Carnegie Mellon Univ.
Dept. of Computer Science
15-415/615 - DB Applications

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Lecture#21: Concurrency Control

(R&G ch. 17)

Today's Class

- Serializability: concepts and algorithms
- Locking-based Concurrency Control:
  - 2PL
  - Strict 2PL
- Deadlocks

Formal Properties of Schedules

- There are different levels of serializability:
  - **Conflict Serializability**
  - **View Serializability**

All DBMSs support this.

This is harder but allows for more concurrency.

Conflicting Operations

- We need a formal notion of equivalence that can be implemented efficiently…
  - Base it on the notion of "conflicting" operations
- Definition: Two operations conflict if:
  - They are by different transactions,
  - They are on the same object and at least one of them is a write.

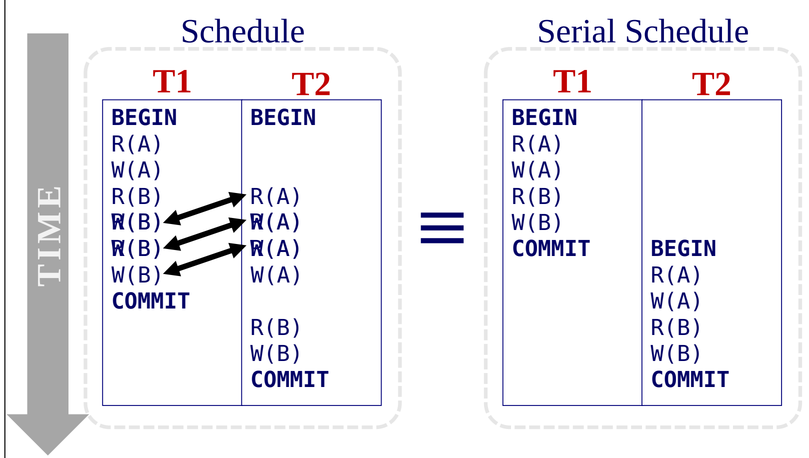
Conflict Serializable Schedules

- Two schedules are ***conflict equivalent*** iff:
  - They involve the same actions of the same transactions, and
  - Every pair of conflicting actions is ordered the same way.
- Schedule S is ***conflict serializable*** if:
  - S is conflict equivalent to some serial schedule.

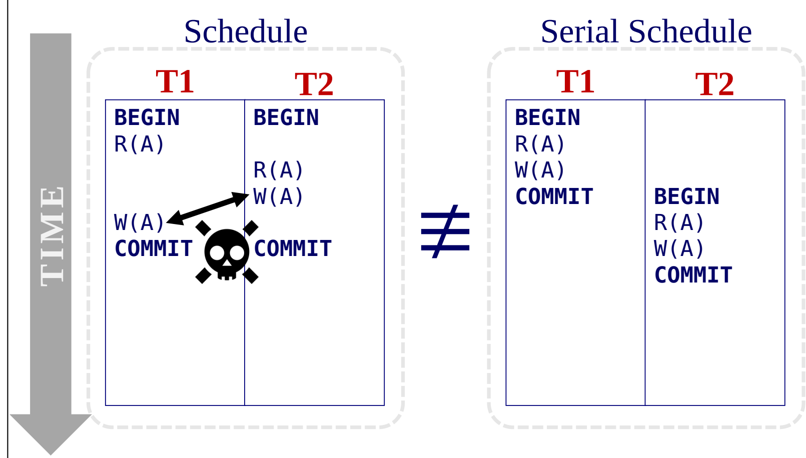
Conflict Serializability Intuition

- A schedule S is ***conflict serializable*** if:
  - You are able to transform S into a serial schedule by swapping consecutive non-conflicting operations of different transactions.

Conflict Serializability Intuition



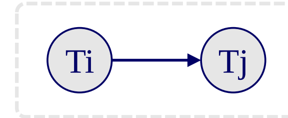
Conflict Serializability Intuition



Serializability

- **Q:** Are there any faster algorithms to figure this out other than transposing operations?

Dependency Graphs



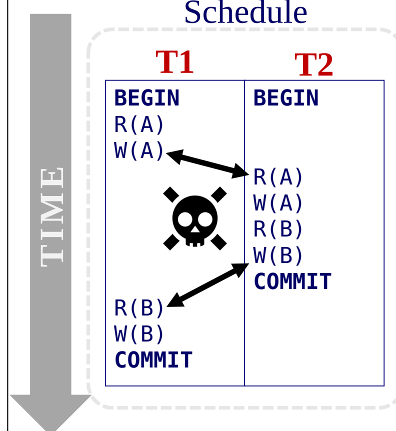
- One node per txn.
- Edge from Ti to Tj if:
  - An operation Oi of Ti conflicts with an operation Oj of Tj and
  - Oi appears earlier in the schedule than Oj.
- Also known as a "precedence graph"

Dependency Graphs

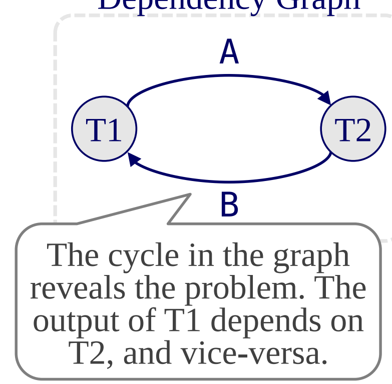
- **Theorem:** A schedule is *conflict serializable* if and only if its dependency graph is acyclic.

Example #1

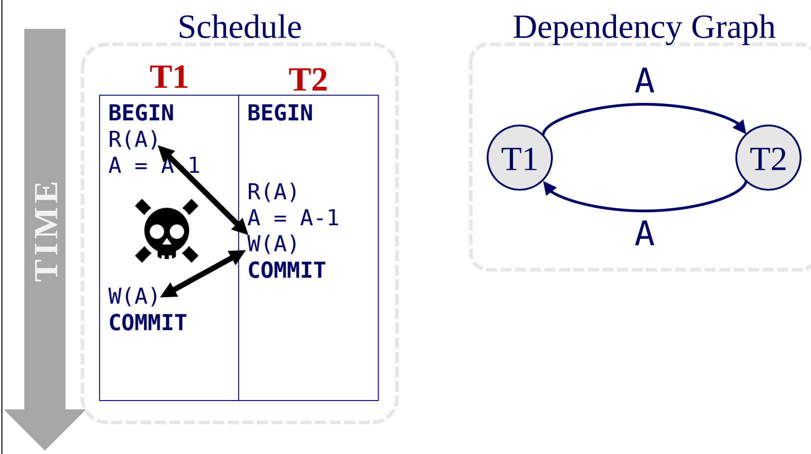
Schedule



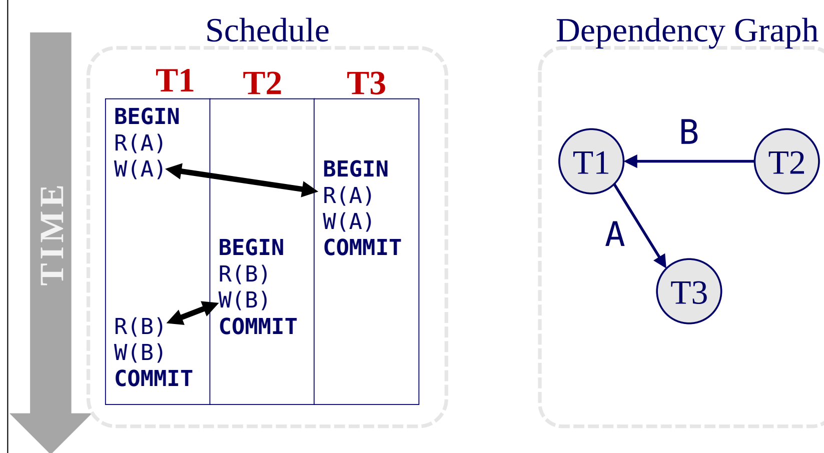
Dependency Graph



Example #2 – Lost Update



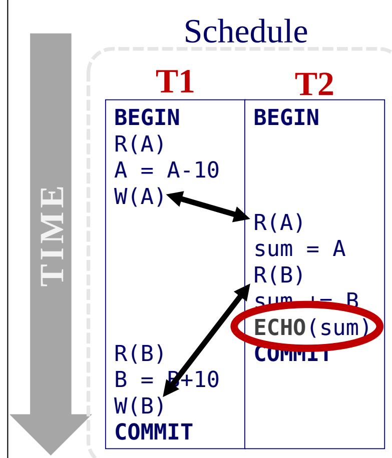
Example #3 – Threesome

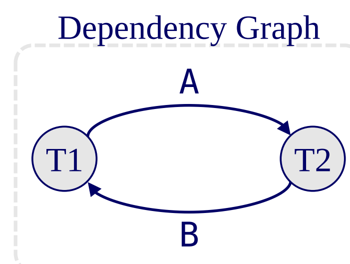


Example #3 – Threesome

- **Q:** Is this equivalent to a serial execution?
- **A:** Yes (T2, T1, T3)
  - Notice that T3 should go after T2, although it starts before it!
- Need an algorithm for generating serial schedule from an acyclic dependency graph.
  - ***Topological Sorting***

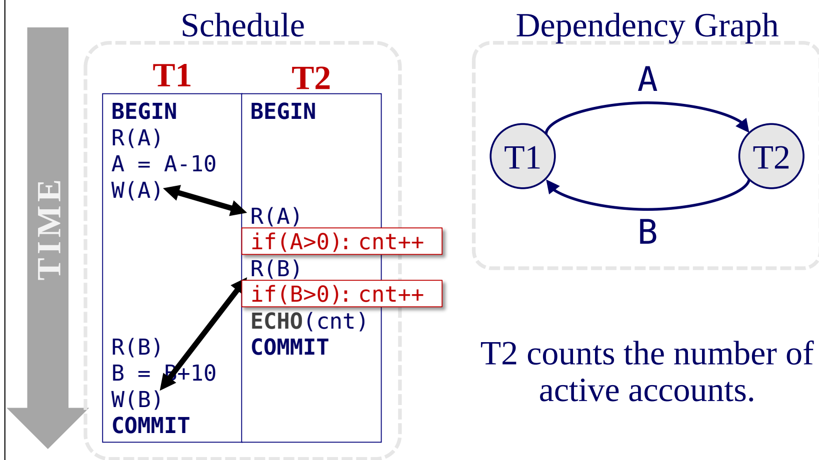
Example #4 – Inconsistent Analysis





Is it possible to create a schedule similar to this that is "correct" but still not conflict serializable?

Example #4 – Inconsistent Analysis

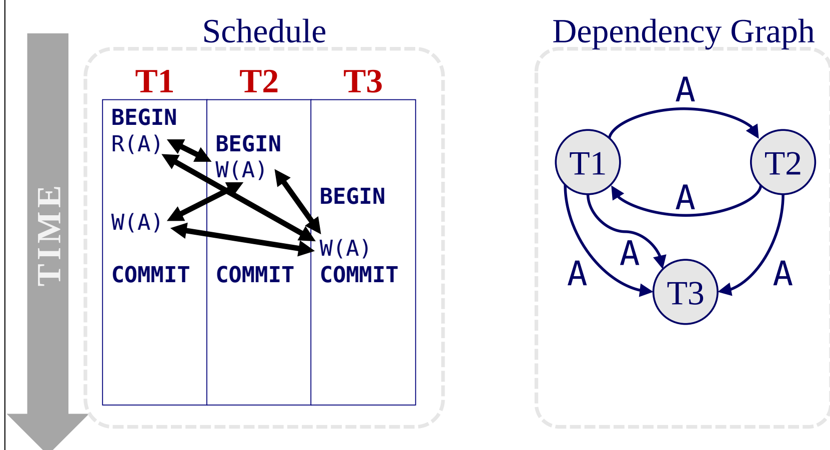


T2 counts the number of active accounts.

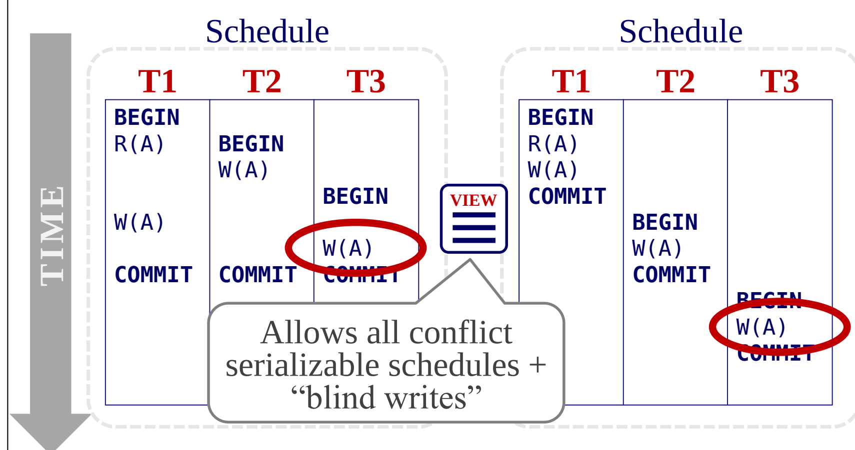
View Serializability

- Alternative (weaker) notion of serializability.
- Schedules S1 and S2 are ***view equivalent*** if:
  - If T1 reads initial value of A in S1, then T1 also reads initial value of A in S2.
  - If T1 reads value of A written by T2 in S1, then T1 also reads value of A written by T2 in S2.
  - If T1 writes final value of A in S1, then T1 also writes final value of A in S2.

View Serializability



View Serializability



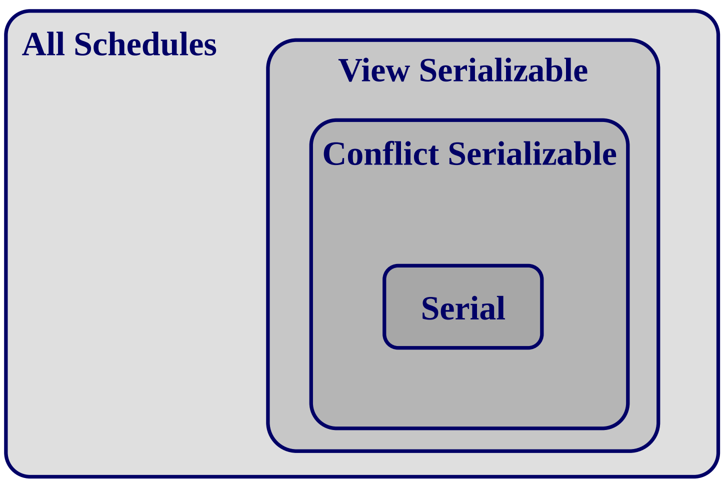
Serializability

- **View Serializability** allows (slightly) more schedules than **Conflict Serializability** does.
  - But is difficult to enforce efficiently.
- Neither definition allows all schedules that you would consider “serializable”.
  - This is because they don’t understand the meanings of the operations or the data (recall example #4)

Serializability

- In practice, **Conflict Serializability** is what gets used, because it can be enforced efficiently.
  - To allow more concurrency, some special cases get handled separately, such as for travel reservations, etc.

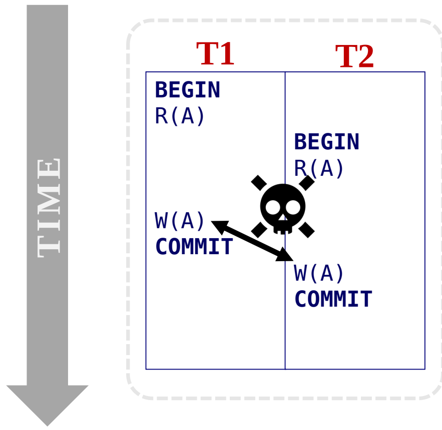
Schedules



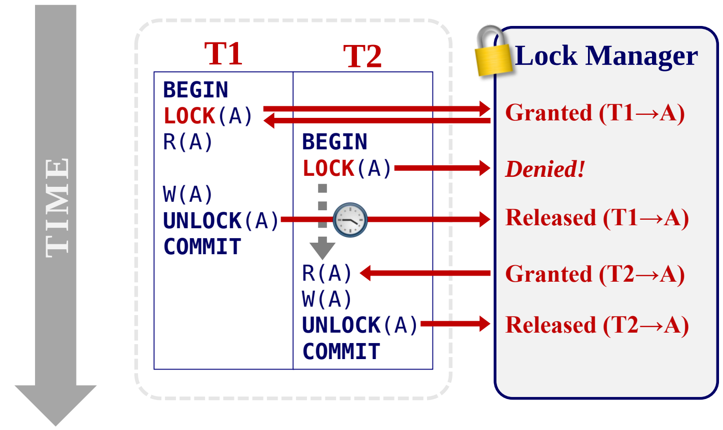
Today’s Class

- Serializability: concepts and algorithms
- Locking-based Concurrency Control:
  - 2PL
  - Strict 2PL
- Deadlocks

Executing without Locks



Executing with Locks



Executing with Locks

- **Q:** If a txn only needs to read 'A', should it still get a lock?
- **A:** Yes, but you can get a shared lock.

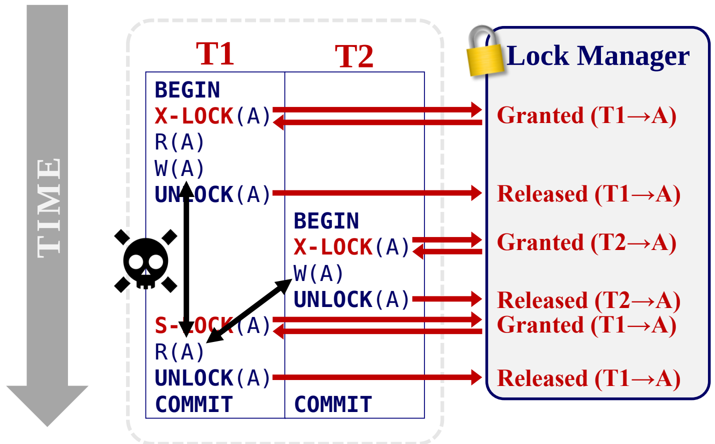
Lock Types

- Basic Types:
  - **S-LOCK** – Shared Locks (reads)
  - **X-LOCK** – Exclusive Locks (writes)

Compatibility Matrix

	Shared	**Exclusive**
Shared	✔	✘
Exclusive	✘	✘

Executing with Locks



Concurrency Control

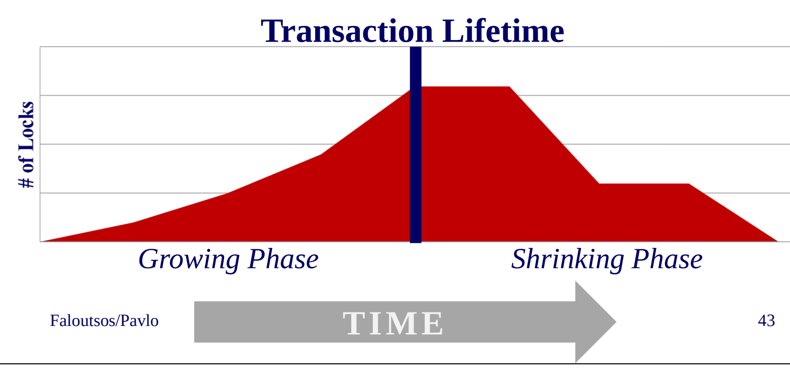
- We need to use a well-defined protocol that ensures that txns execute correctly.

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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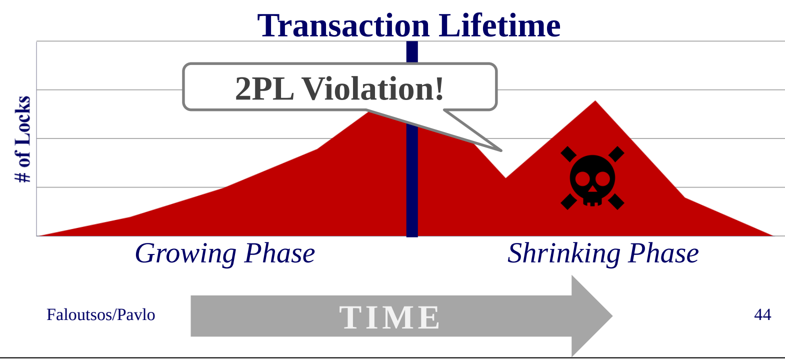
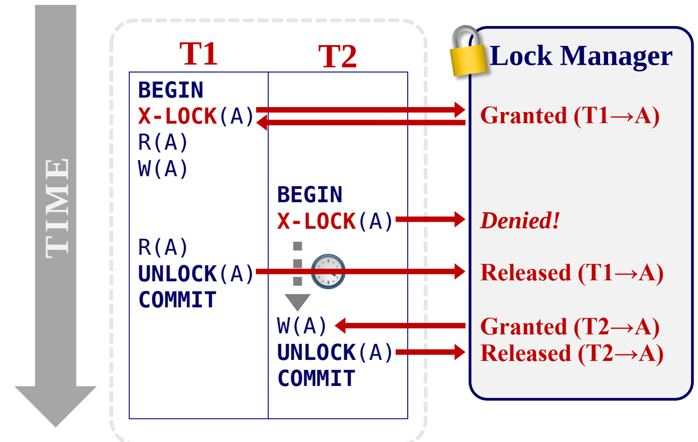


Executing with 2PL



Lock Management

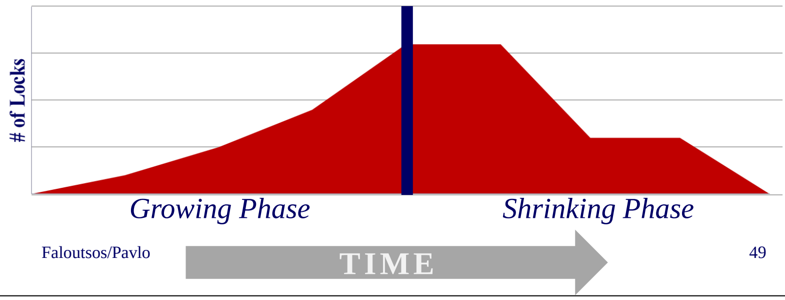
- Lock and unlock requests handled by the DBMS's *lock manager* (LM).
- LM contains an entry for each currently held lock:
  - Pointer to a list of txns holding the lock.
  - The type of lock held (shared or exclusive).
  - Pointer to queue of lock requests.

Lock Management

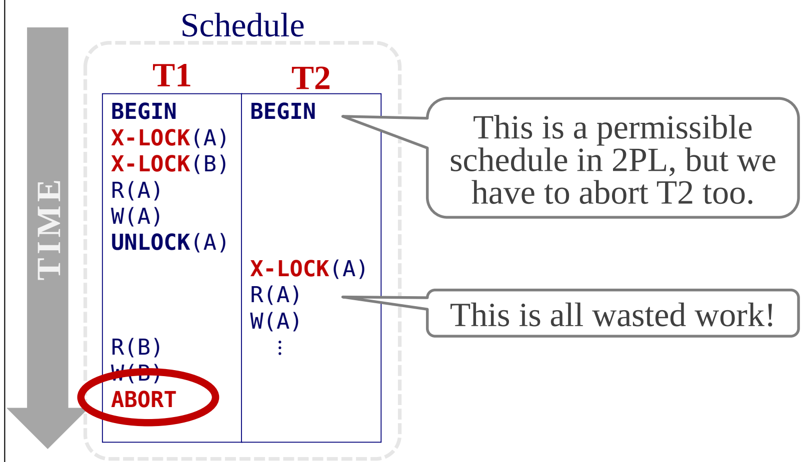
- When lock request arrives see if any other txn holds a conflicting lock.
  - If not, create an entry and grant the lock
  - Else, put the requestor on the wait queue
- All lock operations must be atomic.
- Lock upgrade: The txn that holds a shared lock upgrade to hold an exclusive lock.

Two-Phase Locking

- 2PL on its own is sufficient to guarantee conflict serializability (i.e., schedules whose precedence graph is acyclic), but, it is subject to *cascading aborts*.



2PL – Cascading Aborts

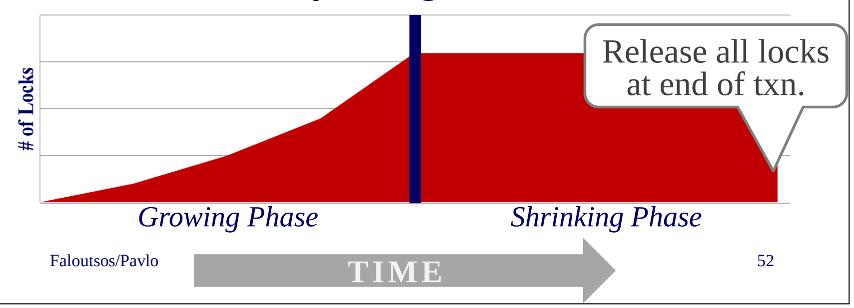


2PL Observations

- There are schedules that are serializable but would not be allowed by 2PL.
- Locking limits concurrency.
- May lead to deadlocks.
- May still have “dirty reads”
  - Solution: **Strict 2PL**

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 actually stronger than needed.



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:
  - Recoverable.
  - Do not require cascading aborts.
  - Aborted txns can be undone by just restoring original values of modified tuples.

Examples

- **T1:** *Move $50 from Christos' account to his bookie's account.*
- **T2:** *Compute the total amount in all accounts and return it to the application.*
- Legend:
  - **A** → Christos' account.
  - **B** → The bookie's account.

Non-2PL Example

TIME

T1	T2
BEGIN	BEGIN
X-LOCK(A)	
R(A)	S-LOCK(A)
A=A-50	
W(A)	
UNLOCK(A)	
	R(A)
	UNLOCK(A)
	S-LOCK(B)
X-LOCK(B)	
	R(B)
	UNLOCK(B)
R(B)	ECHO(A+B)
B=B+50	COMMIT
W(B)	
UNLOCK(B)	
COMMIT	

Initial State

A=100, B=100

T2 Output

150

2PL Example

TIME

T1	T2
BEGIN	BEGIN
X-LOCK(A)	
R(A)	S-LOCK(A)
A=A-50	
W(A)	
X-LOCK(B)	
UNLOCK(A)	
	R(A)
	S-LOCK(B)
R(B)	
B=B+50	
W(B)	
UNLOCK(B)	
COMMIT	R(B)
	UNLOCK(A)
	UNLOCK(B)
	ECHO(A+B)
	COMMIT

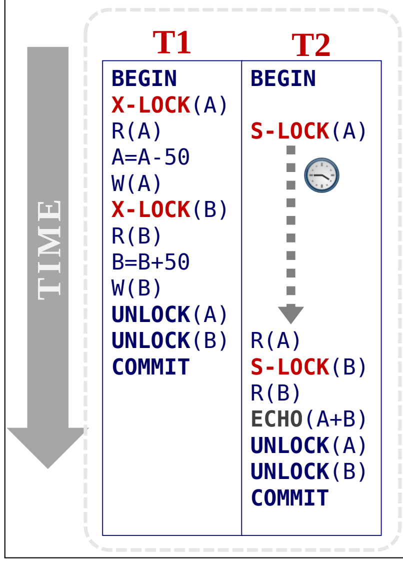
Initial State

A=100, B=100

T2 Output

200

Strict 2PL Example



Initial State

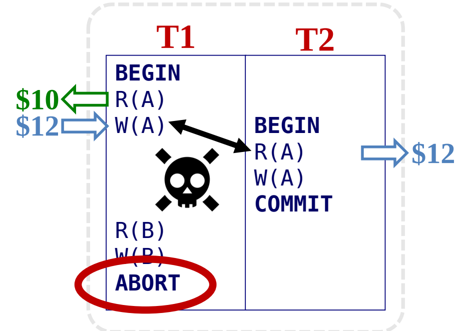
A=100, B=100

T2 Output

200

Strict Two-Phase Locking

- **Q:** Why is avoiding "dirty reads" important?



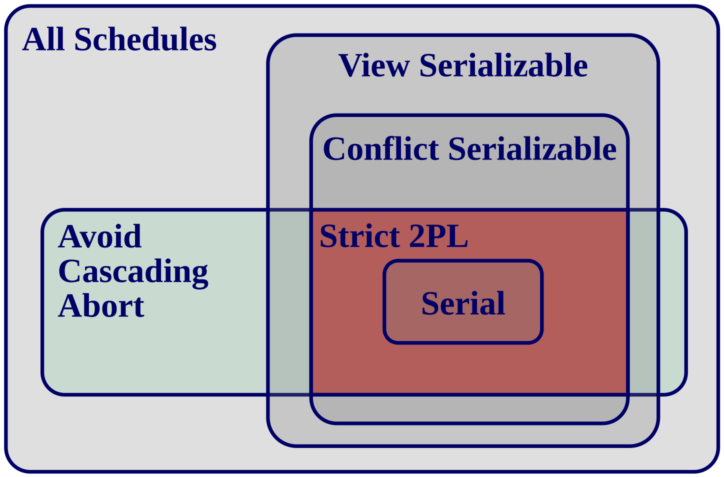
Strict Two-Phase Locking

- **Q:** Why is avoiding "dirty reads" important?
- **A:** If a txn aborts, all actions must be undone. Any txn that read modified data must also be aborted.

Strict Two-Phase Locking

- Txns hold all of their locks until commit.
- Good:
  - Avoids "dirty reads" etc
- Bad:
  - Limits concurrency even more
  - And still may lead to deadlocks

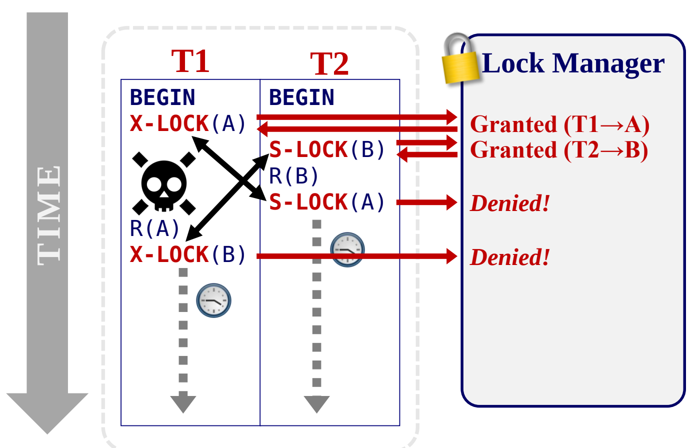
Schedules



Two-Phase Locking

- 2PL seems to work well.
- Is that enough? Can we just go home now?

Shit Just Got Real



Deadlocks

- **Deadlock:** Cycle of transactions waiting for locks to be released by each other.
- Two ways of dealing with deadlocks:
  - Deadlock prevention
  - Deadlock detection
- Many systems just punt and use timeouts
  - What are the dangers with this approach?

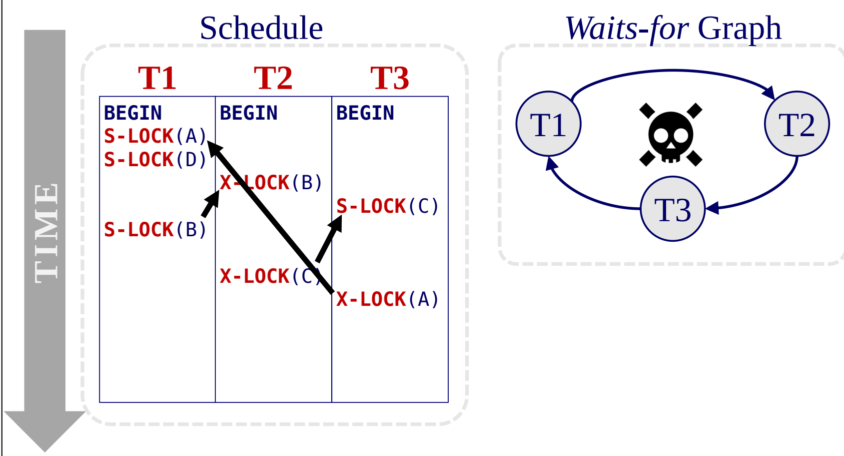
Today's Class

- Serializability: concepts and algorithms
- One solution: Locking
  - 2PL
  - variations
- Deadlocks:
  - Detection
  - Prevention

Deadlock Detection

- The DBMS creates a ***waits-for*** graph:
  - Nodes are transactions
  - Edge from Ti to Tj if Ti is waiting for Tj to release a lock
- The system periodically check for cycles in ***waits-for*** graph.

Deadlock Detection

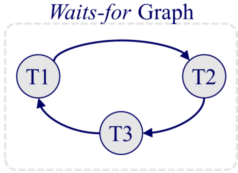


Deadlock Detection

- How often should we run the algorithm?
- How many txns are typically involved?
- What do we do when we find a deadlock?

Deadlock Handling

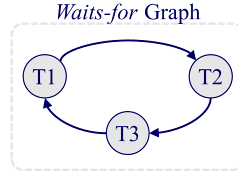
Waits-for Graph



- **Q:** What do we do?
- **A:** Select a "victim" and rollback it back to break the deadlock.

Deadlock Handling

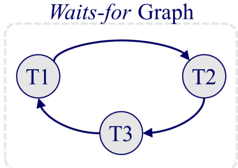
Waits-for Graph



- **Q:** Which one do we choose?
- **A:** It depends…
  – 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.

Deadlock Handling

Waits-for Graph



- **Q:** How far do we rollback?
- **A:** It depends…
  – Completely
  – Minimally (i.e., just enough to release locks)

Today's Class

- Serializability: concepts and algorithms
- One solution: Locking
  – 2PL
  – variations
- Deadlocks:
  – Detection
  – Prevention

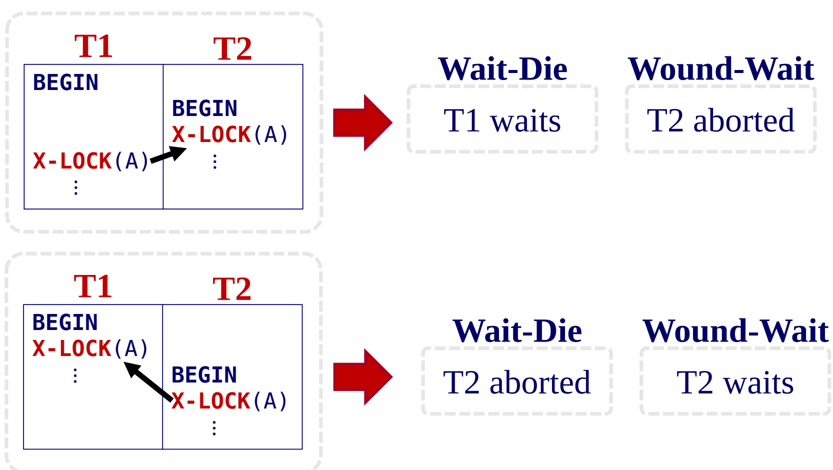
Deadlock Prevention

- When a txn tries to acquire a lock that is held by another txn, kill one of them to prevent a deadlock.
- No *waits-for* graph or detection algorithm.

Deadlock Prevention

- Assign priorities based on timestamps:
  - Older → higher priority (e.g., T1 > T2)
- Two different prevention policies:
  - **Wait-Die:** If T1 has higher priority, T1 waits for T2; otherwise T1 aborts ("old wait for young")
  - **Wound-Wait:** If T1 has higher priority, T2 aborts; otherwise T1 waits ("young wait for old")

Deadlock Prevention



Deadlock Prevention

- **Q:** Why do these schemes guarantee no deadlocks?
- **A:** Only one "type" of direction allowed.

- **Q:** When a transaction restarts, what is its (new) priority?
- **A:** Its original timestamp. Why?

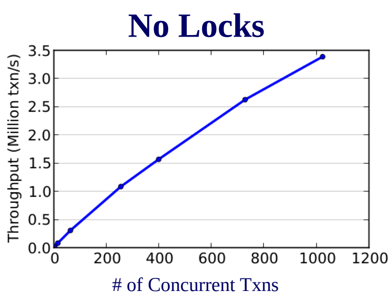
Performance Problems

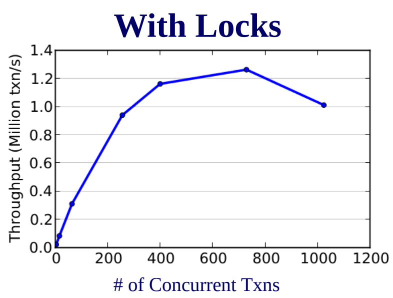
- Executing more txns can increase the throughput.
- But there is a tipping point where adding more txns actually makes performance worse.

Lock Thrashing

- When a txn holds a lock, other txns have to wait for it to finish.
- If you have a lot of txns with a lot of locks, then you will have a lot of waiting.
- A lot of waiting means txns take longer and hold their locks longer…

Lock Thrashing





Locking in Practice

- You typically don't set locks manually.
- Sometimes you will need to provide the DBMS with hints to help it to improve concurrency.
- Also useful for doing major changes.

LOCK TABLE

Postgres

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

MySQL

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

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

SELECT...FOR UPDATE

```
SELECT * FROM <table>
 WHERE <qualification> 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**

Locking Demo

Concurrency Control Summary

- Conflict Serializability ↔ Correctness
- Automatically correct interleavings:
  - Locks + protocol (2PL, S2PL ...)
  - Deadlock detection + handling
  - Deadlock prevention
- **Big Assumption:** The database is fixed.
  - That is, objects are not inserted or deleted.