Transaction Management: Concurrency Control, part 2

CS634
Class 16

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

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) AKA latches, sometimes "locks" (confusing!)
  - 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 to make it look somewhat like the book's discussion…

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

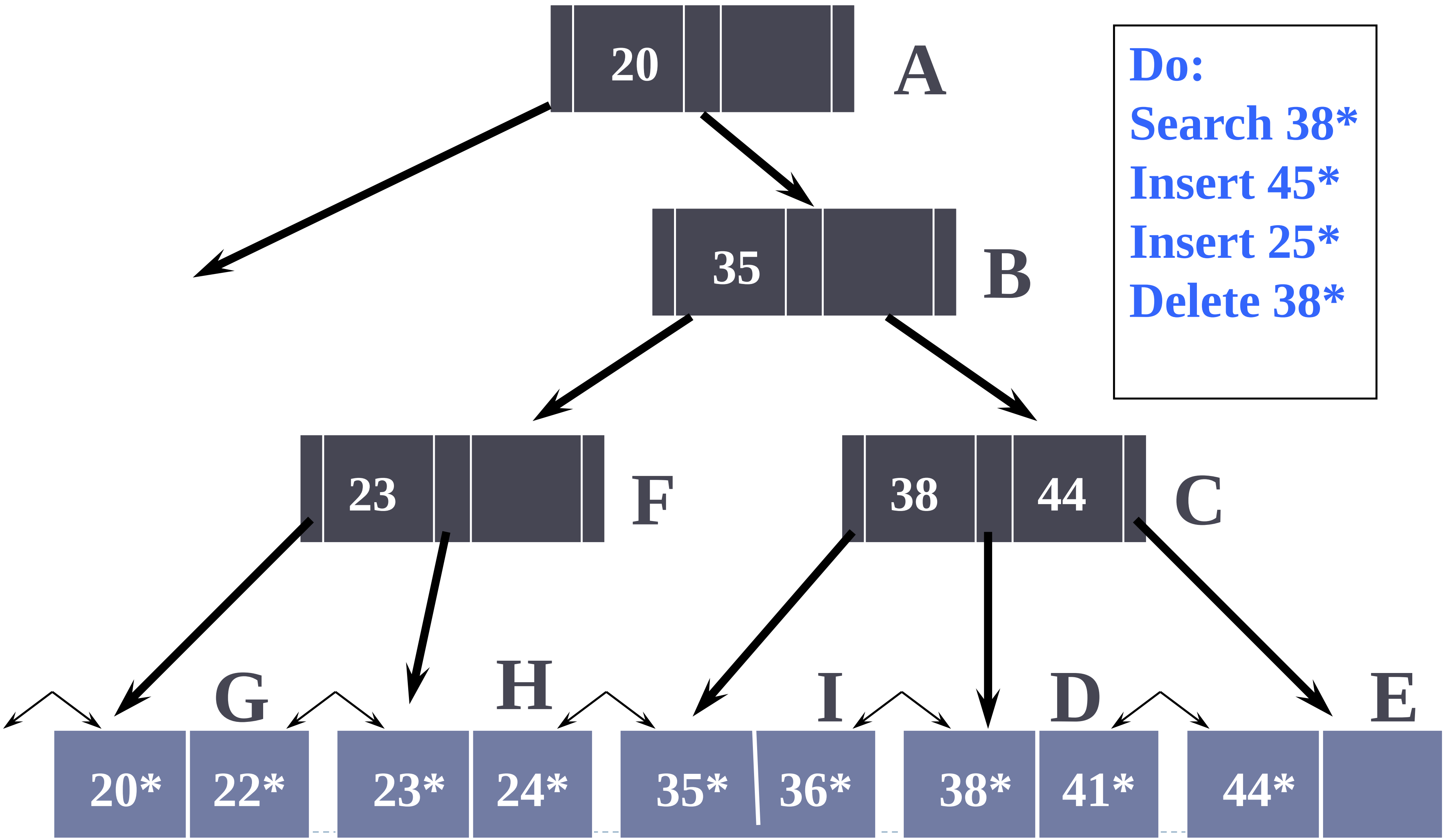
A Simple Tree Locking Algorithm:
(“lock” here is really a latch on tree structure)

- **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. Only 2PL locks are long-term across multiple DB actions.

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 from pg. 563



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

Insert 45 case (corrected 4/12)

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 (its page of rows is in buffer,)
E is safe, so “unXlock” C, and B too
Xlock E (real 2PL page lock)
“UnXLock” E
Return to QP with 2PL Xlock on page, and pointer to it in pinned buffer.
QP will unpin when done with edits to page

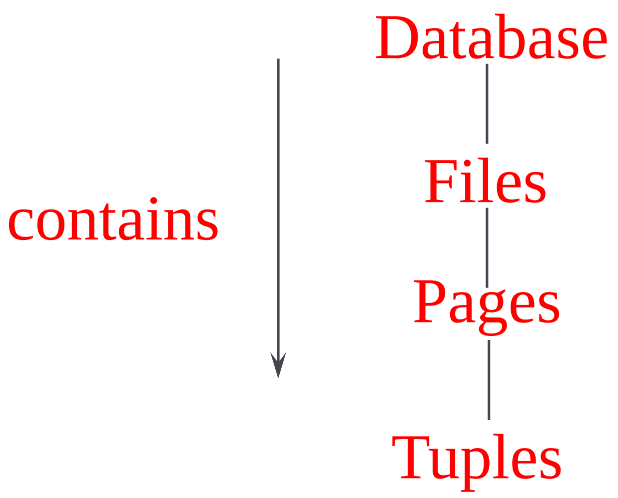
A Variation on Algorithms

- **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)

Multiple-Granularity Locks

- Hard to decide what granularity to lock
  - tuples vs. pages vs. files
- Shouldn't have to decide!
- 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
- 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 transaction starts from the root of the hierarchy
- To get S or IS lock on a node, must hold IS or IX on parent node
- 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

Snapshot Isolation (SI)

- Multiversion Concurrency Control Mechanism (MVCC)
- This means the database holds more than one value for a data item at the same time

- Used in PostgreSQL (open source), Oracle, others

- Readers never conflict with writers unlike traditional DBMS (e.g., IBM DB2)! Read-only transactions run fast.

- Does not guarantee "real" serializability

- But: ANSI "serializability" fulfilled, i.e., avoids anomalies in the ANSI table
- Found in use at Microsoft in 1993, published as example of MVCC

Snapshot Isolation - Basic Idea:

- Every transaction reads from its own snapshot (copy) of the database (will be created when the transaction starts, or reconstructed from the undo log).
- Writes are collected into a writeset (WS), not visible to concurrent transactions.
- Two transactions are considered to be concurrent if one starts (takes a snapshot) while the other is in progress.

First Committer Wins Rule of SI

- At the commit time of a transaction its WS is compared to those of concurrent committed transactions.
- If there is no conflict (overlapping), then the WS can be applied to stable storage and is visible to transactions that begin afterwards.
- However, if there is a conflict with the WS of a concurrent, already committed transaction, then the transaction must be aborted.
- That's the "First Committer Wins Rule"
- Actually Oracle uses first updater wins, basically same idea, but doesn't require separate WS

Write Skew Anomaly of SI

- In MVCC, data items need subscripts to say which version is being considered
  - Zero version: original database value
  - T1 writes new value of X, X_1
  - T2 writes new value of Y, Y_2
- Write skew anomaly schedule:

$R_1(X_0)\ R_2(X_0)\ R_1(Y_0)\ R_2(Y_0,)\ W_1(X_1)\ C_1\ W_2(Y_2)\ C_2$

- Writesets WS(T1) = {X}, WS(T2) = {Y}, do not overlap, so both commit.
- So what's wrong—where's the anomaly?

Write Skew Anomaly of SI

$R_1(X_0)$ $R_2(X_0)$ $R_1(Y_0)$ $R_2(Y_0,)$ $W_1(X_1)$ C_1 $W_2(Y_2)$ C_2

- Scenario:
  - X = husband's balance, orig 100,
  - Y = wife's balance, orig 100.
  - Bank allows withdrawals up to combined balance
  - Rule: X + Y >= 0
  - Both withdraw 150, thinking OK, end up with -50 and -50.
- Easy to make this happen in Oracle at "Serializable" isolation.
- See conflicts, cycle in PG, can't happen with full 2PL
- Can happen with RC/locking

How can an Oracle app handle this?

- If X+Y >= 0 is needed as a constraint, it can be "materialized" as sum in another column value.
- Old program: R(X)R(X-spouse)W(X)C
- New program: R(X)R(X-spouse) W(sum) W(X)C
- So schedule will have W(sum) in both transactions, and sum will be in both Writesets, so second committer aborts.
- Or, after the W(X), run a query for the sum and abort if it's negative.

Oracle, Postgres: new failure to handle

- Recall deadlock-abort handling: retry the aborted transaction
- With SI, get "can't serialize access“
  - ORA-08177: can't serialize access for this transaction
  - Means another transaction won for a contended write
- App handles this error like deadlock-abort: just retry transaction, up to a few times
- This only happens when you set serializable isolation level

Other anomalies under SI

- Oldest sailors example
  - Both concurrent transactions see original sailor data in snapshots, plus own updates
  - Updates are on different rows, so both commit
  - Neither sees the other's update
  - So not serializable: one should see one update, other should see two updates.
- Task Registry example:
  - Both concurrent transactions see original state with 6 hours available for Joe
  - Both insert new task for Joe
  - Inserts involve different rows, so both commit

Fixing the task registry

- Following the idea of the simple write skew, we can materialize the constraint "workhours <= 8"
- Add a workhours column to worker table
- Old program:
- if sum(hours-for-x)+newhours<=8
- insert new task
- New program:
- if workhours-for-x + newhours <=8
- { update worker set workhours = workhours + newhours…
- insert new task
- }

Fixing the Oldest sailor example

- If the oldest sailor is important to the app, materialize it!

Create table oldestsailor (rating int primary key, sid int)

Oracle Read Committed Isolation

- READ COMMITTED is the default isolation level for both Oracle and PostgreSQL.
- A new snapshot is taken for every issued SQL statement (every statement sees the latest committed values).
- If a transaction T2 running in READ COMMITTED mode tries to update a row which was already updated by a concurrent transaction T1, then T2 gets blocked until T1 has either committed or aborted
- Nearly same as 2PL/RC, though all reads occur effectively at the same time for the statement.

Transaction Management: Crash Recovery

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ACID Properties

Transaction Management must fulfill four requirements:

1. Atomicity: either all actions within a transaction are carried out, or none is
   - Only actions of committed transactions must be visible
2. Consistency: concurrent execution must leave DBMS in consistent state
3. Isolation: each transaction is protected from effects of other concurrent transactions
   - Net effect is that of **some sequential execution**
4. Durability: once a transaction commits, DBMS changes will persist
   - Conversely, if a transaction aborts/is aborted, there are no effects

Recovery Manager

- Crash recovery
  - Ensure that atomicity is preserved if the system crashes while one or more transactions are still incomplete
  - Main idea is to keep a log of operations; every action is logged before its page updates reach disk (Write-Ahead Log or WAL)

- The **Recovery Manager** guarantees Atomicity & Durability

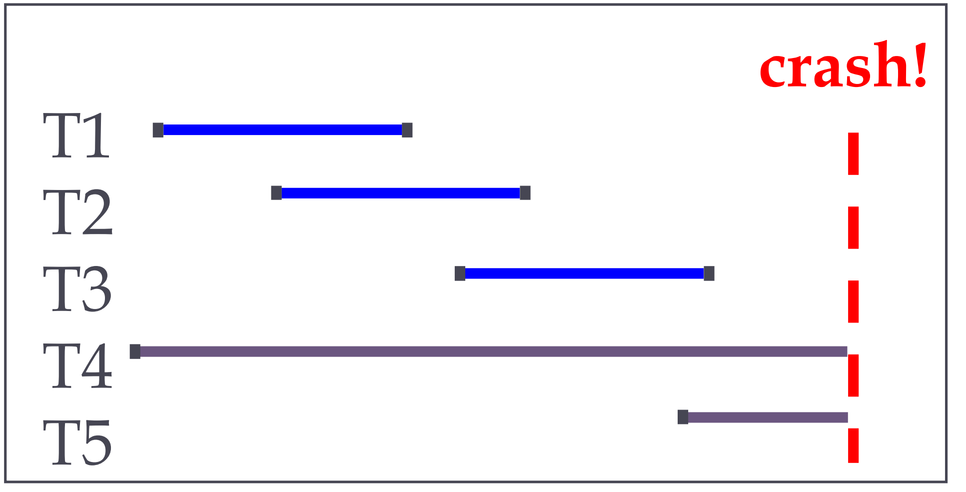
Motivation

- Atomicity:
  - Transactions may abort – must rollback their actions
- Durability:
  - What if DBMS stops running – e.g., power failure?

Desired Behavior after system restarts:

– T1, T2 & T3 should be durable

– T4 & T5 should be aborted (effects not seen)



Assumptions

- Concurrency control is in effect
  - Strict 2PL
- Updates are happening "in place"
  - Data overwritten on (deleted from) the disk
- A simple scheme is needed
  - A protocol that is too complex is difficult to implement
  - Performance is also an important issue