CSE 344

AUGUST 8TH

TRANSACTIONS

ADMINISTRIVIA

- **HW7 due today**
- **HW8 out already**
  - writing a DB application
  - puts together some different pieces
    - DB design, queries, transactions
  - **start early** (has many parts)
- **WQ7 due Monday**

TECH INTERVIEWS

- **Guest lecture in CSE 331**
  - Friday at 1:10pm in GUG 220

- **Topic is <u>tech interviews</u>**

CLASS OVERVIEW

Unit 1: Intro

Unit 2: Relational Data Models and Query Languages

Unit 3: Non-relational data

Unit 4: RDMBS internals and query optimization

Unit 5: Parallel query processing

Unit 6: DBMS usability, conceptual design

Unit 7: Transactions

- Locking and schedules (internals), SQL transactions
- Important for writing DB applications

APPLICATION

Examples

- Bank $$$ transfers
- Online shopping
- Signing up for classes

Work consists of a large set of tasks to complete for users

- Most tasks are independent of the others
- But some are not...
  - two users trying to withdraw from the same account at once
    - (if insufficient funds are available for both, only one is allowed)
  - users trying to buy the last copy of an item for sale
  - students trying to get the last spot in a class

CHALLENGES

Want to execute many apps concurrently

- All these apps read and write data to the same DB

Simple solution: only execute one task at a time

- What's the problem?

Want: multiple operations run simultaneously on the same DBMS

TRANSACTIONS

We use database transactions everyday

- Bank $$$ transfers
- Online shopping
- Signing up for classes

For this class, a transaction is a series of DB queries & updates

- Read / Write / Update / Delete / Insert
- Unit of work issued by a user that is independent from others
- (Note: we won't talk about rows much here...
  transactions are a broader concept than databases)

WHAT CAN GO WRONG?

Manager: balance budgets among projects

- Remove $10k from project A
- Add $7k to project B
- Add $3k to project C

CEO: check company's total balance

- `SELECT SUM(money) FROM budget;`

This is called a dirty / inconsistent read
aka a WRITE-READ conflict

WHAT CAN GO WRONG?

App 1:

```
SELECT inventory FROM products WHERE pid = 1
```

App 2:

```
UPDATE products SET inventory = 0 WHERE pid = 1
```

App 1:

```
SELECT inventory * price FROM products
WHERE pid = 1
```

This is known as an unrepeatable read
aka READ-WRITE conflict

WHAT CAN GO WRONG?

Account 1 = $100
Account 2 = $100
Total = $200

- App 1:
  - Set Account 1 = $200
  - Set Account 2 = $0
- App 2:
  - Set Account 2 = $200
  - Set Account 1 = $0
- At the end:
  - Total = $200

- App 1: Set Account 1 = $200
- App 2: Set Account 2 = $200
- App 1: Set Account 2 = $0
- App 2: Set Account 1 = $0
- At the end:
  - Total = $0

This is called the lost update aka WRITE-WRITE conflict

WHAT CAN GO WRONG?

Paying for Tuition...

- Fill up form with your mailing address
- Put in debit card number (because you don’t trust the gov’t)
- Click submit
- Screen shows money deducted from your account
- [Your browser crashes]

Lesson:

Changes to the database should be ALL or NOTHING

TRANSACTIONS

Collection of statements that are executed atomically (logically speaking)

```
BEGIN TRANSACTION
  [SQL statements]
COMMIT    or     ROLLBACK (=ABORT)
```

```
[single SQL statement]
```

If BEGIN… missing, then TXN consists of a single instruction

KNOW YOUR TRANSACTIONS: ACID

Atomic

- State shows either all the effects of txn, or none of them

Consistent

- Txn moves from a DBMS state where integrity holds, to another where integrity holds
  - remember integrity constraints?

Isolated

- Effect of txns is the same as txns running one after another (i.e., looks like batch mode)

Durable

- Once a txn has committed, its effects remain in the database

ATOMIC

Definition: A transaction is ATOMIC if all its updates must happen or not at all.

Example: move $100 from A to B

- ```
  UPDATE accounts SET bal = bal – 100
  WHERE acct = A;
  ```
- ```
  UPDATE accounts SET bal = bal + 100
  WHERE acct = B;
  ```

- ```
  BEGIN TRANSACTION;
  UPDATE accounts SET bal = bal – 100 WHERE acct = A;
  UPDATE accounts SET bal = bal + 100 WHERE acct = B;
  COMMIT;
  ```
  ```

ISOLATED

- **Definition:**
  - An execution ensures that transactions are isolated, if the effect of each transaction is as if it were the only transaction running on the system.

CONSISTENT

Recall: integrity constraints govern how values in tables are related to each other

- Can be enforced by the DBMS, or ensured by the app

How consistency is achieved by the app:

- App programmer ensures that txns only takes a consistent DB state to another consistent state
- DB makes sure that txns are executed atomically

Can defer checking the validity of constraints until the end of a transaction

DURABLE

A transaction is durable if its effects continue to exist after the transaction and even after the program has terminated

How?

- By writing to disk
  - or multiple disks
- By writing to memory of multiple servers
  - geographically separated

ROLLBACK TRANSACTIONS

If the app gets to a state where it cannot complete the transaction successfully, execute ROLLBACK

The DB returns to the state prior to the transaction

- remove the effects of any WRITEs that occurred

ACID

Atomic

Consistent

Isolated

Durable

Again: by default each statement is its own txn

- Unless auto-commit is off then each statement starts a new txn

SCHEDULES

A schedule is a sequence of interleaved actions from all transactions

SERIAL SCHEDULE

A *serial schedule* is one in which transactions are executed one after the other, in some sequential order

Fact: nothing can go wrong if the system executes txns serially

- (rather, whatever does go wrong is the app's fault)
- But DBMS don't do that because we want better overall system performance

EXAMPLE

A and B are elements in the database
t and s are variables in txn source code

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)

EXAMPLE OF A (SERIAL) SCHEDULE

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

Time ↓

Starting with A=0 B=0

End with A=200 B=200

ANOTHER SERIAL SCHEDULE

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

Time ↓

Starting with A=0 B=0

End with A=100 B=100

SERIALIZABLE SCHEDULE

A schedule is serializable if it is equivalent to a serial schedule

Not necessarily serial

BUT equally good from app's perspective

A SERIALIZABLE SCHEDULE

Starting with A=0 B=0

End with A=200 B=200

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

This is a serializable schedule.
This is NOT a serial schedule

A NON-SERIALIZABLE SCHEDULE

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

Starting with A=0 B=0

End with A=200 B=100

HOW DO WE KNOW IF A SCHEDULE IS SERIALIZABLE?

Notation:

T_1: $r_1(A)$; $w_1(A)$; $r_1(B)$; $w_1(B)$
T_2: $r_2(A)$; $w_2(A)$; $r_2(B)$; $w_2(B)$

Key Idea: Focus on *conflicting* operations
(I.e., where changing order can change result)

CONFLICTS

Write-Read – WR

Read-Write – RW

Write-Write – WW

Read-Read?

CONFLICT SERIALIZABILITY

Conflicts: (i.e., swapping will change program behavior)

Two actions by same transaction T_i:

$r_i(X); w_i(Y)$

Two writes by T_i, T_j to same element

$w_i(X); w_j(X)$

Read/write by T_i, T_j to same element

$w_i(X); r_j(X)$

$r_i(X); w_j(X)$

CONFLICT SERIALIZABILITY

A schedule is ***conflict serializable*** if it can be transformed into a serial schedule by a series of swaps of adjacent non-conflicting actions

Every conflict-serializable schedule is serializable

The converse is not true (why?)

CONFLICT SERIALIZABILITY

Example:

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

CONFLICT SERIALIZABILITY

Example:

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

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

CONFLICT SERIALIZABILITY

Example:

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

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

CONFLICT SERIALIZABILITY

Example:

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

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

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

CONFLICT SERIALIZABILITY

Example:

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

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

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

....

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

TESTING FOR CONFLICT-SERIALIZABILITY

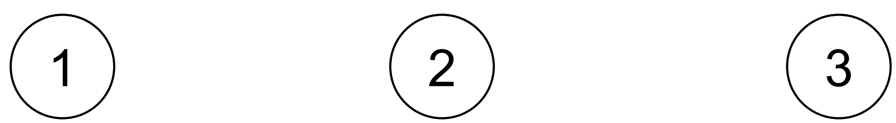
Precedence graph:

- **A node for each transaction T_i,**
- **An edge from T_i to T_j whenever an action in T_i conflicts with, and comes before an action in T_j**

The schedule is conflict-serializable iff the precedence graph is acyclic

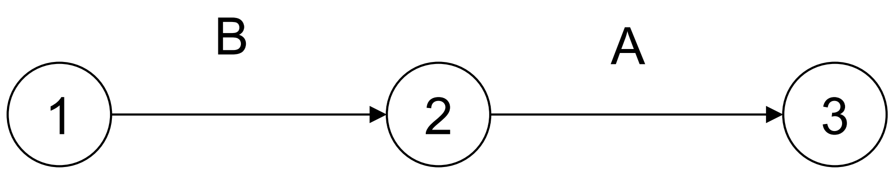
EXAMPLE 1

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



EXAMPLE 1

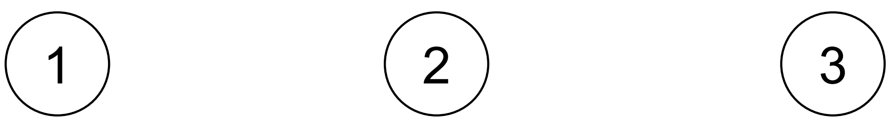
$$r_2(A); r_1(B); w_2(A); r_3(A); w_1(B); w_3(A); r_2(B); w_2(B)$$



This schedule is conflict-serializable

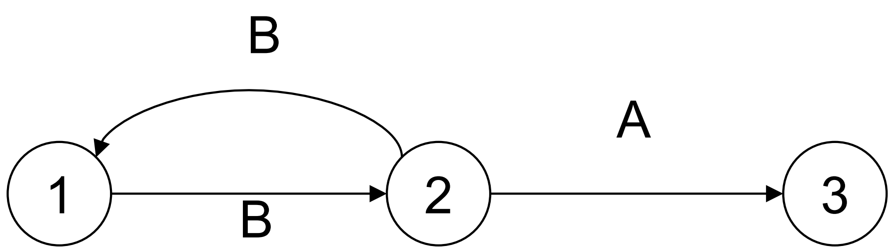
EXAMPLE 2

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



EXAMPLE 2

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



This schedule is NOT conflict-serializable