Distributed Systems

CS425/ECE428

April 9 2021

Instructor: Radhika Mittal

Acknowledgements for the materials: Indy Gupta and Nikita Borisov

Agenda for today

- Distributed Transactions
    - Chapter 17

Transaction Processing

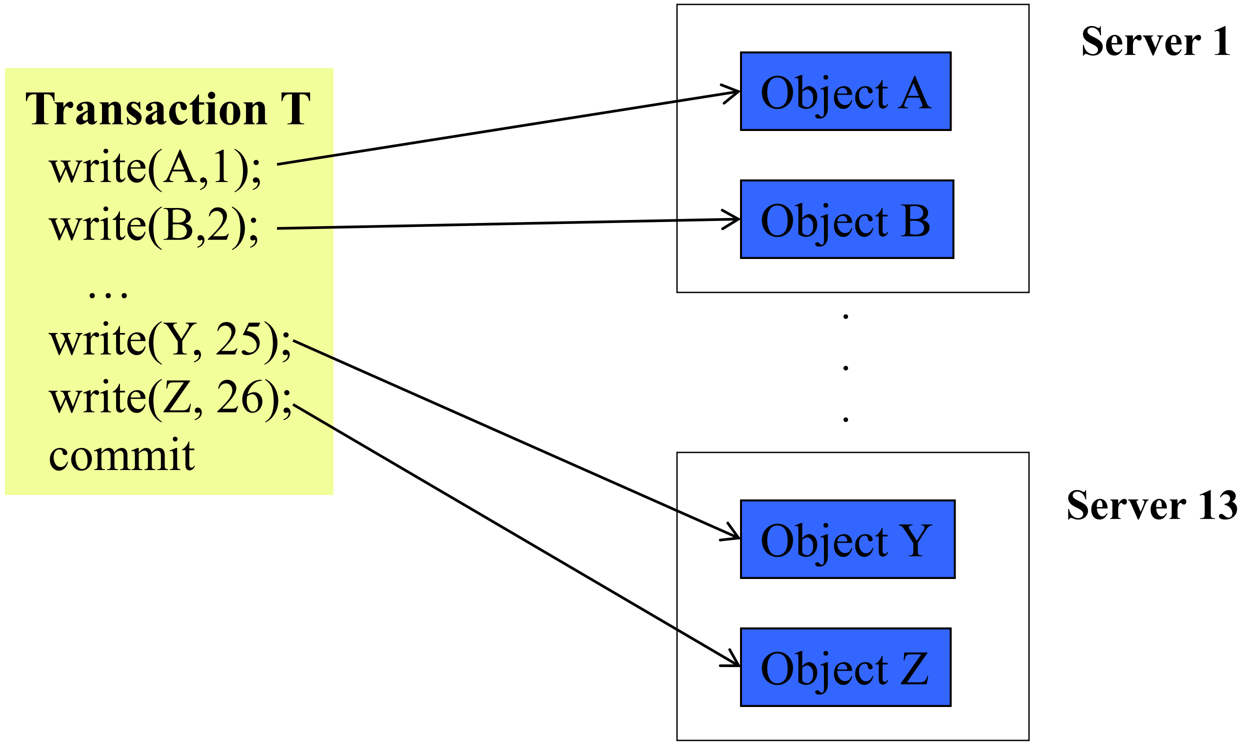
- Required properties: Atomicity, Consistency, Isolation, Durability (ACID).
- *How to prevent transactions from affecting one another?*
- Goal: increase concurrency and transaction throughput while maintaining correctness (ACID).
- Two approaches:
  - Pessimistic concurrency control: locking based.
    - read-write locks with two-phase locking and deadlock detection.
  - Optimistic concurrency control: abort if too late.
    - timestamped ordering.
- Focused on single server and multiple clients.

Distributed Transactions

- Transaction processing can be *distributed* across multiple servers.
  - Different objects can be stored on different servers.
    - Our focus today.
  - An object may be replicated across multiple servers.
    - Next class.

Transactions with Distributed Servers

- Different objects touched by a transaction T may reside on different servers.



Distributed Transaction Challenges

- **A**tomic: all-or-nothing
  - *Must ensure atomicity across servers.*
- **C**onsistent: rules maintained
  - *Generally done locally, but may need to check non-local invariants at commit time.*
- **I**solation: multiple transactions do not interfere with each other
  - *Locks at each server. How to detect and handle deadlocks?*
- **D**urability: values preserved even after crashes
  - *Each server keeps local recovery log.*

Distributed Transaction Challenges

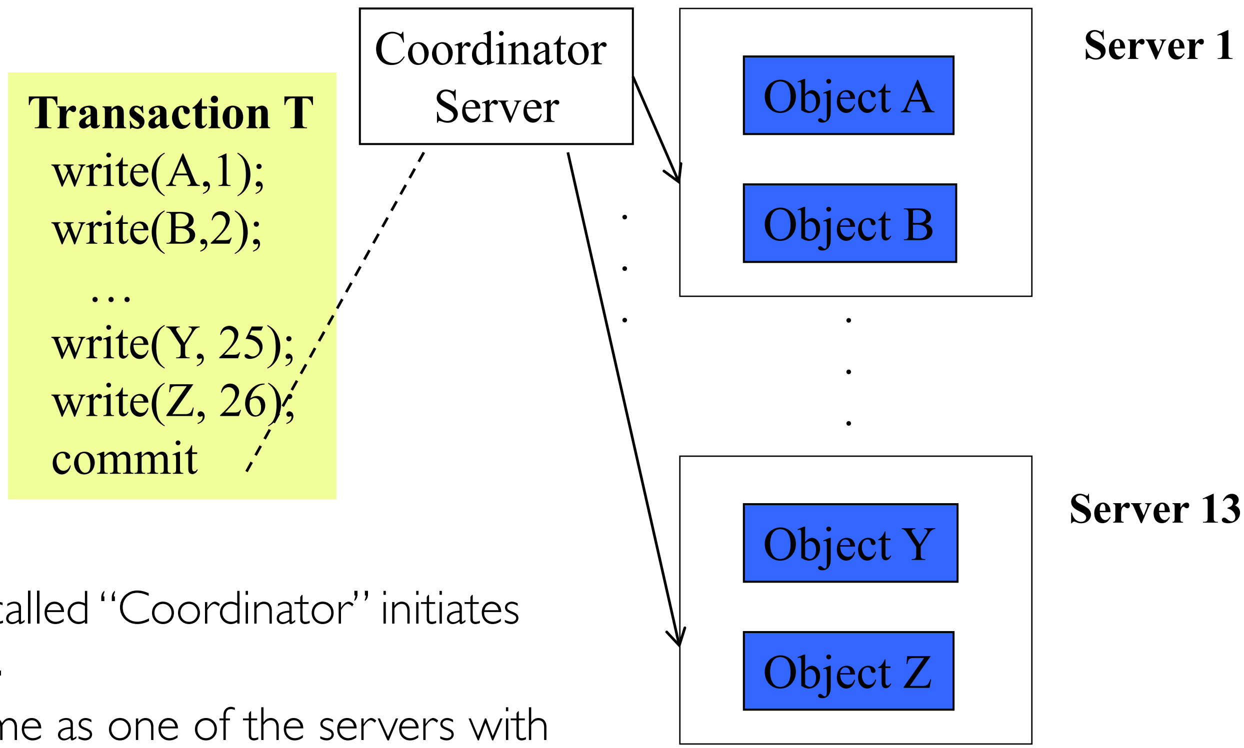
- Atomic: all-or-nothing
  - *Must ensure atomicity across servers.*
- Consistent: rules maintained
  - *Generally done locally, but may need to check non-local invariants at commit time.*
- **Isolation: multiple transactions do not interfere with each other**
  - ***Locks at each server. How to detect and handle deadlocks?***
- Durability: values preserved even after crashes
  - *Each server keeps local recovery log.*

Distributed Transaction Atomicity

- When T tries to commit, need to ensure
  - all these servers commit their updates from T => T will commit
  - Or none of these servers commit => T will abort

- What problem is this?
  - Consensus!
  - (It's also called the "Atomic Commit" problem)

Coordinator Server



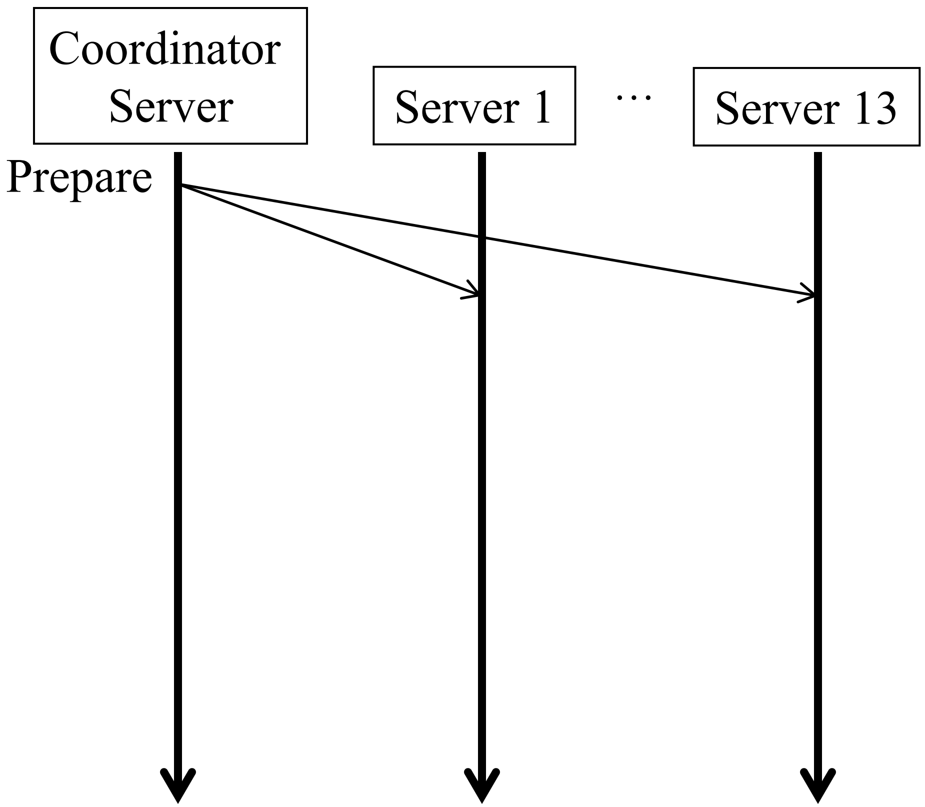
- Special server called "Coordinator" initiates atomic commit.
    - can be same as one of the servers with objects.
- Different transactions may have different coordinators.

One-phase commit

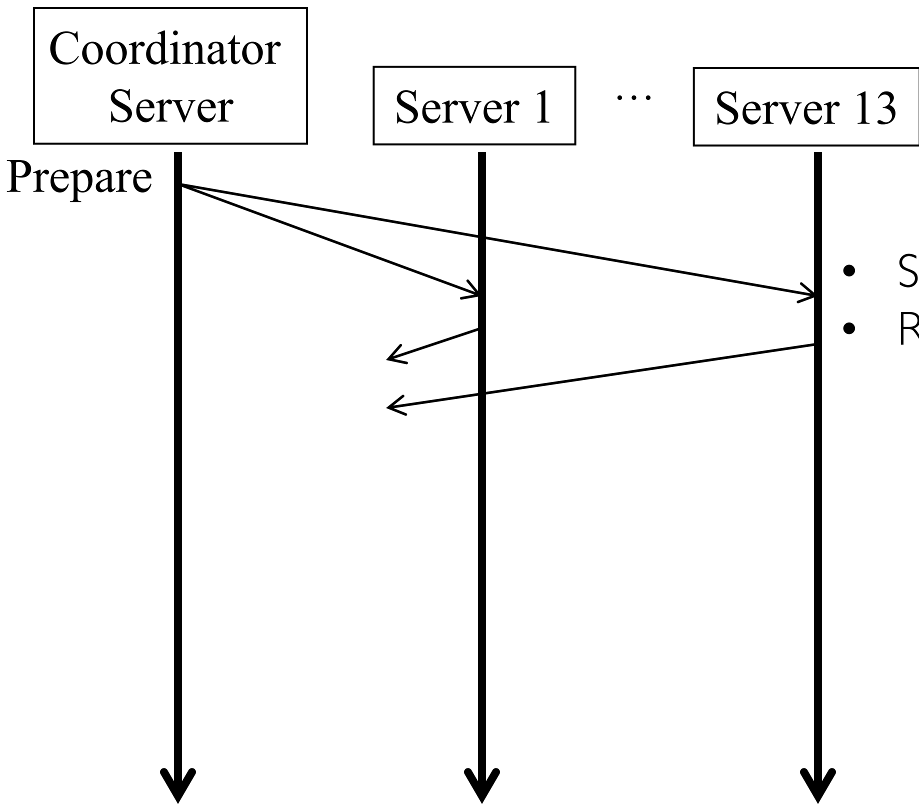
- Client relays the "commit" or "abort" command to the coordinator.
  - Coordinator tells other servers to commit / abort.

- *Issues with this?*
  - Server with object has no say in whether transaction commits or aborts
    - If a local consistency check fails, it just cannot commit (while other servers have committed).
  - A server may crash before receiving commit message, with some updates still in memory.

Two-phase commit

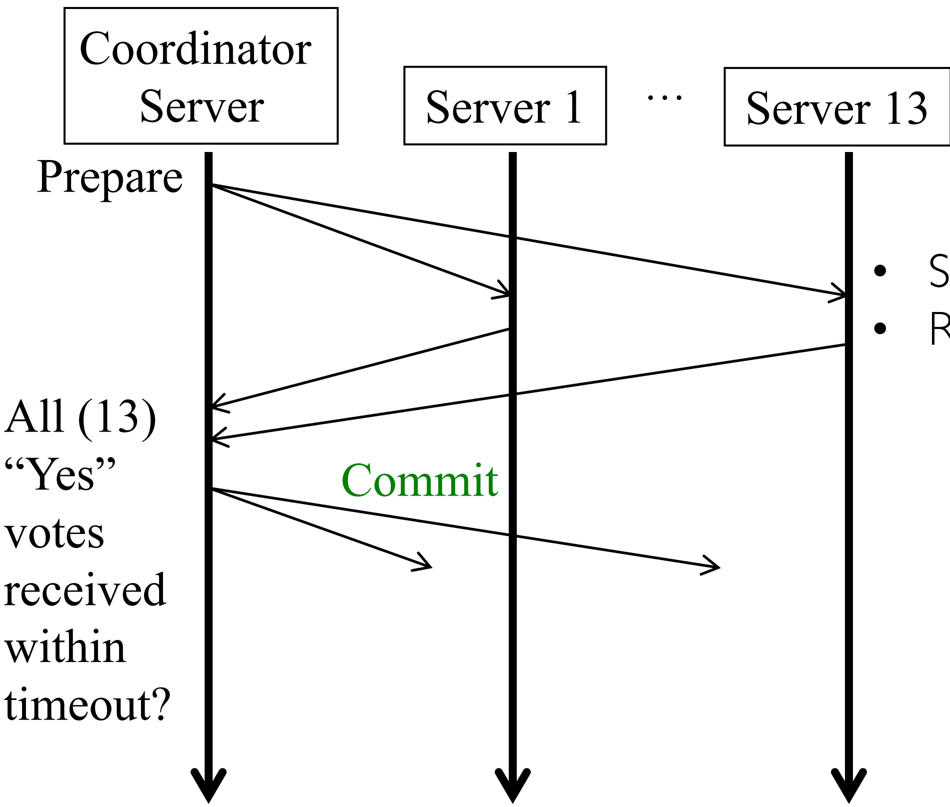


Two-phase commit



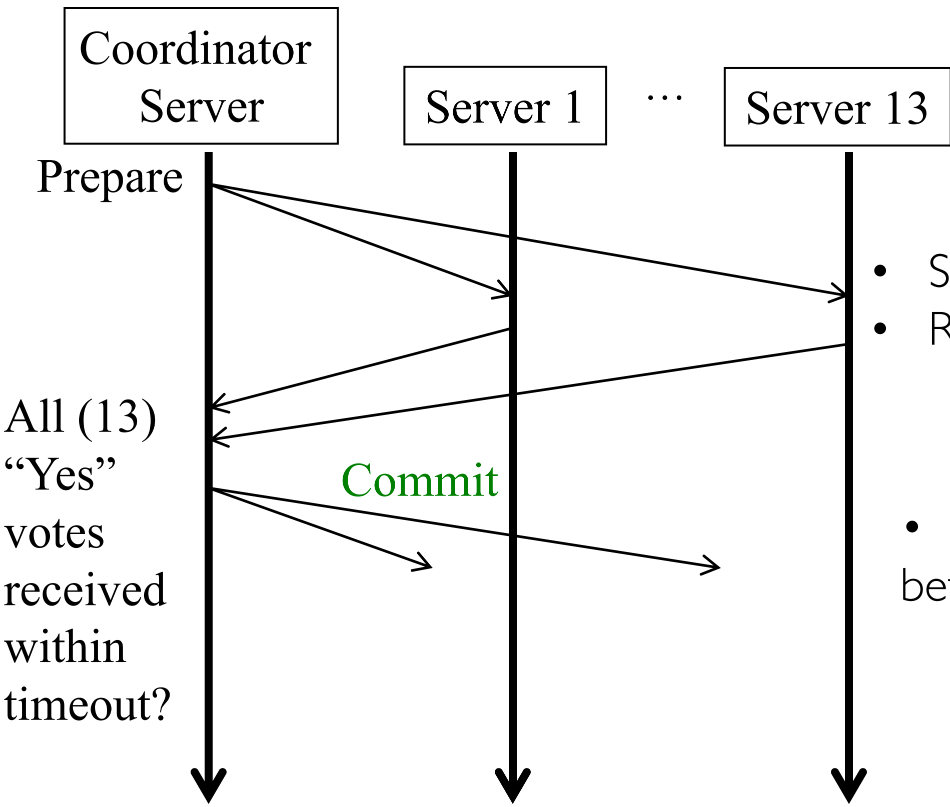
- Save updates to disk
- Respond with "Yes" or "No"

Two-phase commit



- Save updates to disk
- Respond with "Yes" or "No"

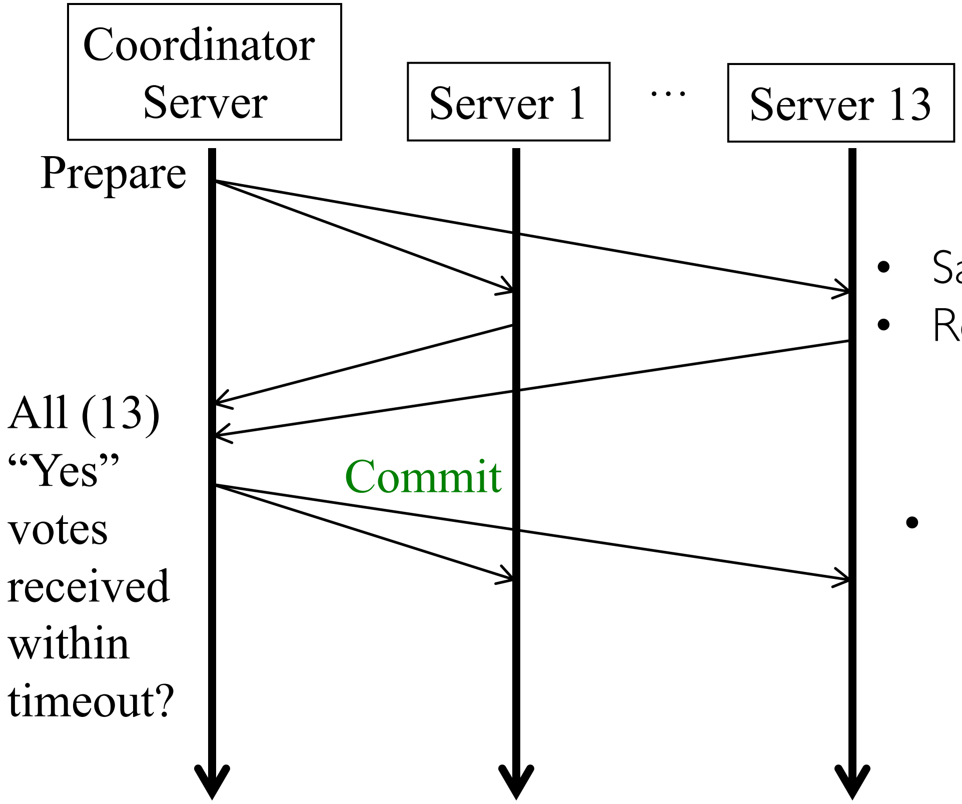
Two-phase commit



- Save updates to disk
- Respond with "Yes" or "No"

- Wait! Can't commit or abort before receiving next message!

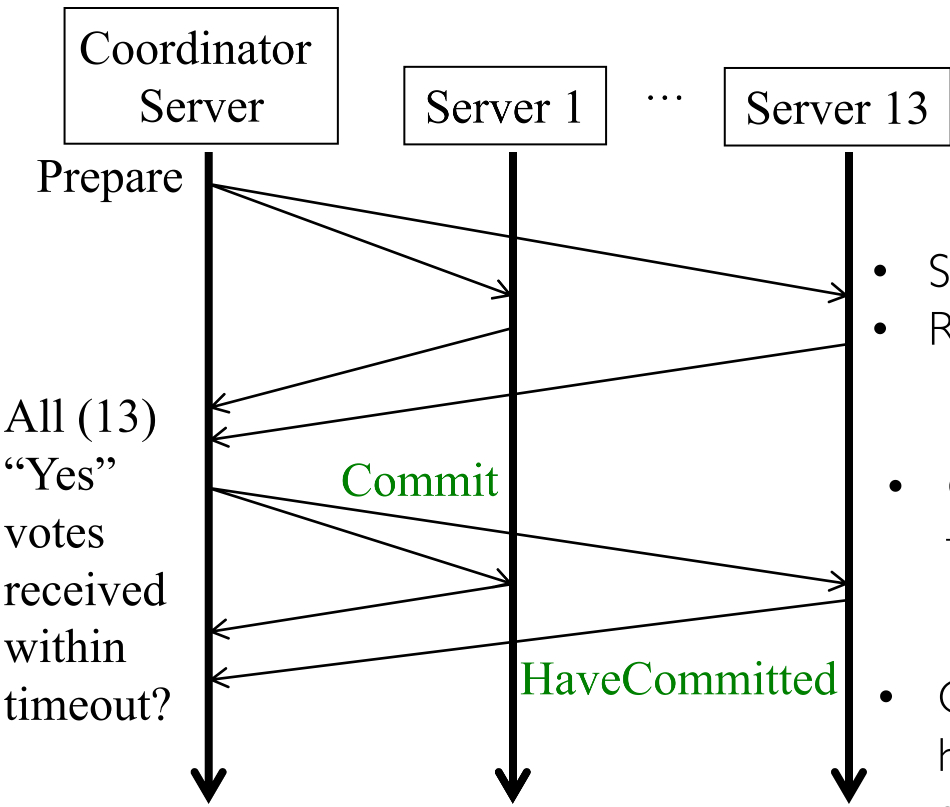
Two-phase commit



- Save updates to disk
- Respond with "Yes" or "No"

- Commit updates from disk to store

Two-phase commit

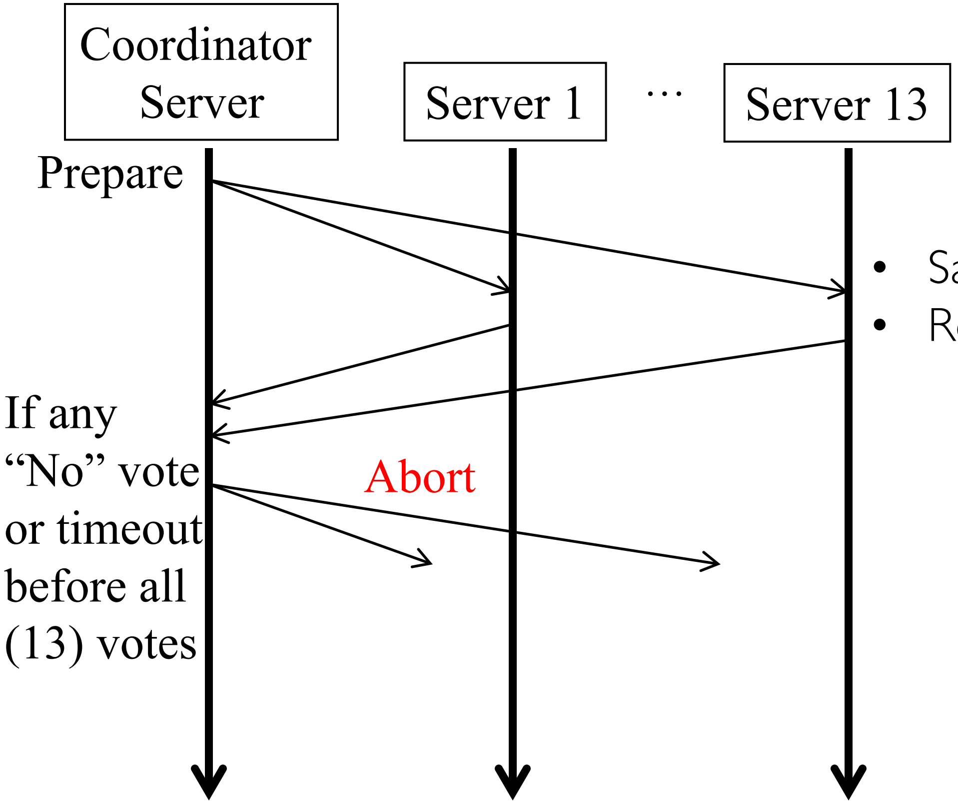


- Save updates to disk
- Respond with "Yes" or "No"

- Commit updates from disk to store

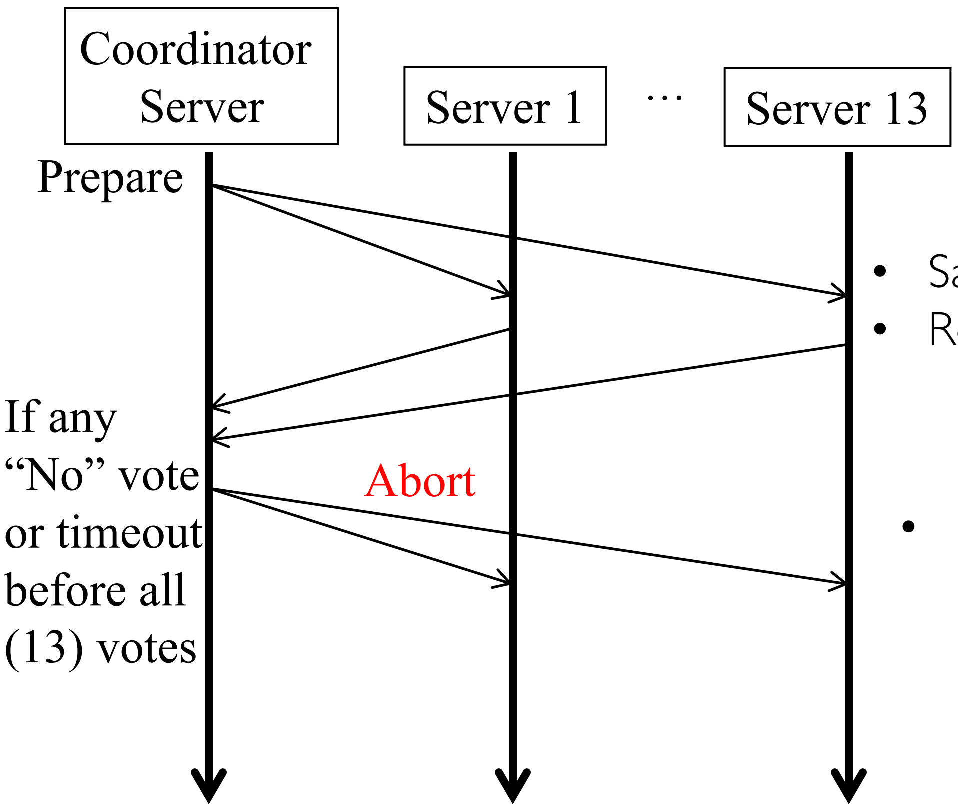
- Coordinator now knows that all servers have committed and it can delete the associated transaction information.

Two-phase commit



- Save updates to disk
- Respond with "Yes" or "No"

Two-phase commit



- Save updates to disk
- Respond with "Yes" or "No"

- Delete tentative updates in disk and abort.

Failures in Two-phase Commit

- If server voted Yes, it cannot commit unilaterally before receiving Commit message.
  - Does not know if other servers voted Yes.
- If server voted No, can abort right away.
  - Knows that the transaction cannot be committed.
- To deal with server crashes
  - Each server saves tentative updates into permanent storage, <u>right before</u> replying Yes/No in first phase. Retrievable after crash recovery.
- To deal with coordinator crashes
  - Coordinator logs all decisions and received/sent messages on disk.
  - After recovery => retrieve the logged state.

Failures in Two-phase Commit (contd)

- To deal with Prepare message loss
  - The server may decide to abort unilaterally after a timeout for first phase (server will vote No, and so coordinator will also eventually abort)
- To deal with Yes/No message loss
  - coordinator aborts the transaction after a timeout (pessimistic!).
  - It must announce Abort message to all.
- To deal with Commit or Abort message loss
  - Server can poll coordinator (repeatedly).

Distributed Transaction Atomicity

- When T tries to commit, need to ensure
  - all these servers commit their updates from T => T will commit
  - Or none of these servers commit => T will abort

- What problem is this?
  - Consensus!
  - (It's also called the "Atomic Commit" problem)

- Consensus is impossible in asynchronous system.
  - What makes two-phase commit work?
  - Crash failures in processes *masked* by replacing the crashed process with a new process whose state is retrieved from permanent storage.
  - *Two-phase commit is blocked until a failed coordinator recovers.*

Distributed Transaction Challenges

- Atomic: all-or-nothing
  - Must ensure atomicity across servers.
- **C**onsistent: rules maintained
  - *Generally done locally, but may need to check non-local invariants at commit time.*
- **Isolation: multiple transactions do not interfere with each other**
  - ***Locks at each server. How to detect and handle deadlocks?***
- **D**urability: values preserved even after crashes
  - *Each server keeps local recovery log.*

Isolation with Distributed Transaction

- Each server is responsible for applying concurrency control to objects it stores.

- Servers are collectively responsible for serial equivalence of operations.

Timestamped Ordering with Distributed Transaction

- Each server is responsible for applying concurrency control to objects it stores.

- Servers are collectively responsible for serial equivalence of operations.

- Timestamped ordering can be applied locally at each server.
    - When a server aborts a transaction, inform the coordinator which will relay the "abort" to other servers.

Locks with Distributed Transaction

- Each server is responsible for applying concurrency control to objects it stores.
- Servers are collectively responsible for serial equivalence of operations.
- Locks are held locally, and cannot be released until all servers involved in a transaction have committed or aborted.
- Locks are retained during 2PC (two-phase commit) protocol.
- How to handle deadlocks?

Deadlock Detection in Distributed Transactions

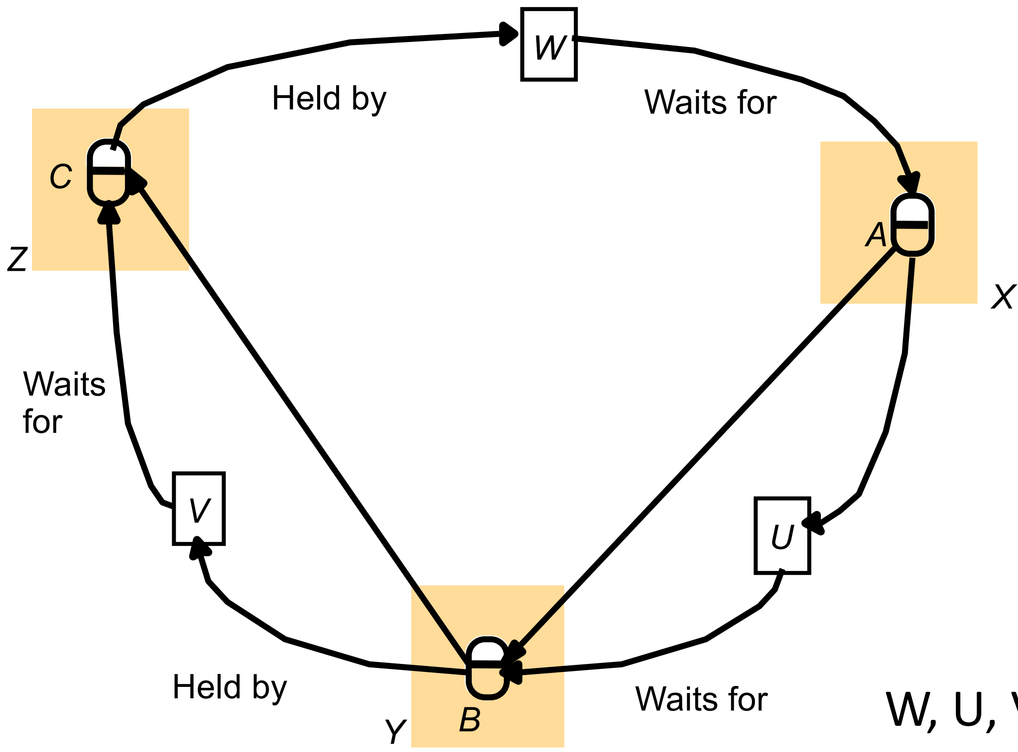
- The wait-for graph in a distributed set of transactions is distributed.

- Centralized detection
  - Each server reports waits-for relationships to central server.
  - Coordinator constructs global graph, checks for cycles.

- Issues:
  - Single point of failure (can get blocked with the central server fails).
  - Scalability.

Decentralized Deadlock Detection

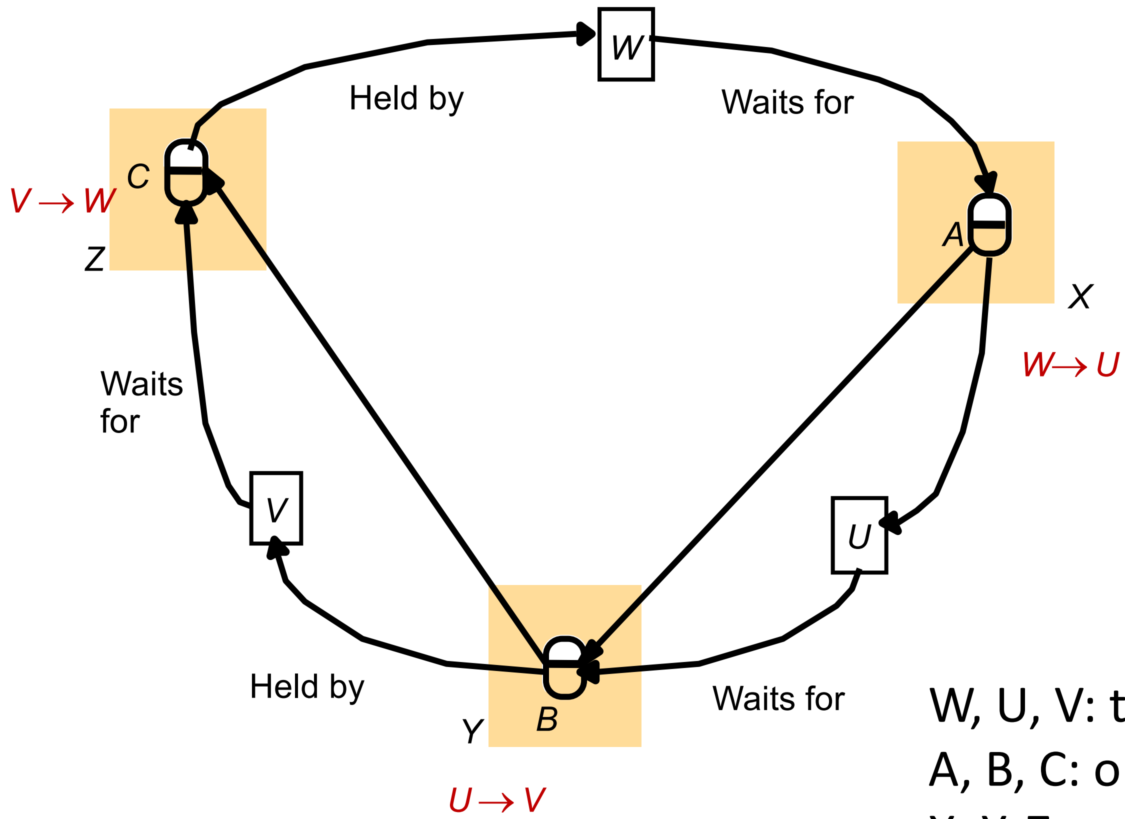
- **Edge chasing:** Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.



W, U, V: transactions
A, B, C: objects
X, Y, Z: servers

Decentralized Deadlock Detection

- **Edge chasing:** Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.



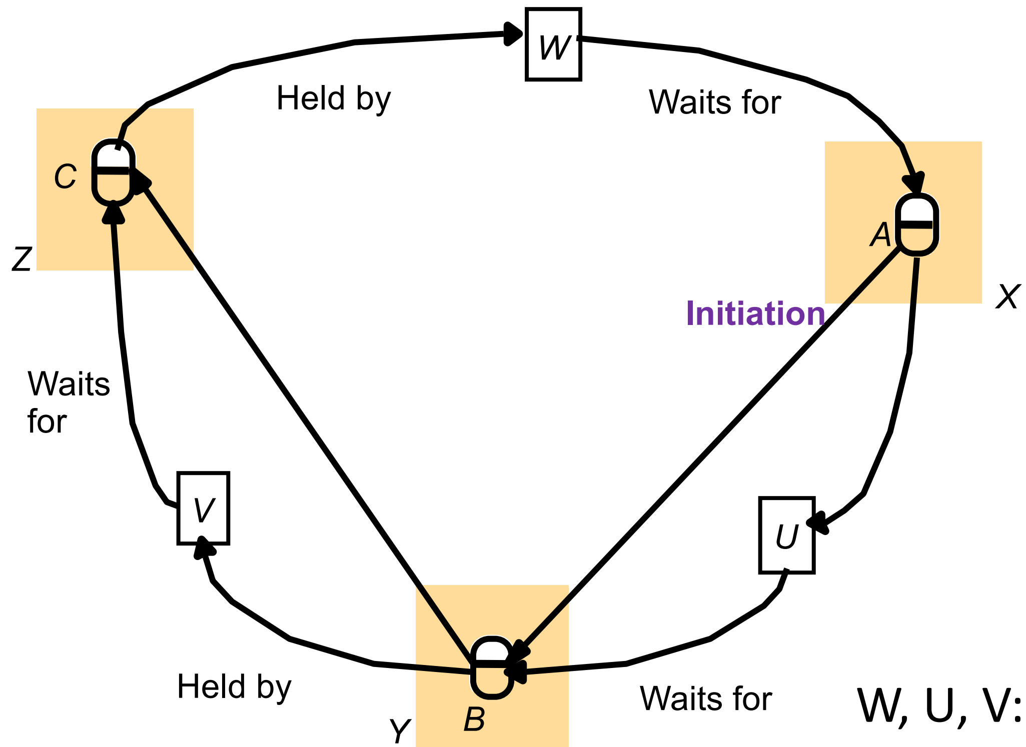
All servers know local wait-for relationships.

Coordinator for each transaction knows whether the transaction is waiting on an object lock, and at which server.

W, U, V: transactions
A, B, C: objects
X, Y, Z: servers

Decentralized Deadlock Detection

- **Edge chasing:** Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.

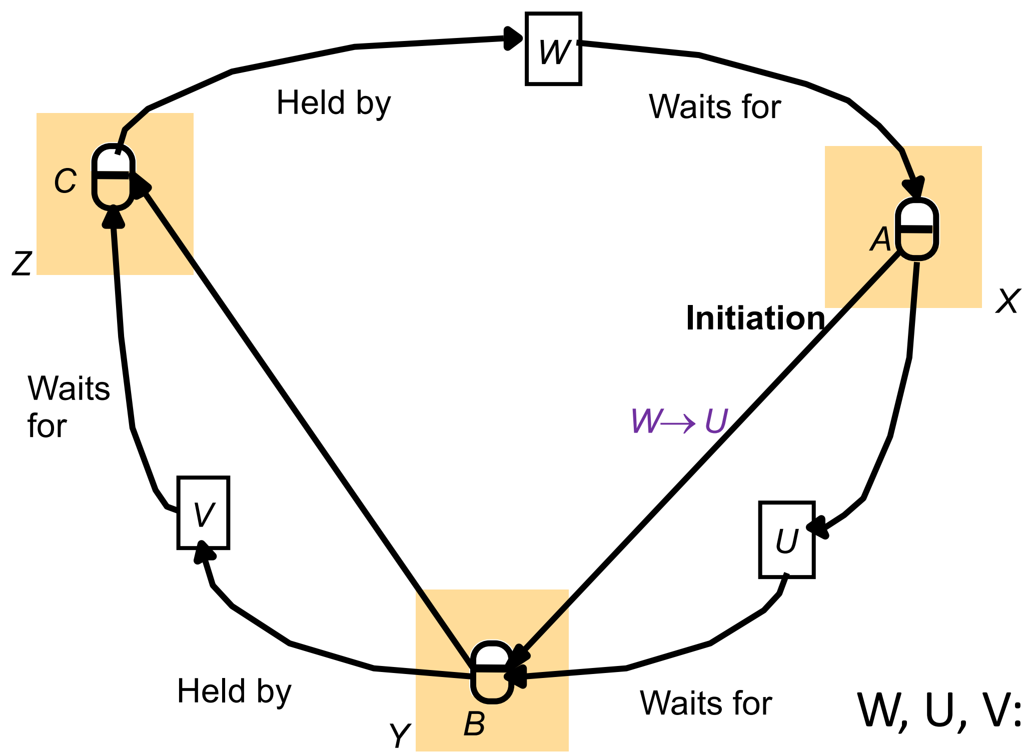


- Server X realizes W is waiting on U (a potential edge in the wait-for graph).
- Ask U's coordinator whether U is waiting on anything, and at which server.

W, U, V: transactions
A, B, C: objects
X, Y, Z: servers

Decentralized Deadlock Detection

- **Edge chasing:** Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.

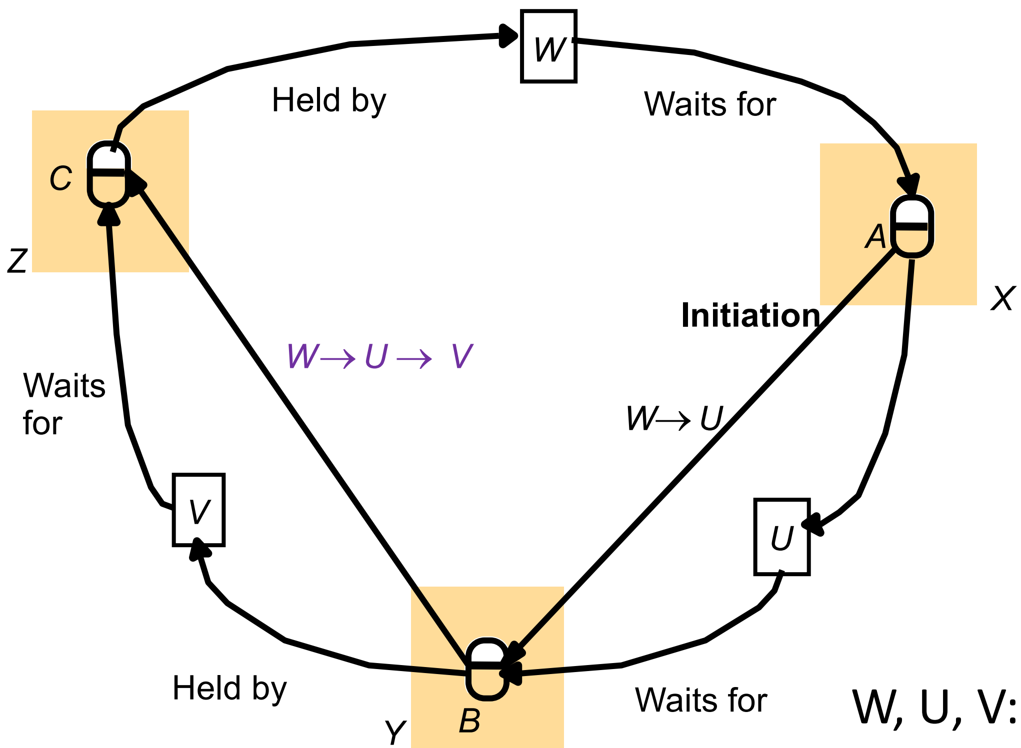


- Server X realizes W is waiting on U (a potential edge in the wait-for graph).
- Ask U's coordinator whether U is waiting on anything, and at which server.
- *Send a probe to the next server.*

W, U, V: transactions
A, B, C: objects
X, Y, Z: servers

Decentralized Deadlock Detection

- **Edge chasing:** Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.

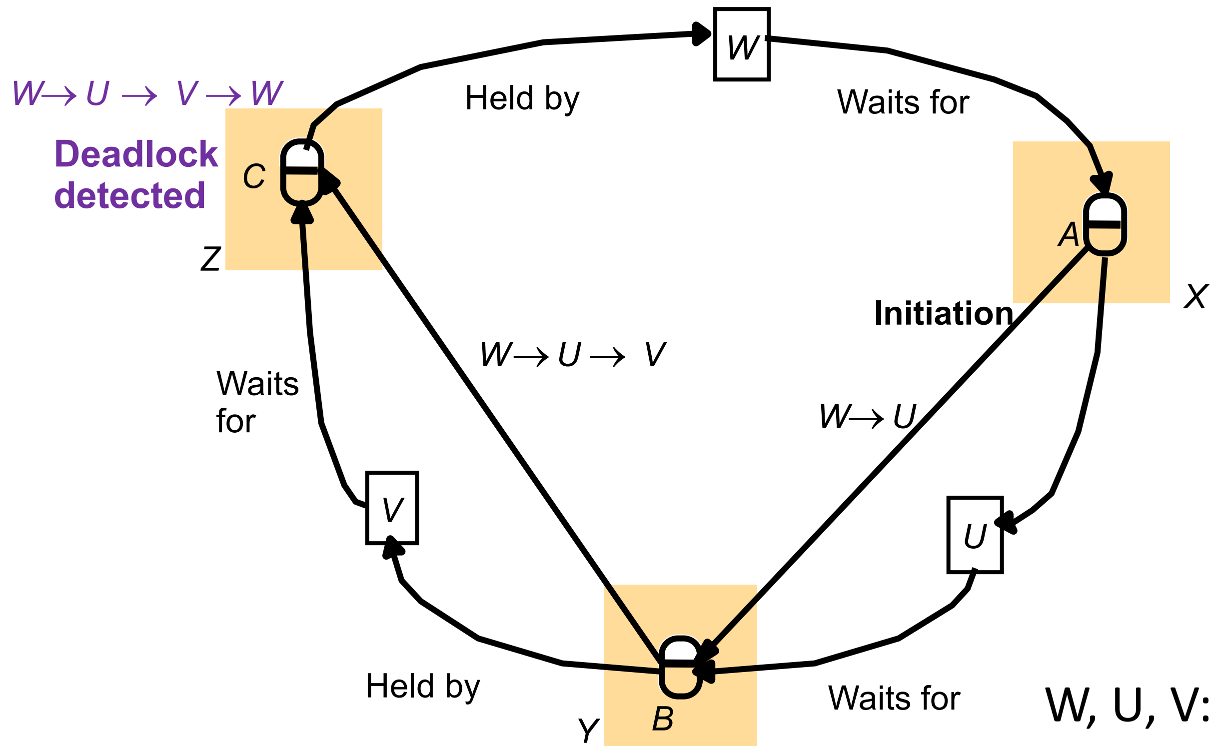


- Y adds another edge, and forwards the probe to the next server.

W, U, V: transactions
A, B, C: objects
X, Y, Z: servers

Decentralized Deadlock Detection

- **Edge chasing:** Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.



- C can now detect a deadlock.
- A transaction in the cycle can now be aborted (by informing its coordinator), and deadlock breaks.

W, U, V: transactions
A, B, C: objects
X, Y, Z: servers

Edge Chasing: Phases

- Initiation: When a server S_1 notices that a transaction T starts waiting for another transaction U, where U is waiting to access an object at another server S_2, it initiates detection by sending <T→U> to S_2.

- Detection: Servers receive probes and decide whether deadlock has occurred and whether to forward the probes.

- Resolution: When a cycle is detected, one or more transactions in the cycle is/are aborted to break the deadlock.

Phantom Deadlocks

- Phantom deadlocks = false detection of deadlocks that don’t actually exist
  - Edge chasing messages contain stale data (Edges may have disappeared in the meantime).
  - So, all edges in a “detected” cycle may not have been present in the system all at the same time.
- Leads to spurious aborts.

Transaction Priority

- Which transaction to abort?
- Transactions may be given priority.
    - e.g. inverse of timestamp.
- When deadlock cycle is found, abort lowest priority transaction
    - Only one aborted even if several simultaneous probes find cycle.

Summary

- Distributed Transaction: Different objects that a transaction touches are stored on different servers.
  - One server process marked out as coordinator
  - Atomic Commit: 2PC
  - Deadlock detection: Centralized, Edge chasing

- Next class: when objects are *replicated* across multiple servers.