Unit 3 – Part 1

Reference Book:
Database System Concepts, Korth F. Henry and Silberschatz Abraham

ACID properties

- A transaction is a unit of program execution that accesses and possibly updates various data items.
- Usually, a transaction is initiated by a user program written in a high-level data-manipulation language (typically SQL), or programming language (for example, C++, or Java), with embedded database accesses in JDBC or ODBC.
- A transaction is delimited by statements (or function calls) of the form begin transaction and end transaction.
- The transaction consists of all operations executed between the begin transaction and end transaction.

- A transaction must preserve database consistency. To ensure this the database system must maintain the following properties of the transactions:
- **Atomicity.** Either all operations of the transaction are reflected properly in the database, or none are.
- **Consistency.** Execution of a transaction in isolation (that is, with no other transaction executing concurrently) preserves the consistency of the database.
- **Isolation**. Even though multiple transactions may execute concurrently, the system guarantees that, for every pair of transactions Ti and Tj , it appears to Ti that either Tj finished execution before Ti started or Tj started execution after Ti finished. Thus, each transaction is unaware of other transactions executing concurrently in the system.
- **Durability.** After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures.

Transactions as SQL Statements

- We presented the SQL syntax for specifying the beginning and end of transactions.
- Now that we have seen some of the issues in ensuring the ACID properties for transactions, we are ready to consider how those properties are ensured when transactions are specified as a sequence of SQL statements rather than the restricted model of simple reads and writes that we considered up to this point.
- In our simple model, we assumed a set of data items exists. While our simple model allowed data-item values to be changed, it did not allow data items to be created or deleted. In SQL, however, insert statements create new data and delete statements delete data.
- These two statements are, in effect, write operations since they change the database, but their interactions with the actions of other transactions are different from what we saw in our simple model.
- As an example, consider the following SQL query on our university database that finds all instructors who earn more than $90,000.

select ID, name

from instructor

where salary > 90000;

- Using our sample instructor relation, we find that only Einstein and Brandt satisfy the condition.
- Now assume that around the same time we are running our query, another user inserts a new instructor named “James” whose salary is $100,000.

insert into instructor values (’11111’, ’James’, ’Marketing’, 100000);

- The result of our query will be different depending on whether this insert comes before or after our query is run.
- In a concurrent execution of these transactions, it is intuitively clear that they conflict, but this is a conflict not captured by our simple model.
- This situation is referred to as the phantom phenomenon, because a conflict may exist on “phantom” data.

- Our simple model of transactions required that operations operate on a specific data item given as an argument to the operation.
- We can look at the read and write steps to see which data items are referenced.
- But in an SQL statement, the specific data items (tuples) referenced may be determined by a where clause predicate.
- So the same transaction, if run more than once, might reference different data items each time it is run if the values in the database change between runs.

- One way of dealing with the above problem is to recognize that it is not sufficient for concurrency control to consider only the tuples that are accessed by a transaction
- The information used to find the tuples that are accessed by the transaction must also be considered for the purpose of concurrency control.
- The information used to find tuples could be updated by an insertion or deletion, or in the case of an index, even by an update to a search-key attribute.
- For example, if locking is used for concurrency control, the data structures that track the tuples in a relation, as well as index structures, must be appropriately locked.
- However, such locking can lead to poor concurrency in some situations; index-locking protocols which maximize concurrency, while ensuring serializability in spite of inserts, deletes, and predicates in queries

- Let us consider again the query:

select ID, name
from instructor
where salary> 90000;

- and the following SQL update:

update instructor
set salary = salary * 0.9
where name = 'Wu';

- whether our query conflicts with the update statement?
- If our query reads the entire instructor relation, then it reads the tuple with Wu's data and conflicts with the update.
- However, if an index were available that allowed our query direct access to those tuples with salary > 90000, then our query would not have accessed Wu's data at all because Wu's salary is initially $90,000 in our example instructor relation, and reduces to $81,000 after the update.

Example of Fund Transfer

- Transaction to transfer $50 from account *A* to account *B*:
  1. **read**(*A*)
  2. *A* := *A* – 50
  3. **write**(*A*)
  4. **read**(*B*)
  5. *B* := *B* + 50
  6. **write**(*B*)
- Consistency requirement – the sum of *A* and *B* is unchanged by the execution of the transaction.
- Atomicity requirement — if the transaction fails after step 3 and before step 6, the system should ensure that its updates are not reflected in the database, else an inconsistency will result.

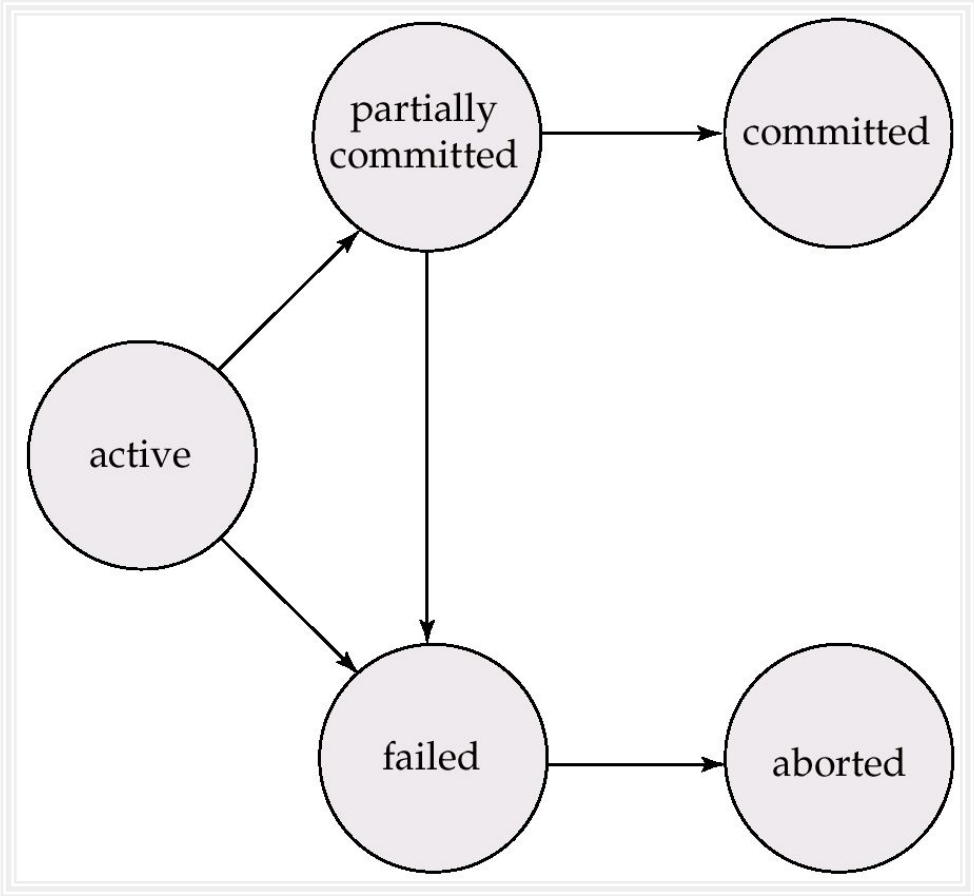
Example of Fund Transfer (Cont.)

- Durability requirement — once the user has been notified that the transaction has completed (i.e., the transfer of the $50 has taken place), the updates to the database by the transaction must persist despite failures.
- Isolation requirement — if between steps 3 and 6, another transaction is allowed to access the partially updated database, it will see an inconsistent database
  (the sum $A + B$ will be less than it should be).
  Can be ensured trivially by running transactions *serially*, that is one after the other. However, executing multiple transactions concurrently has significant benefits, as we will see.

Transaction State

- **Active,** the initial state; the transaction stays in this state while it is executing
- **Partially committed,** after the final statement has been executed.
- **Failed,** after the discovery that normal execution can no longer proceed.
- **Aborted,** after the transaction has been rolled back and the database restored to its state prior to the start of the transaction. Two options after it has been aborted:
  - restart the transaction – only if no internal logical error
  - kill the transaction
- **Committed,** after *successful completion*.

Transaction State (Cont.)



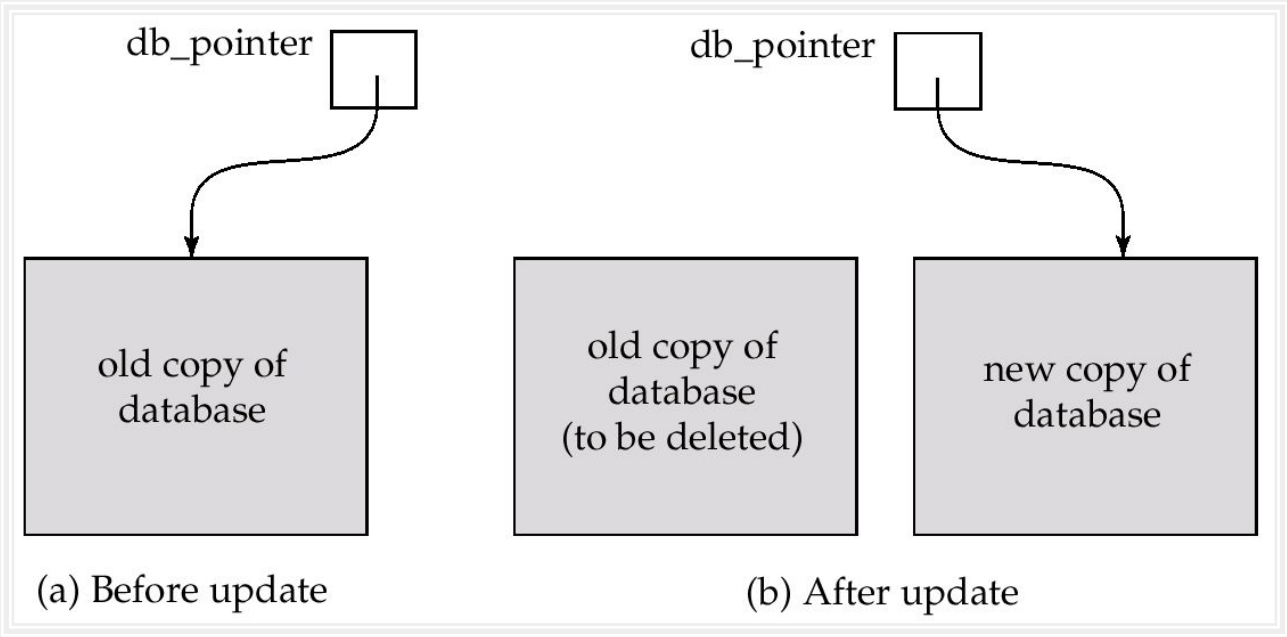
Implementation of Atomicity and Durability

- The recovery-management component of a database system implements the support for atomicity and durability.
- The *shadow-database* scheme:
  - assume that only one transaction is active at a time.
  - a pointer called db_pointer always points to the current consistent copy of the database.
  - all updates are made on a *shadow copy* of the database, and **db_pointer** is made to point to the updated shadow copy only after the transaction reaches partial commit and all updated pages have been flushed to disk.
  - in case transaction fails, old consistent copy pointed to by **db_pointer** can be used, and the shadow copy can be deleted.

Implementation of Atomicity and Durability (Cont.)

The shadow-database scheme:

- Assumes disks to not fail
- Useful for text editors, but extremely inefficient for large databases: executing a single transaction requires copying the *entire* database.



Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:
  - **increased processor and disk utilization**, leading to better transaction *throughput:* one transaction can be using the CPU while another is reading from or writing to the disk
  - **reduced average response time** for transactions: short transactions need not wait behind long ones.
- *Concurrency control schemes* – mechanisms to achieve isolation, i.e., to control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database
  - Will study in Chapter 14, after studying notion of correctness of concurrent executions.

Schedules

- *Schedules* – sequences that indicate the chronological order in which instructions of concurrent transactions are executed
  - a schedule for a set of transactions must consist of all instructions of those transactions
  - must preserve the order in which the instructions appear in each individual transaction.

Example Schedules

- Let T_1 transfer \$50 from A to B, and T_2 transfer 10% of the balance from A to B. The following is a serial schedule (Schedule 1 in the text), in which T_1 is followed by T_2.

T_1	T_2
read(A)	
$A := A - 50$	
write (A)	
read(B)	
$B := B + 50$	
write(B)	
	read(A)
	$temp := A * 0.1$
	$A := A - temp$
	write(A)
	read(B)
	$B := B + temp$
	write(B)

Example Schedule (Cont.)

- Let T_1 and T_2 be the transactions defined previously. The following schedule (Schedule 3 in the text) is not a serial schedule, but it is equivalent to Schedule 1.

T_1	T_2
read(A)	
$A := A - 50$	
write(A)	
	read(A)
	$temp := A * 0.1$
	$A := A - temp$
	write(A)
read(B)	
$B := B + 50$	
write(B)	
	read(B)
	$B := B + temp$
	write(B)

In both Schedule 1 and 3, the sum A + B is preserved.

Example Schedules (Cont.)

- The following concurrent schedule (Schedule 4 in the text) does not preserve the value of the the sum $A + B$.

T_1	T_2
read(A)	
$A := A - 50$	
	read(A)
	$temp := A * 0.1$
	$A := A - temp$
	write(A)
	read(B)
write(A)	
read(B)	
$B := B + 50$	
write(B)	
	$B := B + temp$
	write(B)

Serializability

- Basic Assumption – Each transaction preserves database consistency.
- Thus serial execution of a set of transactions preserves database consistency.
- A (possibly concurrent) schedule is serializable if it is equivalent to a serial schedule. Different forms of schedule equivalence give rise to the notions of:
  1. conflict serializability
  2. view serializability
- We ignore operations other than **read** and **write** instructions, and we assume that transactions may perform arbitrary computations on data in local buffers in between reads and writes. Our simplified schedules consist of only **read** and **write** instructions.

Conflict Serializability

- Instructions I_i and I_j of transactions T_i and T_j respectively, conflict if and only if there exists some item Q accessed by both I_i and I_j, and at least one of these instructions wrote Q.
  1. I_i = **read**(Q), I_j = **read**(Q). I_i and I_j don't conflict.
  2. I_i = **read**(Q), I_j = **write**(Q). They conflict.
  3. I_i = **write**(Q), I_j = **read**(Q). They conflict
  4. I_i = **write**(Q), I_j = **write**(Q). They conflict
- Intuitively, a conflict between I_i and I_j forces a (logical) temporal order between them. If I_i and I_j are consecutive in a schedule and they do not conflict, their results would remain the same even if they had been interchanged in the schedule.

Conflict Serializability (Cont.)

- If a schedule S can be transformed into a schedule S' by a series of swaps of non-conflicting instructions, we say that S and S' are **conflict equivalent.**
- We say that a schedule S is **conflict serializable** if it is conflict equivalent to a serial schedule
- Example of a schedule ~~that is not conflict~~ serializable:

T_3	T_4
read(Q)	
	write(Q)
write(Q)	

We are unable to swap instructions in the above schedule to obtain either the serial schedule $< T_3, T_4 >$, or the serial schedule $< T_4, T_3 >$.

Conflict Serializability (Cont.)

- Schedule 3 below can be transformed into Schedule 1, a serial schedule where T_2 follows T_1, by series of swaps of non-conflicting instructions. Therefore Schedule 3 is conflict serializable.

T_1	T_2
read(A)	
write(A)	
	read(A)
	write(A)
read(B)	
write(B)	
	read(B)
	write(B)

View Serializability

- Let S and S' be two schedules with the same set of transactions. S and S' are view equivalent if the following three conditions are met:
  1. For each data item Q, if transaction T_i reads the initial value of Q in schedule S, then transaction T_i must, in schedule S', also read the initial value of Q.
  2. For each data item Q if transaction T_i executes **read**(Q) in schedule S, and that value was produced by transaction T_j (if any), then transaction T_i must in schedule S' also read the value of Q that was produced by transaction T_j .
  3. For each data item Q, the transaction (if any) that performs the final **write**(Q) operation in schedule S must perform the final **write**(Q) operation in schedule S'.

As can be seen, view equivalence is also based purely on **reads** and **writes** alone.

View Serializability (Cont.)

- A schedule S is view serializable it is view equivalent to a serial schedule.
- Every conflict serializable schedule is also view serializable.
- Schedule 9 (from text) — a schedule which is view-serializable but *not* conflict serializable.

T_3	T_4	T_6
read(Q)		
	write(Q)	
write(Q)		
		write(Q)

- Every view serializable schedule that is not conflict serializable has blind writes.

Other Notions of Serializability

- Schedule 8 (from text) given below produces same outcome as the serial schedule $< T_1, T_5 >$, yet is not conflict equivalent or view equivalent to it.

T_1	T_5
read(A)	
$A := A - 50$	
write(A)	
	read(B)
	$B := B - 10$
	write(B)
read(B)	
$B := B + 50$	
write(B)	
	read(A)
	$A := A + 10$
	write(A)

- Determining such equivalence requires analysis of operations other than read and write.

Recoverability

Need to address the effect of transaction failures on concurrently running transactions.

- **Recoverable schedule** — if a transaction T_j reads a data items previously written by a transaction T_i, the commit operation of T_i appears before the commit operation of T_j.
- The following schedule (Schedule 11) is not recoverable if T_9 commits immediately after the read

T_8	T_9
read(A)	
write(A)	
	read(A)
read(B)	

- If T_8 should abort, T_9 would have read (and possibly shown to the user) an inconsistent database state. Hence database must ensure that schedules are recoverable.

Recoverability (Cont.)

- **Cascading rollback** – a single transaction failure leads to a series of transaction rollbacks. Consider the following schedule where none of the transactions has yet committed (so the schedule is recoverable)

T_{10}	T_{11}	T_{12}
read(A)		
read(B)		
write(A)		
	read(A)	
	write(A)	
		read(A)

If T_{10} fails, T_{11} and T_{12} must also be rolled back.

- Can lead to the undoing of a significant amount of work

Recoverability (Cont.)

- **Cascadeless schedules** — cascading rollbacks cannot occur; for each pair of transactions T_i and T_j such that T_j reads a data item previously written by T_i, the commit operation of T_i appears before the read operation of T_j.
- Every cascadeless schedule is also recoverable
- It is desirable to restrict the schedules to those that are cascadeless

Implementation of Isolation

- Schedules must be conflict or view serializable, and recoverable, for the sake of database consistency, and preferably cascadeless.
- A policy in which only one transaction can execute at a time generates serial schedules, but provides a poor degree of concurrency..
- Concurrency-control schemes tradeoff between the amount of concurrency they allow and the amount of overhead that they incur.
- Some schemes allow only conflict-serializable schedules to be generated, while others allow view-serializable schedules that are not conflict-serializable.

Transaction Definition in SQL

- Data manipulation language must include a construct for specifying the set of actions that comprise a transaction.
- In SQL, a transaction begins implicitly.
- A transaction in SQL ends by:
  - **Commit work** commits current transaction and begins a new one.
  - **Rollback work** causes current transaction to abort.
- Levels of consistency specified by SQL-92:
  - **Serializable** — default
  - **Repeatable read**
  - **Read committed**
  - **Read uncommitted**