Transactions 1

CS348 Spring 2024

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Sections: **002 & 003 only**

Announcements

- Milestone 2
  - Due today!
- Assignment 3
  - Due Friday, July 19th

Outline For Today

1. Motivation For Transactions
2. ACID Properties
3. Different Levels of Isolation Beyond Serializability

User's Perspective

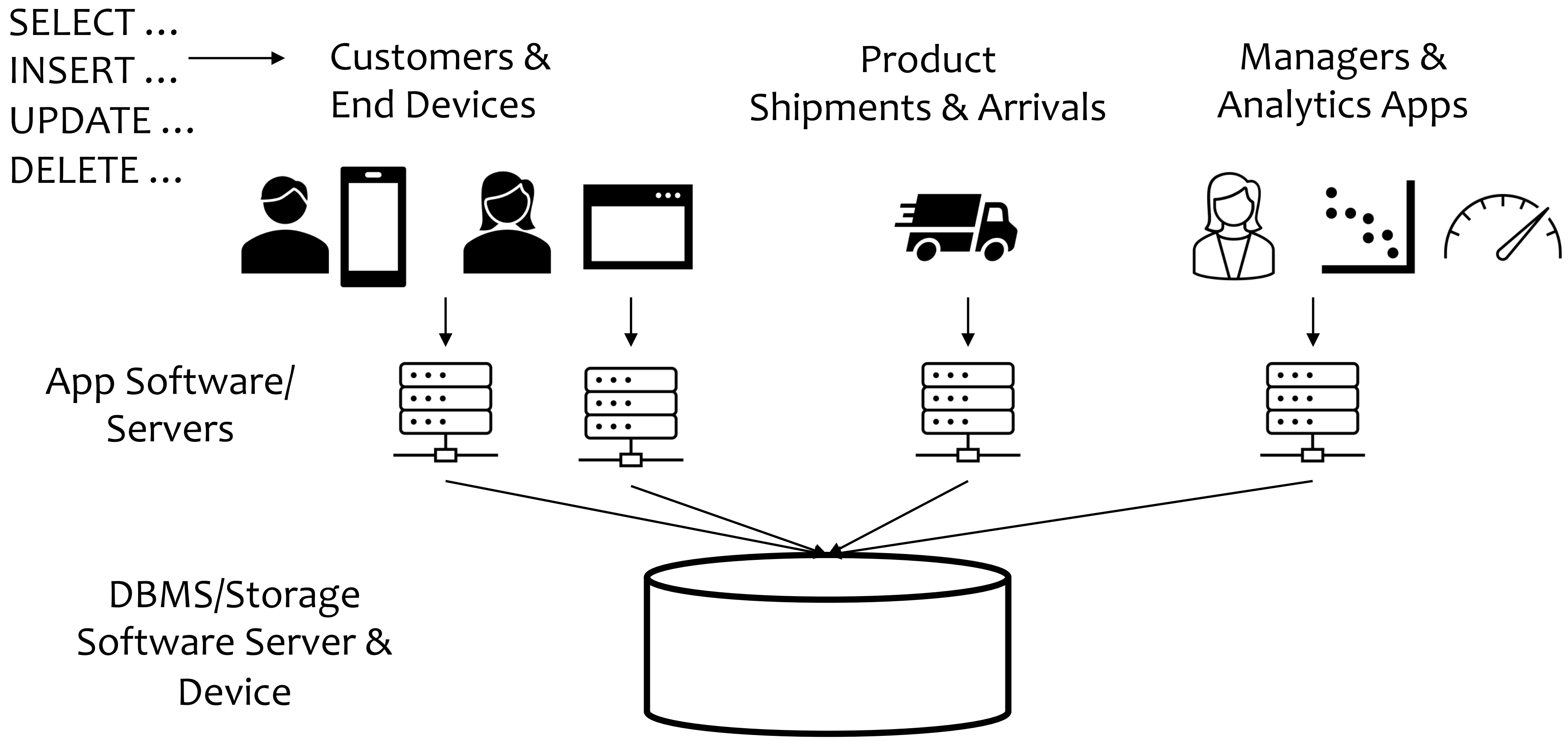
Serializability:

- Execution Histories
- Conflict Equivalence
- Checking For Conflict Equivalence

System's Perspective (next lecture)

Recall example for Lecture 1

➢ Ex Application: Order & Inventory Management in E-commerce


SELECT …
INSERT …
UPDATE …
DELETE …
Customers & End Devices
Product Shipments & Arrivals
Managers & Analytics Apps
App Software/ Servers
DBMS/Storage Software Server & Device

Why we need transactions

- A database is a shared resource accessed by many users and processes concurrently.
  - Both queries and modifications
- Not managing this concurrent access to a shared resource will cause problems
  - Problems due to concurrency
  - Problems due to failures

Example Problems With Concurrency (1)

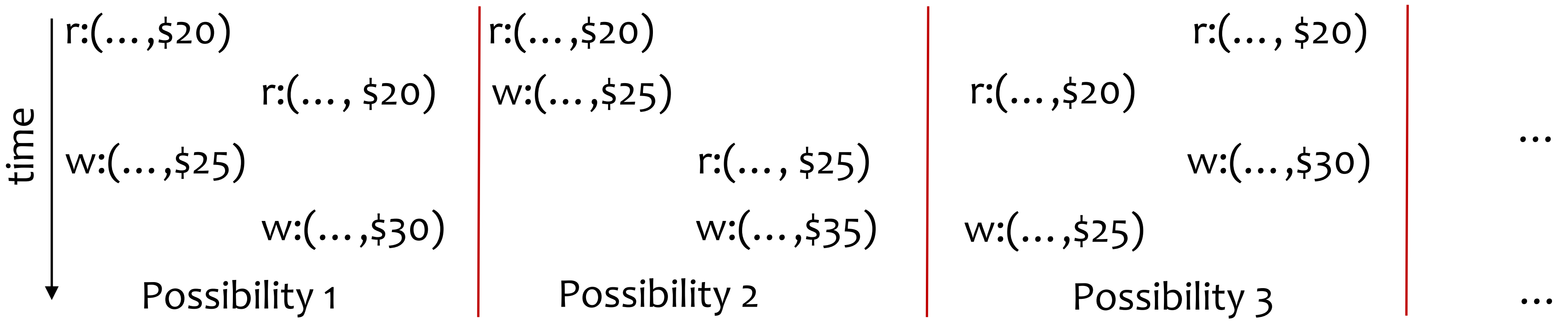
- Read-only queries are simple to execute concurrently.
- Ex: Two clients concurrently update the same relation in DBMS

```
UPDATE Order
SET price = price + 5
WHERE oid = o1
```

```
UPDATE Order
SET price = price + 10
WHERE oid = o1
```

Order			
o1	cust1	bookA	$20
…	…	…	…

- Possible attribute-level inconsistency in absence of safe concurrency:



Example Problems With Concurrency (2)

```
UPDATE Order
SET price = price + 5
WHERE oid = o1
```

```
UPDATE Order
SET pID = WatchA
WHERE oid = o1
```

Order			
o1	cust1	BookA	$20
…	…	…	…

➢ Possible Tuple-level inconsistency

o1	cust1	BookA	$25

o1	cust1	WatchA	$20

o1	cust1	WatchA	$25

Example Problems With Concurrency (3)

```
Update Statement 1:
UPDATE Customer
SET membership = Gold
WHERE cid IN (Select cid FROM Orders
              WHERE price >= 20)
```

```
Update Statement 2:
UPDATE Order
SET price = price*0.9
WHERE pid = BookA
```

Customer		
cid	name	membership
cust1	Alice	Silver
…	…	…

Order			
oid	**cid**	**pid**	**price**
01	cust1	BookA	$20
…	…	…	…

- Possible Relation-level inconsistency
- Statement 1's update on Customer depends on Order table, which is concurrently being updated.
- Data in Customer can be corrupted if the executions overlaps.

Example Problems With Concurrency (4)

```
Client 1
INSERT INTO 2021_Orders
SELECT * FROM Orders WHERE year = 2021

DELETE FROM Orders WHERE year = 2021
```

```
CLIENT 2:
SELECT Count(*) FROM Orders
SELECT Count(*) FROM 2021_Orders
```

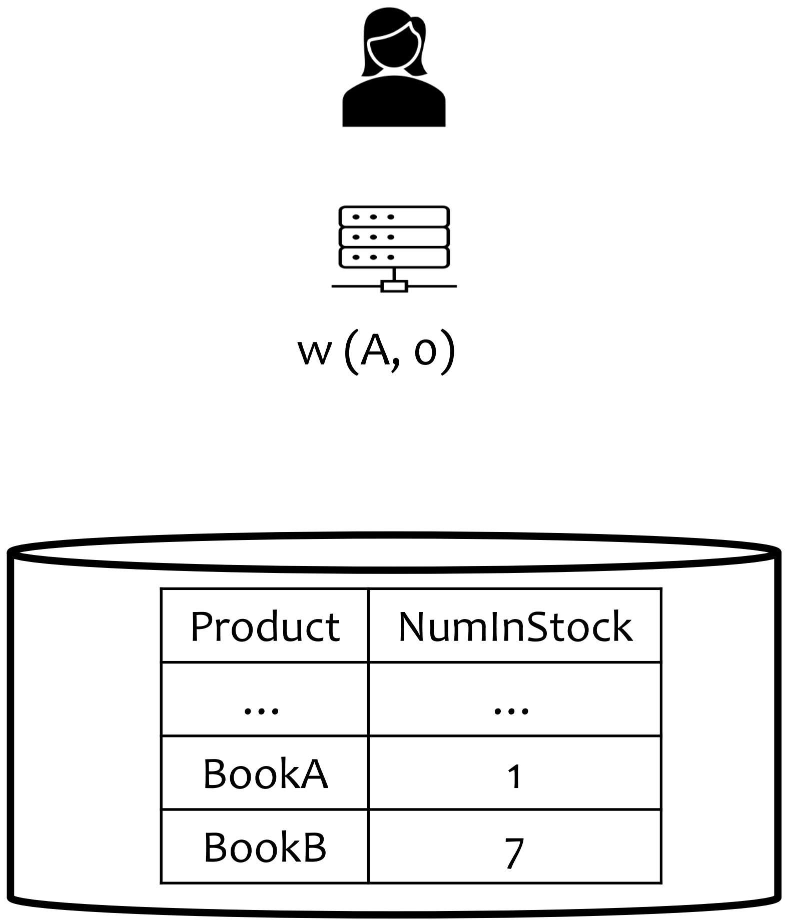
- Possible Database-level inconsistency
- Expectation: Total # orders in the enterprise (across Orders and 2021_Orders) remains unchanged.
- But Client 2 can see an inconsistent number of order counts across both relations depending on how much of the data from Orders has been moved to 2021_Orders and also deleted.

Case For Isolation During Concurrent Access

- Clients want concurrency, because databases are designed to be used my multiple clients, and DBMSs can exploit parallelism
- Clients also want to access the db ***in isolation***, i.e., run a set of queries and statement as if no others are running concurrently.
- All or nothing guarantee: Run the set of statements only if the DBMS can guarantee that they were *all running atomically as if in isolation*.
- Any guarantee on subsets of statements is not useful.

Problems due to failures (Slides From Lecture 1)

- What if your disk fails in the middle of an order?
- What if your server software fails due to a bug?
- What if there is a power outage in the machine storing files?
- Suppose Alice orders both BookA and BookB



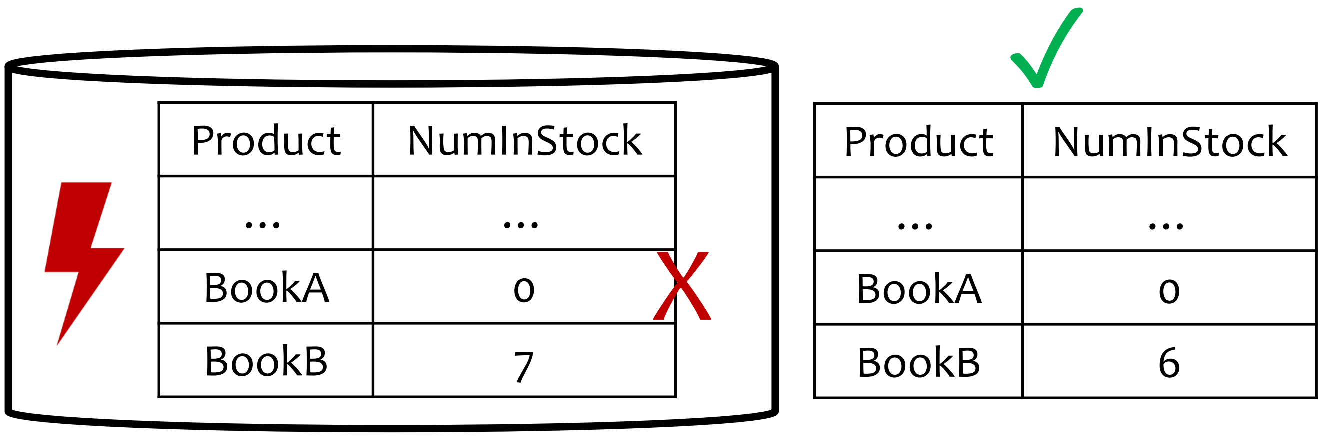
Product	NumInStock
…	…
BookA	1
BookB	7

Problems due to failures (Slides From Lecture 1)

- What if your disk fails in the middle of an order?
- What if your server software fails due to a bug?
- What if there is a power outage in the machine storing files?
- Suppose Alice orders both BookA and BookB

Before (B, 6) is written, there is a crash!
Inconsistent data state!
What happens when the system is back up?
How to recover from inconsistent state?

w (A, 0)



Product	NumInStock
…	…
BookA	0
BookB	7

Product	NumInStock
…	…
BookA	0
BookB	6

Case For Atomicity To Handle Failures

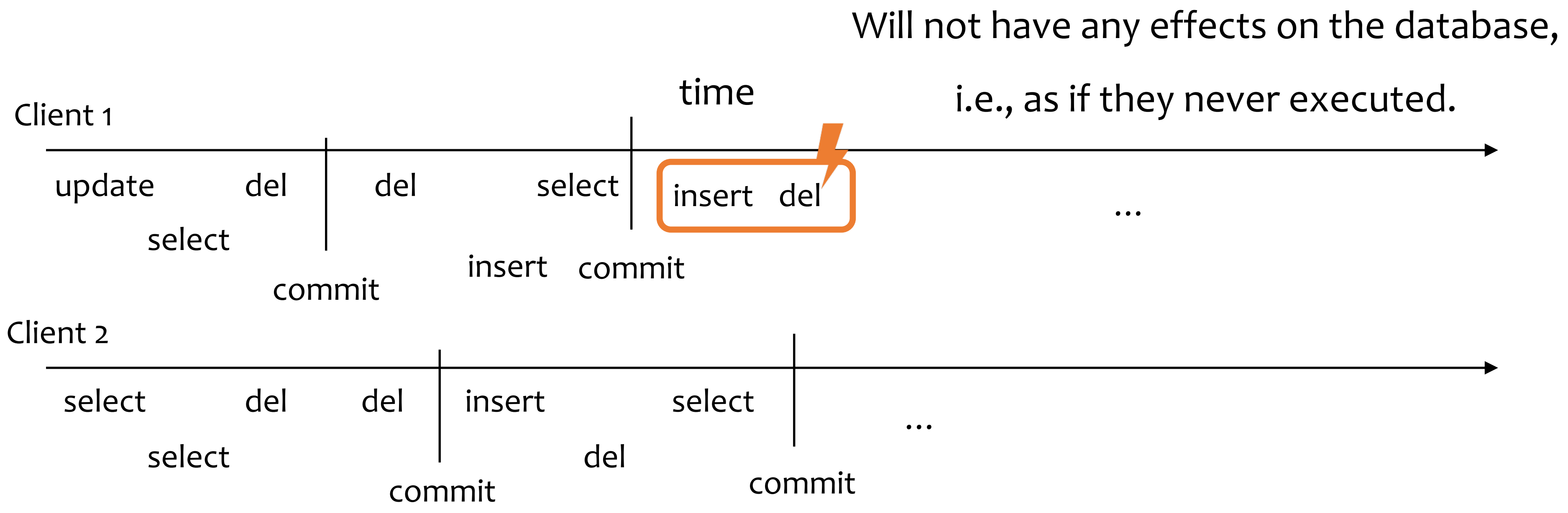
- All or nothing guarantee: Run the set of statements only if the DBMS can guarantee that they *will all succeed and be persistent or all will fail and no update they make will be persistent.*

Transactions solve Concurrency & Failure Problems

- Transactions : a set of queries/updates that are treated as an atomic unit
- Transactions (appear to) run in isolation during concurrent access (different levels of isolation exist; see later in lecture).
- Transactions are atomic, ie., either all queries/statement will run and persist any modifications to the DBMS, or none will.
- From users' perspective: By wrapping a set of queries/updates in one transaction, users obtain concurrency and resilience guarantees
- Note: internally DBMSs use 2 completely different algorithms/protocols to provide these functionalities for transactions
  - E.g.: locking for concurrency; logging for resilience (lecture 19)

Transactions in SQL

- In SQL Standard, transactions begin when a client issues a "Begin Transaction" command & ends with the "commit" or "rollback" keyword.
- Autocommit: treats each statement as a separate transaction



If client statement and operations really run concurrently and overlap: What guarantees can a DBMS really give with transactions?

Outline For Today

1. Motivation For Transactions
2. ACID Properties
3. Different Levels of Isolation Beyond Serializability

ACID Properties

- Transactions provide 4 main properties known as *ACID properties*:

  A: Atomicity

  C: Consistency

  I: Isolation

  D: Durability

ACID: Atomicity

- Provides all-or-nothing guarantee

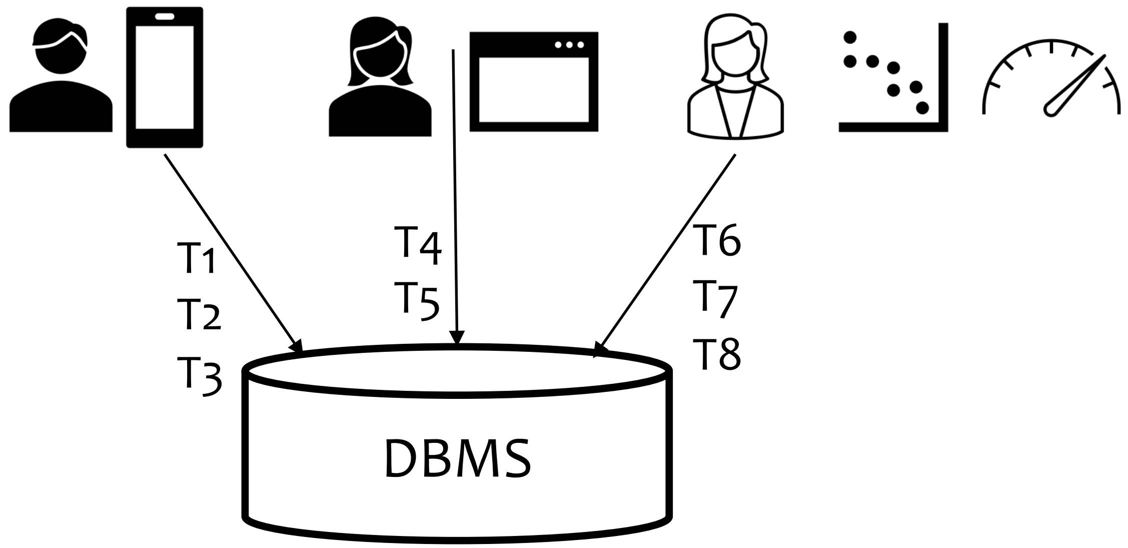
- Partial effects of a transaction must be undone when
  - User explicitly aborts the transaction using ROLLBACK
  - The DBMS crashes before a transaction commits

- 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) –lecture 19

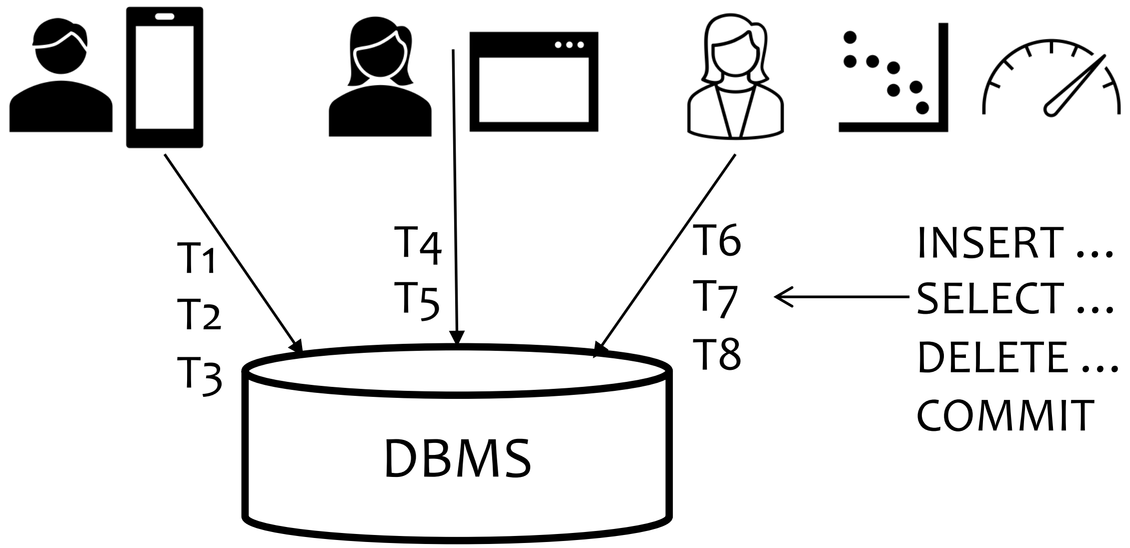
ACID: Consistency



- Guaranteed by constraints and triggers declared in the database and/or transactions themselves
  - E.g., Balance amount > 0

- Whenever inconsistency arises,
  - abort the statement or transaction, or
  - fix the inconsistency within the transaction

ACID: Isolation (focus of this lecture)



- Serializability: A set of transactions **T** might run concurrently and interleave but final outcome is equivalent to ***some serial order*** of executing the transactions in **T**.
- But DBMSs also provide lower isolation guarantees (later).
- Question to ponder: How can a DBMS guarantee serializability?
  - Locking or "verifying modifications at commit time" (next lecture)

Recall Example Problems With Concurrency (1)

```
Txn 1:
UPDATE Order
SET price = price + 5
WHERE oid = o1
```

```
Txn 2:
UPDATE Order
SET price = price + 10
WHERE oid = o1
```

Order			
o1	bust1	bookA	$20

➢ Attribute-level inconsistency In absence of safe concurrency

time							
	r:(…,$20)		r:(…,$20)			r:(…, $20)	
		r:(…, $20)	w:(…,$25)		r:(…,$20)		…
	w:(…,$25)			r:(…, $25)		w:(…,$30)	
↓		w:(…,$30)		w:(…,$35)	w:(…,$25)		
	Possibility 1		Possibility 2		Possibility 3		
	X		✓		X		…

Two correct possibilities: T1; T2 (e.g possibility 2)
or T2; T1 (not shown in figure but also leading to $35)

Recall Example Problems With Concurrency (2)

```
Txn 1:
UPDATE Order
SET price = price + 5
WHERE oid = o1
```

```
Txn 2:
UPDATE Order
SET pID = WatchA
WHERE oid = o1
```

Order			
o1	cust1	BookA	$20

- Possible Tuple-level inconsistency

o1	cust1	BookA	$25

X

o1	cust1	WatchA	$20

X

o1	cust1	WatchA	$25

✓

Two possibilities again: T1; T2 or T2; T1 (both leading to possibility 3)

Recall Example Problems With Concurrency (3)

```
Txn 1:
Update Statement 1:
UPDATE Customer
SET membership = Gold
WHERE cid IN (Select cid FROM Orders
              WHERE price >= 20)
```

```
Txn 2:
Update Statement 2:
UPDATE Order
SET price = price*0.9
WHERE pid = BookA
```

- Possible Relation-level inconsistency

Customer		
cid	name	membership
cust1	Alice	Silver
…	…	…

Order			
oid	**cid**	**pid**	**price**
o1	cust1	BookA	$20
…	…	…	…

Two possibilities again: T1; T2 or T2; T1
Interestingly order now matters unlike Examples 1 & 2 previously.
E.g., suppose Alice has only 1 order:
If execution-order is T1; T2: she becomes a Gold member
If it is T2; T1: she remains a Silver member.

Recall Example Problems With Concurrency (4)

```
Txn 1:
INSERT INTO 2021_Orders
SELECT * FROM Orders WHERE year = 2021

DELETE FROM Orders WHERE year = 2021
```

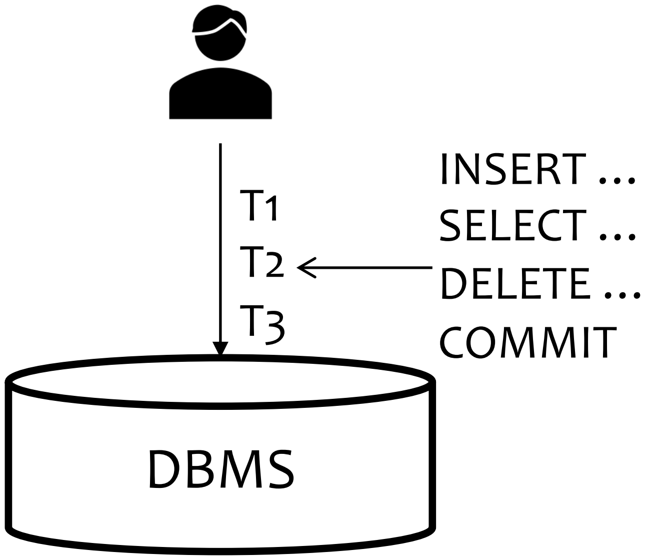
```
Txn 2:
SELECT Count(*) FROM Orders
SELECT Count(*) FROM 2021_Orders
```

- Possible Database-level inconsistency
- 2 count queries are now guaranteed to see a consistent state of the database records (though there are 2 possible "consistent" outputs)

  If T1; T2 => All 2021 records counted once in 2021_Orders

  If T2; T1 => All 2021 records counted once in Order

ACID: Durability



- Durability: Handles guarantees for *crashes after commit*
    - Guarantee: all modifications will persist
- Question to ponder: How can a DBMS guarantee durability?
    - Logging (Lecture 19)

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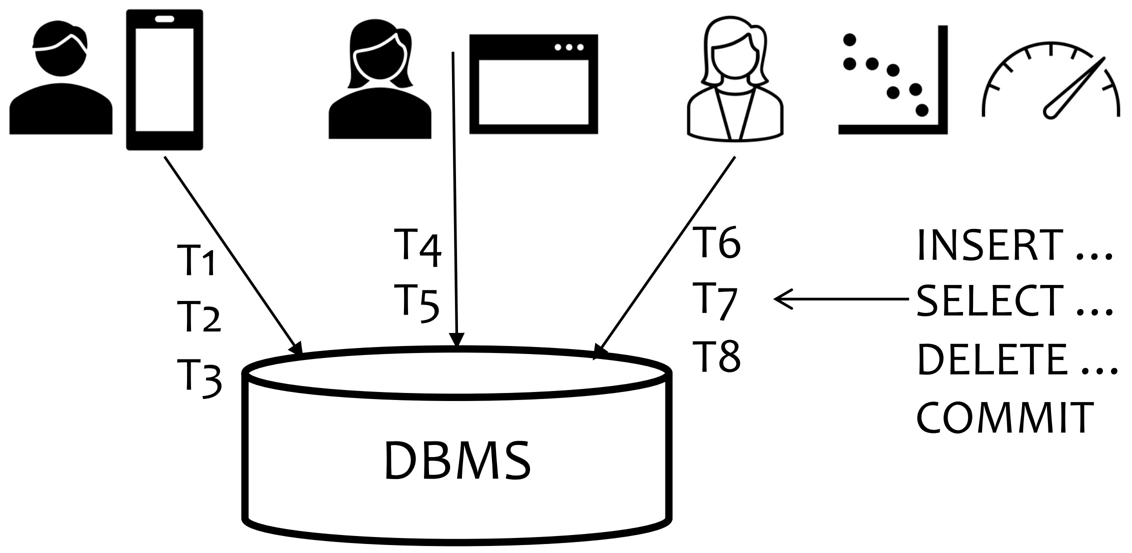
Problems With Serializability



- Serializability: A set of transactions **T** might run concurrently and interleave but final outcome is equivalent to ***some serial order*** of executing the transactions in **T**.
- Best consistency guarantee!
- Guaranteeing at the system-level has performance overheads.
- Q: Can users get weaker guarantees but at higher performance?

Weaker Isolation Levels

Stronger Consistency

Higher Overheads

Less Concurrency

[Isolation Levels in SQL Standard]()
Read Uncommitted
Read Committed
Repeatable Read
Serializable

Weaker Consistency

Lower Overheads

More Concurrency

```
SET TRANSACTION ISOLATION LEVEL REPEATABLE READ;
BEGIN TRANSACTION;
SELECT * FROM Order;
…
COMMIT TRANSACTION
```

How to handle two concurrent transactions with different isolation levels? → CS 448

READ UNCOMMITTED

- Can read *dirty data: an* item written by an uncommitted txn

```
Txn 1:
UPDATE Order
SET price = price + 5
WHERE oid = o1 || oid = o2
```

```
Txn 2: (READ UNCOMMITTED)
SELECT sum(price) FROM Order
WHERE oid = o1 || oid=o2
```

Txn 1	Txn 2
r:(o1,$20)	
w:(o1,$25)	
	r:(o1, $25)
	r:(o2, $40)
	commit
r:(o2,$40)	
w:(o2,$45)	
commit	

time

What can go wrong?

If Serializable would either read:

(i) o1=20 & o2=40; Sum=60; or

(ii) o1=25 & o2=45; Sum=70

- This can happen and no errors would be given.
- If approx. results OK, e.g., computing statistics, e.g., avg price, one can optimize perf. over consistency and pick read uncommitted

Note on Dirty Reads of The Same Transaction

- There is no such thing as dirty read of the same txn!
- Every (uncommitted) txn will read values it has written.
- That is not considered "dirty" even if it comes from uncommitted txn.

Suppose there is only 1 transaction running

```
BEGIN TRANSACTION
UPDATE Order
SET price = price + 5
WHERE oid = 01

SELECT price FROM Order
WHERE oid = 01;

COMMIT
```

Suppose sets $20->$25

Will read $25 (not considered a dirty read)

READ COMMITTED

- No dirty reads but *reads of the same item may not be repeatable*.

```
Txn 1:
UPDATE Order
SET price = price + 5
WHERE oid = o1 || oid = o2
```

```
Txn 2: (READ COMMITTED)
SELECT sum(price) FROM Order
WHERE oid = o1 || oid=o2

SELECT sum(price) FROM Order
WHERE oid = o1 || oid=o2
```

Txn 1	Txn 2
r:(o1,$20)	
w:(o1,$25)	
	r:(o1, $20)
	r:(o2, $40)
r:(o2,$40)	
w:(o2,$45)	
commit	
	r:(o1, $25)
	r:(o2, $45)
	commit

time

- This behavior is allowed.
- Still not serializable: serializable execution would give 60 or 70 twice.

REPEATABLE READ

- ➢ Repeatable reads but *phantom reads may appear*

```
Txn 1:
UPDATE Order SET price = price+5
WHERE oid = o1

INSERT INTO Order VALUES (o3, 10)
```

```
Txn 2: (REPEATABLE READ)
SELECT sum(price) FROM Order

SELECT sum(price) FROM Order
```

time	Txn 1	Txn 2	
	r:(o1,$20)		
	w:(o1,$25)		
		r:(o1, $20)	
		r:(o2, $40)	
	w:(o3,$10)		
	commit		
		r:(o1, $20)	
		r:(o2, $40)	
		$\boxed{\text{r:(o3, \$10)}}$	← phantom read
↓		commit	

- ➢ Suppose only o1 and o2 exist
- ➢ Still not serializable: serializable would give 60 or 75 twice.
- ➢ Caused due to inserts (or deletes) to a table

SERIALIZABLE

- All the three anomalies should be avoided:
  Dirty reads
  Unrepeatable reads
  Phantoms

- For any two txns T1 and T2:
  - Serial executions of T1 and T2 definitely prevent the three anomalies:
    T1 followed by T2 or T2 followed by T1

- Can we run T1 and T2 concurrently and achieve the same serial effect?

Summary of Isolation Levels

Isolation level/read 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

Example: Lowest Isolation Level To Set? (1)

- -- T1:
  INSERT INTO Order
  VALUES (03,10)
  COMMIT;

Isolation level	Possible anomalies for T1
READ UNCOMMITTED	Dirty reads
READ COMMITTED	Unrepeatable Reads
REPEATABLE READ	Phantoms
SERIALIZABLE	None

- Consider other possible concurrent transactions
  - Does not do any reads
  - No read concern
  - Lowest isolation level: read uncommitted

Example: Lowest Isolation Level To Set? (2)

- -- T1:

```
UPDATE Order
SET price = 25
WHERE oid = 01;
COMMIT;
```

Isolation level	Possible anomalies for T1
READ UNCOMMITTED	Dirty reads
READ COMMITTED	Unrepeatable Reads
REPEATABLE READ	Phantoms
SERIALIZABLE	None

- Consider other possible concurrent transactions
  - Does not read same item twice: reads Order only once
  - Only concern: transaction T2 might be updating oid=01 => may lead to dirty reads
  - Lowest isolation level: read committed

Example: Lowest Isolation Level To Set? (3)

- -- T1:
```
SELECT sum(price)
FROM Order;
COMMIT;
```

Isolation level	Possible anomalies for T1
READ UNCOMMITTED	Dirty reads
READ COMMITTED	Unrepeatable Reads
REPEATABLE READ	Phantoms
SERIALIZABLE	None

- Consider other possible concurrent transactions
  - Does not read same item twice: reads Order only once
  - Only concern: transaction T2 might be updating Order => may lead to dirty reads
  - Lowest isolation level: read committed

Example: Lowest Isolation Level To Set? (4)

➢ -- T1:

```
SELECT AVG(price)
FROM Order;

SELECT MAX(price)
FROM Order;
COMMIT;
```

Isolation level	Possible anomalies for T1
READ UNCOMMITTED	Dirty reads
READ COMMITTED	Unrepeatable Reads
REPEATABLE READ	Phantoms
SERIALIZABLE	None

➢ Consider other possible concurrent transactions

- Txn reads same tuples twice
- Concerns: transaction T2 might be inserting/updating/deleting a row to Order, i.e., reads many not be repeatable and phantoms might appear
- Lowest isolation level: serializable

Summary

1. Motivation For Transactions

   User's Perspective

2. ACID Properties

3. Different Levels of Isolation Beyond Serializability

Serializability:

System's Perspective (next lecture)

- Execution Histories
- Conflict Equivalence
- Checking For Conflict Equivalence