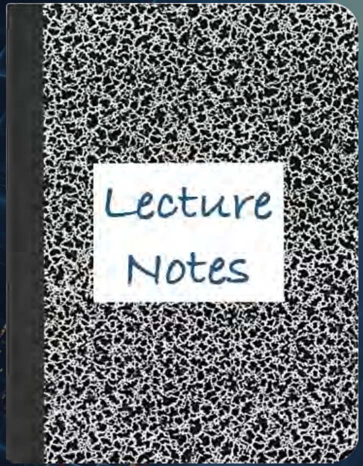
CS 417 – DISTRIBUTED SYSTEMS

Week 8: Distributed Transactions

Part 1: Two-Phase Commit



Paul Krzyzanowski

Atomic Transactions

Transaction

- An operation composed of a sequence of discrete steps.

- All the steps must be completed for the transaction to be **committed**. The results are made permanent.

- Otherwise, the transaction is **aborted** and the state of the system reverts to what it was before the transaction started.
  - **rollback** = revert to a previous state (undo changes)

Example: buying a house

- Make an offer
- Sign contract
- Deposit money in escrow
- Inspect the house
- Critical problems from inspection?
- Get a mortgage
- Have seller make repairs

Commit: sign closing papers & transfer deed

Abort: return escrow and revert to pre-purchase state

All or nothing property

Another Example

Book a flight from Allentown, PA to Inyokern, CA
No non-stop flights are available:

Transaction begin

1. Reserve a seat for Allentown to O'Hare (ABE→ORD)
2. Reserve a seat for O'Hare to Los Angeles (ORD→LAX)
3. Reserve a seat for Los Angeles to Inyokern (LAX→IYK)

Transaction end

If there are no seats available on the LAX→IYK leg of the journey, the entire transaction is *aborted* and reservations for (1) and (2) are undone.

Basic Operations

Transaction primitives:

- ***Begin** transaction* (***prepare***): mark the start of a transaction

  Then read/write/compute data – modify files, objects, program state

  But any changes will have to be restored if the transaction is aborted

- ***End** transaction*: mark the end of a transaction – no more tasks

- ***Commit** transaction*: make the results permanent

- ***Abort** transaction*: kill the transaction, restore old values

Properties of transactions: ACID

- **Atomic**
  - The transaction happens as a single **indivisible** action. Everything succeeds or else the entire transaction is rolled back. Others do not see intermediate results.
- **Consistent**
  - A transaction cannot leave the database in an inconsistent state & all invariants must be preserved. E.g., total amount of money in all accounts must be the same before and after a *transfer funds* transaction.
- **Isolated** (Serializable)
  - Transactions cannot interfere with each other or see intermediate results
    If transactions run at the same time, the result must be the same as if they executed in some serial order.
- **Durable**
  - Once a transaction commits, the results are made permanent.

Distributed Transaction

Transaction that updates data on two or more systems

Implemented as a set of sub-transactions

Challenge

- Handle machine, software, & network failures while preserving transaction integrity

Distributed Transactions

Each computer runs a **transaction manager**

- Responsible for sub-transactions on that system
- Performs *prepare*, *commit*, and *abort* calls for sub-transactions

Every sub-transaction must agree to commit changes before the overall transaction can complete

Commits Among Sub-transactions = Consensus

- Remember consensus?
  - Agree on a value proposed by at least one process

- *BUT* – here we need unanimous agreement to commit

- The coordinator proposes to commit a transaction
  - All participants agree ⇒ all participants then **commit**
  - Not all participants agree ⇒ all participants then **abort**

Core Properties

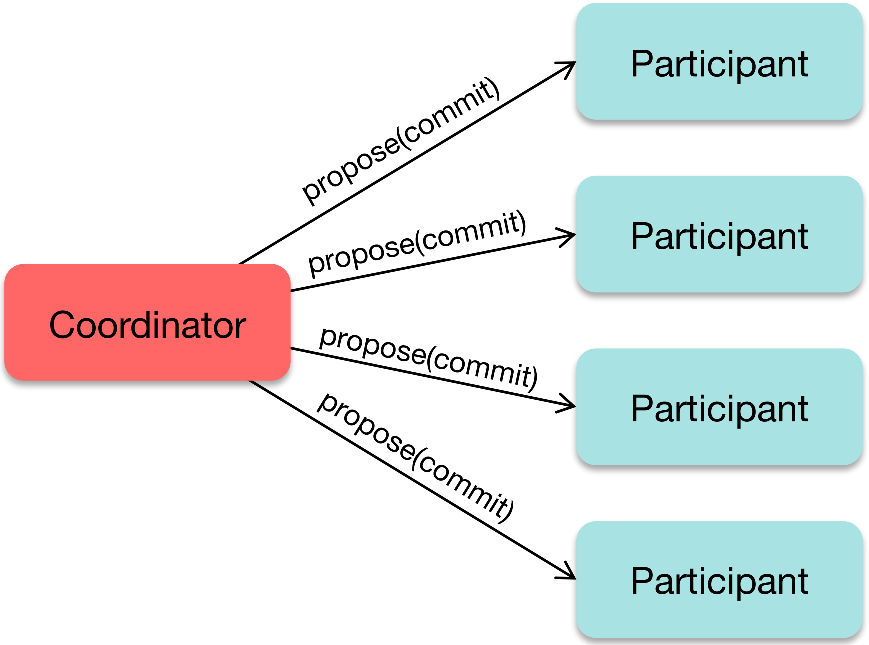
The algorithm must have these properties:

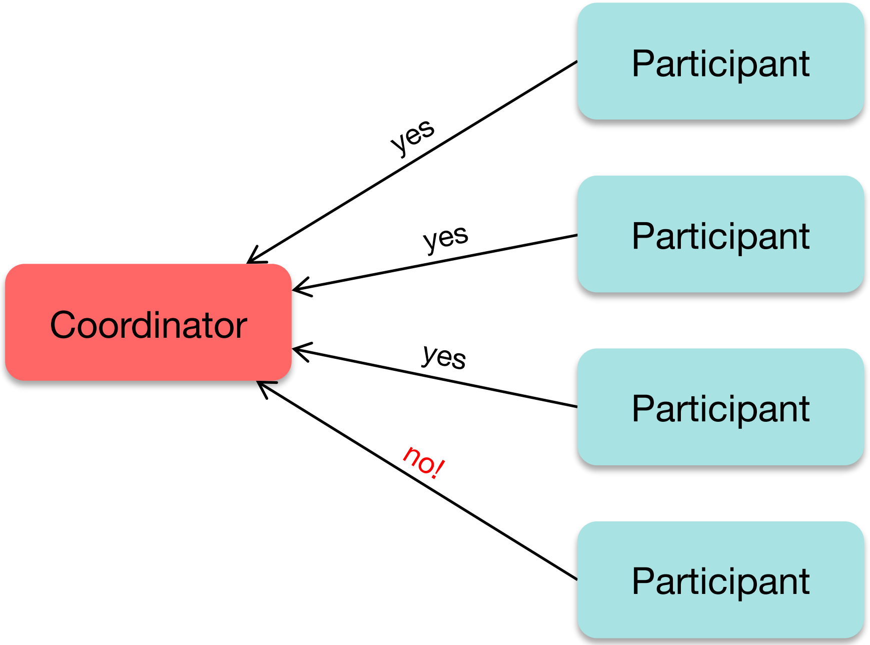
1. **Safety** (the algorithm must work correctly)
   - If one sub-transaction commits, no other sub-transaction will abort
   - If one sub-transaction needs to abort, no sub-transactions will commit

2. **Liveness** (the algorithm must make progress & reach its goal)
   - If no sub-transactions fail, the transaction will commit
   - If any sub-transactions fail, the algorithm will reach a conclusion to abort

Two-Phase Commit Protocol

Two-Phase Commit Protocol



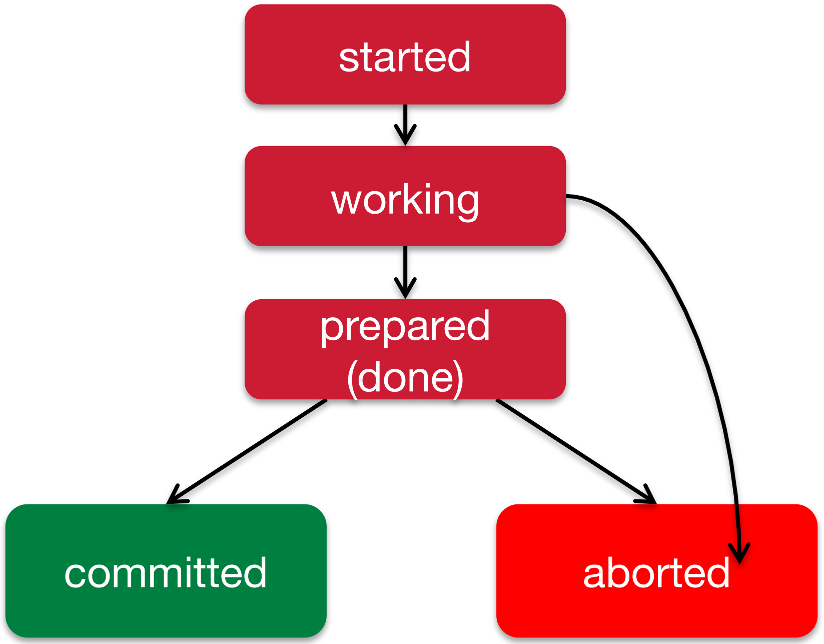


Two-phase commit protocol

Goal: *reliably agree to commit or abort a collection of sub-transactions*

- All processes in the transaction will agree to commit or abort
- Consensus: all processes agree on whether or not to commit
- One transaction manager is *elected* as a **coordinator**
  – the rest are **participants**
- Assume:
  - **write-ahead log** in **stable storage**
    - Enables recording transaction state if the system restarts
      and saving old values of data in case they need to be restored
  - No system dies forever
  - Systems can always communicate with each other

Transaction States

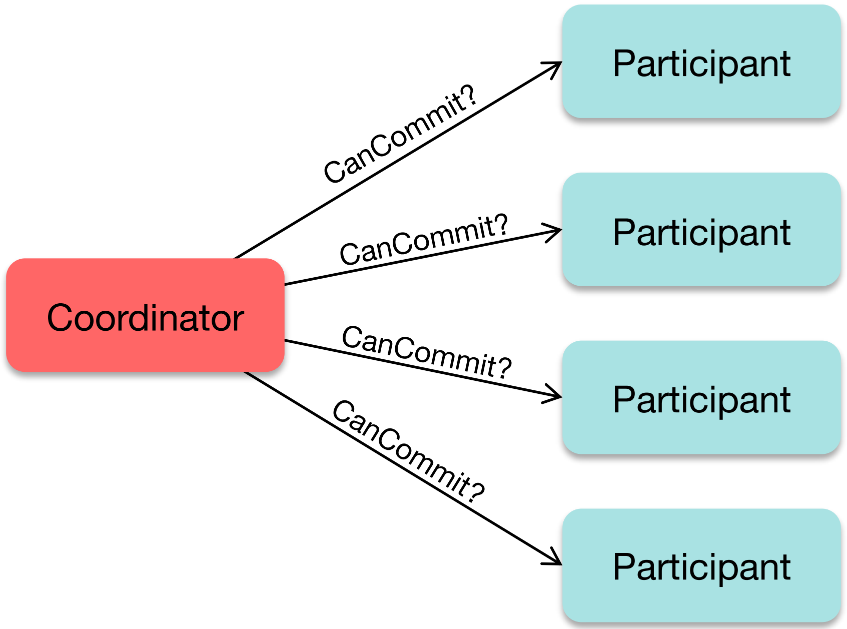


When a participant enters the ***prepared*** state, it contacts the coordinator to start the commit protocol to commit the entire transaction

Two-Phase Commit Protocol

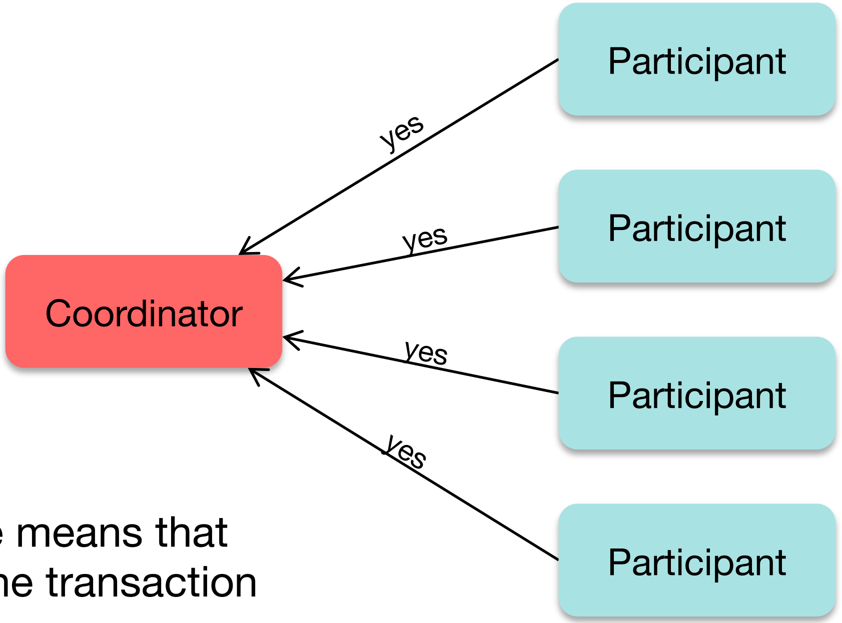
Phase 1: Voting Phase

Get commit agreement from *every* participant



Two-Phase Commit Protocol

Phase 1: Voting Phase
Get commit agreement from *every* participant

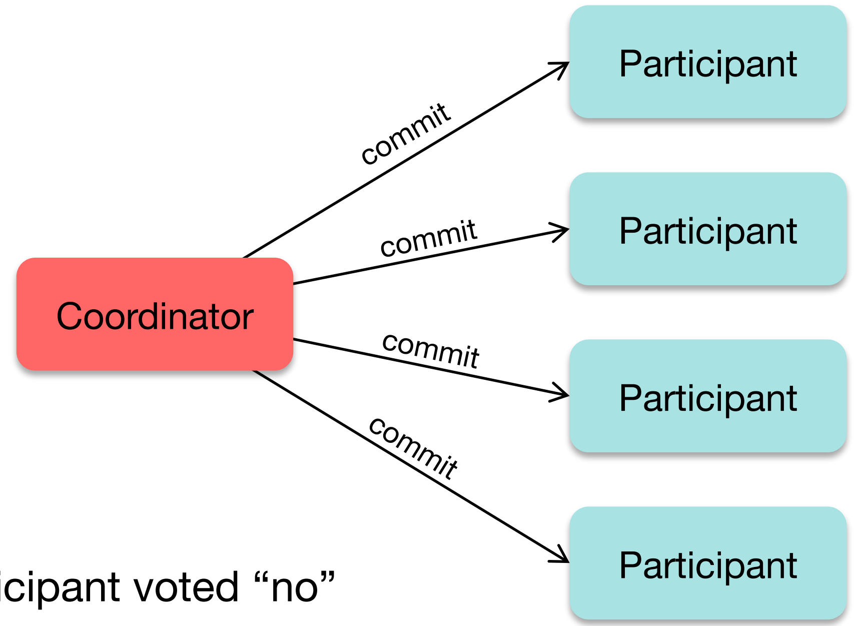


A single "no" response means that we will have to abort the transaction

Two-Phase Commit Protocol

Phase 2: Commit Phase

Send the results of the vote to every participant

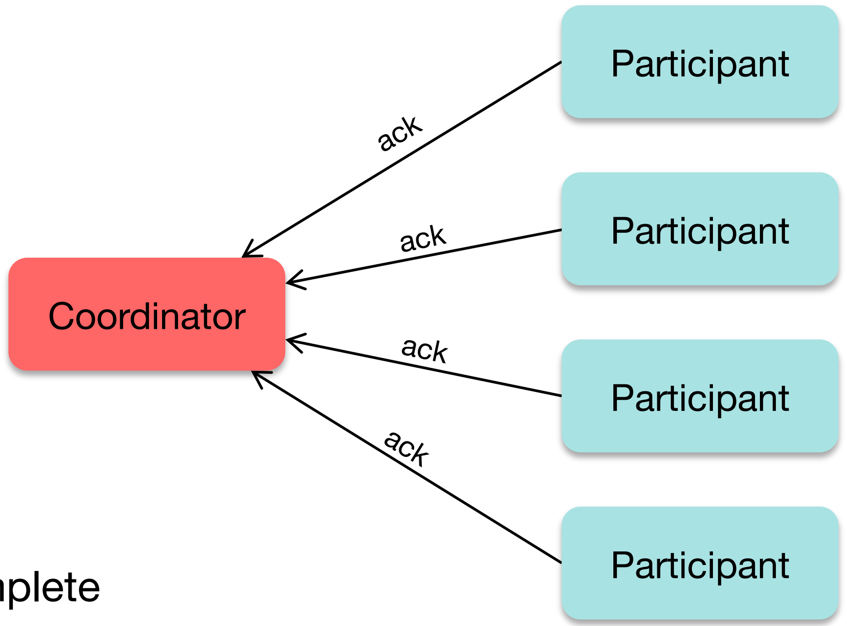


Send *abort* if any participant voted "no"

Two-Phase Commit Protocol

Phase 2: Commit Phase

Get "I have committed" acknowledgements from *every* participant



The transaction is complete

Dealing with failure

- 2PC assumes a *fail-recover* model
  - Any failed system will eventually recover

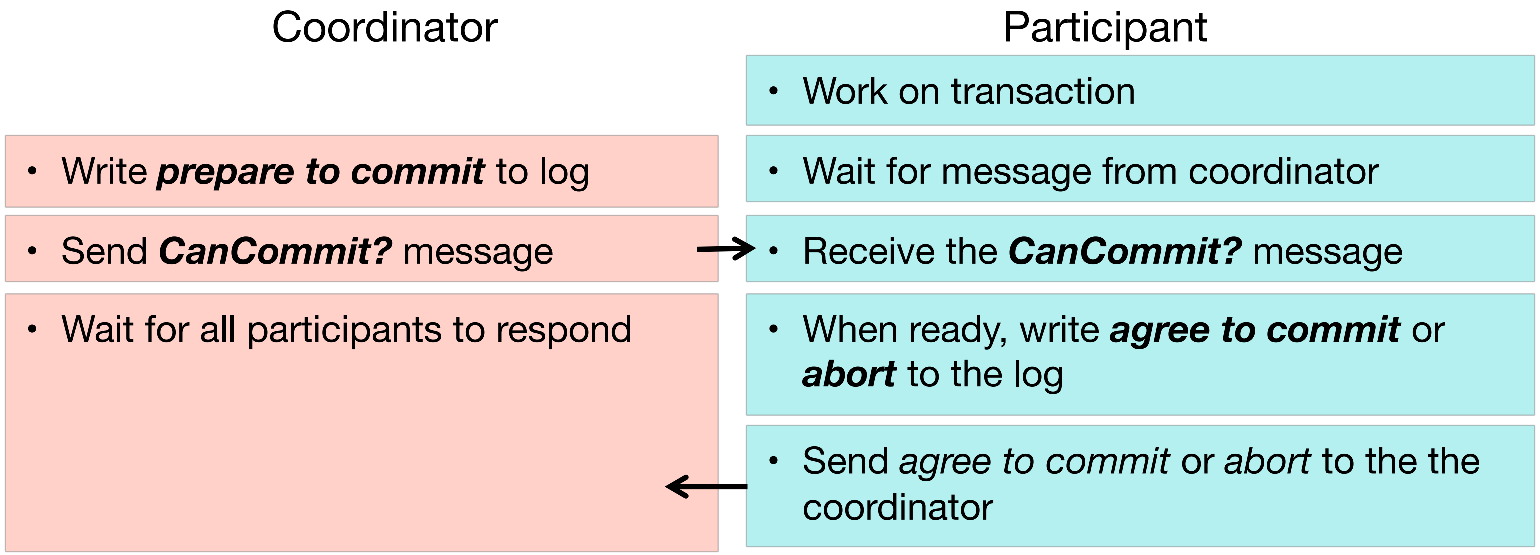
- A recovered system cannot change its mind
  - If a node agreed to commit and then crashed, it must be willing and able to commit upon recovery

We need to handle fail-restart failure & support recovery

- Each system will use a write-ahead (transaction) log
  - Keep track of where it is in the protocol (and what it agreed to)
  - As well as values to enable commit or abort (rollback)

Two-Phase Commit Protocol: Phase 1

1. Voting Phase



Coordinator	Participant
	• Work on transaction
• Write ***prepare to commit*** to log	• Wait for message from coordinator
• Send ***CanCommit?*** message	• Receive the ***CanCommit?*** message
• Wait for all participants to respond	• When ready, write ***agree to commit*** or ***abort*** to the log
	• Send *agree to commit* or *abort* to the the coordinator

Get distributed agreement: the coordinator asked each participant if it will commit or abort and received replies from each coordinator.

Two-Phase Commit Protocol: Phase 2

2. Commit Phase

Coordinator		Participant
• Write *commit* or *abort* to log		• Wait for *commit/abort* message
• Send ***commit*** or ***abort***	→	• Receive *commit* or *abort*
• Wait for all participants to respond		• If a *commit* was received, write "*commit*" to the log, release all locks, update databases. • If an *abort* was received, undo all changes
	←	• Send *done* message
• Clean up all state. Done!		

Tell *all participants* to *commit* or *abort*
Get everyone's response that they're done.

Consensus Properties

- **Validity property**
  - Aborts in every case except when every process agrees to commit
  - The final value (commit or not) has been voted on by at least one process
- **Uniform Agreement property**
  - Every process agrees on the value proposed by the coordinator if and only if they are instructed to do so by the coordinator in phase 2
- **Integrity property**
  - Every process proposes only a single value (commit or abort) and does not change its mind
- **Termination property**
  - Every process is guaranteed to make progress and eventually return a vote to the coordinator

Dealing with failure

Failure during Phase 1 (voting)

Coordinator dies

Some participants may have responded; others have no clue

⇒ Coordinator restarts voting: checks log; sees that voting was in progress

Participant dies

The participant may have died before or after sending its vote to the coordinator

⇒ If the coordinator received the vote, it waits for other votes and then goes to phase 2

⇒ Otherwise: wait for the participant to recover and respond (keep querying it)

Dealing with failure

Failure during Phase 2 (commit/abort)

Coordinator dies

Some participants may have been given commit/abort instructions

⇒ Coordinator restarts; checks log; informs all participants of chosen action

Participant dies

The participant may have died before or after getting the commit/abort request

⇒ Coordinator keeps trying to contact the participant with the request

⇒ Participant recovers; checks log; gets request from coordinator

- If it committed/aborted, acknowledge the request
- Otherwise, process the commit/abort request and send back the acknowledgement

Adding a recovery coordinator

- Another system can take over for the coordinator
  - It could be a participant that detected a timeout to the coordinator
- Recovery node needs to find the state of the protocol
  - Contact ALL participants to see how they voted
  - If we get voting results from all participants
    - We know that Phase 1 has completed
    - If all participants voted to commit ⇒ send *commit* request
    - Otherwise send *abort* request
  - If ANY participant states that it has *not* voted
    - We know that Phase 1 has *not* completed
    - ⇒ Restart the protocol
- But … if any participant node also crashes, we're stuck!
  - Must wait for recovery

The End