Chapter Two

Introduction to Transaction Processing Concepts and Theory

Chapter Outline

1. Introduction to Transaction Processing

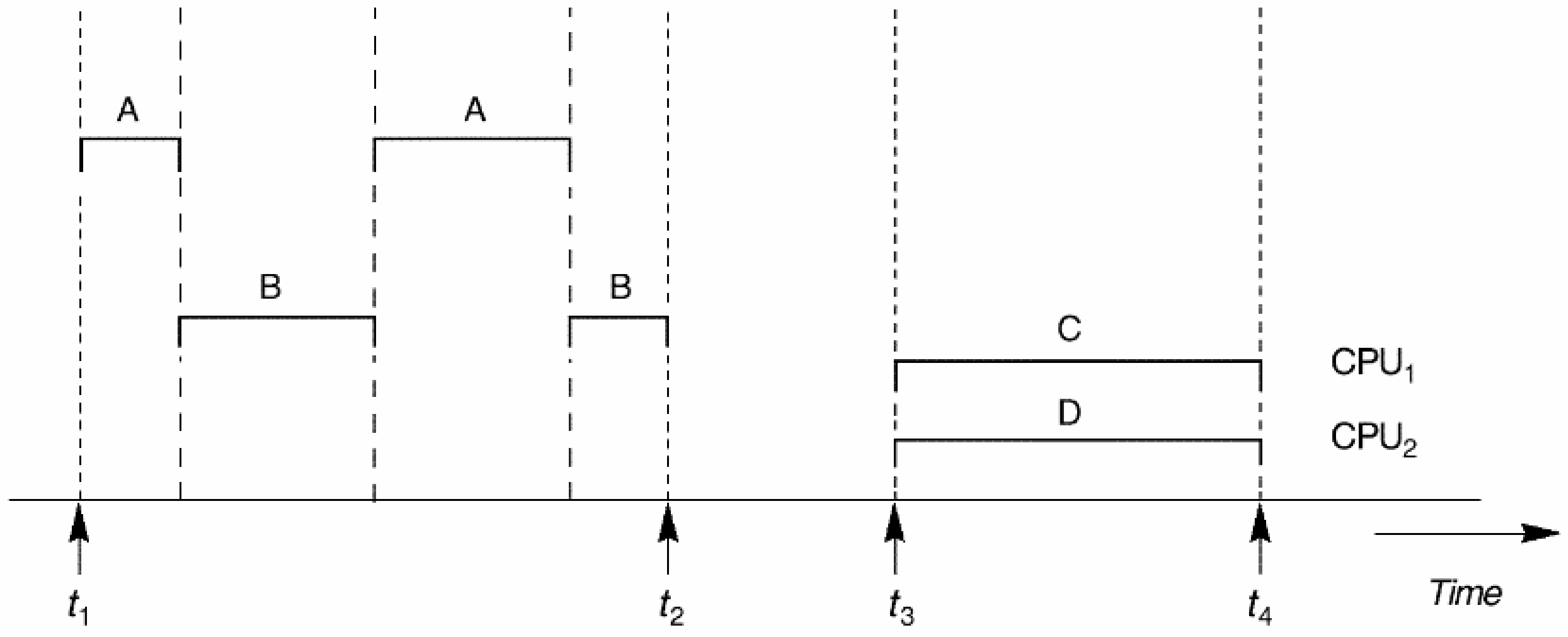
- **Single-User System:**
  - ***At most one user at a time can use the database management system.***
  - ***Eg. Personal computer system***
- **Multiuser System:**
  - ***Many users can access the DBMS concurrently.***
  - ***Eg. Air line reservation, Bank and the like system are operated by many users who submit transaction concurrently to the system***
  - ***This is achieved by multiprogramming , which allows the computer to execute multiple programs /processes at the same time.***

- **Concurrency**

  - ***Interleaved processing:***
    - Concurrent execution of processes is interleaved in a single CPU using for example, round robin algorithm

    Advantages:

    - keeps the CPU busy when the process requires I/O by switching to execute another process rather than remaining idle during I/O time and hence this will increase system throughput (average no. of transactions completed within a given time)
    - prevents long process from delaying other processes (minimize unpredictable delay in the response time).
  - ***Parallel processing:***
    - If Processes are concurrently executed in multiple CPUs.



Interleaved processing versus parallel processing of concurrent transactions.

- **A Transaction:**
    - Logical unit of database processing that includes one or more access operations (read - retrieval, write - insert or update, delete).
- Examples include ATM transactions, credit card approvals, flight reservations, hotel check-in, phone calls, supermarket scanning, academic registration and billing.
- **Transaction boundaries**:
    - Any single transaction in an application program is bounded with Begin and End statements.
- An **application program** may contain several transactions separated by the *Begin* and *End* transaction boundaries.

SIMPLE MODEL OF A DATABASE :

- **A database** is a collection of named data items
- **Granularity** of data - a field, a record , or a whole disk block that measure the size of the data item
- Basic operations that a transaction can perform are **read** and **write**
  - *read_item(X):* Reads a database item named X into a program variable.

    To simplify our notation, we assume that the program variable is also named X.
  - *write_item(X):* Writes the value of program variable X into the database item named X.

- Basic unit of data transfer from the disk to the computer main memory is one block.
- read_item(X) command includes the following steps:
  - Find the address of the disk block that contains item X.
  - Copy that disk block into a buffer in main memory (if that disk block is not already in some main memory buffer).
  - Copy item X from the buffer to the program variable named X.
- **write_item(X)** command includes the following steps:
  - Find the address of the disk block that contains item X.
  - Copy that disk block into a buffer in main memory (if that disk block is not already in some main memory buffer).
  - Copy item X from the program variable named X into its correct location in the buffer.
  - Store the updated block from the buffer back to disk (either immediately or at some later point in time).

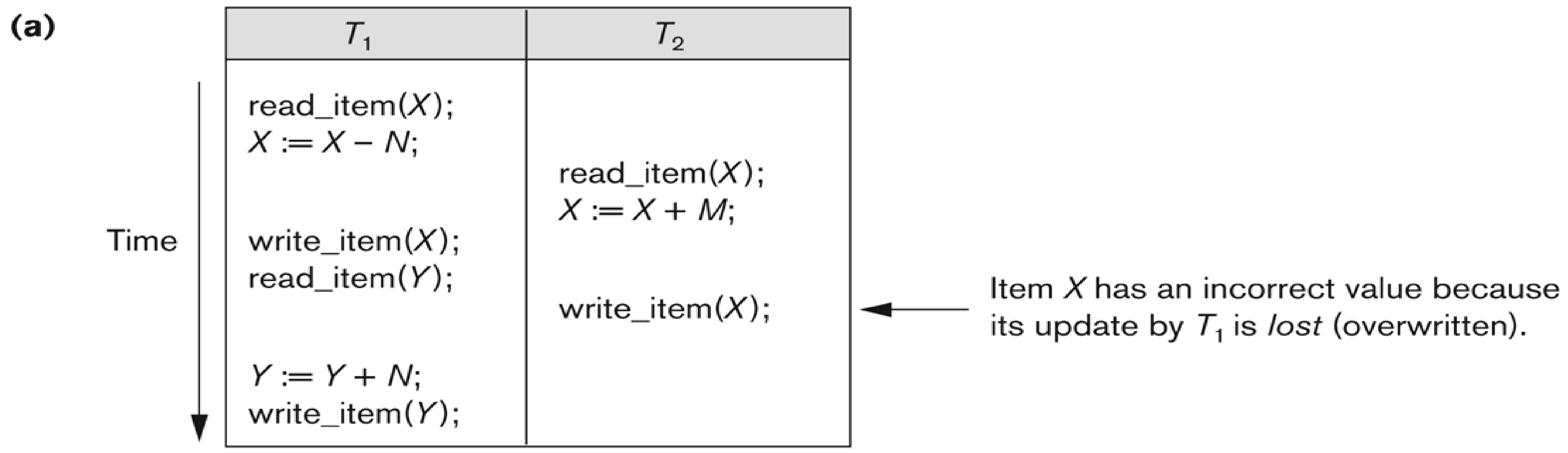
- The DBMS maintains a number of buffers in the main memory that holds database disk blocks which contains the database items being processed.
  - When this buffers are occupied and
  - if there is a need for additional database block to be copied to the main memory ;
- some buffer management policy is used to choose for replacement but if the chosen buffer has been modified , it must be written back to disk before it is used.

Why Concurrency Control is needed: Three cases

i. The Lost Update Problem

- This occurs when two transactions that access the same database items have their operations interleaved in a way that makes the value of some database item incorrect.

Figure 1 .3
Some problems that occur when concurrent execution is uncontrolled.



(a)

T_1	T_2
read_item(X); $X := X - N$;	
	read_item(X); $X := X + M$;

write_item(X);
read_item(Y);	

	write_item(X);
$Y := Y + N$; write_item(Y);	

Time
Item X has an incorrect value because its update by T_1 is *lost* (overwritten).

- E.g. Account with balance A=100.
  - T1 reads the account A
  - T1 withdraws 10 from A
  - T1 makes the update in the Database
  - T2 reads the account A
  - T2 adds 100 on A
  - T2 makes the update in the Database
- In the above case, if done one after the other (serially) then we have no problem.
  - If the execution is T1 followed by T2 then A=190
  - If the execution is T2 followed by T1 then A=190
- But if they start at the same time in the following sequence:
  - T1 reads the account A=100
  - T1 withdraws 10 making the balance A=90
  - T2 reads the account A=100
  - T2 adds 100 making A=200
  - T1 makes the update in the Database A=90
  - T2 makes the update in the Database A=200

T1	**T2**
Read_item(A)	
A=A-10	
	Read_item(A)
	A=A+100
Write_item(A)	
	Rite_item(A)

- After the successful completion of the operation the final value of A will be 200 which override the update made by the first transaction that changed the value from 100 to 90.

ii. The Temporary Update (or Dirty Read) Problem

- This occurs when one transaction updates a database item and then the transaction fails for some reason .
- The updated item is accessed by another transaction before it is changed back to its original value. Based on the above scenario:

T1	T2
	Read_item(A)
	A=A+100
	Write_item(A)
Read_item(A)	
A=A-10	
Write_item(A)	
	Abort

Fig 2: Temporal update problem

Transaction T2 fails and must change the values of A back to its old value; Meanwhile T1has read the temporary incorrect value of A

❑T2 increases 100 making it 200 but then aborts the transaction before it is committed. T1 gets 200, subtracts 10 and make it 190. But the actual balance should be 90

iii. The Incorrect Summary Problem

- If one transaction is calculating an aggregate summary function on a number of records while other transactions are updating some of these records, the aggregate function may calculate some values before they are updated and others after they are updated.

•Example: T1 would like to add the values of A=10, B=20 and C=30. after the values are read by T1 and before its completion, T2 updates the value of B to be 50. at the end of the execution of the two transactions T1 will come up with the sum of 60 while it should be 90 since B is updated to 50

T1	T2
Sum= 0;	
Read_item(A)	
Sum=Sum+A	
Read_item(B)	
Sum=Sum+B	
	Read_item(B)
	B=50
Read_item(C)	
Sum=Sum+C	

- **Why recovery is needed:**

  -Whenever a transaction is submitted to the DBMS for execution, the system is responsible for making sure that either all operations in the transaction to be completed successfully or the transaction has no effect on the database or any other transaction.

  -The DBMS may permit some operations of a transaction T to be applied to the database but a transaction may fails after executing some of its operations

- **What causes a Transaction to fail**

1. A computer failure (system crash):

   A hardware or software error occurs in the computer system during transaction execution. If the hardware crashes, the contents of the computer's internal memory may be lost.

2. A transaction or system error:

   Some operation in the transaction may cause it to fail, such as integer overflow or division by zero. Transaction failure may also occur because of erroneous parameter values or because of a logical programming error. In addition, *the user may interrupt the transaction during its execution.*

3. Exception conditions detected by the transaction:

- Certain conditions forces cancellation of the transaction.
- For example, data for the transaction may not be found. such as insufficient account balance in a banking database, may cause a transaction, such as a fund withdrawal from that account, to be canceled.

4. Concurrency control enforcement:

The concurrency control method may decide to abort the transaction, to be restarted later, because it violates serializability or because several transactions are in a state of deadlock (*see Chapter 2*).

5. Disk failure:

Some disk blocks may lose their data because of a read or write malfunction or because of a disk read/write head crash. This may happen during a read or a write operation of the transaction.

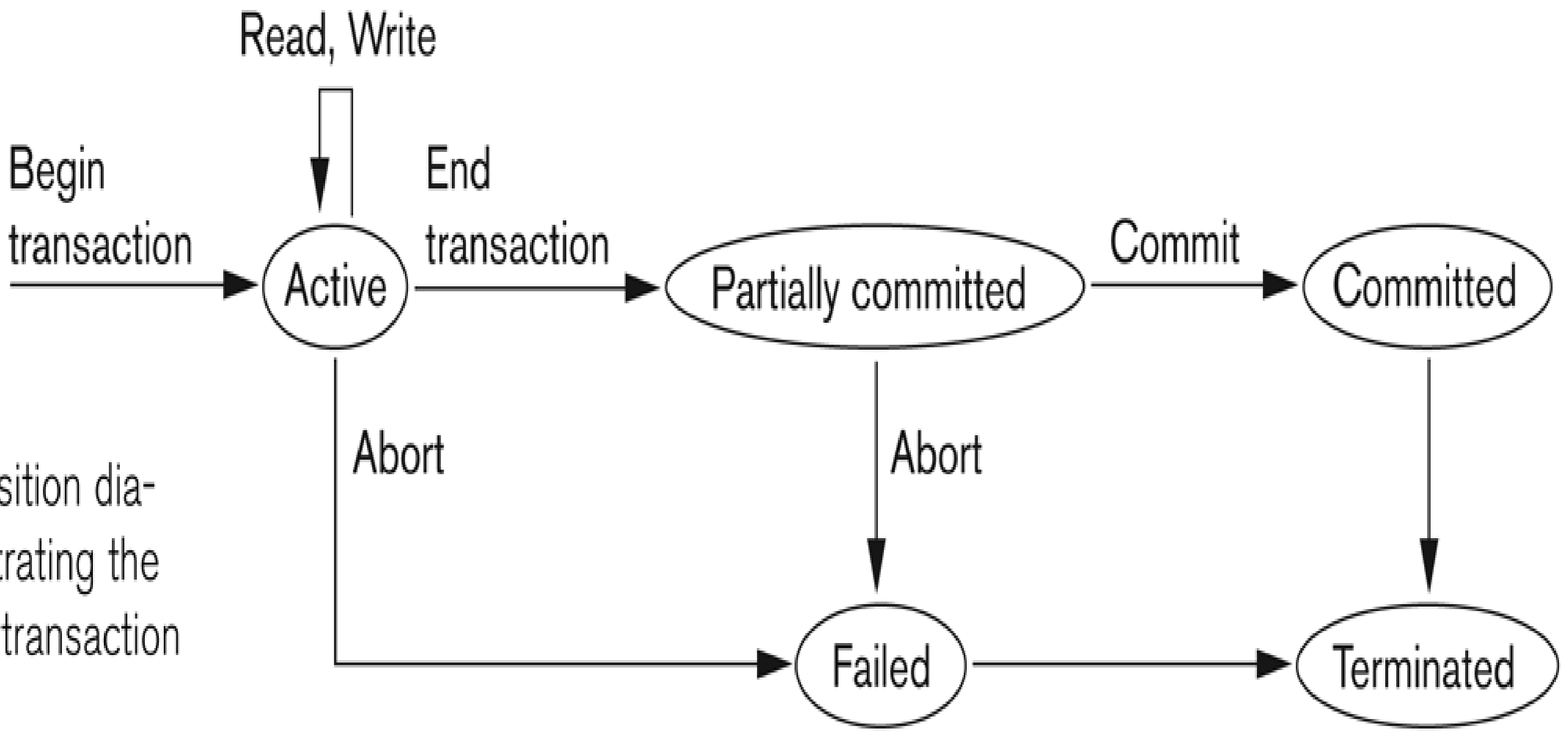
6. Physical problems and catastrophes:

This refers to an endless list of problems that includes power or air-conditioning failure, fire, theft, overwriting disks or tapes by mistake

2. Transaction and System Concepts

- A **transaction** is an atomic unit of work that is either completed in its entirety or not done at all.
  - For recovery purposes, the system needs to keep track of when the transaction starts, terminates, and commits or aborts.
- Transaction states:
  - Active state -indicates the beginning of a transaction execution
  - Partially committed state shows the end of read/write operation but this will not ensure permanent modification on the data base
  - Committed state -ensures that all the changes done on a record by a transition were done persistently
  - Failed state happens when a transaction is aborted   during its active state or if one of the rechecking is fails
  - Terminated State -corresponds to the transaction leaving the system

State transition diagram illustrating the states for transaction execution



State transition diagram illustrating the states for transaction execution.

- T in the following discussion refers to a unique **transaction-id** that is generated automatically by the system and is used to identify each transaction:
- Types of log record:
  - [start_transaction,T]: Records that transaction T has started execution.
  - [write_item,T,X,old_value,new_value]: Records that transaction T has changed the value of database item X from old_value to new_value.
  - [read_item,T,X]: Records that transaction T has read the value of database item X.
  - [commit,T]: Records that transaction T has completed successfully, and affirms that its effect can be committed (recorded permanently) to the database.
  - [abort,T]: Records that transaction T has been aborted.

3. Desirable Properties of Transactions

To ensure data integrity , DBMS should maintain the following **ACID** properties:

- **Atomicity**: A transaction is an atomic unit of processing; it is either performed in its entirety or not performed at all.
- **Consistency preservation**: A correct execution of the transaction must take the database from one consistent state to another.
- **Isolation:** A transaction should not make its updates visible to other transactions until it is committed; this property, when enforced strictly, solves the temporary update problem and makes cascading rollbacks of transactions unnecessary
- **Durability or permanency**: Once a transaction changes the database and the changes are committed, these changes must never be lost because of subsequent failure.

Example:

- Suppose that Ti is a transaction that transfer 200 birr from account CA2090(which is 5,000 Birr) to SB2359(which is 3,500 birr) as follows
    - ***Read(CA2090)***
    - ***CA2090= CA2090-200***
    - ***Write(CA2090)***
    - ***Read(SB2359)***
    - ***SB2359= SB2359+200***
    - **Write(*SB2359*)**
- Atomicity- either all or none of the above operation will be done – this is materialized by **transaction management** component of DBMS
- Consistency-the sum of CA2090 and SB2359 be unchanged by the execution of Ti i.e 8500- this is the responsibility of application programmer who codes the transaction
- Isolation- when several transaction are being processed concurrently on a data item they may create many inconsistent problems. So handling such case is the responsibility of Concurrency control component of the DBMS
- Durability - once Ti writes its update this will remain there when the database restarted from failure . This is the responsibility **of recovery management** components of the DBMS

4. Characterizing Schedules

- **Transaction schedule or history**:
  - When transactions are executing concurrently in an interleaved fashion, the order of execution of operations from the various transactions forms what is known as a transaction schedule (or history).
- A **schedule** S of n transactions T1, T2, ..., Tn:
  - It is an ordering of the operations of the transactions subject to the constraint that, for each transaction Ti that participates in S, the operations of T1 in S must appear in the same order in which they occur in Ti.
  - Note, however, that operations from other transactions Tj can be interleaved with the operations of Ti in S. Eg. Consider fig 2 on slide 12

S_a : r2(X);w2(X);r1(X);w1(X);a1;

- Two operations in a schedule are side to be conflict if they satisfy all the three of the following conditions.
  - They belongs to different transaction
  - They access the same data item X
  - At least one of the operation is a write_Item(X)

  Eg. S_a: r1(X); r2(x); w1(X); r1(Y); W2(X); W1(Y);

  - r1(X) and w2(X)
  - r2(X) and w1(X);
  - W1(X) and w2(X)

  Conflicting operations

  - r1(X) and r2(X)
  - W2(X) and w1(Y)

  No Conflict

i. Schedules classified by recoverability:

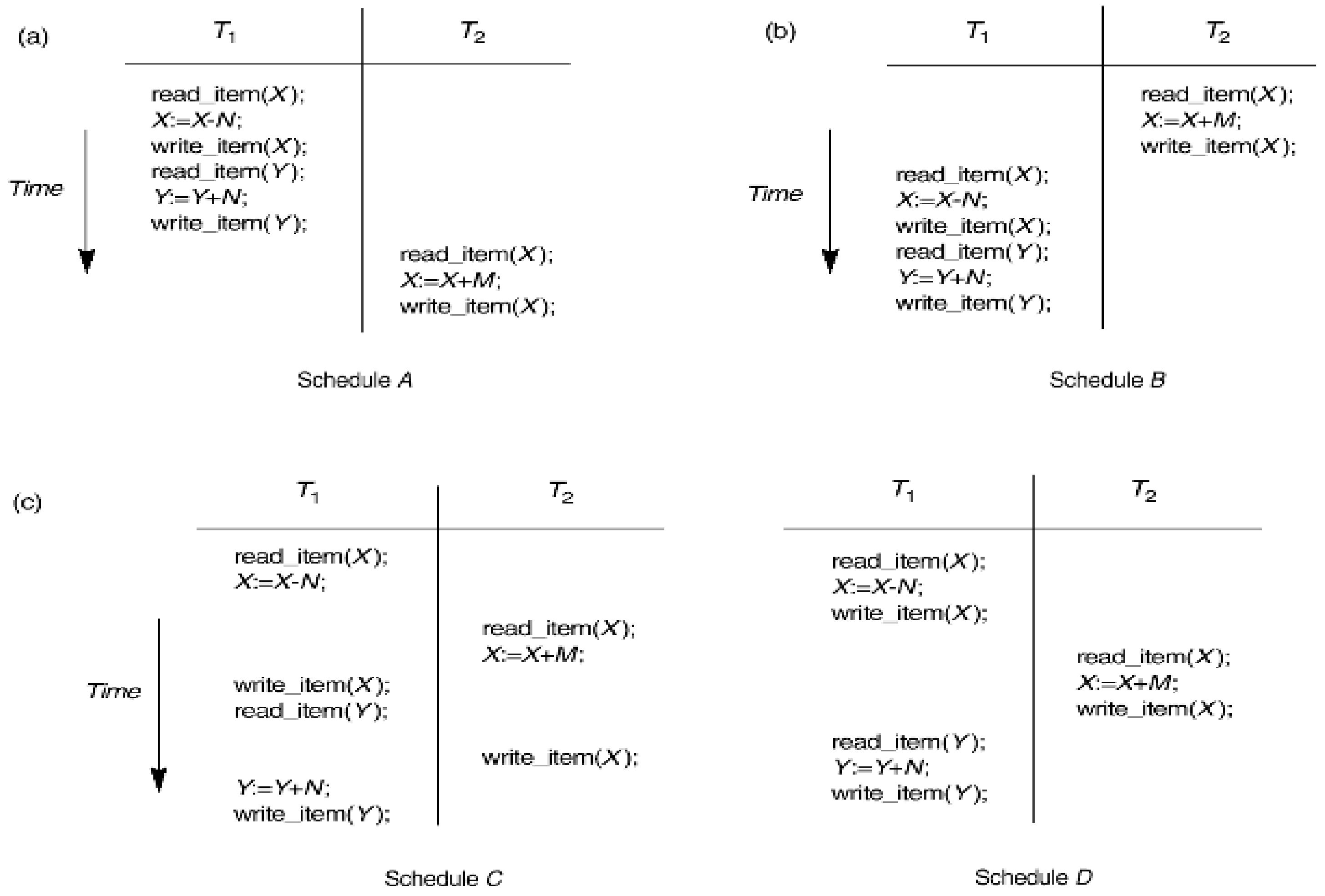
- **Recoverable schedule**:
  - One where no committed transaction needs to be rolled back.
  - A schedule S is recoverable if no transaction T in S commits until all transactions T' that have written an item that T reads have committed. Examples,
    - **Sc**: r1(X); w1(X); r2(X); r1(Y);w2(x);c2;a1; not recoverable
    - **Sd**: r1(X); w1(X); r2(X); r1(Y); w2(X);w1(Y); c1; c2;
    - **Se**: r1(X); w1(X); r2(X); r1(Y); w2(x) ; w1(Y); a1; a2;

    Recoverable
- **Cascadeless schedule**:
  - One where every transaction reads only the items that are written by committed transactions. Eg.
    - **Sf**: r1(X); w1(X); r1(Y); c1; r2(X); w2(X);w1(Y); c2;
- **Strict Schedules:**
  - A schedule in which a transaction can neither read or write an item X until the last transaction that wrote X has committed/aborted.
  - Eg. **Sg**: w1(X,5) ; c1; w2(x,8);

ii. Characterizing Schedules based on Serializability

– The concept of Serializable of schedule is used to identify which schedules are correct when concurrent transactions executions have interleaving of their operations in the schedule

- Serial schedule:
  - A schedule S is serial if, for every transaction T participating in the schedule, all the operations of T are executed consecutively in the schedule. Otherwise, the schedule is called nonserial schedule.
  - For example, in the banking example suppose there are two transaction where one transaction calculate the interest on the account and another deposit some money into the account. hence the order of execution is important for the final result
- Serializable schedule:
  - a schedule whose effect on any consistent database instance is identical to that of some complete serial schedule over the set of *committed* transactions in *S*.
  - A nonserial schedule S is serializable is equivalent to say that it is correct to the result of one of the serial schedule .Example,



(a)

T_1	T_2

read_item(X);
X:=X-N;
write_item(X);
read_item(Y);
Y:=Y+N;
write_item(Y);	

	read_item(X);
	X:=X+M;
	write_item(X);

Schedule *A*

(b)

T_1	T_2

	read_item(X);
	X:=X+M;
	write_item(X);

read_item(X);
X:=X-N;
write_item(X);
read_item(Y);
Y:=Y+N;
write_item(Y);	

Schedule *B*

(c)

T_1	T_2
read_item(X); X:=X-N;	
	read_item(X); X:=X+M;

write_item(X);
read_item(Y);	

	write_item(X);
Y:=Y+N; write_item(Y);	

Schedule *C*

T_1	T_2

read_item(X);
X:=X-N;
write_item(X);	

	read_item(X);
	X:=X+M;
	write_item(X);

read_item(Y);
Y:=Y+N;
write_item(Y);	

Schedule *D*

Examples of serial and nonserial schedules involving transactions T_1 and T_2.

- Result equivalent:
  - Two schedules are called result equivalent if they produce the same final state of the database
  - Two types of equivalent schedule: Conflict and view

i. Conflict equivalent:

- Two schedules are said to be conflict equivalent if the order of any two conflicting operations is the same in both schedules. Eg
  - S1: r1(x); w2(x) & S2: w2(x); r1(x)
  - S1: w1(x); w2(x); & S2: w2(x); w1(x);

  $\}$ Not conflict equivalent
- Conflict serializable:
- A schedule S is said to be conflict serializable if it is conflict equivalent to some serial schedule S'.
- Every conflict serializable schedule is serializable .

- If you can transform an interleaved schedule by swapping consecutive *non-conflicting* operations of different transactions into a serial schedule, then the original schedule is *conflict serializable*.
- *Example:*

```
R(A)  W(A)                  R(B) W(B)
           R(A) W(A)                  R(B) W(B)
                         ≡
R(A)  W(A) R(B) W(B)
                         R(A)  W(A) R(B) W(B)
```

ii. Two schedules are said to be view equivalent if the following three conditions hold:

1. The same set of transactions participates in S and S’, and S and S’ include the same operations of those transactions.
2. If Ti reads a value **A** written by Tj in S1 , it must also read the value of **A** written by Tj in S2
3. for each data object A, the transaction that perform the final write on x in S1 must also perform the final write on **A** in S2

S’

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

view $\equiv$

S

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

- **Relationship between view and conflict equivalence**:
  - The two are same under **constrained write assumption** which assumes that if T writes X, it is constrained by the value of X it read; i.e., new X = f(old X)
  - Conflict serializability is **stricter** than view serializability. With unconstrained write (or blind write), a schedule that is view serializable is not necessarily conflict serializable.

- Consider the following schedule of three transactions
  - T1: r1(X), w1(X); T2: w2(X); and T3: w3(X):
- **Schedule Sa: r1(X); w2(X); w1(X); w3(X); c1; c2; c3;**

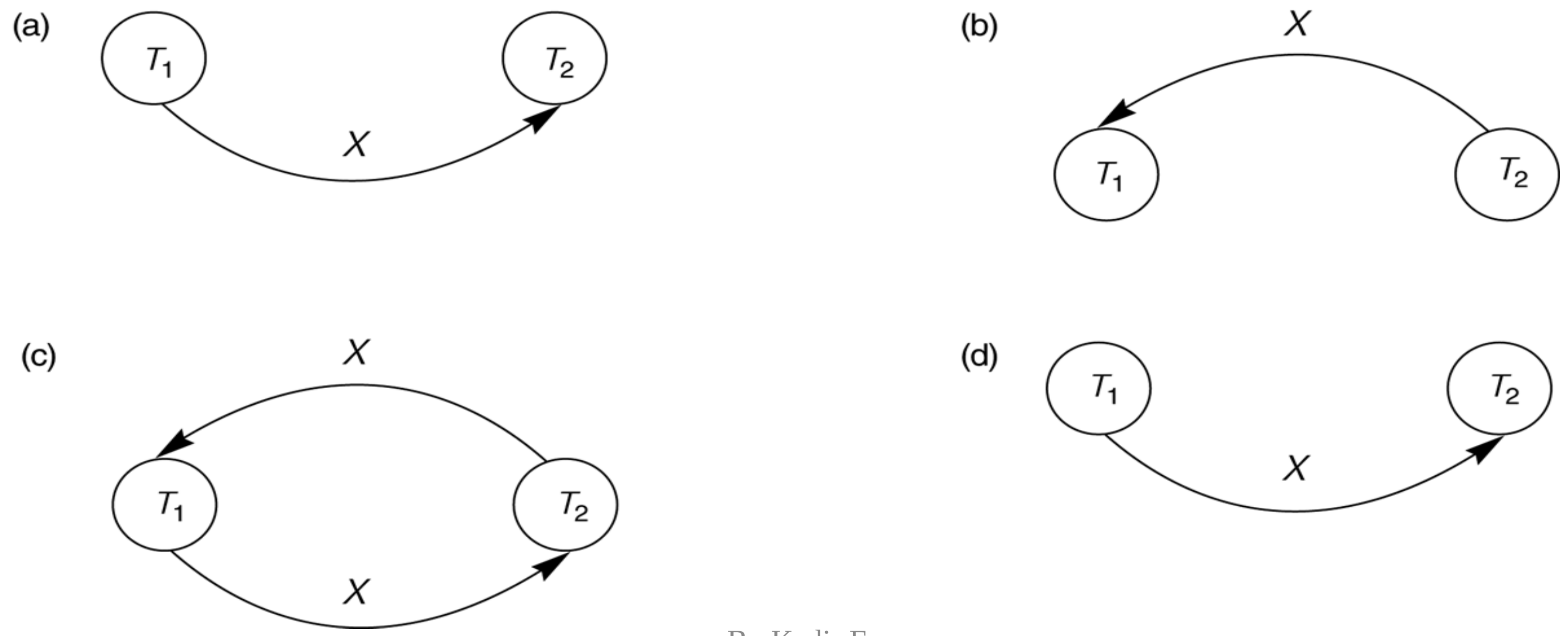
- In Sa, the operations w2(X) and w3(X) are blind writes, since T1 and T3 do not read the value of X.
  - Sa is view serializable, since it is view equivalent to the serial schedule T1, T2, T3.
  - However, Sa is not conflict serializable, since it is not conflict equivalent to any serial schedule.

Testing for conflict serializability: Algorithm

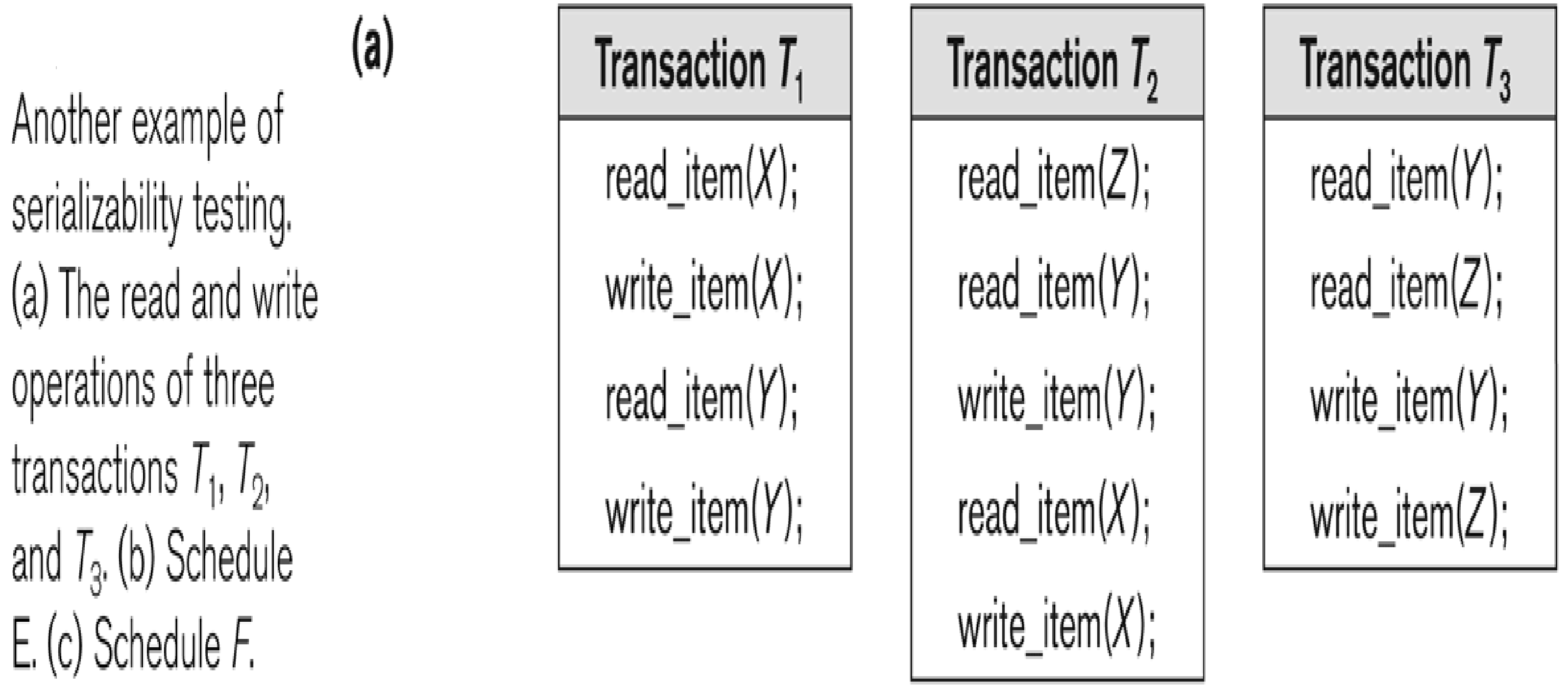
- Looks at only read_Item (X) & write_Item (X) operations
- Constructs a precedence graph (serialization graph) - a graph with directed edges
- An edge is created from Ti to Tj if one of the operations in Ti appears before a conflicting operation in Tj
- The schedule is serializable if and only if the precedence graph has no cycles.

Constructing the Precedence Graphs

- FIGURE 5: Constructing the precedence graphs for schedules A and D from Figure 4 (from slide No 29)to test for conflict serializability.
    - (a) Precedence graph for serial schedule A.
    - (b) Precedence graph for serial schedule B.
    - (c) Precedence graph for schedule C (not serializable).
    - (d) Precedence graph for schedule D (serializable, equivalent to schedule A).



Another example of serializability Testing



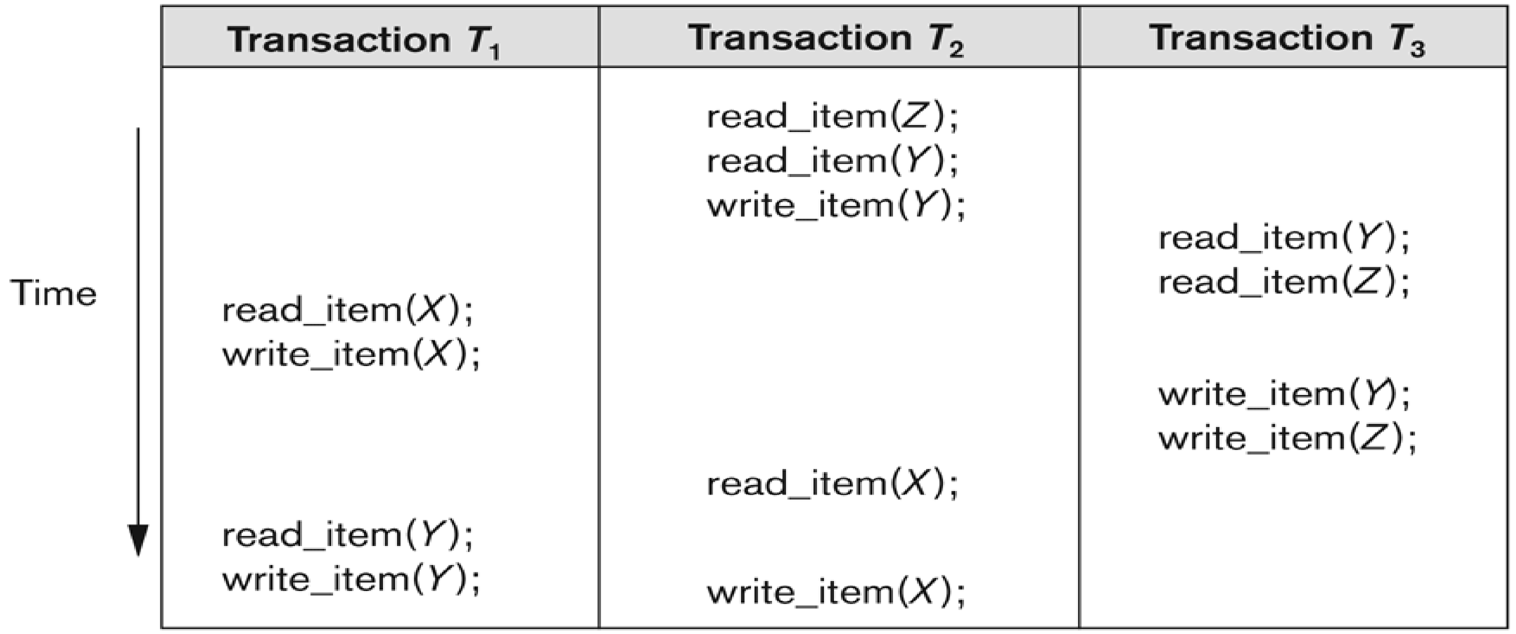
Another example of serializability testing. (a) The read and write operations of three transactions T_1, T_2, and T_3. (b) Schedule E. (c) Schedule F.

(a)

Transaction T_1	Transaction T_2	Transaction T_3
read_item(X);	read_item(Z);	read_item(Y);
write_item(X);	read_item(Y);	read_item(Z);
read_item(Y);	write_item(Y);	write_item(Y);
write_item(Y);	read_item(X);	write_item(Z);
	write_item(X);	

Another example of serializability testing. (a) The read and write operations of three transactions T_1, T_2, and T_3. (b) Schedule E. (c) Schedule F.

(b)

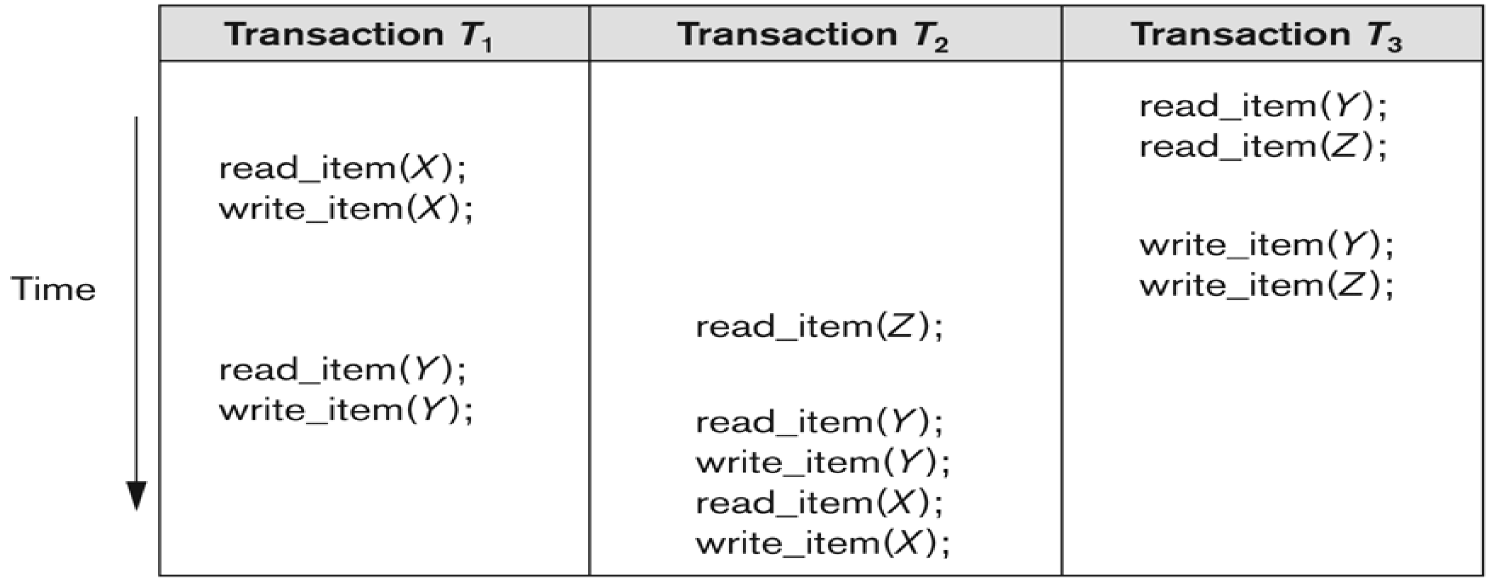


Transaction T_1	Transaction T_2	Transaction T_3
	read_item(Z);	
	read_item(Y);	
	write_item(Y);	
		read_item(Y);
		read_item(Z);
read_item(X);		
write_item(X);		
		write_item(Y);
		write_item(Z);
	read_item(X);	
read_item(Y);		
write_item(Y);		
	write_item(X);	

Schedule E

Another example of serializability testing. (a) The read and write operations of three transactions T_1, T_2, and T_3. (b) Schedule E. (c) Schedule F.

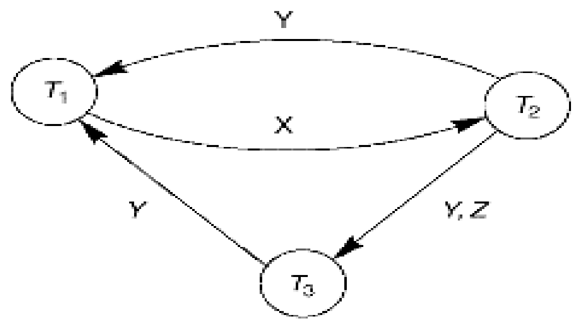
(c)



Transaction T_1	Transaction T_2	Transaction T_3
		read_item(Y);
		read_item(Z);
read_item(X);		
write_item(X);		
		write_item(Y);
		write_item(Z);
	read_item(Z);	
read_item(Y);		
write_item(Y);		
	read_item(Y);	
	write_item(Y);	
	read_item(X);	
	write_item(X);	

Schedule F

(d)



Equivalent serial schedules

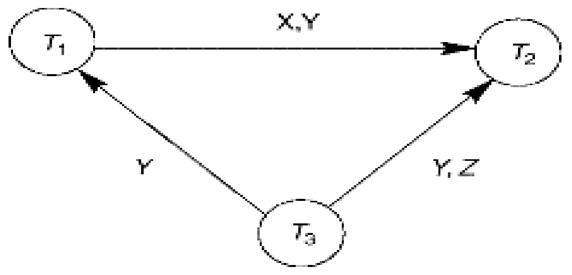
None

Reason

cycle $X(T_1 \rightarrow T_2)$, $Y(T_2 \rightarrow T_1)$

cycle $X(T_1 \rightarrow T_2)$, $YZ(T_2 \rightarrow T_3)$, $Y(T_3 \rightarrow T_1)$

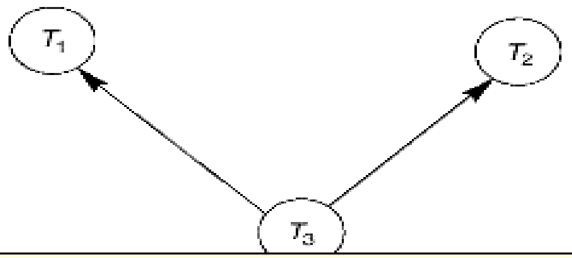
(e)



Equivalent serial schedules

$T_3 \rightarrow T_1 \rightarrow T_2$

(f)



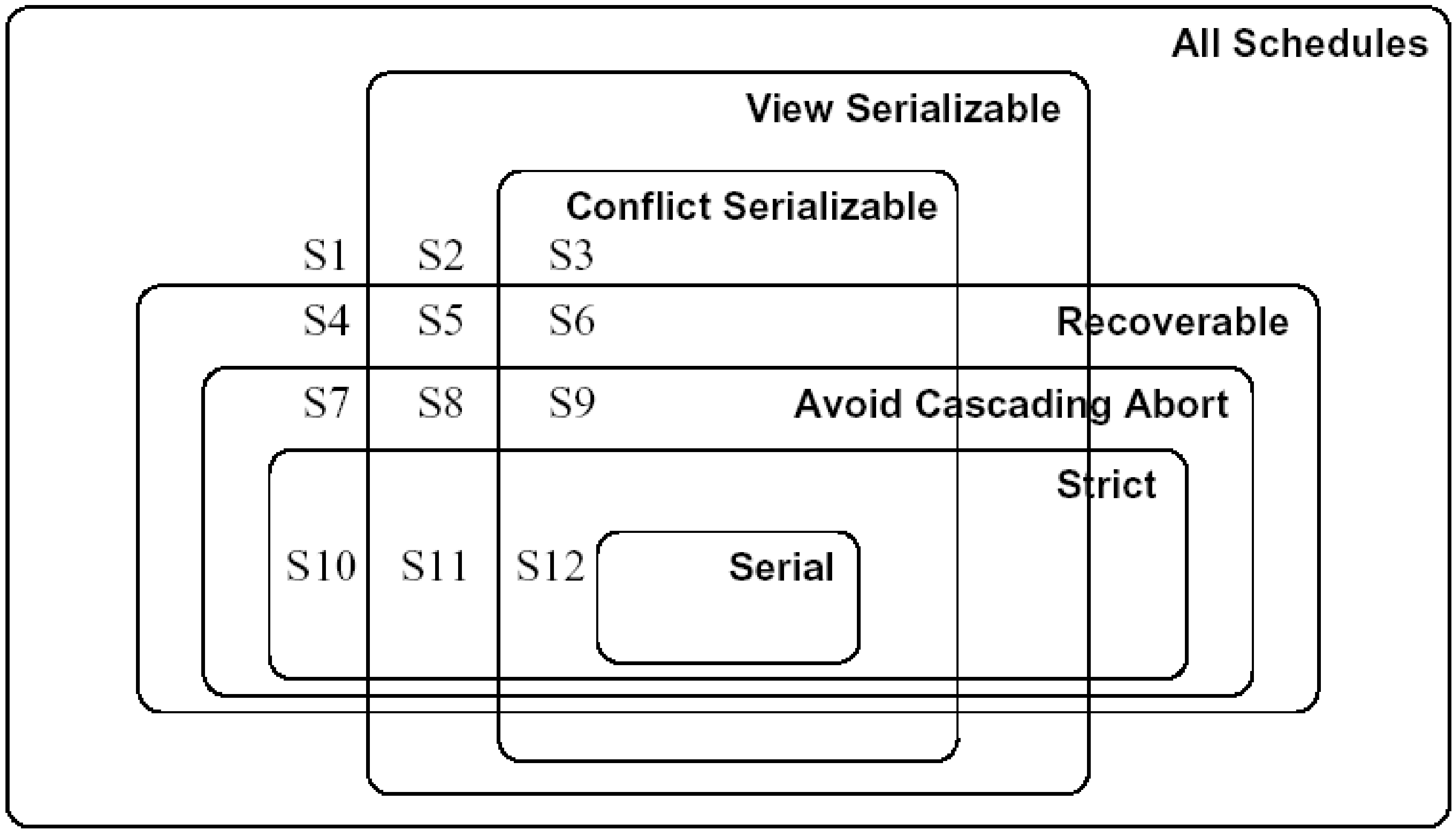
Equivalent serial schedules

$T_3 \rightarrow T_1 \rightarrow T_2$

$T_3 \rightarrow T_2 \rightarrow T_1$

Another example of serializability testing. (d) Precedence graph for schedule *E*. (e) Precedence graph for schedule *F*. (f) Precedence graph with two equivalent serial schedules.

Summery of Schedule types



Venn Diagram for Classes of Schedules

6 Transaction Support in SQL

- A **single** SQL statement is always considered to be **atomic**.
  - Either the statement completes execution without error or it fails and leaves the database unchanged.
- Every transaction has three characteristics: Access mode, Diagnostic size and isolation

  i. **Access mode**:
  - READ ONLY or READ WRITE
    - If the access mode is Read ONLY , INSERT, DELET , UPDATE & CREATE commands cannot be executed on the data base
    - The default is READ WRITE unless the isolation level of READ UNCOMITTED is specified, in which case READ ONLY is assumed.

  ii. **Diagnostic size n**, specifies an integer value n, indicating the number of error conditions that can be held simultaneously in the diagnostic area.

  iii. **Isolation level** can be
  - READ UNCOMMITTED,
  - READ COMMITTED,
  - REPEATABLE READ or
  - SERIALIZABLE. The default is SERIALIZABLE.

- Sample SQL transaction:

```
EXEC SQL whenever sqlerror go to UNDO;
EXEC SQL SET TRANSACTION
             READ WRITE
             DIAGNOSTICS SIZE 5
             ISOLATION LEVEL SERIALIZABLE;
EXEC SQL INSERT
            INTO EMPLOYEE (FNAME, LNAME, SSN, DNO, SALARY)
            VALUES ('Robert','Smith','991004321',2,35000);
EXEC SQL UPDATE EMPLOYEE
            SET SALARY = SALARY * 1.1
            WHERE DNO = 2;
EXEC SQL COMMIT;
            GOTO  THE_END;
UNDO: EXEC SQL ROLLBACK;
THE_END:  ...
```

- With SERIALIZABLE: the interleaved execution of transactions will adhere to the notion of serializability.
- However, if any transaction executes at a lower level, then serializability may be violated.

❑ Potential problem with lower isolation levels: Four types

i. Unrepeatable Reads: RW Conflicts

- a transaction *T*2 could change the value of an object *A* that has been read by a transaction *T*1, while *T*1 is still in progress.
- If T1 tries to read the value a again it will get a different value

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

ii. Reading Uncommitted Data ("dirty reads"): WR Conflicts

•a transaction *T*2 could read a database object A that has been modified by another transaction *T*1, which has not yet committed.

T1:	R(A), W(A),		R(B), W(B), Abort
T2:		R(A), W(A), C	

iii. Overwriting Uncommitted Data: WW Conflicts

- A transaction *T*2 could overwrite the value of an object *A*, which has already been modified by a transaction *T*1, while *T*1 is still in progress.

T1:	W(A),		W(B), C
T2:		W(A), W(B), C	

iv. Phantoms:

- New rows being read using the same read with a condition.
  - A transaction T1 may read a set of rows from a table, perhaps based on some condition specified in the SQL WHERE clause.
  - Now suppose that a transaction T2 inserts a new row that also satisfies the WHERE clause condition of T1, into the table used by T1.
  - If T1 is repeated, then T1 will see a row that previously did not exist, called a phantom.

- Possible violation of serializabilty:

Type of Violation

Isolation level	Dirty read	nonrepeatable read	phantom
READ UNCOMMITTED	yes	yes	yes
READ COMMITTED	no	yes	yes
REPEATABLE READ	no	no	yes
SERIALIZABLE	no	no	no

- Recovery techniques use the following operators:
  - **undo**: Similar to rollback except that it applies to a single operation rather than to a whole transaction.
  - **redo**: This specifies that certain *transaction operations* must be *redone* to ensure that all the operations of a committed transaction have been applied successfully to the database.
- The System Log
  - **Log** or **Journal**: The log keeps track of all transaction operations that affect the values of database items.
    - This information may be needed to permit recovery from transaction failures.
    - The log is kept on disk, so it is not affected by any type of failure except for disk or catastrophic failure.
    - In addition, the log is periodically backed up to archival storage (tape) to guard against such catastrophic failures.

Recovery using log records:

- If the system crashes, we can recover to a consistent database state by examining the log and using one of the techniques described in *Chapter two*.

1. Because the log contains a record of every write operation that changes the value of some database item, it is possible to undo the effect of these write operations of a transaction T by tracing backward through the log and resetting all items changed by a write operation of T to their old_values.
2. We can also **redo** the effect of the write operations of a transaction T by tracing forward through the log and setting all items changed by a write operation of T (that did not get done permanently) to their new_values.

- **Redoing transactions:**
  - Redoing transaction operations is needed if all its updates are recorded on the Log but a failure occurs before we can be sure that all the new items have been written permanently on the database on the disk.
  - Transactions that have written their commit entry in the log must also have recorded all their write operations in the log; otherwise they would not be committed, so their effect on the database can be redone from the log entries. (Notice that the log file must be kept on disk.
  - At the time of a system crash, only the log entries that have been written back to disk are considered in the recovery process because the contents of main memory may be lost.)
- **Force writing a log:**
  - Before a transaction reaches its commit point, any portion of the log that has not been written to the disk yet must now be written to the disk.
  - This process is called force-writing the log file before committing a transaction.