Chapter 17: Transactions

Sistemas de Bases de Dados 2020/21

Capítulo refere-se a: Database System Concepts, 7th Ed

Outline

- Transaction Concept
- Transaction State
- Concurrent Executions
- Serializability
- Recoverability
- Implementation of Isolation
- Transaction Definition in SQL
- Testing for Serializability.

Transaction Concept

- 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

Transaction Properties

- 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*)

Transaction Properties

- 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 – **all or nothing execution**

Transaction Properties

- 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 – **all or nothing execution**
- **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.

Transaction Properties (Cont.)

- 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)

Transaction Properties (Cont.)

- 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** in the example: The sum of A and B is unchanged by the execution of the transaction

Transaction Properties (Cont.)

- 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** in the 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, minus sum of loan amounts must equal value of cash-in-hand
  - A transaction must see a consistent database.
  - During transaction execution the database may be temporarily inconsistent.
  - **When the transaction completes successfully the database must be consistent**

Transaction Properties (Cont.)

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)	

Transaction Properties (Cont.)

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*)	

- If between steps 3 and 6, another transaction T2 can access the partially updated database, it will see an inconsistent database (the sum $A + B$ will be less than it should be).

Transaction Properties (Cont.)

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*)	

- If between steps 3 and 6, another transaction T2 can access the partially updated database, it will see an inconsistent database (the sum $A + B$ will be less than it should be).
- **Isolation requirement** — If concurrent transactions are allowed, each transaction must execute as if it were executing alone
  - Intermediate results of a transaction must be hidden from other concurrent ones

Transaction Properties (Cont.)

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)	

- If between steps 3 and 6, another transaction T2 can access the partially updated database, it will see an inconsistent database (the sum $A + B$ will be less than it should be).
- **Isolation requirement** — If concurrent transactions are allowed, each transaction must execute as if it were executing alone
  - Intermediate results of a transaction must be hidden from other concurrent ones
- Isolation can be ensured trivially by running transactions **serially** (i.e. one after the other)

Transaction Properties (Cont.)

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)	

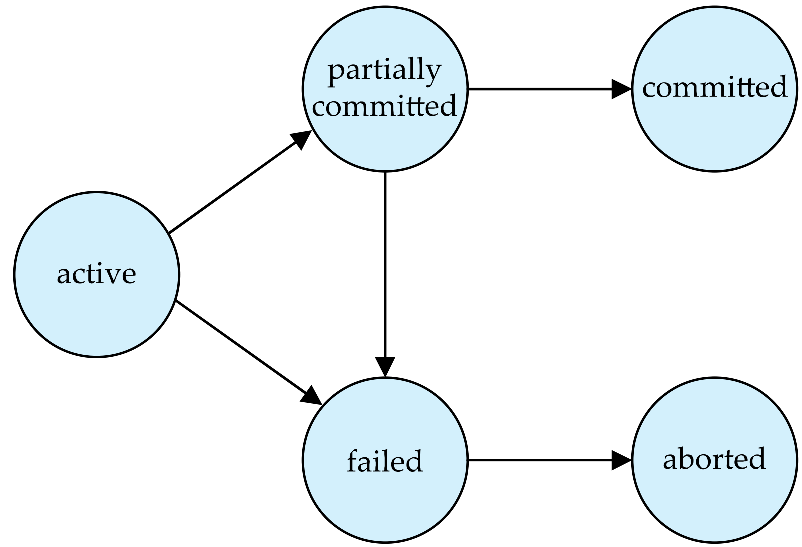
- If between steps 3 and 6, another transaction T2 can access the partially updated database, it will see an inconsistent database (the sum $A + B$ will be less than it should be).
- **Isolation requirement** — If concurrent transactions are allowed, each transaction must execute as if it were executing alone
  - Intermediate results of a transaction must be hidden from other concurrent ones
- Isolation can be ensured trivially by running transactions **serially** (i.e. one after the other)
- However, executing multiple transactions concurrently has significant benefits.

ACID Properties - Summary

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:

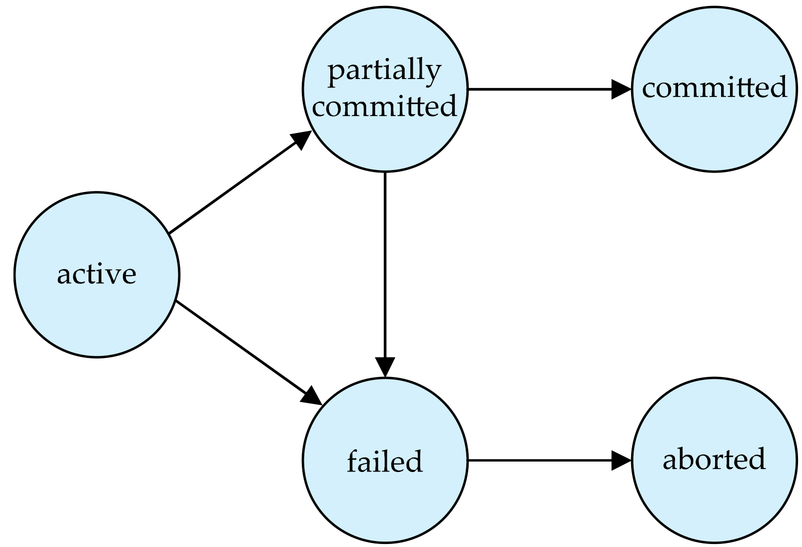
- **Atomicity.** Either all operations of the transaction are properly reflected in the database or none are.
- **Consistency.** Execution of a transaction preserves the consistency of the database in the end.
- **Isolation.** Although multiple transactions may execute concurrently, each transaction 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 States



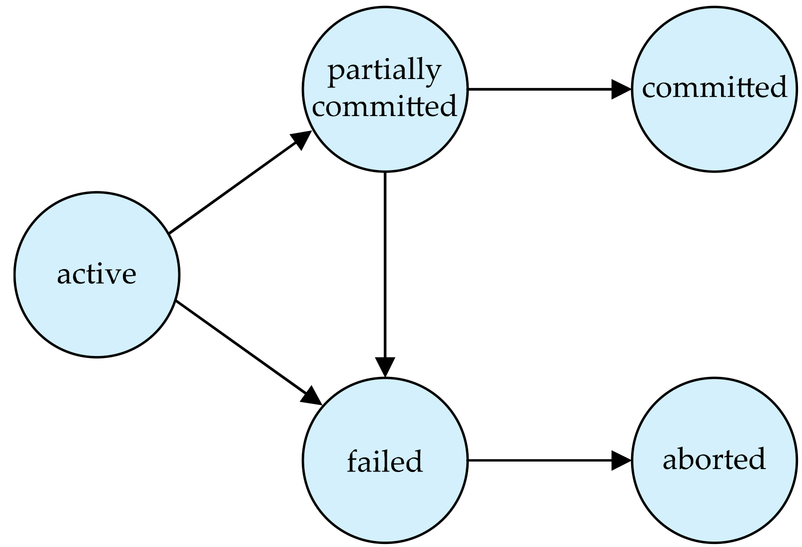
Transaction States

- **Active** – the initial state; the transaction stays in this state while it is executing



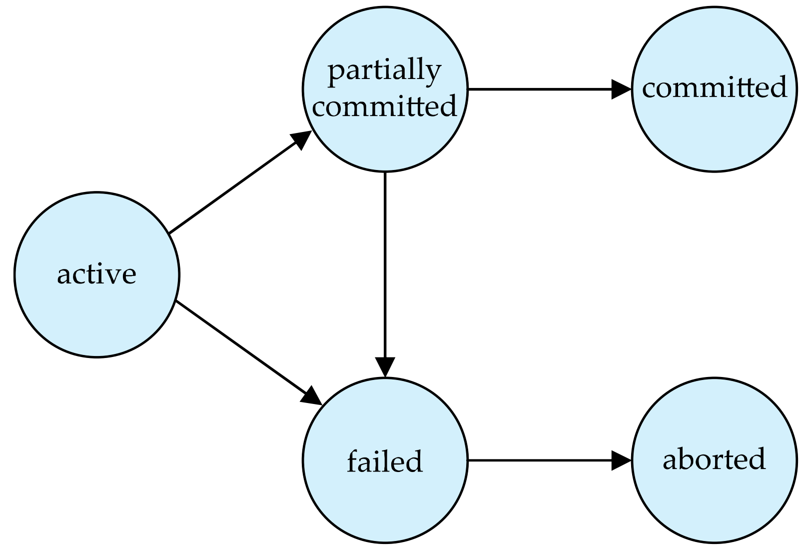
Transaction States

- **Active** – the initial state; the transaction stays in this state while it is executing
- **Partially committed** – after the final statement has been executed.



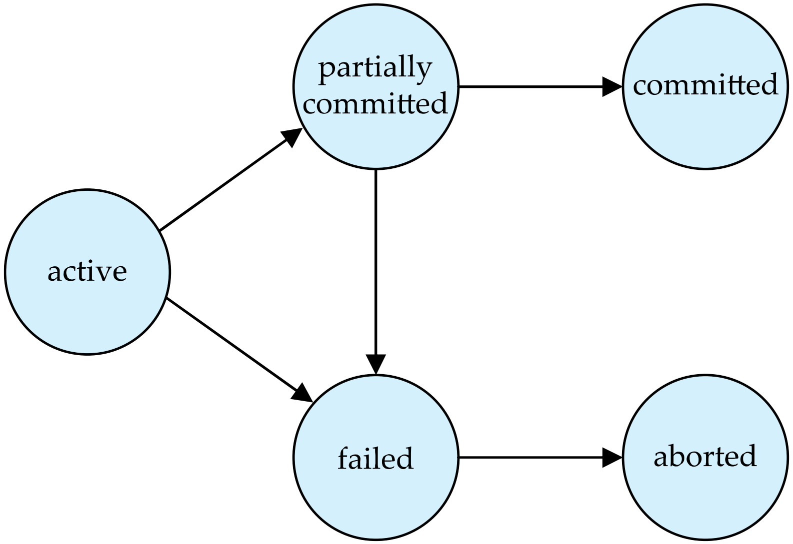
Transaction States

- **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.



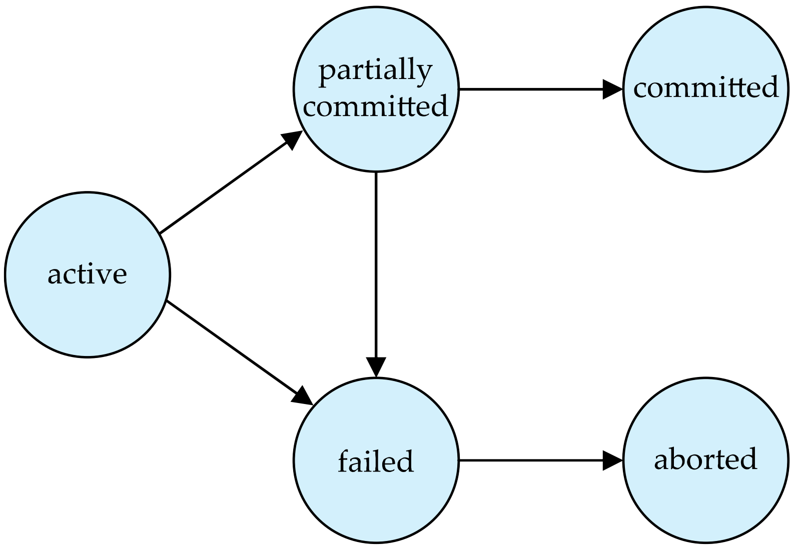
Transaction States

- **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



Transaction States

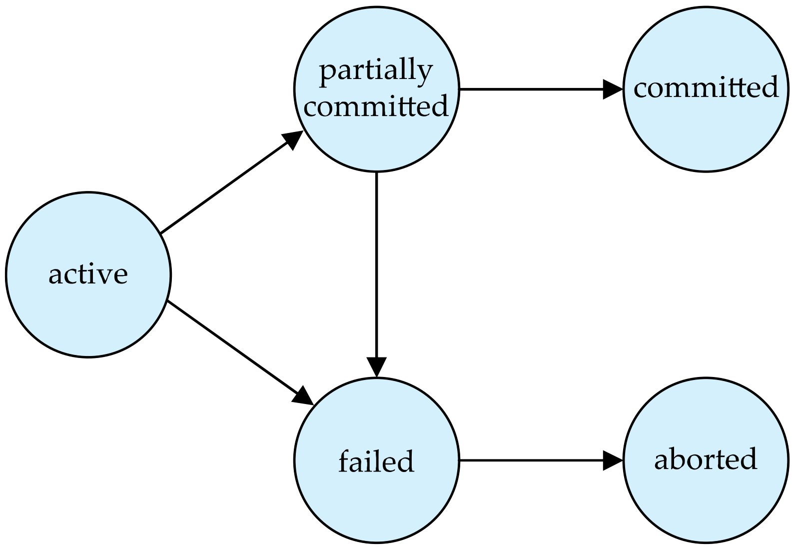
- **Active** – the initial state; the transaction stays in this state while it is executing
- **Partially committed** – after the final statement has been executed.
- **Failed --** after the discovery that normal execution can no longer proceed.
- **Aborted** – after the transaction has been rolled back 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 States

- **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.

- To guarantee atomicity, external observable actions should all be performed (in order) after the transaction is committed.



Non-ACID transactions

- There are application domains where ACID properties are not necessarily desired or, most likely, not always possible.
- This is the case of so-called **long-duration transactions**
  - Suppose that a transaction takes a lot of time
  - In this case it is unlikely that isolation can/should be guaranteed
    - E.g. Consider a transaction of booking a hotel and a flight
- Without Isolation, Atomicity may be compromised
- Consistency and Durability should be preserved
- A usual solution for long-duration transactions is to define **compensation actions** – what to do if later the transaction fails
- In (centralised) databases long-duration transactions are usually not considered.
- But these are more and more important, especially in the context of the Web.

Concurrent Executions

- Multiple transactions can 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.

Concurrent Executions

- Multiple transactions can 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
    - We'll study that next week,

Concurrent Executions

- Multiple transactions can 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
    - We'll study that next week,

- Before seeing how to implement correct concurrent transaction, let's define the notion of correctness of concurrent executions.

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
  - In the slides, we'll assume, by default, that a transaction executes a commit instruction as its last step
- A transaction that fails to successfully complete its execution will have an abort instruction as the last statement
- The goal is to find schedules that preserves consistency

Schedule 1

- Let T_1 transfer €50 from A to B, and T_2 transfer 10% of the balance from A to B.
- 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

Schedule 2

- A serial schedule where 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	

- If each transaction, by itself, preserves consistency, serial schedules obviously also preserve consistency!

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

- In Schedules 1, 2 and 3, the sum A + B is preserved.

Schedule 4

- The following concurrent schedule does not preserve the value 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

- **Goal:** Deal with concurrent schedules that are equivalent to some serial execution:
  - **Basic Assumption** – Each transaction preserves database consistency.
  - Thus serial execution of a set of transactions preserves database consistency.

Serializability

- **Goal:** Deal with concurrent schedules that are equivalent to some serial execution:
  - **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**

Serializability

- **Goal:** Deal with concurrent schedules that are equivalent to some serial execution:
  - **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 transaction:
  - 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

- 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.

Conflicting Instructions

- Instructions l_i and l_j of transactions T_i and T_j respectively, **conflict** if and only if there exists some item Q accessed by both l_i and l_j, and at least one of these instructions wrote Q.
   1. l_i = **read**(Q), l_j = **read**(Q). l_i and l_j don't conflict.
   2. l_i = **read**(Q), l_j = **write**(Q). They conflict.
   3. l_i = **write**(Q), l_j = **read**(Q). They conflict
   4. l_i = **write**(Q), l_j = **write**(Q). They conflict

Conflicting Instructions

- Instructions l_i and l_j of transactions T_i and T_j respectively, **conflict** if and only if there exists some item Q accessed by both l_i and l_j, and at least one of these instructions wrote Q.
    1. l_i = **read**(Q), l_j = **read**(Q). l_i and l_j don't conflict.
    2. l_i = **read**(Q), l_j = **write**(Q). They conflict.
    3. l_i = **write**(Q), l_j = **read**(Q). They conflict
    4. l_i = **write**(Q), l_j = **write**(Q). They conflict

- Intuitively, a conflict between l_i and l_j forces a (logical) temporal order between them.
    - If l_i and l_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

- 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**.

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

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

- E.g. Schedule 3 can be transformed into Schedule 6, 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*)

Schedule 3

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

Schedule 6

Conflict Serializability (Cont.)

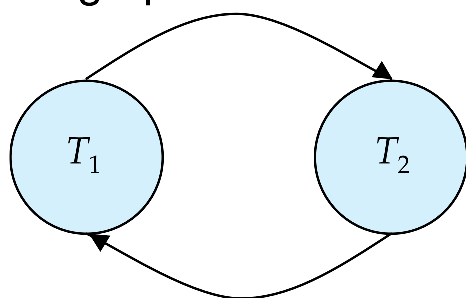
- Example of a schedule that is not conflict serializable:

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 >.

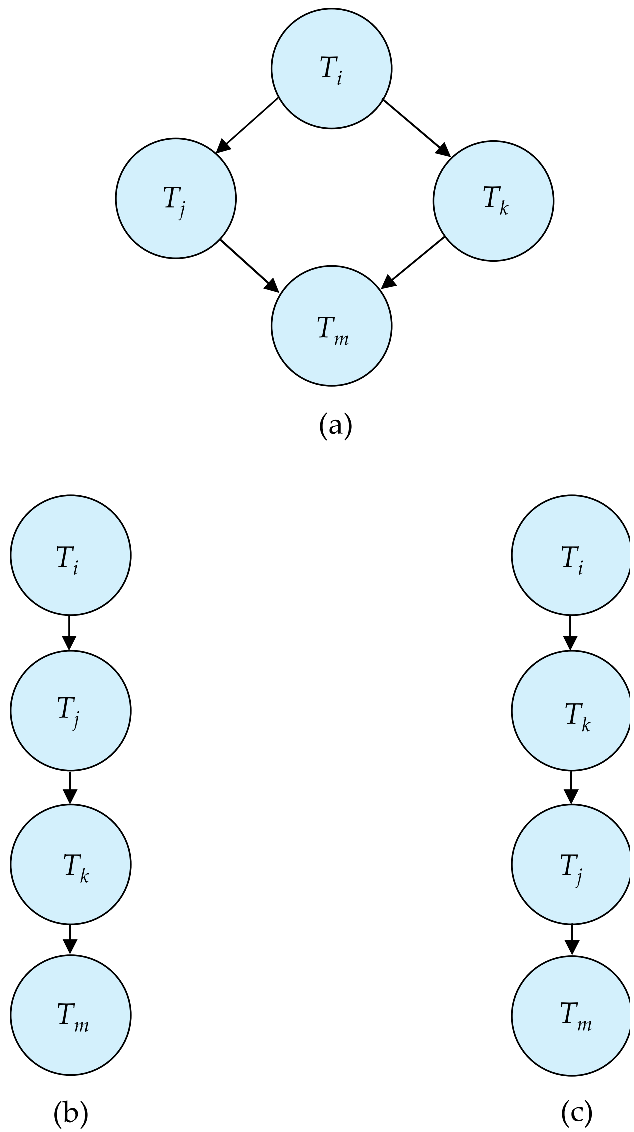
Testing for Serializability

- Consider some schedule of a set of transactions T_1, T_2, ..., T_n
- **Precedence graph** — a direct graph where
  - the vertices are the transactions (names).
  - there is an arc from T_i to T_j if the two transactions conflict, and T_i accessed the data item on which the conflict arose earlier.
- We may label the arc by the item that was accessed.
- Example of a precedence graph



Test for Conflict Serializability

- A schedule is conflict serializable if and only if its precedence graph is acyclic.
- Cycle-detection algorithms exist which take order n^2 time, where n is the number of vertices in the graph.
  - (Better algorithms take order $n + e$ where e is the number of edges.)
- If precedence graph is acyclic, the serializability order can be obtained by a *topological sorting* of the graph.
  - This is a linear order consistent with the partial order of the graph.
  - For example, a serializability order for Schedule A would be $T_5 \rightarrow T_1 \rightarrow T_3 \rightarrow T_2 \rightarrow T_4$
    - Are there others?



Example of Schedule and Precedence Graph

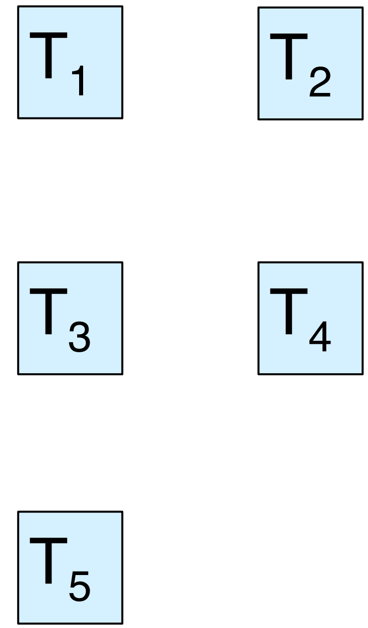
Is this schedule is serializable?

T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				

Example of Schedule and Precedence Graph

Is this schedule is serializable?

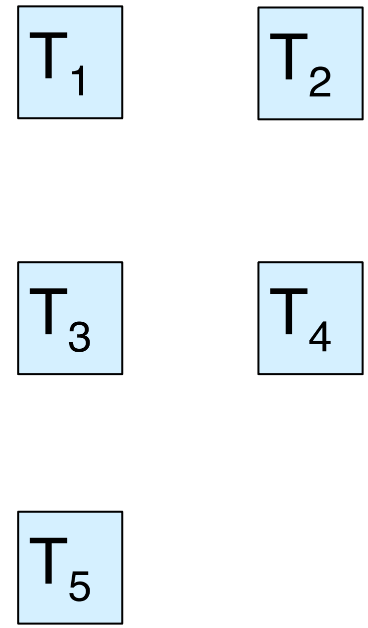
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

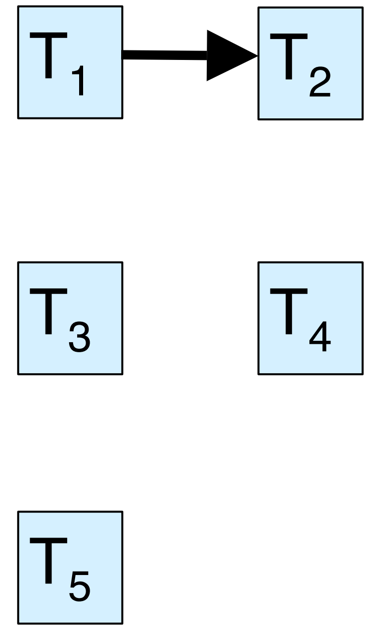
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

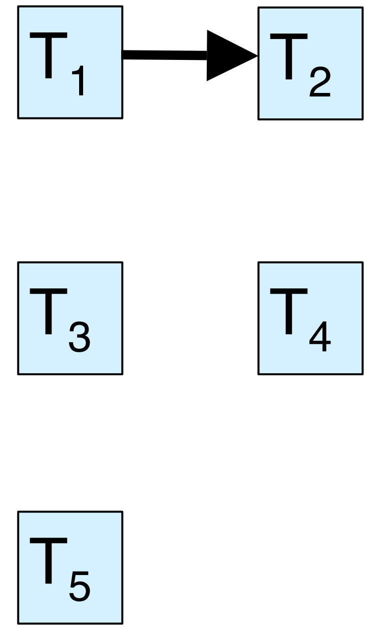
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

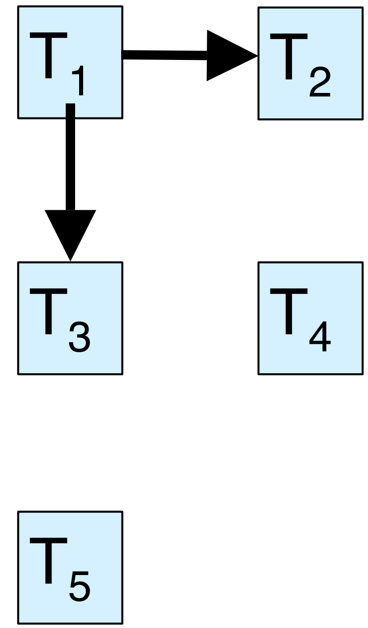
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

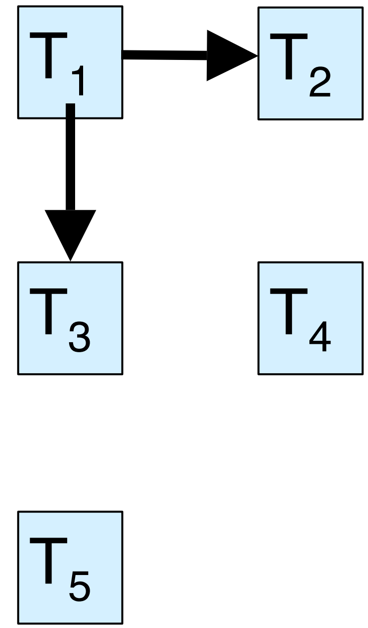
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

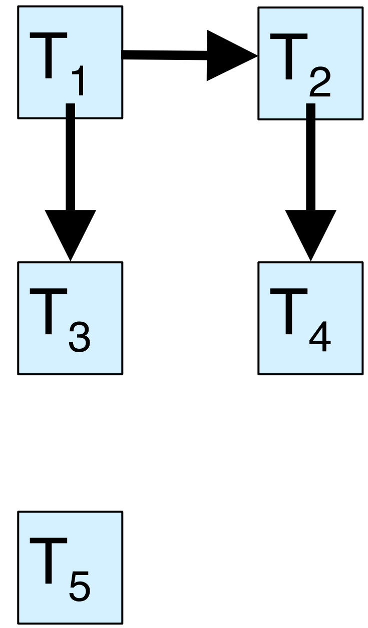
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

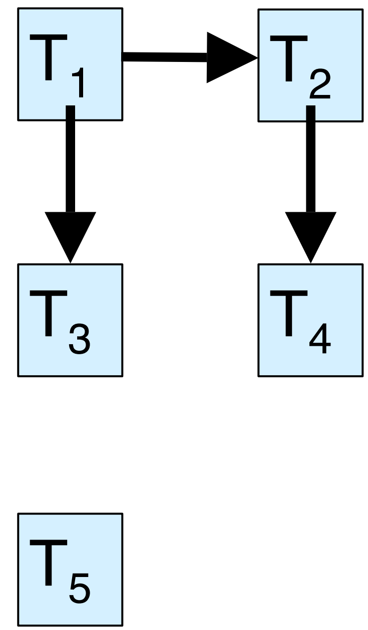
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

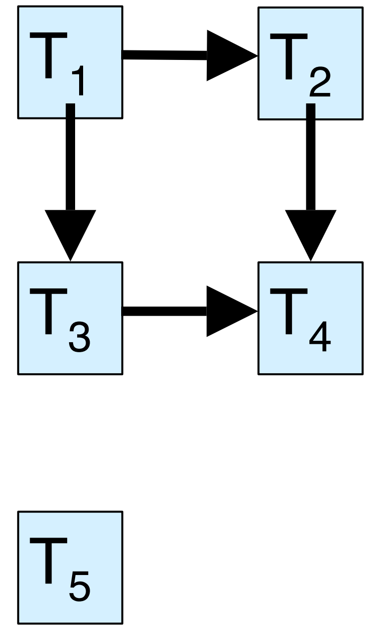
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable?

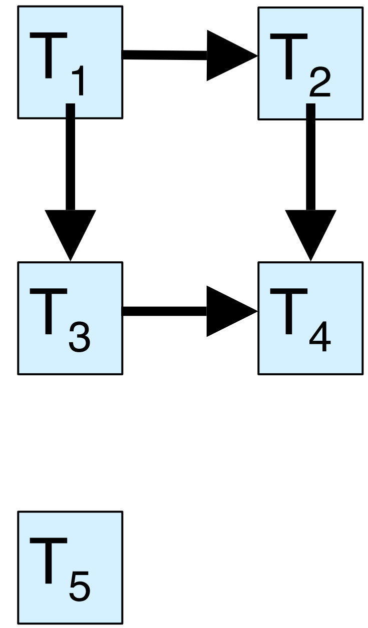
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



Example of Schedule and Precedence Graph

Is this schedule is serializable? **Yes**

T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



View Serializability

- Sometimes it is possible to serialize schedules that are not conflict serializable. E.g.

T_{27}	T_{28}	T_{29}
read (Q)		
	write (Q)	
write (Q)		
		write (Q)

View Serializability

- Sometimes it is possible to serialize schedules that are not conflict serializable. E.g.

T_{27}	T_{28}	T_{29}
read (Q)		
	write (Q)	
write (Q)		
		write (Q)

- This schedule is not conflict serializable

View Serializability

- Sometimes it is possible to serialize schedules that are not conflict serializable. E.g.

T_{27}	T_{28}	T_{29}
read (Q)		
	write (Q)	
write (Q)		
		write (Q)

- This schedule is not conflict serializable
- But it is serializable:
  - It is equivalent to either <T27,T28,T29> or <T28,T27,T29>

View Serializability

- Sometimes it is possible to serialize schedules that are not conflict serializable. E.g.

T_{27}	T_{28}	T_{29}
read (Q)		
	write (Q)	
write (Q)		
		write (Q)

- This schedule is not conflict serializable
- But it is serializable:
  - It is equivalent to either <T27,T28,T29> or <T28,T27,T29>

- **View serialisability** provides a weaker and still consistency preserving notion of serialization

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, for each data item *Q*,
  1. If in schedule S, transaction T_i reads the initial value of *Q*, then in schedule *S'* also transaction T_i must read the initial value of *Q*.
  2. If in schedule S transaction T_i executes **read**(*Q*), and that value was produced by transaction T_j (if any), then in schedule *S'* also transaction T_i must read the value of *Q* that was produced by the same **write**(Q) operation of transaction T_j .
  3. The transaction (if any) that performs the final **write**(*Q*) in schedule *S* must also perform the final **write**(*Q*) operation in schedule *S'*.

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, for each data item *Q*,
  1. If in schedule S, transaction T_i reads the initial value of *Q*, then in schedule *S'* also transaction T_i must read the initial value of *Q*.
  2. If in schedule S transaction T_i executes **read**(*Q*), and that value was produced by transaction T_j (if any), then in schedule *S'* also transaction T_i must read the value of *Q* that was produced by the same **write**(Q) operation of transaction T_j .
  3. The transaction (if any) that performs the final **write**(*Q*) in schedule *S* must also 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

- 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, for each data item *Q*,
  1. If in schedule S, transaction T_i reads the initial value of *Q*, then in schedule *S'* also transaction T_i must read the initial value of *Q*.
  2. If in schedule S transaction T_i executes **read**(*Q*), and that value was produced by transaction T_j (if any), then in schedule *S'* also transaction T_i must read the value of *Q* that was produced by the same **write**(Q) operation of transaction T_j .
  3. The transaction (if any) that performs the final **write**(*Q*) in schedule *S* must also perform the final **write**(*Q*) operation in schedule *S'*.
- As can be seen, view equivalence is also based purely on **reads** and **writes** alone.
- A schedule *S* is **view serialisable** if it is view equivalent to a serial schedule.
  - Every conflict serializable schedule is also view serializable
  - Every view serializable schedule that is not conflict serializable has **blind writes** (i.e. writes that don't read the item in the same transaction)

Test for View Serializability

- The precedence graph test for conflict serializability cannot be used directly to test for view serializability.
  - Extension to test for view serializability has cost exponential in the size of the precedence graph.
- The problem of checking if a schedule is view serializable falls in the class of *NP*-complete problems.
  - Thus, existence of an efficient algorithm is *extremely* unlikely.
- However practical algorithms that just check some **sufficient conditions** for view serializability can still be used.

Recoverable Schedules

What to do if some transaction fails? One needs to address the effect of failures on concurrently running transactions.

Recoverable Schedules

What to do if some transaction fails? One needs to address the effect of failures on concurrently running transactions.

- **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 appears before the commit operation of T_j.

Recoverable Schedules

What to do if some transaction fails? One needs to address the effect of failures on concurrently running transactions.

- **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 appears before the commit operation of T_j.
- The following schedule is not recoverable

Recoverable Schedules

What to do if some transaction fails? One needs to address the effect of failures on concurrently running transactions.

- **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 appears before the commit operation of T_j.
- The following schedule is not recoverable

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

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

Cascading Rollbacks

- **Cascading rollback** – when 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)
abort		

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

- Can lead to undoing of a significant amount of work
- Avoided, in this case, by *anticipating* the commit of T_{10} to before the read in T_{11}, and the commit of T_{11} to before the read in T_{12}

Cascadeless Schedules

- **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

Concurrency Control

- A database must provide a mechanism that will ensure that all possible schedules are
  - either conflict or view serializable, and
  - are recoverable 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
  - Are serial schedules recoverable/cascadeless?
- Testing a schedule for serializability *after* it has executed is a little too late!
- **Goal** – to develop concurrency control protocols that will assure serializability
  - Lock-based protocols
  - Timestamp-based protocols

Concurrency Control (Cont.)

- 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.

Concurrency Control vs. Serializability Tests

- Concurrency-control protocols allow concurrent schedules but ensure that the schedules are conflict/view serializable and are recoverable and cascadeless .
- Concurrency control protocols (generally) do not examine the precedence graph as it is being created
  - Instead a protocol imposes a discipline that avoids non-serializable schedules.
  - We study such protocols next week
- Different concurrency control protocols provide different tradeoffs between the amount of concurrency they allow and the amount of overhead that they incur.
- Tests for serializability help us understand why a concurrency control protocol is correct.

Weak Levels of Consistency

- Some applications are willing to live with weak levels of consistency, allowing schedules that are not serializable
  - E.g., a read-only transaction that wants to get an approximate total balance of all accounts
  - E.g., database statistics computed for query optimization can be approximate (why?)
  - Such transactions need not be serializable with respect to other transactions
- Tradeoff accuracy for performance

Levels of Consistency in SQL

- **Serializable** — default
- **Repeatable read** — only committed records to be read.
  - Repeated reads of same record must return same value.
  - However, a transaction may not be serializable – it may find some records inserted by a transaction but not find others.
- **Read committed** — only committed records can be read.
  - Successive reads of record may return different (but committed) values.
- **Read uncommitted** — even uncommitted records may be read.

Levels of Consistency

- Lower degrees of consistency are useful for gathering approximate information about the database
- Warning: some database systems do not ensure serializable schedules by default
- E.g., Oracle (and PostgreSQL prior to version 9) by default support a level of consistency called snapshot isolation (not part of the SQL standard)

Transaction Definition in SQL

- 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.
- In almost all database systems, by default, every SQL statement also commits implicitly if it executes successfully
  - Implicit commit can be turned off by a database directive
    - E.g., in JDBC -- connection.setAutoCommit(false);
- Isolation level can be set at database level
- Isolation level can be changed at start of transaction
    - E.g. In SQL **set transaction isolation level serializable**
    - E.g. in JDBC -- connection.setTransactionIsolation(
      Connection.TRANSACTION_SERIALIZABLE)

Implementation of Isolation Levels

- Locking
  - Lock on whole database vs lock on items
  - How long to hold lock?
  - Shared vs exclusive locks
- Timestamps
  - Transaction timestamp assigned e.g. when a transaction begins
  - Data items store two timestamps
    - Read timestamp
    - Write timestamp
  - Timestamps are used to detect out of order accesses
- Multiple versions of each data item
  - Allow transactions to read from a “snapshot” of the database

Transactions as SQL Statements

- E.g., Transaction 1:
  select *ID, name* **from** *instructor* **where** *salary* > 90000
- E.g., Transaction 2:
  insert into *instructor* **values** ('11111', 'James', 'Marketing', 100000)
- Suppose
  - T1 starts, finds tuples salary > 90000 using index and locks them
  - And then T2 executes.
  - Do T1 and T2 conflict? Does tuple level locking detect the conflict?
  - Instance of the **phantom phenomenon**
- Also consider T3 below, with Wu's salary = 90000
  update *instructor*
  set *salary* = *salary* * 1.1
  where *name* = 'Wu'
- Key idea: Detect "**predicate**" conflicts, and use some form of "**predicate locking**"