Database Applications (15-415)

DBMS Internals- Part XII
Lecture 23, April 14, 2015

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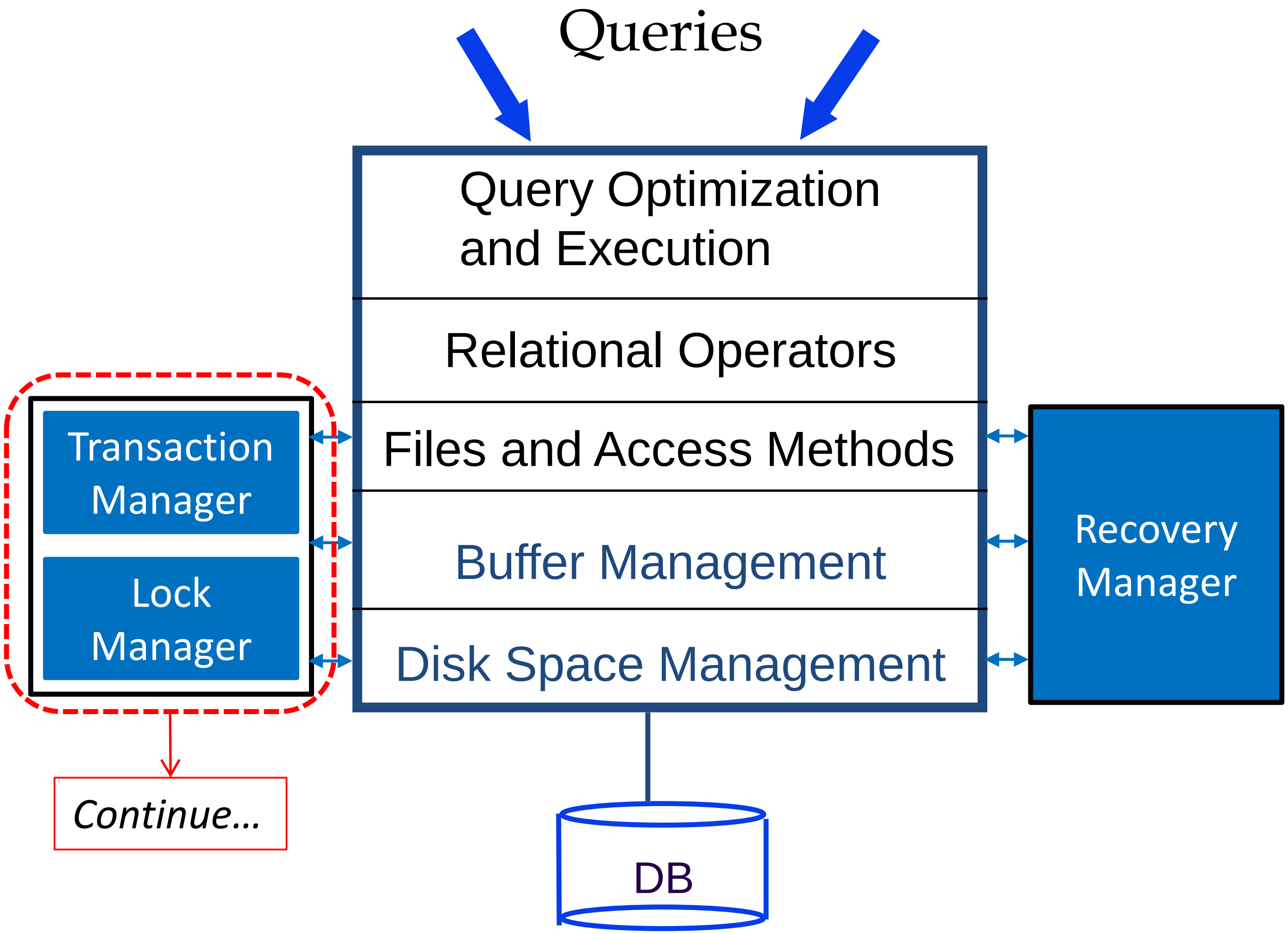
Today…

- Last Two Sessions:
  - DBMS Internals- Part XI
    - Transaction Management
- Today's Session:
  - Transaction Management (*Cont'd*)
- Announcements:
  - PS5 (the "last" assignment) is now posted. It is due on Thursday, April 23rd
  - The final exam is on Monday April 27th, from 8:30AM to 11:30AM in room 1190 (*all materials are included- open book, open notes*)

DBMS Layers



Queries

Query Optimization and Execution

Relational Operators

Files and Access Methods

Buffer Management

Disk Space Management

DB

Transaction Manager

Lock Manager

Recovery Manager

Continue…

Outline

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

Performance of Locking

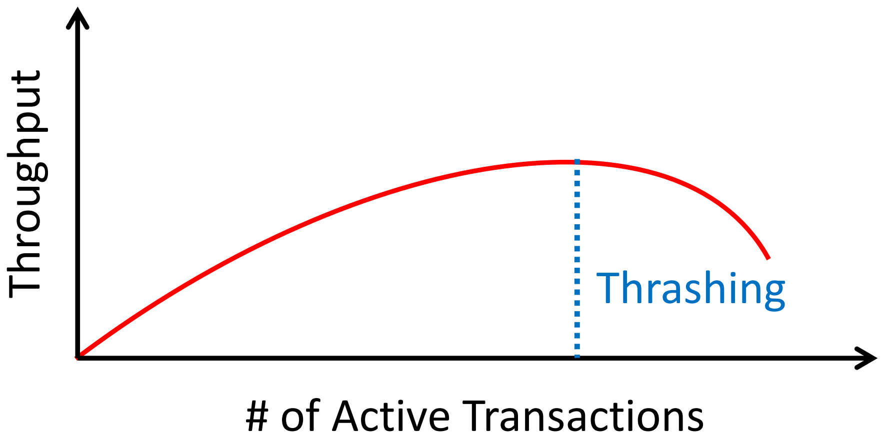
- Locking comes with delays mainly from *blocking*

- Usually, the first few transactions are unlikely to conflict
  - Throughput can rise in proportion to the number of active transactions

- As more transactions are executed concurrently, the likelihood of blocking increases
  - Throughput will increase more slowly with the number of active transactions

- There comes a point when adding another active transaction will actually decrease throughput
  - When the system *thrashes*!

Performance of Locking (*Cont'd*)



- If a database begins to *thrash*, the DBA should reduce the number of active transactions

- Empirically, thrashing is seen to occur when 30% of active transactions are blocked!

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 *on each row*, ***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 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 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*

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Deadlock Detection

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

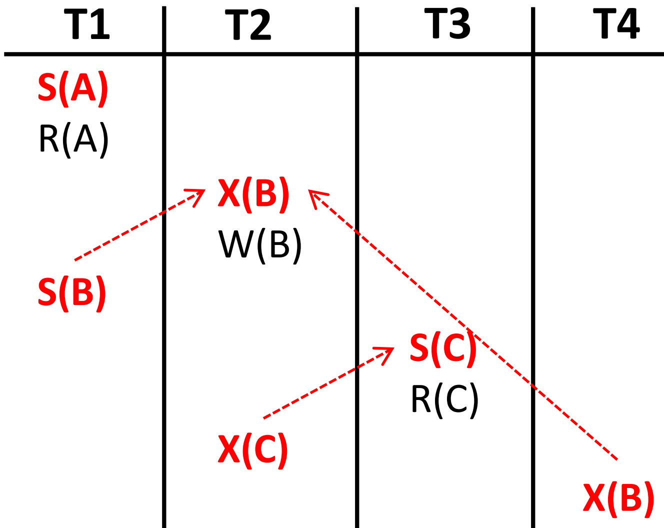
- In a waits-for graph:
  - The nodes correspond to active transactions
  - There is an edge from Ti to Tj *if and only if* Ti is waiting for Tj to release a lock

- 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

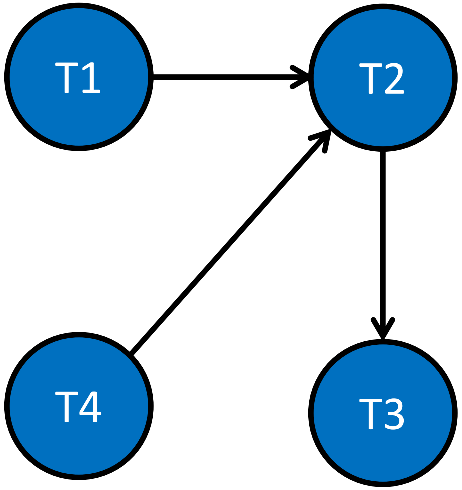
Deadlock Detection (*Cont'd*)

- The following schedule is free of deadlocks:



T1	T2	T3	T4
S(A)			
R(A)			
	X(B)		
	W(B)		
S(B)			
		S(C)	
		R(C)	
	X(C)		
			X(B)

A schedule *without* a deadlock



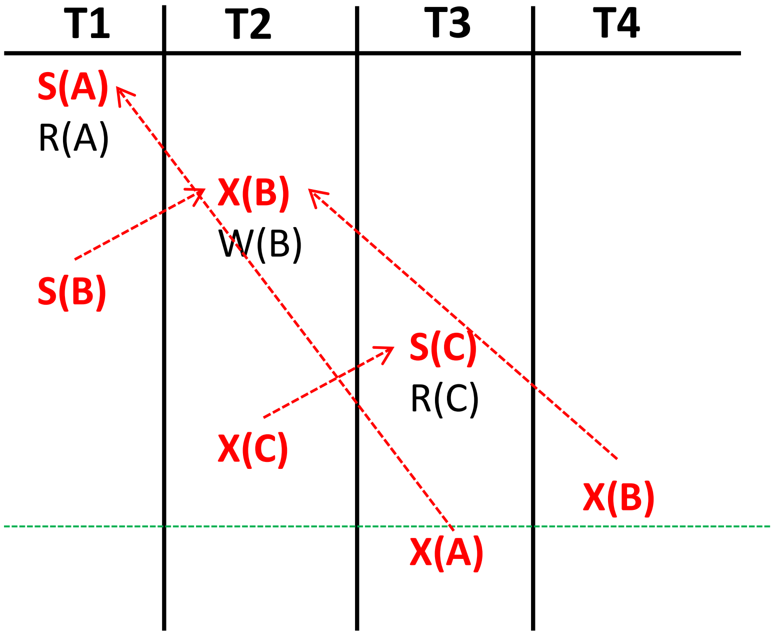
No cycles; hence, no deadlocks!

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

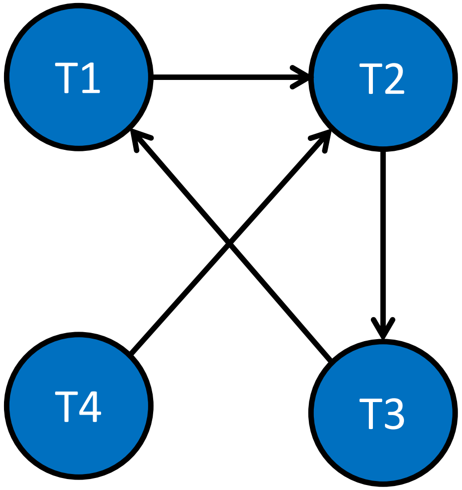
Deadlock Detection (*Cont'd*)

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



T1	T2	T3	T4
S(A)			
R(A)			
	X(B)		
	W(B)		
S(B)			
		S(C)	
		R(C)	
	X(C)		
			X(B)
		X(A)	

A schedule *with* a deadlock



The Corresponding **Waits-For Graph***

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Deadlock Detection (*Cont'd*)

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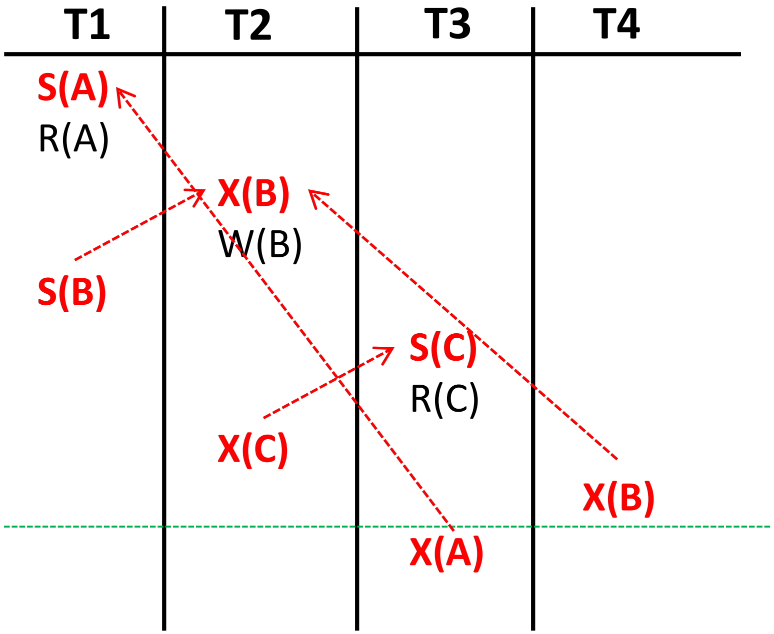
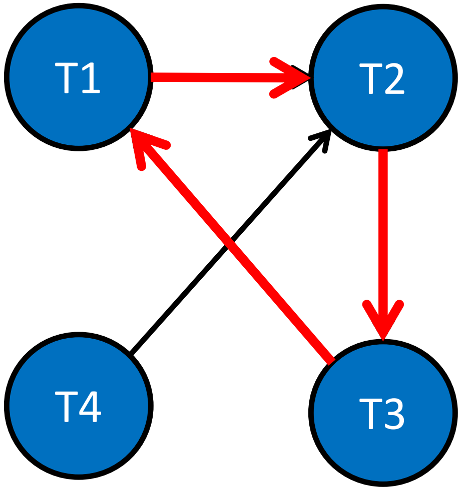


T1	T2	T3	T4
S(A)			
R(A)			
	X(B)		
	W(B)		
S(B)			
		S(C)	
		R(C)	
	X(C)		
			X(B)
		X(A)	

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!

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- Dynamic Databases and the Phantom Problem ✓
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Dynamic Databases

- Thus far, we have assumed *static databases*
- 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 *only* scans S to find the oldest Sailor for specific rating levels
  - A transaction ***T2*** which updates Sailor while T1 is running

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):

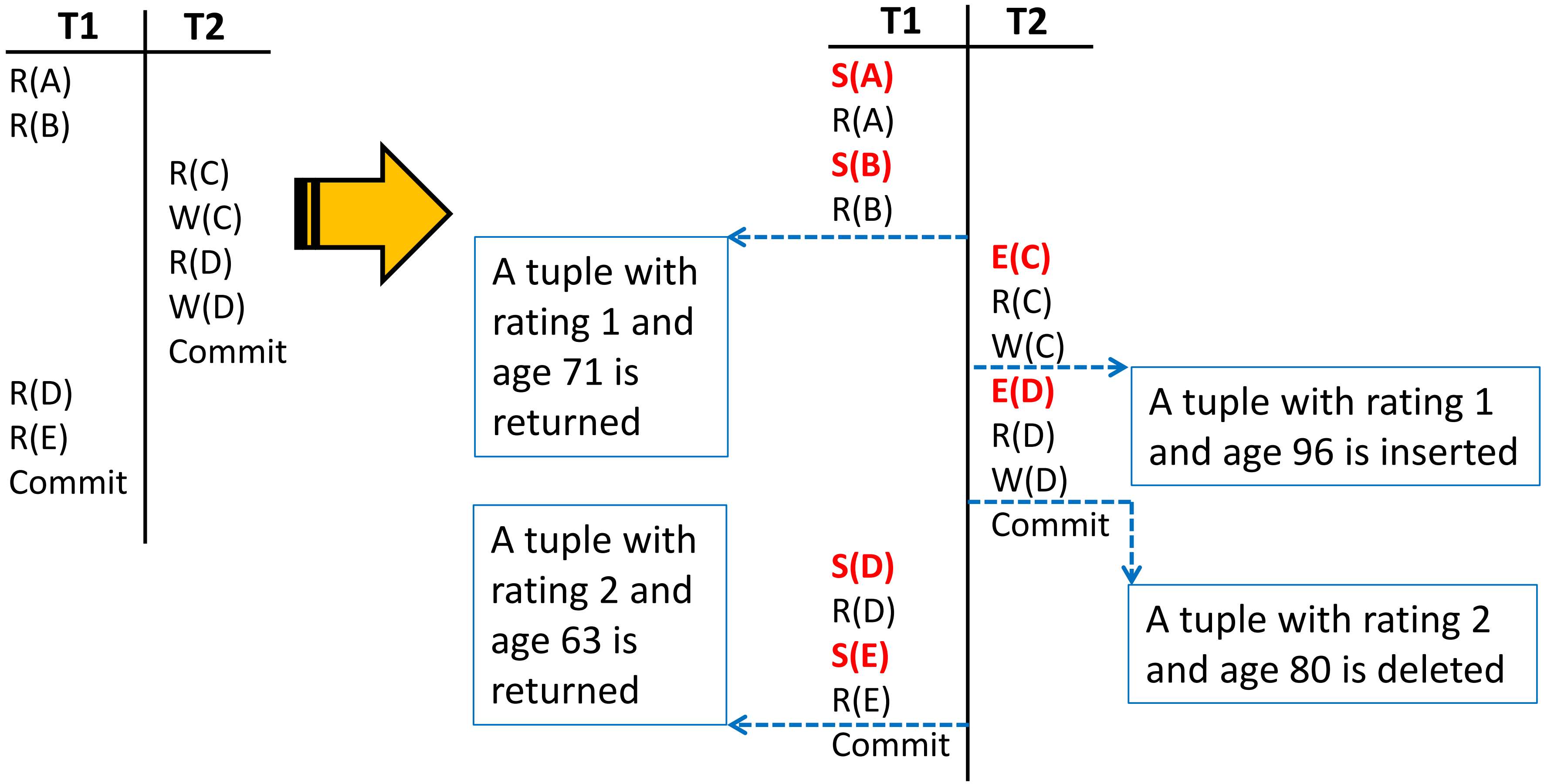
T1	T2
R(A)	
R(B)	
	R(C)
	W(C)
	R(D)
	W(D)
	Commit
R(D)	
R(E)	
Commit	

⇨

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	

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 tuple with rating 1 and age 71 is returned

A tuple with rating 1 and age 96 is inserted

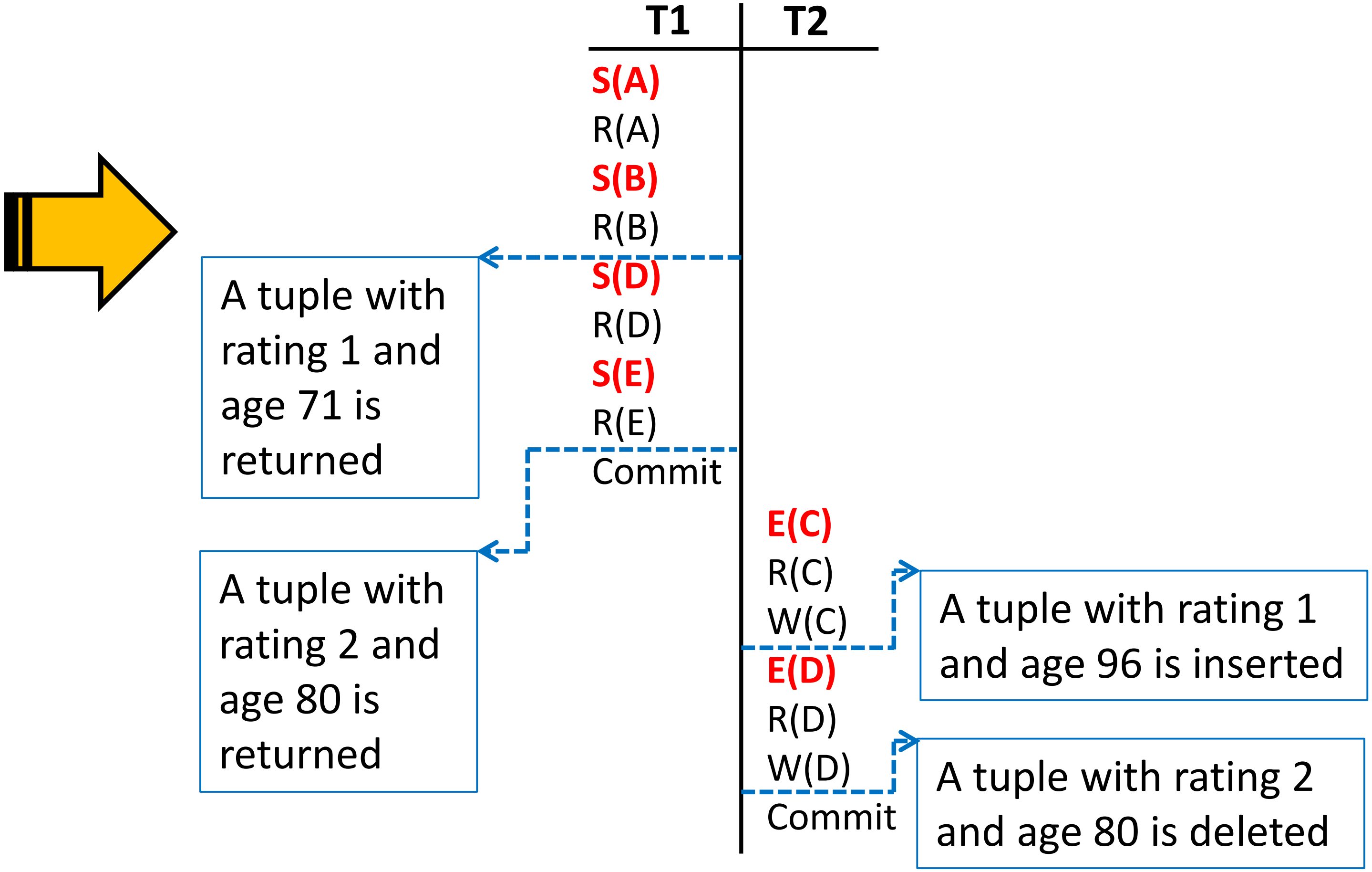
A tuple with rating 2 and age 80 is deleted

A tuple with rating 2 and age 63 is returned

A Possible Scenario (*Cont’d*)

- One possible serial execution 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



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

A tuple with rating 1 and age 71 is returned

A tuple with rating 2 and age 80 is returned

A tuple with rating 1 and age 96 is inserted

A tuple with rating 2 and age 80 is deleted

A Possible Scenario (*Cont'd*)

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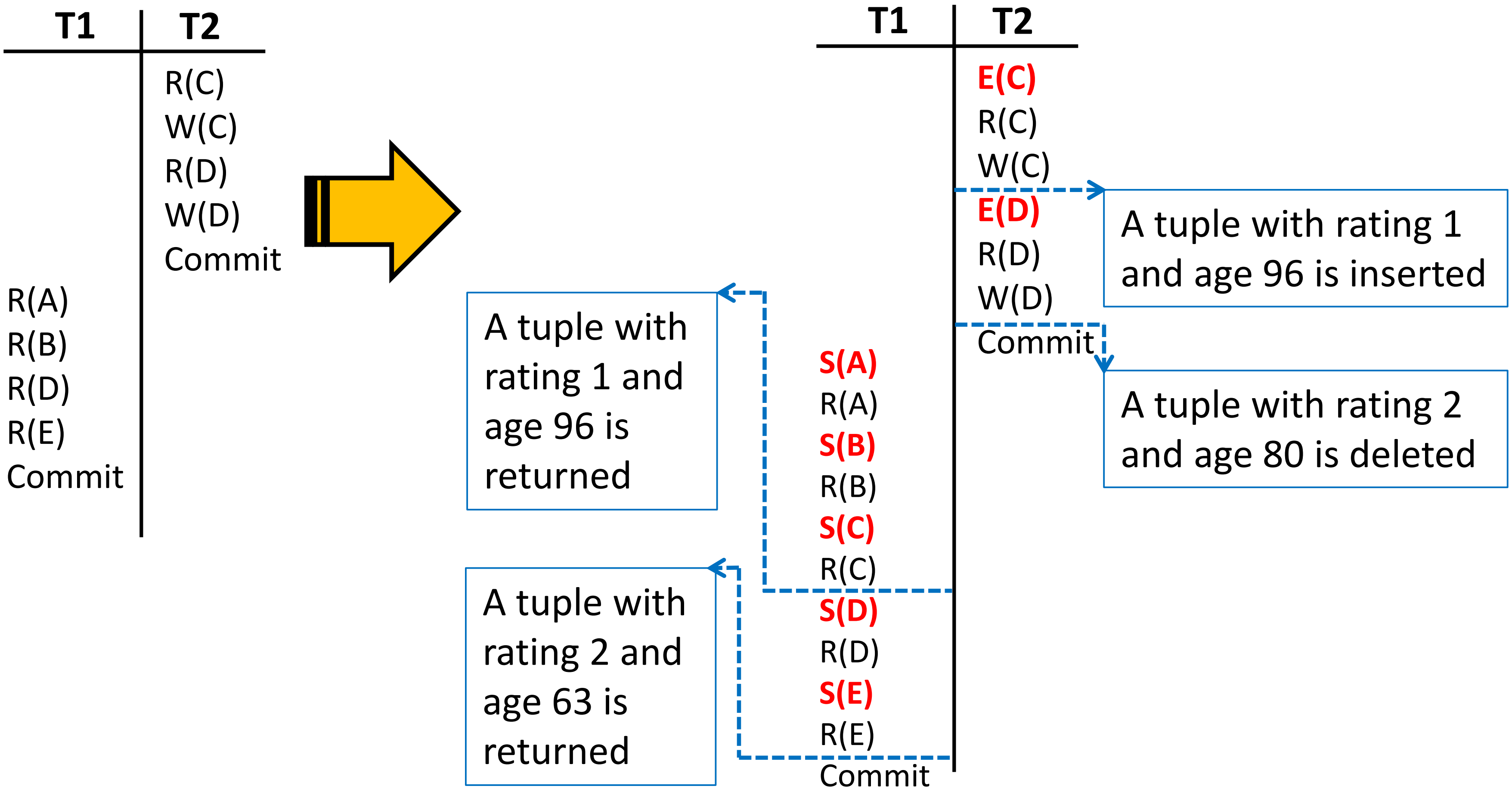


T1	T2
	R(C)
	W(C)
	R(D)
	W(D)
	Commit
R(A)	
R(B)	
R(D)	
R(E)	
Commit	

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

A tuple with rating 1 and age 96 is inserted

A tuple with rating 2 and age 80 is deleted

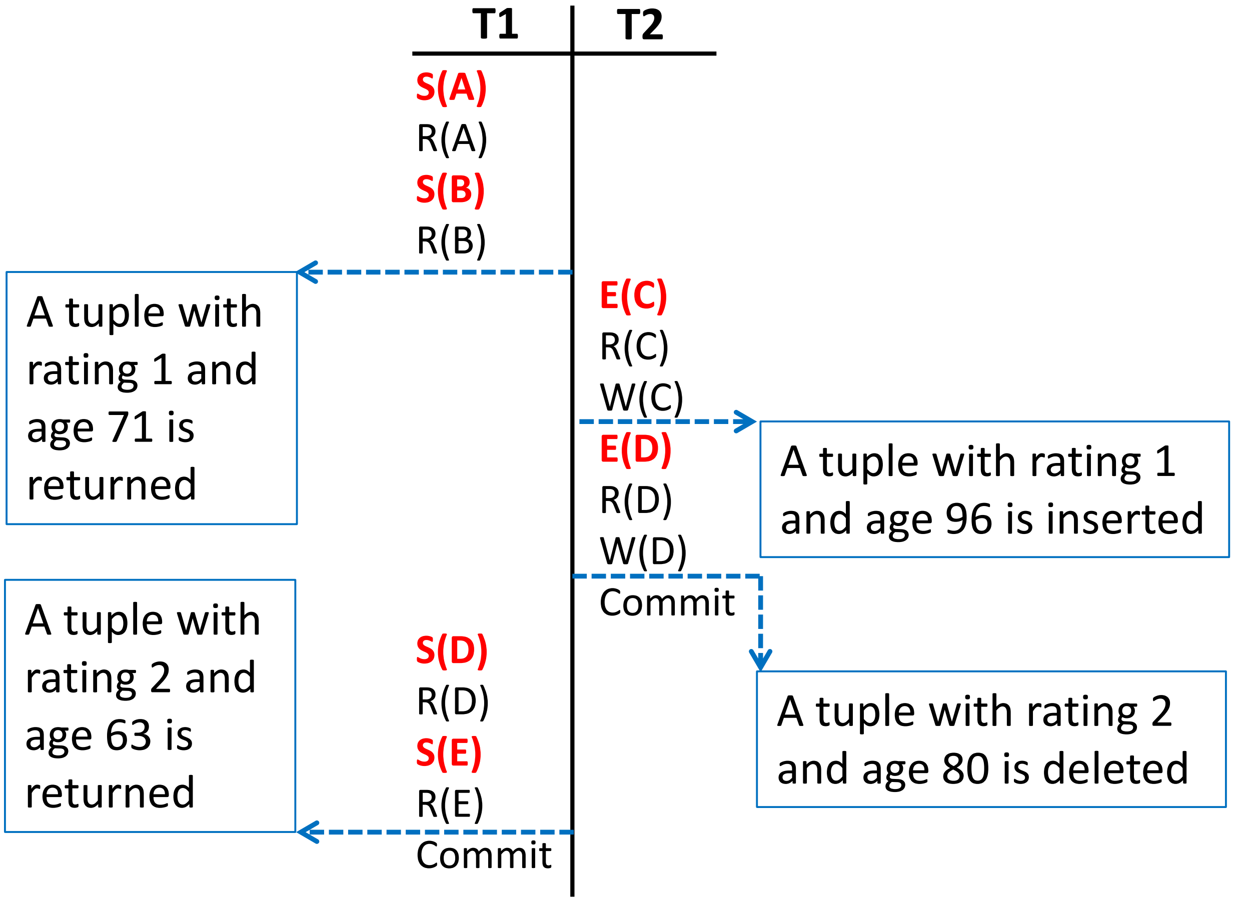
A tuple with rating 1 and age 96 is returned

A tuple with rating 2 and age 63 is returned

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	



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 tuple with rating 1 and age 71 is returned

A tuple with rating 1 and age 96 is inserted

A tuple with rating 2 and age 80 is deleted

A tuple with rating 2 and age 63 is returned

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 *<u>phantom</u>* 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*

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Concurrency Control in B+ Trees

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

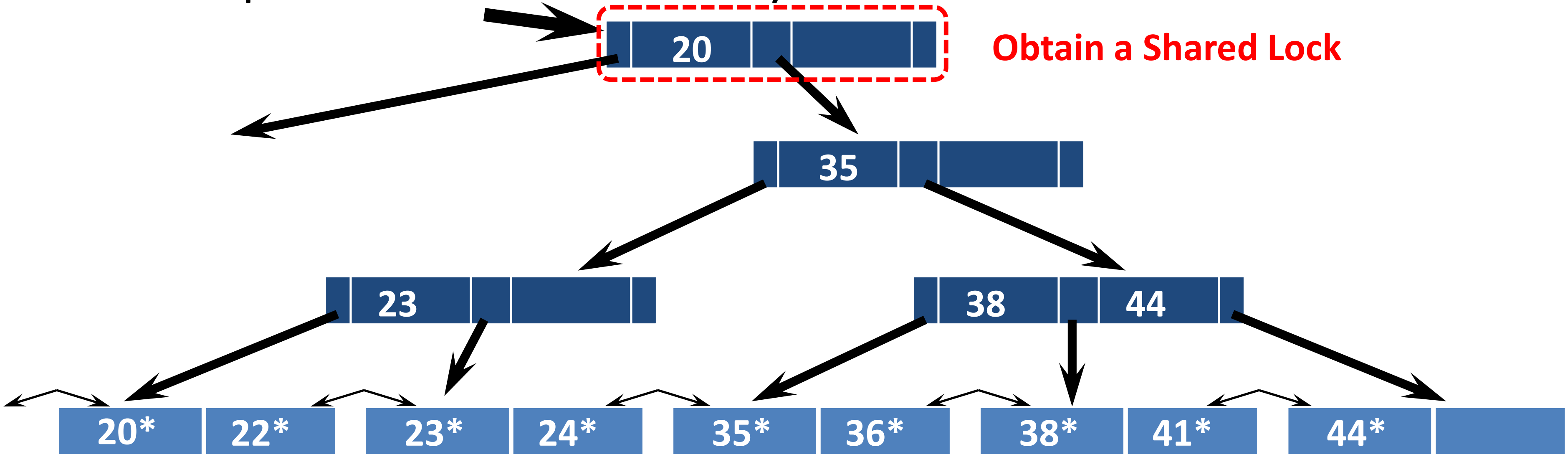
- *Three* observations provide the necessary insights to apply a locking protocol for B+ trees:
  1. The higher levels of a B+ tree only direct searches
  2. Searches never go back up a B+ tree when they proceed along paths to desired leafs
  3. Insertions/deletions can cause splits/merges, which might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



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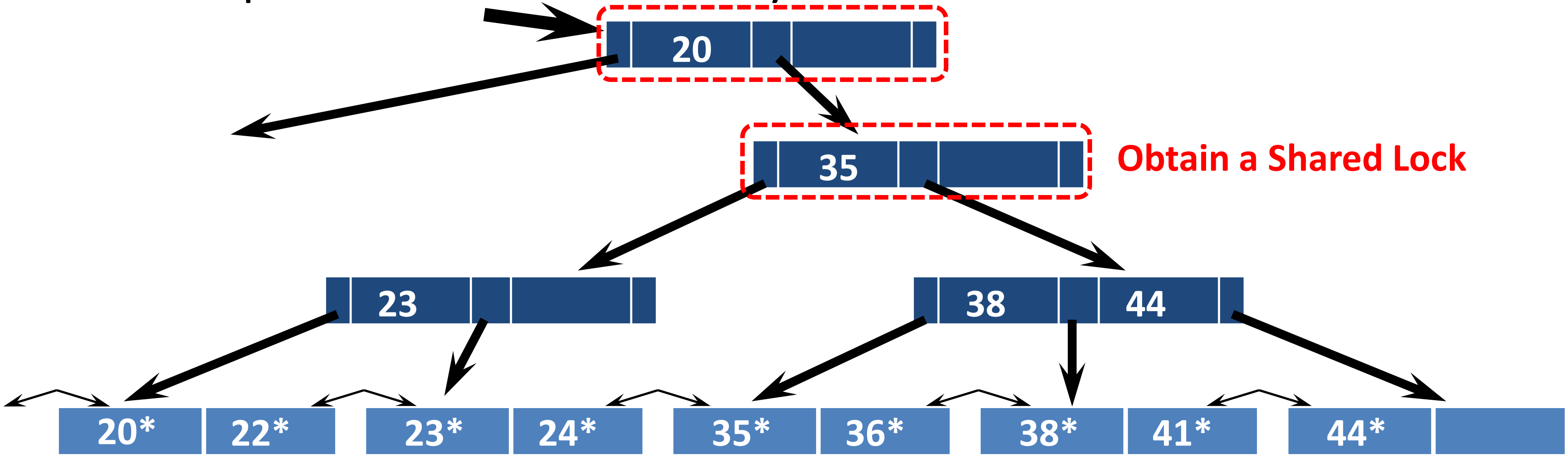

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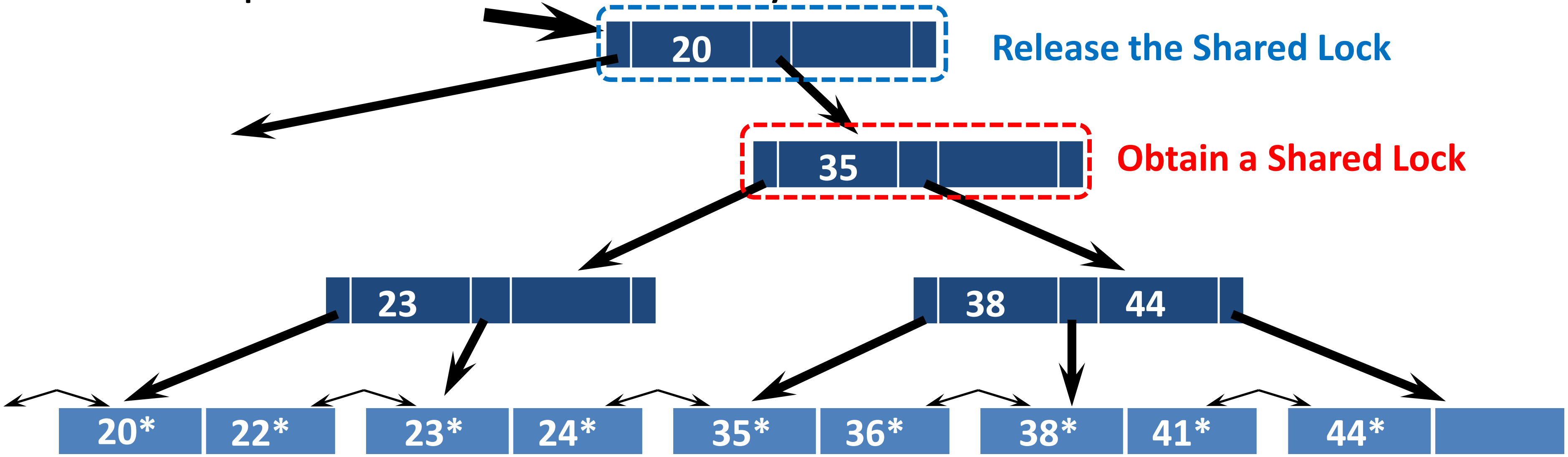

Release the Shared Lock

Obtain a Shared Lock

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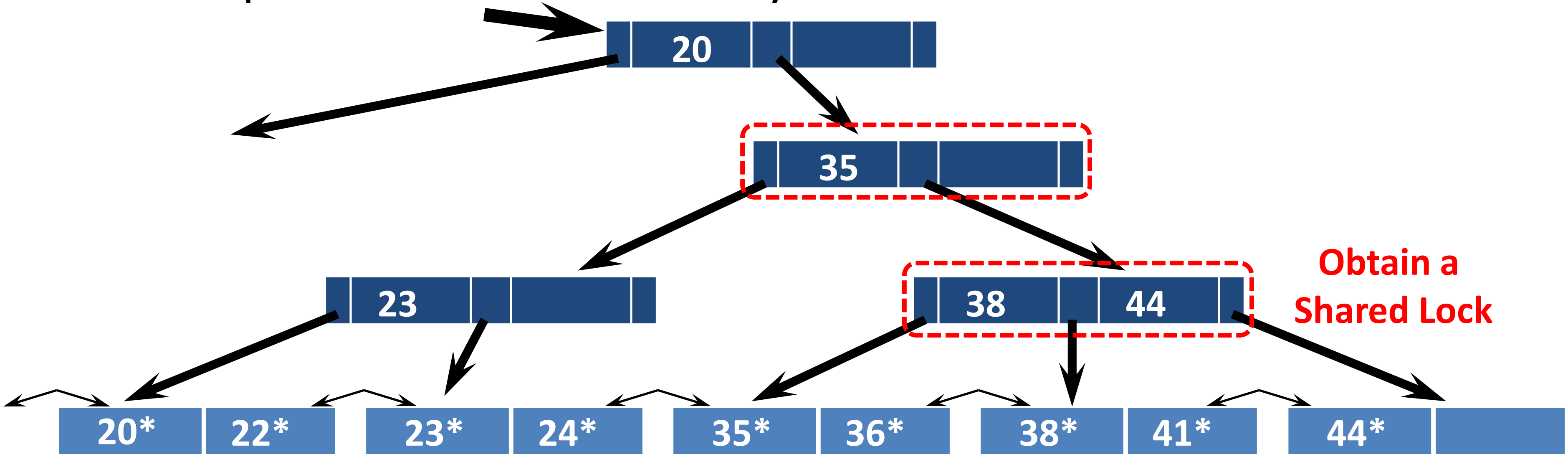

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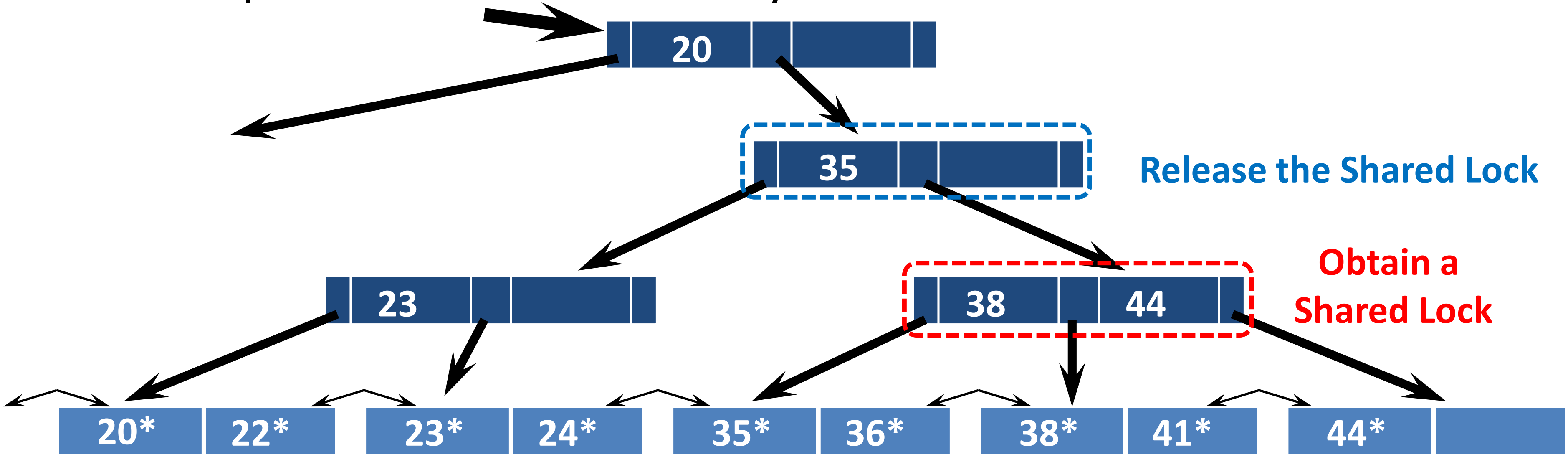

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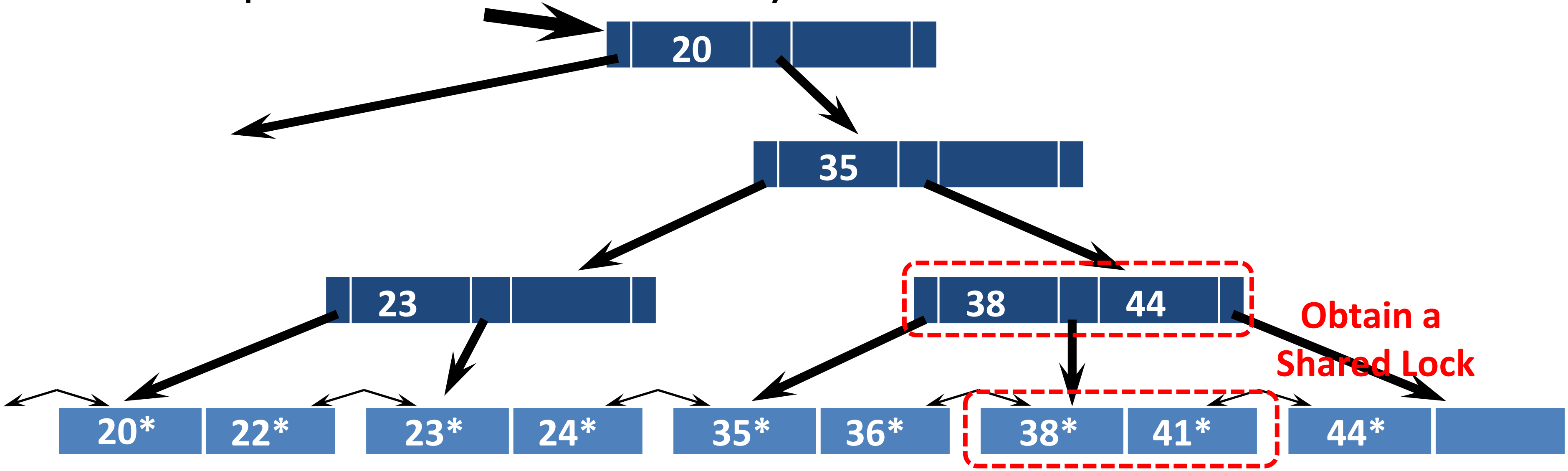

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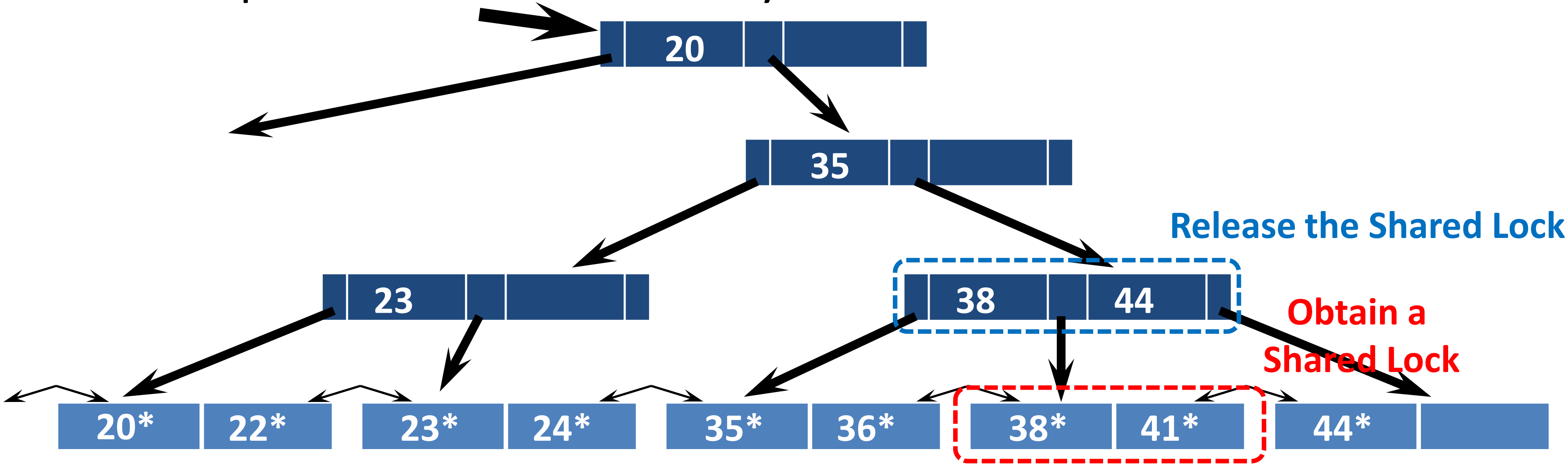

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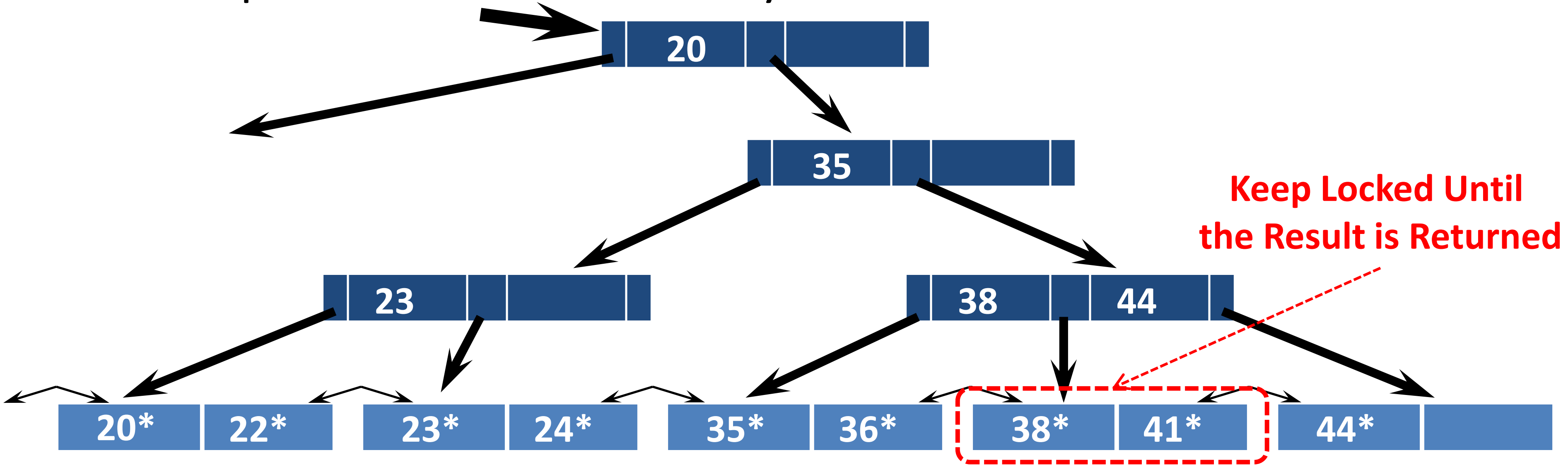


Towards A Locking Strategy for Insertions/Deletions

- 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*

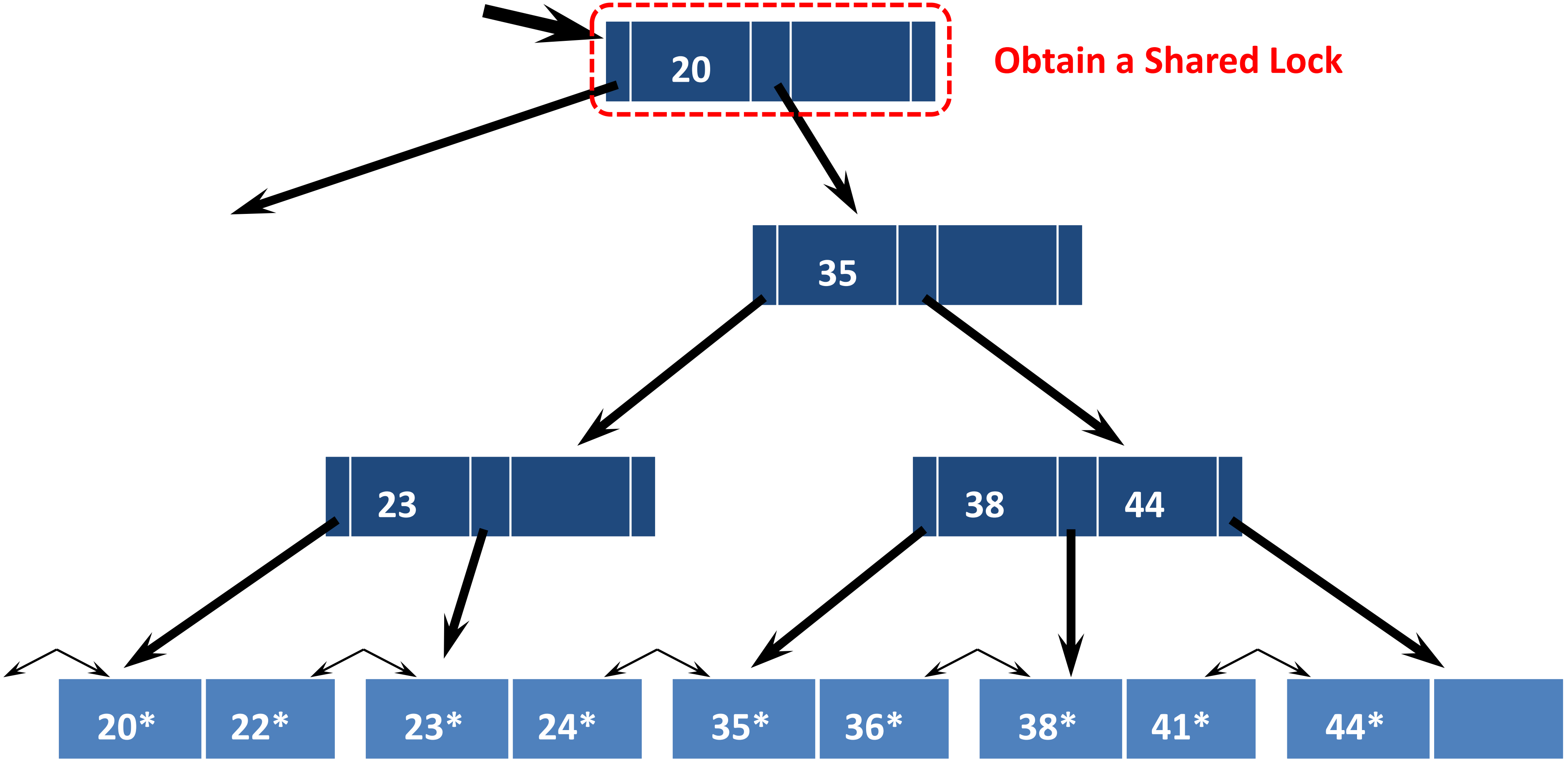
Lock-Coupling: A Locking Strategy for Insertions/Deletions (*Cont'd*)

- 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***:



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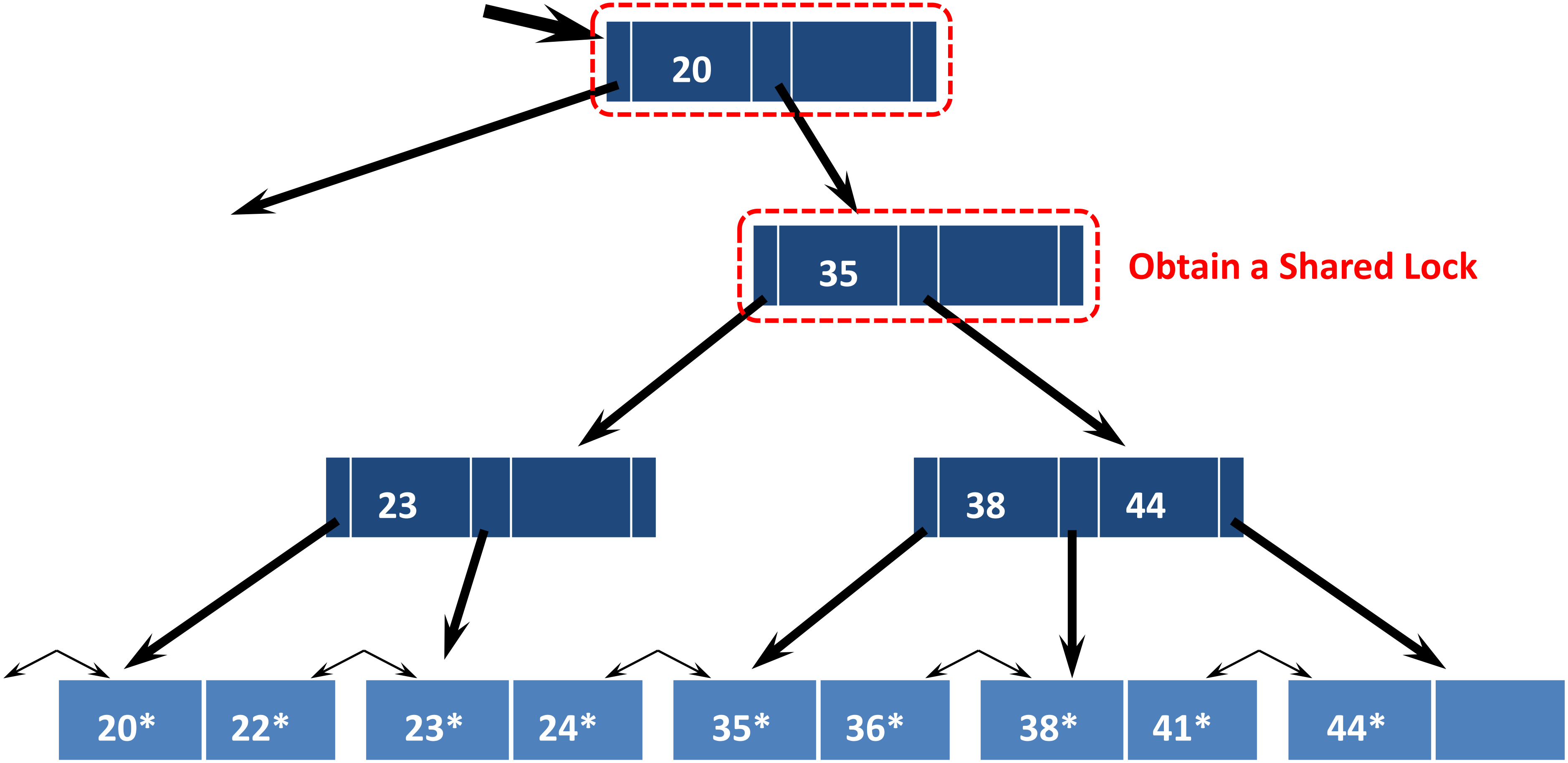

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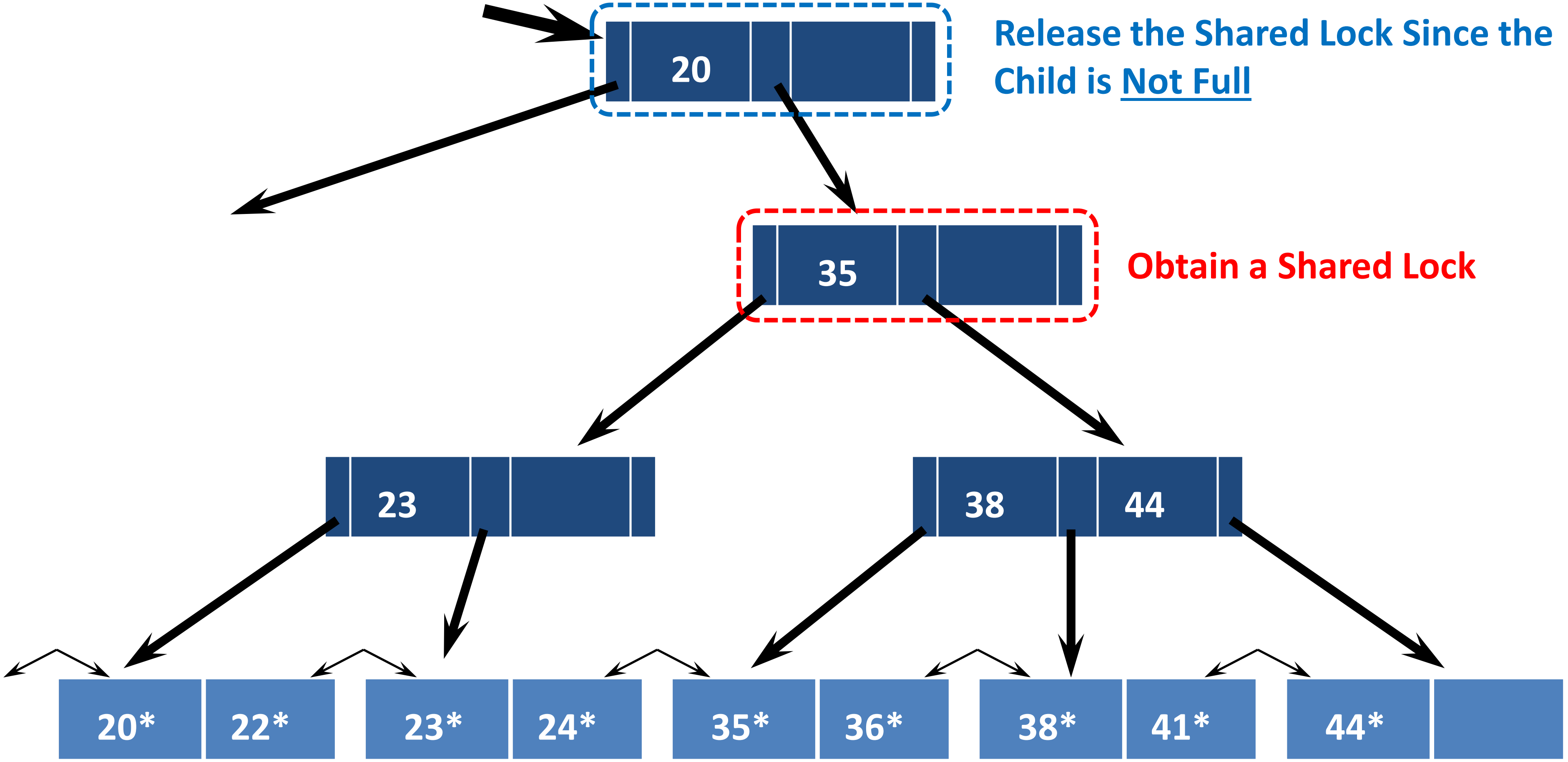
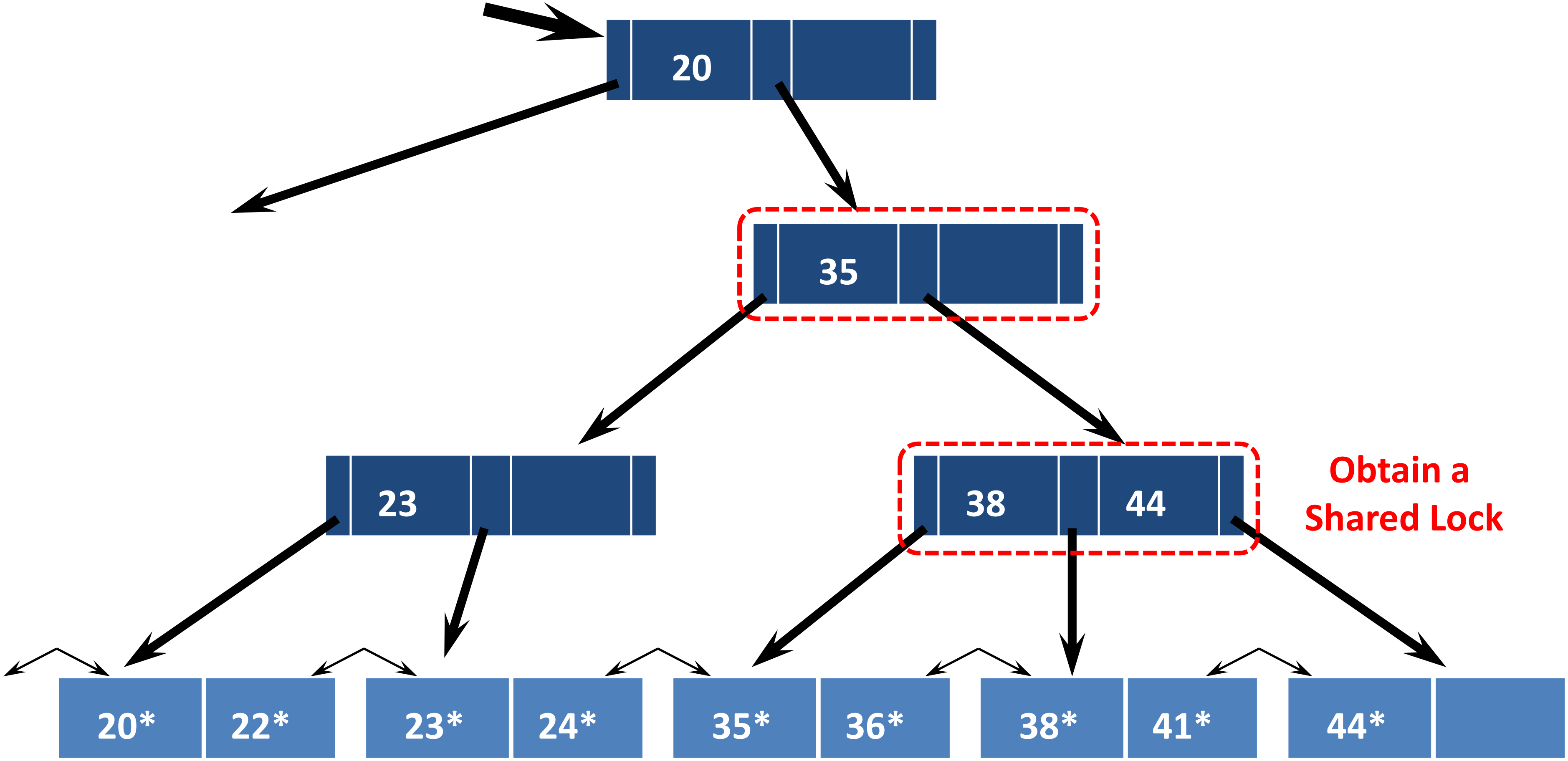


Release the Shared Lock Since the Child is Not Full

Obtain a Shared Lock

Lock-Coupling: An Example

- Insert data entry **45***:



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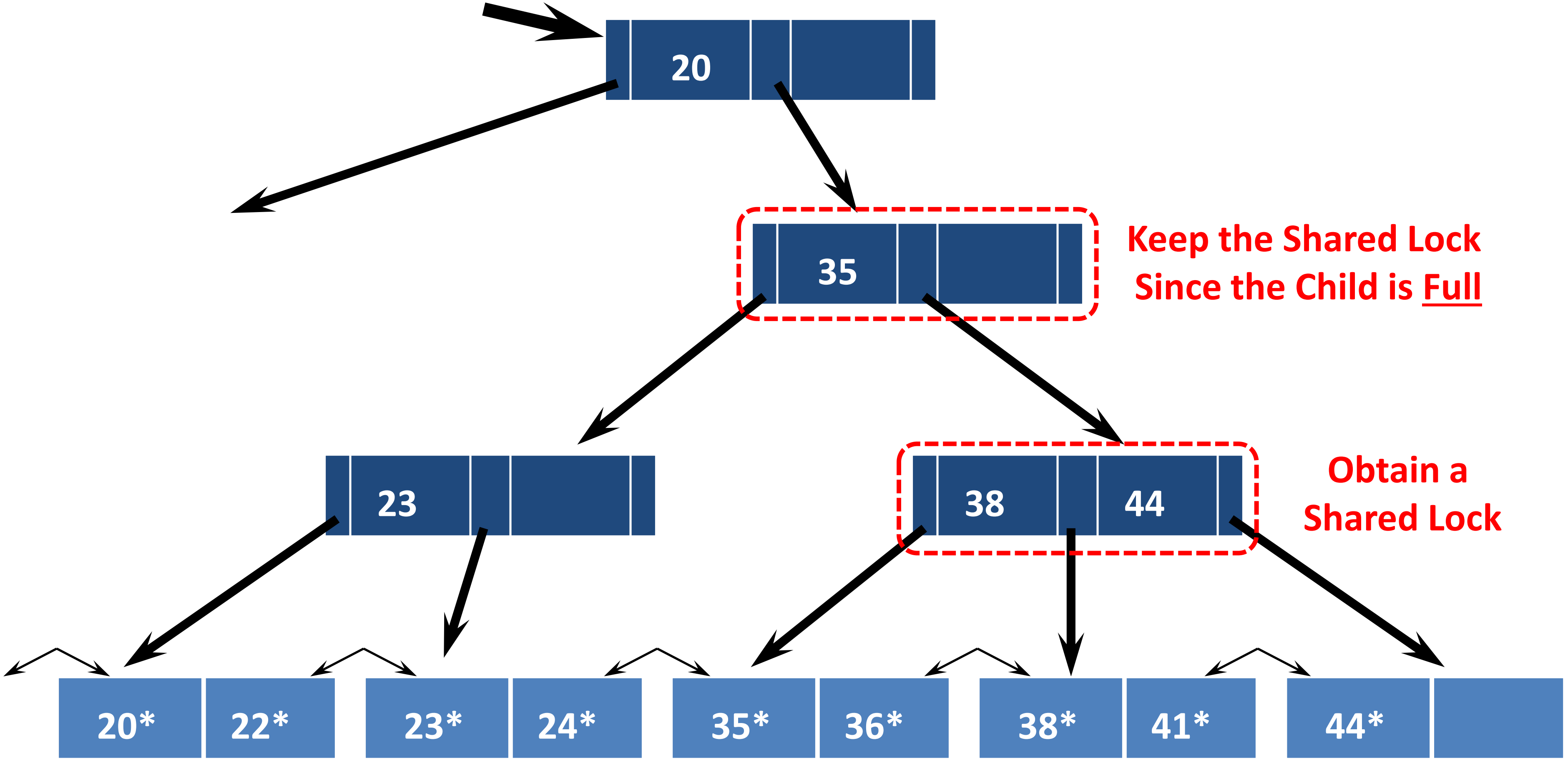
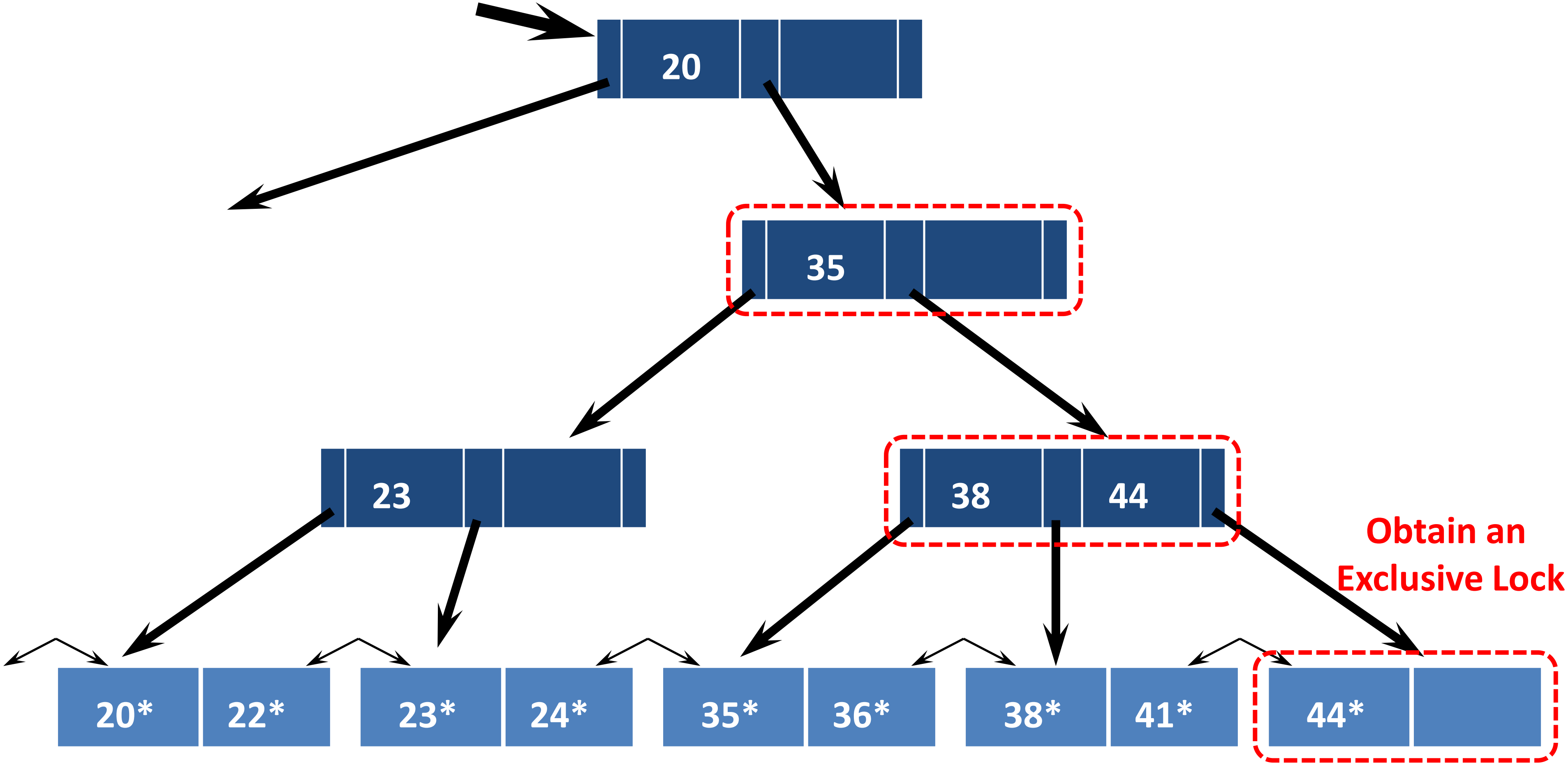


Keep the Shared Lock
Since the Child is Full

Obtain a
Shared Lock

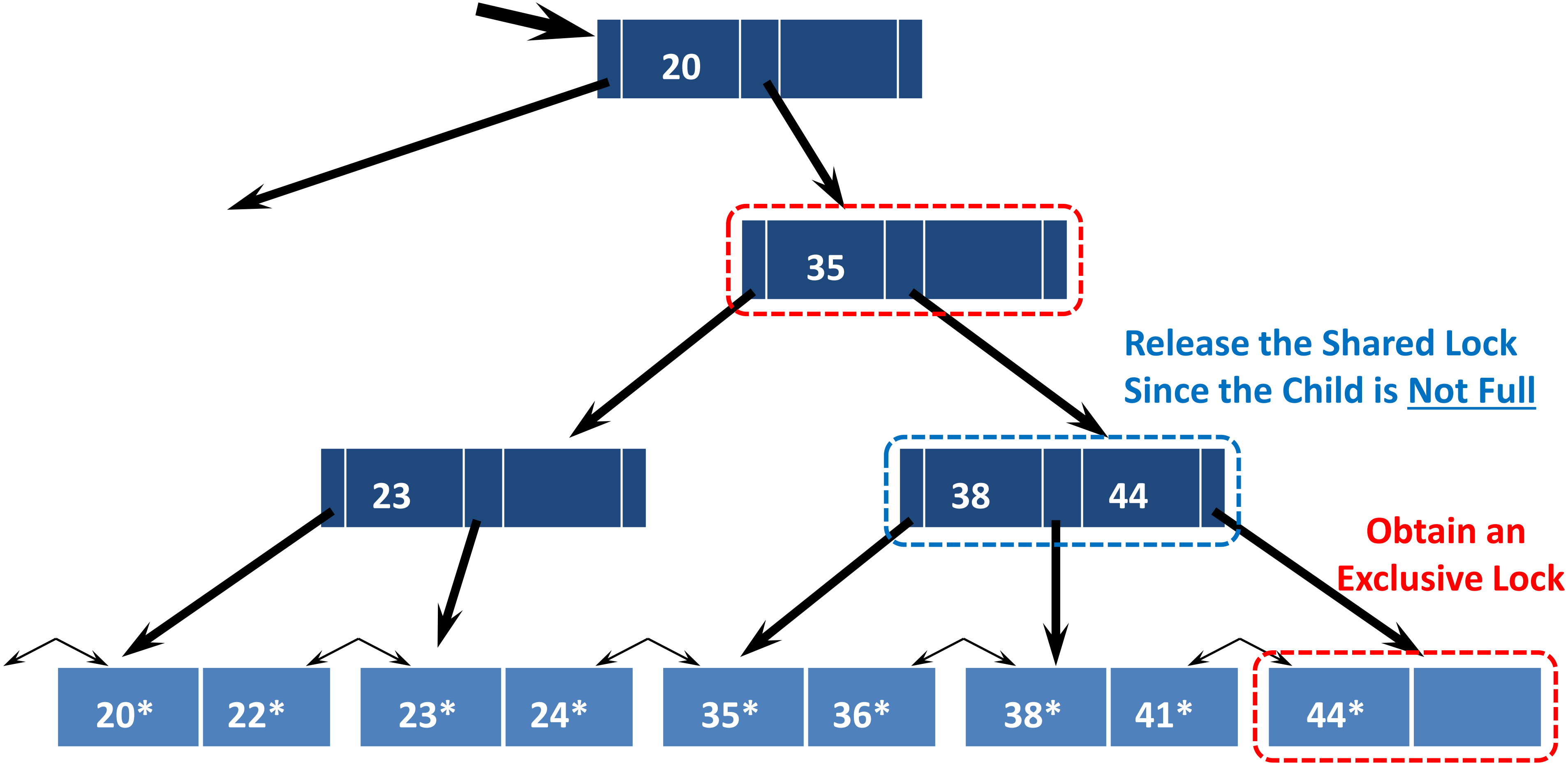
Lock-Coupling: An Example

- Insert data entry **45***:



Lock-Coupling: An Example

- Insert data entry **45***:

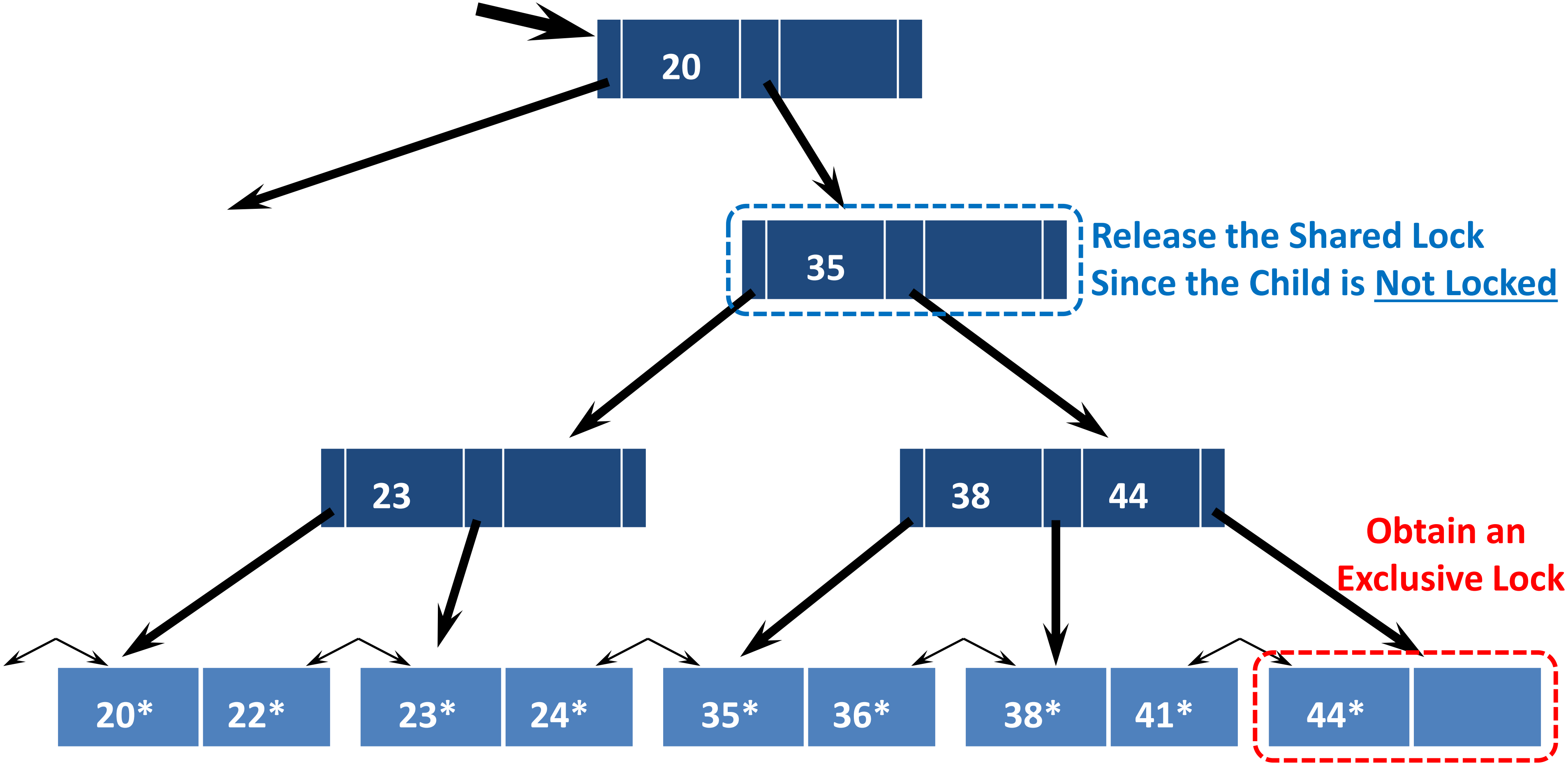


Release the Shared Lock
Since the Child is Not Full

Obtain an
Exclusive Lock

Lock-Coupling: An Example

- Insert data entry **45***:

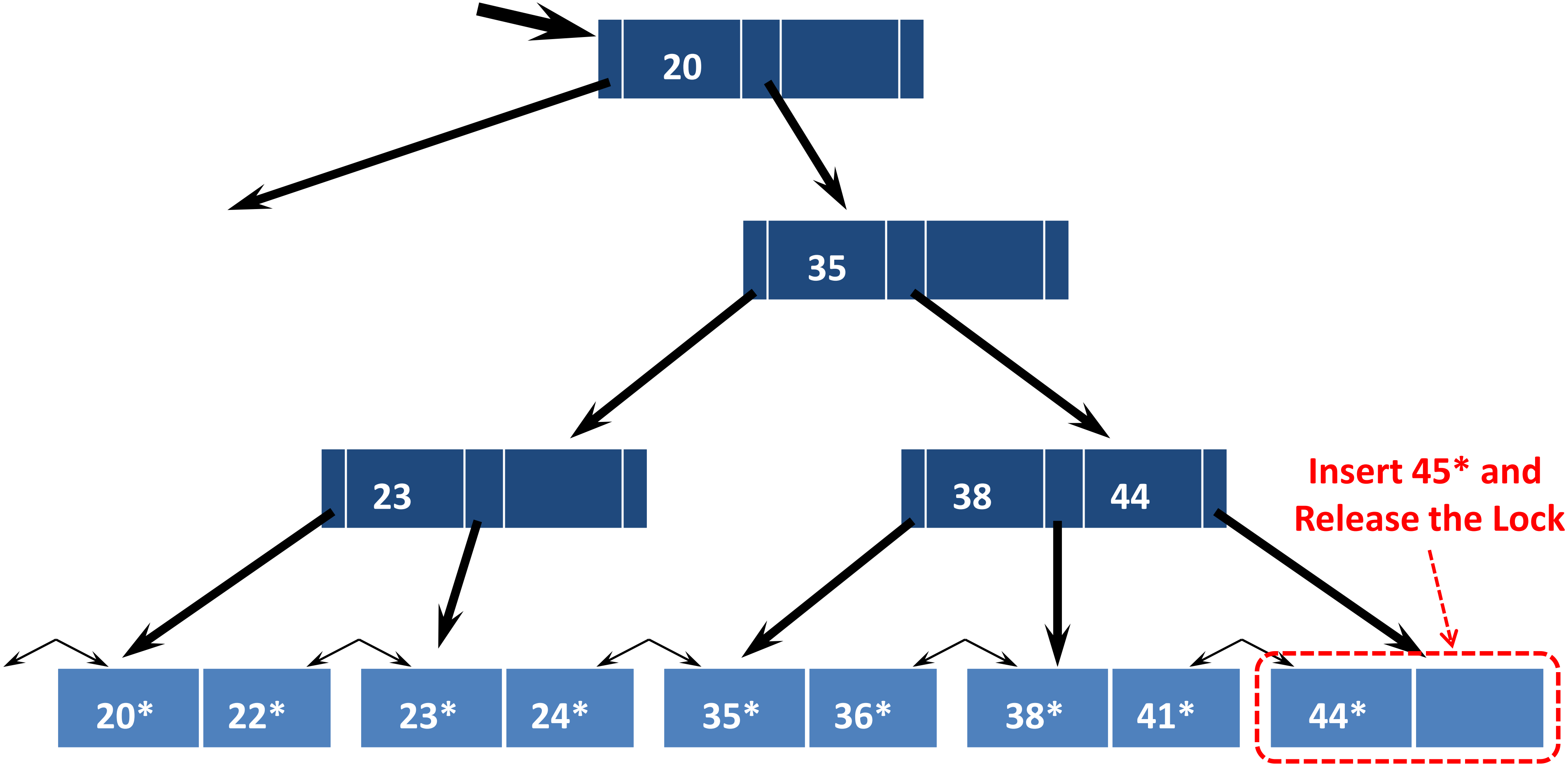


Release the Shared Lock
Since the Child is Not Locked

Obtain an
Exclusive Lock

Lock-Coupling: An Example

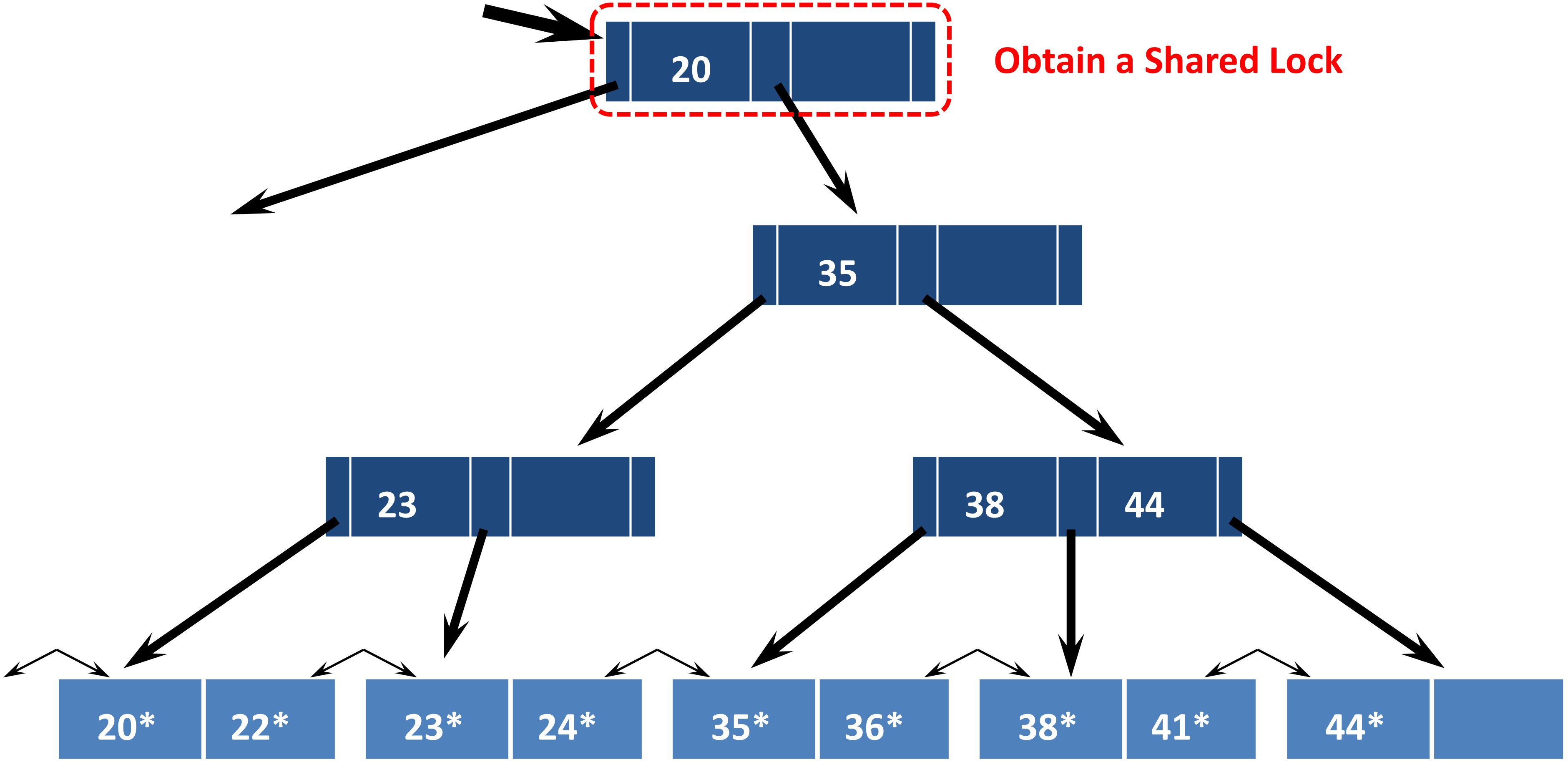
- Insert data entry **45***:



Insert 45* and Release the Lock

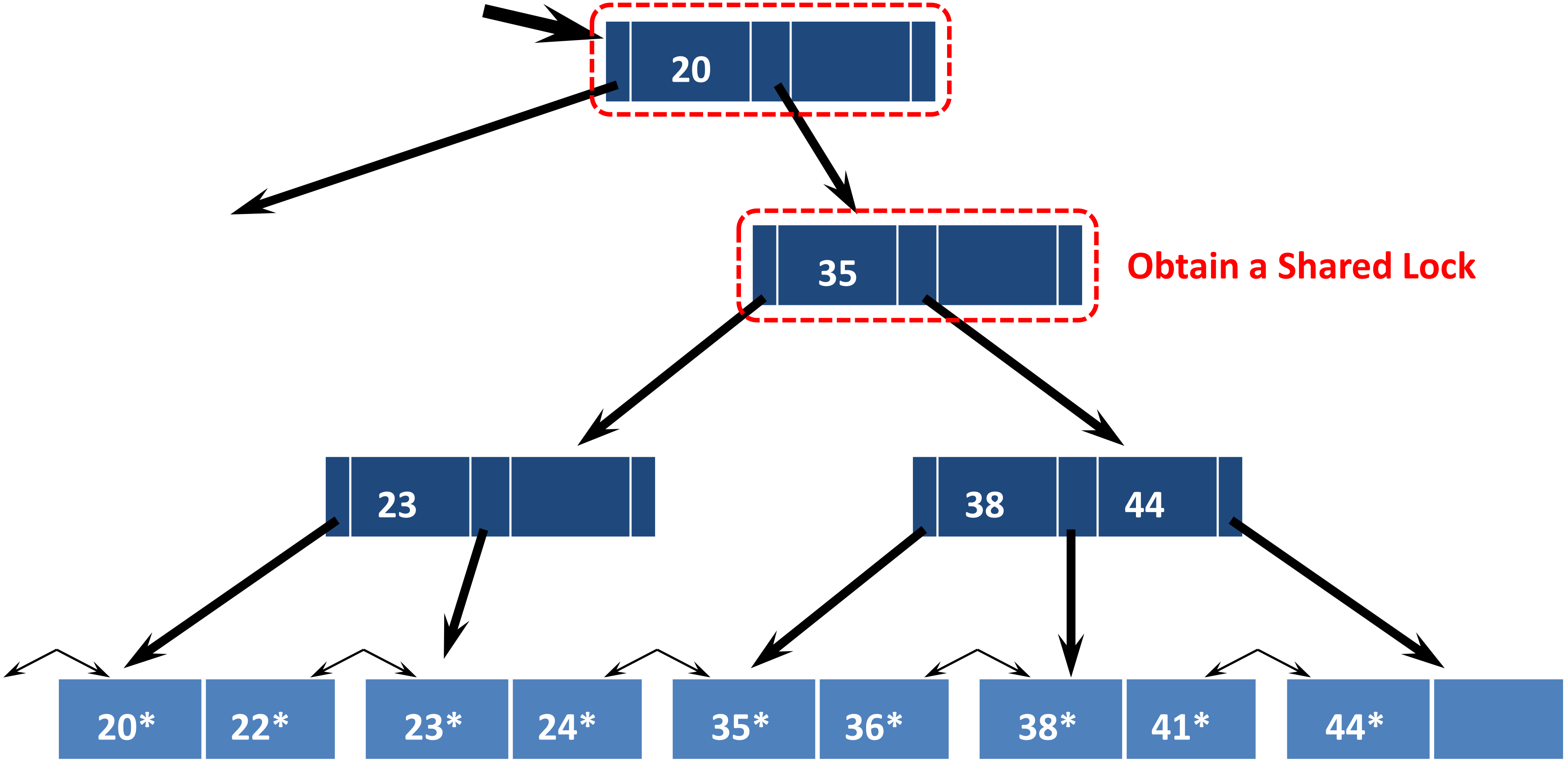
Lock-Coupling: Another Example

- Insert data entry **25***:



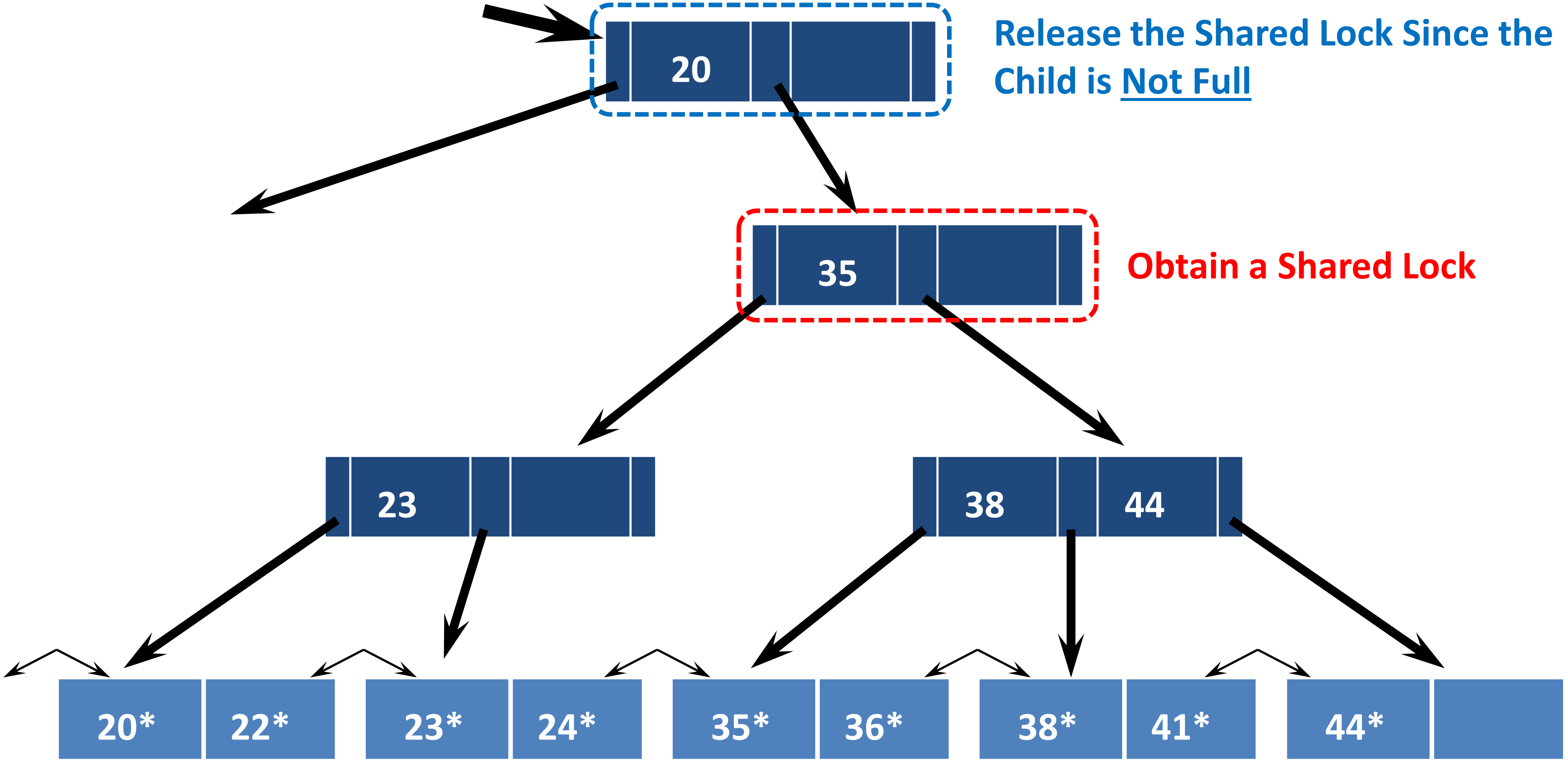
Lock-Coupling: Another Example

- Insert data entry **25***:



Lock-Coupling: Another Example

- Insert data entry **25***:

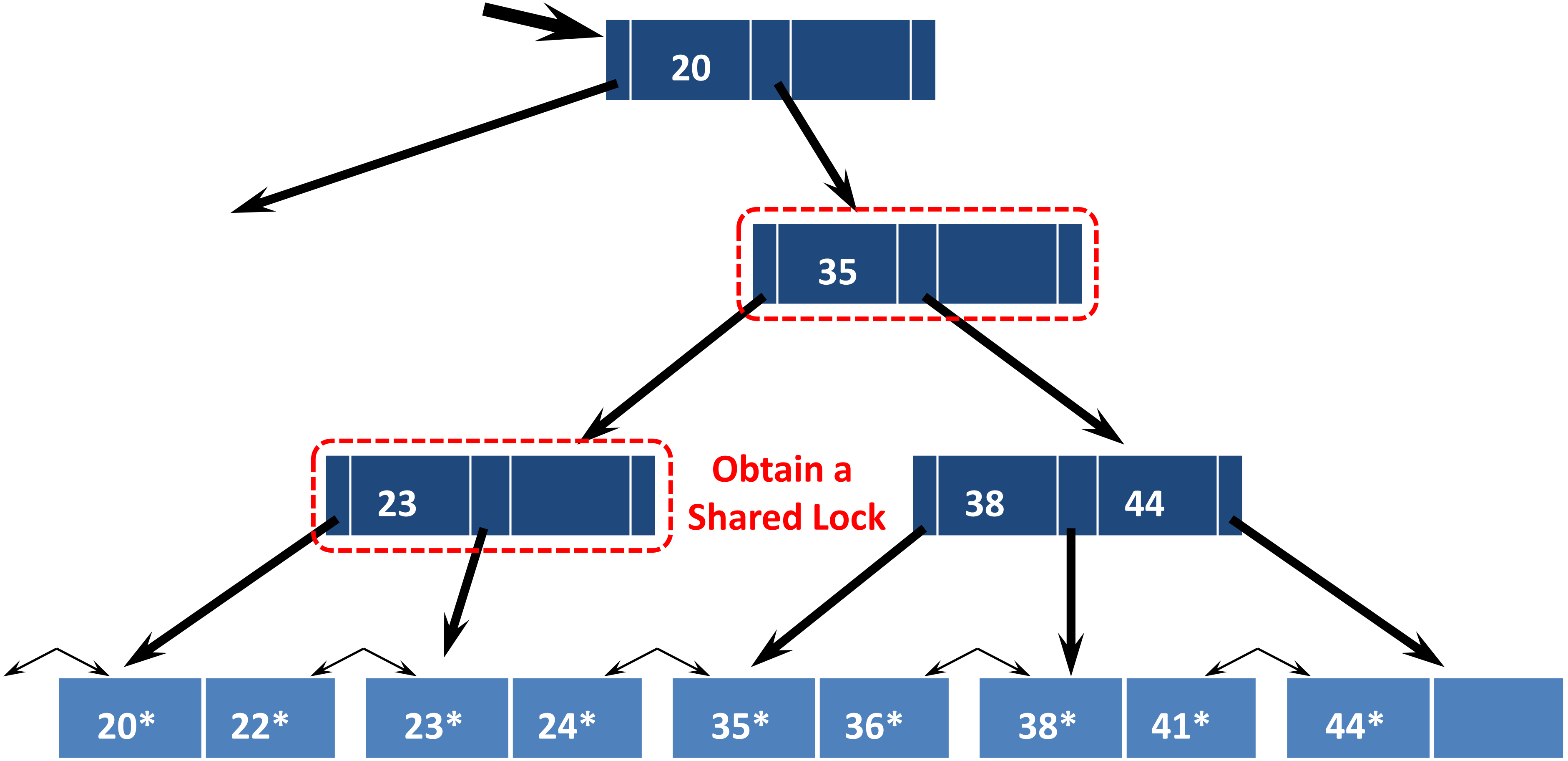


Release the Shared Lock Since the Child is Not Full

Obtain a Shared Lock

Lock-Coupling: Another Example

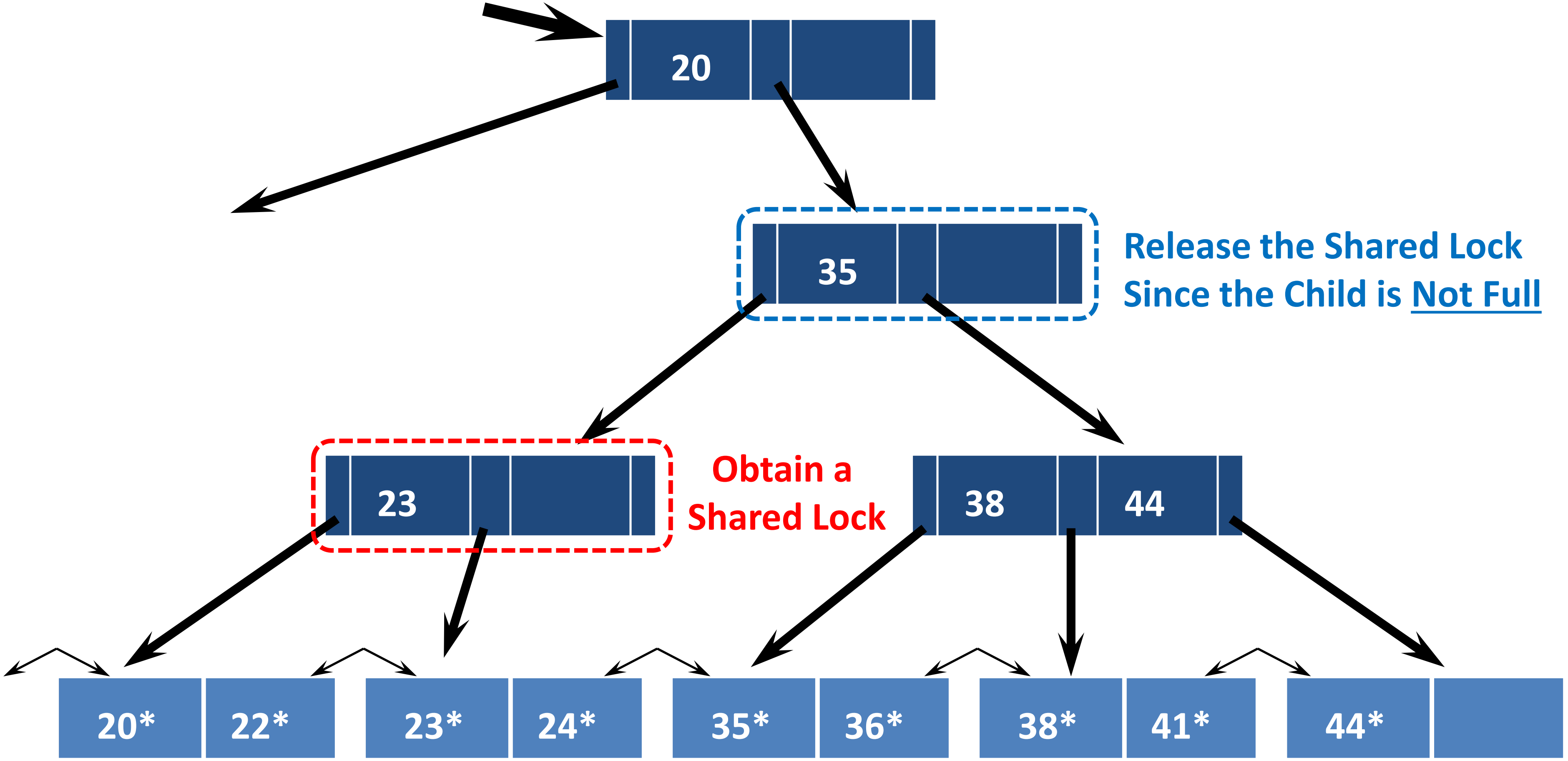
- Insert data entry **25***:



Obtain a Shared Lock

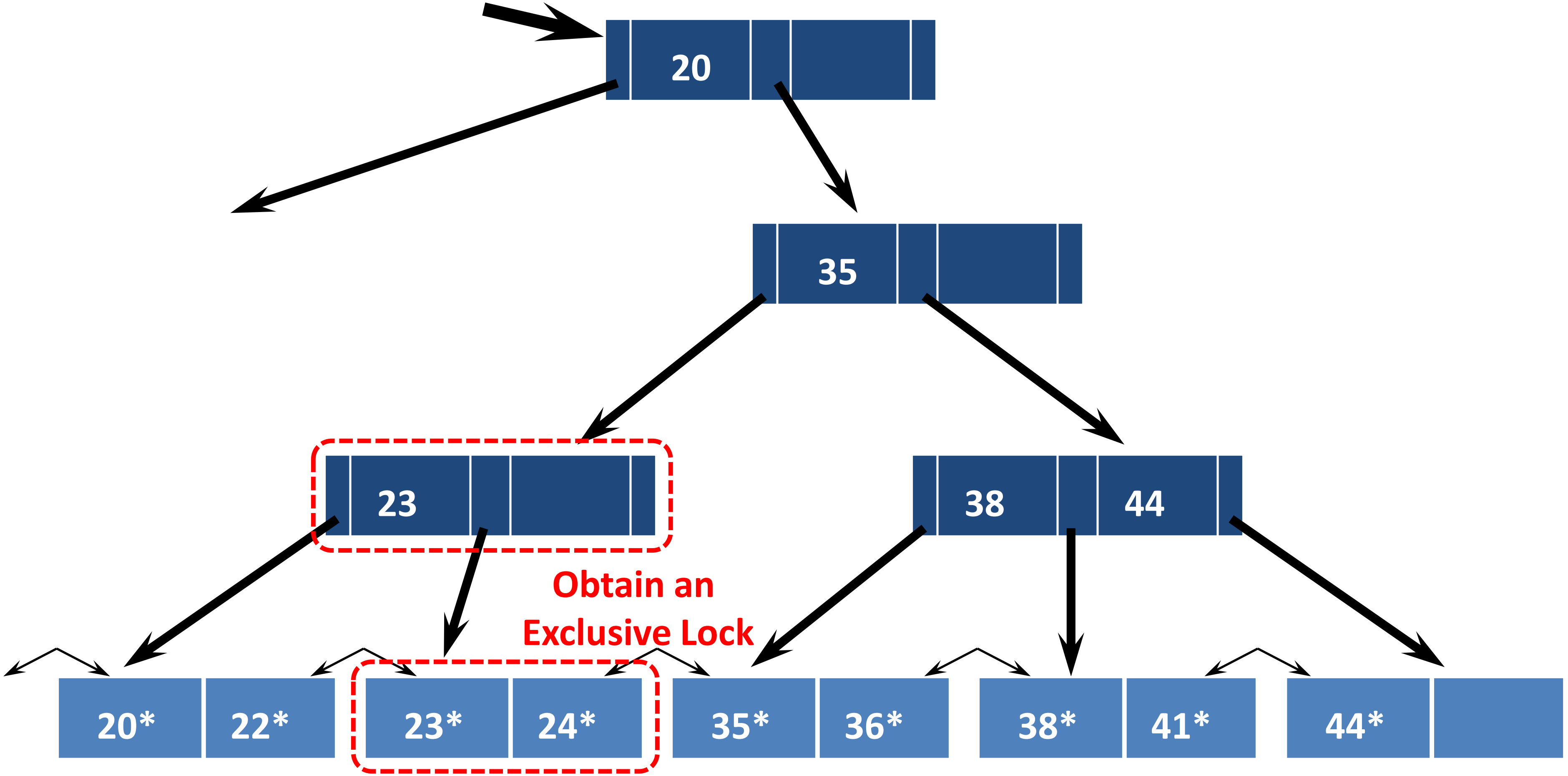
Lock-Coupling: Another Example

- Insert data entry **25***:



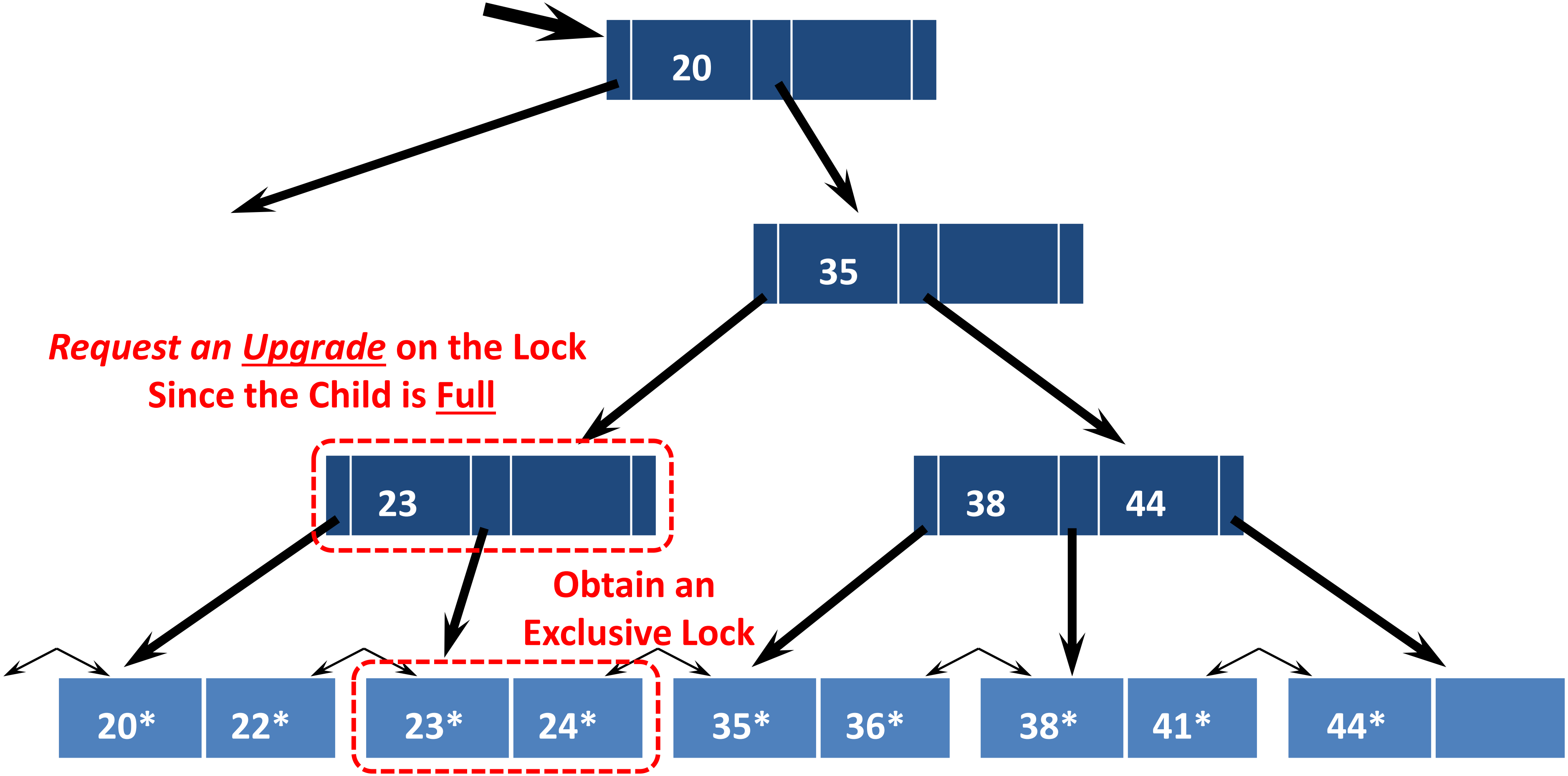
Lock-Coupling: Another Example

- Insert data entry **25***:



Lock-Coupling: Another Example

- Insert data entry **25***:

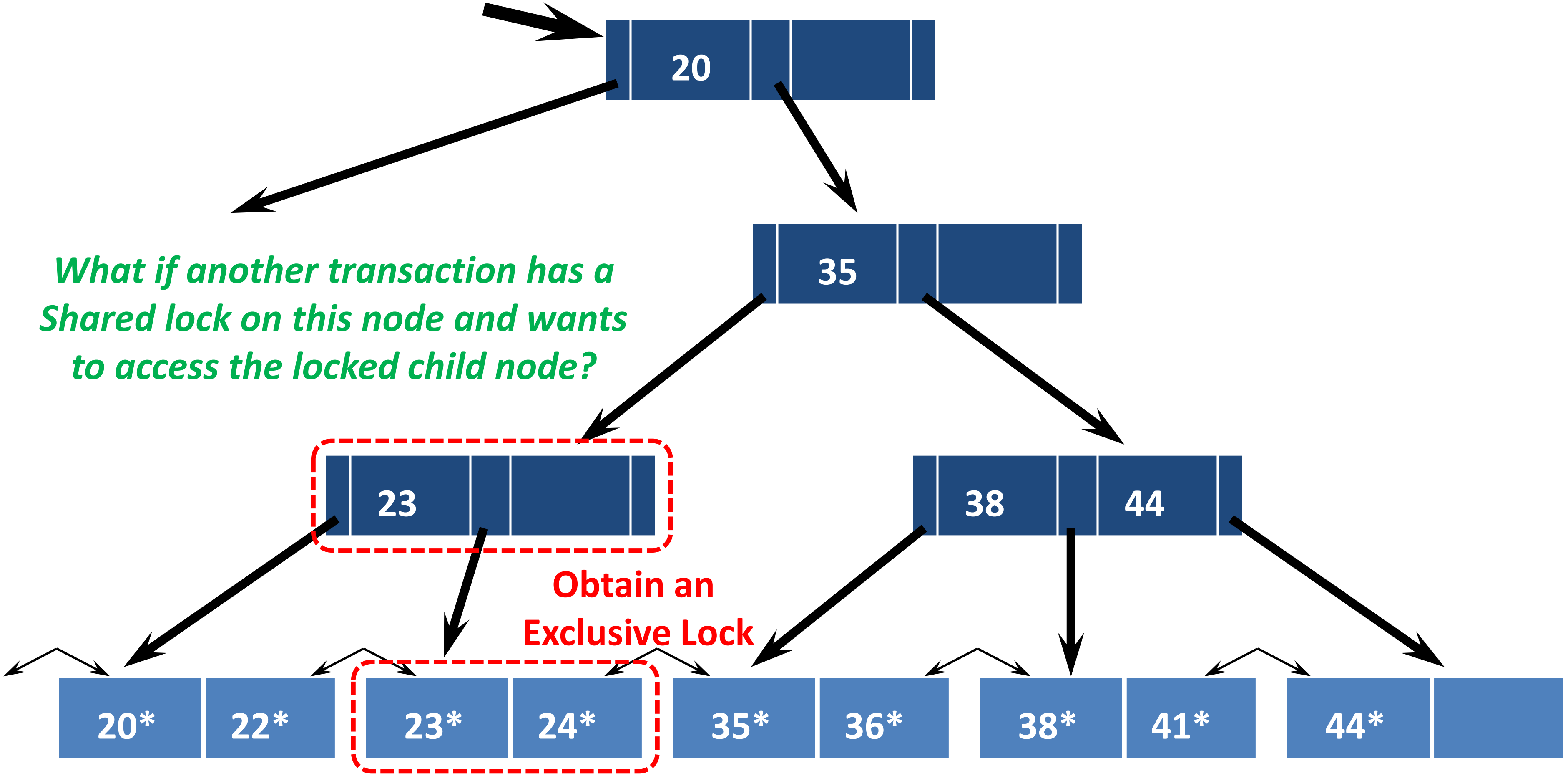


Request an <u>Upgrade</u> **on the Lock Since the Child is <u>Full</u>**

Obtain an Exclusive Lock

Lock-Coupling: Another Example

- Insert data entry **25***:

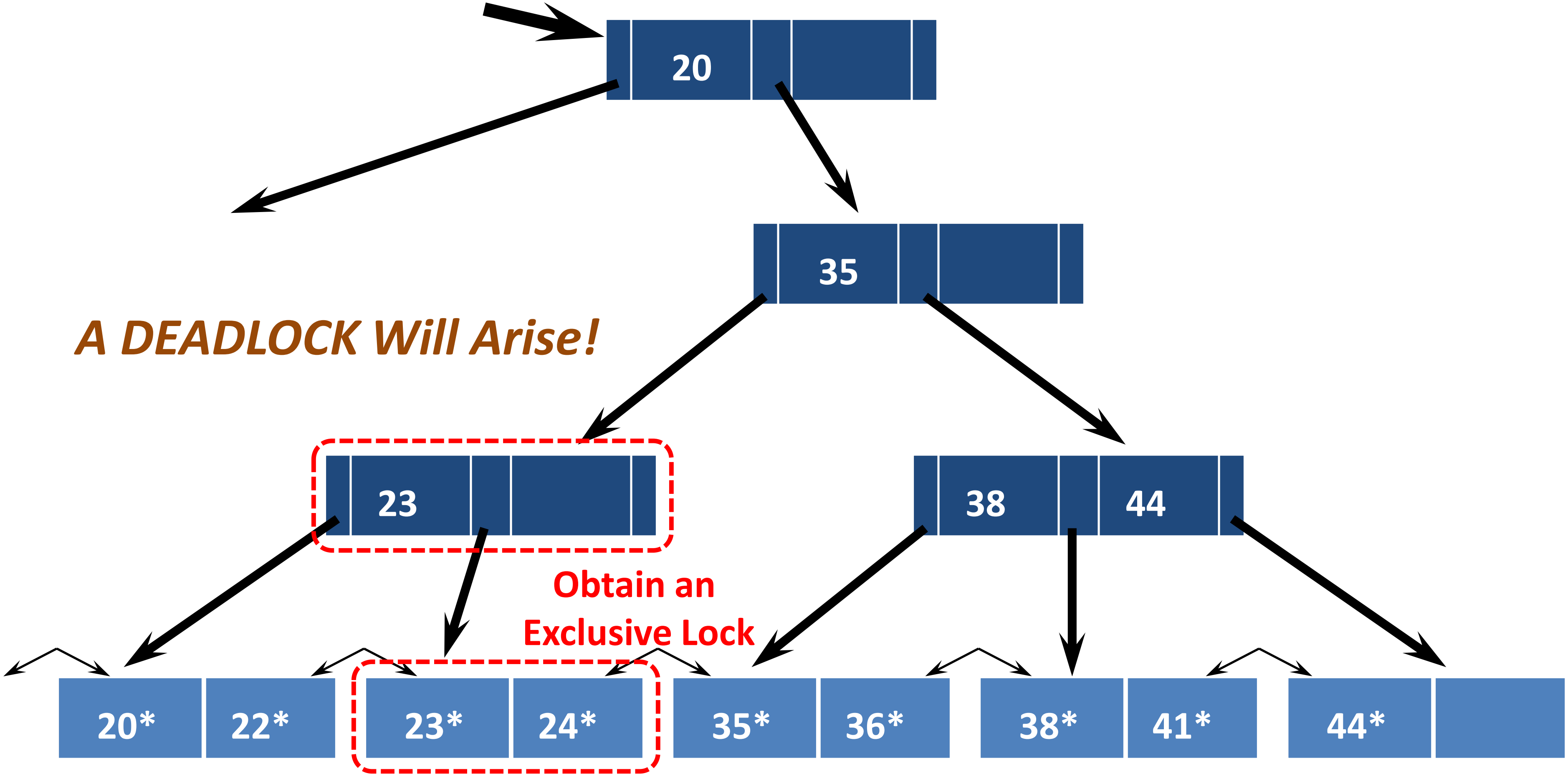


What if another transaction has a Shared lock on this node and wants to access the locked child node?

Obtain an Exclusive Lock

Lock-Coupling: Another Example

- Insert data entry **25***:

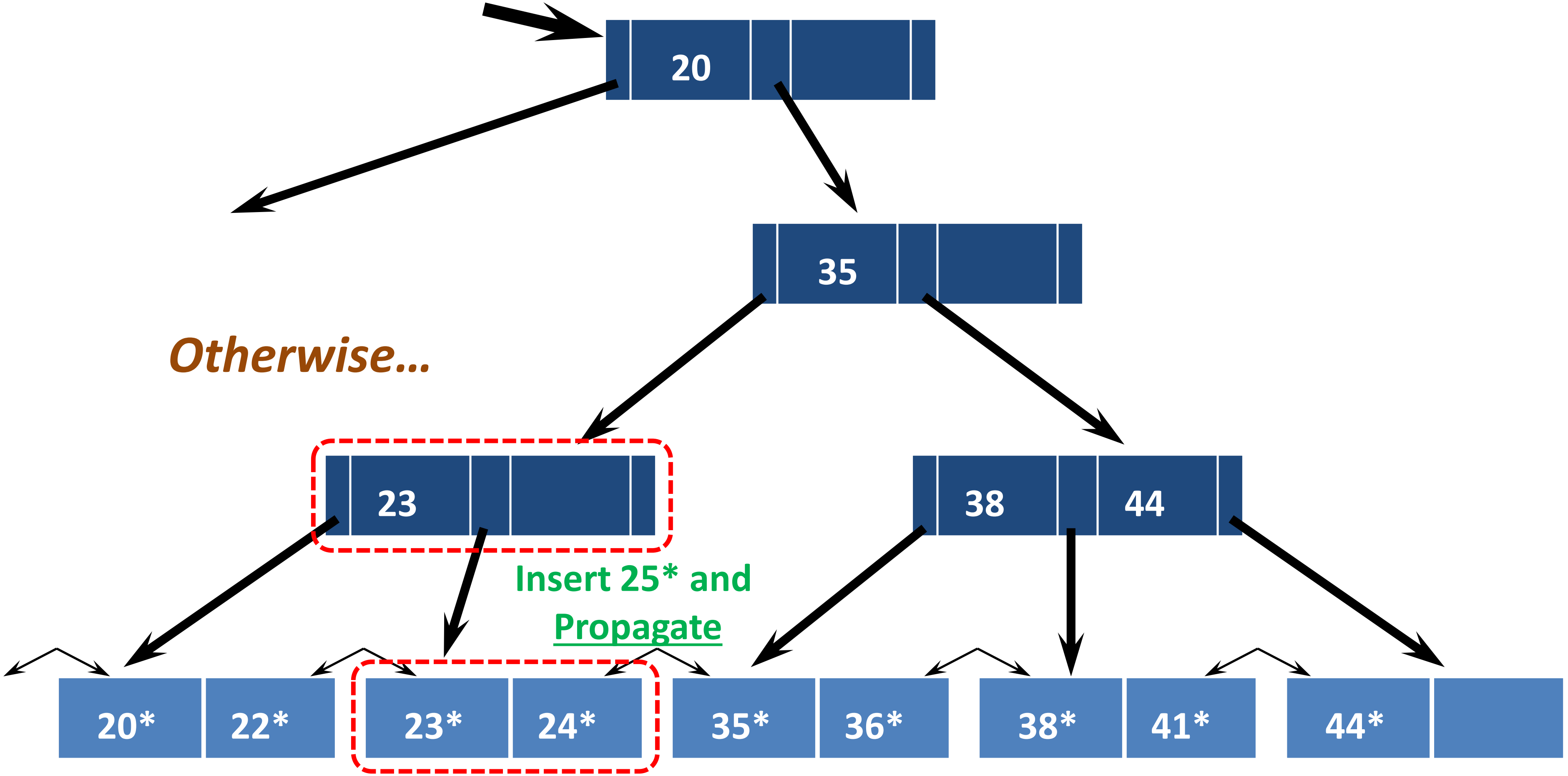


A DEADLOCK Will Arise!

Obtain an Exclusive Lock

Lock-Coupling: Another Example

- Insert data entry **25***:



Otherwise…

Insert 25* and
Propagate

Summary

- There are several *lock-based* concurrency control schemes (e.g., 2PL & Strict 2PL)
  - The *lock manager* keeps track of the locks issued

- Deadlocks can arise, but they can either be detected and resolved, or initially prevented

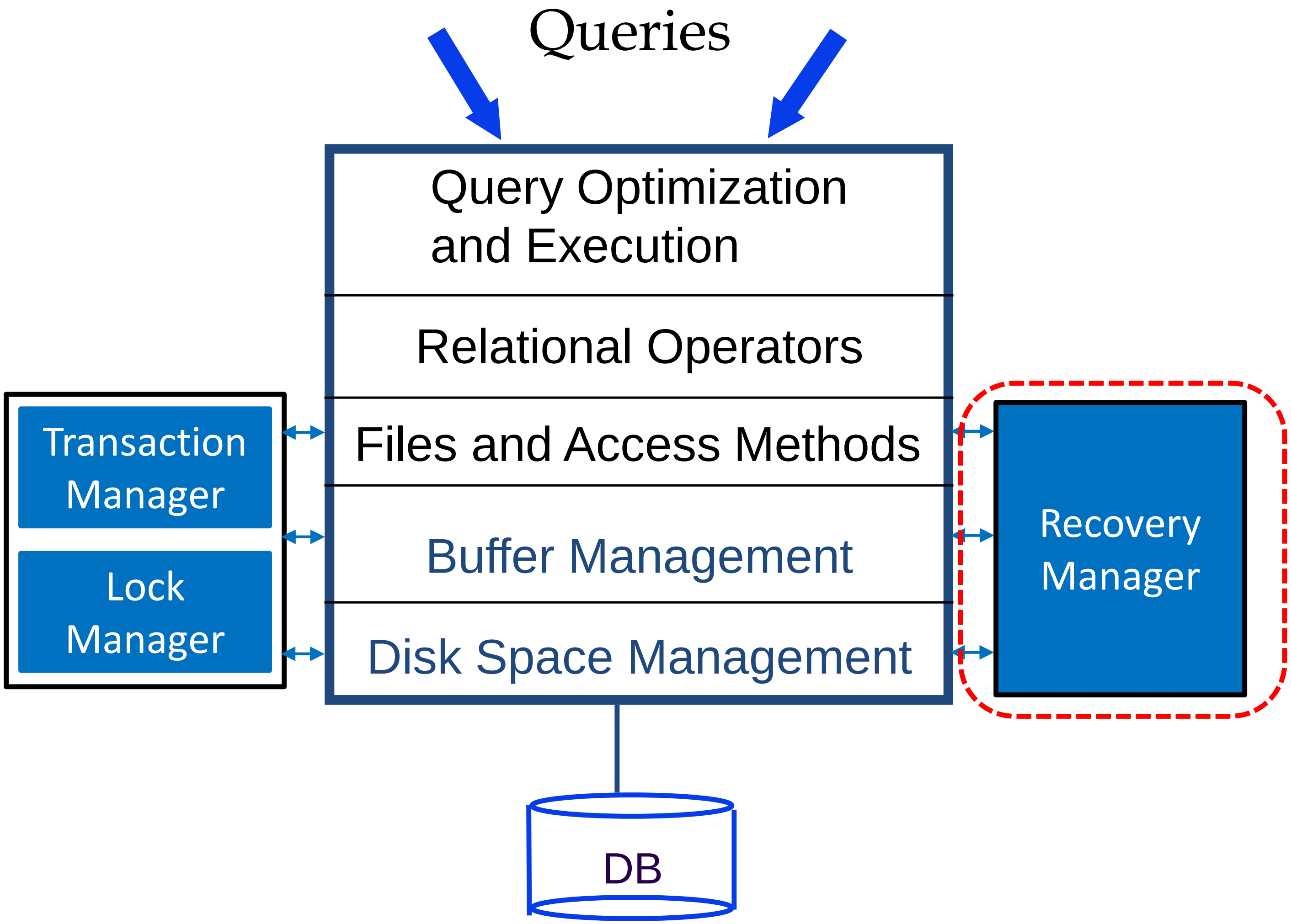
- With dynamic databases, naïve locking strategies may expose the *phantom problem*
  - Resolving this problem has to do with the *locking granularity*

Summary

- *Index locking* is common, and affects performance significantly
  - Needed when accessing records via an index
  - Needed for *locking logical sets of records* (index locking/predicate locking)

- Tree-structured Indexes:
  - A straightforward use of 2PL is very inefficient
  - Bayer-Schkolnick illustrates a high potential for performance improvement

Next Class


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