Timestamp Ordering

Assign each transaction a unique *timestamp (ts)*

- Serialize transactions according to timestamps

Keep track of timestamp last transaction to read and write an object

Invariants

1. If T reads O, last write timestamp must be lower than T
2. If T writes O, last read and write timestamp must be lower than T's

If T tries to read/write object with higher timestamp, abort and rollback

T (1)	U (2)	V (3)
read X (X.rts=1)		
write Y(Y.wts=1)		
	read X (X.rts=2)	
		read Y (Y.rts = 3)
		write X (X.wts=3)
	read Y (Y.rts=3)	
write X: abort!		

Timestamp Ordering Invariants

Let T1 and T2 have timestamps 1 and 2

Invariants enforce order T1 ; T2

I1: If T reads O, last write timestamp must be lower than T

- If T1 reads O after T2 writes O, T1 sees T2's write

T1	T2
	write O
read O	

Timestamp Ordering Invariants

Let T1 and T2 have timestamps 1 and 2

Invariants enforce order T1 ; T2

I1: If T reads O, last write timestamp must be lower than T

- If T1 reads O after T2 writes O, T1 sees T2's write

I2: If T writes O, last read and write timestamp must be lower than T's

- If T2 reads O before T1 writes O, T2 missed T1's write

T1	T2
	read O
write O	

Timestamp Ordering Invariants

Let T1 and T2 have timestamps 1 and 2

Invariants enforce order T1 ; T2

I1: If T reads O, last write timestamp must be lower than T

- If T1 reads O after T2 writes O, T1 sees T2's write

I2: If T writes O, last read and write timestamp must be lower than T's

- If T2 reads O before T1 writes O, T2 missed T1's write
- If T1 writes O after T2 writes O, T2's write has been lost

T1	T2
	write O
write O	

Thomas Write Rule

Let T1 and T2 have timestamps 1 and 2

Invariants enforce order T1 ; T2

I1: If T reads O, last write timestamp must be lower than T

- If T1 reads O after T2 writes O, T1 sees T2's write

I2: If T writes O, last read and write timestamp must be lower than T's

- If T2 reads O before T1 writes O, T2 missed T1's write
- If T1 writes O after T2 writes O, T2's write has been lost

If T writes O and last write timestamp > T's, skip write!

T1	T2
	write O
write O	

Should we abort or skip here?

T (1)	U (2)	V (3)
read X (X.rts=1)		
write Y(Y.wts=1)		
	read X (X.rts=2)	
		read Y (Y.rts = 3)
		write X (X.wts=3)
	read Y (Y.rts=3)	
write X: ???		

Dependency Tracking

Start with X=0, Y=0, Z=0

T1	T2
Read X -> 0	
Write Y = 1	
	Read Y -> 1
	Write Z = 2
Read Z—ABORT!	

Dependency Tracking

Start with X=0, Y=0, Z=0

T2 has read value that was produced by aborted transaction!

T1	T2
~~Read X -> 0~~	
~~Write Y = 1~~	
	Read Y -> 1
	Write Z = 2
~~Read Z—ABORT!~~	

Dependency Tracking

Start with X=0, Y=0, Z=0

T2 has read value that was produced by aborted transaction!

When reading object O, add its RTS to dependency list

At commit time, check dependency list

- If tx in dependency list has aborted, abort
- If tx in dependency list is still active, wait

T1	T2
~~Read X -> 0~~	
~~Write Y = 1~~	
	Read Y -> 1
	Write Z = 2
~~Read Z—ABORT!~~	

Timestamp Ordering

T (1)	U (2)	V (3)
read X (X.rts=1)		
write Y(Y.wts=1)		
	read X (X.rts=2)	
		read Y (Y.rts = 3)
		write X (X.wts=3)
		write Z (Z.wts=3)
	read Y (Y.rts=3)	
write Z: skip!		

T (1)	U(2)	V(3)
read X		
write Y		
write Z		
	read X	
	read Y	
		read Y
		write X
		write Z

Timestamp Summary

```
read(X)
  if WTS(X) > myTS:
    abort()
  myDEPS.add(WTS(X))
  RTS(X) =
    max(RTS(X), myTS)
```

```
write(X)
  if RTS(X) > myTS:
    abort()
  if WTS(X) > myTS:
    return # skip write
  WTS(X) = myTS
```

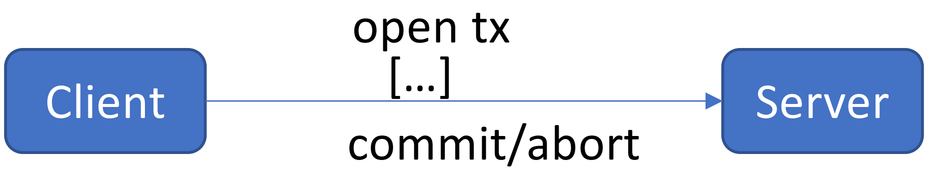
At commit time, wait for myDEPS to complete, abort if any has aborted

Distributed Transactions

CS425/ECE428 – Distributed Systems – Spring 2020

Material derived from slides by I. Gupta, M. Harandi,
J. Hou, S. Mitra, K. Nahrstedt, N. Vaidya

Client-Server Transactions



Client

open tx

[…]

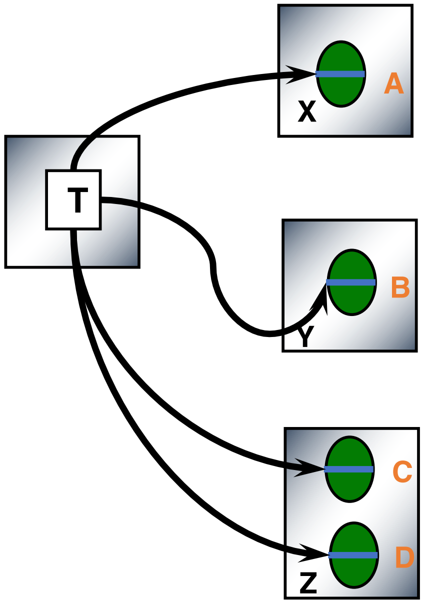
commit/abort

Server

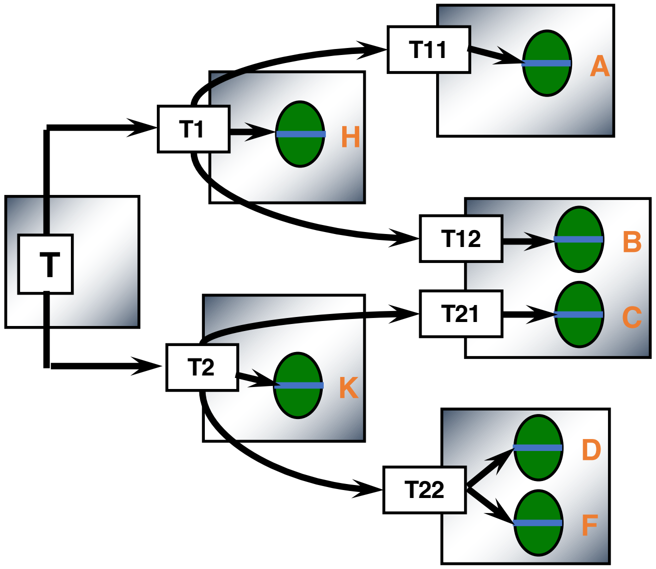
- **Atomicity**: all-or-nothing
  - Make updates on a shadow copy
  - Real update on commit, discard on abort
- **Consistency**: invariants satisfied
  - Check and abort on violations
- **Isolation**: concurrent transactions serially equivalent
  - Two-phase locking (strict or otherwise)
- **Durability**: results preserved after crashes
  - Save committed updates to disk, recover state after crash

Distributed Transactions

- A transaction that invokes operations at several servers.

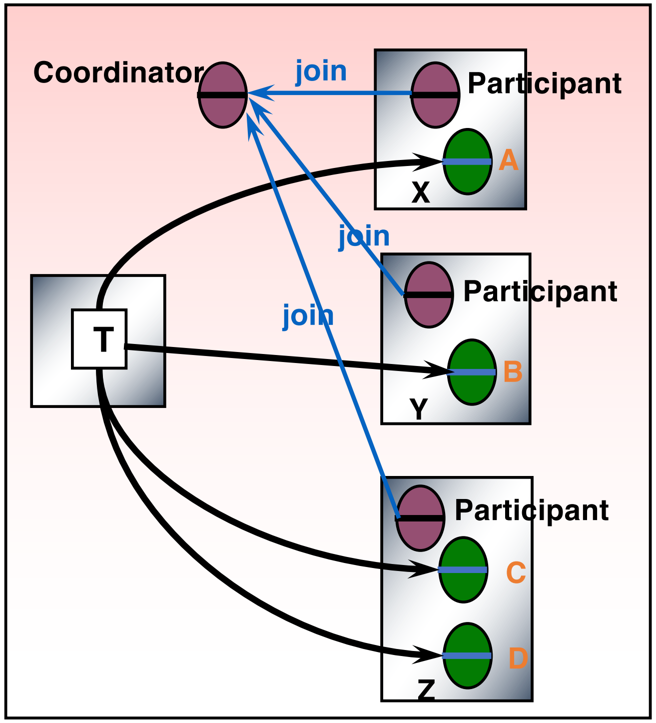


Flat Distributed Transaction

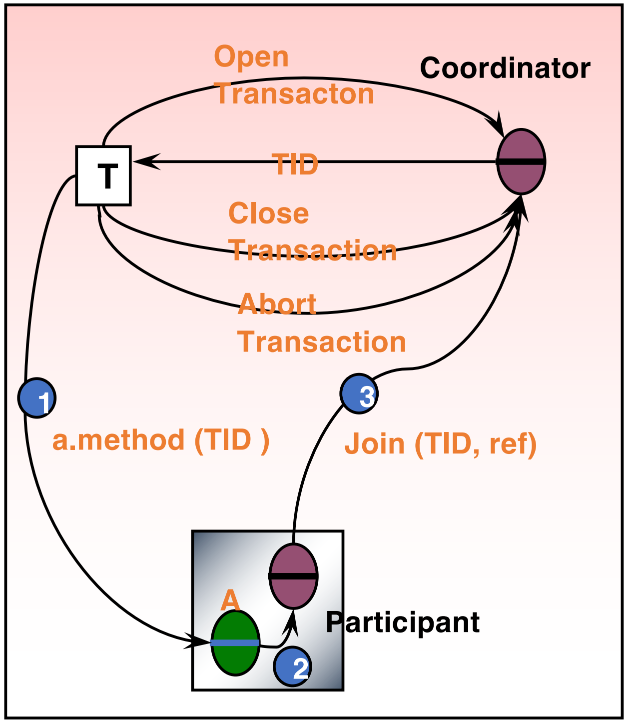


Nested Distributed Transaction

Coordination in Distributed Transactions

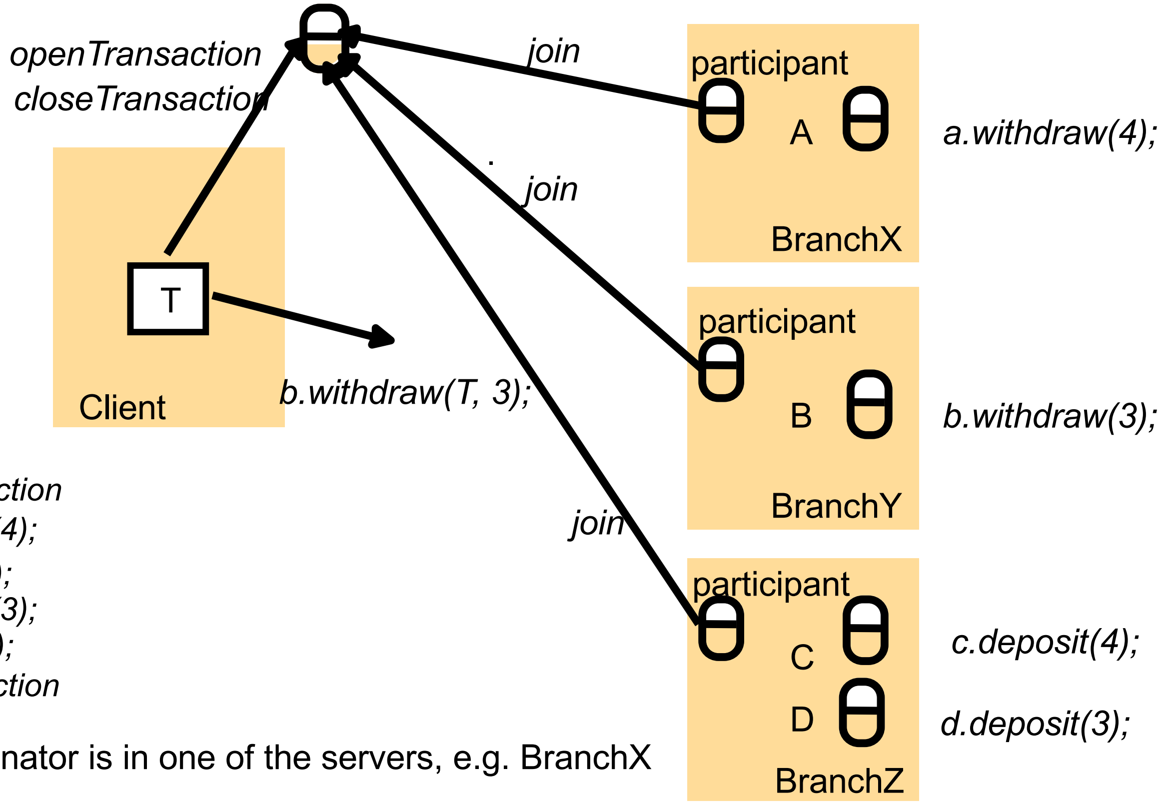


Coordinator & Participants



The Coordination Process

Distributed banking transaction



openTransaction
closeTransaction

join

join

join

participant
A
BranchX
a.withdraw(4);

participant
B
BranchY
b.withdraw(3);

participant
C
D
BranchZ
c.deposit(4);
d.deposit(3);

T
Client
b.withdraw(T, 3);

```
T = openTransaction
    a.withdraw(4);
    c.deposit(4);
    b.withdraw(3);
    d.deposit(3);
  closeTransaction
```

Note: the coordinator is in one of the servers, e.g. BranchX

Distributed Transaction Challenges

- **Atomicity**: all-or-nothing
  - Must ensure atomicity across servers
- **Consistency**: invariants satisfied
  - Generally done locally, but may need to check non-local invariants at commit time
- **Isolation**: concurrent transactions serially equivalent
  - Locks at each server.
- **Durability**: results preserved after crashes
  - Each server keeps local recovery log

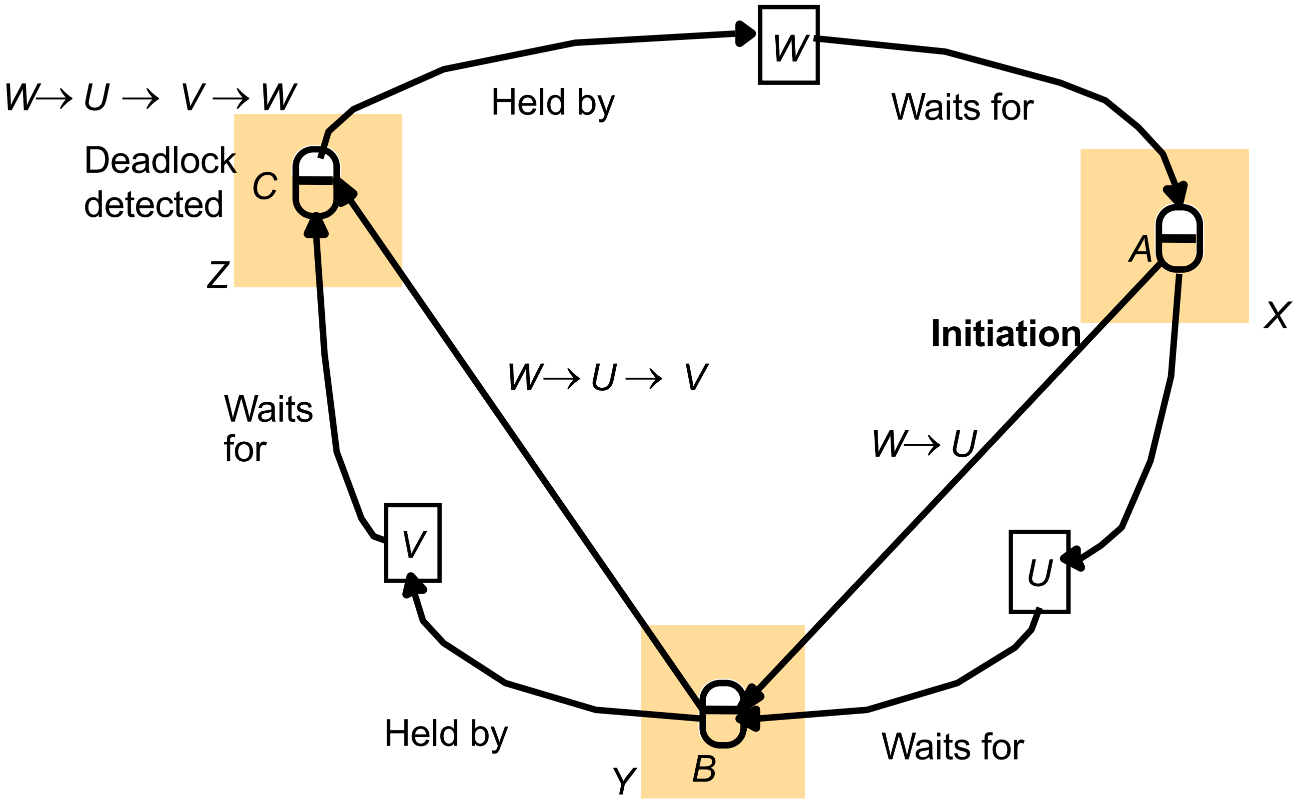
I. Locks in Distributed Transactions

- 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 protocol.
- Since lock managers work independently, deadlocks are possible (likely?)

Distributed Deadlocks

- The wait-for graph in a distributed set of transactions is distributed
- Centralized detection
  - Each server reports waits-for relationships to coordinator
  - Coordinator constructs global graph, checks for cycles
- Decentralized — edge chasing
  - Forward "probe" messages to servers in the edges of wait-for graph, pushing the graph forward, until cycle is found.

Probes Transmitted to Detect Deadlock



Edge Chasing

- 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=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.

Transaction Priority

- Transactions are given priorities
  - E.g., inverse of timestamp
  - Total order
- When deadlock cycle is found, abort lowest priority transaction
  - Only one aborted even if several simultaneous probes find cycle

II. Atomic Commit Problem

- At some point, client executes closeTransaction()
  - Result -> commit, abort
- Atomicity requires all-or-nothing
  - All operations on all servers are committed, or
  - All operations on all servers are aborted
- What problem statement is this?

Atomic Commit Protocols

- **Consensus!**
  - Impossible to be totally correct
  - Possible to ensure safety, at the (possible) expense of liveness
  - Plus, we already have a leader (coordinator)
- First attempt: Coordinator decides
  - Pick commit or abort
  - Send message to all participants
  - (Retransmit until acknowledged)
- Problems?
  - Participant crashes before receiving commit message
  - Participant decides to abort (deadlock, other problems)