Database Applications (15-415)

DBMS Internals- Part XII
Lecture 20, April 9, 2014

Mohammad Hammoud

جامعة كارنيجي ميلون في قطر
Carnegie Mellon University Qatar

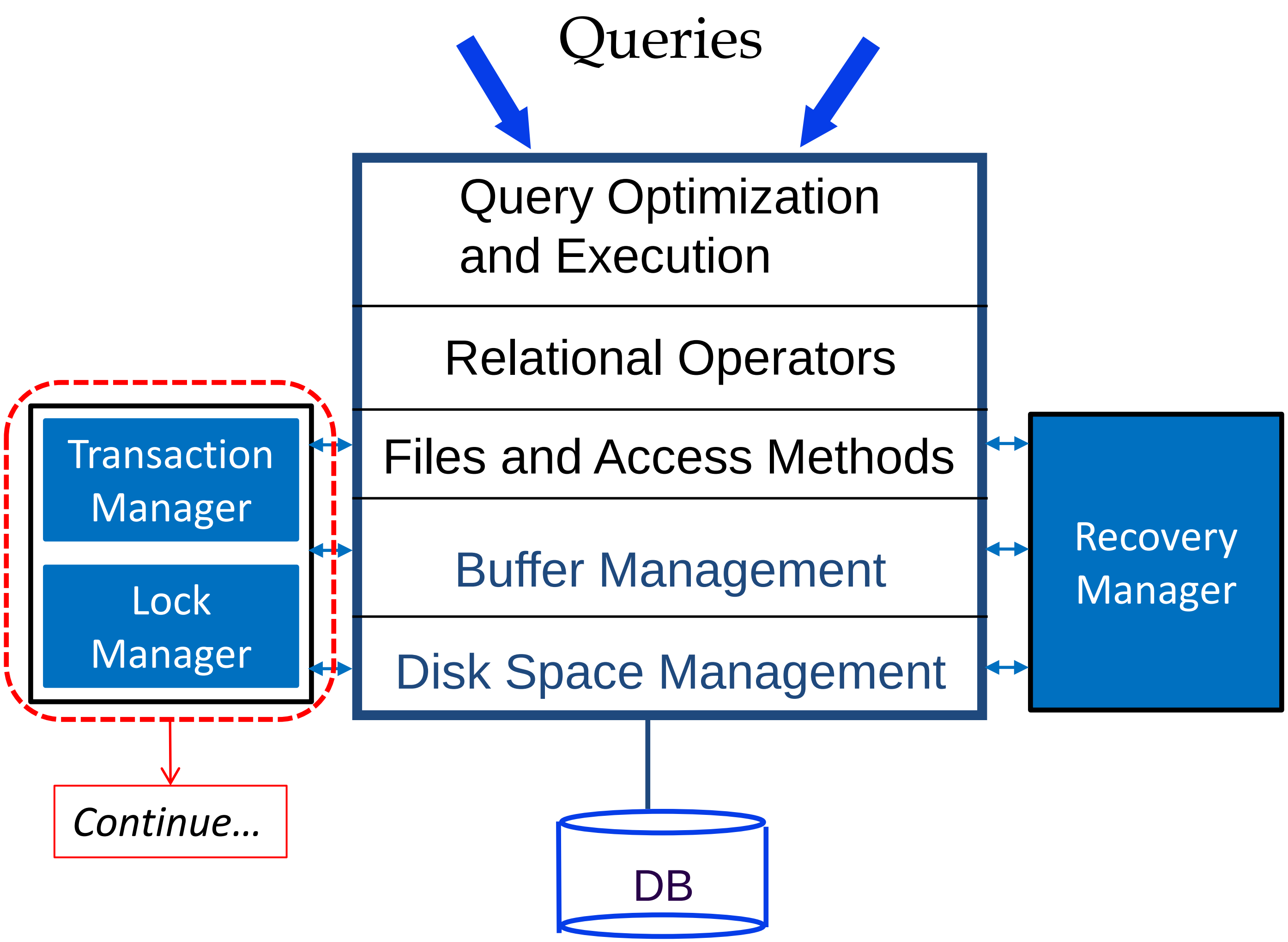
Today…

- Last Two Sessions:
  - DBMS Internals- Part XI
    - Transaction Management
  - Student Presentations of P3

- Today's Session:
  - Transaction Management (*Cont'd*)

- Announcement:
  - PS4 is due on Tuesday, April 15th

DBMS Layers


Queries
Query Optimization and Execution
Relational Operators
Files and Access Methods
Buffer Management
Disk Space Management
Transaction Manager
Lock Manager
Recovery Manager
Continue…
DB

Outline

- Lock Conversions ✓
- Dealing with Deadlocks
- Dynamic Databases and the Phantom Problem
- Concurrency Control in B+ Trees

Lock Conversions

- A transaction may need to change the lock it already acquires on an object
  - From Shared to Exclusive
    - This is referred to as *lock upgrade*
  - From Exclusive to Shared
    - This is referred to as *lock downgrade*

- For example, an SQL update statement might acquire a Shared lock <u>*on each row*</u>, ***R***, in a table and if ***R*** satisfies the condition (in the WHERE clause), an Exclusive lock must be obtained for ***R***

Lock Upgrades

- A lock upgrade request from a transaction ***T*** on object ***O*** must be handled specially by:
  - Granting an Exclusive lock to ***T*** immediately *if no other transaction holds a Shared lock on* **O**
  - Otherwise, queuing ***T*** at the *front* of ***O***'s queue (i.e., ***T** is favored*)

- ***T*** is *favored* because it already holds a Shared lock on ***O***
  - Queuing ***T*** *in front of* another transaction ***T'*** that holds no lock on ***O***, but requested an Exclusive lock on ***O*** averts a deadlock!
  - However, if ***T*** and ***T'*** hold a Shared lock on ***O***, and both request upgrades to an Exclusive lock, a deadlock will arise regardless!

Lock Downgrades

- Lock upgrades can be entirely avoided by obtaining Exclusive locks *initially*, and downgrade them to Shared locks once needed

- Would this violate any 2PL requirement?
  - On the surface yes; since the transaction (say, ***T***) may need to upgrade later
  - This is, however, a special case as ***T*** *conservatively* obtained an Exclusive lock, and did nothing but read the object that it downgraded
  - 2PL can be safely extended to allow lock downgrades in the growing phase, *provided that the transaction has not modified the object*
  - This might reduce concurrency (due to obtaining some unnecessary Exclusive locks) but improve throughput (due to reducing deadlocks)!

Outline

- Lock Conversions
- Dealing with Deadlocks ✓
- Dynamic Databases and the Phantom Problem
- Concurrency Control in B+ Trees

Deadlock Detection

- The lock manager maintains a structure called a *waits-for graph* to *periodically* detect deadlocks

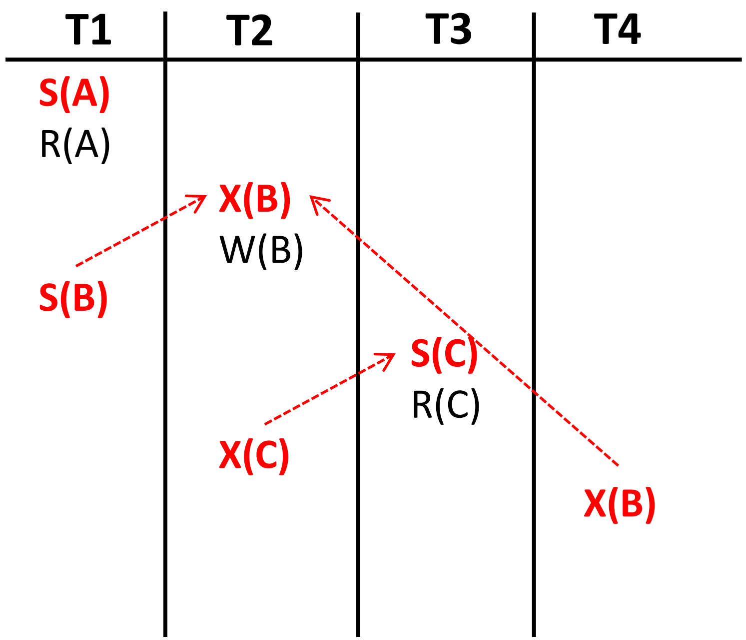
- In a waits-for graph:
  - The nodes correspond to active transactions
  - There is an edge from Ti to Tj *if and only if* Ti is waiting for Tj to release a lock

- The lock manager *adds* and *removes* edges to and from a waits-for graph when it *queues* and *grants* lock requests, respectively

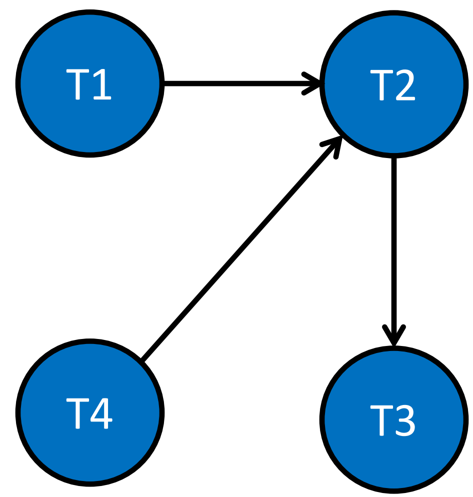
- A deadlock is detected when a *cycle* in the waits-for graph is found

Deadlock Detection (*Cont'd*)

- The following schedule is free of deadlocks:



A schedule *without* a deadlock



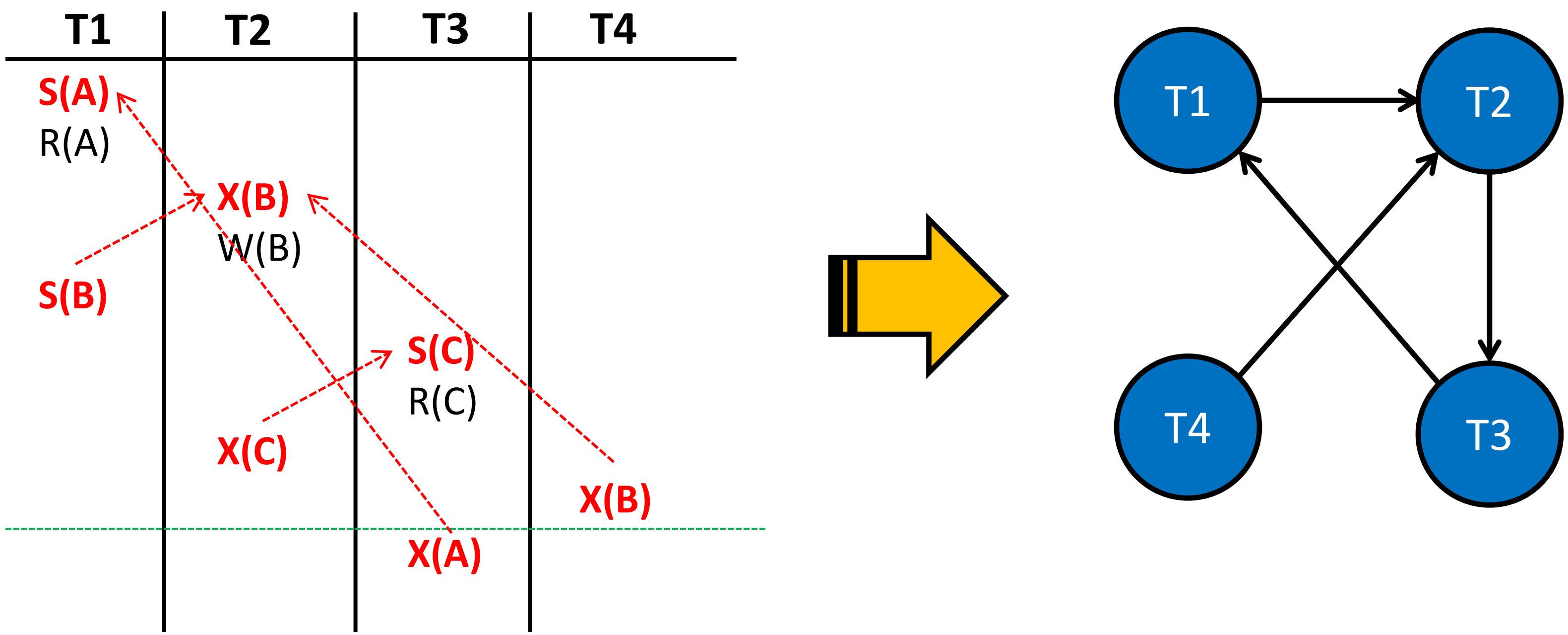
No cycles; hence, no deadlocks!

The Corresponding **Waits-For Graph***

*The nodes correspond to active transactions and there is an edge from Ti to Tj *if and only if* Ti is waiting for Tj to release a lock

Deadlock Detection (*Cont'd*)

- The following schedule is **NOT** free of deadlocks:



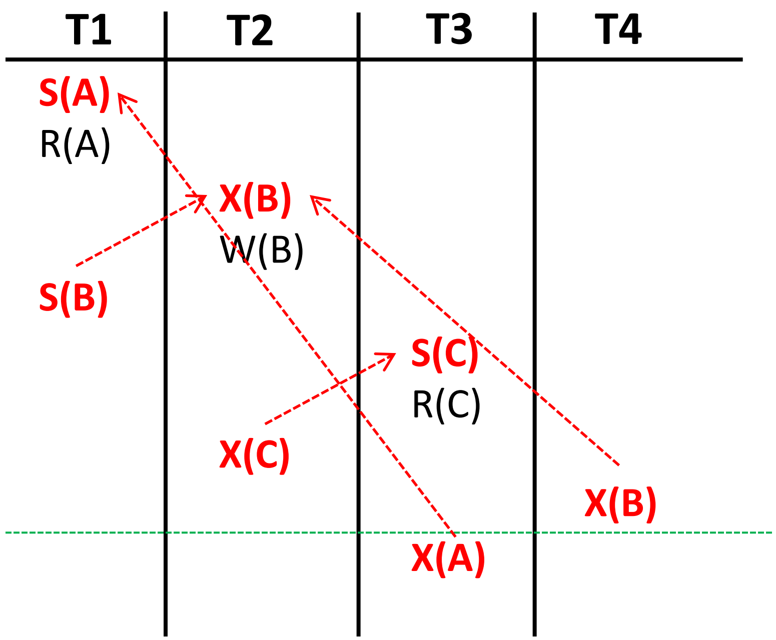
A schedule *with* a deadlock

The Corresponding **Waits-For Graph***

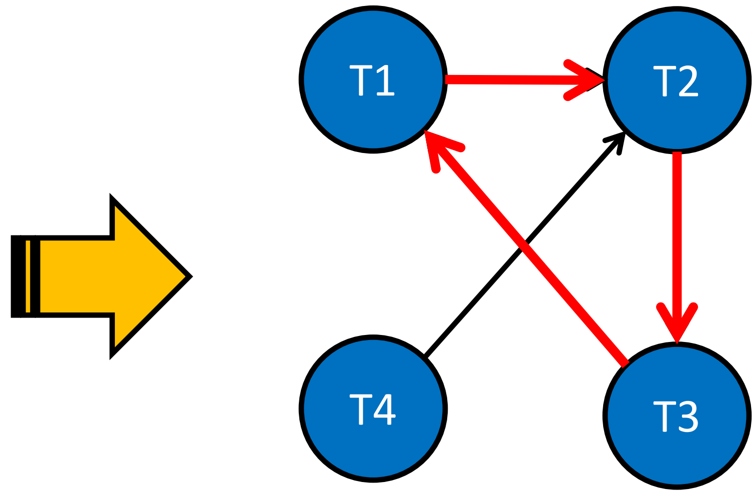
*The nodes correspond to active transactions and there is an edge from Ti to Tj *if and only if* Ti is waiting for Tj to release a lock

Deadlock Detection (*Cont'd*)

- The following schedule is **NOT** free of deadlocks:



A schedule *with* a deadlock



Cycle detected; hence, a deadlock!

The Corresponding **Waits-For Graph***

*The nodes correspond to active transactions and there is an edge from Ti to Tj *if and only if* Ti is waiting for Tj to release a lock

Resolving Deadlocks

- A deadlock is resolved by aborting a transaction that is on a cycle and releasing its locks
  - This allows some of the waiting transactions to proceed

- The choice of which transaction to abort can be made using different criteria:
  - The one with the fewest locks
  - Or the one that has done the least work
  - Or the one that is farthest from completion (*more accurate*)

- Caveat: a transaction that was aborted in the past, should be *favored* subsequently and not aborted upon a deadlock detection!

Deadlock Prevention

- Studies indicate that deadlocks are relatively infrequent and *detection-based schemes* work well in practice

- However, if there is a high level of *contention* for locks, *prevention-based schemes* could perform better

- Deadlocks can be averted by giving each transaction a *priority* and ensuring that lower-priority transactions are not allowed to wait for higher-priority ones
(or vice versa)

Deadlock Prevention (*Cont'd*)

- One way to assign priorities is to give each transaction a *timestamp* when it is started
  - Thus, the lower the timestamp, the higher is the transaction's priority

- If a transaction ***Ti*** requests a lock and a transaction ***Tj*** holds a conflicting lock, the lock manager can use one of the following policies:
  - Wound-Wait: If ***Ti*** has higher priority, ***Tj*** is aborted; otherwise, ***Ti*** waits
  - Wait-Die: If ***Ti*** has higher priority, it is allowed to wait; otherwise, it is aborted

Reissuing Timestamps

- A subtle point is that we must ensure that no transaction is perennially aborted because it never had a sufficiently high priority

- To avoid that, when a transaction is aborted and restarted, it should be given the same timestamp it had originally
  - This policy is referred to as reissuing timestamps

- Reissuing timestamps ensures that each transaction will eventually become the oldest and accordingly get all the locks it requires!

Outline

- Lock Conversions
- Dealing with Deadlocks
- Dynamic Databases and the Phantom Problem ✓
- Concurrency Control in B+ Trees

Dynamic Databases

- Thus far, we have assumed *static databases* in a sense that they do not *grow* and *shrink*

- We now relax that condition and assume *dynamic databases* (i.e., databases that grow and shrink)

- To study locking protocols for dynamic databases, we consider the following:
  - A Sailors relation S
  - A transaction ***T1*** which scans S to find the oldest Sailor for each of the rating levels 1 and 2
  - A transaction ***T2*** which inserts a new Sailor with rating 1 and age 96

A Possible Scenario

- Assume a scenario whereby the actions of ***T1*** and ***T2*** are interleaved as follows:
  - ***T1*** identifies all *pages* containing Sailors with rating 1 (say, pages ***A*** and ***B***)
  - ***T1*** finds the age of the oldest Sailor with rating 1 (say, 71)
  - ***T2*** inserts a new Sailor with rating 1 and age 96 (perhaps into page ***C*** which does not contain any Sailor with rating 1)
  - ***T2*** locates the page containing the oldest Sailor with rating 2 (say, page ***D***) and deletes this Sailor (whose age is, say, 80)
  - ***T2*** commits
  - ***T1*** identifies all pages containing Sailors with rating 2 (say pages ***D*** and ***E***), and finds the age of the oldest such Sailor (which is, say, 63)
  - ***T1*** commits

A Possible Scenario (*Cont'd*)

- We can apply strict 2PL to the given interleaved actions of ***T1*** and ***T2*** as follows (**S** = Shared; **X** = Exclusive):

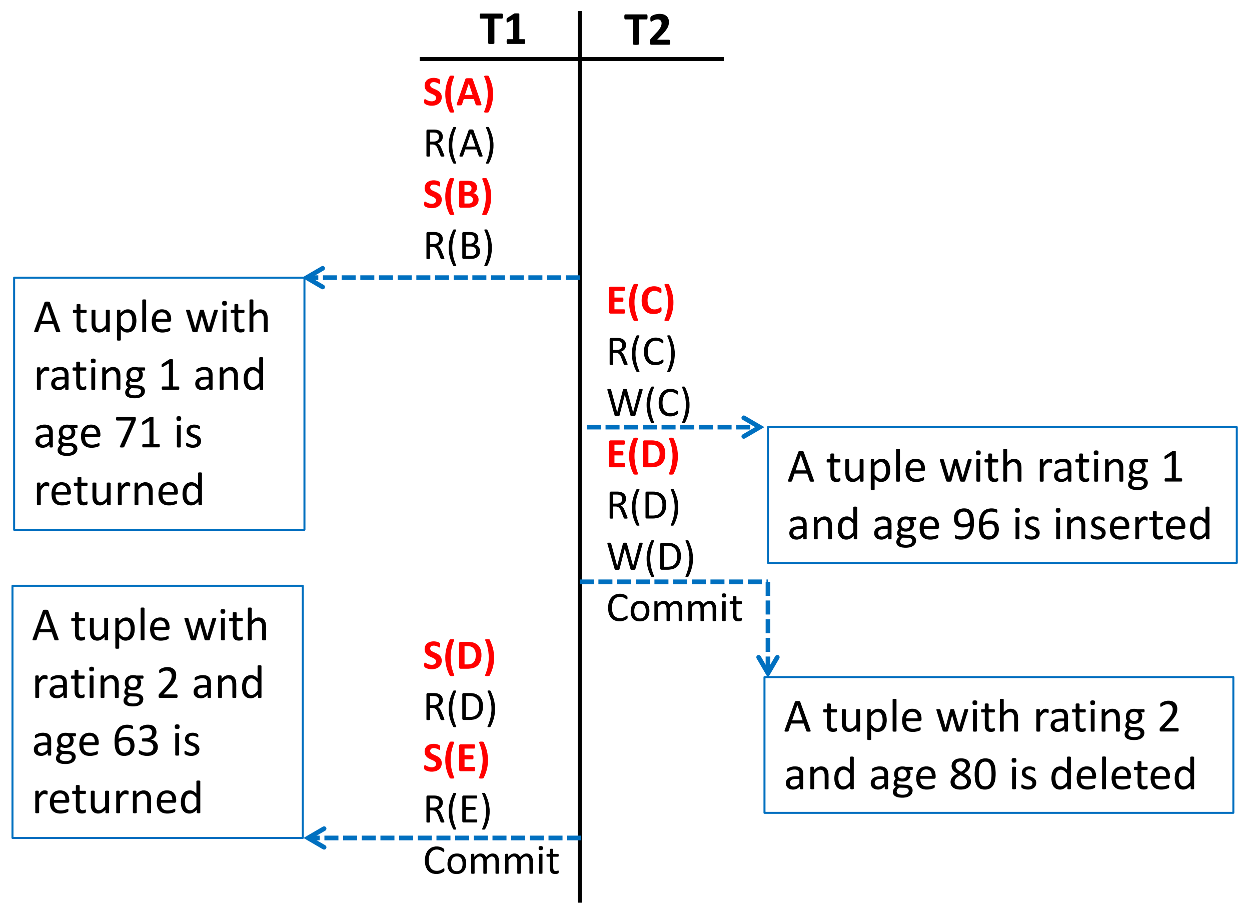
T1	T2
R(A)	
R(B)	
	R(C)
	W(C)
	R(D)
	W(D)
	Commit
R(D)	
R(E)	
Commit	

T1	T2
S(A)	
R(A)	
S(B)	
R(B)	
	E(C)
	R(C)
	W(C)
	E(D)
	R(D)
	W(D)
	Commit
S(D)	
R(D)	
S(E)	
R(E)	
Commit	

A Possible Scenario (*Cont'd*)

- We can apply strict 2PL to the given interleaved actions of ***T1*** and ***T2*** as follows (**S** = Shared; **X** = Exclusive):

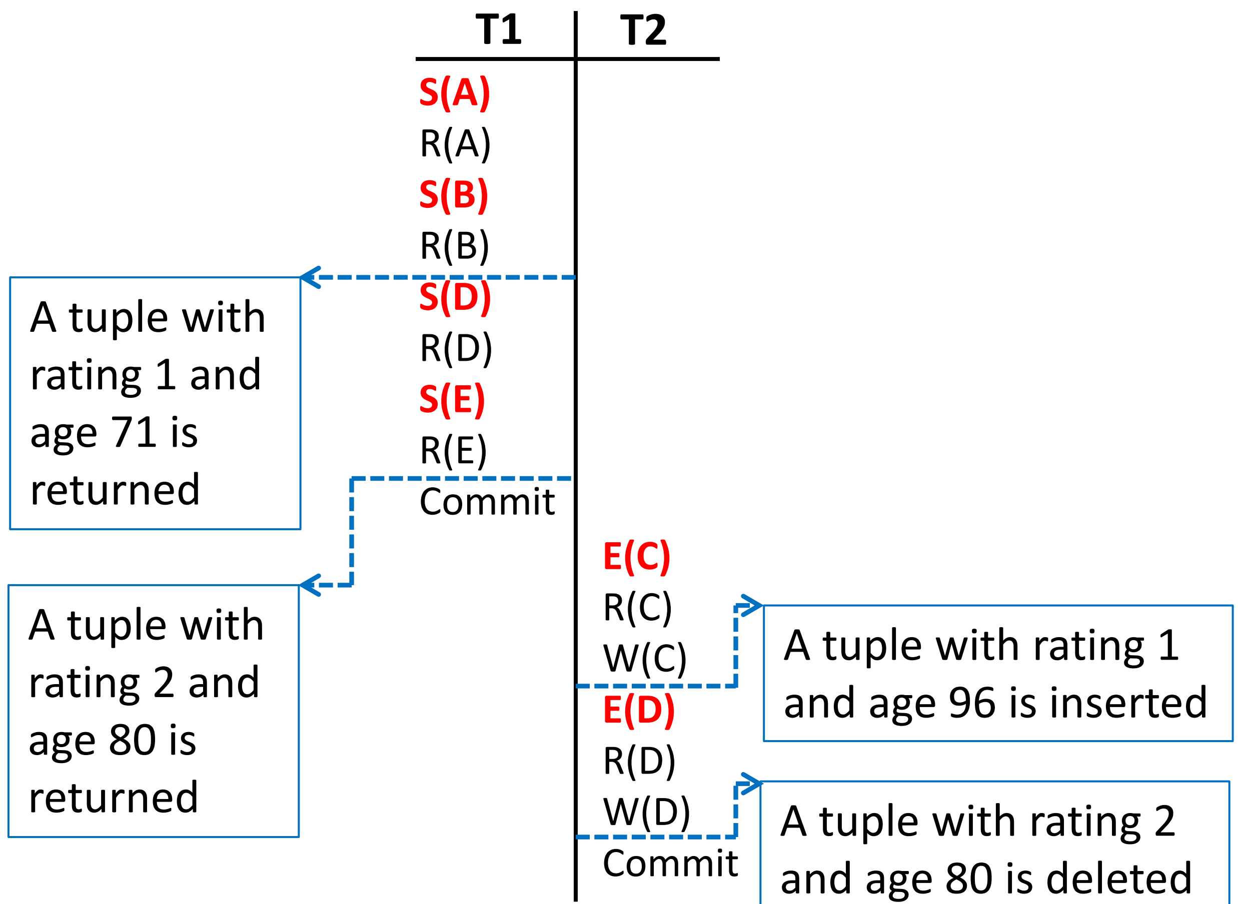
T1	T2
R(A)	
R(B)	
	R(C)
	W(C)
	R(D)
	W(D)
	Commit
R(D)	
R(E)	
Commit	



A Possible Scenario (*Cont'd*)

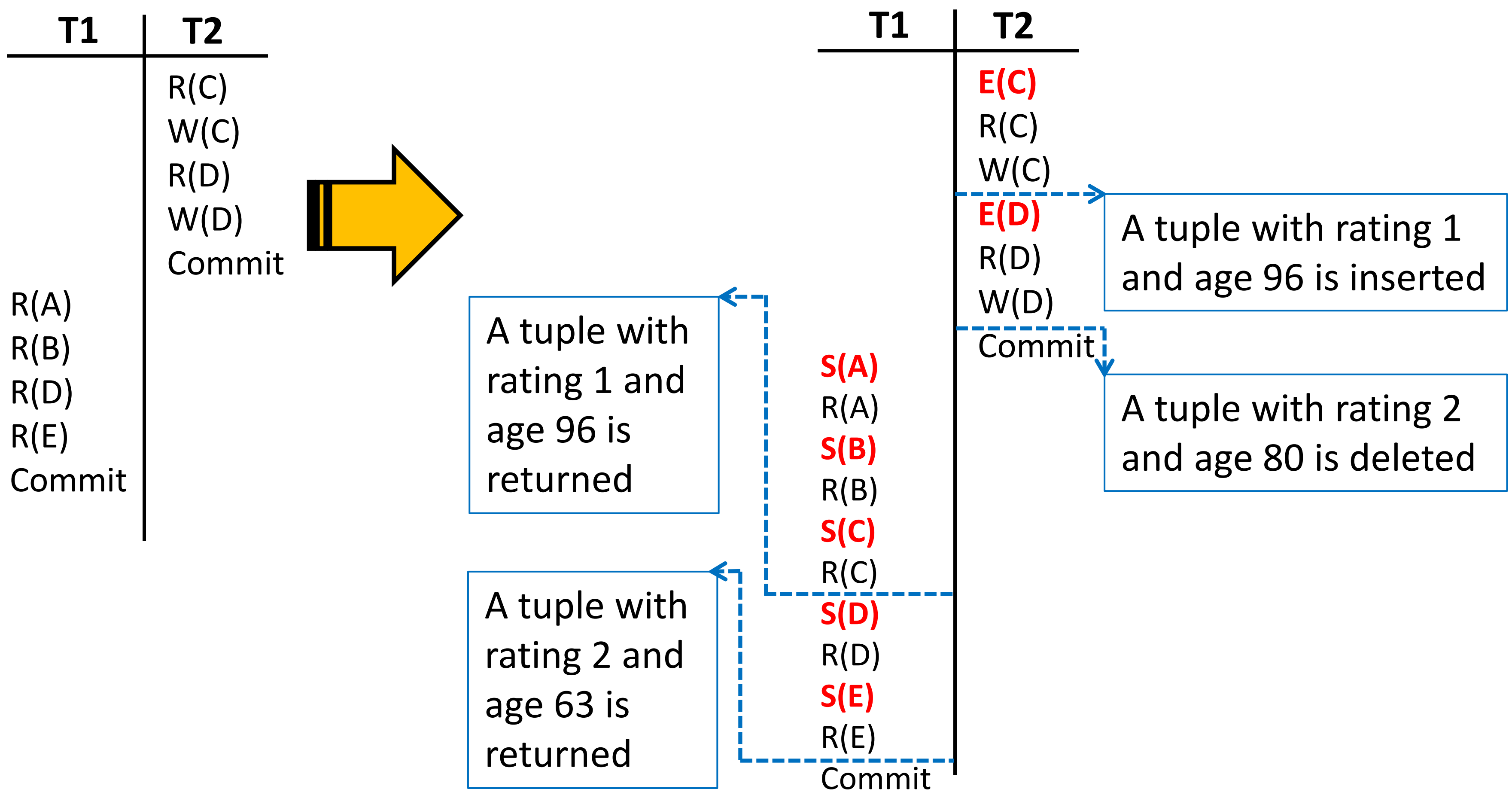
- One possible <u>serial execution</u> of ***T1*** and ***T2*** is as follows (**S** = Shared; **X** = Exclusive):

T1	T2
R(A)	
R(B)	
R(D)	
R(E)	
Commit	
	R(C)
	W(C)
	R(D)
	W(D)
	Commit



A Possible Scenario (*Cont’d*)

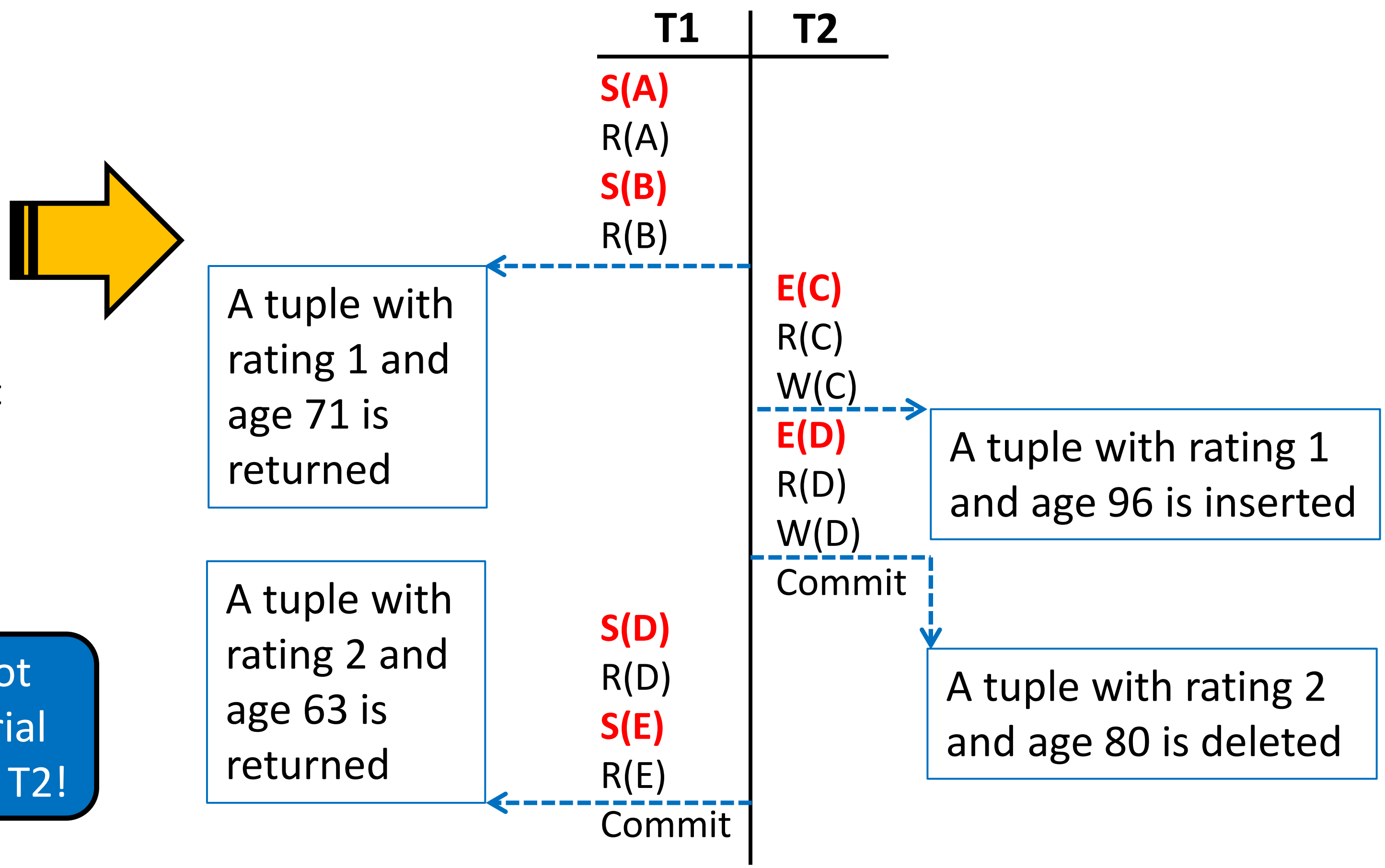
- Another possible serial execution of T1 and T2 is as follows (**S** = Shared; **X** = Exclusive):



A Possible Scenario: *Revisit*

- We can apply strict 2PL to the given interleaved actions of ***T1*** and ***T2*** as follows (**S** = Shared; **X** = Exclusive):

T1	T2
R(A)	
R(B)	
	R(C)
	W(C)
	R(D)
	W(D)
	Commit
R(D)	
R(E)	
Commit	



This schedule is not identical to any serial execution of T1 and T2!

The Phantom Problem

- The problem is that ***T1*** assumes that it has locked “all” the pages which contain Sailors records with rating 1

- This assumption is violated when ***T2*** inserts a new Sailor record with rating 1 on a *different* page

- Hence, locking pages at any given time does not prevent new *phantom* records from being added on other pages!
  - This is commonly known as the *“Phantom Problem”*

- The Phantom Problem is caused, not because of a flaw in the Strict 2PL protocol, but because of ***T1***’s unrealistic assumptions

How Can We Solve the Phantom Problem?

- If there is *no index* on rating and all pages in Sailors must be scanned, ***T1*** should somehow ensure that no *new* pages are inserted to the Sailors relation
  - This has to do with the *locking granularity*

- If there is an *index* on rating, ***T1*** can lock the index entries and the data pages which involve the targeted ratings, and accordingly prevent new insertions
  - This technique is known as *index locking*

Outline

- Lock Conversions
- Dealing with Deadlocks
- Dynamic Databases and the Phantom Problem
- Concurrency Control in B+ Trees ✓

Concurrency Control in B+ Trees

- We focus on applying concurrency control on B+ trees for:
  - Searches
  - Insertions/deletions

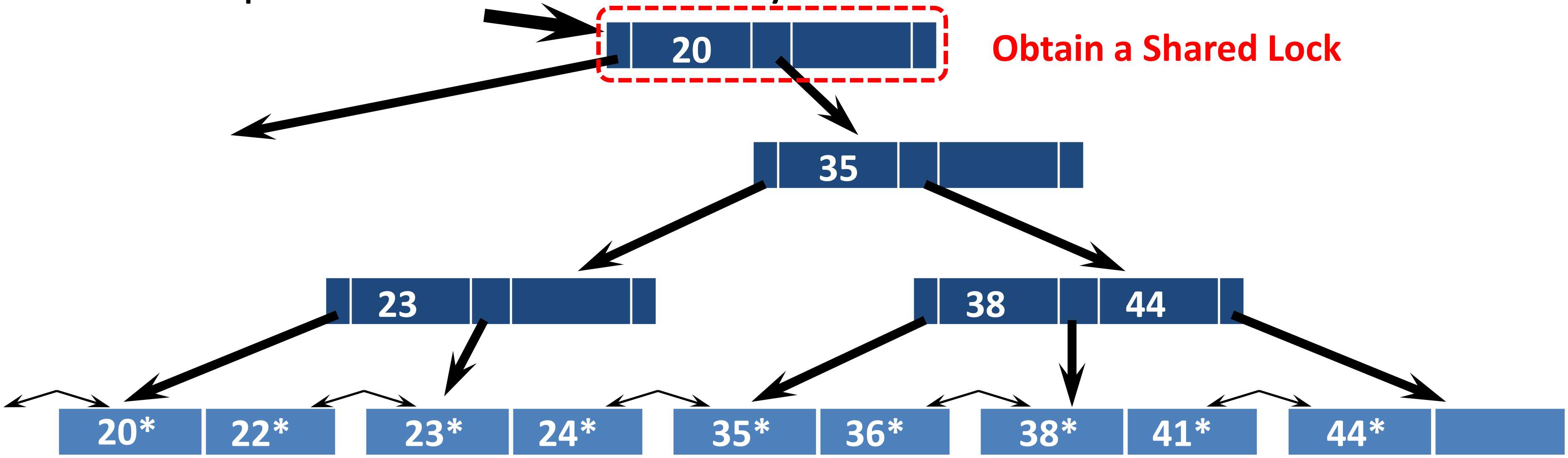
- *Three* observations provide the necessary insights to apply a locking protocol for B+ trees:
  1. The higher levels of a B+ tree only direct searches
  2. Searches never go back up a B+ tree when they proceed along paths to desired leafs
  3. Insertions/deletions can cause splits/merges, which might propagate all the way up, from leafs to the root of a B+ tree

A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf

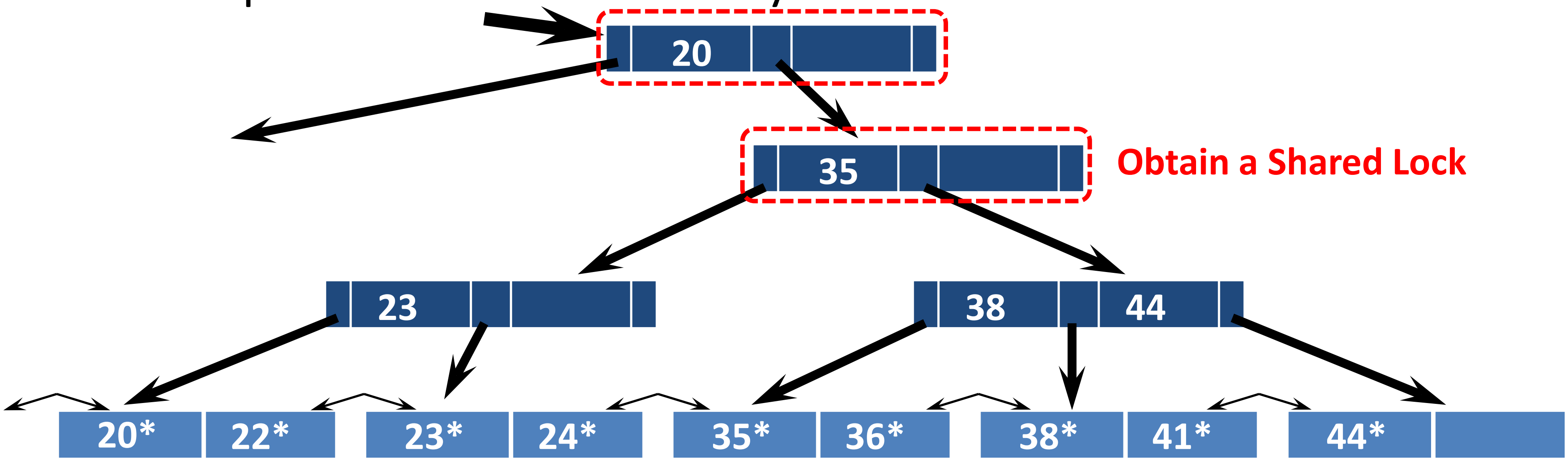
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained

- Example: Search for data entry 38*



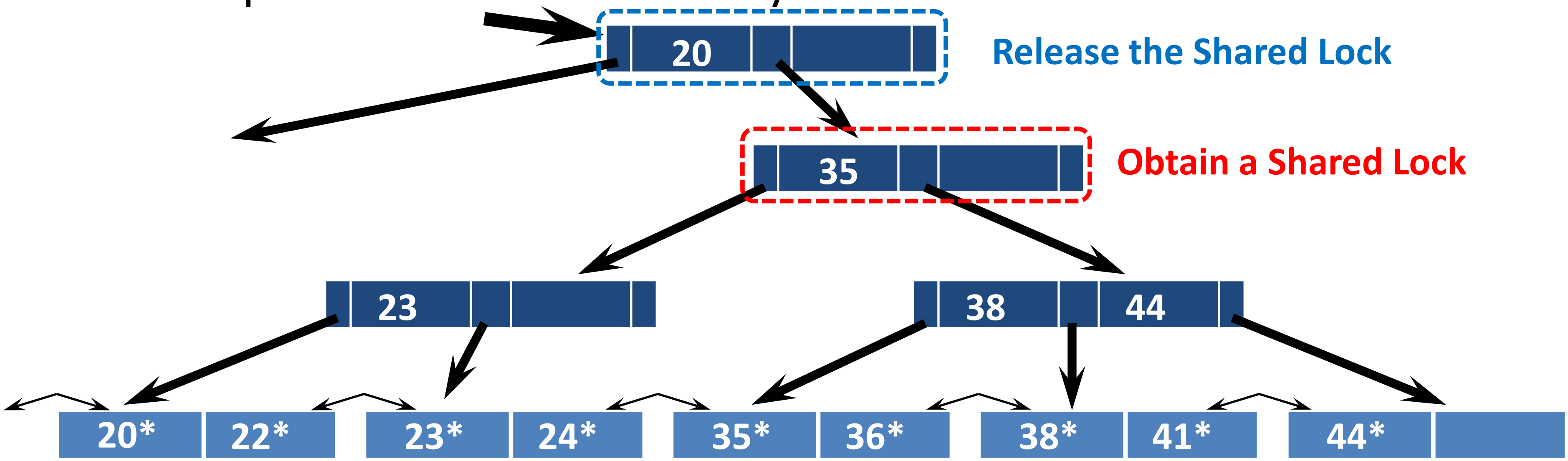
A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained
- Example: Search for data entry 38*



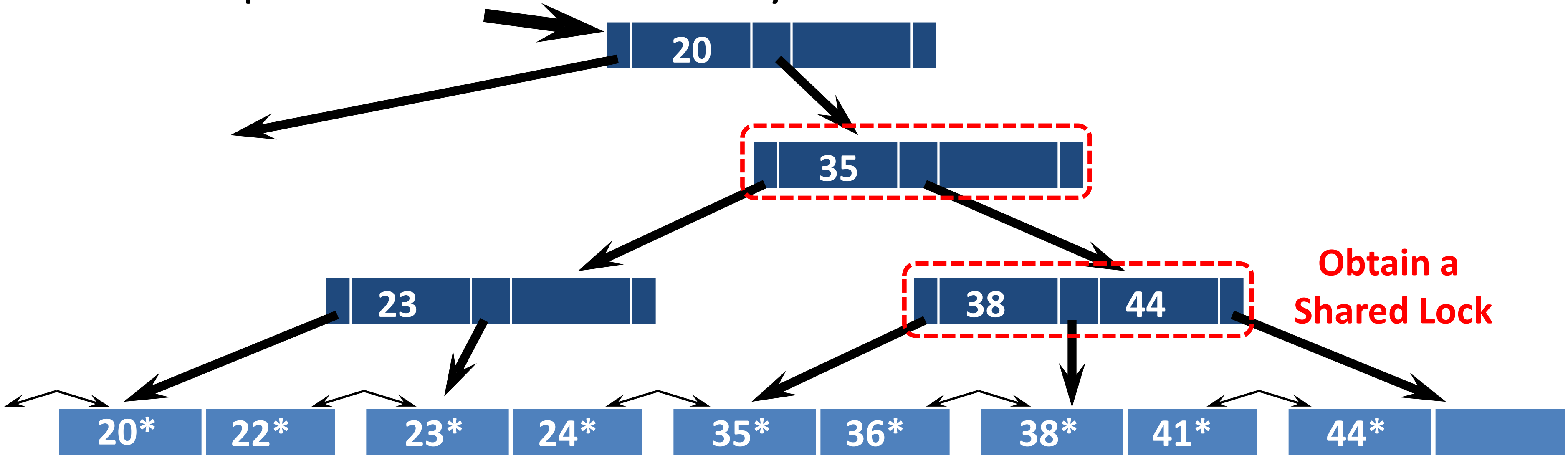
A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained
- Example: Search for data entry 38*



A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained
- Example: Search for data entry 38*

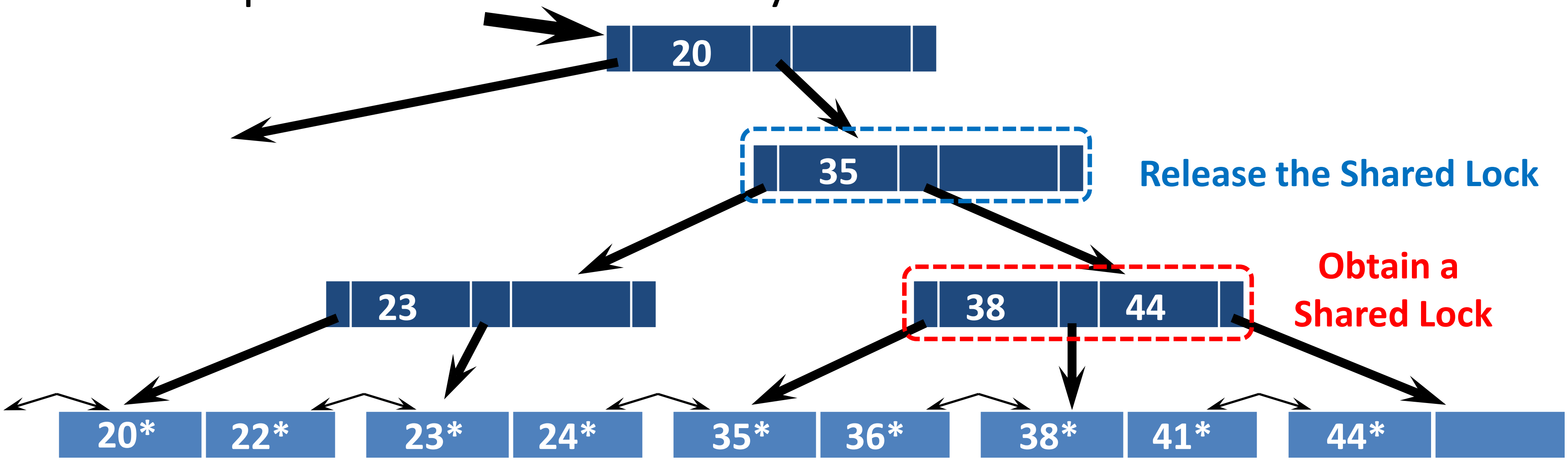


A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf

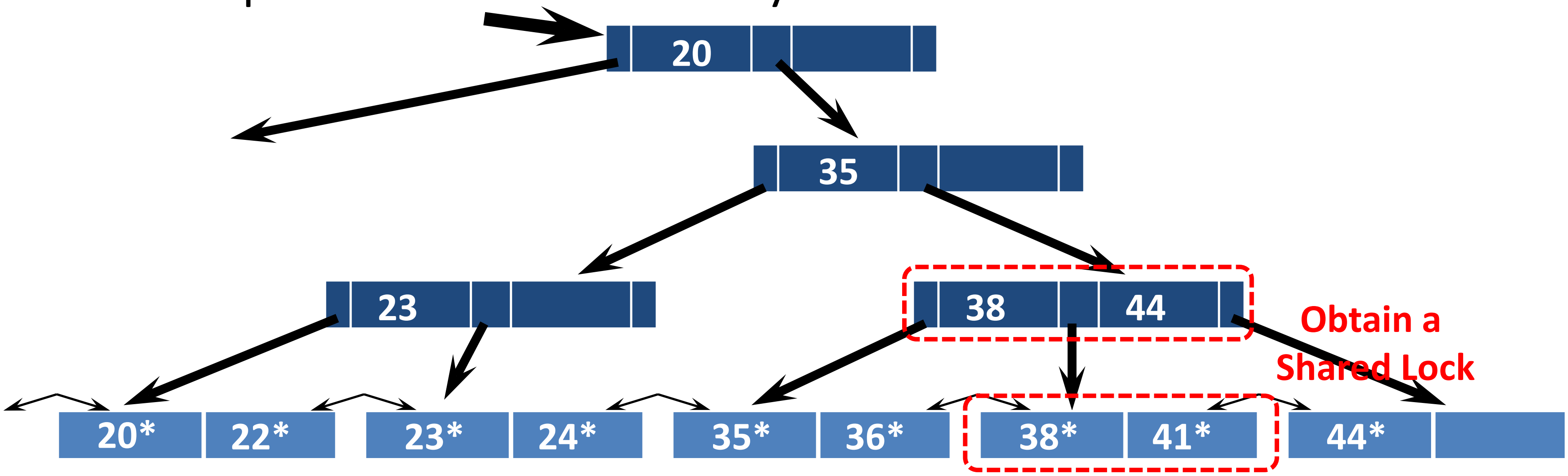
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained

- Example: Search for data entry 38*



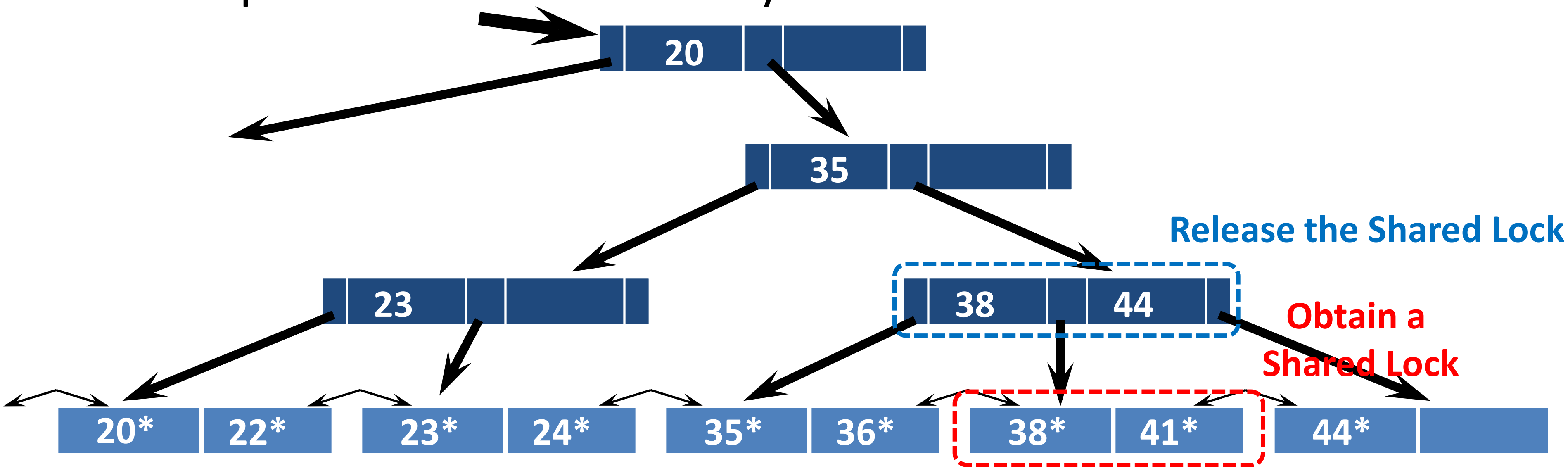
A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained
- Example: Search for data entry 38*



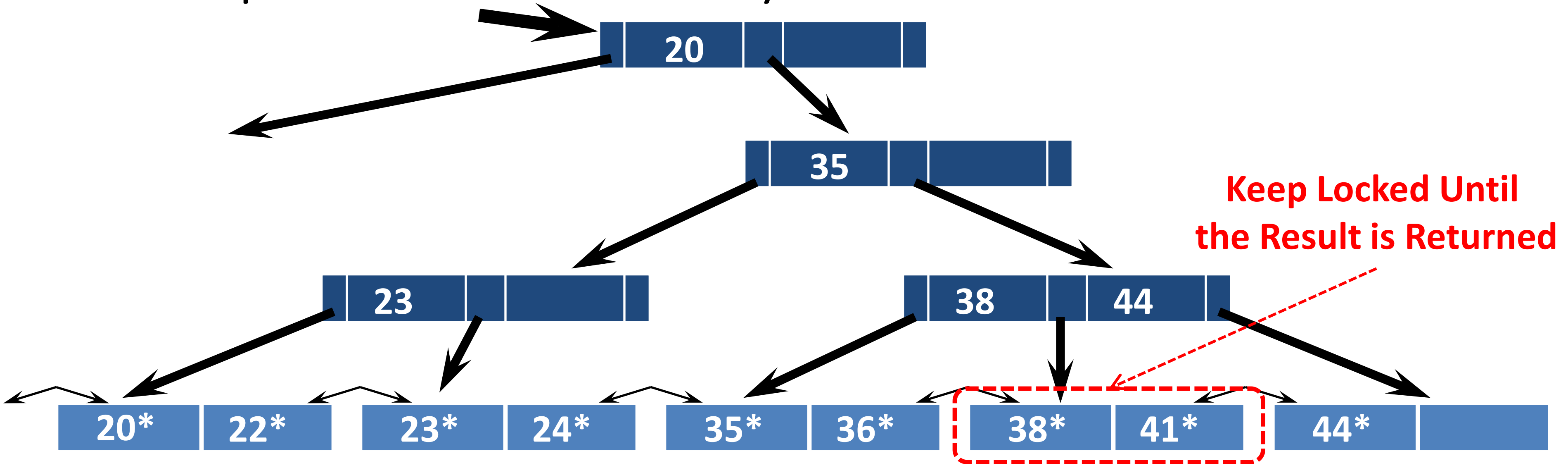
A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained
- Example: Search for data entry 38*



A Locking Strategy for Searches

- A search should obtain Shared locks on nodes, starting at the root and proceeding along the path to the desired leaf
- Since searches never go back up the tree, a lock on a node can be released as soon as a lock on a child node is obtained
- Example: Search for data entry 38*



Towards A Locking Strategy for Insertions/Deletions

- A conservative strategy for an insertion/deletion would be to obtain Exclusive locks on all the nodes along the path to the desired leaf
  - This is because splits/merges can propagate all the way up to the root

- However, once a child is locked, its lock will be needed only if a split/merge propagates back to it

- When won't a split propagate back to a node?
  - When the node's child is *not full*

- When won't a merge propagate back to a node?
  - When the node's child is *more than half-empty*

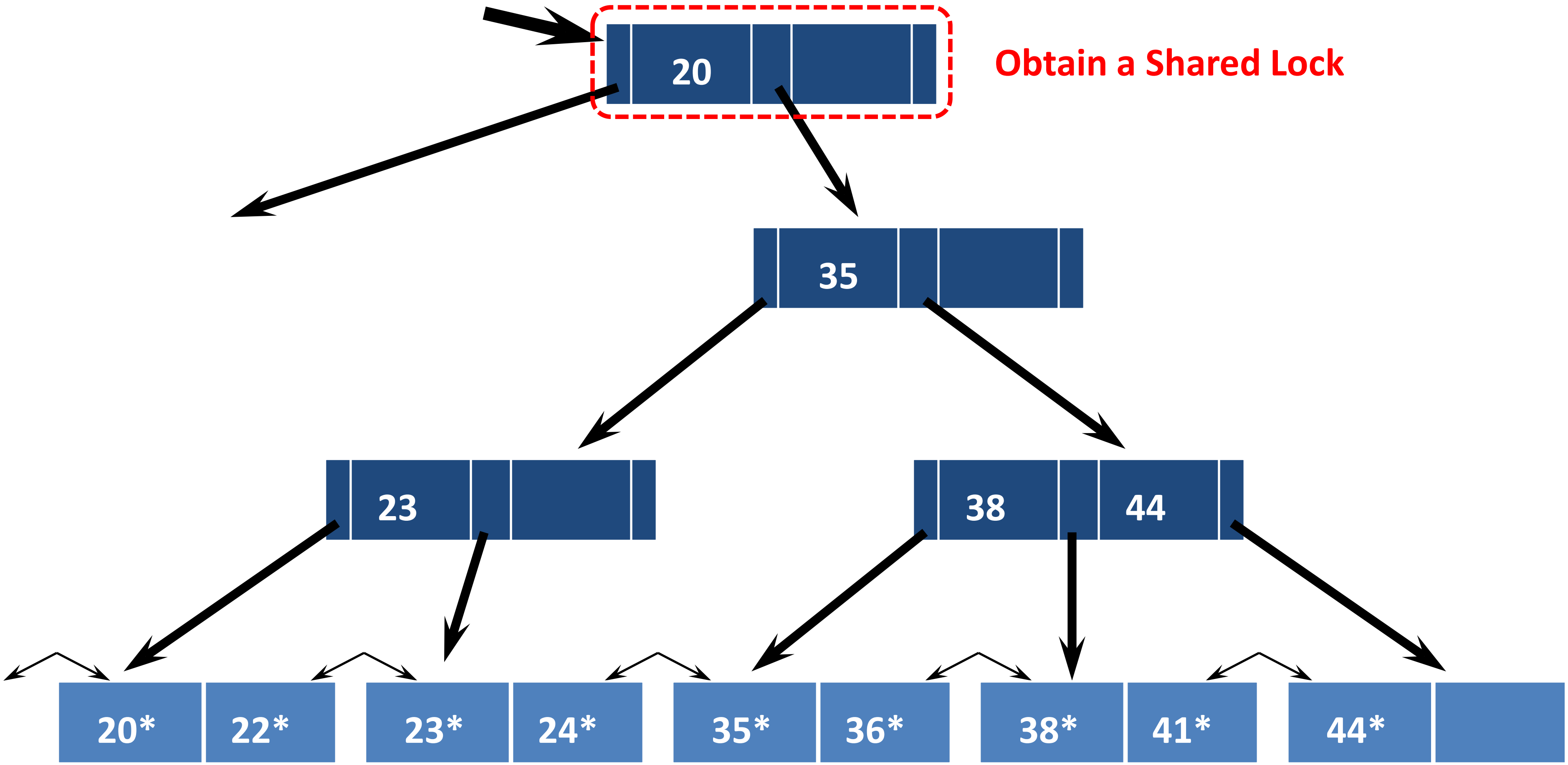
Lock-Coupling: A Locking Strategy for Insertions/Deletions (*Cont'd*)

- A strategy, known as *lock-coupling*, for insertions/deletions can be pursued as follows:
  - Start at the root and go down, obtaining Shared locks as needed (an Exclusive lock is only obtained for the desired leaf node)
  - Once a child is locked, check if it is safe
  - If the child is safe, release all locks on ancestors

- A node is safe when changes will not propagate up beyond it
  - A safe node for an insertion is the one that is not full
  - A safe node for a deletion is the one that is more than half-empty

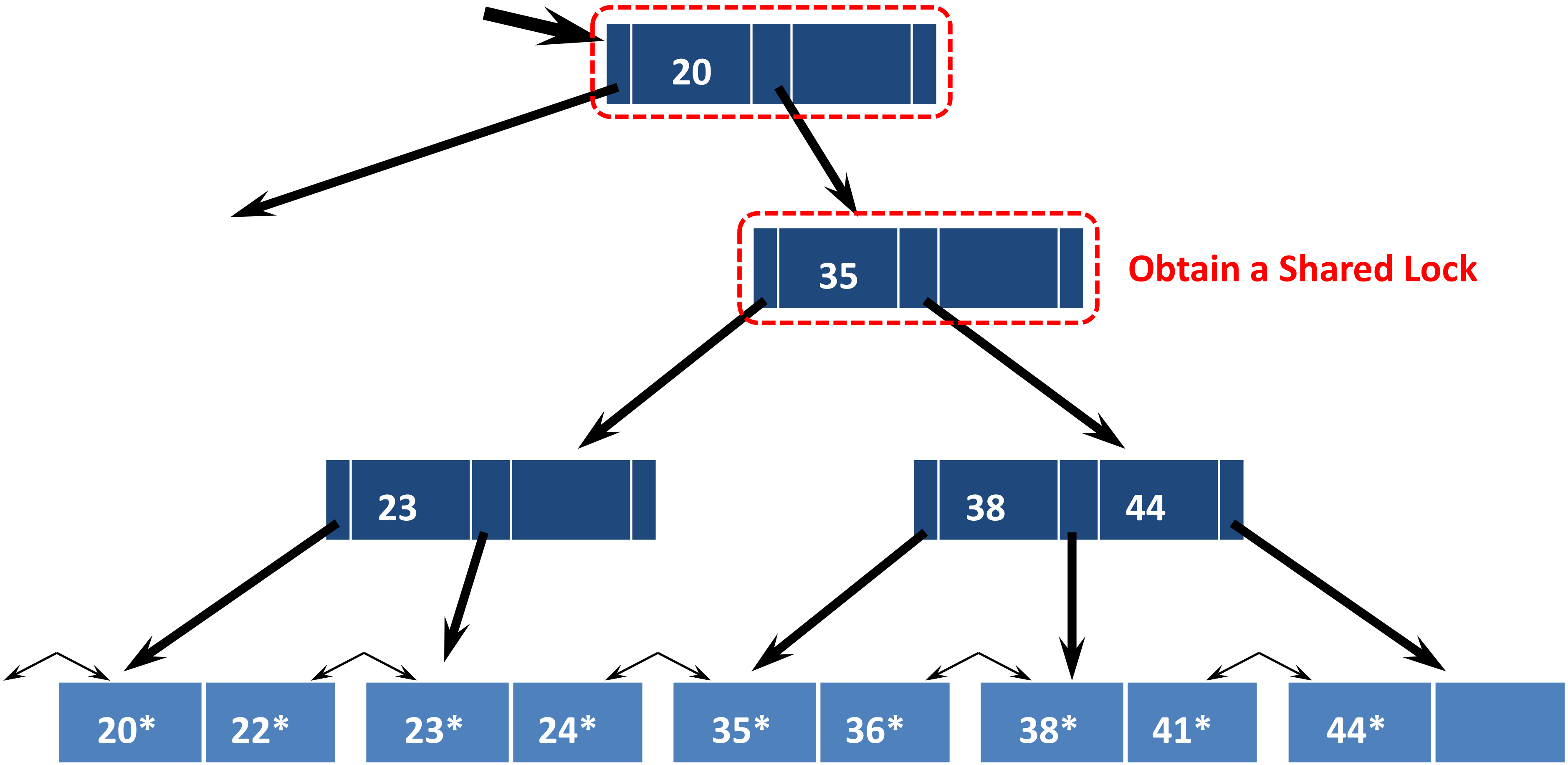
Lock-Coupling: An Example

- Insert data entry **45***:



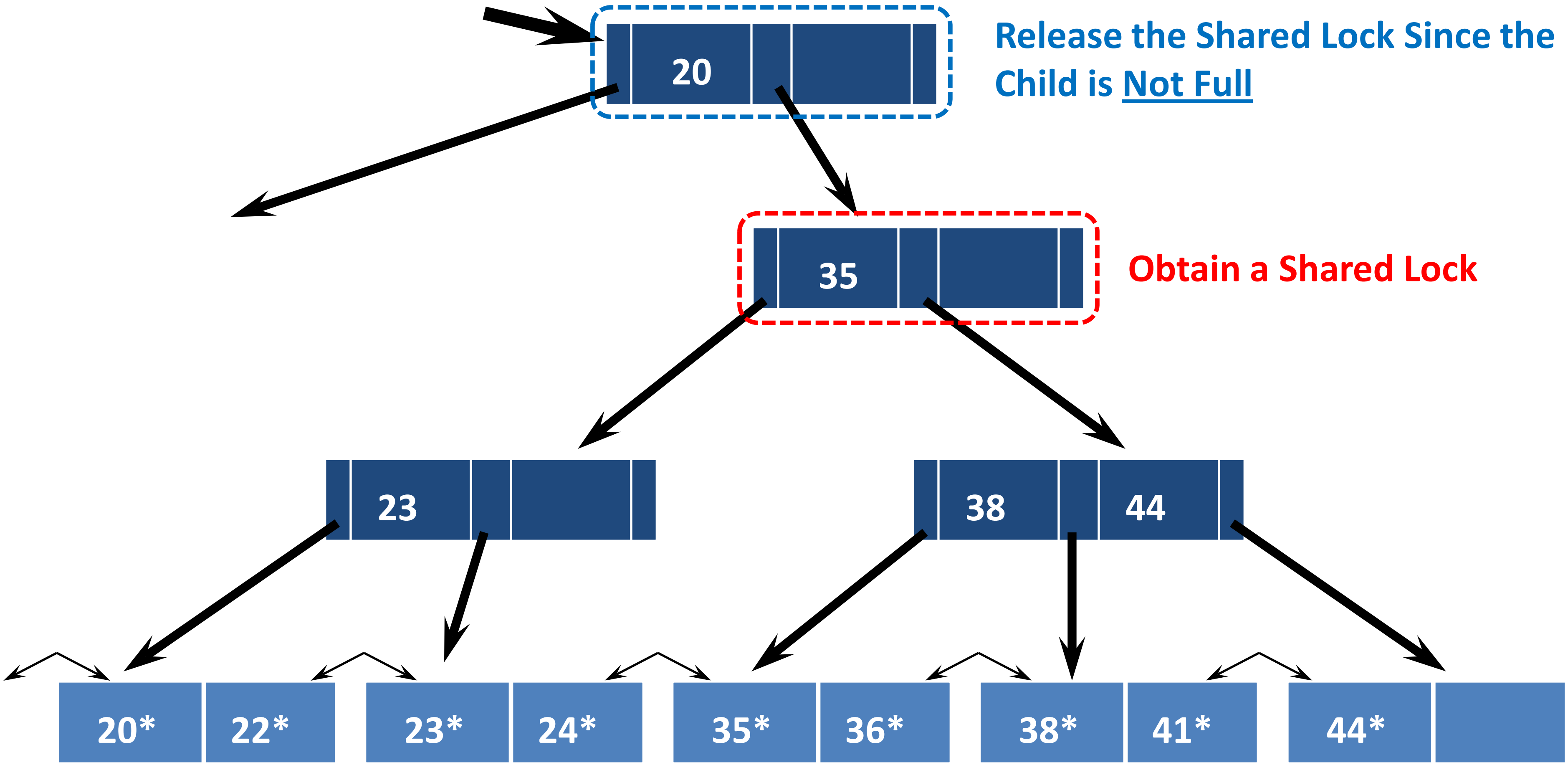
Lock-Coupling: An Example

- Insert data entry **45***:



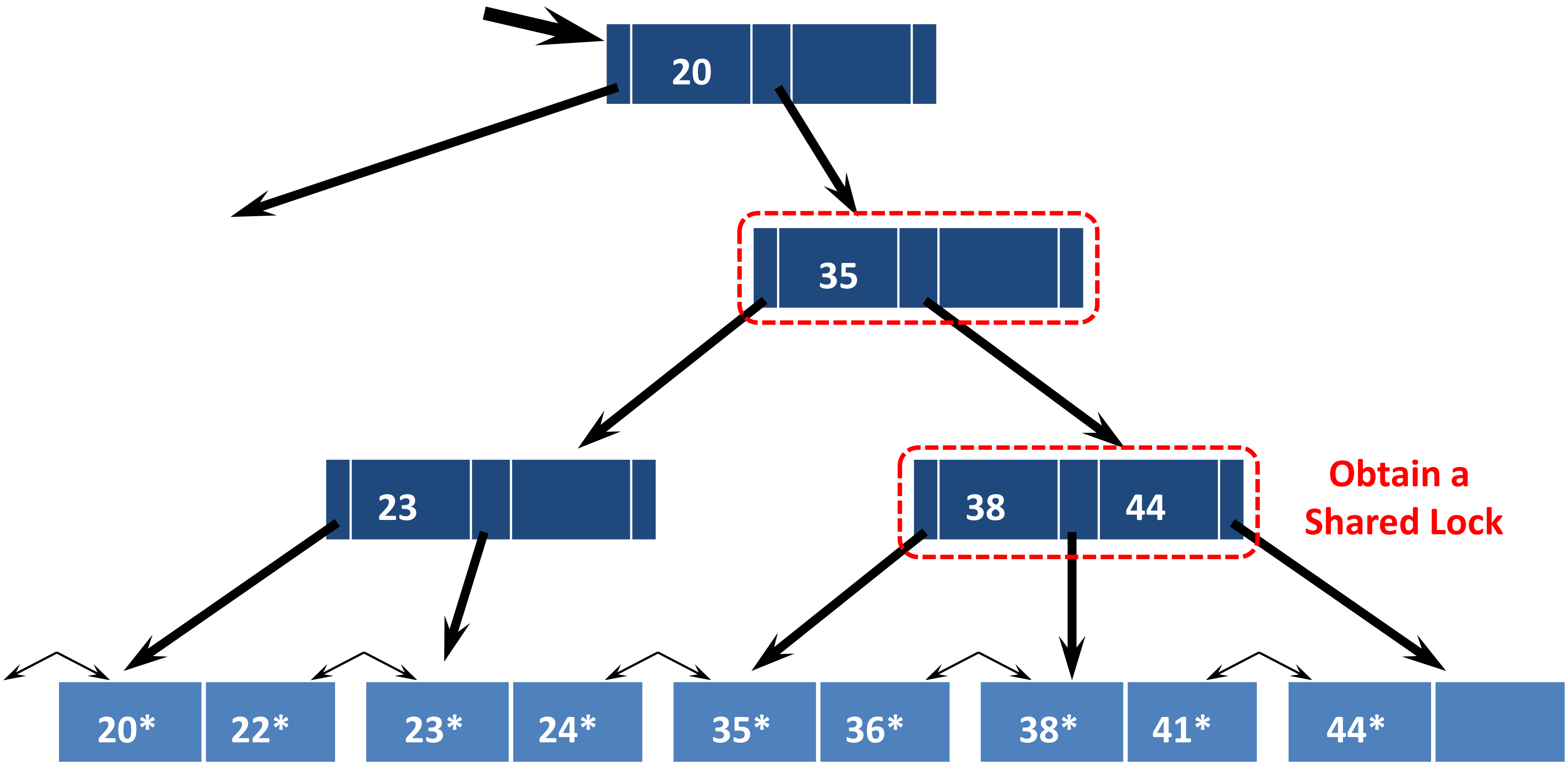
Lock-Coupling: An Example

- Insert data entry **45***:



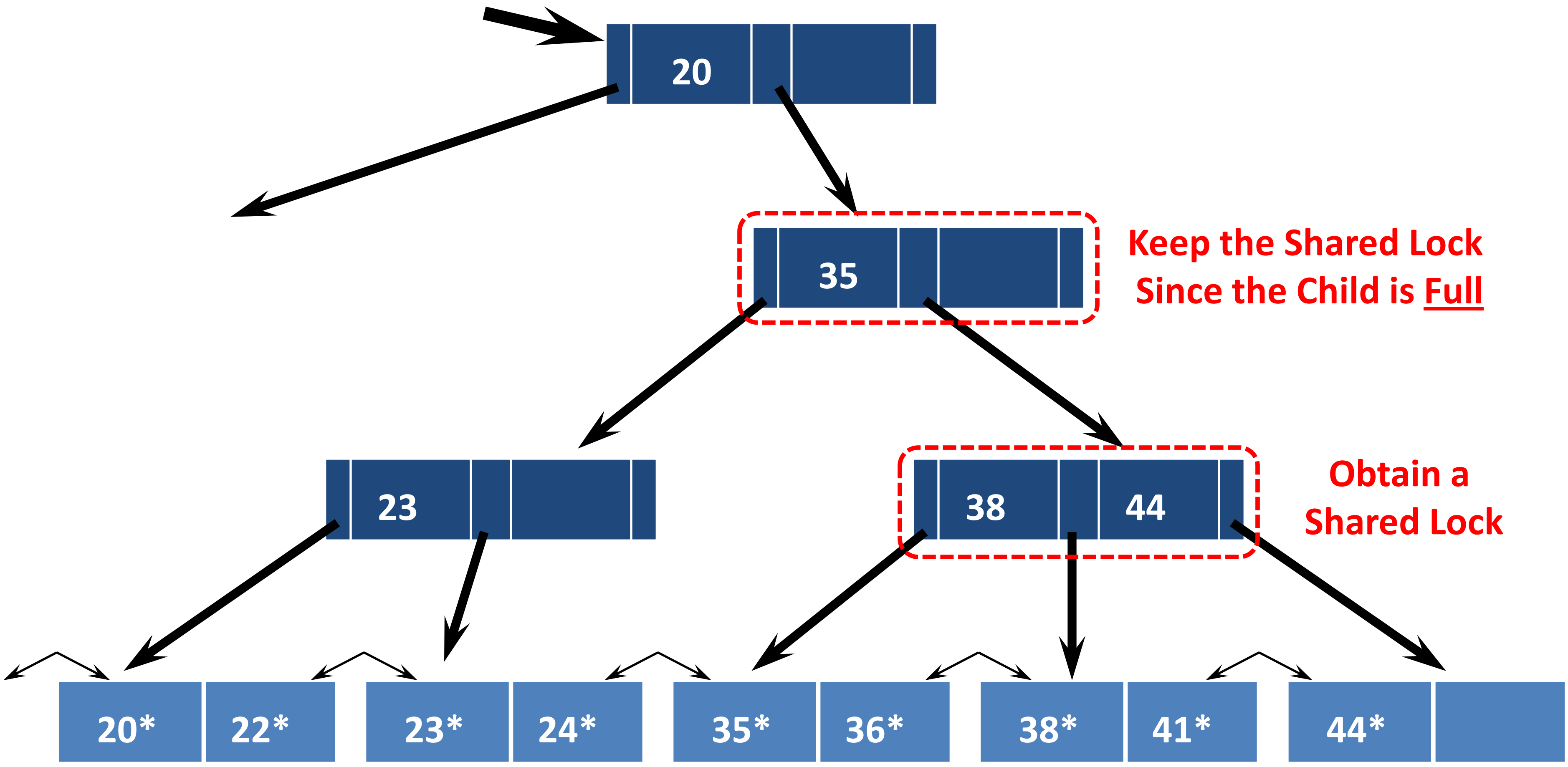
Lock-Coupling: An Example

- Insert data entry **45***:



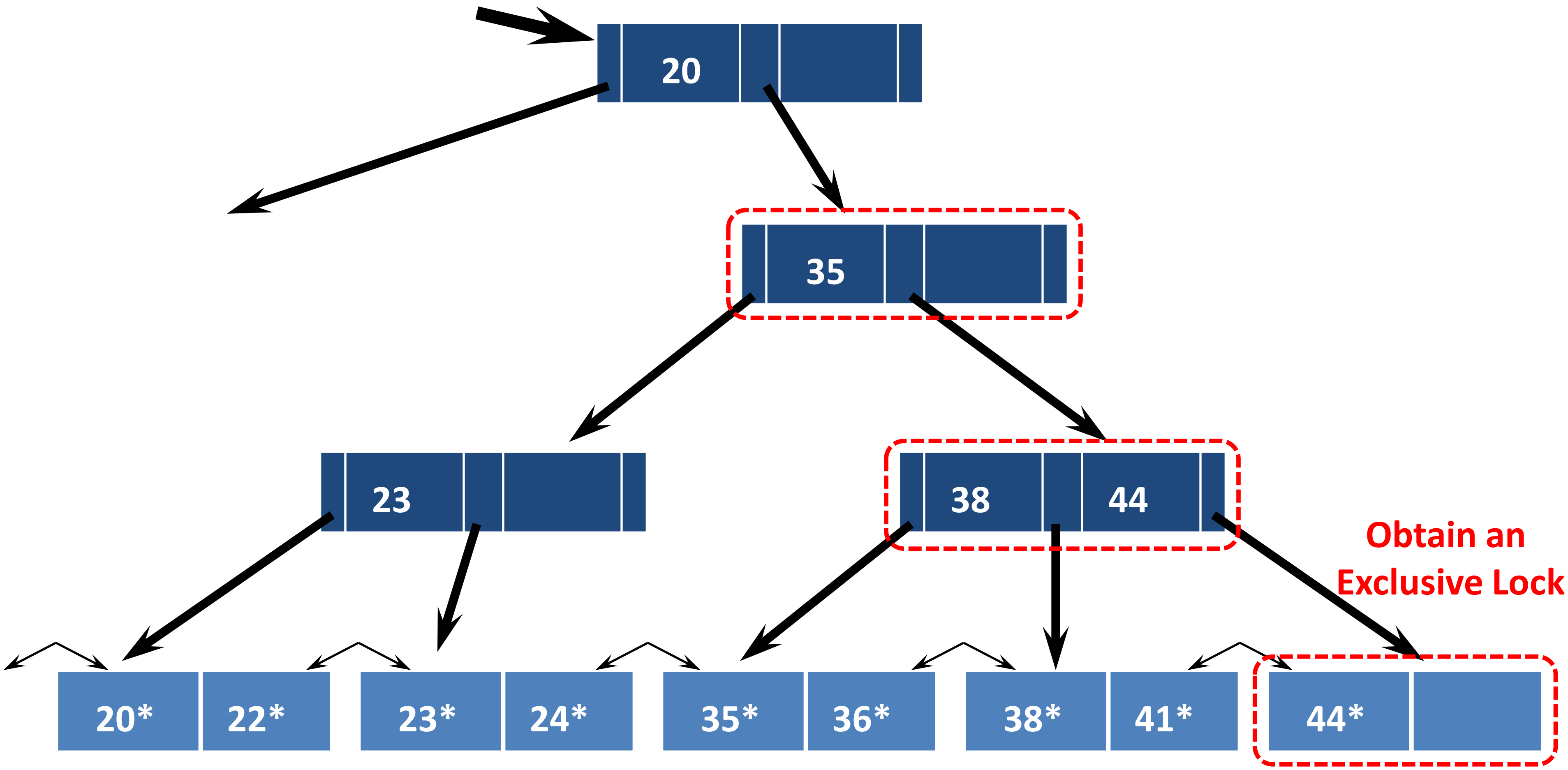
Lock-Coupling: An Example

- Insert data entry **45***:



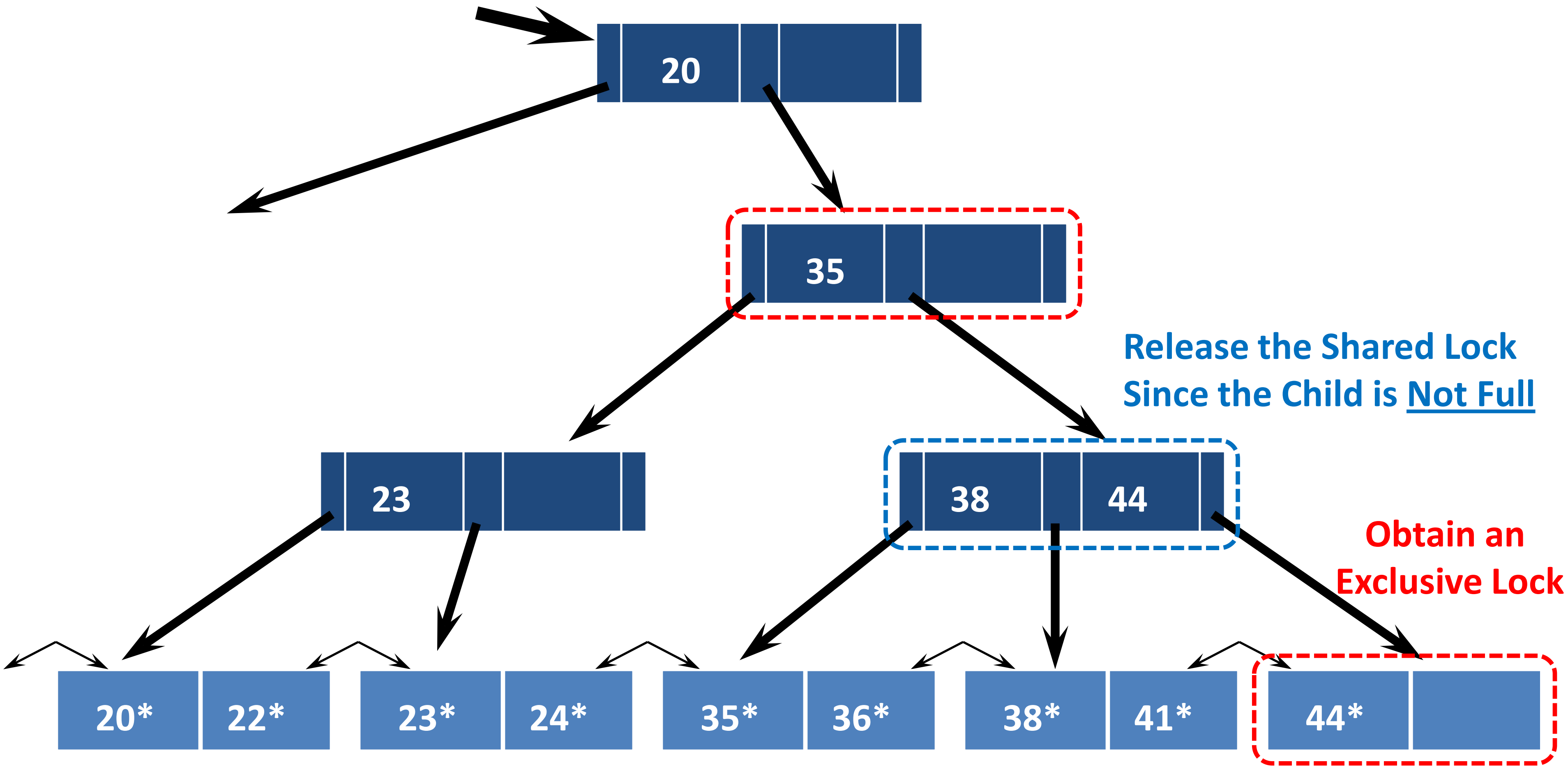
Lock-Coupling: An Example

- Insert data entry **45***:



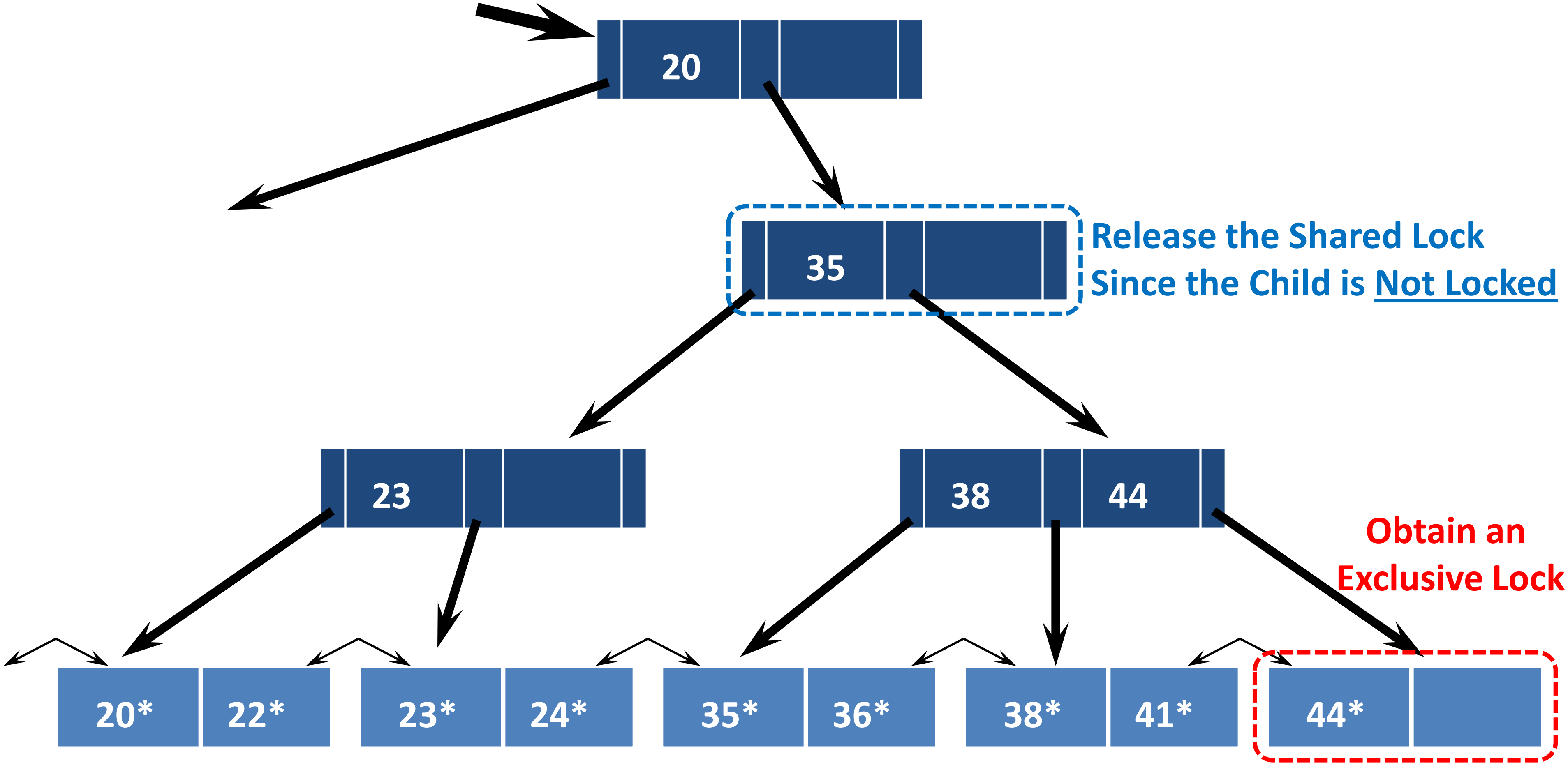
Lock-Coupling: An Example

- Insert data entry **45***:



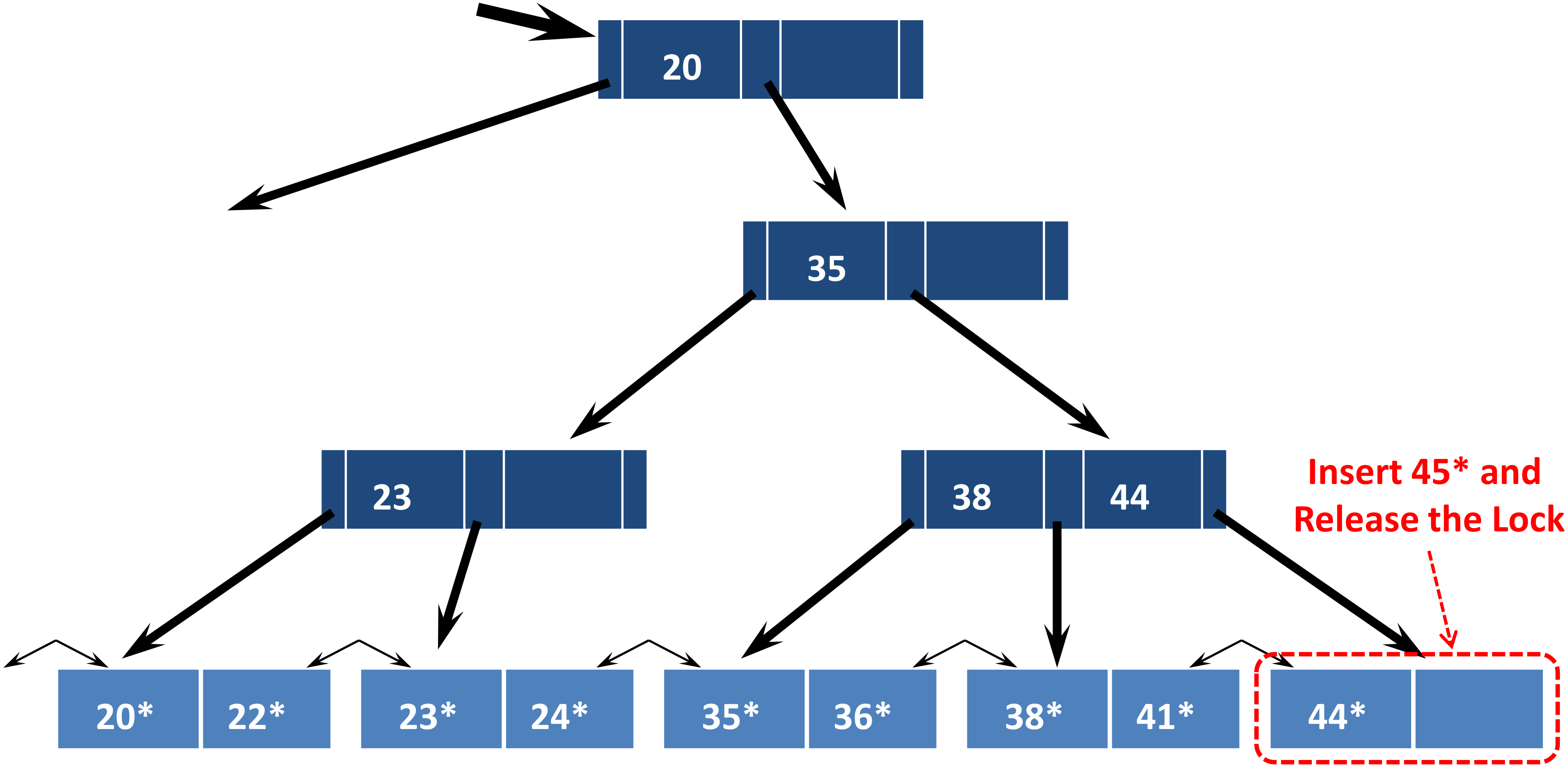
Lock-Coupling: An Example

- Insert data entry **45***:



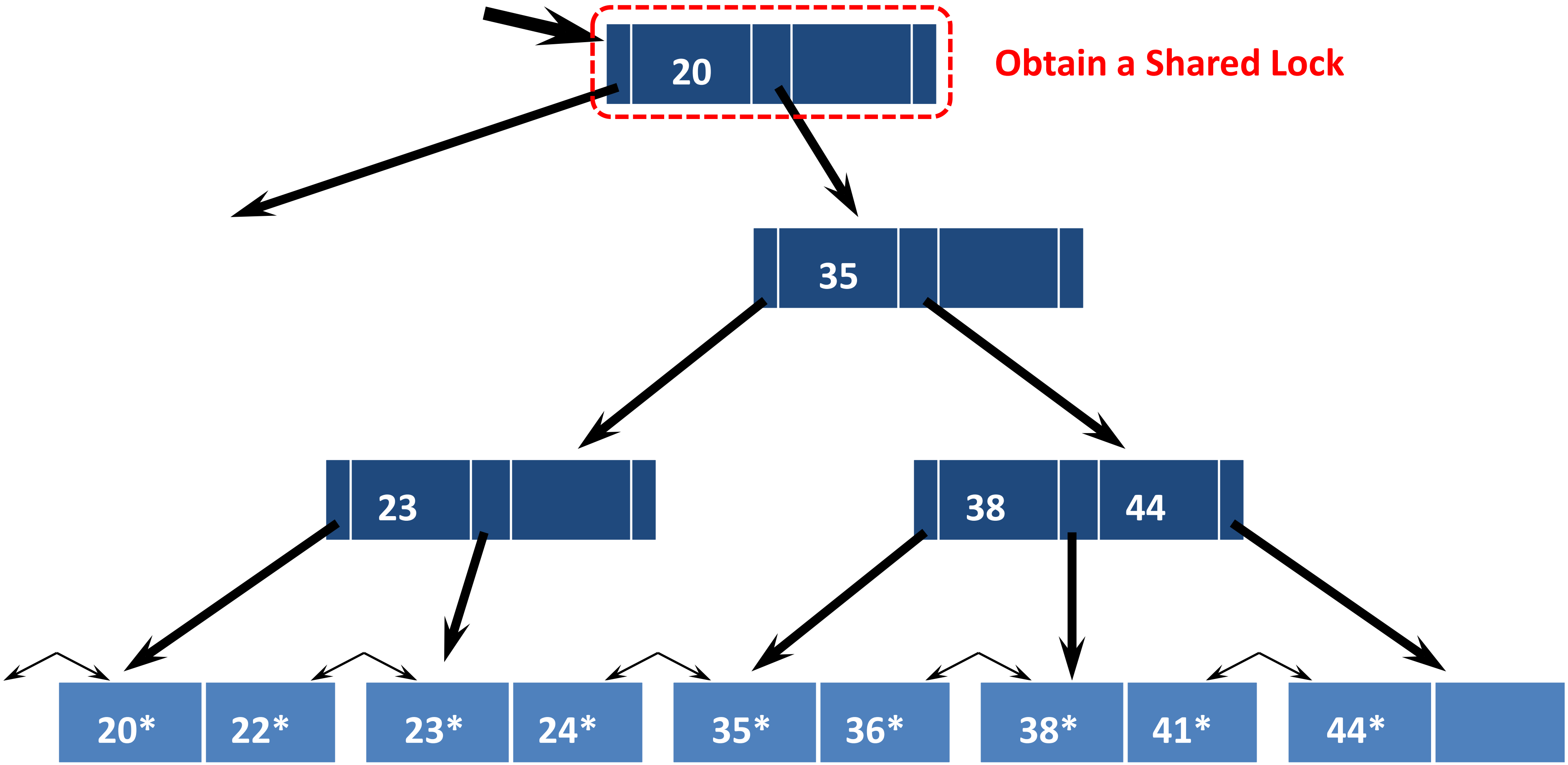
Lock-Coupling: An Example

- Insert data entry **45***:



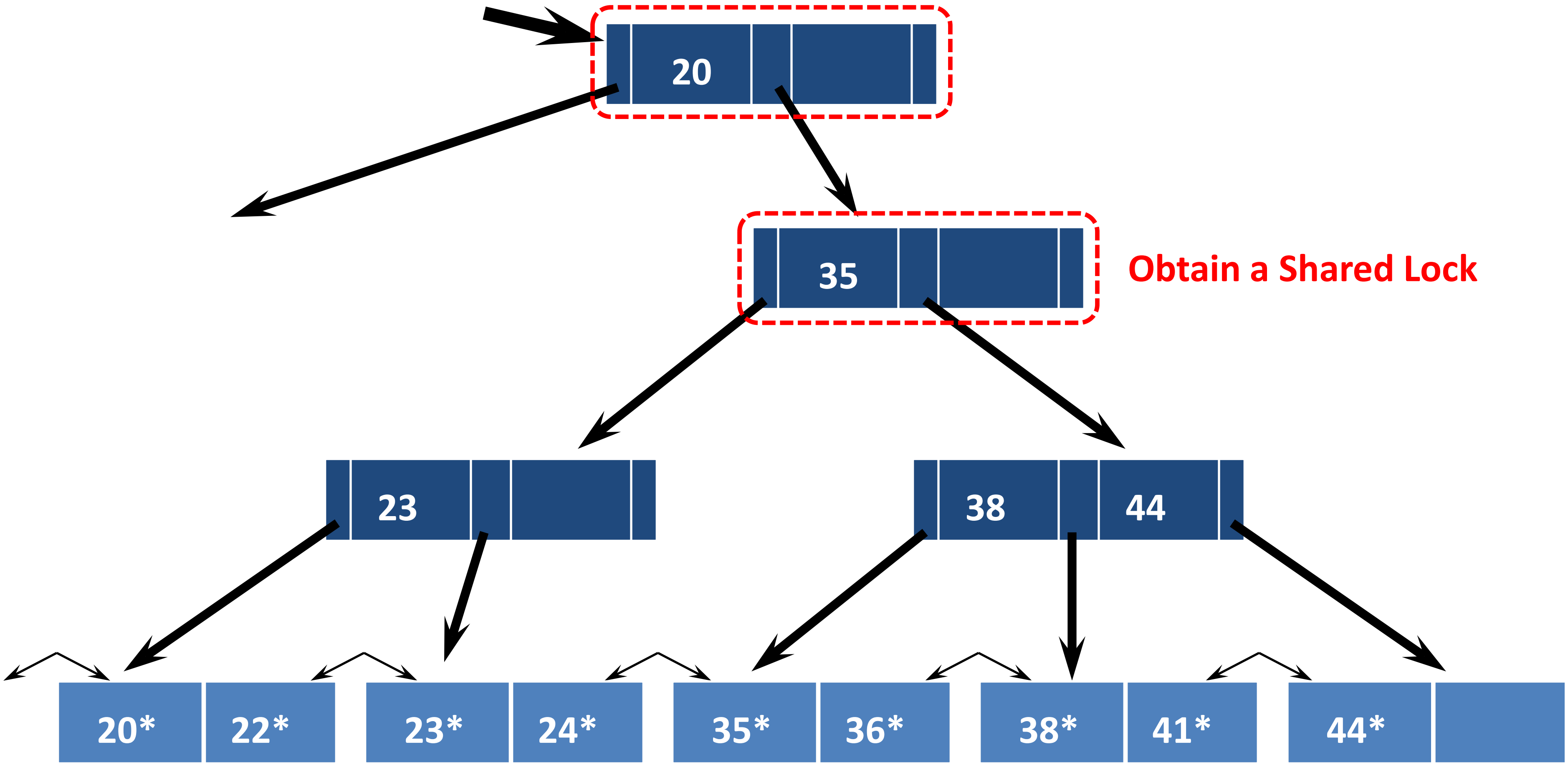
Lock-Coupling: Another Example

- Insert data entry **25***:



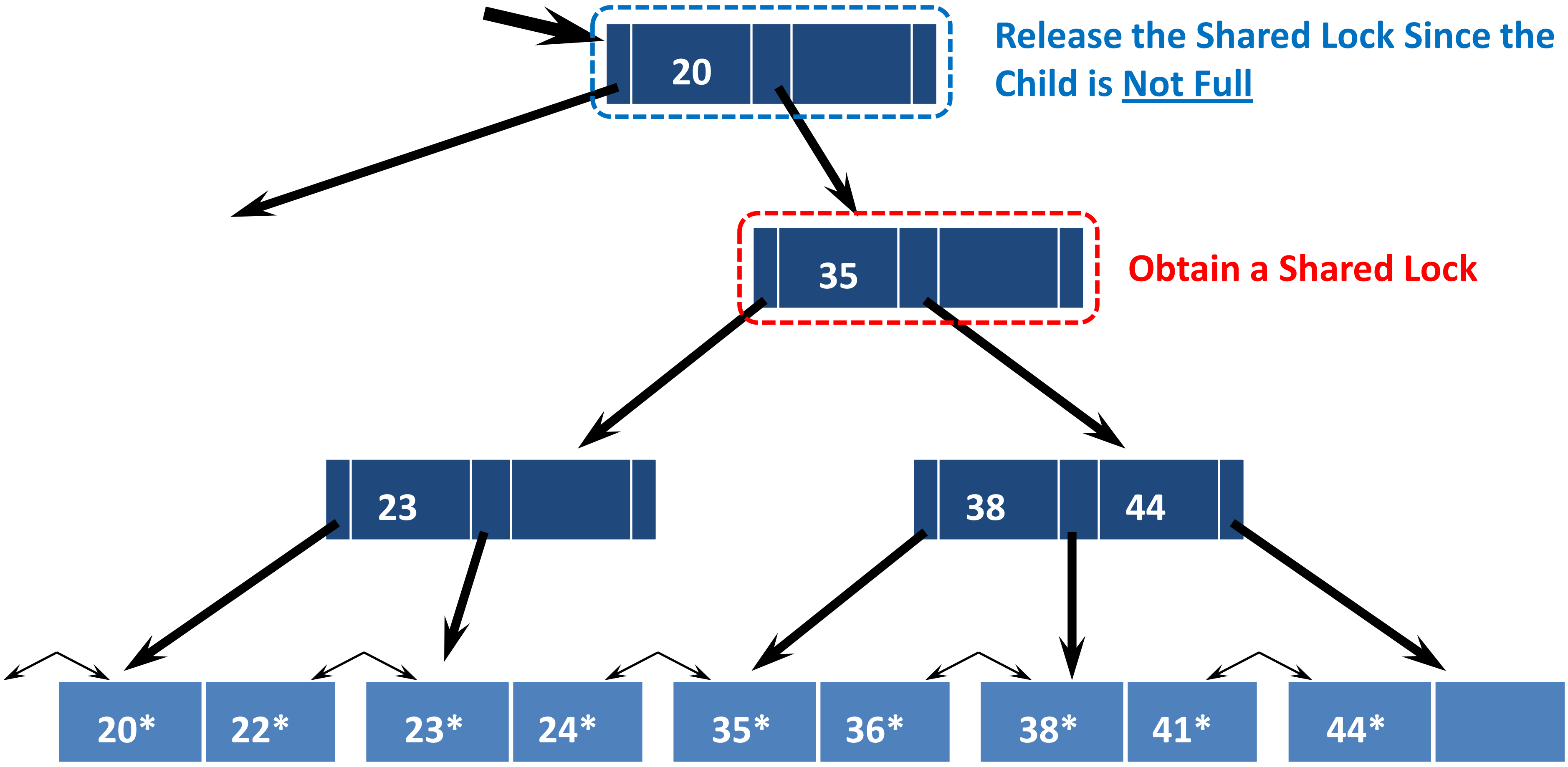
Lock-Coupling: Another Example

- Insert data entry **25***:



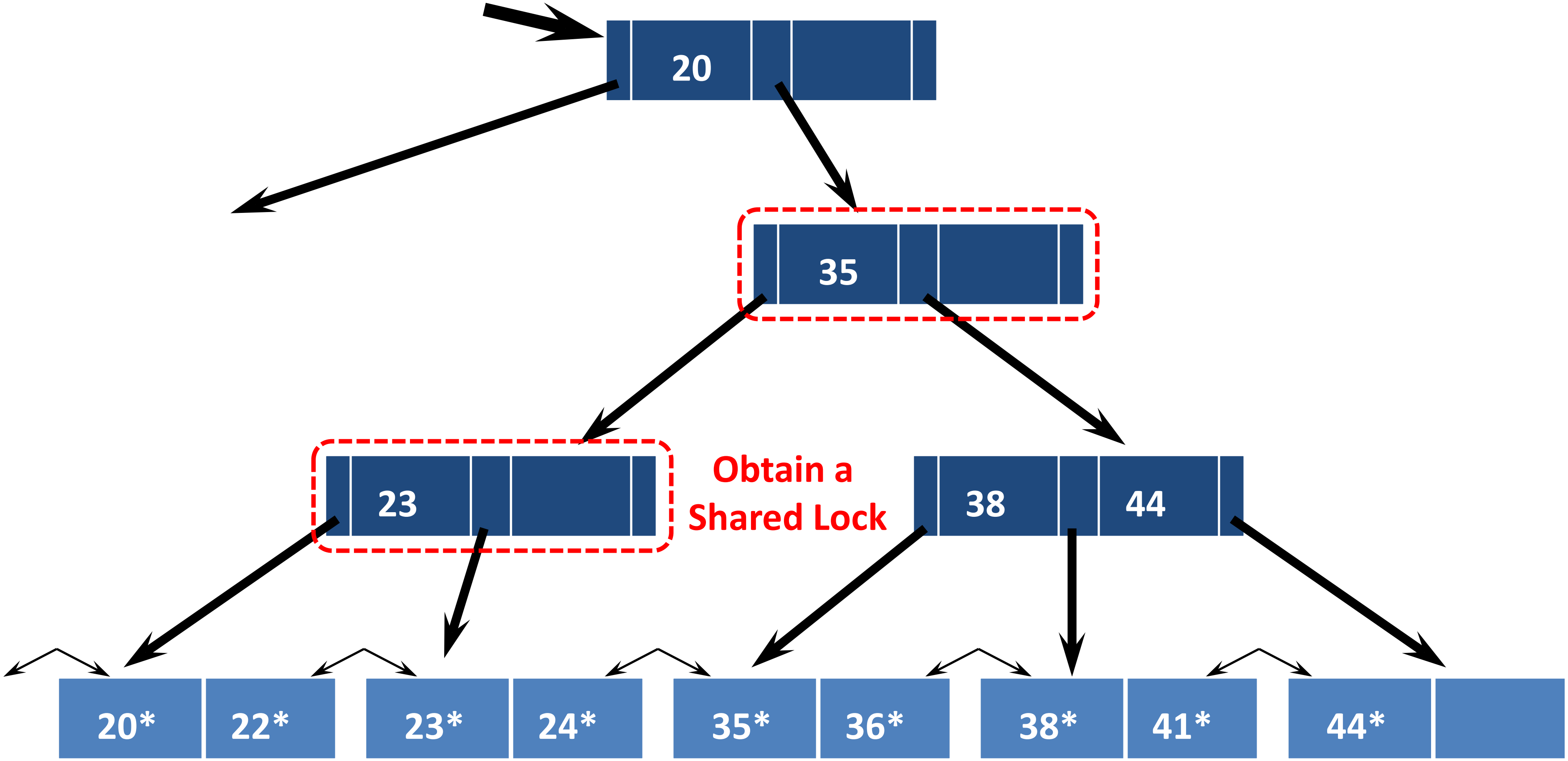
Lock-Coupling: Another Example

- Insert data entry **25***:



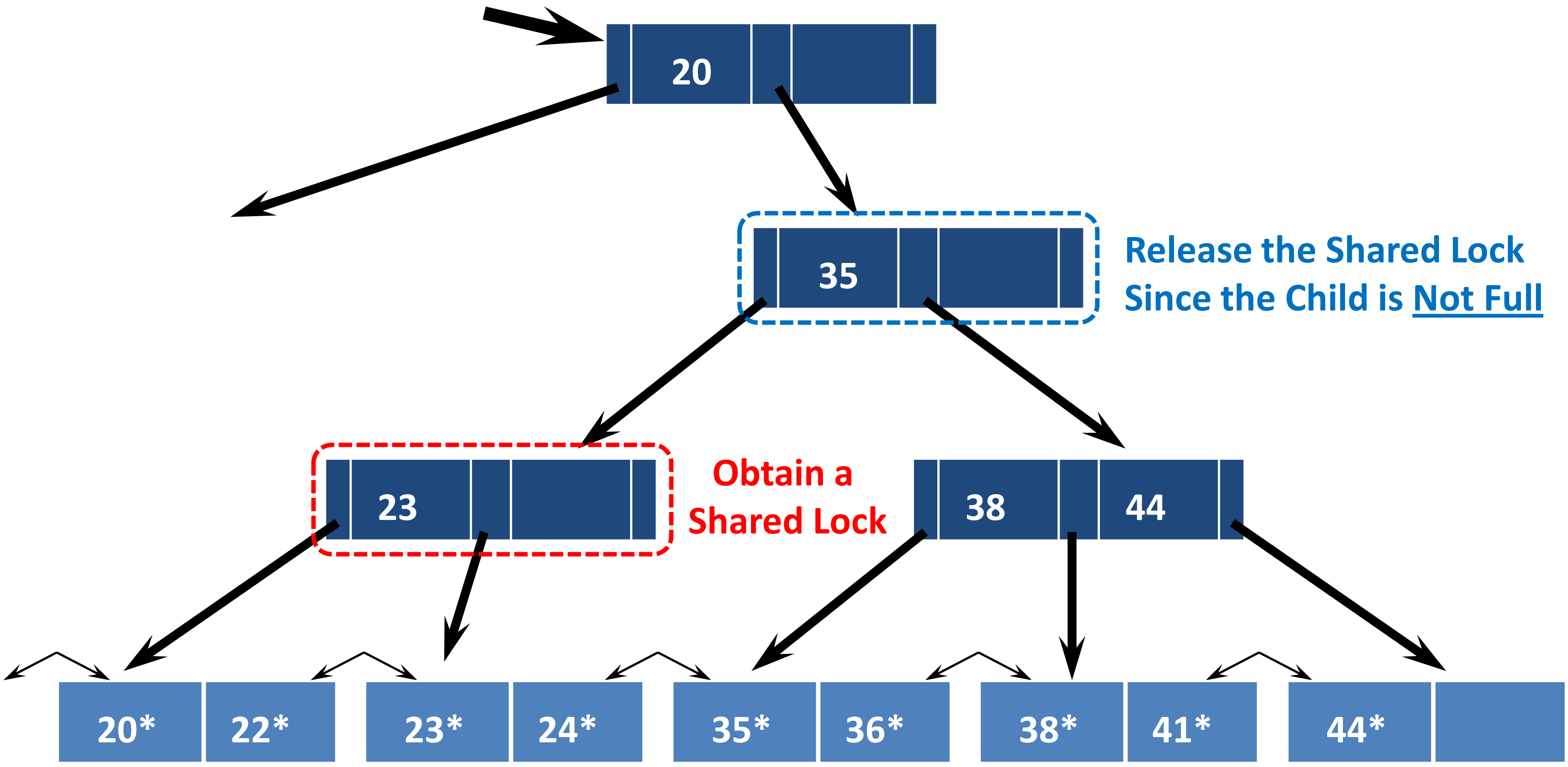
Lock-Coupling: Another Example

- Insert data entry **25***:



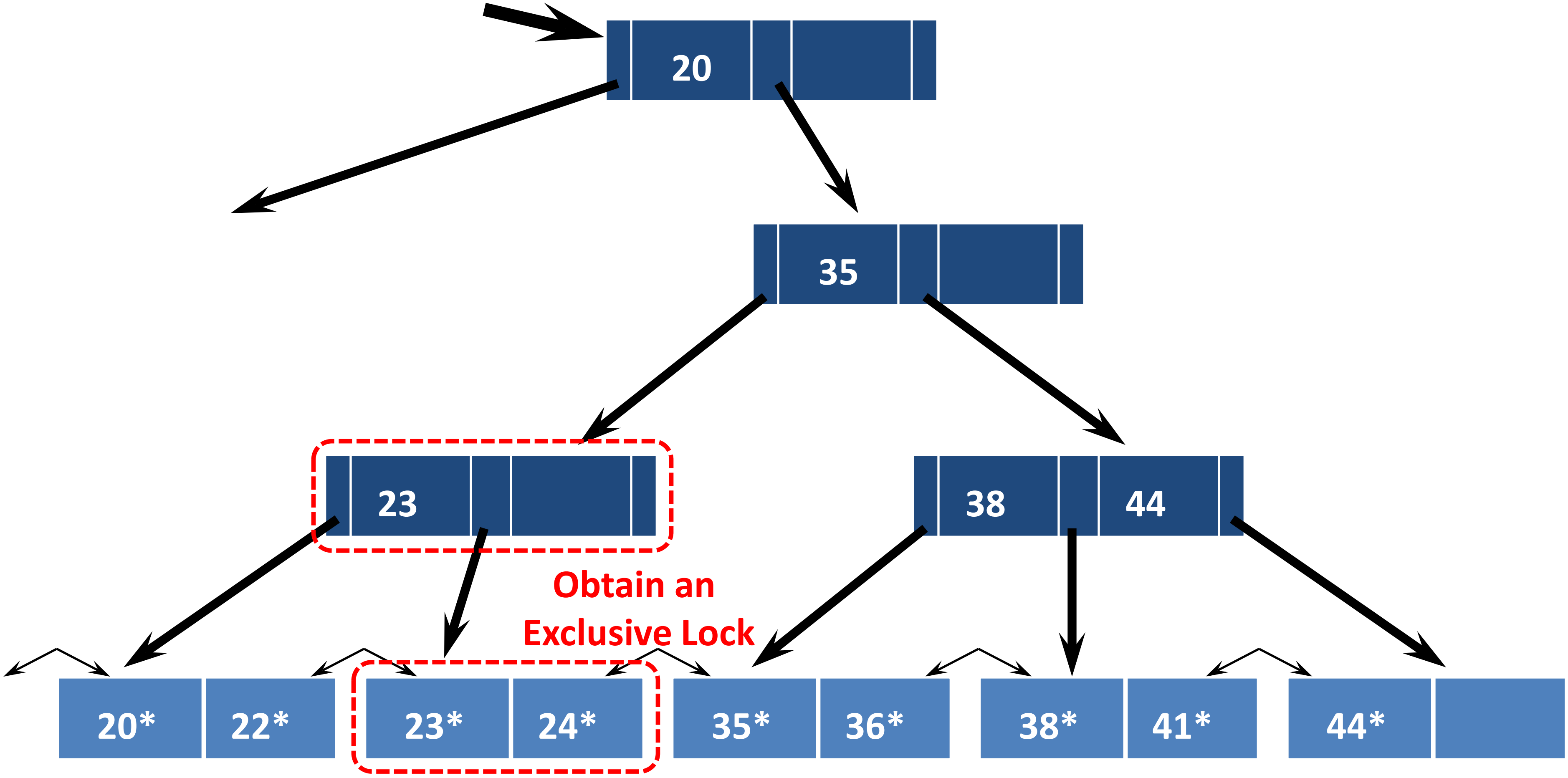
Lock-Coupling: Another Example

- Insert data entry **25***:



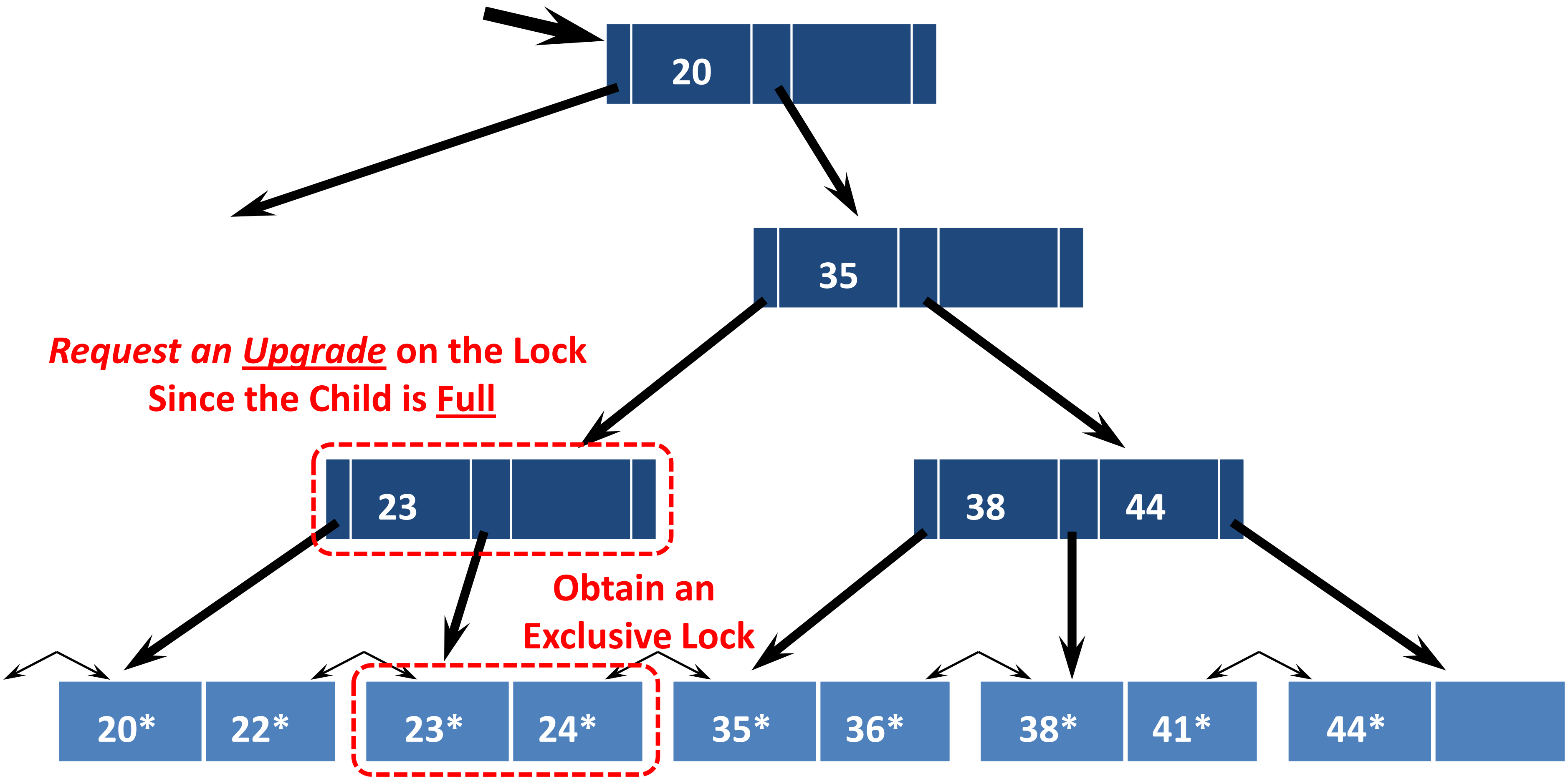
Lock-Coupling: Another Example

- Insert data entry **25***:



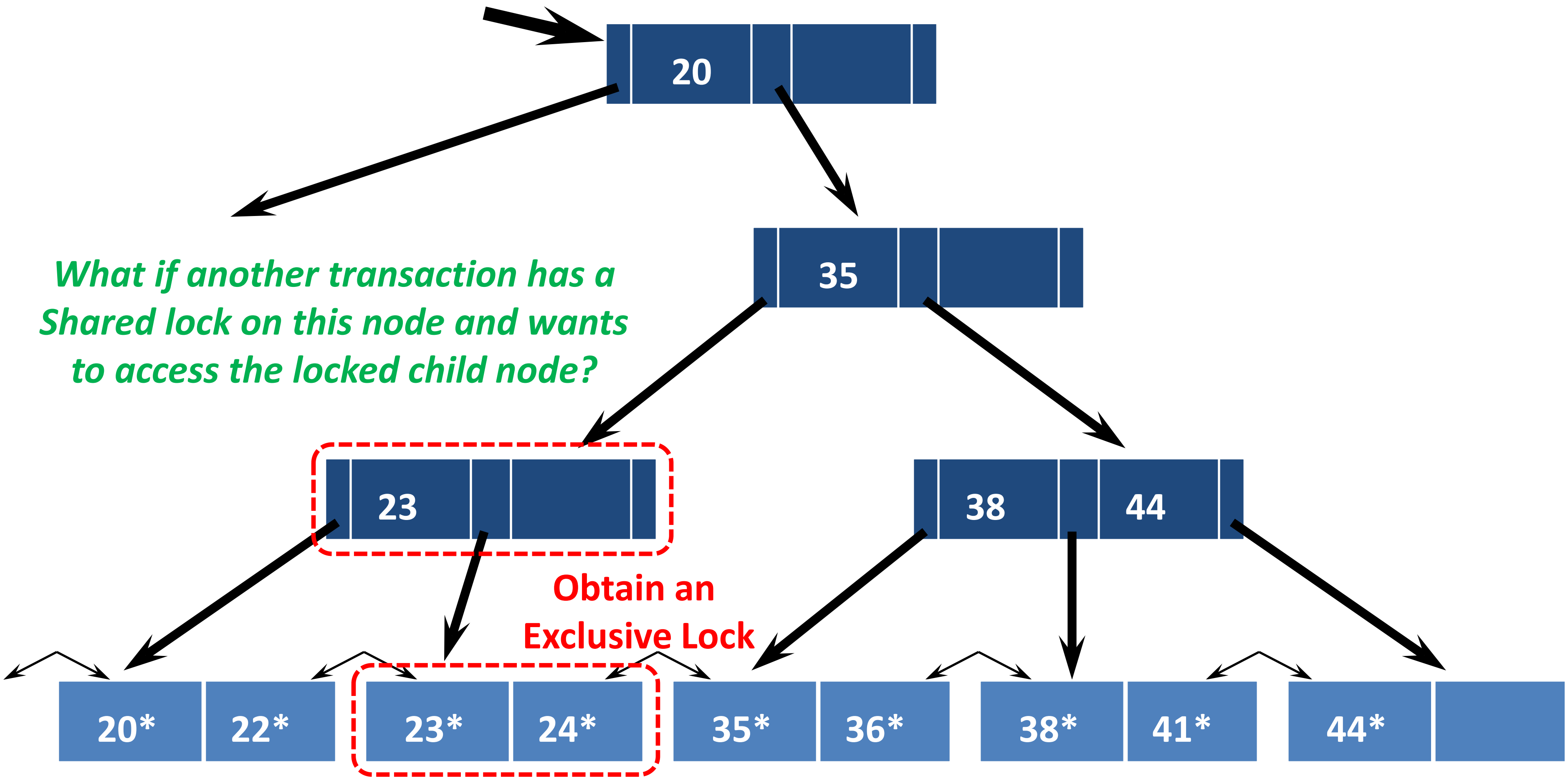
Lock-Coupling: Another Example

- Insert data entry **25***:



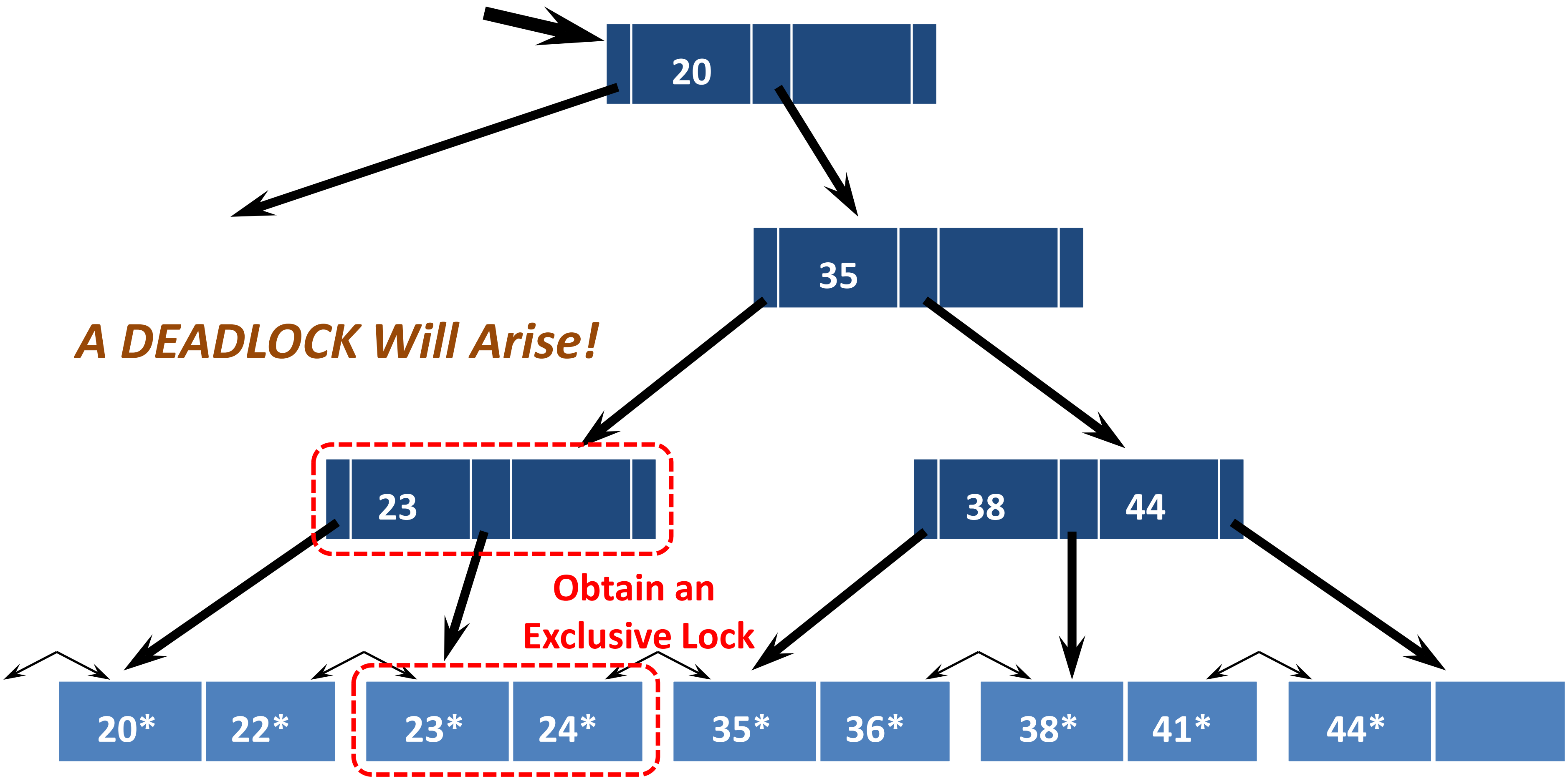
Lock-Coupling: Another Example

- Insert data entry **25***:



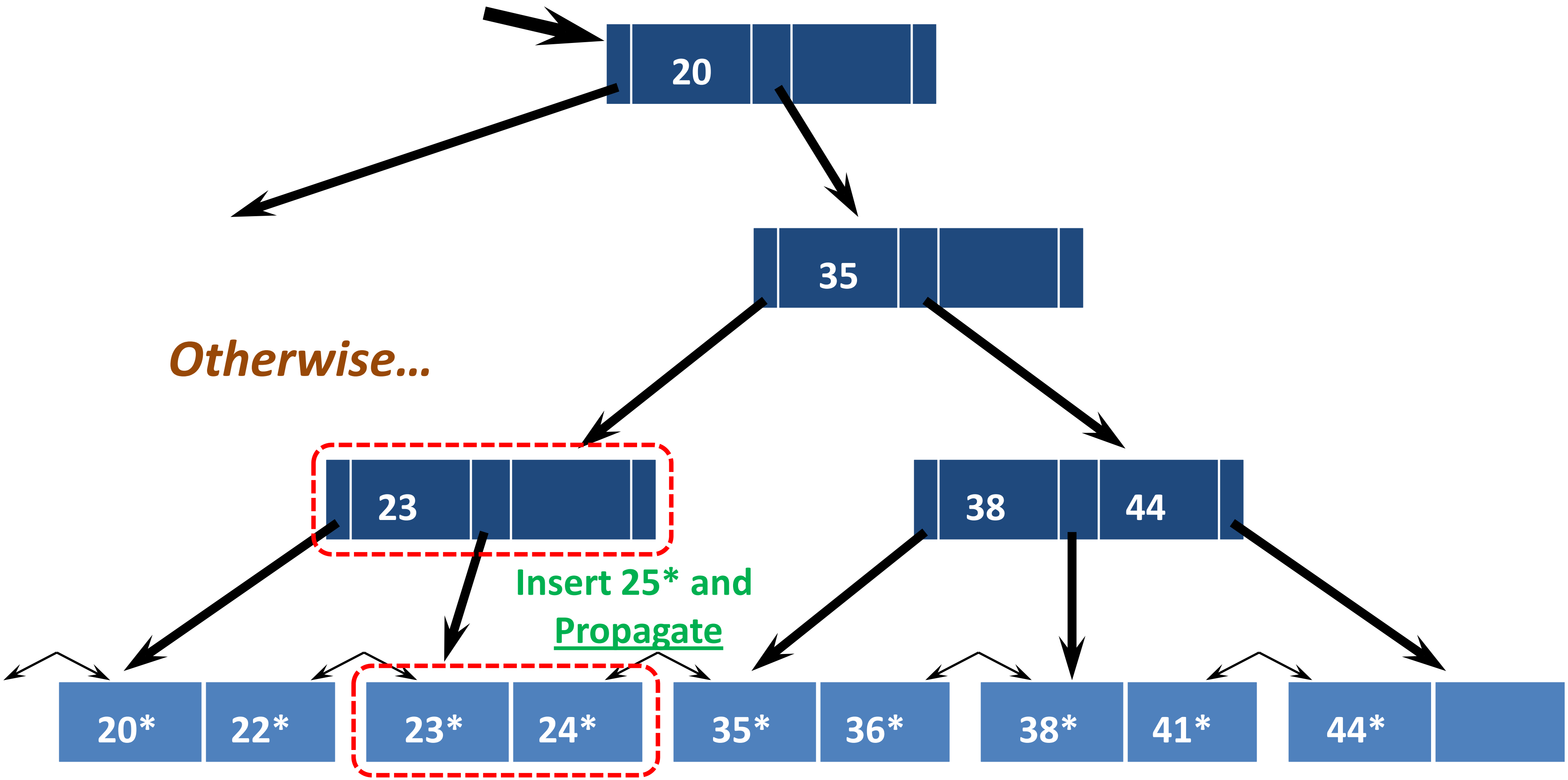
Lock-Coupling: Another Example

- Insert data entry **25***:

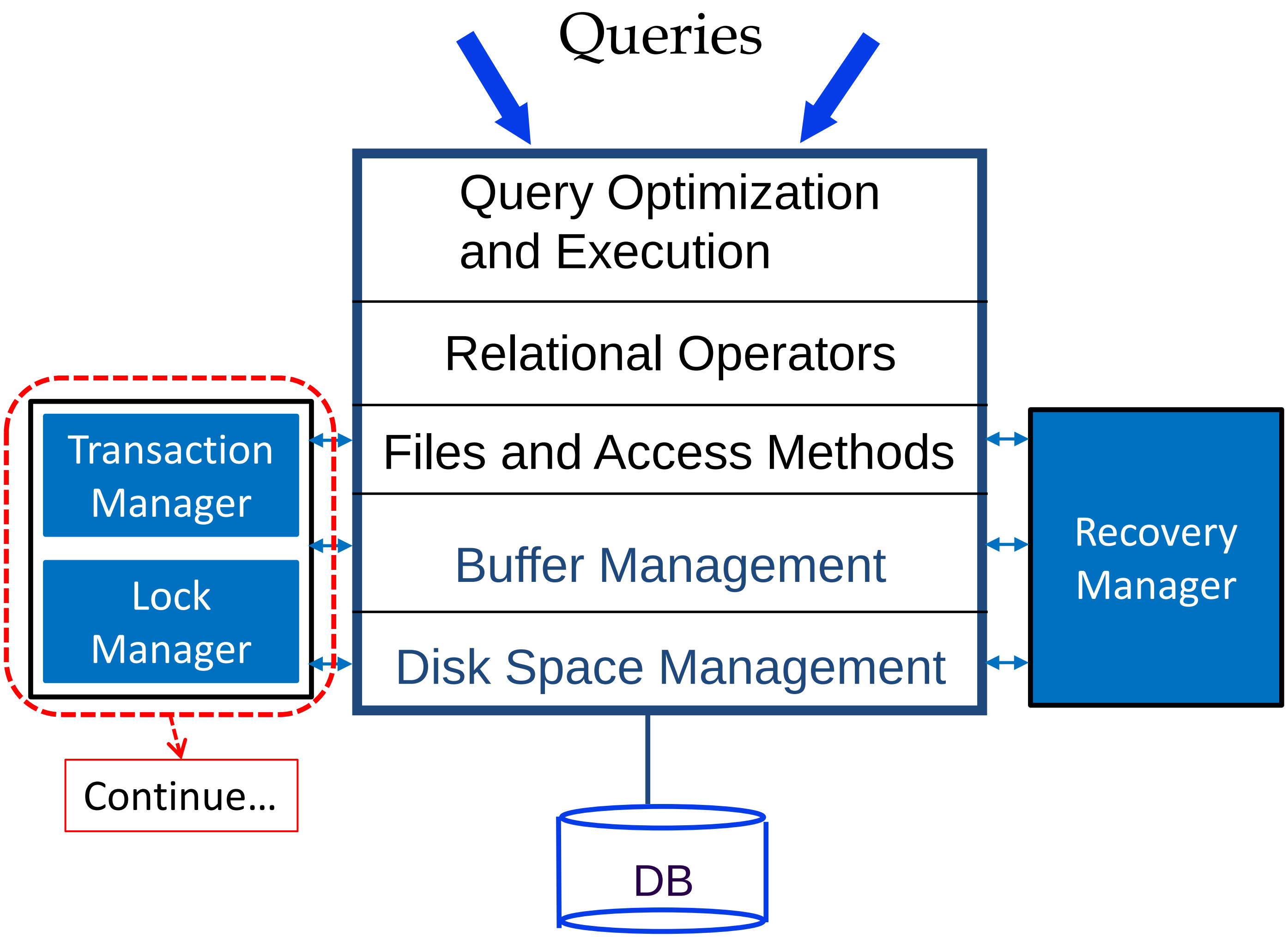


Lock-Coupling: Another Example

- Insert data entry **25***:



Next Class


Queries
Query Optimization
and Execution
Relational Operators
Files and Access Methods
Buffer Management
Disk Space Management
Transaction
Manager
Lock
Manager
Continue…
Recovery
Manager
DB