>
020:<T1, COMMIT>
```

One More Time, with Logging, Part 16

Phase 2:

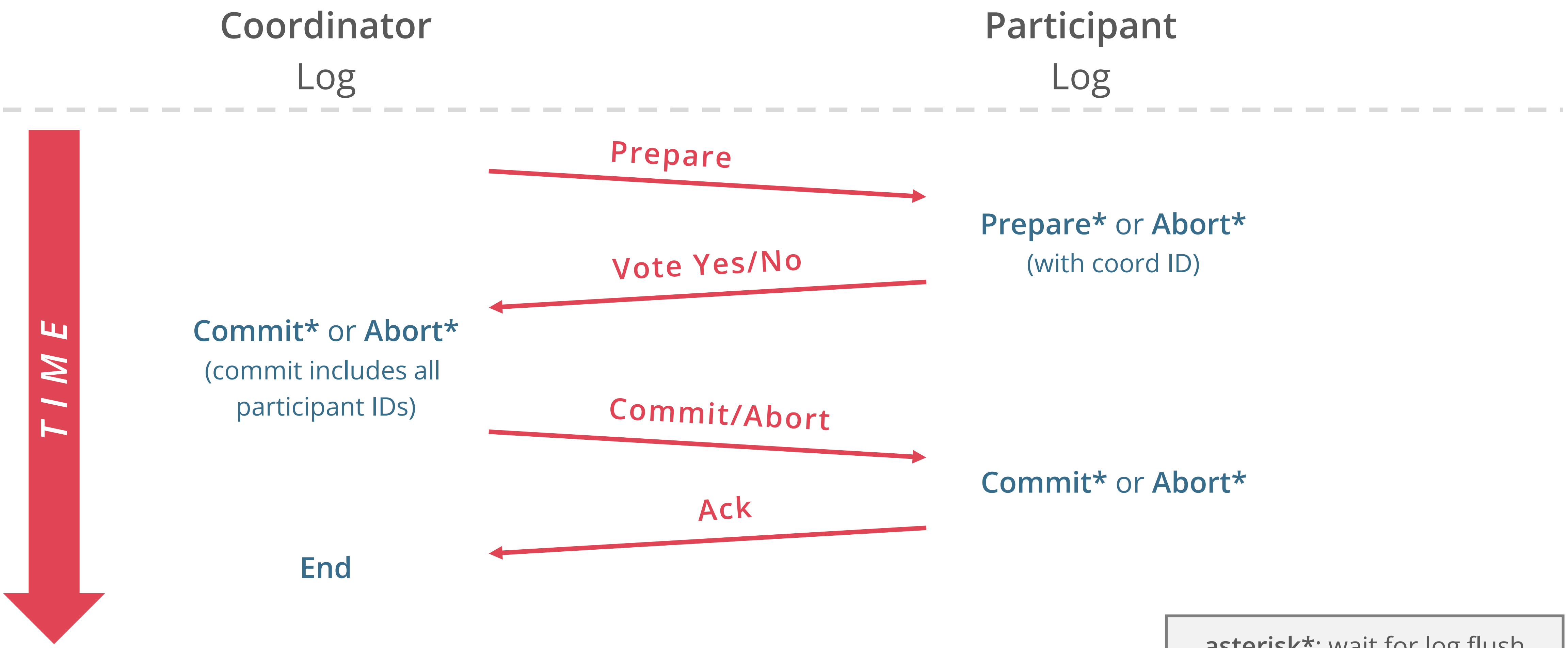
- Coordinator broadcasts result of vote
- Participants make commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



```
080:<T1, COMMIT>
090:<T1, TXN-END>
```

```
010:<T1, PREPARE>
020:<T1, COMMIT>
```

2PC In a Nutshell



Coordinator
Log

Participant
Log

TIME

Prepare

Prepare* or **Abort***
(with coord ID)

Vote Yes/No

Commit* or **Abort***
(commit includes all participant IDs)

Commit/Abort

Commit* or **Abort***

Ack

End

asterisk*: wait for log flush before sending next msg

Outline

Distributed Locking

Distributed Deadlock Detection

Distributed Two-Phase Commit (2PC)

Recovery and 2PC

FAILURE HANDLING

Assume everybody recovers eventually

- Big assumption!
- Depends on WAL (and short downtimes)

Coordinator notices a Participant is down?

- If participant hasn’t voted yet, coordinator aborts transaction
- If waiting for a commit Ack, hand to “recovery process”

Participant notices Coordinator is down?

- If it hasn’t yet logged prepare, then abort unilaterally
- If it has logged prepare, hand to “recovery process”

Note

- Thinking a node is “down” may be incorrect!

Integration with ARIES Recovery

On recovery

- Assume there's a "Recovery Process" at each node
- It will be given tasks to do by the Analysis phase of ARIES
- These tasks can run in the background (asynchronously)

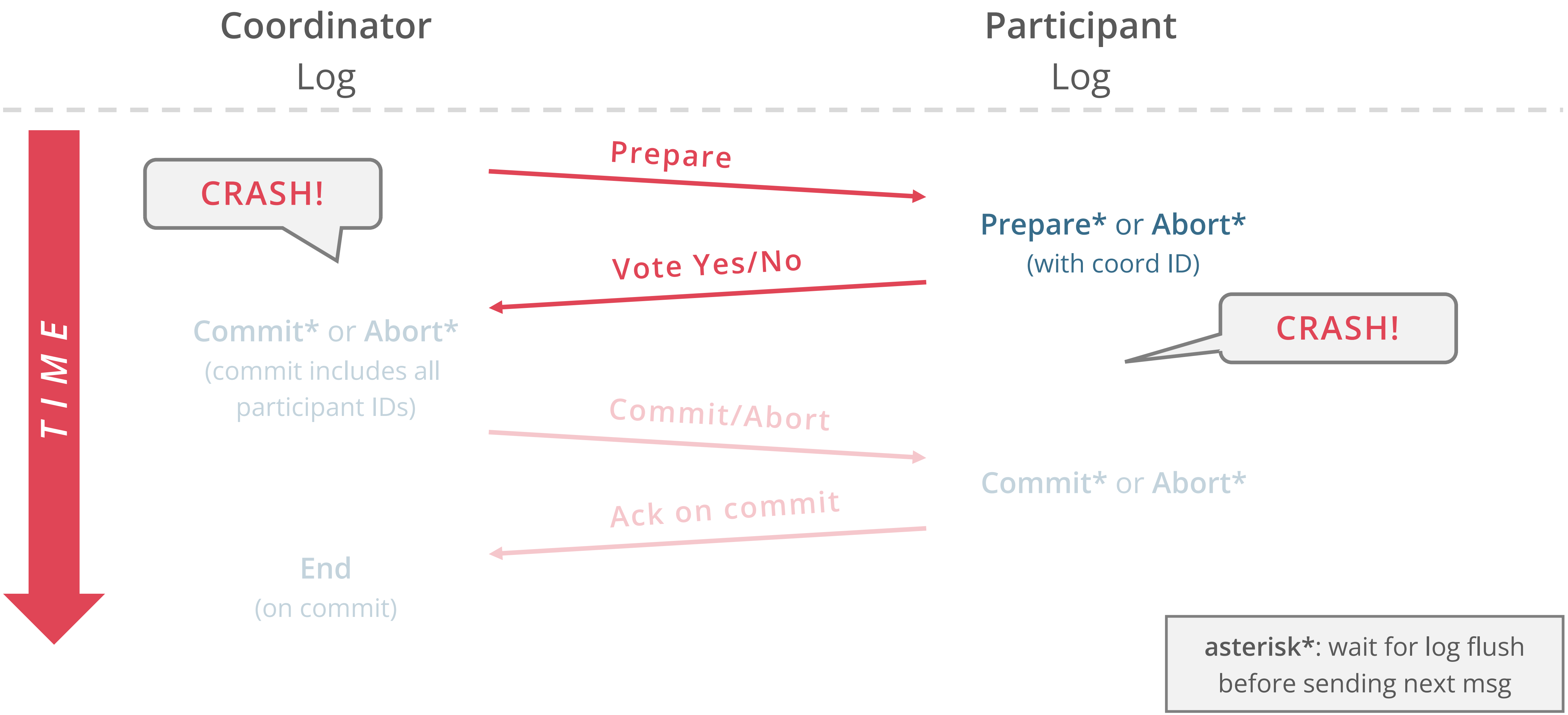
Note: multiple roles on a single node

- Coordinator for some transactions, Participant for others

How Does Recovery Process Work?

- Coordinator recovery process gets inquiry from a “prepared” participant
  - If transaction table at coordinator says aborting/committing
    - Send appropriate response and continue protocol on both sides
  - If transaction table at coordinator says nothing: **send ABORT**
    - Only happens if coordinator had also crashed before writing commit/abort
    - Inquirer does the abort on its end

2PC In a Nutshell



asterisk*: wait for log flush before sending next msg

Recovery: Think it through

What happens when coordinator recovers?

- With “commit” and “end”?
- With just “commit”?
- With “abort”?

Commit iff coordinator logged a commit

What happens when participant recovers:

- With no prepare/commit/abort?
- With “prepare” and “commit”?
- With just “prepare”?
- With “abort”?

Recovery: Think it through

What happens when coordinator recovers?

- With “commit” and “end”? **Nothing**
- With just “commit”? **Rerun Phase 2!**
- With “abort”? **Nothing (presumed abort)**

Commit iff coordinator logged a commit

What happens when participant recovers:

- With no prepare/commit/abort? **Nothing (presumed abort)**
- With “prepare” and “commit”? **Send Ack to coordinator**
- With just “prepare”? **Send inquiry to coordinator**
- With “abort”? **Nothing (presumed abort)**

2PC + Strict 2PL

Ensure point-to-point messages are densely ordered

- 1,2,3,4,5…
- Dense per (sender/receiver/transaction ID)
- Receiver can detect anything missing or out-of-order
- Receiver buffers message k+1 until [1..k] received
- Effect: receiver considers messages in order

Commit:

- When a participant processes Commit request, it has all the locks it needs
- Flush log records and drop locks atomically

Abort:

- Its safe to abort autonomously, locally: no cascade
- Log appropriately to 2PC (presumed abort in our case)
- Perform local Undo, drop locks atomically

Availability Concerns

- What happens while a node is down?
    - Other nodes may be in limbo, holding locks
    - So certain data is unavailable
    - This may be bad…
- Dead Participants? Respawned by coordinator
    - Recover from log
    - And if the old participant comes back from the dead, just ignore it and tell it to recycle itself
- Dead Coordinator?
    - This is a problem!
    - 3-Phase Commit was an early attempt to solve it
    - Paxos Commit provides a more comprehensive solution
        - Gray + Lamport paper. Out of scope for this course

Summary

- Data partitioning provides scale-up
- Can also partition lock tables and logs
- But need to do some global coordination:
  - Deadlock detection: easy
  - Commit: trickier
- Two-phase commit is a classic distributed consensus protocol
  - Logging/recovery aspects unique:
    - Many distributed protocols gloss over
  - But 2PC is unavailable on any single failure
    - This is bad news for scale-up, because odds of failure go up with #machines
    - Paxos Commit addresses that problem