CS150A Database

Lu Sun

School of Information Science and Technology

ShanghaiTech University

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Today:

- Distributed Transactions:
    - Two-Phase Commit

Readings:

- Database Management Systems (DBMS), Chapter 20

Acknowledgement: Joe Hellerstein@UCBerkeley's scourse notes

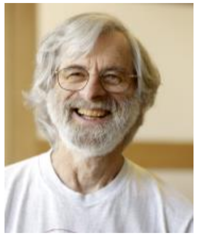
Distributed vs. Parallel?

- Earlier we discussed Parallel DBMSs
  - Shared-memory
  - Shared-disk
  - Shared-nothing
- Distributed is basically $\underline{\text{shared-nothing parallel}}$
  - Perhaps with a slower network

What’s Special About Distributed Computing?

- Parallel computation
- No shared memory/disk
- Unreliable Networks
  - Delay, reordering, loss of packets
- Unsynchronized clocks
  - Impossible to have perfect synchrony
- Partial failure: can’t know what’s up, what’s down

“A distributed system is one in which the failure of a computer you didn't even know existed can render your own computer unusable”.
— Leslie Lamport, Turing 2013



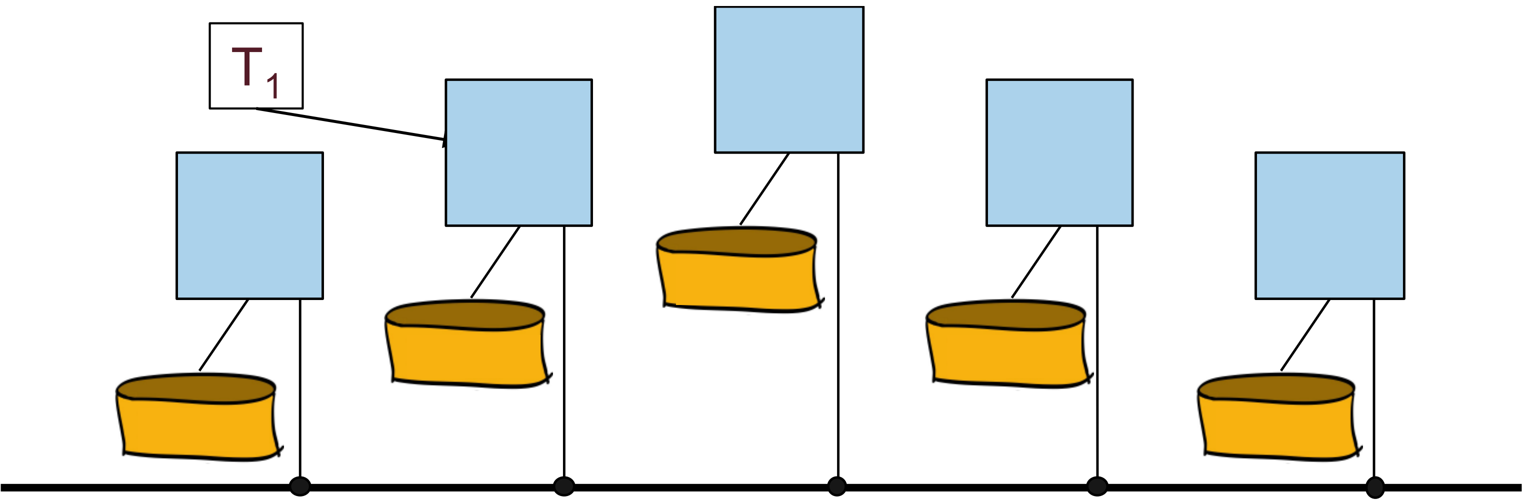
Distributed Database Systems transactional

- DBMS an influential special case of distributed computing
  - The trickiest part of distributed computing is state, i.e. Data
  - Transactions provide an influential model for concurrency/parallelism
  - DBMSs worried about fault handling early on
- Special-case because not all programs are written transactionally
  - And if not, database techniques may not apply
- Many of today's most complex distributed systems are databases
  - Cloud SQL databases like Spanner, Aurora, Azure SQL
  - NoSQL databases like DynamoDB, Cassandra, MongoDB, Couchbase…
- We'll focus on transactional concurrency control and recovery
  - You already know many lessons of distributed query processing

DISTRIBUTED LOCKING

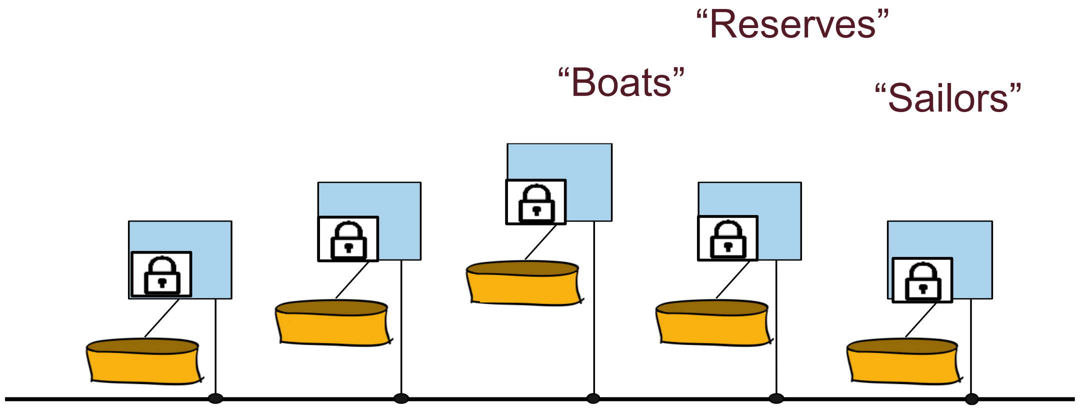
Distributed Concurrency Control

- 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



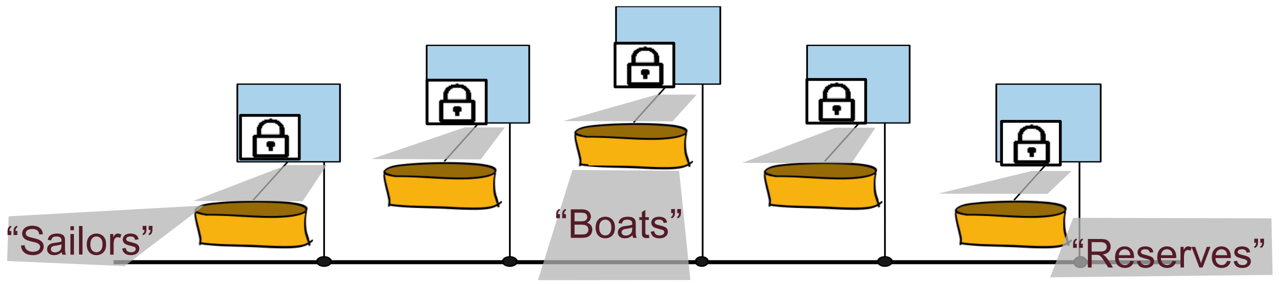
Where is the Lock Table

- 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



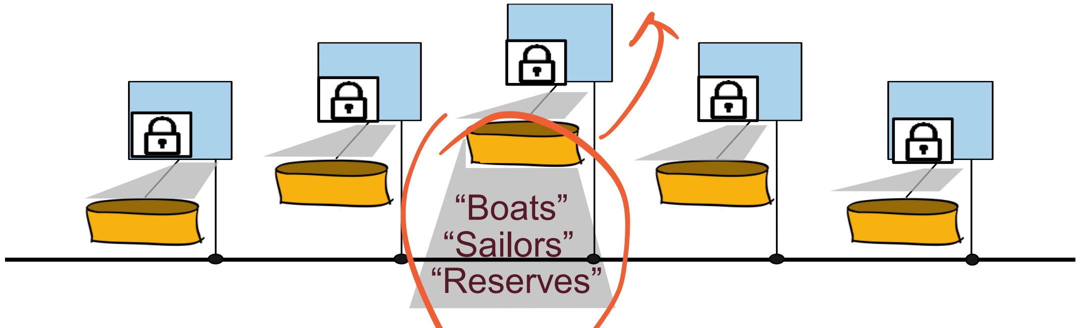
Where is the Lock Table, Pt 2

- 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



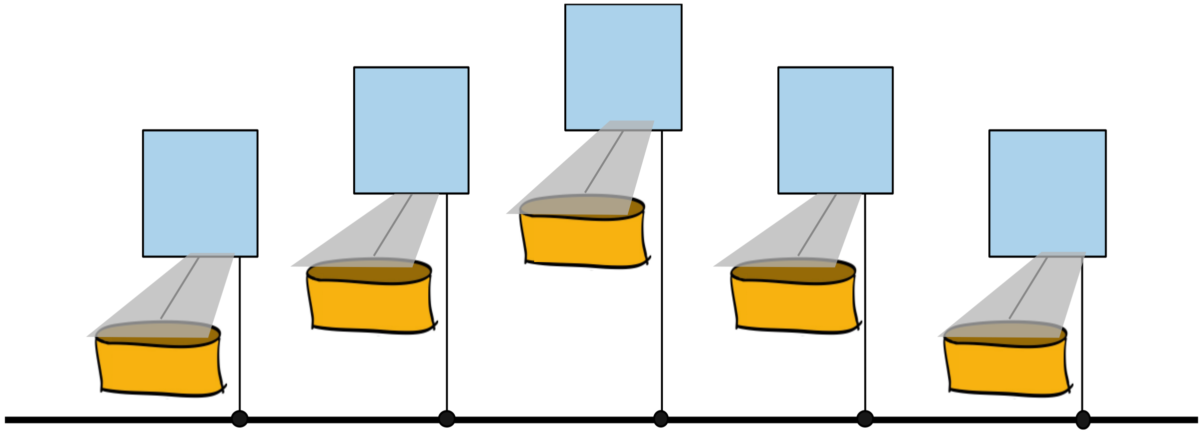
Where is the Lock Table, Pt 3

- 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 a master node



Ignore global locks for a moment…

- Every node does its own locking
  - Clean and efficient
- “Global” issues remain:
  - Deadlock
  - Commit/Abort

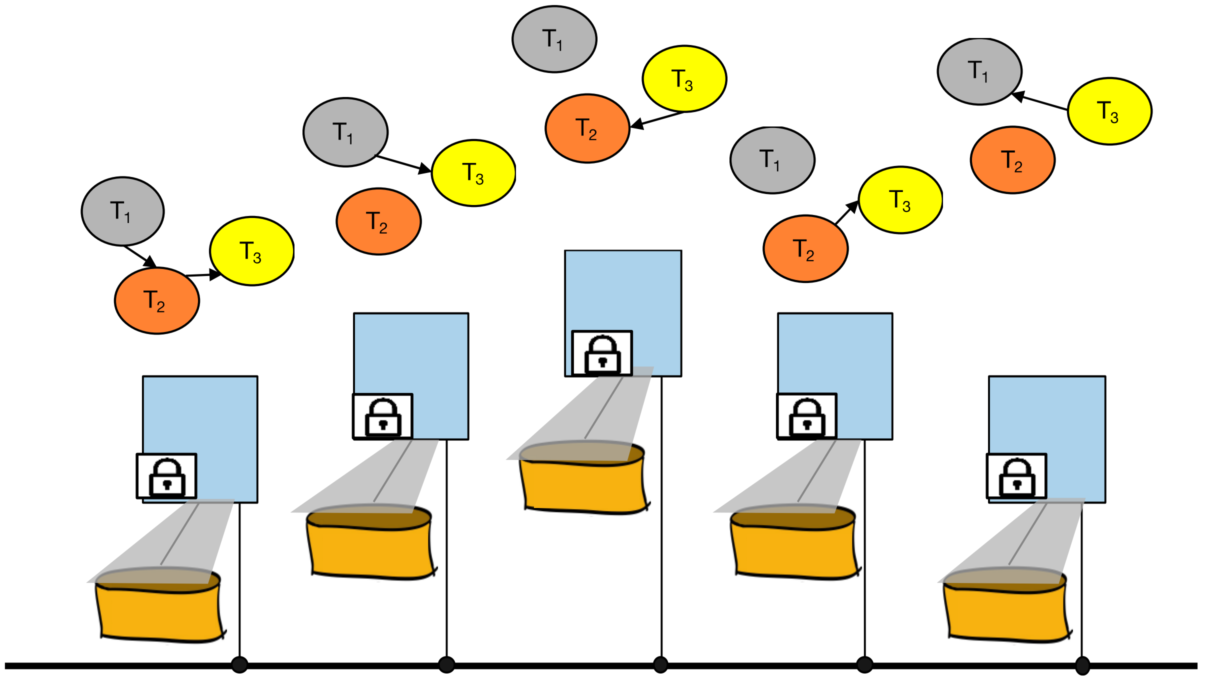


DISTRIBUTED DEADLOCK DETECTION

What Could Go Wrong? #1

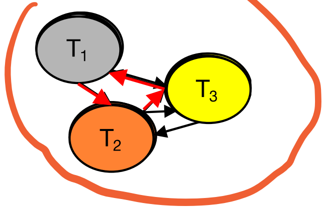
- Deadlock detection

$\rightarrow$: waiting for

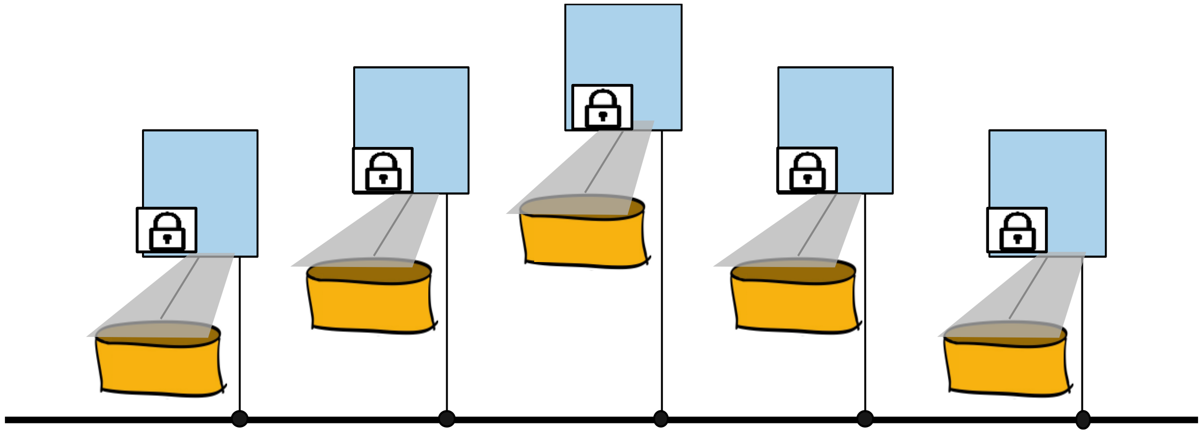


What Could Go Wrong? #1 Part 2

- Deadlock detection
  - Easy fix: periodically union at designated master



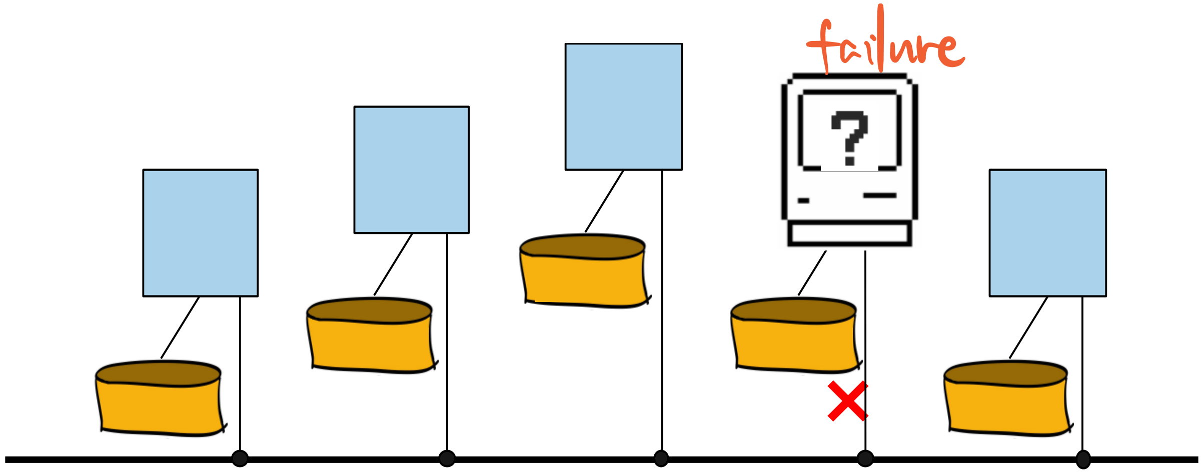
circle cross-node



DISTRIBUTED COMMIT: 2PC

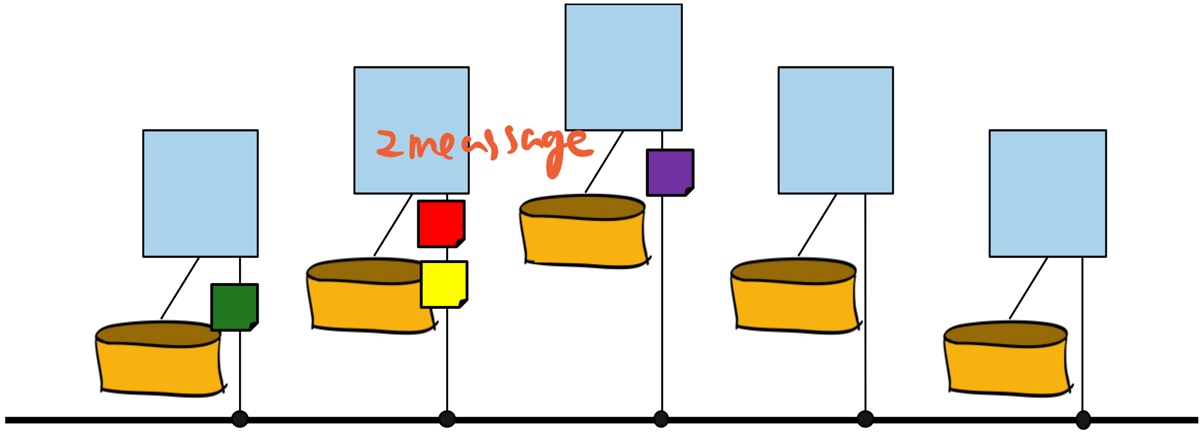
What Could Go Wrong? #2

- Failures/Delays: Nodes
  - Commit? Abort?
  - When the node comes back, how does it recover in a world that moved forward?



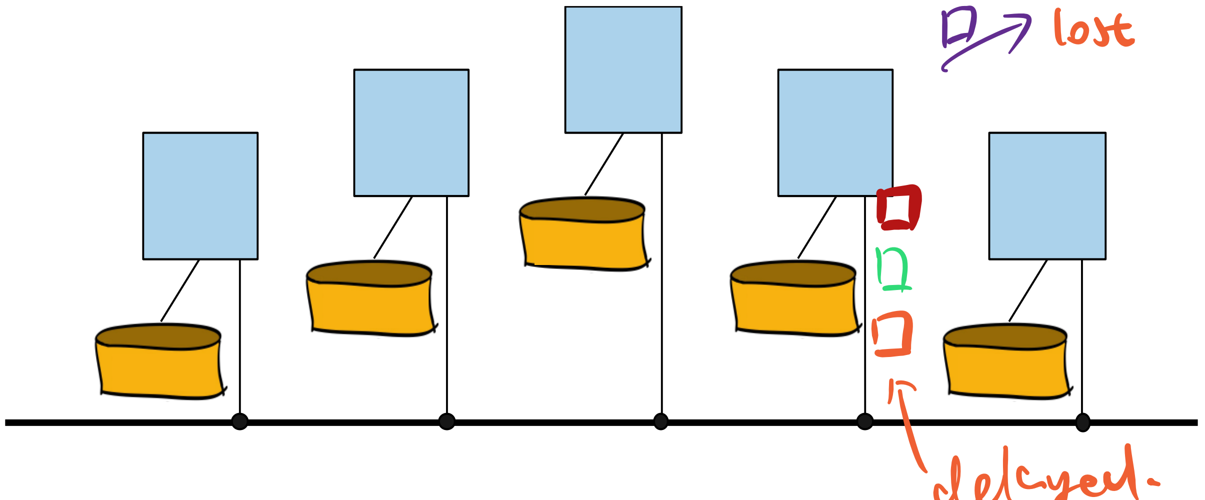
What Could Go Wrong? #2, Part 2

- Failures/Delays: Nodes
- Failures/Delays: Messages
  - Non-deterministic reordering per channel, interleaving across channels
  - “Lost” (very delayed) messages



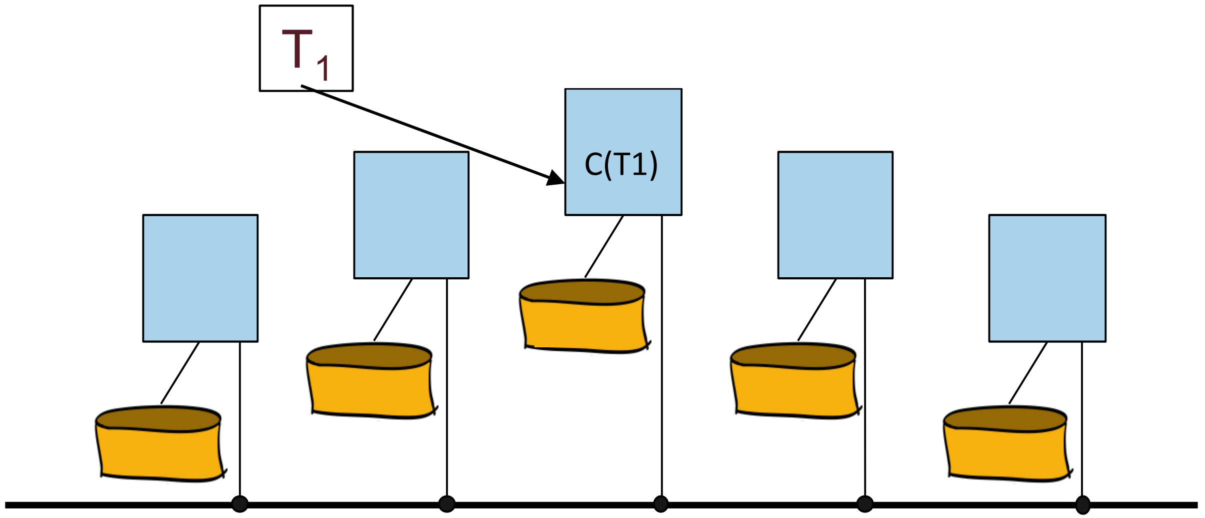
What Could Go Wrong? #2, Part 3

- Failures/Delays: Nodes
- Failures/Delays: Messages
  - Non-deterministic reordering per channel, interleaving across channels
  - “Lost” (very delayed) messages
- How do all nodes agree on Commit vs. Abort?



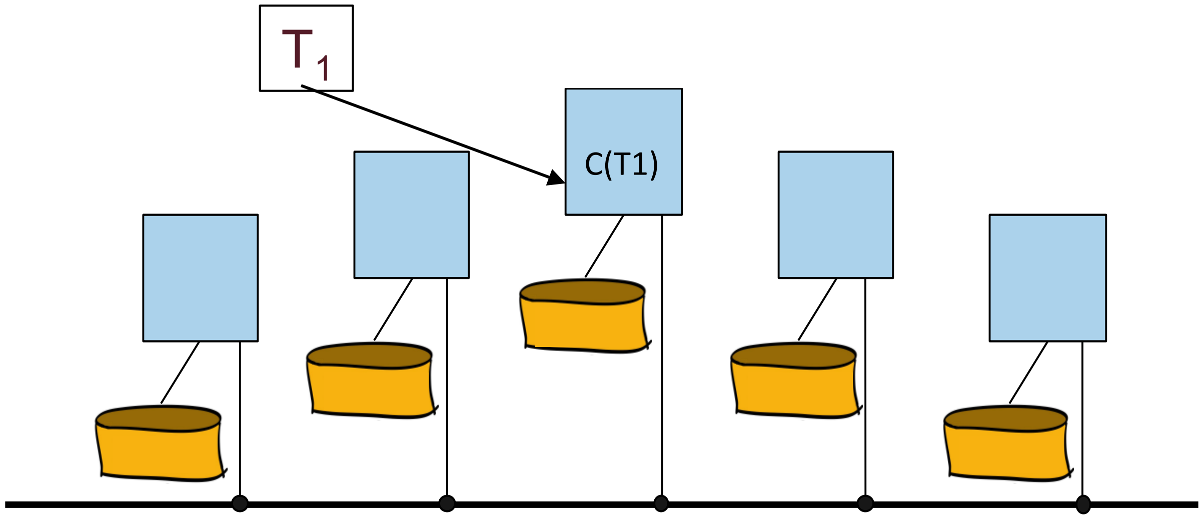
Basic Idea: Distributed Voting

- 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. = all have to



Distributed voting? How?

- How do we implement distributed voting?!
  - In the face of message/node failure/delay?



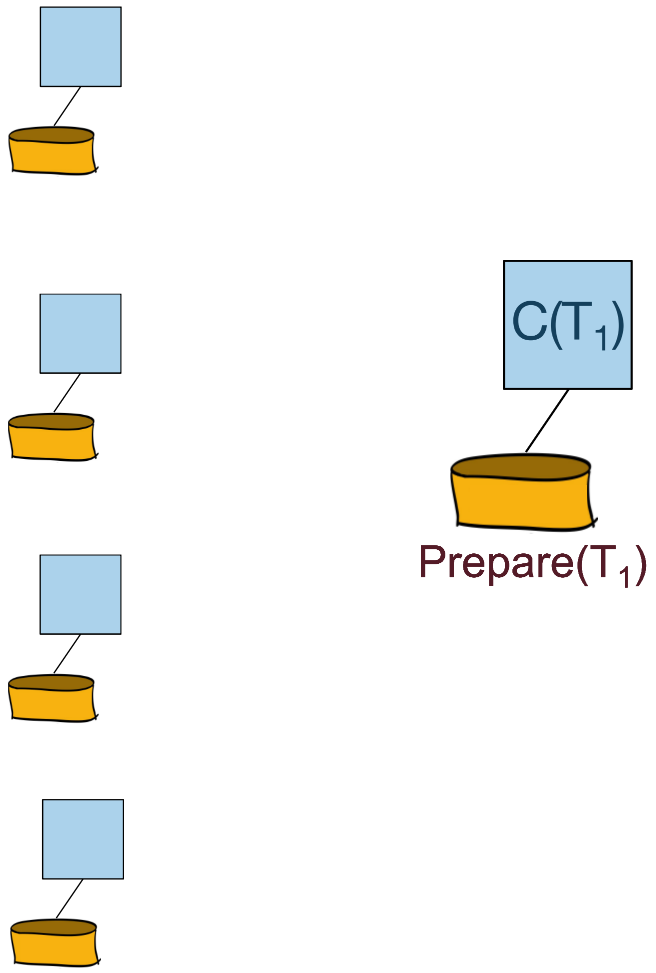
2-Phase Commit

- A.k.a. 2PC. (Not to be confused with 2PL!)
- Like a wedding ceremony!
- **Phase 1: "do you take this man/woman..."**
  - Coordinator tells participants to "prepare"
  - Participants respond with yes/no votes
    - Unanimity required for yes!
- **Phase 2: "I now pronounce you..."**
  - Coordinator disseminates result of the vote

    [illegible]传播
- Need to do some logging for failure handling....

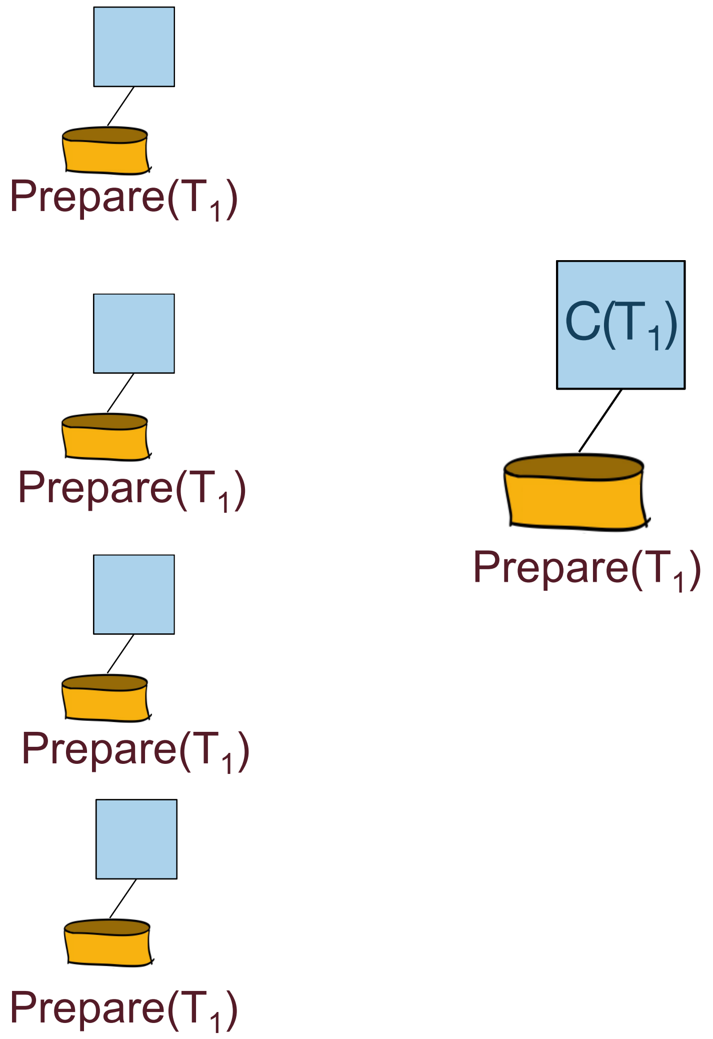
2-Phase Commit, Part 1

- **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



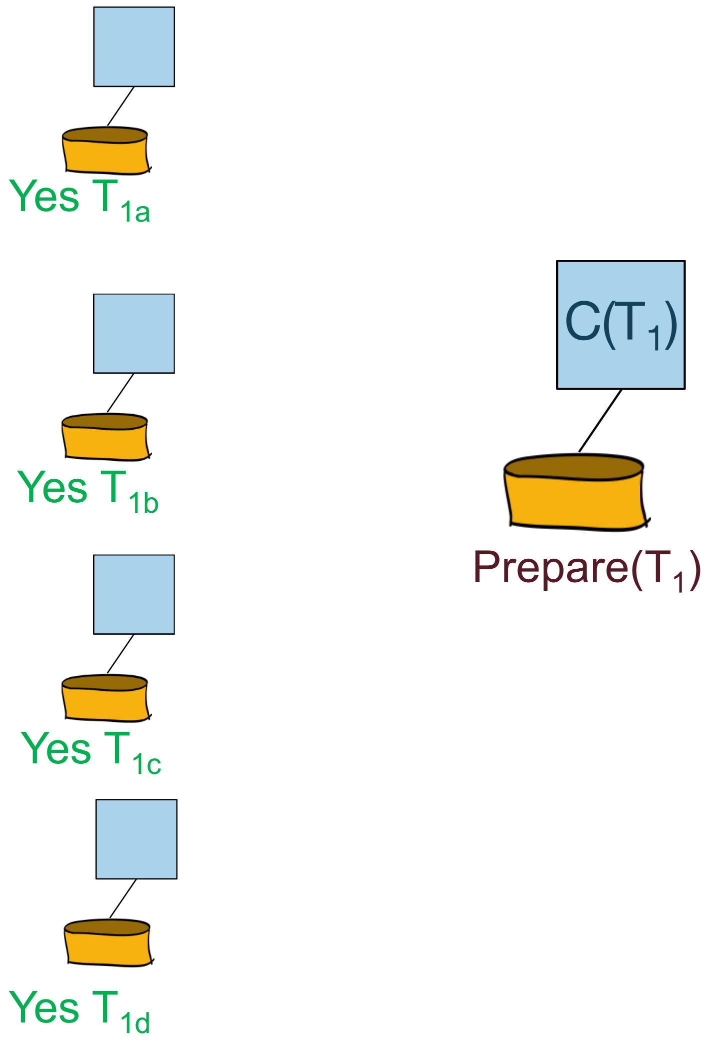
2-Phase Commit, Part 2

- **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



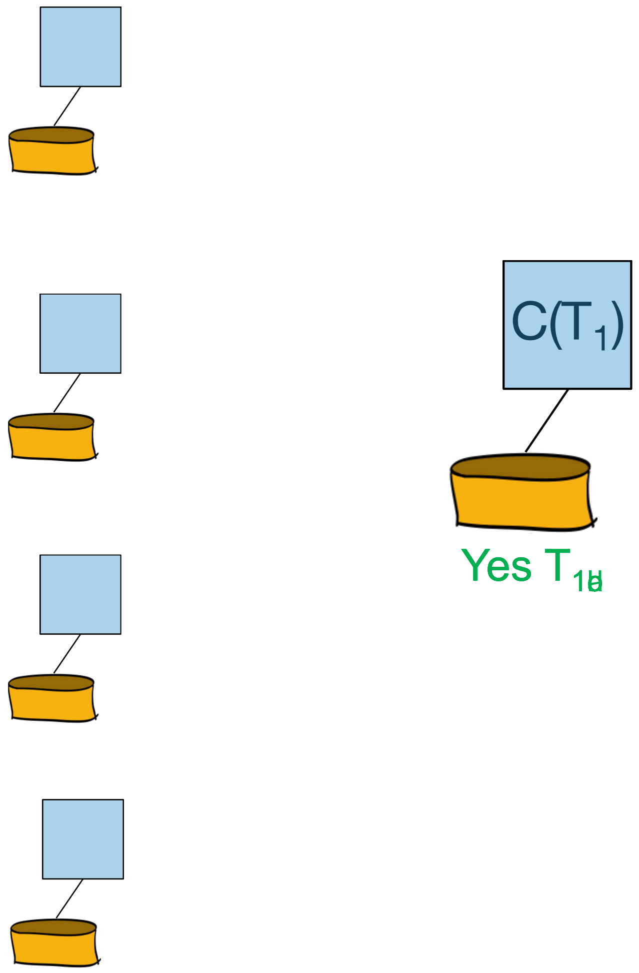
2-Phase Commit, Part 3

- **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

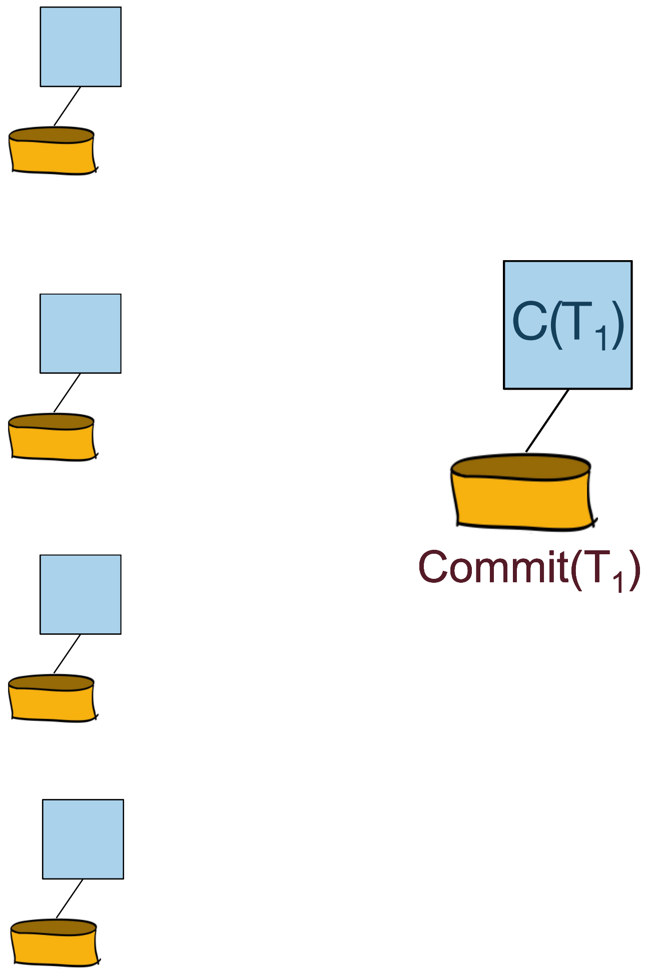
- **Phase 1:**
  - Coordinator tells participants to “prepare”
  - **Participants respond with yes/no votes**
    - **Unanimity required for commit!**
- Phase 2:
  - Coordinator disseminates result of the vote
  - Participants respond with Ack



2-Phase Commit, Part 5

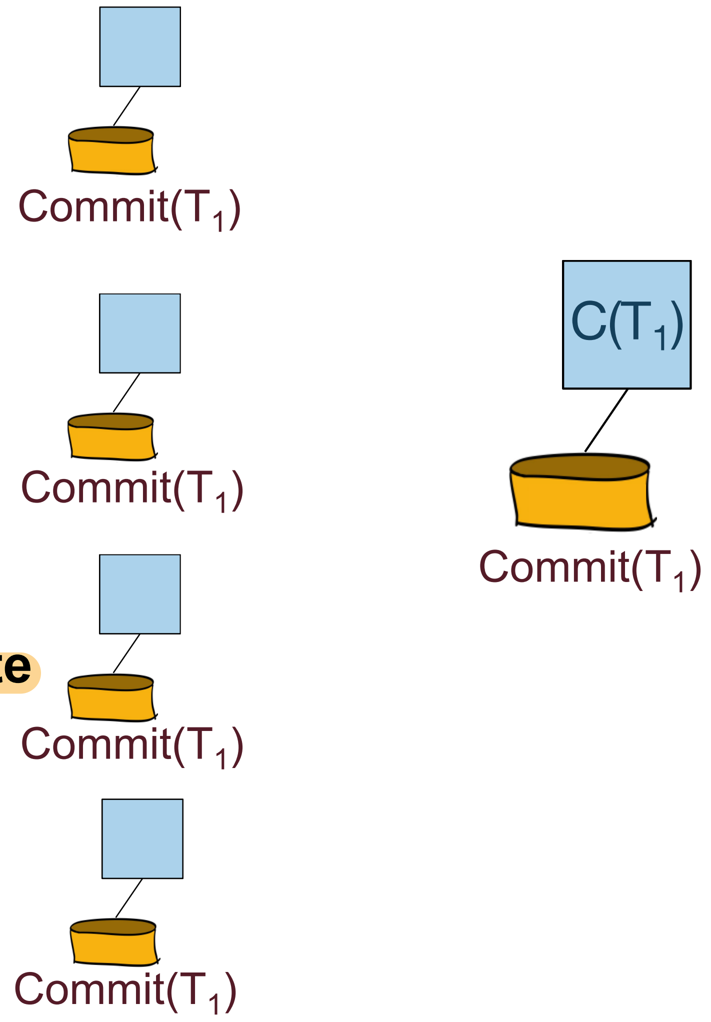
- Phase 1:
  - Coordinator tells participants to "prepare"
  - Participants respond with yes/no votes
    - Unanimity required for commit!
- **Phase 2:**

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



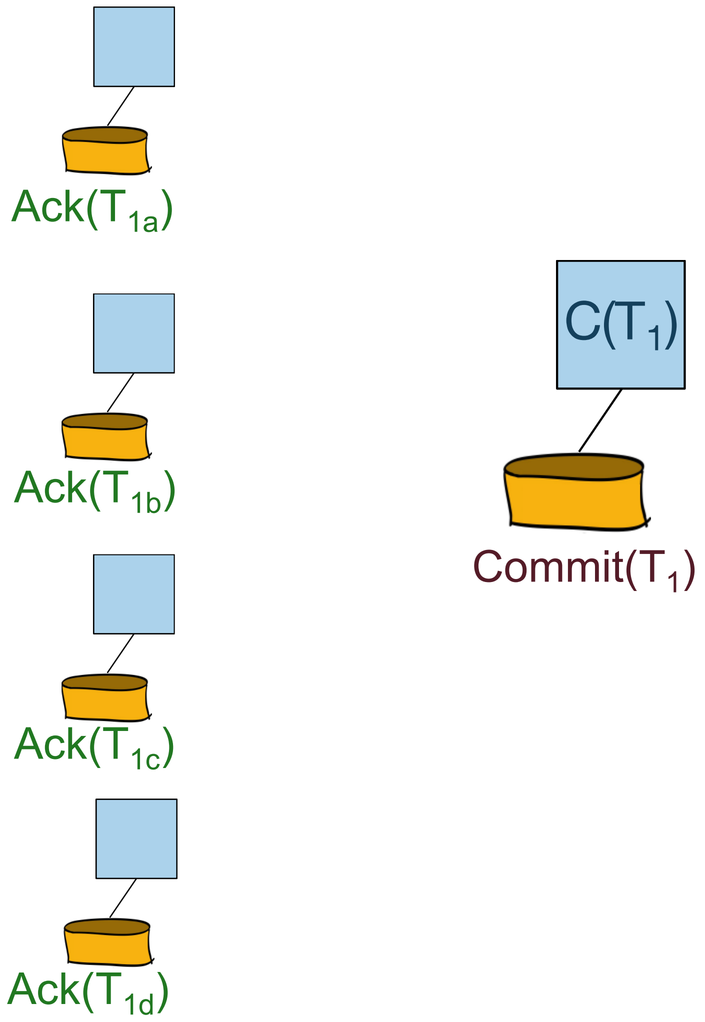
2-Phase Commit, Part 6

- 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



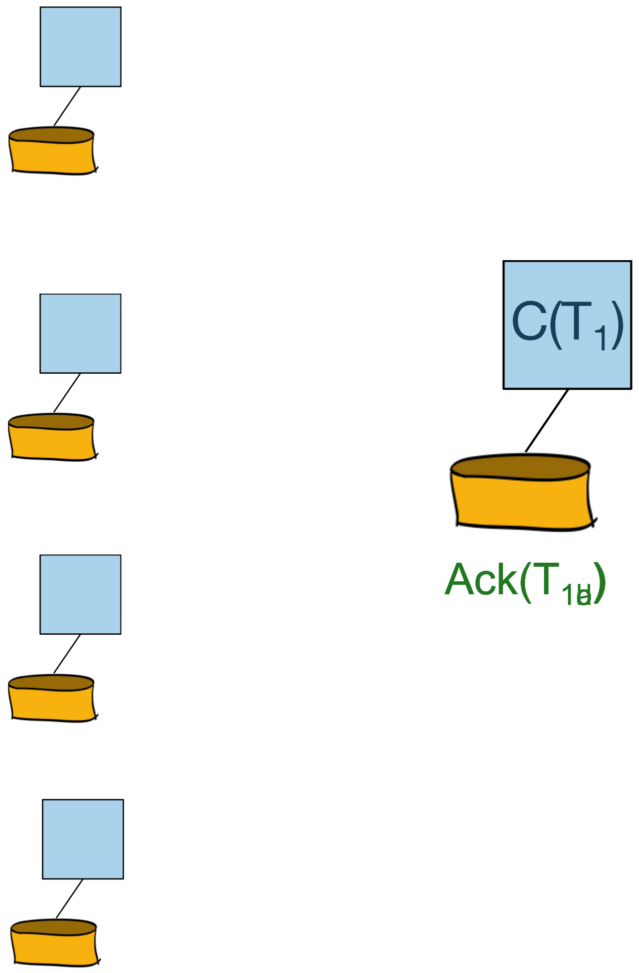
2-Phase Commit, Part 7

- 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**



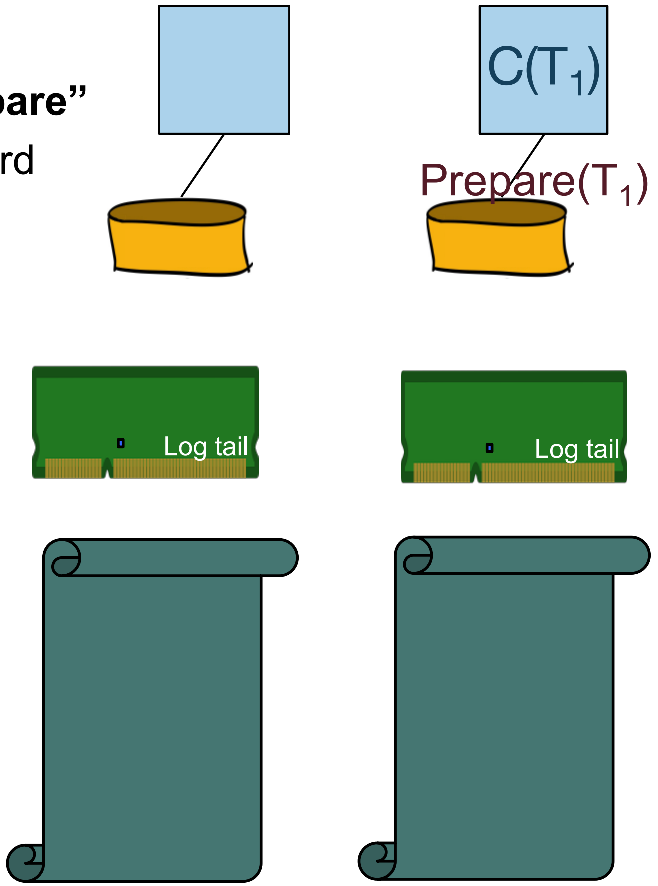
2-Phase Commit, Part 8

- 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**



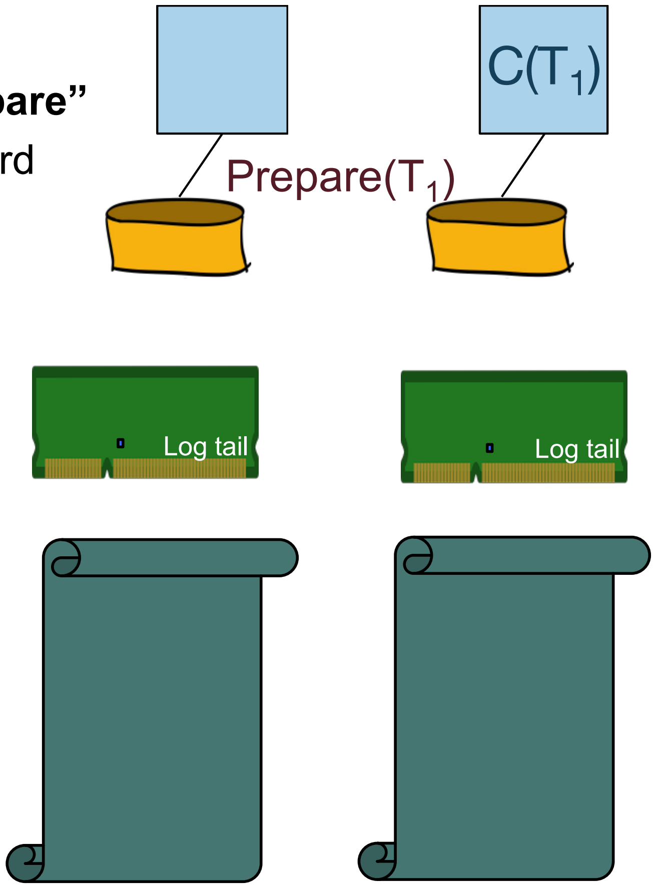
One More Time, With Logging

- **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



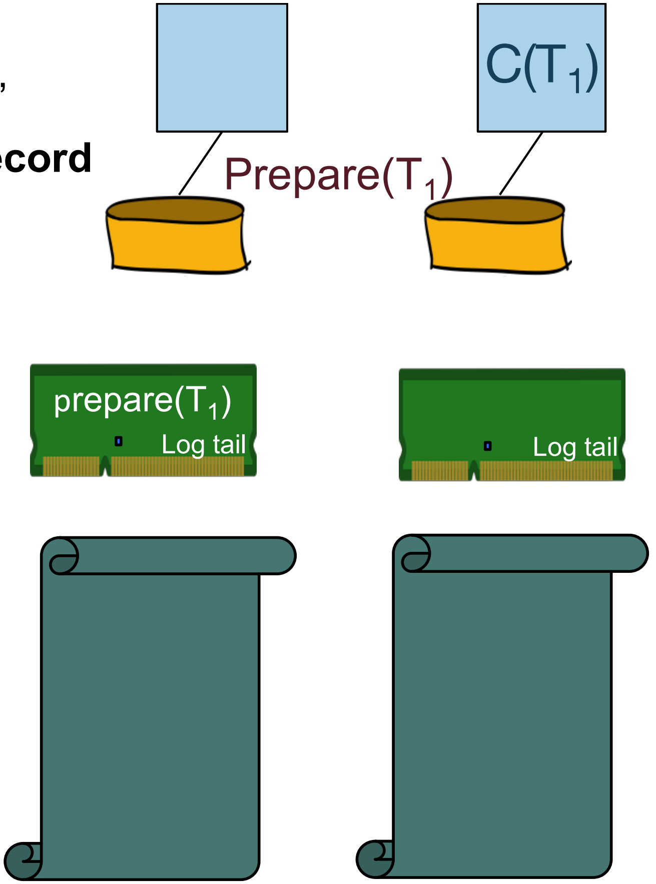
One More Time, With Logging, Part 2

- **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



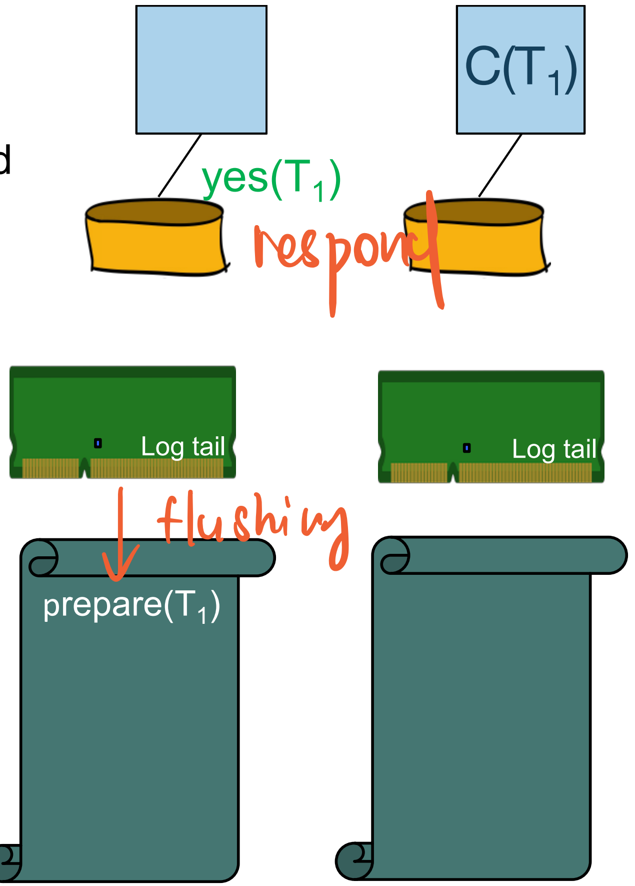
One More Time, With Logging, Part 3

- **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



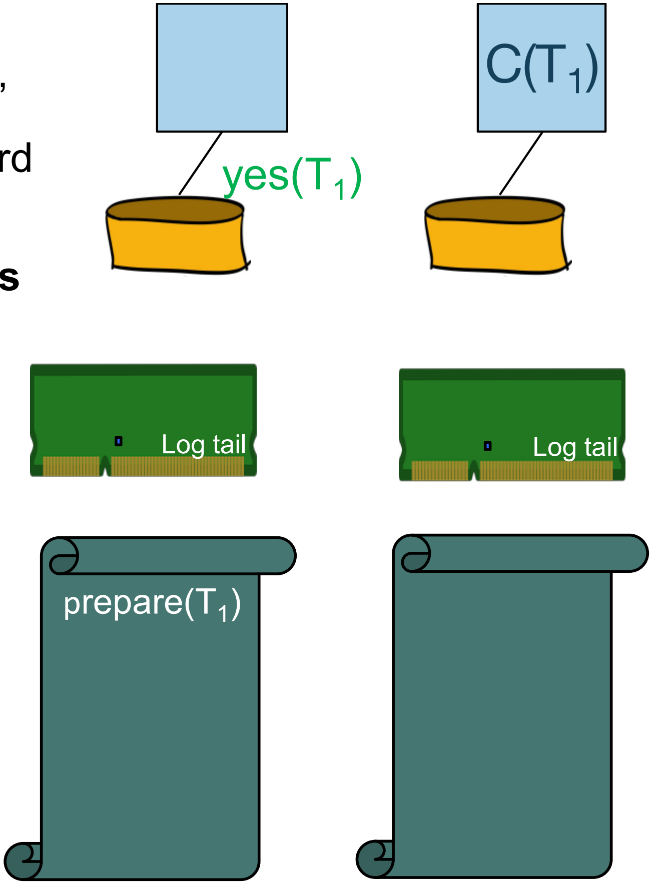
One More Time, With Logging, Part 4

- **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



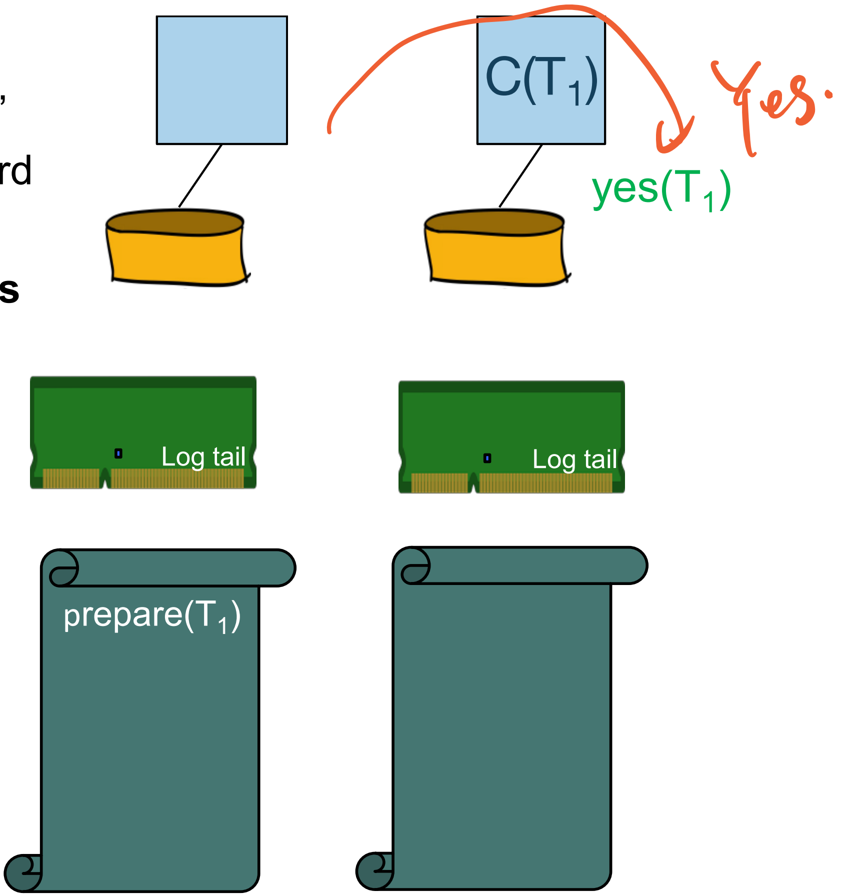
One More Time, With Logging, Part 5

- **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



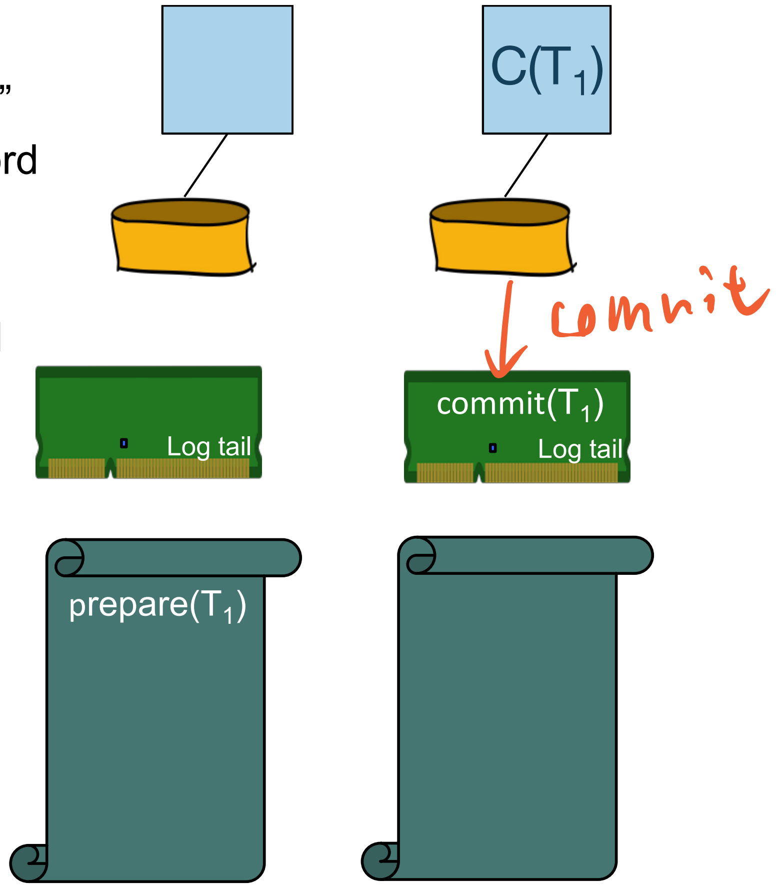
One More Time, With Logging, Part 6

- **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



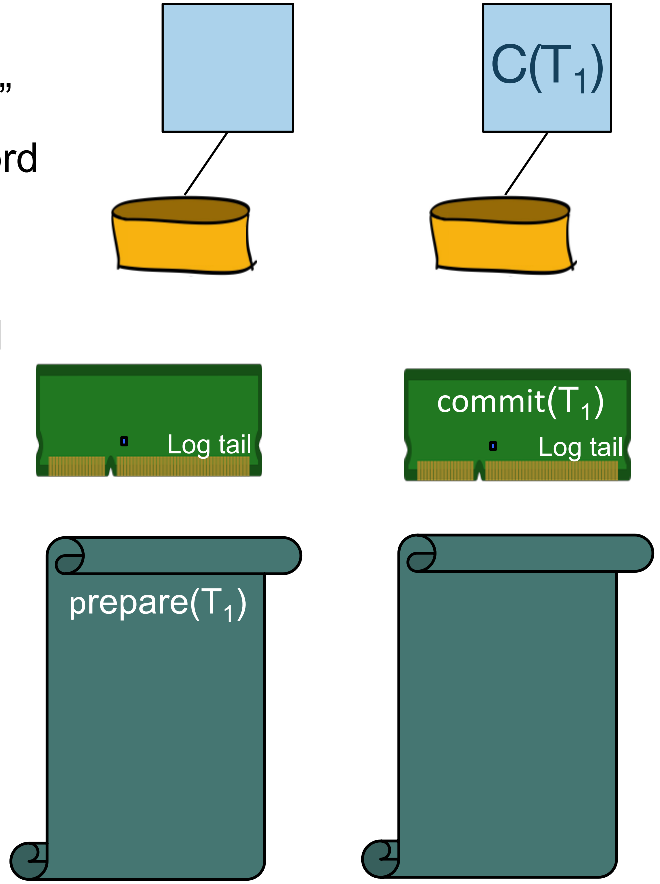
One More Time, With Logging, Part 7

- **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



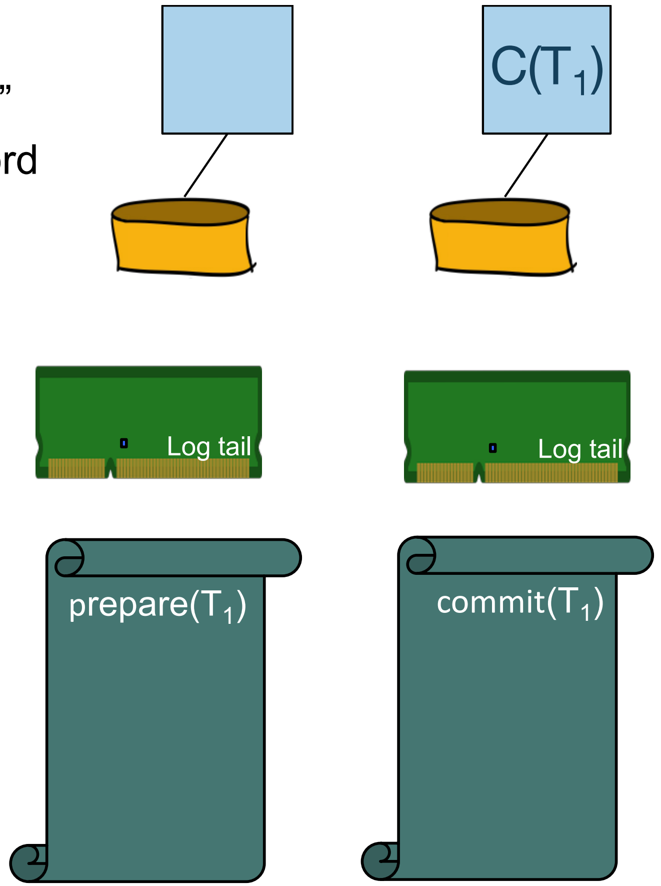
One More Time, With Logging, Part 8

- **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



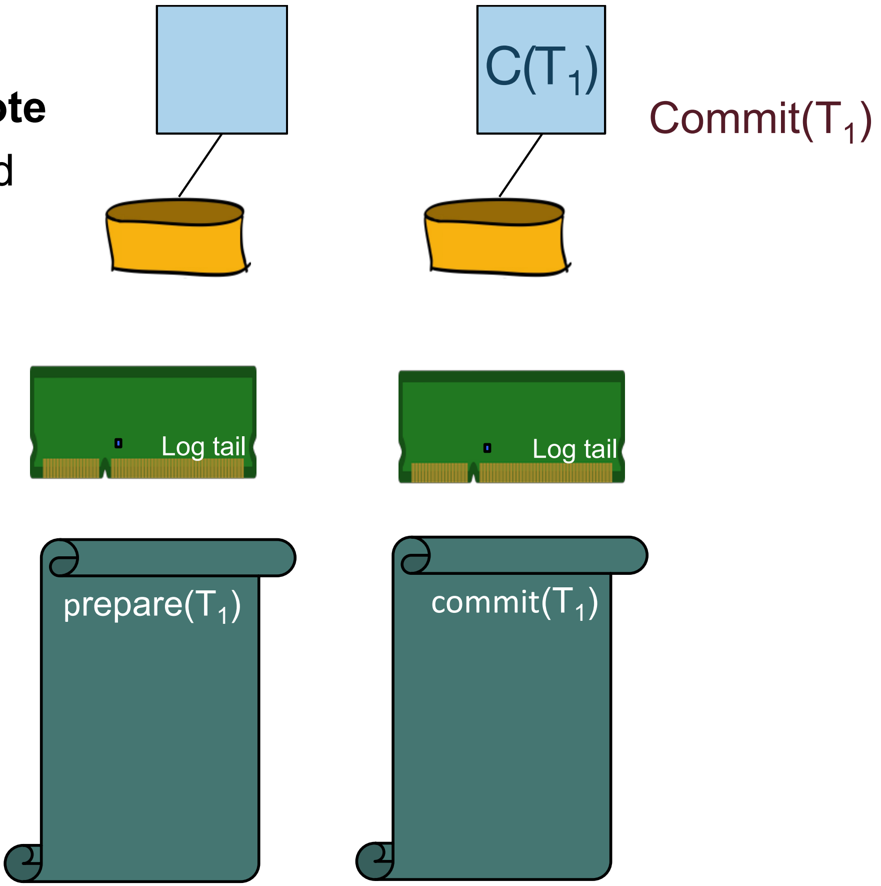
One More Time, With Logging, Part 9

- **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**



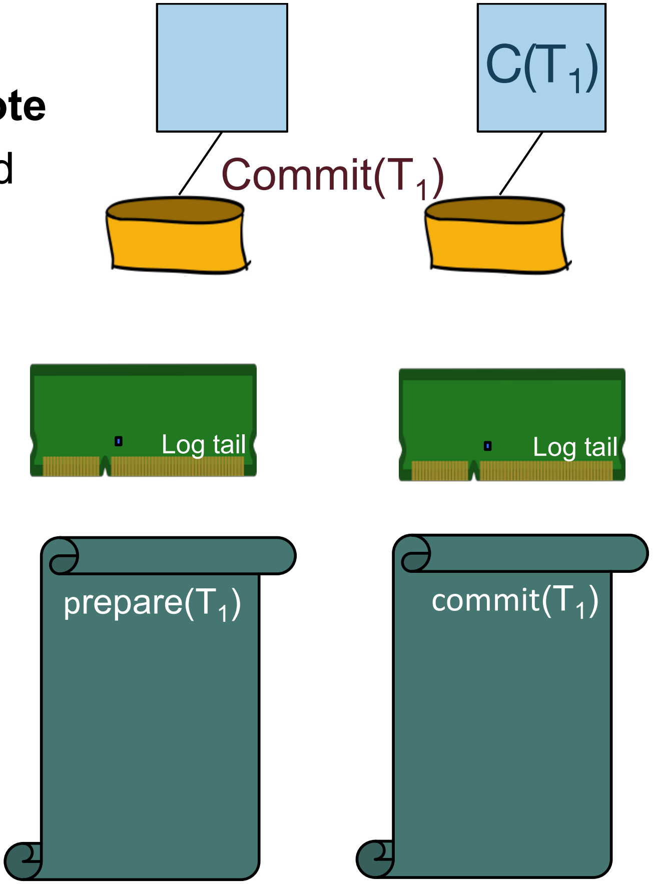
One More Time, With Logging, Part 10

- **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



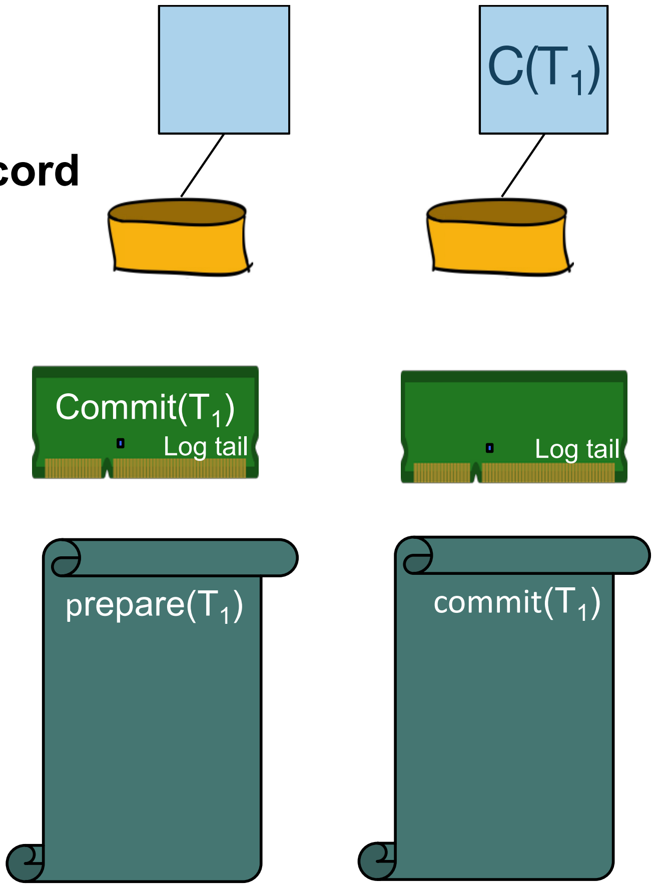
One More Time, With Logging, Part 11

- **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



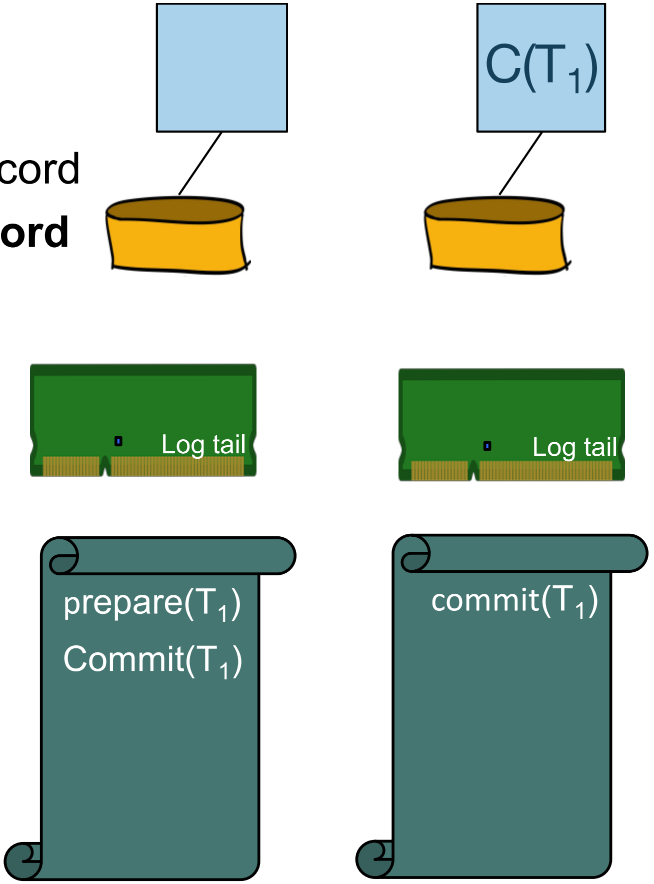
One More Time, With Logging, Part 12

- **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



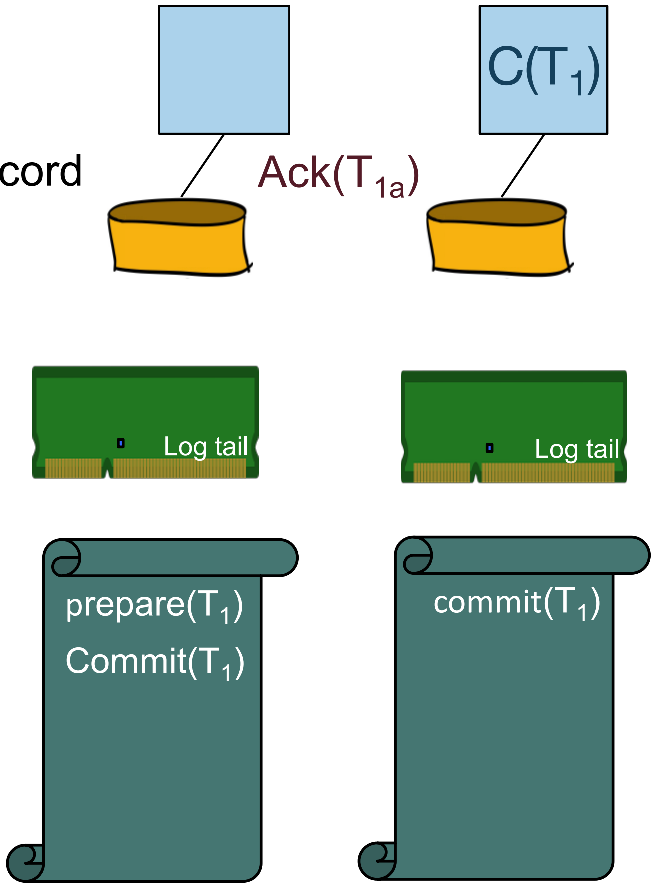
One More Time, With Logging, Part 13

- **Phase 2:**
- Coordinator broadcasts result of vote
- Participants generate commit/abort record
- **Participants flush commit/abort record**
- Participants respond with Ack
- Coordinator generates end record
- Coordinator flushes end record



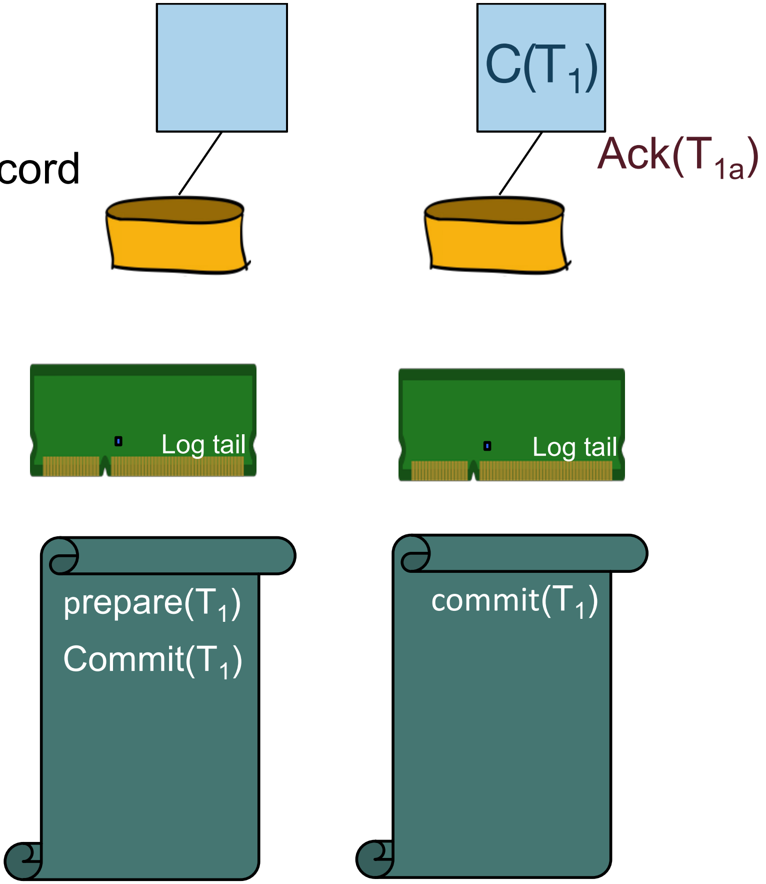
One More Time, With Logging, Part 14

- **Phase 2:**
- Coordinator broadcasts result of vote
- Participants generate commit/abort record
- Participants flush commit/abort record
- **Participants respond with Ack**
- Coordinator generates end record
- Coordinator flushes end record



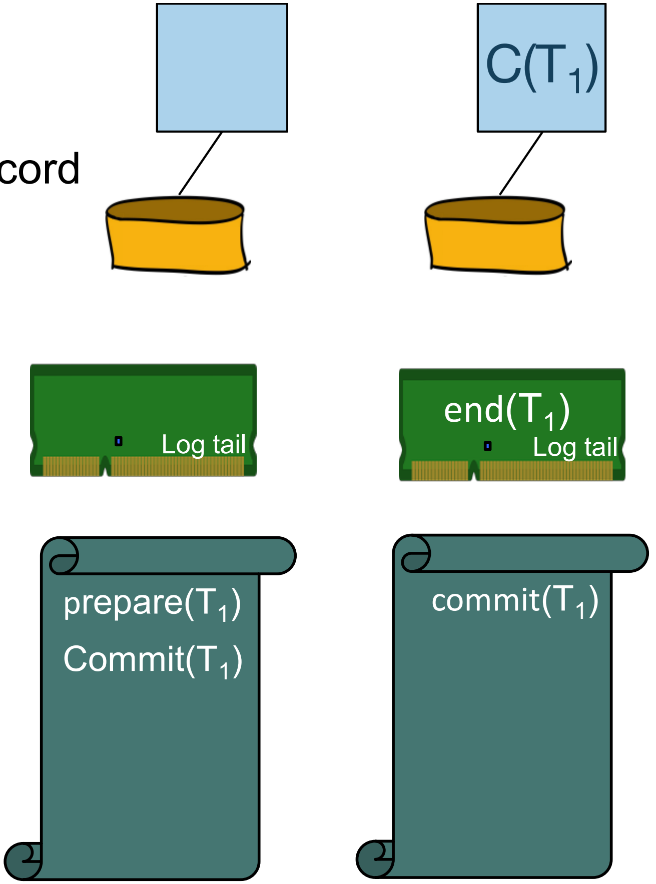
One More Time, With Logging, Part 15

- **Phase 2:**
- Coordinator broadcasts result of vote
- Participants generate commit/abort record
- Participants flush commit/abort record
- **Participants respond with Ack**
- Coordinator generates end record
- Coordinator flushes end record



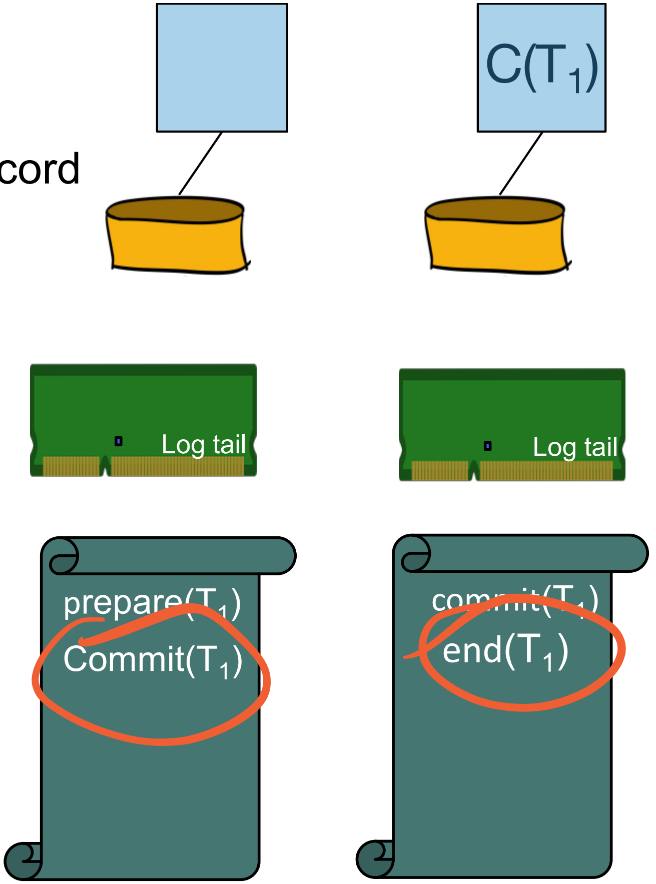
One More Time, With Logging, Part 16

- **Phase 2:**
- Coordinator broadcasts result of vote
- Participants generate commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- **Coordinator generates end record**
- Coordinator flushes end record



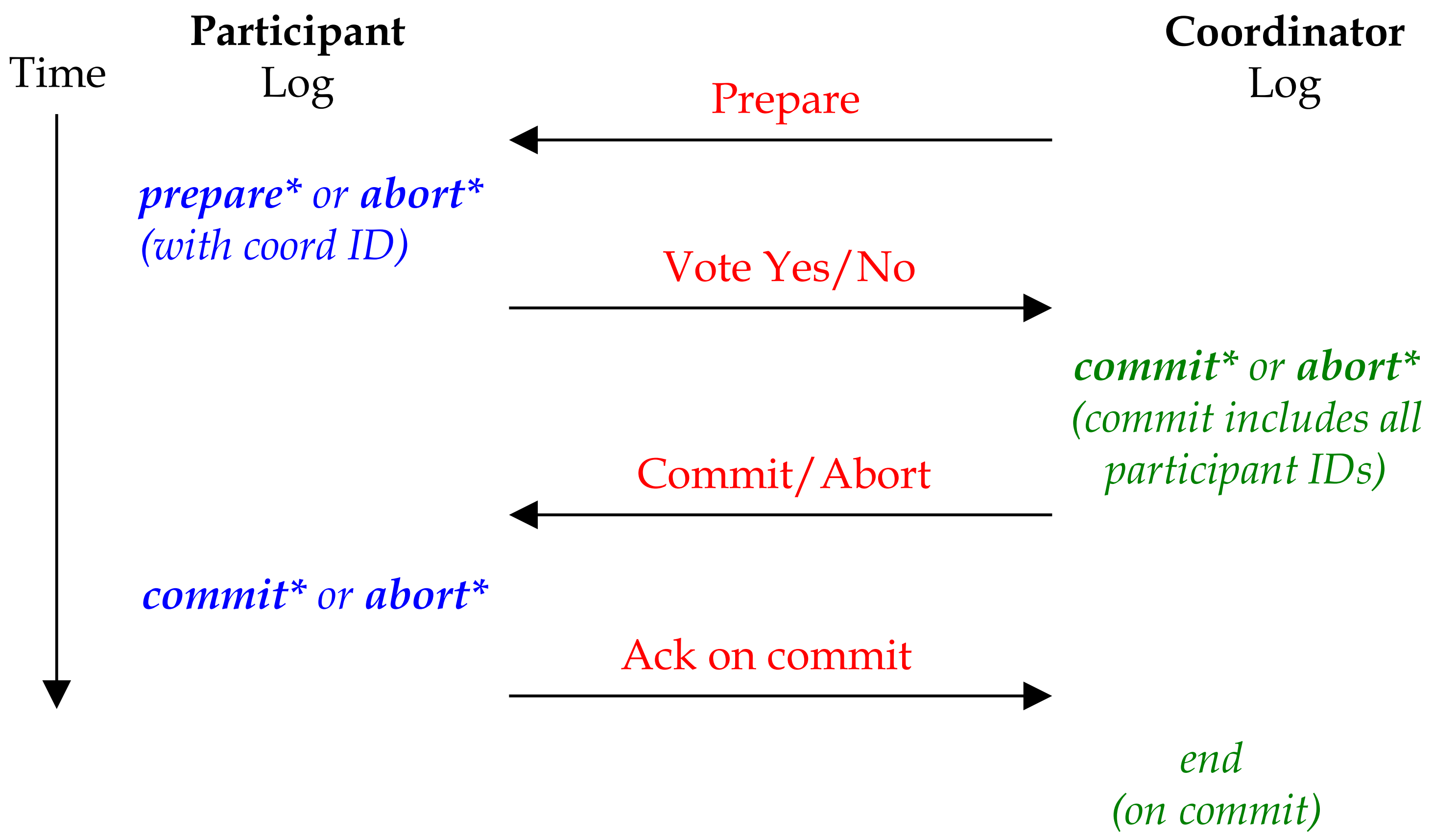
One More Time, With Logging, Part 17

- **Phase 2:**
- Coordinator broadcasts result of vote
- Participants generate commit/abort record
- Participants flush commit/abort record
- Participants respond with Ack
- Coordinator generates end record
- **Coordinator flushes end record**



2PC In a Nutshell

NOTE
asterisk*: wait for log flush before sending next msg


Time
Participant
Log
Coordinator
Log
Prepare
prepare* or ***abort****
(with coord ID)
Vote Yes/No
commit* or ***abort****
(commit includes all participant IDs)
Commit/Abort
commit* or ***abort****
Ack on commit
end
(on commit)

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, coordinate 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 xacts, Participant for others

Integration with ARIES: Analysis

- Recall transaction table states
  - Running, Committing, Aborting
- On seeing Prepare log record (participant)
  - Change state to committing
  - Tell recovery process to ask coordinator recovery process for status
  - When coordinator responds, recovery process handles commit/abort as usual
  - (Note: During REDO, Strict 2PL locks will be acquired)

Integration with ARIES: Analysis, cont

- On seeing Commit/Abort log record (coordinator)
    - Change state to committing/aborting respectively
    - Tell recovery process to send commit/abort msgs to participants
    - Once all participants ack commit, recovery process writes End and forgets
- If at end of analysis there's no 2PC log records for xact X
    - Simply set to Aborting locally, and let ToUndo handle it.
    - Same for participant and coordinator
    - A.k.a. "Presumed Abort"
        - There is an optimization called "Presumed Commit"

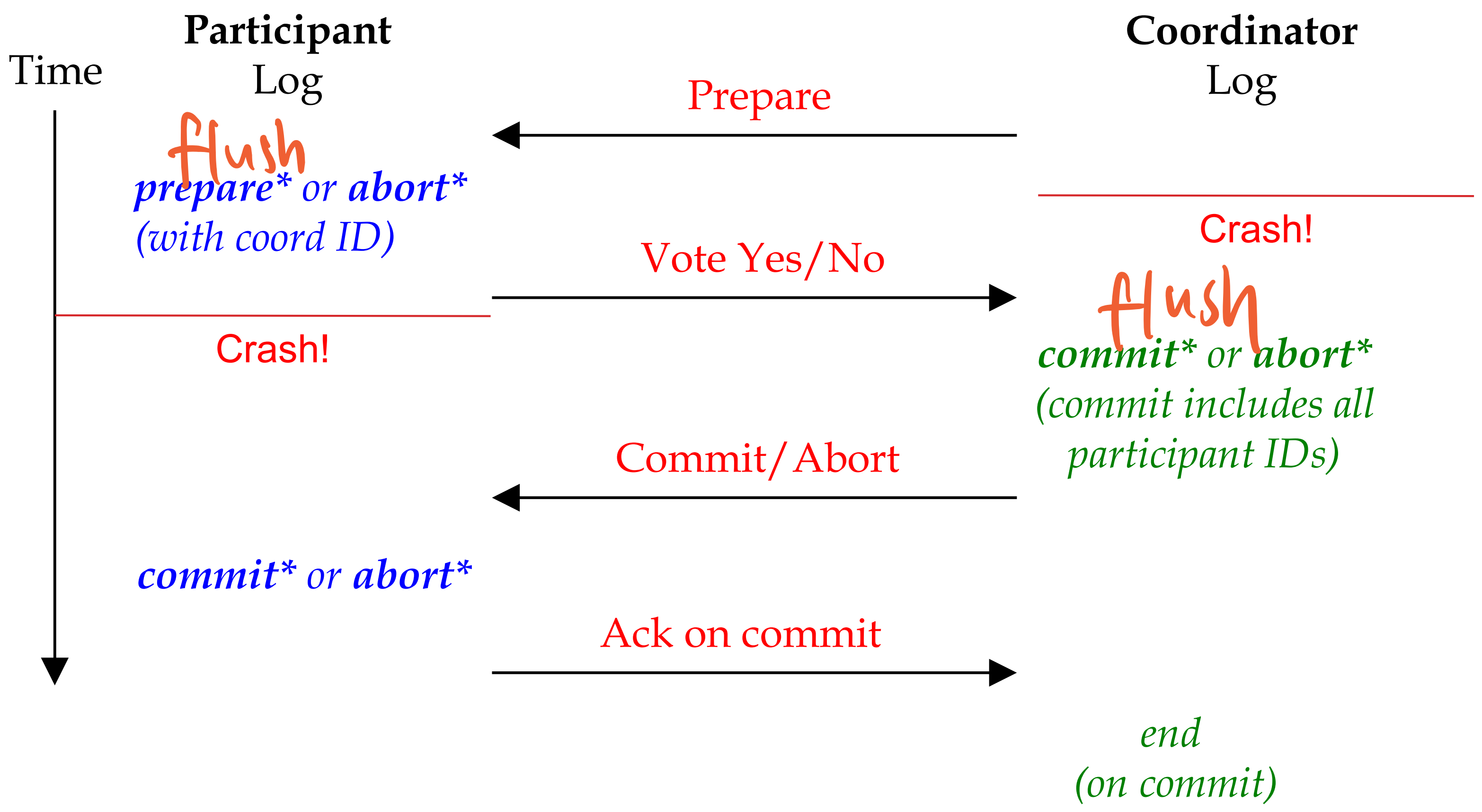
if coordinator crashes no log flushed → coordinator abort locally

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

NOTE
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”?
- What happens when participant recovers:
  - With no prepare/commit/abort?
  - With “prepare” and “commit”?
  - With just “prepare?
  - With “abort”?

Commit iff coordinator logged a commit

Recovery: Think it through, cont

✓

- What happens when coordinator recovers?
  - With “commit” and “end”? **Nothing**
  - With just “commit”? **Rerun Phase 2!** → no know if all coordinate down yet.
  - With “abort”? **Nothing (Presumed Abort)**
- What happens when participant recovers:
  - With no prepare/commit/abort? **Nothing (Presumed Abort)**
  - With “prepare” & “commit”? **Send Ack to coordinator.**
  - With just “prepare”? **Send inquiry to Coordinator**
  - With “abort”? **Nothing (Presumed Abort)**

Commit iff coordinator logged a commit

2PC + 2PL

✓

- Ensure point-to-point messages are densely ordered
  - 1,2,3,4,5…
  - Dense per (sender/receiver/XID)
  - Receiver can detect anything missing or out-of-order
  - Receiver buffers message k+1 until [1..k] received
- 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 class.

Summing Up

- Distributed Databases
  - A central aspect of Distributed Systems
- 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 (Gray+Lamport) addresses that problem