Atomic Commit and Concurrency Control

COS 418/518: Distributed Systems
Lecture 14

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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

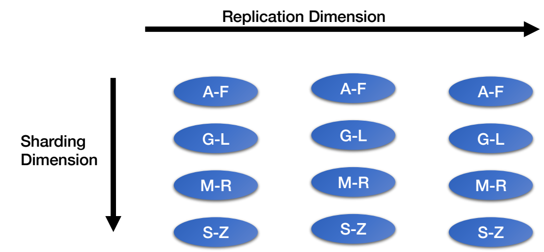
- Maintaining symmetric relationships
  - Lovelace FriendOf Turing
  - Turing FriendOf Lovelace

- Order product
  - Charge customer card
  - Decrement stock
  - Ship stock

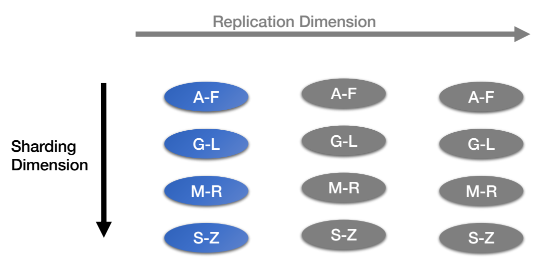
Relationship with Replication

- 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

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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?

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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., it appears that all ops of a 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., 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?*

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

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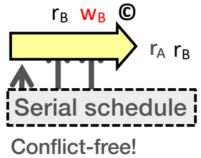
A Serializable Schedule

- A schedule is **serializable** if 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 ©



Time →

© = commit

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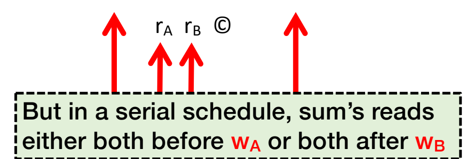
A Non-Serializable Schedule

- 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 ©



Time →

© = commit

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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
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

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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

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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

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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

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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 ◣ $_A$ ⊘ r_B w_B ◣ $_B$ ©

sum: ⊿ $_A$ r_A ◺ $_A$ ⊘ 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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