Chapter 14: Transactions

Database System Concepts, 6th 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

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
  - 4 Explicitly specified integrity constraints such as primary keys and foreign keys
  - 4 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, 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

- **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. $A := A - 50$	1000-50
3. **write**(A)	950
	read(A), read(B), print(A+B) 950,2000,2950
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.
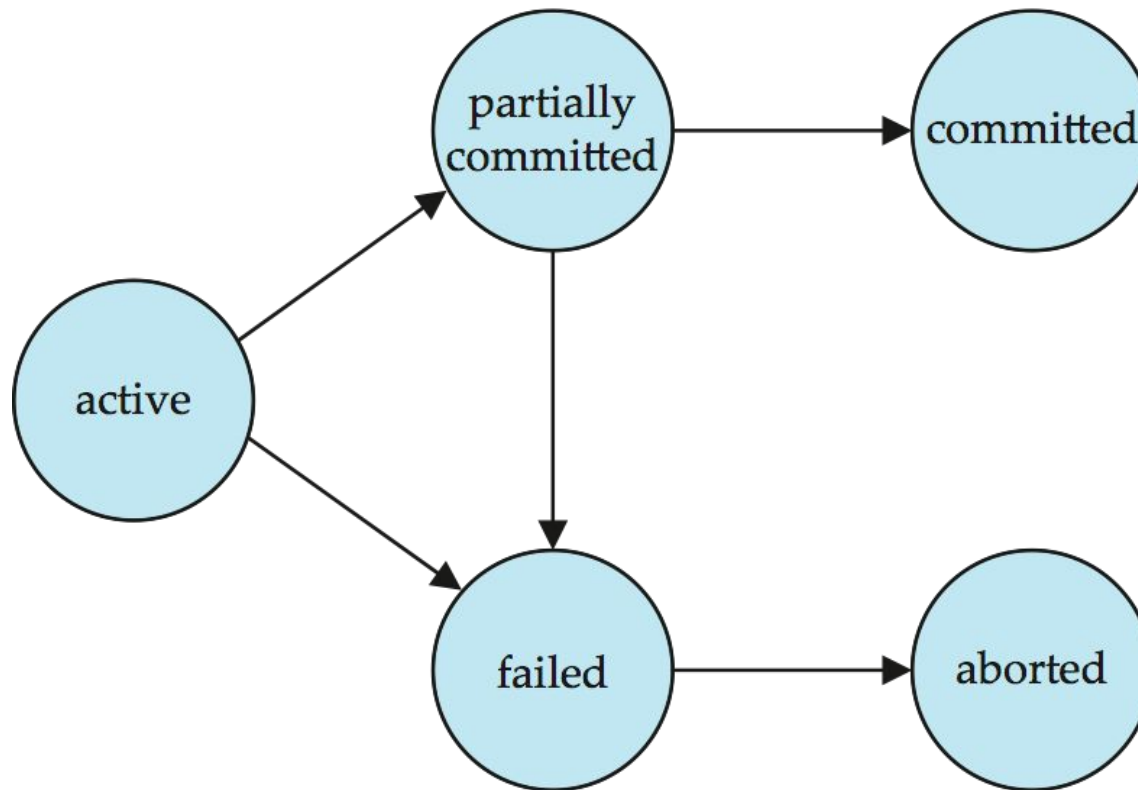
Transaction State

- **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

        4 can be done only if no internal logical error

    - Kill the transaction

- **Committed** – after successful completion.

Transaction State (Cont.)

Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:

  - **Increased processor and disk utilization**, leading to better transaction *throughput*

    4 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

    4 Will study in Chapter 15, after studying 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

  - 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

Schedule 1

- Let T_1 transfer $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

T1	T2
1000	
950	
950	
2000	
2050	
	950
	95
	855
	2050
	2145
	2145

2000+1000=3000
855 +2145=3000

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	

T1	T2
	1000
	100
	900
	2000
	2100
900	
850	
850	
2100	
2150	

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

T1	T2
1000	
950	
	950
	95
	855
2000	
2050	
	2050
	2145
	2145

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

T1	T2
1000	
950	
	1000
	100
	900
	2000
950	
2000	
2050	
2050	
	2095
	2095

$$1000+2000=3000$$
$$950+2095=3045$$

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 l_i and l_j be two Instructions of transactions T_i and T_j respectively. Instructions l_i and l_j **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**.

- We say that a schedule S is **conflict serializable** if it is conflict equivalent to a serial schedule

Conflict Serializability (Cont.)

- Schedule 3 can be transformed into Schedule 6 -- 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)

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 $< T_4, T_3 >$.

Precedence Graph

- 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).

- We draw an arc from T_i to T_j if the two transaction 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**
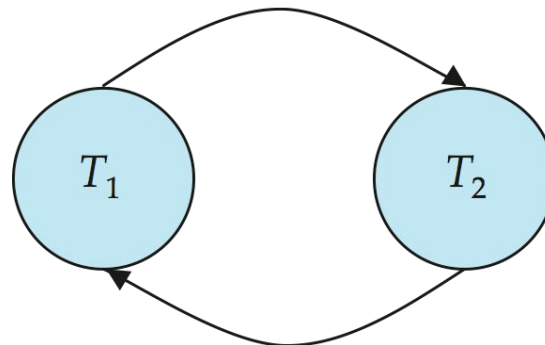
Testing for Conflict Serializability

- 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.

  - That is, a linear order consistent with the partial order of the graph.

  - For example, a serializability order for the schedule (a) would be one of either (b) or (c)

(a)

(b)

(c)
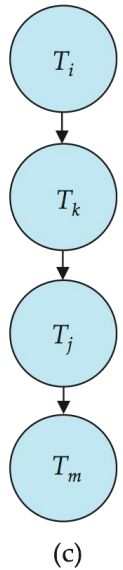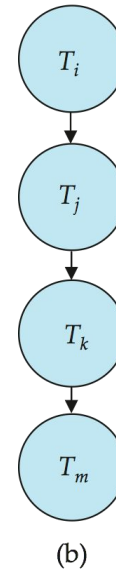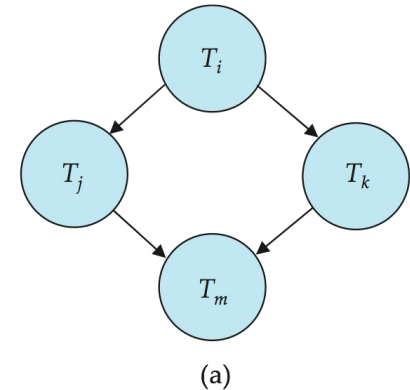
Recoverable Schedules

- **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.

- The following schedule is not recoverable if T_9 commits immediately after the read(A) operation.

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) an inconsistent database state. Hence, database must ensure that schedules are recoverable.

Cascading Rollbacks

- **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)
abort		

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

Cascadeless Schedules

- **Cascadeless schedules** — 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

- Example of a schedule that is NOT cascadeless

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

Concurrency Control

- A database must provide a mechanism that will ensure that all possible schedules are both:

    - Conflict serializable.

    - 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

- Concurrency-control schemes tradeoff between the amount of concurrency they allow and the amount of overhead that they incur

- Testing a schedule for serializability *after* it has executed is a little too late!

    - Tests for serializability help us understand why a concurrency control protocol is correct

- **Goal** – to develop concurrency control protocols that will assure serializability.

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-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 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

- Warning: some database systems do not ensure serializable schedules by default
  - E.g., Oracle and PostgreSQL by default support a level of consistency called snapshot isolation (not part of the SQL standard)

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.

- 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

    - 4 E.g. in JDBC, connection.setAutoCommit(false);

Other Notions of Serializability

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) operation 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 (Cont.)

- A schedule S is **view serializable** if it is view equivalent to a serial schedule.
- Every conflict serializable schedule is also view serializable.
- Below is a schedule which is view-serializable but *not* conflict serializable.

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

T27   t28   t29

Read
Write
     write   write

- What serial schedule is above equivalent to?
- Every view serializable schedule that is not conflict serializable has **blind writes.**

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.
- Below is a schedule which is view-serializable but *not* conflict serializable.

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

T27   t28   t29

Read
Write
     write   write

- What serial schedule is above equivalent to?
- Every view serializable schedule that is not conflict serializable has **blind writes.**

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.

More Complex Notions of Serializability

- The schedule below produces the 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)

- If we start with A = 1000 and B = 2000, the final result is 960 and 2040
- Determining such equivalence requires analysis of operations other than read and write.

End of Chapter 14

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