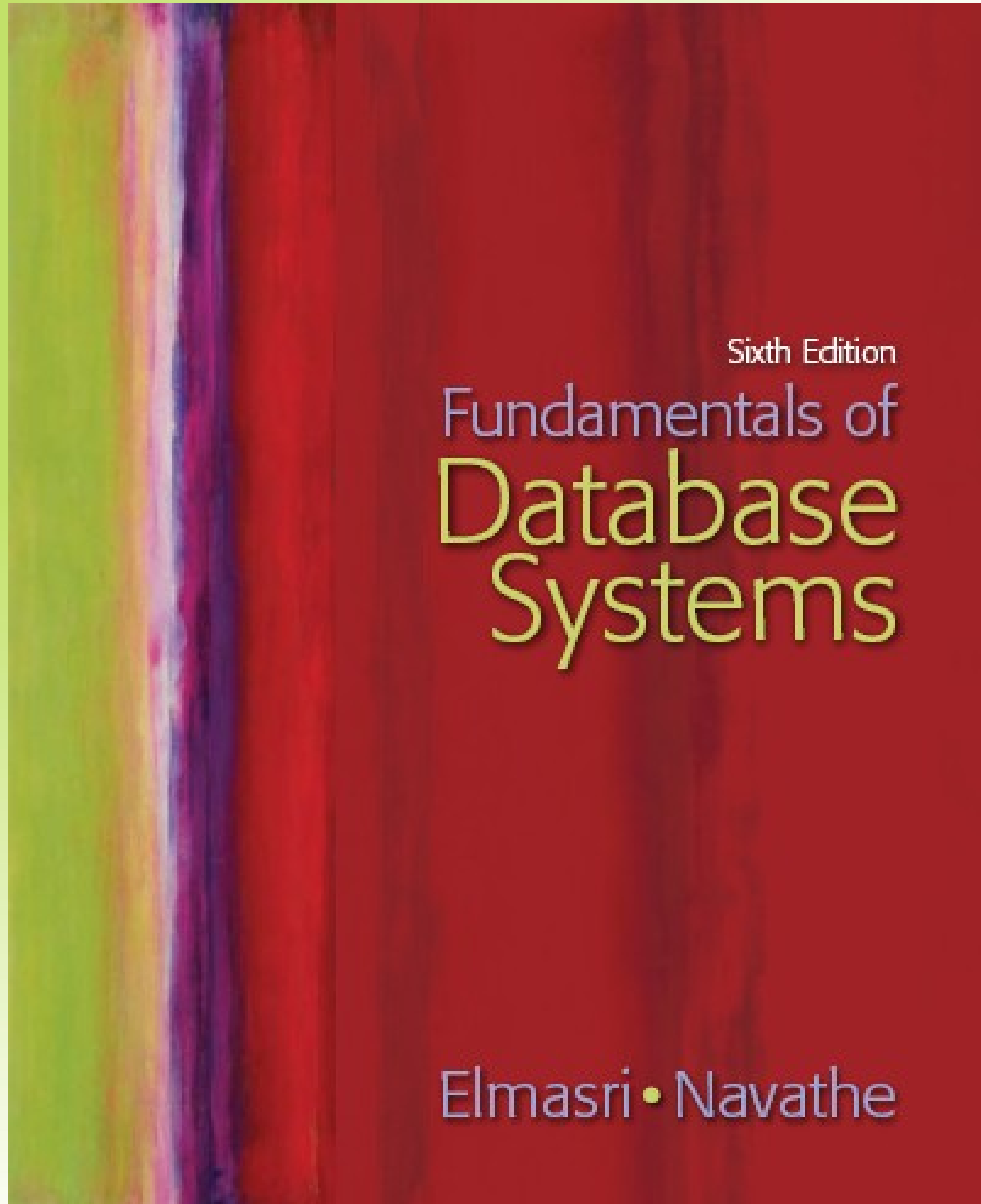
Chapter 22

Concurrency Control Techniques



Addison-Wesley is an imprint of PEARSON

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.

Database Concurrency Control

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.

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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

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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

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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.

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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;
```

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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;

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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;
```

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Two-Phase Locking Techniques: Essential components

- The following code performs the write lock operation:

```
B: if LOCK(X) = “unlocked”
        then LOCK(X) ← “write-locked”
  else begin wait (until LOCK(X) = “unlocked” and
        the lock manager wakes up the transaction);
        go to B
  end;
```

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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;
```

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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) ($i \neq j$) 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)

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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.

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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);	

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Two-Phase Locking Techniques: The algorithm

T1	T2
read_lock (Y); read_item (Y); **unlock (Y);**	
	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);	

Time

Result

X=50; Y=50
Nonserializable because it.
violated two-phase policy.

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Two-Phase Locking Techniques: The algorithm

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

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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.

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Dealing with Deadlock and Starvation

- **Deadlock**

<u>**T'1**</u>	<u>**T'2**</u>
read_lock (Y);	
read_item (Y);	
	read_lock (X);
	read_item (X);
write_lock (X);	
(waits for X)	write_lock (Y);
	(waits for Y)

T1 and T2 did follow two-phase policy but they are deadlock

- Deadlock (T'1 and T'2)

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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.

Database Concurrency Control

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.

To construct and maintain a wait-for graph.

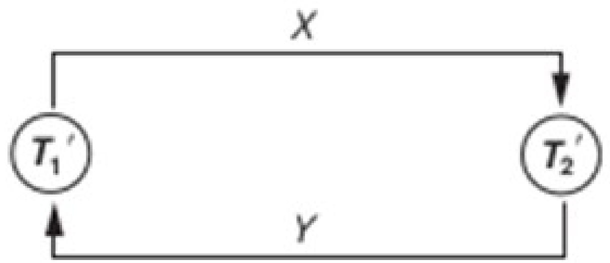
- One node is created in the wait-for graph for each transaction that is currently executing.
- Whenever a transaction Ti is waiting to lock an item X that is currently locked by a transaction Tj, a directed edge (Ti → Tj) is created in the wait-for graph.
- When Tj releases the lock(s) on the items that Ti was waiting for, the directed edge is dropped from the wait-for graph.
- We have a state of deadlock if and only if the wait-for graph has a cycle.

(a)

Time ↓

T_1'	T_2'
read_lock(Y);	
read_item(Y);	
	read_lock(X);
	read_item(X);
write_lock(X);	
	write_lock(Y);

(b)



Illustrating the deadlock problem. (a) A partial schedule of T_1' and T_2' that is in a state of deadlock. (b) A wait-for graph for the partial schedule in (a).

Database Concurrency Control

Dealing with Deadlock and Starvation

- **Deadlock avoidance**
  - There are many variations of two-phase locking algorithm.
  - Some avoid deadlock by not letting the cycle to complete.
  - That is as soon as the algorithm discovers that blocking a transaction is likely to create a cycle, it rolls back the transaction.
  - Wound-Wait and Wait-Die algorithms use timestamps to avoid deadlocks by rolling-back victim.

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Dealing with Deadlock and Starvation

Deadlock avoidance

- Suppose that transaction Ti tries to lock an item X but is not able to because X is locked by some other transaction Tj with a conflicting lock.
- Wait-die. If TS(Ti) < TS(Tj), then (Ti older than Tj) Ti is allowed to wait; otherwise (Ti younger than Tj) abort Ti (Ti dies) and restart it later with the same timestamp.
- Wound-wait. If TS(Ti) < TS(Tj), then (Ti older than Tj) abort Tj (Ti wounds Tj) and restart it later with the same timestamp; otherwise (Ti younger than Tj) Ti is allowed to wait.

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Dealing with Deadlock and Starvation

Starvation

Starvation occurs when a particular transaction consistently waits or restarted and never gets a chance to proceed further.

Solutions for starvation:

- To have a fair waiting scheme, such as using a first-come-first-served queue.
- To increase the priority of a transaction the longer it waits, until it eventually gets the highest priority and proceeds.
- To use higher priorities for transactions that have been aborted multiple times.
- The Wait-Die and Wound-Wait schemes avoid starvation, because they restart a transaction that has been aborted with its same original timestamp.

Database Concurrency Control

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.

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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) $\leq$ 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).

Database Concurrency Control

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).

Database Concurrency Control

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).