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 (e.g., JDBC)
    - 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
    - However, only this statement is rolled back; the transaction continues
  - How is atomicity achieved?
    - Logging (to support undo)
Durability

- 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: DBMS manipulates data in memory
  - 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
  - SQL default
- 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:  -- T2:
    UPDATE Student
    SET GPA = 3.0
    WHERE SID = 142;
    SELECT AVG(GPA)
    FROM Student;
    ROLLBACK;
    COMMIT;
    -- T2:
    SELECT AVG(GPA)
    FROM Student;
    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:  -- T2:
    UPDATE Student
    SET GPA = 3.0
    WHERE SID = 142;
    COMMIT;
    SELECT AVG(GPA)
    FROM Student;
    COMMIT;
    -- T2:
    SELECT AVG(GPA)
    FROM Student;
    COMMIT;
REPEATABLE READ

- Reads are repeatable, but may see phantoms
- Example: different average (still!)
  - -- T1:
    ```sql
    INSERT INTO Student
    VALUES(789, 'Nelson', 10, 1.0);
    COMMIT;
    ```
  - -- T2:
    ```sql
    SELECT AVG(GPA) FROM Student;
    ```
  - Possible under snapshot isolation because the writes (to A and to B) do not conflict
  - But is NOT equivalent to SERIALIZABLE because of write skew anomaly

Transactions in programming (JDBC)

- Set isolation level for the current transaction
  - `con.setTransactionIsolationLevel(isolation_level)`
  - `TRANSACTION_SERIALIZABLE` (default), `TRANSACTION_REPEATABLE_READ`, `TRANSACTION_READ_COMMITTED`, and `TRANSACTION_READ_UNCOMMITTED`
- Set the transaction to be read-only or read/write (default)
  - `con.setReadOnly(true|false)`
- Turn on/off `AUTOCOMMIT` (commits every single statement)
  - `con.setAutoCommit(true|false)`
- Commit/rollback the current transaction (when `AUTOCOMMIT` is off)
  - `con.commit();`
  - `con.rollback();`

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,
  ```sql
  SET TRANSACTION ISOLATION LEVEL isolation_level {READ ONLY|READ WRITE};
  ```
  - READ UNCOMMITTED can only be READ ONLY

ANSI isolation levels are lock-based

- **READ UNCOMMITTED**
  - Short-duration locks: lock, access, release immediately
- **READ COMMITTED**
  - Long-duration write lock: 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

An isolation level 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

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 dependant 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