# Concurrency Control

# Outline

- Lock-Based Protocols
- Timestamp-Based Protocols
- Validation-Based Protocols
- Multiple Granularity
- Multiversion Schemes
- Insert and Delete Operations
- Concurrency in Index Structures

# Lock-Based Protocols

- A lock is a mechanism to control concurrent access to a data item
- Data items can be locked in two modes :
  1. *exclusive (X) mode*. Data item can be both read as well as written. X-lock is requested using **lock-X** instruction.
  2. *shared (S) mode*. Data item can only be read. S-lock is requested using **lock-S** instruction.
- Lock requests are made to the concurrency-control manager by the programmer. Transaction can proceed only after request is granted.

# Lock-Based Protocols (Cont.)

- **Lock-compatibility matrix**

| | S | X |
|---|---|---|
| S | true | false |
| X | false | false |

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

# Lock-Based Protocols (Cont.)

- Example of a transaction performing locking:

  $T_2$: **lock-S**(*A*);
  **read** (*A*);
  **unlock**(*A*);
  **lock-S**(*B*);
  **read** (*B*);
  **unlock**(*B*);
  **display**(*A+B*)

- Locking as above is not sufficient to guarantee serializability — if *A* and *B* get updated in-between the read of *A* and *B*, the displayed sum would be wrong.
- A **locking protocol** is a set of rules followed by all transactions while requesting and releasing locks. Locking protocols restrict the set of possible schedules.

# The Two-Phase Locking Protocol

- This protocol ensures conflict-serializable schedules.
- Phase 1: Growing Phase
  - Transaction may obtain locks
  - Transaction may not release locks
- Phase 2: Shrinking Phase
  - Transaction may release locks
  - Transaction may not obtain locks
- The protocol assures serializability. It can be proved that the transactions can be serialized in the order of their **lock points** (i.e., the point where a transaction acquired its final lock).

# The Two-Phase Locking Protocol (Cont.)

- There can be conflict serializable schedules that cannot be obtained if two-phase locking is used.
- However, in the absence of extra information (e.g., ordering of  access to data), two-phase locking is needed for conflict serializability in the following sense:
  - Given a transaction $T_\mathrm{i}$ that does not follow two-phase locking, we can find a transaction $T_j$ that uses two-phase locking, and a schedule for $T_i$ and $T_j$ that is not conflict serializable.

# Lock Conversions

- Two-phase locking with lock conversions:
  - First Phase:
    - can acquire a lock-S on item
    - can acquire a lock-X on item
    - can convert a lock-S to a lock-X (upgrade)
  - Second Phase:
    - can release a lock-S
    - can release a lock-X
    - can convert a lock-X to a lock-S (downgrade)
- This protocol assures serializability. But still relies on the programmer to insert the various locking instructions.

# Automatic Acquisition of Locks

- A transaction $T_i$ issues the standard read/write instruction, without explicit locking calls.
- The operation **read**($D$) is processed as:

  **if** $T_i$ has a lock on $D$
  **then**
  read($D$)
  **else begin**
  if necessary wait until no other transaction has a **lock-X** on $D$
  grant $T_i$ a **lock-S** on $D$;
  read($D$)
  **end**

# Automatic Acquisition of Locks (Cont.)

- **write**$(D)$ is processed as:

  **if** $T_i$ has a **lock-X** on $D$
  **then**
  write($D$)
  **else begin**
  if necessary wait until no other transaction has any lock on $D$,
  if $T_i$ has a **lock-S** on $D$
  **then**
  **upgrade** lock on $D$ to **lock-X**
  **else**
  grant $T_i$ a **lock-X** on $D$
  write($D$)
  **end**;

- All locks are released after commit or abort

# Deadlocks

- Consider the partial schedule

| $T_3$ | $T_4$ |
|---|---|
| lock-x ($B$) | |
| read ($B$) | |
| $B := B - 50$ | |
| write ($B$) | |
| | lock-s ($A$) |
| | read ($A$) |
| | lock-s ($B$) |
| lock-x ($A$) | |

- Neither $T_3$ nor $T_4$ can make progress — executing **lock-S**$(B)$ causes $T_4$ to wait for $T_3$ to release its lock on $B$, while executing **lock-X**$(A)$ causes $T_3$ to wait for $T_4$ to release its lock on $A$.
- Such a situation is called a **deadlock**.
  - To handle a deadlock one of $T_3$ or $T_4$ must be rolled back and its locks released.

# Deadlocks (Cont.)

- Two-phase locking *does not* ensure freedom from deadlocks.
- In addition to deadlocks, there is a possibility of **starvation.**
- **Starvation** occurs if the concurrency control manager is badly designed. For example:
  - 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.
  - The same transaction is repeatedly rolled back due to deadlocks.
- Concurrency control manager can be designed to prevent starvation.

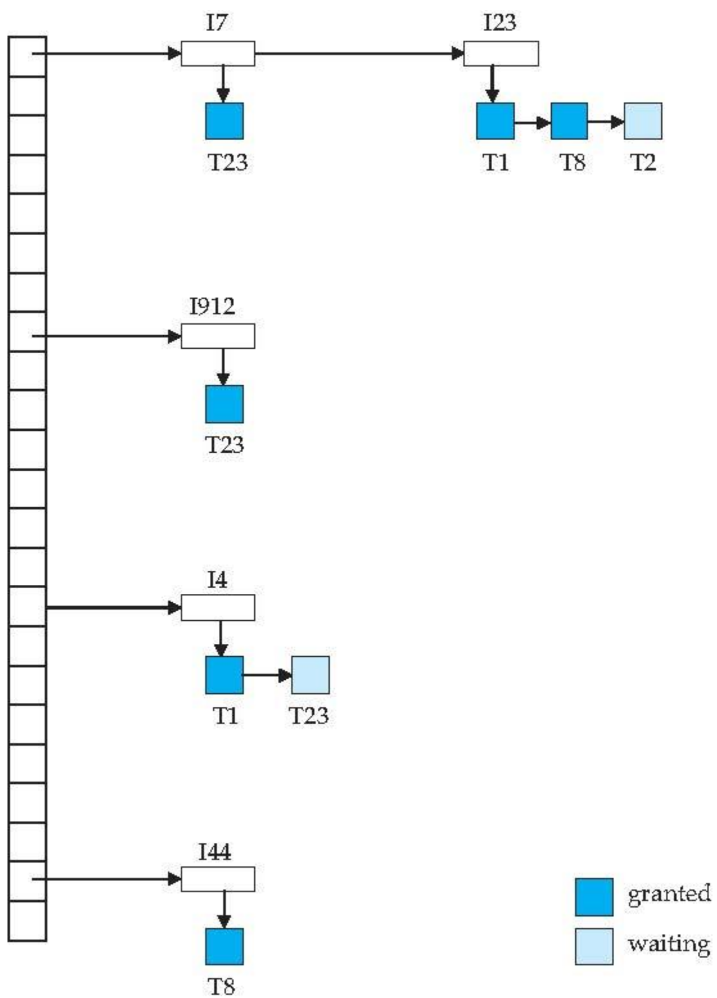
# Deadlocks (Cont.)

- The potential for deadlock exists in most locking protocols. Deadlocks are a necessary evil.
- When a deadlock occurs there is a possibility of cascading roll-backs.
- Cascading roll-back is possible under two-phase locking. To avoid this, follow a modified protocol called **strict two-phase locking** -- a transaction must hold all its exclusive locks till it commits/aborts.
- **Rigorous two-phase locking** is even stricter. Here, *all* locks are held till commit/abort. In this protocol transactions can be serialized in the order in which they commit.

# 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 messages (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




- Dark blue rectangles indicate granted locks; light blue indicate waiting requests
- Lock table also records the type of lock granted or requested
- 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 are checked to see if they can now be granted
- If transaction aborts, all waiting or granted requests of the transaction are deleted
  - lock manager may keep a list of locks held by each transaction, to implement this efficiently

# Deadlock Handling

- System is deadlocked if there is a set of transactions such that every transaction in the set is waiting for another transaction in the set.
- ***Deadlock prevention*** protocols ensure that the system will *never* enter into a deadlock state. Some prevention strategies :
  - Require that each transaction locks all its data items before it begins execution (predeclaration).
  - Impose partial ordering of all data items and require that a transaction can lock data items only in the order specified by the partial order.

# More Deadlock Prevention Strategies

- Following schemes use transaction timestamps for the sake of deadlock prevention alone.
- **wait-die** scheme — non-preemptive
  - older transaction may wait for younger one to release data item. (older means smaller timestamp) Younger transactions never Younger transactions never wait for older ones; they are rolled back instead.
  - a transaction may die several times before acquiring needed data item
- **wound-wait** scheme — preemptive
  - older transaction *wounds* (forces rollback) of younger transaction instead of waiting for it. Younger transactions may wait for older ones.
  - may be fewer rollbacks than *wait-die* scheme.

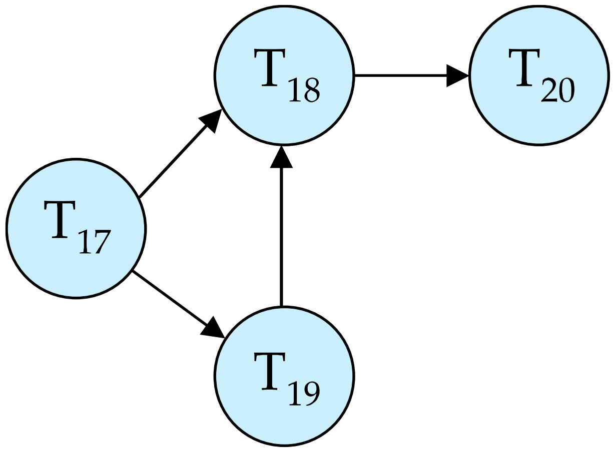
# Deadlock prevention (Cont.)

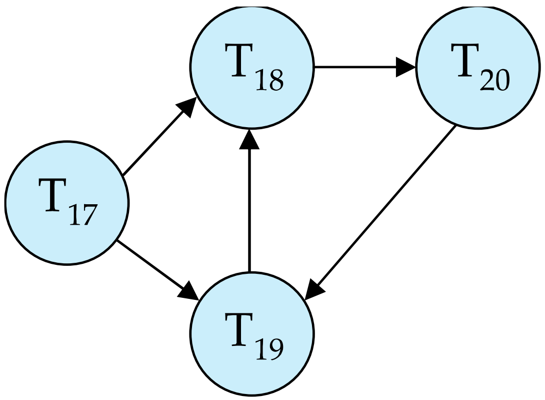
- Both in *wait-die* and in *wound-wait* schemes, a rolled back transactions is restarted with its original timestamp. Older transactions thus have precedence over newer ones, and starvation is hence avoided.
- **Timeout-Based Schemes:**
  - a transaction waits for a lock only for a specified amount of time. If the lock has not been granted within that time, the transaction is rolled back and restarted,
  - Thus, deadlocks are not possible
  - simple to implement; but starvation is possible. Also difficult to determine good value of the timeout interval.

# Deadlock Detection

- Deadlocks can be described as a *wait-for graph*, which consists of a pair $G = (V,E)$,
  - $V$ 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 in 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. Must invoke a deadlock-detection algorithm periodically to look for cycles.

# Deadlock Detection (Cont.)




- Wait-for graph without a cycle
- Wait-for graph with a cycle

# Deadlock Recovery

- When deadlock is detected :
  - Some transaction will have to rolled back (made a victim) to break deadlock. Select that transaction as victim that will incur minimum cost.
  - Rollback -- determine how far to roll back transaction
    - Total rollback: Abort the transaction and then restart it.
    - More effective to roll back transaction only as far as necessary to break deadlock.
  - Starvation happens if same transaction is always chosen as victim. Include the number of rollbacks in the cost factor to avoid starvation