TRANSACTION MANAGEMENT

CS 564- Spring 2018

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WHAT IS THIS LECTURE ABOUT?

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

The ACID Properties

ACID PROPERTIES

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

ACID: ATOMICITY

Atomicity: All actions in the transaction happen, or none happen

- Two possible outcomes for a TXN
  - **commit**: all the changes are made
  - **abort**: no changes are made

ACID: CONSISTENCY

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

- Examples*:*
  - account number is unique
  - stock amount can’t be negative
- How consistency is achieved:
  - the *programmer* makes sure a TXN takes a consistent state to a consistent state
  - the *DBMS* makes sure that the TXN is **atomic**

ACID: ISOLATION

Isolation: the execution of one transaction is isolated from other (possibly interleaved) transactions

Example:

- if T1, T2 are interleaved, the result should be the same as executing first T1 then T2, or first T2 then T1

ACID: DURABILITY

Durability: if a transaction commits, its effects must persist

- for example, if the system crashes after a commit, the effects must remain
- essentially, this means that we have to write to disk

CONCURRENCY

CONCURRENCY

- 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 **<u>serializable</u>** 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

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

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

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

Conflicts help us characterize different schedules

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

Anomalies 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!

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 a not yet committed 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!

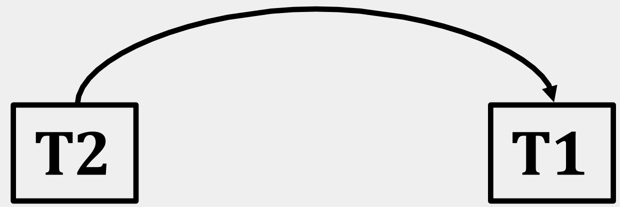
T1	*T2*
	R(A)
R(A)	
W(A)	
	W(A)
	R(B)
	W(B)
R(B)	
W(B)	

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

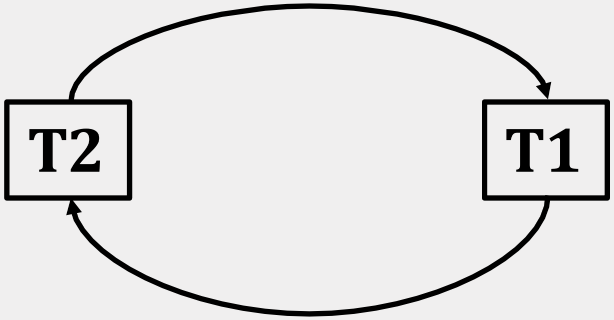
T1	*T2*
	R(A)
	W(A)
R(A)	
W(A)	
	R(B)
	W(B)
R(B)	
W(B)	



- 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)	

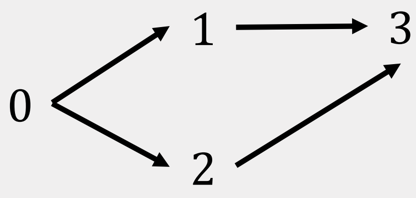


- Since R(A) in T1 is before W(A) in T2, we add an edge from T1 to T2
- Since W(B) in T2 is before R(B) in T1, we also add an edge from T2 to T1

THE CONFLICT GRAPH: THEOREM

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

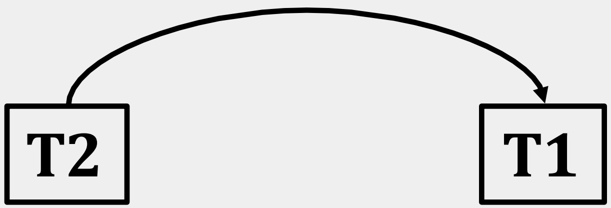
- A topological ordering of a directed graph is a linear ordering of its vertices that respects all the directed edges
- A directed acyclic graph (DAG) always has one or more topological orderings
  - if there are cycles, there exists no such ordering!



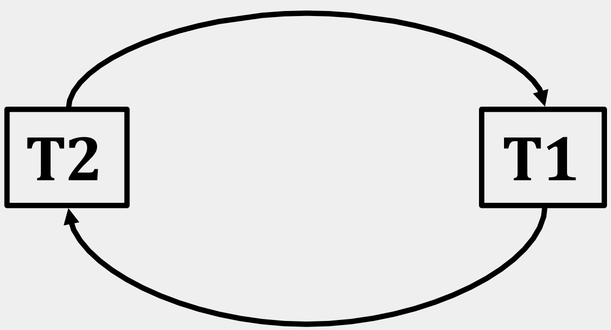
There are 2 possible topological orderings:
- 0, 2, 1, 3
- 0, 1, 2, 3

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	√		

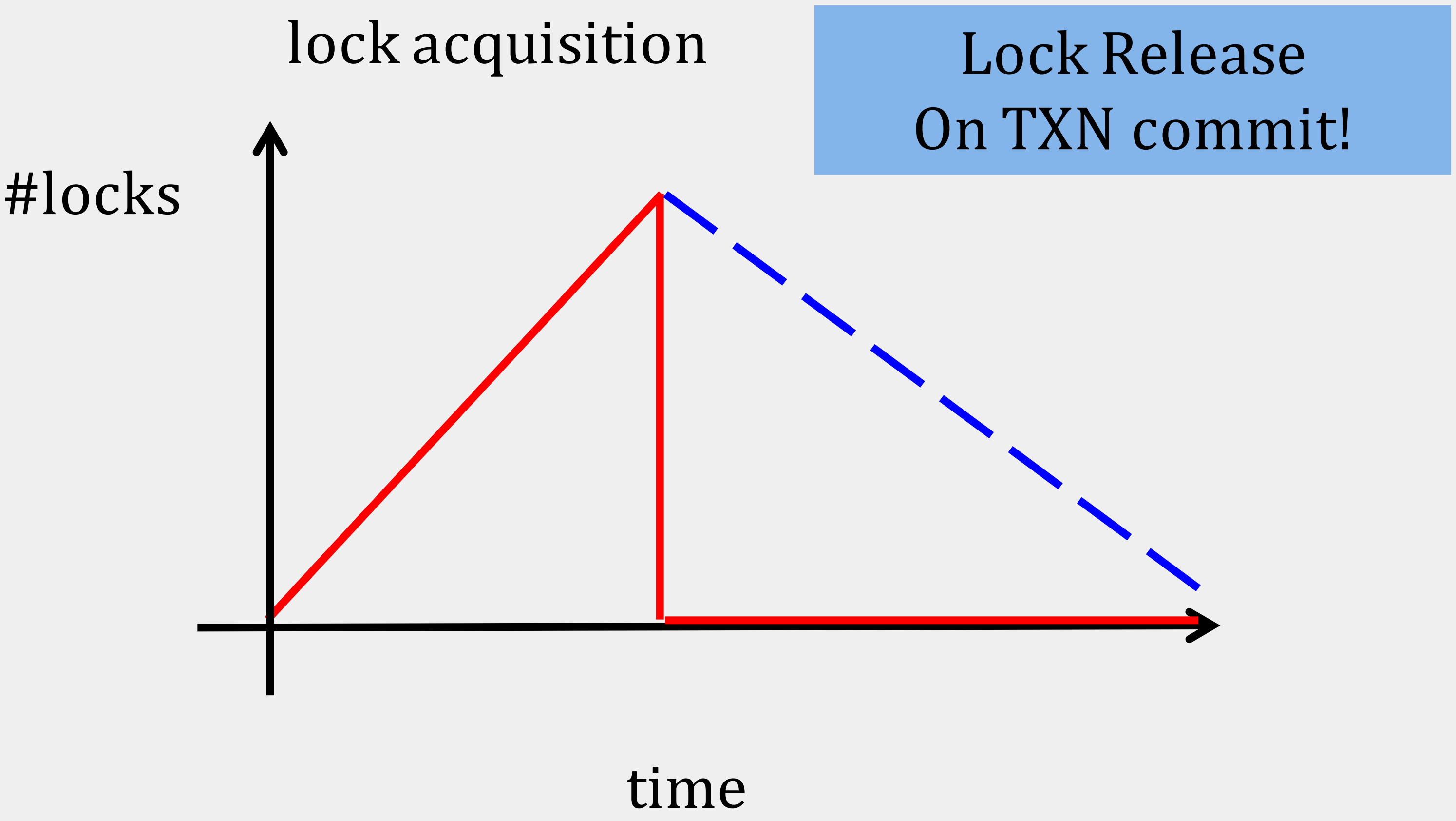
- If a transaction cannot get a lock, it has to wait in a queue

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



DEADLOCKS

- 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!

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 phantom 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)