Introduction to Database Systems
CSE 414

Lecture 25: Introduction to Transactions
Class Overview

• Unit 1: Intro
• Unit 2: Relational Data Models and Query Languages
• Unit 3: Non-relational data
• Unit 4: RDMBS internals and query optimization
• Unit 5: Parallel query processing
• Unit 6: DBMS usability, conceptual design

• Unit 7: Transactions
  – Locking and schedules
  – Writing DB applications

• Unit 8: Advanced topics
Data Management Pipeline

Application programmer

Schema designer

Conceptual Schema

Database administrator

Physical Schema
Transactions

• We use database transactions everyday
  – Bank $$$ transfers
  – Online shopping
  – Signing up for classes

• For this class, a transaction is a series of DB queries
  – Read / Write / Update / Delete / Insert
  – Unit of work issued by a user that is independent from others
What’s the big deal?
Challenges

• Want to execute many apps concurrently
  – All these apps read and write data to the same DB

• Simple solution: only serve one app at a time
  – What’s the problem?

• Want: multiple operations to be executed \textit{atomically} over the same DBMS
What can go wrong?

• Manager: balance budgets among projects
  – Remove $10k from project A
  – Add $7k to project B
  – Add $3k to project C

• CEO: check company’s total balance
  – SELECT SUM(money) FROM budget;

• This is called a dirty / inconsistent read aka a WRITE-READ conflict
What can go wrong?

- App 1:
  SELECT inventory FROM products WHERE pid = 1

- App 2:
  UPDATE products SET inventory = 0 WHERE pid = 1

- App 1:
  SELECT inventory * price FROM products WHERE pid = 1

- This is known as an unrepeatable read aka READ-WRITE conflict
What can go wrong?

Account 1 = $100
Account 2 = $100
Total = $200

• App 1:
  – Set Account 1 = $200
  – Set Account 2 = $0

• App 2:
  – Set Account 2 = $200
  – Set Account 1 = $0

• At the end:
  – Total = $200

• App 1: Set Account 1 = $200

• App 2: Set Account 2 = $200

• App 1: Set Account 2 = $0

• App 2: Set Account 1 = $0

• At the end:
  – Total = $0

This is called the lost update aka WRITE-WRITE conflict
What can go wrong?

• Buying tickets to the next Bieber concert:
  – Fill up form with your mailing address
  – Put in debit card number
  – Click submit
  – Screen shows money deducted from your account
  – [Your browser crashes]

Lesson:
Changes to the database should be **ALL or NOTHING**
Transactions

• Collection of statements that are executed atomically (logically speaking)

BEGIN TRANSACTION
  [SQL statements]
COMMIT or
ROLLBACK (=ABORT)

[single SQL statement]

If BEGIN… missing, then TXN consists of a single instruction
Transactions Demo
Turing Awards in Data Management

Charles Bachman, 1973
*IDS and CODASYL*

Ted Codd, 1981
*Relational model*

Jim Gray, 1998
*Transaction processing*

Michael Stonebraker, 2014
*INGRES and Postgres*
Know your chemistry transactions: ACID

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

• **Consistent**
  – Txn moves from a DBMS state where integrity holds, to another where integrity holds
    • remember integrity constraints?

• **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
Atomic

**Definition:** A transaction is ATOMIC if all its updates must happen or not at all.

**Example:** move $100 from A to B

- UPDATE accounts SET bal = bal - 100
  WHERE acct = A;
- UPDATE accounts SET bal = bal + 100
  WHERE acct = B;

BEGIN TRANSACTION;

UPDATE accounts SET bal = bal - 100
WHERE acct = A;
UPDATE accounts SET bal = bal + 100
WHERE acct = B;

COMMIT;
Isolated

• **Definition** An execution ensures that txns are isolated, if the effect of each txn is as if it were the only txn running on the system.
Consistent

• Recall: integrity constraints govern how values in tables are related to each other
  – Can be enforced by the DBMS, or ensured by the app

• How consistency is achieved by the app:
  – App programmer ensures that txns only takes a consistent DB state to another consistent state
  – DB makes sure that txns are executed atomically

• Can defer checking the validity of constraints until the end of a transaction
Durable

• A transaction is durable if its effects continue to exist after the transaction and even after the program has terminated

• How?
  – By writing to disk!
  – More in CSE 444
Rollback transactions

• If the app gets to a state where it cannot complete the transaction successfully, execute ROLLBACK

• The DB returns to the state prior to the transaction

• What are examples of such program states?
ACID

- Atomic
- Consistent
- Isolated
- Durable

- Enjoy this in HW8!

- Again: by default each statement is its own txn
  - Unless auto-commit is off then each statement starts a new txn
Transaction Schedules
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
  – (up to what we have learned so far)
  – But DBMS don’t do that because we want better overall system 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>
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</tbody>
</table>

A and B are elements in the database. t and s are variables in txn source code.
Example of a (Serial) Schedule

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

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Another Serial Schedule

T1

T2

READ(A, s)
s := s*2
WRITE(A, s)
READ(B, s)
s := s*2
WRITE(B, s)

READ(A, t)
t := t+100
WRITE(A, t)
READ(B, t)
t := t+100
WRITE(B, t)
A schedule is **serializable** if it is equivalent to a serial schedule.
A Serializable Schedule

<table>
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<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>
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</tbody>
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This is a **serializable** schedule.
This is NOT a serial schedule.

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# A Non-Serializable Schedule

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</tr>
<tr>
<td></td>
<td>READ(B, s)</td>
</tr>
<tr>
<td></td>
<td>s := s*2</td>
</tr>
<tr>
<td></td>
<td>WRITE(B, s)</td>
</tr>
<tr>
<td>READ(B, t)</td>
<td></td>
</tr>
<tr>
<td>t := t+100</td>
<td></td>
</tr>
<tr>
<td>WRITE(B, t)</td>
<td></td>
</tr>
</tbody>
</table>
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
• Read-Read?
Conflicts: (i.e., swapping will change program behavior)

Two actions by same transaction $T_i$: $r_i(X); w_i(Y)$

Two writes by $T_i$, $T_j$ to same element $w_i(X); w_j(X)$

Read/write by $T_i$, $T_j$ to same element $w_i(X); r_j(X)$
$r_i(X); w_j(X)$
Conflict Serializability

• A schedule is \textit{conflict serializable} if it can be transformed into a serial schedule by a series of swappings of adjacent non-conflicting actions.

• Every conflict-serializable schedule is serializable.
• The converse is not true (why?)
Conflict Serializability

Example:

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

```
r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)
```
Conflict Serializability

Example:

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

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

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

Example:

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

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

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

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

\[ r_1(A); w_1(A); r_1(B); r_2(A); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B) \]
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 conflict-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

r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B)