Transaction Management: Concurrency Control, part 2

CS634
Class 18, Apr 6, 2016

Slides based on "Database Management Systems" 3rd ed, Ramakrishnan and Gehrke

More Dynamic Databases

- If the set of DB objects changes, Strict 2PL using row or page locks will not ensure serializability (locking whole tables will work but is horribly slow)
- Example:
  - T1 finds oldest sailor for each of rating=1 and rating=2
  - T2 does an insertion and a deletion

1. T1 locks all pages with *rating* = 1, finds oldest sailor (*age* = 71)
2. Next, T2 inserts a new sailor; *rating* = 1, *age* = 96
3. T2 deletes oldest sailor with rating = 2 (*age* = 80), commits
4. T1 locks all pages with *rating* = 2, and finds oldest (*age* = 63)

- No serial schedule gives same outcome!

The "Phantom" 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!

- Two mechanisms to address the problem
  - Index locking
  - Predicate locking

Another phantom example

- Table tasks has one row for each worker task, with worker name, task name, number of hours
- Rule that no worker has more than 8 hours total
- Application A to add a task sums hours for worker, adds task if it fits under 8 hours max
  - T1 running A sees 'Joe' has 6 hours, adds task of 2 hours
  - Concurrently, T2 running A sees 'Joe' has 6 hours, adds task of 1 hour.
  - Joe ends up with 9 hours of work.
- Again, the problem is there is no lock on the *set* of rows being examined to make a decision

Index Locking

- Assume index on the *rating* field
- T1 should lock the index page(s) containing the data entries with *rating* = 1, and their immediate neighbors
  - If there are no records with *rating* = 1, T1 must lock the index page where such a data entry *would* be, if it existed!
  - e.g., lock the page with rating = 0 and beginning of rating=2
  - Or lock pages for just one extra data item on one side, if a lock is understood to cover the key value plus gap to one side.
- If there is no suitable index, T1 must lock all data pages, and lock the file to prevent new pages from being added

Index Locking

- Assume index on the *rating* field
- Row locking is the industry standard now
- T1 should lock all the data entries with *rating* = 1 and at least one neighbor (depending on details of protocol)
  - If there are no records with *rating* = 1, T1 must lock the entries adjacent to where data entry *would* be, if it existed!
  - e.g., lock the last entry with rating = 0 and beginning of rating=2
- If there is no suitable index, T1 must lock all the rows and lock the file to prevent new rows from being added, or use a "table lock".

Predicate Locking

- Grant lock on all records that satisfy some logical predicate
  - But note that a general predicate can depend on *data* in the row: salary > 50000 + 1000*years
  - Or a whole table: salary > (select avg(salary) in emps)
- Index locking is a special case of predicate locking
  - Index supports efficient implementation of the predicate lock
  - Predicate is specified in WHERE clause
- In general, predicate locking is expensive to implement!
  - Can avoid the runtime cost by using Repeatable Read isolation level, but that opens up anomaly possibilities.

Index Locking, Blow by blow

- Index locking happens in the storage engine, based on FILE calls coming from query processor as directed by the query plan
- Example: Transaction T1 accesses a heap table with certain index, gets row for certain index key value, say 100. Suppose the next data entry is for another key, 102.
  - Storage engine share-locks the accessed data entry for key 100, guarding it and the gap between that key and the next key.
  - Then if another transaction T2 tries to change the row with key 100, can't get necessary X lock, waits. Same with key 101.
  - Original transaction T1 can ask for next key, get 102.
  - But if another transaction updates row with key 102 (not guarded by T1's share lock), then then T1 has to wait for the next key.

Index Locking Scenario, cont.

- There is an underlying assumption in that story: that all the accesses in fact use the index on this column.
- Well, the important thing is that all accesses that change the column value go through the index. It's OK for another reader to access the value.
- An insert or delete need to change the index, so they are naturally involved.
- An update to this column also needs to change the index, in two places, so it also collides with the old lock.
- You can see this has to be checked out carefully!

Locking for B+ Trees

- Naïve solution
  - Ignore tree structure, just lock its pages following 2PL
- Very poor performance!
  - Root node (and many higher level nodes) become bottlenecks
  - Every tree access begins at the root!
- Not needed anyway!
  - Only row data needs 2PL (contents of tree)
  - Tree structure also needs protection from concurrent access
  - But only like other shared data of the server program
  - Note this modern view is not covered in book
  - See Graefe, A Survey of B-tree locking techniques (2010)
  - B-tree locking is a huge challenge!

Locking vs. Latching

- To protect shared data in memory, multithreaded programs use mutex (semaphores)
  - API: enter_section/leave_section, or lock/unlock
  - Every Java object contains a mutex, for convenience of Java programming: underlies synchronized methods
  - Database people call mutexes and related mechanisms "latches"
  - Need background in multi-threaded programming to understand this topic fully
- The tree *structure* needs mutex/latch protection
- Example: split node. No row data is changed, just the details in pages in the buffer pool. No i/o is needed (can't hold a latch across disk i/o without ruining performance.)
- Latches can be provided by the same lock manager as does 2PL locking, and can have share and exclusive types like locks.
- In these slides, will use "lock" in quotes to mean non-2PL lock/latch…

Locking for B+ Trees (contd.)

- **Searches**
  - Higher levels only direct searches for leaf pages
- **Insertions**
  - Node on a path from root to modified leaf must be “locked” in X mode only if a split can propagate up to it
  - Similar point holds for deletions

- There are efficient locking protocols that keep the B-tree healthy under concurrent access, and support 2PL on rows

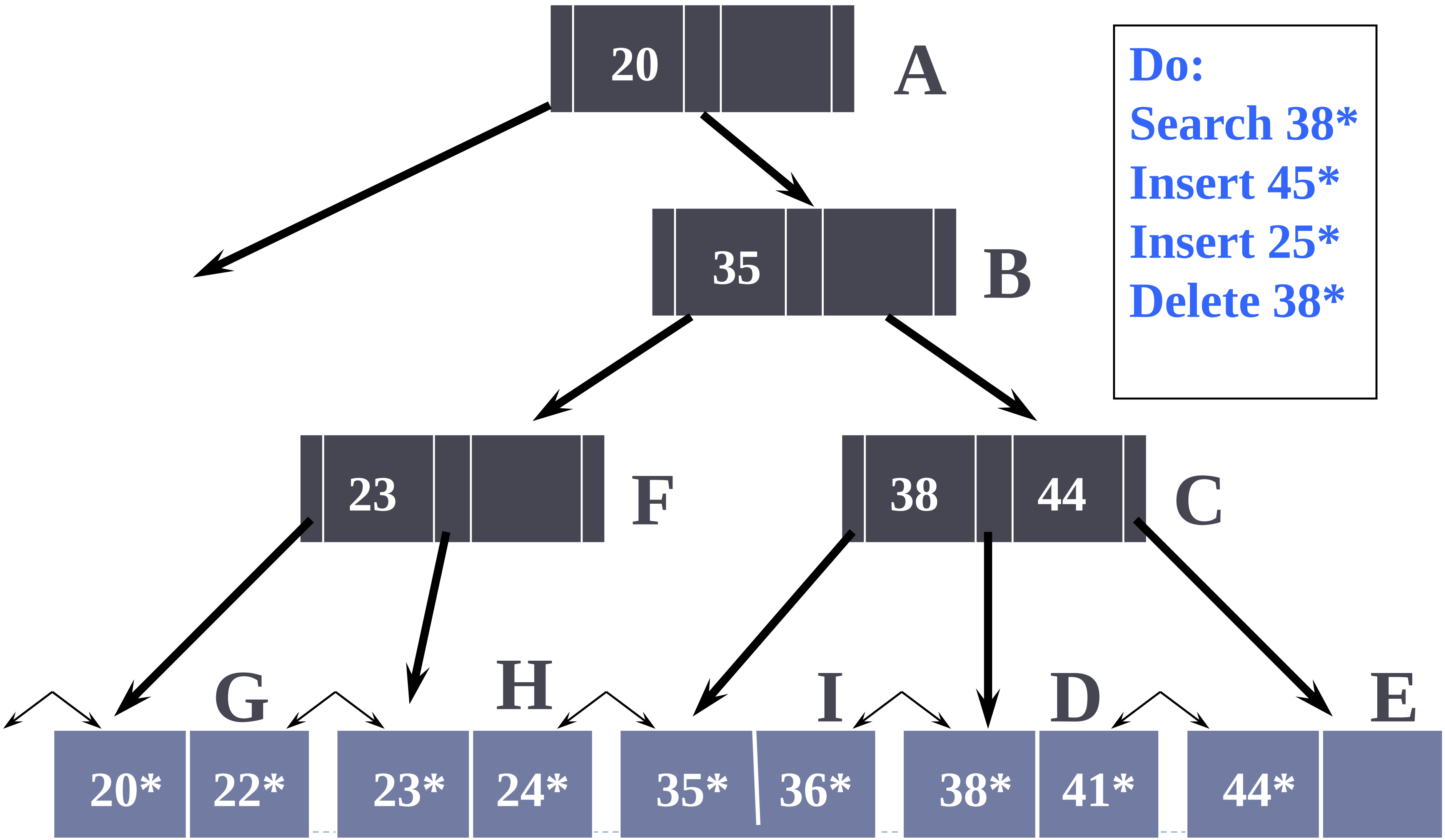
A Simple Tree Locking Algorithm:
(“lock” here is really a latch on tree structure)

- **Search**
  - Start at root and descend: “crabbing down the tree”
  - repeatedly, get S “lock” for child then “unlock” parent, end up with S “lock” on leaf page
  - Get 2PL S lock on row, provide row pointer to caller
  - Later, caller is done with reading row, arranges release of S “lock”
- **Insert/Delete**
  - Start at root and descend, crabbing, obtaining X “locks” as needed
  - Once child is “locked”, check if it is **safe**
  - If child is safe, release “lock” on parent, leaving X “lock” on child
  - Get 2PL X lock on place for new row/old row, insert/delete row, release “lock”
- **Safe node**: not about to split or coalesce
  - Inserts: Node is not full
  - Deletes: Node is not half-empty
- When control gets back to QP, transaction only has 2PL locks on rows

Difference from text

- The algorithm actions described in the text are valid, for example, crabbing down the tree, worrying about full nodes, etc.
- What's different is that the locks for index nodes are shorter lived than described in the text: only 2PL locks on rows are kept until end of transaction, not any locks on index nodes.
- Note that text uses locks and releases them before commit, a sign that they are not actually Strict 2PL locks.
- Note the admission on pg. 564 that the text's coverage on this topic is "not state of the art". Graefe's paper is.

An Example



Do:
Search 38*
Insert 45*
Insert 25*
Delete 38*

Insert 45 case

Crab down tree getting X “locks” (really latches)
“Xlock” A
“Xlock” B
B is safe, so “unXlock” A
“Xlock” C
C is unsafe, so can’t “unXlock” B now
“Xlock” E (page of rows)
E is safe, so “unXlock” C
Xlock row (2PL lock) for 45, copy out row or pin buffer, provide row pointer to caller
“UnXLock” E
Return to QP with 2PL X lock on row with key 45 (or index entry and row)

A Variation on Algorithms

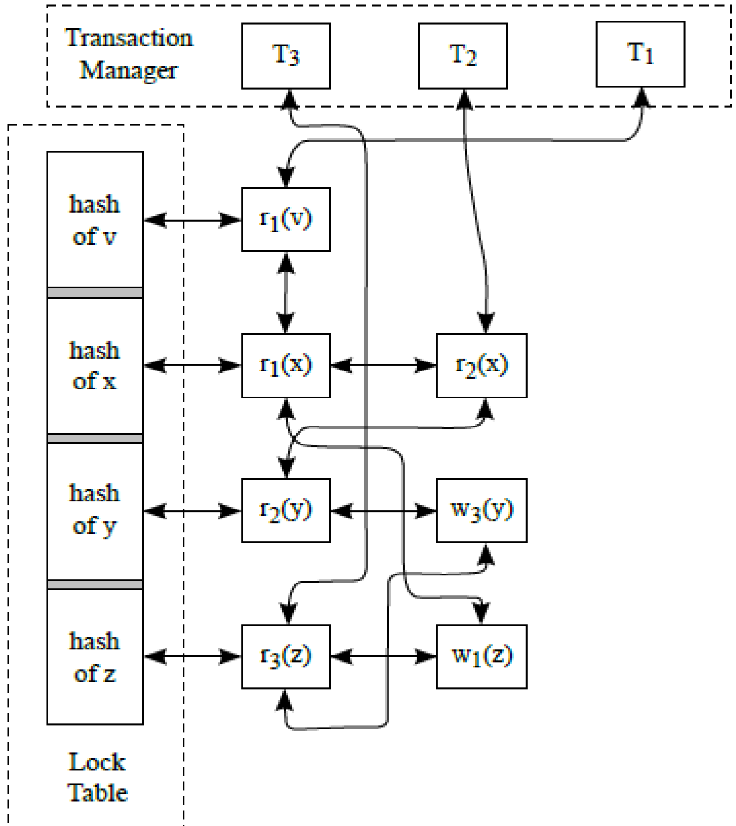
- **Search**
  - As before
- **Insert/Delete**
  - Set "locks" as if for search, get to leaf, and set 2PL X lock on leaf
  - If leaf is not safe, release all "locks", and restart using previous Insert/Delete protocol

- This is what happens if the search down the tree happens on a page that is not in buffer—don't want to hold a latch across a disk i/o (takes too long)

Lock Management

- Lock and unlock requests are handled by the lock manager (see Sec. 17.2.1)
- Lock table entry:
  - Lock name/identifier
  - Number of transactions currently holding a lock
  - Type of lock held (shared or exclusive)
  - Pointer to queue of lock requests
- Locking and unlocking have to be atomic operations (need mutex protection)
- Lock table entries are kept in order, to prevent starvation (lots of reads preventing a writer from ever getting a lock, etc.)

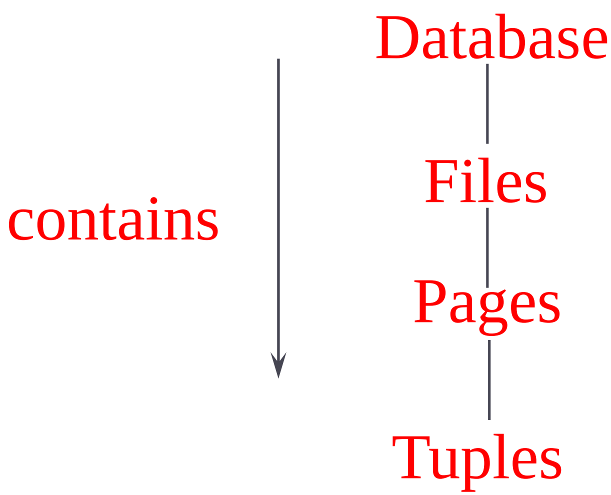
Lock Manager Data structure: a multilist



- Need access to lock entry by lock name or transaction id
- Some of these transactions are blocked on the lock

Multiple-Granularity Locks

- Hard to decide what granularity to lock
  - tuples vs. pages vs. files
  - Inefficient to have a million row locks to scan a relation
- Shouldn't have to decide once and for all!
- Data containers are nested:



New Lock Modes, Protocol

- Allow transactions to lock at each level, but with a special protocol using new **intention locks**

- Before locking an item, must set intention locks on ancestors
- To lock an item with an S lock (X lock), need an IS (IX) lock or stronger on 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	√				

New Lock Modes, Protocol

- Lock manager doesn't care: just make up lock names with table name or item id, use new lock compatibility table
- Protocol makes client check higher level(s) first, then target level, so lock manager itself (or its kernel part) has no responsibility to know relationship between locks

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