Chapter 14: Transactions

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Database System Concepts, 6th Ed.

Transaction

- A **transaction** is a *unit* of program execution that accesses and possibly updates various data items.
- E.g., 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*)
- Two main issues to deal with:
  - Failures of various kinds, such as hardware failures and system crashes
  - Concurrent execution of multiple transactions

Required Properties of a Transaction

- Consider a 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)*
- **Atomicity requirement**
  - If the transaction fails after step 3 and before step 6, money will be "lost" leading to an inconsistent database state
    - Failure could be due to software or hardware
  - The system should ensure that updates of a partially executed transaction are not reflected in the database
- **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 even if there are software or hardware failures.

Required Properties of a Transaction (Cont.)

- **Consistency requirement** in above example:
  - The sum of A and B is unchanged by the execution of the transaction
- In general, consistency requirements include
  - Explicitly specified integrity constraints such as primary keys and foreign keys
  - Implicit integrity constraints
    - e.g., sum of balances of all accounts
- A transaction, when starting to execute, must see a consistent database.
- During transaction execution the database may be temporarily inconsistent.
- When the transaction completes successfully the database must be consistent
  - Erroneous transaction logic can lead to inconsistency

Required Properties of a Transaction (Cont.)

- **Isolation requirement** — if between steps 3 and 6 (of the fund transfer transaction) , another transaction **T2** 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).

T1	**T2**
1. **read**(*A*)	
2. *A* := *A* – 50	
3. **write**(*A*)	
	read(A), read(B), print(A+B)
4. **read**(*B*)	
5. *B* := *B* + 50	
6. **write**(*B*	

- Isolation 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 later.

ACID Properties

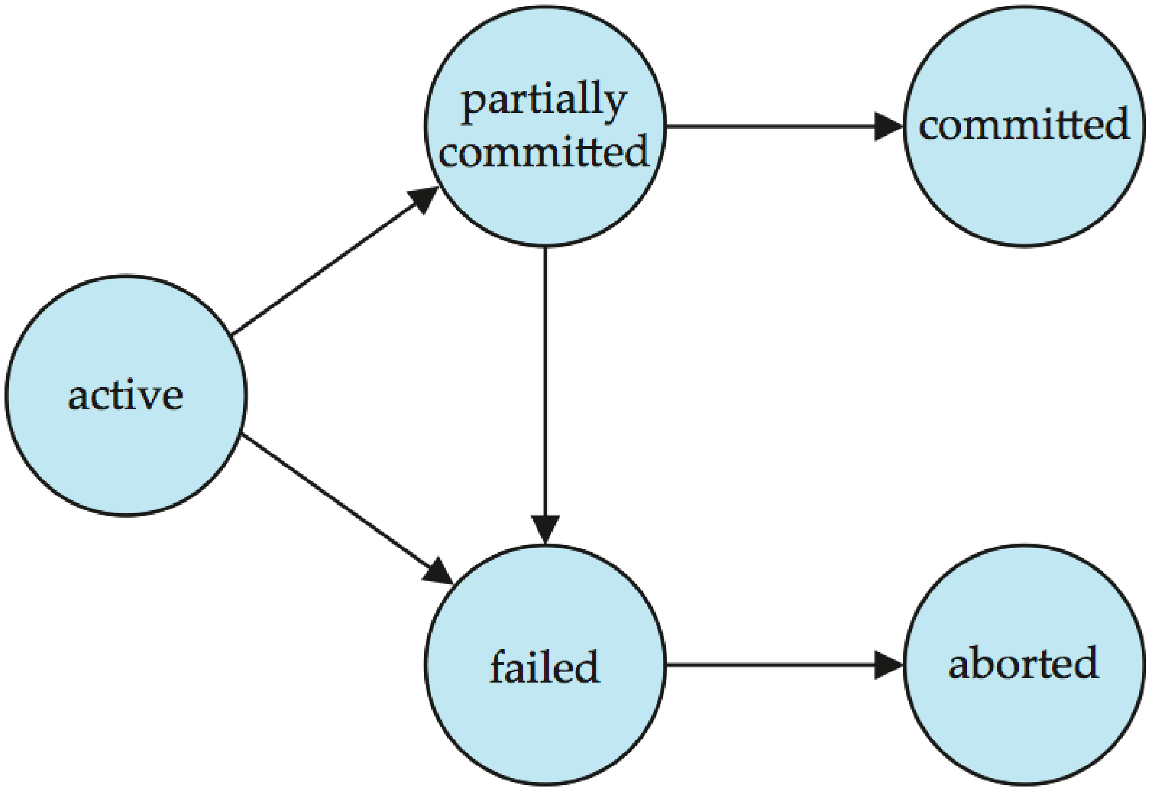
A **transaction** is a unit of program execution that accesses and possibly updates various data items. To preserve the integrity of data the database system must ensure:

- **Atomicity.** Either all operations of the transaction are properly reflected in the database or none are.
- **Consistency.** Execution of a transaction in isolation preserves the consistency of the database.
- **Isolation.** Although multiple transactions may execute concurrently, each transaction must be unaware of other concurrently executing transactions. Intermediate transaction results must be hidden from other concurrently executed transactions.
  - That is, for every pair of transactions T_i and T_j, it appears to T_i that either T_j, finished execution before T_i started, or T_j started execution after T_i finished.
- **Durability.** After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures.

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
    - can be done only if no internal logical error
  - Kill the transaction
- **Committed** – after successful completion.

Transaction State (Cont.)



Observable external writes

- Observable external writes
  - Allow them to take place only after the transaction is committed
  - If the system restarts after a commit, perform the external write after restart
- More complex situations may require compensating transactions

Concurrent Executions

- Multiple transactions are allowed to run concurrently
  - **Increased processor and disk utilization**, leading to better transaction *throughput*
    - E.g. one transaction can use 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.

Schedule 1

- Let T_1 transfer Rs 50 from A to B, and T_2 transfer 10% of the balance from A to B.
- An example of a **serial schedule** 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)	
commit	
	read (A)
	$temp := A * 0.1$
	$A := A - temp$
	write (A)
	read (B)
	$B := B + temp$
	write (B)
	commit

Schedules

- **Schedule** – a sequence of instructions that specify 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.
- A transaction that successfully completes its execution will have a **commit** instruction as the last statement
  - By default a transaction assumed to execute commit instruction as its last step
- A transaction that fails to successfully complete its execution will have an **abort** instruction as the last statement

A serial schedule

- A serial schedule
  - consists of a sequence of instructions from various transactions,
  - where the instructions belonging to a transaction appear together in that schedule
- Any schedule that is executed must leave the database system in a consistent state

Schedule 2

- A **serial** schedule in which T_2 is followed by T_1 :

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

Concurrency control

- **Concurrency control schemes** – mechanisms to achieve **isolation**
  - That is, to control the interaction among concurrent transactions
    - in order to prevent them from destroying the consistency of the database
    - Will study later

Schedule 3

- Let T_1 and T_2 be the transactions defined previously. The following schedule 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)	
commit	
	read (B)
	$B := B + temp$
	write (B)
	commit

Note -- In schedules 1, 2 and 3, the sum “A + B” is preserved.

Schedule 4

- The following concurrent schedule does not preserve the sum of "$A + B$"

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)	
commit	
	$B := B + temp$
	write (B)
	commit

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**

Simplified view of transactions

- We ignore operations other than **read** and **write** instructions
- 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.

Conflicting Instructions

- Let I_i and I_j be two Instructions of transactions T_i and T_j respectively.
- Instructions I_i and I_j **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.