Atomic Commit and Concurrency Control

COS 418: Distributed Systems
Lecture 17

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Let’s Scale Strong Consistency!

1. Atomic Commit
   - Two-phase commit (2PC)
2. Serializability
   - Strict serializability
3. Concurrency Control:
   - Two-phase locking (2PL)
   - Optimistic concurrency control (OCC)

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Atomic Commit

- Atomic: All or nothing
- Either all participants do something (commit) or no participant does anything (abort)
- Common use: commit a transaction that updates data on different shards

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Transaction Examples

- Bank account transfer
  - Turing -= $100
  - Lovelace += $100
- Maintaining symmetric relationships
  - Lovelace FriendOf Turing
  - Turing FriendOf Lovelace
- Order product
  - Charge customer card
  - Decrement stock
  - Ship stock

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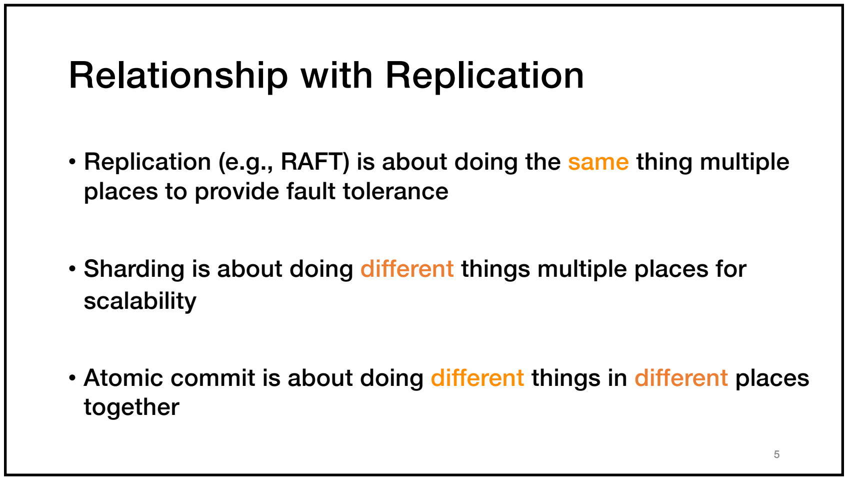

Relationship with Replication

- Replication (e.g., RAFT) is about doing the same thing multiple places to provide fault tolerance
- Sharding is about doing different things multiple places for scalability
- Atomic commit is about doing different things in different places together

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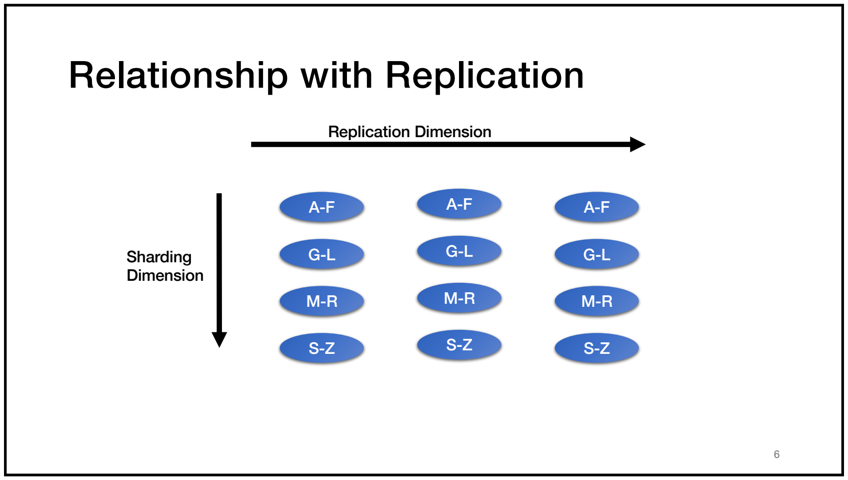

Relationship with Replication

Replication Dimension

Sharding Dimension

A-F	A-F	A-F
G-L	G-L	G-L
M-R	M-R	M-R
S-Z	S-Z	S-Z

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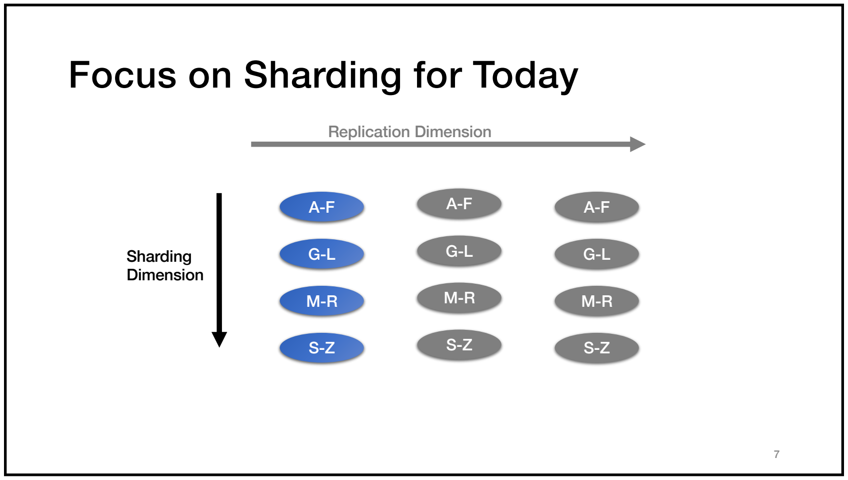

Focus on Sharding for Today

Replication Dimension

Sharding Dimension

A-F	A-F	A-F
G-L	G-L	G-L
M-R	M-R	M-R
S-Z	S-Z	S-Z

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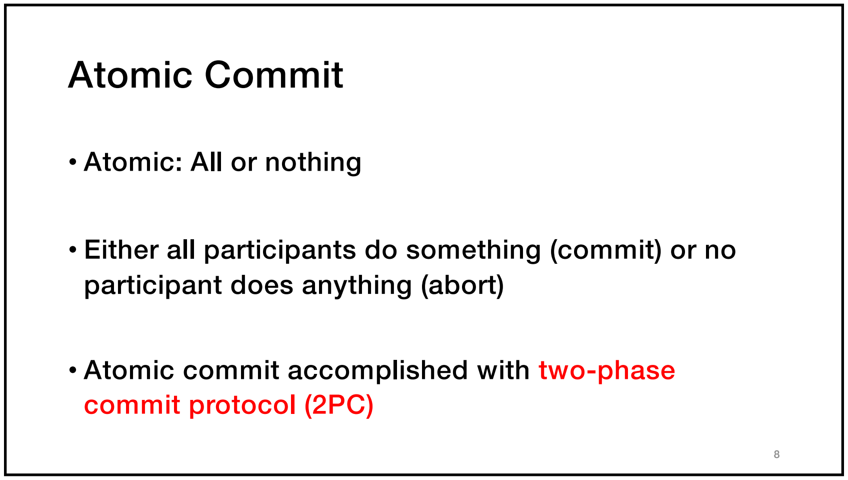

Atomic Commit

- Atomic: All or nothing
- Either all participants do something (commit) or no participant does anything (abort)
- Atomic commit accomplished with two-phase commit protocol (2PC)

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Two-Phase Commit

- Phase 1
  - Coordinator sends Prepare request to all participants
  - Each participant votes yes or no
    - Sends yes or no back to coordinator
    - Typically acquires locks if vote yes
- Coordinator inspects all votes
  - If all yes, then commit
  - If any no, then abort
- Phase 2
  - Coordinator sends Commit or Abort to all participants
  - If commit, each participants acts
  - Each participant releases locks
  - Each participant sends Ack back to coordinator

Unilateral Abort

- Any participant can cause an abort
- With 100 participants, if 99 vote yes and 1 votes no => abort!
- Common reasons to abort:
  - Cannot acquire required lock
  - No memory or disk space available to do write
  - Transaction constraint fails, e.g., Alan does not have $100
- Q: Why do we want unilateral abort for atomic commit?

Atomic Commit

- All-or-nothing
- Unilateral abort
- Two-phase commit: Prepare -> Commit/abort

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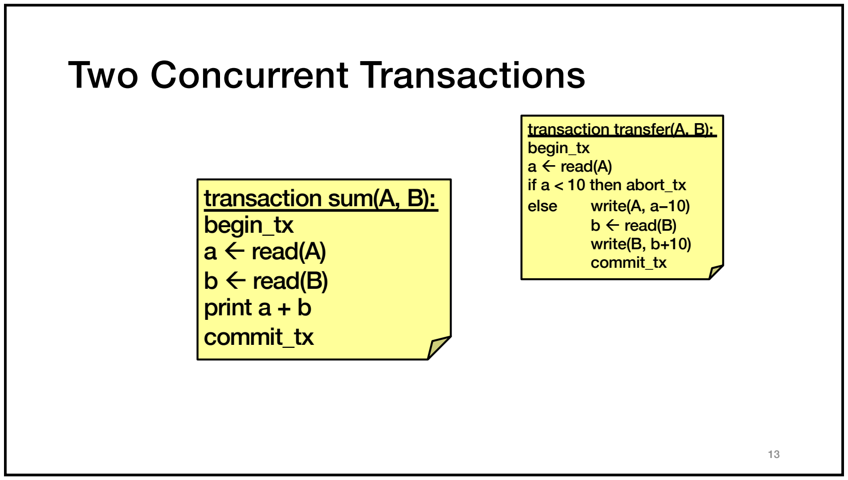

Two Concurrent Transactions

```
transaction sum(A, B):
begin_tx
a ← read(A)
b ← read(B)
print a + b
commit_tx
```

```
transaction transfer(A, B):
begin_tx
a ← read(A)
if a < 10 then abort_tx
else      write(A, a−10)
          b ← read(B)
          write(B, b+10)
          commit_tx
```

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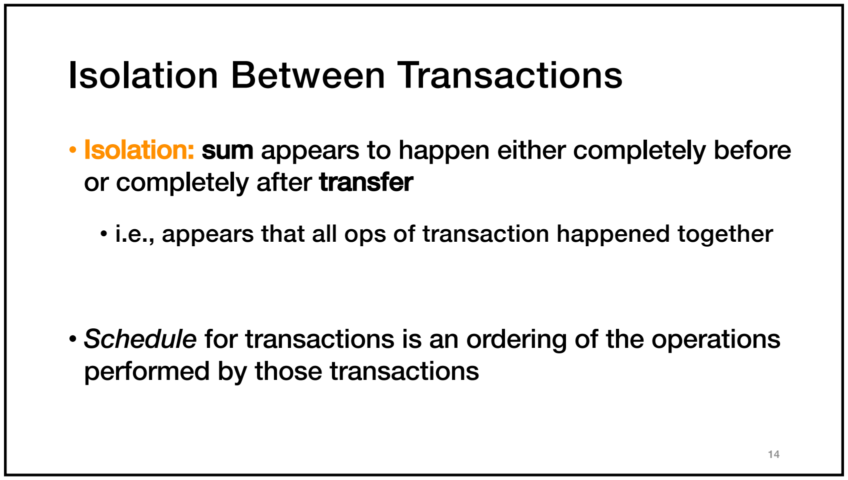

Isolation Between Transactions

- **Isolation: sum** appears to happen either completely before or completely after **transfer**
  - i.e., appears that all ops of transaction happened together

- *Schedule* for transactions is an ordering of the operations performed by those transactions

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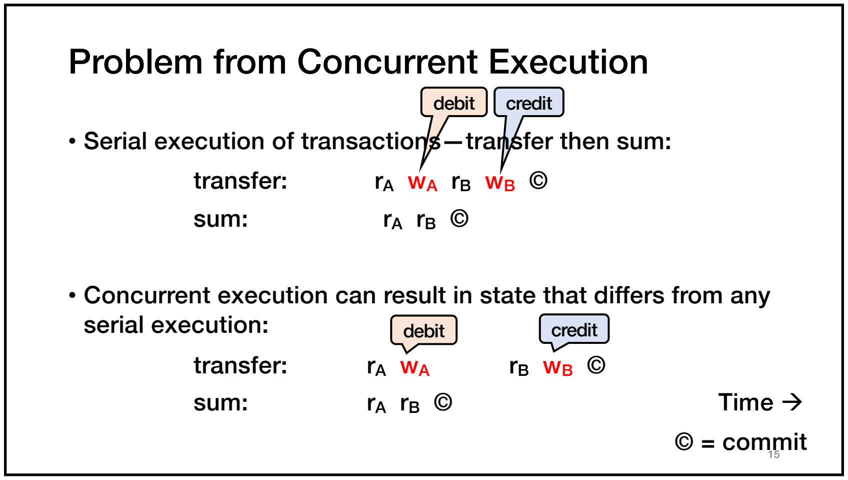

Problem from Concurrent Execution

- Serial execution of transactions—transfer then sum:

debit
credit

transfer: r_A w_A r_B w_B ©

sum: r_A r_B ©

- Concurrent execution can result in state that differs from any serial execution:

debit
credit

transfer: r_A w_A r_B w_B ©

sum: r_A r_B ©

Time →

© = commit

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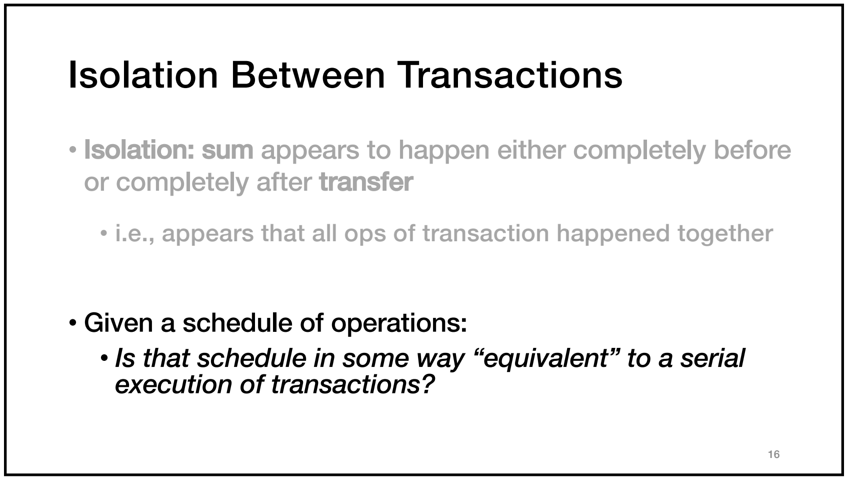

Isolation Between Transactions

- **Isolation: sum** appears to happen either completely before or completely after **transfer**
  - i.e., appears that all ops of transaction happened together

- Given a schedule of operations:
  - *Is that schedule in some way "equivalent" to a serial execution of transactions?*

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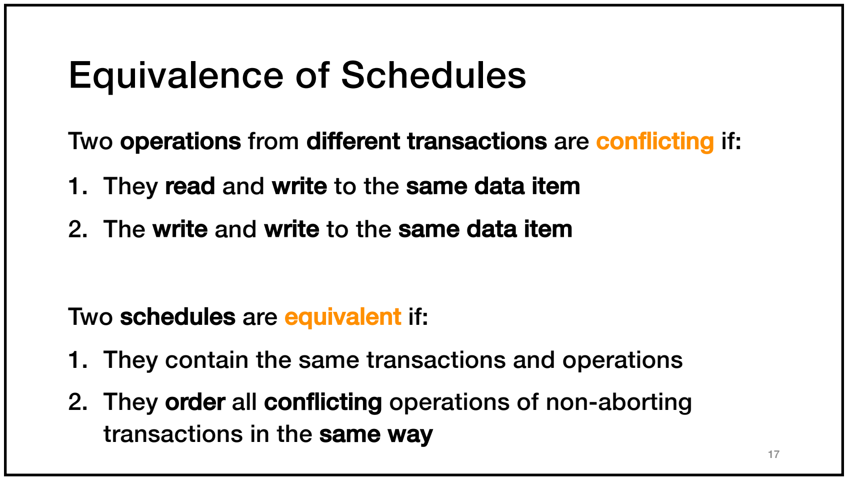

Equivalence of Schedules

Two **operations** from **different transactions** are conflicting if:

1. They **read** and **write** to the **same data item**
2. The **write** and **write** to the **same data item**

Two **schedules** are equivalent if:

1. They contain the same transactions and operations
2. They **order** all **conflicting** operations of non-aborting transactions in the **same way**

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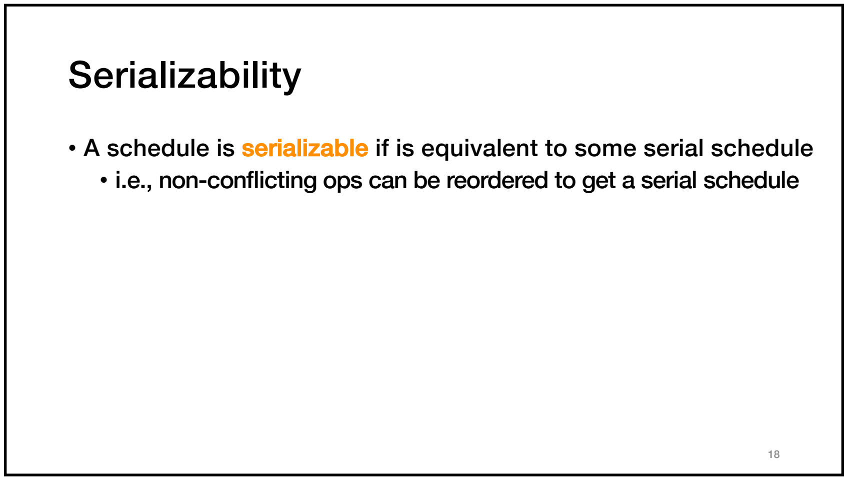

Serializability

- A schedule is serializable if is equivalent to some serial schedule
  - i.e., non-conflicting ops can be reordered to get a serial schedule

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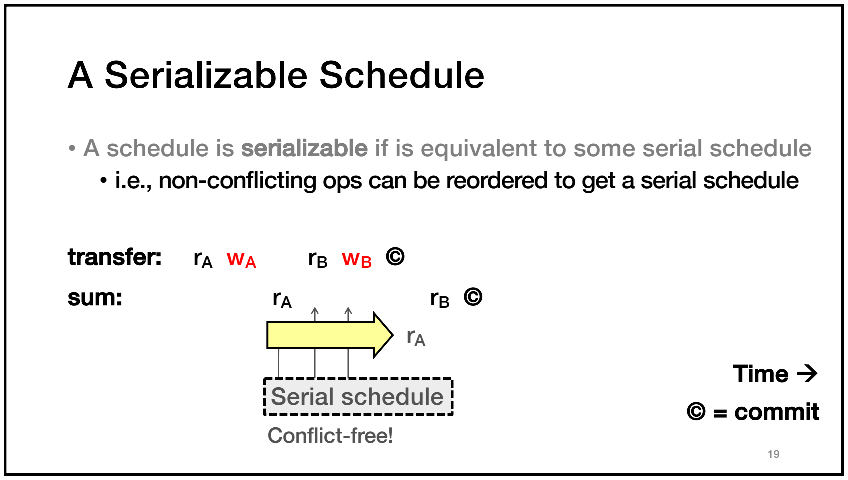

A Serializable Schedule

- A schedule is **serializable** if is equivalent to some serial schedule
  - i.e., non-conflicting ops can be reordered to get a serial schedule

transfer: r_A w_A r_B w_B ©
sum: r_A r_B ©
r_A
Serial schedule
Conflict-free!

Time →

© = commit

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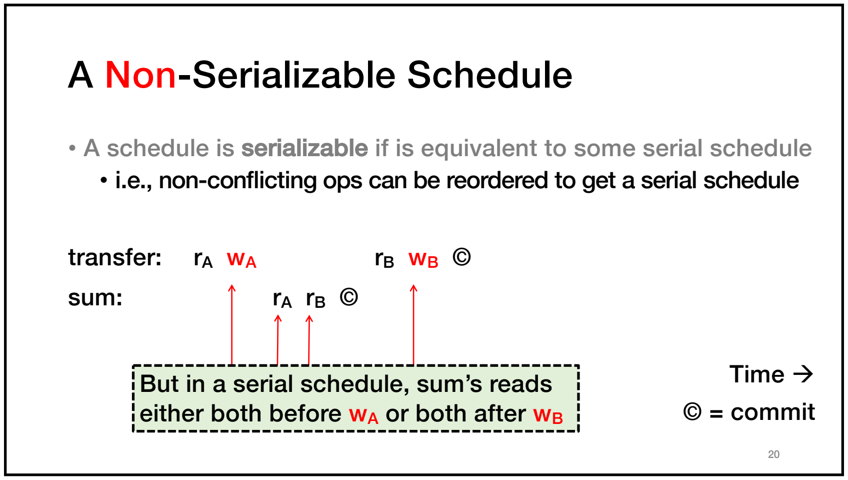

A Non-Serializable Schedule

- A schedule is **serializable** if is equivalent to some serial schedule
  - i.e., non-conflicting ops can be reordered to get a serial schedule

transfer: r_A w_A r_B w_B ©
sum: r_A r_B ©

But in a serial schedule, sum's reads either both before w_A or both after w_B

Time →

© = commit

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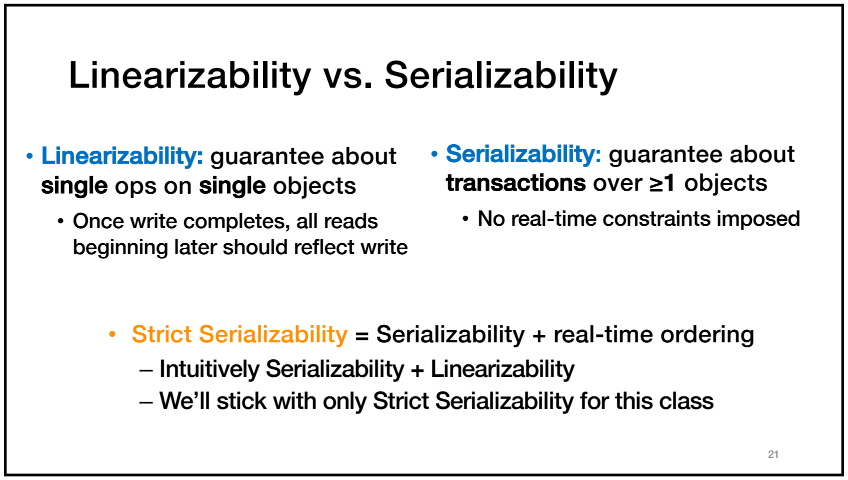

Linearizability vs. Serializability

- **Linearizability:** guarantee about **single** ops on **single** objects
  - Once write completes, all reads beginning later should reflect write
- **Serializability:** guarantee about **transactions** over **≥1** objects
  - No real-time constraints imposed

- Strict Serializability = Serializability + real-time ordering
  - – Intuitively Serializability + Linearizability
  - – We'll stick with only Strict Serializability for this class

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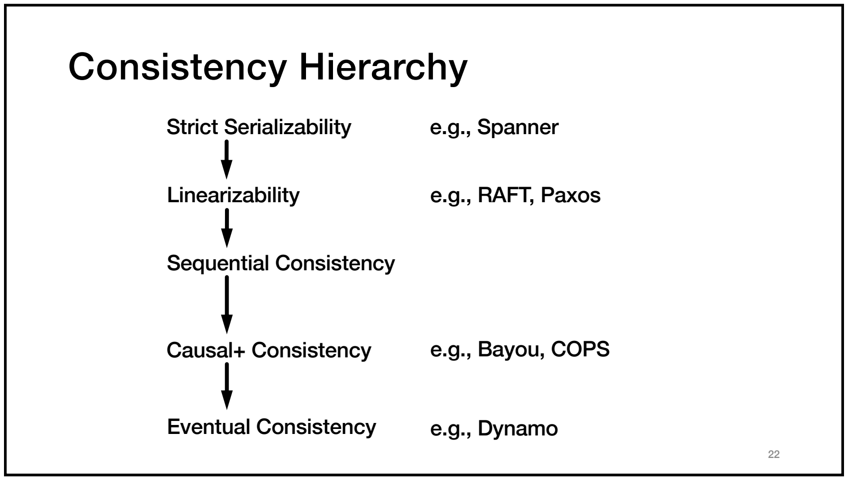

Consistency Hierarchy

Strict Serializability	e.g., Spanner
↓	
Linearizability	e.g., RAFT, Paxos
↓	
Sequential Consistency	
↓	
Causal+ Consistency	e.g., Bayou, COPS
↓	
Eventual Consistency	e.g., Dynamo

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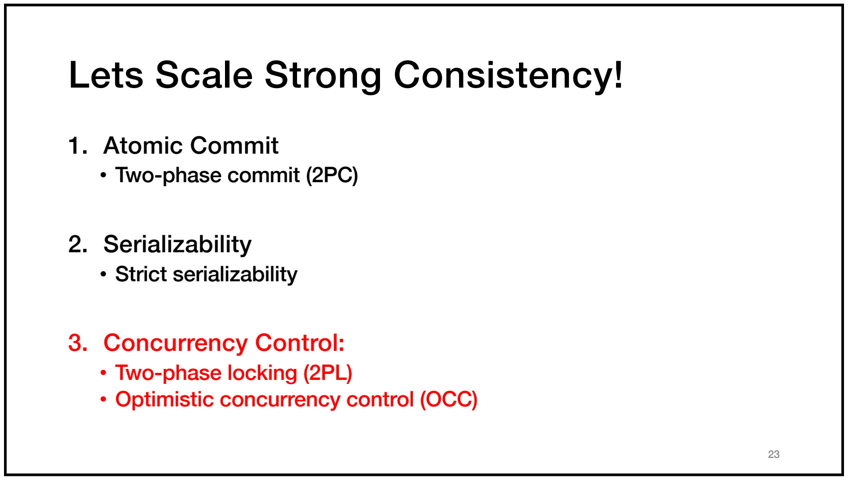

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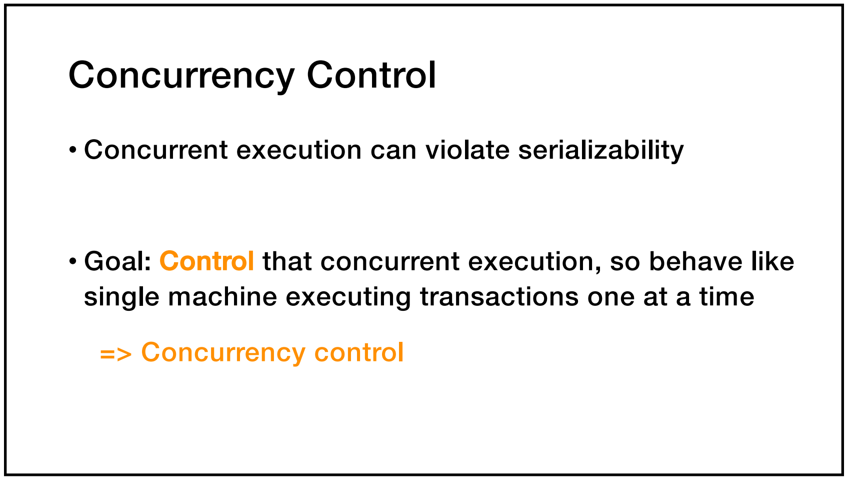

Concurrency Control

- Concurrent execution can violate serializability

- Goal: Control that concurrent execution, so behave like single machine executing transactions one at a time

  => Concurrency control

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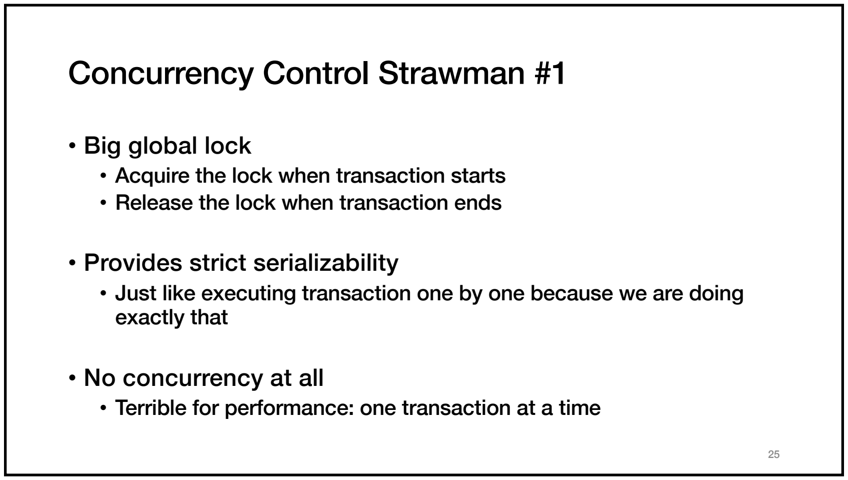
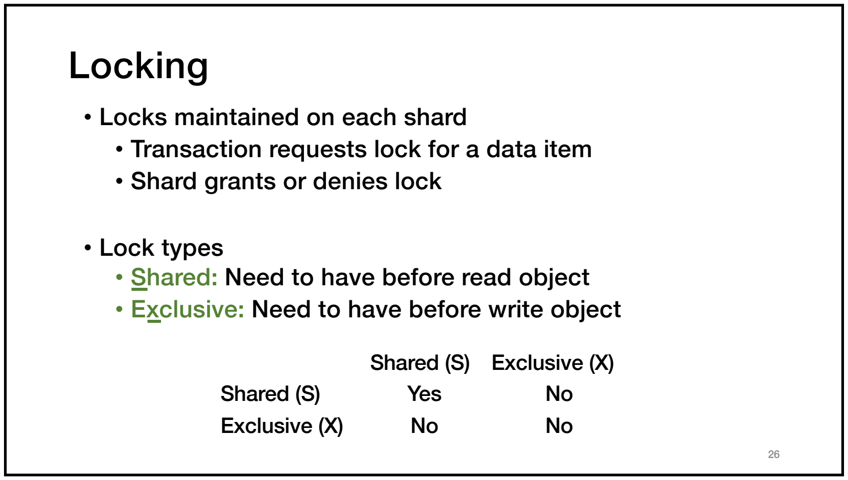


Concurrency Control Strawman #1

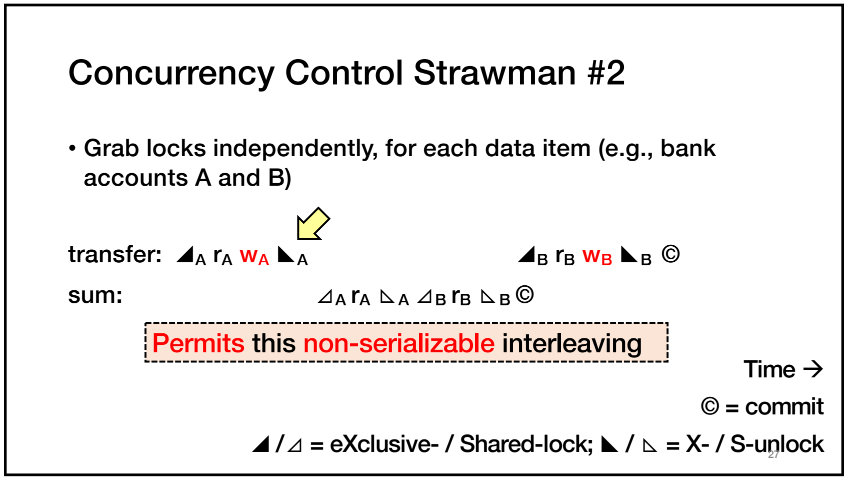
- Big global lock
  - Acquire the lock when transaction starts
  - Release the lock when transaction ends
- Provides strict serializability
  - Just like executing transaction one by one because we are doing exactly that
- No concurrency at all
  - Terrible for performance: one transaction at a time



Locking

- Locks maintained on each shard
  - Transaction requests lock for a data item
  - Shard grants or denies lock
- Lock types
  - Shared: Need to have before read object
  - Exclusive: Need to have before write object

	Shared (S)	Exclusive (X)
Shared (S)	Yes	No
Exclusive (X)	No	No



Concurrency Control Strawman #2

- Grab locks independently, for each data item (e.g., bank accounts A and B)

transfer: ◢$_A$ r_A w_A ◣$_A$ ◢$_B$ r_B w_B ◣$_B$ ©

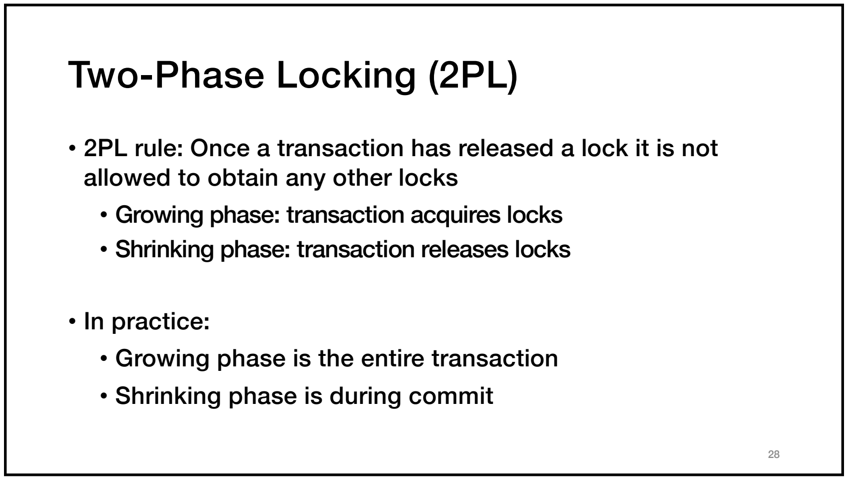
sum: ⊿$_A$ r_A ◺$_A$ ⊿$_B$ r_B ◺$_B$ ©

Permits this non-serializable interleaving

Time →

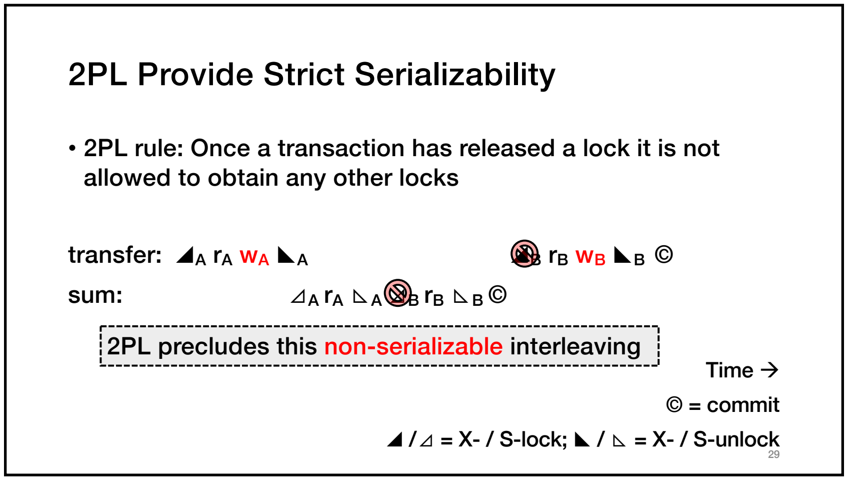
© = commit

◢ / ⊿ = eXclusive- / Shared-lock; ◣ / ◺ = X- / S-unlock



Two-Phase Locking (2PL)

- 2PL rule: Once a transaction has released a lock it is not allowed to obtain any other locks
  - Growing phase: transaction acquires locks
  - Shrinking phase: transaction releases locks
- In practice:
  - Growing phase is the entire transaction
  - Shrinking phase is during commit



2PL Provide Strict Serializability

- 2PL rule: Once a transaction has released a lock it is not allowed to obtain any other locks

transfer: ◢$_A$ r_A w_A ◣$_A$ 🚫◢$_B$ r_B w_B ◣$_B$ ©

sum: ⊿$_A$ r_A ◺$_A$ 🚫⊿$_B$ r_B ◺$_B$ ©

2PL precludes this non-serializable interleaving

Time →

© = commit

◢ / ⊿ = X- / S-lock; ◣ / ◺ = X- / S-unlock

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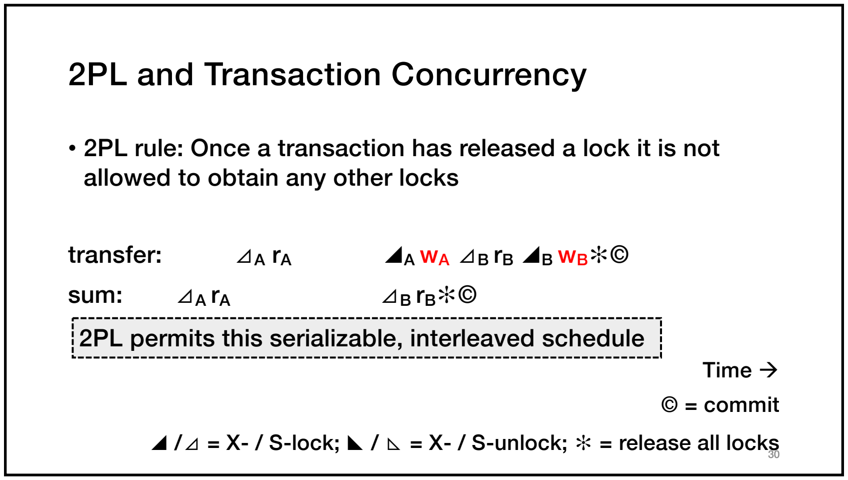

2PL and Transaction Concurrency

- 2PL rule: Once a transaction has released a lock it is not allowed to obtain any other locks

transfer: ⊿$_A$ r_A ◢$_A$ w_A ⊿$_B$ r_B ◢$_B$ w_B✻©

sum: ⊿$_A$ r_A ⊿$_B$ r_B✻©

2PL permits this serializable, interleaved schedule

Time →

© = commit

◢ / ⊿ = X- / S-lock; ◣ / ◺ = X- / S-unlock; ✻ = release all locks

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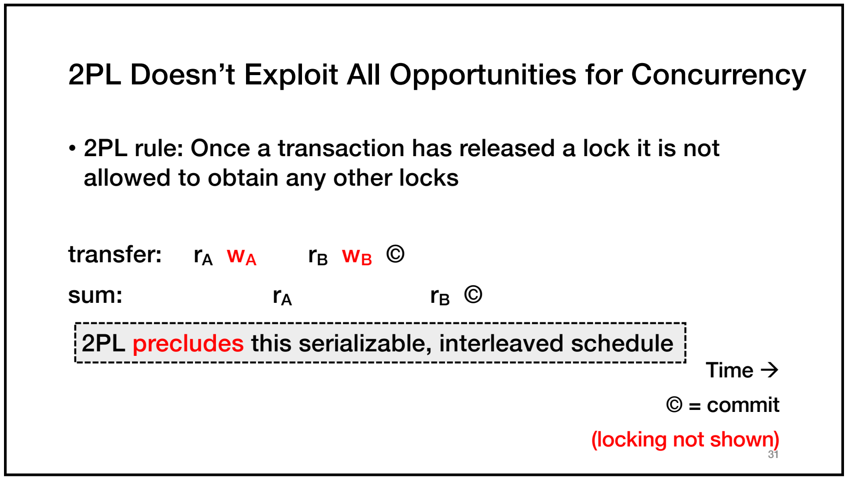

2PL Doesn’t Exploit All Opportunities for Concurrency

- 2PL rule: Once a transaction has released a lock it is not allowed to obtain any other locks

transfer: r_A w_A r_B w_B ©

sum: r_A r_B ©

2PL precludes this serializable, interleaved schedule

Time →

© = commit

(locking not shown)

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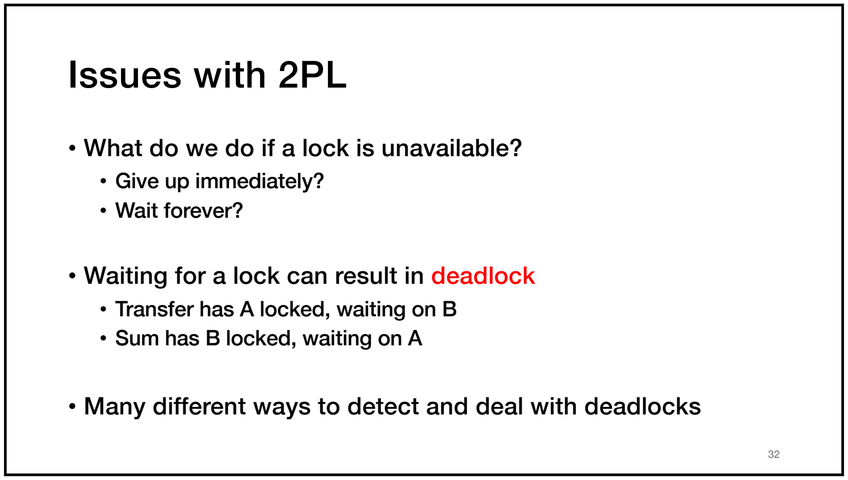

Issues with 2PL

- What do we do if a lock is unavailable?
  - Give up immediately?
  - Wait forever?
- Waiting for a lock can result in deadlock
  - Transfer has A locked, waiting on B
  - Sum has B locked, waiting on A
- Many different ways to detect and deal with deadlocks

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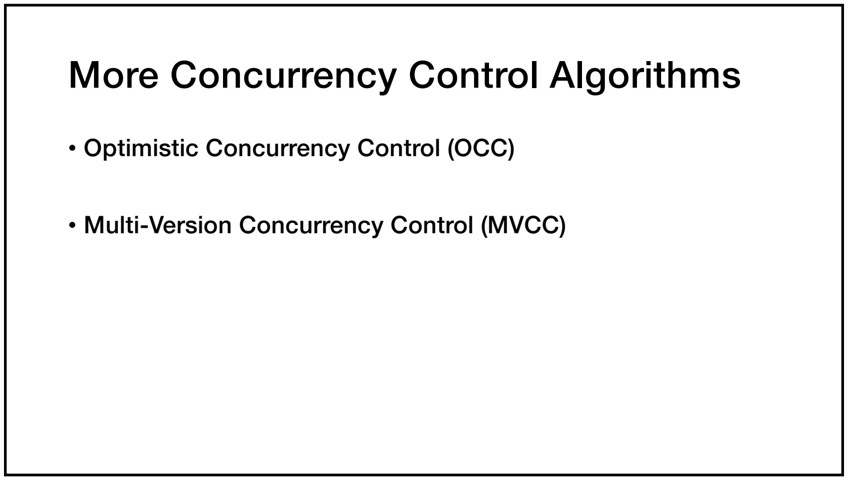

More Concurrency Control Algorithms

- Optimistic Concurrency Control (OCC)
- Multi-Version Concurrency Control (MVCC)

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