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 gives 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 a 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 **read**s and **write**s alone.

View Serializability (Cont.)

- A schedule S is *view serializable* if 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 which 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**

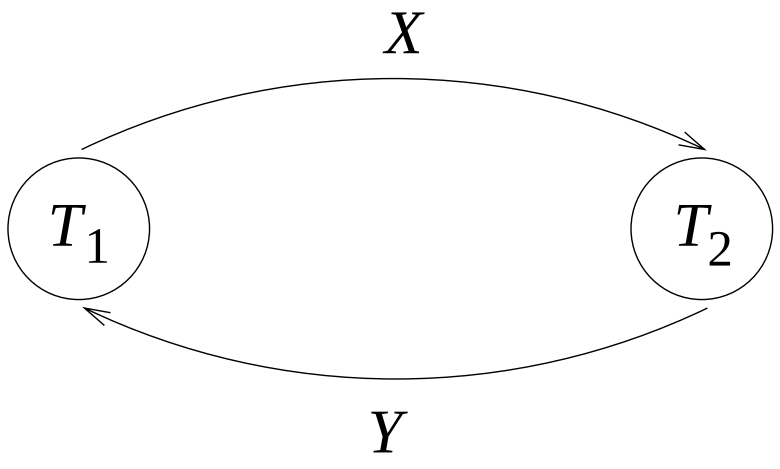
Levels of Consistency in SQL-92

- **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, but successive reads of a record may return different (but committed) values.
- **Read uncommitted** — even uncommitted records may be read.

Lower degrees of consistency useful for gathering approximate information about the database, e.g. statistics for query optimizer.

Testing for Serializability

- Consider some schedule of a set of transactions T_1, T_2, ... , T_n
- *Precedence graph* — a directed graph where the vertices are the transactions (names).
- We draw 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 1**



Example Schedule (Schedule A)

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

Precedence Graph for Schedule A

$$\begin{tikzcd}
T_1 \arrow[r, bend left] \arrow[d, bend right] \arrow[dr] & T_2 \arrow[d, bend left] & \\
 & & T_5 \\
T_3 \arrow[r, bend right] & T_4 &
\end{tikzcd}$$

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 $T_5 \rightarrow T_1 \rightarrow T_3 \rightarrow T_2 \rightarrow T_4$.

Test for View Serializability

- The precedence graph test for conflict serializability must be modified to apply to a test for view serializability.
- Construct a *labeled precedence graph*. Look for an acyclic graph which is derived from the labeled precedence graph by choosing one edge from every pair of edges with the same non-zero label. Schedule is view serializable if and only if such an acyclic graph can be found.
- The problem of looking for such an acyclic graph falls in the class of *NP*-complete problems. Thus existence of an efficient algorithm is unlikely.

  However practical algorithms that just check some *sufficient conditions* for view serializability can still be used.

Concurrency Control vs. Serializability Tests

- Testing a schedule for serializability *after* it has executed is a little too late!
- Goal – to develop concurrency control protocols that will assure serializability. They will generally not examine the precedence graph as it is being created; instead a protocol will impose a discipline that avoids nonserializable schedules.

  Will study such protocols in Chapter 14.
- Tests for serializability help understand why a concurrency control protocol is correct.

Chapter 14: Concurrency Control

- Lock-Based Protocols
- Timestamp-Based Protocols
- Validation-Based Protocols
- Multiple Granularity
- Multiversion Schemes
- Deadlock Handling
- Insert and Delete Operations
- Concurrency in Index Structures

Lock-Based Protocols

- A lock is a mechanism to control concurrent access to a data item
- Data items can be locked in two modes :
  1. *exclusive (X) mode*. Data item can be both read as well as written. X-lock is requested using **lock-X** instruction.
  2. *shared (S) mode*. Data item can only be read. S-lock is requested using **lock-S** instruction.
- Lock requests are made to concurrency-control manager. Transaction can proceed only after request is granted.

Lock-Based Protocols (Cont.)

- Lock-compatibility matrix

	S	X
S	true	false
X	false	false

- A transaction may be granted a lock on an item if the requested lock is compatible with locks already held on the item by other transactions
- The matrix allows any number of transactions to hold shared locks on an item, but if any transaction holds an exclusive on the item no other transaction may hold any lock on the item.
- If a lock cannot be granted, the requesting transaction is made to wait till all incompatible locks held by other transactions have been released. The lock is then granted.

Lock-Based Protocols (Cont.)

- Example of a transaction performing locking:

```
T2: lock-S(A);
    read(A);
    unlock(A);
    lock-S(B);
    read(B);
    unlock(B);
    display(A + B).
```

- Locking as above is not sufficient to guarantee serializability — if *A* and *B* get updated in-between the read of *A* and *B*, the displayed sum would be wrong.
- A *locking protocol* is a set of rules followed by all transactions while requesting and releasing locks. Locking protocols restrict the set of possible schedules.

Pitfalls of Lock-Based Protocols

- Consider the partial schedule

T_3	T_4
lock-X(B)	
read(B)	
$B := B - 50$	
write(B)	
	lock-S(A)
	read(A)
	lock-S(B)
lock-X(A)	

- Neither T_3 nor T_4 can make progress — executing **lock-S**(B) causes T_4 to wait for T_3 to release its lock on B, while executing **lock-X**(A) causes T_3 to wait for T_4 to release its lock on A.
- Such a situation is called a **deadlock**. To handle a deadlock one of T_3 or T_4 must be rolled back and its locks released.

Pitfalls of Lock-Based Protocols (Cont.)

- The potential for deadlock exists in most locking protocols. Deadlocks are a necessary evil.
- **Starvation** is also possible if concurrency control manager is badly designed. For example:
  - A transaction may be waiting for an X-lock on an item, while a sequence of other transactions request and are granted an S-lock on the same item.
  - The same transaction is repeatedly rolled back due to deadlocks.
- Concurrency control manager can be designed to prevent starvation.

The Two-Phase Locking Protocol

- This is a protocol which ensures conflict-serializable schedules.
- Phase 1: Growing Phase
  - transaction may obtain locks
  - transaction may not release locks
- Phase 2: Shrinking Phase
  - transaction may release locks
  - transaction may not obtain locks
- The protocol assures serializability. It can be proved that the transactions can be serialized in the order of their *lock points* (i.e. the point where a transaction acquired its final lock).

The Two-Phase Locking Protocol (Cont.)

- Two-phase locking *does not* ensure freedom from deadlocks
- Cascading roll-back is possible under two-phase locking. To avoid this, follow a modified protocol called *strict two-phase locking*. Here a transaction must hold all its exclusive locks till it commits/aborts.
- *Rigorous two-phase locking* is even stricter: here *all* locks are held till commit/abort. In this protocol transactions can be serialized in the order in which they commit.

The Two-Phase Locking Protocol (Cont.)

- There can be conflict serializable schedules that cannot be obtained if two-phase locking is used.
- However, in the absence of extra information (e.g., ordering of access to data), two-phase locking is needed for conflict serializability in the following sense:

  Given a transaction T_i that does not follow two-phase locking, we can find a transaction T_j that uses two-phase locking, and a schedule for T_i and T_j that is not conflict serializable.