Transactions, Recovery and Concurrency (II)

Concurrency Control

Concurrency Control Methods

- **Locking Mechanism**

  The idea of locking some data item *X* is to:

  - give a transaction exclusive use of the data item *X*,
  - do not restrict the access of other data items.

  This prevents one transaction from changing a data item currently being used in another transaction.

- We will discuss a simple locking scheme which locks individual items, using read and write locks

Locking Rules

- In this schema, every transaction T must obey the following rules.

- 1) If T has only one operation (read/write) manipulating an item X:
  - obtain a read lock on X before reading it,
  - obtain a write lock on X before writing it,
  - unlock X when done with it.

- 2) If T has several operations manipulating X:
  - obtain one proper lock only on X:

  a read lock if all operations on X are reads;

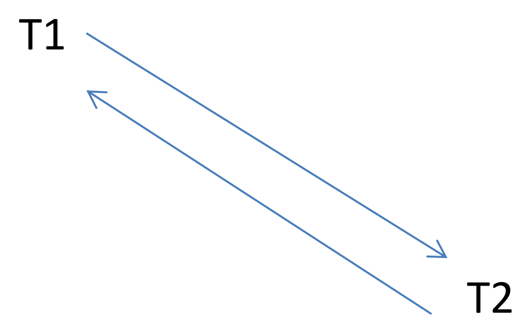
  a write lock if one of these operations on X is a write.
  - unlock X after the last operation on X in T has been executed.

Locking Rules (cont.)

- In this scheme,
  - Several read locks can be issued on the same data item at the same time.
  - A read lock and a write lock cannot be issued on the same data item at the same time, neither two write locks.
- This still does not guarantee serializability.

Example: Based on E/N Fig 18.3.

T_1	T_2
read_lock(Y)	
read(Y)	
unlock(Y)	
	read_lock(X)
	read(X)
	unlock(X)
	write_lock(Y)
	read(Y)
	$Y \leftarrow X + Y$
	write(Y)
	unlock(Y)
write_lock(X)	
read(X)	
$X \leftarrow X + Y$	
write(X)	
unlock(X)	



Two Phase Locking (2PL)

- To guarantee serializability, transactions must also obey the *two-phase locking protocol*:
  - *Growing Phase*: all locks for a transaction must be obtained before any locks are released, and
  - *Shrinking Phase*: gradually release all locks (once a lock is released no new locks may be requested).

Two Phase Locking (2PL) (Cont.)

Example: Based on E/N Fig 18.4.

T_1
read_lock(Y)
read(Y)
write_lock(X)
unlock(Y)
read(X)
$X \leftarrow X + Y$
write(X)
unlock(X)

- Locking thus provides a solution to the problem of correctness of schedules.

Two phase locking ensures conflict serializability

Deadlock

- A problem that arises with locking is **deadlock**.
- Deadlock occurs when two transactions are each waiting for a lock on an item held by the other.

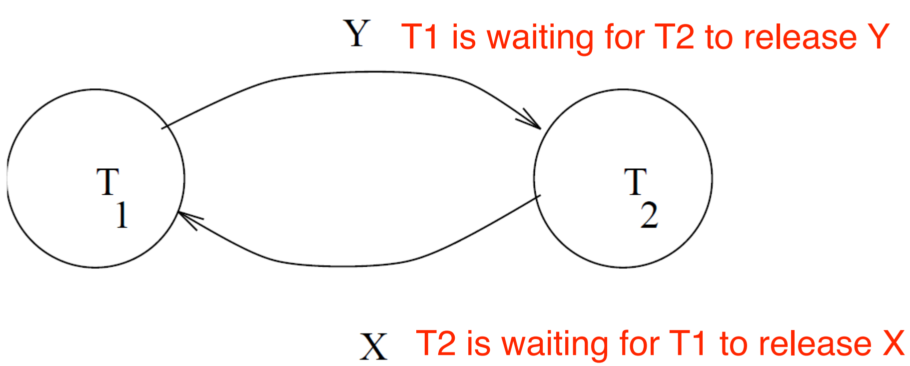
T_1	T_2
write_lock(X)	
read(X)	
	write_lock(Y)
	read(Y)
write_lock(Y)	
waiting for Y*	write_lock(X)
waiting for Y*	***waiting for X***

Deadlock Check

- Create the *wait-for graph* for currently active transactions:
  - create a vertex for each transaction; and
  - an arc from T_i to T_j if T_i is waiting for an item locked by T_j.

- If the graph has a cycle, then a *deadlock* has occurred.

Example:



Several methods to deal with deadlocks

- *deadlock detection*
  - periodically check for deadlocks, abort and rollback some transactions (restart them later). This is a good choice if transactions are very short or very independent.

Several methods to deal with deadlocks (Cont.)

- *deadlock prevention* - Assign priorities based on timestamps. Assume Ti wants a lock that Tj holds. Two policies are possible:
  - Wait-Die: If Ti has higher priority, Ti waits for Tj; otherwise Ti aborts
  - Wound-wait: If Ti has higher priority, Tj aborts; otherwise Ti waits
- If a transaction re-starts, make sure it has its original timestamp

Timestamp ordering

- The idea here is:
  - to assign each transaction a timestamp (e.g. start time of transaction), and
  - to ensure that the schedule used is equivalent to executing the transactions in timestamp order

- Each data item, X, is assigned
  - a read timestamp, *read TS*(*X*) - the latest timestamp of a transaction that read X, and
  - a write timestamp, *write TS*(*X*) - the latest timestamp of a transaction that write X.

- These are used in read and write operations as follows. Suppose the transaction timestamp is *T*.

$read(X)$:

```
If T >= write_TS(X) then
    { execute read(X);
    if T >= read_TS(X) then
          read_TS(X) <- T }
else
   rollback the transaction and restart
```

$write(X)$:

```
If T >= read_TS(X) and T >= write_TS(X) then
   { execute write(X); write_TS(X) <- T }
else
   rollback and restart
```

- **Thomas' write rule:**

$write(X)$:

```
If T < read_TS(X) then
   rollback and restart
else if T < write_TS(X) then
        ignore the write
      else
        { execute write(X);
          write_TS(X) <- T }
```

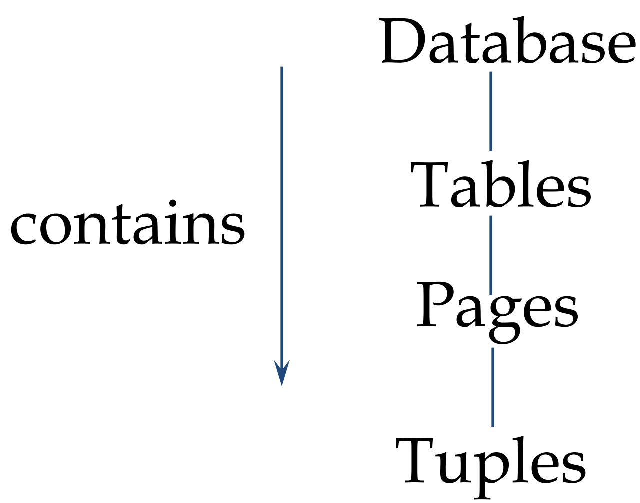
T_1	T_2	T_3
read (x)		
	read (y)	
	write (y)	
read (z)		
		read (z)
		write (z)
Write (z)		

r_TS (x) = 0 → 1
w_TS(x) = 0
r_TS (y) = 0 → 2
w_TS(y) = 0 → 2
r_TS (z) = 0 → 1 → 3
w_TS(z) = 0 → 3

- Some problems:
  - Cyclic restart: There is no deadlock, but a kind of livelock can occur - some transactions may be constantly aborted and restarted.
  - Cascading rollback: When a transaction is rolled back, so are any transactions which read a value written by it, and any transactions which read a value written by them . . . etc. This can be avoided by not allowing transactions to read values written by uncommitted transactions (make them wait).

Multiple-Granularity Locks

- Hard to decide what granularity to lock (tuples vs. pages vs. tables).
- Shouldn't have to decide!
- Data "containers" are nested:



Solution: New Lock Modes, Protocol

- Allow Xacts to lock at each level, but with a special protocol using new "intention" locks:

Intentional write lock

Intentional share lock

- Before locking an item, Xact must set "intention locks" on all its ancestors.
- For unlock, go from specific to general (i.e., bottom-up).
- SIX mode: Like S & IX at the same time.

	--	IS	IX	S	X
--	√	√	√	√	√
IS	√	√	√	√	
IX	√	√	√		
S	√	√		√	
X	√				

Multiple Granularity Lock Protocol

- Each Xact starts from the root of the hierarchy.
- To get S or X lock on a node, must hold IS or IX on parent node.
  - What if Xact holds SIX on parent? S on parent?
- To get X or IX or SIX on a node, must hold IX or SIX on parent node.
- Must release locks in bottom-up order.

Protocol is correct in that it is equivalent to directly setting locks at the leaf levels of the hierarchy.

Examples

- T1 scans R, and updates a few tuples:
  – T1 gets an SIX lock on R, then repeatedly gets an S lock on tuples of R, and occasionally upgrades to X on the tuples.
- T2 uses an index to read only part of R:
  – T2 gets an IS lock on R, and repeatedly gets an S lock on tuples of R.
- T3 reads all of R:
  – T3 gets an S lock on R.
  – OR, T3 could behave like T2; can use lock escalation to decide which.

	--	IS	IX	S	X
--	√	√	√	√	√
IS	√	√	√	√	
IX	√	√	√		
S	√	√		√	
X	√				

Dynamic Databases

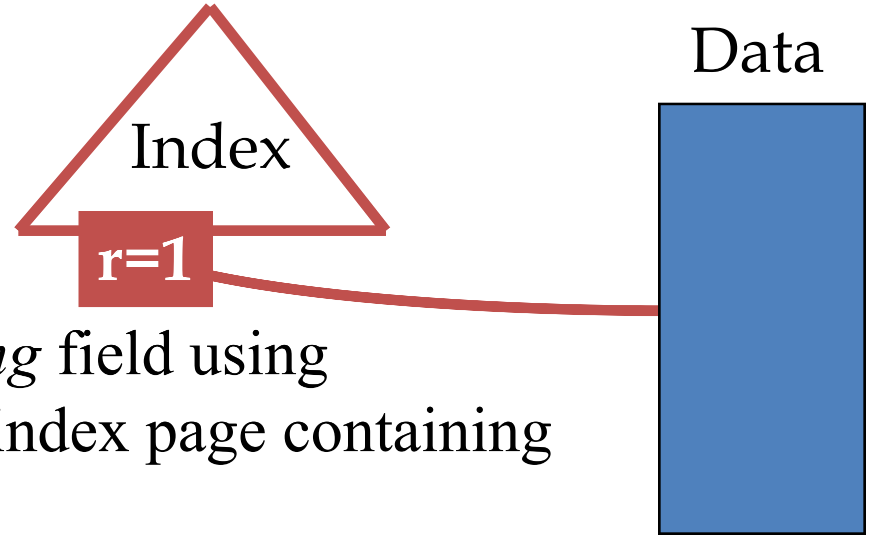
Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)

- If we relax the assumption that the DB is a fixed collection of objects, even Strict 2PL will not assure serializability:
  - T1 locks all pages containing sailor records with *rating* = 1, and finds oldest sailor (say, *age* = 71).
  - Next, T2 inserts a new sailor; *rating* = 1, *age* = 96.
  - T2 also deletes oldest sailor with rating = 2 (and, say, *age* = 80), and commits.
  - T1 now locks all pages containing sailor records with *rating* = 2, and finds oldest (say, *age* = 63).
- No consistent DB state; however T1 “correctly” gets through!

The Problem

- T1 implicitly assumes that it has locked the set of all sailor records with *rating* = 1.
  - Assumption only holds if no sailor records are added while T1 is executing!
  - Need some mechanism to enforce this assumption. (Index locking and predicate locking.)
- Example shows that conflict serializability guarantees serializability only if the set of objects is fixed!

Index Locking



- If there is a dense index on the *rating* field using Alternative (2), T1 should lock the index page containing the data entries with *rating* = 1.
  - ➢ If there are no records with *rating* = 1, T1 must lock the index page where such a data entry *would* be, if it existed!
- If there is no suitable index, T1 must lock all pages, and lock the file/table to prevent new pages from being added, to ensure that no new records with *rating* = 1 are added.

Predicate Locking

- Grant lock on all records that satisfy some logical predicate, e.g. *age > 2*salary*.
- Index locking is a special case of predicate locking for which an index supports efficient implementation of the predicate lock.
- What is the predicate in the sailor example?
- In general, predicate locking has a lot of locking overhead.

Locking in B+ Trees

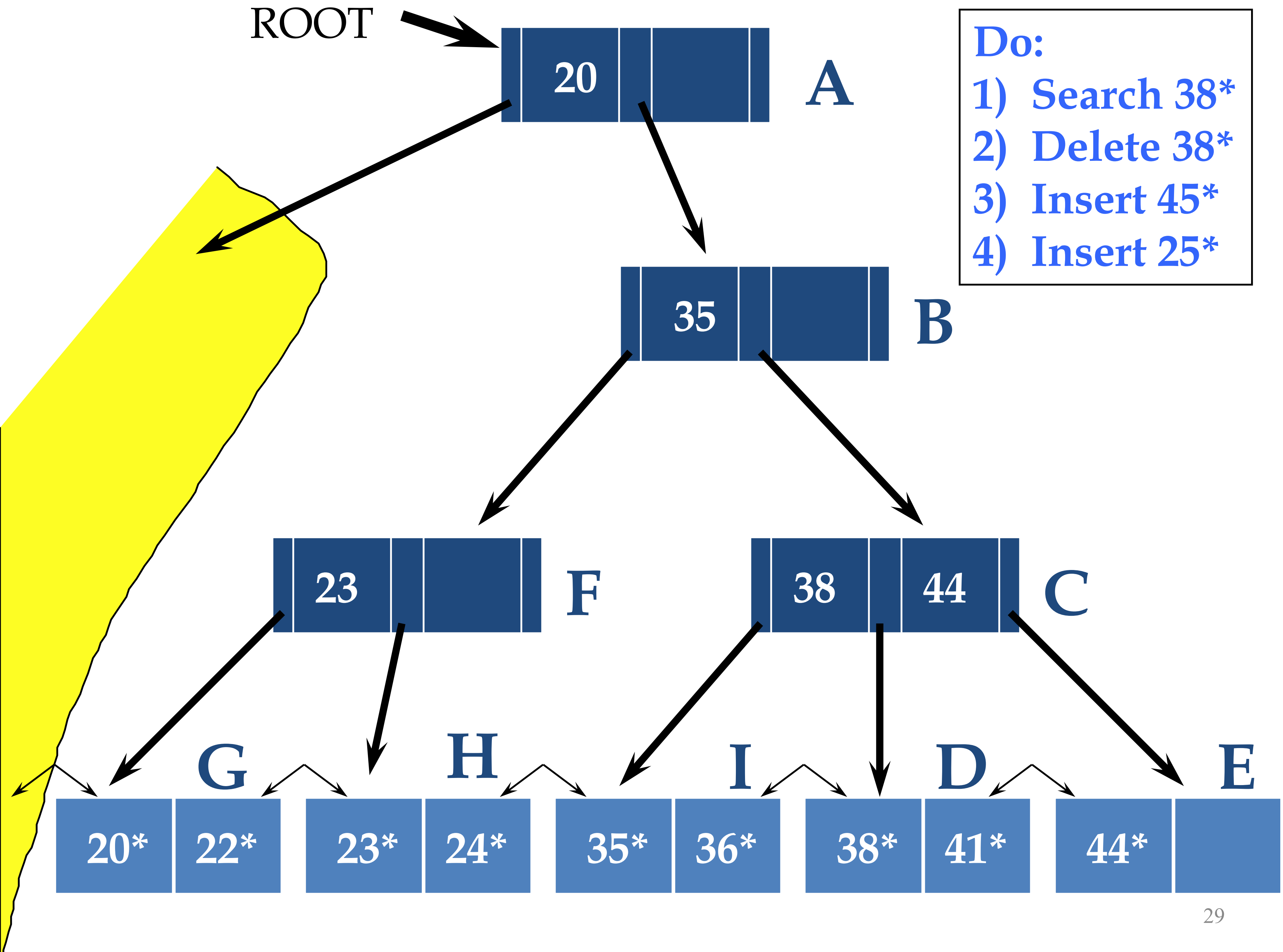
- How can we efficiently lock a particular leaf node?
  - Btw, don't confuse this with multiple granularity locking!
- One solution: Ignore the tree structure, just lock pages while traversing the tree, following 2PL.
- This has terrible performance!
  - Root node (and many higher level nodes) become bottlenecks because every tree access begins at the root.

Two Useful Observations

- Higher levels of the tree only direct searches for leaf pages.
- For inserts, a node on a path from root to modified leaf must be locked (in X mode, of course), only if a split can propagate up to it from the modified leaf. (Similar point holds w.r.t. deletes.)
- We can exploit these observations to design efficient locking protocols that guarantee serializability *even though they violate 2PL.*

A Simple Tree Locking Algorithm

- Search: Start at root and go down; repeatedly, S lock child then unlock parent.
- Insert/Delete: Start at root and go down, obtaining X locks as needed. Once child is locked, check if it is safe:
  - If child is safe, release all locks on ancestors.
- Safe node: Node such that changes will not propagate up beyond this node.
  - Inserts: Node is not full.
  - Deletes: Node is not half-empty.

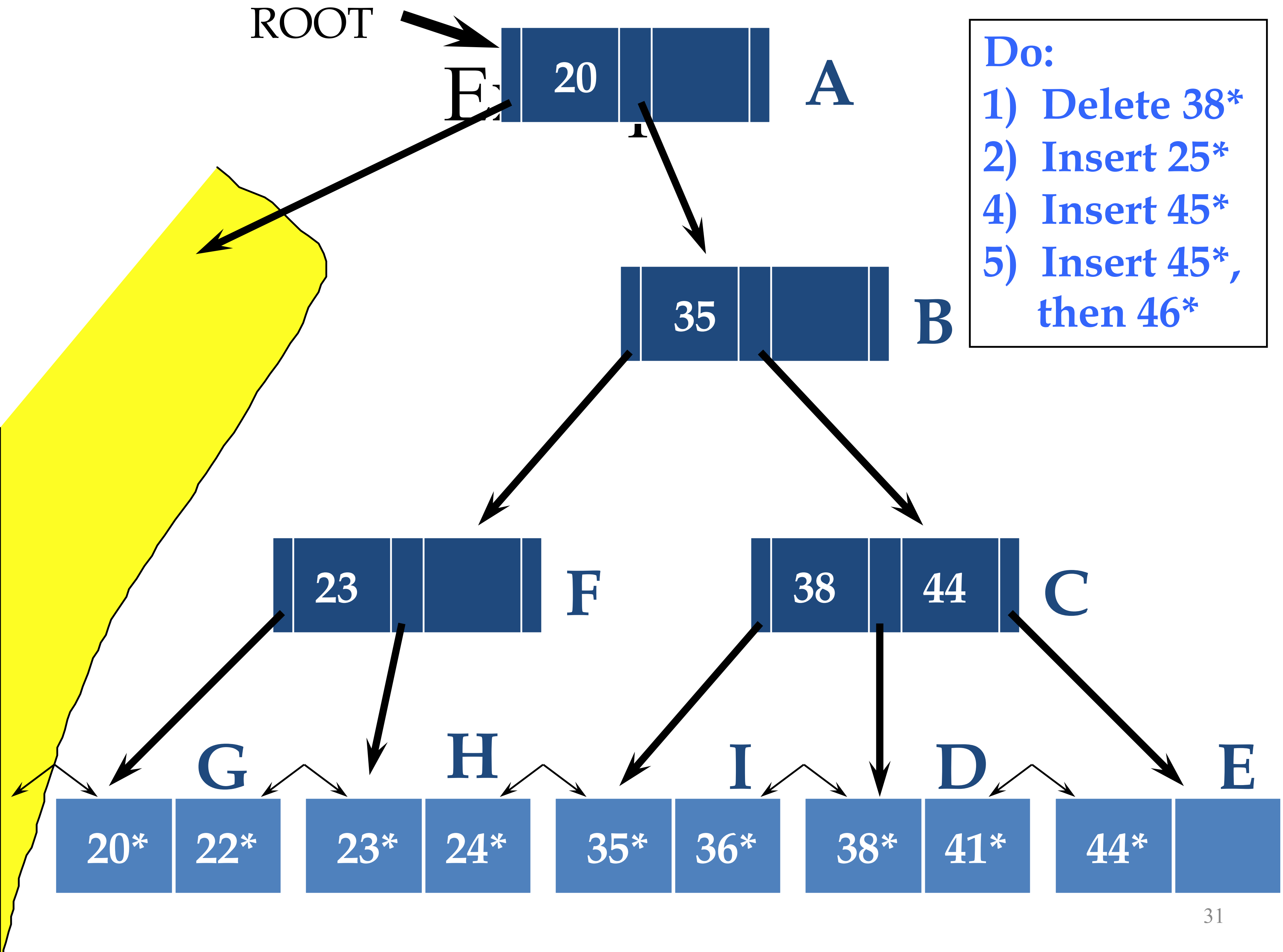


Do:

1) Search 38*
2) Delete 38*
3) Insert 45*
4) Insert 25*

A Better Tree Locking Algorithm (See Bayer-Schkolnick paper)

- Search: As before.
- Insert/Delete:
  - Set locks as if for search, get to leaf, and set X lock on leaf.
  - If leaf is not safe, release all locks, and restart Xact using previous Insert/Delete protocol.
- Gambles that only leaf node will be modified; if not, S locks set on the first pass to leaf are wasteful. In practice, better than previous alg.



Do:

1) Delete 38*
2) Insert 25*
4) Insert 45*
5) Insert 45*, then 46*

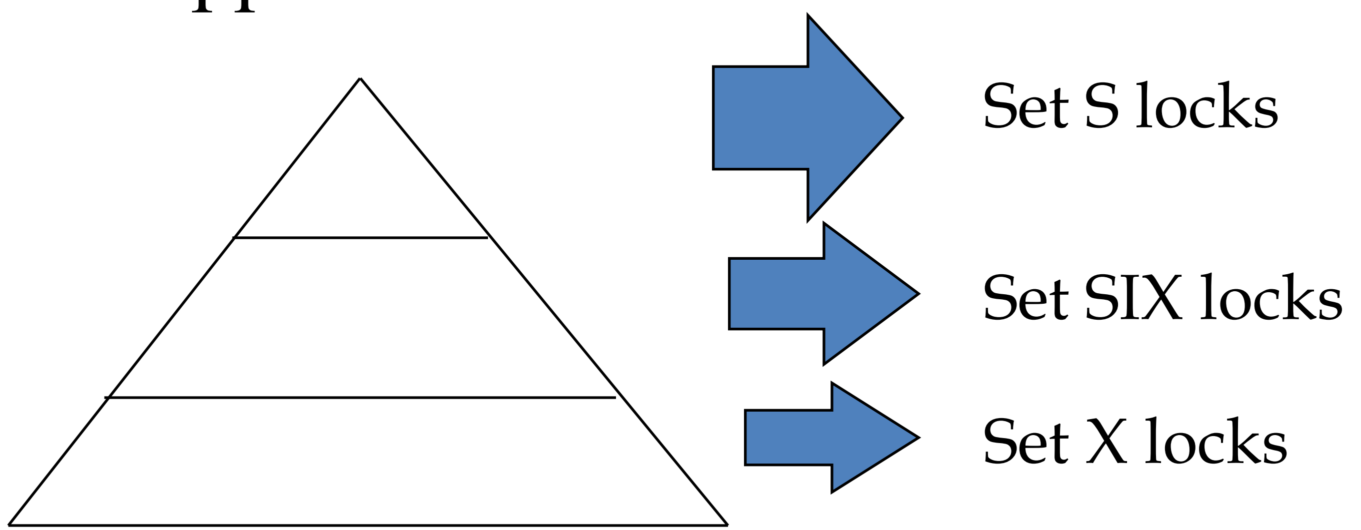
Even Better Algorithm

- Search: As before.
- Insert/Delete:
  - Use original Insert/Delete protocol, but set IX locks instead of X locks at all nodes.
  - Once leaf is locked, convert all IX locks to X locks top-down: i.e., starting from node nearest to root. (Top-down reduces chances of deadlock.)

(Contrast use of IX locks here with their use in multiple-granularity locking.)

Hybrid Algorithm

- The likelihood that we really need an X lock decreases as we move up the tree.
- Hybrid approach:



Multiversioning

- Similar to the timestamp ordering approach; but is allowed to access “old” versions of a table.
- A history of the values and timestamps (versions) of each item is kept.
- When the value of an item is needed, the system chooses a **proper** version of the item that maintains serializability.
- This results in fewer aborted transactions at the cost of greater complexity to maintain more versions of each item.

- We will look at a scheme, several versions $X_1, \ldots, X_k$ of each data item are kept. For each X_i we also keep
  - *read* $TS(X_i)$ - as for timestamp ordering.
  - *write* $TS(X_i)$ - as for timestamp ordering.

- Read and write are done as follows for a transaction *P* with timestamp T.

$read(X)$:

```
Find Xi s.t. write_TS(Xi) is the
   highest write timestamp but <= T
update read_TS(Xi) (and do read(Xi))
return Xi as the value for X
```

$write(X)$:

```
Find Xi s.t. write_TS(Xi) is the
   highest write timestamp but <= T
if T < read_TS(Xi) then
   rollback and restart
else
   { create a new version X(k+1) of X;
     set read_TS(X(k+1)) to T;
     set write_TS(X(k+1)) to T}
```

- *Note:* Cascading rollback and cyclic restart problems can still occur, but should be reduced.

- However, there is an increased overhead in maintaining multiple versions of items.

Optimistic scheduling

- In two-phase locking, timestamp ordering, and multiversioning concurrency control techniques, a certain degree of checking is done **before** a database operation can be executed.

- The idea here is to push on and hope for the best!

- No checking is done while the transaction is executing.

- The protocol has three phases.
  - *read phase* - A transaction can read data items from the database into local variables. However, updates are applied only to local copies of the data items kept in the transaction workspace.
  - *validation phase* - checks are made to ensure that serializability is not violated,
  - *write phase* -if validation succeeds, updates are applied and the transaction is committed. Otherwise, the updates are discarded and the transaction is restarted.

- A scheme uses timestamps and keeps each transaction's
  - read-set - the set of items read by the transaction,
  - write-set - the set of items written by the transaction.

- During validation, we check that the transaction does not interfere with any transaction that is committed or currently validating.

- Each transaction T is assigned 3 timestamps:

  $Start(T)$, $Validation(T)$, $Finish(T)$.

- To pass the validation test for T, one of the following must be true:
  - 1. $Finish(S) < Start(T)$; or
  - 2. for S s.t. $Start(T) < Finish(S)$, then
    a) write set of S is disjoint from the read set of T, and
    b) $Finish(S) < Validation(T)$.

- Optimistic control is a good option if there is not much interaction between transactions.

- **Note:** Our earlier treatment of recovery methods largely ignored concurrency issues.

2PL vs. TSO vs. MV vs. OP

- A Comparison among two-phase locking (2PL), timestamp ordering (TSO), multiversioning (MV), optimistic (OP) concurrency control techniques.

- MV should provide the greatest concurrency degree (in average). However, we need to maintain multiversions for each data item.

- 2PL can offer the second greatest concurrency degree (in average); but will result in deadlocks. To resolve the deadlocks, either
  – need additional computation to detect deadlocks and to resolve the deadlocks, or
  – reduce the concurrency degree to prevent deadlocks by adding other restrictions.

2PL vs. TSO vs. MV vs. OP (cont.)

- If most transactions are very short, we can use 2PL + deadlock detection and resolution.

- TSO has a less concurrency degree than that of 2PL if a proper deadlock resolution is found. However, TSO does not cause deadlocks. Other problems, such as cyclic restart and cascading rollback, will appear in TSO.

- If there are not much interaction between transactions, OP is a very good choice. Otherwise, OP is a bad choice.