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

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
    - 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*)
- **Consistency requirement** in above 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
    - Erroneous transaction logic can lead to inconsistency

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

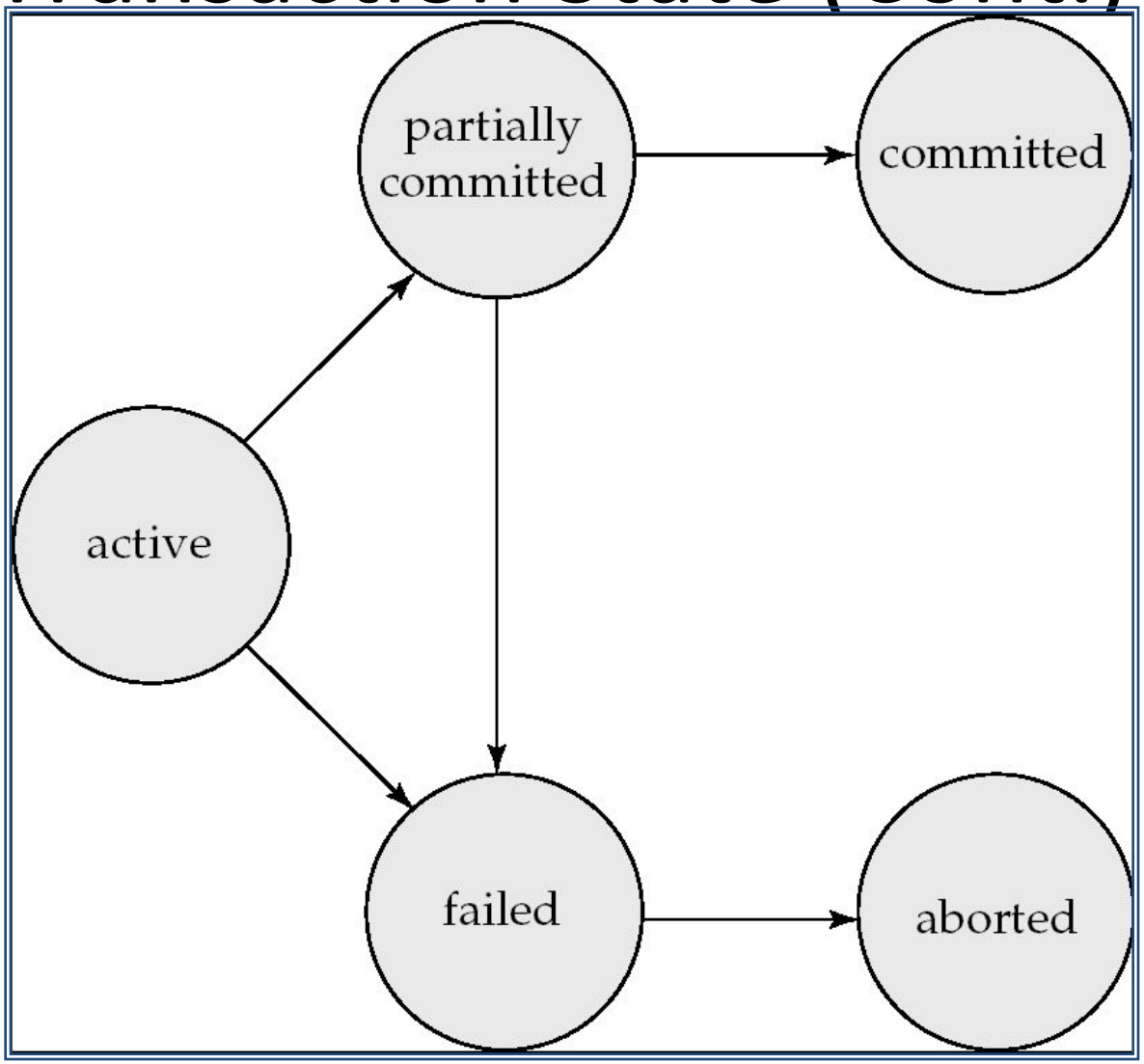
A **transaction** is a unit of program execution that accesses and possibly updates various data items.To preserve the integrity of data the database system must ensure:

- **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.
- **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

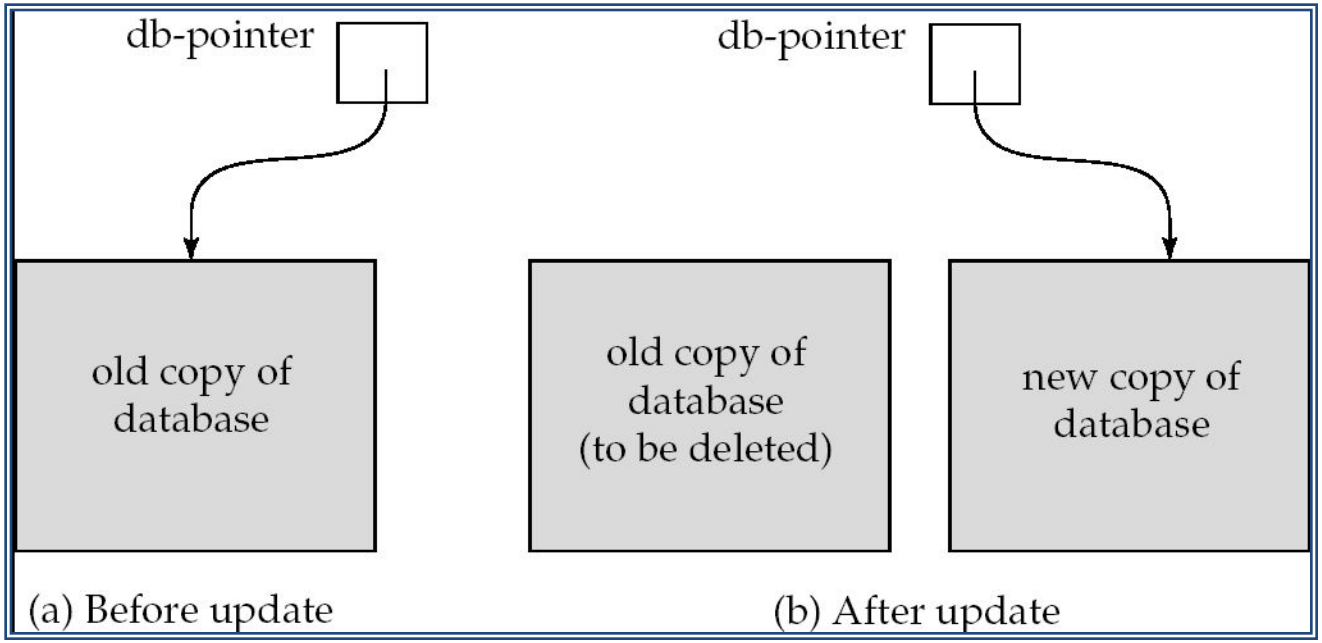
- **Active** – the initial state; the transaction stays in this state while it is executing
- **Partially committed** – after the final statement has been executed.
- **Failed** -- after the discovery that normal execution can no longer proceed.
- **Aborted** – after the transaction has been rolled back and the database restored to its state prior to the start of the transaction. Two options after it has been aborted:
  - restart the transaction
    - can be done only if no internal logical error
  - kill the transaction
- **Committed** – after successful completion.

Transaction State (Cont.)



Implementation of Atomicity and Durability

- The **recovery-management** component of a database system implements the support for atomicity and durability.
- E.g. the ***shadow-database*** scheme:
  - all updates are made on a *shadow copy* of the database
    - **db_pointer** is made to point to the updated shadow copy after
      - the transaction reaches partial commit and
      - all updated pages have been flushed to disk.



Implementation of Atomicity and Durability (Cont.)

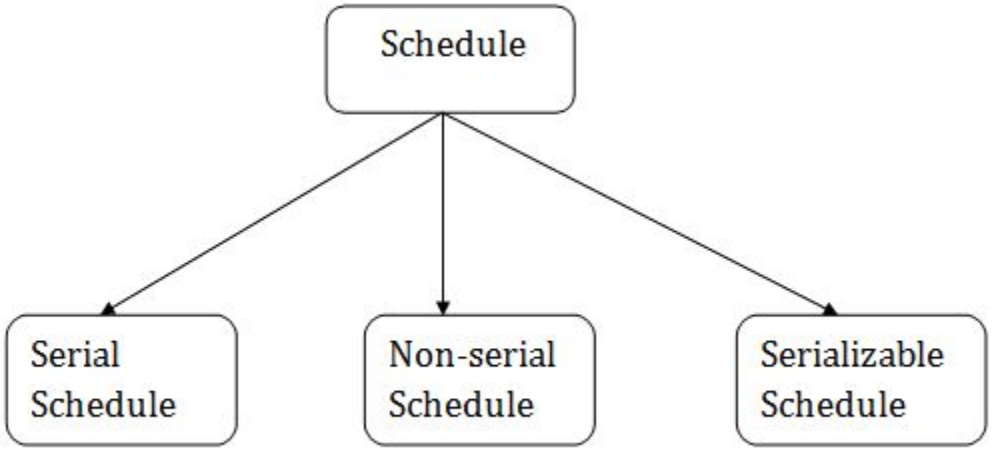
- db_pointer always points to the current consistent copy of the database.
  - In case transaction fails, old consistent copy pointed to by **db_pointer** can be used, and the shadow copy can be deleted.
- The shadow-database scheme:
  - Assumes that only one transaction is active at a time.
  - Assumes disks do not fail
  - Useful for text editors, but
    - extremely inefficient for large databases (why?)
      - Variant called shadow paging reduces copying of data, but is still not practical for large databases
  - Does not handle concurrent transactions

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** – it is chronological execution sequence of multiple transactions.
- 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



1. Serial Schedule

- The serial schedule is a type of schedule where one transaction is executed completely before starting another transaction. In the serial schedule, when the first transaction completes its cycle, then the next transaction is executed.
- **For example:** Suppose there are two transactions T1 and T2 which have some operations. If it has no interleaving of operations, then there are the following two possible outcomes:

1. Execute all the operations of T1 which was followed by all the operations of T2.
2. Execute all the operations of T2 which was followed by all the operations of T1.

- In the given, Schedule 1 shows the serial schedule where T1 followed by T2.
- In the given, Schedule 2 shows the serial schedule where T2 followed by T1.

Schedule 1

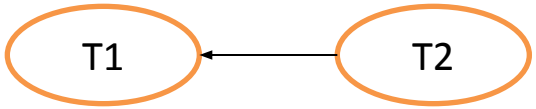
- Let T_1 transfer \$50 from *A* to *B*, and T_2 transfer 10% of the balance from *A* to *B.*
- A serial schedule in which T_1 is followed by T_2 :

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

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)
read(A) $A := A - 50$ write(A) read(B) $B := B + 50$ write(B)	



2. Non-serial Schedule

- If interleaving of operations is allowed, then there will be non-serial schedule.
- It contains many possible orders in which the system can execute the individual operations of the transactions.
- In the given figure (3) and (4), Schedule 3 and Schedule 4 are the non-serial schedules. It has interleaving of operations.

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)	
	read(B)
	$B := B + temp$
	write(B)

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)	
	$B := B + temp$
	write(B)

Serializability

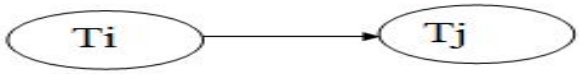
- **Basic Assumption** – Each transaction preserves database consistency.
- Thus serial execution of a set of transactions preserves database consistency.
- A (possibly concurrent) schedule is serializable if it is equivalent to a serial schedule. Different forms of schedule equivalence give rise to the notions of:
  1. **conflict serializability (** A schedule is called **conflict serializable** if it can be transformed into a serial schedule by swapping non-conflicting)
  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.

Testing of Serializability

- Serialization Graph is used to test the Serializability of a schedule.
- Assume a schedule S. For S, we construct a graph known as precedence graph. This graph has a pair G = (V, E), where V consists a set of vertices, and E consists a set of edges. The set of vertices is used to contain all the transactions participating in the schedule. The set of edges is used to contain all edges Ti ->Tj for which one of the three conditions holds:

1. Create a node Ti → Tj if Ti executes write (Q) before Tj executes read (Q).
2. Create a node Ti → Tj if Ti executes read (Q) before Tj executes write (Q).
3. Create a node Ti → Tj if Ti executes write (Q) before Tj executes write (Q).

Precedence graph for Schedule S



- If a precedence graph contains a single edge Ti → Tj, then all the instructions of Ti are executed before the first instruction of Tj is executed.
- If a precedence graph for schedule S contains a cycle, then S is non-serializable. If the precedence graph has no cycle, then S is known as serializable.

Examples : To find Schedule is non-serializable and Serializable

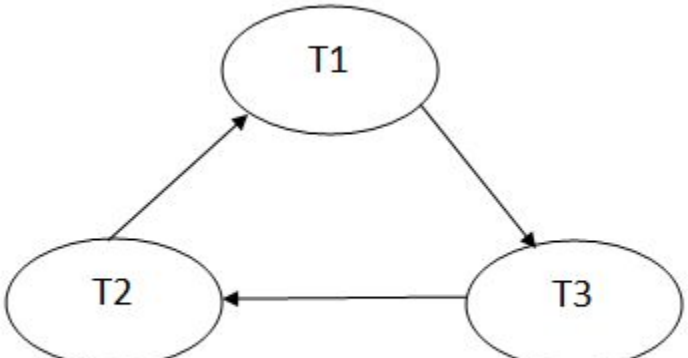
T1	T2	T3
Read(A)		
	Read(B)	
A:= f_1(A)		
		Read(C)
	B:= f_2(B)	
	Write(B)	
		C:= f_3(C)
		Write(C)
Write(A)		
		Read(B)
	Read(A)	
	A:= f_4(A)	
Read(C)		
	Write(A)	
C:= f_5(C)		
Write(C)		
		B:= f_6(B)
		Write(B)

Time

Schedule S1

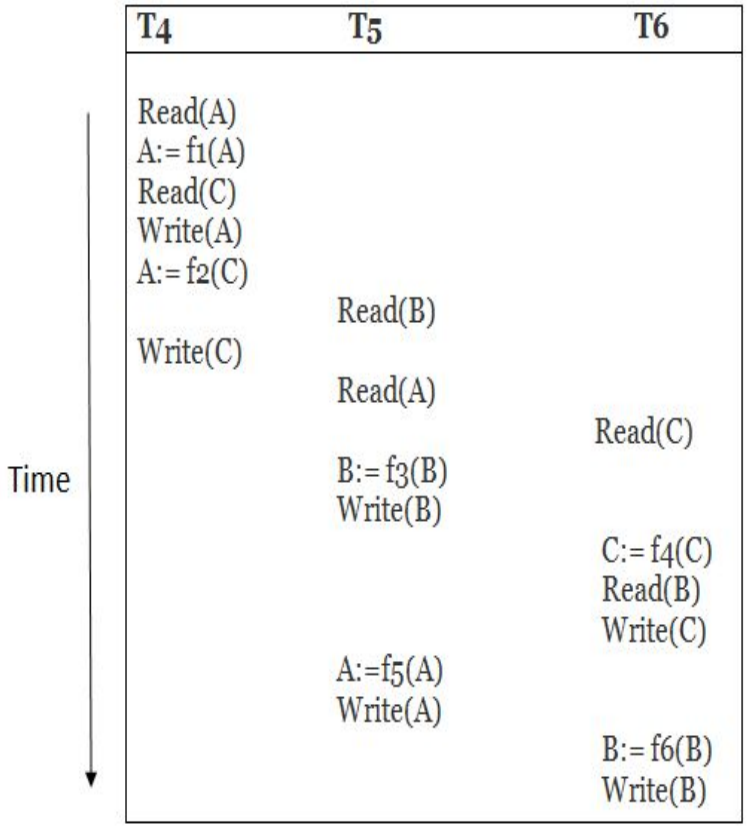
Explanation:
Read(A): In T1, no subsequent writes to A, so no new edges
Read(B): In T2, no subsequent writes to B, so no new edges
Read(C): In T3, no subsequent writes to C, so no new edges
Write(B): B is subsequently read by T3, so add edge T2 → T3
Write(C): C is subsequently read by T1, so add edge T3 → T1
Write(A): A is subsequently read by T2, so add edge T1 → T2
Write(A): In T2, no subsequent reads to A, so no new edges
Write(C): In T1, no subsequent reads to C, so no new edges
Write(B): In T3, no subsequent reads to B, so no new edges

Precedence graph for schedule S1:



The precedence graph for schedule S1 contains a cycle that's why Schedule S1 is non-serializable.

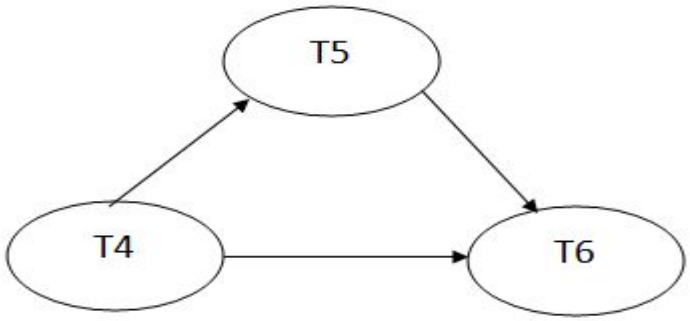
Examples : To find Schedule is Serializable



Schedule S2

Explanation:
Read(A): In T4,no subsequent writes to A, so no new edges
Read(C): In T4, no subsequent writes to C, so no new edges
Write(A): A is subsequently read by T5, so add edge T4 → T5
Read(B): In T5,no subsequent writes to B, so no new edges
Write(C): C is subsequently read by T6, so add edge T4 → T6
Write(B): A is subsequently read by T6, so add edge T5 → T6
Write(C): In T6, no subsequent reads to C, so no new edges
Write(A): In T5, no subsequent reads to A, so no new edges
Write(B): In T6, no subsequent reads to B, so no new edges

Precedence graph for schedule S2:



The precedence graph for schedule S2 contains no cycle that's why ScheduleS2 is serializable.

Illustrate serial schedule in which T1 followed by T2 the values after final execution are Rs 855 and Rs 2145 current value of account A is 1000 and account B is 2000 ?

- Given current balance of account A is 1000 and account B is 2000.
- While the value after the transaction are Rs 855 and Rs 2145 respectively for account A and account B.
- Lets assume 10% of the transfer for T2 followed after completion of T1.
- Hence the supposed amount for transaction T1 is Rs.50.
- Therefore the transactions T1 followed by T2 using serial scheduling are as follows:

T1	T2
Read(A) □ 1000	
A:=A-50 □ 950	
Write(A) □ 950	
Read(B) □ 2000	
B:=B+50 □ 2050	
Write(B) □ 2050	
	Read(A) □ 950
	Temp =A*0.1 □ 95
	A:=A-Temp □ 855
	Write(A) □ 855
	Read(B) □ 2050
	B:=B+Temp □ 2145
	Write(B) □ 2145

Conflict Serializable Schedule

- A schedule is called conflict serializability if after swapping of non-conflicting operations, it can transform into a serial schedule.
- The schedule will be a conflict serializable if it is conflict equivalent to a serial schedule.
- Conflicting Operations
- The two operations become conflicting if all conditions satisfy:

1. Both belong to separate transactions.
2. They have the same data item.
3. They contain at least one write operation.

Pair of Non Conflict & Conflict pairs

Non Conflict Pair	Conflict Pair
Read (A) Read (A)	Read (A) Write (A)
Read (B) Read (A)	Write (A) Read (A)
Write (B) Read (A)	Write (A) Write (A)
Read (B) Write (A)	-
Write (A) Write (B)	-

Example:

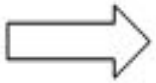
Swapping is possible only if S1 and S2 are logically equal.

1. T1: Read(A) T2: Read(A)

T1	T2
Read(A)	
	Read(A)

Schedule S1

Swapped



T1	T2
	Read(A)
Read(A)	

Schedule S2

Here, S1 = S2. That means it is non-conflict.

Example:

Swapping is possible only if S1 and S2 are logically equal.

2. T1: Read(A) T2: Write(A)

T1	T2
Read(A)	
	Write(A)

Schedule S1

Swapped

T1	T2
	Write(A)
Read(A)	

Schedule S2

Here, S1 ≠ S2. That means it is conflict.

Conflict Equivalent

- In the conflict equivalent, one can be transformed to another by swapping non-conflicting operations. In the given example, S2 is conflict equivalent to S1 (S1 can be converted to S2 by swapping non-conflicting operations).
- Two schedules are said to be conflict equivalent if and only if:

1. They contain the same set of the transaction.
2. If each pair of conflict operations are ordered in the same way.

Example:

Non-serial schedule

T1	T2
Read(A)	
Write(A)	
	Read(A)
	Write(A)
Read(B)	
Write(B)	
	Read(B)
	Write(B)

Schedule S1

Serial Schedule

T1	T2
Read(A)	
Write(A)	
Read(B)	
Write(B)	
	Read(A)
	Write(A)
	Read(B)
	Write(B)

Schedule S2

Schedule S2 is a serial schedule because, in this, all operations of T1 are performed before starting any operation of T2. Schedule S1 can be transformed into a serial schedule by swapping non-conflicting operations of S1.

After swapping of non-conflict operations, the schedule S1 becomes:

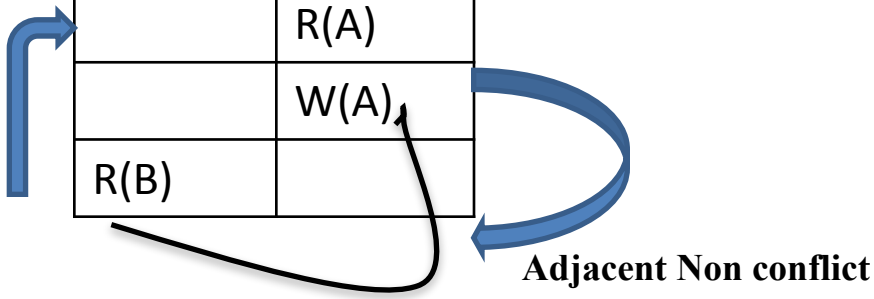
T1	T2
Read(A)	
Write(A)	
Read(B)	
Write(B)	
	Read(A)
	Write(A)
	Read(B)
	Write (B)

Finding Conflict Equivalent Schedule

(Now consider two schedule i.e S & S' & Transaction T1 & T2

S

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
R(B)	



Adjacent Non conflict

S'

T1	T2
R(A)	
W(A)	
R(B)	
	R(A)
	W(A)

Step 2

T1	T2
R(A)	
W(A)	
	R(A)
R(B)	
	W(A)

Step 3

T1	T2
R(A)	
W(A)	
R(B)	
	R(A)
	W(A)

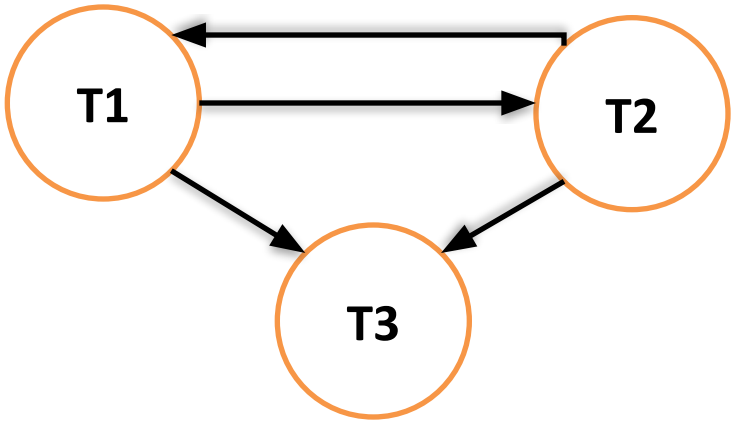
So, Schedule S ≡ S' Conflict Equivalent Schedule

To Check whether Schedule is Conflict serializable or Not

(Consider a Schedule S = (R1(A), W2(A), W1(A), W3(A))

T1	T2	T3
R(A)		
	W(A)	
W(A)		
		W(A)

Draw the precedence Graph



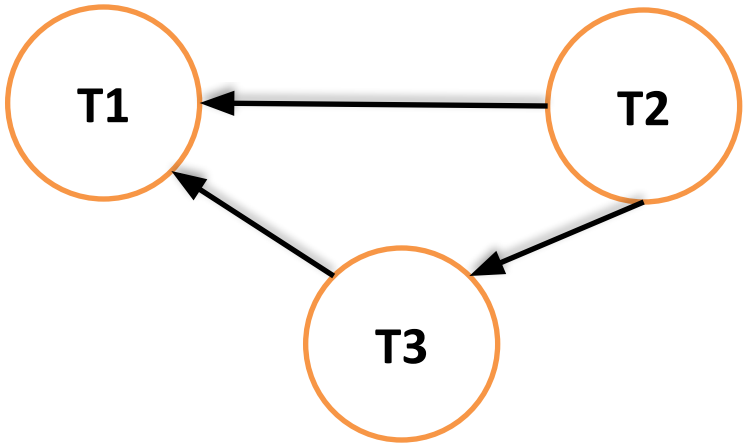
In this Graph Loop is present so, it is Non Conflict Serializable

To Check whether Schedule is Conflict serializable or Not

(Consider a Schedule S = (R1(X), R3(Y), R3(X), R2(Y), R2(Z), W3(Y), W2(Z), R1(Z), W1(X), W1(Z))

T1	T2	T3
R(X)		
		R(Y)
		R(X)
	R(Y)	
	R(Z)	
		W(Y)
	W(Z)	
R(Z)		
W(X)		
W(Z)		

Draw the precedence Graph



In this Graph No Loop & No Cycle, So this Schedule is Conflict Serializable

To Check Indegree = 0

T1	T2	T3
	0	
		0
0		

T2→T3 →T1 , So, This Graph is conflict, Serializable, & Consistence)

Exercises

1. Which of the following schedule is conflict serializable? For each serializable schedule, Determine the equivalent serial schedule.

a) r1(X);r3(X);w1(X);r2(X);w3(X);

b) r1(X);r3(X);w3(X);w1(X); r2(X);

c) r3(X);r2(X);w3(X);r1(X); w1(X);

d) r3(X);r2(X);r1(X);w3(X); w1(X);

2. Consider three transaction T1,T2,T3 and the schedules S1and S2 given below. Draw the serializability (precedence) graph for S1 and S2 and state whether each schedule is serializable or not. If a schedule is serializable, write down the equivalent serial schedule (s).

T1: r1(X); r1(Z); w1(X);

T2: r2(Z); r2 (Y); w2(Z); w2(Y);

T3: r3(x); r3(Y); w3(Y);

S1 : r1(X);r2(Z);r1(Z);r3(X);r3(Y);w1(X);w3(Y);r2(Y);w2(Z);w2(Y);

S2 : r1(X);r2(Z);r3(X);r1(Z);r2(Y);r3(Y);w1(X);w2(Z);w3(Y);w2(Y);