Atomic Commit and Concurrency Control

COS 418: Distributed Systems
Lecture 15

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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

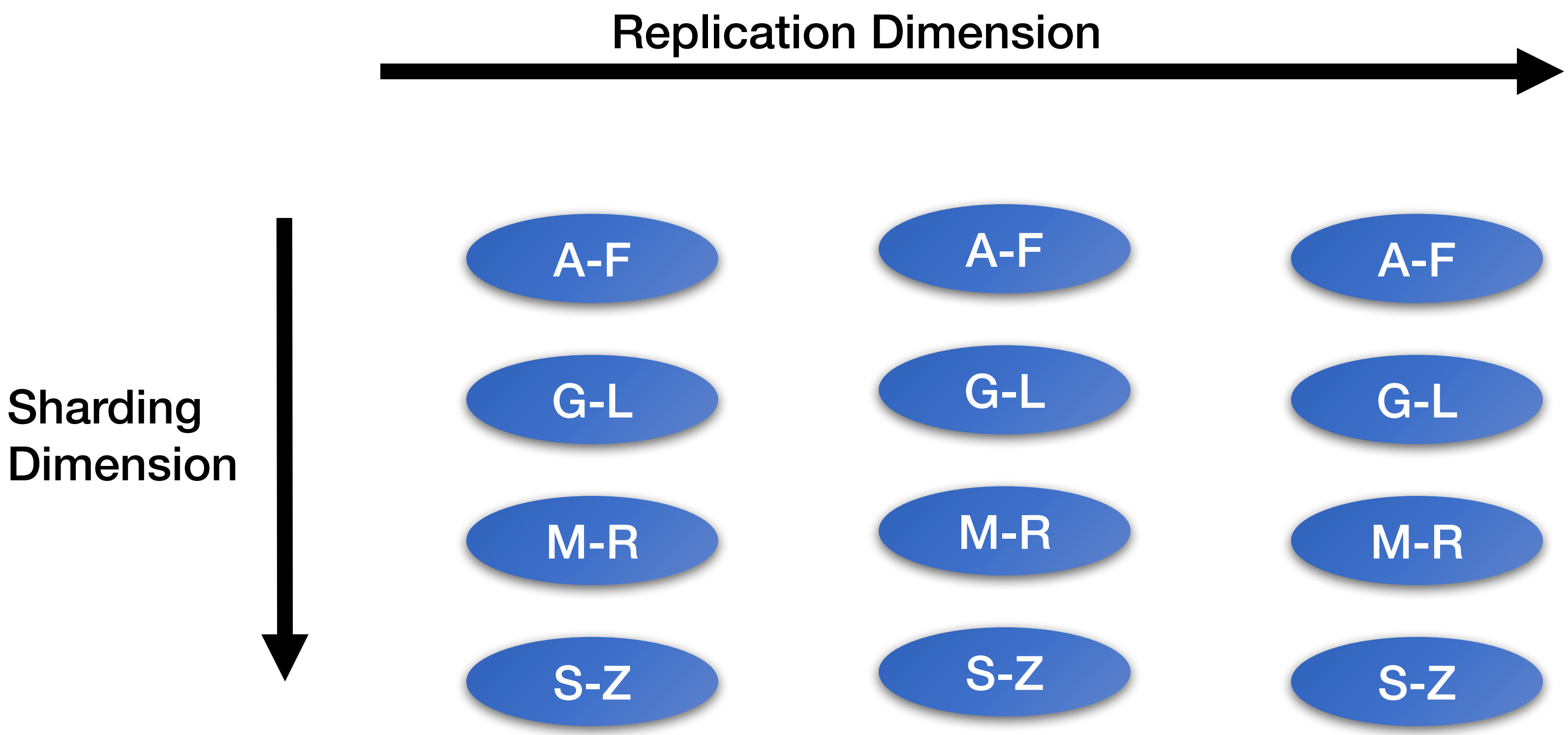
Relationship with Replication

- Replication (e.g., RAFT) is about doing the same thing multiple places to provide fault tolerance

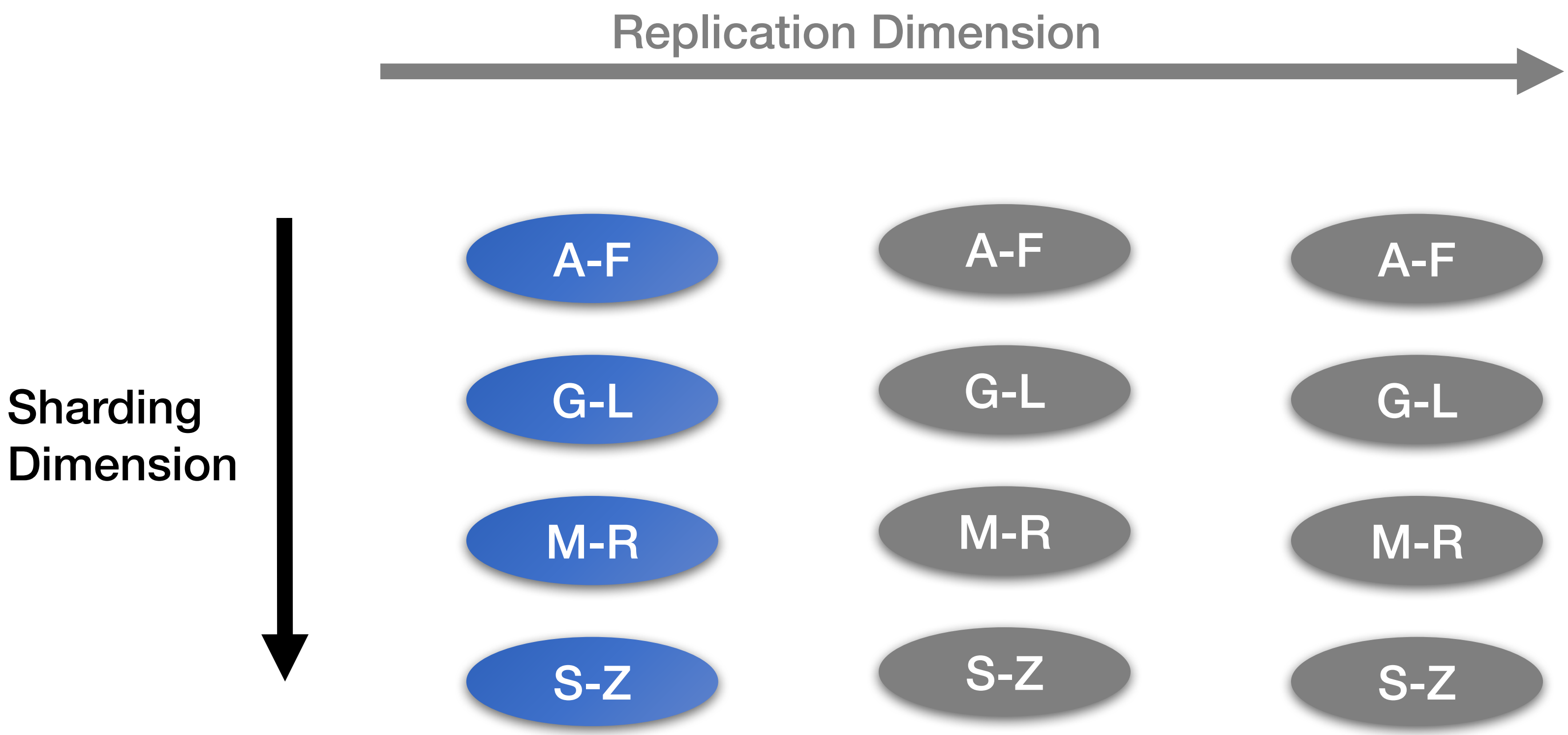
- Sharding is about doing different things multiple places for scalability

- 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 is accomplished with the 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 vote 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 operations 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:

transfer: r_A w_A (debit) r_B w_B (credit) ©

sum: r_A r_B ©

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

transfer: r_A w_A (debit) r_B w_B (credit) ©

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 operations 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. The **write** and **write** to the **same data item**

- Two **schedules** are equivalent if:

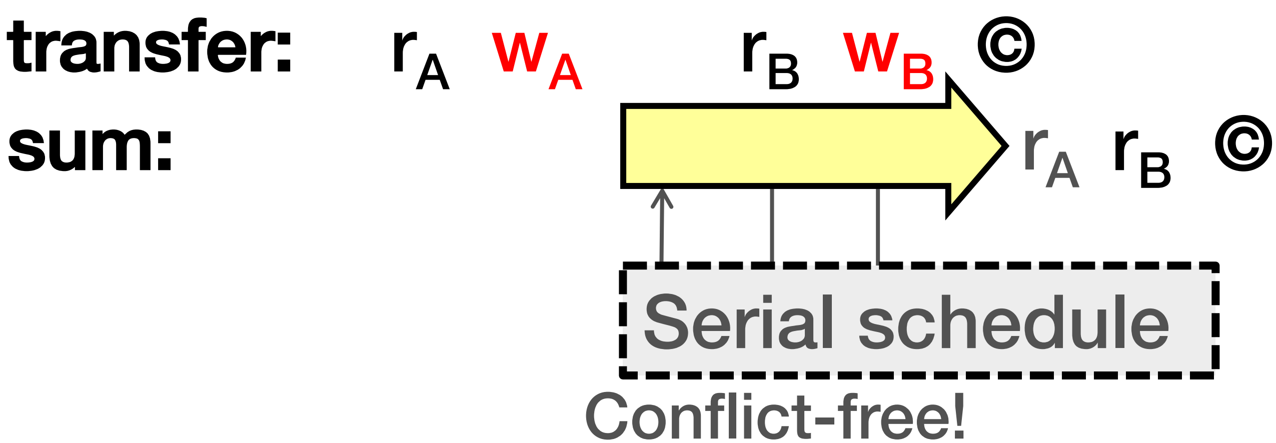
1. They contain the same transactions and operations
2. They **order** all **conflicting** operations of non-aborting transactions in the **same way**

Serializability

- A schedule is **serializable** if it is equivalent to some serial schedule
  - i.e., non-conflicting operations 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 operations 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 operations 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 a 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

↓

CAP

PRAM 1988 (Princeton)

Causal+ Consistency — e.g., Bayou

↓

Eventual Consistency — e.g., Dynamo

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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

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2PL is Pessimistic

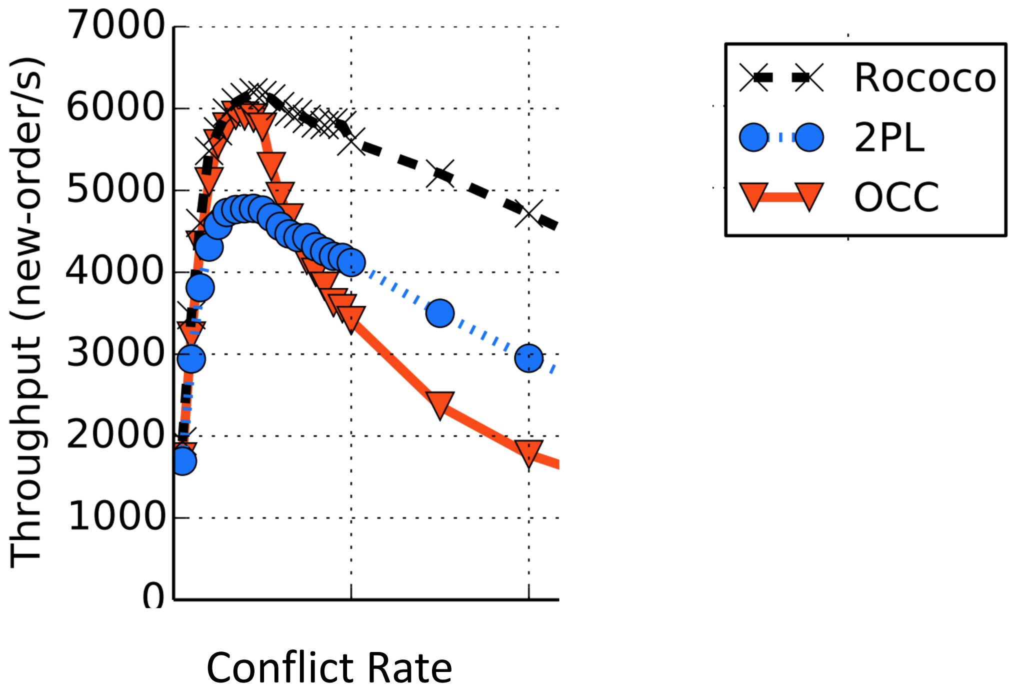
- Acquires locks to prevent all possible violations of serializability

- But leaves a lot of concurrency on the table that is okay

Be Optimistic!

- Goal: Low overhead for non-conflicting txns
- Assume success!
  - Process transaction as if would succeed
  - Check for serializability only at commit time
  - If fails, abort transaction
- Optimistic Concurrency Control (OCC)
  - Higher performance when few conflicts vs. locking
  - Lower performance when many conflicts vs. locking

2PL vs OCC



- From Rococo paper in OSDI 2014. Focus on 2PL vs. OCC.
- **Observe OCC better when write rate lower (fewer conflicts), worse than 2PL with write rate higher (more conflicts)**

Optimistic Concurrency Control

- Optimistic Execution:
  - Execute reads against shards
  - Buffer writes locally
- Validation and Commit:
  - Validate that data is still the same as previously observed
    - (i.e., reading now would give the same result)
  - Commit the transaction by applying all buffered writes
  - Need this to all happen together, how?

OCC Uses 2PC

- Validation and Commit use Two-Phase Commit

- Client sends each shard a prepare
  - Prepare includes read values and buffered writes for each shard
  - Each shard acquires shared locks on read locations and exclusive locks on write locks
  - Each shard checks if read values validate
  - Each shard sends vote to client
    - If all locks acquired and reads validate => Vote Yes
    - Otherwise => Vote No

- Client collects all votes, if all yes then commit
  - Client sends commit/abort to all shards
  - If commit: shards apply buffered writes
  - Shards release all locks

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     - Uses 2PC