CSE 544
Principles of Database Management Systems

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Fall 2015

Lecture 14 – Distributed Transactions

Transactions

- Main issues:
  - Concurrency control
  - Recovery from failures

Distributed Transactions

References

- C. Mohan, B. Lindsay, and R. Obermarck. Transaction Management in the R* Distributed Database Management System. ACM Transactions On Database Systems 11 (4), 1986. Also in the Red Book (3rd and 4th ed).

- Chapters 8 and 9 in Principles of Transaction Processing. Second Ed. Phil Bernstein and Eric Newcomer.

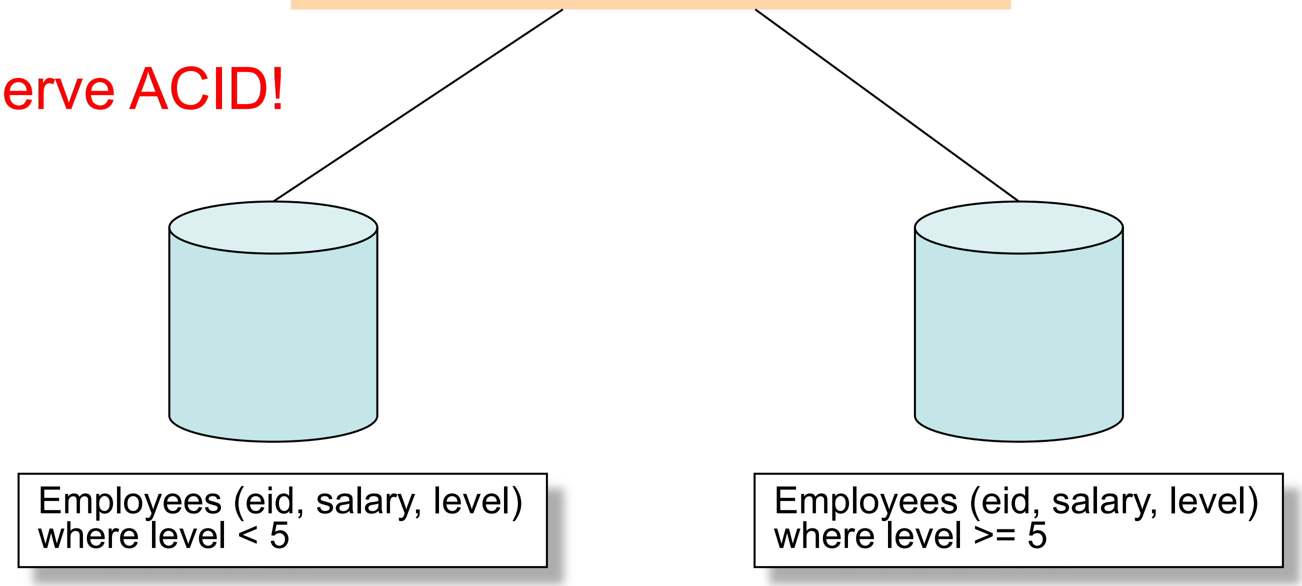
- Chapter 22 in Ramakrishnan and Gehrke

Distributed Transactions

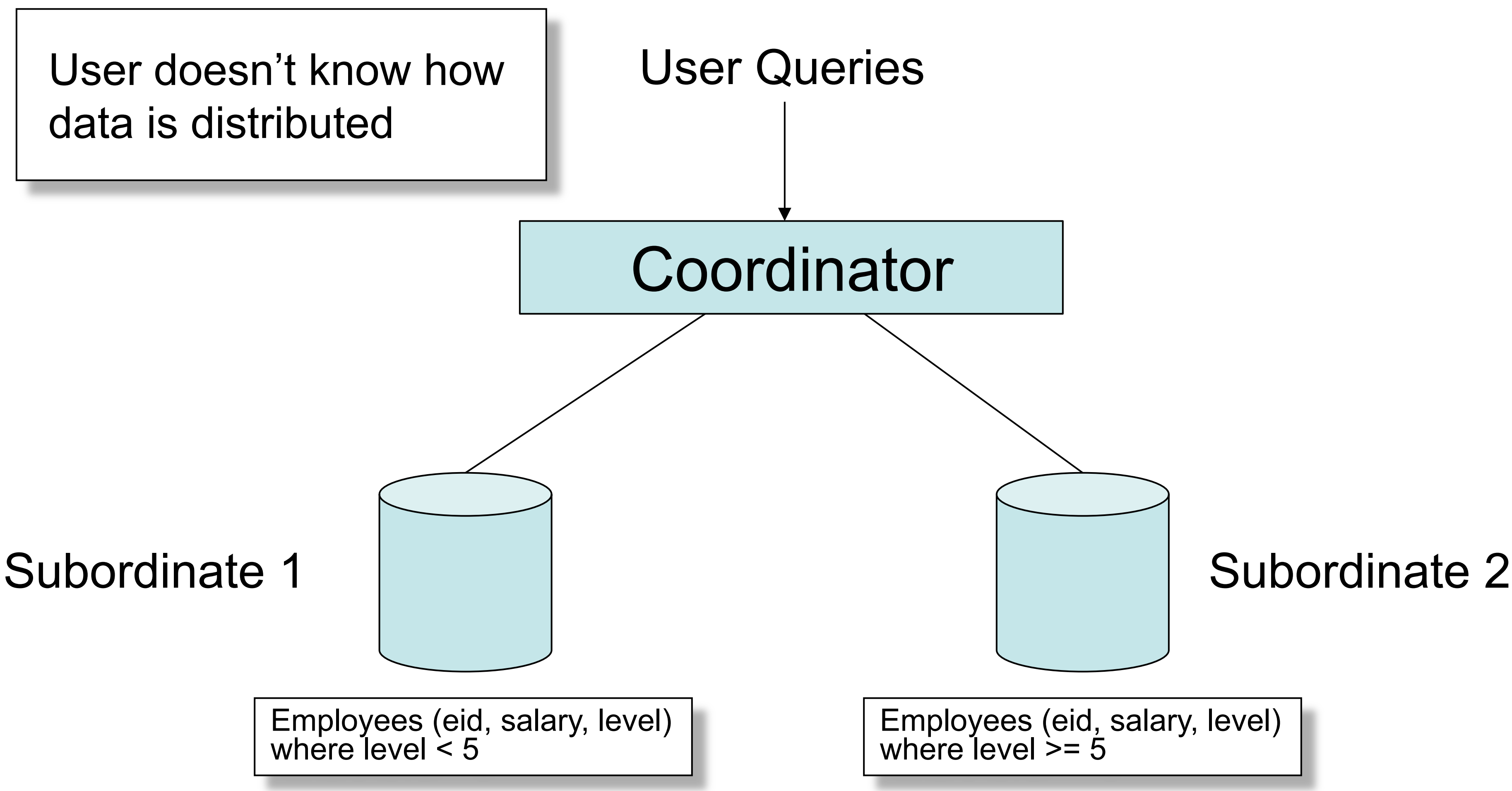
```
UPDATE Employees
SET salary = salary * 1.05
WHERE level < 7

UPDATE Employees
SET salary = salary * 1.03
WHERE level >= 7
```

Need to update both partitions

Must preserve ACID!



Typical Architecture



Distributed Transactions

- Concurrency control
  - Allow multiple distributed queries execute at the same time

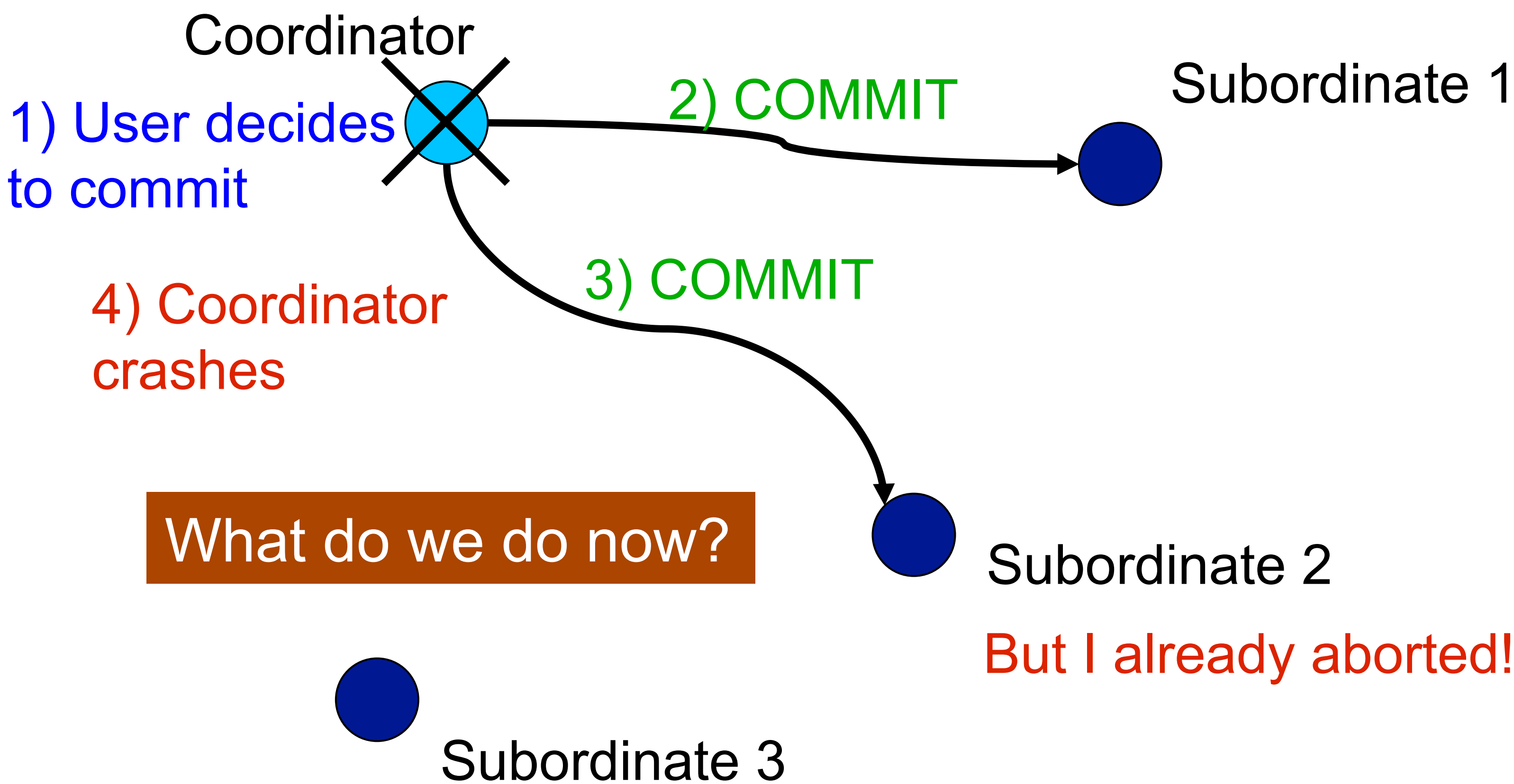
- Failure recovery
  - Transaction must be committed at all sites or at none of the sites!
    - No matter what failures occur and when they occur
  - Two-phase commit protocol (2PC)

Distributed Concurrency Control

- Different techniques are possible
  - Pessimistic, optimistic, locking, timestamps
- Common implementation: distributed two-phase locking
  - Simultaneously hold locks at all sites involved
- Deadlock detection techniques
  - Global wait-for graph (not very practical)
  - Timeouts
- If deadlock: abort least costly local transaction
  - How to define cost?

What about failures?

Two-Phase Commit: Motivation

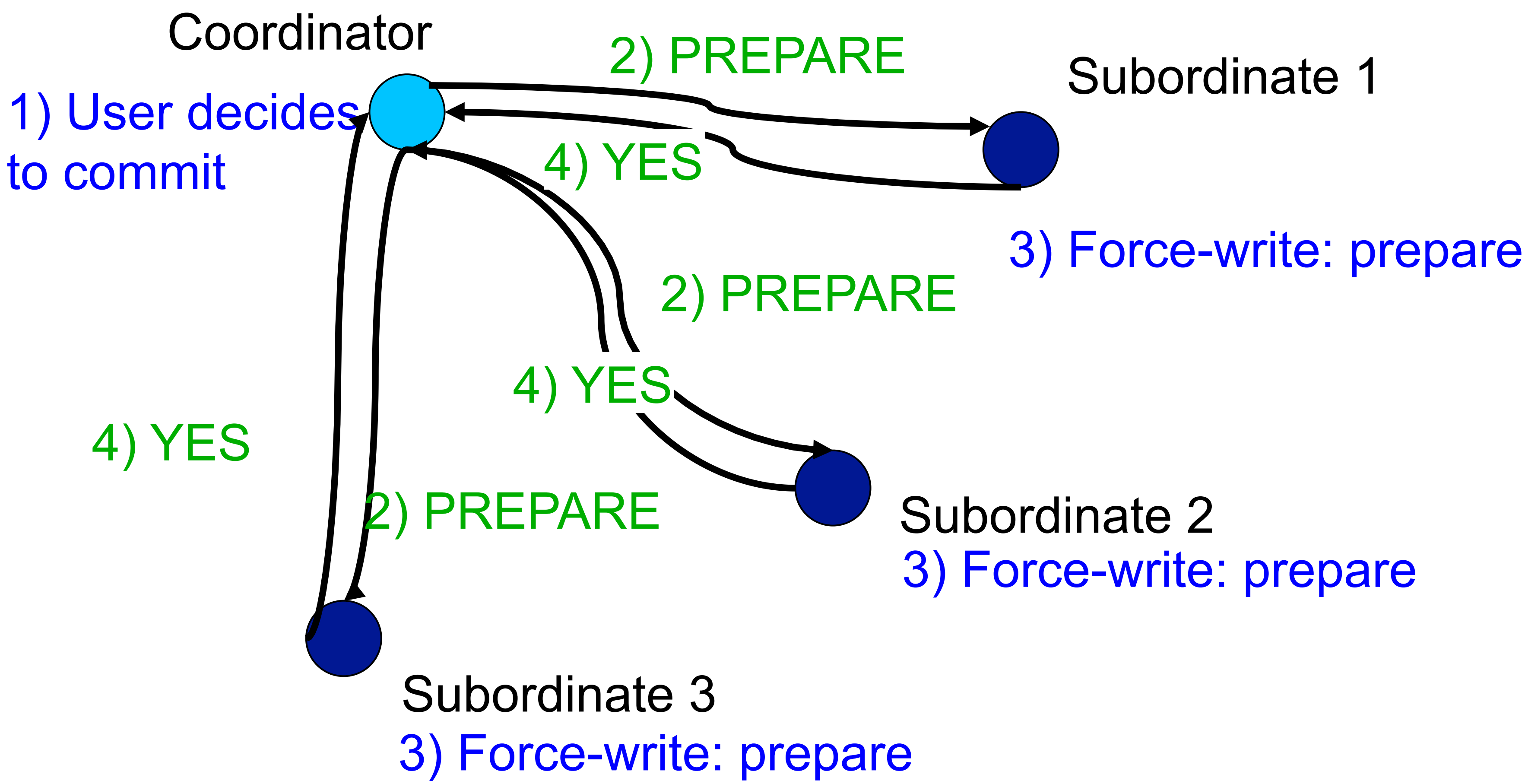


Two-Phase Commit Protocol

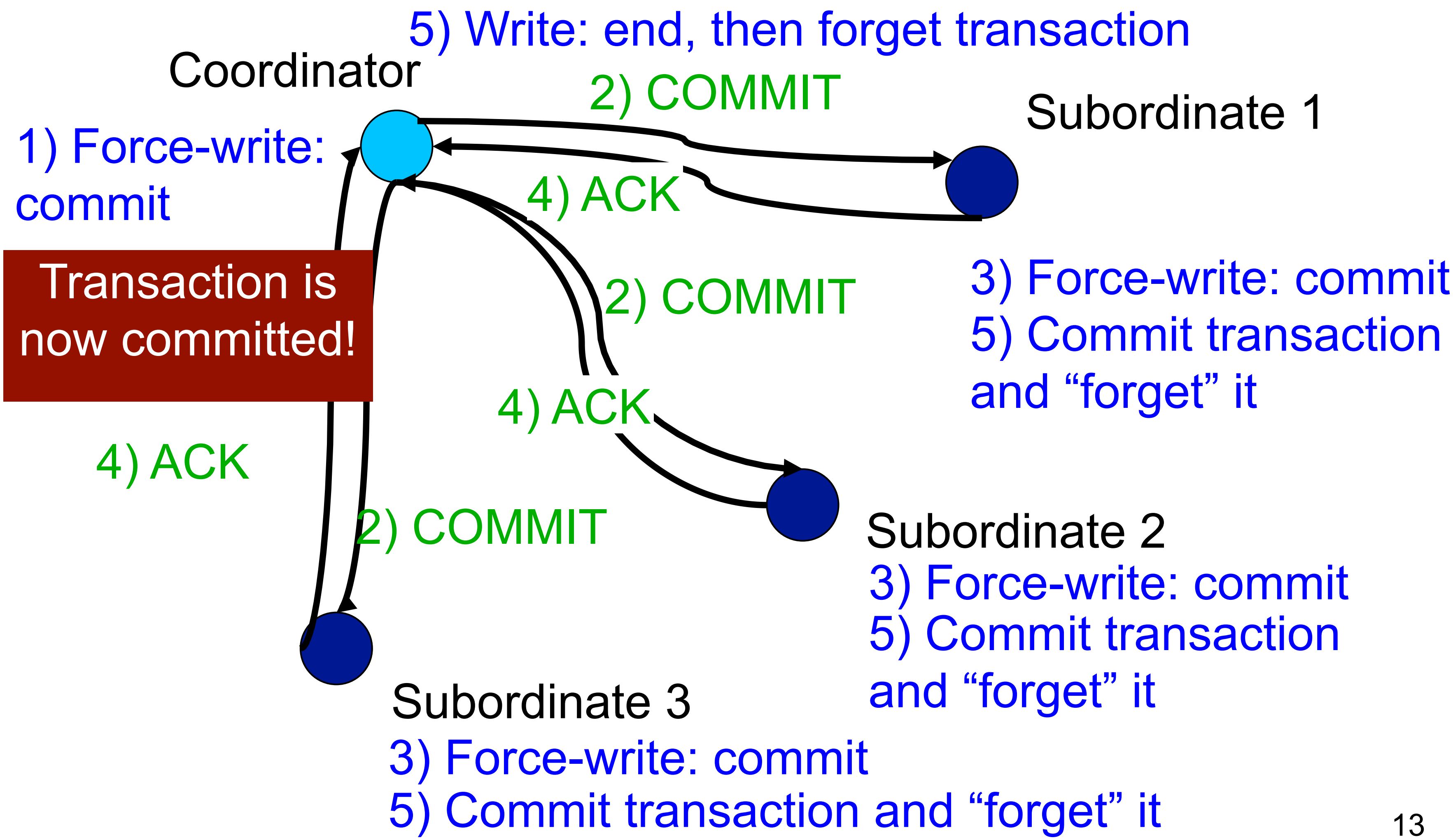
- One coordinator and many subordinates
  - Phase 1: prepare
    - All subordinates must flush tail of write-ahead log to disk before ack
    - Must ensure that if coordinator decides to commit, they can commit!
  - Phase 2: commit or abort
  - Log records for 2PC include transaction and coordinator ids
  - Coordinator also logs ids of all subordinates

- Principle
  - When a process makes a decision: vote yes/no or commit/abort
  - Or when a subordinate wants to respond to a message: ack
  - First force-write a log record (to make sure it survives a failure)
  - Only then send message about decision

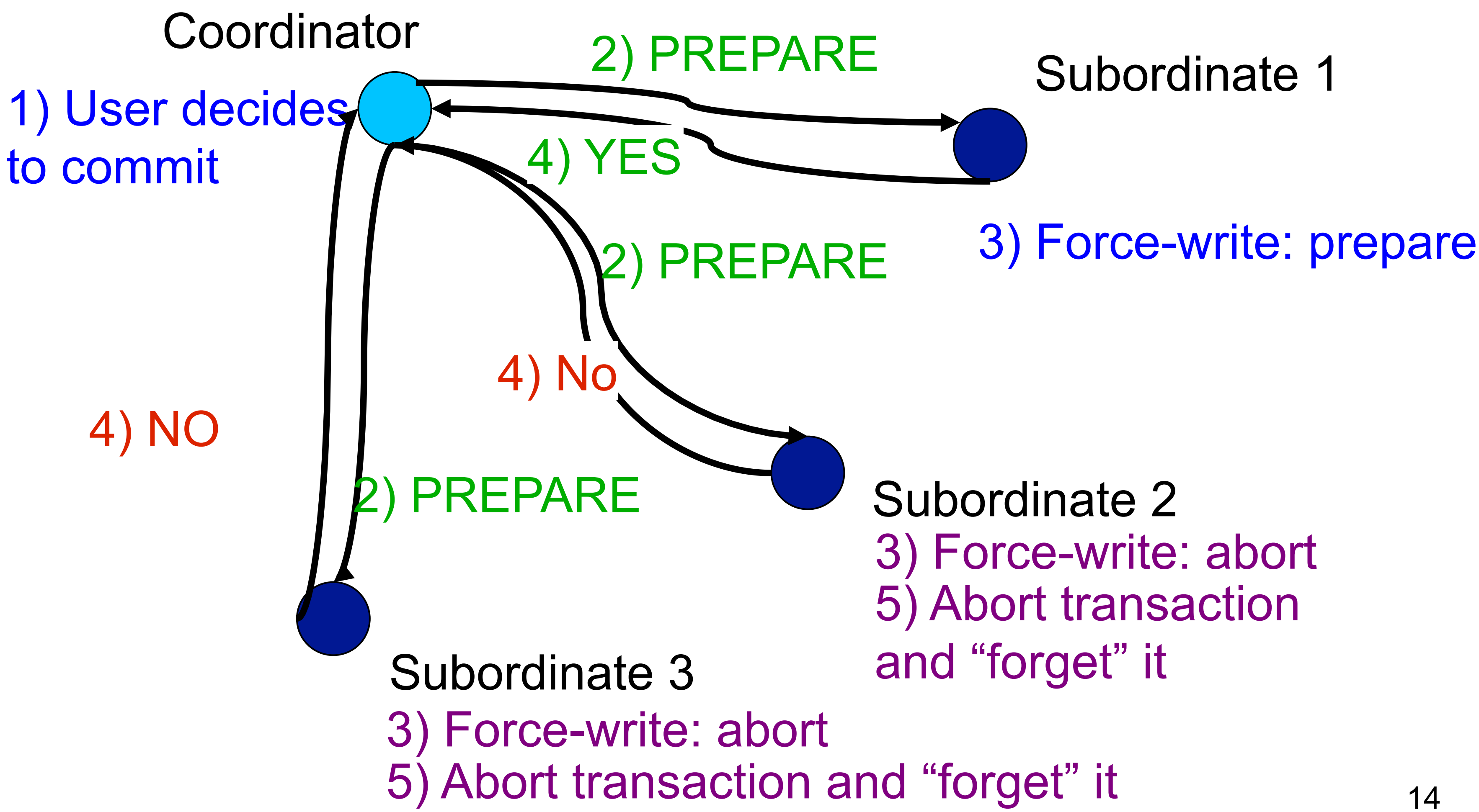
2PC: Phase 1, Prepare



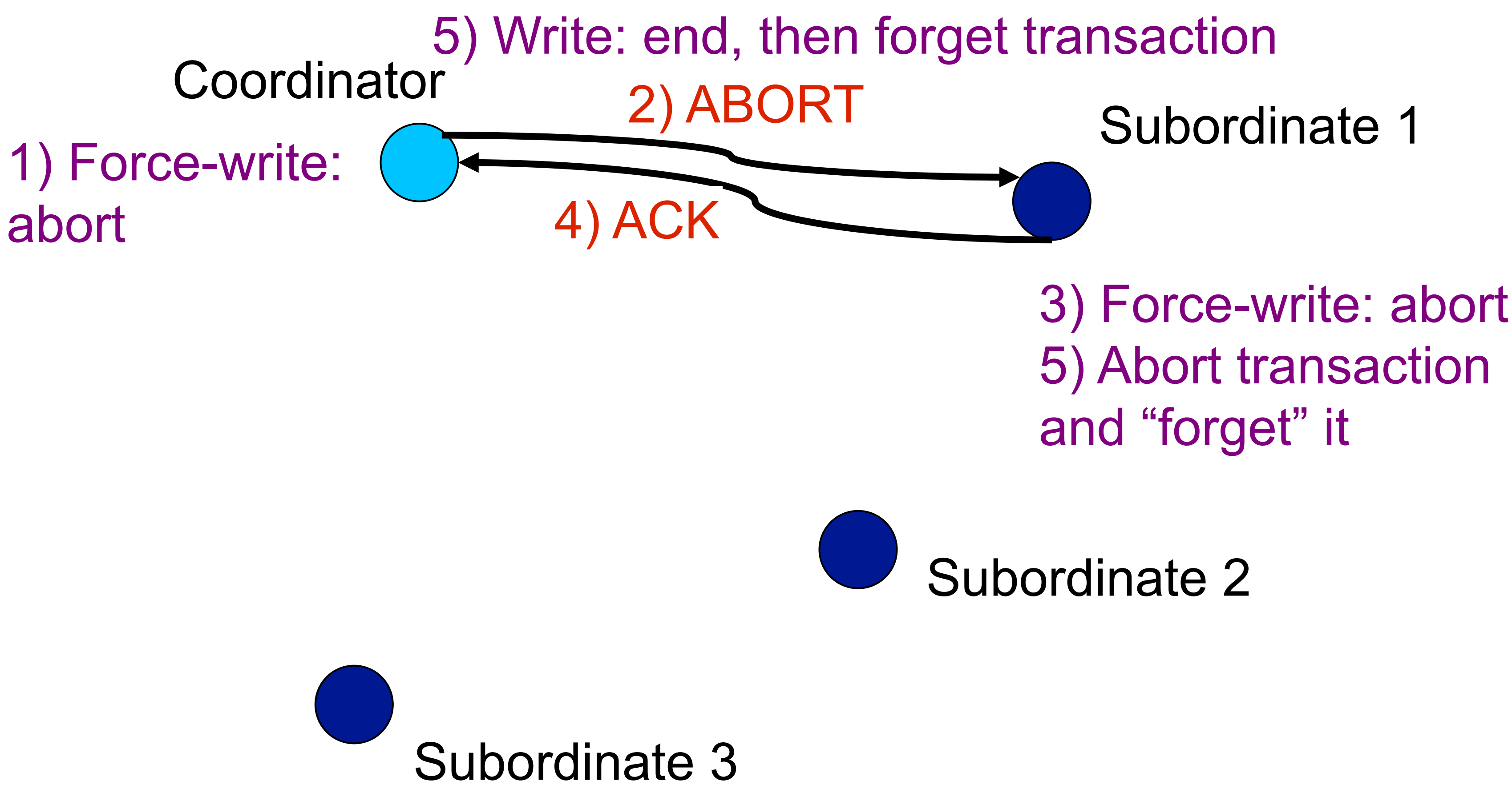
2PC: Phase 2, Commit



2PC with Abort

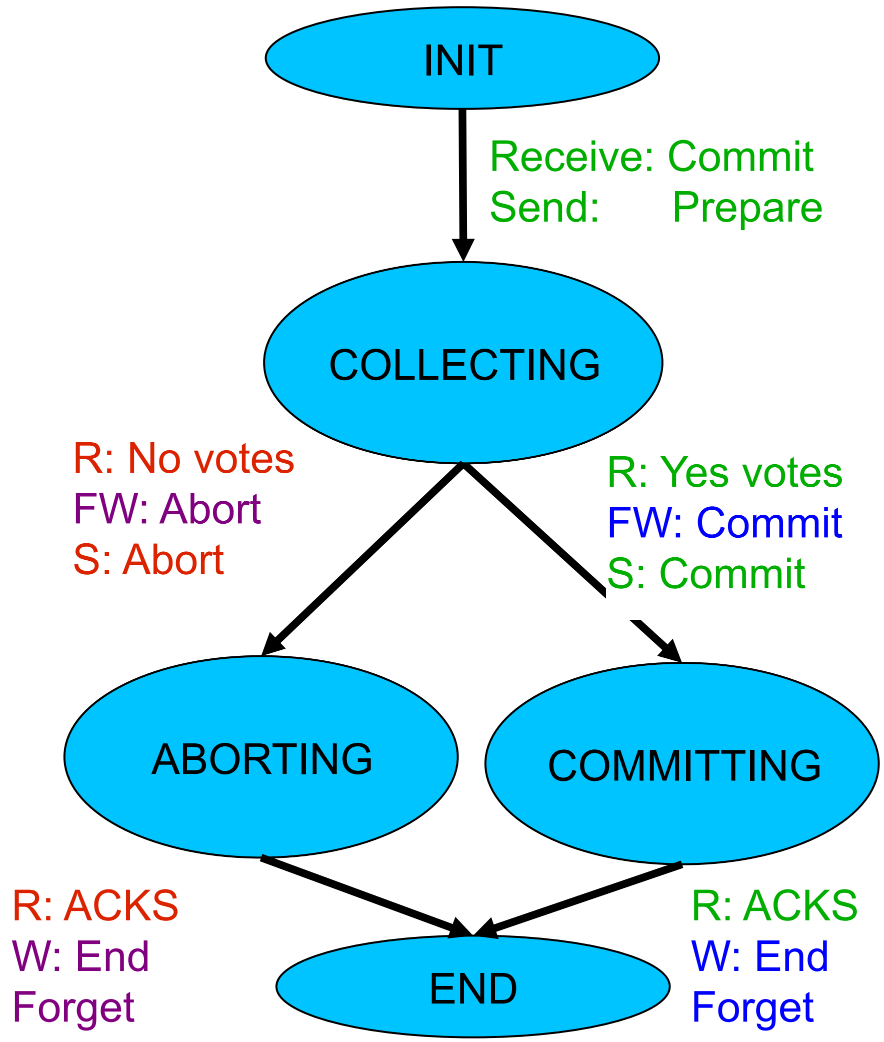


2PC with Abort



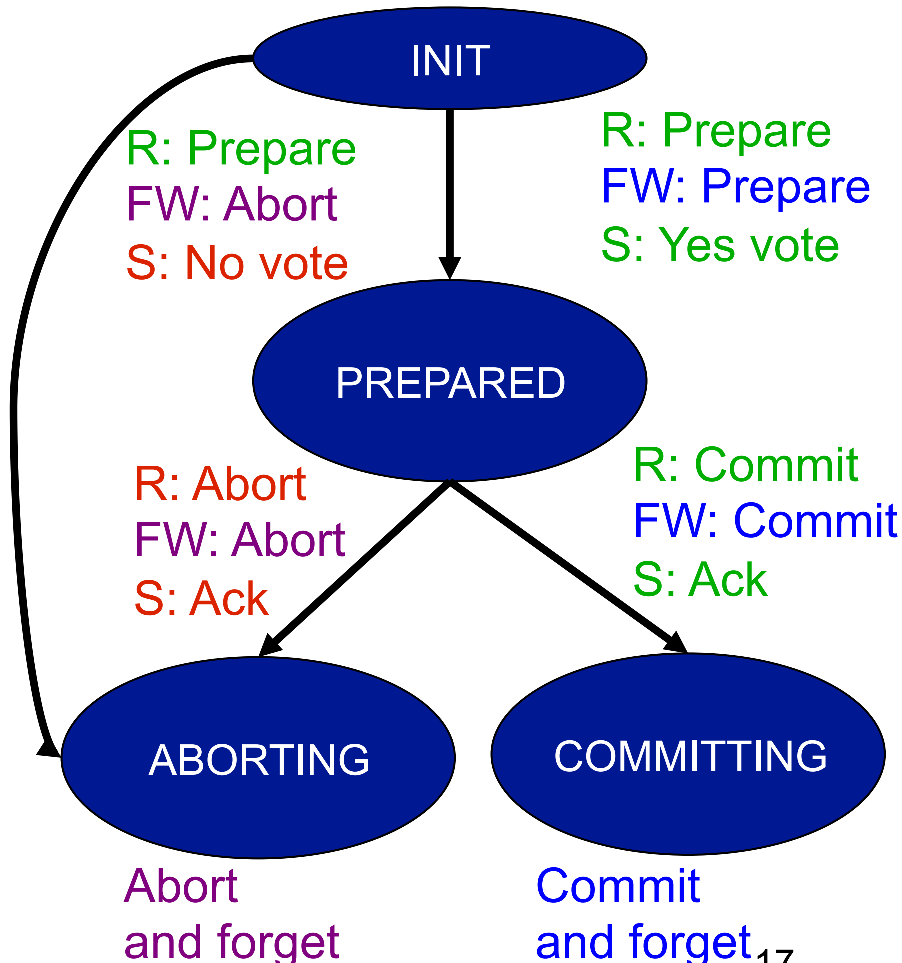
Coordinator State Machine

- All states involve waiting for messages



Subordinate State Machine

- INIT and PREPARED involve waiting



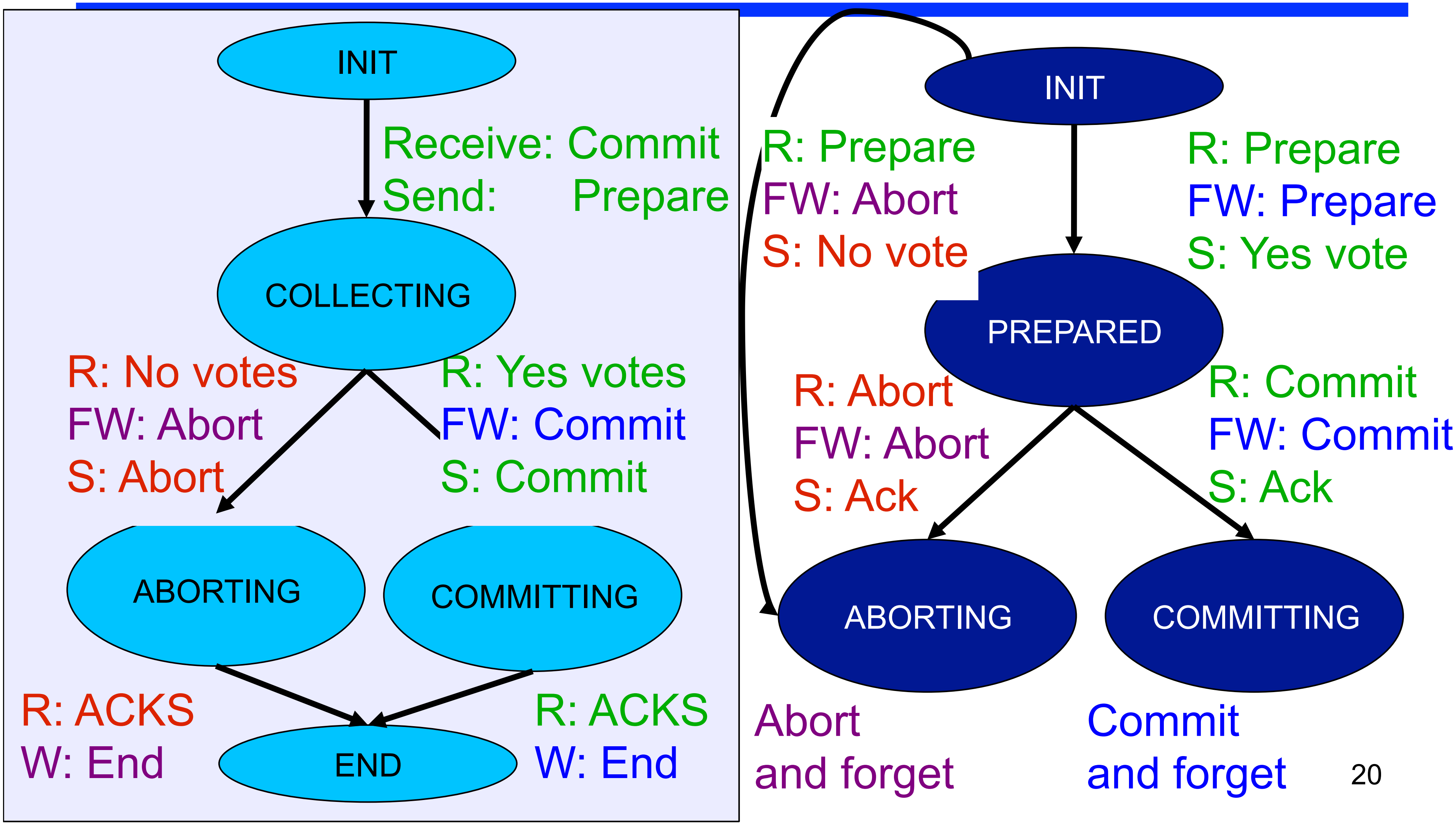
Handling Site Failures

- Approach 1: no site failure detection
  - Can only do retrying & blocking
- Approach 2: timeouts
  - Since unilateral abort is ok,
  - Subordinate can timeout in init state
  - Coordinator can timeout in collecting state
  - Prepared state is still blocking
- 2PC is a blocking protocol

Site Failure Handling Principles

- Retry mechanism
  - In prepared state, periodically query coordinator
  - In committing/aborting state, periodically resend messages to subordinates
- If doesn't know anything about transaction respond “abort” to inquiry messages about fate of transaction
- If there are no log records for a transaction after a crash then abort transaction and “forget” it

Site Failure Scenarios



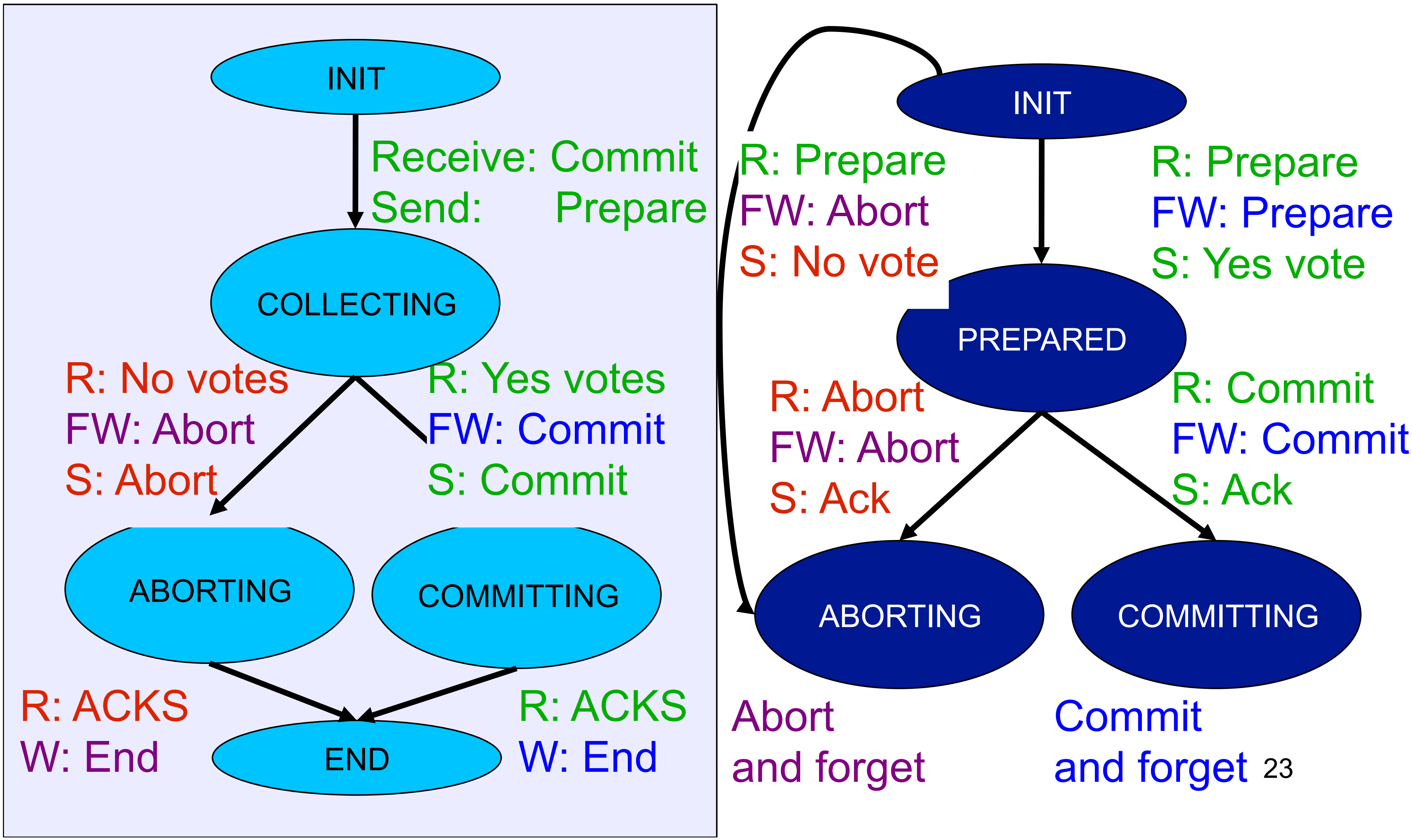
Observations

- Coordinator keeps transaction in transactions table until it receives all acks
  - To ensure subordinates know to commit or abort
  - So acks enable coordinator to “forget” about transaction
- Read-only transactions: no changes ever need to be undone nor redone
- After crash, if recovery process finds no log records for a transaction, the transaction is presumed to have aborted

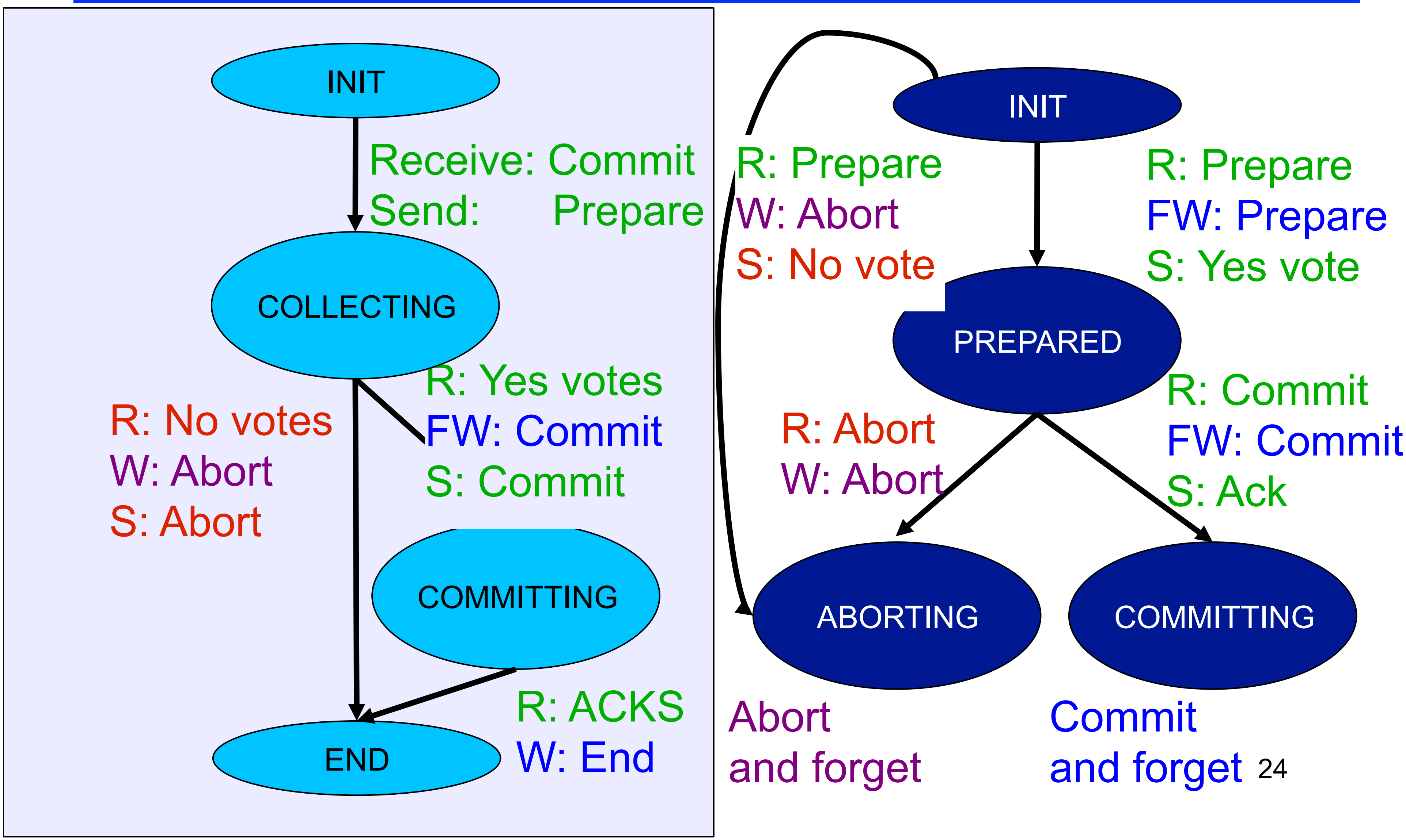
Presumed Abort Protocol

- Optimization goals
  - Fewer messages and fewer force-writes
- Principle
  - If nothing known about a transaction, assume ABORT
- Aborting transactions need no force-writing
- Avoid log records for read-only transactions
  - Reply with a READ vote instead of YES vote
- Optimizes read-only transactions

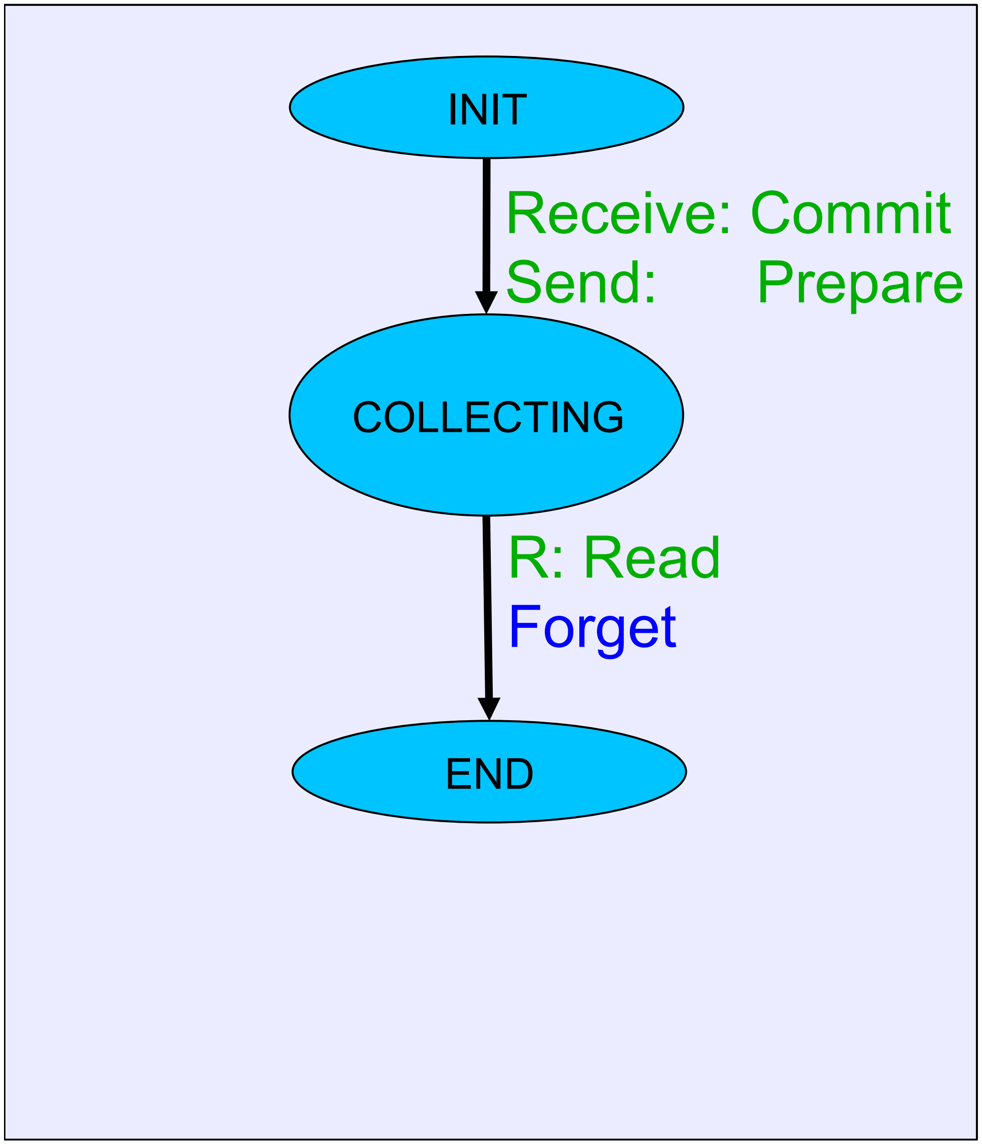
2PC State Machines (repeat)

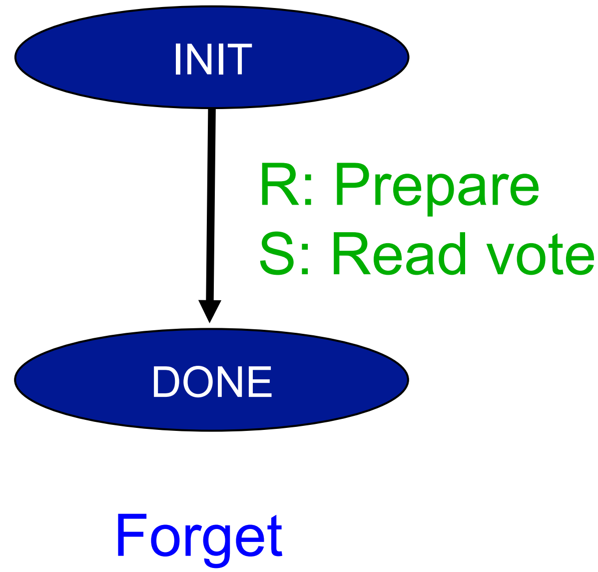


Presumed Abort State Machines



Presumed Abort for Read-Only





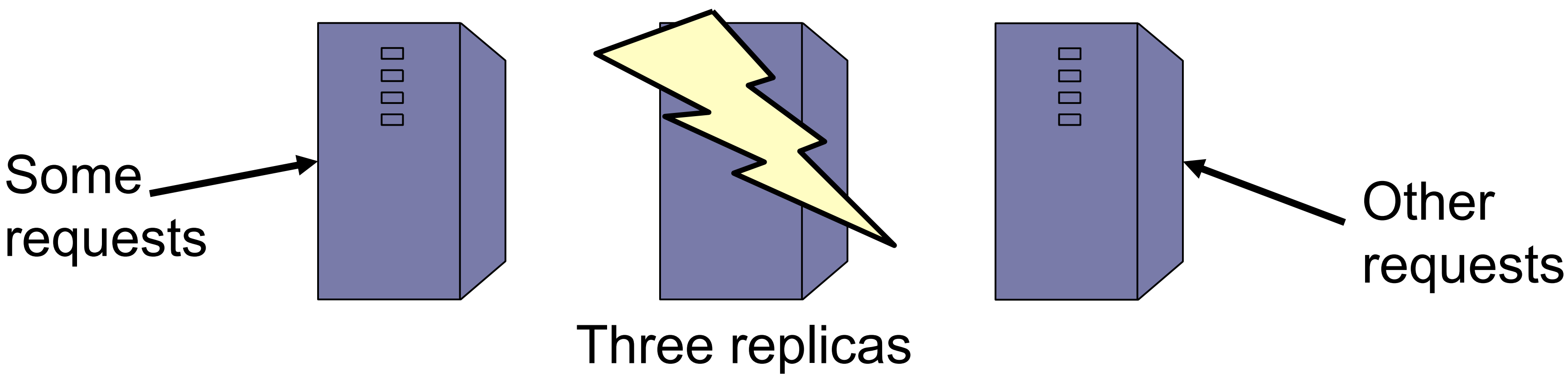
Replication

Outline

- Goals of replication
- Three types of replication
  - Eager replication
  - Lazy replication
  - Two-tier replication

Goals of Replication

- Goal 1: availability
- Goal 2: performance



- As expected, it's easy to build a replicated system that reduces performance and availability

Eager Replication

- Also called synchronous replication
- All updates are applied to all replicas (or to a majority) as part of a single transaction (need two phase commit)
  - E.g., triggers on tables apply updates to replicas within transaction
- Main goal: as if there was only one copy
  - Maintain consistency
  - Maintain **one-copy serializability**
  - i.e., execution of transactions has same effect as an execution on a non-replicated db
- Transactions must acquire global locks

Eager Master

- One master for each object holds primary copy
  - The “Master” is also called “Primary”
  - To update object, transaction must acquire a lock at the master
  - Lock at the master is global lock

- Master propagates updates to replicas synchronously
  - Updates propagate as part of the same distributed transaction
  - For example, using triggers

Crash Failures

- What happens when a secondary crashes?
  - Nothing happens
  - When secondary recovers, it catches up
- What happens when the master/primary fails?
  - Blocking would hurt availability
  - Must chose a new primary: run election
  - See the Paxos algorithm (CSE 550)

Network Failures / Partitions

- Network failures can cause trouble...
  - Secondaries think that primary failed
  - Secondaries elect a new primary
  - But primary can still be running
  - Now have two primaries!

Majority Consensus

- To avoid problem, only majority partition can continue processing at any time

- In general,
  - Whenever a replica fails or recovers...
  - a set of communicating replicas must determine...
  - whether they have a majority before they can continue

Eager Group

- With n copies
  - Exclusive lock on x copies is global exclusive lock
  - Shared lock on s copies is global shared lock
  - Must have: $2x > n$ and $s + x > n$
- Majority locking
  - $s = x = \lceil (n+1)/2 \rceil$
  - No need to run any reconfiguration algorithms
- Read-locks-one, write-locks-all
  - $s=1$ and $x = n$, high read performance
  - Need to make sure algorithm runs on quorum of machines

Eager Replication Properties

- Favors consistency over availability
  - Only majority partition can process requests
  - There appears to be a single copy of the db
- High runtime overhead
  - Must lock and update at least majority of replicas
  - Two-phase commit
  - Runs at pace of slowest replica in quorum
  - So overall system is now slower
  - Higher deadlock rate (transactions take longer)

Lazy Replication

- Also called asynchronous replication
- Also called optimistic replication

- Main goals: availability and performance

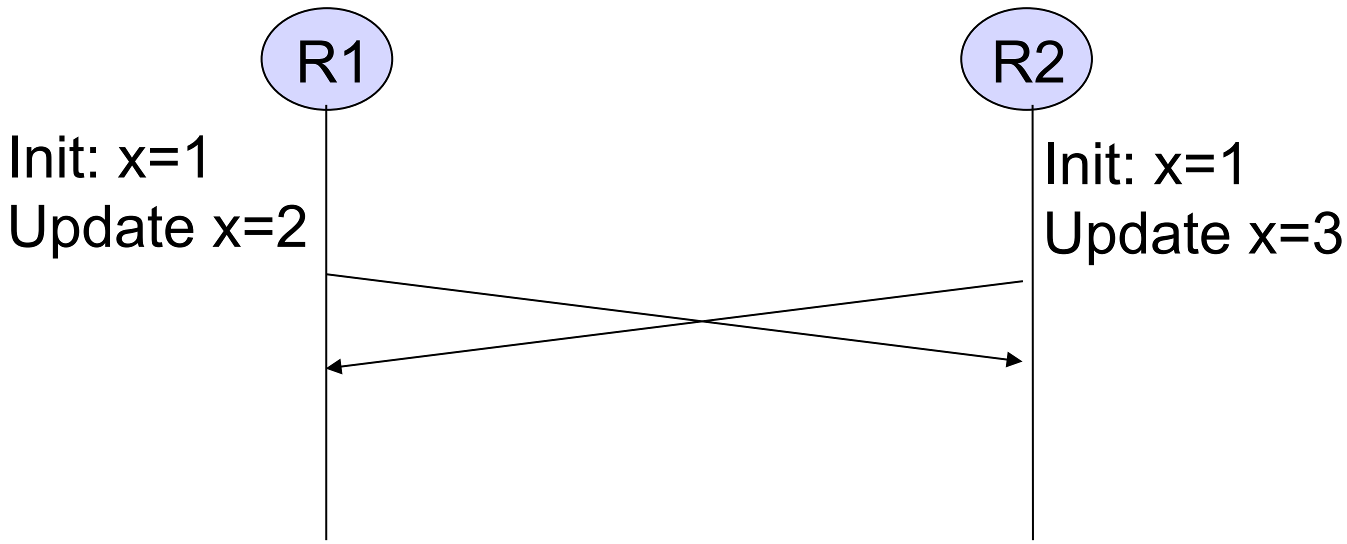
- Approach
  - One replica updated by original transaction
  - Updates propagate asynchronously to other replicas

Lazy Master

- One master holds primary copy
  - Transactions update primary copy
  - Master asynchronously propagates updates to replicas, which process them in same order (e.g. through log shipping)
  - Ensures single-copy serializability
- What happens when master/primary fails?
  - Can lose most recent transactions when primary fails!
  - After electing a new primary, secondaries must agree who is most up-to-date

Lazy Group

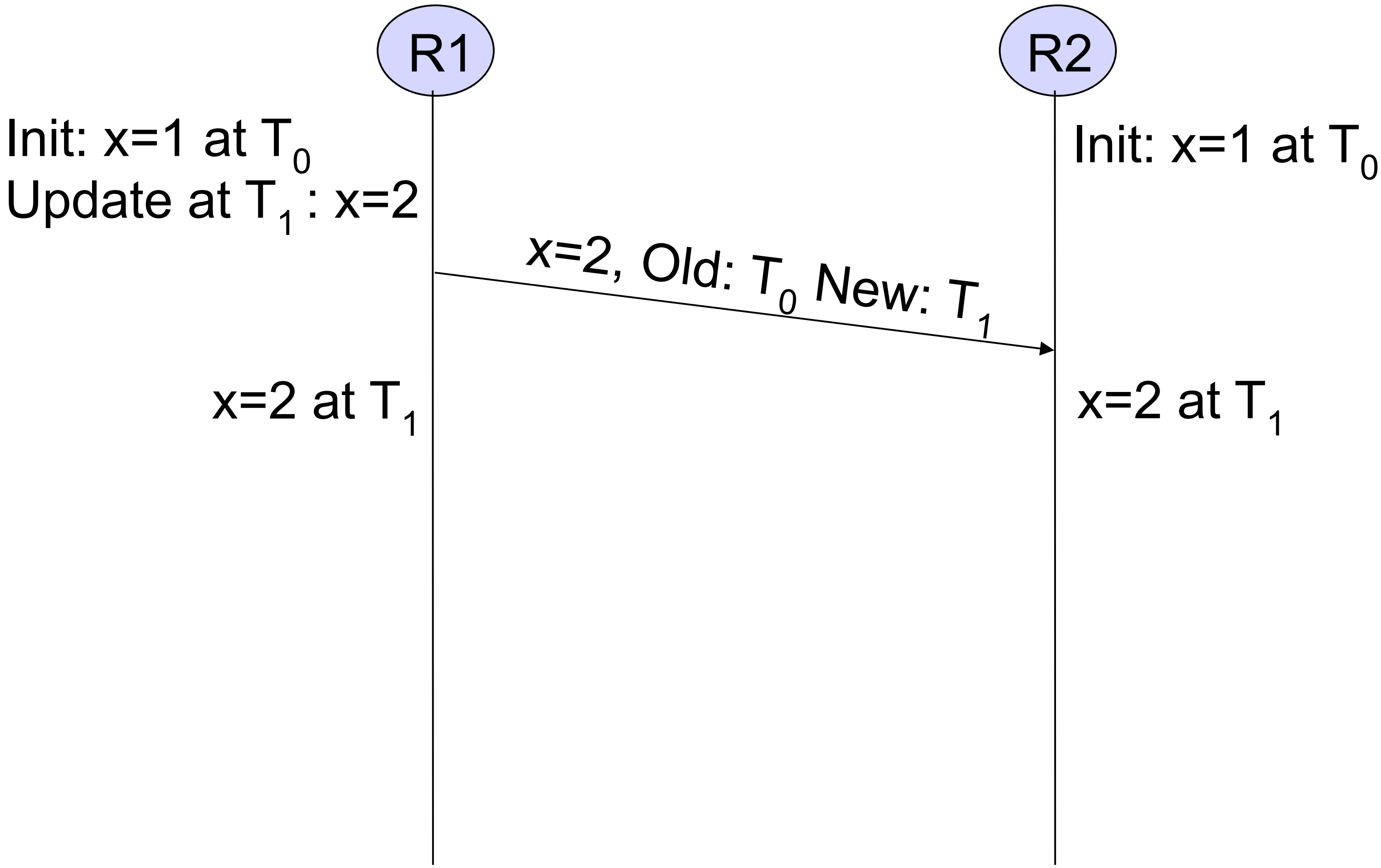
- Also called multi-master
- Best scheme for availability
- Cannot guarantee one-copy serializability!



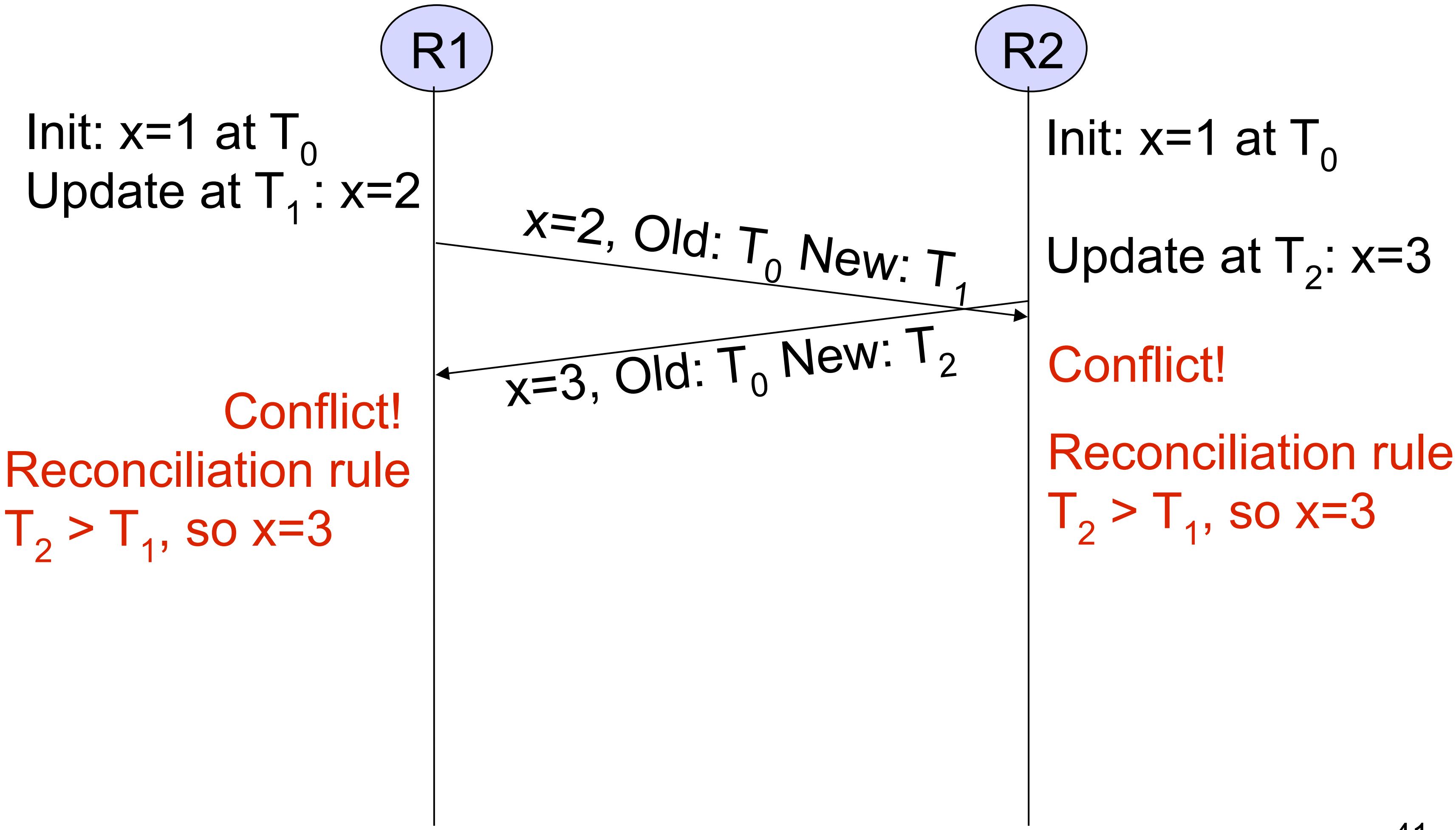
Lazy Group

- Cannot guarantee one-copy serializability!
- Instead guarantee convergence
  - DB state does not reflect any serial execution
  - But all replicas have the same state
- Detect conflicts and reconcile replica states
- Different reconciliation techniques are possible
  - Manual
  - Most recent timestamp wins
  - Site A wins over site B
  - User-defined rules, etc.

Detecting Conflicts Using Timestamps



Detecting Conflicts Using Timestamps



Lazy Group Replication Properties

- Favors availability over consistency
  - Can read and update any replica
  - High runtime performance
- Weak consistency
  - Conflicts and reconciliation

Important principle in systems research:
TINSTAAFL

Two-Tier Replication

- Benefits of lazy master and lazy group
- Each object has a master with primary copy
- When disconnected from master
  - Secondary can only run tentative transactions
- When reconnects to master
  - Master reprocesses all tentative transactions
  - Checks an acceptance criterion
  - If passes, we now have final commit order
  - Secondary undoes tentative and redoes committed

Conclusion (distributed txns and replication)

- Distributed transactions are very important
  - Necessary for scalability (throughput and global services)
  - But ACID properties require expensive 2PC protocol
- Replication is a very important problem
  - Fault-tolerance (various forms of replication)
  - Caching (lazy master)
  - Warehousing (lazy master)
  - Mobility (two-tier techniques)
- Replication is complex, but basic techniques and trade-offs are **very well known**
  - Eager or lazy replication
  - Master or no master
  - For eager replication: use quorum