Announcements (Tue., Oct. 6)

• **Homework #1** grades/feedback available soon
• **Homework #2** due today
  • Sample solution to be posted by Wednesday noon
    • Submissions later than that receive no credit
• **Midterm** in class on Thursday
  • Open-book, open-notes
  • Same format as the sample midterm (posted on Sakai)
• **Project Milestone #1** due next Thursday
  • Please use Sakai to find teams/members!
Transactions

• A transaction is a sequence of database operations with the following properties (ACID):
  • Atomic: Operations of a transaction are executed all-or-nothing, and are never left “half-done”
  • Consistency: Assume all database constraints are satisfied at the start of a transaction, they should remain satisfied at the end of the transaction
  • Isolation: Transactions must behave as if they were executed in complete isolation from each other
  • Durability: If the DBMS crashes after a transaction commits, all effects of the transaction must remain in the database when DBMS comes back up
SQL transactions

• A transaction is automatically started when a user executes an SQL statement

• Subsequent statements in the same session are executed as part of this transaction
  • Statements see changes made by earlier ones in the same transaction
  • Statements in other concurrently running transactions do not

• **COMMIT** command commits the transaction
  • Its effects are made final and visible to subsequent transactions

• **ROLLBACK** command aborts the transaction
  • Its effects are undone
Fine prints

• Schema operations (e.g., CREATE TABLE) implicitly commit the current transaction
  • Because it is often difficult to undo a schema operation

• Many DBMS support an AUTOCOMMIT feature, which automatically commits every single statement
  • You can turn it on/off through the API
    • Examples later in this lecture
  • For PostgreSQL:
    • psql command-line processor turns it on by default
    • You can turn it off at the psql prompt by typing: \set AUTOCOMMIT 'off'
Atomicity

• Partial effects of a transaction must be undone when
  • User explicitly aborts the transaction using ROLLBACK
    • E.g., application asks for user confirmation in the last step and issues COMMIT or ROLLBACK depending on the response
  • The DBMS crashes before a transaction commits

• Partial effects of a modification statement must be undone when any constraint is violated
  • Usually only this statement is rolled back; the transaction may continue

• How is atomicity achieved?
  • Logging (to support undo)
Durability

• DBMS accesses data on stable storage by bringing data into memory

• Effects of committed transactions must survive DBMS crashes

• How is durability achieved?
  • Forcing all changes to disk at the end of every transaction?
    • Too expensive
  • Logging (to support redo)
Consistency

- Consistency of the database is guaranteed by constraints and triggers declared in the database and/or transactions themselves
  - Whenever inconsistency arises, abort the statement or transaction, or (with deferred constraint checking or application-enforced constraints) fix the inconsistency within the transaction
Isolation

• Transactions must appear to be executed in a **serial schedule** (with no interleaving operations)

• For performance, DBMS executes transactions using a **serializable schedule**
  • In this schedule, operations from different transactions can interleave and execute concurrently
  • But the schedule is guaranteed to produce the same effects as a serial schedule

• How is isolation achieved?
  • Locking, multi-version concurrency control, etc.
SQL isolation levels

• Strongest isolation level: **SERIALIZABLE**
  • Complete isolation

• Weaker isolation levels: **REPEATABLE READ, READ COMMITTED, READ UNCOMMITTED**
  • Increase performance by eliminating overhead and allowing higher degrees of concurrency
  • Trade-off: sometimes you get the “wrong” answer
READ UNCOMMITTED

• Can read “dirty” data
  • A data item is dirty if it is written by an uncommitted transaction

• Problem: What if the transaction that wrote the dirty data eventually aborts?

• Example: wrong average
  • -- T1: 
    UPDATE User 
    SET pop = 0.99 
    WHERE uid = 142; 
  
  ROLLBACK;

  • -- T2: 
    SELECT AVG(pop) 
    FROM User; 

    COMMIT;
READ COMMITTED

• No dirty reads, but non-repeatable reads possible
  • Reading the same data item twice can produce different results

• Example: different averages
  • -- T1:
    
    UPDATE User
    SET pop = 0.99
    WHERE uid = 142;
    COMMIT;

  • -- T2:
    SELECT AVG(pop)
    FROM User;

  SELECT AVG(pop)
  FROM User;
  COMMIT;
REPEATABLE READ

• Reads are repeatable, but may see **phantoms**

• Example: different average (still!)

  • -- T1:

    ```sql
    INSERT INTO User
    VALUES(789, 'Nelson', 10, 0.1);
    COMMIT;
    ```

  • -- T2:

    ```sql
    -- T2: 
    SELECT AVG(pop) 
    FROM User;
    INSERT INTO User
    VALUES(789, 'Nelson', 10, 0.1);
    COMMIT;
    SELECT AVG(pop) 
    FROM User;
    COMMIT;
    ```
Summary of SQL isolation levels

<table>
<thead>
<tr>
<th>Isolation level/anomaly</th>
<th>Dirty reads</th>
<th>Non-repeatable reads</th>
<th>Phantoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>READ UNCOMMITTED</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>READ COMMITTED</td>
<td>Impossible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>REPEATABLE READ</td>
<td>Impossible</td>
<td>Impossible</td>
<td>Possible</td>
</tr>
<tr>
<td>SERIALIZABLE</td>
<td>Impossible</td>
<td>Impossible</td>
<td>Impossible</td>
</tr>
</tbody>
</table>

- Syntax: At the beginning of a transaction, `SET TRANSACTION ISOLATION LEVEL isolation_level [READ ONLY|READ WRITE];`
  - READ UNCOMMITTED can only be READ ONLY

- PostgreSQL defaults to READ COMMITTED
Transactions in programming

Using *psycopg2* as an example:

```python
cconn = psycopg2.connect(dbname='beers')
conn.set_session(isolation_level='SERIALIZABLE',
                 ready_only=False,
                 autocommit=True)

• isolation_level defaults to READ COMMITTED
• read_only defaults to False
• autocommit defaults to False

• When autocommit is False, commit/abort current transaction as follows:

  conn.commit()
  conn.rollback()
```
ANSI isolation levels are lock-based

• **READ UNCOMMITTED**
  - **Short-duration locks**: lock, access, release immediately

• **READ COMMITTED**
  - **Long-duration write locks**: do not release write locks until commit

• **REPEATABLE READ**
  - **Long-duration locks** on all data items accessed

• **SERIALIZABLE**
  - **Lock ranges** to prevent insertion as well
Isolation levels not based on locks?

Snapshot isolation in Oracle

• Based on *multiversion concurrency control*
  • Used in Oracle, PostgreSQL, MS SQL Server, etc.

• How it works
  • Transaction $X$ performs its operations on a private snapshot of the database taken at the start of $X$
  • $X$ can commit only if it does not write any data that has been also written by a transaction committed after the start of $X$

• Avoids all ANSI anomalies

• But is **NOT** equivalent to **SERIALIZABLE** because of **write skew** anomaly
Write skew example

• Constraint: combined balance $A + B \geq 0$
• $A = 100, B = 100$
• $T_1$ checks $A + B - 200 \geq 0$, and then proceeds to withdraw 200 from $A$
• $T_2$ checks $A + B - 200 \geq 0$, and then proceeds to withdraw 200 from $B$
• Possible under snapshot isolation because the writes (to $A$ and to $B$) do not conflict
• But $A + B = -200 < 0$ afterwards!
Bottom line

• Group reads and dependent writes into a transaction in your applications
  • E.g., enrolling a class, booking a ticket

• Anything less than SERIALABLE is potentially very dangerous
  • Use only when performance is critical
  • READ ONLY makes weaker isolation levels a bit safer