Transaction Management

- Locking to Ensure Serializability
  - Concurrent access to database items is controlled by strategies based on locking, timestamping or certification.
  - A lock is an access privilege to a single database item.
  - Transactions can lock items by passing a request to the Lock Manager.
  - The locks obtained by transactions are stored in a lock table which consists of tuples of the form: (item, lock-type, transaction), where
    - item is the item that the transaction locks
    - lock-type can be shared or exclusive
    - transaction is the transaction identifier

Transaction Management

- When a transaction holds an exclusive lock on a database item, no other transaction can read or write the item
  - used for writing
- When a transaction holds a shared lock, other transactions can obtain a shared lock on the same item
  - used for reading

- For simplicity assume there is a single type of lock and every transaction must obtain a lock on an item before accessing it.
- All items locked by a transaction must be unlocked, otherwise no other transaction may gain access to them.
- A transaction requesting a lock on an item that is already locked by another transaction, must wait until the lock is released.

Transaction Management

- Locking can prevent the lost update problem:

  T_1 = Lock(A) R_1(A) W_1(A) Unlock(A) C_1

  T_2 = Lock(A) R_2(A) W_2(A) Unlock(A) C_2

- Locking enforces a serial execution of the transactions
- Locking can also prevent the blind write problem:

  T_1 = Lock(A) W_1(A) Lock(B) W_1(B) Unlock(A) Unlock(B) C_1

  T_2 = Lock(A) W_2(A) Lock(B) W_2(B) Unlock(A) Unlock(B) C_1

- Then the following schedule is valid:

  $Lock_1$(A) W_1(A) $Lock_1$(B) W_1(B) $Unlock_1$(A) $Lock_2$(A) W_2(A) $Unlock_1$(B) $Lock_2$(B) W_2(B) $Unlock_2$(A) $Unlock_2$(B) C_1 C_2

Transaction Management

- Livelock
  - Undesirable phenomena may occur if locks are granted arbitrarily
  - E.g., while T_2 is waiting for T_1 to release the lock on A, another transaction T_3 that has also requested a lock on A is granted the lock instead of T_2. When T_3 releases the lock on A, the lock is granted to transaction T_4 that requests it. ……
  - The situation where a transaction may wait indefinitely while other transactions obtain a lock on a DB item is called a livelock.
  - Livelocks can be avoided by using a first-come first-served lock granting policy.
  - Even such a policy cannot solve problems such as deadlocks.

Transaction Management

- Deadlock
  - Consider the transactions:

    T_1 = Lock(A) Lock(B) …. Unlock(A) Unlock(B) C_1

    T_2 = Lock(B) Lock(A) …. Unlock(B) Unlock(A) C_2

  Assume T_1 is granted a lock on A and T_2 is granted a lock on B. Then T_1 requests a lock on B but is forced to wait because T_2 has the lock on B. Similarly, T_2 requests a lock on A but is forced to wait because T_1 has the lock on A.

  Neither transaction can proceed because each is waiting for the other to release a lock. They both wait for ever.

- The situation in which each member of a set of transactions is waiting to lock an item that is currently locked by some other transaction in the set is called a deadlock.

Transaction Management

- Solutions to the deadlock problem:
  - Require each transaction to request all locks at once. Either all locks are granted or none.
  - Assign an arbitrary linear order to the items and require all transactions to request their locks in that order.
  - Do nothing to prevent deadlocks. Abort one or more of the deadlocked transactions if a deadlock arises.
- Deadlocks can be discovered by using wait-for graphs:
  - Given a set of transactions a wait-for graph is a directed graph whose vertices correspond to transactions in the set. There exists an edge from T_i to T_j if T_i is waiting to lock an item on which T_j is holding a lock.

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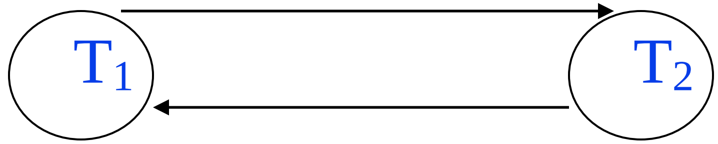
- Theorem: A set of transactions is deadlocked if and only if there exists a cycle in the wait-for graph.
- Example: The wait-for graph for the transactions

  T_1 = Lock(A) Lock(B) …. Unlock(A) Unlock(B) C_1

  T_2 = Lock(B) Lock(A) …. Unlock(B) Unlock(A) C_2

  contains a cycle



Transaction Management

- 2-Phase Locking (2PL): a protocol ensuring serializability of schedules
- Definition: A schedule is said to obey the 2-phase locking protocol if the following rules are obeyed by each transaction in the schedule
  1. When a transaction attempts to read (write) a data item, a read lock (write lock) must be acquired first
  2. If a data item is locked because some conflicting operation is currently holding a lock on the item, the transaction requesting the lock is forced to wait until no conflicting lock on the item exists (only read locks are non-conflicting)
  3. All locks to the data items that the transaction will access are acquired during the growing phase.
  4. All locks are released during the shrinking phase. After the beginning of this phase no lock can be acquired.

Transaction Management

- 2-Phase Locking (2PL)
- Note:
  - Two locks by the same transaction never conflict: a transaction with a read lock on a data item can acquire a write lock on the item as long as no other transaction has a lock on the data item; a transaction with a write lock on a data item need not acquire a read lock on the same item.
  - 2PL permits the early release of locks
- Notation:
  - RL_i: transaction T_i obtains a read lock
  - WL_i: transaction T_i obtains a write lock
  - RU_i: transaction T_i releases a read lock
  - WU_i: transaction T_i releases a write lock

Transaction Management

- Example: Does the following schedule obey the 2PL protocol?

$$S = R_1(A)\ R_2(B)\ W_2(B)\ R_2(A)\ W_2(A)\ R_1(B)\ C_1\ C_2$$

Lock/unlock operations must be added first. The schedule becomes:

$$S = RL_1(A)\ R_1(A)\ RU_1(A)\ RL_2(B)\ R_2(B)\ WL_2(B)\ W_2(B)\ WU_2(B)$$
$$RL_2(A)\ R_2(A)\ WL_2(A)\ W_2(A)\ RL_1(B)\ R_1(B)\ C_1\ C_2$$

  - rule 1 is obeyed: no item is accessed without a lock being granted to the requested transaction
  - rule 2 is obeyed: no two conflicting operations have a lock on the same item at the same time
  - rules 3,4 are violated because both transactions lock items after they have released locks

Transaction Management

- Applying the 2PL discipline to the schedule

$$S = R_1(A)\ R_2(B)\ W_2(B)\ R_2(A)\ W_2(A)\ R_1(B)\ C_1\ C_2$$

yields the following interleaved execution (all locks are released at commit time)

T1	RL1(A)	R1(A)							
T2			RL2(B)	R2(B)	WL2(B)	W2(B)	RL2(A)	R2(A)	WL2(A)

T1		RL1(B)	wait	abort			restart	C1
T2	wait				W2(A)	C2		

- The deadlock had to be resolved by aborting and restarting one of the transactions.

Transaction Management

- Theorem: A schedule that follows 2PL is always serializable.
- Example:
  - Under 2PL the schedule $S = R_1(A)\ R_2(B)\ W_2(B)\ R_2(A)\ W_2(A)\ R_1(B)\ C_1\ C_2$ is equivalent to the serial schedule $T_2\ T_1$
  - The schedule $S' = R_1(A)\ R_2(A)\ W_1(A)\ W_2(A)\ C_1\ C_2$ is forced to execute as follows by a transaction scheduler that uses 2PL:

T1	RL1(A)	R1(A)			WL1(A)	wait			abort
T2			RL2(A)	R2(A)			WL2(A)	wait	

T1			restart	C1
T2	W2(A)	C2		

If no locking was imposed S' would be non-serializable.

Transaction Management

- Example: Consider the following transactions
  - T_1: $W_1(U)$ $R_1(Y)$ $W_1(U)$ C_1
  - T_2: $R_2(X)$ $W_2(U)$ $W_2(Y)$ $W_2(W)$ C_2
  - T_3: $W_3(W)$ $R_3(X)$ $W_3(U)$ $W_3(Z)$ C_3
- Is it possible to add lock/unlock steps to these transactions so that every legal schedule is serializable?
- Answer: yes, add lock/unlock steps using 2PL

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T_1							
T_2					$RL_2(X)$	$WL_2(U)$	wait
T_3	$WL_3(W)$	$RL_3(X)$	$WL_3(U)$	$WL_3(Z)$			$W_3(W)$

T_1							$WL_1(U)$
T_2	wait	wait	wait	wait	wait	$WL_2(Y)$	
T_3	$WU_3(W)$	$R_3(X)$	$RU_3(X)$	$W_3(U)$	$WU_3(U)$		

Transaction Management

T_1	wait	wait	wait	wait	wait	$RL_1(Y)$	wait
T_2	$WL_2(W)$	$R_2(X)$		$W_2(U)$	$WU_2(U)$		$W_2(Y)$
T_3			$W_3(Z)$				

T_1	$WL_1(Z)$	wait	$W_1(U)$				$R_1(Y)$		$W_1(Z)$
T_2					$W_2(W)$	$WU_2(U)$		C_2	
T_3		$WU_3(Z)$		C_3					

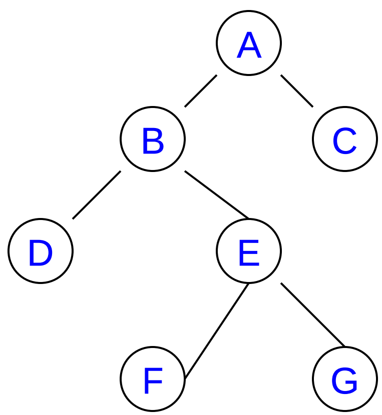
T_1	$WU_1(U)$	$RU_1(Y)$	$WU_1(Z)$	C_1
T_2				
T_3				

Transaction Management

- Tree Protocols
  - In many instances, the set of items accessed by a transaction can be viewed naturally as a tree or forest
  - E.g., items are nodes in a B-tree; items have different granularities (relations, tuples, attributes).
  - Two different policies may be followed:
    1. each node in the tree is locked independently of its descendants
    2. a lock on an item implies a lock on all of its descendants
  - The latter policy saves time by avoiding locking many items separately
  - E.g., when the content of an entire relation needs to be read, the relation can be locked in one step instead of locking each tuple individually

Transaction Management

- Tree Protocol #1 (TP1)
- Definition: A transaction obeys the TP1 policy if:
  - except for the first item locked, no item can be locked unless the transaction holds a lock on the item's parent
  - no item is ever locked twice by a transaction
- A schedule obeys the TP1 policy if every transaction in the schedule obeys it.
- Example: Consider the following hierarchy of items



Transaction Management

- The following schedule obeys TP1

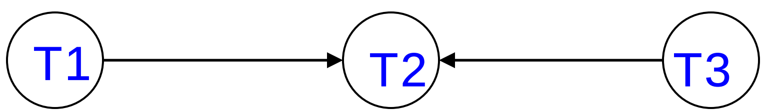
T_1	$L_1(A)$	$L_1(B)$	$L_1(D)$	$U_1(B)$		$L_1(C)$		$U_1(D)$	
T_2					$L_2(B)$				
T_3							$L_3(E)$		$L_3(F)$

T_1	$U_1(A)$		$U_1(C)$						
T_2					$L_2(E)$		$U_2(B)$		$U_2(E)$
T_3		$L_3(G)$		$U_3(E)$		$U_3(F)$		$U_3(G)$	

- Does it obey 2PL?

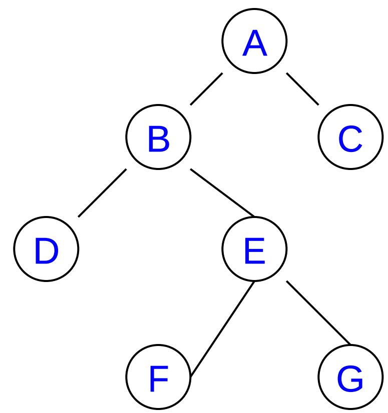
Transaction Management

- Note: A transaction that obeys TP1 need not necessarily obey 2PL.
- Theorem: Every legal schedule that obeys the protocol TP1 is serializable
- Example: The schedule of the previous example is serializable.
  - its precedence graph is acyclic



Transaction Management

- Tree Protocol #2 (TP2)
- Definition: A transaction obeys the TP2 policy if whenever an item is locked, all its descendants are locked
- Indiscriminate locking under TP2 may result in schedules where two transactions hold a lock on the same item at the same time.
- Example: in the hierarchy



transaction T_1 locks E (therefore F,G). Then T_2 locks B, therefore acquires conflicting locks on E,F,G.

Transaction Management

- To avoid conflicts of this sort, the warning protocol may be followed:
  - a transaction cannot place a lock on an item unless it first places a warning on all its ancestors
  - a warning on an item X prevents any other transaction from locking X, but does not prevent them from also placing a warning on X, or from locking some descendant of X that does not have a warning
- Definition: A transaction obeys the warning protocol if:
  1. It begins by placing a lock or warning at the root
  2. It does not place a lock or warning on an item unless it holds a warning on its parent.
  3. It does not remove a lock or warning unless it holds no lock or warnings on its children

Transaction Management

4. It obeys 2PL in the sense that all unlock operations follow all warnings or lock operations

- This protocol acts in conjunction with the assumption that a lock can be placed on an item only if no other transaction has a lock or warning on the same item.
- Furthermore, a warning can be placed on an item as long as not other transaction has a lock on the item.
- Theorem: Legal schedules obeying the warning protocol are serializable.