Database Systems
CSE 414

Lecture 22:
Transaction Implementations
Announcements

• WQ7 (last!) due on Sunday

• HW7:
  – due on Wed, May 24
  – using JDBC to execute SQL from Java
  – using SQL Server via Azure
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

None -> READ LOCK

first write

READ LOCK -> RESERVED LOCK

commit requested

RESERVED LOCK -> PENDING LOCK

no more read locks

PENDING LOCK -> EXCLUSIVE LOCK

commit executed

EXCLUSIVE LOCK -> None

commit

CSE 414 - Spring 2017
Locks in the Abstract
**Notation**

\[ L_i(A) = \text{transaction } T_i \text{ acquires lock for element } A \]

\[ U_i(A) = \text{transaction } T_i \text{ releases lock for element } A \]
# A Non-Serializable Schedule

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>READ(A)</td>
<td>READ(A)</td>
</tr>
<tr>
<td>A := A + 100</td>
<td>A := A * 2</td>
</tr>
<tr>
<td>WRITE(A)</td>
<td>WRITE(A)</td>
</tr>
<tr>
<td>READ(B)</td>
<td>READ(B)</td>
</tr>
<tr>
<td>B := B + 100</td>
<td>B := B * 2</td>
</tr>
<tr>
<td>WRITE(B)</td>
<td>WRITE(B)</td>
</tr>
</tbody>
</table>
Example

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1(A); ) READ(A)</td>
<td>( L_2(A); ) READ(A)</td>
</tr>
<tr>
<td>A := A+100</td>
<td>A := A*2</td>
</tr>
<tr>
<td>WRITE(A); ( U_1(A); ) ( L_1(B) )</td>
<td>WRITE(A); ( U_2(A); ) ( L_2(B); ) BLOCKED…</td>
</tr>
<tr>
<td>READ(B)</td>
<td>...GRANTED; ( U_2(B); )</td>
</tr>
<tr>
<td>B := B+100</td>
<td>WRITE(B); ( U_2(B); )</td>
</tr>
</tbody>
</table>

Scheduler has ensured a conflict-serializable schedule
But…

T1
L₁(A); READ(A)
A := A+100
WRITE(A); U₁(A);

L₁(B); READ(B)
B := B+100
WRITE(B); U₁(B);

T2
L₂(A); READ(A)
A := A*2
WRITE(A); U₂(A);
L₂(B); READ(B)
B := B*2
WRITE(B); U₂(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

\[
\begin{align*}
L_1(A); & \quad L_1(B); \quad \text{READ}(A) \\
A := & \quad A + 100 \\
\text{WRITE}(A); & \quad \text{U}_1(A) \\
\end{align*}
\]

T2

\[
\begin{align*}
L_2(A); & \quad \text{READ}(A) \\
A := & \quad A \times 2 \\
\text{WRITE}(A); & \\
L_2(B); & \quad \text{BLOCKED} \ldots \\
\end{align*}
\]

\[
\begin{align*}
\text{READ}(B) \\
B := & \quad B + 100 \\
\text{WRITE}(B); & \quad \text{U}_1(B); \\
\end{align*}
\]

\[
\begin{align*}
\ldots & \quad \text{GRANTED}; \quad \text{READ}(B) \\
B := & \quad B \times 2 \\
\text{WRITE}(B); & \quad \text{U}_2(A); \quad \text{U}_2(B); \\
\end{align*}
\]

Now it is conflict-serializable
Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability
Theorem: 2PL ensures conflict serializability

Proof. Suppose not: then there exists a cycle in the precedence graph.
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:
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: $U_1(A) \rightarrow L_2(A)$ 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:

- $U_1(A) \rightarrow L_2(A)$
- $L_2(A) \rightarrow U_2(B)$

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

<table>
<thead>
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<th>T1</th>
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<tr>
<td>(L_1(A); L_1(B); \text{READ}(A))</td>
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<tr>
<td>(A := A + 100)</td>
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<td>WRITE(A); (U_1(A))</td>
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<td>READ(B)</td>
<td>(L_2(B); \text{BLOCKED…})</td>
</tr>
<tr>
<td>(B := B + 100)</td>
<td>(…\text{GRANTED}; \text{READ}(B))</td>
</tr>
<tr>
<td>WRITE(B); (U_1(B));</td>
<td>(B := B \times 2)</td>
</tr>
<tr>
<td>Rollback</td>
<td>WRITE(B); (U_2(A); U_2(B));</td>
</tr>
<tr>
<td></td>
<td>Commit</td>
</tr>
</tbody>
</table>
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

L₁(A); READ(A)
A := A+100
WRITE(A);

L₁(B); READ(B)
B := B+100
WRITE(B);
ROLLBACK; U₁(A), U₁(B)

T2

L₂(A); BLOCKED…

…GRANTED; READ(A)
A := A*2
WRITE(A);
L₂(B); READ(B)
B := B*2
WRITE(B);
COMMIT; U₂(A); U₂(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:

<table>
<thead>
<tr>
<th></th>
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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
Throughput (TPS)

TPS = Transactions per second

Lock Performance

# Active Transactions

Why?

thrashing

To avoid, use admission control
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**

<table>
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<tr>
<th>T1</th>
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<tr>
<td>SELECT *</td>
<td>INSERT INTO Product(name, color)</td>
</tr>
<tr>
<td>FROM Product</td>
<td>VALUES ('A3','blue')</td>
</tr>
<tr>
<td>WHERE color='blue'</td>
<td></td>
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</table>

Is this schedule serializable ?
Suppose there are two blue products, A1, A2:

### Phantom Problem

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R1(A1), R1(A2), W2(A3), R1(A1), R1(A2), R1(A3)
Suppose there are two blue products, A1, A2:

Phantom Problem

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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
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

This is not serializable yet !!!

Why ?
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 and different isolation levels can lead to different probs
• **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