CS 4440 A

# Emerging Database Technologies

Lecture 12

02/24/25

# Announcement

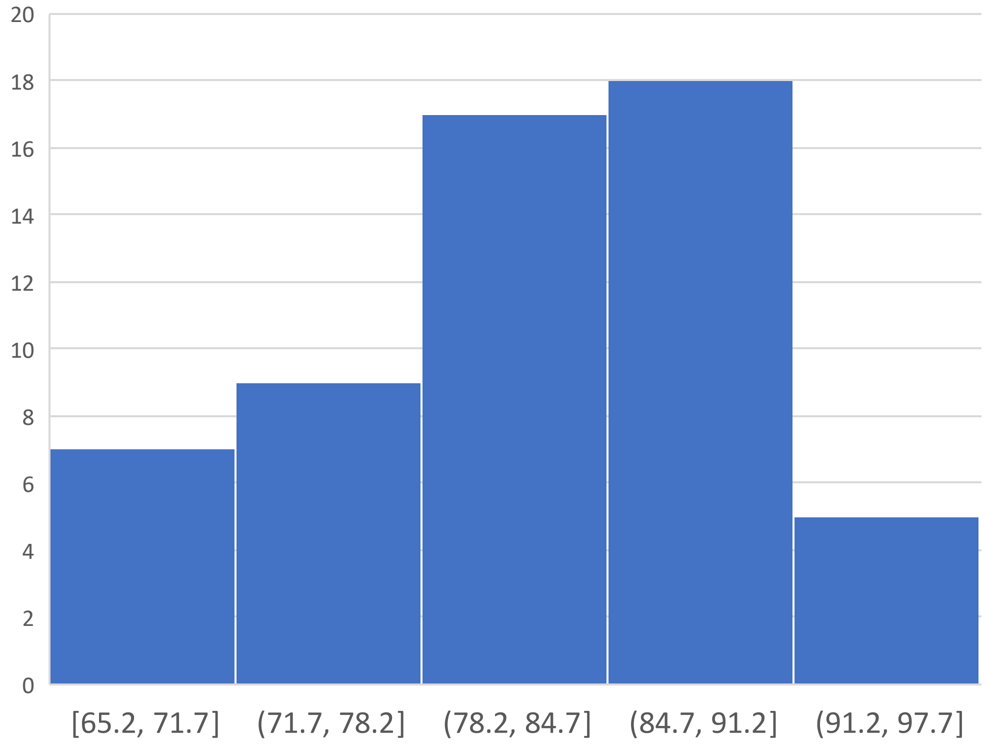
Exam 1 grades

- Max: 97.7, Mean: 82.4, Median: 83.9
- Regrade request open on Gradescope (until March 5)

Tech Presentation starting this Wednesday

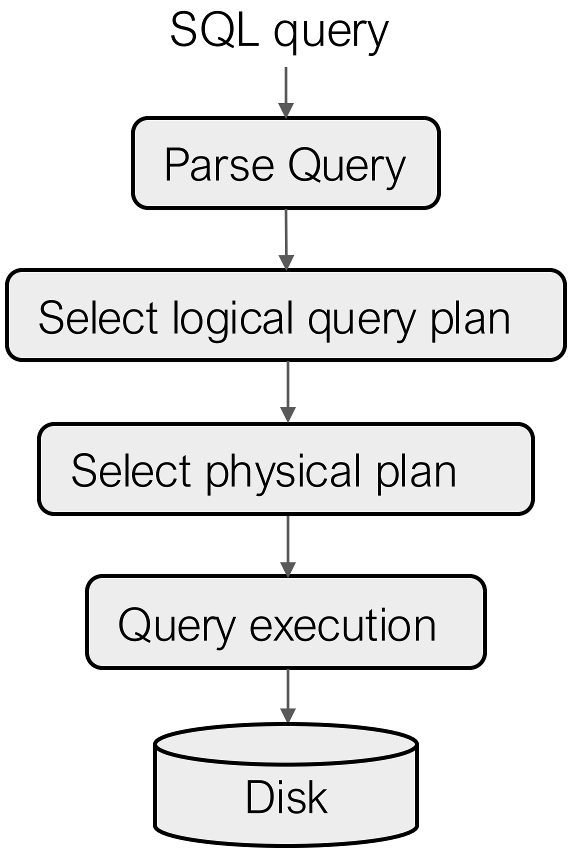
- A1. Document Databases
- A2. Vector Databases

Revised Project Proposal due next Wednesday



# Recap: RDBMS Architecture

How does a SQL engine work ?



Translate to RA expression and find logically equivalent but more efficient plans

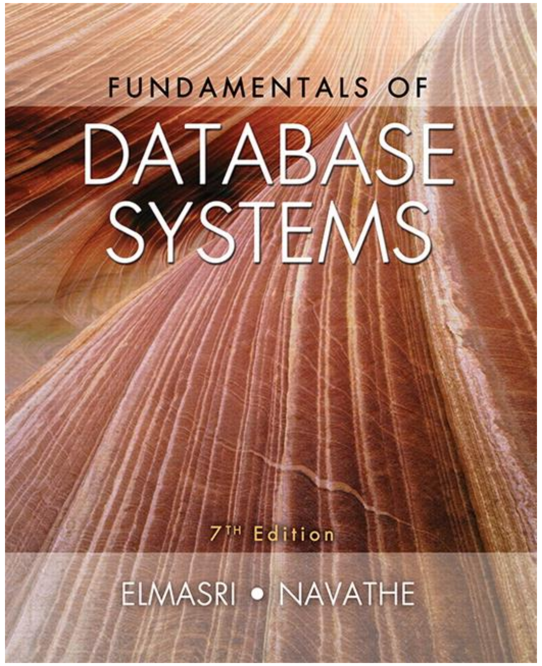
Cost-based query optimization: estimate cost and select physical plan with the smallest cost

Query execution (e.g., run join algorithms against tuples on disk)

# Reading Materials

Fundamental of Database Systems (7th Edition)

- Chapter 20 - Introduction to Transaction Processing Concepts and Theory



Acknowledgement:
The following slides have been created adapting the instructor material of the [RG] book provided by the authors Dr. Ramakrishnan and Dr. Gehrke.

# Agenda

1. Transaction Basics

2. ACID properties

3. Using transactions in SQL

4. Schedule

# 1. Transaction Basics

# Transactions: Basic Definition

A transaction (“TXN”) is a sequence of one or more operations (reads or writes) which reflects a **single real-world transition.**

In the real world, a TXN either happened completely or not at all

```
START TRANSACTION
        UPDATE Product
        SET Price = Price – 1.99
        WHERE pname = ‘Gizmo’
COMMIT
```

# Transactions: Basic Definition

A <u>transaction ("TXN")</u> is a sequence of one or more operations (reads or writes) which reflects a **single real-world transition**.

In the real world, a TXN either happened completely or not at all

<u>Examples:</u>

- Transfer money between accounts
- Purchase a group of products
- Register for a class (either waitlist or allocated)

# Transactions in SQL

In “ad-hoc” SQL:

- Default: each statement = one transaction
- No need to explicitly start or end a transaction.

In a program, multiple statements can be grouped together as a transaction:

```
START TRANSACTION
        UPDATE Bank SET amount = amount – 100
        WHERE name = ‘Bob’
        UPDATE Bank SET amount = amount + 100
        WHERE name = ‘Joe’
COMMIT
```

# Model of Transaction in this class

We assume that the DBMS is only concerned about reads and writes to data

- It doesn't care about what the user's program does with the data **outside the database**.

A transaction is the DBMS's abstract view of a user program

- The same program executed multiple times would be considered as different transactions
- The DBMS does not really understand the "semantics" of the data, it only cares about read and write sequences

# Motivation for Transactions

Grouping user actions (reads & writes) into *transactions* helps with two goals:

1. Recovery & Durability: Keeping the DBMS data consistent and durable in the face of crashes, aborts, system shutdowns, etc.

2. Concurrency: Achieving better performance by parallelizing TXNs *without* creating anomalies

# Motivation

1. Recovery & Durability of user data is essential for reliable DBMS usage

- The DBMS may experience crashes (e.g. power outages, etc.)
- Individual TXNs may be aborted (e.g. by the user)

**Idea**: Make sure that TXNs are either **durably stored in full**, **or not at all**; keep log to be able to “roll-back” TXNs

# Protection against crashes / aborts

```
Client 1:
          INSERT INTO SmallProduct(name, price)
                    SELECT pname, price
                    FROM Product
                    WHERE price <= 0.99

          DELETE Product
                    WHERE price <=0.99
```

Crash / abort!

What goes wrong?

# Protection against crashes / aborts

```
Client 1:
        START TRANSACTION
                INSERT INTO SmallProduct(name, price)
                        SELECT pname, price
                        FROM Product
                        WHERE price <= 0.99

                DELETE Product
                        WHERE price <=0.99
        COMMIT OR ROLLBACK
```

Now we’d be fine!

# Motivation

## 2. Concurrent execution of user programs is essential for good DBMS performance.

- Disk accesses may be frequent and **slow**- optimize for throughput (# of TXNs), trade for latency (time for any one TXN)

- Users should still be able to execute TXNs as if in **isolation** and such that **consistency** is maintained

**Idea**: Have the DBMS handle running several user TXNs concurrently, in order to keep CPUs buzy…

# Multiple users: single statements

```
Client 1: UPDATE Product
                SET Price = Price – 1.99
                WHERE pname = ‘Gizmo’

Client 2:       UPDATE Product
                SET Price = Price*0.5
                WHERE pname=‘Gizmo’
```

Two managers attempt to discount products *concurrently*- What could go wrong?

# Multiple users: single statements

```
Client 1: START TRANSACTION
                    UPDATE Product
                    SET Price = Price – 1.99
                    WHERE pname = ‘Gizmo’
          COMMIT

Client 2: START TRANSACTION
                    UPDATE Product
                    SET Price = Price*0.5
                    WHERE pname=‘Gizmo’
          COMMIT
```

Now works like a charm - we’ll see how / why in the following lectures…

# 2. ACID Properties

# Desirable Properties of Transactions: ACID

Atomicity: A transaction is an atomic unit of processing; it is either performed in its entirety or not performed at all.

Consistency: A correct execution of the transaction must take the database from one consistent state to another.

Isolation: A transaction should not make its updates visible to other transactions until it is committed.

Durability: Once a transaction changes the database and the changes are committed, these changes must never be lost because of subsequent failure.

# ACID: Atomicity

TXN’s activities are atomic: all or nothing

- Intuitively: in the real world, a transaction is something that would either occur *completely* or *not at all*

Two possible outcomes for a TXN

- It *commits*: all the changes are made
- It *aborts*: no changes are made

# ACID: Consistency

The tables must always satisfy user-specified ***integrity constraints***

- *Examples:*
    - Account number is unique
    - Stock amount can't be negative
    - Sum of *debits* and of *credits* is 0

**Consistency** is one of the ACID properties of transactions. It ensures that a transaction brings the database from one valid state (satisfying all integrity constraints) to another valid state.

How consistency is achieved:

- Programmer makes sure a txn takes a consistent state to a consistent state
- *System* makes sure that the txn is **atomic**

# ACID: Isolation

A transaction executes concurrently with other transactions

Isolation: the effect is as if each transaction executes in *isolation* of the others.

- A user should be able to understand a transaction without considering the effect of any other concurrently running transaction, even if the DBMS interleaves their actions

# ACID: Durability

The effect of a TXN must continue to exist (*"persist"*) after the TXN

- And after the whole program has terminated
- And even if there are power failures, crashes, etc.
- And etc…

- Means: Write data to **disk**

Change on the horizon?
Non-Volatile Ram (NVRam).
Byte addressable.

# Ensuring Consistency

User’s responsibility to maintain the integrity constraints, as the DBMS may not be able to catch such errors in user program’s logic

- e.g., if you transfer money from the savings account to the checking account, the total amount still remains the same

However, the DBMS may be in inconsistent state “during a transaction” between actions

- which is ok, but it should leave the database at a consistent state when it commits or aborts

# Ensuring Atomicity

Transactions can be incomplete due to several reasons

- Aborted (terminated) by the DBMS because of some anomalies during execution
  - in that case automatically restarted and executed anew
- The system may crash (e.g., no power supply)
- A transaction may decide to abort itself encountering an unexpected situation
  - e.g., read an unexpected data value or unable to access disks

# Ensuring Atomicity

A transaction interrupted in the middle can leave the database in an inconsistent state

- DBMS has to remove the effects of partial transactions from the database

DBMS ensures atomicity by “undoing” the actions of incomplete transactions

DBMS maintains a “log” of all changes to do so

# Ensuring Durability

The log also ensures durability

If the system crashes before the changes made by a completed transactions are written to the disk, the log is used to remember and restore these changes when the system restarts

"recovery manager"

- takes care of atomicity and durability

# Ensuring Isolation

DBMS guarantees isolation

- If T1 and T2 are executed concurrently, either the effect would be T1->T2 or T2->T1 (and from a consistent state to a consistent state)

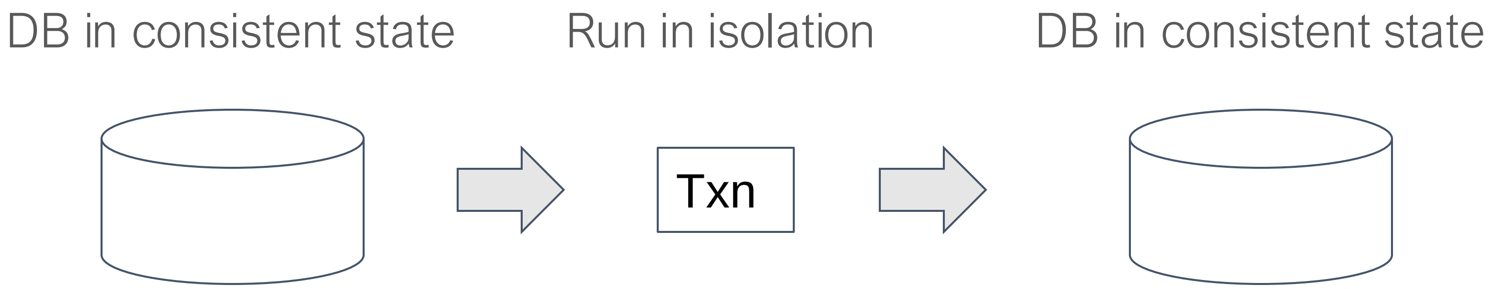
But DBMS provides no guarantee on which of these order is chosen

Often ensured by "locks" but there are other methods too

# The Correctness Principle

A fundamental assumption about transaction is:

If a transaction executes in the absence of any other transactions or system errors, and it starts with the database in a consistent state, then the database is also in a consistent state when the transactions ends.



# A Note: ACID is contentious!

Many debates over ACID, both **historically** and **currently**

Many “NoSQL” DBMSs relax ACID

In turn, now “NewSQL” reintroduces ACID compliance to NoSQL-style DBMSs…

ACID is an extremely important & successful paradigm, but still debated!

# 3. Using Transactions in SQL

# Using Transactions in SQL

- SQL allows the programmer to group several statements in a single *transaction*

- Either all operations are performed or none are

- A single SQL statement is always considered to be atomic.

Marks beginning of transaction

```
START TRANSACTION

UPDATE Accounts
SET balance = balance + 100
WHERE acctNo = 456;

UPDATE Accounts
SET balance = balance - 100
WHERE acctNo = 123;

COMMIT;
```

Causes transaction to end successfully

# Using Transactions in SQL

- ROLLBACK causes the transaction to abort and undo any changes

```
START TRANSACTION

UPDATE Accounts
SET balance = balance + 100
WHERE acctNo = 456;




ROLLBACK;
```

We find that there are insufficient funds to make transfer

# Using Transactions in SQL

SET TRANSACTION ***transaction_mode*** [, ...]

where ***transaction_mode*** is one of:

- ISOLATION LEVEL {
  SERIALIZABLE
  | REPEATABLE READ
  | READ COMMITTED
  | READ UNCOMMITTED }
- READ WRITE | READ ONLY

## Isolation Levels

- With SERIALIZABLE: the interleaved execution of transactions will adhere to our notion of serializability.
- However, if any transaction executes at a lower level, then serializability may be violated.

## Access Mode

- The default is READ WRITE unless the isolation level of READ UNCOMITTED is specified, in which case READ ONLY is assumed.

Source: https://www.postgresql.org/docs/current/sql-set-transaction.html

# Read-only transactions

Transactions that only read data and do not write can be executed in parallel

Tell DBMS before running transaction:

```
SET TRANSACTION READ ONLY;
```

# Dirty reads

Reading data written by a transaction that has not yet committed

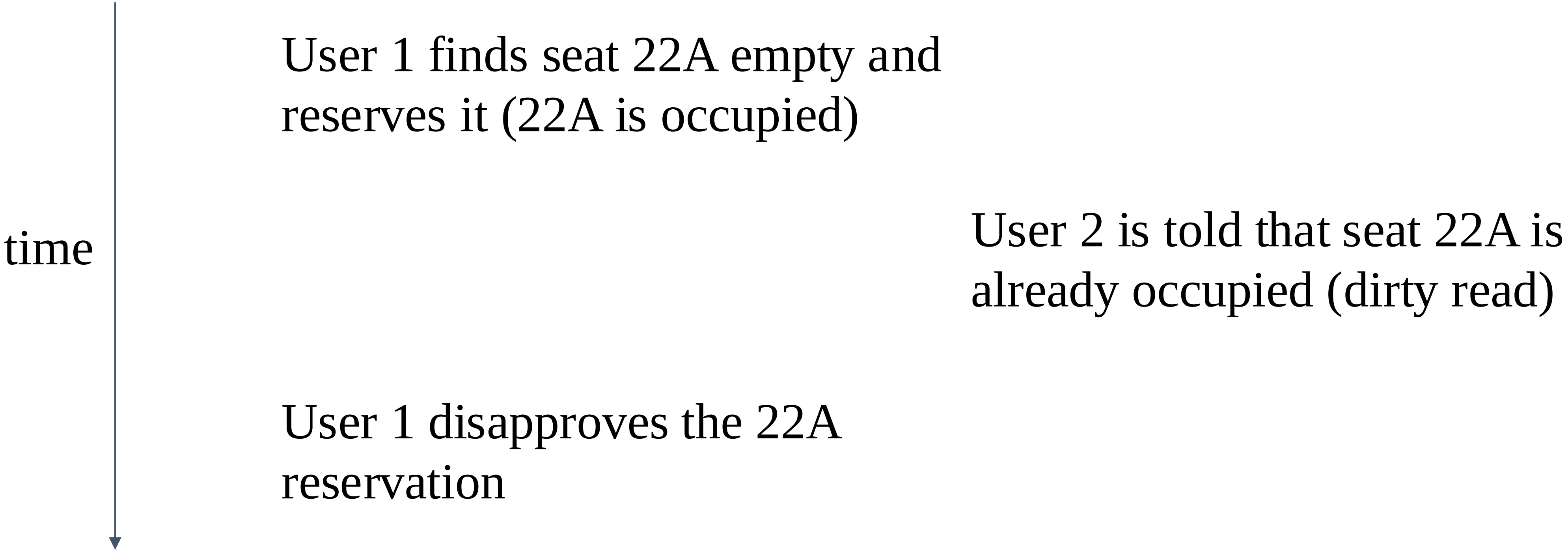
Consider this seat selection example:

1. Find available seat and reserve by setting *seatStatus* to ‘occupied’

2. Ask customer for approval of seat
    a. If so, commit
    b. If not, release seat by setting seatStatus to ‘available’ and repeat Step (1)

# Dirty read

If we allow dirty reads, this can happen



time

User 1 finds seat 22A empty and reserves it (22A is occupied)

User 2 is told that seat 22A is already occupied (dirty read)

User 1 disapproves the 22A reservation

# Dirty reads

If this result is acceptable, the transaction processing can be done faster

- DBMS does not have to prevent dirty reads
- Allows more parallelism

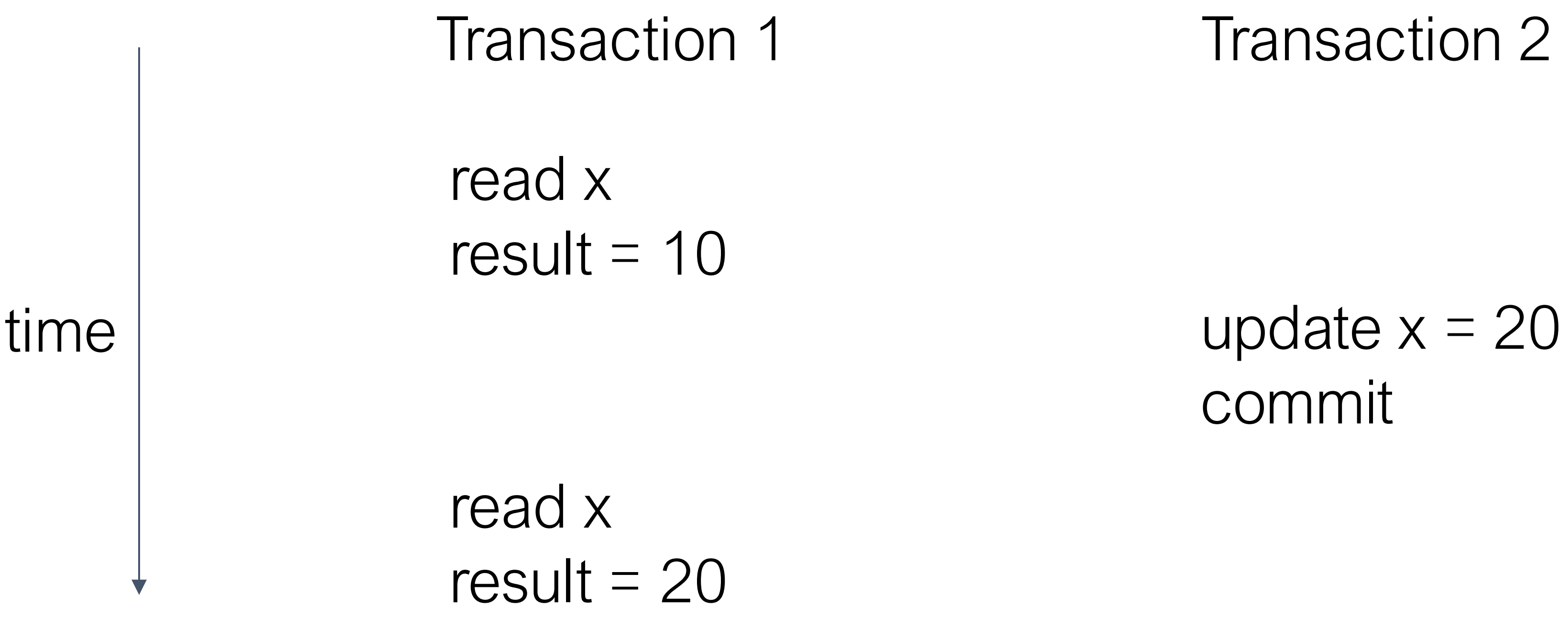
Tell DBMS before running transaction:

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

# Read committed

Only allow reads from committed data, but same query may get different answers

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

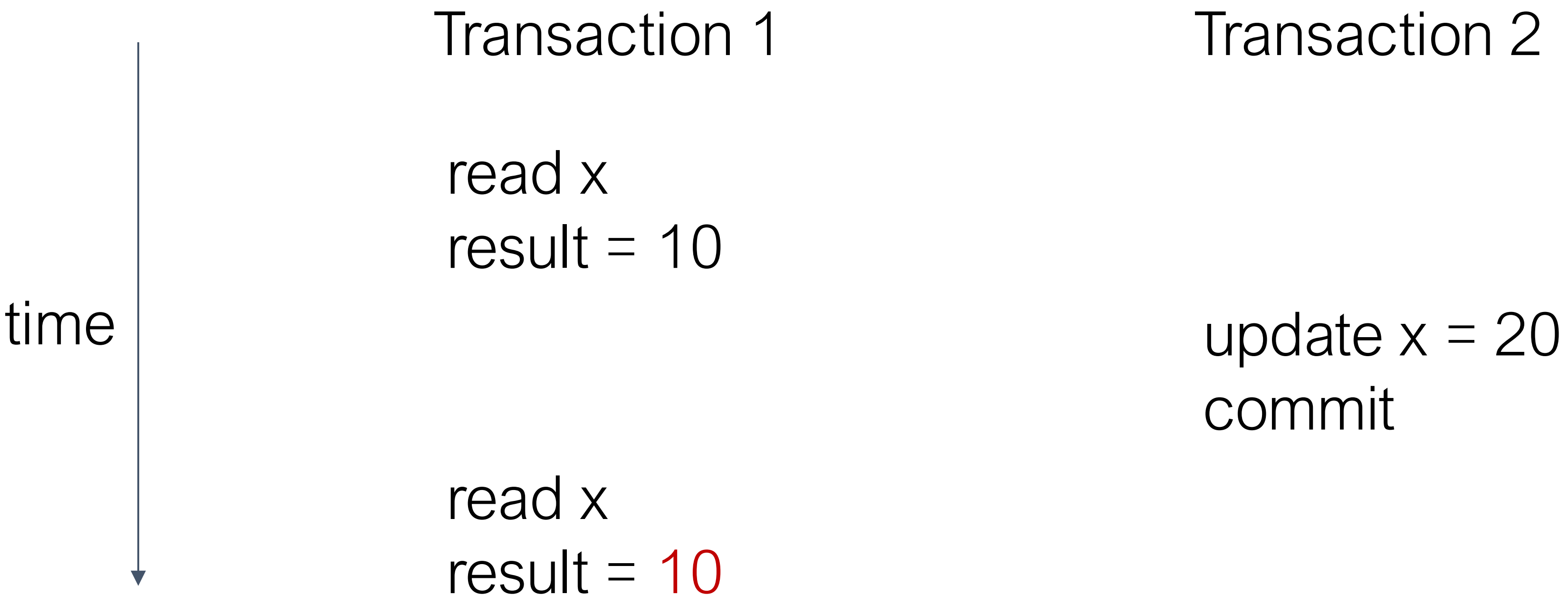


| Transaction 1 | Transaction 2 |
|---|---|
| read x<br>result = 10 | |
| | update x = 20<br>commit |
| read x<br>result = 20 | |

# Repeatable read

Any tuple that was retrieved will be retrieved again if the same query is repeated, even though other transactions may modify the individual rows that were read.

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



Transaction 1

Transaction 2

time

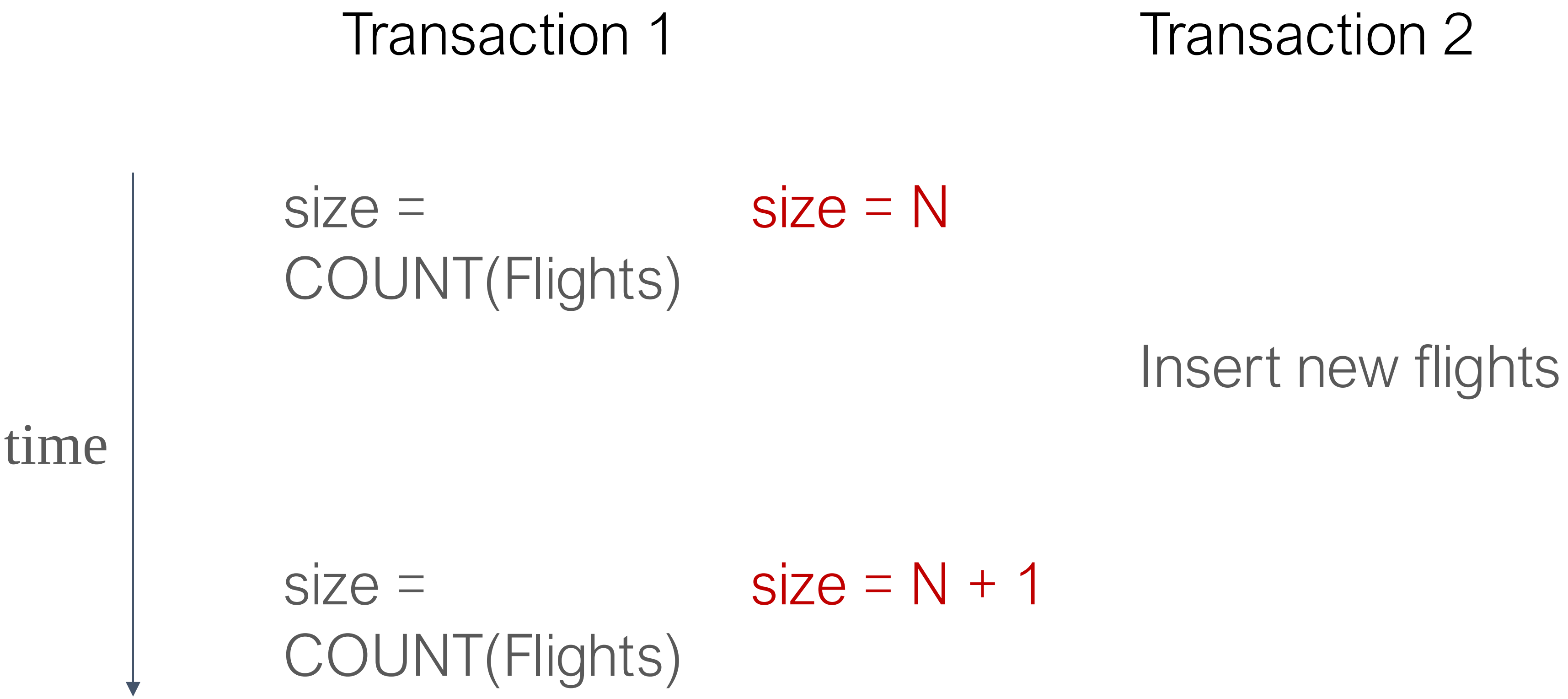
read x
result = 10

update x = 20
commit

read x
result = 10

# Repeatable read

May allow “phantom” tuples, which are new tuples inserted between queries



Transaction 1

Transaction 2

time

size = COUNT(Flights)

size = N

Insert new flights

size = COUNT(Flights)

size = N + 1

# Repeatable Read

Guarantee: rows read by a transaction will not change if read again in that transaction.

- Doesn’t guarantee anything about rows that weren't originally read.

Why Phantom Reads Can Occur

- Locking: Repeatable read typically locks the rows it reads, but not the gaps between rows.
- New Inserts: Without gap locking, new rows could be inserted that match your WHERE clause.

# Comparison of SQL isolation levels

| Isolation Level | Dirty Reads | Nonrepeatable Reads | Phantoms |
|---|---|---|---|
| READ UNCOMMITTED | ✓ | ✓ | ✓ |
| READ COMMITTED | 🚫 | ✓ | ✓ |
| REPEATABLE READ | 🚫 | 🚫 | ✓ |
| SERIALIZABLE | 🚫 | 🚫 | 🚫 |

# Comparison of SQL isolation levels

| Isolation Level | Dirty Reads | Nonrepeatable Reads | Phantoms |
|---|---|---|---|
| READ UNCOMMITTED | ✓ | ✓ | ✓ |
| READ COMMITTED | 🚫 | ✓ | ✓ |
| REPEATABLE READ | 🚫 | 🚫 | ✓ |
| SERIALIZABLE | 🚫 | 🚫 | 🚫 |

- Rarely used in practice, as the performance is not much better than other levels

- In fact, PostgreSQL doesn’t support this isolation level

- No lock on data

# Comparison of SQL isolation levels

| Isolation Level | Dirty Reads | Nonrepeatable Reads | Phantoms |
|---|---|---|---|
| READ UNCOMMITTED | ✓ | ✓ | ✓ |
| READ COMMITTED | 🚫 | ✓ | ✓ |
| REPEATABLE READ | 🚫 | 🚫 | ✓ |
| SERIALIZABLE | 🚫 | 🚫 | 🚫 |

- Fast and simple to use; adequate for many applications

- Shared lock (read lock) on rows when they are read, exclusive lock (write lock) on rows when they are being modified

# Comparison of SQL isolation levels

| Isolation Level | Dirty Reads | Nonrepeatable Reads | Phantoms |
|---|---|---|---|
| READ UNCOMMITTED | ✓ | ✓ | ✓ |
| READ COMMITTED | 🚫 | ✓ | ✓ |
| REPEATABLE READ | 🚫 | 🚫 | ✓ |
| SERIALIZABLE | 🚫 | 🚫 | 🚫 |

- Good for reporting, data warehousing types of workload
- Shared locks on all rows read by a transaction

# Comparison of SQL isolation levels

| Isolation Level | Dirty Reads | Nonrepeatable Reads | Phantoms |
|---|---|---|---|
| READ UNCOMMITTED | ✓ | ✓ | ✓ |
| READ COMMITTED | 🚫 | ✓ | ✓ |
| REPEATABLE READ | 🚫 | 🚫 | ✓ |
| SERIALIZABLE | 🚫 | 🚫 | 🚫 |

- Recommended only when updating transactions contain logic sufficiently complex that they might give wrong answers in READ COMMITED mode

- Locking the entire range of rows that could potentially be accessed by a transaction's queries

# 4. Schedule

# Schedule

A transaction is seen by DBMS as a list of actions.

- READ, WRITE of database objects
- ABORT, COMMIT

Assumption: Transactions communicate only through READ and WRITE

Schedule is a list of actions from a set of transactions as seen by the DBMS

- Two actions from the same transaction T MUST appear in the schedule in the same order that they appear in T
- Intuitively, a schedule represents an actual or potential execution sequence

# Transaction primitives

- INPUT(X): copy block X from disk to memory
- READ(X, t): copy X to transaction's local variable t
  (run INPUT(X) if X is not in memory)
- WRITE(X, t): copy value of t to X (run INPUT(X) if X is not in memory)
- OUTPUT(X): copy X from memory to disk

# Schedule

- Actions taken by one or more transactions

| *T1* | *T2* |
|---|---|
| READ(*A*, *t*) | READ(*A*, s) |
| *t* := *t*+100 | *s* := *s**2 |
| WRITE(*A*, *t*) | WRITE(*A*, *s*) |
| READ(*B*, *t*) | READ(*B*, *s*) |
| *t* := *t*+100 | *s* := *s**2 |
| WRITE(*B*, *t*) | WRITE(*B*, *s*) |

# Characterizing Schedules based on Serializability (1)

## Serial schedule

- A schedule S is serial if, for every transaction T participating in the schedule, all the operations of T are executed consecutively in the schedule.
  - Otherwise, the schedule is called nonserial schedule.

## Serializable schedule

- A schedule S is serializable if it is equivalent to some serial schedule of the same n transactions.

Serial and serializable schedules are guaranteed to preserve the consistency of database states

# Serial schedule

- One transaction is executed at a time

| *T1* | *T2* | *A* | *B* |
|---|---|---|---|
| | | 25 | 25 |
| READ(*A*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*A*, *t*) | | | |
| READ(*B*, *t*) | | 125 | |
| *t* := *t*+100 | | | |
| WRITE(*B*, *t*) | | | |
| | | | 125 |
| | READ(*A*, s) | | |
| | *s* := *s**2 | | |
| | WRITE(*A*, *s*) | 250 | |
| | READ(*B*, *s*) | | |
| | *s* := *s**2 | | |
| | WRITE(*B*, *s*) | | 250 |

Schedule: (T1, T2)

Q: Do serial schedules allow for high throughput?

# Serializable schedule

- There exists a serial schedule with the same effect

| *T1* | *T2* | *A* | *B* |
|---|---|---|---|
| | | 25 | 25 |
| READ(*A*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*A*, *t*) | | 125 | |
| | READ(*A*, s) | | |
| | *s* := *s**2 | | |
| | WRITE(*A*, *s*) | 250 | |
| READ(*B*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*B*, *t*) | | | 125 |
| | READ(*B*, *s*) | | |
| | *s* := *s**2 | | |
| | WRITE(*B*, *s*) | | 250 |

Same effect as (T1, T2)

# Serializable schedule

- This is not serializable

| *T1* | *T2* | *A* | *B* |
|---|---|---|---|
| | | 25 | 25 |
| READ(*A*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*A*, *t*) | | 125 | |
| | READ(*A*, s) | | |
| | s := s*2 | | |
| | WRITE(*A*, *s*) | 250 | |
| | READ(*B*, *s*) | | |
| | s := s*2 | | |
| | WRITE(*B*, *s*) | | 50 |
| READ(*B*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*B*, *t*) | | | 150 |

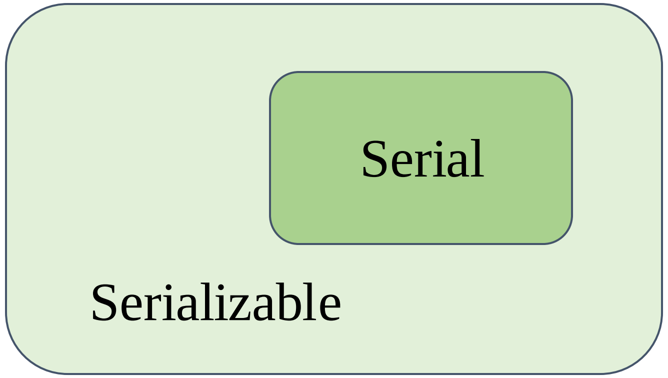
# Serializable schedule

- Serializable, but only due to the detailed transaction behavior

| *T1* | *T2* | *A* | *B* |
|---|---|---|---|
| | | 25 | 25 |
| READ(*A*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*A*, *t*) | | 125 | |
| | READ(*A*, s) | | |
| | *s* := *s*+200 | | |
| | WRITE(*A*, *s*) | 325 | |
| | READ(*B*, *s*) | | |
| | *s* := *s*+200 | | |
| | WRITE(*B*, *s*) | | 225 |
| READ(*B*, *t*) | | | |
| *t* := *t*+100 | | | |
| WRITE(*B*, *t*) | | | 325 |

Same effect as (T1, T2)

# Serial vs Serializable Schedule



Being serializable is not the same as being serial

Being serializable implies that the schedule is a correct schedule.

- It will leave the database in a consistent state.

Interleaving improves efficiency due to concurrent execution, e.g.,

- While one transaction is blocked on I/O, the CPU can process another transaction
- Interleaving short and long transactions might allow the short transaction to finish sooner (otherwise it need to wait until the long transaction is done)

# Abstract view of TXNs: reads and writes

Serializability is hard to check - cannot always know detailed behaviors

DBMS's abstract view of transactions:

$r_i(X)$: Ti reads X
$w_i(X)$: Ti writes X

T1: $r_1(A)$; $w_1(A)$; $r_1(B)$; $w_1(B)$
T2: $r_2(A)$; $w_2(A)$; $r_2(B)$; $w_2(B)$

Serializable schedule: $r_1(A)$; $w_1(A)$; $r_2(A)$; $w_2(A)$; $r_1(B)$; $w_1(B)$; $r_2(B)$; $w_2(B)$;

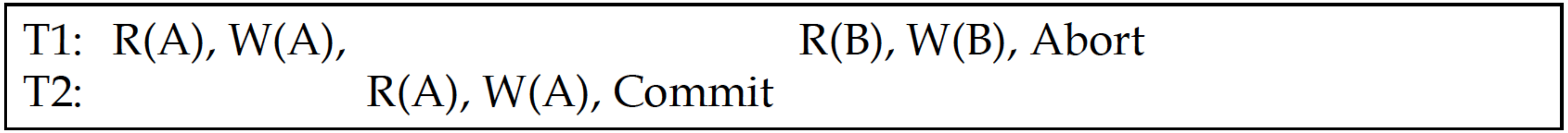
# Conflicts: Anomalies with Interleaved Execution

A pair of consecutive actions that cannot be interchanged without changing behavior

- Write-Read (WR)
- Read-Write (RW)
- Write-Write (WW)

* No conflict with “RR” if no write is involved

# WR Conflict

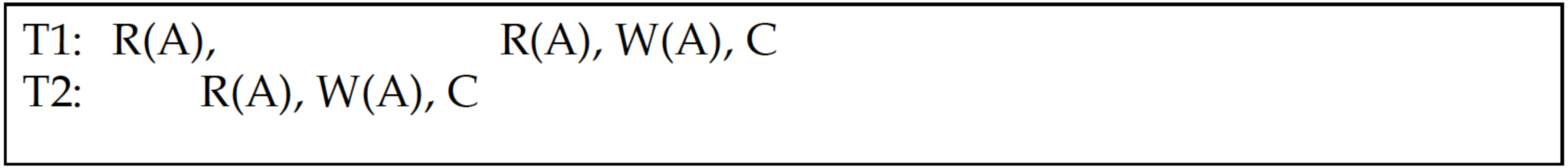


```
T1:  R(A), W(A),                              R(B), W(B), Abort
T2:              R(A), W(A), Commit
```

Reading Uncommitted Data (WR Conflicts, “dirty reads”):

- transaction T2 reads an object that has been modified by T1 but not yet committed

# RW Conflict

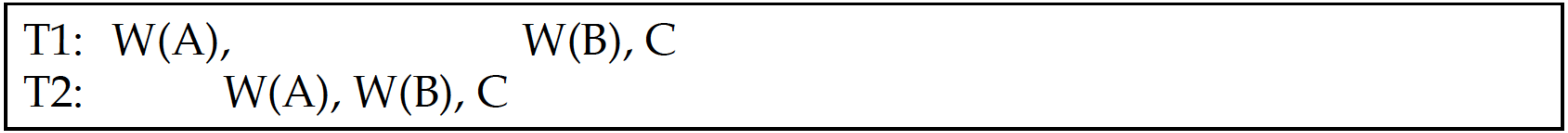


```
T1:  R(A),                      R(A), W(A), C
T2:        R(A), W(A), C
```

## Unrepeatable Reads (RW Conflicts):

- T2 changes the value of an object A that has been read by transaction T1, which is still in progress
- If T1 tries to read A again, it will get a different result

# WW Conflict



```
T1:  W(A),                  W(B), C
T2:        W(A), W(B), C
```

Overwriting Uncommitted Data (WW Conflicts, “lost update”):

- T2 overwrites the value of A, which has been modified by T1, still in progress
- Suppose we need the salaries of two employees (A and B) to be the same
  - T1 sets them to $1000
  - T2 sets them to $2000

# Characterizing Schedules based on Serializability (2)

## Conflict equivalent

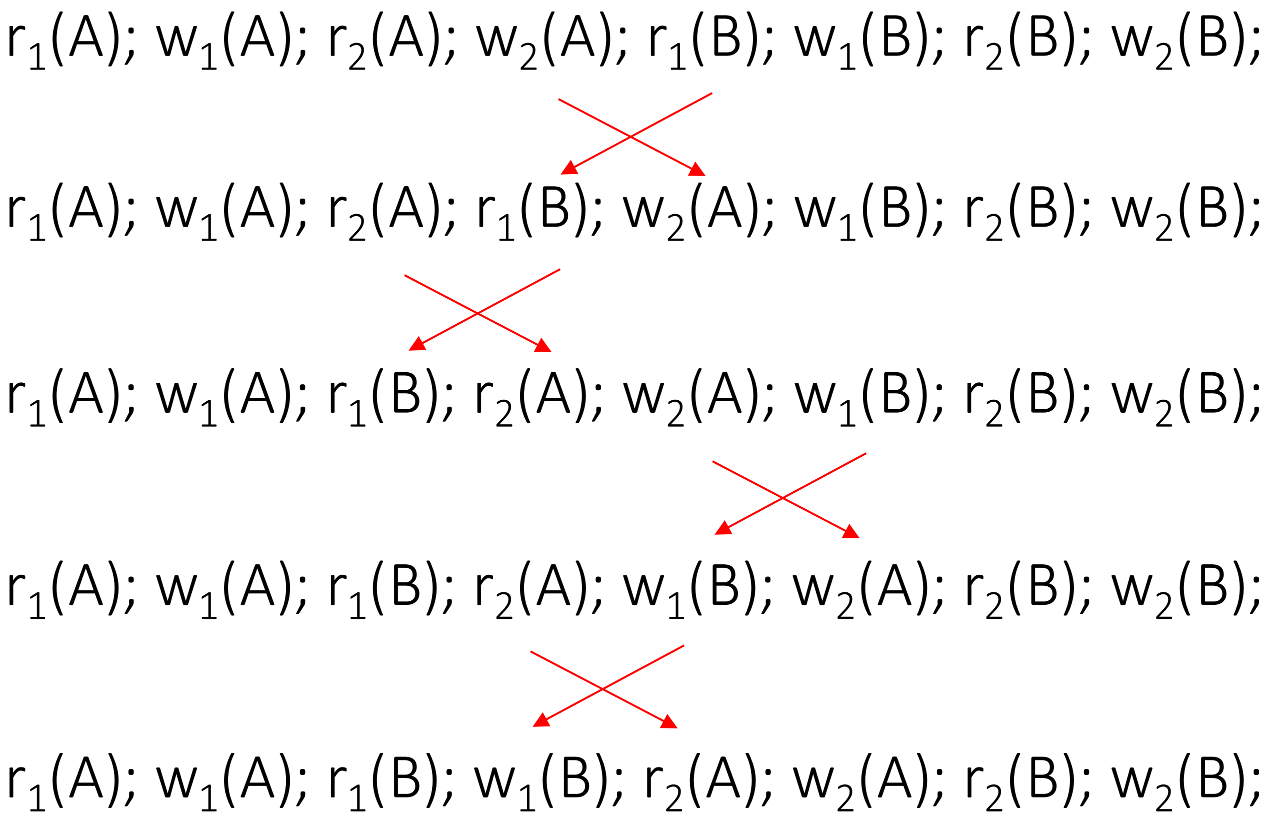
- Two conflict equivalent schedules have the same effect on a database
- All pairs of conflicting actions are in same order
- one schedule can be obtained from the other by swapping "non-conflicting" actions
    - either on two different objects
    - or both are read on the same object

## Conflict serializable

- A schedule S is said to be conflict serializable if it is conflict equivalent to some serial schedule S'.

# Conflict-serializable schedule

- Conflict-equivalent to serial schedule



$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B);$

$r_1(A); w_1(A); r_2(A); r_1(B); w_2(A); w_1(B); r_2(B); w_2(B);$

$r_1(A); w_1(A); r_1(B); r_2(A); w_2(A); w_1(B); r_2(B); w_2(B);$

$r_1(A); w_1(A); r_1(B); r_2(A); w_1(B); w_2(A); r_2(B); w_2(B);$

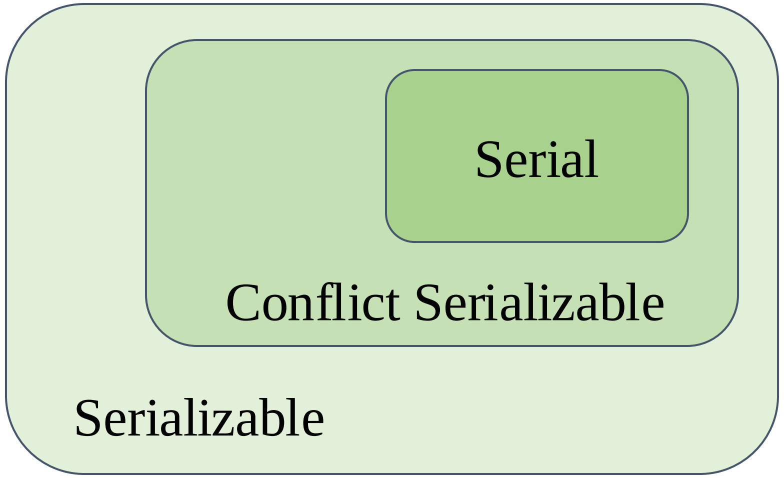
Serial $r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B);$

# Conflict-serializable schedule

- A conflict-serializable schedule is always serializable
- But not vice versa (e.g., serializable schedule due to detailed transaction behavior)

S1: $w_1(Y)$; $w_1(X)$; $w_2(Y)$; $w_2(X)$; $w_3(X)$; Serial

S2: $w_1(Y)$; $w_2(Y)$; $w_2(X)$; $w_1(X)$; $w_3(X)$; Serializable, but not conflict serializable



# In-class Exercise

- What are schedules that are conflict-equivalent to (T1, T2)?

T1: $r_1(A)$; $w_1(A)$; $r_1(B)$; $w_1(B)$;

T2: $r_2(B)$; $w_2(B)$; $r_2(A)$; $w_2(A)$;

# Testing for conflict serializability

Through a precedence graph:

- Looks at only read_Item (X) and write_Item (X) operations
- Constructs a precedence graph (serialization graph) - a graph with directed edges
- An edge is created from Ti to Tj if one of the operations in Ti appears before a conflicting operation in Tj
- The schedule is serializable if and only if the precedence graph has no cycles.

# Precedence graph

Can use to decide conflict serializability

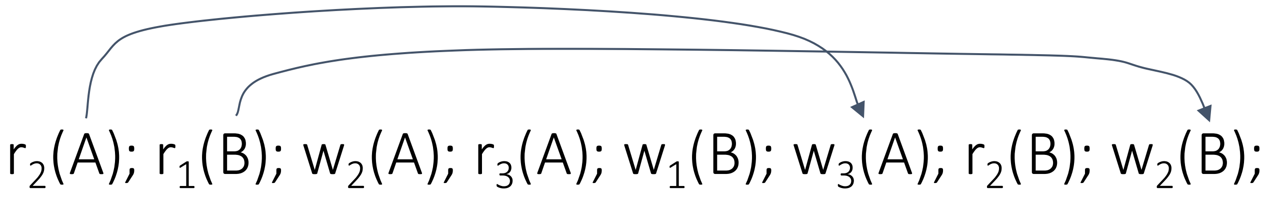
$r_2(A)$; $r_1(B)$; $w_2(A)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $r_2(B)$; $w_2(B)$;

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

** Also called dependency graph, conflict graph, or serializability graph*

# Precedence graph

Can use to decide conflict serializability



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

T1 → T2 → T3

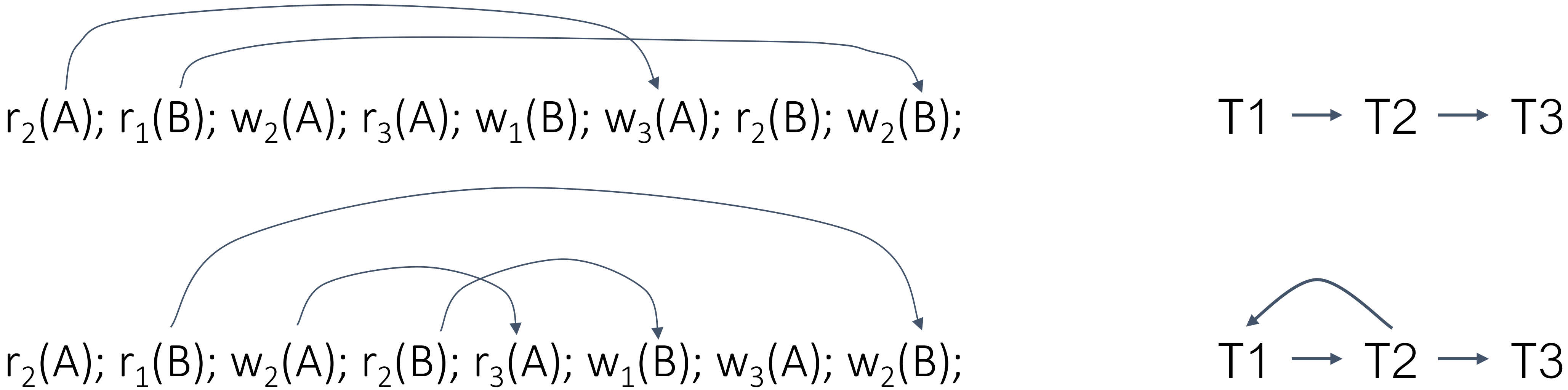
$r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B);$

T1 T2 T3

- One node per committed transaction
- Edge from Ti to Tj if an action of Ti precedes and conflicts with one of Tj’s actions
  - Wi(A) --- Rj(A), or Ri(A) --- Wj(A), or Wi(A) --- Wj(A)

# Precedence graph

Can use to decide conflict serializability



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

T1 → T2 → T3

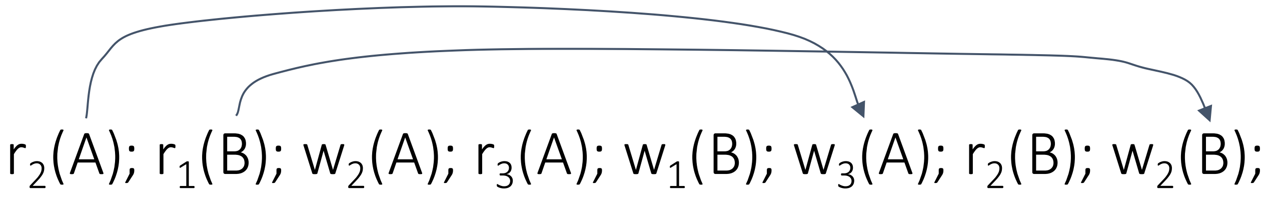
$r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B);$

T1 → T2 → T3

- One node per committed transaction
- Edge from Ti to Tj if an action of Ti precedes and conflicts with one of Tj's actions
  – Wi(A) --- Rj(A), or Ri(A) --- Wj(A), or Wi(A) --- Wj(A)

# Precedence graph

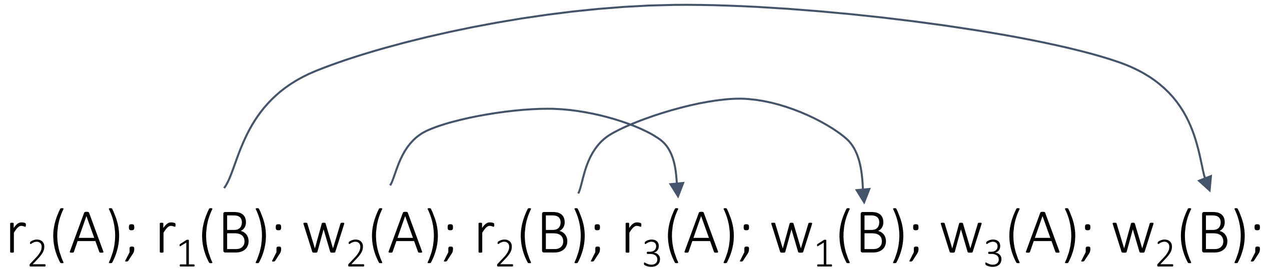
Can use to decide conflict serializability



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

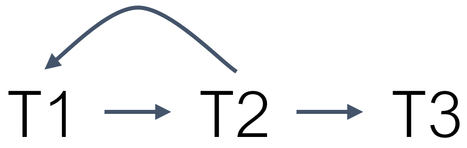
This is conflict serializable

T1 → T2 → T3



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

This is not because of cycle



- One node per committed transaction
- Edge from Ti to Tj if an action of Ti precedes and conflicts with one of Tj's actions
  - Wi(A) --- Rj(A), or Ri(A) --- Wj(A), or Wi(A) --- Wj(A)

# In-class Exercise

- What is the precedence graph for the schedule:

$r_1(A)$; $r_2(A)$; $r_1(B)$; $r_2(B)$; $r_3(A)$; $r_4(B)$; $w_1(A)$; $w_2(B)$;

- One node per committed transaction
- Edge from Ti to Tj if an action of Ti precedes and conflicts with one of Tj's actions
  - Wi(A) --- Rj(A), or Ri(A) --- Wj(A), or Wi(A) --- Wj(A)