TRANSACTION MANAGEMENT II

CS 564 - Spring 2025

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WHAT IS THIS LECTURE ABOUT?

- Transaction (TXN) management
- **ACID** properties
  - atomicity
  - consistency
  - isolation
  - durability
- Logging
- Scheduling & locking

ACID PROPERTIES: RECAP

Atomicity: all actions in the TXN happen, or none happen

Consistency: a database in a consistent state will remain in a consistent state after the TXN

Isolation: the execution of one TXN is isolated from other (possibly interleaved) TXNs

Durability: once a TXN commits, its effects must persist

CONCURRENCY

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- The DBMS runs multiple TXNs concurrently
- To achieve better performance, interleaving the operations of the TXNs is critical
  - possibly slow TXNs
  - CPU/IO overlap
- But interleaving can lead to problems!

Remember: we must guarantee **isolation** & **consistency**!

EXAMPLE

T1: *transfer $100 from A to B*

```
BEGIN TRANSACTION ;
  UPDATE account
    SET balance = balance – 100
    WHERE account_name = A;
  UPDATE account
    SET balance = balance + 100
    WHERE account_name = B;
COMMIT ;
```

T2: *add 10% interest to both accounts*

```
BEGIN TRANSACTION ;
  UPDATE account
    SET balance = balance * 1.1
COMMIT ;
```

Let’s see how the DBMS can schedule the 2 transactions

EXAMPLE

First run T1, then run T2

T1	*T2*
A ← A - 100	
B ← B + 100	
	A ← A * 1.1
	B ← B * 1.1

time

Beginning
- A = 200, B = 100

End
- A = 110, B = 220

This is called a **serial** schedule

EXAMPLE

First run T2, then run T1

T1	***T2***
	A ← A * 1.1
	B ← B * 1.1
A ← A - 100	
B ← B + 100	

time

Beginning
- A = 200, B = 100

End
- A = 120, B = 210

This is also a serial schedule

EXAMPLE

Interleaving the operations of T1 and T2

T1	*T2*
	A ← A * 1.1
A ← A - 100	
	B ← B * 1.1
B ← B + 100	

time

Beginning
- A = 200, B = 100

End
- A = 120, B = 210

Same result as if we run serially T2 and then T1! This is called a **serializable** schedule

EXAMPLE

Different interleaving of the operations of T1 and T2

T1	*T2*
	A ← A * 1.1
A ← A - 100	
B ← B + 100	
	B ← B * 1.1

time

Beginning

- A = 200, B = 100

End

- A = 120, B = 220

Different result from both serial schedules!
This is called a **not serializable** schedule

SCHEDULES: DEFINITIONS

Schedule: an interleaving of actions from a set of TXNs, where the actions of any TXN are in the original order

Serial schedule: a schedule where there is no interleaving of actions from different TXNs

Equivalent schedules: two schedules are equivalent if *for every* database state, they will have the same effect

Serializable schedule: a schedule that is equivalent to *some* serial schedule

Note: we assume that all TXNs commit in the schedules!

THE DBMS'S VIEW OF THE SCHEDULE

T1	*T2*
	A ← A * 1.1
A ← A - 100	
B ← B + 100	
	B ← B * 1.1

time

Each action is a read (**R**) followed by a write (**W**)

T1	*T2*
	R(A)
	W(A)
R(A)	
W(A)	
R(B)	
W(B)	
	R(B)
	W(B)

CONFLICTS IN SCHEDULES

Two actions **conflict** if they are part of different TXNs, involve the same variable, and at least one of them is a write

- Write-Read conflict
- Read-Write conflict
- Write-Write conflict

A conflict does not always lead to a problem when interleaving!

CONFLICTS VS ANOMALIES

<u>Conflicts</u> help us characterize different schedules

- present in both “good” and “bad” schedules

<u>Anomalies</u> are instances where isolation and/or consistency is broken because of a “bad” schedule

- we often characterize different anomaly types by what types of conflicts predicated them

DIRTY READ

T1	T2
	W(A)
R(B)	
R(A)	
Commit	
	W(C)

time

A **dirty read** occurs when a TXN reads data that was modified by a not yet committed TXN

- in the example, T1 reads A, which was previously modified by T2
- occurs because of a W-R conflict!

If T2 aborts, this will lead to inconsistency!

UNREPEATABLE READ

T1	*T2*
	R(A)
W(A)	
R(B)	
Commit	
	R(A)

time

An **unrepeatable read** occurs when a TXN reads data twice, but in between the data was modified by another TXN

- in the example, T2 reads A, T1 then modifies T1, and T2 reads again
- occurs because of a R-W conflict!

OVERWRITING UNCOMMITTED DATA

T1	T2
	W(A)
W(A)	
W(B)	
Commit	
	W(B)

time

This occurs when a TXN overwrites the data of an uncommitted TXN

- in the example, the last version of A and B would not be consistent with any serial schedule
- occurs because of a W-W conflict!

CONFLICT SERIALIZABILITY

CONFLICT SERIALIZABILITY

- Two schedules are **conflict equivalent** if:
  - they involve *the same actions of the same TXNs*
  - every *pair of conflicting actions* of two TXNs are *ordered in the same way*
- A schedule is **conflict serializable** if it is *conflict equivalent* to *some* serial schedule
- This provides us with a way to distinguish "good" from "bad" schedules

Conflict serializable ⇒ serializable

So if we have conflict serializable, we have consistency & isolation

EXAMPLE

T1	T2
	R(A)
	W(A)
	R(B)
	W(B)
R(A)	
W(A)	
R(B)	
W(B)	

- In both, W(A) in T2 comes before R(A) in T1
- The same happens with all other pairs of conflicting actions
- Since the left schedule is serial, the right schedule is conflict serializable!

T1	T2
	R(A)
	W(A)
R(A)	
W(A)	
	R(B)
	W(B)
R(B)	
W(B)	

EXAMPLE

T1	T2
	R(A)
	W(A)
	R(B)
	W(B)
R(A)	
W(A)	
R(B)	
W(B)	

- The order has changed now!
- The two schedules are not conflict equivalent
- We still need to check all other serial schedules!

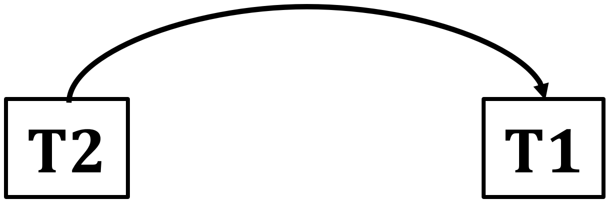
T1	T2
	R(A)
R(A)	
W(A)	
	W(A)
	R(B)
	W(B)
R(B)	
W(B)	

THE CONFLICT GRAPH

- The conflict graph looks at conflicts at the transaction level
- the nodes are TXNs
- there is an edge from T_i to T_j *if any actions in T_i precede and conflict with any actions in T_j*

THE CONFLICT GRAPH

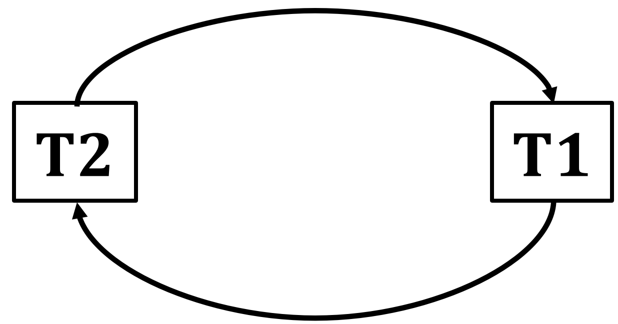
T1	*T2*
	R(A)
	W(A)
R(A)	
W(A)	
	R(B)
	W(B)
R(B)	
W(B)	



- Since W(A) in T2 is before R(A) in T1, we add an edge from T2 to T1
- There is no edge from T1 to T2 in this case!

THE CONFLICT GRAPH

T1	*T2*
	R(A)
R(A)	
W(A)	
	W(A)
	R(B)
	W(B)
R(B)	
W(B)	

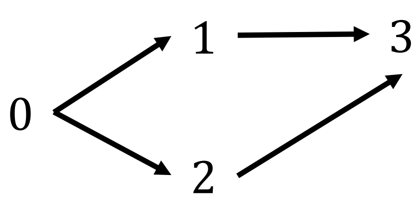


- Since R(A) in T1 is before W(A) in T2, we add an edge from T1 to T2
- Since W(B) in T2 is before R(B) in T1, we also add an edge from T2 to T1

THE CONFLICT GRAPH: THEOREM

<u>Theorem</u>: a schedule is conflict serializable if and only if its conflict graph is acyclic (i.e. it has no directed cycles)

- A topological ordering of a directed graph is a linear ordering of its vertices that respects all the directed edges
- A directed acyclic graph (DAG) always has one or more topological orderings
  - if there are cycles, there exists no such ordering!

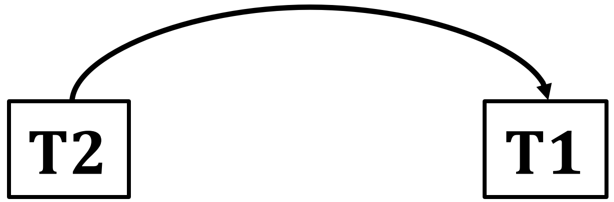


There are 2 possible topological orderings:

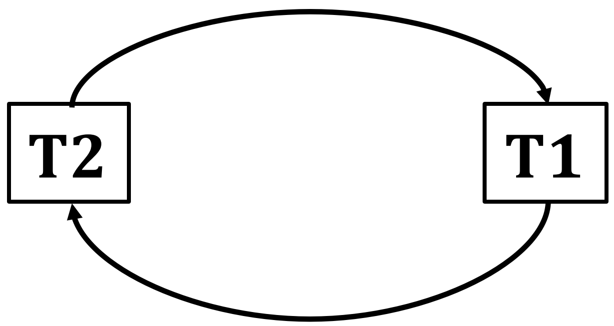
- 0, 2, 1, 3
- 0, 1, 2, 3

THE CONFLICT GRAPH

- In the conflict graph, a topological ordering of the nodes corresponds to a serial ordering of TXNs (serial schedule)
- Thus an **acyclic** conflict graph → conflict serializable!



top ordering: T2, T1
this is conflict equivalent to a
serial schedule with first T2, then T1



there is a cycle, so no topological ordering
not conflict serializable!

LOCKING

LOCKING

- Locking is a technique for concurrency control
- Lock information maintained by a *lock manager*:
  - stores (TID, RID, Mode) triples
  - mode is either Shared (S) or Exclusive (X)

	--	S	X
--	√	√	√
S	√	√	
X	√		

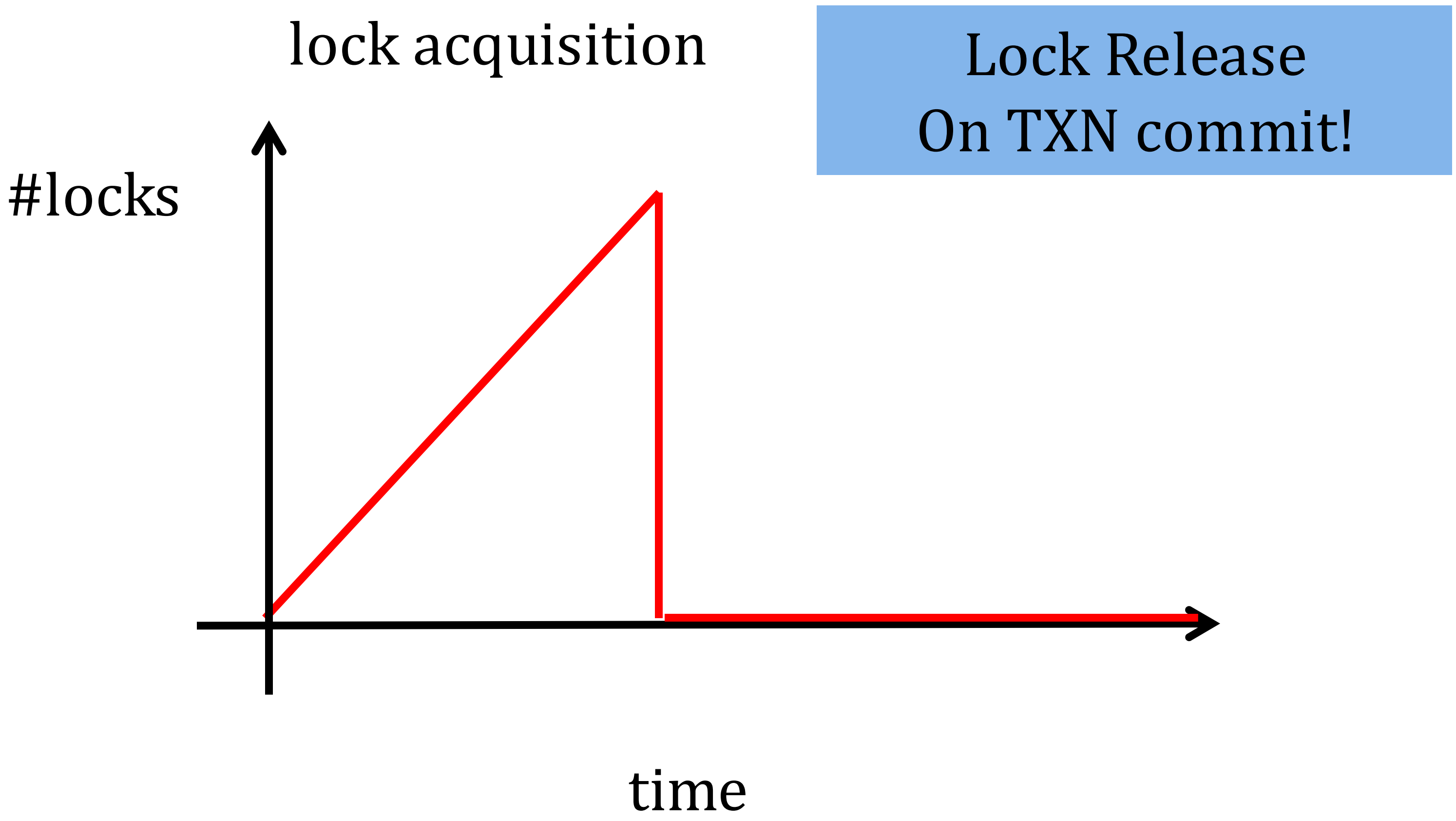
- If a transaction cannot get a lock, it has to wait in a queue

STRICT 2 PHASE LOCKING

- Each transaction must obtain a **S** lock on object before reading, and an **X** lock on object before writing
- If a transaction holds an **X** lock on an object, no other transaction can get a lock (S or X) on that object
- All locks held by a transaction are released only when the transaction completes

Strict 2PL guarantees conflict serializability!

STRICT 2PL: FIGURE



STRICT 2PL

- If a schedule follows strict 2PL and locking, it is conflict serializable
  - and thus serializable
  - and thus maintains isolation & consistency!

- Not all serializable schedules are allowed by strict 2PL
- But running a strict 2PL protocol has some issues!

DEADLOCKS

T1	*T2*
R(B)	
W(B)	
	R(A)
	W(A)
R(A)	
	R(B)

T1 gets an X-lock on B

T2 gets an X-lock on A

T1 wants to read A, but has to wait…

T2 wants to read B, but also has to wait…

We now have a **deadlock**!

DEADLOCKS

- Deadlocks can cause the system to wait forever
- We need to detect deadlocks and break, or prevent deadlocks
- Simple mechanism: timeout and abort
- More sophisticated methods exist

PERFORMANCE OF LOCKING

- Locks have a performance penalty:
  - blocked actions
  - aborted transactions
- Because of blocking, we can not increase forever the throughput of transactions
- At the point where the throughput cannot increase, we say that the system thrashes

TRANSACTIONS IN SQL

TRANSACTIONS IN SQL

- What object should we lock?

```
SELECT COUNT(*)
FROM   Employee
WHERE  age = 20 ;
```

- We can apply locking at different granularities:
  - lock the whole table Employee
  - lock only the rows with age = 20

TRANSACTIONS IN SQL

Transaction characteristics:

- Access mode: `READ ONLY, READ WRITE`
- Isolation level
  - Serializable: default (Strict 2PL)
  - Repeatable reads: (R/W locks, but phantoms can occur)
    - Read only committed records
    - Between two reads by the same transaction, no updates by another transaction
  - Read committed (W locks longterm, R locks shortterm)
    - Read only committed records
  - Read uncommitted (only reads, no locks)