Transactions

- **Transaction Concept**
- Concurrent Executions and Schedules
- Serializability
- Recoverable and Cascadeless Schedules

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 that may result in the database becoming inconsistent during transaction execution:
  - Failures of various kinds, such as hardware failures and system crashes
  - Concurrent execution of multiple transactions ← *You will learn this very soon!*

Example of Fund Transfer

- 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, i.e., the sum of *A* and *B* is no longer preserved.

    - 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.

Example of Fund Transfer (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*)

- In general, **consistency requirements** include

  - Explicit integrity constraints such as primary keys and foreign keys
  - Implicit integrity constraints, e.g., sum of *A* and *B* be unchanged by the execution of the transaction

- A transaction must see a consistent database.
- If the database is consistent before an execution of the transaction, the database remains consistent after the execution of the transaction.
  - Erroneous transaction logic can lead to inconsistency
- However, during transaction execution, the database may be temporarily inconsistent…..

Example of Fund Transfer (Cont.)

- **Isolation requirement**
  - If between steps 3 and 6, 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.

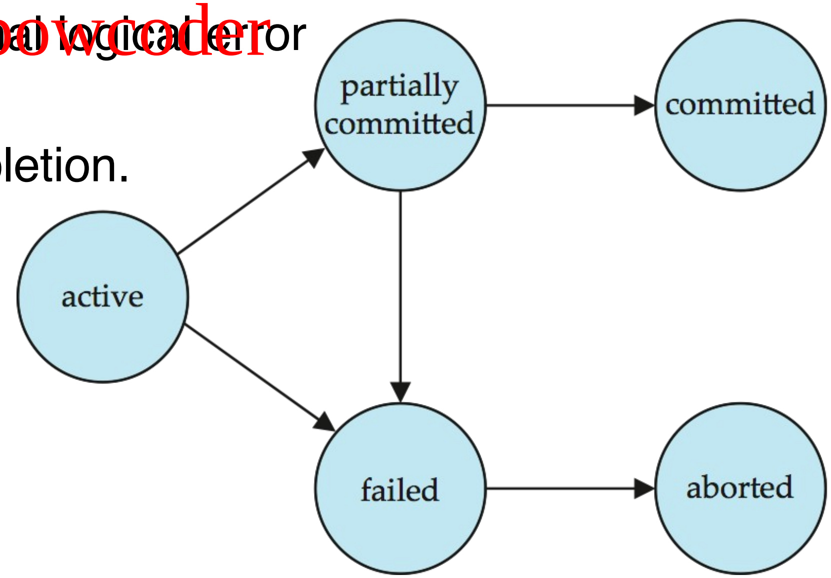
- **Consistency.** Execution of a transaction in isolation preserves the consistency of the database. ← *Responsibility of application programmers!*

- **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. ← *Responsibility of concurrency-control system!*
  - 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.



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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***
  - To control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database
    - Will study after studying notion of correctness of concurrent executions.

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 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.
- 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	

Schedule 3

- Let T_1 and T_2 be the transactions defined previously. The following schedule is **not** a serial schedule, but it arrives at the same state as 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

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Serializability

- **Basic Assumption** – Each transaction preserves database consistency.
- Thus serial execution of a set of transactions preserves database consistency.
- So, database consistency under concurrent execution can be ensured by making sure that any schedule has the same effect as a serial schedule.
- 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**
     - Is not used in practice due to its high computational complexity.

Simplified view of transactions

- From a scheduling point of view, the only significant operations of a transaction are **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.
- A common notation:
  - Example:
    - T_1: $r_1(A)$; $w_1(A)$; $r_1(B)$; $w_1(B)$;
    - T_2: $r_2(A)$; $w_2(A)$; $r_2(B)$; $w_2(B)$;
    - S_3: $r_1(A)$; $w_1(A)$; $r_2(A)$; $w_2(A)$; $r_1(B)$; $w_1(B)$; $r_2(B)$; $w_2(B)$;

Schedule 3

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

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.

  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

- 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 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 >.

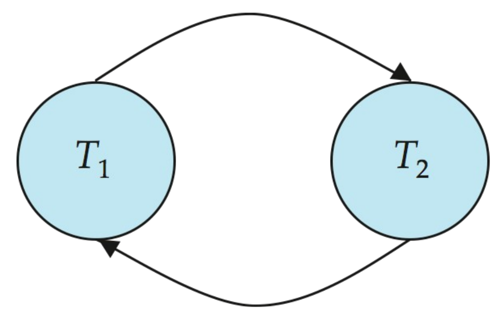
Testing for Serializability

- A simple method for determining conflict serializability.
- Consider a 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.

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

Schedule 4

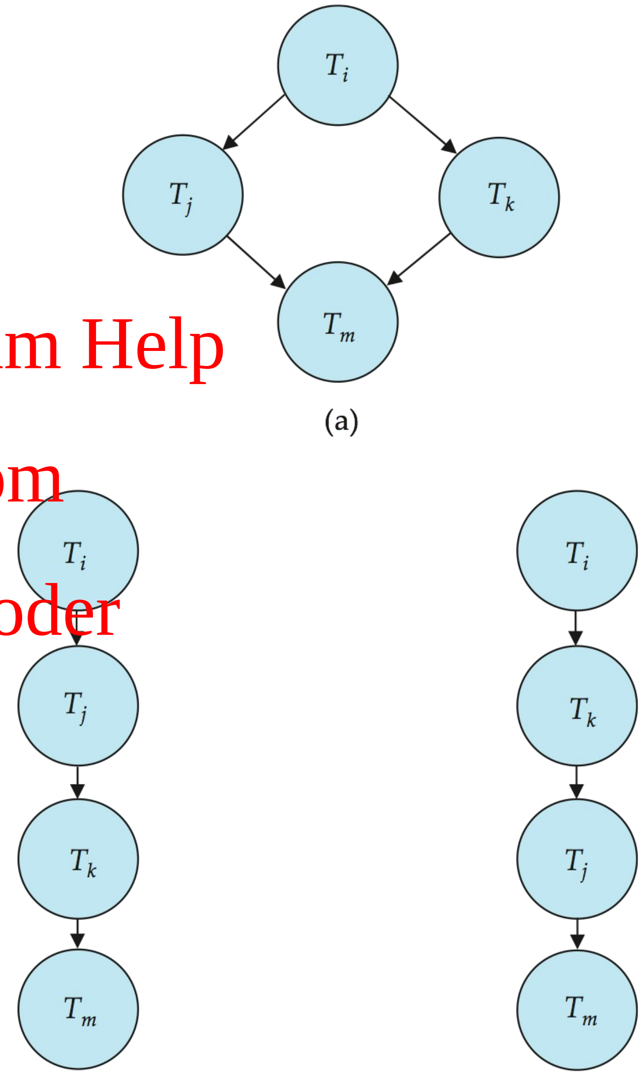
S_4: $r_1(A)$; $r_2(A)$; $w_2(A)$; $r_2(B)$; $w_1(A)$; $r_1(B)$; $w_1(B)$; $w_2(B)$;



Precedence graph for Schedule 4

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.



(a) (b) (c)

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Recoverable Schedules

Need to address the effect of **transaction failures** on concurrently running transactions.

- 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)
	commit
read (B)	

- If T_8 should abort, T_9 would have read (and possibly shown to the user) an inconsistent database state (the value of A written by the aborted T_8). We must abort T_9 to ensure atomicity.
- Hence, database must ensure that schedules are recoverable.
- **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.

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** — 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, i.e., allow transaction to only read committed data.

- Every cascadeless schedule is also recoverable

- It is desirable to restrict the schedules to those that are cascadeless

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