Introduction to Data Management
CSE 344

Lecture 22:
Transaction Implementations

Announcements

- WQ7 and HW7 are out
  - Due next Tues and Wed
  - Start early, there is little time!

Review

- What are transactions
  - And why do we need them
- How to maintain ACID properties via schedules
  - We focus on the **isolation** property
  - Learn about durability in 444
- How to ensure conflict-serializable schedules with locks

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 ensures 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

Review: SQLite

- SQLite is very simple
- More info: http://www.sqlite.org/atomiccommit.html

- Lock types
  - READ LOCK (to read)
  - RESERVED LOCK (to write)
  - PENDING LOCK (wants to commit)
  - EXCLUSIVE LOCK (to commit)

SQLite

Step 1: when a transaction begins

- Acquire a READ LOCK (aka "SHARED" lock)
- All these transactions may read happily
- They all read data from the database file
- If the transaction commits without writing anything, then it simply releases the lock

SQLite

Step 2: when one transaction wants to write

- Acquire a RESERVED LOCK
- May coexists with many READ LOCKs
- Writer TXN may write; these updates are only in main memory; others don't see the updates
- Reader TXN continue to read from the file
- New readers accepted
- No other TXN is allowed a RESERVED LOCK

SQLite

Step 3: when writer transaction wants to commit, it needs *exclusive lock*, which can't coexists with *read locks*

- Acquire a PENDING LOCK
- May coexists with old READ LOCKs
- No new READ LOCKS are accepted
- Wait for all read locks to be released

Why not write to disk right now?

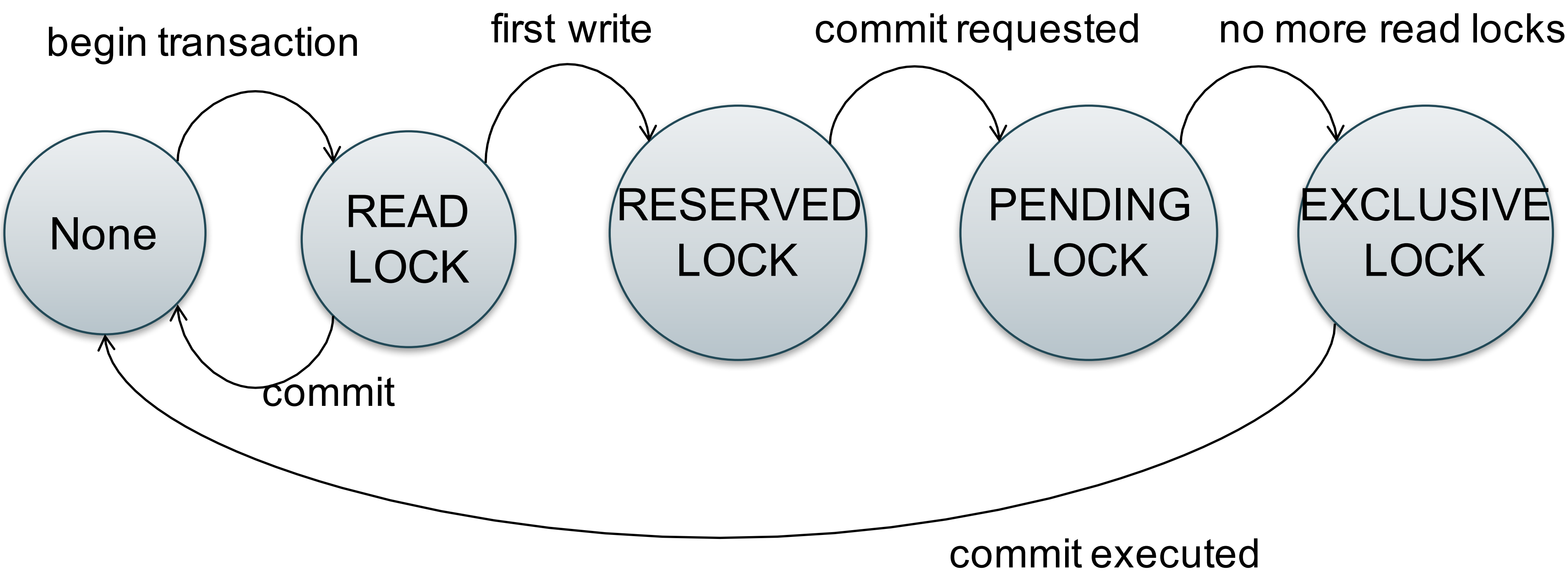
SQLite

Step 4: when all read locks have been released

- Acquire the EXCLUSIVE LOCK
- Nobody can touch the database now
- All updates are written permanently to the database file

- Release the lock and COMMIT

SQLite



Lecture notes contains a SQLite demo

SQLite Demo

```
create table r(a int, b int);
insert into r values (1,10);
insert into r values (2,20);
insert into r values (3,30);
```

Demonstrating Locking in SQLite

T1:

```
begin transaction;
select * from r;
-- T1 has a READ LOCK
```

T2:

```
begin transaction;
select * from r;
-- T2 has a READ LOCK
```

Demonstrating Locking in SQLite

T1:

update r set b=11 where a=1;

-- T1 has a RESERVED LOCK

T2:

update r set b=21 where a=2;

-- T2 asked for a RESERVED LOCK: DENIED

Demonstrating Locking in SQLite

T3:

```
begin transaction;
select * from r;
commit;
-- everything works fine, could obtain READ LOCK
```

Demonstrating Locking in SQLite

T1:

```
commit;
-- SQL error: database is locked
-- T1 asked for PENDING LOCK -- GRANTED
-- T1 asked for EXCLUSIVE LOCK -- DENIED
```

Demonstrating Locking in SQLite

T3':

begin transaction;

select * from r;

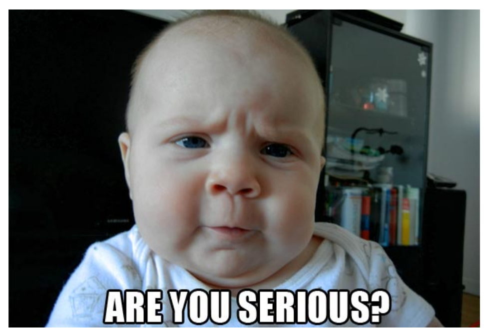
-- T3 asked for READ LOCK-- DENIED (due to T1)

T2:

commit;

-- releases the last READ LOCK; T1 can commit

Now for something more serious…



More Notations

$L_i(A)$ = 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); $U_2(B)$;

$T_1 ; T_2$

Scheduler has ensured a conflict-serializable schedule

But…

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); $U_2(A)$;
	$L_2(B)$; 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

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

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

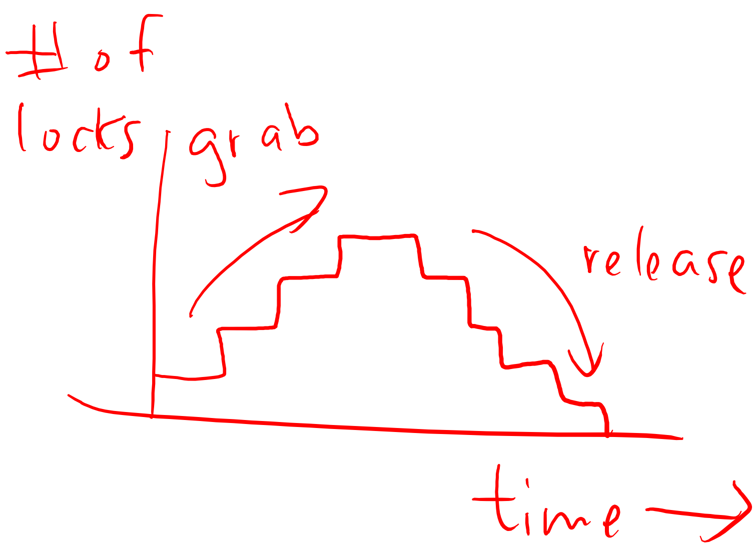
The Strict 2PL rule:

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);	
$U_1(A)$,$U_1(B)$; Rollback	
	…GRANTED; READ(A)
	A := A*2
	WRITE(A);
	$L_2(B)$; READ(B)
	B := B*2
	WRITE(B);
	$U_2(A)$; $U_2(B)$; Commit



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)

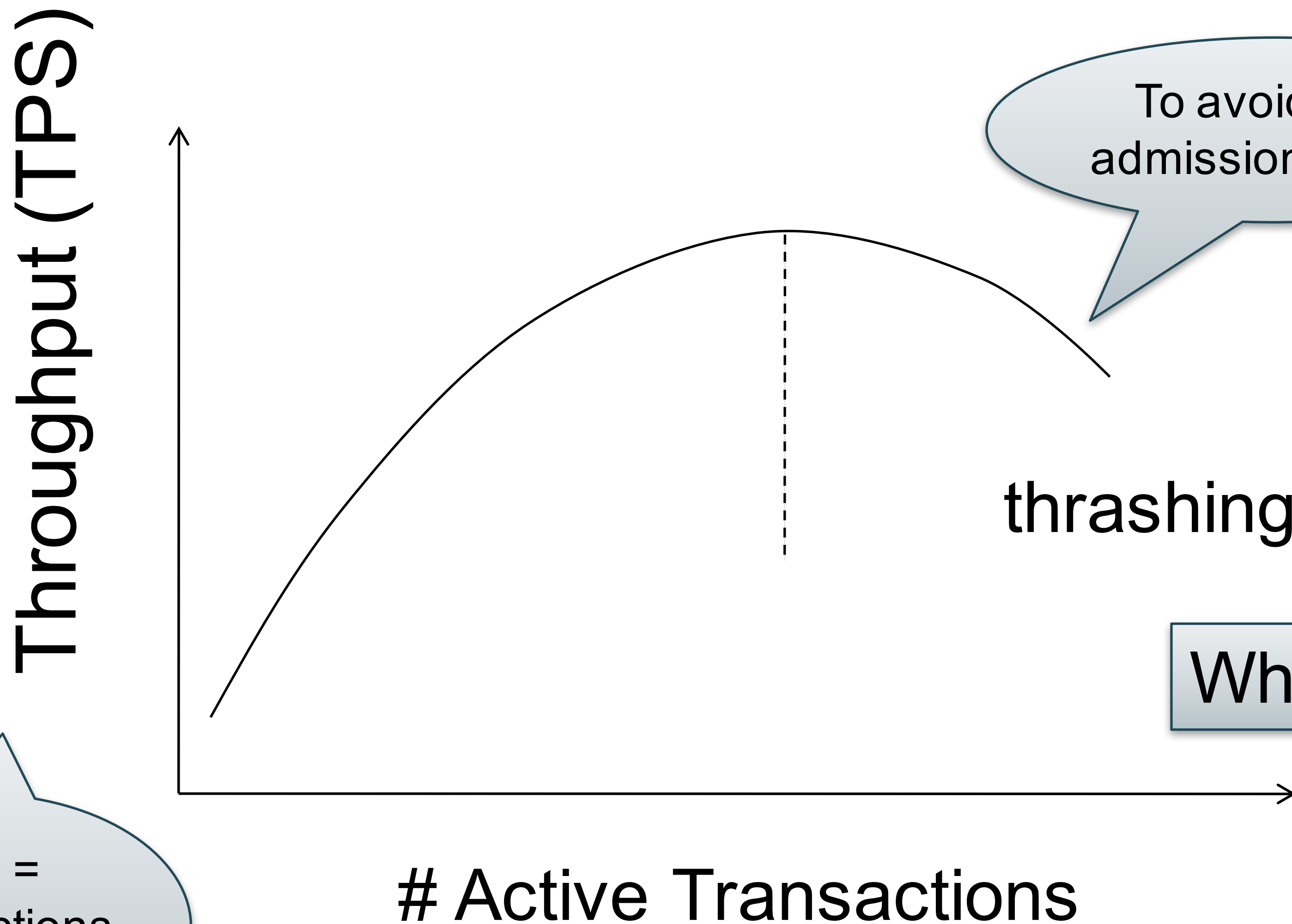
Lock compatibility matrix:

	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., SQL Lite
- 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'	

$R_1(A1);R_1(A2);W_2(A3);R_1(A1);R_1(A2);R_1(A3)$

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'	

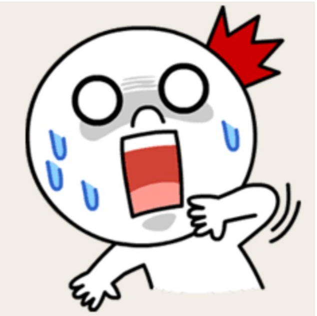
$R_1(A1);R_1(A2);W_2(A3);R_1(A1);R_1(A2);R_1(A3)$

$W_2(A3);R_1(A1);R_1(A2);R_1(A1);R_1(A2);R_1(A3)$

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 !

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
- 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 and different isolation levels can lead to different pbs
- Bottom line: Read the doc for your DBMS!