# Atomic Commit and Concurrency Control

COS 418/518: Distributed Systems
Lecture 16

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# Lets 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)

# 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

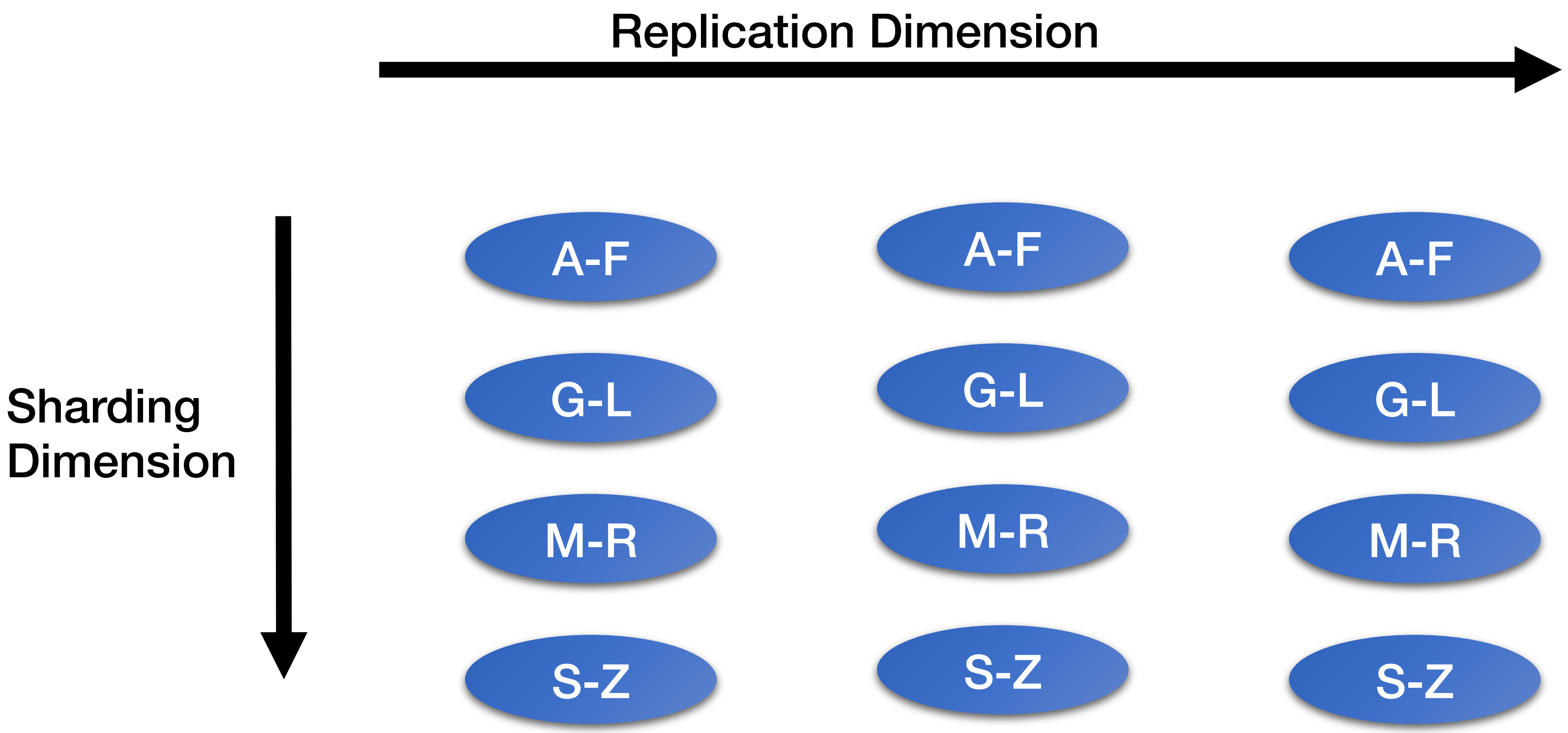
# Transaction Examples

- 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

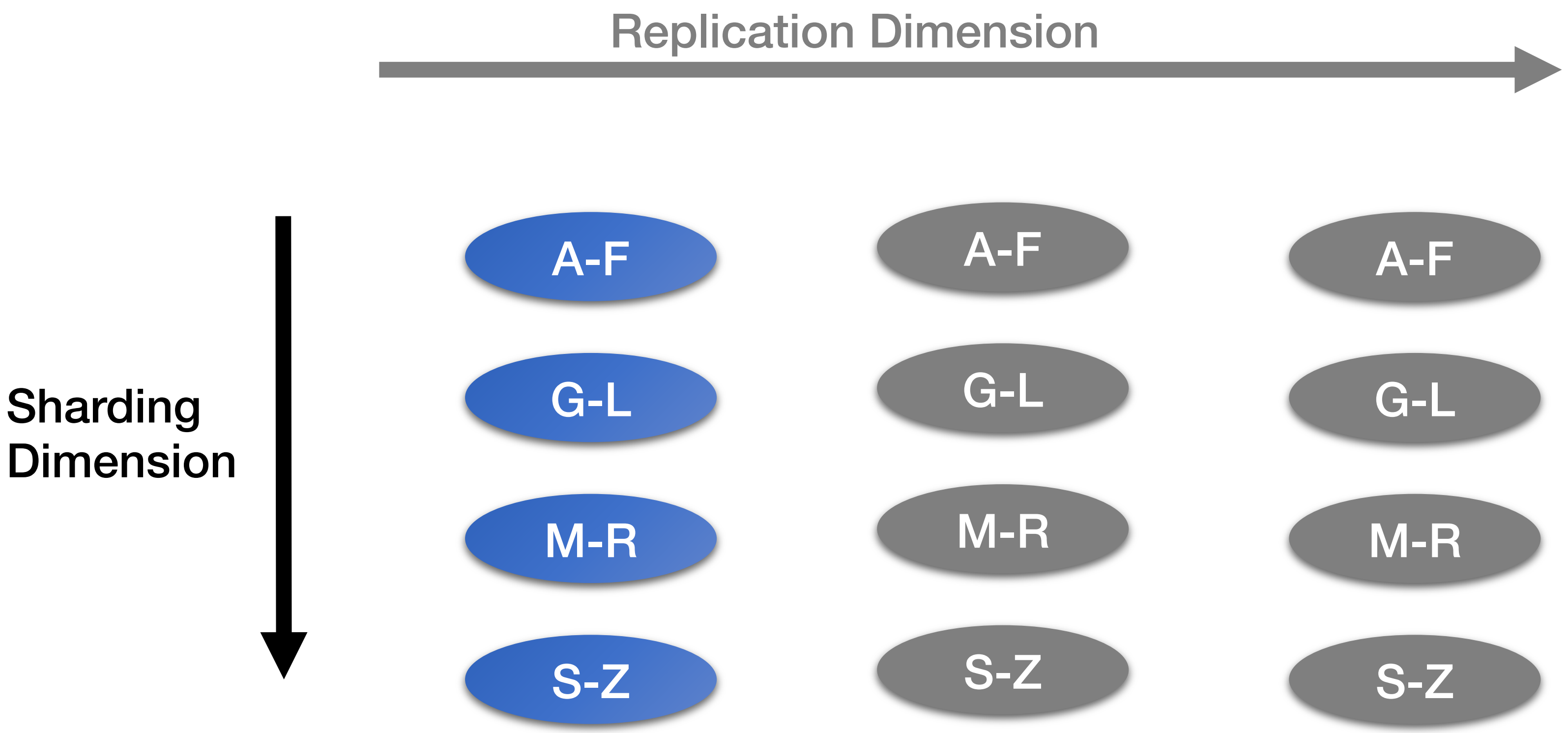
# Relationship with Replication

- 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

# Relationship with Replication



# Focus on Sharding for Today



# 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)

# Two-Phase Commit

- Phase 1
  - Coordinator sends Prepare requests to all participants
  - Each participant votes yes or no
    - Sends yes or no vote back to coordinator
    - Typically acquires locks if they 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 participant does something
  - Each participant releases locks
  - Each participant sends an Ack back to the 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
```

# Isolation Between Transactions

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

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

# 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

# Isolation Between Transactions

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

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

# Equivalence of Schedules

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

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

- Two **schedules** are **equivalent** if:

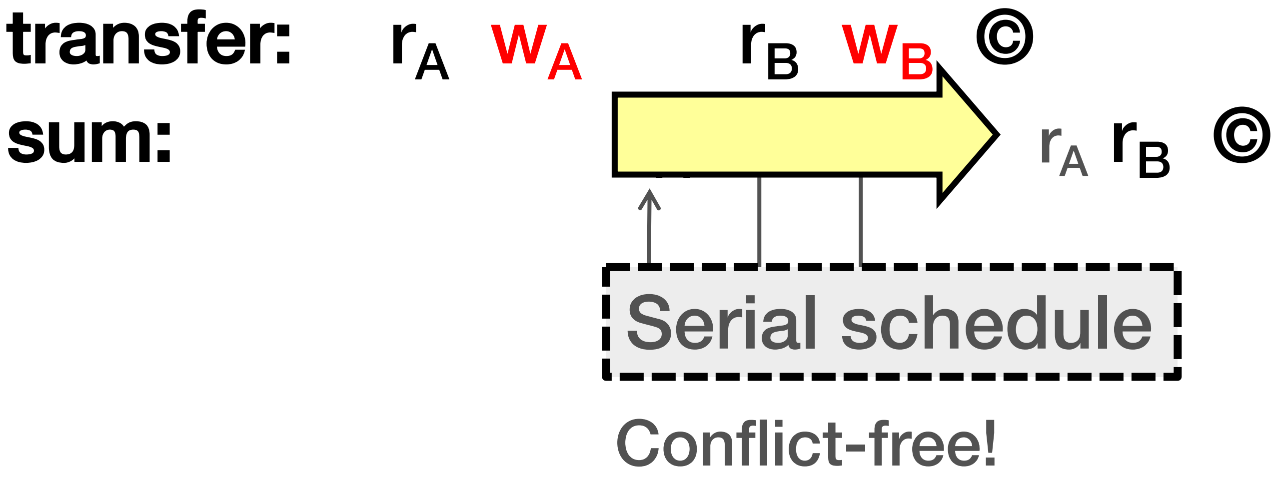
1. They contain the same transactions and operations
2. They **order all conflicting** operations of non-aborting transactions in the **same way**

# Serializability

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

# A Serializable Schedule

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




Time →

© = commit

# A Non-Serializable Schedule

- A schedule is **serializable** if it 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

# Linearizability vs. Serializability

- **Linearizability:** a guarantee about **single** operations on **single** objects
  - Once write completes, all reads that begin later should reflect that write

- **Serializability** is guarantee about **transactions** over **one or more** objects
  - Doesn't impose real-time constraints

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

# Consistency Hierarchy

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

# Lets Scale Strong Consistency!

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# Concurrency Control

- Concurrent execution can violate serializability
- We need to **control** that concurrent execution so we do things a single machine executing transactions one at a time would
  - Concurrency control

# 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

# 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

# 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)

# 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

# More Concurrency Control Algorithms

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