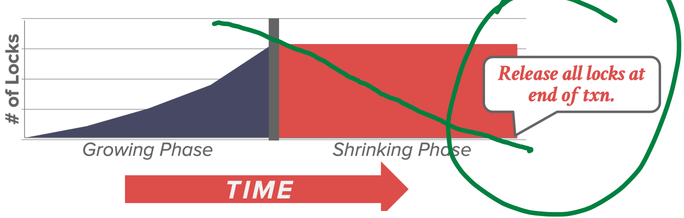
Lecture 14: Timestamp Ordering

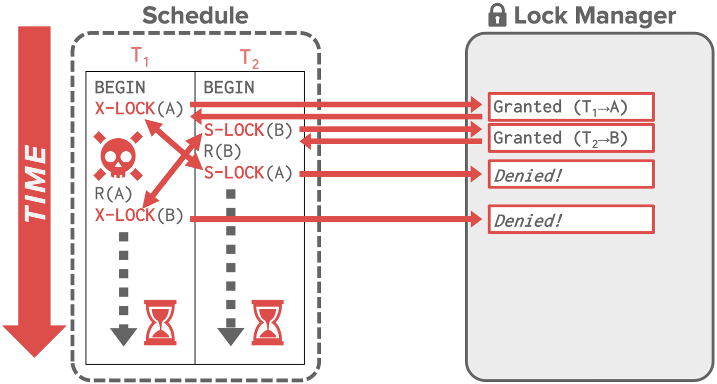
Recap

Strong Strict Two-Phase Locking

- The txn is not allowed to acquire/upgrade locks after the growing phase finishes.
- Allows only conflict serializable schedules, but it is often stronger than needed for some apps.



Deadlocks


Schedule
TIME
T1
T2
BEGIN
X-LOCK(A)
R(A)
X-LOCK(B)
BEGIN
S-LOCK(B)
R(B)
S-LOCK(A)
Lock Manager
Granted (T1→A)
Granted (T2→B)
Denied!
Denied!

2PL Deadlocks

- A **deadlock** is a cycle of transactions waiting for locks to be released by each other.
- Two ways of dealing with deadlocks:
  - **Approach 1: Deadlock Detection**
  - **Approach 2: Deadlock Prevention**

2PL: Summary

- 2PL is used in almost all DBMSs.
- Automatically generates correct interleaving:
  - Locks + protocol (2PL, SS2PL ...)
  - Deadlock detection + handling
  - Deadlock prevention

Concurrency Control Approaches

- Two-Phase Locking (2PL)
  - **Pessimistic approach**
  - Assumption that collisions are commonplace.
  - Determine serializability order of conflicting operations at runtime while txns execute.
- Timestamp Ordering (T/O)
  - **Optimistic approach**
  - Assumption that collisions between transactions will rarely occur.
  - Determine serializability order of txns before they execute.

Today's Agenda

- Basic Timestamp Ordering
- Partition-based Timestamp Ordering

Basic Timestamp Ordering

T/O Concurrency Control

- Use timestamps to determine the serializability order of txns.
- If $TS(T_i) < TS(T_j)$, then the DBMS must ensure that the execution schedule is equivalent to a serial schedule where T_i appears before T_j.

Timestamp Allocation

- Each txn T_i is assigned a unique fixed timestamp that is monotonically increasing.
  - Let $TS(T_i)$ be the timestamp allocated to txn T_i.
  - Different schemes assign timestamps at different times during the txn.
- Multiple implementation strategies:
  - Physical system clock (*e.g.*, timezones)
  - Logical counter (*e.g.*, overflow)
  - Hybrid

Basic T/O

- Txns read and write objects without locks.
- Every object X is tagged with timestamp of the last txn that successfully did read/write:
  - W – TS(X) – Write timestamp on X
  - R – TS(X) – Read timestamp on X
- Check timestamps for every operation:
  - If txn tries to access an object **<u>from the future</u>**, it aborts and restarts.

Basic T/O – Reads

- If $TS(T_i) < W - TS(X)$, this violates timestamp order of T_i with regard to the writer of X.
  - Abort T_i and restart it with a newer TS (so that is later than the writer of X).
- Else:
  - Allow T_i to read X.
  - Update $R - TS(X)$ to $\max(R - TS(X), TS(T_i))$
  - Have to make a local copy of X to ensure repeatable reads for T_i.

Basic T/O – Writes

- If $TS(T_i) < R-TS(X)$ or $TS(T_i) < W-TS(X)$
  - Abort and restart T_i.
- Else:
  - Allow T_i to write X and update $W-TS(X)$
  - Also have to make a local copy of X to ensure repeatable reads for T_i.

Basic T/O – Example 1

Schedule (TIME ↓)

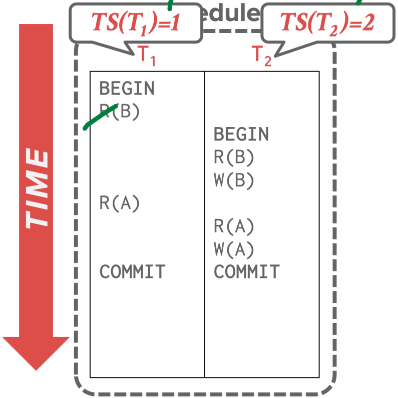
T_1	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	0	0
B	0	0

PostgreSQL

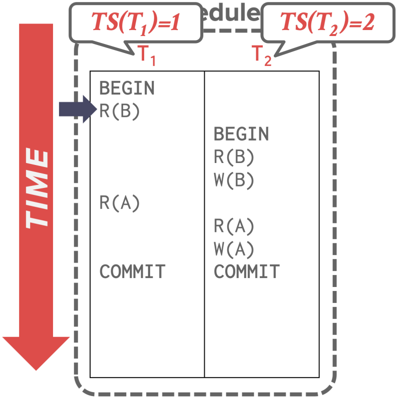
Basic T/O – Example 1



Database

Object	R-TS	W-TS
A	0	0
B	0	0

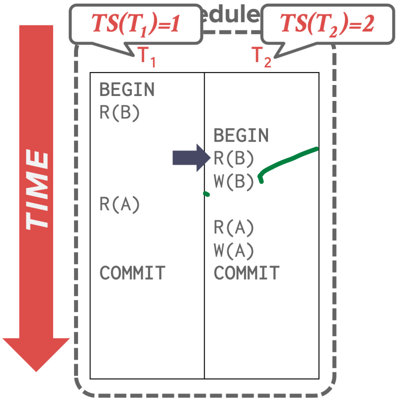
Basic T/O – Example 1



Database

Object	R-TS	W-TS
A	0	0
B	1	0

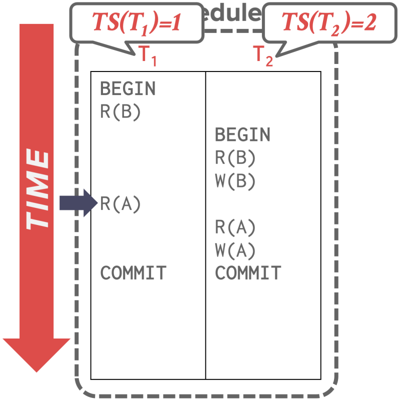
Basic T/O – Example 1



Database

Object	R-TS	W-TS
A	0	0
B	2	0

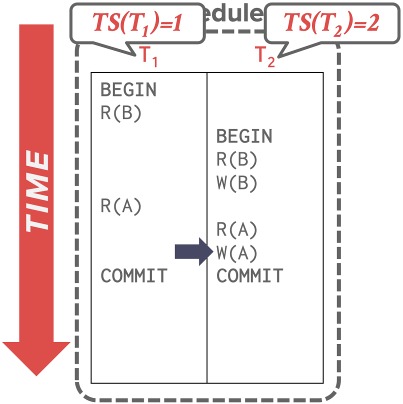
Basic T/O – Example 1



Database

Object	R-TS	W-TS
A	1	0
B	2	2

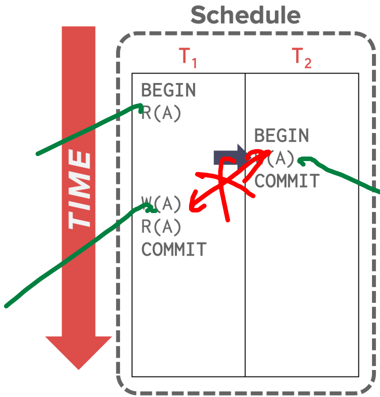
Basic T/O – Example 1



Object	R-TS	W-TS
A	2	2
B	2	2

No violations so both txns are safe to commit.

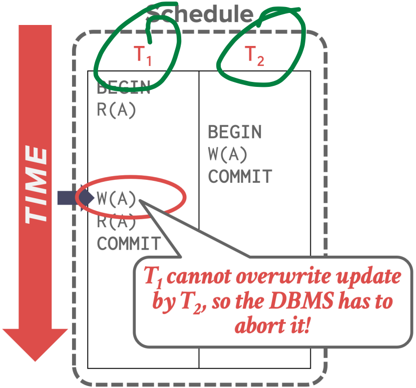
Basic T/O – Example 2



Database

Object	R-TS	W-TS
A	1	2
B	0	0

Basic T/O – Example 2



Database

Object	R-TS	W-TS
A	1	2
B	0	0

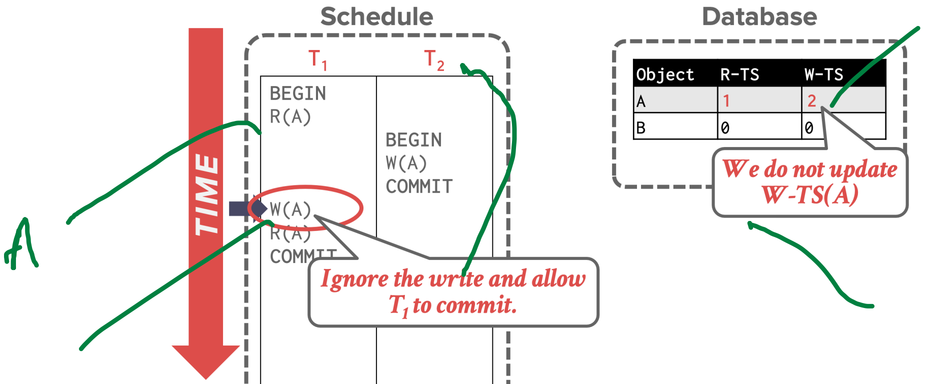
Violation:
$TS(T_1) < W\text{-}TS(A)$

Thomas Write Rule

: Optimization

- If $TS(Ti) < R - TS(X)$:
  - Abort and restart T_i.
- If $TS(T_i) < W - TS(X)$:
  - **Thomas Write Rule:** Ignore the write, make a local copy, and allow the txn to continue.
  - This violates timestamp order of T_i.
- Else:
  - Allow T_i to write X and update $W - TS(X)$

Basic T/O – Example 2

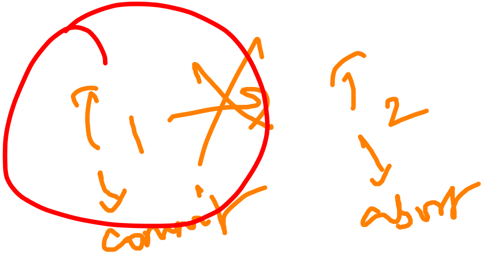


Basic T/O

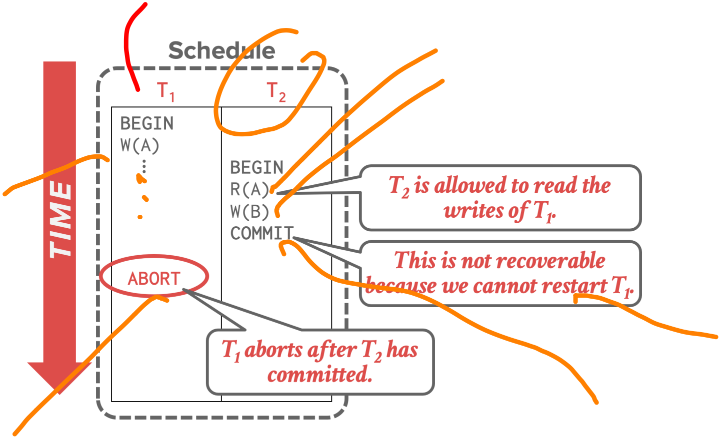
- Generates a schedule that is conflict serializable if you do **not** use the Thomas Write Rule.
  - No deadlocks because no txn ever waits.
  - Possibility of starvation for long txns if short txns keep causing conflicts.
- Permits schedules that are **not recoverable**.

Recoverable Schedules

- A schedule is **recoverable** if txns commit only after all txns whose changes they read, commit.
- Otherwise, the DBMS cannot guarantee that txns read data that will be restored after recovering from a crash.



Recoverable Schedules



Basic T/O – Performance Issues

- High overhead from copying data to txn's **local workspace** and from updating timestamps.
- Long running txns can get **starved**.
  - The likelihood that a txn will read something from a newer txn increases.

Observation

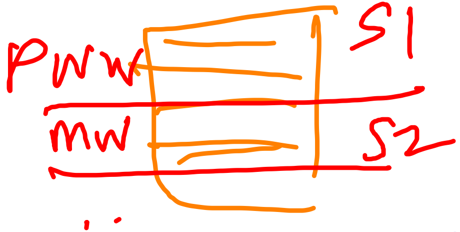
- When a txn commits, the T/O protocol checks to see whether there is a conflict with concurrent txns.
  - This requires latches.
- If you have a lot of concurrent txns, then this is slow even if the conflict rate is low.

data structures

Partition-based Timestamp Ordering

Partition-based T/O

- Split the database up in disjoint subsets called **horizontal partitions** (aka shards).
- Use timestamps to order txns for serial execution at each partition.
  - Only check for conflicts between txns that are running in the same partition.

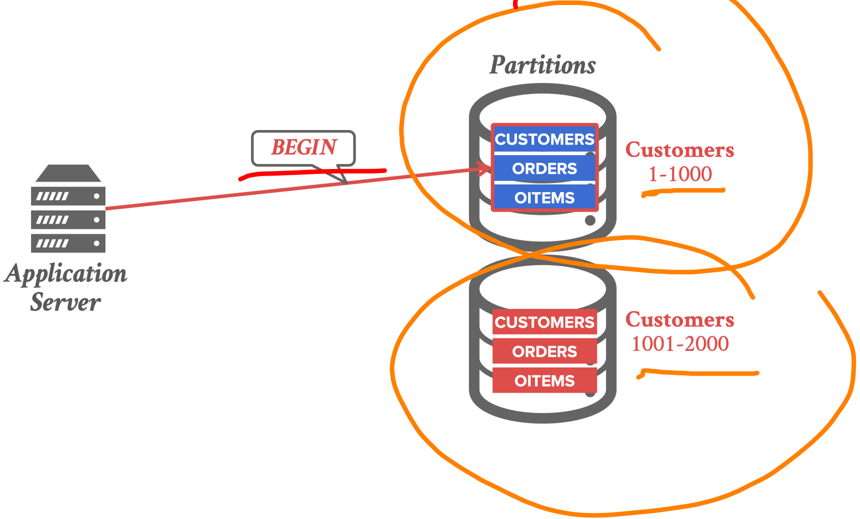


Database Partitioning

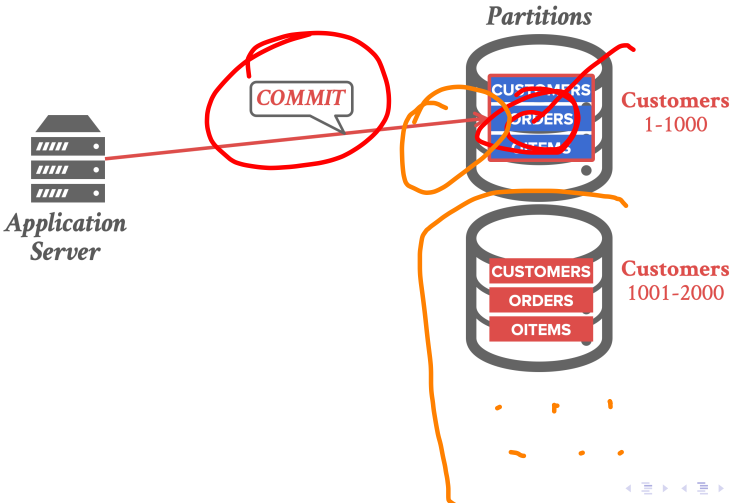
```
CREATE TABLE customer (
   c_id INT PRIMARY KEY,
   c_email VARCHAR UNIQUE,
 );

CREATE TABLE orders (
   o_id INT PRIMARY KEY,
   o_c_id INT REFERENCES customer (c_id)  --- Foreign key
);

CREATE TABLE oitems (
   oi_id INT PRIMARY KEY,
   oi_o_id INT REFERENCES orders (o_id),
   o_c_id INT REFERENCES orders (o_c_id)  --- Foreign key
);
```

Horizontal Partitioning

DSM / column-store



Horizontal Partitioning



Partition-based T/O

- Txns are assigned timestamps based on when they arrive at the DBMS.
- Partitions are protected by a **single lock**:
  - Each txn is queued at the partitions it needs.
  - The txn acquires a partition's lock if it has the lowest timestamp in that partition's queue.
  - The txn starts when it has all of the locks for all the partitions that it will read/write.
- **Examples:** VoltDB, FaunaDB

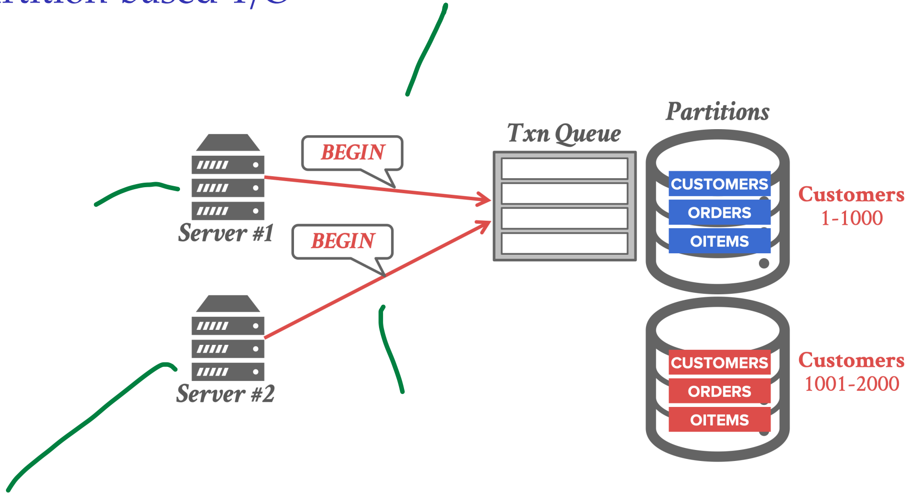
Partition-based T/O – Reads

- Txns can read anything that they want at the partitions that they have locked.
- If a txn tries to access a partition that it does not have the lock, it is **aborted + restarted**.

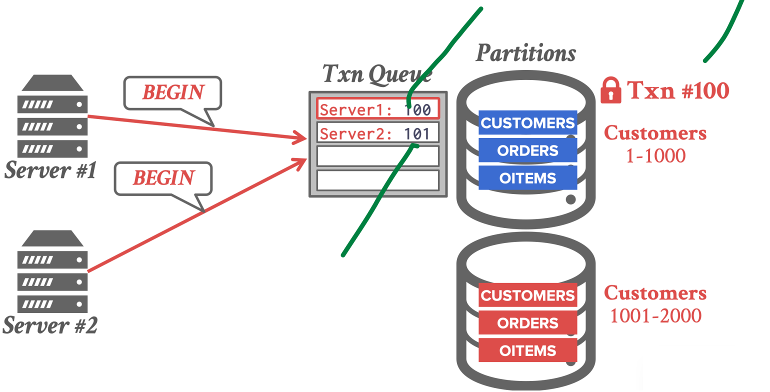
Partition-based T/O – Writes

- All updates occur in place (*i.e.*, no private workspace).
  - Maintain a separate in-memory buffer to undo changes if the txn aborts.
- If a txn tries to write to a partition that it does not have the lock, it is aborted + restarted.

Partition-based T/O



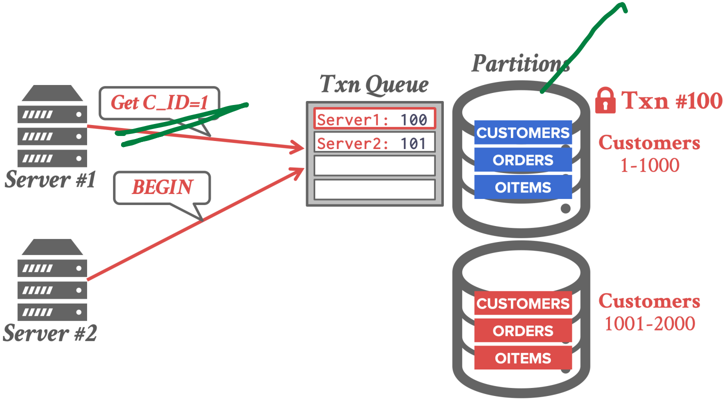
Partition-based T/O



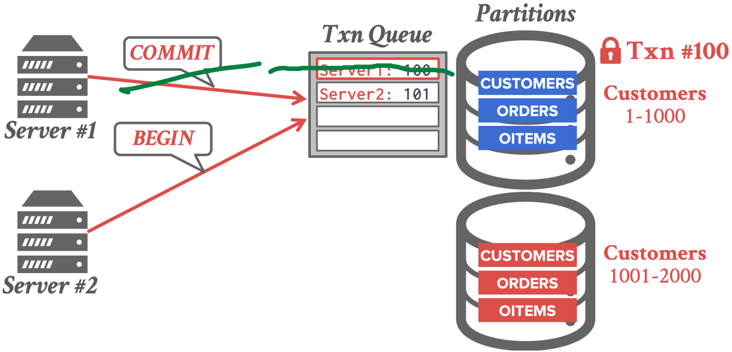
V

Partition-based T/O

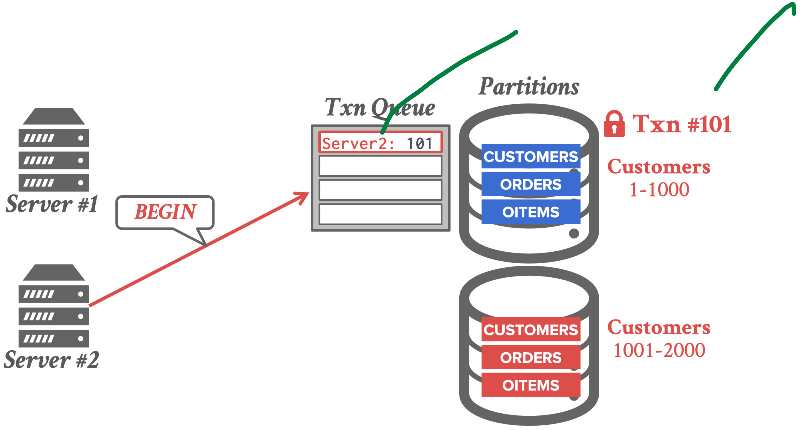
TPC-C



Partition-based T/O



Partition-based T/O



Partition-based T/O – Performance Issues

- Partition-based T/O protocol is fast if:
  - The DBMS knows what partitions the txn needs before it starts.
  - Most (if not all) txns only need to access a single partition.
- Multi-partition txns causes partitions to be **idle** while txn executes.
  - Stored procedures
  - Reconnaissance mode

Conclusion

Parting Thoughts

- Every concurrency control can be broken down into the basic concepts that I have described in the last two lectures.
  - Two-Phase Locking (2PL): Assumption that collisions are commonplace
  - Timestamp Ordering (T/O): Assumption that collisions are rare.
- I am not showing benchmark results because I don't want you to get the wrong idea.

Next Class

- Optimistic Concurrency Control
- Isolation Levels