Combining Concurrency Control and Recovery

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Outline

What makes a schedule serializable?

Conflict serializability

Precedence graphs

Enforcing serializability via 2-phase locking

- Shared and exclusive locks
- Lock tables and multi-level locking

Optimistic concurrency with validation

Concurrency control + recovery

Concurrency Control & Recovery

Example:

Tj	**Ti**
⋮	⋮
wj(A)	
	⋮
	ri(A)
⋮	Commit Ti
⋮	⋮
Abort Tj	

Non-persistent commit (bad!)

avoided by **recoverable** schedules

Concurrency Control & Recovery

Example:

Tj	**Ti**
⋮	⋮
wj(A)	⋮
⋮	ri(A)
⋮	wi(B)
	⋮
Abort Tj	
	[Commit Ti]

Cascading rollback (bad!)

avoided by **avoids-cascading -rollback (ACR)** schedules

Core Problem

Schedule is conflict serializable

$Tj \longrightarrow Ti$

But not recoverable

To Resolve This

Need to mark “final” decision for each transaction:

- **Commit decision:** system guarantees transaction will or has completed, no matter what
- **Abort decision:** system guarantees transaction will or has been rolled back

To Model This, 2 New Actions:

c_i = transaction T_i commits

a_i = transaction T_i aborts

Back to Example

T_j	T_i
⋮	⋮
$w_j(A)$	
⋮	$r_i(A)$
	⋮
	c_i ← can we commit here?

Definition

T_i **reads from** T_j in S ($T_j \Rightarrow_S T_i$) if:

1. $w_j(A) <_S r_i(A)$

2. $a_j \not<_S r(A)$ ($\not<_S$: does not precede)

3. If $w_j(A) <_S w_k(A) <_S r_i(A)$ then $a_k <_S r_i(A)$

Definition

Schedule S is **recoverable** if

whenever $T_j \Rightarrow_S T_i$ and $j \neq i$ and $C_i \in S$

then $C_j <_S C_i$

Notes

In all transactions, reads and writes must precede commits or aborts

$\Leftrightarrow$ If $c_i \in T_i$, then $r_i(A) < a_i$, $w_i(A) < a_i$

$\Leftrightarrow$ If $a_i \in T_i$, then $r_i(A) < a_i$, $w_i(A) < a_i$

Also, just one of c_i, a_i per transaction

How to Achieve Recoverable Schedules?

With 2PL, Hold Write Locks Until Commit (“Strict 2PL”)

Tj	**Ti**
Wj(A)	⋮
⋮	⋮
Cj	⋮
uj(A)	⋮
⋮	ri(A)

With Validation, No Change!

Each transaction’s validation point is its commit point, and only write after

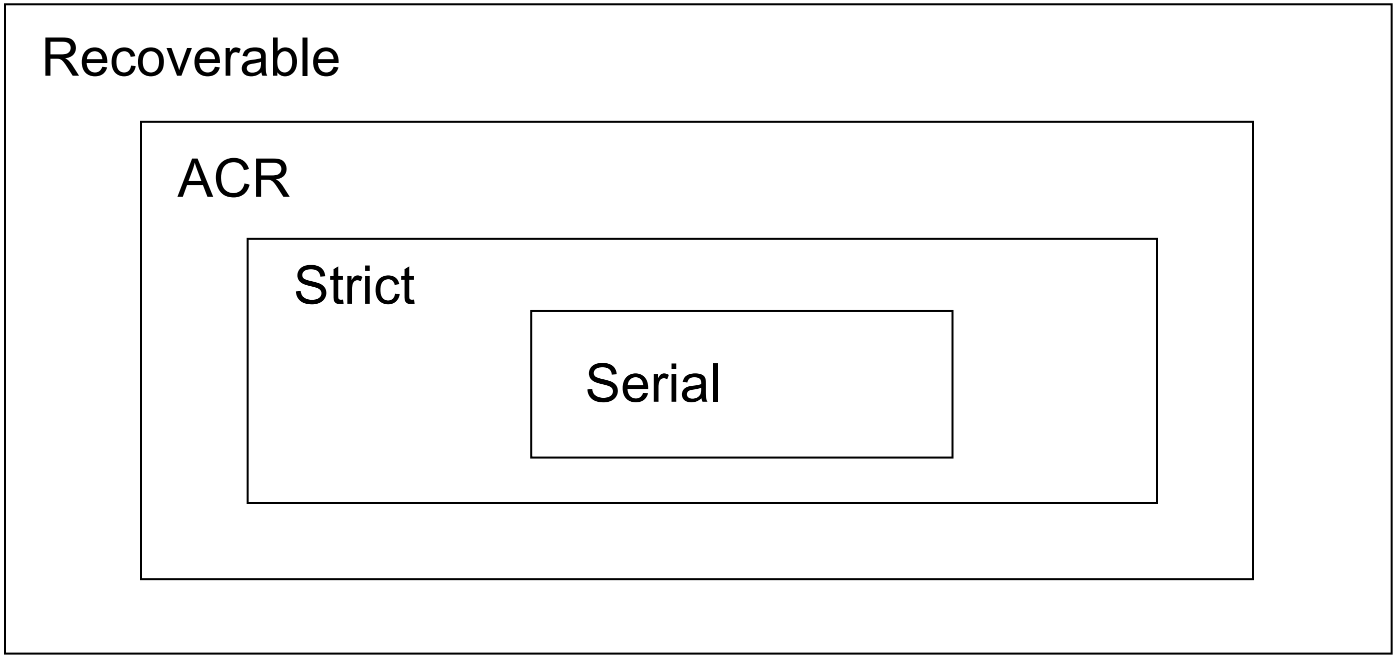
Definitions

S is **recoverable** if each transaction commits only after all transactions from which it read have committed.

S **avoids cascading rollback** if each transaction may read only those values written by committed transactions.

S is **strict** if each transaction may read and write only items previously written by committed transactions (≡ strict 2PL).

Relationship of Recoverable, ACR & Strict Schedules



Recoverable

ACR

Strict

Serial

Examples

Recoverable:

$w_1(A)\ w_1(B)\ w_2(A)\ r_2(B)\ c_1\ c_2$

Avoids Cascading Rollback:

$w_1(A)\ w_1(B)\ w_2(A)\ c_1\ r_2(B)\ c_2$

Strict:

$w_1(A)\ w_1(B)\ c_1\ w_2(A)\ r_2(B)\ c_2$

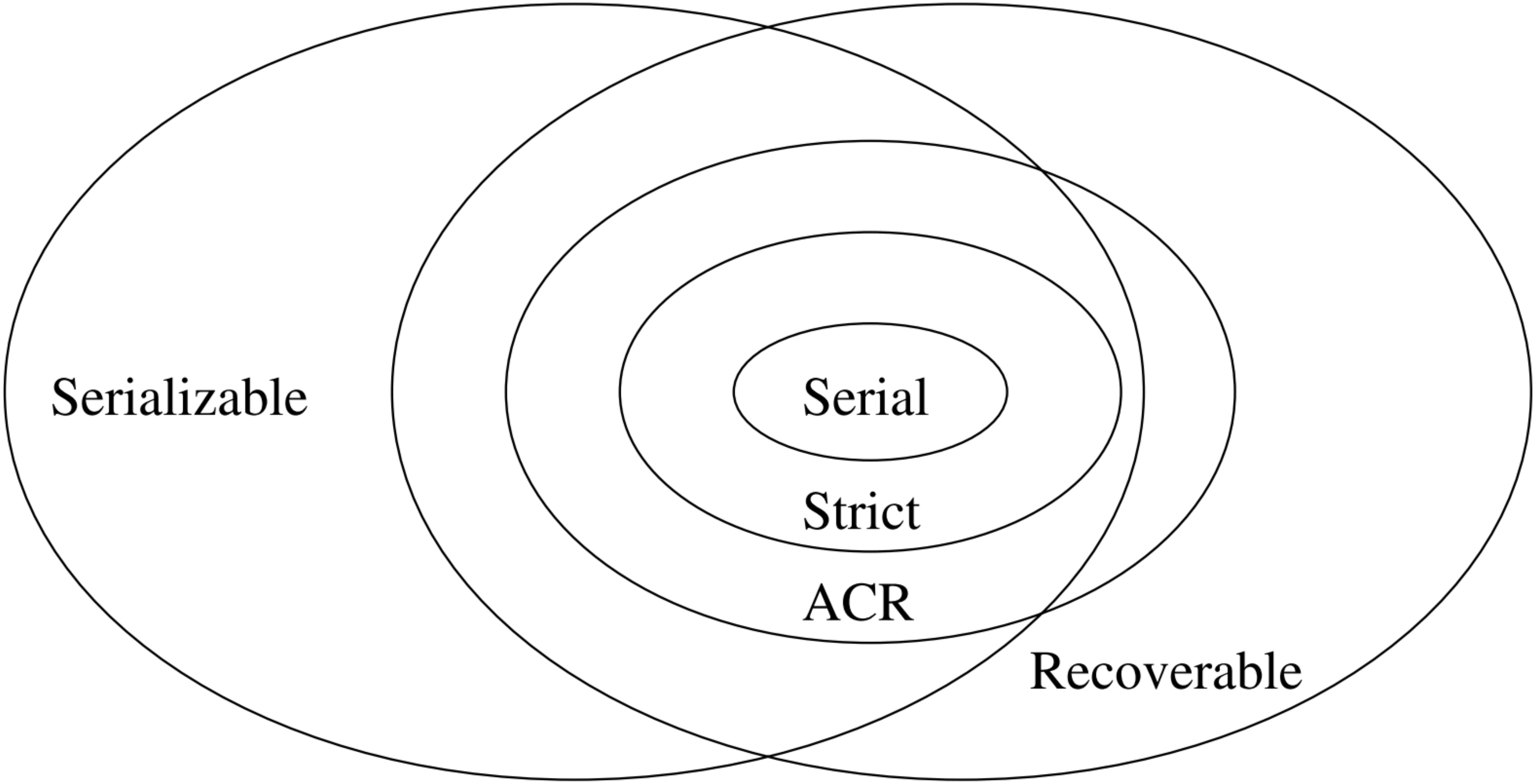
Recoverability & Serializability

Every strict schedule is serializable

Proof: equivalent to serial schedule based on the order of commit points

- » Only read/write from previously committed transactions

Recoverability & Serializability



Distributed Databases

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Why Distribute Our DB?

Store the same data item on multiple nodes to survive node failures (**replication**)

Divide data items & work across nodes to increase scale, performance (**partitioning**)

Related reasons:

- Maintenance without downtime
- Elastic resource use (don’t pay when unused)

Outline

Replication strategies

Partitioning strategies

AC & 2PC

CAP

Avoiding coordination

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Replication

General problem:

- How do recover from server failures?
- How to handle network failures?

The Eight Fallacies of Distributed Computing

Peter Deutsch

Essentially everyone, when they first build a distributed application, makes the following eight assumptions. All prove to be false in the long run and all cause *big* trouble and *painful* learning experiences.

1. The network is reliable
2. Latency is zero
3. Bandwidth is infinite
4. The network is secure
5. Topology doesn't change
6. There is one administrator
7. Transport cost is zero
8. The network is homogeneous

For more details, read the article by Arnon Rotem-Gal-Oz

Replication

Store each data item on multiple nodes!

Question: how to read/write to them?

Primary-Backup

Elect one node “primary”

Store other copies on “backup”

Send requests to primary, which then forwards operations or logs to backups

Backup coordination is either:

- Synchronous (write to backups before acking)
- Asynchronous (backups slightly stale)

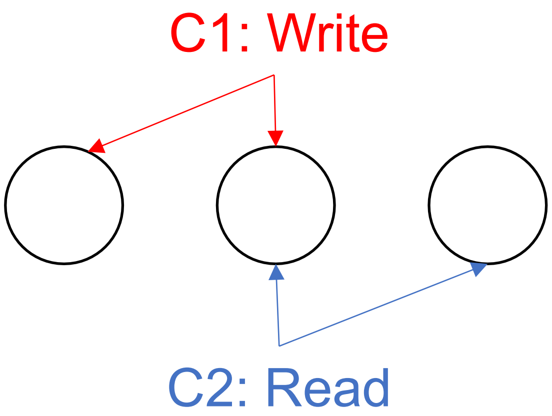
Quorum Replication

Read and write to intersecting sets of servers; no one “primary”

Common: majority quorum

- » More exotic ones exist, like grid quorums

Surprise: primary-backup is a quorum too!



C1: Write

C2: Read

What If We Don’t Have Intersection?

What If We Don’t Have Intersection?

Alternative: “eventual consistency”

- If writes stop, eventually all replicas will contain the same data
- Basic idea: asynchronously broadcast all writes to all replicas

When is this acceptable?

How Many Replicas?

In general, to survive F fail-stop failures, need F+1 replicas

Question: what if replicas fail arbitrarily? Adversarially?

What To Do During Failures?

Cannot contact primary?

What To Do During Failures?

Cannot contact primary?

- » Is the primary failed?
- » Or can we simply not contact it?

What To Do During Failures?

Cannot contact majority?

- » Is the majority failed?
- » Or can we simply not contact it?

Solution to Failures:

Traditional DB: page the DBA

Distributed computing: use **consensus**

- Several algorithms: Paxos, Raft
- Today: many implementations
  - Zookeeper, etcd, Consul
- Idea: keep a reliable, distributed shared record of who is “primary”

Consensus in a Nutshell

Goal: distributed agreement

- e.g., on who is primary

Participants broadcast votes

- If majority of notes ever accept a vote v, then they will eventually choose v
- In the event of failures, retry
- Randomization greatly helps!

Take CS244B

What To Do During Failures?

Cannot contact majority?

- Is the majority failed?
- Or can we simply not contact it?

Consensus can provide an answer!

- Although we may need to stall…
- (more on that later)

Replication Summary

Store each data item on multiple nodes!

Question: how to read/write to them?

- Answers: primary-backup, quorums
- Use consensus to decide on configuration

Outline

Replication strategies

Partitioning strategies

AC & 2PC

CAP

Avoiding coordination

Partitioning

General problem:

- Databases are big!
- What if we don’t want to store the whole database on each server?

Partitioning Basics

Split database into chunks called “partitions”

- Typically partition by row
- Can also partition by column (rare)

Put one or more partitions per server

Partitioning Strategies

Hash keys to servers

- » Random assignment

Partition keys by range

- » Keys stored contiguously

What if servers fail (or we add servers)?

- » Rebalance partitions (use consensus!)

Pros/cons of hash vs range partitioning?

What About Distributed Transactions?

Replication:

- Must make sure replicas stay up to date
- Need to reliably replicate commit log!

Partitioning:

- Must make sure all partitions commit/abort
- Need cross-partition concurrency control!

Outline

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Atomic Commitment

Informally: either all participants commit a transaction, or none do

“participants” = partitions involved in a given transaction

So, What’s Hard?

So, What’s Hard?

All the problems as consensus…

…plus, if *any* node votes to *abort*, all must decide to *abort*

- » In consensus, simply need agreement on “some” value

Two-Phase Commit

Canonical protocol for atomic commitment (developed 1976-1978)

Basis for most fancier protocols

Widely used in practice

Use a transaction *coordinator*

- » Usually client – not always!

Two Phase Commit (2PC)

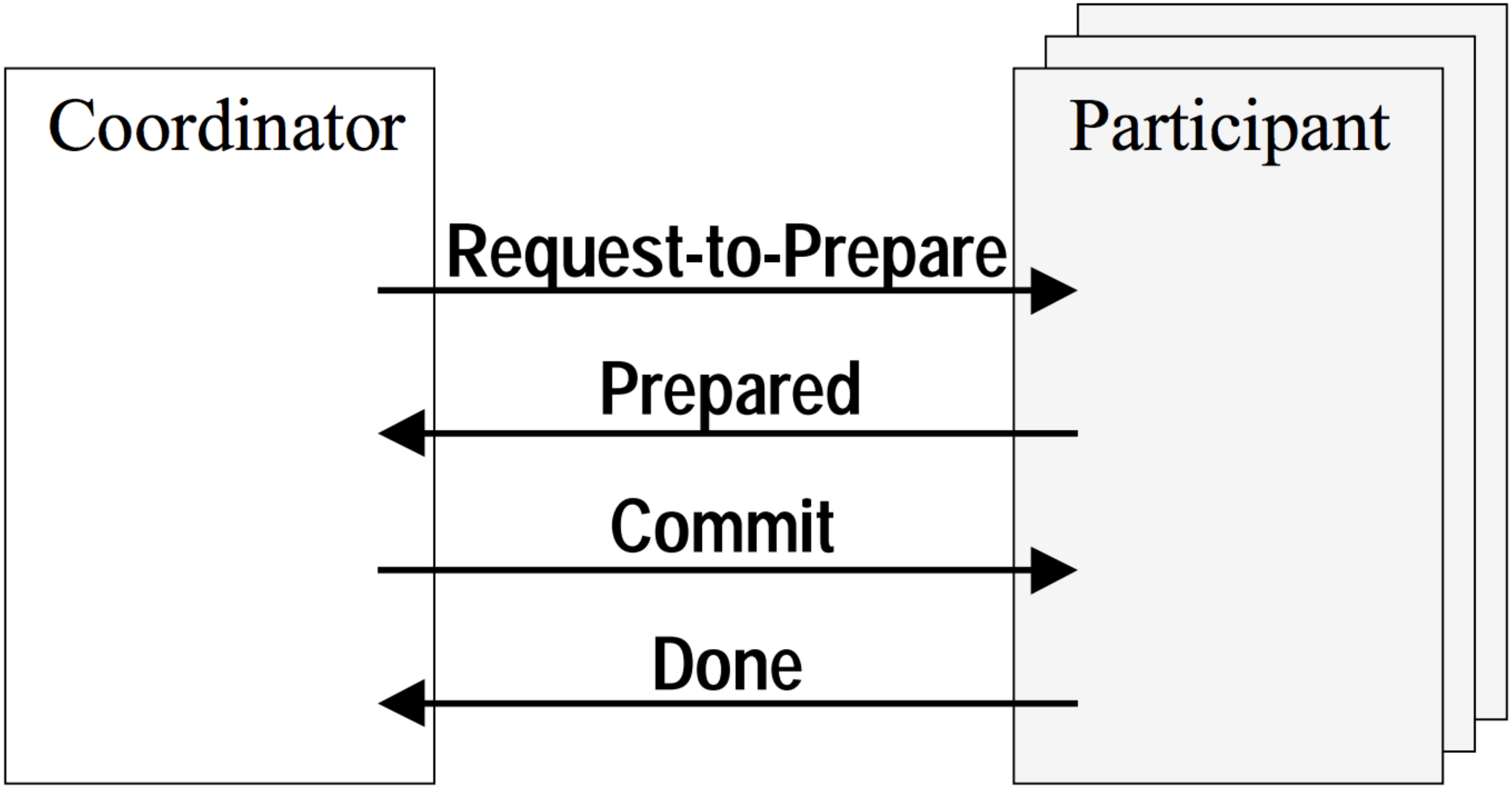
1. Transaction coordinator sends *prepare* message to each participating node

2. Each participating node responds to coordinator with *prepared* or *no*

3. If coordinator receives all *prepared*:
   - » Broadcast *commit*

4. If coordinator receives any *no:*
   - » Broadcast *abort*

Case 1: Commit



Coordinator

Participant

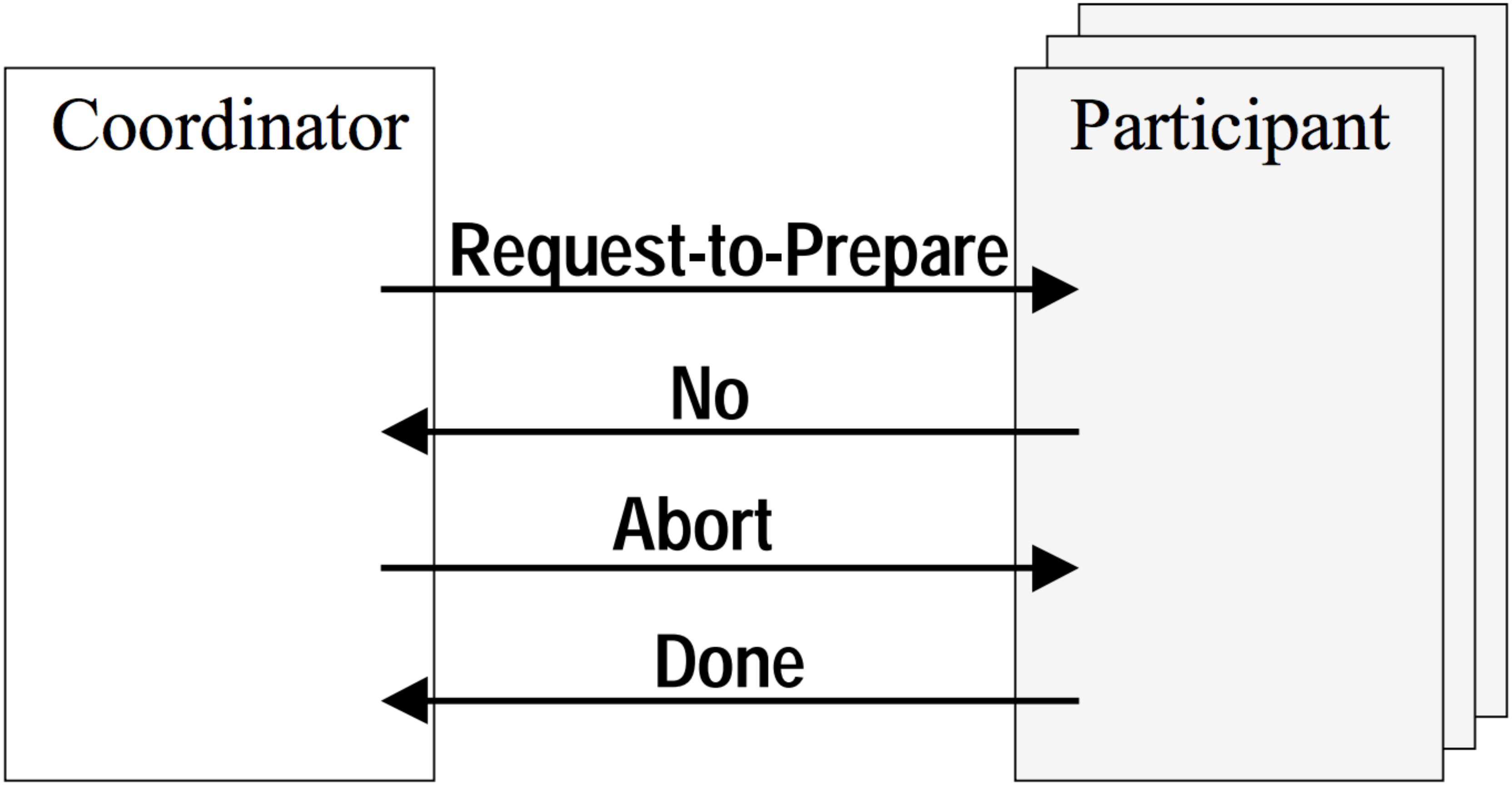
Request-to-Prepare

Prepared

Commit

Done

Case 2: Abort



2PC + Validation

Participants perform validation upon receipt of *prepare* message

Validation essentially blocks between *prepare* and *commit* message

2PC + 2PL

Traditionally: run 2PC at commit time

- i.e., perform locking as usual, then run 2PC when transaction would normally commit

Under strict 2PL, run 2PC before unlocking write locks

2PC + Logging

Log records must be flushed to disk on each participant before it replies to *prepare*

- (And updates must be replicated to F other replicas if doing replication)