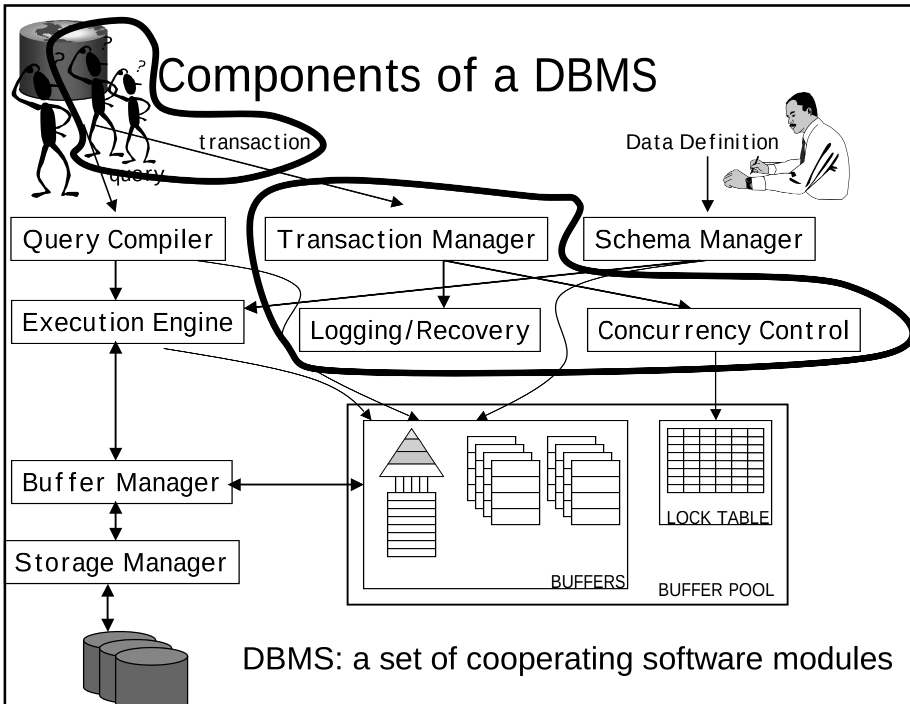
Transaction Management Overview

15-415, Spring 2003, Lecture 21
R & G Chapter 16

There are three side effects of acid.
Enhanced long term memory,
decreased short term memory,
and I forget the third.
- Timothy Leary

Components of a DBMS



DBMS: a set of cooperating software modules

Concurrency Control & Recovery

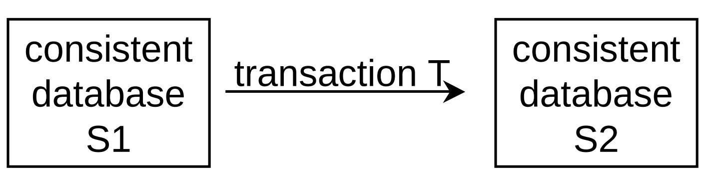
- **Very valuable properties of DBMSs**
  - without these, DBMSs would be much less useful
- **Based on concept of transactions with ACID properties**
- **Remainder of the lectures discuss these issues**

Definitions

- Database
  - a fixed set of named resources (entities)
- Consistency constraints
  - must be true for DB to be considered consistent
  - **Example:**

    Σ(ACCT-BALS) = Σ(ASSETS)

    ACCT-BAL >= 0
- Key point



Statement of Problem

- **Concurrent execution of independent transactions**
  - utilization/throughput (“hide” waiting for I/Os.)
  - response time
  - fairness
- **Example:**

	T1:	T2:
t0:	tmp1 := read(X)	
t1:		tmp2 := read(X)
t2:	tmp1 := tmp1 – 20	
t3:		tmp2 := tmp2 + 10
t4:	write tmp1 into X	
t5:		write tmp2 into X

Statement of problem (cont.)

- **Arbitrary interleaving can lead to**
  - Temporary inconsistency (ok, unavoidable)
  - “Permanent” inconsistency
- **Need correctness criteria:**
  - **schedule**: a particular action sequencing for a set of transactions
  - **consistent schedule**: each transaction sees consistent view of DB

Concurrent Execution & Transactions

- **Concurrent execution essential for good performance.**
  - Because disk accesses are frequent, and relatively slow, it is important to keep the CPU humming by working on several user programs concurrently.
- **A program may carry out many operations on the data retrieved from the database, but the DBMS is only concerned about what data is read/written from/to the database.**
- ***transaction*** **- DBMS's abstract view of a user program:**
  - a sequence of reads and writes.

Goal: The ACID properties

- **A tomicity: All actions in the Xact happen, or none happen.**
- **C onsistency: If each Xact is consistent, and the DB starts consistent, it ends up consistent.**
- **I solation: Execution of one Xact is isolated from that of other Xacts.**
- **D urability: If a Xact commits, its effects persist.**

Atomicity of Transactions

- **A transaction might *commit* after completing all its actions, or it could *abort* (or be aborted by the DBMS) after executing some actions.**
- **A very important property guaranteed by the DBMS for all transactions is that they are *atomic*. That is, a user can think of a Xact as always either executing all its actions, or not executing any actions at all.**
  – One approach: DBMS *logs* all actions so that it can *undo* the actions of aborted transactions.
  – Another approach: *Shadow Pages*
  – Logs won because of need for audit trail and for efficiency reasons.

Transaction Consistency

- **"Consistency" - data in DBMS is accurate in modeling real world, follows integrity constraints**
- **User must ensure transaction consistent by itself**
  – I.e., if DBMS consistent before Xact, it will be after also
- **System checks ICs and if they fail, the transaction rolls back (i.e., is aborted).**
  – DBMS enforces some ICs, depending on the ICs declared in CREATE TABLE statements.
  – Beyond this, DBMS does not understand the semantics of the data. (e.g., it does not understand how the interest on a bank account is computed).

Isolation (Concurrency)

- **Users submit transactions, and**
- **Each transaction executes <u>as if</u> it was running by itself.**
  - Concurrency is achieved by DBMS, which interleaves actions (reads/writes of DB objects) of various transactions.
- **We will formalize this notion shortly.**
- **Many techniques have been developed. Fall into two basic categories:**
  - Pessimistic – don't let problems arise in the first place
  - Optimistic – assume conflicts are rare, deal with them *after* they happen.

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

- 1st xact transfers $100 from B's account to A's
- 2nd credits both accounts with 6% interest.
- Assume at first A and B each have $1000. What are the <u>legal outcomes</u> of running T1 and T2???
  - $2000 *1.06 = $2120
- There is no guarantee that T1 will execute before T2 or vice-versa, if both are submitted together. But, the net effect *must* be equivalent to these two transactions running serially in some order.

Example (Contd.)

- **Legal outcomes: A=1166,B=954 or A=1160,B=960**
- **Consider a possible interleaved *schedule*:**

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

❖ This is OK (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)	

Scheduling Transactions

- ***Serial schedule:*** **Schedule that does not interleave the actions of different transactions.**
- ***Equivalent schedules*:** **For any database state, the effect (on the set of objects in the database) of executing the first schedule is identical to the effect of executing the second schedule.**
- ***Serializable schedule*:** **A schedule that is equivalent to some serial execution of the transactions.**

  (Note: If each transaction preserves consistency, every serializable schedule preserves consistency.)

Anomalies with Interleaved Execution

- **Reading Uncommitted Data (WR Conflicts, "dirty reads"):**

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

- **Unrepeatable Reads (RW Conflicts):**

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

Anomalies (Continued)

- **Overwriting Uncommitted Data (WW Conflicts):**

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

Lock-Based Concurrency Control

- **Here's a simple way to allow concurrency but avoid the anomalies just descibed…**
- ***Strict Two-phase Locking (Strict 2PL) Protocol*:**
  - Each Xact must obtain a S (*shared*) lock on object before reading, and an X (*exclusive*) lock on object before writing.
  - System can obtain these locks *automatically*
  - Two phases: acquiring locks, and releasing them
    - no lock is ever acquired after one has been released
  - All locks held by a transaction are released when the transaction completes
  - If an Xact holds an X lock on an object, no other Xact can get a lock (S or X) on that object.
- **Strict 2PL allows only serializable schedules.**

Aborting a Transaction (i.e., Rollback)

- **If a xact *Ti* aborted, all actions must be undone.**
  - Also, if *Tj* reads object last written by *Ti*, *Tj* must be aborted!
- **Most systems avoid such *cascading aborts* by releasing locks only at EOT (i.e., strict locking).**
  - If *Ti* writes an object, *Tj* can read this only after *Ti* finishes.
- **In order to *undo* actions of an aborted transaction, DBMS maintains *log* which records every write. Log also used to recover from system crashes: all active Xacts at time of crash are aborted when system comes back up.**

The Log

- **Log consists of "records" that are written sequentially.**
  - Typically chained together by Xact id
  - Log is often *duplexed* and *archived* on stable storage.
- **Need for UNDO and/or REDO depend on Buffer Mgr.**
  - UNDO required if uncommitted data can overwrite stable version of committed data (STEAL buffer management).
  - REDO required if xact can commit before all its updates are on disk (NO FORCE buffer management).
- **The following actions are recorded in the log:**
  - *if Ti writes an object*, write a log record with:
  - If UNDO required need "before image"
  - IF REDO required need "after image".
  - *Ti commits/aborts*: a log record indicating this action.

Logging Continued

- **Write Ahead Logging protocol**
  - Log record must go to disk ***before*** the changed page!
    - implemented via a handshake between log manager and the buffer manager.
  - All log records for a transaction (including it's commit record) must be written to disk before the transaction is considered "Committed".
- **All log related activities (and in fact, all CC related activities such as lock/unlock, dealing with deadlocks etc.) are handled transparently by the DBMS.**

Durability - Recovering From a Crash

- **There are 3 phases in Aries recovery (and most others):**
  - *Analysis*: Scan the log forward (from the most recent *checkpoint*) to identify all Xacts that were active, and all dirty pages in the buffer pool at the time of the crash.
  - *Redo*: Redoes all updates to dirty pages in the buffer pool, as needed, to ensure that all logged updates are in fact carried out and written to disk.
  - *Undo*: The writes of all Xacts that were active at the crash are undone (by restoring the *before value* of the update, as found in the log), working backwards in the log.
- **At the end --- all committed updates and only those updates are reflected in the database.**
- **Some care must be taken to handle the case of a crash occurring during the recovery process!**

Summary

- **Concurrency control and recovery are among the most important functions provided by a DBMS.**
- **Concurrency control is automatic.**
  - System automatically inserts lock/unlock requests and schedules actions of different Xacts in such a way as to ensure that the resulting execution is equivalent to executing the Xacts one after the other in some order.
- **Write-ahead logging (WAL) and the recovery protocol are used to undo the actions of aborted transactions and to restore the system to a consistent state after a crash.**