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Unit 4

Part-1

Transaction Processing Concepts and Theory

Original Content: Ramez Elmasri and Shamkant B. Navathe

Chapter Outline

1 Introduction to Transaction Processing

2 Transaction and System Concepts

3 Desirable Properties of Transactions

4 Characterizing Schedules based on Recoverability

5 Characterizing Schedules based on Serializability

6 Transaction Support in SQL

Introduction to Transaction Processing

- **Single-User System**:
  - At most one user at a time can use the system.
- **Multiuser System**:
  - Many users can access the system concurrently.
- **Concurrency**
  - **Interleaved processing**:
    - Concurrent execution of processes is interleaved in a single CPU
  - **Parallel processing**:
    - Processes are concurrently executed in multiple CPUs.

Introduction to Transaction Processing

- A **Transaction**:
  - Logical unit of database processing that includes one or more access operations (read -retrieval, write - insert or update, delete).
- A transaction (set of operations) may be stand-alone specified in a high level language like SQL submitted interactively, or may be embedded within a program.

- **Transaction boundaries**:
  - Begin and End transaction.

- An **application program** may contain several transactions separated by the Begin and End transaction boundaries.

Introduction to Transaction Processing

SIMPLE MODEL OF A DATABASE (for purposes of discussing transactions):

- **A database** is a collection of named data items
- **Granularity** of data - a field, a record , or a whole disk block (Concepts are independent of granularity)
- Basic operations 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.

Introduction to Transaction Processing

READ AND WRITE OPERATIONS:

- Basic unit of data transfer from the disk to the computer main memory is one block. In general, a data item (what is read or written) will be the field of some record in the database, although it may be a larger unit such as a record or even a whole 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.

Introduction to Transaction Processing

READ AND WRITE OPERATIONS (contd.):

- **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).

Two sample transactions

(a) T_1

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

(b) T_2

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

Why Concurrency Control is needed:

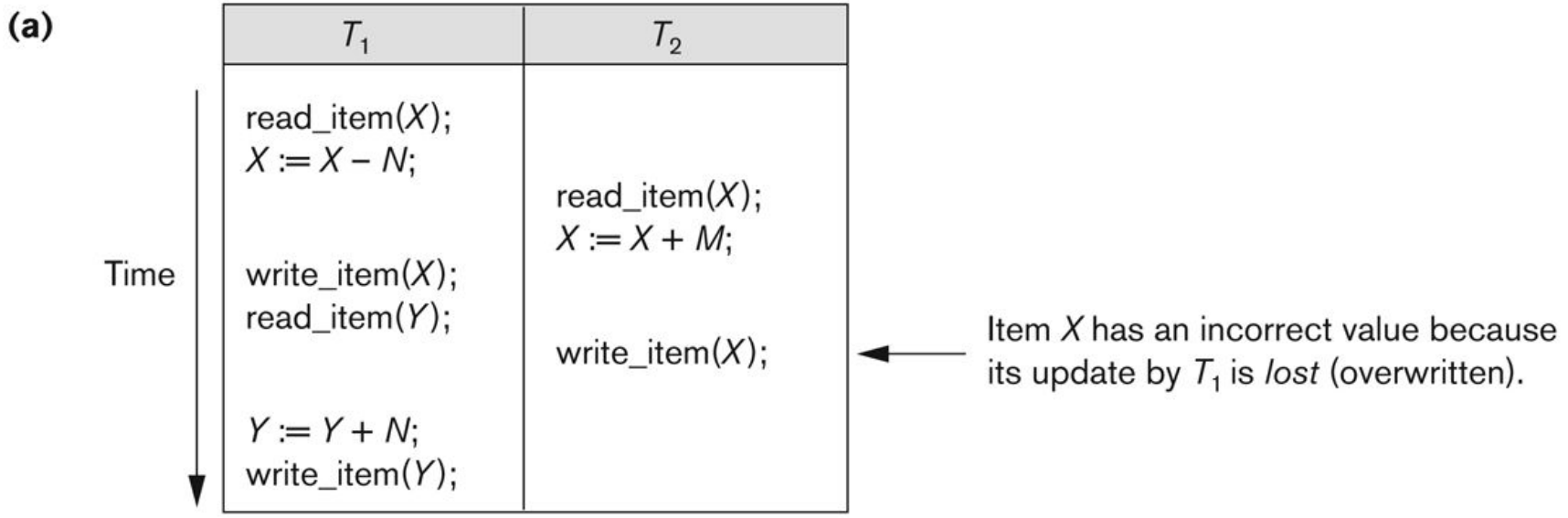
- **The Lost Update Problem**
  - This occurs when two transactions that access the same database items have their operations interleaved in a way that makes the value of some database item incorrect.

- **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.

- **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.

Concurrent execution is uncontrolled: (a) The lost update problem.

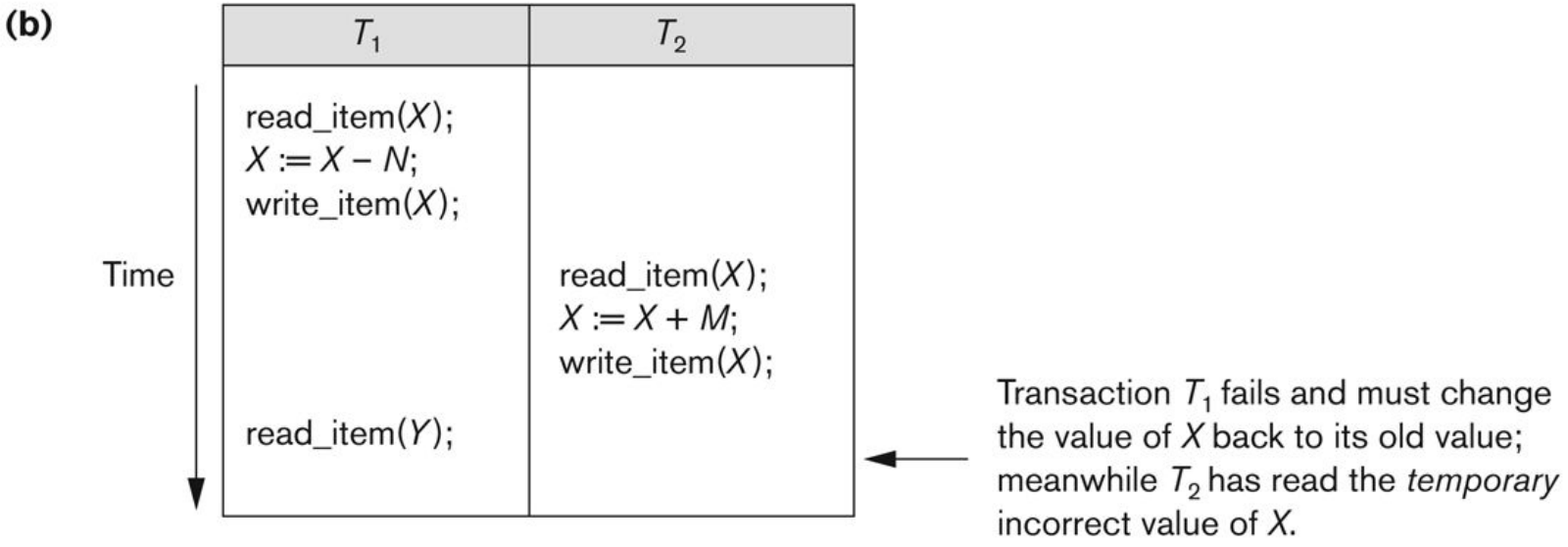
Figure 17.3
Some problems that occur when concurrent execution is uncontrolled. (a) The lost update problem. (b) The temporary update problem. (c) The incorrect summary problem.



Concurrent execution is uncontrolled: (b) The temporary update problem.

Figure 17.3

Some problems that occur when concurrent execution is uncontrolled. (a) The lost update problem. (b) The temporary update problem. (c) The incorrect summary problem.



Concurrent execution is uncontrolled: (c) The incorrect summary problem.

Figure 17.3

Some problems that occur when concurrent execution is uncontrolled. (a) The lost update problem. (b) The temporary update problem. (c) The incorrect summary problem.

(c)

T_1	T_3

	sum := 0;
	read_item(*A*);
	sum := *sum* + *A*;
	• • •

read_item(*X*);
X := *X* − *N*;
write_item(*X*);	

	read_item(*X*);
	sum := *sum* + *X*;
	read_item(*Y*);
	sum := *sum* + *Y*;

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

← T_3 reads *X* after *N* is subtracted and reads *Y* before *N* is added; a wrong summary is the result (off by *N*).

Why recovery is needed:

(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.

Why recovery is needed:

3. Local errors or exception conditions detected by the transaction:

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

A programmed abort in the transaction causes it to fail.

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

Why recovery is needed:

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, sabotage, overwriting disks or tapes by mistake, and mounting of a wrong tape by the operator.

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
  - Partially committed state
  - Committed state
  - Failed state
  - Terminated State

Transaction and System Concepts

Recovery manager keeps track of the following operations:

begin_transaction: This marks the beginning of transaction execution.

read or write: These specify read or write operations on the database items that are executed as part of a transaction.

end_transaction: This specifies that read and write transaction operations have ended and marks the end limit of transaction execution.

At this point it may be necessary to check whether the changes introduced by the transaction can be permanently applied to the database or whether the transaction has to be aborted because it violates concurrency control or for some other reason.

Transaction and System Concepts

- Recovery manager keeps track of the following operations (cont):
  - **commit_transaction**: This signals a successful end of the transaction so that any changes (updates) executed by the transaction can be safely committed to the database and will not be undone.
  - **rollback** (or **abort**): This signals that the transaction has ended unsuccessfully, so that any changes or effects that the transaction may have applied to the database must be undone.

- 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.

State transition diagram

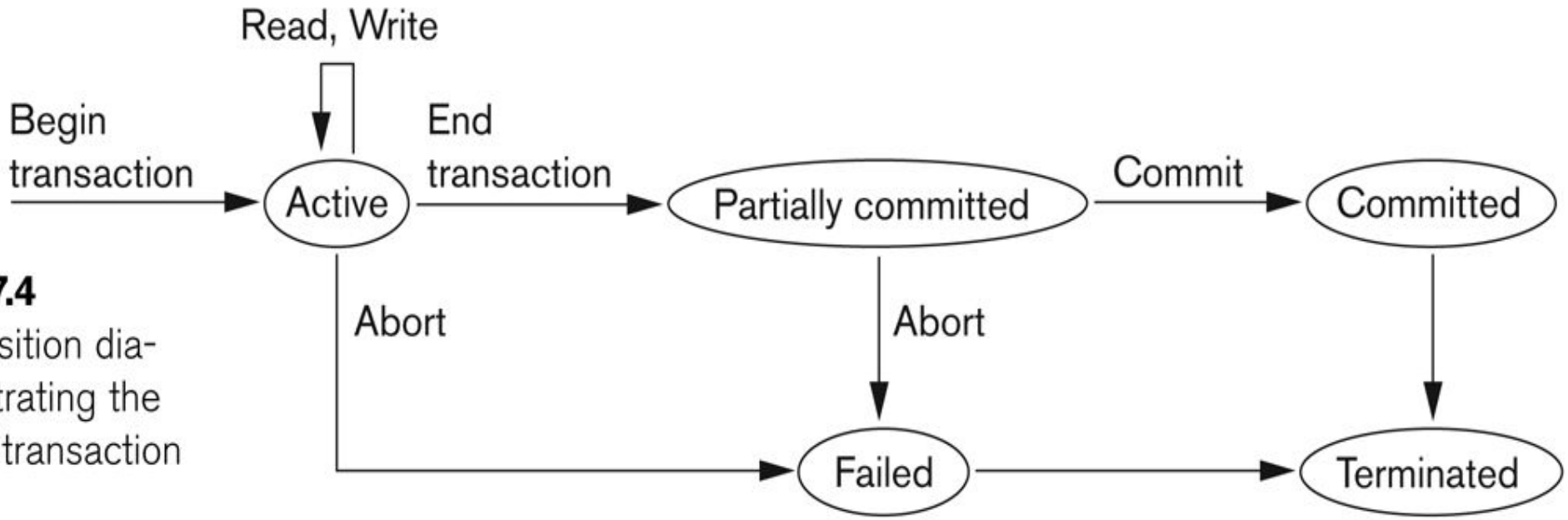


Figure 17.4
State transition diagram illustrating the states for transaction execution.

- 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.

- The System Log (cont):
  - 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.

- The System Log (cont):
  - Protocols for recovery that *avoid cascading rollbacks do not require that read operations be written to the system log*, whereas other protocols require these entries for recovery.
  - Strict protocols require simpler write entries that do not include new_value

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 19.
  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.

Commit Point of a Transaction:

- **Definition a Commit Point:**
  - A transaction T reaches its **commit point** when all its operations that access the database have been executed successfully *and* the effect of all the transaction operations on the database has been recorded in the log.
  - Beyond the commit point, the transaction is said to be committed, and its effect is assumed to be permanently recorded in the database.
  - The transaction then writes an entry [commit,T] into the log.
- **Roll Back of transactions:**
  - Needed for transactions that have a [start_transaction,T] entry into the log but no commit entry [commit,T] into the log.

Commit Point of a Transaction (cont):

- **Redoing transactions:**
  - 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.

Desirable Properties of Transactions

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 (see Chapter 21).
- **Durability or permanency**: Once a transaction changes the database and the changes are committed, these changes must never be lost because of subsequent failure.

Characterizing Schedules based on Recoverability

- **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** (or **history**) 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 T1.
  - Note, however, that operations from other transactions Tj can be interleaved with the operations of Ti in S.

Characterizing Schedules based on Recoverability

Schedules classified on recoverability:

- **Recoverable schedule**:
  - One where no 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.
- **Cascadeless schedule**:
  - One where every transaction reads only the items that are written by committed transactions.

Characterizing Schedules based on Recoverability

Schedules classified on recoverability (contd.):

- **Schedules requiring cascaded rollback**:
  - A schedule in which uncommitted transactions that read an item from a failed transaction must be rolled back.
- **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.

Characterizing Schedules based on Recoverability

- 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.
- Serializable schedule:
  - A schedule S is serializable if it is equivalent to some serial schedule of the same n transactions.

Characterizing Schedules based on Recoverability

- Result equivalent:
  - Two schedules are called result equivalent if they produce the same final state of the database.
- Conflict equivalent:
  - Two schedules are said to be conflict equivalent if the order of any two conflicting operations is the same in both schedules.
- Conflict serializable:
  - A schedule S is said to be conflict serializable if it is conflict equivalent to some serial schedule S'.

Characterizing Schedules based on Recoverability

- Being serializable is not the same as being serial
- Being serializable implies that the schedule is a correct schedule.
  - It will leave the database in a consistent state.
  - The interleaving is appropriate and will result in a state as if the transactions were serially executed, yet will achieve efficiency due to concurrent execution.
- Serializability is hard to check.
  - Interleaving of operations occurs in an operating system through some scheduler
  - Difficult to determine beforehand how the operations in a schedule will be interleaved.

Characterizing Schedules based on Recoverability

Practical approach:

- Come up with methods (protocols) to ensure serializability.
- It's not possible to determine when a schedule begins and when it ends.
  - Hence, we reduce the problem of checking the whole schedule to checking only a **committed project** of the schedule (i.e. operations from only the committed transactions.)
- Current approach used in most DBMSs:
  - Use of locks with two phase locking

Characterizing Schedules based on Recoverability

- View equivalence:
  - A less restrictive definition of equivalence of schedules
- View serializability:
  - Definition of serializability based on view equivalence.
  - A schedule is *view serializable* if it is *view equivalent* to a serial schedule.

Characterizing Schedules based on Recoverability

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. For any operation Ri(X) of Ti in S, if the value of X read by the operation has been written by an operation Wj(X) of Tj (or if it is the original value of X before the schedule started), the same condition must hold for the value of X read by operation Ri(X) of Ti in S'.
3. If the operation Wk(Y) of Tk is the last operation to write item Y in S, then Wk(Y) of Tk must also be the last operation to write item Y in S'.

Characterizing Schedules based on Recoverability

- The premise behind view equivalence:
  - As long as each read operation of a transaction reads the result of *the same write operation* in both schedules, the write operations of each transaction must produce the same results.
  - "**The view**": the read operations are said to see *the same view* in both schedules.

Characterizing Schedules based on Recoverability

- **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.
  - Any conflict serializable schedule is also view serializable, but not vice versa.

Characterizing Schedules based on Recoverability

- Relationship between view and conflict equivalence (cont):
  - 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.

Characterizing Schedules based on Recoverability

Testing for conflict serializability: Algorithm 17.1:

- Looks at only read_Item (X) and 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

- Constructing the precedence graphs for schedules A and D from Figure 17.5 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).

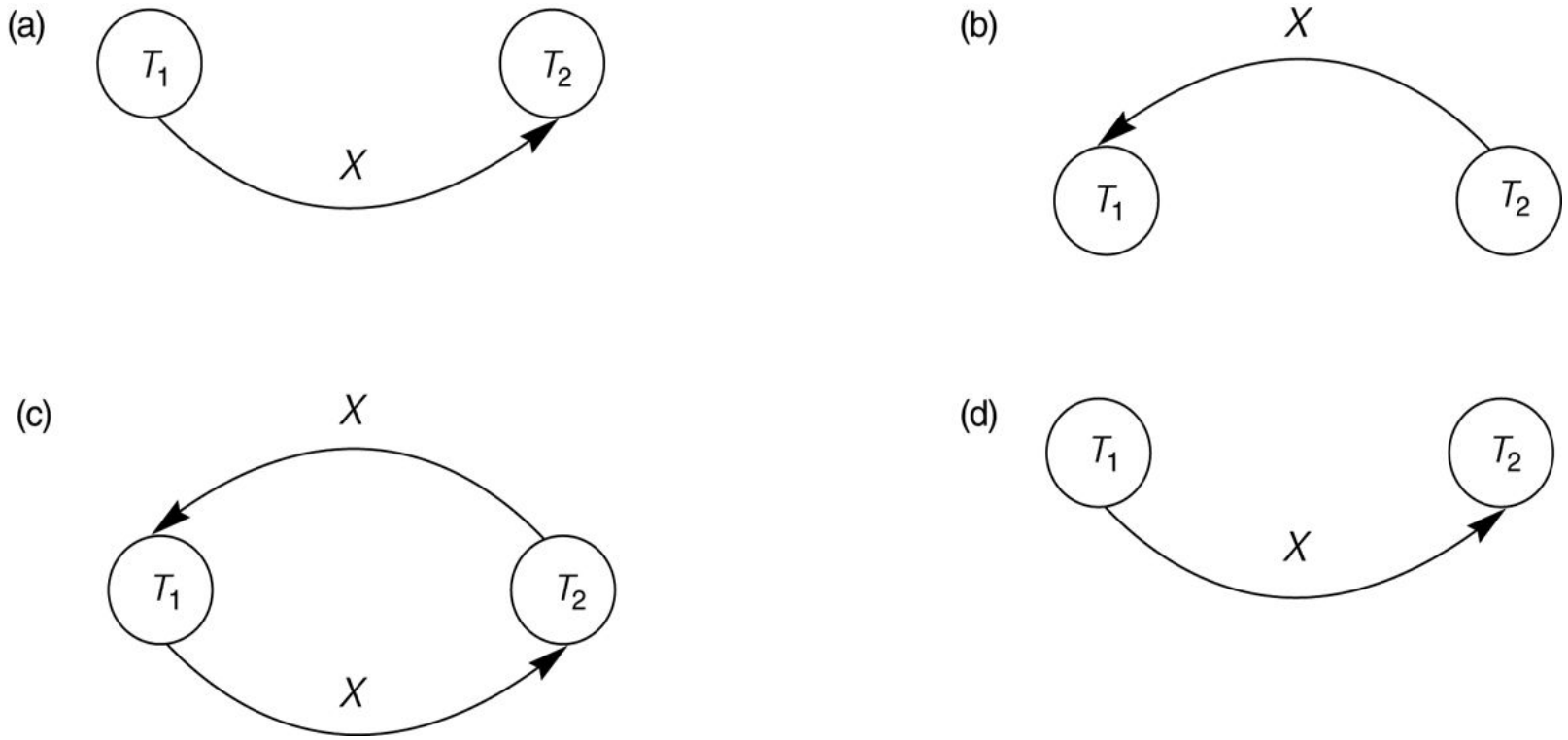


Figure 17.8
Another example of serializability testing. (a) The read and write operations of three transactions T_1, T_2, and T_3. (b) Schedule E. (c) Schedule *F*.

(a)

Transaction T_1
read_item(X);
write_item(X);
read_item(Y);
write_item(Y);

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

Transaction T_3
read_item(Y);
read_item(Z);
write_item(Y);
write_item(Z);

Figure 17.8
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)

Time

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

Figure 17.8
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)

Time

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

Other Types of Equivalence of Schedules

- Under special **semantic constraints**, schedules that are otherwise not conflict serializable may work correctly.
  - Using commutative operations of addition and subtraction (which can be done in any order) certain non-serializable transactions may work correctly

Other Types of Equivalence of Schedules (contd.)

- Example: bank credit / debit transactions on a given item are **separable** and **commutative**.
  - Consider the following schedule S for the two transactions:
  - Sh : r1(X); w1(X); r2(Y); w2(Y); r1(Y); w1(Y); r2(X); w2(X);
  - Using conflict serializability, it is **not serializable**.
  - However, if it came from a (read,update, write) sequence as follows:
    - r1(X); X := X – 10; w1(X); r2(Y); Y := Y – 20;r1(Y);
    - Y := Y + 10; w1(Y); r2(X); X := X + 20; (X);
  - Sequence explanation: debit, debit, credit, credit.
  - It is a *correct schedule for the given semantics*

Transaction Support in SQL2

- 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.
- With SQL, there is no explicit Begin Transaction statement.
  - Transaction initiation is done implicitly when particular SQL statements are encountered.
- Every transaction must have an explicit end statement, which is either a COMMIT or ROLLBACK.

Transaction Support in SQL2

Characteristics specified by a SET TRANSACTION statement in SQL2:

- **Access mode**:
  - READ ONLY or READ WRITE.
    - The default is READ WRITE unless the isolation level of READ UNCOMITTED is specified, in which case READ ONLY is assumed.
- **Diagnostic size** n, specifies an integer value n, indicating the number of conditions that can be held simultaneously in the diagnostic area.

Transaction Support in SQL2

Characteristics specified by a SET TRANSACTION statement in SQL2 (contd.):

- **Isolation level** <isolation>, where <isolation> can be READ UNCOMMITTED, READ COMMITTED, REPEATABLE READ or SERIALIZABLE. The default is SERIALIZABLE.
  - With SERIALIZABLE: the interleaved execution of transactions will adhere to our notion of serializability.
  - However, if any transaction executes at a lower level, then serializability may be violated.

Transaction Support in SQL2

Potential problem with lower isolation levels:

- **Dirty Read**:
  - Reading a value that was written by a transaction which failed.
- **Nonrepeatable Read**:
  - Allowing another transaction to write a new value between multiple reads of one transaction.
  - A transaction T1 may read a given value from a table. If another transaction T2 later updates that value and T1 reads that value again, T1 will see a different value.
    - Consider that T1 reads the employee salary for Smith. Next, T2 updates the salary for Smith. If T1 reads Smith's salary again, then it will see a different value for Smith's salary.

Transaction Support in SQL2

- Potential problem with lower isolation levels (contd.):
  - 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.

Transaction Support in SQL2

- 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:  ...
```

Transaction Support in SQL2

- Possible violation of serializabilty:

Isolation level	Type of Violation: Dirty read	nonrepeatable read	phantom
READ UNCOMMITTED	yes	yes	yes
READ COMMITTED	no	yes	yes
REPEATABLE READ	no	no	yes
SERIALIZABLE	no	no	no

Summary

- Transaction and System Concepts
- Desirable Properties of Transactions
- Characterizing Schedules based on Recoverability
- Characterizing Schedules based on Serializability
- Transaction Support in SQL

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Unit 4

Part-2

Concurrency Control Techniques

Original Content: Ramez Elmasri and Shamkant B. Navathe

Outline

Databases Concurrency Control

1. Purpose of Concurrency Control
2. Two-Phase locking
3. Limitations of CCMs
4. Index Locking
5. Lock Compatibility Matrix
6. Lock Granularity

Database Concurrency Control

- 1 Purpose of Concurrency Control
  - To enforce Isolation (through mutual exclusion) among conflicting transactions.
  - To preserve database consistency through consistency preserving execution of transactions.
  - To resolve read-write and write-write conflicts.

- Example:
  - In concurrent execution environment if T1 conflicts with T2 over a data item A, then the existing concurrency control decides if T1 or T2 should get the A and if the other transaction is rolled-back or waits.

Two-Phase Locking Techniques

- Locking is an operation which secures
  - (a) permission to Read
  - (b) permission to Write a data item for a transaction.
- Example:
  - Lock (X). Data item X is locked in behalf of the requesting transaction.
- Unlocking is an operation which removes these permissions from the data item.
- Example:
  - Unlock (X): Data item X is made available to all other transactions.
- Lock and Unlock are Atomic operations.

Two-Phase Locking Techniques: Essential components

- Two locks modes:
  - (a) shared (read) (b) exclusive (write).
- Shared mode: shared lock (X)
  - More than one transaction can apply share lock on X for reading its value but no write lock can be applied on X by any other transaction.
- Exclusive mode: Write lock (X)
  - Only one write lock on X can exist at any time and no shared lock can be applied by any other transaction on X.
- Conflict matrix

	Read	Write
Read	Y	N
Write	N	N

Two-Phase Locking Techniques: Essential components

- Lock Manager:
  - Managing locks on data items.
- Lock table:
  - Lock manager uses it to store the identify of transaction locking a data item, the data item, lock mode and pointer to the next data item locked. One simple way to implement a lock table is through linked list.

Transaction ID	Data item id	lock mode	Ptr to next data item
T1	X1	Read	Next

Two-Phase Locking Techniques: Essential components

- Database requires that all transactions should be well-formed. A transaction is well-formed if:
  - It must lock the data item before it reads or writes to it.
  - It must not lock an already locked data items and it must not try to unlock a free data item.

Two-Phase Locking Techniques: Essential components

- The following code performs the lock operation:

```
B:  if LOCK (X) = 0 (*item is unlocked*)
    then LOCK (X) ← 1 (*lock the item*)
    else begin
        wait (until lock (X) = 0) and
        the lock manager wakes up the transaction);
    goto B
    end;
```

Two-Phase Locking Techniques: Essential components

- The following code performs the unlock operation:

```
LOCK (X) ← 0 (*unlock the item*)
if any transactions are waiting then
    wake up one of the waiting the transactions;
```

Two-Phase Locking Techniques: Essential components

- The following code performs the read operation:

```
B: if LOCK (X) = "unlocked" then
begin LOCK (X) ← "read-locked";
        no_of_reads (X) ← 1;
end
else if LOCK (X) ← "read-locked" then
            no_of_reads (X) ← no_of_reads (X) +1
          else begin wait (until LOCK (X) = "unlocked" and
                the lock manager wakes up the transaction);
                go to B
               end;
```

Two-Phase Locking Techniques: Essential components

- The following code performs the write lock operation:

```
B: if LOCK (X) = "unlocked" then
begin LOCK (X) ← "read-locked";
        no_of_reads (X) ← 1;
end
else if LOCK (X) ← "read-locked" then
            no_of_reads (X) ← no_of_reads (X) +1
          else begin wait (until LOCK (X) = "unlocked" and
                the lock manager wakes up the transaction);
                go to B
               end;
```

Two-Phase Locking Techniques: Essential components

- The following code performs the unlock operation:

```
if LOCK (X) = "write-locked" then
begin LOCK (X) ← "unlocked";
        wakes up one of the transactions, if any
end
else if LOCK (X) ← "read-locked" then
        begin
            no_of_reads (X) ← no_of_reads (X) -1
            if  no_of_reads (X) = 0 then
            begin
                LOCK (X) = "unlocked";
              wake up one of the transactions, if any
            end
        end;
```

Two-Phase Locking Techniques: Essential components

- Lock conversion
  - Lock upgrade: existing read lock to write lock

    if Ti has a read-lock (X) and Tj has no read-lock (X) (i ≠ j) then
    convert read-lock (X) to write-lock (X)
    else
    force Ti to wait until Tj unlocks X

  - Lock downgrade: existing write lock to read lock

    Ti has a write-lock (X) (*no transaction can have any lock on X*)
    convert write-lock (X) to read-lock (X)

Two-Phase Locking Techniques: The algorithm

- Two Phases:
  - (a) Locking (Growing)
  - (b) Unlocking (Shrinking).
- **Locking (Growing) Phase:**
  - A transaction applies locks (read or write) on desired data items one at a time.
- **Unlocking (Shrinking) Phase:**
  - A transaction unlocks its locked data items one at a time.
- **Requirement:**
  - For a transaction these two phases must be mutually exclusively, that is, during locking phase unlocking phase must not start and during unlocking phase locking phase must not begin.

Two-Phase Locking Techniques: The algorithm

T1	T2	Result
read_lock (Y);	read_lock (X);	Initial values: X=20; Y=30
read_item (Y);	read_item (X);	Result of serial execution
unlock (Y);	unlock (X);	T1 followed by T2
write_lock (X);	Write_lock (Y);	X=50, Y=80.
read_item (X);	read_item (Y);	Result of serial execution
X:=X+Y;	Y:=X+Y;	T2 followed by T1
write_item (X);	write_item (Y);	X=70, Y=50
unlock (X);	unlock (Y);	

Two-Phase Locking Techniques: The algorithm

T1	T2	Result
read_lock (Y);		X=50; Y=50
read_item (Y);		Nonserializable because it.
unlock (Y);		violated two-phase policy.
	read_lock (X);	
	read_item (X);	
	unlock (X);	
	write_lock (Y);	
	read_item (Y);	
	Y:=X+Y;	
	write_item (Y);	
	unlock (Y);	
write_lock (X);		
read_item (X);		
X:=X+Y;		
write_item (X);		
unlock (X);		

Two-Phase Locking Techniques: The algorithm

T'1	**T'2**	
read_lock (Y);	read_lock (X);	T1 and T2 follow two-phase
read_item (Y);	read_item (X);	policy but they are subject to
write_lock (X);	Write_lock (Y);	deadlock, which must be
unlock (Y);	unlock (X);	dealt with.
read_item (X);	read_item (Y);	
X:=X+Y;	Y:=X+Y;	
write_item (X);	write_item (Y);	
unlock (X);	unlock (Y);	

Two-Phase Locking Techniques: The algorithm

- Two-phase policy generates two locking algorithms
  - (a) **Basic**
  - (b) **Conservative**
- **Conservative**:
  - Prevents deadlock by locking all desired data items before transaction begins execution.
- **Basic**:
  - Transaction locks data items incrementally. This may cause deadlock which is dealt with.
- **Strict**:
  - A more stricter version of Basic algorithm where unlocking is performed after a transaction terminates (commits or aborts and rolled-back). This is the most commonly used two-phase locking algorithm.

Dealing with Deadlock and Starvation

- **Deadlock**

T'1	**T'2**	
read_lock (Y);		T1 and T2 did follow two-phase
read_item (Y);		policy but they are deadlock
	read_lock (X);	
	read_item (Y);	
write_lock (X);		
(waits for X)	write_lock (Y);	
	(waits for Y)	

- Deadlock (T'1 and T'2)

Dealing with Deadlock and Starvation

- **Deadlock prevention**
  - A transaction locks all data items it refers to before it begins execution.
  - This way of locking prevents deadlock since a transaction never waits for a data item.
  - The conservative two-phase locking uses this approach.

Dealing with Deadlock and Starvation

- **Deadlock detection and resolution**
  - In this approach, deadlocks are allowed to happen. The scheduler maintains a wait-for-graph for detecting cycle. If a cycle exists, then one transaction involved in the cycle is selected (victim) and rolled-back.
  - A wait-for-graph is created using the lock table. As soon as a transaction is blocked, it is added to the graph. When a chain like: Ti waits for Tj waits for Tk waits for Ti or Tj occurs, then this creates a cycle. One of the transaction o

Dealing with Deadlock and Starvation

- **Starvation**
  - Starvation occurs when a particular transaction consistently waits or restarted and never gets a chance to proceed further.
  - In a deadlock resolution it is possible that the same transaction may consistently be selected as victim and rolled-back.
  - This limitation is inherent in all priority based scheduling mechanisms.
  - In Wound-Wait scheme a younger transaction may always be wounded (aborted) by a long running older transaction which may create starvation.

Timestamp based concurrency control algorithm

- **Timestamp**
  - A monotonically increasing variable (integer) indicating the age of an operation or a transaction. A larger timestamp value indicates a more recent event or operation.
  - Timestamp based algorithm uses timestamp to serialize the execution of concurrent transactions.

Timestamp based concurrency control algorithm

- **Basic Timestamp Ordering**
  - 1. Transaction T issues a write_item(X) operation:
    - If read_TS(X) > TS(T) or if write_TS(X) > TS(T), then an younger transaction has already read the data item so abort and roll-back T and reject the operation.
    - If the condition in part (a) does not exist, then execute write_item(X) of T and set write_TS(X) to TS(T).
  - 2. Transaction T issues a read_item(X) operation:
    - If write_TS(X) > TS(T), then an younger transaction has already written to the data item so abort and roll-back T and reject the operation.
    - If write_TS(X) ≤ TS(T), then execute read_item(X) of T and set read_TS(X) to the larger of TS(T) and the current read_TS(X).

Timestamp based concurrency control algorithm

- **Strict Timestamp Ordering**
  - 1. Transaction T issues a write_item(X) operation:
    - If TS(T) > read_TS(X), then delay T until the transaction T’ that wrote or read X has terminated (committed or aborted).
  - 2. Transaction T issues a read_item(X) operation:
    - If TS(T) > write_TS(X), then delay T until the transaction T’ that wrote or read X has terminated (committed or aborted).

Timestamp based concurrency control algorithm

- **Thomas's Write Rule**
  - If read_TS(X) > TS(T) then abort and roll-back T and reject the operation.
  - If write_TS(X) > TS(T), then just ignore the write operation and continue execution. This is because the most recent writes counts in case of two consecutive writes.
  - If the conditions given in 1 and 2 above do not occur, then execute write_item(X) of T and set write_TS(X) to TS(T).

Summary

- Databases Concurrency Control
  1. Purpose of Concurrency Control
  2. Two-Phase locking
  3. Limitations of CCMs
  4. Index Locking
  5. Lock Compatibility Matrix
  6. Lock Granularity