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

- Timothy Leary

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
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.

Transaction Consistency

- **User must ensure transaction consistent by itself**
  - I.e., if DBMS consistent before Xact, it will be after also

- **“Consistency” - data in DBMS is accurate in modeling real world, follows integrity constraints**
Goal: The ACID properties

- **Atomicity**: All actions in the Xact happen, or none happen.
- **Consistency**: If each Xact is consistent, and the DB starts consistent, it ends up consistent.
- **Isolation**: Execution of one Xact is isolated from that of other Xacts.
- **Durability**: 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.
Concurrency in a DBMS

• **Users submit transactions, and**
• **Each transaction executes as if it was running by itself.**
  - Concurrency is achieved by DBMS, which interleaves actions (reads/writes of DB objects) of various transactions.
  - Each transaction must leave the database in a consistent state if the DB is consistent when the transaction begins.
    • 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).

• **Issues:** Effect of interleaving transactions, and crashes.

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

  ▶ Intuitively,
    ▶ first transaction transfers $100 from B’s account to A’s
    ▶ second credits both accounts with a 6% interest payment.

  ▶ There is no guarantee that T1 will execute before T2 or vice-versa, if both are submitted together. However, the net effect must be equivalent to these two transactions running serially in some order.
Example (Contd.)

- **Consider a possible interleaving (schedule):**

<table>
<thead>
<tr>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: ( A = A + 100 ), ( B = B - 100 )</td>
</tr>
<tr>
<td>T2: ( A = 1.06^4 A ), ( B = 1.06^4 B )</td>
</tr>
</tbody>
</table>

  - This is OK. But what about:

  ```
<table>
<thead>
<tr>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: ( A = A + 100 ), ( B = B - 100 )</td>
</tr>
<tr>
<td>T2: ( A = 1.06^4 A ), ( B = 1.06^4 B )</td>
</tr>
</tbody>
</table>
  ```

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

<table>
<thead>
<tr>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: R(A), W(A), R(B), W(B)</td>
</tr>
<tr>
<td>T2: R(A), W(A), R(B), W(B)</td>
</tr>
</tbody>
</table>

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

• **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.  
  - 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

• *If a transaction 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 a transaction’s locks only at commit time.**  
  - If Ti writes an object, Tj can read this only after Ti commits.  
• *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

- **The following actions are recorded in the log:**
  - Ti writes an object: the old value and the new value.
    - Log record must go to disk before the changed page!
  - Ti commits/aborts: a log record indicating this action.
- **Log records are chained together by Xact id, so it’s easy to undo a specific Xact.**
- **Log is often duplexed and archived on stable storage.**
- **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.**

Recovering From a Crash

- **There are 3 phases in the Aries recovery algorithm (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, which is in the log record for the update), working backwards in the log. (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) is used to undo the actions of aborted transactions and to restore the system to a consistent state after a crash.**
  - Consistent state: Only the effects of committed Xacts seen.