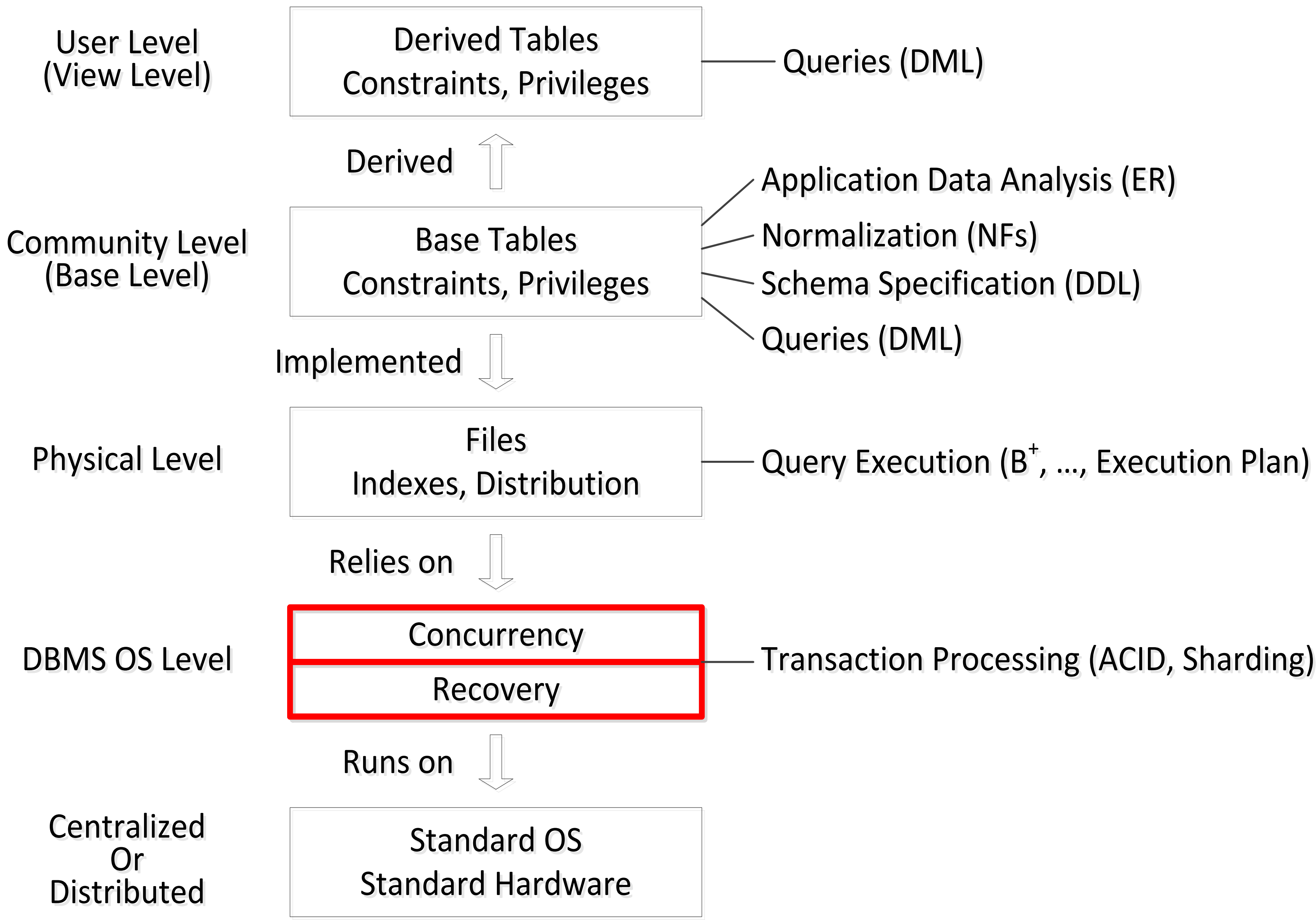
Unit 10.5
Transaction Processing: Concurrency

Concurrency in Context



Transactions

- Transaction is an execution of a user's program
- In the ***cleanest and most important*** model a transaction is supposed to satisfy the ***ACID*** conditions
  - ***Atomic***
  - ***Consistent***
  - ***Isolated***
  - ***Durable***

- Some transactions may not satisfy all of these conditions in order to improve performance, as we will see later

Recovery and Concurrency Management

- The job of these recovery/concurrency modules of the database operating system is to assure the ***ACID*** properties, and handle other related issues
- Recovery does ***ACD***, but can use help from Concurrency, though strictly Recovery is needed even if there is no Concurrency
- Concurrency does ***I*** while possibly (and in our description, definitely) supporting ***ACD***

The Concurrency Problem

- Here we focus on ***Isolation*** in the presence of concurrently executing transactions
- Each transaction should run as if there were no other transactions in the system
- Our execution platform: a single centralized system, with concurrent execution of transactions
- Distributed databases more difficult to handle, as we will see briefly later in the class

Optimistic Concurrency Control

- Locking frequently can hurt performance
  - Overhead of acquiring locks
  - Blocking for reads

- It may not be necessary if there are few conflicts
- With ***optimistic concurrency control***, the transaction uses data without acquiring locks
- Before committing, each transaction verifies that no other transaction modified data that it has read
- If there was a conflict, abort the transaction

Optimistic Concurrency Control

- Use a compare operation CMP to check if a value has changed
- System often stores a ***version number*** with the data to facilitate compare operations. We discuss later.

T1: READ x

T2: WRITE x

T2: COMMIT

T1: CMP x

abort

Serial Execution

- With ***serial execution***, it appears as if transactions follow each other: no concurrency
- Example of a serial execution

T1: READ x
T1: WRITE x
T1: READ y
T1: WRITE y
T2: READ x
T2: WRITE x
T2: READ y
T2: WRITE y

Snapshot Isolation

- With ***snapshot isolation,*** each transaction has it own copy of the state (i.e., has its own snapshot)
- Before committing, compare write sets. A write-write conflicts may cause transactions to abort
- Resolve conflicts with "first committer wins" rule

T1	T2
T1: READ x	
T1: WRITE x	
	T2: READ x
	T2: WRITE x
	T2: READ y
	T2: WRITE y
T1: READ y	
T1: WRITE y	
T1: CMP(x)	
T1: CMP(y)	
abort	

Multiversion Concurrency Control

- Snapshot isolation is usually implemented with ***multiversion concurrency control***
- When items are written to the database, the old value is not over-written
- The DBMS assigns each item a version number
- A transaction may not read the latest version. It reads the version from the time the transaction started
- The transaction sees a “snapshot” of the database from that time

Snapshot Isolation Benefits

- Performance similar to read committed, since read operations do not block
- No dirty reads (because of multiple versions)
- No lost reads
- No inconsistent reads
- No phantoms
- But, it ***may have write skew***

Example

- A database consisting of two items: x, y
- Initially $x = 100$ and $y = 100$
- The only criterion for correctness is the single integrity constraint:

$$x + y >= 0$$

- Consider two simple transactions, T1 and T2
  - T1: $x := x - 200$
  - T2: $y := y - 200$
- Both transactions in isolation are correct: they preserve the consistency of the database

An Execution History

- An execution history

T1	T2
x := x - 200	
	y := y - 200
check (x + y >= 0)	
	check (x + y >= 0)

- In a ***serial*** execution, T2 should abort
- With ***snapshot isolation***, T1 and T2 commit
- The is called ***write skew***

Advanced Material

Locking Is Prone To Starvation

T1	T2	T3	T4	T5	T6
S x					
	X x (waits)				
		S x			
N x					
			S x		
		N x			
				S x	
			N x		
					S x
				N x	

- This can continue indefinitely: T7, …
- Unless something is done, T2 will never gets the lock it wants
- Obvious solution, stop granting S-locks and when the last S-lock is released, give X-lock to T2

Two-Phase Locking Is Prone To Deadlocks

- Two transactions

  T1: x := x + 1; y := y + 1

  T2: y := 2y; x := 2x

	T1	T2
1.	T1	T2
2.	X x	
3.	R x	
4.	W x	
5.		X y
6.		R y
7.		W y
8.		X x (waits)
9.	X y (waits)	

- We got a deadlock
- ***In fact this deadlock prevented a non-serializable history***
- "Deadlocks are not a bug, but a feature"

Detecting And Avoiding Deadlocks

- Deadlocks are characterized by a cyclic “wait for” graph
- Ours was very simple, T1 waited for T2 and T2 waited for T1
- To detect if there is a deadlock, draw a “wait for” graph
  - Nodes: Transactions
  - Arc from T1 to T2 iff T1 waits for T2
- If there are cycles, some transaction need to be aborted
- There are protocols that avoid deadlock by aggressive abortion of transactions, sometimes not necessary
- They abort enough transactions, so that no cycles could ever appear in the “wait for” graph, so not need to draw it during execution
  - But they may abort transactions unnecessarily

Kill-Wait Protocol: Locking + More

- Each transaction, when entering the system is timestamped with the current time: timestamp of T is denoted by TS(T)
- If transaction Ti wants to lock x, which another transaction Tj holds in a conflicting mode (at least one of the two locks is an X-lock),
  - If TS(T1) < TS(T2), then abort T2 and give the lock to T1 (the older transaction kills the younger transaction)
  - If TS(T1) > TS(T2), then TS(T1) waits
- If a transaction unlocks a lock, the oldest from among the waiting transactions (all younger than the unlocking transaction) gets it
- In the “wait for” graph all the arcs are from a younger transaction to an older transaction, and therefore there cannot be a cycle

Wait-Die Protocol: Locking + More

- Each transaction, when entering the system is timestamped with the current time: timestamp of T is denoted by TS(T)
- If transaction Ti wants to lock x, which another transaction Tj holds in a conflicting mode (at least one of the two locks is an X-lock),
  - If TS(T1) < TS(T2), then T1 waits
  - If TS(T1) > TS(T2), TS(T1) abort T1 (T1 dies)
- If a transaction unlocks a lock, the youngest from among the waiting transactions (all older than the unlocking transaction) gets it
- In the “wait for” graph all the arcs are from an older transaction to a younger transaction, and therefore there cannot be a cycle

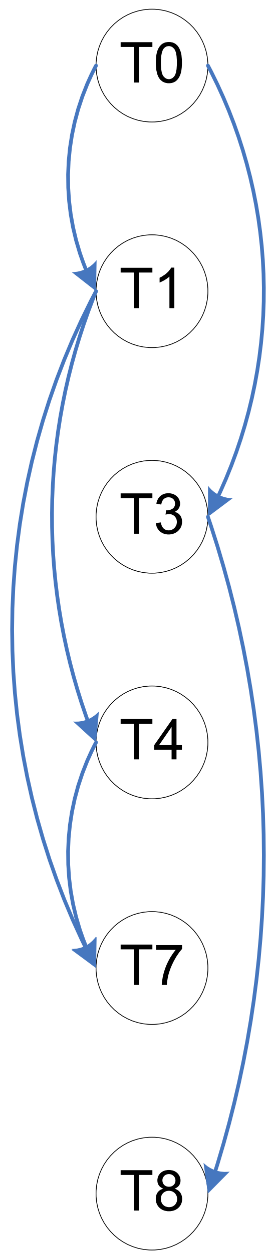
Timestamp-Based Protocol For Concurrency

- Each transaction is issued a timestamp when accepted by DB OS
- The first transaction gets the timestamp 1
- Every subsequent transaction gets the timestamp that is the previously largest assigned timestamp + 1
- So will can refer to transactions as “older” and “younger” based on their timestamps and also use timestamp value for transaction identification
- The system maintains for each item x two timestamps:
  - ***RT(x)*** is the youngest transaction (largest timestamp) that read it
  - ***WT(x)*** is the youngest transaction (largest timestamp) that wrote it

Timestamp-Based Protocol

- Assume that T1, T2, … arrive in this order and that the time stamp of Ti is i
- For simplicity assume that the database was created by transaction T0
- ***We want to get schedules equivalent to the serial order T0, T1, T2, …, or some subsequence of this***, as some transactions can abort, so will not appear in the schedule
- ***If we do this, our schedule will be serializable***
- Similarly to what we did during topological sort, we could say that Ti executed instantaneously at virtual time Ti

Equivalent Serial Schedule



Scenario

RT(x) = 5 WT(x) = 8

Virtual Time

1
2
3
4
5 T5: Read x
6
7
8 T8: Write x
9

	RT(x) = 5	WT(x) = 8
1–4	unknown who read	unknown who wrote
6–9	nobody read	nobody wrote

Scenario

RT(x) = 8 WT(x) = 5

Virtual Time

1	unknown who read	unknown who wrote
2		
3		
4		
5 T5: Write x		nobody wrote
6		
7		
8 T8: Read x	nobody read	
9		

Timestamp-Based Protocol: Reading

- RT(x) = 5; this is the youngest transaction that read it
- WT(x) = 8; this is the youngest transaction that wrote it
- If a transaction Ti with a timestamp of $i \leq 7$, say T6, wants to read x
  - The value it wanted no longer exists (it had to be written by T0 (i.e., initial state of the DB), or by Ti with $i \leq 6$)
  - T6 cannot read x and has to be aborted
- If a transaction with a timestamp of $i \geq 8$, say T9, wants to read it,
  - T9 reads x, and RT(x) := 9

Timestamp-Based Protocol: Reading

- RT(x) = 8; this is the youngest transaction that read it
- WT(x) = 5; this is the youngest transaction that wrote it
- If a transaction Ti with a timestamp of $i \leq 4$, say T3, wants to read x
  - T3 cannot read x and has to be aborted (as too new a value of x exists
- If a transaction Ti with a timestamp i, $5 \leq i \leq 8$, say T6, wants to read x
  - T6 reads x
- If a transaction Ti with a timestamp of $i \geq 9$, say T9, wants to read it
  - T9 reads x and RT(x) := 9

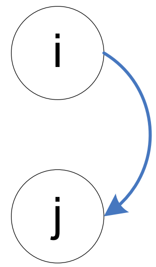
Timestamp-Based Protocol: Writing

- RT(x) = 5; this is the youngest transaction that read it
- WT(x) = 8; this is the youngest transaction that wrote it
- If a transaction Ti with a timestamp of i < 5 wants to write, say T3,
  - T3 has to be aborted
  - Because there was a read of a value of x by transaction T5, and maybe this was a value produced actually by T2. If we allow T3 to write, this would have meant that T5 read a value that was produced by a transaction that was too old
- If a transaction Ti with a timestamp of i > 8 wants to write
  - T9 writes and WT(x) = 9
- If a transaction Ti with a timestamp of i , 6 ≤ i ≤ 7, say T7, wants to write
  - We just throw out the write and let T7 proceed
  - This was a blind write, nobody read it and it is obsolete (and nobody will be allowed to read it as described above; we will not go back to re-examine this case and check this out)

Timestamp-Based Protocol: Writing

- RT(x) = 8; this is the youngest transaction that read it
- WT(x) = 5; this is the youngest transaction that wrote it
- If a transaction Ti with a timestamp of i < 8, say T6, wants to write
  - T6 has to be aborted
  - Because there was a read of a value of x by transaction T8, and if we allow T6 to write x, this would mean that T8 read a value that was too old
- If a transaction Ti with a timestamp of i > 8, say T9, wants to write
- T9 writes and WT(x) = 9

Conflict Serializability And Deadlock Freedom



- In the conflict graph all the arcs will be from an older transaction to a younger transaction
- Therefore the history will be conflict-serializable
- And as transactions never wait, there will be no deadlocks
- But the history may not even be recoverable
- We can make it strict, or even rigorous, by having transactions wait until the relevant transactions commit
- There still will not be any deadlocks, because younger transactions wait for older transactions to commit, but not the other way around

Granularity Of Locks

- The problem of phantoms can be avoided, by say, locking the file that has all the accounts, and therefore no account can be added during the processing
- Sometimes we may want to lock all the accounts (logically, so no new accounts can be added)
- Sometimes we may want to lock an account, to add money to it, for instance
  - And of course, it is not efficient to lock all the accounts in order to modify one account only
- So "lockable" objects are no longer disjoint items
- This can be handled using somewhat more complex types of locks (called ***intention*** locks)
- You can read about Intention Locks and the protocol using them at http://en.wikipedia.org/wiki/Multiple_granularity_locking

Granularity Of Locks (Simplified Granularity-Based Locking)

- See https://docs.oracle.com/cd/E17952_01/refman-5.1-en/innodb-lock-modes.html
- There are 4 types of locks and their compatibility matrix is

Type	**N**	**S**	**X**	**IS**	**IX**
N	Yes	Yes	Yes	Yes	Yes
S	Yes	Yes	No	Yes	No
X	Yes	No	No	No	No
IS	Yes	Yes	No	Yes	Yes
IX	Yes	No	No	Yes	Yes

- IS stands for “Intent ***S***hared”
- IX stands for “Intent e***X***clusive”

- As usual, the matrix states what two transactions can hold simultaneously, a transaction can hold any set of locks on an item (as long as not conflicting with other transactions)

Granularity Of Locks (Simplified Granularity-Based Locking)

- Assume one table R and five rows 1, 2, 3, 4, 5.
- The items that can be locked are R, 1, 2, 3, 4, 5.
- To have write access to all of R, a transaction needs an X-lock on R
- To have a read access on all of R, a transaction needs an X-lock or an S-lock on R
- To have write access to a row of R, a transaction needs an X-lock on that row
- To have a read access on a row of R, a transaction needs an X-lock or an S-lock on that row
- To set an X-lock on a row of R, a transaction needs an IX-lock on R
- To set an S-lock on a row of R, a transaction needs an IX-lock or an IS-lock on R
- Locking is top to bottom; unlocking is bottom to top

Granularity Of Locks (Simplified Granularity-Based Locking)

- The goal is to prevent situations such as
  - T1 holds X-lock on R and T2 holds an S-lock on 1
  - T1 holds X-lock on R and T2 holds an X-lock on 1
  - T1 holds S-lock on R and T2 holds an X-lock on 1
- The goal is to permit situations such as
  - T1 holds S-lock on R and T2 holds an S-lock on 1
  - T1 holds S-lock on 1 and T2 holds an X-lock on 2
  - T1 holds X-lock on 1 and T2 holds an X-lock on 2