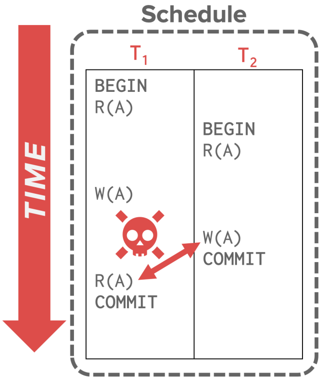
Lecture 13: Two Phase Locking

Recap

Formal Properties of Schedules

- Conflict Serializable
  - Verify using either the "swapping" method or dependency graphs.
  - Any DBMS that says that they support "serializable" isolation does this.
- View Serializable
  - No efficient way to verify.
  - No DBMS supports this.

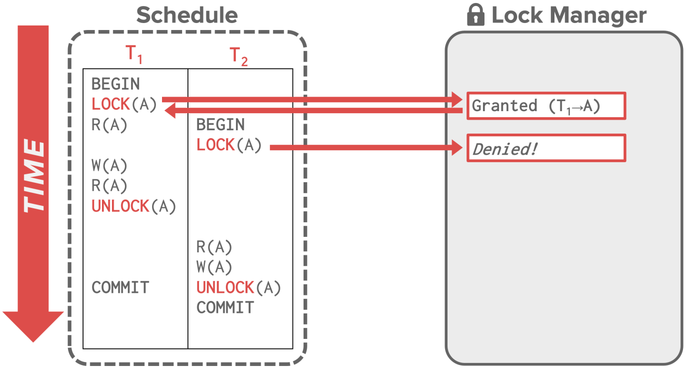
Example: Entire Schedule



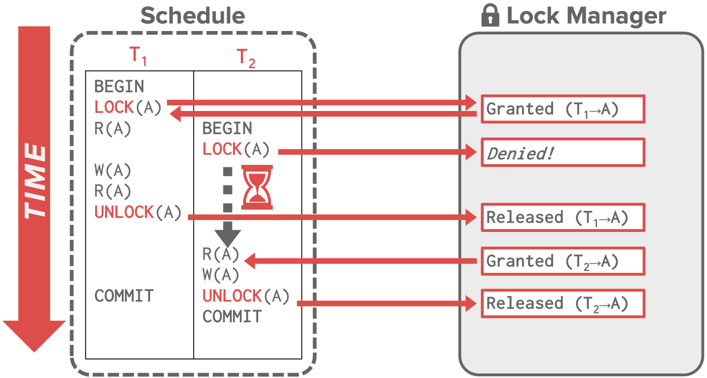
Observation

- We need a way to guarantee that all execution schedules are correct (*i.e.*, serializable) without knowing the entire schedule ahead of time.
- Solution: Use **locks** to protect database objects.

Executing with Locks



Executing with Locks



Today's Agenda

- Lock Types
- Two-Phase Locking
- Deadlock Detection + Prevention
- Hierarchical Locking
- Locking in Practice

Lock Types

Locks vs. Latches

	Locks	**Latches**
Separate. . .	User transactions	Threads
Protect. . .	Database Contents	In-Memory Data Structures
During. . .	Entire Transactions	Critical Sections
Modes. . .	Shared, Exclusive, Update, Intention	Read, Write (*a.k.a.*, Shared, Exclusive)
Deadlock	Detection & Resolution	Avoidance
. . . by. . .	Waits-for, Timeout, Aborts	Coding Discipline
Kept in. . .	Lock Manager	Protected Data Structure

Reference

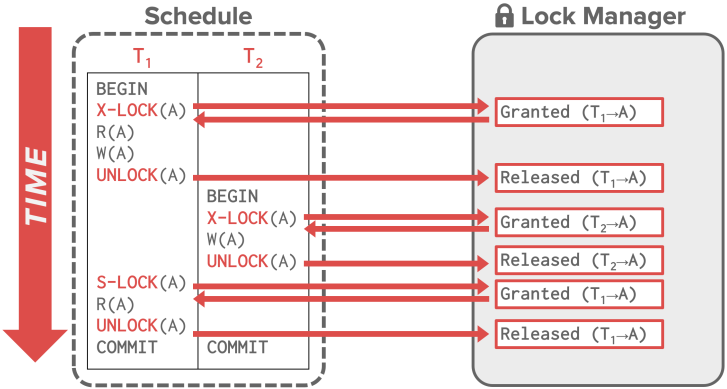
Basic Lock Types

- **S-LOCK**: Shared locks for reads.
- **X-LOCK**: Exclusive locks for writes.

Executing with Locks

- Transactions request locks (or upgrades).
- Lock manager grants or blocks requests.
- Transactions release locks.
- Lock manager updates its internal lock-table.
  - It keeps track of what transactions hold what locks and what transactions are waiting to acquire any locks.

Executing with Locks: Not Sufficient



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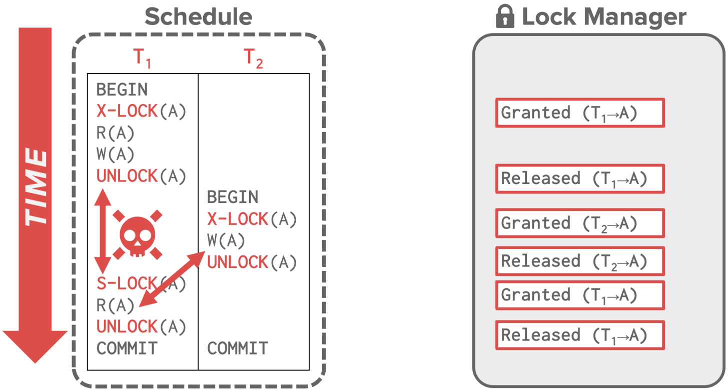


Two-Phase Locking

Concurrency Control Protocol

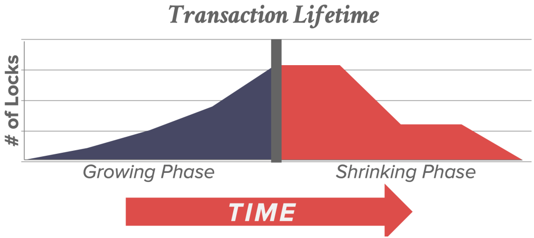
- Two-phase locking (2PL) is a concurrency control protocol that determines whether a txn can access an object in the database on the fly.
- The protocol does **not** need to know all the queries that a txn will execute ahead of time.

Two-Phase Locking

- **Phase 1: Growing**
  - Each txn requests the locks that it needs from the DBMS's lock manager.
  - The lock manager grants/denies lock requests.
- **Phase 2: Shrinking**
  - The txn is allowed to only release locks that it previously acquired. It cannot acquire new locks.

Two-Phase Locking

- The txn is not allowed to acquire/upgrade locks after the growing phase finishes.



Two-Phase Locking

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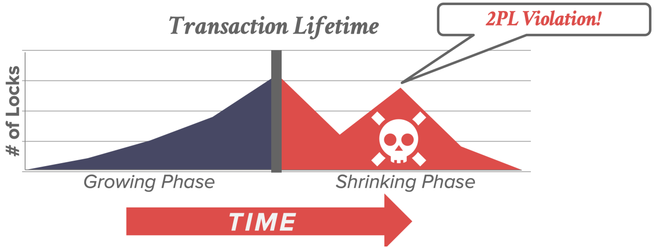
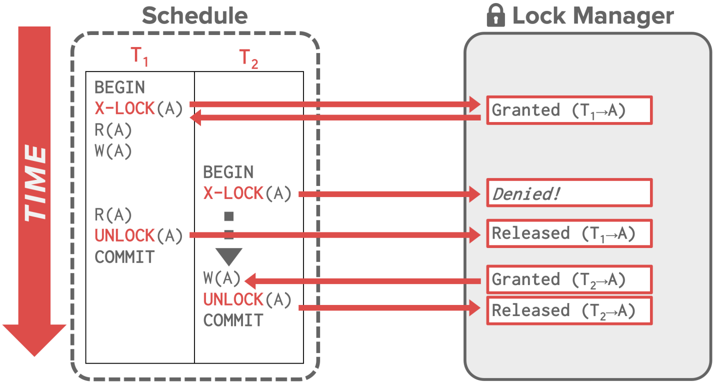


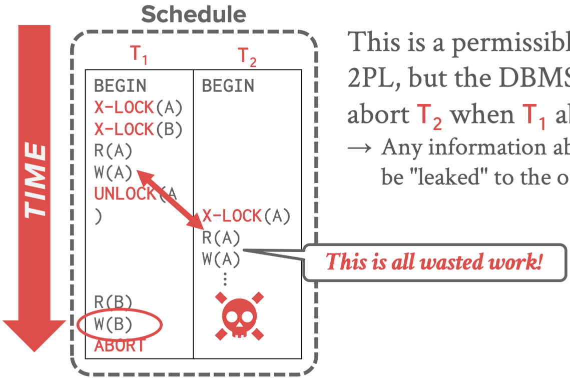
Executing with 2PL



Two-Phase Locking

- 2PL on its own is sufficient to guarantee conflict serializability.
  - It generates schedules whose precedence graph is acyclic.
- But it is subject to **cascading aborts**.

2PL – Cascading Aborts



This is a permissible schedule in 2PL, but the DBMS has to also abort T_2 when T_1 aborts.

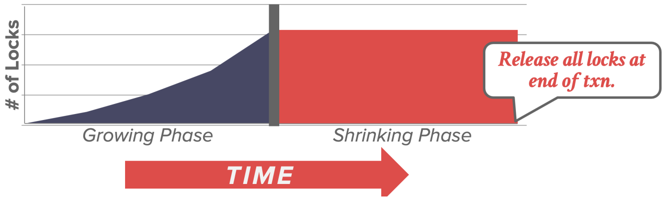
→ Any information about T_1 cannot be "leaked" to the outside world.

2PL: Observations

- There are potential schedules that are serializable but would not be allowed by 2PL.
  - Locking limits concurrency.
- **May still have "dirty reads"**.
  - Solution: Strong Strict 2PL (aka Rigorous 2PL)
- **May lead to deadlocks**.
  - Solution: Detection or Prevention

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.



Strong Strict Two-Phase Locking

- A schedule is **strict** if a value written by a txn is not read or overwritten by other txns until that txn finishes.
- Advantages:
  - Does not incur cascading aborts.
  - Aborted txns can be undone by just restoring original values of modified tuples.

Examples

- T1 – Move $100 from A's account to B's account.
- T2 – Compute the total amount in all accounts and return it to the application.

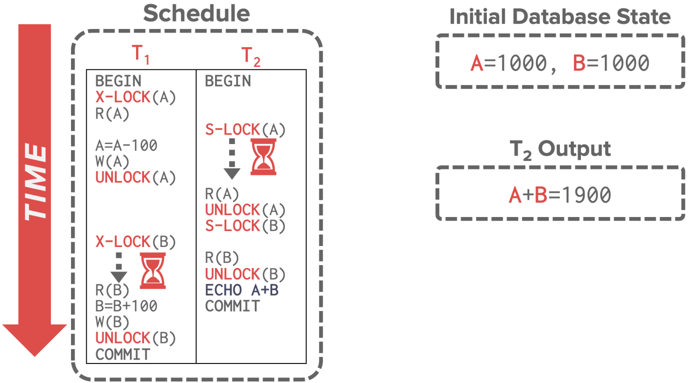
T_1

```
BEGIN
A=A-100
B=B+100
COMMIT
```

T_2

```
BEGIN
ECHO A+B
COMMIT
```

Non-2PL Example



2PL Example

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
X-LOCK(A)	
R(A)	S-LOCK(A)
A=A-100	
W(A)	
X-LOCK(B)	
UNLOCK(A)	R(A)
	S-LOCK(B)
R(B)	
B=B+100	
W(B)	
UNLOCK(B)	R(B)
COMMIT	UNLOCK(A)
	UNLOCK(B)
	ECHO A+B
	COMMIT

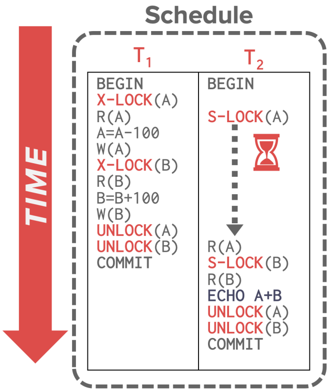
Initial Database State

A=1000, B=1000

T_2 Output

A+B=2000

Strong Strict 2PL Example



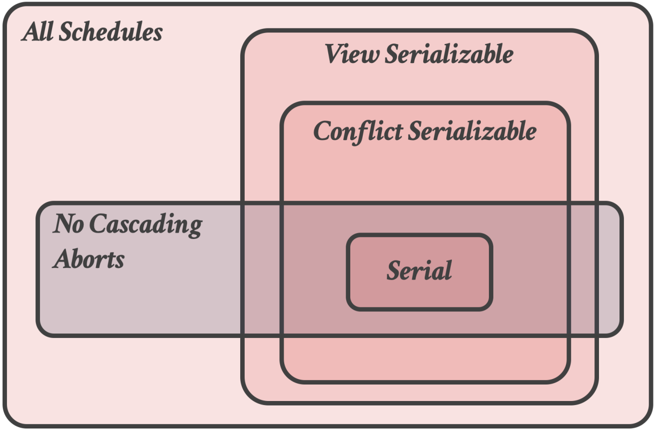
Initial Database State

A=1000, B=1000

T_2 Output

A+B=2000

Universe of Schedules

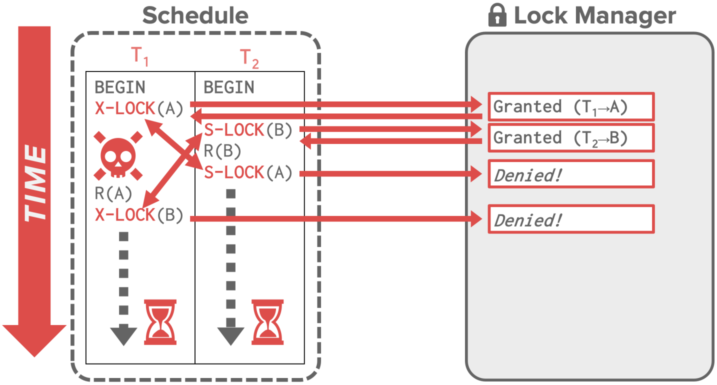


2PL: Observations

- There are potential schedules that are serializable but would not be allowed by 2PL.
  - Locking limits concurrency.
- **May still have "dirty reads"**.
  - Solution: Strong Strict 2PL (Rigorous)
- **May lead to deadlocks**.
  - Solution: Detection or Prevention

Deadlock Detection + Prevention

Deadlocks


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

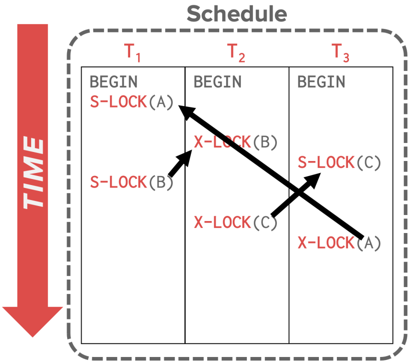
2PL Deadlocks

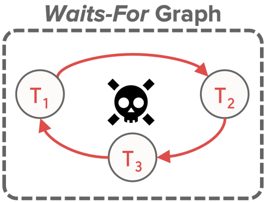
- A **deadlock** is a cycle of transactions waiting for locks to be released by each other.
- Two ways of dealing with deadlocks:
  - **Approach 1: Deadlock Detection**
  - **Approach 2: Deadlock Prevention**

Deadlock Detection

- The DBMS creates a **waits-for** graph to keep track of what locks each txn is waiting to acquire:
  - Nodes are transactions
  - Edge from T_i to T_j if T_i is waiting for T_j to release a lock.
- The system periodically checks for cycles in waits-for graph and then decides how to break it.

Deadlock Detection





Deadlock Handling

- When the DBMS detects a deadlock, it will select a "victim" txn to rollback to break the cycle.
- The victim txn will either restart or abort(more common) depending on how it was invoked.
- There is a trade-off between the frequency of checking for deadlocks and how long txns have to wait before deadlocks are broken.

Deadlock Handling: Victim Selection

- Selecting the proper victim depends on a lot of different variables. . . .
  - By age (lowest timestamp)
  - By progress (least/most queries executed)
  - By the of items already locked
  - By the of txns that we have to rollback with it
- We also should consider the of times a txn has been restarted in the past to prevent starvation.

Deadlock Handling: Rollback Length

- After selecting a victim txn to abort, the DBMS can also decide on how far to rollback the txn's changes.
- **Approach 1:** Completely
- **Approach 2:** Minimally (*i.e.*, release a subset of locks)

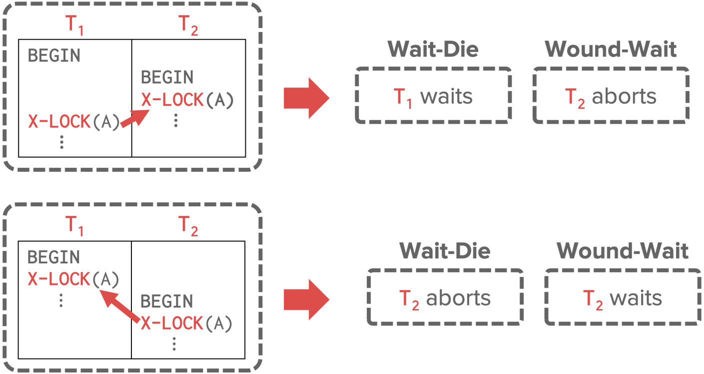
Deadlock Prevention

- When a txn tries to acquire a lock that is held by another txn, the DBMS kills one of them to prevent a deadlock.
- This approach does **not** require a waits-for graph or detection algorithm.

Deadlock Prevention

- Assign priorities based on timestamps:
  - Older Timestamp = Higher Priority (*e.g.*, T1 > T2)
- **Wait-Die** ("Old Waits for Young")
  - If requesting txn has higher priority than holding txn, then requesting txn waits for holding txn.
  - Otherwise requesting txn aborts.
- **Wound-Wait** ("Young Waits for Old")
  - If requesting txn has higher priority than holding txn, then holding txn aborts and releases lock.
  - Otherwise requesting txn waits.

Deadlock Prevention



Deadlock Prevention

- **Why do these schemes guarantee no deadlocks?**
- Only one "type" of direction allowed when waiting for a lock.
- **When a txn restarts, what is its (new) priority?**
- Its original timestamp. Why?

Observation

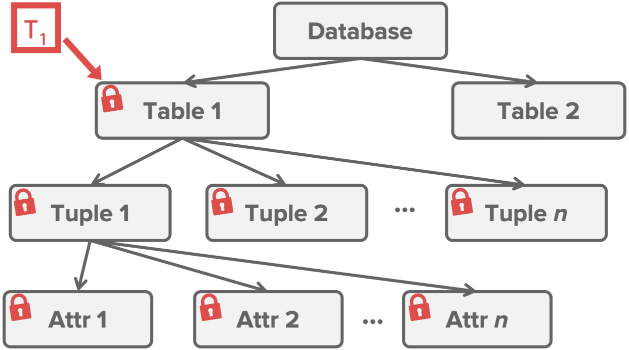
- All of these examples have a one-to-one mapping from database objects to locks.
- If a txn wants to update one billion tuples, then it has to acquire one billion locks.

Hierarchical Locking

Lock Granularities

- When we say that a txn acquires a “lock”, what does that actually mean?
  - On an Attribute? Tuple? Page? Table?
- Ideally, each txn should obtain fewest number of locks that is needed. . .

Database Lock Hierarchy



Example

- T1 – Get the balance of A's account.
- T2 – Increase B's bank account balance by 1%.
- What locks should these txns obtain?
- Multiple:
  - **Exclusive** + **Shared** for leafs of lock tree.
  - Special **Intention locks** for higher levels.

Intention Locks

- An **intention lock** allows a higher level node to be locked in **shared** or **exclusive** mode without having to check all descendent nodes.
- If a node is in an intention mode, then explicit locking is being done at a lower level in the tree.

Intention Locks

- **Intention-Shared** (IS)
  - Indicates explicit locking at a lower level with shared locks.
- **Intention-Exclusive** (IX)
  - Indicates locking at lower level with exclusive or shared locks.

Intention Locks

- **Shared+Intention-Exclusive** (SIX)
  - The subtree rooted by that node is locked explicitly in **shared mode** and explicit locking is being done at a lower level with **exclusive-mode** locks.

Compatibility Matrix

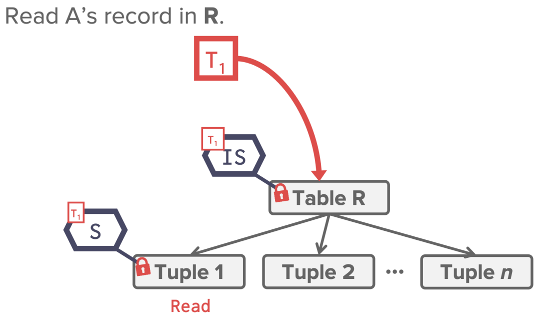
T_2 Wants

T_1 Holds	IS	IX	S	SIX	X
IS	✓	✓	✓	✓	✗
IX	✓	✓	✗	✗	✗
S	✓	✗	✓	✗	✗
SIX	✓	✗	✗	✗	✗
X	✗	✗	✗	✗	✗

Hierarchical Locking Protocol

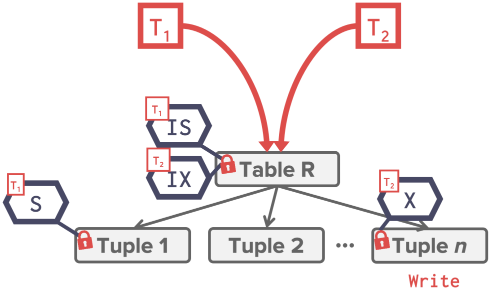
- Each txn obtains appropriate lock at highest level of the database hierarchy.
- To get **S** or **IS** lock on a node, the txn must hold at least **IS** on parent node.
- To get **X**, **IX**, or **SIX** on a node, must hold at least **IX** on parent node.

Example – Two-Level Hierarchy



Example – Two-Level Hierarchy

Update B's record in **R**.

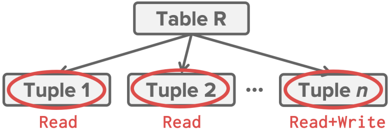


Example – Three Transactions

- Assume three txns execute at same time:
  - T1 – Scan R and update a few tuples.
  - T2 – Read a single tuple in R.
  - T3 – Scan all tuples in R.

Example – Three Transactions

Scan R and update a few tuples. T_1



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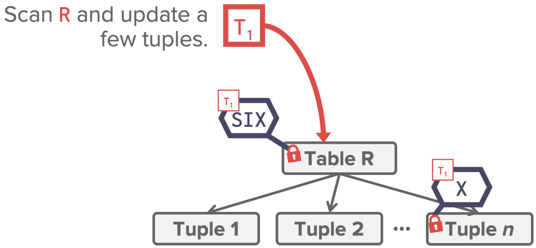

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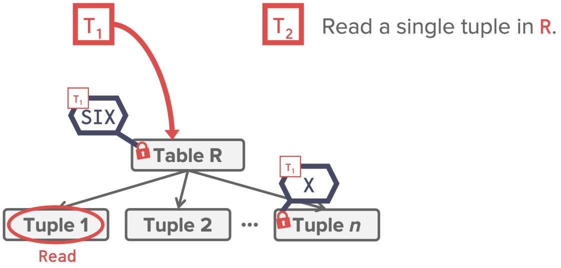

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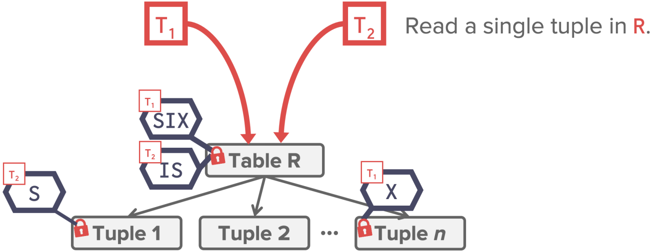

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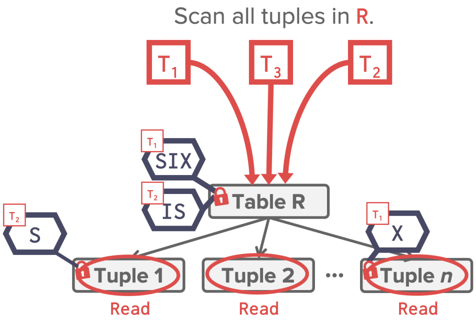

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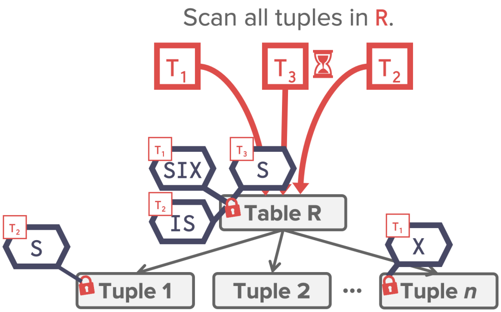

Multiple Lock Granularities

- Hierarchical locks are useful in practice as each txn only needs a few locks.
- Intention locks help improve concurrency:
  - **Intention-Shared** (IS): Intent to get S lock(s) at finer granularity.
  - **Intention-Exclusive** (IX): Intent to get X lock(s) at finer granularity.
  - **Shared+Intention-Exclusive** (SIX): Like S and IX at the same time.

Lock Escalation

- Lock escalation dynamically asks for coarser-grained locks when too many low level locks acquired.
- This reduces the number of requests that the lock manager has to process.

Locking in Practice

Locking in Practice

- You typically don't set locks manually in txns.
- Sometimes you will need to provide the DBMS with hints to help it to improve concurrency.
- Explicit locks are also useful when doing major changes to the database.

Lock Table

- Explicitly locks a table.
- Not part of the SQL standard.
  - Postgres/DB2/Oracle Modes: **SHARE**, **EXCLUSIVE**
  - MySQL Modes: **READ**, **WRITE**

PostgreSQL / ORACLE / IBM DB2

```
LOCK TABLE <table> IN <mode> MODE;
```

Microsoft SQL Server

```
SELECT 1 FROM <table> WITH (TABLOCK, <mode>);
```

MySQL

```
LOCK TABLE <table> <mode>;
```

Select... For Update

- Perform a select and then sets an exclusive lock on the matching tuples.
- Can also set shared locks:
  - Postgres: **FOR SHARE**
  - MySQL: **LOCK IN SHARE MODE**

```
SELECT * FROM <table>
  WHERE <qualification> FOR UPDATE;
```

Conclusion

Parting Thoughts

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

Next Class

- Timestamp Ordering Concurrency Control