Transaction Management

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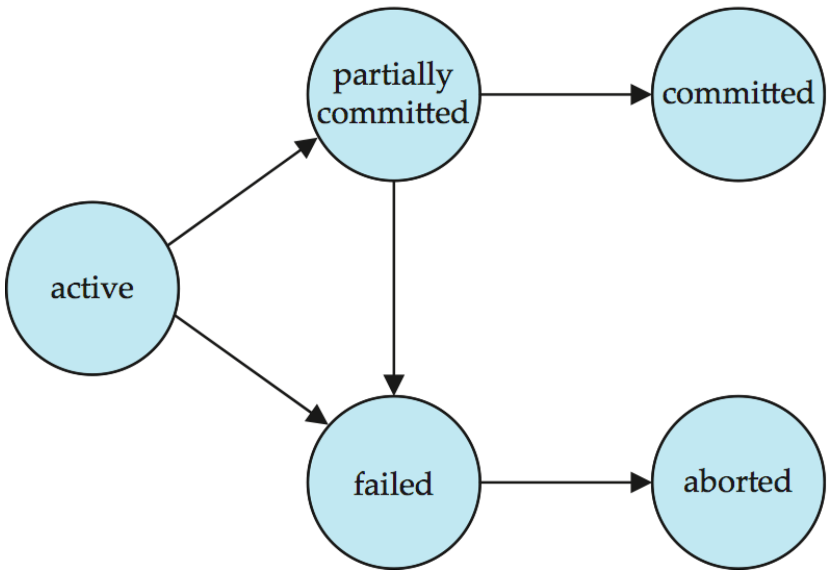
Transaction Concept

- A **transaction** is a *unit* of program execution that accesses and possibly updates various data items.
- E.g., transaction to transfer Rs. 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*)

One Transaction consists of a Set of instruction

- Two main issues to deal with:
  - Failures of various kinds, such as hardware failures and system crashes
  - Concurrent execution of multiple transactions

Transaction State - I



- **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.

ACID Properties

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.

ACID Properties w.r.t. a Transaction

- **Atomicity requirement**
  - If the transaction fails after step 3, money will be "lost" leading to an inconsistent database state
  - The system should ensure that updates of a partially executed transaction are not reflected in the database

1. **read**(A)
2. $A := A - 50$
3. **write**(A)
4. **read**(B)
5. $B := B + 50$
6. **write**(B)

- **Durability requirement** —The database should be durable enough to hold all its latest updates even if the system fails or restarts. If a transaction updates a chunk of data in a database and commits, then the database will hold the modified data. If a transaction commits but the system fails before the data could be written on to the disk, then that data will be updated once the system springs back into action.
- **Consistency requirement** in above example:
  - The sum of A and B is unchanged by the execution of the transaction

Required Properties of a Transaction (Cont.)

- **Isolation requirement** — if between steps 3 and 6, another transaction **T2** is allowed to access the partially updated database

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.

Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:
  - **Increased processor and disk utilization**, leading to better transaction *throughput*
    - E.g. 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
  - That is, to control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database

Schedules

- **Schedule** – a sequences 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** instructions as the last statement
  - By default 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

Serial 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

Serial execution of transactions always ensures isolation and consistence in database

Consistency is preserved
i.e. A+B remains same

Serial 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	

Consistency is preserved irrespective of execution sequence of both T1 and T2

Concurrent Schedule 3

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

- concurrent schedule does not preserve the sum of A+B

Concurrent Schedule 4

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

- the sum "A + B" is preserved
- It is not a serial schedule, but it is **equivalent** to a serial Schedule.
- These schedules are called serializable schedules.
- i.e. out of multiple possible concurrent schedules, some may ensure isolation and other may not.
- Hence only the concurrent schedules that ensures isolation and consistency shall be acceptable.

Serializability

- If the final outcome of a concurrent schedule S_1, is same as that of a serial schedule S_2, then S_1 is said to be a seralizable schedule.
- i.e. A 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 transaction
  - We ignore operations other than **read** and **write** instructions
  - We assume that transactions may perform arbitrary computations in between reads and writes

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, order does not matter
  - 2. I_i = **read**(Q), I_j = **write**(Q). They conflict, as the order maters
  - 3. I_i = **write**(Q), I_j = **read**(Q). They conflict, as the order maters
  - 4. I_i = **write**(Q), I_j = **write**(Q). They conflict, order does not affect.

  However, the value obtained by the next read(Q) is affected, since the result of only the latter of the two write instructions is preserved in the database
- 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.
  - i.e. if both I_i and I_j represent read operation, then they can be swapped, but if any one of them is a write operation then they can not be swapped.

Conflict Serializability

- 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

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

conflicts

Does not conflicts, as different data

conflicts

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

write(A) of T_2 can be swapped with read(B) of T_1

Conflict Serializability (Cont.)

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

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

- Swap the read(B) *instruction of* T_1 *with the read*(A) *instruction of* T_2.
- Swap the write(B) *instruction of T1 with the write*(A) *instruction of T2.*
- The final result of these swaps is a serial schedule
- i.e. *S* and *S'* are conflict equivalent
- and hence *S* is conflict serializable

Conflict Serializability (Cont.)

- Example of a schedule that is not conflict serializable:

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

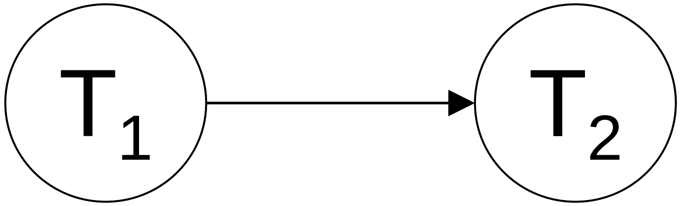
- It is not possible to swap instructions in the above schedule to obtain a serial schedule

Precedence Graph

- It is a simple and efficient method for determining conflict serializability
- Consider schedule S of a set of transactions T_1, T_2, ..., T_n
- **Precedence graph** — a direct graph G=(V,E),
  - where the vertices are participating transactions.
  - We draw a directed from T_i to T_j if the two transaction conflict, i.e.
  - T_i executes write(Q) before T_j executes read(Q)
  - T_i executes read(Q) before T_j executes write(Q)
  - T_i executes write(Q) before T_j executes write(Q)
- If the precedence graph for S has a cycle, then S is not conflict serializable

Precedence graph for Schedule 1

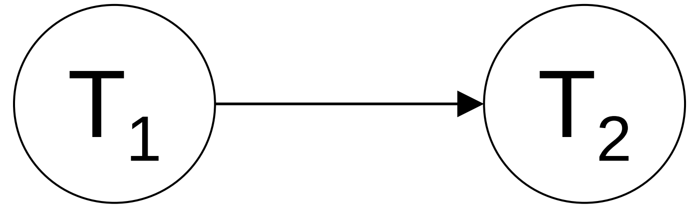
T_1	T_2
read (A)	
$A := A - 50$	
write (A)	
read (B)	
$B := B + 50$	
write (B)	
commit	
	read (A)
	$temp := A * 0.1$
	$A := A - temp$
	write (A)
	read (B)
	$B := B + temp$
	write (B)
	commit



- Since all instructions of T_1 are executed before the first instruction of T_2 is executed.
- An edge is formed from T_1 to T_2
- As there is no cycle, therefore S_1 is conflict serializable

Concurrent Schedule 4

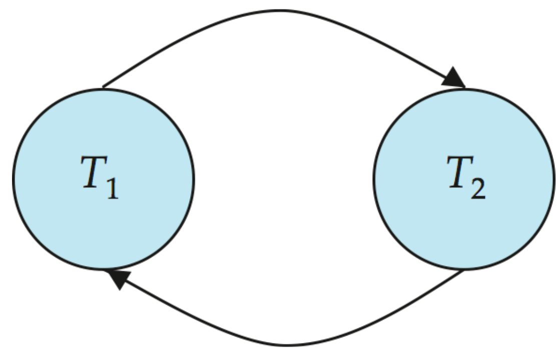
T_1	T_2
read (A)	
$A := A - 50$	
write (A)	
	read (A)
	$temp := A * 0.1$
	$A := A$ - $temp$
	write (A)
read (B)	
$B := B + 50$	
write (B)	
commit	
	read (B)
	$B := B + temp$
	write (B)
	commit



- T_1 executes write(A) before T_2 executes read(A)
- T_1 executes read(B) before T_2 executes write(B)
- T_1 executes write(B) before T_2 executes write(B)
- As there is no cycle, therefore S_4 is conflict serializable

Precedence Graph Schedule 3

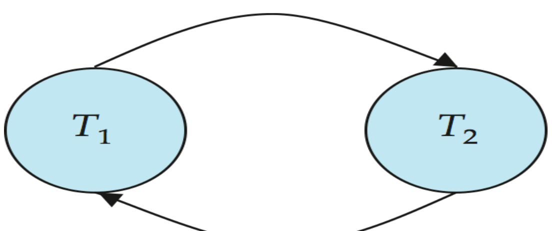
T_1	T_2
read (A)	
$A := A - 50$	
	read (A)
	$temp := A * 0.1$
	$A := A$ - $temp$
	write (A)
	read (B)
write (A)	
read (B)	
$B := B + 50$	
write (B)	
commit	
	$B := B + temp$
	write (B)
	commit



- One edge from $T_1 \rightarrow T_2$, as T_1 executes read(A), before T_2 executes write(A)
- *Another edge $T_2 \rightarrow T_1$, as T_2 executes read(B), before T_1 executes write(B)*
- *As the precedence graph contains a cycle, therefore S_3 is not conflict serializable*

Concurrent Schedule 5

T_1	T_2
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)



- Test for Conflict serializablity
- Test for schedule equivalence
- Precedence Graph
  - T_1 executes write(A) before T_2 executes read(A) (edge from $T_1 \rightarrow T_2$)
  - T_2 executes write(B) before T_1 executes read(B) (edge from $T_2 \rightarrow T_1$)
  - So S5 is not conflict serializable
- Schedule equivalence (A+B)
  - Before transaction, A+B =1500
  - After transaction, A+B = 1500
  - So S_5 and S_5' (Any schedule equivalent to S_5 by swapping non conflicting instructions) are equivalent schedules
- It is possible to have two schedules that produce same outcome but are not conflict serializable
- Schedule equivalence have less-stringent definitions

Recoverability

- If a transaction fails during its execution

Then, the partial executed failed transaction must be rolled back, thereby undoing all its effects as to preserve the Atomicity property.

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

Roll back

Recoverable schedules

In a concurrent transaction execution failure of transaction requires rolling back of that transaction along with those transaction, which are dependent on failed transaction inorder to preserve atomicity.

Recoverable Schedules

- **Recoverable schedule** — if a transaction T_j reads a data item previously written by a transaction T_i , then the commit operation of T_i **must** appear before the commit operation of T_j.
  - To make this schedule recoverable, T_9 have to delay commiting until after T_8 commits

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

- This is a non recoverable schedule because
  - If T_8 fails before it commits, then T_9 reads new value of A. i.e. T_9 is dependent on T_8.
  - Therefore T_9 should also be aborted along with T_8
  - But T_9 already committed with a inconsistent database sate.

Cascading Rollbacks

- A single transaction failure may lead to a series of transaction rollbacks.

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

- T_{10} writes A, read by T_{11}
- T_{11} writes A, read by T_{12}
- T_{12} depends on T_{11} and T_{11} depends on T_{10}
- Now if T_{10} fails, then T_{11}, and T_{12} has also to be rolled back along with T_{10}due their interdependency.
- If a transaction failure leads to a series of rollbacks, is called cascading rollback
- It is undesirable as involves significant amount of work.

Cascadeless Schedules

- It is desirable to restrict the schedules so that cascading rollback can't occur.
- These schedules are called cascadeless schedule.
- i.e. 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

End of Chapter

Thank you