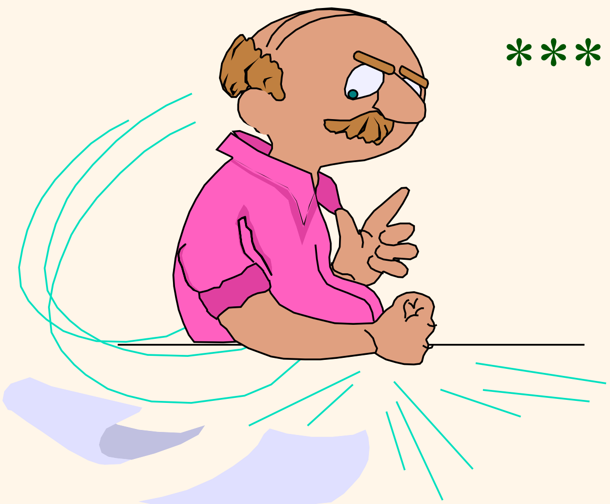
Introduction to Data Management



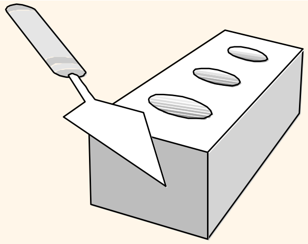
*** The "Flipped" Edition ***

Lecture #26
(**Transactions**:
The Final Frontier…!)

Instructor: Mike Carey
mjcarey@ics.uci.edu

Announcements

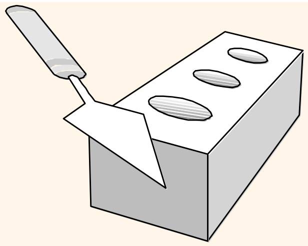
- HW wrap-up:
  - HW #8 is currently in flight!
  - Due **Wednesday** at **6 PM!** (Or Thursday at 6 PM if late)
- A note on Piazza points:
  - Pay attention to Piazza – don't miss the 1-point "final"! ☺
- Endterm exam: **Fri, Dec 3, in person, as usual!!!**
    - Same logistics as Midterms 1 & 2 (Gradescope + cheat sheet)
    - **Non**-cumulative (see Wiki syllabus for the official scope)
  - A sample exam and solution from the past are available
  - ***Indexes, physical design, NoSQL/JSON, DS topics, transactions, ...***
- Final quiz and discussion sessions:
  - Quiz 10 will be available by Monday evening, and we'll also offer Endterm reviewing in this week's discussion sessions



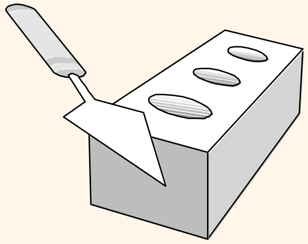
Transactions

- Concurrent execution of user programs is essential for good DBMS performance (and wait times).
  - Disk I/Os are slow, so DBMSs keep the CPU cores busy by running multiple concurrent requests.
- A program may perform many operations on data from the DB, but the DBMS only cares about what's being read (R) and written (W) from/to the DB.
- A ***transaction*** is the DBMS's view of a user program:
  - It is seen as a sequence of database R's and W's.
  - The targets of the R's and W's are records (or pages).

The **ACID** Properties



- **A**tomicity: Each transaction is all or nothing.
  - No worries about partial effects (if failures) and cleanup!
- **C**onsistency: Each transaction moves the database from one consistent state to another one.
  - This is largely the application builder's responsibility…
- **I**solation: Each transaction can be written as if it's the only transaction in existence.
  - No concurrency worries while building applications!
- **D**urability: Once a transaction has committed, its effects will not be lost.
  - Application code doesn't have to worry about data loss!



Concurrency in a DBMS

- Users run **transactions** and can think of each one as executing ***all by itself***.
  - Concurrency is handled by the DBMS, which allows the actions (R's & W's) of various transactions to interleave.
  - Each transaction must leave the DB in a consistent state if it was consistent when the transaction started.
    - The DBMS may enforce some ICs, depending on the constraints declared in CREATE TABLE statements. (CHECK, PK, FK, ...)
    - But the DBMS does *not* understand the semantics of the data! (It doesn't know how interest on a bank account is computed.)
- ***Issues****:* Effects of *interleaving* and effects of *crashes*.

Atomicity of Transactions

- A transaction may *commit* after completing all of its actions, or it might *abort* (or might *be* aborted) after executing some of its actions.
  - Could violate a constraint, encounter some other error, be caught in a crash, or be picked to resolve a deadlock.
- The DBMS guarantees that transactions are *atomic.* A user can think of a Xact as doing **all** of its actions, in one step, or else executing **none** of its actions.
  - The DBMS *logs* all actions so that it can *undo* the actions of any aborted transactions.

Example

- Consider two transactions (*Xacts*):

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

- E.g., T1 is transferring $100 from bank account B to account A, while T2 is crediting both with 6% interest.
- No guarantee that T1 will execute before T2, or vice-versa, if both arrive together. The net effect *must* be *equivalent* to running them serially in some (either!) order.

A Quick Aside on "A" & "B"

- What *are* these two transactions, really?

```
T1:  START TRANSACTION;    -- needed to couple the statements
             UPDATE Acct SET bal = bal + 100 WHERE acct_no = 101;
             UPDATE Acct SET bal = bal – 100 WHERE acct_no = 201;
       COMMIT;

T2:  START TRANSACTION;    -- not needed if just one statement
             UPDATE Acct SET bal = bal * 1.06 WHERE acct_type = 'SV';
       COMMIT;
```

- Again, T1 is transferring $100 from account B (201) to account A (101). T2 is giving all accounts their 6% interest payment.

Example (Cont'd.)

- Consider a possible interleaving (*schedule*):

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

- That is OK. But what happens if:

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

←*Too much interest!)*

- The DBMSs view of the second schedule:

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

Scheduling Transactions (*Defn's.*)

- *Serial schedule:* Any schedule that does not interleave the actions of different transactions.
- *Equivalent schedules*: If for any database state, the effect (on the DB) of executing the first schedule is identical to the effect of the second schedule.
- *Serializable schedule*: A schedule that is equivalent to ***some*** (*any!*) serial execution of the transactions.

→ If each transaction preserves consistency, then *every* serializable schedule preserves consistency!

Anomalies with Interleaved Execution

❖ Reading Uncommitted Data ("dirty reads"):

T3:	R(A), **W(A),**		R(B), W(B), **Abort**
T4:		**R(A), W(A),** C	

❖ Unrepeatable Reads:

T5:	**R(A),**		**R(A),** W(A), C
T6:		R(A), **W(A),** C	

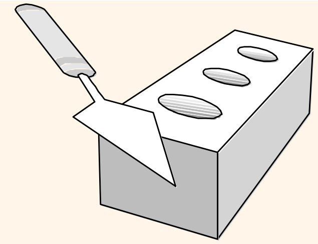
Anomalies (Continued)

- Overwriting Uncommitted Data:

T7:	W(A),		**W(B),**	C
T8:		**W(A),** W(B), C		

(Results are a "must have been concurrent!" mix of T7's & T8's writes – B from T7, and A from T8, yet both transactions wrote both A and B.)

Lock-Based Concurrency Control



- *Strict Two-phase Locking (**2PL**) Protocol*:
  - Each Xact acquires an S (*shared*) lock on an object before reading it, and an X (*exclusive*) lock on it before writing.
  - All of the locks held by a transaction are released only when the transaction completes.
  - *Note*: If a Xact holds an X lock on an object, no other Xact can get a lock (S or X) on that object – they must wait.
- Strict 2PL allows only serializable schedules.
  - And additionally, it simplifies transaction aborts!

2PL Prevents the Anomalies

- Reading Uncommitted Data (WR Conflicts, a.k.a. “dirty reads”):

T3:	R(A), **W(A)**,			R(B), W(B), **Abort**
T4:			**~~R(A)~~, W(A)**, C	

(T4 will be blocked until after T3.)

- Unrepeatable Reads (RW Conflicts):

T5:	**R(A)**,			**R(A)**, W(A), C
T6:		R(A), **~~W(A)~~**, C		

(T6 will be blocked and later aborted, due to a deadlock, after T5.)

2PL & Anomalies (Continued)

- Overwriting Uncommitted Data (WW Conflicts):

T7:	W(A),		**W(B)**, C
T8:		**~~W(A)~~**, W(B), C	

(T8 will be blocked until after T7.)

(Now results will no longer be a "must have been concurrent!" intermingling of T7's & **T8's** writes…)

Aborting a Transaction

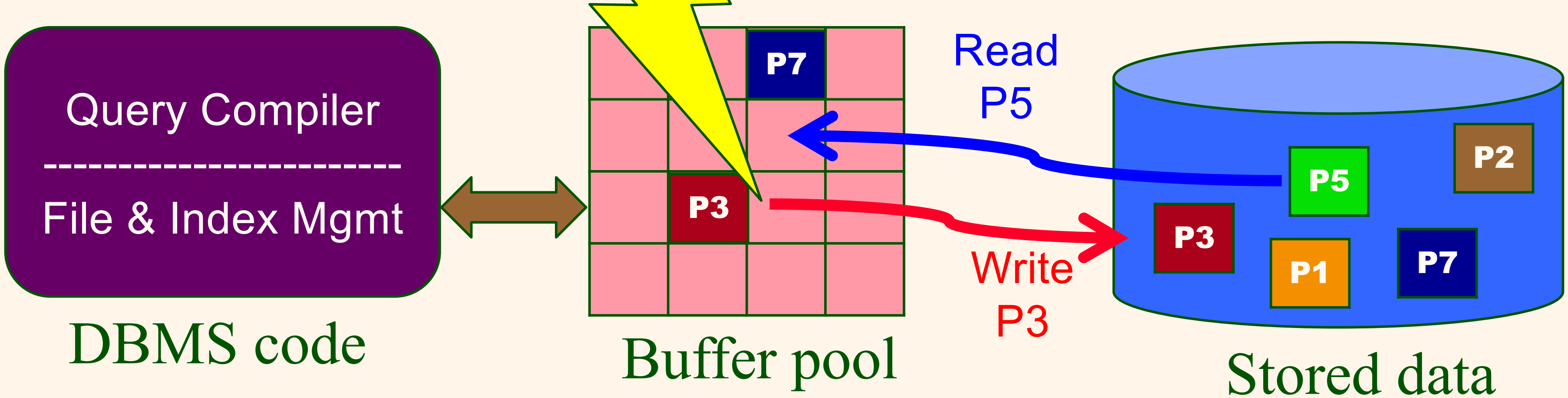
- If transaction *Ti* aborts, all its actions must be undone.
  - And, if some *Tj* already read a value last written by *Ti*, *Tj* must also be aborted! ("If I tell you, I'll have to kill you..."☺)
- Most systems avoid such *cascading aborts* by releasing a transaction's locks only at *commit time*.
  - If *Ti* writes an object, *Tj* can read it only after *Ti* commits.
- In order to *undo* the actions of an aborted transaction, the DBMS keeps a *log* where every write is recorded.
  - Also used to recover from system crashes: active Xacts at crash time are aborted when the DBMS comes back up.

The Transaction Log

- The following actions are recorded in the log:
  - *Ti writes an object*: record its old and new values.
    - Log record must go to disk *before* the changed page – hence the name *write-ahead logging* (WAL).
  - *Ti commits/aborts*: write a log record noting the outcome.
- All log related activities (and all concurrency-related activities, like locking) are ***transparently*** taken care of by the DBMS.

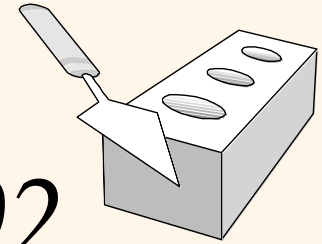
Reminder: Disks and Files

- DBMSs store all information on disk.
- This has major implications for DBMS design!
  - READ: transfer data from disk to main memory (RAM).
  - WRITE: transfer data from RAM to disk.
  - Both are high-cost operations, relative to in-memory operations, so must be considered carefully!



Recovering From a Crash

- A three-phase recovery algorithm (***Aries***):
  - *Analysis*: Scan log (starting from most recent *checkpoint*) to identify the Xacts that were active, and the pages that were "dirty" in the buffer pool, when the system crashed.
  - *Redo*: Redo any updates to dirty pages to ensure that all logged updates were carried out and made it to disk. (*Establishes the state from which to recover.*)
  - *Undo*: Undo the writes of all Xacts that were active at the crash (restoring the *before value* of each update from its log record), working backwards through the log, to abort any partially-completed transactions.



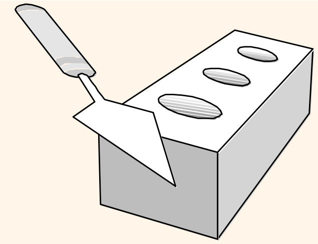
Support for Transactions in SQL-92

- A transaction is *automatically* started whenever a statement accesses or modifies the database
  - SELECT, UPDATE, CREATE TABLE, INSERT, ...
  - Multi-statement transactions also supported
- A transaction can be terminated by
  - A COMMIT statement
  - A ROLLBACK statement (SQL-speak for **abort**)
- Each transaction runs under a combination of an access mode and an isolation level

Transactions in SQL-92 *(Cont'd.)*

- Access mode – controls what the transaction can potentially do to the database:
  - READ ONLY: not permitted to modify the DB
  - READ WRITE (*default*): allowed to modify the DB
- Isolation level – controls the transaction's exposure to other (concurrent) transactions:
  - READ UNCOMMITTED: Can see "dirty" data!
  - READ COMMITTED: Won't ever see dirty data.
  - REPEATABLE READ: Re-reads get same result.
  - SERIALIZABLE: No concurrency worries!

Increasing isolation



Which Isolation Level is for Me?

- An application-“controllable” tradeoff:
  - Consistency *vs.* performance (concurrency)
  - Warning: It ***will*** affect your programming model!
- Things to watch out for:
  - Default consistency level is DBMS engine-specific
  - Some engines may not support all levels
  - Default consistency level often not SERIALIZABLE
- You may also hear about “snapshot isolation”
  - DBMS keeps multiple versions of data
  - Transactions see versions as of when they started

*Remember the **ACID** Properties!*

- **Atomicity**: Each transaction is *all or nothing*.
  - No worries about partial effects (if failures) and cleanup.
- **Consistency**: Each transaction moves the database from one *consistent state* to another one.
  - This is largely the application builder's responsibility.
- **Isolation**: Each transaction can be written as if it's the *only transaction* in existence (*if so desired*).
  - Minimize concurrency worries when building applications.
- **Durability**: Once a transaction has committed, its *effects will not be lost*.
  - Application code needn't worry about data loss.

*A Few Quick **NoSQL** Xact Notes*

- For transactions, NoSQL systems tend to be limited to ***record-level*** transactions (in order to ***scale*** on a cluster)
- As a result, one sometimes considers an application's transactional needs when picking a schema (deciding what to "nest") for it, sigh!

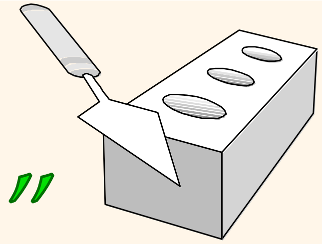
You Made It!

Topic Coverage and Exam Schedule

Syllabus

Topic	Reading (Required!)
Databases and DB Systems	Ch. 1
Entity-Relationship (E-R) Data Model	Ch. 6.1-6.5, 6.8-6.9
Relational Data Model	Ch. 2.1-2.4, 3.1-3.2
E-R to Relational Translation	Ch. 6.6-6.7
Relational Design Theory	Ch. 7.1-7.4.2
Midterm Exam 1	***Fri, Oct 22*** (during lecture time)
Relational Algebra	Ch. 2.5-2.7
Relational Calculus	Wikipedia: Tuple relational calculus
SQL Basics (SPJ and Nested Queries)	Ch. 3.3-3.5
SQL Analytics: Aggregation, Nulls, and Outer Joins	Ch. 3.6-3.9, 4.1
Advanced SQL: Constraints, Triggers, Views, and Security	Ch. 4.2, 4.4-4.5, 4.7
Midterm Exam 2	***Mon, Nov 15*** (during lecture time)
Storage	Ch. 12.1-12.4, 12.6-12.7
Indexing	Ch. 14.1-14.4, 14.5
Physical DB Design	Ch. 14.6-14.7, 15.1-15.3, 15.5.3
Semistructured Data Management (*a.k.a.* NoSQL)	Ch. 8.1, AsterixDB SQL++ Primer, Couchbase SQL++ Book
Data Science 1: Advanced SQL Analytics	Ch. 5.5, 11.3
Data Science 2: Notebooks, Dataframes, and Python/Pandas	Lecture notes and Jupyter notebook
Basics of Transactions	Ch. 4.3, Ch. 17
Endterm Exam	***Fri, Dec 3*** (during lecture time)

"But Wait!.... I Need More…!!!"



- **CS122A** has just given you an "outside" view of database management systems.
- **CS122B** is available to give you a "programmer's" view – with an emphasis on data-centric web applications.
- **CS122C** (*a.k.a.* CS222 lite) is available to give you an "insider's" (engine developer's) view of DB systems.
- **CS122D** goes "Beyond SQL Data Management"– NoSQL, Graph DBs, Hadoop/Spark, and more.
- **CS223** is available for learning all about transactions and distributed databases.
- **CS199** (independent project work) is also a possible avenue for gaining further experience.