Database Systems I

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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
  - 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
  - Some systems roll back only this statement and let the transaction continue; others roll back the whole transaction
- 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:                    -- T2:
    UPDATE User
    SET pop = 0.99
    WHERE uid = 142;          SELECT AVG(pop)
                              FROM User;
    ROLLBACK;
                              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:
                                SELECT AVG(pop)
                                FROM User;
    UPDATE User
    SET pop = 0.99
    WHERE uid = 142;
    COMMIT;
                                SELECT AVG(pop)
      FROM User;
                                COMMIT;
    ```
    ```

REPEATABLE READ

- Reads are repeatable, but may see phantoms
- Example: different average (still!)
  - ```
    -- T1:                          -- 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

Isolation level/anomaly	Dirty reads	Non-repeatable reads	Phantoms
READ UNCOMMITTED	Possible	Possible	Possible
READ COMMITTED	Impossible	Possible	Possible
REPEATABLE READ	Impossible	Impossible	Possible
SERIALIZABLE	Impossible	Impossible	Impossible

- 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 SQLAlchemy as an example:

```
with engine.connect() as conn:
  conn.execution_options\
    (isolation_level='SERIALIZABLE',
     postgresql_readonly=False)
```

- `isolation_level` defaults to `READ COMMITTED`
  - Setting it to AUTOCOMMIT would implicitly commit every modification statement, but there is no isolation level guarantee
- `postgresql_readonly` defaults to False
- Unless `AUTOCOMMIT` is on, 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!

To avoid write skew, when committing, ensure the transaction didn't *read* any object others wrote and committed after this transaction started

Bottom line

- Group reads and dependent writes into a transaction in your applications
  - E.g., enrolling a class, booking a ticket
- Anything less than `SERIALIZABLE` is potentially very dangerous
  - Use only when performance is critical
  - READ ONLY makes weaker isolation levels a bit safer