# Transaction Management

## Ch 6.6.1 – 6.6.3 and 18.1-18.4

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CS411: Database Systems



Some slides were adopted from Prof. Dan Suciu

# Learning Objectives

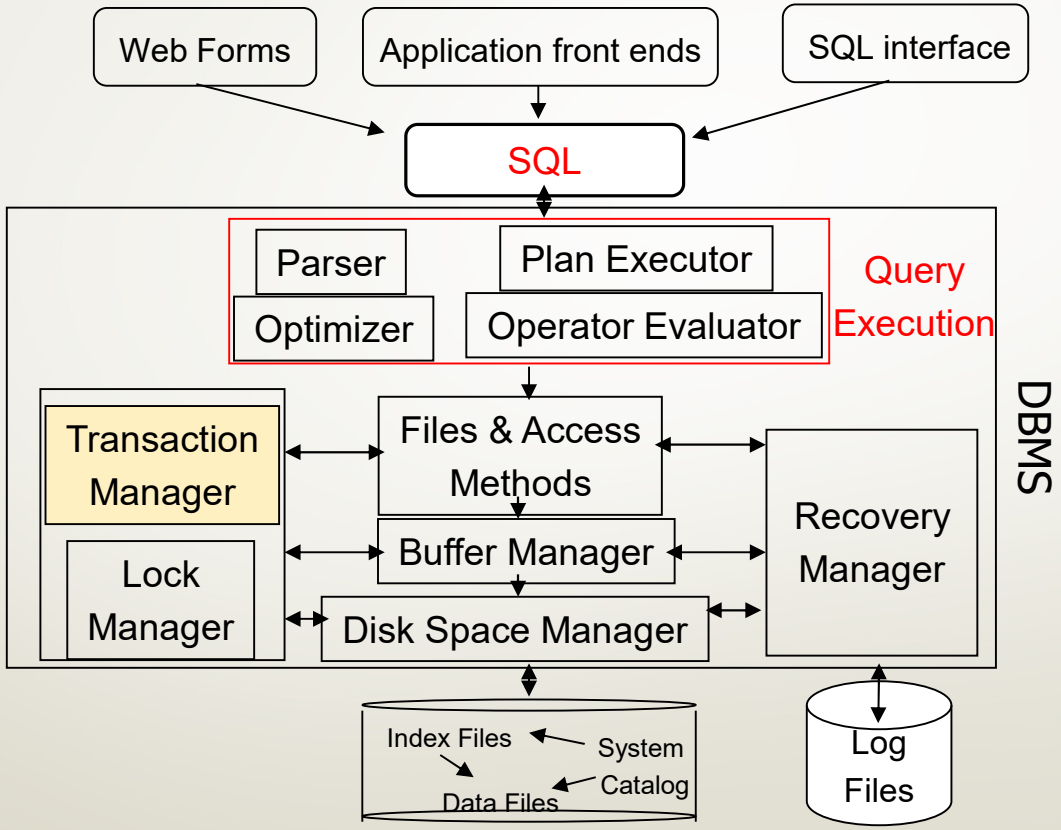
After this lecture, you should be able:

- Describe transactions, ACID properties and issues related to concurrent exaction of transactions.
- Describe how database systems implement isolation levels

# Outline

- Transactions and ACID properties
- Transactions in SQL
- Isolation levels
- Isolation Levels and Locking

# DBMS Architecture



# Motivating "Transactions"

- We've learned how to interact with DB using SQL.
- We assumed that:
  - each operation (e.g., UPDATE … SET … WHERE) is executed one at a time.
  - One operation executes, perhaps changes the DB state, then next operation executes. (ISOLATION)
  - each operation is executed in entirety or not executed at all. (ATOMIC)

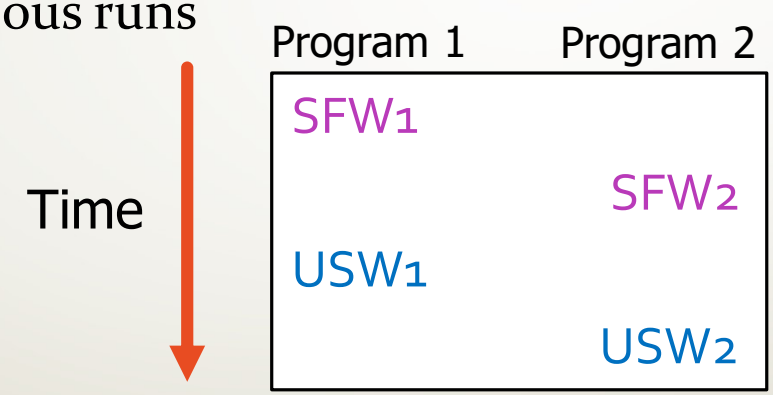
# Motivating "Transactions"

- Complications arise if these assumptions are violated
  - multiple operations acting on the same table simultaneously?
  - system crash in the middle of an operation
    - e.g., half the tuples have been updated the others not

# Example 1: flight seat selection

- Program:
  - A. Check if seat is available : SELECT FROM WHERE (SFW)
  - B. Book seat (change availability to "occupied"): UPDATE SET WHERE (USW)

Two simultaneous runs



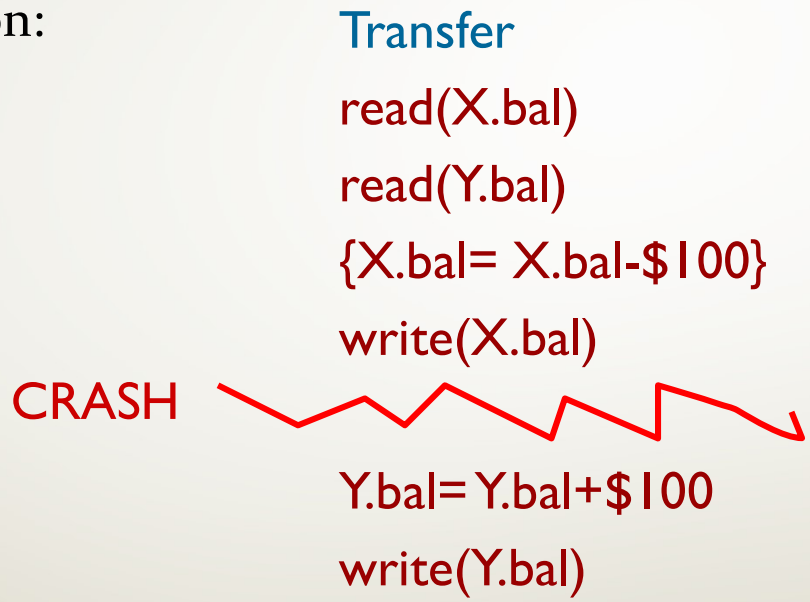

Two executions of the same "UPDATE … SET … WHERE" leads to seat being double-booked

# Example 1: lesson

- Group the SFW (which retrieved seat availability) and the USW (which reserved a seat) into one **TRANSACTION**.
- Transaction is a sequence of statements that are considered a "unit of operation" on a database
- Either user 1's transaction executes first and then user 2's transaction, or the other way, but not in parallel. ***Serializability of transactions***.

# Example 2: bank inter-account transfer

Problems can also occur if a crash occurs in the middle of executing a transaction:




Need to guarantee that the write to X does not persist (ABORT)

- Default assumption if a transaction doesn't commit

# Example 2: lesson

- Steps 1 and 2 must be done as one unit. *Atomically*.
- Either they both execute, or neither does.
- *Transactions must be atomic.*

# Transactions

**Definition:** Transaction is a sequence of read and write operations on the database with the property that either all actions complete or none completes.

a transaction may

- Succeed: the effects of all write operations persist (*COMMIT*)
- Or fail, no effects persist (*ABORT or ROLLBACK*)

- These guarantees are made despite concurrent activity in the system, and despite failures that may occur

# Transaction Manager

The part DBMS that ensures a transaction is executed as expected.

- **Purpose 1: Ensure that transactions that execute in parallel don't *interfere* with each other.**
- Purpose 2: Talks to "Log Manager", ensures that steps inside a transaction are being "logged".
- Purpose 3: Performs recovery after crashes, using logs.

**We will not cover recovery in this class.**

# ACID Properties

**A**tomicity

- either all of the actions of a transaction are executed, or none are.

**C**onsistency

- each transaction executed in isolation keeps the database in a consistent state

**I**solation

- Transactions are isolated from the effects of other, concurrently executing, transactions.

**D**urability

- updates stay in the DBMS!!!

# Outline

- ✓ Transactions and ACID properties
- Transactions in SQL
- Isolation levels
- Isolation Levels and Locking

# Transactions in SQL

- A transaction begins when any SQL statement that queries the db begins.
- To end a transaction, the user issues a COMMIT or ROLLBACK statement.

May be omitted if autocommit is off

```
START TRANSACTION

[SQL statements]

COMMIT or ROLLBACK;
```

# Read-Only Transactions

- When a transaction only reads information, we have more freedom to let the transaction execute concurrently with other transactions.
- We signal this to the system by stating:

```
SET TRANSACTION READ ONLY;
SELECT * FROM Accounts
WHERE account#= '1234' ;
...
```

# Read-Write Transactions

- If we state "read-only", then the transaction cannot perform any updates.

ILLEGAL!

```
SET TRANSACTION READ ONLY;
UPDATE Accounts
SET balance = balance - $100
WHERE account#= '1234' ; ...
```

- Instead, we must specify that the transaction may update (the default):

```
SET TRANSACTION READ WRITE;
update Accounts
set balance = balance - $100
where account#= '1234' ; ...
```

# Concurrent Execution Problems

- **Write-Read conflict (WR): dirty read, inconsistent read**

  A transaction reads a value written by another transaction that has not yet committed

- **Read-Write conflict (RW): unrepeatable read**

  A transaction reads the value of the same object twice.

  Another transaction modifies that value in between the two reads

- **Write-Write conflict (WW): lost update**

  Two transactions update the value of the same object. The second one to write the value overwrites the first change

# Example of Dirty Reads

| sid | name | zip |
|---|---|---|
| 123 | Qin | 14001 |
| 321 | Kristin | 14104 |

| Transaction 1 | Transaction 2 |
|---|---|
| START TRANSACTION; | START TRANSACTION; |
| | UPDATE student<br>SET zip = 14111 WHERE sid = 123; |
| SELECT zip FROM student WHERE sid = 123;<br>/* will read 14111*/ | |
| | ROLLBACK<br>/* zip code will revert to 14001*/ |

# Example of Non-repeatable Reads

| sid | name | zip |
|---|---|---|
| 123 | Qin | 14001 |
| 321 | Kristin | 14104 |

| Transaction 1 | Transaction 2 |
|---|---|
| START TRANSACTION; | START TRANSACTION; |
| SELECT zip FROM student WHERE sid = 123;<br>/* will read 14001*/ | |
| | UPDATE student<br>SET zip = 14111 WHERE sid = 123; |
| | COMMIT; |
| SELECT zip FROM student WHERE sid = 123;<br>/* will read 14111*/ | |

# Another concurrency problem:
# Phantom Reads

A **phantom read** occurs when, in the course of a transaction, new rows are added by another transaction to the records being read.*

* https://en.wikipedia.org/wiki/Isolation_(database_systems)

# Example of Phantom Reads

| sid | name | zip |
|---|---|---|
| 123 | Qin | 14001 |
| 321 | Kristin | 14104 |

| Transaction 1 | Transaction 2 |
|---|---|
| START TRANSACTION; | START TRANSACTION; |
| SELECT COUNT(*) FROM students WHERE sid BETWEEN 100 AND 400; /* will return 2 */ | |
| | INSERT INTO students(sid,name,zip) VALUES ( 100, 'Abdu', 14444 ); |
| | COMMIT; |
| SELECT COUNT(*) FROM students WHERE sid BETWEEN 100 AND 400; /* will return 3 */ | |

# Outline

- ✓ Transactions and ACID properties
- ✓ Transactions in SQL
- Isolation levels
- Isolation Levels and Locking

# Isolation

- The problems we've seen are all related to *isolation*
- General rules of thumb w.r.t. isolation:
  - Fully serializable isolation is more expensive than "no isolation"
    - We can't do as many things concurrently (or we have to undo them frequently)
  - For performance, we generally want to specify the most relaxed *isolation level* that's acceptable
    - Note that we're "slightly" violating a correctness constraint to get performance!

# Specifying Acceptable Isolation Levels

- To signal to the system that a dirty read is acceptable,

```
SET TRANSACTION
ISOLATION LEVEL READ UNCOMMITTED;
```

- In addition, there are

```
SET TRANSACTION
ISOLATION LEVEL READ COMMITTED;
SET TRANSACTION
ISOLATION LEVEL REPEATABLE READ;
```

# Specifying Acceptable Isolation Levels

- READ COMMITTED:
  - Forbids the reading of dirty (uncommitted) data, but allows a transaction T to issue the same query several times and get different answers
  - No value written by T can be modified until T completes
- REPEATABLE READ
  - If a tuple is retrieved once it will be retrieved again if the query is repeated
  - But it is NOT a guarantee that the same query will get the same answer!

# Summary of Isolation Levels

| Level | Dirty Read | Unrepeatable Read | Phantoms |
|---|---|---|---|
| READ UN-COMMITTED | Maybe | Maybe | Maybe |
| READ COMMITTED | No | Maybe | Maybe |
| REPEATABLE READ | No | No | Maybe |
| SERIALIZABLE | No | No | No |

# Outline

- ✓ Transactions and ACID properties
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# Implementing Isolation Levels

- One approach – use locking at some level (tuple, page, table, etc.):
  - each data item is either locked (in some mode, e.g. shared or exclusive) or is available (no lock)
  - an action on a data item can be executed if the transaction holds an appropriate lock
  - consider *granularity* of locks – how big of an item to lock
    - Larger granularity = fewer locking operations but more contention!
- Appropriate locks:
  - Before a read, a shared lock must be acquired
  - Before a write, an exclusive lock must be acquired

# Lock Compatibility Matrix

Locks on a data item are granted based on a lock compatibility matrix:

| Request mode | Mode of Data Item: None | Shared | Exclusive |
|---|---|---|---|
| Shared | Y | Y | N |
| Exclusive | Y | N | N |

When a transaction requests a lock, it must wait (block) until the lock is granted

# Locks Prevent "Bad" Execution

If the system used locking, the first "bad" execution could have been avoided: X = Seat 22A

| User 1 | User 2 |
|---|---|
| xlock(X) | |
| read(X.avail) | |
| IF (!X. avail) | {xlock(X) is not granted} |
| {X. avail := 1} | |
| write(X. avail) | |
| release(X) | |
| | xlock(X) |
| | read(X.avail) |
| | IF(!X. avail) |
| | {X. avail := 1} |
| | write(X. avail) |
| | release(X) |

Is this a "good" concurrent execution?

| User 1 | User 2 |
| --- | --- |
| slock(X) | |
| read(X.avail) | |
| | slock(X) |
| | read(X.avail) |
| | release(X) |
| release(X) | |
| | IF (!X.avail) |
| | {X.avail := 1} |
| IF (!X.avail) | |
| {X.avail := 1} | |
| xlock(X) | |
| write(X.avail) | |
| release(X) | |
| | xlock(X) |
| | write(X.avail) |
| | release(X) |

No, this is a "bad" execution.

Locks are not enough

| User 1 | User 2 |
| --- | --- |
| slock(X) | |
| read(X.avail) | |
| | slock(X) |
| | read(X.avail) |
| | release(X) |
| release(X) | |
| | IF (!X.avail) |
| | {X.avail := 1} |
| IF (!X.avail) | |
| {X.avail := 1} | |
| xlock(X) | |
| write(X.avail) | |
| release(X) | |
| | xlock(X) |
| | write(X.avail) |
| | release(X) |

# Isolation Levels and Locking

READ UNCOMMITTED allows queries in the transaction to read data *without acquiring any lock*

- Access mode READ ONLY, no updates are allowed

READ COMMITTED requires a read-lock to be obtained for all tuples touched by queries, but it releases the locks immediately after the read

- Exclusive locks must be obtained for updates and held to end of transaction

# Isolation levels and locking, cont.

REPEATABLE READ places shared locks on tuples retrieved by queries, holds them until the end of the transaction

- Exclusive locks must be obtained for updates and held to end of transaction

SERIALIZABLE places shared locks on tuples retrieved by queries *as well as the index*, holds them until the end of the transaction

- Exclusive locks must be obtained for updates and held to end of transaction

Holding locks to the end of a trxn is called "strict" locking

# A Notation for Transactions and Schedules

- We only care about reads and writes
  - Transaction is a sequence of R(A)'s and W(A)'s

$$\text{T1: } r_1(\text{A}); w_1(\text{A}); r_1(\text{B}); w_1(\text{B})$$
$$\text{T2: } r_2(\text{A}); w_2(\text{A}); r_2(\text{B}); w_2(\text{B})$$

  - E.g. of a schedule:

$$r_1(\text{A}); w_1(\text{A}); r_2(\text{A}); w_2(\text{A}); r_1(\text{B}); w_1(\text{B}); r_2(\text{B}); w_2(\text{B})$$

# Concurrent execution: Example 1

- Suppose we have two transactions:

T1: SET TRANSACTION READ WRITE
ISOLATION LEVEL READ COMMITTED;
SQL code that translates to: R1(A), R1(B) W1(B) W1(C)

T2: SET TRANSACTION READ WRITE
ISOLATION LEVEL READ COMMITTED;
SQL code that translates to: R2(C), R2(A) W2(A)

One possible interleaved execution of the transactions above:
R1(A) R2(C) R2(A) W2(A) R1(B) W1(B) W1(C)

S1(A) R1(A) REL1(A) S2(C) R2(C) REL2(C) S2(A) R2(A) X2(A) W2(A)
REL2(A) S1(B) R1(B) X1(B) W1(B) X1(C) W1(C) REL1(B,C)

# Concurrent execution: Example 2

- Now suppose that T1 is REPEATABLE READ:

T1: SET TRANSACTION READ WRITE
ISOLATION LEVEL REPEATABLE READ;
SQL code that translates to: R1(A), R1(B) W1(B) W1(C)

T2: SET TRANSACTION READ WRITE
ISOLATION LEVEL READ COMMITTED;
SQL code that translates to: R2(C), R2(A) W2(A)

One possible interleaved execution of the transactions above:
R1(A) R2(C) R2(A) R1(B) W1(B) W1(C) W2(A)

S1(A) R1(A) S2(C) R2(C) REL2(C) S2(A) R2(A) Rel2(A) S1(B) R1(B) X1(B) W1(B) X1(C) W1(C) REL1(A, B,C) X2(A) W2(A) REL2(A)

# Outline

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