Database Systems
CSE 414

Lecture 27:
Transaction Implementations

Announcements

- Final exam will be on Dec. 14 (next Thursday) 14:30-16:20 in class
  - Note the time difference, the exam will last ~2 hours

- Bring your laptop to the lecture on Wednesday

Recap

- What are transactions?
  - Why do we need them?
- Maintain ACID properties via schedules
  - We focus on the **isolation** property
  - We briefly discussed **consistency** & **durability**
  - We do not discuss **atomicity**
- Ensure conflict-serializable schedules with locks

Implementing a Scheduler

Major differences between database vendors

- Locking Scheduler
  - Aka “pessimistic concurrency control”
  - SQLite, SQL Server, DB2
- Multiversion Concurrency Control (MVCC)
  - Aka “optimistic concurrency control”
  - Postgres, Oracle

We discuss only locking in 414

Locking Scheduler

Simple idea:

- Each element has a unique lock
- Each transaction must first acquire the lock before reading/writing that element
- If lock is taken by another transaction, then wait
- The transaction must release the lock(s)

By using locks, scheduler **can** ensure conflict-serializability

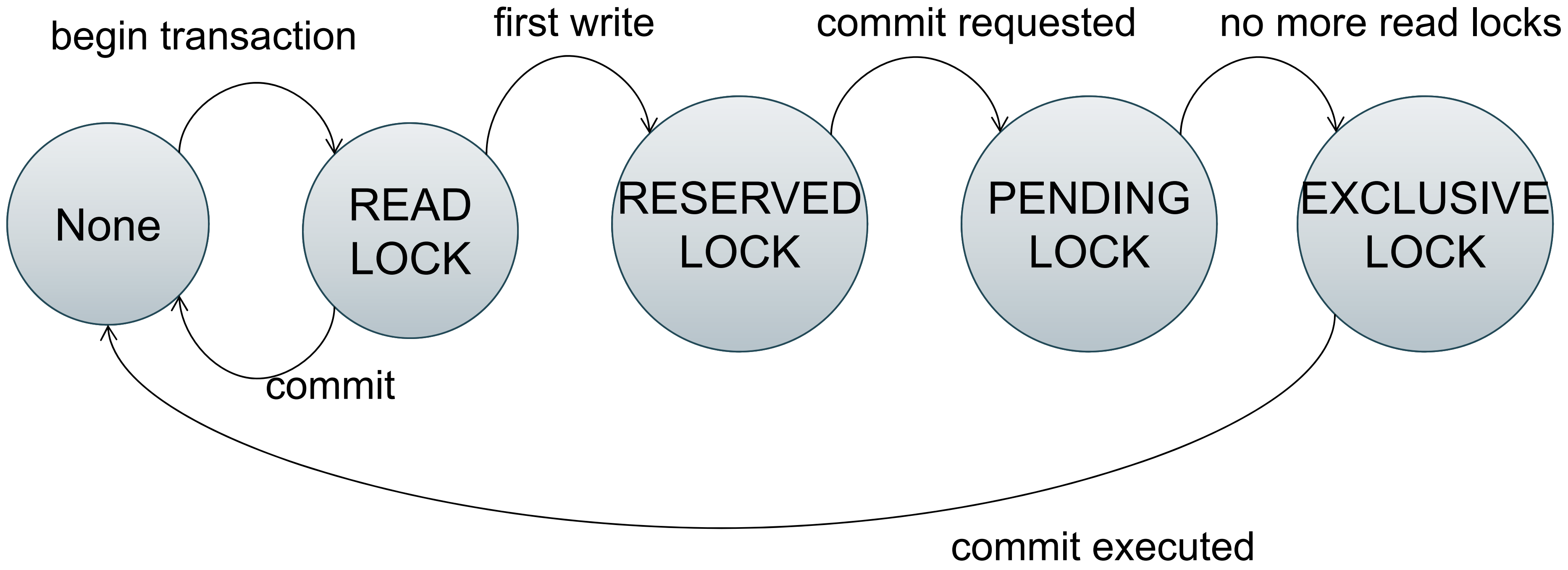
What Data Elements are Locked?

Major differences between vendors:

- Lock on the entire database
  - SQLite

- Lock on individual records
  - SQL Server, DB2, etc.
  - can be even more fine-grained by having **different types** of locks (allows more txns to run simultaneously)

SQLite


begin transaction
first write
commit requested
no more read locks
None
READ LOCK
RESERVED LOCK
PENDING LOCK
EXCLUSIVE LOCK
commit
commit executed

Locks in the Abstract

Notation

$L_i(A)$ = transaction T_i acquires lock for element A

$U_i(A)$ = transaction T_i releases lock for element A

A Non-Serializable Schedule

T1	T2
READ(A)	
A := A+100	
WRITE(A)	
	READ(A)
	A := A*2
	WRITE(A)
	READ(B)
	B := B*2
	WRITE(B)
READ(B)	
B := B+100	
WRITE(B)	

Example

T1	T2
L_1(A); READ(A)	
A := A+100	
WRITE(A); U_1(A); L_1(B)	
	L_2(A); READ(A)
	A := A*2
	WRITE(A); U_2(A);
	L_2(B); BLOCKED…
READ(B)	
B := B+100	
WRITE(B); U_1(B);	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); U_2(B);

Scheduler has ensured a conflict-serializable schedule

But…

T1	T2
$L_1(A)$; READ(A)	
A := A+100	
WRITE(A); $U_1(A)$;	
	$L_2(A)$; READ(A)
	A := A*2
	WRITE(A); $U_2(A)$;
	$L_2(B)$; READ(B)
	B := B*2
	WRITE(B); $U_2(B)$;
$L_1(B)$; READ(B)	
B := B+100	
WRITE(B); $U_1(B)$;	

Locks did not enforce conflict-serializability !!! What’s wrong ?

Two Phase Locking (2PL)

The 2PL rule:

In every transaction, all lock requests must precede all unlock requests

2PL approach developed by Jim Gray

Example: 2PL transactions

T1	T2
L_1(A); L_1(B); READ(A)	
A := A+100	
WRITE(A); U_1(A)	
	L_2(A); READ(A)
	A := A*2
	WRITE(A);
	L_2(B); BLOCKED…
READ(B)	
B := B+100	
WRITE(B); U_1(B);	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); U_2(A); U_2(B);

Now it is conflict-serializable

Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

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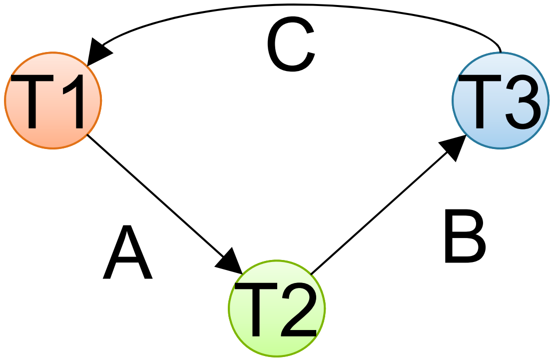
Theorem: 2PL ensures conflict serializability

Proof. Suppose not: then there exists a cycle in the precedence graph.



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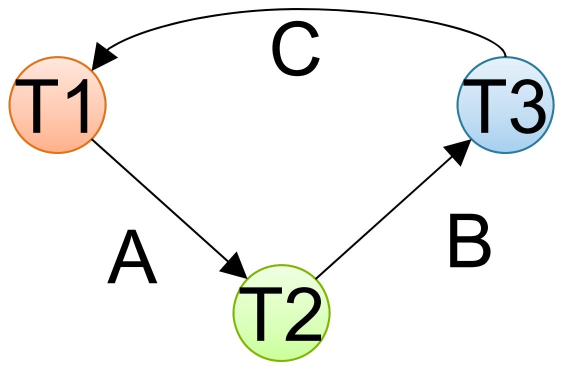

Then there is the following **temporal** cycle in the schedule:

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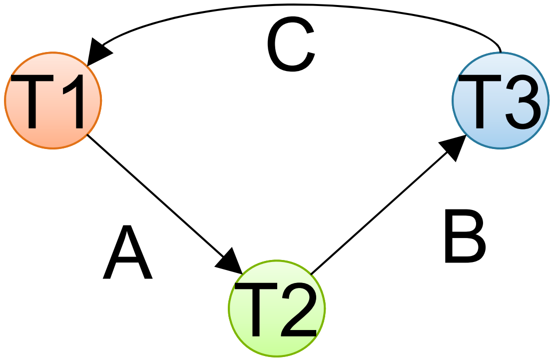

Then there is the following **temporal** cycle in the schedule:

$U_1(A) \rightarrow L_2(A)$ why?

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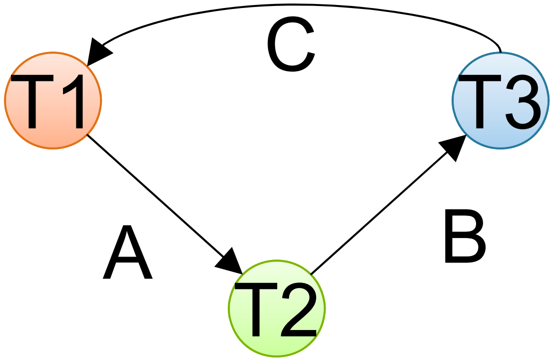


Then there is the following **temporal** cycle in the schedule:

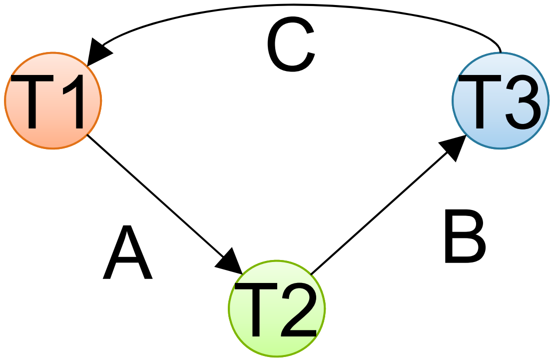
$U_1(A) \rightarrow L_2(A)$

$L_2(A) \rightarrow U_2(B)$ why?

Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

Proof. Suppose not: then there exists a cycle in the precedence graph.



Then there is the following **temporal** cycle in the schedule:

$U_1(A) \rightarrow L_2(A)$
$L_2(A) \rightarrow U_2(B)$
$U_2(B) \rightarrow L_3(B)$
$L_3(B) \rightarrow U_3(C)$
$U_3(C) \rightarrow L_1(C)$
$L_1(C) \rightarrow U_1(A)$

Contradiction

A New Problem: Non-recoverable Schedule

T1	T2
$L_1(A)$; $L_1(B)$; READ(A)	
A :=A+100	
WRITE(A); $U_1(A)$	
	$L_2(A)$; READ(A)
	A := A*2
	WRITE(A);
	$L_2(B)$; BLOCKED…
READ(B)	
B :=B+100	
WRITE(B); $U_1(B)$;	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); $U_2(A)$; $U_2(B)$;
	Commit
Rollback	

Strict 2PL

The Strict 2PL rule:

All locks are held until the transaction commits or aborts.

With strict 2PL, we will get schedules that are both conflict-serializable and recoverable

Strict 2PL

T1	T2
L_1(A); READ(A)	
A :=A+100	
WRITE(A);	
	L_2(A); BLOCKED…
L_1(B); READ(B)	
B :=B+100	
WRITE(B);	
ROLLBACK; U_1(A),U_1(B)	
	…GRANTED; READ(A)
	A := A*2
	WRITE(A);
	L_2(B); READ(B)
	B := B*2
	WRITE(B);
	COMMIT; U_2(A); U_2(B)

Another problem: Deadlocks

- T_1 waits for a lock held by T_2;
- T_2 waits for a lock held by T_3;
- T_3 waits for . . . .
- . . .
- T_n waits for a lock held by T_1

SQL Lite: there is only one exclusive lock; thus, never deadlocks

SQL Server: checks periodically for deadlocks and aborts one TXN

Lock Modes

- S = shared lock (for READ)
- X = exclusive lock (for WRITE)

Lock compatibility matrix:

	None	S	X
None			
S			
X			

Lock Modes

- S = shared lock (for READ)
- X = exclusive lock (for WRITE)

Lock compatibility matrix:

	None	S	X
None	✓	✓	✓
S	✓	✓	✗
X	✓	✗	✗

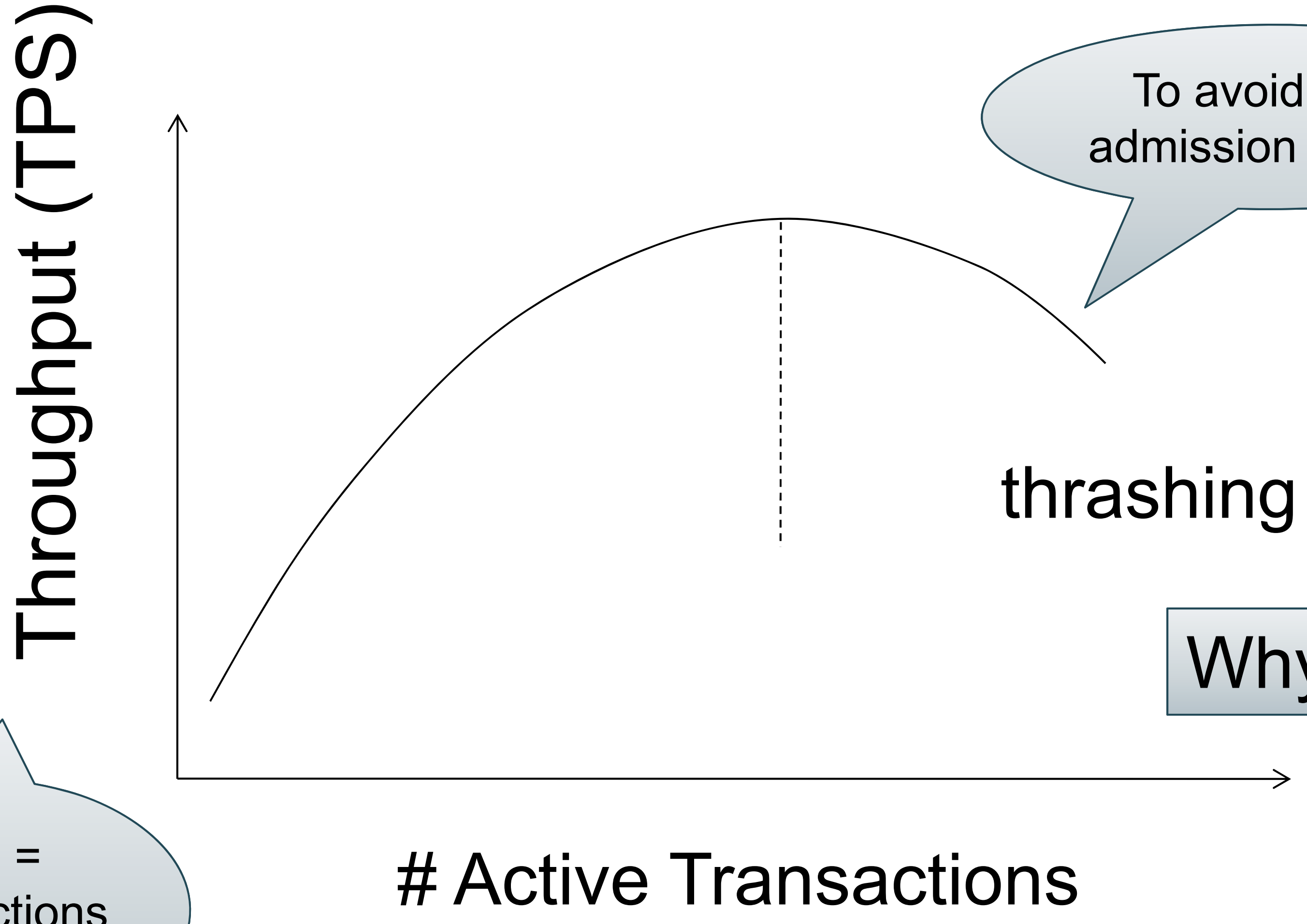
Lock Granularity

- Fine granularity locking (e.g., tuples)
  - High concurrency
  - High overhead in managing locks
  - E.g. SQL Server

- Coarse grain locking (e.g., tables, entire database)
  - Many false conflicts
  - Less overhead in managing locks
  - E.g. SQLite

- Solution: lock escalation changes granularity as needed

Lock Performance



To avoid, use admission control

Why ?

TPS = Transactions per second

Phantom Problem

- So far we have assumed the database to be a *static* collection of elements (=tuples)

- If tuples are inserted/deleted then the *phantom problem* appears

Suppose there are two blue products A1 & A2

Phantom Problem

T1	T2
SELECT * FROM Product WHERE color='blue'	
	INSERT INTO Product(name, color) VALUES ('A3', 'blue')
SELECT * FROM Product WHERE color='blue'	

Is this schedule serializable ?

Suppose there are two blue products A1 & A2

Phantom Problem

T1	T2
SELECT * FROM Product WHERE color=‘blue’	
	INSERT INTO Product(name, color) VALUES (‘A3’, ‘blue’)
SELECT * FROM Product WHERE color=‘blue’	

R1(A1), R1(A2), W2(A3), R1(A1), R1(A2), R1(A3)

Suppose there are two blue products A1 & A2

Phantom Problem

T1	T2
SELECT * FROM Product WHERE color=‘blue’	
	INSERT INTO Product(name, color) VALUES (‘A3’, ‘blue’)
SELECT * FROM Product WHERE color=‘blue’	

R1(A1), R1(A2), W2(A3), R1(A1), R1(A2), R1(A3)

W2(A3), R1(A1), R1(A2), R1(A1), R1(A2), R1(A3)

Phantom Problem

- A “phantom” is a tuple that is invisible during part of a transaction execution, but not invisible during the entire execution
- In our example:
  - T1: reads list of products
  - T2: inserts a new product
  - T1: re-reads: a new product appears !

Dealing With Phantoms

- Lock the entire table
- Lock the index entry for ‘blue’
  - If index is available
- Or use predicate locks
  - A lock on an arbitrary predicate

Dealing with phantoms is expensive !

Locking & SQL

Isolation Levels in SQL

1. “Dirty reads”
   SET TRANSACTION ISOLATION LEVEL READ UNCOMMITTED
2. “Committed reads”
   SET TRANSACTION ISOLATION LEVEL READ COMMITTED
3. “Repeatable reads”
   SET TRANSACTION ISOLATION LEVEL REPEATABLE READ
4. Serializable transactions
   SET TRANSACTION ISOLATION LEVEL SERIALIZABLE

ACID

1. Isolation Level: Dirty Reads

- "Long duration" WRITE locks
  - Strict 2PL
- No READ locks
  - Read-only transactions are never delayed

Possible problems: dirty and **inconsistent** reads

2. Isolation Level: Read Committed

- “Long duration” WRITE locks
  - Strict 2PL
- “Short duration” READ locks
  - Only acquire lock while reading (not 2PL)

Unrepeatable reads
When reading same element twice, may get two different values

3. Isolation Level: Repeatable Read

- “Long duration” WRITE locks
  - Strict 2PL
- “Long duration” READ locks
  - Strict 2PL

Why ?

This is not serializable yet !!!

4. Isolation Level Serializable

- "Long duration" WRITE locks
  - Strict 2PL
- "Long duration" READ locks
  - Strict 2PL
- Predicate locking
  - To deal with phantoms

Beware!

In commercial DBMSs:

- Default level is often **NOT** serializable (SQL Server!)
- Default level differs between DBMSs
- Some engines support subset of levels
- Serializable may not be exactly ACID
  - Locking ensures isolation, not atomicity
- Also, some DBMSs do NOT use locking. Different isolation levels can lead to different problems
- Bottom line: Read the doc for your DBMS!

Next two slides: try them on Azure

Demonstration with SQL Server

Application 1:

```
create table R(a int);
insert into R values(1);
set transaction isolation level serializable;
begin transaction;
select * from R; -- get a shared lock
waitfor delay '00:01';  -- wait for one minute
```

Application 2:

```
set transaction isolation level serializable;
begin transaction;
select * from R; -- get a shared lock
insert into R values(2); -- blocked waiting on exclusive lock
      -- App 2 unblocks and executes insert after app 1 commits/aborts
```

Demonstration with SQL Server

Application 1:

```
create table R(a int);
insert into R values(1);
set transaction isolation level repeatable read;
begin transaction;
select * from R; -- get a shared lock
waitfor delay '00:01';  -- wait for one minute
```

Application 2:

```
set transaction isolation level repeatable read;
begin transaction;
select * from R; -- get a shared lock
insert into R values(3); -- gets an exclusive lock on new tuple
        -- If app 1 reads now, it blocks because read dirty
        -- If app 1 reads after app 2 commits, app 1 sees new value
```