Concurrency Control: 2PL

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Lock Management

- A lock is a mechanism to control concurrent access to a data item
- Lock requests are made to concurrency-control manager or lock manager. Transaction can proceed only after request is granted.
- Lock table entry:
  - Number of transactions currently holding a lock
  - Type of lock held (shared or exclusive)
  - Pointer to queue of lock requests

3 Types of Locks

- We allow transactions to **lock** objects.

Shared lock (S): Data item can **only be read**. S-lock is requested using **lock-S** instruction.

Exclusive lock (X): Data item can be **both read** as well as **write**. X-lock is requested using **lock-X** instruction.

Lock-Based Protocols (Cont.)

- **Lock-compatibility matrix**

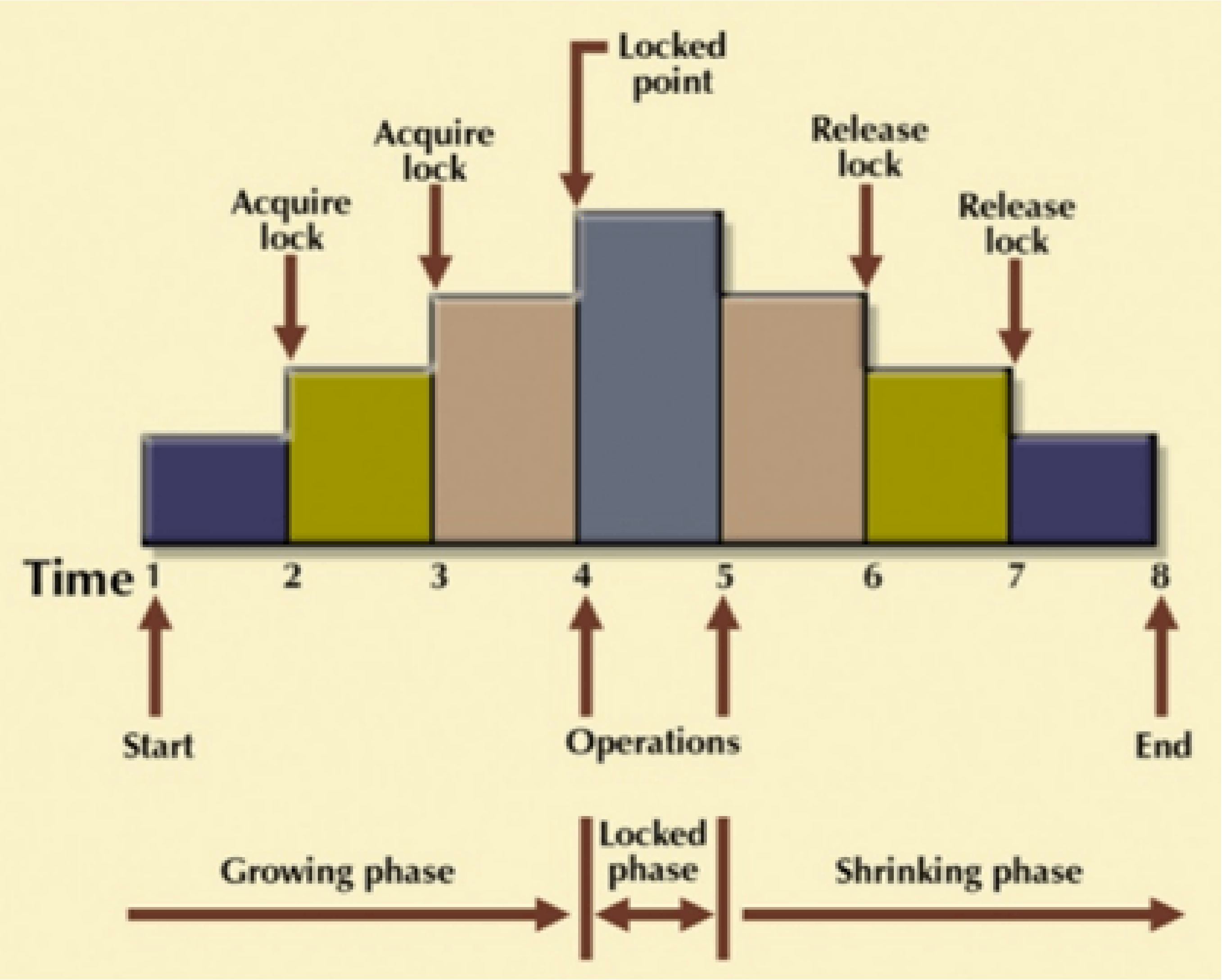
	S	X
S	true	false
X	false	false

- **Any number of transactions can 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.

The Two-Phase Locking (2PL) 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).

2 PL


Locked
point
Acquire
lock
Acquire
lock
Release
lock
Release
lock
Time 1 2 3 4 5 6 7 8
Start
Operations
End
Growing phase
Locked
phase
Shrinking phase

The Two-Phase Locking Protocol (Cont.)

- 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
- 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.
- .

Lock Conversions

- Two-phase locking with lock conversions:
  - First Phase:
    - can acquire a lock-S on item
    - can acquire a lock-X on item
    - can convert a lock-S to a lock-X (upgrade)
  - Second Phase:
    - can release a lock-S
    - can release a lock-X
    - can convert a lock-X to a lock-S (downgrade)
- This protocol assures serializability. But still relies on the programmer to insert the various locking instructions.

2 PL: Automatic Acquisition of Locks - read

- A transaction T_i issues the standard read/write instruction, without explicit locking calls.
- The operation **read**(*D*) is processed as:

if T_i has a lock on *D*   // **lock-X** OR **lock-S**

then

read(*D*)

else begin

if necessary wait until no other transaction has a **lock-X** on *D*

grant T_i a **lock-S** on *D*;

read(*D*)

end

2PL: Automatic Acquisition of Locks - write

- **write**(*D*) is processed as:

if T_i has a **lock-X** on *D*
then
write(*D*)
else begin
if necessary wait until no other trans. has any lock on *D*,
if T_i has a **lock-S** on *D*
then
upgrade lock on *D* to **lock-X**
else
grant T_i a **lock-X** on *D*
write(*D*)
end;

- **All locks are released after commit or abort**

Lock-Based Protocols (Cont.)

- **Example** of a transaction performing locking:

T_2: **begin**

lock-S(A);

read (A);

unlock(A);

lock-S(B);

read (B);

unlock(B);

display$(A+B)$

commit;

T2:

read(A)
read(B)
display(A+B)

Lock-Based Protocols – 2PL

T1:	T2:
read(X)	
read(Y)	
	read(Y)
write (Y)	

T1:	T2:
begin	
lock-S(X)	
read(X)	
lock-S(Y)	
read(Y)	
	begin
	lock-S(Y)
	read(Y)
	unlock(Y)
	commit
upgrade(Y)	
write (Y)	
unlock(X)	
unlock(Y)	
commit	

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.

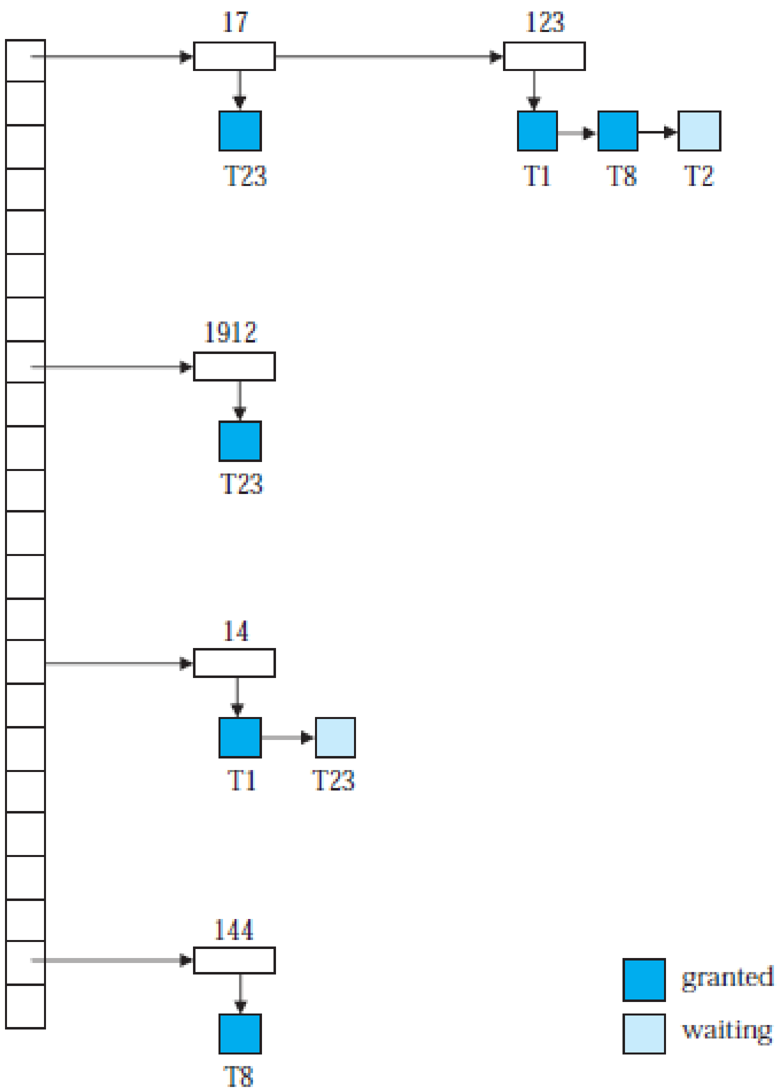
Pitfalls of Lock-Based Protocols (Cont.)

- **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.

Implementation of Locking

- A **lock manager** can be implemented as a separate process to which transactions send lock and unlock requests
- The lock manager replies to a lock request by sending a lock grant messages (or a message asking the transaction to roll back, in case of a deadlock)
- The requesting transaction waits until its request is answered
- The lock manager maintains a data-structure called a **lock table** to record granted locks and pending requests
- The lock table is usually implemented as an in-memory hash table indexed on the name of the data item being locked

Lock Table



- Lock table records the type of lock granted or requested
- New request is added to the end of the queue of requests for the data item, and granted if it is compatible with all earlier locks
- Unlock requests result in the request being deleted, and later requests are checked to see if they can now be granted
- If transaction aborts, all waiting or granted requests of the transaction are deleted
  - lock manager may keep a list of locks held by each transaction, to implement this efficiently

Timestamp-Based Protocols

1. Use the value of the system clock as the timestamp; that is, a transaction’s timestamp is equal to the value of the clock when the transaction enters the system.
2. Use a logical counter that is incremented after a new timestamp has been assigned; that is, a transaction’s timestamp is equal to the value of the counter when the transaction enters the system.

Timestamp-based Protocols

- Suppose there are there transactions T1, T2, and T3.
- T1 has entered the system at time 0010
- T2 has entered the system at 0020
- T3 has entered the system at 0030
- Priority will be given to transaction T1, then transaction T2 and lastly Transaction T3.

Thank You!

Transactions –
Concurrent Executions

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Transactions

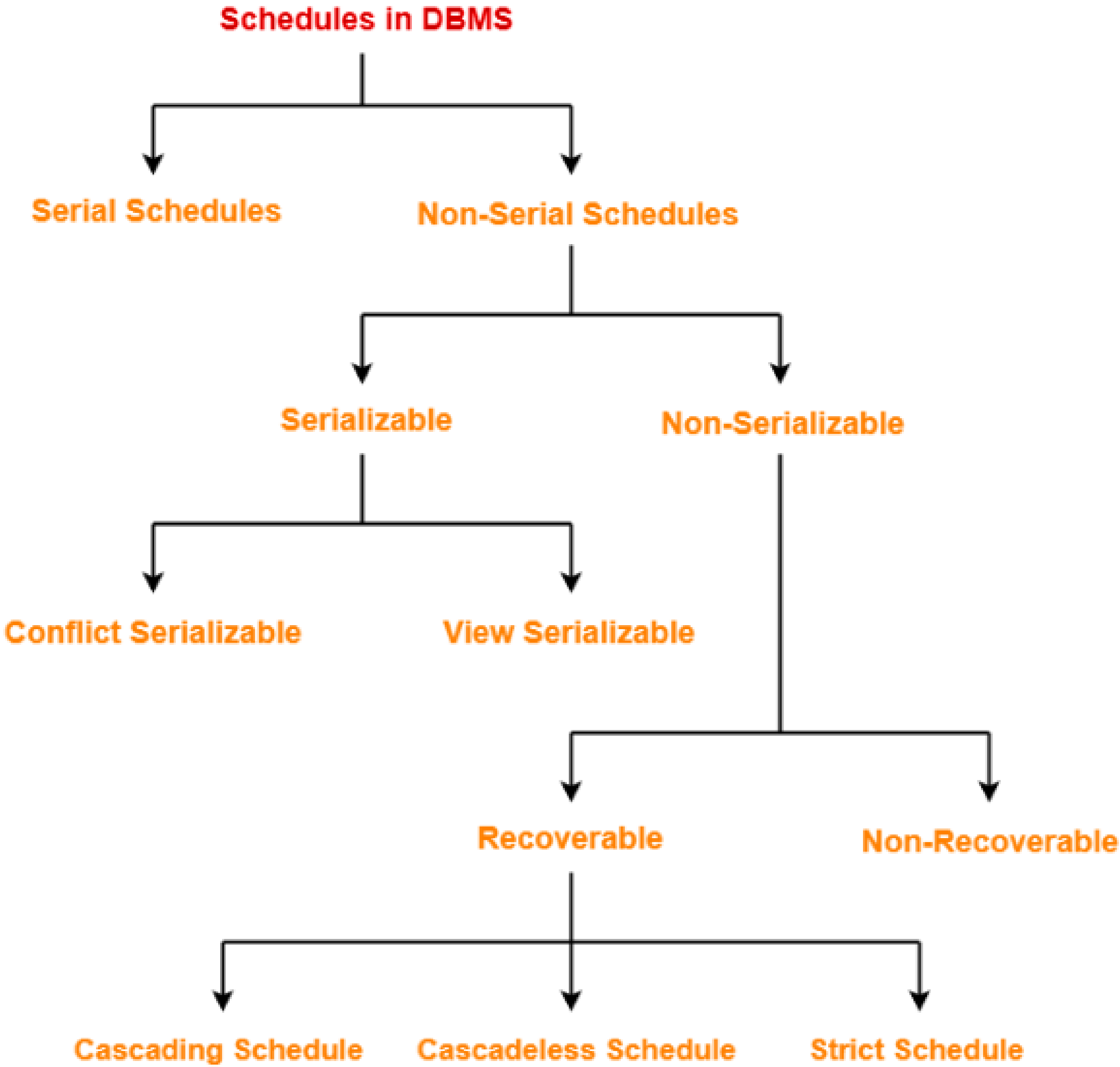
- Concurrent Executions
- Serializability
- Conflict Serializable
- Testing for Serializability
- View Serializable
- Recoverability
- Transaction Definition in SQL
- Recoverable Schedules

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** – 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


Schedules in DBMS
Serial Schedules
Non-Serial Schedules
Serializable
Non-Serializable
Conflict Serializable
View Serializable
Recoverable
Non-Recoverable
Cascading Schedule
Cascadeless Schedule
Strict Schedule

Serial Vs Serializable

Serial Schedules	Serializable Schedules
No concurrency is allowed. Thus, all the transactions necessarily execute serially one after the other.	**Concurrency** is allowed. Thus, multiple transactions can execute concurrently.
Serial schedules lead to less resource utilization and CPU throughput.	Serializable schedules improve both resource utilization and CPU throughput.
Serial Schedules are less efficient as compared to serializable schedules.	Serializable Schedules are always better than serial schedules.

Serial

S2

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

Non-Serial

S1

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

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

Let A=150, B=50
A=150-50=**100**
B=50+50=**100**

temp=100*0.1=10
A=100-10=**90**
B=100+10=**110**

Sum(A+B)=200

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	

Let A=150, B=50
Temp=150*0.1=15
A=150-15=**135**
B=50+15=**65**

A=135-50=**85**
B=65+50=**115**

Sum(A+B)=200

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

Let A=150, B=50
A=150-50=100

temp=100*0.1=10
A=100-10=**90**

B=50+50=100

B=100+10=**110**

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

Sum(A+B)=200

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

Let A=150, B=50
A=150-50

temp=150*0.1=15
A=150-15=**135**

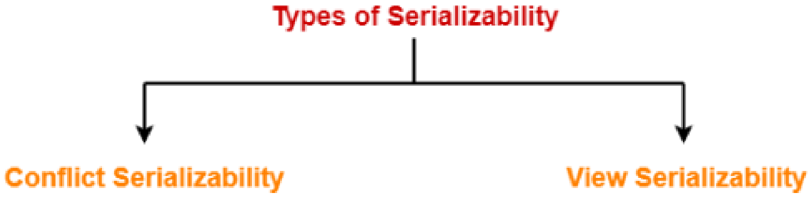
A=100
B=50+50=**100**

B=50+15=**65**

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.

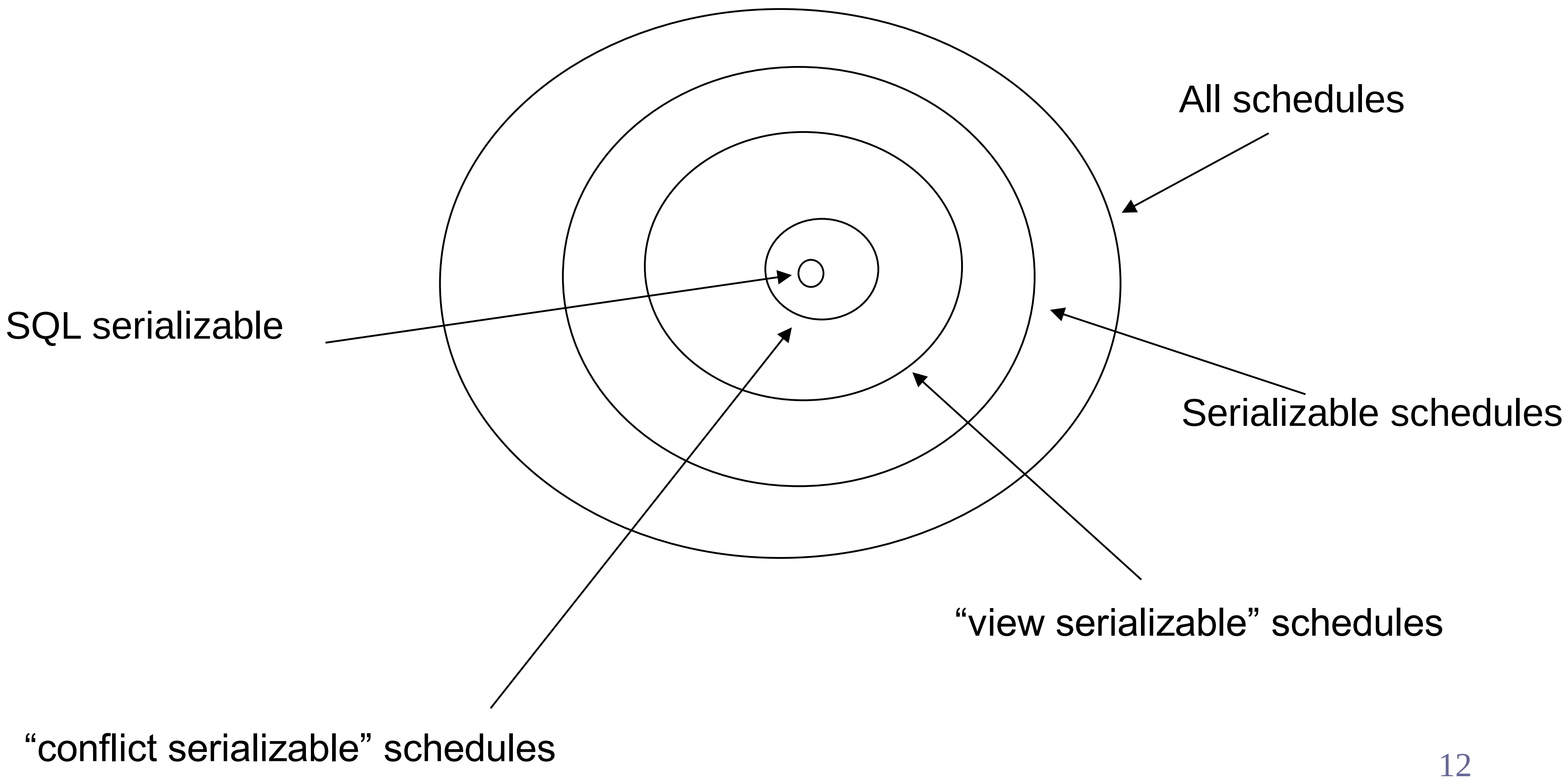
- Different forms of schedule equivalence give rise to the notions of:
  1. **view serializability**
  2. **conflict serializability**



Serializability

Serializable: A schedule is serializable if its effects on the database are the equivalent to some serial schedule.

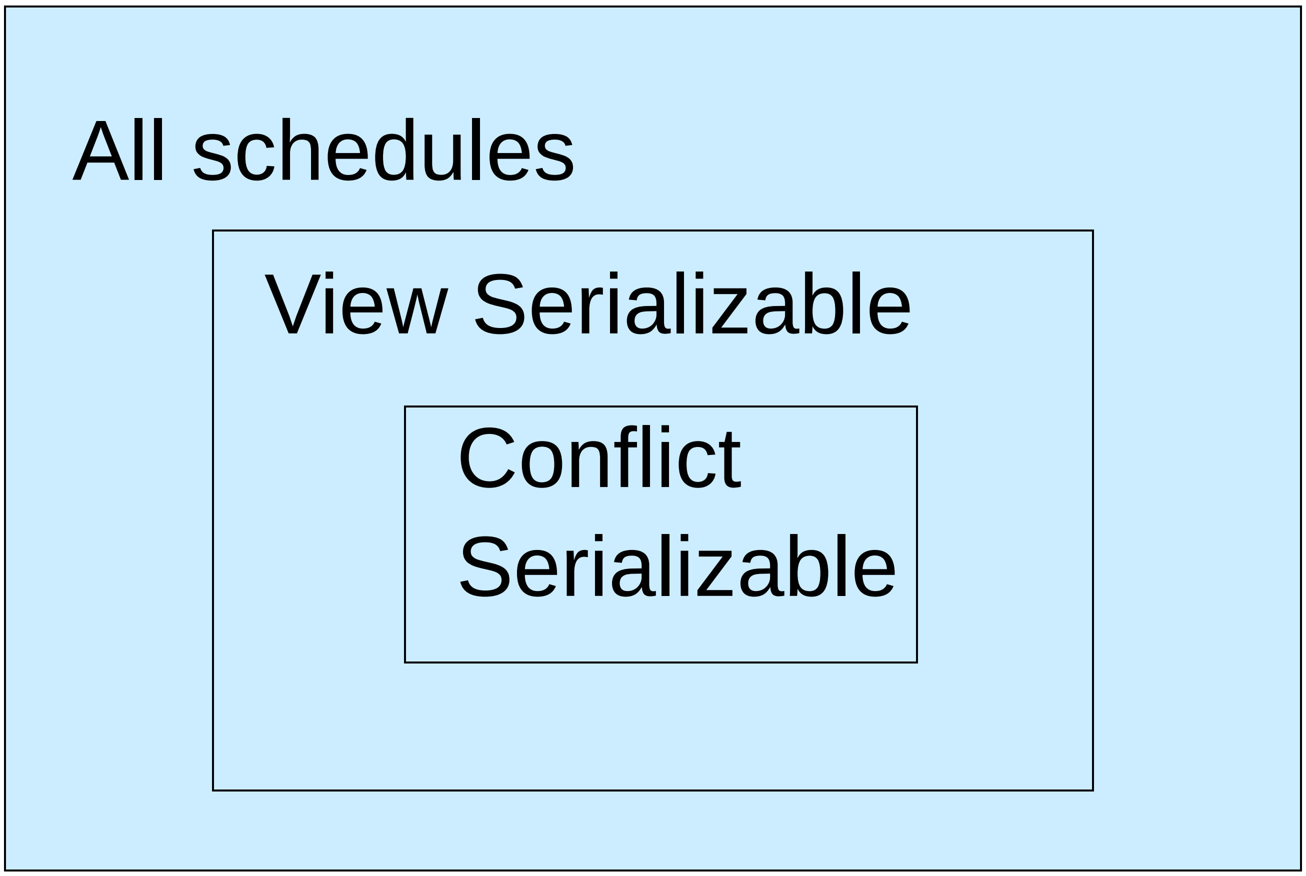
Hard to ensure; more conservative approaches are used in practice



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.

Diagram



Conflicts

- Definition
  - is a pair of consecutive actions in a schedule such that, if their order is interchanged, then the behavior of at least one of the transactions involved can change.

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.

Conflicting Instructions

- Non-conflicting actions: Let T_i and T_j be two different transactions ($i \neq j$), then:
  - $r_i(X)$; $r_j(Y)$ is never a conflict, even if $X = Y$.
  - $r_i(X)$; $w_j(Y)$ is not a conflict provided $X \neq Y$.
  - $w_i(X)$; $r_j(Y)$ is not a conflict provided $X \neq Y$.
  - Similarly, $w_i(X)$; $w_j(Y)$ is also not a conflict, provided $X \neq Y$.

continued…

- Three situations of conflicting actions (where we **may not swap** their order)
  - **Two actions of the same transaction.**
    - e.g., $r_i(X);w_i(X)$
  - **Two writes of the same database** element by different transactions.
    - e.g., $w_i(X);w_j(X)$
  - **A read and a write of the same database** element by different transactions.
    - e.g., $r_i(X);w_j(X)$

- To summarize, any two actions of different transactions may be swapped unless:
  - **They involve the same database element, and**
  - **At least one of them is a write operation.**

Converting conflict-serializable schedule to a serial schedule

- S: $r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B);$

- $r_1(A); w_1(A); r_2(A);$ $\underline{\mathbf{w_2(A); r_1(B)}}$**;** $w_1(B); r_2(B); w_2(B);$
- $r_1(A); w_1(A);$ $\underline{\mathbf{r_2(A); r_1(B)}}$**;** $w_2(A); w_1(B); r_2(B); w_2(B);$
- $r_1(A); w_1(A); r_1(B); r_2(A);$ $\underline{\mathbf{w_2(A); w_1(B)}}$**;** $r_2(B); w_2(B);$
- $r_1(A); w_1(A); r_1(B);$ $\underline{\mathbf{r_2(A); w_1(B)}}$**;** $w_2(A); r_2(B); w_2(B);$
- $r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B);$

conflict-serializable schedule

- **Schedule 3 can be transformed into Schedule 6**, a serial schedule, by series of swaps of non-conflicting instructions..

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)

conflict-serializable schedule

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

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

Schedule 3

- **S3:** r1(A), w1(A), r2(A), **<u>w2(A), r1(B),</u>** w1(B), r2(B), w2(B)
- r1(A),w1(A),r2(A),r1(B),**<u>w2(A), w1(B),</u>** r2(B), w2(B)
- r1(A),w1(A),**<u>r2(A),r1(B),</u>** w1(B), w2(A), r2(B), w2(B)
- r1(A),w1(A),r1(B),**<u>r2(A),w1(B),</u>** w2(A), r2(B), w2(B)
- **S6:** r1(A),w1(A), r1(B), w1(B),r2(A), w2(A), r2(B), w2(B)

conflict-serializable schedule

- 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-serializable 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 & Graphs

- Theorem: **A schedule is conflict serializable iff its precedence graph is acyclic**.
- Theorem: 2PL ensures that the precedence graph will be acyclic!
- Strict 2PL improves on this by avoiding cascading aborts, problems with undoing WW conflicts; i.e., ensuring recoverable schedules.

Precedence Graphs

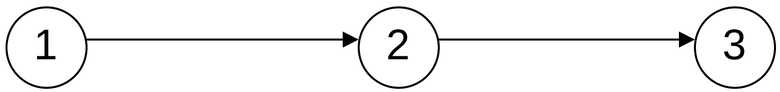
- For a schedule S, involving transactions T_1 and T_2 (among other transactions), we say that T_1 takes precedence over T_2 (written as $T_1 <_s T_2$)if there are actions A_1 of T_1 and A_2 of T_2, such that:
  - A_1 is ahead of A_2 in S,
  - **Both A_1 and A_2 involve the same database element, and**
  - **At least one of them is a write operation.**

Example of a precedence graph:

Consider a schedule S which involves three transactions T_1, T_2 and T_3, i.e.,

S: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $r_2(B)$; $w_2(B)$;

The precedence graph for this as is shown below



Do not consider
Same database, same transaction, Read – Read, which will not conflict

Test for conflict-serializability

- Construct the precedence graph for S and observe if there are any cycles.
  - If yes, then S is not conflict-serializable
  - Else, it is a conflict-serializable schedule.
- Example of a cyclic precedence graph:
  - Consider the below schedule

    S_1: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_2(B)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $w_2(B)$;

    The precedence graph for this as shown below:

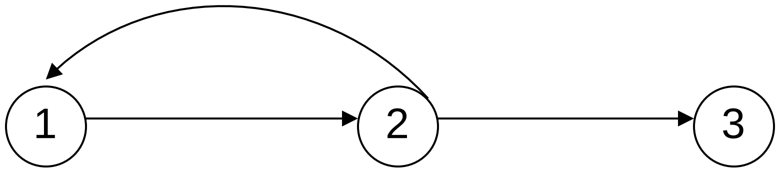


Figure 2

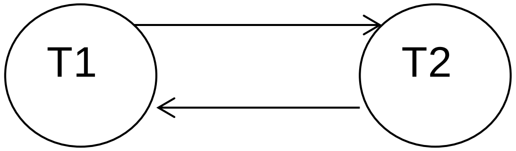
Precedence Graph- Algorithm

1. Create a node T in the graph for each participating transaction in the schedule.
2. Draw an edge from T_i to T_j in the graph for the conflicting operation.
   - read_item(X) and write_item(X)
   - write_item(X) and read_item(X)
   - write_item(X) and write_item(X)
3. **The Schedule S is serializable if there is no cycle in the precedence graph**.

Precedence Graph - Conflict serializable

- S : r1(x) r1(y) w2(x) w1(x) r2(y)
  - x: r1(x) w2(x) w1(x)
  - y: r1(y) r2(y)
- Step 1: Make two nodes corresponding to Transaction T_1 and T_2.

- Step 2: Draw edges for the conflicting pair

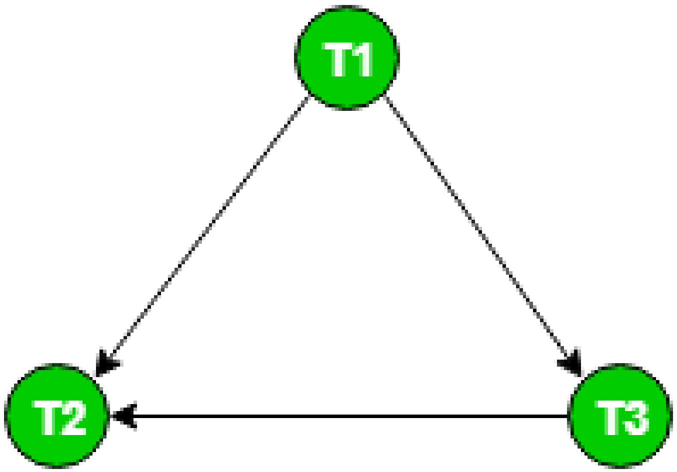


- Step 3: Check if there is any cycle formed in the graph. If there is no cycle found, then the schedule is conflict serializable otherwise not

Since the above graph is cyclic, we can conclude that it is **not conflict serializable**

Example

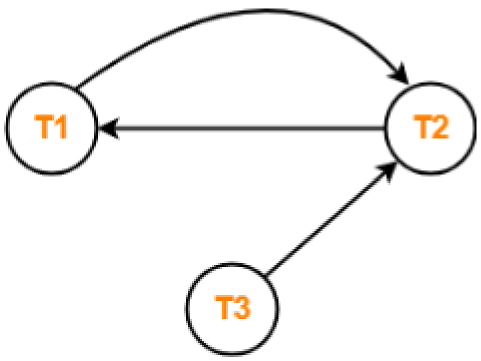
- S1: r1(x) r3(y) w1(x) w2(y) r3(x) w2(x)
  - x: r1(x) **w1(x)** r3(x) **w2(x)**
  - y: r3(y) w2(y)



Since the graph is acyclic, the schedule is conflict serializable.

Example

- Check whether the given schedule S is conflict serializable or not-
  - **S : $R_1(A)$, $R_2(A)$, $R_1(B)$, $R_2(B)$, $R_3(B)$, $W_1(A)$, $W_2(B)$**
  - **A: $R_1(A)$, $R_2(A)$, $W_1(A)$**
  - **B: $R_1(B)$, $R_2(B)$, $R_3(B)$, $W_2(B)$**

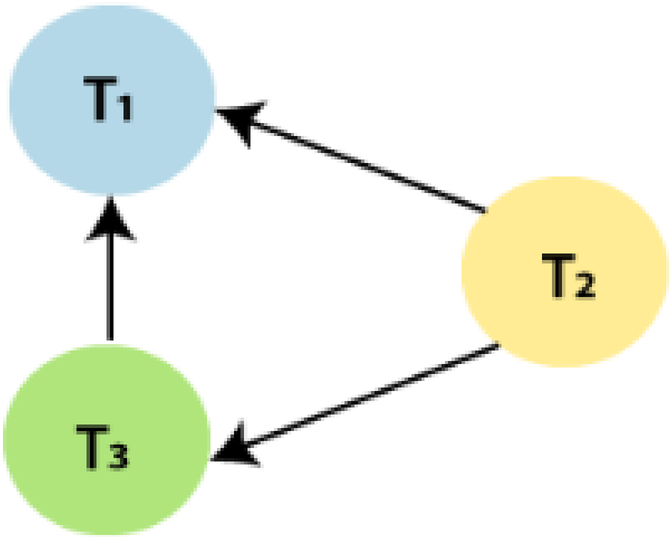


- Clearly, there exists a cycle in the precedence graph.
- Therefore, the given schedule S is not conflict serializable.

Exercise

Time	Transaction T1	Transaction T2	Transaction T3
t1	Read(X)		
t2			Read(Y)
t3			Read(X)
t4		Read(Y)	
t5		Read(Z)	
t6			Write(Y)
t7		Write(Z)	
t8	Read(Z)		
t9	Write(X)		
t10	Write(Z)		

Solution



- Since the graph is acyclic, the schedule is conflict serializable.

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. **Initial reads:** 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. **W-R Conflict:** If in schedule S transaction T_i executes **read**(Q), and that value was produced by transaction T_j –**write(Q)** (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. **Final write:** 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

Initial reads

- S1: r1(A)
- S2: r1(A)

```
T1          T2           T1         T2
------------          ----------------
R(A)                     R(A)
          W(A)         W(A)
W(A)                               W(A)
```

W-R Conflict:

- These two schedule are not view-equivalent:
- S1: w2(A), r3(A)
- S2: w1(A), r3(A)

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

Final write

- S1: w1(A)
- S2: w1(A)

```
T1          T2           T1         T2
-----------           ---------------
R(A)                     R(A)
          W(A)         W(A)
W(A)                               W(A)
```

View Serializability

- S1: r1(P), w2(P)
- S2: w2(P) r1(P)
- Initial reads
  - Step1: Satisfied
- W-R Conflict
  - Step2: Not Satisfied
- Final write

  Step3: Satisfied
- Conclusion
  - Not view serializable

Schedule S1:

Time	Transaction T1	Transaction T2
T1	Read (P)	
T2		Write (P)

Schedule S2:

Time	Transaction T1	Transaction T2
T1		Write (P)
T2	Read (P)	

View Serializability

- S1: w1(P), r2(P), w3(P)
- S2: r2(P), w1(P), w3(P)
- Initial reads
  - Step1: Satisfied
- W-R Conflict
  - Step2: Not Satisfied
- Final write
  - Step3: Satisfied
- Conclusion
  - Not view serializable

Schedule S1:

Time	Transaction T1	Transaction T2	Transaction T3
T1	Write (P)		
T2		Read (P)	
T3			Write (P)

Schedule S2:

Time	Transaction T1	Transaction T2	Transaction T3
T1		Read (P)	
T2	Write (P)		
T3			Write (P)

Exercise

Schedules S1 and S2 are view equivalent

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

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

View Serializability Example

S: r2(B) w2(A) r1(A) r3(A) w1(B) w2(B) w3(B)

S’: r2(B) w2(A) w1(B) r1(A) w2(B) r3(A) w3(B)

View Serializability Example

Step 1: Initial reads

r2(**B**) w2(A) r1(A) r3(A) w1(B) w2(B) w3(B)

---

r2(**B**) w2(A) w1(B) r1(A) w2(B) r3(A) w3(B)

View Serializability Example

Step 2: W-R Conflict

r2(B) **w2(A) r1(A) r3(A)** w1(B) w2(B) w3(B)

---

r2(B) **w2(A)** w1(B) **r1(A)** w2(B) **r3(A)** w3(B)

r2(B) w1(B) w2(B) w3(B)

w2(A) r1(A) r3(A)

View Serializability Example

Step 3: Final write

r2(B) w2(A) r1(A) r3(A) w1(B) w2(B) w3(B)

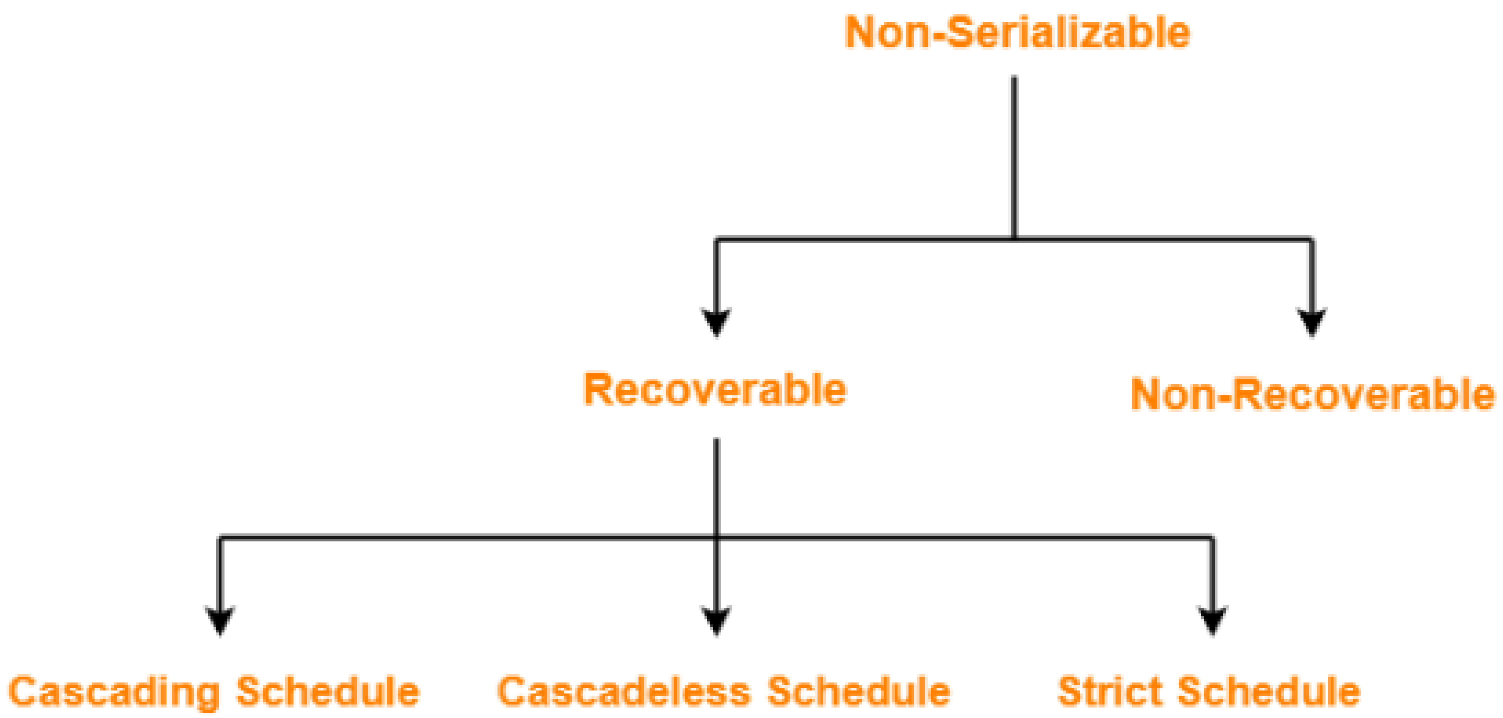
---

r2(B) w2(A) w1(B) r1(A) w2(B) r3(A) w3(B)

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.**

Recoverable Schedules



Non-recoverable Schedule.

- If in a schedule,
  - A transaction performs a **dirty read** operation from an uncommitted transaction
  - And **commits before the transaction from which it has read the value**
    - then such a schedule is known as an **Non-recoverable Schedule**.

Recoverable Schedules

Need to address the effect of transaction 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 (Schedule 11) is not recoverable if T_9 commits immediately after the read

T_8	T_9	
read (A)		
write (A)		
	read (A)	// Dirty Read
	commit	
read (B)		

Rollback

- T2 performs a dirty read operation.
- T2 commits before T1.
- T1 fails later and roll backs.
- The value that T2 read now stands to be incorrect.
- T2 can not recover since it has already committed.

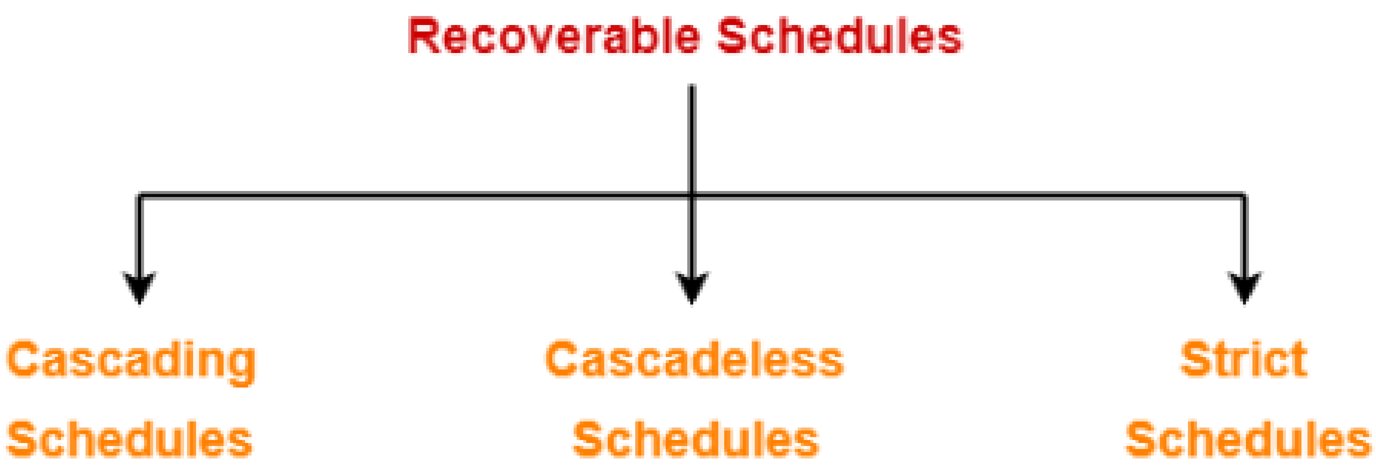
Recoverable Schedules

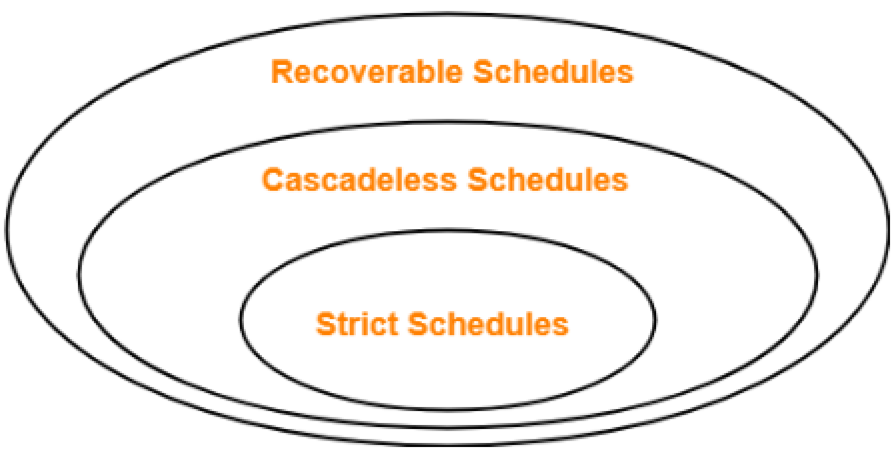
Transaction T1	Transaction T2
R (A)	
W (A)	
	R (A) // Dirty Read
	W (A)
Commit	
	Commit // Delayed

Recoverable Schedule

- T2 performs a dirty read operation.
- The commit operation of T2 is delayed till T1 commits or roll backs.
- T1 commits later.
- T2 is now allowed to commit.
- In case, T1 would have failed, T2 has a chance to recover by rolling back.

Types of Recoverable Schedules





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

Cascading Schedules and Rollbacks

T1	T2	T3	T4
R (A)			
W (A)			
	R (A)		
	W (A)		
		R (A)	
		W (A)	
			R (A)
			W (A)
abort / Failure			

Cascading Recoverable Schedule

Transaction T2 depends on transaction T1.
Transaction T3 depends on transaction T2.
Transaction T4 depends on transaction T3
The failure of transaction T1 causes T2, T3 and T4 to rollback.
Such a rollback is called as a **Cascading Rollback**.

Cascadeless Schedule

- If in a schedule, a transaction is **not allowed to read a data item** until the last transaction that has written it is committed or aborted, then such a schedule is called as a **Cascadeless Schedule**.

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

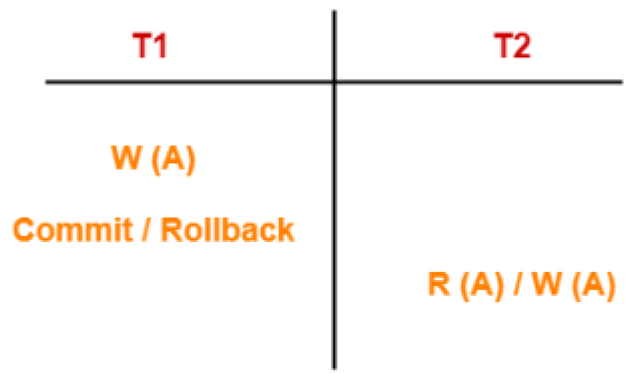
Cascadeless Schedule

T1	T2
R (A)	
W (A)	
	W (A) // Uncommitted Write
Commit	

Cascadeless Schedule

Strict Schedule

- If in a schedule, a transaction is **neither allowed to read nor write a data item** until the last transaction that has written it is committed or aborted, then such a schedule is called as a **Strict Schedule**.



Strict Schedule

References

- Abraham Silberschatz, Henry F. Korth and S. Sudarshan, *Database System Concepts*, 6th Edition, McGraw-Hill
- https://www.gatevidyalay.com/serializability-in-dbms-conflict-serializability/