Database Systems
CSE 414

Lecture 26: More Transactions
(Ch 8.1-3)
Announcements

• HW7 is due today 11pm
Outline

• Serial and Serializable Schedules (18.1)
• Conflict Serializability (18.2)
• Locks (18.3)
Review: Transactions

• **Problem**: An application must perform several writes and reads to the database, as a unit

• **Solution**: multiple actions of the application are bundled into one unit called a *Transaction*

• Turing awards to database researchers
  – Charles Bachman 1973 for CODASYL
  – Edgar Codd 1981 for relational databases
  – Jim Gray 1998 for transactions
  – Michael Stonebraker 2014 for modern database systems
BEGIN TRANSACTION
   [SQL statements]
COMMIT or
ROLLBACK (=ABORT)

If BEGIN… missing, then TXN consists of a single instruction
Review: ACID

- **Atomic**
  - State shows either all the effects of txn, or none of them

- **Consistent**
  - Txn moves from a state where integrity holds, to another where integrity holds

- **Isolated**
  - Effect of txns is the same as txns running one after another (i.e., looks like batch mode)

- **Durable**
  - Once a txn has committed, its effects remain in the database
Isolation: The Problem

- Multiple transactions are running concurrently $T_1, T_2, \ldots$

- They read/write some common elements $A_1, A_2, \ldots$

- How can we prevent unwanted interference?
- The SCHEDULER is responsible for that

Notation says nothing about tables…
(These techniques apply more generally.)
Schedules

A schedule is a sequence of interleaved actions from all transactions
Serial Schedule

• A **serial schedule** is one, in which transactions are executed one after the other, in some sequential order

• Fact: nothing can go wrong if the system executes transactions serially
  – But database systems don’t do that, because we need better performance
Example

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

A and B are elements in the database. t and s are variables in txn source code.
A Serial Schedule

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</tr>
<tr>
<td>READ(B, t)</td>
<td>READ(A, s)</td>
</tr>
<tr>
<td>s := s*2</td>
<td>s := s*2</td>
</tr>
<tr>
<td>WRITE(A, s)</td>
<td>WRITE(B, s)</td>
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Time
Another Serial Schedule

<table>
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<tr>
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</tr>
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<td>READ(A, t)</td>
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<td></td>
</tr>
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<td></td>
</tr>
<tr>
<td>WRITE(B, t)</td>
<td></td>
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</table>
Serializable Schedule

A schedule is **serializable** if it is equivalent to some serial schedule.
A Serializable Schedule

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This is a **serializable** schedule.
This is NOT a serial schedule.
A Non-Serializable Schedule

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<td>WRITE(B, t)</td>
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How do We Know if a Schedule is Serializable?

Notation

\[
T_1: r_1(A); w_1(A); r_1(B); w_1(B) \\
T_2: r_2(A); w_2(A); r_2(B); w_2(B)
\]

Key Idea: Focus on conflicting operations
Conflicts

- Write-Read – WR
- Read-Write – RW
- Write-Write – WW
Conflict Serializability

Conflicts: (it means: cannot be swapped)

Two actions by same transaction $T_i$:

$ri(X); wi(Y)$

Two writes by $T_i$, $T_j$ to same element

$wi(X); wj(X)$

Read/write by $T_i$, $T_j$ to same element

$wi(X); rj(X)$

$r_i(X); w_j(X)$
Conflict Serializability

- A schedule is *conflict serializable* if it can be transformed into a serial schedule by a series of swaps of adjacent non-conflicting actions.

- Every conflict-serializable schedule is serializable.
- A serializable schedule may not necessarily be conflict-serializable.
Conflict Serializability

Example:

\[ r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B) \]
Conflict Serializability

Example:

\[ r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B) \]
Conflict Serializability

Example:

\[
\begin{align*}
&\text{r}_1(\text{A}); \text{w}_1(\text{A}); \text{r}_2(\text{A}); \\text{w}_2(\text{A}); \text{r}_1(\text{B}); \text{w}_1(\text{B}); \text{r}_2(\text{B}); \text{w}_2(\text{B}) \\
&\downarrow \\
&\text{r}_1(\text{A}); \text{w}_1(\text{A}); \text{r}_2(\text{A}); \text{r}_1(\text{B}); \text{w}_2(\text{A}); \text{w}_1(\text{B}); \text{r}_2(\text{B}); \text{w}_2(\text{B}) \\
&\downarrow \\
&\text{r}_1(\text{A}); \text{w}_1(\text{A}); \text{r}_1(\text{B}); \text{w}_1(\text{B}); \text{r}_2(\text{A}); \text{w}_2(\text{A}); \text{r}_2(\text{B}); \text{w}_2(\text{B})
\end{align*}
\]
Conflict Serializability

Example:

\[
\begin{align*}
&\text{r}_1(A); \text{w}_1(A); \text{r}_2(A); \text{w}_2(A); \text{r}_1(B); \text{w}_1(B); \text{r}_2(B); \text{w}_2(B) \\
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\end{align*}
\]
Testing for Conflict-Serializability

Precedence graph:

• A node for each transaction $T_i$,
• An edge from $T_i$ to $T_j$ whenever an action in $T_i$ conflicts with, and comes before an action in $T_j$

• The schedule is serializable iff the precedence graph is acyclic
Example 1

\[ r_2(A); r_1(B); w_2(A); r_3(A); w_1(B); w_3(A); r_2(B); w_2(B) \]
Example 1

This schedule is conflict-serializable.
Example 2

\[ r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B) \]
Example 2

This schedule is NOT conflict-serializable
Scheduler

• **Scheduler** is the module that schedules the transaction’s actions, ensuring serializability

• Also called **Concurrency Control Manager**

• We discuss next how a scheduler may be implemented
Implementing a Scheduler

Major differences between database vendors

• **Locking Scheduler**
  – Aka “pessimistic concurrency control”
  – SQLite, SQL Server, DB2, Spanner

• **Multiversion Concurrency Control (MVCC)**
  – Aka “optimistic concurrency control”
  – Postgres, Oracle, Spanner

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 the 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.
Let’s Study SQLite First

• 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

begin transaction → READ LOCK → first write → RESERVED LOCK → commit requested → PENDING LOCK → no more read locks → EXCLUSIVE LOCK → commit executed → commit
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