CS 133: Databases

Fall 2019
Lec 16 – 11/05
Transactions

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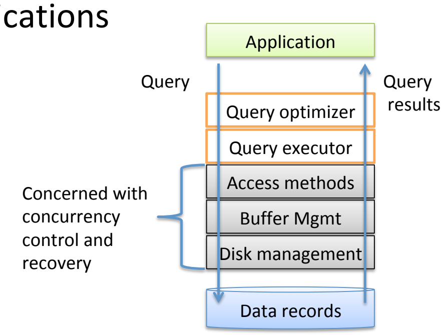
Administrivia

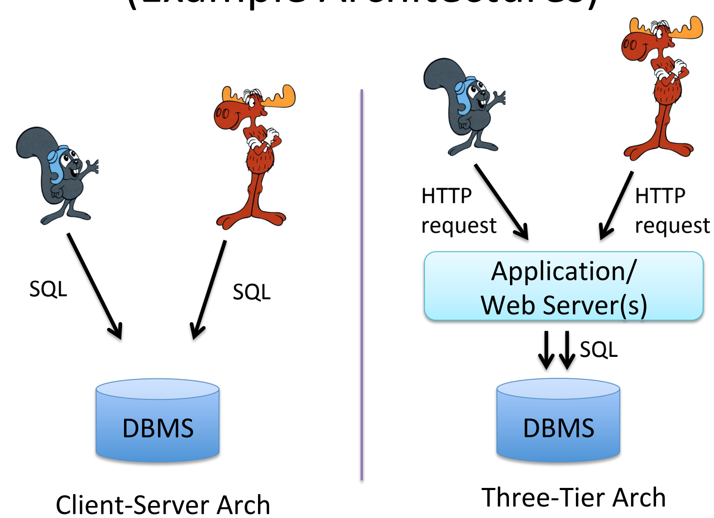
- Labs:
  - Lab 3 due tomorrow midnight
  - Lab 4 starts Thursday after class
- Reminder: new additional office hour Thursdays
  - Check for me in Beckman B102 if not in B105

Goals for Today

- Understand the challenges that *concurrent access* to a DBMS pose for data consistency
- Reason about which actions on data can *conflict* and the possible implications



Querying a DBMS (Example Architectures)



Concurrent execution

- ***Why not just run queries one at a time?***

- Concurrent execution is essential for good DBMS performance

These two can happen at the same time!

Reading a page from disk

Evaluating WHERE condition(s) on page in buffer pool

Important: keep the CPU busy while slow disk accesses are occurring

Note: A user's "program" may carry out many operations on the data retrieved from the database, **but the DBMS is only concerned about what data is *read* and *written* from/to the database**

Transactions

- **Transaction** (xact): an atomic *sequence* of read/write *actions* on the database

- Moves the database from one **consistent** state to another

consistent state 1 —**transaction**→ consistent state 2

- Final action of xact is **commit** or **abort**

Example: Transferring Money

checking: $200
savings: $1000 —**transaction**→ checking: $300
savings: $900

- In this example, ***consistency*** is based on knowledge of banking semantics

- In general, up to the writer of the transaction to ensure a transaction preserves consistency
  - DBMS provides (limited) automatic enforcement, via specified **integrity constraints**
    - e.g., account balances must be >= 0

Example: Transaction in SQL

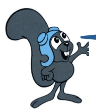
```
BEGIN;     --BEGIN TRANSACTION

 UPDATE accounts
   SET balance = balance - 100.00
   WHERE account_num = SavingsAccountNum
       AND user_id= 18;


 UPDATE accounts
   SET balance = balance + 100.00
   WHERE account_num = CheckingAccountNum
       AND user_id= 18;

 COMMIT;     --COMMIT WORK
```

Concurrency in a DBMS



I should be able to submit *transactions*, and can think of each transaction as executing by itself

- Concurrency is achieved by the DBMS, which **interleaves *actions*** (reads/writes of DB "objects") of multiple transactions

- *Issues:*
  - Effect of *interleaving* transactions
  - System *crashes*

Example: Concurrency Outcomes

- Consider two transactions (*xacts*):

T1:	T2:
BEGIN	*BEGIN*
A=A+100	A=1.06*A
B=B-100	B=1.06*B
END	*END*

We'll often use letters like A and B to refer to database "objects"

T1 transfers $100 from account B to A
T2 credits both accounts with 6% interest

- Assume accounts A and B initially each contain $1000
  - Q. What is a legal outcome for A and B after running T1 and T2?
    A+B should add up to $2000 *1.06 = $2120

If T1 and T2 submitted at the same time, there is **no guarantee that T1 will execute before T2** or vice-versa.

Consistency: the net effect *must* be **equivalent to** these two transactions running serially in ***some order***.

Example: Concurrency Outcomes

- Consider a possible **interleaved** *schedule*:

T1:	A=A+100,		B=B-100	
T2:		A=1.06*A,		B=1.06*B

This is OK (result same as T1;T2)

- But what about:

T1:	A=A+100,		B=B-100
T2:		A=1.06*A, B=1.06*B	

Result: A=1166, B=960; A+B = 2126 → Bank loses $6!

- **The DBMS's view of the second schedule:**

T1:	R(A), W(A),		R(B), W(B)
T2:		R(A), W(A), R(B), W(B)	

ACID: Transaction Atomicity

- A transaction ends in one of two ways:
  - It ***commits*** after completing all its actions
  - or it could ***abort*** (self-inflicted or by the DBMS) *after executing some actions*

- User expectation: **atomic transactions**
  - a transaction must either execute **all its actions**, or **not execute any actions at all**

Wait, what?!
What if the xact already started making changes to the database?

Later: logging and recovery

ACID: Transaction Consistency

- Consistency: the data in the DBMS is accurate in **modeling the real world**, follows appropriate integrity constraints

The user must ensure a transaction maintains consistency!

- *DBMS Guarantee*:
  if DBMS is consistent before transaction,
  it will still be consistent after the transaction completes

- DBMS checks integrity constraints and if they fail, the transaction **rolls back** (i.e., is ***aborted***)

ACID: Transaction Isolation

- Transactions must be protected from concurrent access

- **Isolation**: each xact executes as if it was running **by itself**
  - Concurrency is achieved by DBMS, which interleaves actions (*reads and writes of DB objects*) of multiple transactions

- Many techniques for isolation, two basic categories:
  - **Pessimistic** – don't let problems arise in the first place

  - **Optimistic** – assume conflicts are rare, deal with them *after* they happen

Image: http://www.clker.com/cliparts/b/W/I/b/F/8/half-full-half-empty-md.png

ACID: Transaction Durability (Recovering From a Crash)

- **Failure** scenarios
  - System crash
    - Data/updates in memory are lost, hard disk is okay
    - This is the case we will look at when we cover **recovery**
  - Hard Disk crash
    - ☹ need backups, RAID and data replication can help

- **Durability**: all updates from committed transactions and *only those updates* will be reflected in the database

A.C.I.D. Properties of Transactions

Atomicity:
All actions in the transaction happen, or none happen.

Consistency:
If each transaction is consistent, and the DB starts consistent, it ends up consistent.

Isolation:
Execution of one transaction is isolated from that of all others.

Durability:
If a transaction commits, its effects persist.

Concurrency Control

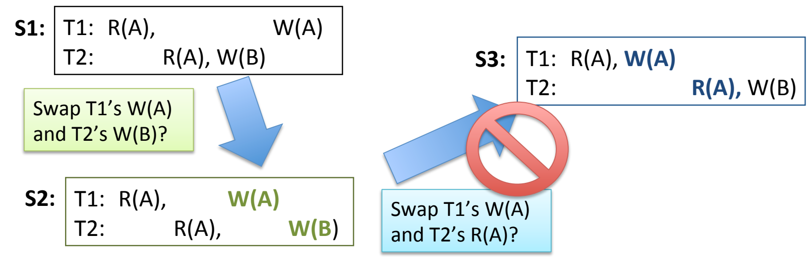
- *Now*: focus on the "I" (isolation) part
- *Later*: when we talk about recovery, we'll get to the "A" (atomicity) and "D" (durability)

What about "C" ??

If the system can achieve guarantees for A, I, and D, then we get C for free!

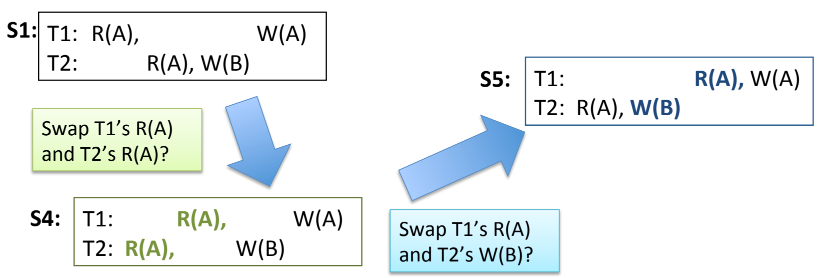
Serial and Equivalent Schedules

- ***Serial schedule:*** A schedule that **does not interleave** the actions of different transactions.
  - i.e., transactions run *serially* (one at a time)
- ***Equivalent schedules***: Given two schedules… for any database state, **the effect** (on the set of objects in the database) **and output** of executing the first schedule **is identical** to the effect of executing the second schedule.



Serializable Schedules

- ***Serializable schedule***: A schedule that **is equivalent to some serial execution** of the transactions.
  - *Intuition*: with a serializable schedule you only see things that could happen in situations where you were running transactions one-at-a-time.



Try Exercise 2

(a) yes, both T2, T1 and T1, T2

(b) yes, only T2, T1

(c) no

All About *Conflict*

- **Conflicting actions**
  - Two actions from different transactions **on the same data objects** conflict if **at least one of the actions is a write**

Order of conflicting actions matters!
If T2's R(A) precedes T1's W(A),
then conceptually **T2 should precede T1**

- Two schedules are **conflict equivalent** iff:
  - They involve the same actions of the same transactions
  - Every pair of conflicting actions is **ordered the same way**
- Schedule *S* is **conflict serializable** if *S* is conflict equivalent to some serial schedule

Note: a pair of conflicting actions does not always mean a "problem" (or that we care)

Anomalies from Interleaved Execution

Unrepeatable Reads (RW conflict):

T1:	R(A),		R(A), W(A), Commit
T2:		R(A), W(A), Commit	

Reading Uncommitted Data ("dirty reads", WR conflict):

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

Overwriting Uncommitted Data: ("lost update", WW conflict)

T1:	W(A),		W(B), Commit
T2:		W(A), W(B), Commit	

Precedence Graph

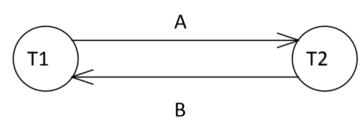
Also called a *dependency* graph

- Node = transaction
- Directed edges:
  - Edge from T_i to T_j if an action in T_i *precedes and conflicts with* an action in T_j
- **Theorem**: Schedule is **conflict serializable** if and only if its precedence graph is *acyclic*

Example: Bank Concurrency Schedule

- A schedule that is ***not*** conflict serializable (earlier banking example):

T1:	R(A), W(A),		R(B), W(B)
T2:		R(A), W(A), R(B), W(B)	



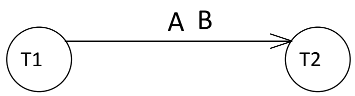
Precedence graph

- The cycle in the graph reveals the problem: The output of T1 depends on T2, and vice-versa

Example: Bank Concurrency Schedule

- A schedule that IS conflict serializable:

T1:	R(A), W(A),		R(B), W(B),	
T2:		R(A), W(A),		R(B), W(B)



Precedence graph

No cycle here!

Try Exercise 3

(a)
T1 R(A), T2 W(A)
T2 R(A), T1 W(A)
T1 W(A) T2 W(A)
not conflict serializable

(b)
T1 R(A) T3 W(A)
T2 R(B), T1 W(B)
T2 W(B), T1 R(B)
T2 W(B), T1 W(B)
is conflict serializable

Notes on Conflict Serializability

- Conflict Serializability does not allow all schedules that you would consider correct
  - This is because it is **strictly *syntactic***; it doesn't consider the meanings of the operations or the data.

T1:	R(A), A=A-50,W(A)		**R(B), B=B+50,W(B)**	
T2:		**R(B), B=B-10,W(B)**		R(A), A=A+10,W(A)

Same result as the serial schedule T1, T2 (addition commutative)

- In practice, conflict serializability is what gets used, because it can be done efficiently
  - Note: in order to allow more concurrency, some special cases do get implemented, such as for travel reservations, etc.