Part 4: Transaction Management

Database System Concepts, 6th Ed.

Transaction

- Example: Transfer of money from one account to another is a transaction consisting of two updates, one to each account
- A collection of operations that form a single logical unit of work
  - 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)*
  - If **A=$1000** and **B=$ 2000**
  - If Success and only T1, *then at the end A=$950 and B=$2050,*
  - *Thus A+B=3000 (**before 1000+2000** **and** **after 950+2050**)*

Issues

- In case of some **failure** in complete execution, partial effects of each incomplete transaction be undone, called **Atomicity**
- If **successful**, then its effects must persist in the database, called **Durability**
- **Multiple transactions** executing concurrently which may result in erroneous updates, require **Isolation**, to isolate transactions from others
- Chapter 14
  - Study of INDIVIDUAL transaction in detail
  - ACID Properties
  - Isolation by Serializability
- Chapter 15
  - Concurrency control techniques for **CONCURRENT** transactions Isolation
- Chapter 16
  - Recovery management for Atomicity and Durability for **CONCURRENT** transactions

Chapter 14: Transactions

Database System Concepts, 6th Ed.

Chapter 14: Transactions

- INDIVIDUAL Transaction Concept
- Transaction State
- Concurrent Executions
- Serializability
- Recoverability
- Implementation of Isolation
- Transaction Definition in SQL
- Testing for Serializability

Transaction Concept

- **Transaction**
  - 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)
- Main issues to deal with:
  - Completely execute
  - Concurrent execution of multiple transactions
  - Failures of various kinds, such as hardware failures and system crashes

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)
- **Suppose either of following happens**
  1. **read**(A)
  2. $A := A – 50$
  3. **write**(A)

  OR

  1. **read**(A)
  2. $A := A – 50$
  3. **write**(A)
  4. **read**(B)
  5. $B := B + 50$

Example of Fund Transfer

- **Atomicity requirement**
  - If the transaction FAILS after step 3 or before step 6,
    - Failure could be due to software or hardware
    - Money will be “LOST” leading to an INCONSISTENT database state
  - The system should ensure that updates of a partially executed transaction are not reflected in the database
  - In an atomic transaction,
    - A series of database operations **either ALL occur**,

      OR
    - **NOTHING occurs**

Example of Fund Transfer (Cont.)

- **Consistency requirement**
  - **The information in the database must be kept in a consistent state**
  - For example:
    - If we have one table *B that includes keys from another* table *A (such as **bank account transactions** that have account IDs referencing rows in a table of* **bank accounts**),
      - Then **shouldn't allow deleting a row from *A without deleting those* rows from *B*** *referring to the account being deleted*
  - To ensure consistency for an individual transaction is the responsibility of the **application programmer** who codes the transaction

Example of Fund Transfer (Cont.)

- **Consistency requirement**
  - Task facilitated by **automatic testing of integrity constraints**
  - **Explicit**ly 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
    - In given example, The sum of A and B is unchanged by the execution of the transaction (*A+B=3000* ***(before 1000+2000 and after 950+2050)****)*

Example of Fund Transfer (Cont.)

- **Consistency requirement**
  - 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**

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)	

- Computes $A+B$
  - *If A=\$1000 and B=\$ 2000*
  - *And only T1, then at the end A=\$950 and B=\$2050,*
  - *Thus A+B=3000 (**before 1000+2000 and after 950+2050**)*
- ***But, if T2 occurs, then T2 will observe an Inconsistent value***
  - As it accesses the partially updated database, it will see an INCONSISTENT database (**the sum $A + B$ = \$950+\$2000=\$2950 will be less than it should be**)

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*)	

- DB is temporarily inconsistent after Step 3, *If T2* concurrently occurs and reads *A and B at intermediate* point
  - Computes *A+B, It will observe an Inconsistent value (**2950 not 3000**)*
  - ***Furthermore,* if T2 then performs updates on *A and B based on the* inconsistent values that it read, the database may be left in an inconsistent state even after both transactions have completed**

Example of Fund Transfer (Cont.)

- **Isolation requirement**
  - 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

Example of Fund Transfer

- **Durability requirement**
  - Once the user has been notified that the transaction has completed (i.e., the transfer of the $50 has taken place),
    - Then the updates to the database by the transaction must **PERSIST**
      - Even if there are DBMS Software crashes or HARDWARE FAILURES

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:

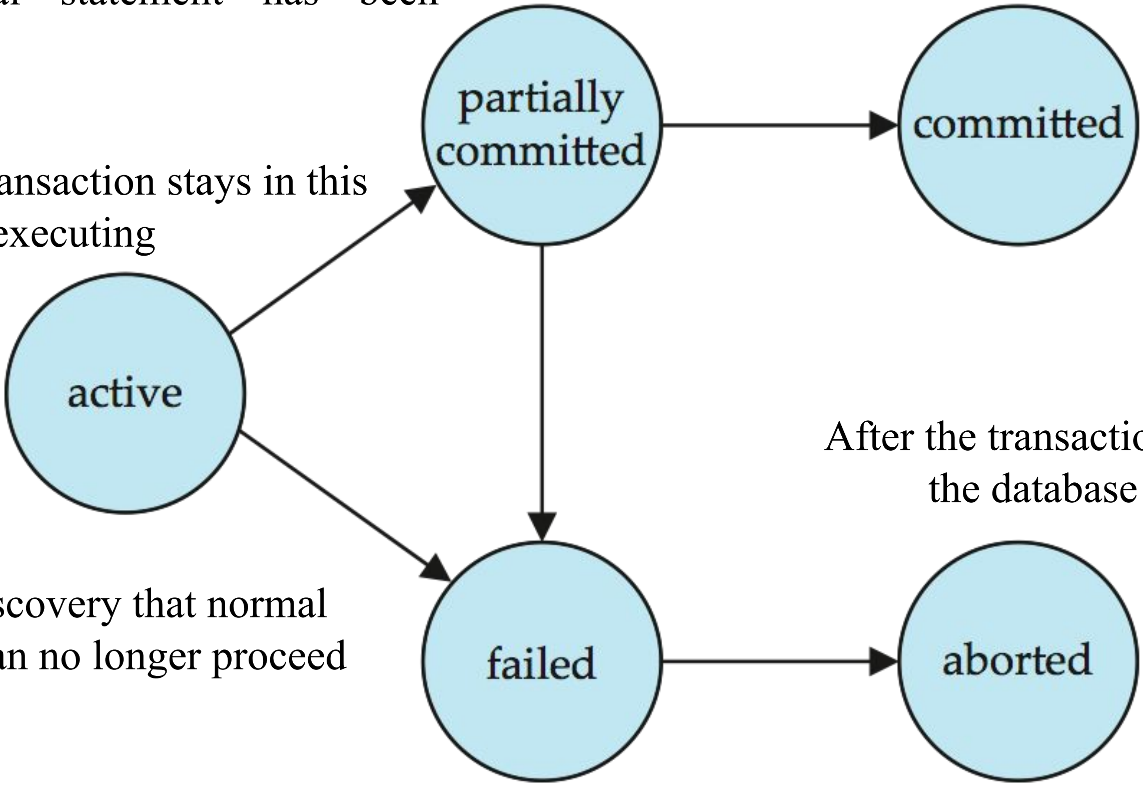
- **Atomicity.** Either all operations of the transaction are properly reflected in the database or none are
- **Consistency.** Execution of a transaction in isolation preserves the consistency of the database
- **Isolation.** Although multiple transactions may execute concurrently, each transaction 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 (Cont.)

After the final statement has been executed

After successful completion

Initial state -Transaction stays in this state while it is executing



After the transaction has been rolled back and the database restored to its state prior to the start of the transaction

After the discovery that normal execution can no longer proceed

- Two options after it has been aborted:
  - Restart the transaction - Can be done only if no internal logical error
  - Kill the transaction

Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system
- Advantages
  - **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 in Chapter 16, after studying notion of correctness of concurrent executions

Schedules

- **Schedule**
  - A chronological execution sequence of transaction
    - A schedule can have many transactions in it,
      - Each transaction comprising of number of instructions/tasks
  - **Must preserve the order** in which the **instructions appear in each individual transaction**
- It is some interleaving of the operations from the two transactions (without violating the order of operations within any individual transaction)
- A transaction that successfully completes its execution will have a commit instructions as the last statement (By default)
- A transaction that fails to successfully complete its execution will have an abort instruction as the last statement

Example of Schedule

- Let
  - T_1 transfer \$50 from *A* to *B*, and
  - T_2 transfer 10% of the balance from *A* to *B*
- Write the possible schedules.
- Verify: A=\$1000, B=\$2000
  - Before execution of both T_1 and T_2 □A+B=3000
  - After execution of both T_1 and T_2 □A+B=3000

- First, write operations:

Transaction 1:

r1(A), A=A-50, w1(A), r1(B), B=B+50, w1(B),

Transaction 2:

*r2(A), tmp=A*0.10, A=A-temp, w2(A), r2(B), B=B+temp, w2(B)*

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

Suppose current values of accounts

A = \$1000 and B = \$2000

Before starting: A+B=\$3000

Schedule 1: T1 followed by T2

After T1: A=\$950, B=\$2050

***After T2:A* = \$855(=950-95),**

***B* = \$2145(=2050+95)**

A + B = \$855+\$2145= \$3000

Preserved after the execution of both transactions

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	

Suppose current values of accounts
A = $1000 and B = $2000
Before starting: A+B=$3000
Schedule 1: T2 followed by T1
After T2: A=$900(=1000-100),
B=$2100(=2000+100)

After T1:A **= $850,*B*** **= $2150**
A + B = $850+$2150= $3000
Preserved after the execution of both transactions

Serial Schedule

- T_1 and T_2 schedules are **serial:**
  - **Each serial schedule consists of a sequence of** instructions from various transactions, where the **instructions belonging to one single transaction appear together in that schedule**
  - Recalling a well-known formula from combinatorics,
    - **For a set of *n transactions***, *there* ***exist n*** **factorial (*n!*)** ***different valid serial schedules***

- To describe consistent transaction behavior when transactions run at the same time uses transaction isolation model called **serializability**
- The serializable mode of transaction behavior tries to ensure that transactions run in such a way that they appear to be executed one at a time, or serially, rather than concurrently

Schedule 3

- Let T_1 and T_2 be the transactions defined previously
- Following schedule is **NOT a serial schedule, <u>but it is *equivalent* to Schedule 1</u>**

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

Current values of accounts

A = $1000 and B = $2000

Before starting: A+B=$3000

After Part1 ofT1: A=950, B=2000

***After Part 1ofT2:A* = 855(=950-95), *B* = 2000, temp=95**

After Part2 ofT1: A=855, B=2050

***After Part 2ofT2:A* = 855, *B* = 2145(=2050+95)**

A + B = $855+$2145= $3000

Preserved after the execution of both transactions

Schedule 4

Check the following concurrent schedule, is it preserving 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

Suppose the current values of accounts
A = $1000 and B = $2000

*T1**: A=950***
T2: A=1000 (not written by T1)
temp=100
A=900
B=2000

T1:A=950
B=2000
B=2050

Final state is an *inconsistent state, since we have gained $50*
and the sum *A + B is not preserved by the execution* of the two transactions

B=2000+100=2100
Final values after execution ***A* =$950, *B*= $2100**
Total amount of money in accounts *A and B, the sumA + B (= 950+2100=3050) (Before execution = $3000) is NOT preserved* after the execution of both transactions

Serial Schedule

- When the database system executes several transactions concurrently, the corresponding schedule no longer needs to be serial
  - If two transactions are running concurrently, the **OS** may execute one transaction for a little while, then perform a context switch, execute the second transaction for some time, and then switch back to the first transaction for some time, and so on
  - With multiple transactions, the CPU time is shared among all the transactions
  - In general, it is **not possible to predict exactly how many instructions of a transaction will be executed** before the CPU switches to another transaction

Serial Schedule

- If control of concurrent execution is left entirely to the **OS**, many possible schedules, including ones that leave the database in an inconsistent state
- **It is the job of the database system to ensure that any schedule that is executed will leave the database in a consistent state**
- The **concurrency-control component of the database system carries out this** task

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** **(Later Ch. 15 Concurrency)**
2. **Conflict serializability**

Serializability

Conflict serializability

- Schedule is defined by equivalence to a serial schedule (no overlapping transactions) with the same transactions, **such that both schedules have the same sets of respective chronologically ordered pairs of conflicting operations (same precedence relations of respective conflicting operations)**
- Widely utilized
  - Because it is easier to determine and covers a substantial portion of the view-serializable schedules

Simplified view of transactions

- Since transactions are programs, it is difficult to determine exactly
  - What operations a transaction performs and
  - How operations of various transactions interact
- For this reason, here NOT considered the various types of operations that a transaction can perform on a data item,
  - Ignore operations other than **read** and **write** instructions
- 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
- Commit operations, though relevant, **are not considered until Section 14.7**

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

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**
- A schedule *S* is **conflict serializable** if it is conflict equivalent to a serial schedule

Conflict Serializability (Cont.)

- Check Schedule 3, is it a conflict serializable schedule.
- Sol: Try the possibility of swaps of non-conflicting instructions, to produce serial schedule.

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

Schedule 3

Conflict Serializability (Cont.)

- Check Schedule 3, is it a conflict serializable schedule.
- Sol: Try the possibility of swaps of non-conflicting instructions, to produce serial schedule.

T_1	T_2

Read(A)
Write(A)	

	Read(A)
	Write(A)

Read(B)
Write(B)	

	Read(B)
	Write(B)

Schedule 3

$\Rightarrow$

T_1	T_2

Read(A)
Write(A)	

Read(B)	Read(A)
Write(B)	**Write(A)**

	Read(B)
	Write(B)

$\Rightarrow$

T_1	T_2

Read(A)
Write(A)	

Read(B)	Read(A)
Write(B)	**Write(A)**

	Read(B)
	Write(B)

$\Rightarrow$

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.)

- 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.)

- Check the serializability of following schedule.

T_3	T_4
read (Q)	
	write (Q)
write (Q)	

- Schedule is **not conflict serializable**
  - 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 >
  - As read and write both are on single item Q

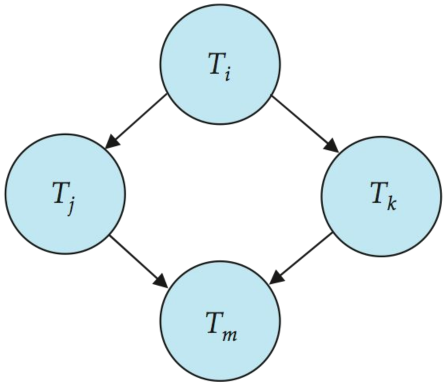
Testing for Serializability

- Consider some schedule of a set of transactions T_1, T_2, ..., T_n
- **Precedence graph**
  - Simple and Efficient method to determine conflict serializability of schedule
  - A directed graph where the Vertices are the transactions (names)
  - Draw an Edge(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
    - Label the arc by the item that was accessed
    - Draw edge from *Ti →Tj with label Q for one of three conditions:*

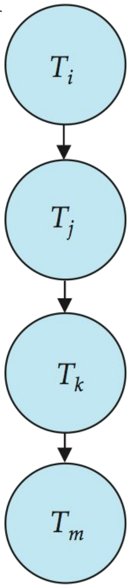
T_i	T_j
1. *write(Q)*	*read(Q)*
2. *read(Q)*	*write(Q)*
3. *write(Q)*	*write(Q)*

Test for Conflict Serializability

- A schedule is **conflict serializable**
  - **If** and only if 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)



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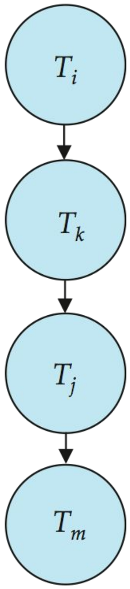


(c)

Testing for Serializability

- Draw edge from *Ti →Tj for one of three conditions:*

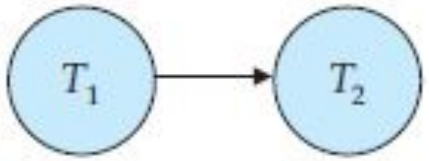
	T_i	T_j
1.	*write(Q)*	*read(Q)*
2.	*read(Q)*	*write(Q)*
3.	*write(Q)*	*write(Q)*

- **Example: Schedule 1**

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

As all the instructions of T_1 are executed before the T_2

$$\Rightarrow$$



CONFLICT SERIALIZABLE Schedule

Testing for Serializability

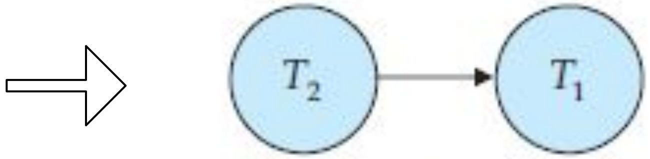
- Draw edge from *Ti* →*Tj for one of three conditions:*

	T_i	T_j
1.	*write(Q)*	*read(Q)*
2.	*read(Q)*	*write(Q)*
3.	*write(Q)*	*write(Q)*

4. **Example: Schedule 2**

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	

As all the instructions of T_2 are executed before the T_1



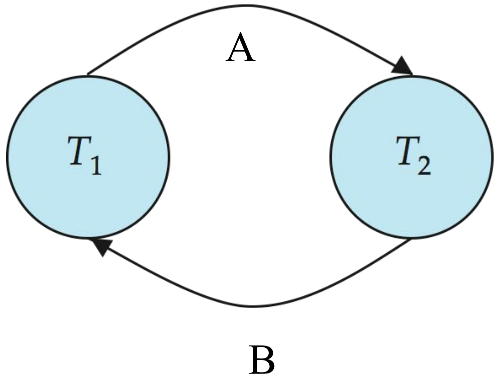
CONFLICT SERIALIZABLE Schedule

Testing for Serializability

- **Example: Schedule 4**
- Contains the edge *T1 →T2, because T1 executes read(A) before T2 executes write(A)*
- *Also* contains the edge *T2→T1, because T2 executes read(B) before T1 executes write(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

NOT CONFLICT SERIALIZABLE Schedule

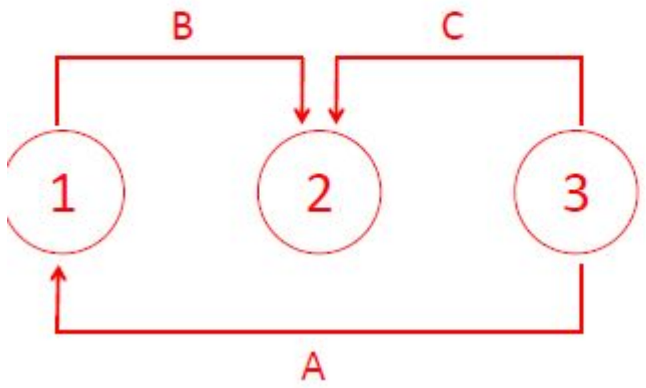


Cycle is present in graph

Testing for Conflict Serializability

Example: Schedule A

$$\begin{tikzcd}[row sep=small]
\mathbf{W3\ (A)} \arrow[d, bend right] \\
\mathbf{R1\ (A)} \\
\mathbf{W1\ (B)} \arrow[d, bend right] \\
\mathbf{R2\ (B)} \\
\mathbf{W3(C)} \arrow[d, bend right] \\
\mathbf{R2\ (C)}
\end{tikzcd}$$



No cycles: **YES,conflict serializable**

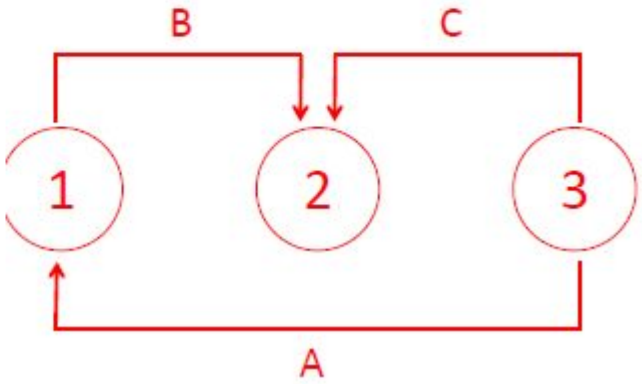
Test for Conflict Serializability

Example: Schedule A

W3 (A)
R1 (A)
W1 (B)
R2 (B)
W3(C)
R2 (C)

Serial Equivalent Schedule?

W3 (A)
W3(C)
R1 (A)
W1 (B)
R2 (B)
R2 (C)



No cycles: **YES,conflict serializable**

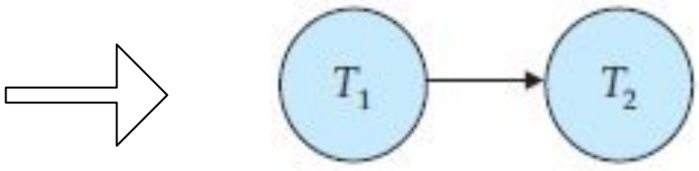
Only serial equivalent schedule: T3, T1, T2

Test for Conflict Serializability

- **Example: Schedule 3**

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

As all the instructions of T_1 are executed before the completion of T_2



CONFLICT SERIALIZABLE Schedule

Transaction Failure

- Upto this considered that **NO TRANSACTION FAILURE**
  - But, this is not really true

T_8	T_9
read (A)	
write (A)	
	read (A)
	commit
read (B)	

- **IF TRANSACTION FAILURE** is there,
  - Need to **UNDO the effect of that transaction** to ensure **ATOMICITY**
  - Requires that any transaction T_j that dependent on T_i is also aborted
  - Achieved by restricted type of schedules
    - Recoverable Schedule and Cascadeless Schedule

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 appears before the commit operation of T_j
- The Schedule 11

T_8	T_9
read (A)	
write (A)	
	read (A)
	commit
read (B)	

  - Only commit is with T_9 not with T_8 (**Partial Schedule**)
  - T_9 reads the value written by T_8 (**T_9 is dependent upon T_8**)
  - If T_8 is failed, Requires Undo for T_9 also, which is not possible

Recoverable Schedules

Schedule 11

T_8	T_9
read (*A*)	
write (*A*)	
	read (*A*)
	commit
read (*B*)	

- Database must ensure that schedules are recoverable
  - *T_9 is **dependent*** on *T_8*
    - *Because of this, must abort T_9 to ensure atomicity*
    - *However, T_9 has* already committed and cannot be aborted
      - » Thus, a situation where it is impossible to recover correctly from the failure of *T8*
  - If T_8 should abort, T_9 would have read (and possibly shown to the user) an inconsistent database state
  - Schedule is **NOT RECOVERABLE**

Recoverable Schedules

Schedule 10

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

- Database must ensure that schedules are recoverable
  - *T_{11} is dependent upon T_{10} and T_{12} is dependent* on T_{11}
    - *Abort is there with T_{10}, it is possible to abort T_{11} and T_{12}*
  - Schedule is **RECOVERABLE**

Cascading Rollbacks

- The schedule is **RECOVERABLE, BUT REQUIRES CASCADING ROLLBACKS**
  - 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

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

- A single transaction failure leads to a series of transaction rollbacks
  - As none of the transactions has committed till abort of T_{10}

Cascadeless Schedules

- Cascading rollback is undesirable
    - As requires a lot many rollback
- For each pair of transactions T_x and T_y such that T_y reads a data item previously written by T_x, the commit operation of T_X appears before the read operation of T_y

T_x	T_y
Write(Q)	
Commit	
	Read(Q)

- Every CASCADELESS schedule is RECOVERABLE schedule

Concurrency Control

- If only one transaction is allowed to execute at a time
  - It generates serial schedules
  - BUT, provides a poor degree of concurrency
- For concurrent transactions, DBMS need to check
  - Either conflict or view serializable schedule ?
  - Recoverable and preferably cascadeless schedule ?
  - Are serial schedules recoverable/cascadeless ?

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
  - Allowing not to wait for other transactions serial order
    - E.g. Permit the transaction to read a data item even if it was written by a transaction that has not been committed
  - To benefit the long transactions whose results do not need to be precise

Transaction Isolation Levels of Consistency

- With different possible outcomes for the same transaction scenario
  - The same work performed in the same fashion with the same inputs may result in different answers, depending on your isolation level
  - Isolation levels
    - **Serializable (Default)**
    - **Repeatable read**
    - **Read committed**
    - **Read uncommitted**
  - These levels are defined in terms of three phenomena that are either permitted or not permitted at a given isolation level

Transaction Isolation Levels of Consistency

- **Serializable (Default)**
  - Serializable schedule are the ideal way to ensure consistency, but in our day-to-day lives, NOT IMPOSING SUCH STRINGENT REQUIREMENT
  - Ensured serializability only for the transactions that run on the database, without user interaction
    - In Online Shopping, when user surfing for an item it is available in stock, but by the time user goes through the checkout process, that item might no longer be available □ this would be a nonrepeatable read
- **Repeatable read**
- **Read committed**
- **Read uncommitted**

Transaction Isolation Levels of Consistency

- **Serializable (Default)**
  - Ensured serializability only for the transactions that run on the database, without user interaction
- **Repeatable read**
  - Allows only committed data to be read and further requires that, between two reads of a data item by a transaction, **no other transaction is allowed to update it**
  - Only committed records to be read, repeated reads of same record must return same value
  - However, a transaction may not be serializable with respect to other transactions, so it may find some records inserted by a transaction but not find others

4 For instance, when it is searching for data satisfying some conditions, a transaction may find some of the data inserted by a committed transaction, but may not find other data inserted by the same transaction (until it is committed-as this will read only committed one)

- **Read committed**
- **Read uncommitted**

Transaction Isolation Levels of Consistency

- **Serializable (Default)**
- **Repeatable read**
- **Read committed**
  - Allows only committed data to be read, but successive reads of record may return different (but committed) values
    - Does not require repeatable reads
  - For instance, between two reads of a data item by the transaction, another transaction **may have updated the data item and committed**
- **Read uncommitted**
  - Allows uncommitted data to be read and the lowest isolation level allowed by SQL

Transaction Isolation Levels of Consistency

Read phenomena that violate serializability

- Three different *read phenomena* when Transaction 1 reads data that Transaction 2 might have changed
  1. **Dirty read**
  2. **Nonrepeatable read**
  3. **Phantom read**
- Examples, two transactions queries use the data table: USERS

id	name	age
1	Joe	20
2	Jill	25

1. First Query 1 is performed
2. Then, in the second transaction, Query 2 is performed on same table
3. Finally, in the first transaction, Query 1 is performed again

Transaction Isolation Levels of Consistency

Read phenomena - Dirty read - Aka *uncommitted dependency*

- Occurs when a transaction is allowed to read data from a row that has been modified by another running transaction and not yet committed

id	name	age
1	Joe	20
2	Jill	25

Transaction 1

```
/* Query 1 */ SELECT age FROM users
WHERE id = 1; /* will read 20 */
```

Transaction 2

Changes a row,
but does not commit the changes

```
/* Query 2 */ UPDATE users SET age = 21
WHERE id = 1; /* No commit here */
```

Transaction 1

```
/* Query 1 */ SELECT age FROM users
WHERE id = 1;
```

Reads the uncommitted data
will read 21 for id=1

Transaction 2

```
ROLLBACK;
```

Changes (already read by Transaction 1) or updates different changes to the database, then the view of the data may be wrong in the records of Transaction 1

Transaction Isolation Levels of Consistency

- **Read phenomena - Non-repeatable reads**
  - Occurs, when during the course of a transaction, a row is retrieved twice and the values within the row differ between reads

id	name	age
1	Joe	20
2	Jill	25

Transaction 1

```
/* Query 1 */ SELECT age FROM users
WHERE id = 1; /* will read 20 */
```

Transaction 2

Changes a row, with commit

```
/* Query 2 */ UPDATE users SET age = 21
WHERE id = 1; /* No commit here */
COMMIT;
```

```
/* Query 1 */ SELECT age FROM users
WHERE id = 1;     will read 21
COMMIT;
```

Transaction 1 has already seen a different value for *age* in that row – as non-repeatable reads

Transaction Isolation Levels of Consistency

- **Read phenomena - Phantom reads**
  - Occurs when, in the course of a transaction, two identical queries are executed, and the collection of rows returned by the second query is different from the first
  - A special case of *Non-repeatable reads* when Transaction 1 repeats a ranged *SELECT … WHERE* query and, between both operations, Transaction 2 creates (i.e. INSERT) new rows (in the target table) which fulfill that *WHERE* clause

id	name	age
1	Joe	20
2	Jill	25

Transaction 1	Transaction 2
/* *Query 1* */ **SELECT** * **FROM** users **WHERE** age **BETWEEN** 10 **AND** 30;	
	/* *Query 2* */ **INSERT INTO** users(id,name,age) **VALUES** (3, 'Bob', 27); **COMMIT**;
/* *Query 1* */ **SELECT** * **FROM** users **WHERE** age **BETWEEN** 10 **AND** 30; **COMMIT**;	

A different set of rows may be returned the second time

Transaction Isolation Levels of Consistency

- **Dirty read**
  - The meaning of this term is as bad as it sounds
  - Related to reading UNCOMMITTED data, and occur when an UPDATE, INSERT, or DELETE from another transaction is read, and the other transaction has NOT yet committed the data
  - Permitted to read uncommitted or dirty data
  - It is reading "in progress" data, which may not be complete, and may never actually be committed
  - Example: Open an OS file that someone else is writing and reading whatever data happens to be there
  - Data integrity is compromised, foreign keys are violated, and unique constraints are ignored

Transaction Isolation Levels of Consistency

- **Non-repeatable and phantom read**
  - Deal with data modification operations from a different transaction, which were committed after your transaction began, and then read by your transaction
- **Nonrepeatable read**
  - Simply means that if you read a row at time T1 and try to reread that row at time T2, the row may have changed
  - Transaction reads committed **UPDATES** from another transaction
  - It may have disappeared, it may have been updated, and so on
  - The same row now has different values than it did when your transaction began

Transaction Isolation Levels of Consistency

- **Non-repeatable and phantom read**
  - Deal with data modification operations from a different transaction, which were committed after your transaction began, and then read by your transaction
- **Phantom read**
  - Similar to non-repeatable, but when reading from committed **INSERTS** and/or **DELETES** from another transaction
  - Means that if you execute a query at time T1 and re-execute it at time T2, additional rows may have been added to the database, which may affect your results
  - Differs from a non-repeatable read in that with a phantom read, data you already read hasn't been changed, but instead, more data satisfies your query criteria than before
    - There are new rows or rows that have disappeared since you began the transaction

Transaction Isolation Levels of Consistency

Isolation Levels vs Read Phenomena

Isolation level	Dirty reads	Non-repeatable reads	Phantom reads
Read Uncommitted	may occur	may occur	may occur
Read Committed	-	may occur	may occur
Repeatable Read	-	-	may occur
Serializable	-	-	-

Transaction Isolation Levels of Consistency

- Explicitly you can set the isolation level
  - SET TRANSACTION ISOLATION LEVEL SERIALIZABLE
  - SET TRANSACTION ISOLATION LEVEL READ COMMITTED
  - SET TRANSACTION ISOLATION LEVEL REPEATABLE READ
  - SET TRANSACTION ISOLATION LEVEL READ UNCOMMITTED
  - Oracle supports first two only and one more READ ONLY
  - To change, this setting has to be the first statement of a transaction
  - Also Turn OFF "Auto Commit"

Concurrency Control

- Implementation of Isolation level
  - Upto this, seen properties of schedule to leave the database in consistent state and allow transaction failures to be handled in a safe manner
  - Concurrency control policies
    - When multiple transactions executed concurrently, only acceptable schedules are generated, regardless of how the OS time shares resources (such as CPU time) among the transactions

Concurrency Control

- Implementation of Isolation level
  - Upto this, seen properties of schedule to leave the database in consistent state and allow transaction failures to be handled in a safe manner
  - Concurrency control policies
    - 4 Example: Transaction acquires a lock on the entire database before it starts and releases the lock after it has committed
      - – While a transaction holds a lock, no other transaction is allowed to acquire the lock, and all must therefore wait for the lock to be released
        - » Only one transaction can execute at a time, Serial schedule which is recoverable and cascadeless
        - » POOR PERFORMANCE, only one transaction, No concurrency

Concurrency Control

- Implementation of Isolation level
  - To provide high degree of concurrency with assurance of generated schedules are conflict or view serializable, recoverable and cascadeless
    - Ch. 15 Concurrency Control

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);

ACID Properties

To Achieve ACID Properties

- **Atomicity. Recovery**
- **Consistency. Developer**
- **Isolation. Concurrency Controller**
- **Durability. Recovery**

End of Chapter 14