Chapter 15: Concurrency Control

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15.1 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 concurrency-control manager. 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.

Pitfalls of Lock-Based Protocols

- 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.

Pitfalls of Lock-Based Protocols (Cont.)

- The potential for deadlock exists in most locking protocols. Deadlocks are a necessary evil.
- **Starvation** is also possible if 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.

T1	T2	T3	T4
	lock-S(A)		
lock-X(*A*)	…	**lock-S**(A)	
Wait…	…	…	**lock-S**(A)
Wait…	…	…	…

The Two-Phase Locking Protocol

- This is a protocol which 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.)

- Two-phase locking *does not* ensure freedom from deadlocks

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)	

Partial Schedule Under Two-Phase Locking

- Cascading roll-back is possible under two-phase locking.
- To avoid this, follow a modified protocol called **strict two-phase locking**. Here 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.

T_5	T_6	T_7
lock-X(A)		
read(A)		
lock-S(B)		
read(B)		
write(A)		
unlock(A)		
	lock-X(A)	
	read(A)	
	write(A)	
	unlock(A)	
		lock-S(A)
		read(A)

事务T_7的 read(A)步骤之后事务T_5发生故障，从而导致T_6与T_7级联回滚。

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.

Incomplete Schedule With a Lock Conversion

- T8:
  - Read(a1)
  - Read(a2)
  - ……
  - Read(an)
  - Write(a1)
- T9:
  - Read(a1)
  - Read(a2)
  - Display(a1 + a2)

T_8	T_9
lock-S (a_1)	
	lock-S (a_1)
lock-S (a_2)	
	lock-S (a_2)
lock-S (a_3)	
lock-S (a_4)	
	unlock (a_1)
	unlock (a_2)
lock-S (a_n)	
upgrade (a_1)	

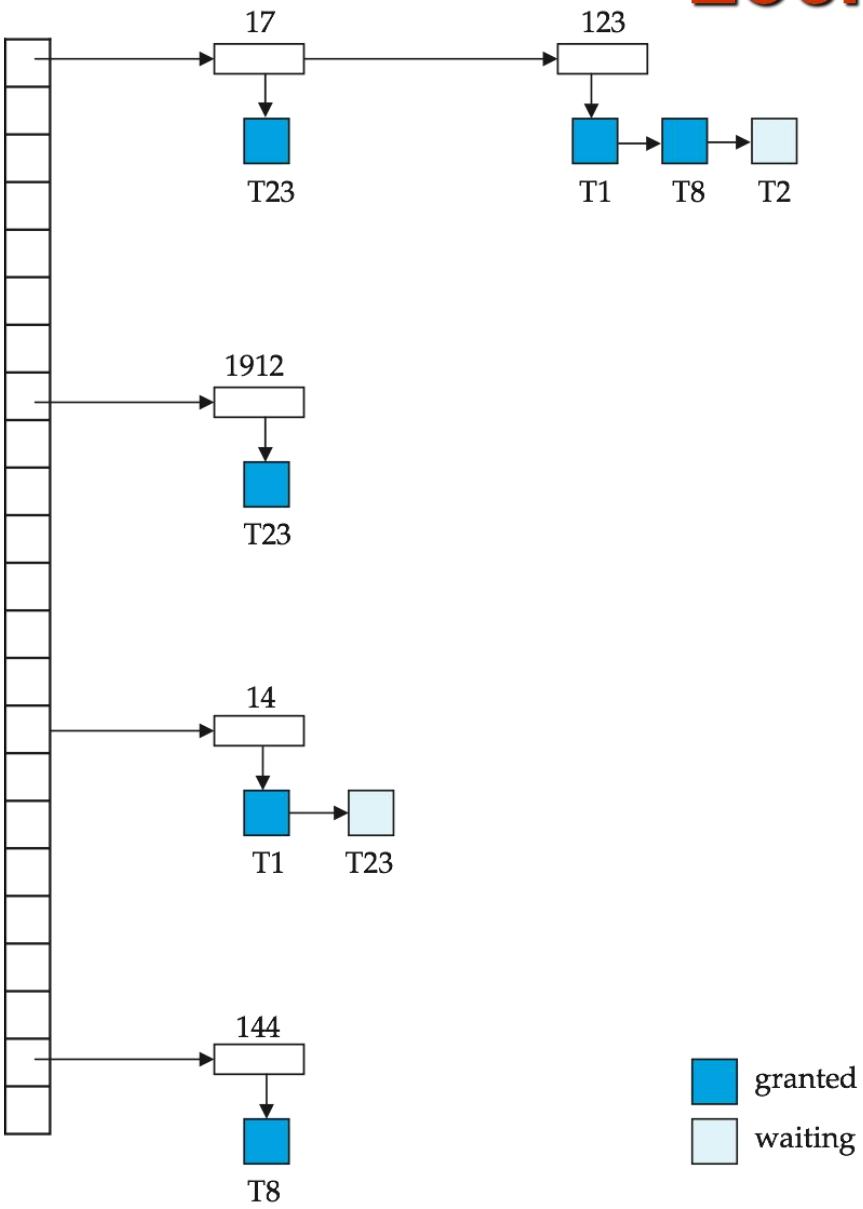
T8 and T9 can access a1 and a2 simultaneously.

- If we employ the two-phase locking protocol, then T8 musk lock a1 in X-mode. Then any concurrent execution of both transactions amounts to a serial execution.

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



- Deep blue rectangles indicate granted locks, light ones 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

15.2 Deadlock Handling

- A system is in a deadlock state if there exists a set of transactions such that every transaction in the set is waiting for another transaction in the set.
- Schedule with deadlock

T_1	T_2
lock-X on A	
write (A)	
	lock-X on B
	write (B)
	wait for **lock-X** on A
wait for **lock-X** on B	

- There are two principal methods:
  - deadlock prevention protocol to ensure that the system will never enter a deadlock state
  - allow the system to enter a deadlock state, and then try to recover by using a deadlock detection and deadlock recovery scheme

15.2.1 Deadlock Handling

- ***Deadlock prevention*** protocols ensure that the system will *never* enter into a deadlock state. Some prevention strategies :
  - 要求每个事务在开始之前封锁它的所有数据项(先声明)
    - 事务开始之前很难预知所需要的所有数据项
    - 导致数据项的使用率很低
  - 对所有数据项强加一个次序，事务只能按要求的次序顺序封锁数据项
    - 例如：两阶段锁协议

More Deadlock Prevention Strategies

- The second approach for preventing deadlocks is to use preemption (抢占) and transaction rollbacks (事务回滚).
  - **wait-die** scheme — non-preemptive
    - older transaction may wait for younger one to release data item. 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.
- 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.

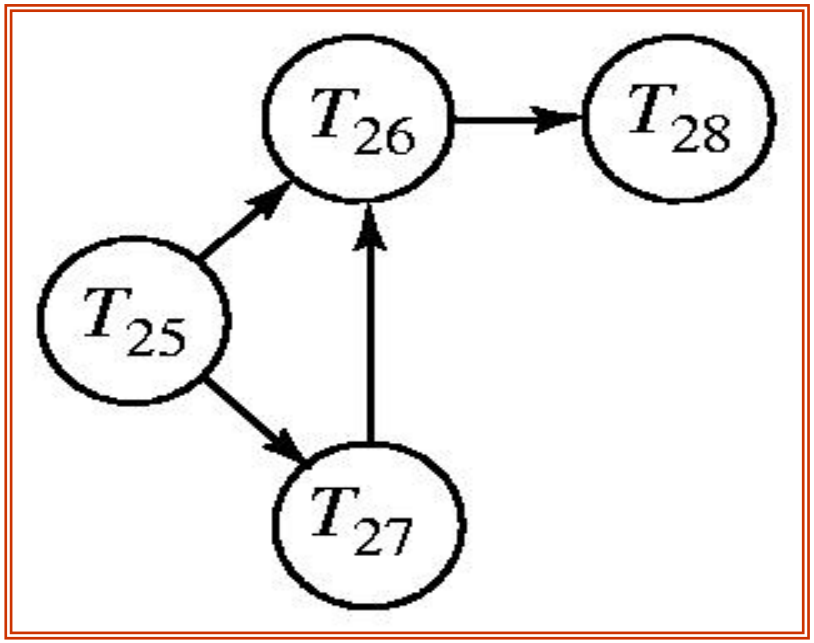
Deadlock prevention (Cont.)

- Another simple approach to deadlock prevention is based on lock timeouts.:
  - a transaction waits for a lock only for a specified amount of time. After that, the wait times out and the transaction is rolled back.
  - thus deadlocks are not possible
  - simple to implement; but starvation is possible. Also difficult to determine good value of the timeout interval.

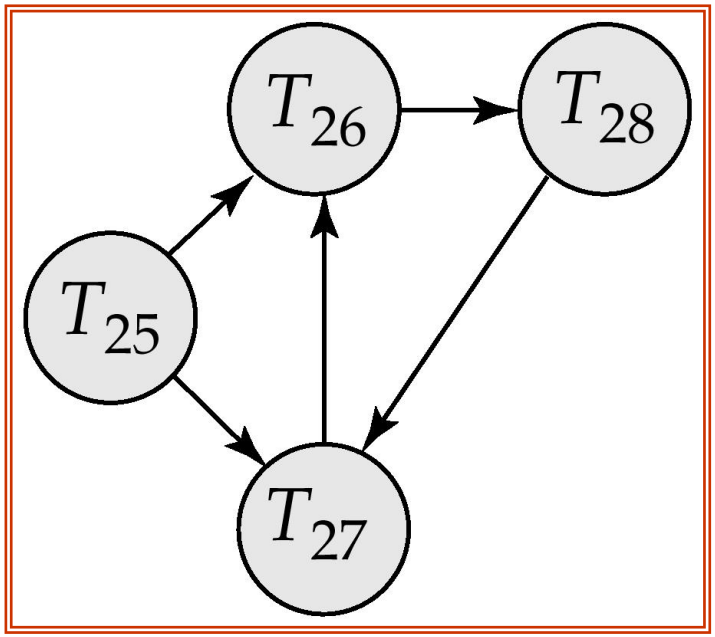
15.2.2 Deadlock Detection

- 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 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 :
  - Selection of a victim. Some transaction will have to rolled back (made a victim) to break deadlock. Select that transaction as victim that will incur minimum cost.
    - a. How long the transaction has computed, and how much longer the transaction will compute before it completes its designated task.
    - b. How many data items the transaction has used.
    - c. How many more data items the transaction needs for it to complete.
    - d. How many transactions will be involved in the rollback.
  - 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

15.4 Timestamp-Based Protocols

- Each transaction is issued a timestamp when it enters the system. If an old transaction T_i has time-stamp TS(T_i), a new transaction T_j is assigned time-stamp TS(T_j) such that TS(T_i) <TS(T_j).
- The protocol manages concurrent execution such that the time-stamps determine the serializability order.
- In order to assure such behavior, the protocol maintains for each data Q two timestamp values:
  - **W-timestamp**(Q) 表示成功执行**write**(Q)的所有事务的最大时间戳.
  - **R-timestamp**(Q)表示成功执行**read**(Q的所有事务的最大时间戳.

Timestamp-Based Protocols (Cont.)

- 基于时间戳的排序协议可以保证任何有冲突的**read**和 **write** 操作按时间戳顺序执行。
- Suppose a transaction T_i issues a **read**(Q):
  1. If TS(T_i) ≤ **W**-timestamp(Q), then T_i needs to read a value of Q that was already overwritten.
     - Hence, the **read** operation is rejected, and T_i is rolled back.
  2. If TS(T_i)≥ **W**-timestamp(Q), then the **read** operation is executed, and R-timestamp(Q) is set to **max**(R-timestamp(Q), TS(T_i)).

Timestamp-Based Protocols (Cont.)

- Suppose that transaction T_i issues **write**(Q).
  1. If TS(T_i) < R-timestamp(Q), then the value of Q that T_i is producing was needed previously, and the system assumed that that value would never be produced.
     - Hence, the **write** operation is rejected, and T_i is rolled back.
  2. If TS(T_i) < W-timestamp(Q), then T_i is attempting to write an obsolete value of Q.
     - Hence, this **write** operation is rejected, and T_i is rolled back.
  3. Otherwise, the **write** operation is executed, and W-timestamp(Q) is set to TS(T_i).

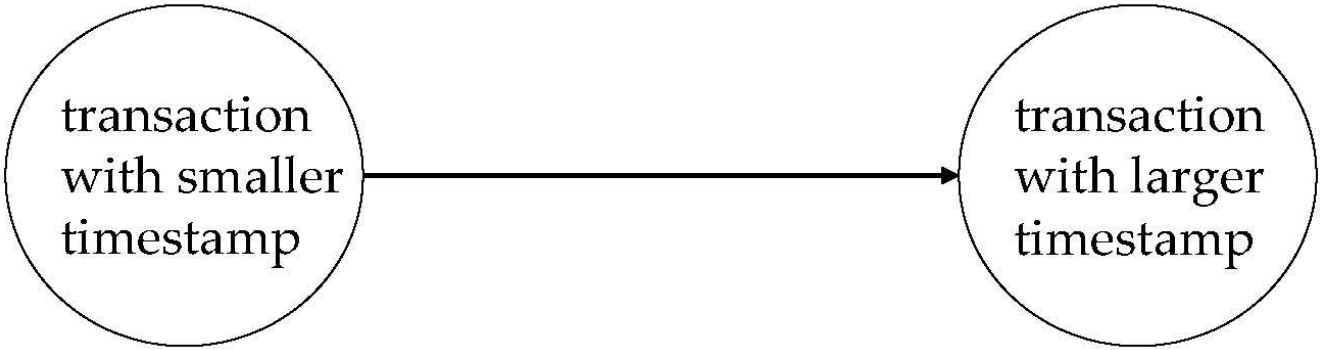
Example Use of the Protocol

A partial schedule for several data items for transactions with timestamps 1, 2, 3, 4, 5. (Analysis it by youself)

T_1	T_2	T_3	T_4	T_5
				read (X)
	read (Y)			
read (Y)				
		write (Y)		
		write (Z)		
				read (Z)
	read (Z)			
	abort			
read (X)				
			read (W)	
		write (W)		
		abort		
				write (Y)
				write (Z)

Correctness of Timestamp-Ordering Protocol

- The timestamp-ordering protocol guarantees serializability since all the arcs in the precedence graph are of the form:



Thus, there will be no cycles in the precedence graph.

- Timestamp protocol ensures freedom from deadlock as no transaction ever waits.
- But the schedule may not be cascade-free, and may not even be recoverable.

End of Chapter

Assignment

- 15.21,29
- A scheduled flight has 50 tickets. Agency one wants to book 10 tickets and agency two want to book 20 tickets. Please design a lock strategy to implement the concurrency control.

Agency one	Agency two
Read(A)	
	Read(A)
A=A-10	
Write(A)	
	A=A-20
	Write(A)