COMP 3311
DATABASE MANAGEMENT SYSTEMS

LECTURE 21
CONCURRENCY CONTROL: LOCK-BASED PROTOCOLS

CONCURRENCY CONTROL: OUTLINE

Lock-based Protocols

- Two-phase Locking Protocols
- Deadlock Handling
- Graph-based Protocols

Timestamp-based Protocols

- Timestamp-ordering Protocols
- Validation-based Protocols

Multiversion Schemes

Snapshot Isolation

GOAL OF CONCURRENCY CONTROL SCHEMES

Atomicity Handled by database recovery.

– Either all transaction operations are properly reflected in the database or none are.

Consistency Handled by concurrency control.

– Execution of a transaction in isolation preserves the consistency of the database.

Isolation Handled by concurrency control.

– Although multiple transactions may execute concurrently, each transaction must be unaware of other concurrently executing transactions.

Durability Handled by database recovery.

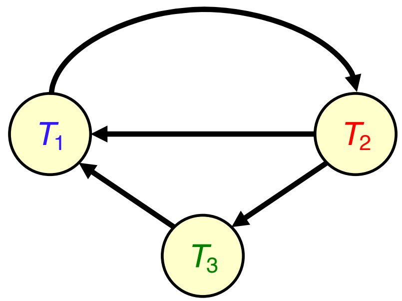
– After a transaction completes successfully, the changes it made to the database persist, even if there are system failures.

☞ **Generate schedules that enforce the isolation property.**

CONCURRENY CONTROL SCHEME CORRECTNESS

T_1	T_2	T_3
	read(Z)	
	read(Y)	
	write(Y)	
		read(Y)
		read(Z)
read(X)		
write(X)		
		write(Y)
		write(Z)
	read(X)	
read(Y)		
write(Y)		
	write(X)	

Based on serializability



The schedule is not serializable.
Therefore, it should not be generated
by any concurrency control scheme.

LOCKING

Lock: a mechanism to control concurrent access to a data item.

- A data item *Q* can be locked in one of two modes:
  1. shared-mode (shared lock)
     - Can *only* read Q. An s-lock is requested using a lock-s(*Q*) instruction.
  2. exclusive-mode (exclusive lock)
     - Can *both* read *and* write Q. An x-lock is requested using a lock-x(*Q*) instruction.
  - A data item *Q* is unlocked using an unlock(*Q*) instruction.
- A transaction must make a lock request to the concurrency-control manager before accessing a data item.
- A transaction can proceed only after a request is granted.

☞ **The concurrency control manager should allow *only* conflict-serializable schedules.**

LOCK-COMPATIBILITY MATRIX

Lock Mode	Shared (S)	Exclusive (X)
Shared (S)	true (grant)	false (deny)
Exclusive (X)	false (deny)	false (deny)

Shared lock - can *only* read
Exclusive lock - can read and write

- A transaction may be granted a lock on a data item *Q* if the requested lock is *compatible* with locks already held on *Q* by other transactions.
- Any number of transactions can hold shared locks on a data item *Q*.
- If any transaction holds an exclusive lock on the data item, then no other transaction may hold any lock on the data item.
- If a lock cannot be granted, the requesting transaction is made to wait until all incompatible locks held by other transactions have been released. The lock is then granted.

LOCKING EXAMPLE

Start with A=100, B=200

	T_1	T_2	
	read(B)		
	B := B - 50		
B=150	write(B)		
	read(A)		
	A := A - 50		
A=50	write(A)		
		read(A)	
		read(B)	
		display(A+B)	200

Locking requires a set of rules, called a locking protocol, that all transactions follow when requesting and releasing locks. The rules restrict the set of possible schedules.

	T_1	T_2	CC Manager
	lock-x(B)		grant-X(B)
	read(B)		
	B := B - 50		
B=150	write(B)		
	unlock(B)		
		lock-s(A)	grant-S(A)
	A=100	read(A)	
		unlock(A)	
		lock-s(B)	grant-S(B)
	B=150	read(B)	
		unlock(B)	
		display(A+B)	250 **INCORRECT!**
	lock-x(A)		grant-X(A)
	read(A)		
	A := A - 50		
	write(A)		
	unlock(A)		

Serializability may not be ensured if a transaction unlocks a data item immediately after its final access of that data item.

DEADLOCKS

- A system is deadlocked if there is a set of transactions such that every transaction is waiting for another transaction in the set.

- Neither T_1 nor T_2 can make progress — executing lock-s(B) causes T_2 to wait for T_1 to release its lock on B, while executing lock-x(A) causes T_1 to wait for T_2 to release its lock on A.

T_1	T_2
lock-x(B)	
read(B)	
write(B)	
	lock-s(A)
	read(A)
	lock-s(B)
lock-x(A)	

☞ **Such a situation is called a deadlock.**

☞ **To handle a deadlock, either T_1 or T_2 must be rolled back and its locks released.**

☞ **A rollback requires all transaction operations to be undone.**

☞ **A locking protocol needs to be able to handle deadlocks.**

STARVATION

Starvation (waiting forever) is possible if the concurrency control manager is badly designed.

– A transaction may be waiting for an x-lock on an item, while a sequence of other transactions request, and are granted, an s-lock on the same item.

T_1	T_2	T_3	T_4	T_5
lock-s(A)				
	lock-x(A)			
		lock-s(A)		
			lock-s(A)	
	wait			
				lock-s(A)
unlock(A)				

☞ **A locking protocol needs to be able to handle starvation.**

TWO-PHASE LOCKING (2PL) PROTOCOL

Phase 1: Growing Phase

A transaction may obtain locks, but may not release any locks.

Phase 2: Shrinking Phase

A transaction may release locks, but may not obtain any new locks.

Using 2PL, transactions can be serialized in the order of their lock points (i.e., the point where a transaction acquired its final lock).

☞ **If a schedule is executed by 2PL, then it must be conflict serializable.**

☞ **If a schedule is conflict serializable, then it may or may not be executed by 2PL.**

☞ **Not all conflict serializable schedules are allowed by 2PL.**

LOCK CONVERSIONS

- Allow shared locks to be upgraded to exclusive locks and exclusive locks to be downgraded to shared locks.

Phase 1: Growing Phase (request or upgrade locks)

– A transaction can acquire a lock-s on a data item.
– A transaction can acquire a lock-x on a data item.
– A transaction can convert a lock-s to a lock-x (upgrade) on a data item.

Phase 2: Shrinking Phase (release or downgrade locks)

– A transaction can release a lock-s on a data item.
– A transaction can release a lock-x on a data item.
– A transaction can convert a lock-x to a lock-s (downgrade) on a data item.

☞ **Schedules are cascadeless if exclusive–locks are held until the end of the transaction.**

STRICT AND RIGOROUS TWO-PHASE LOCKING

Under 2PL, cascading roll-back is possible.

Strict Two-phase Locking

– Requires that all exclusive-mode locks be held until a transaction commits (shared-mode locks can be released anytime).

– Ensures that any data written by an uncommitted transaction are locked in exclusive mode until the transaction commits.

Rigorous Two-phase Locking

– Requires that all locks (both shared-mode and exclusive-mode) be held until a transaction commits.

– The transactions can be serialized in the order in which they commit.

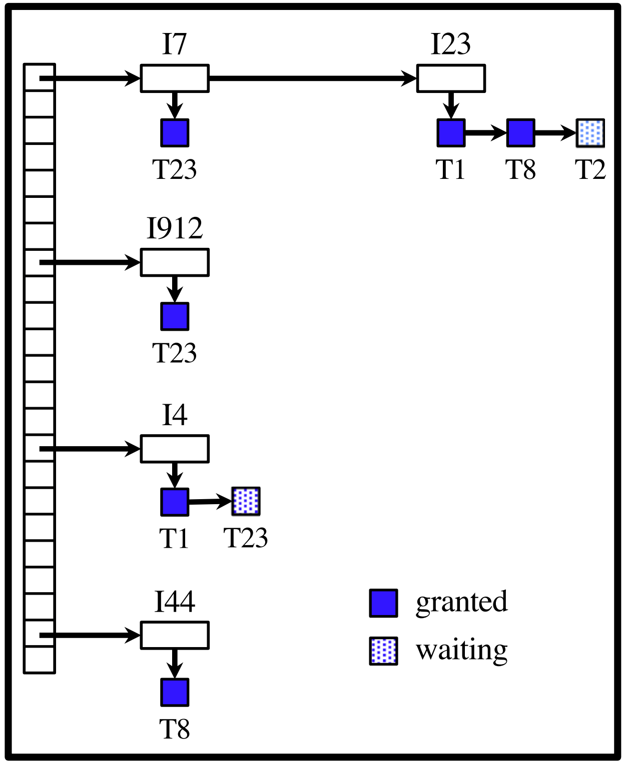
☞ **Strict and rigorous 2PL schedules are cascadeless.**

IMPLEMENTATION OF LOCKING

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

LOCK TABLE EXAMPLE

- Dark blue rectangles indicate granted locks, light blue ones indicate waiting requests.
- The lock table also records the type of lock granted or requested.
- A new request is added to the end of the queue of requests for the data item, and granted if it is compatible with all earlier locks.
- Unlock requests result in the request being deleted and later requests being checked to see if they can now be granted.



- If a transaction aborts, all waiting or granted requests of the transaction are deleted.
  - ➢ The lock manager also may keep a list of locks held by each transaction, to implement this efficiently.

☞ **This algorithm guarantees freedom from starvation.**

DEADLOCK HANDLING

Start with A=100, B=200

	T_1	T_2	
	read(B)		
	B := B - 50		
B=150	write(B)		
	read(A)		
	A := A - 50		
A=50	write(A)		
		read(A)	
		read(B)	
		display(A+B)	200

	T_1	T_2	CC Manager
	lock-x(B)		grant-X(B)
	read(B)		
	B := B - 50		
B=150	write(B)		
		lock-s(A)	grant-S(A)
	A=100	read(A)	
		lock-s(B)	wait-S(B) (for T_1)
	lock-x(A)		wait-X(A) (for T_2)
		deadlock!	

☞ **2PL permits deadlocks.**

The *potential* for deadlock exists in most locking protocols.
Deadlocks are a necessary evil of locking protocols.

DEADLOCK PREVENTION

- A deadlock prevention protocol ensures that the system will *never* enter into a deadlock state.

Strategy 1: Order lock requests

- Require that each transaction locks all its data items *before* it begins execution (pre-declaration).
  - Often hard to predict, beforehand, what data items need to be locked.
  - Locked data items may be unused for a long time.
- Impose a partial/total ordering of all data items and require that a transaction can *lock data items only in the order specified by the partial/total order* (e.g., tree protocol).

Strategy 2: Preemption and/or rollback

- Preempt and/or rollback a transaction when needed.
- Use transaction timestamps to control preemption and rollback.

DEADLOCK PREVENTION (CONT'D)

Wait-die Scheme — non-preemptive

- An older transaction may wait for a younger one to release a data item.
- A younger transaction never waits for an older one; it is rolled back instead.
- A transaction may die several times before acquiring the needed data item.

Wound-wait Scheme — preemptive

- An older transaction ***wounds*** (forces the rollback of) a younger transaction instead of waiting for it.
- A younger transaction may wait for an older one to release a data item.
- There may be fewer rollbacks than in the wait-die scheme.

- In both schemes, a rolled back transaction is restarted with its original timestamp so that older transactions have precedence over younger ones, thus, avoiding starvation.

DEADLOCK PREVENTION (CONT'D)

Timeout-Based Schemes

- A transaction waits for a lock only for a specified amount of time.
- After a pre-defined waiting period, the transaction is rolled back.
- Simple to implement; but starvation is possible.
- Often difficult to determine a good value of the timeout interval.

DEADLOCK DETECTION

- Deadlocks can be detected using a wait-for graph $G = (V, E)$, where

  V is a set of vertices (all the transactions in the system).

  E is a set of edges; each element is an ordered pair $T_i \rightarrow T_j$.

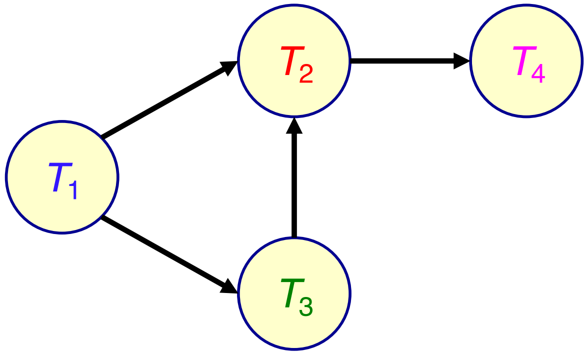
  - If $T_i \rightarrow T_j$ is in E, then there is a directed edge from T_i to T_j implying that T_i is waiting for T_j to release a data item.
  - When T_i requests a data item currently being held by T_j, then the edge $T_i \rightarrow T_j$ is inserted into the wait-for graph.
  - This edge is removed only when T_j is no longer holding a data item needed by T_i.

☞ **The system is in a deadlock state *if and only if* the wait-for graph has a cycle.**

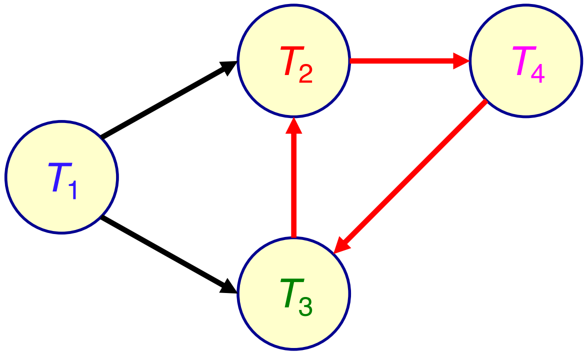
☞ **The system must invoke a deadlock-detection algorithm periodically to look for cycles in the wait-for graph.**

DEADLOCK DETECTION (CONT'D)

Example



Wait-for graph
without a cycle.



Wait-for graph
with a cycle.

☞ **This is not the same as a precedence graph!**

DEADLOCK RECOVERY

Victim Selection

– Select as a victim the transaction that will incur minimum cost.

Rollback

– Need to determine how far to roll back the transaction.

  - Total rollback: abort the transaction and then restart it.
  - Partial rollback: roll back the transaction only as far as necessary to break the deadlock. (Requires the system to maintain additional information.)

Starvation

– Can happen if the same transaction is always chosen as the victim.

– Can include the number of rollbacks in the cost factor to avoid starvation.

GRAPH-BASED PROTOCOLS

- For protocols that are not two phase, additional information is needed about how each transaction accesses the database.

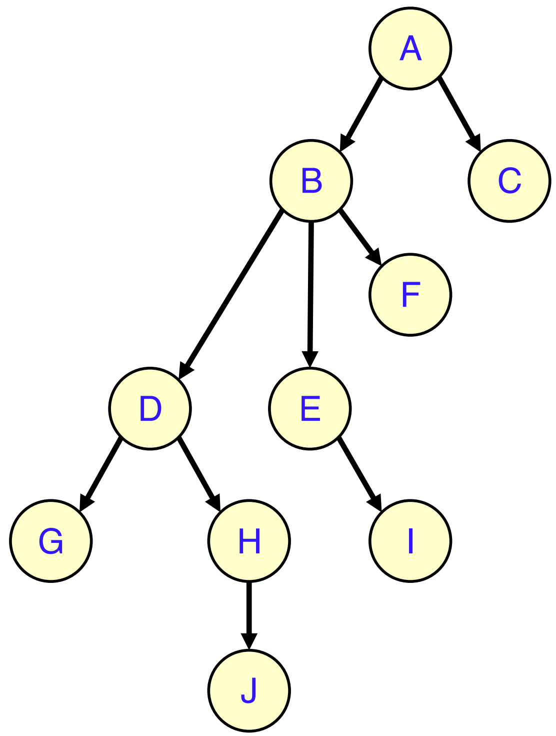
- The simplest such protocols require knowledge about the order in which the data items will be accessed.

- This knowledge can be acquired by imposing a partial ordering on the set **D** = $\{d_1, d_2, \ldots, d_h\}$ of all data items.
  - If d_i precedes d_j in the ordering, then any transaction accessing both d_i and d_j *must* access d_i *before* accessing d_j.
  - The set **D** may be viewed as a directed acyclic graph, called a *database graph*.

- For simplicity, we consider only those graphs that are rooted trees.

TREE PROTOCOL

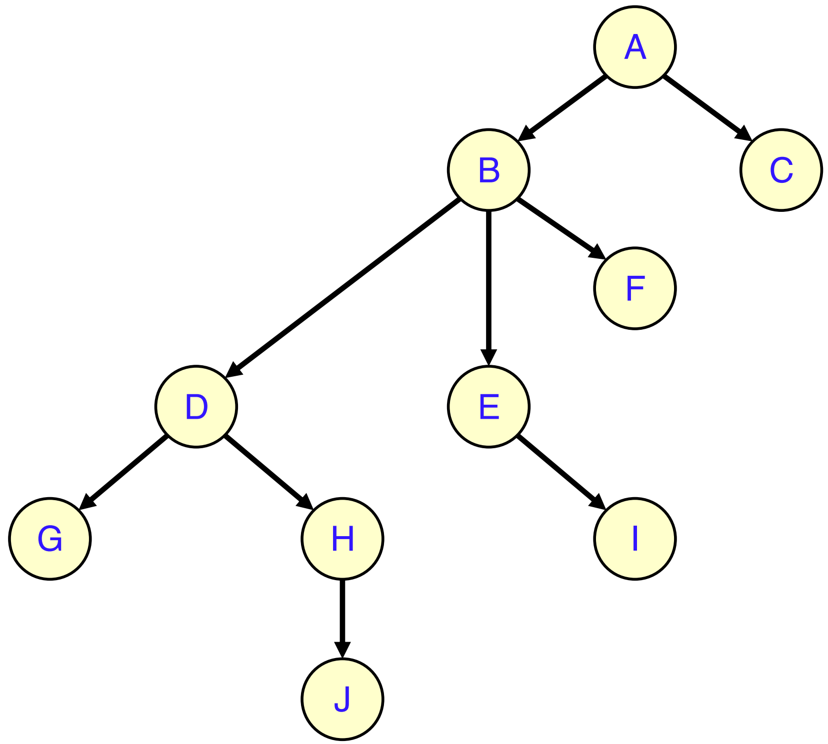
1. Only lock-x instructions are allowed.
2. The first lock by T_i may be on any data item.
3. Subsequently, a data item Q can be locked by T_i *only if* the parent of Q is currently locked by T_i.
4. Data items may be unlocked at any time.
5. A data item that has been unlocked by T_i cannot be locked again by T_i.

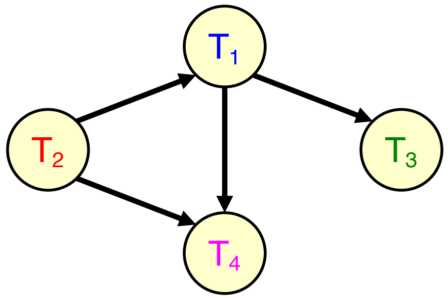


☞ **All legal schedules under the tree protocol are conflict serializable.**

TREE PROTOCOL: SERIALIZABLE SCHEDULE

T_1	T_2	T_3	T_4
lock-X(B)			
	lock-X(D)		
	lock-X(H)		
	unlock(D)		
lock-X(E)			
lock-X(D)			
unlock(B)			
unlock(E)			
		lock-X(B)	
		lock-X(E)	
	unlock(H)		
lock-X(G)			
unlock(D)			
			lock-X(D)
			lock-X(H)
			unlock(D)
			unlock(H)
		unlock(E)	
		unlock(B)	
unlock(G)			





Precedence Graph

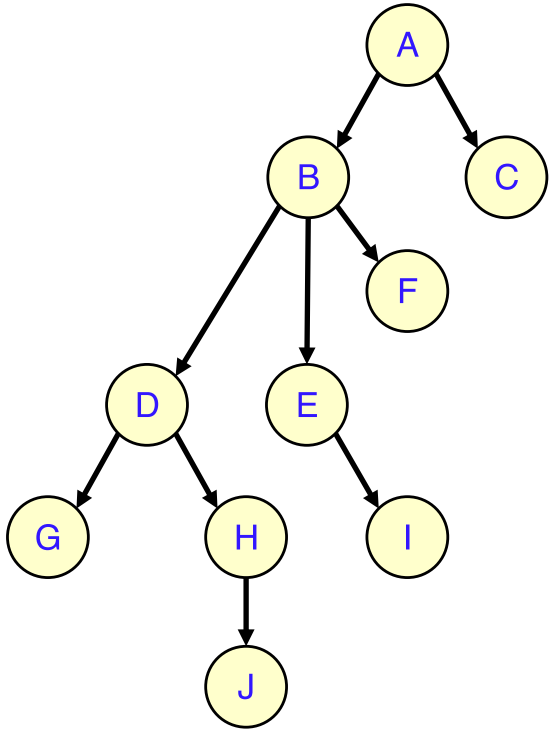
Equivalent serial schedule:
T_2, T_1, T_4, T_3
or
T_2, T_1, T_3, T_4

TREE PROTOCOL: PROPERTIES

- The tree protocol
  - ensures conflict serializability.
  - is deadlock free.

- Unlocking may occur earlier than in the two-phase locking protocol.
  - Shorter waiting times and an increase in concurrency.

- However, a transaction may have to lock data items that it does not access.
  - Increased locking overhead and additional waiting time.
  - Potential decrease in concurrency.



☞ **Schedules not possible under two-phase locking are possible under the tree protocol, and vice versa.**