

The background of the slide is a light gray gradient. It is decorated with numerous realistic water droplets of various sizes. Some droplets are large and prominent, while others are small and subtle. They are scattered across the slide, with a higher concentration in the top-left and bottom-right corners. Each droplet has a soft highlight and a gentle shadow, giving it a three-dimensional appearance.

Chapter 20

Introduction To Transaction Processing Concepts And Theory

Chapter Outline

- Introduction To Transaction Processing
- Transaction And System Concepts
- Desirable Properties Of Transactions
- Characterizing Schedules Based On Recoverability
- Characterizing Schedules Based On Serializability

Introduction To Transaction Processing (1)

- **Transaction:** an executing program (process) that includes one or more database access operations
 - Read operations (database retrieval, such as SQL SELECT)
 - Write operations (modify database, such as SQL INSERT, UPDATE, DELETE)
 - Transaction: A logical unit of database processing
 - Example: bank balance transfer of \$100 dollars from a checking account to a saving account in a BANK database
- **Note:** each execution of a program is a *distinct transaction* with different parameters
 - Bank transfer program parameters: savings account number, checking account number, transfer amount

Introduction To Transaction Processing (2)

- **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.

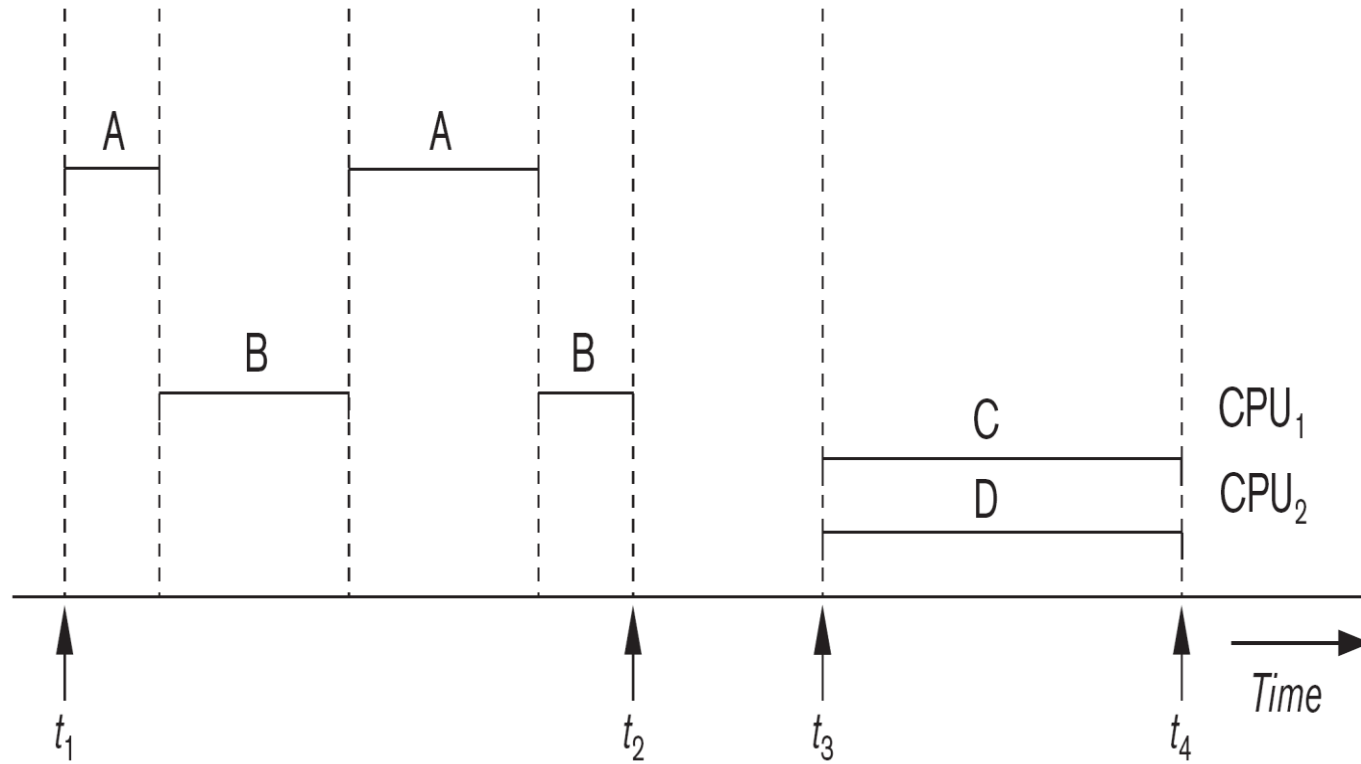


Figure 21.1

Interleaved processing versus parallel processing of concurrent transactions.

Introduction To Transaction Processing (3)

- **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 (4)

Simple Model Of A Database (for purposes of discussing transactions):

- **A database** is a collection of named data items
- The size of data item is called its **Granularity**
- **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 (5)

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).
 - The size of buffer is the same as the disk block size.
 - Copy item x from the buffer to the program variable named x.

Introduction To Transaction Processing (6)

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

- Figure 17.2 two sample transactions:
 - (A) transaction T1
 - (B) transaction T2

(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);

Introduction To Transaction Processing (7)

Why concurrency control is needed:

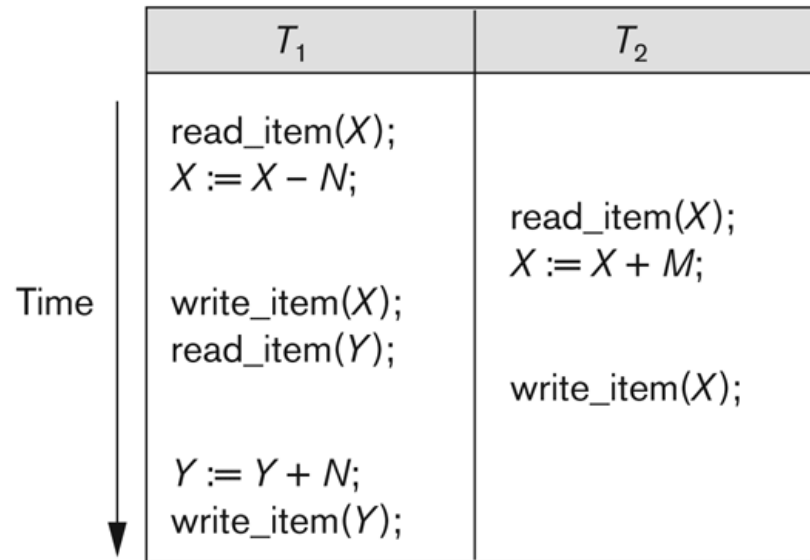
- **The lost update problem**
 - This occurs when two transactions that access the same database items have their operations interleaved in a way that makes the value of some database item incorrect.
- **The temporary update (or dirty read) problem**
 - This occurs when one transaction updates a database item and then the transaction fails for some reason (see section 17.1.4).
 - 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.

(a)



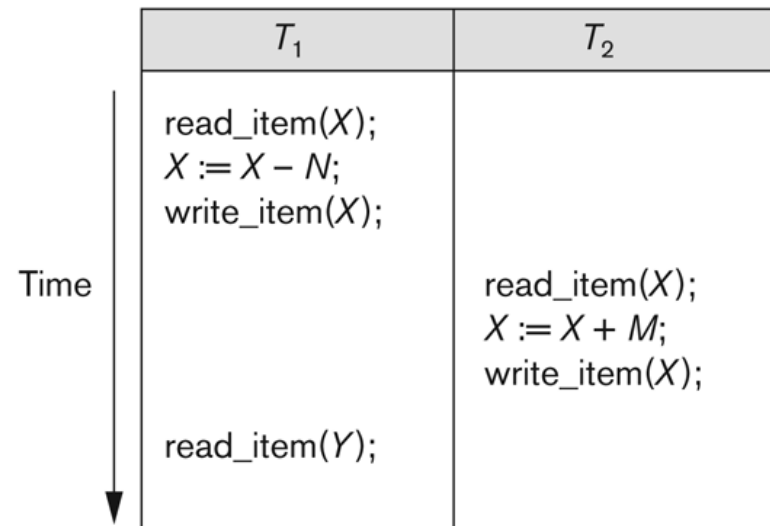
Item X has an incorrect value because its update by T_1 is *lost* (overwritten).

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.

(b)



Transaction T_1 fails and must change the value of X back to its old value; meanwhile T_2 has read the *temporary* incorrect value of X .

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
<pre>read_item(X); X := X - N; write_item(X); read_item(Y); Y := Y + N; write_item(Y);</pre>	<pre>sum := 0; read_item(A); sum := sum + A; ⋮ read_item(X); sum := sum + X; read_item(Y); sum := sum + Y;</pre>

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

Introduction To Transaction Processing (8)

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.

Introduction To Transaction Processing (9)

Why **recovery** is needed (contd.):

(What causes a transaction to fail)

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 (see in next chap.).

Introduction To Transaction Processing (10)

Why **recovery** is needed (contd.):

(What causes a transaction to fail)

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 (1)

- 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

State Transition Diagram Illustrating The States For Transaction Execution

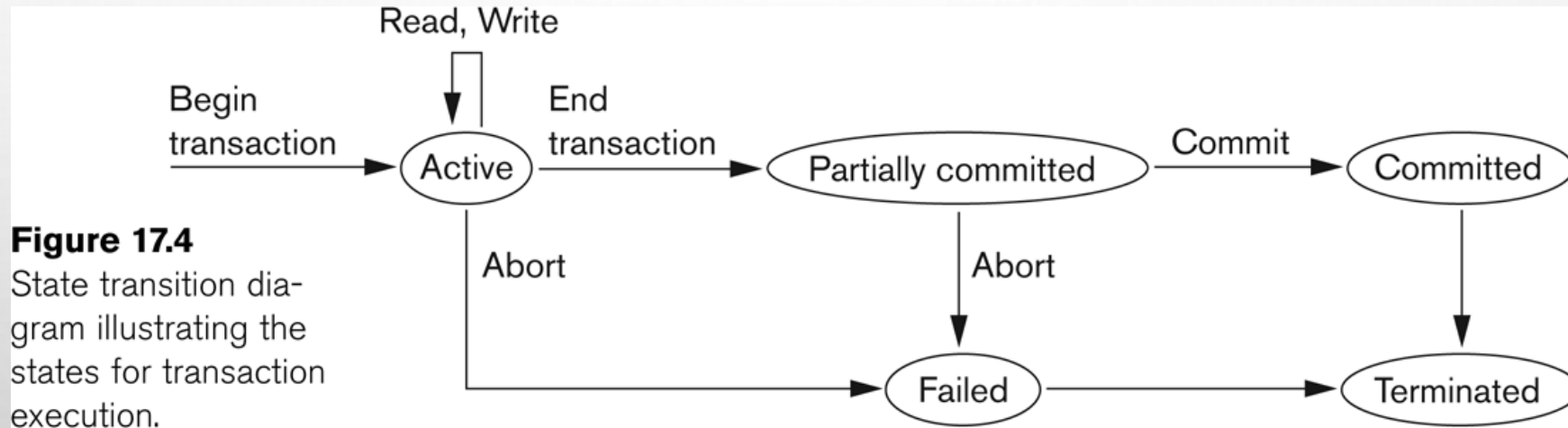


Figure 17.4
State transition diagram illustrating the states for transaction execution.

Transaction And System Concepts (2)

- 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 (3)

- 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.

Transaction And System Concepts (4)

- 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.

Transaction And System Concepts (6)

- 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.

Transaction And System Concepts (7)

- 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.

Transaction And System Concepts (9)

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 next chapter.
 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`.

Transaction And System Concepts (10)

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.

Transaction And System Concepts (11)

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 (1)

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.

Characterizing Schedules Based On Recoverability (1)

- **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 t_1, t_2, \dots, t_n :
 - It is an ordering of the operations of the transactions subject to the constraint that, for each transaction t_i that participates in S , the operations of T_i in S must appear in the same order in which they occur in T_i .
 - Note, however, that operations from other transactions t_j can be interleaved with the operations of t_i in s .

Characterizing Schedules Based On Serializability (2)

- **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.

(a)

T_1	T_2
$\text{read_item}(X);$ $X := X - N;$ $\text{write_item}(X);$ $\text{read_item}(Y);$ $Y := Y + N;$ $\text{write_item}(Y);$	$\text{read_item}(X);$ $X := X + M;$ $\text{write_item}(X);$

Schedule A

(b)

T_1	T_2
$\text{read_item}(X);$ $X := X - N;$ $\text{write_item}(X);$ $\text{read_item}(Y);$ $Y := Y + N;$ $\text{write_item}(Y);$	$\text{read_item}(X);$ $X := X + M;$ $\text{write_item}(X);$

Schedule B

(c)

T_1	T_2
$\text{read_item}(X);$ $X := X - N;$ $\text{write_item}(X);$ $\text{read_item}(Y);$ $Y := Y + N;$ $\text{write_item}(Y);$	$\text{read_item}(X);$ $X := X + M;$ $\text{write_item}(X);$

Schedule C

T_1	T_2
$\text{read_item}(X);$ $X := X - N;$ $\text{write_item}(X);$ $\text{read_item}(Y);$ $Y := Y + N;$ $\text{write_item}(Y);$	$\text{read_item}(X);$ $X := X + M;$ $\text{write_item}(X);$

Schedule D

Figure 20.5 Examples of serial and nonserial schedules involving transactions T_1 and T_2 (a) Serial schedule A: T_1 followed by T_2 (b) Serial schedule B: T_2 followed by T_1 (c) Two nonserial schedules C and D with interleaving of operations

Conflicting Operations in a Schedule

- Two operation in a schedule are said to conflict if they satisfy all three conditions:
 - They belongs to different transactions,
 - They access the same item x ,
 - At least one of the operations is a `write_item(x)`.
- A schedule S on n transactions T_1, T_2, \dots, T_n is said to be a complete schedule if following conditions hold:
 - The operations in S are exactly those operations in T_1, T_2, \dots, T_n including a commit or abort operation as the last operation for each truncation in the schedule.
 - For any pair of operations from the same transaction T_i , their relative order of appearance in S is the same as their order of appearance in T_i .
 - For any two conflicting operation, one of the two must occur before the order in the schedule.

Characterizing Schedules Based On Recoverability (3)

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 (3)

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 Serializability (2)

- Problem with serial schedules
 - Limit concurrency by prohibiting interleaving of operations
 - Unacceptable in practice
 - Solution: determine which schedules are equivalent to a serial schedule and allow those to occur
- Serializable schedule of n transactions
 - Equivalent to some serial schedule of same n transactions

Characterizing Schedules Based On Serializability (3)

- Result equivalent:
 - Two schedules are called result equivalent if they produce the same final state of the database.

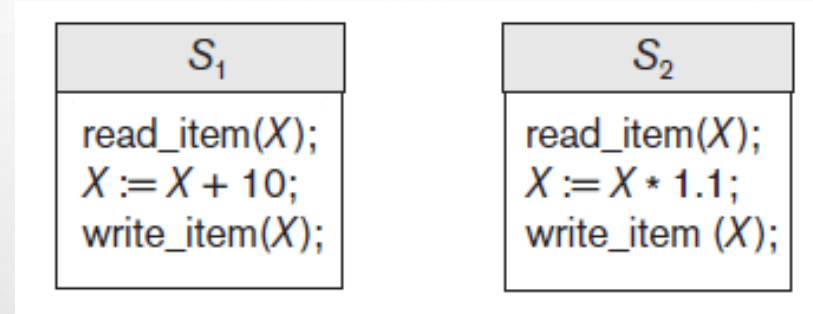


Figure 20.6 Two schedules that are result equivalent for the initial value of $X = 100$ but are not result equivalent in general

- 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 Serializability (4)

- Testing For Serializability Of A Schedule

1. For each transaction T_i participating in schedule S , create a node labeled T_i in the precedence graph.
2. For each case in S where T_j executes a `read_item(X)` after T_i executes a `write_item(X)`, create an edge $(T_i \rightarrow T_j)$ in the precedence graph.
3. For each case in S where T_j executes a `write_item(X)` after T_i executes a `read_item(X)`, create an edge $(T_i \rightarrow T_j)$ in the precedence graph.
4. For each case in S where T_j executes a `write_item(X)` after T_i executes a `write_item(X)`, create an edge $(T_i \rightarrow T_j)$ in the precedence graph.
5. The schedule S is serializable if and only if the precedence graph has no cycles.

Algorithm 20.1 Testing conflict serializability of a schedule S

Characterizing Schedules Based On Serializability (5)

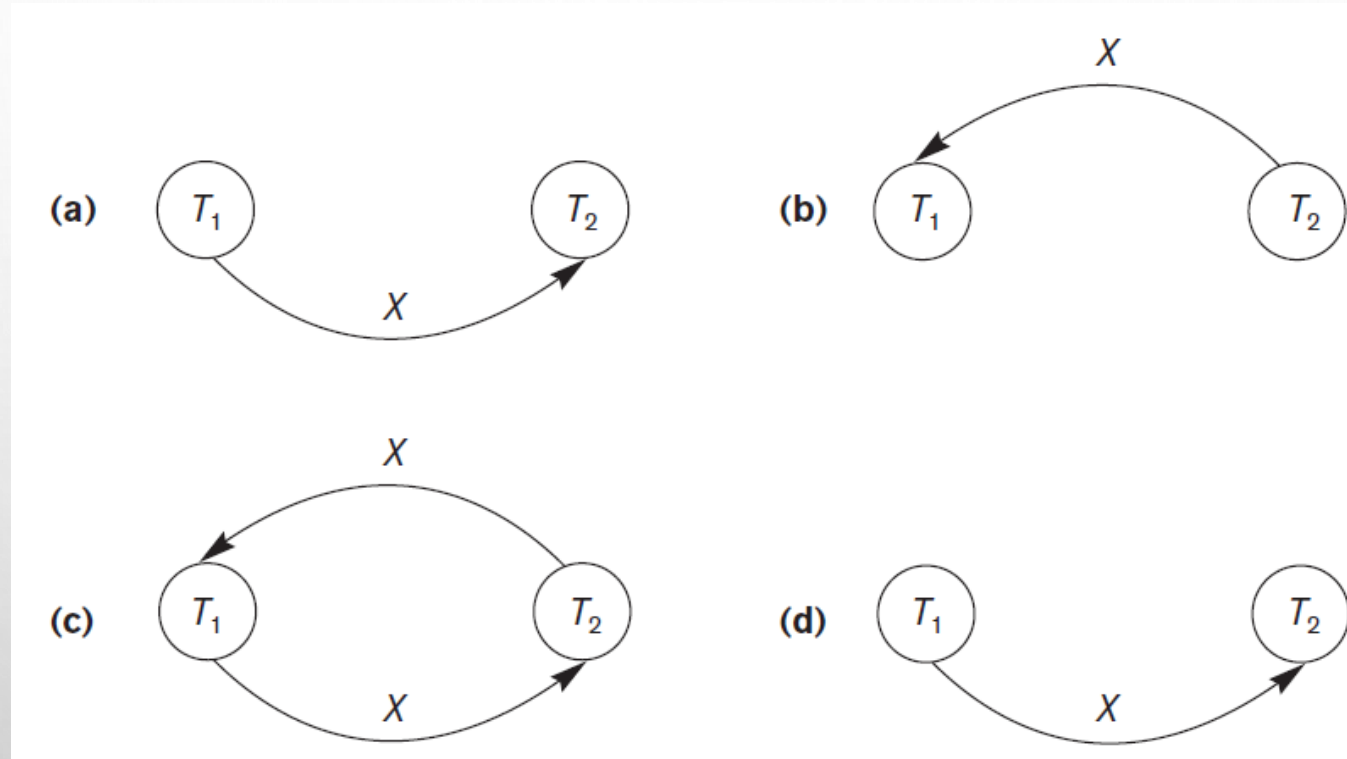


Figure 20.7 Constructing the precedence graphs for schedules A to D from Figure 20.5 to test for conflict serializability (a) Precedence graph for serial schedule A (b) Precedence graph for serial schedule B (c) Precedence graph for schedule C (not serializable) (d) Precedence graph for schedule D (serializable, equivalent to schedule A)

ANOTHER EXAMPLE OF SERIALIZABILITY TESTING

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	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

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
	<div>read_item(X); write_item(X);</div> <div>read_item(Y); write_item(Y);</div>	<div>read_item(Z); read_item(Y); write_item(Y);</div> <div>read_item(X);</div> <div>write_item(X);</div>	<div>read_item(Y); read_item(Z);</div> <div>write_item(Y); write_item(Z);</div>

Schedule E

Another Example Of Serializability Testing

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
	<code>read_item(X);</code> <code>write_item(X);</code> <code>read_item(Y);</code> <code>write_item(Y);</code>	 <code>read_item(Z);</code> <code>read_item(Y);</code> <code>write_item(Y);</code> <code>read_item(X);</code> <code>write_item(X);</code>	<code>read_item(Y);</code> <code>read_item(Z);</code> <code>write_item(Y);</code> <code>write_item(Z);</code>

Schedule F

How Serializability Is Used For Concurrency Control

- Being serializable is different from being serial
- Serializable schedule gives benefit of concurrent execution
 - Without giving up any correctness
- Difficult to test for serializability in practice
 - Factors such as system load, time of transaction submission, and process priority affect ordering of operations
- DBMS enforces protocols
 - Set of rules to ensure serializability

View Equivalence And View Serializability

- View equivalence of two schedules
 - 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
 - Read operations said to see the same view in both schedules
- View serializable schedule
 - View equivalent to a serial schedule

View Equivalence And View Serializability(2)

- Conflict serializability similar to view serializability if constrained write assumption (no blind writes) applies
- Unconstrained write assumption
 - Value written by an operation can be independent of its old value
- Debit-credit transactions
 - Less-stringent conditions than conflict serializability or view serializability



THANK YOU