CS 6530: Advanced Database Systems Fall 2022

Lecture 06
Concurrency control #1

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Acknowledgement: Slides taken from Prof. Andy Pavlo, CMU

SCHOOL OF COMPUTING
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OBSERVATION

We assumed that all the data structures that we have discussed so far are single-threaded.

But we need to allow multiple threads to safely access our data structures to take advantage of additional CPU cores and hide disk I/O stalls.

CONCURRENCY CONTROL

A **concurrency control** protocol is the method that the DBMS uses to ensure "correct" results for concurrent operations on a shared object.

A protocol's correctness criteria can vary:

→ **Logical Correctness:** Can a thread see the data that it is supposed to see?

→ **Physical Correctness:** Is the internal representation of the object sound?

LOCKS VS. LATCHES

Locks

→ Protects the database's logical contents from other txns.
→ Held for txn duration.
→ Need to be able to rollback changes.

Latches

→ Protects the critical sections of the DBMS's internal data structure from other threads.
→ Held for operation duration.
→ Do not need to be able to rollback changes.

LOCKS VS. LATCHES

	Locks	*Latches*
Separate…	User transactions	Threads
Protect…	Database Contents	In-Memory Data Structures
During…	Entire Transactions	Critical Sections
Modes…	Shared, Exclusive, Update, Intention	Read, Write
Deadlock	Detection & Resolution	Avoidance
…by…	Waits-for, Timeout, Aborts	Coding Discipline
Kept in…	Lock Manager	Protected Data Structure

Source: Goetz Graefe

LOCKS VS. LATCHES

Next

	Locks	*Latches*
Separate…	User transactions	Threads
Protect…	Database Contents	In-Memory Data Structures
During…	Entire Transactions	Critical Sections
Modes…	Shared, Exclusive, Update, Intention	Read, Write
Deadlock	Detection & Resolution	Avoidance
…by…	Waits-for, Timeout, Aborts	Coding Discipline
Kept in…	Lock Manager	Protected Data Structure

Source: Goetz Graefe

B+TREE CONCURRENCY CONTROL

We want to allow multiple threads to read and update a B+Tree at the same time.

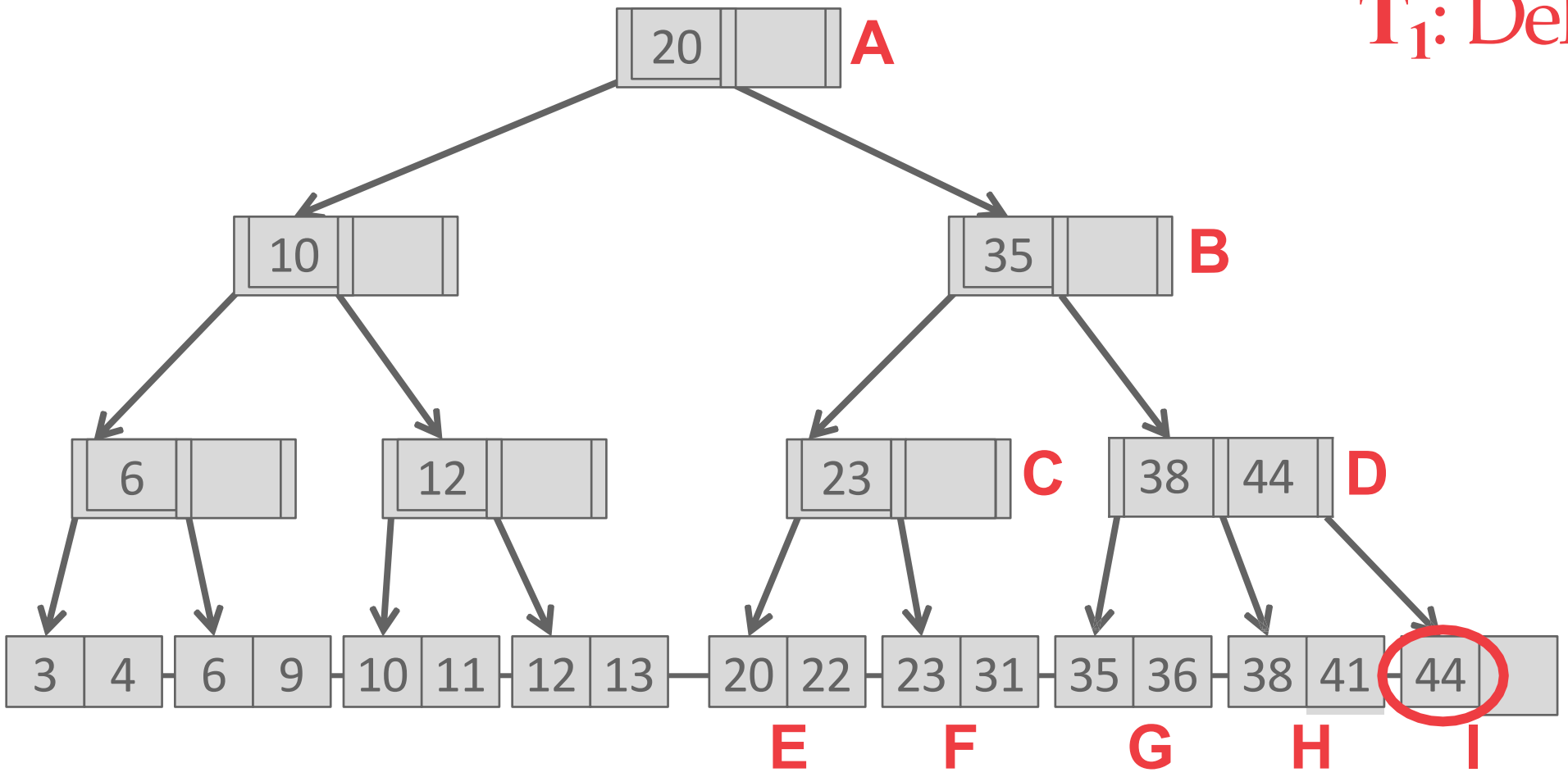
We need to protect from two types of problems:

→ Threads trying to modify the contents of a node at the same time.

→ One thread traversing the tree while another thread splits/merges nodes.

B+ TREE MULTI-THREADED EXAMPLE

T_1: Delete 44



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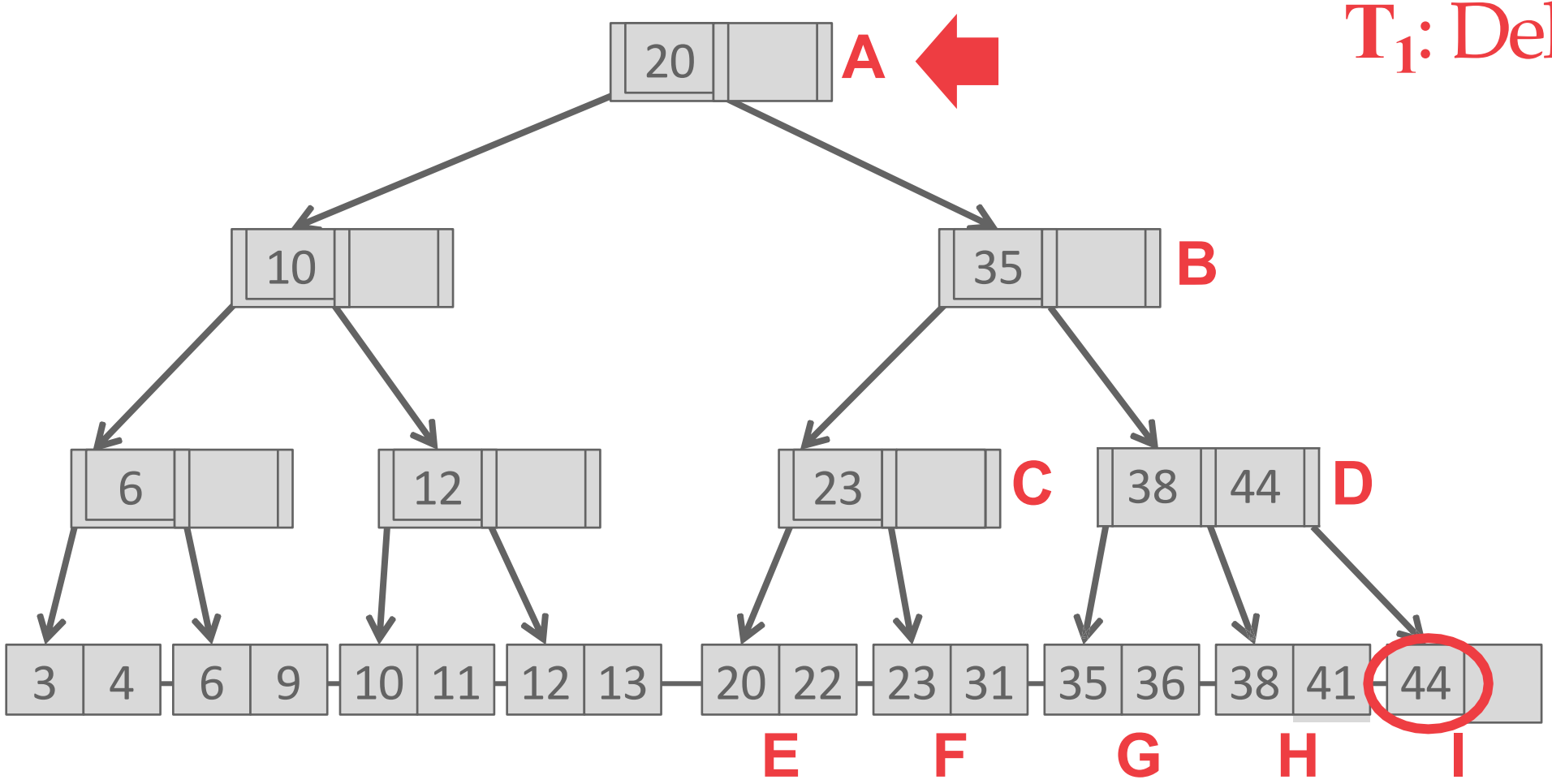

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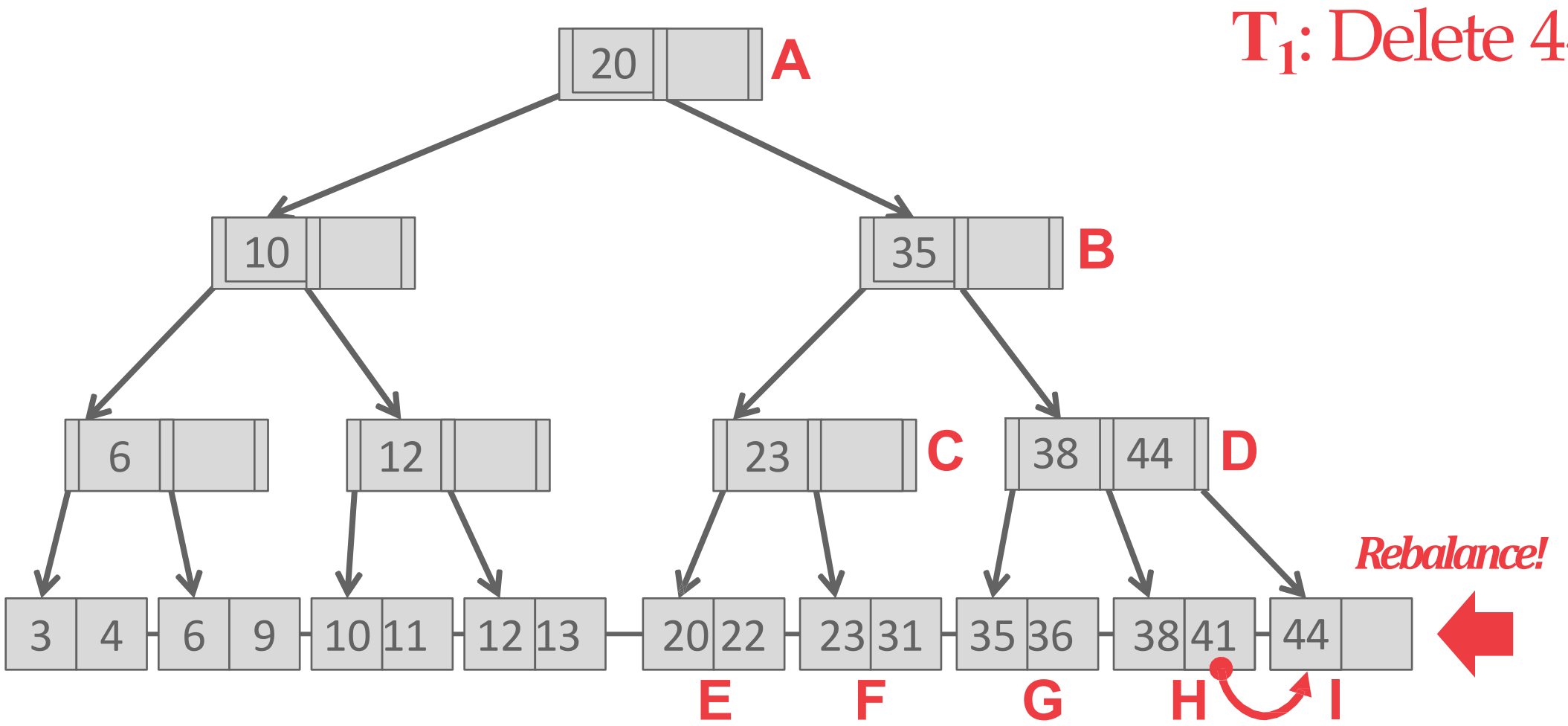

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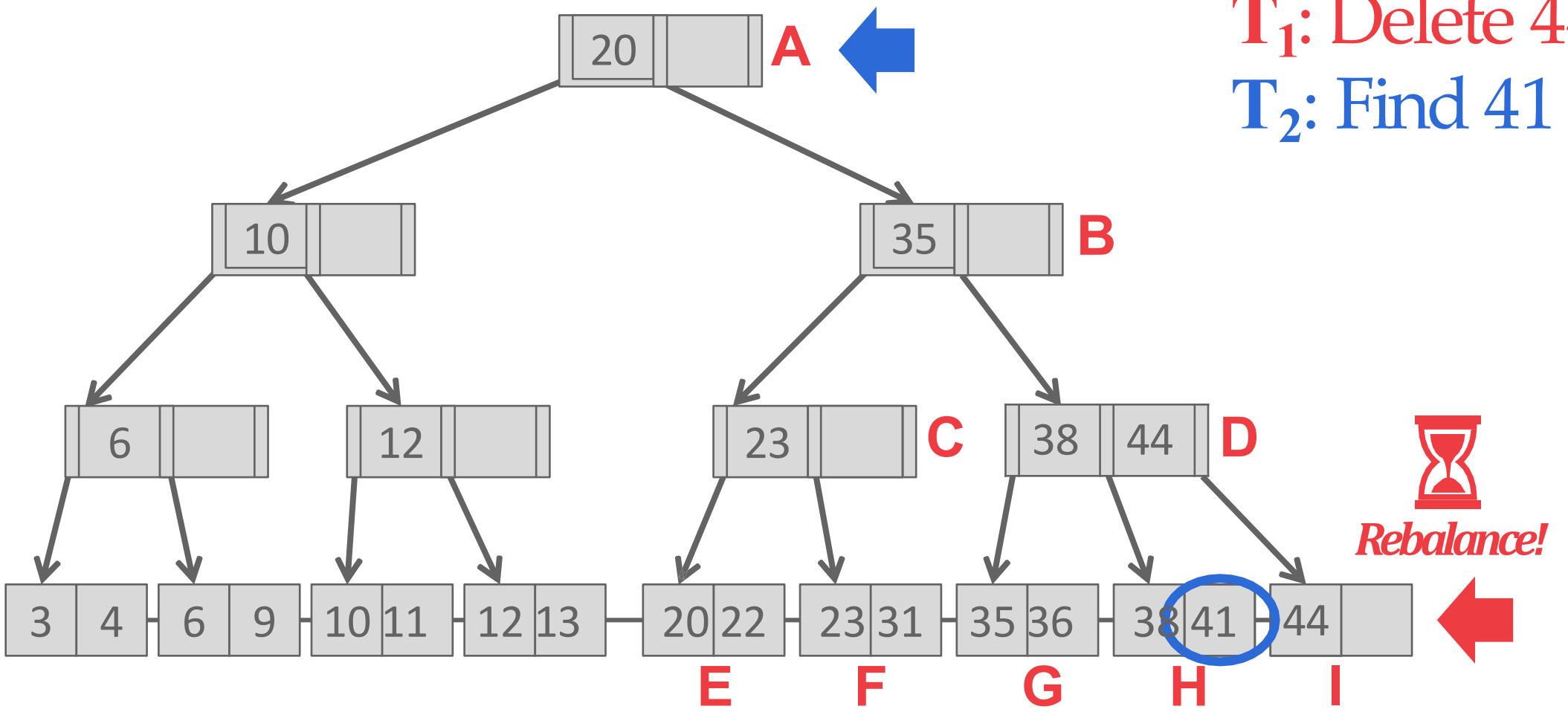

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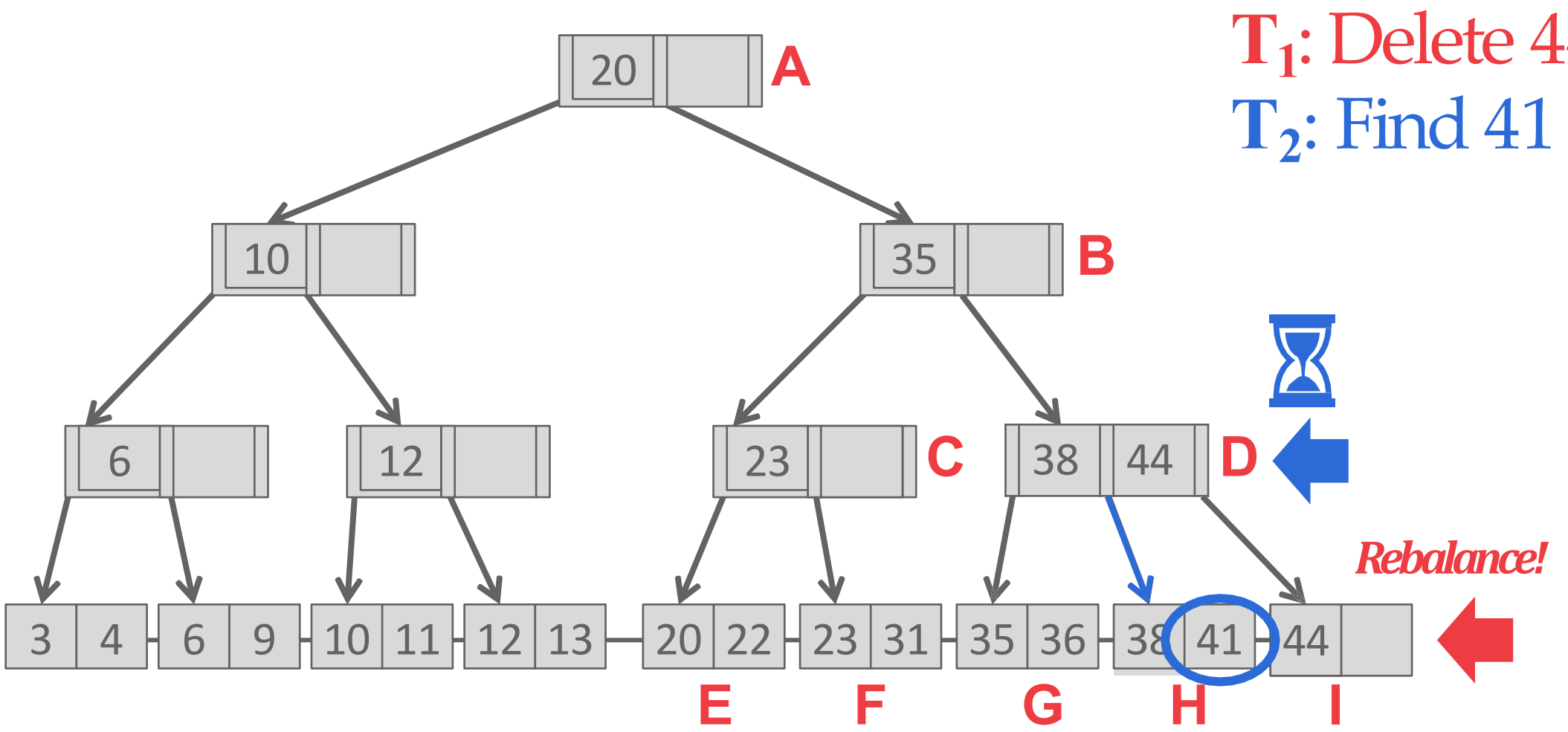

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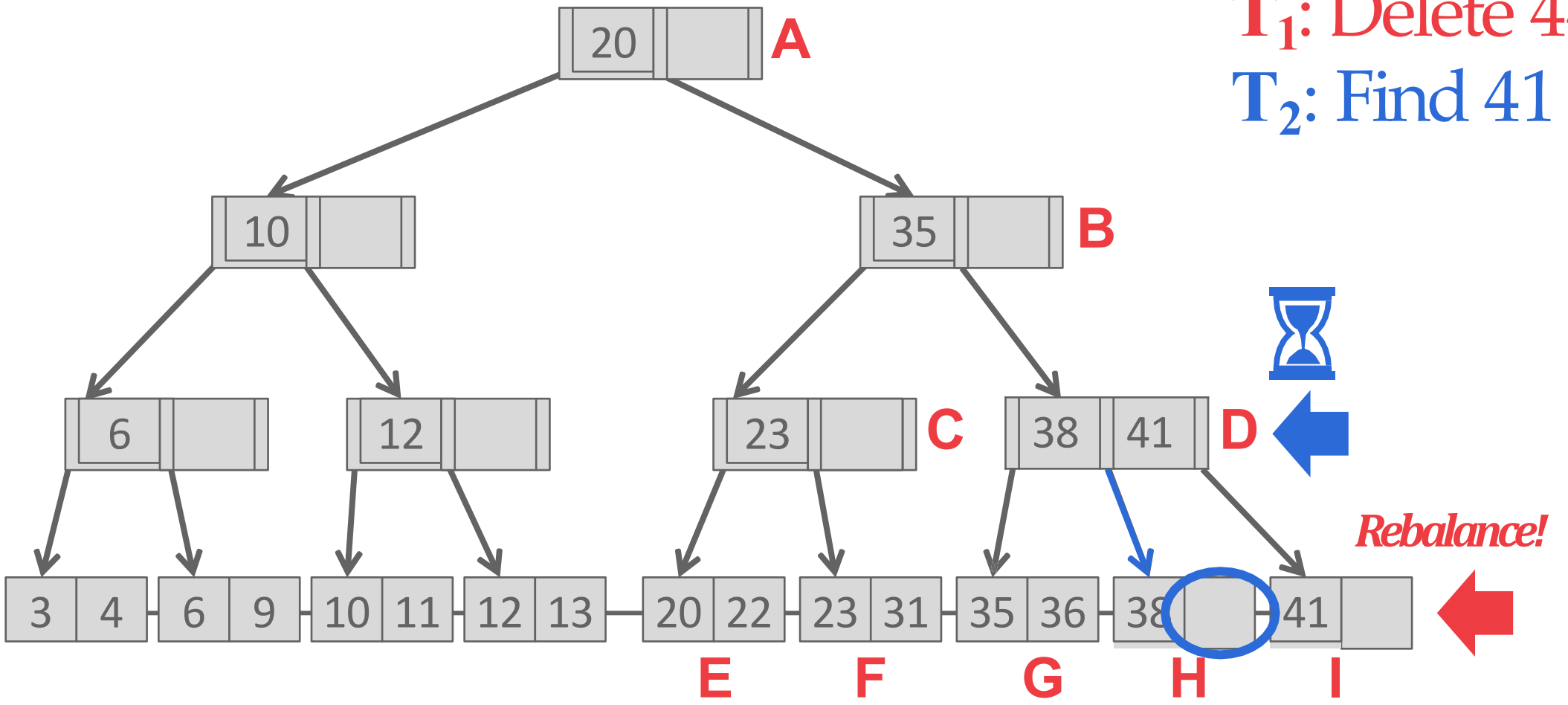

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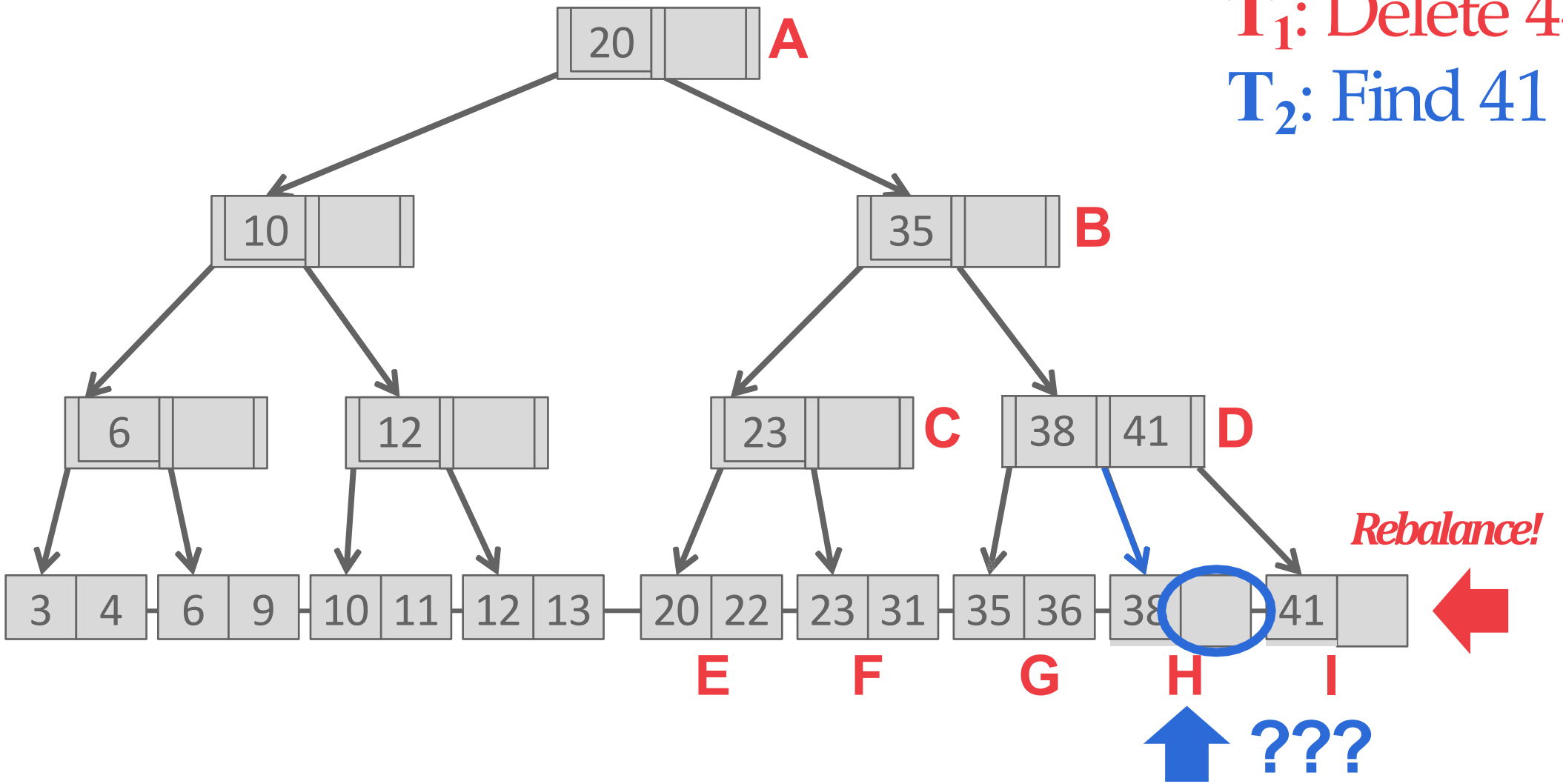


LATCH CRABBING/COUPLING

Protocol to allow multiple threads to access/modify B+Tree at the same time.

Basic Idea:

→ Get latch for parent.
→ Get latch for child
→ Release latch for parent if "safe".

A **safe node** is one that will not split or merge when updated.

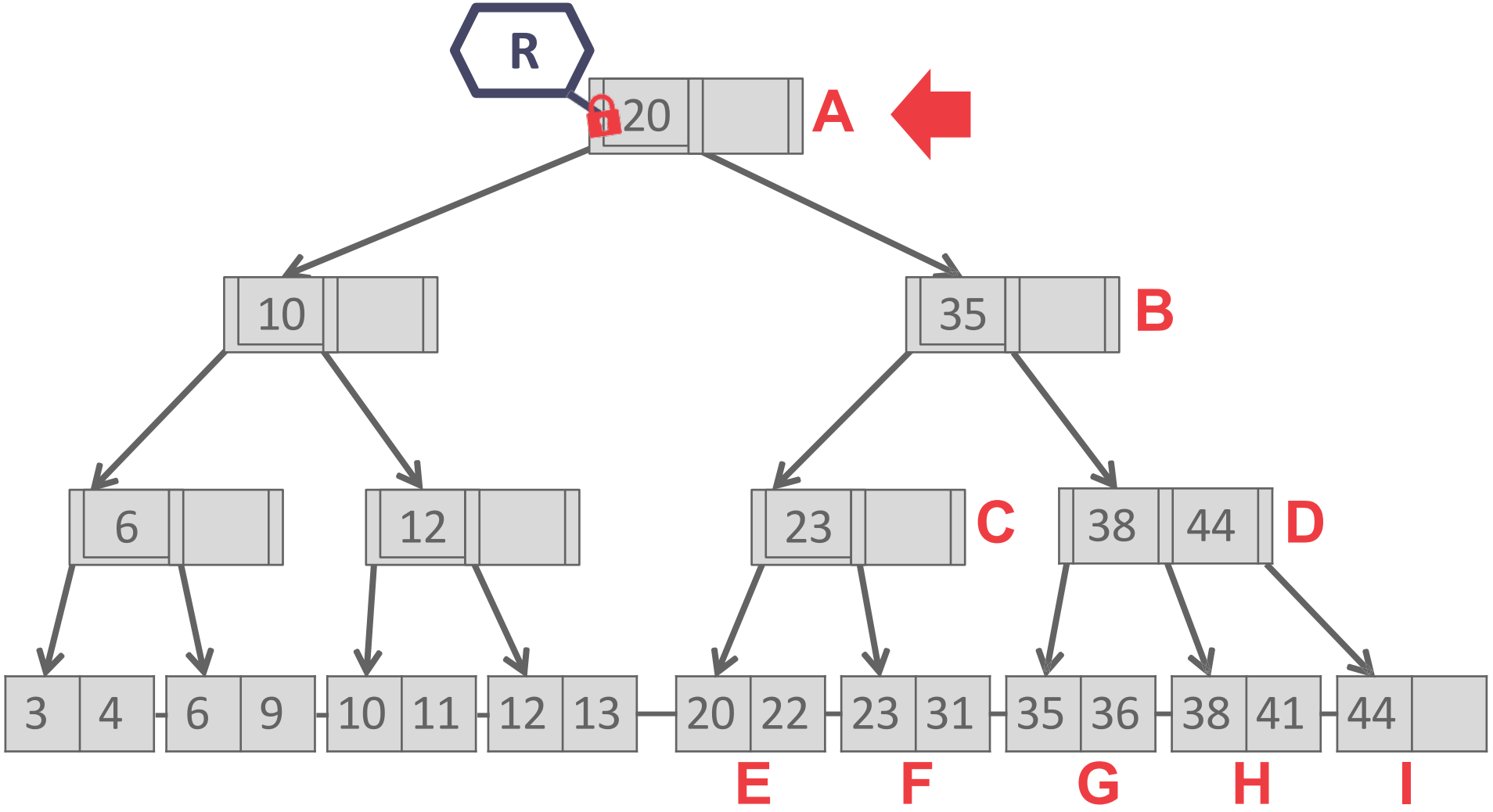
→ Not full (on insertion)
→ More than half-full (on deletion)

LATCH CRABBING/COUPLING

Find: Start at root and go down; repeatedly,
→ Acquire **R**latch on child
→ Then unlatch parent

Insert/Delete: Start at root and go down, obtaining **W**latches as needed. Once child is latched, check if it is safe:
→ If child is safe, release all latches on ancestors.

EXAMPLE #1 – FIND 38



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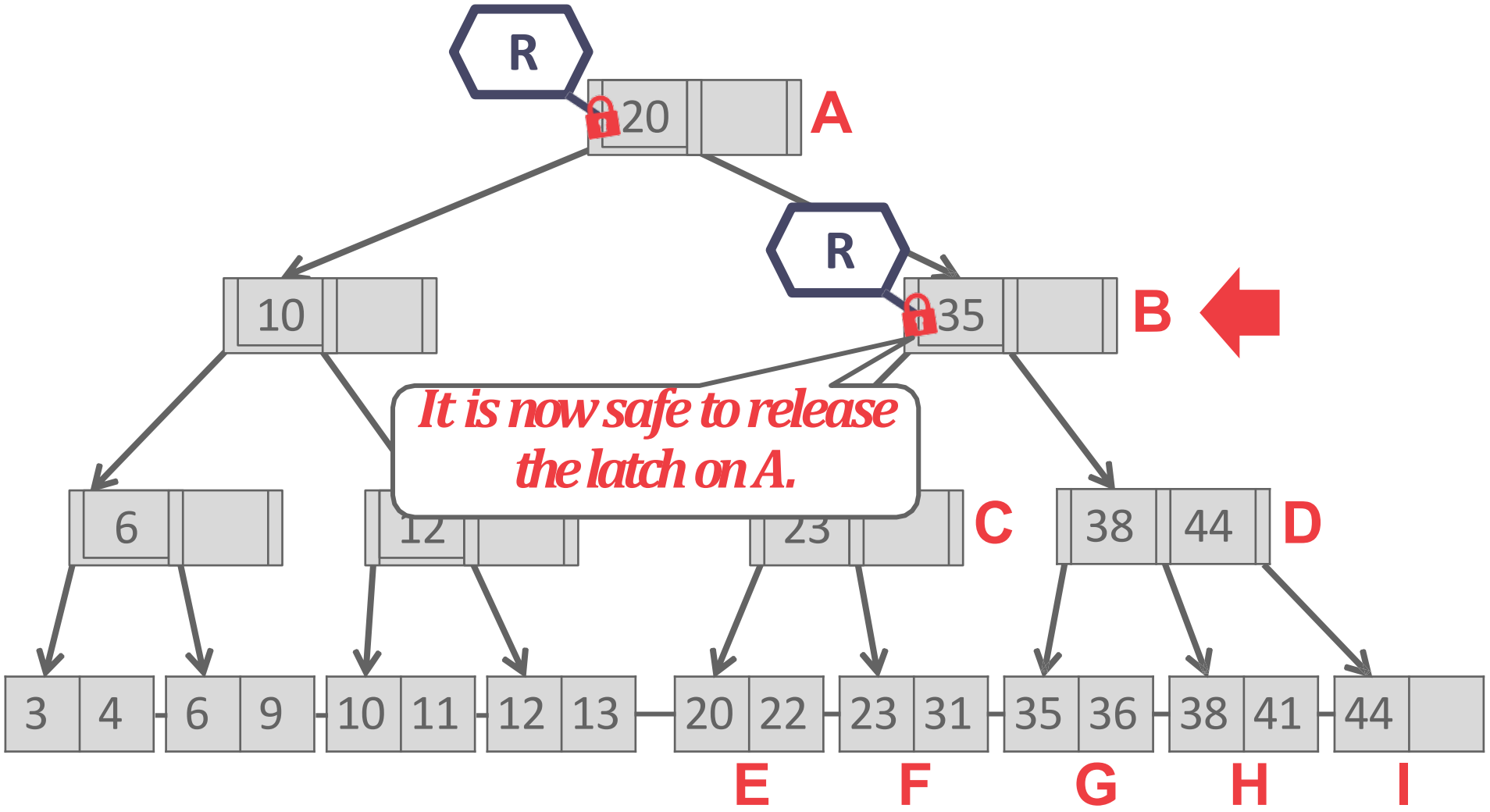

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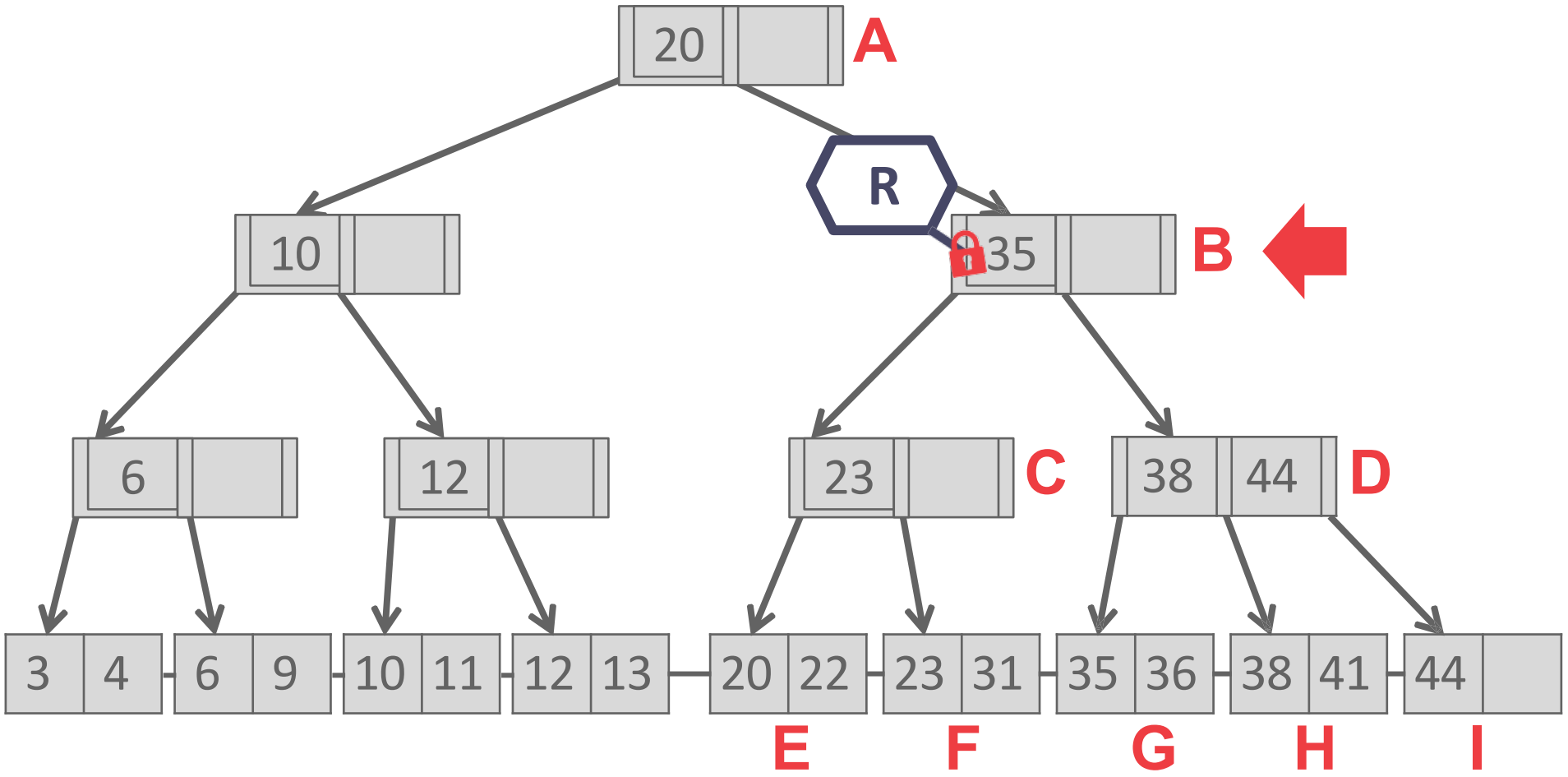

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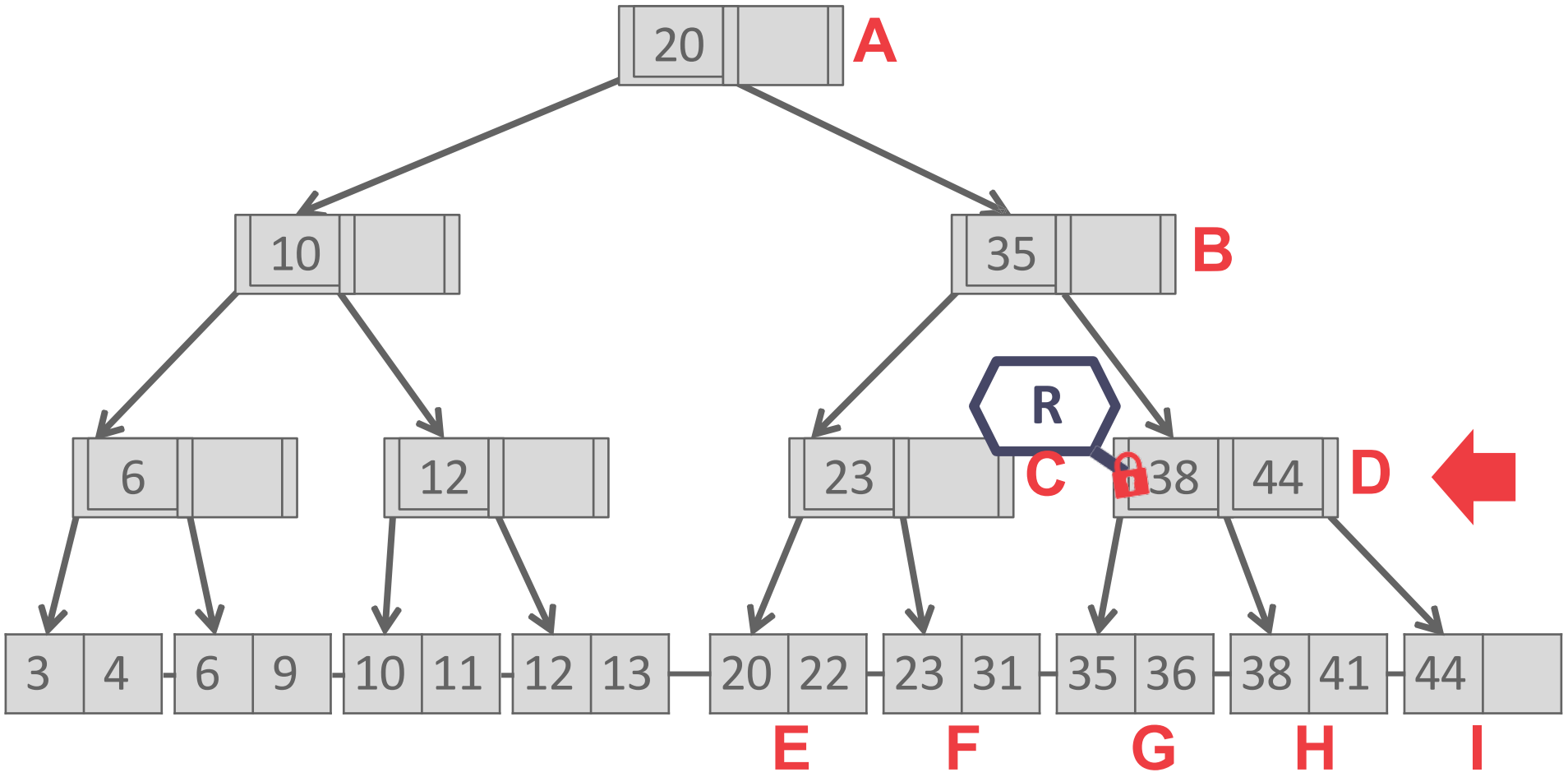

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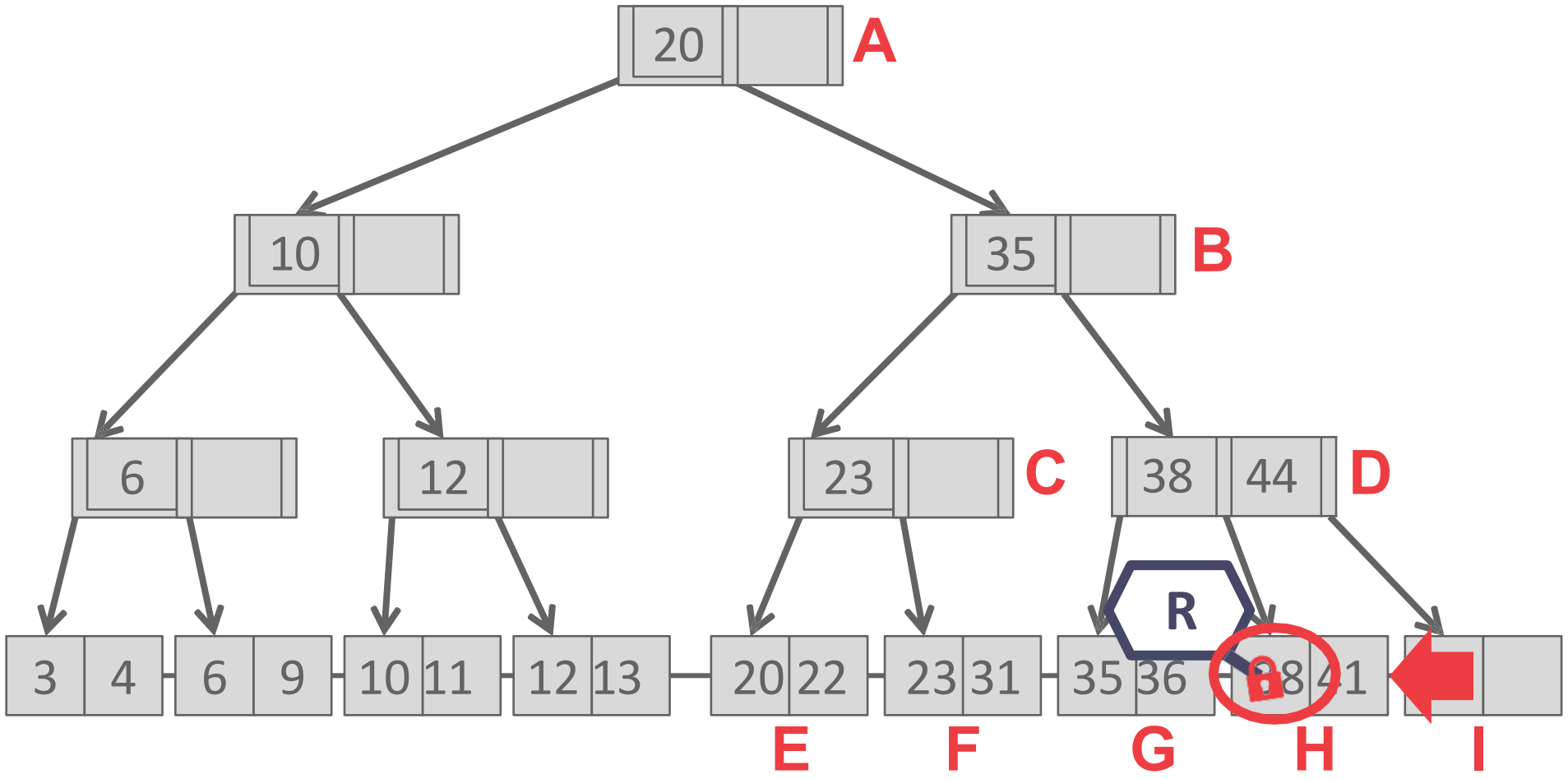

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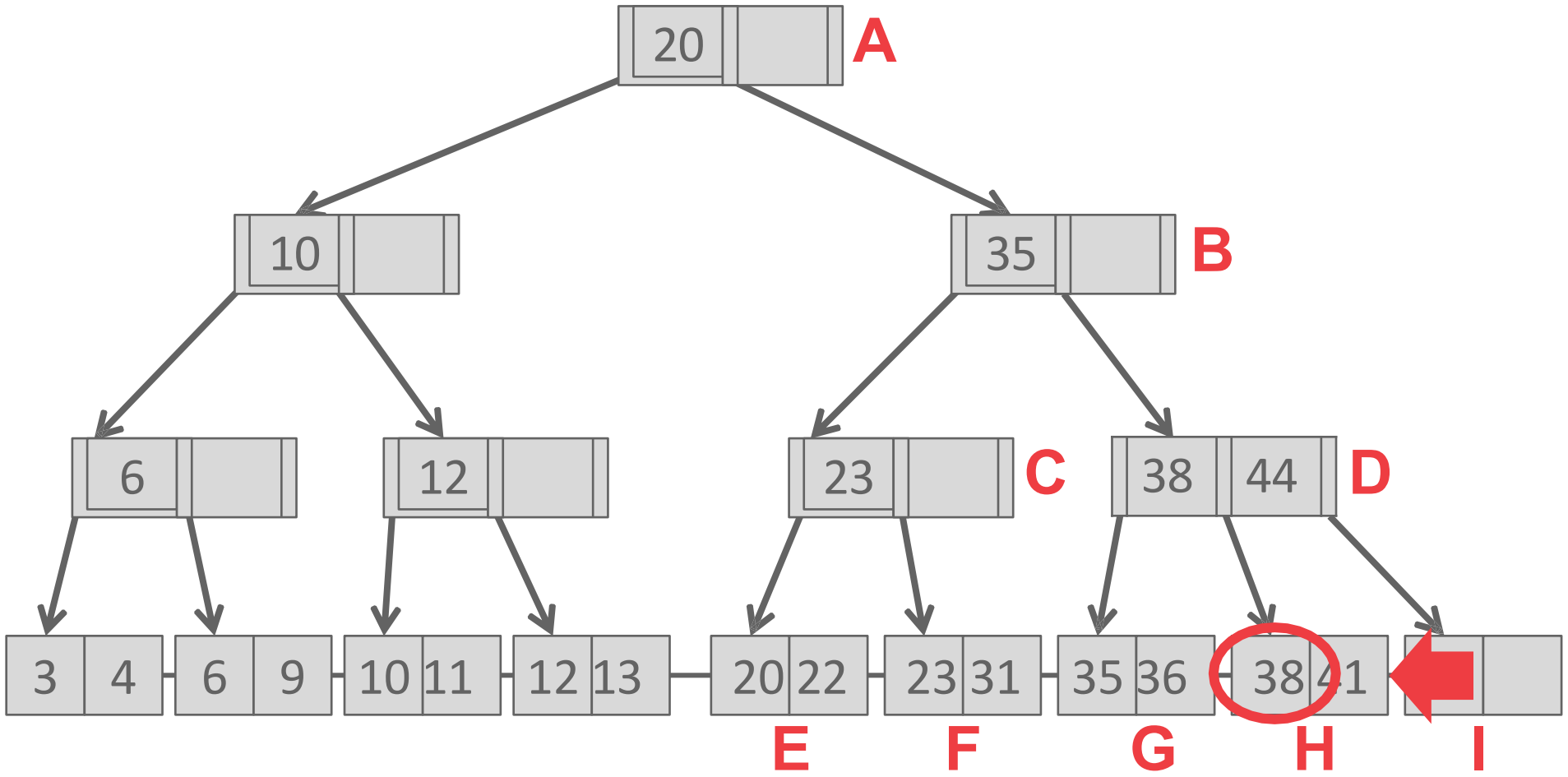
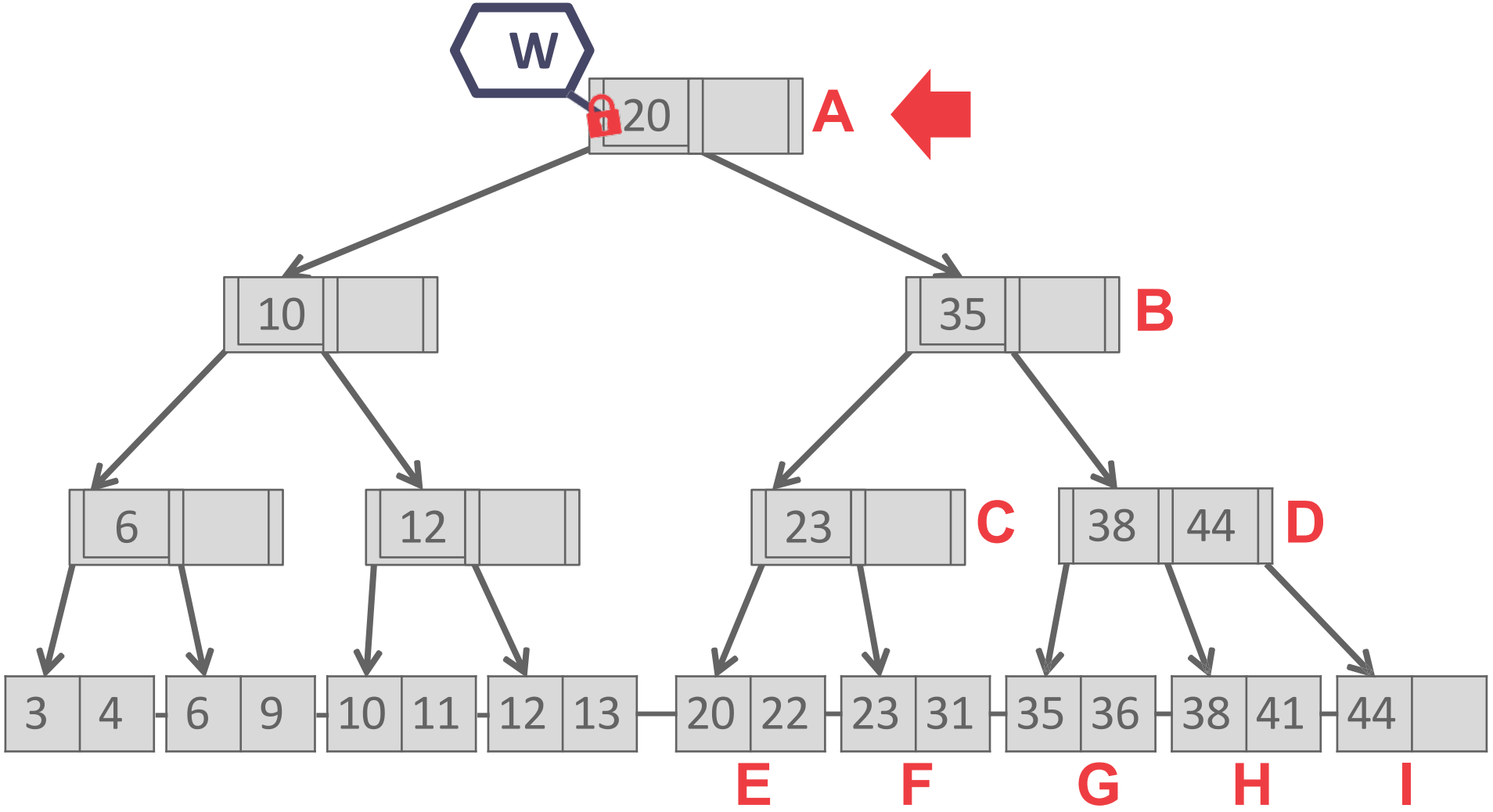


EXAMPLE #2 – DELETE 38



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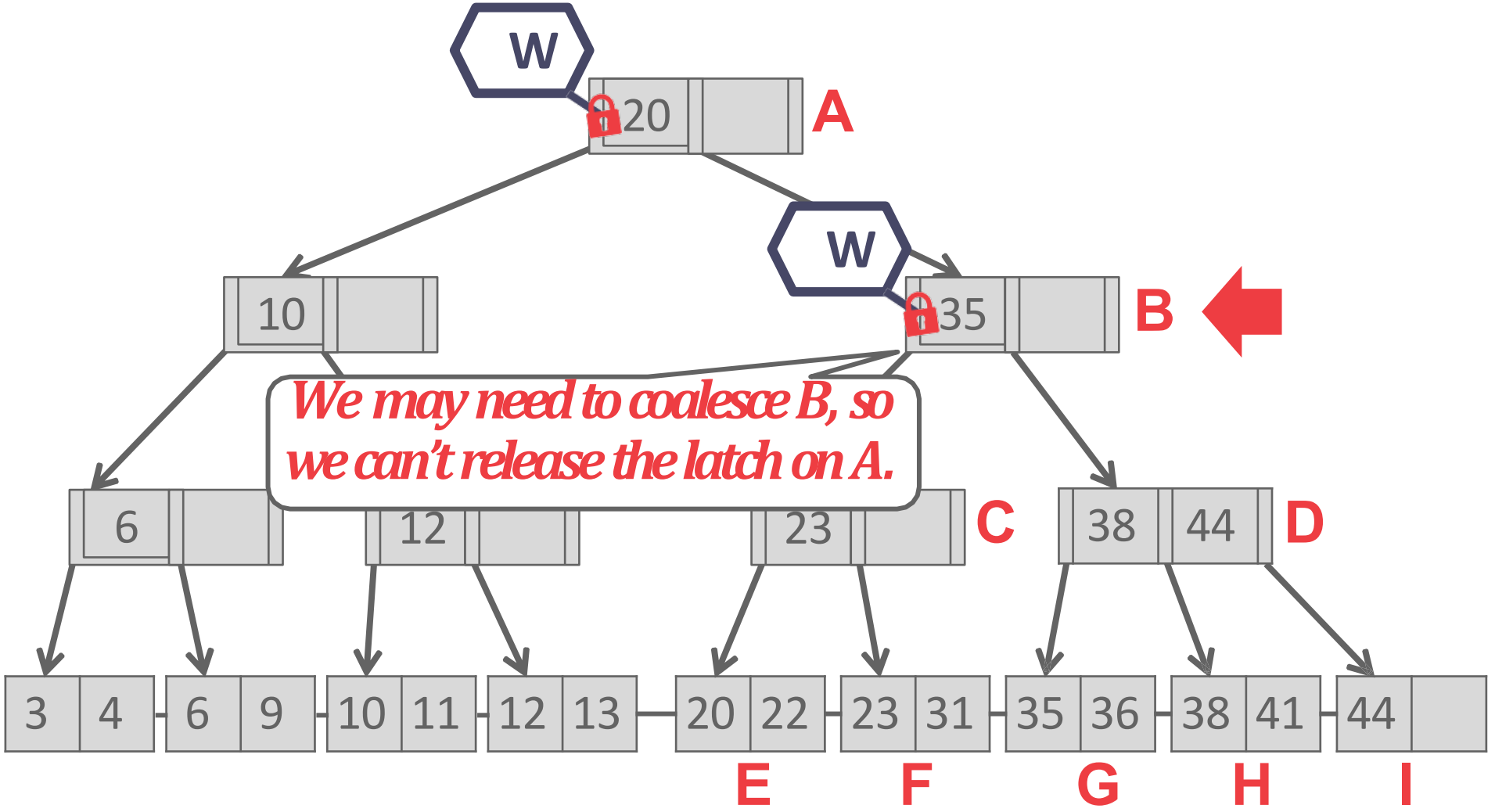

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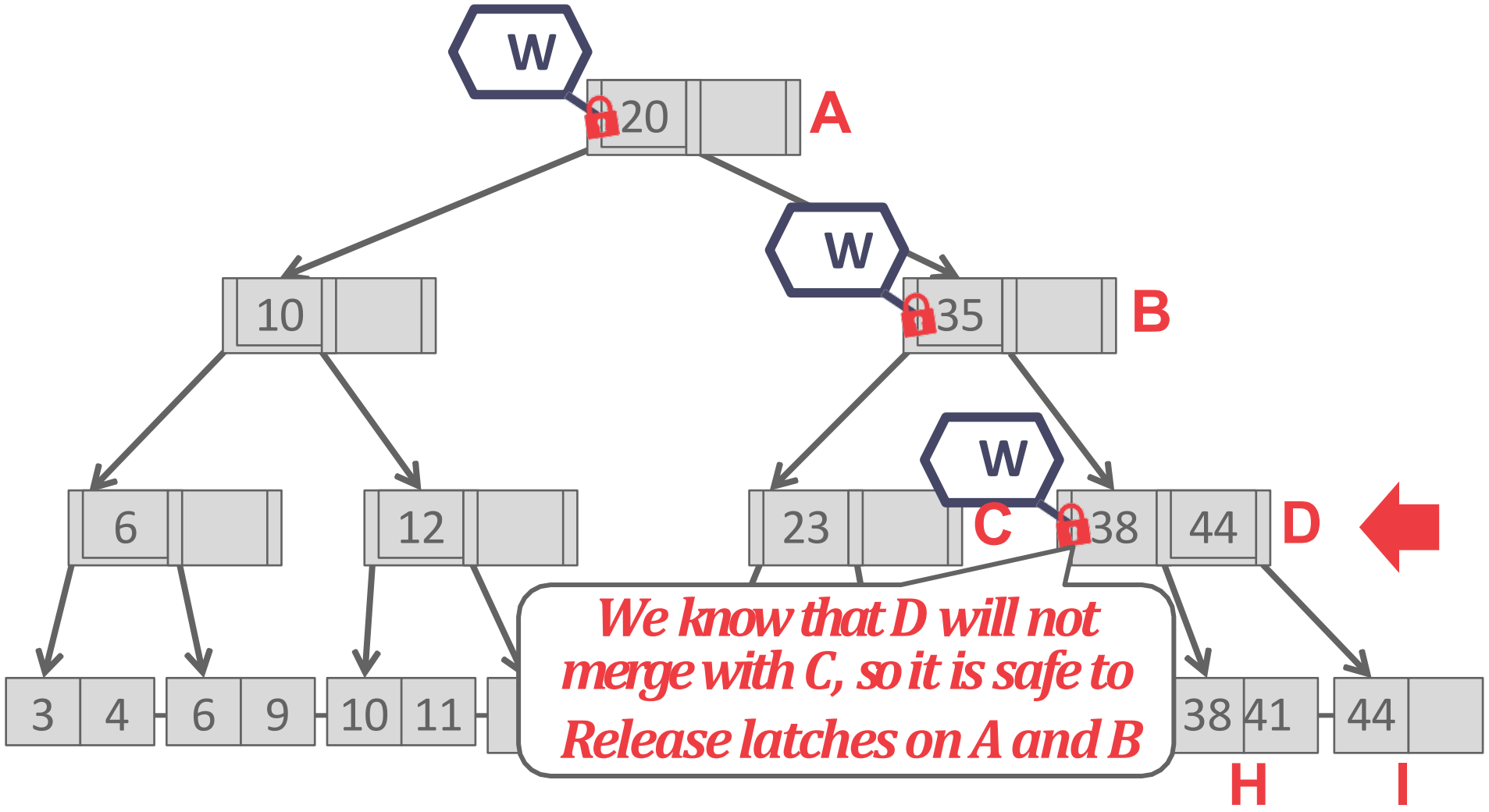

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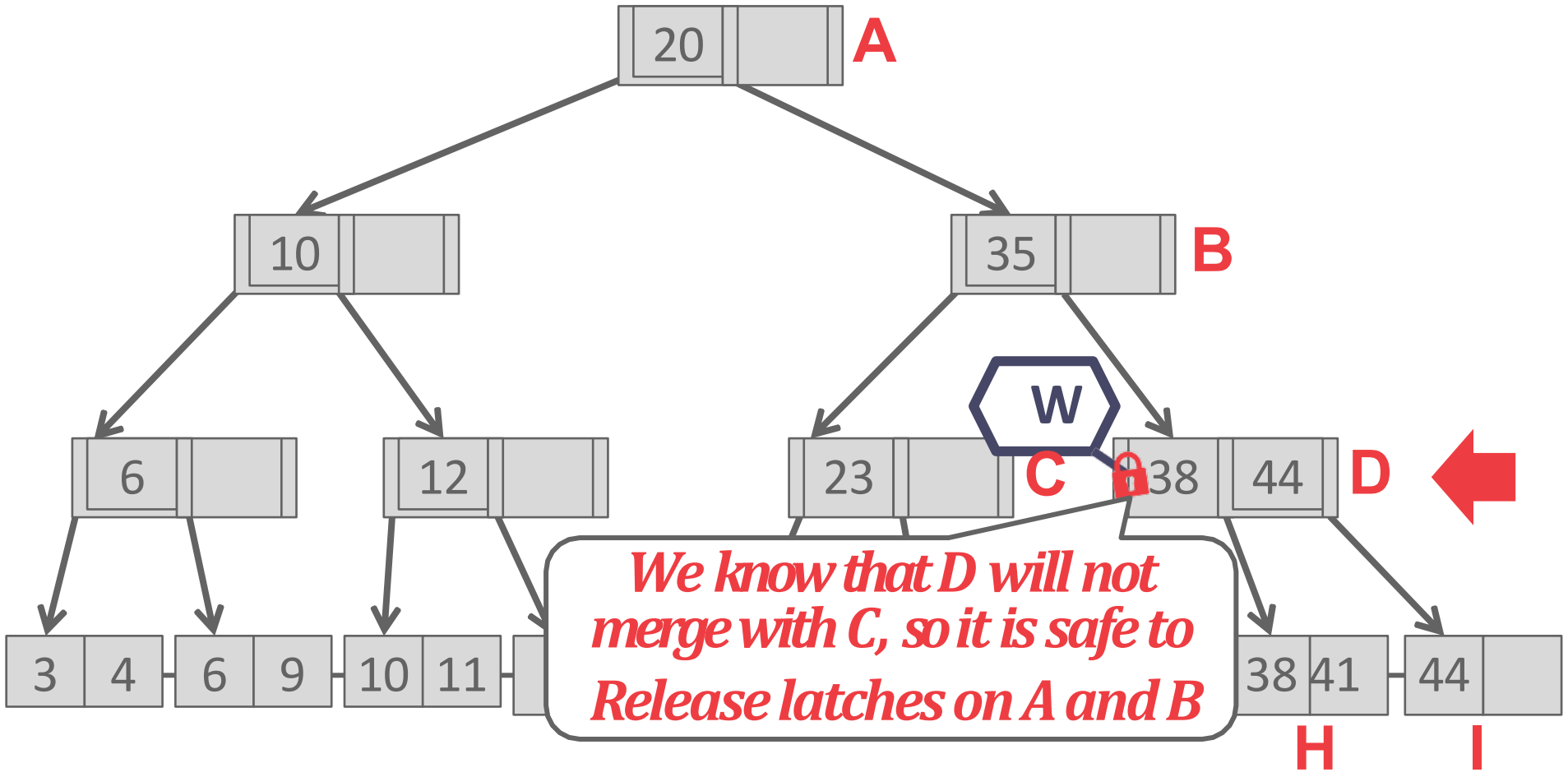

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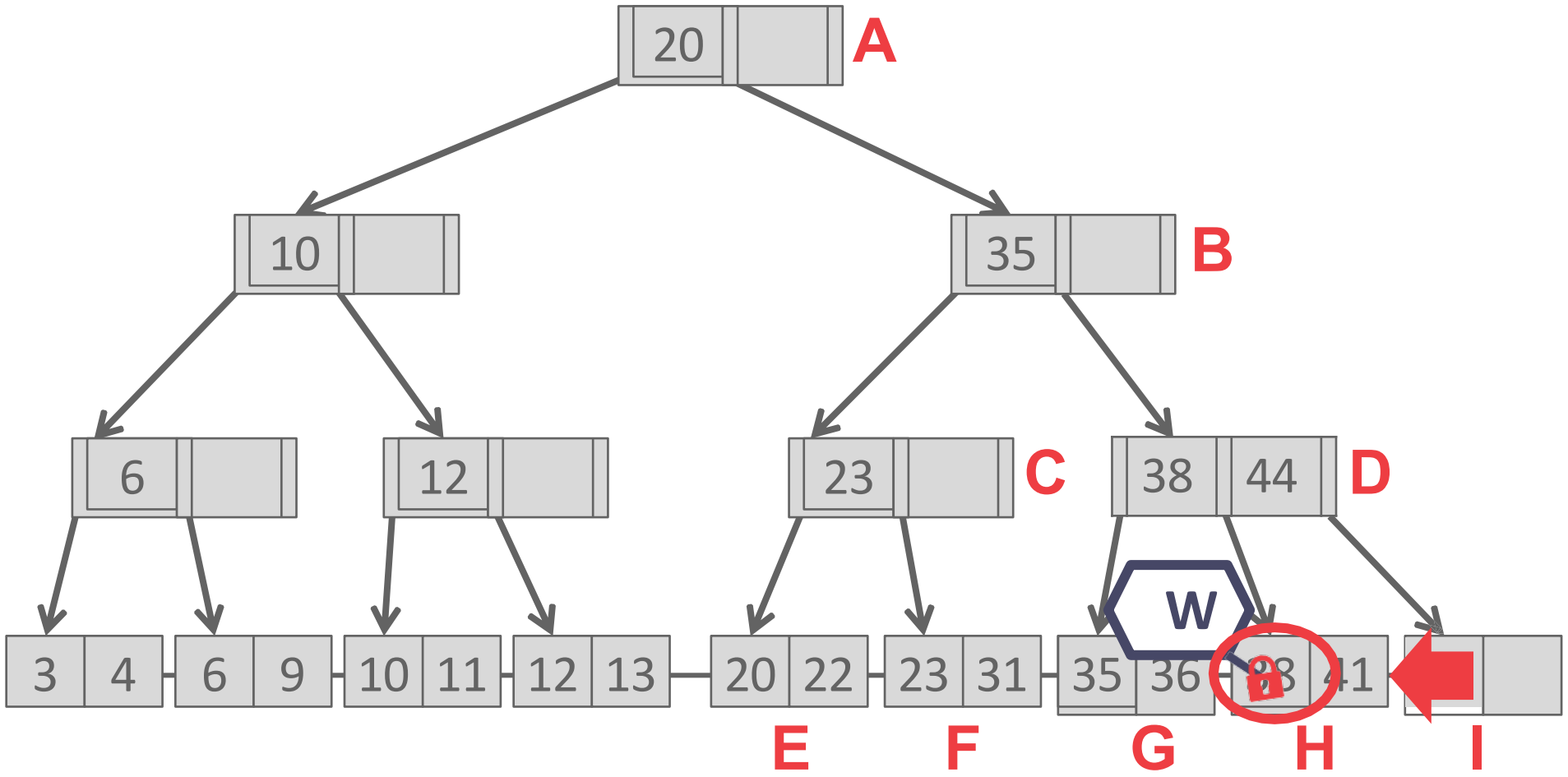
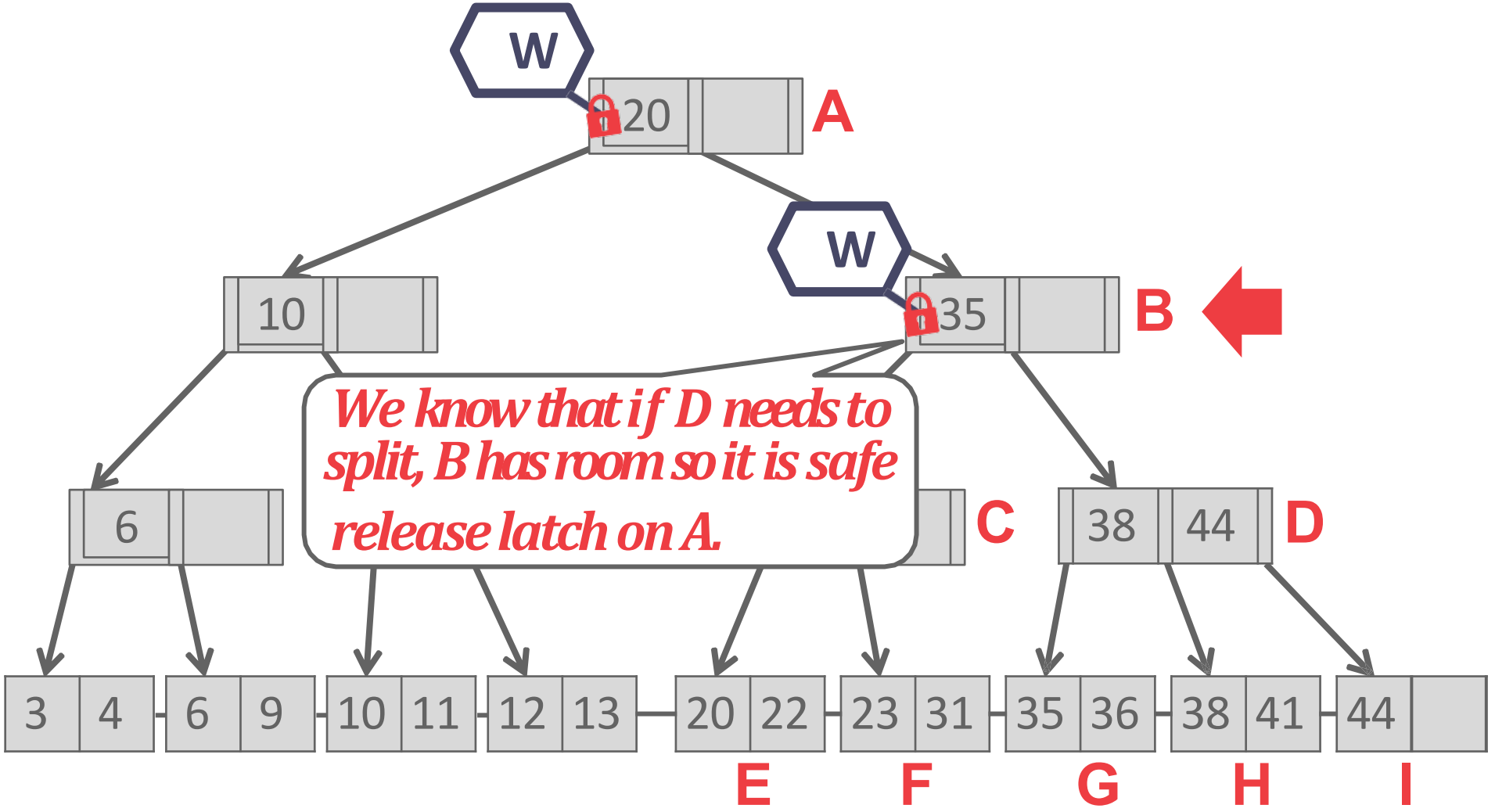


EXAMPLE #3 – INSERT 45



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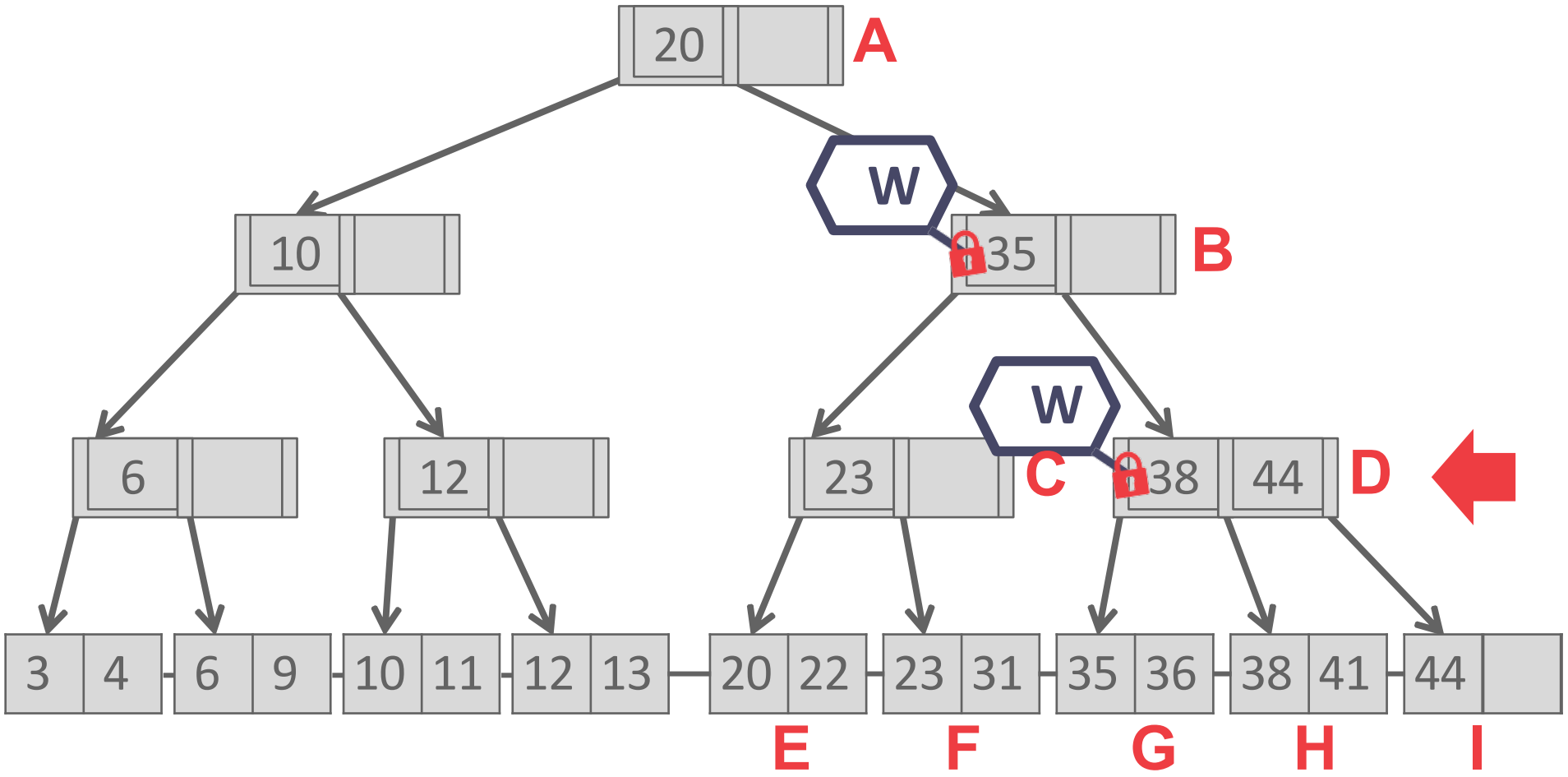

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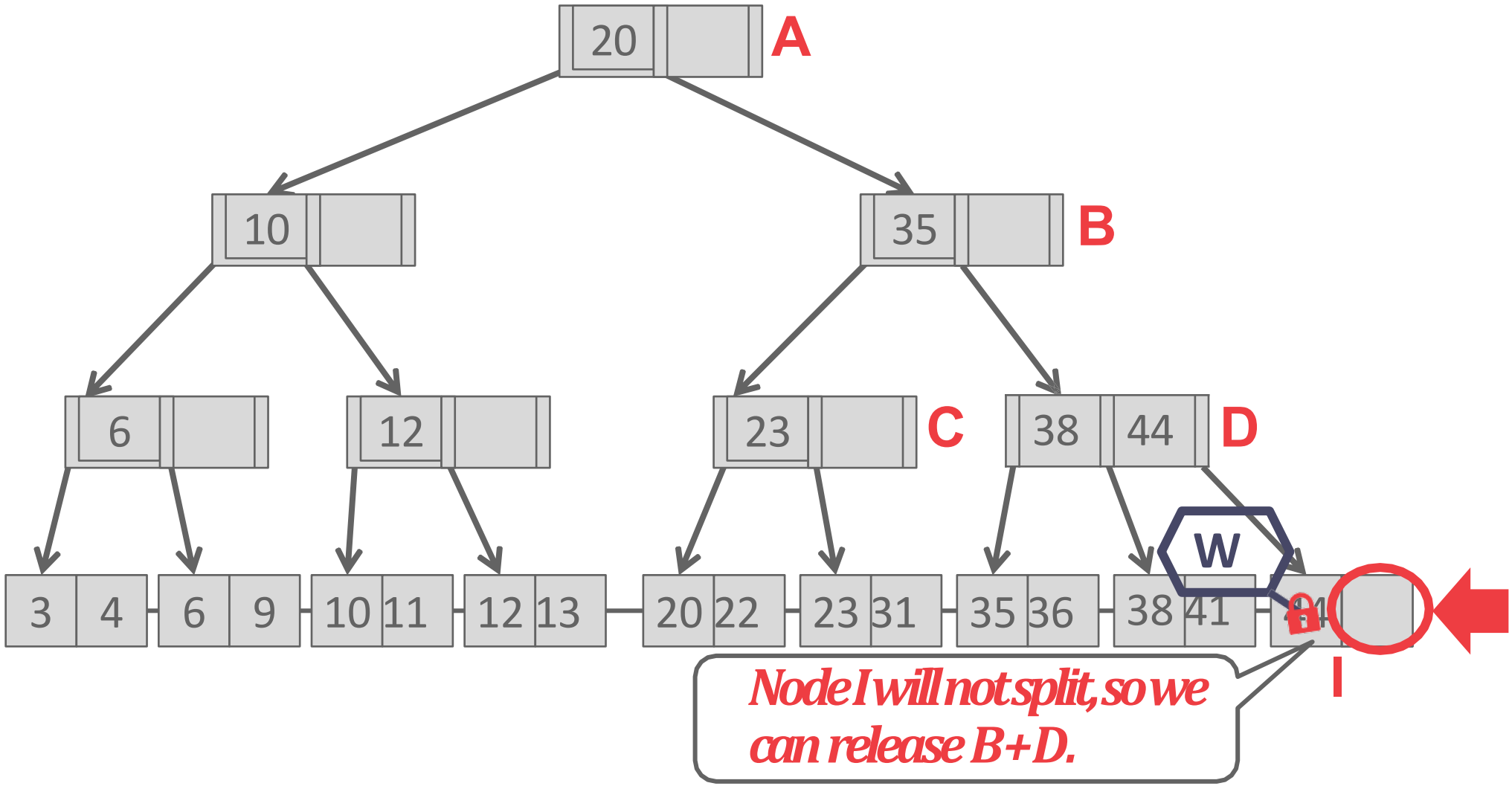

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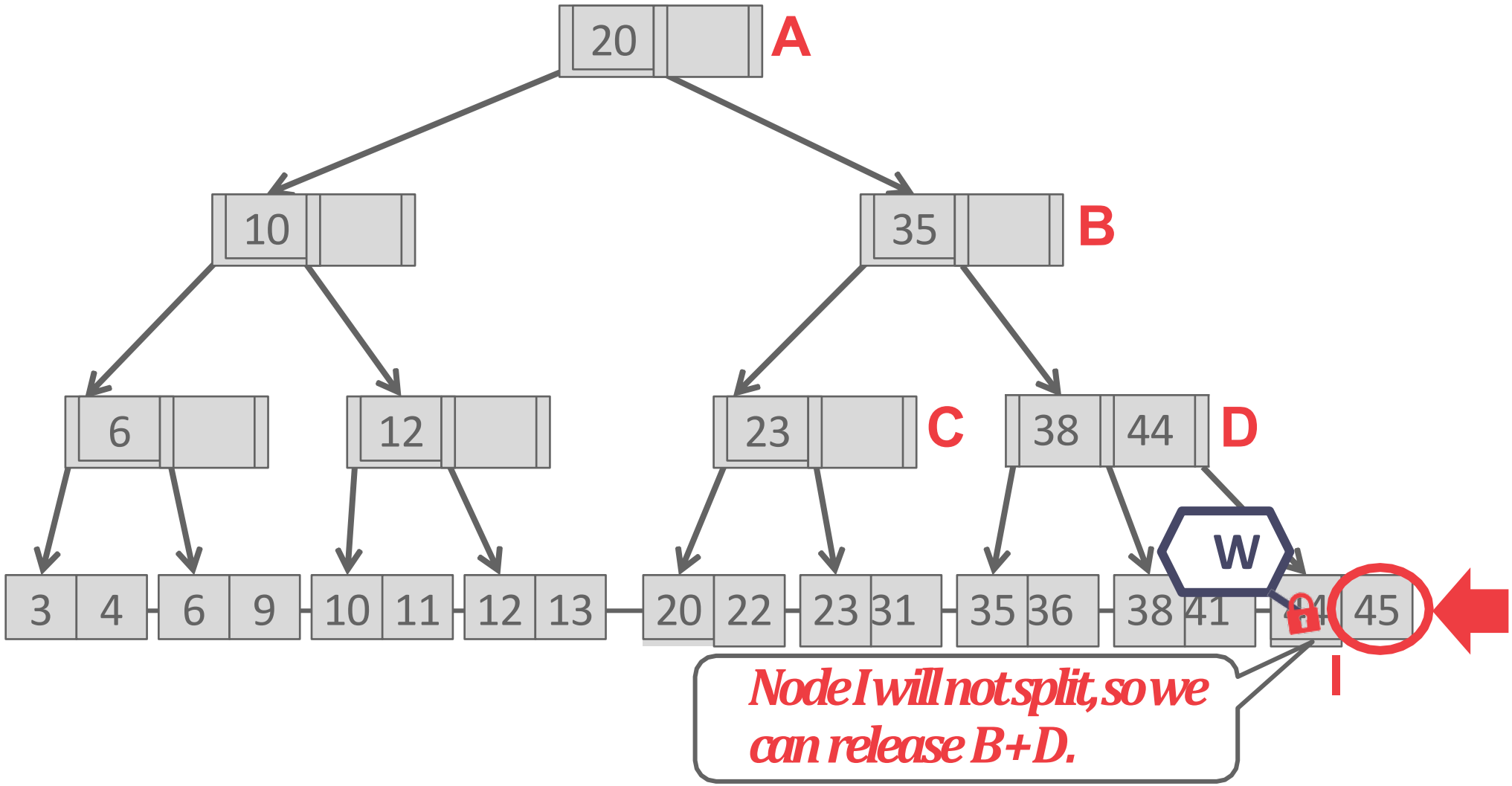
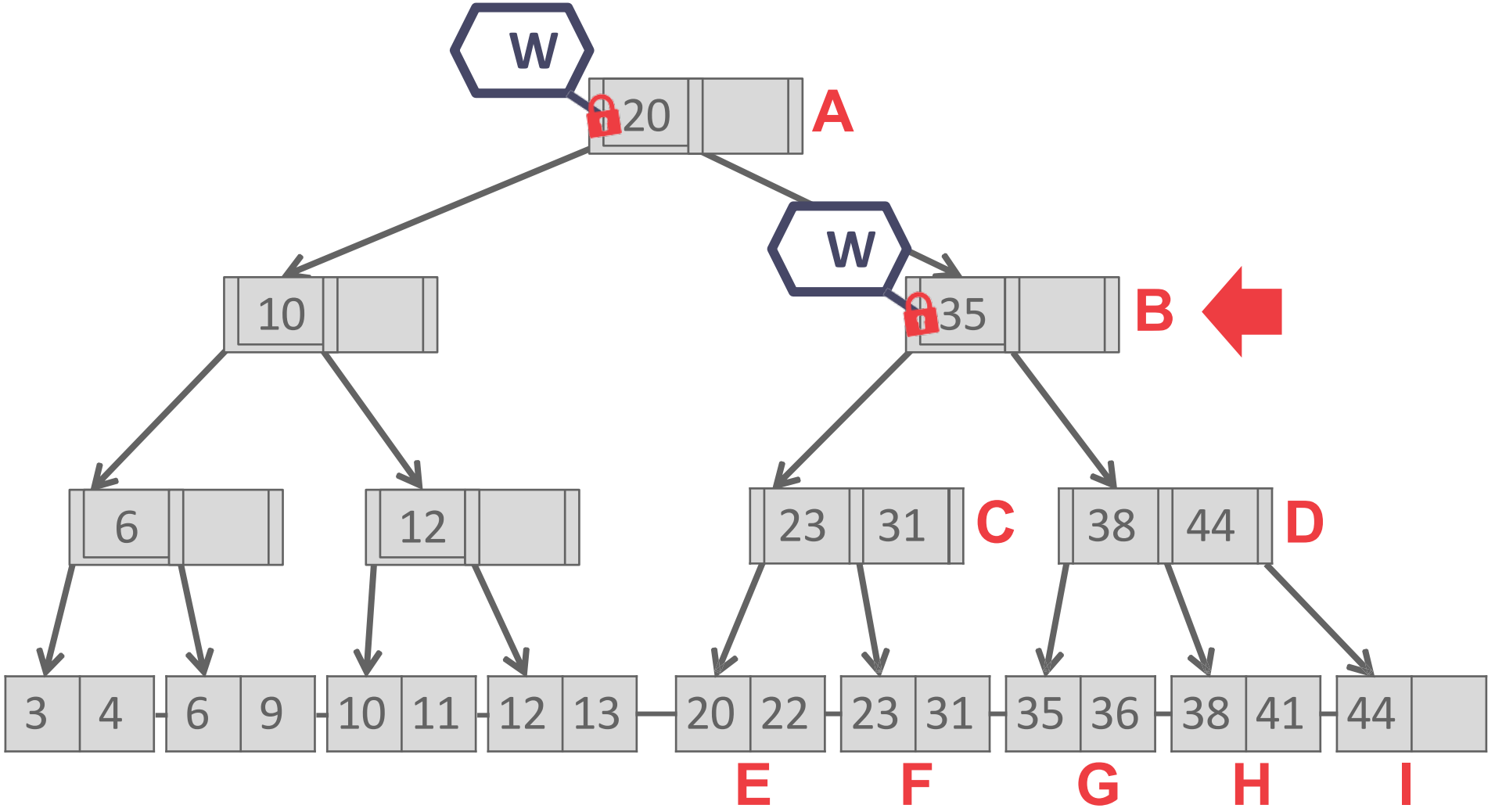


EXAMPLE #4 – INSERT 25



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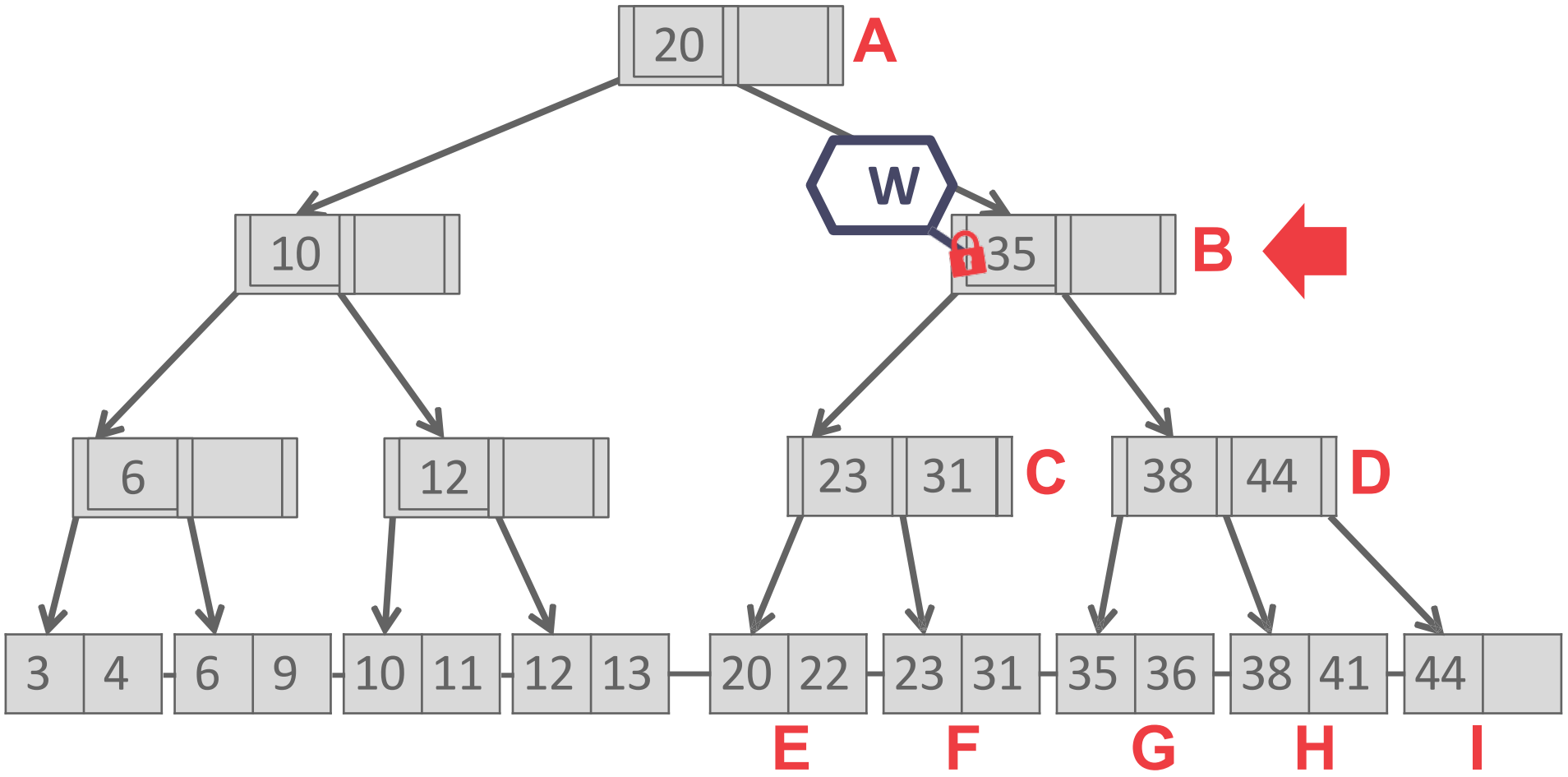

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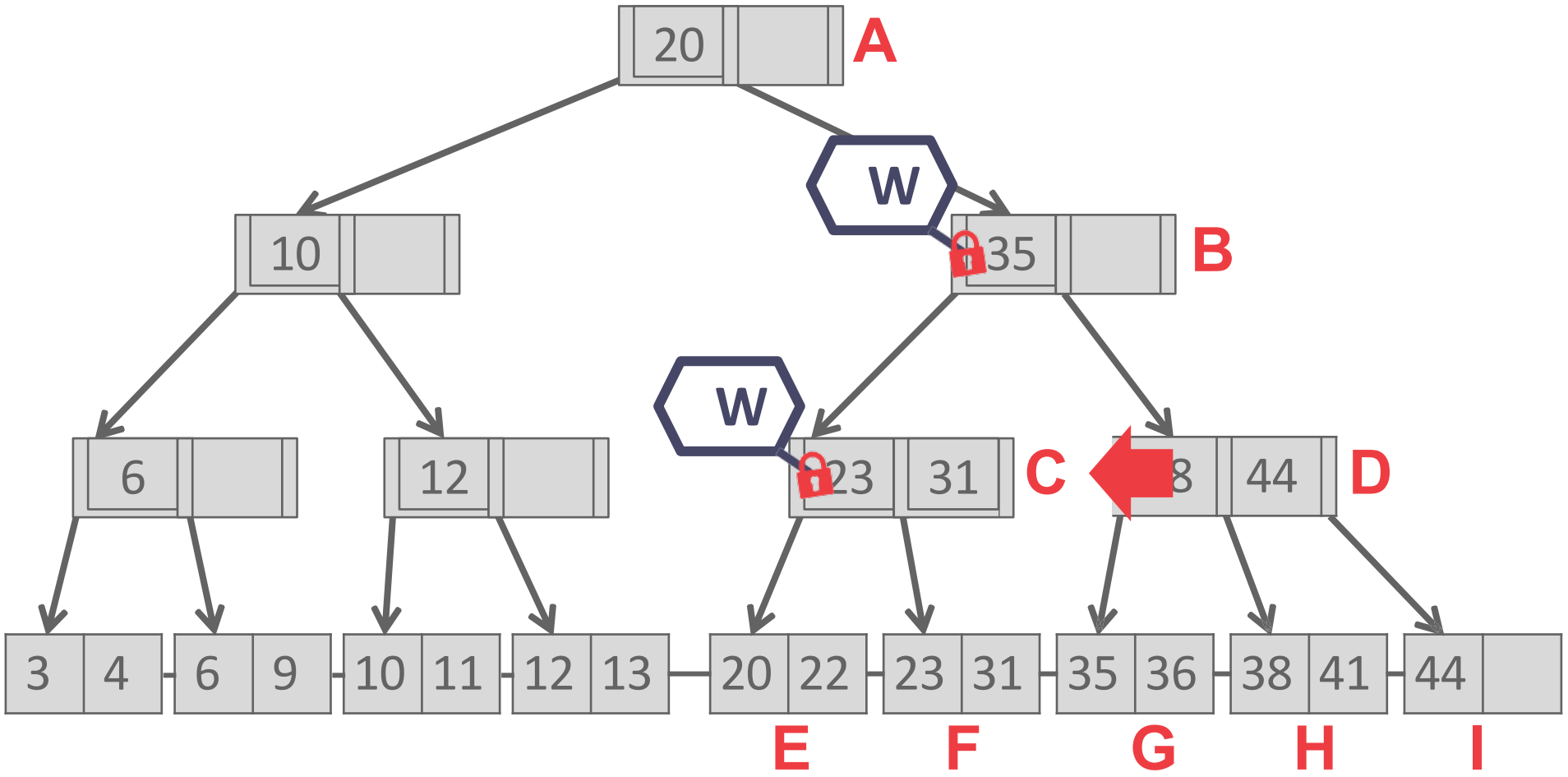

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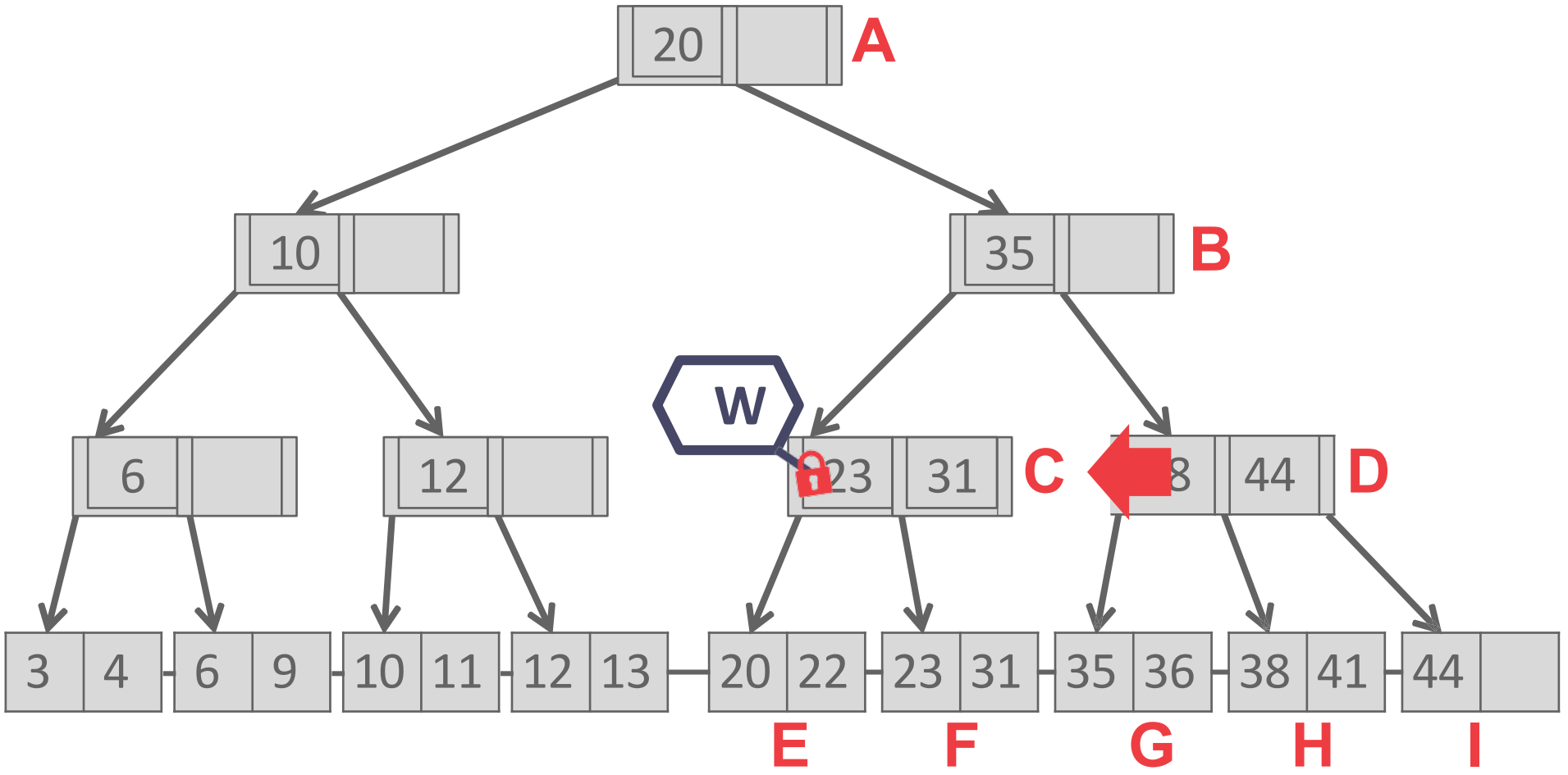

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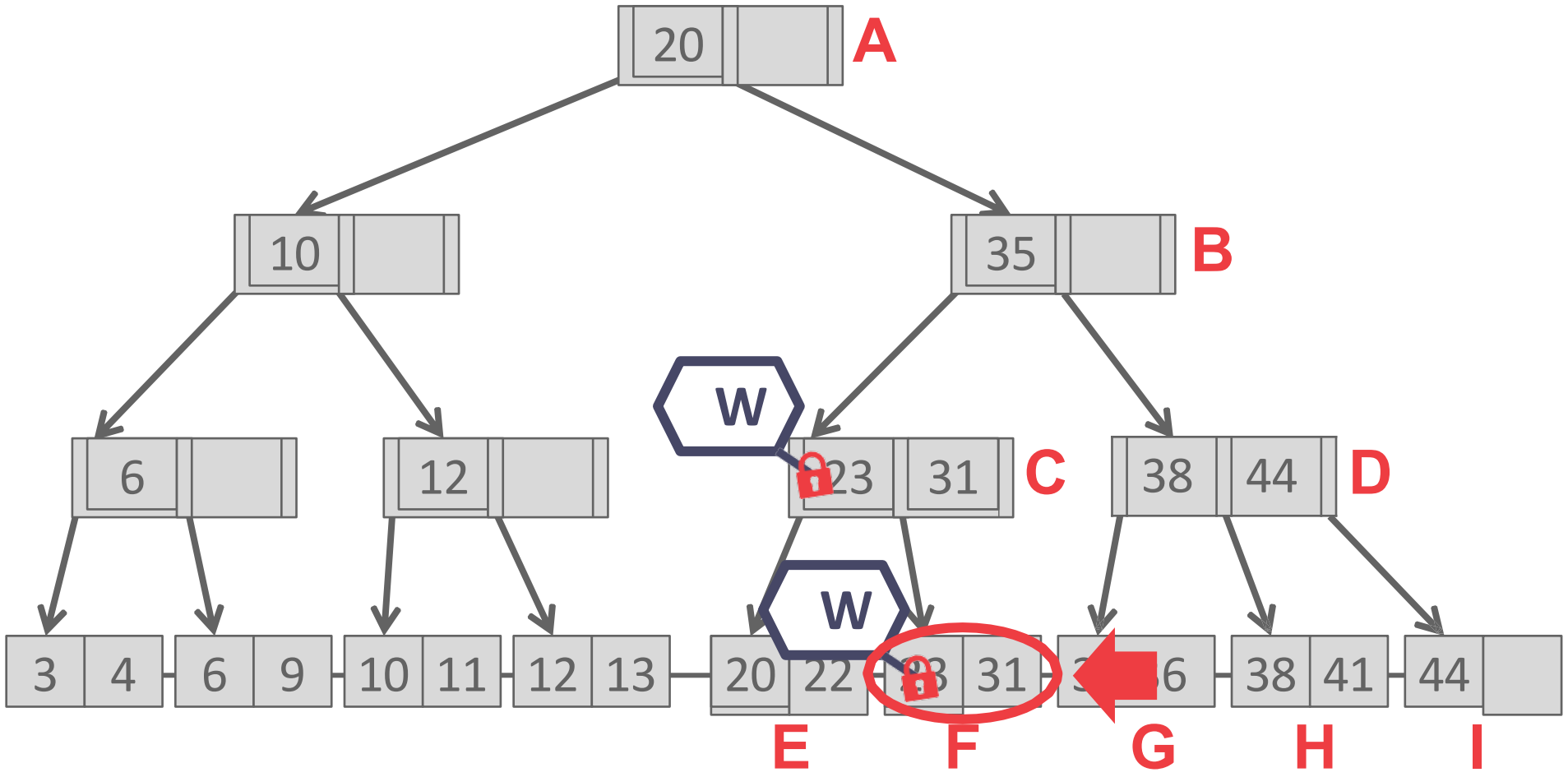

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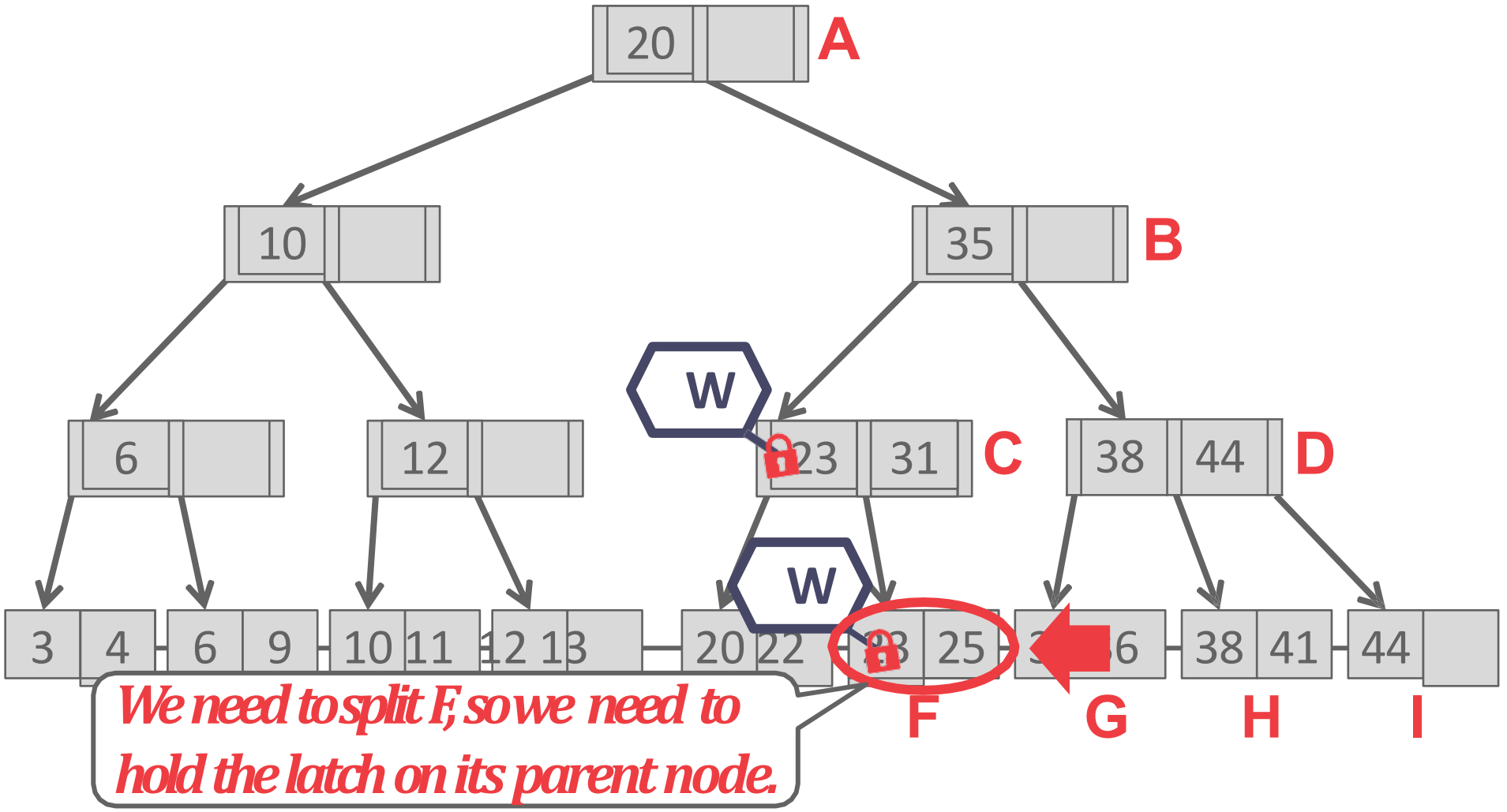

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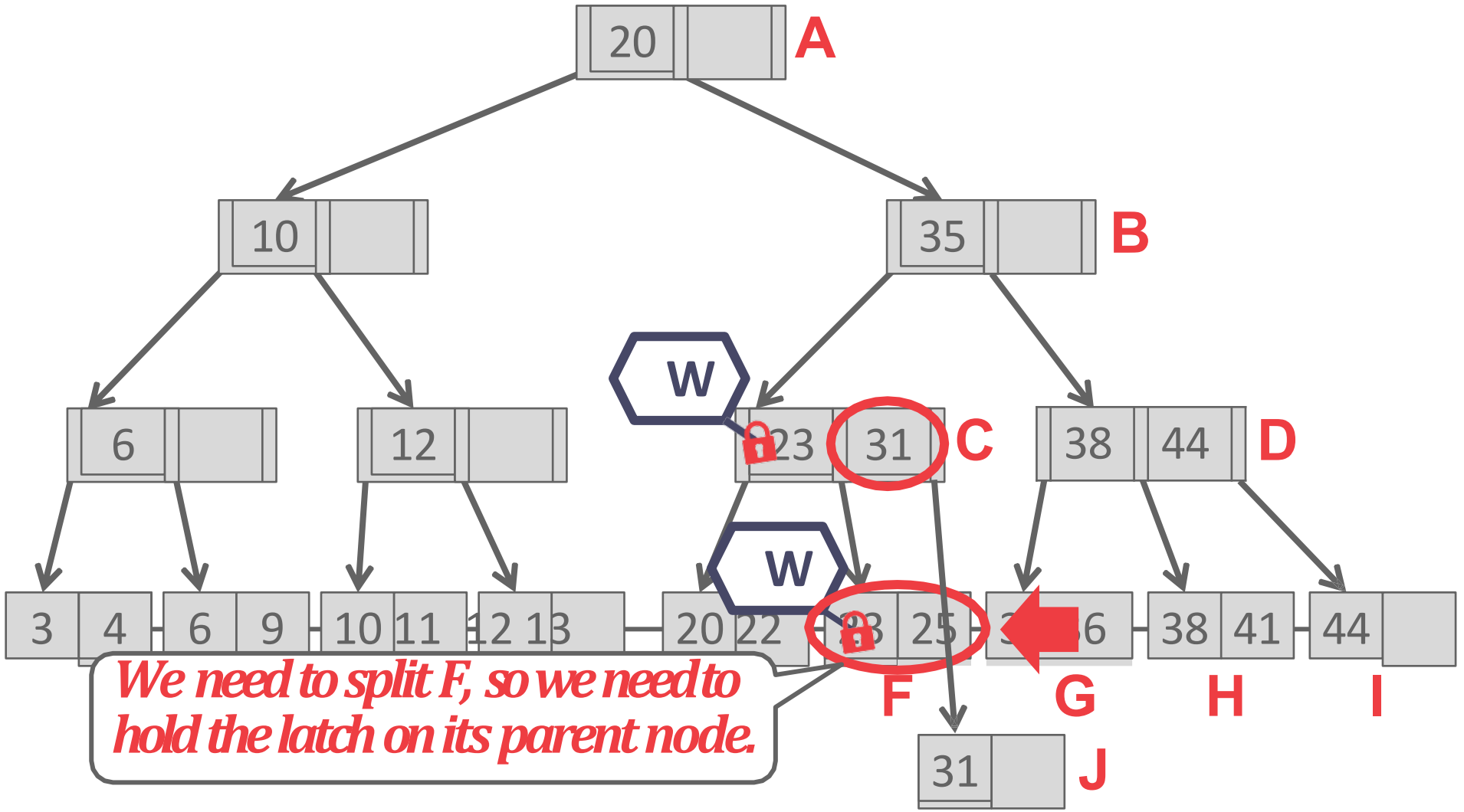
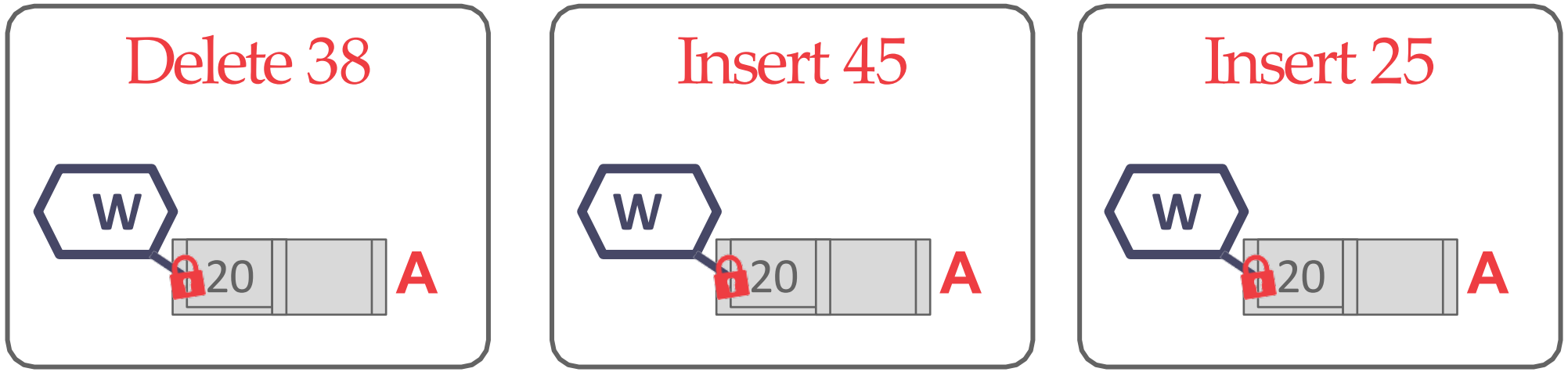


OBSERVATION

What was the first step that all the update examples did on the B+Tree?



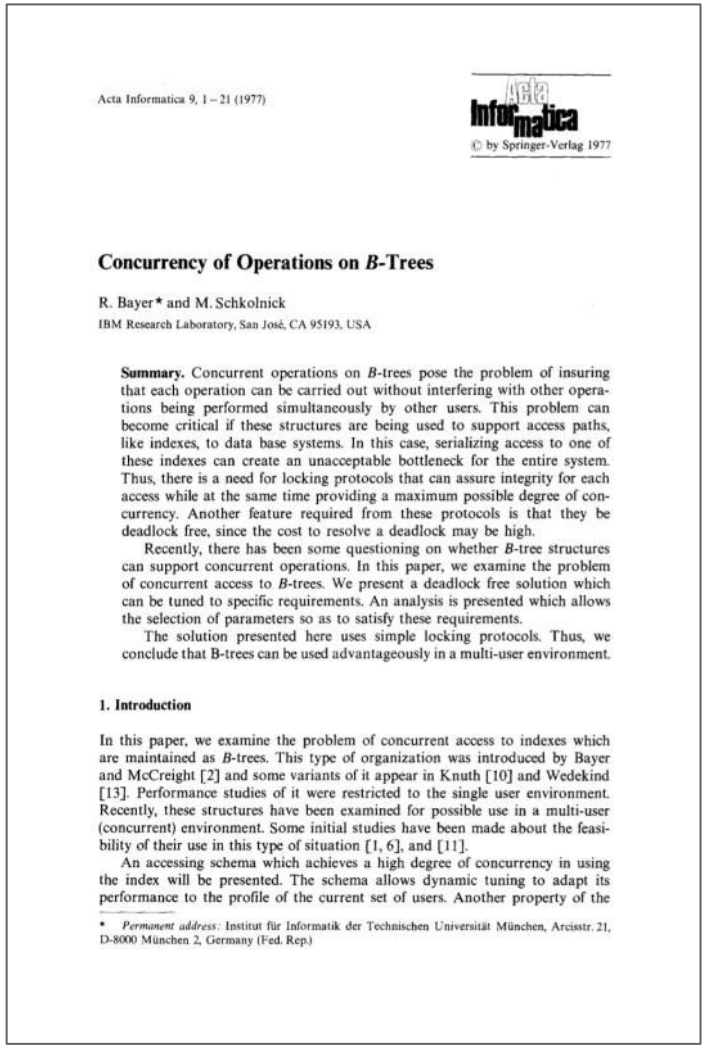
Taking a write latch on the root every time becomes a bottleneck with higher concurrency.

BETTER LATCHING ALGORITHM

Most modifications to a B+Tree will not require a split or merge.

Instead of assuming that there will be a split/merge, optimistically traverse the tree using read latches.

If you guess wrong, repeat traversal with the pessimistic algorithm.



Acta Informatica 9, 1–21 (1977)

Acta Informatica

Concurrency of Operations on *B*-Trees

R. Bayer* and M. Schkolnick
IBM Research Laboratory, San José, CA 95193, USA

Summary. Concurrent operations on *B*-trees pose the problem of insuring that each operation can be carried out without interfering with other operations being performed simultaneously by other users. This problem can become critical if these structures are being used to support access paths, like indexes, to data base systems. In this case, serializing access to one of these indexes can create an unacceptable bottleneck for the entire system. Thus, there is a need for locking protocols that can assure integrity for each access while at the same time providing a maximum possible degree of concurrency. Another feature required from these protocols is that they be deadlock free, since the cost to resolve a deadlock may be high.

Recently, there has been some questioning on whether *B*-tree structures can support concurrent operations. In this paper, we examine the problem of concurrent access to *B*-trees. We present a deadlock free solution which can be tuned to specific requirements. An analysis is presented which allows the selection of parameters so as to satisfy these requirements.

The solution presented here uses simple locking protocols. Thus, we conclude that B-trees can be used advantageously in a multi-user environment.

1. Introduction

In this paper, we examine the problem of concurrent access to indexes which are maintained as *B*-trees. This type of organization was introduced by Bayer and McCreight [2] and some variants of it appear in Knuth [10] and Wedekind [13]. Performance studies of it were restricted to the single user environment. Recently, these structures have been examined for possible use in a multi-user (concurrent) environment. Some initial studies have been made about the feasibility of their use in this type of situation [1, 6], and [11].

An accessing schema which achieves a high degree of concurrency in using the index will be presented. The schema allows dynamic tuning to adapt its performance to the profile of the current set of users. Another property of the

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BETTER LATCHING ALGORITHM

Search: Same as before.

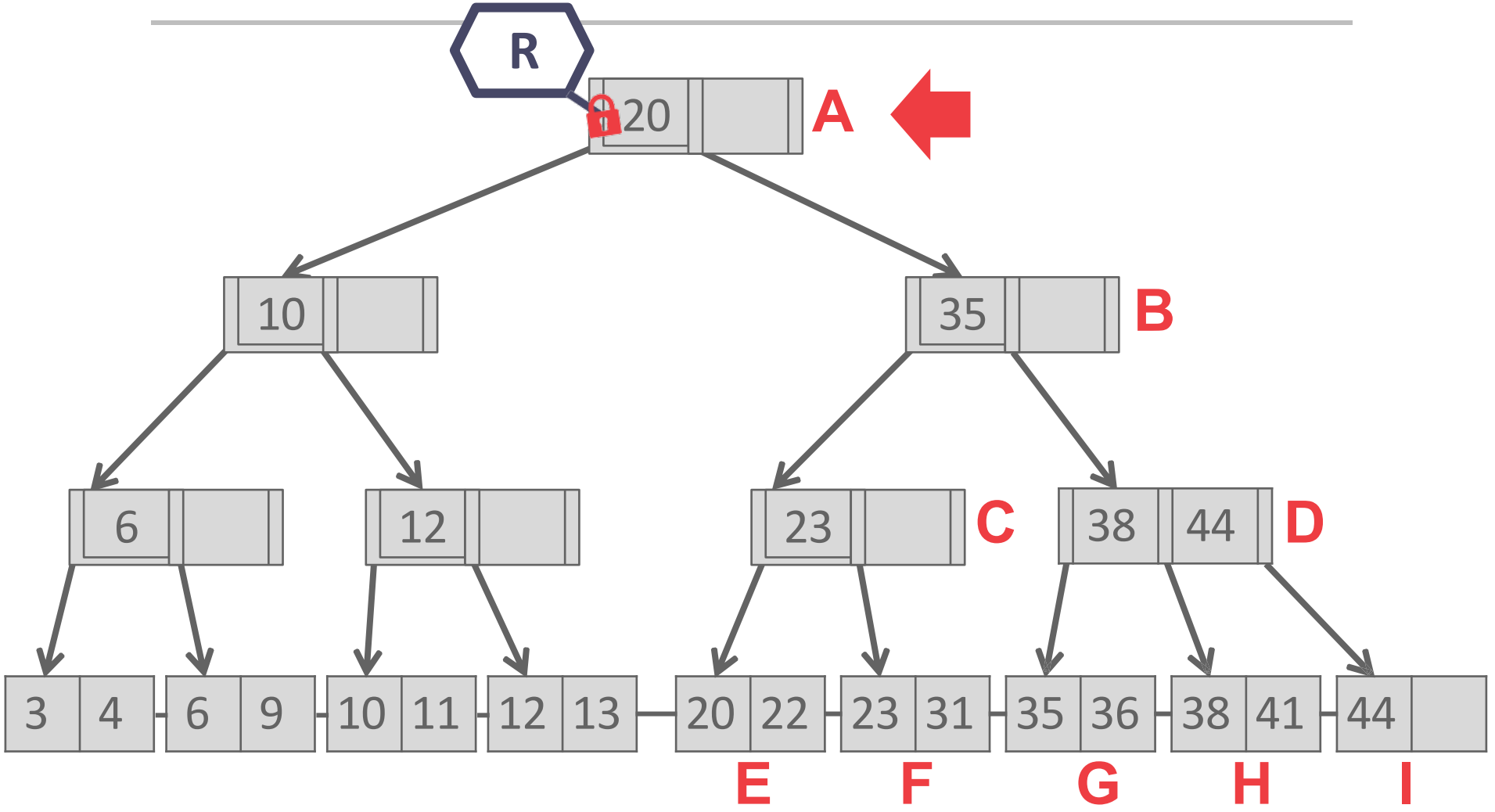
Insert/Delete:

→ Set latches as if for search, get to leaf, and set **W**latch on leaf.

→ If leaf is not safe, release all latches, and restart thread using previous insert/delete protocol with write latches.

This approach optimistically assumes that only leaf node will be modified; if not, **R**latches set on the first pass to leaf are wasteful.

EXAMPLE #2 – DELETE 38



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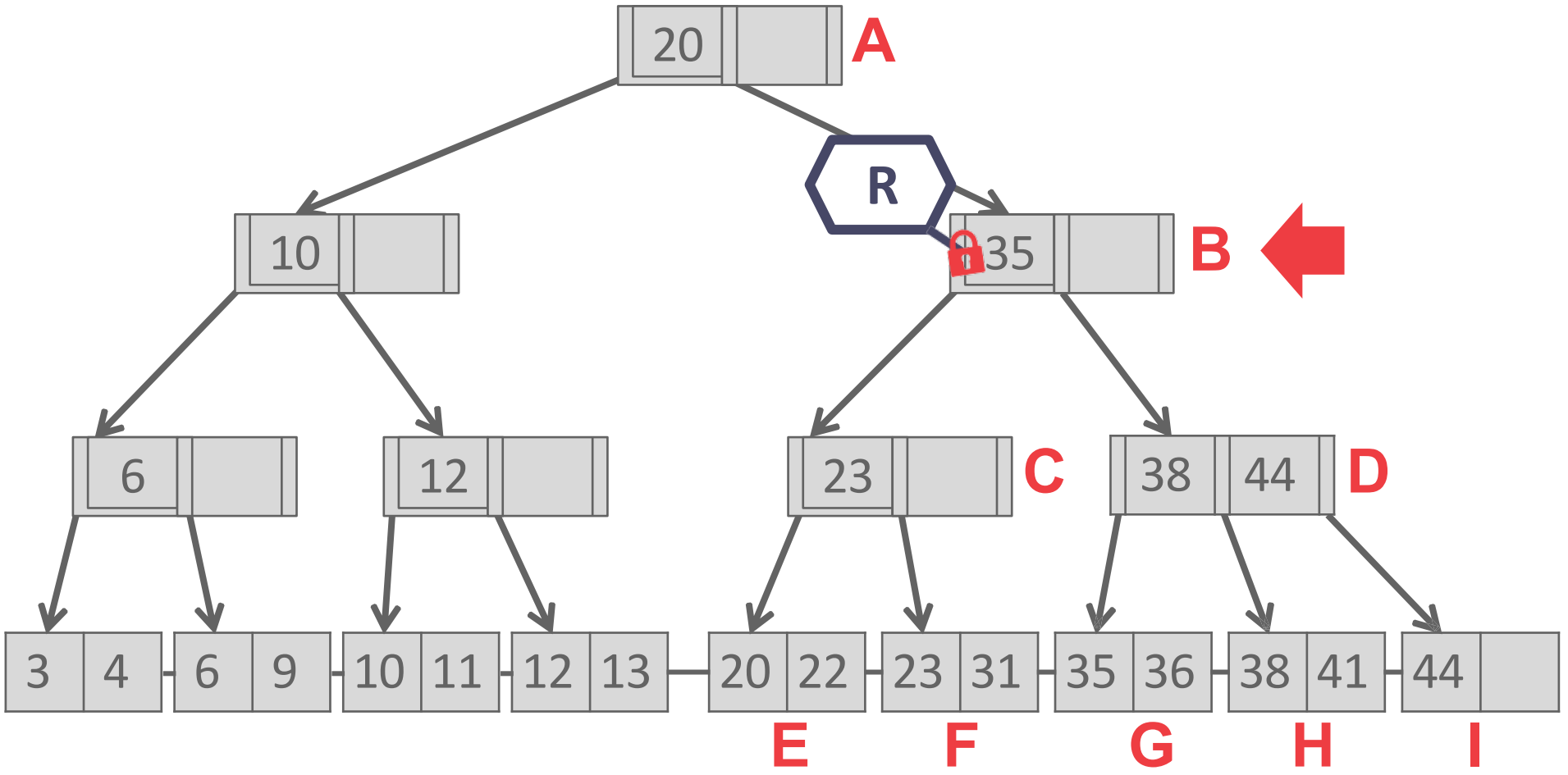

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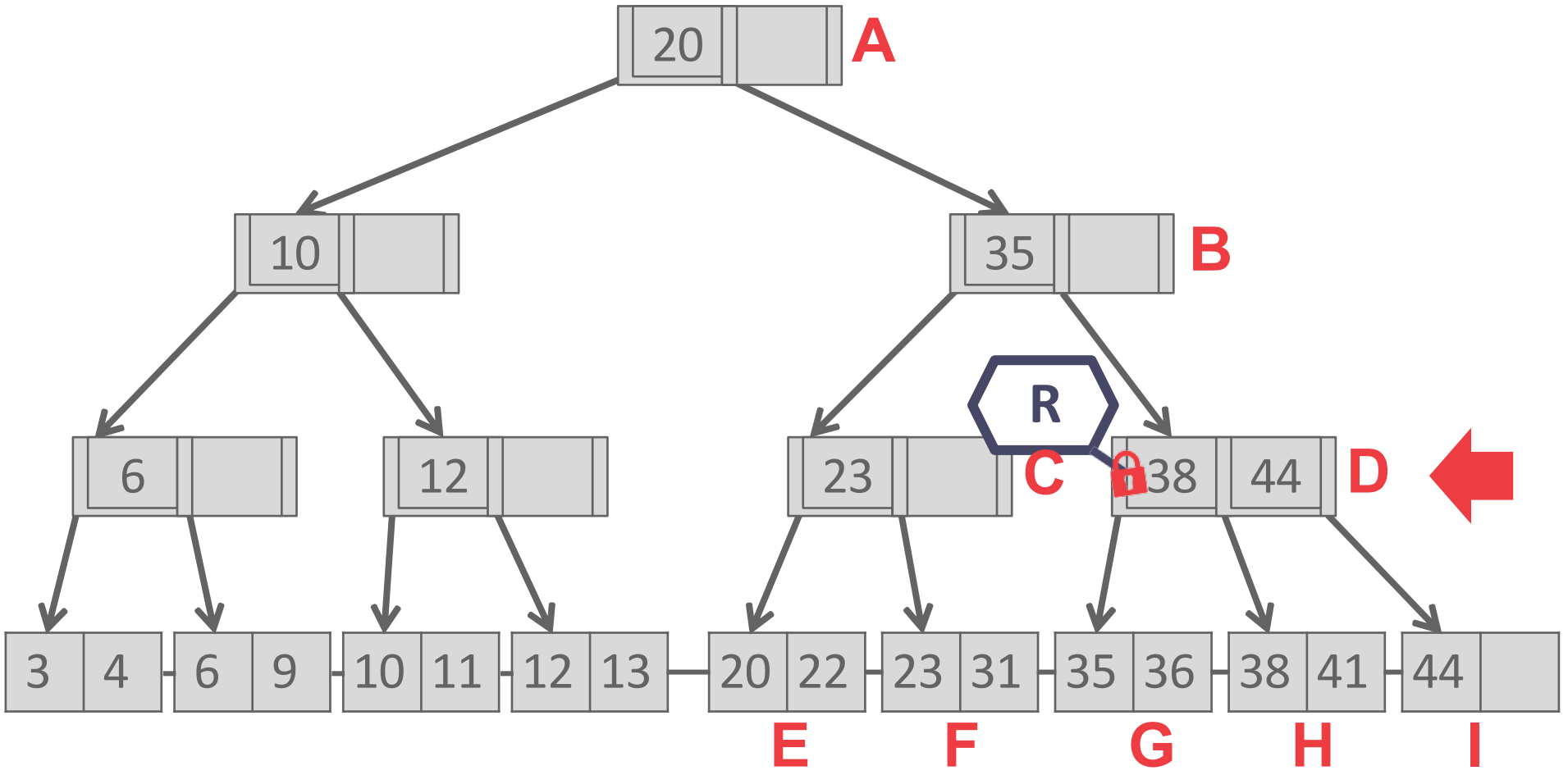

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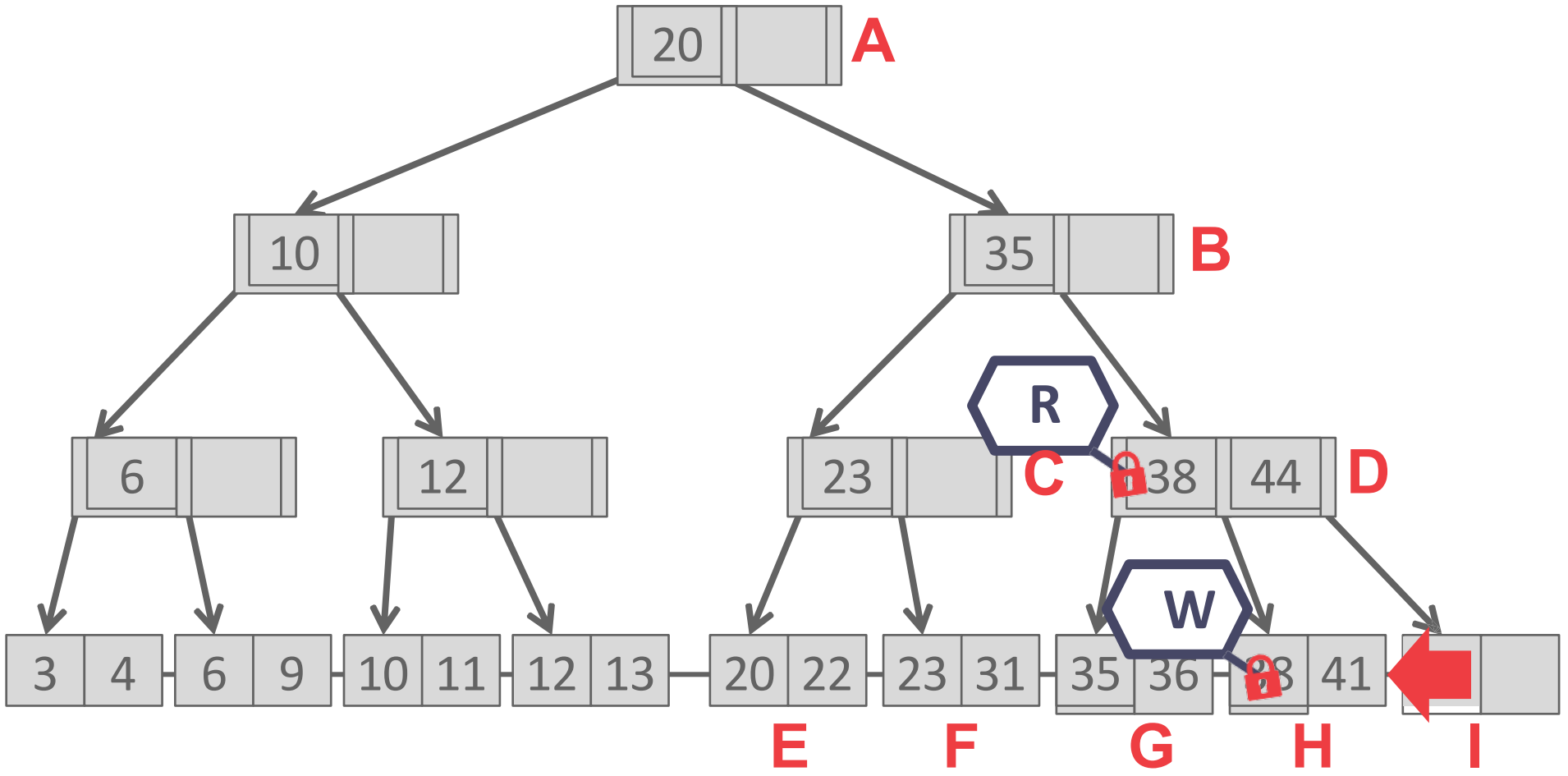

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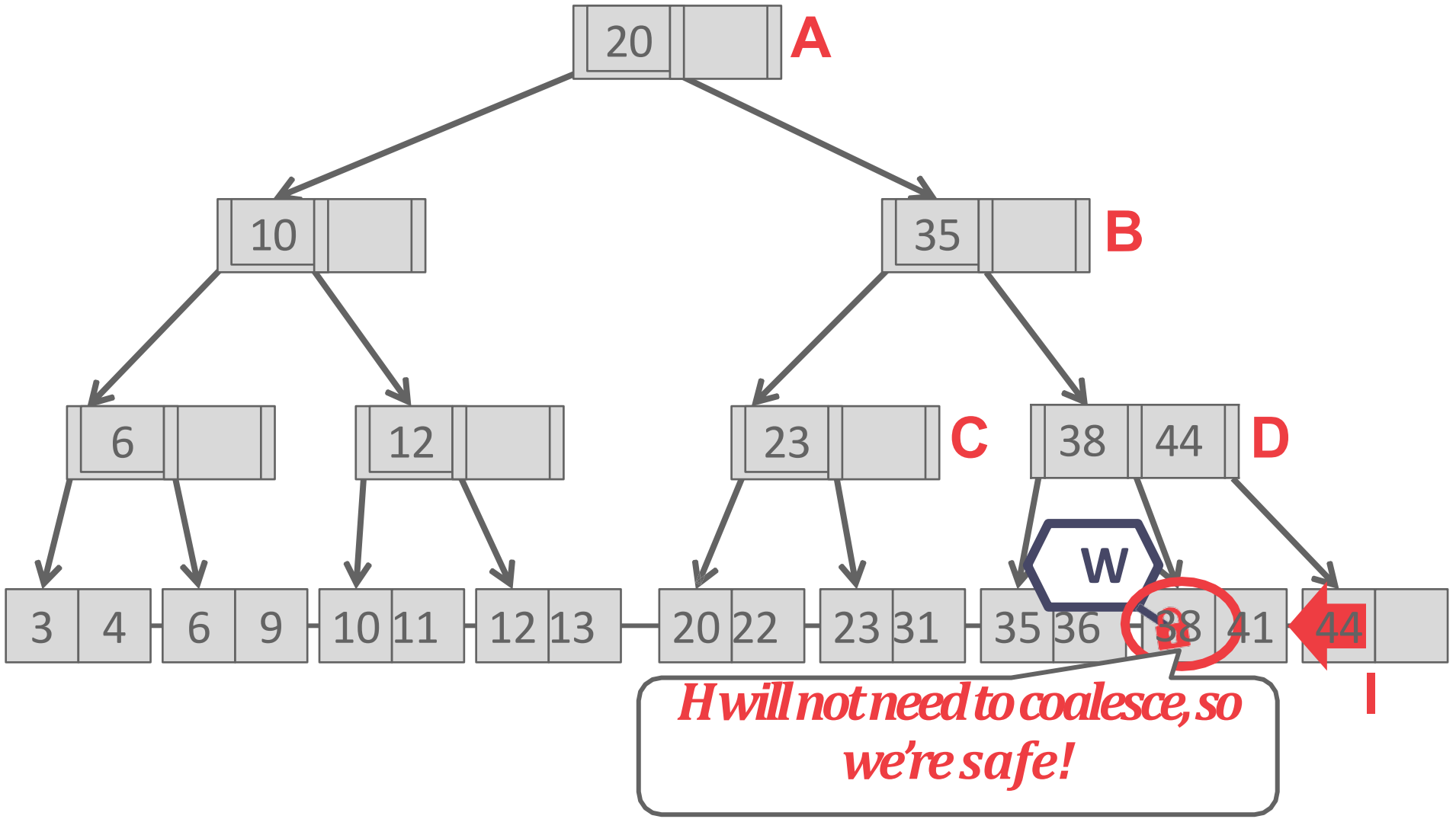

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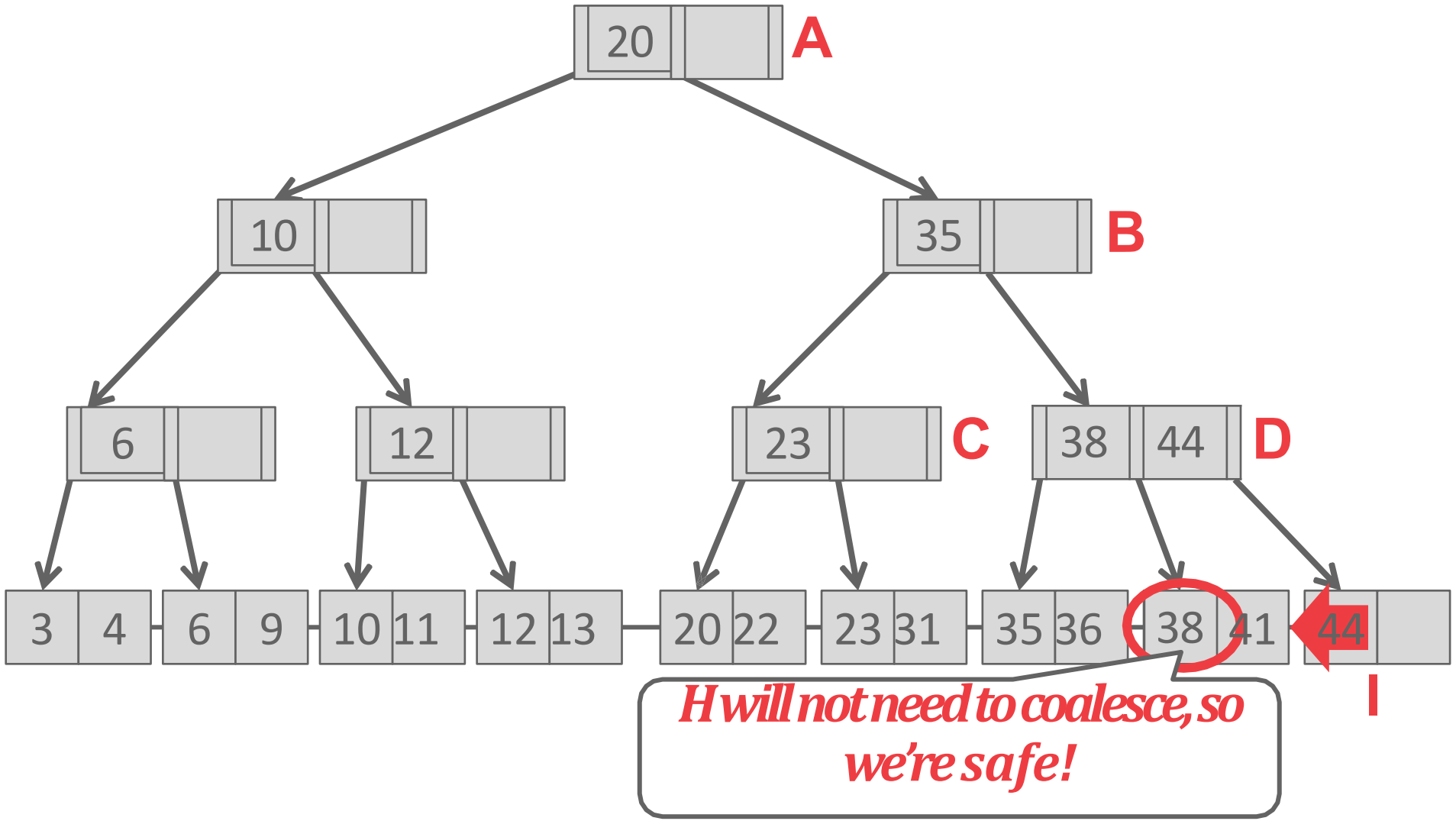

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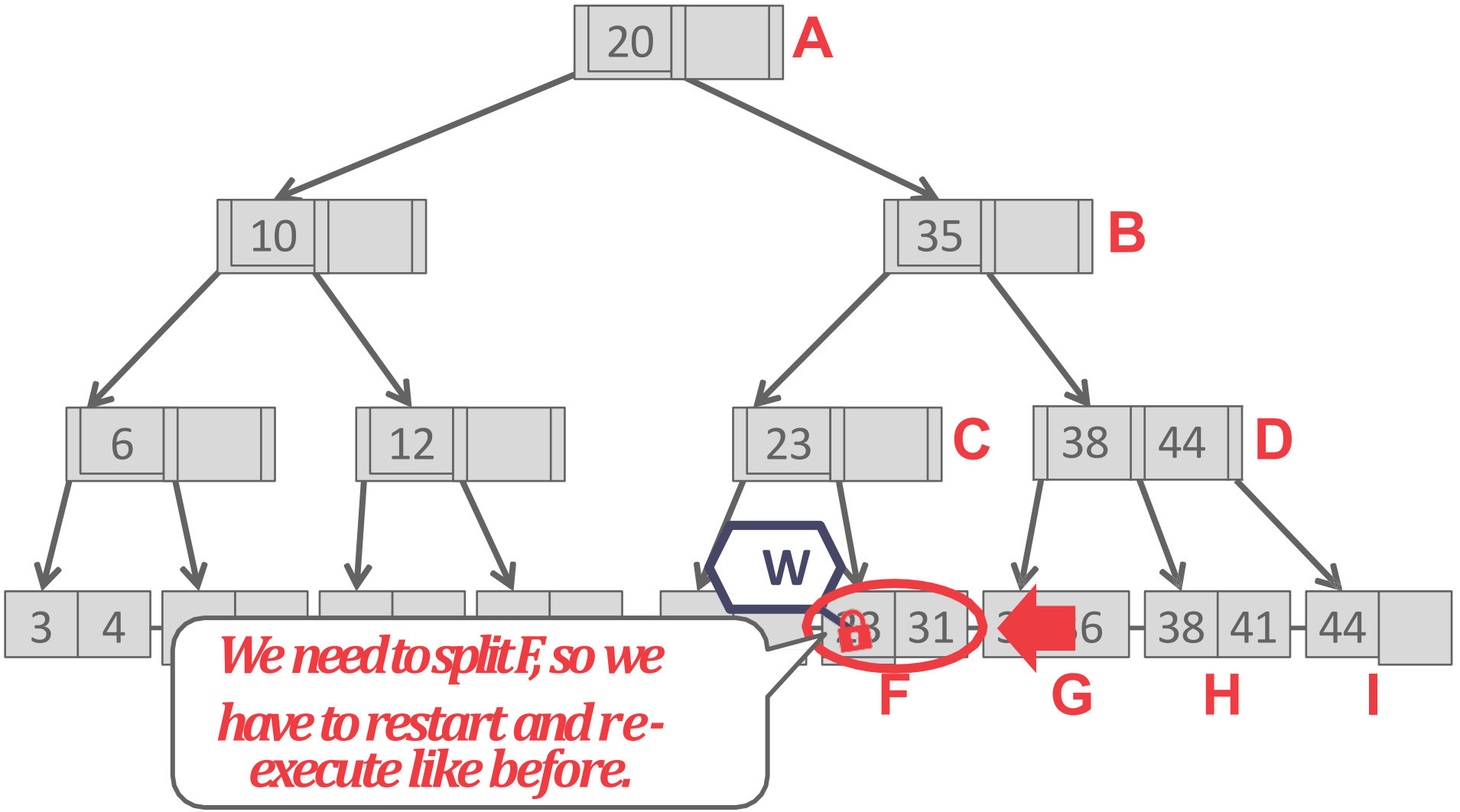


OBSERVATION

The threads in all the examples so far have acquired latches in a "top-down" manner.

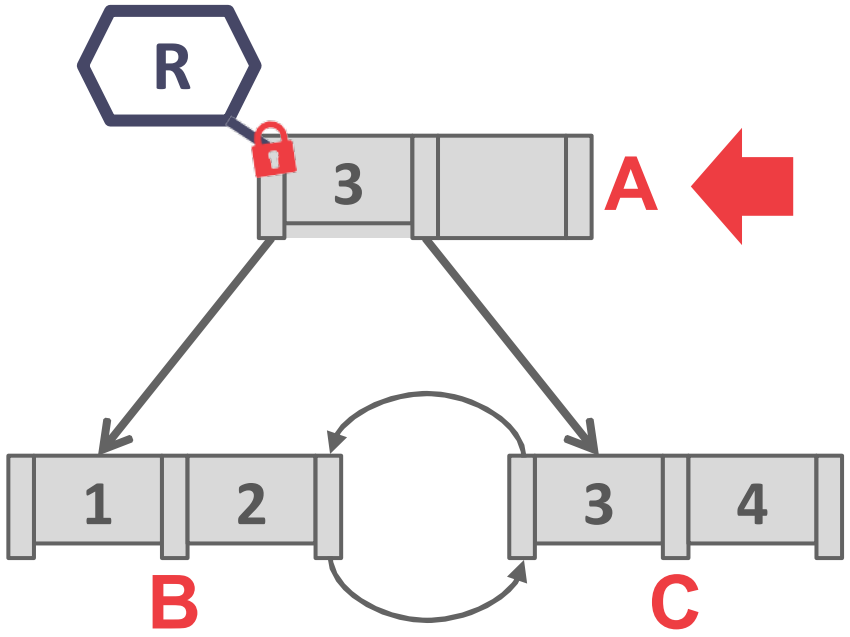
→ A thread can only acquire a latch from a node that is below its current node.

→ If the desired latch is unavailable, the thread must wait until it becomes available.

But what if we want to move from one leaf node to another leaf node?

LEAF NODE SCAN EXAMPLE #1

T_1: Find Keys < 4



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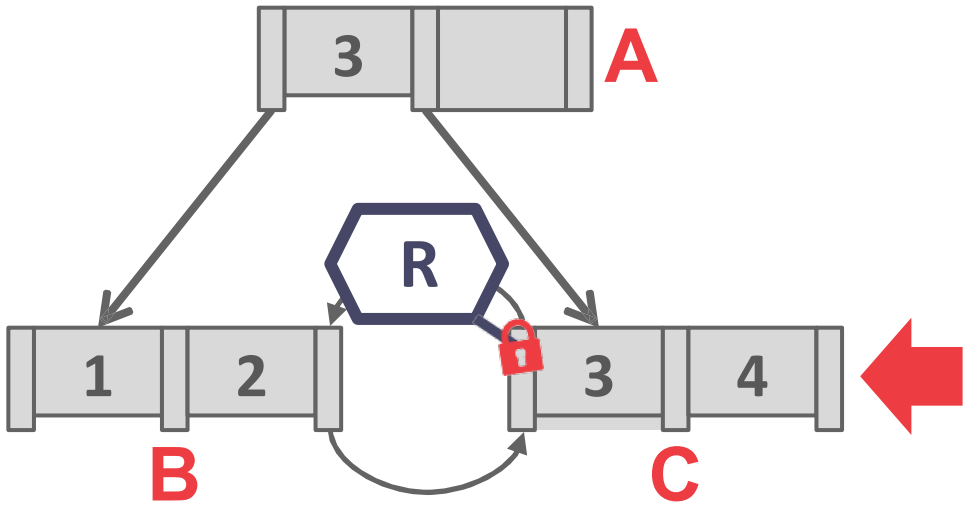

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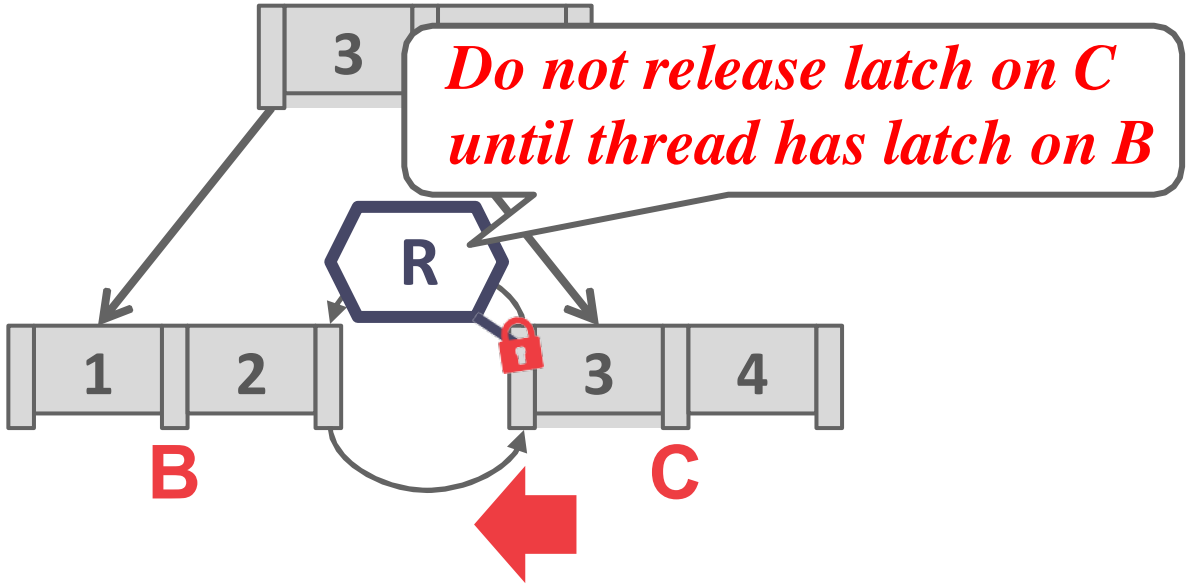

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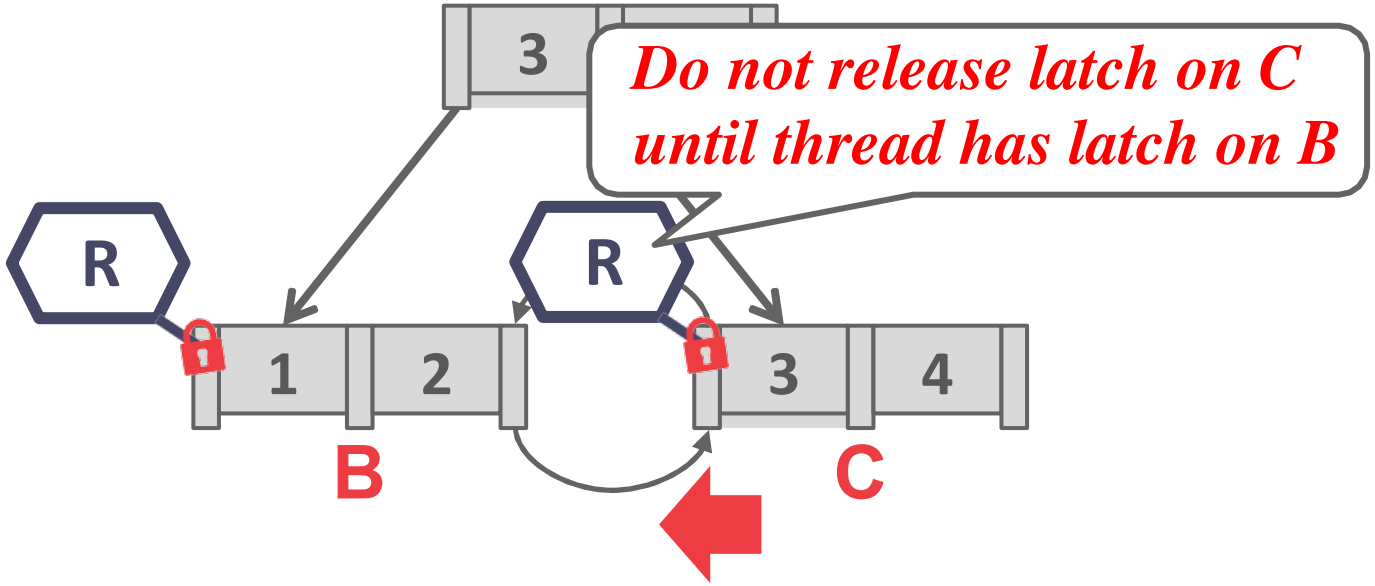

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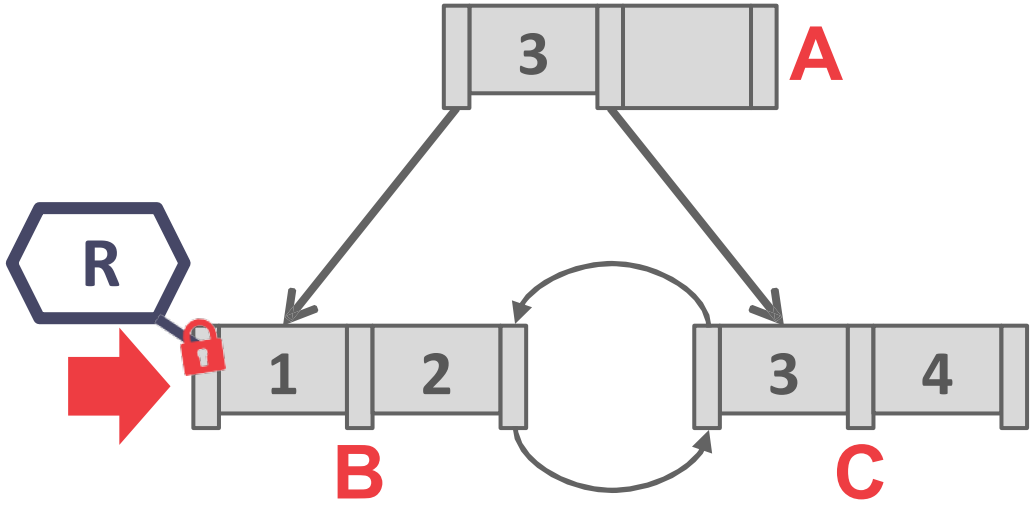
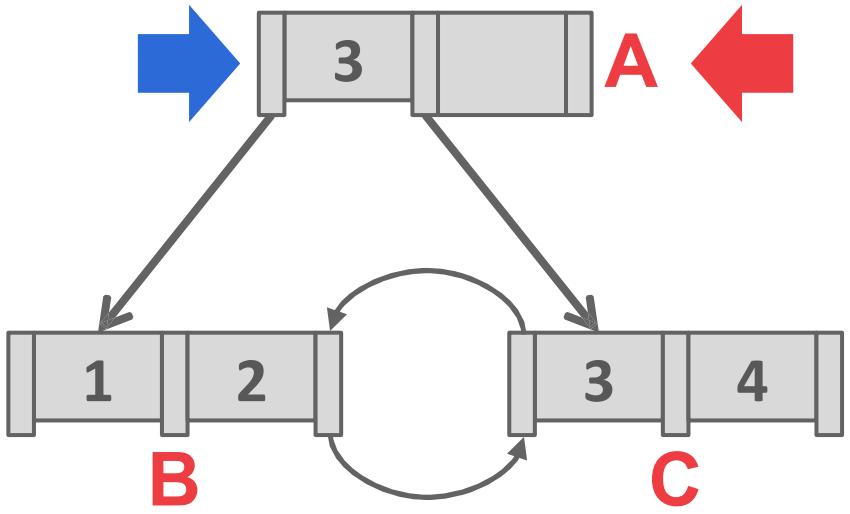


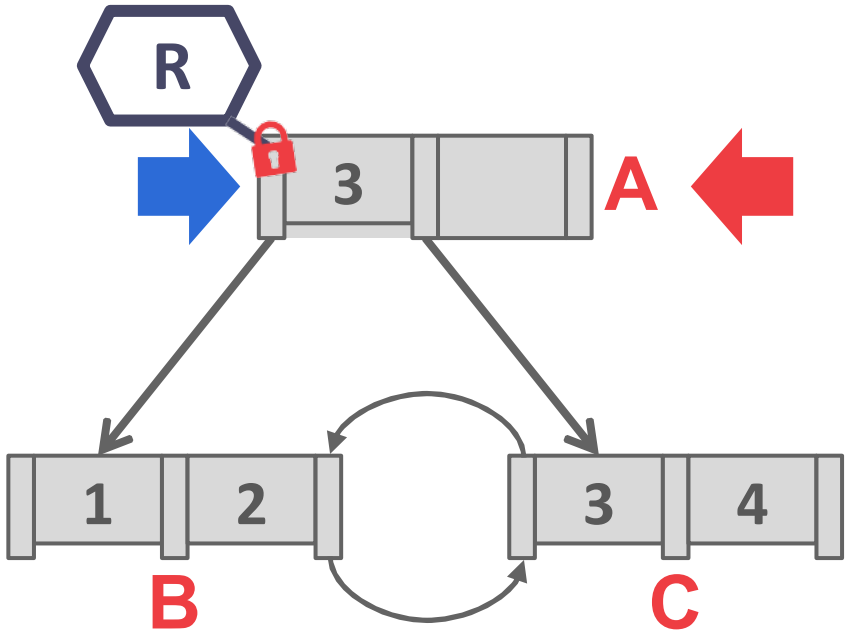
LEAF NODE SCAN EXAMPLE #2

T_1: Find Keys < 4

T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #2



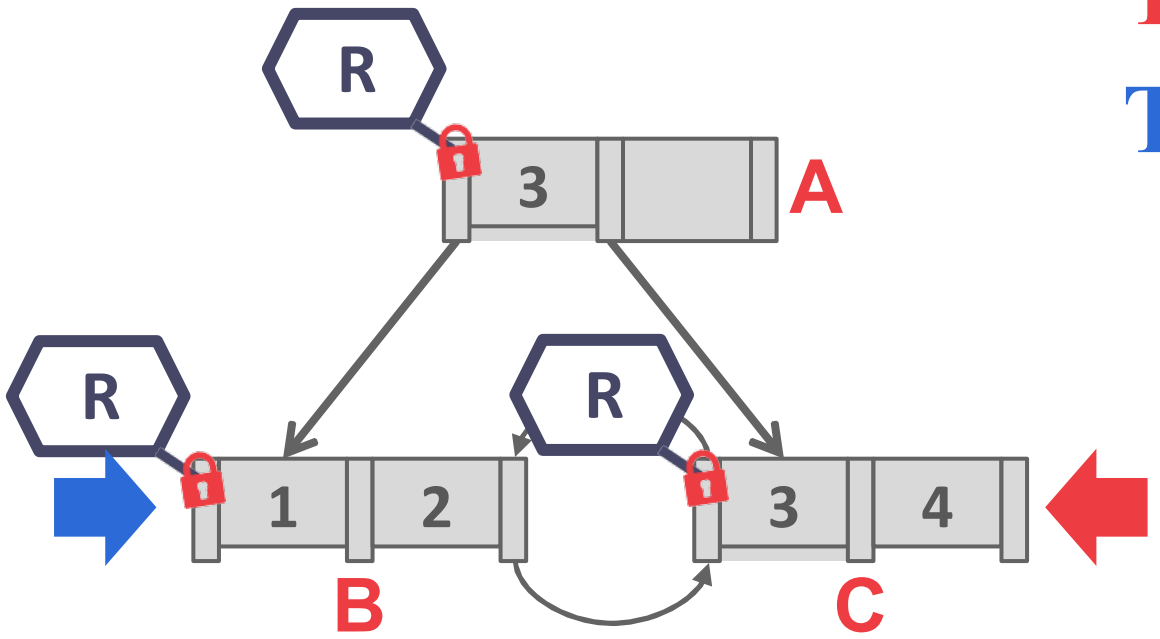
T_1: Find Keys < 4

T_2: Find Keys > 1

LEAF NODE SCAN EXAMPLE #2

T_1: Find Keys < 4

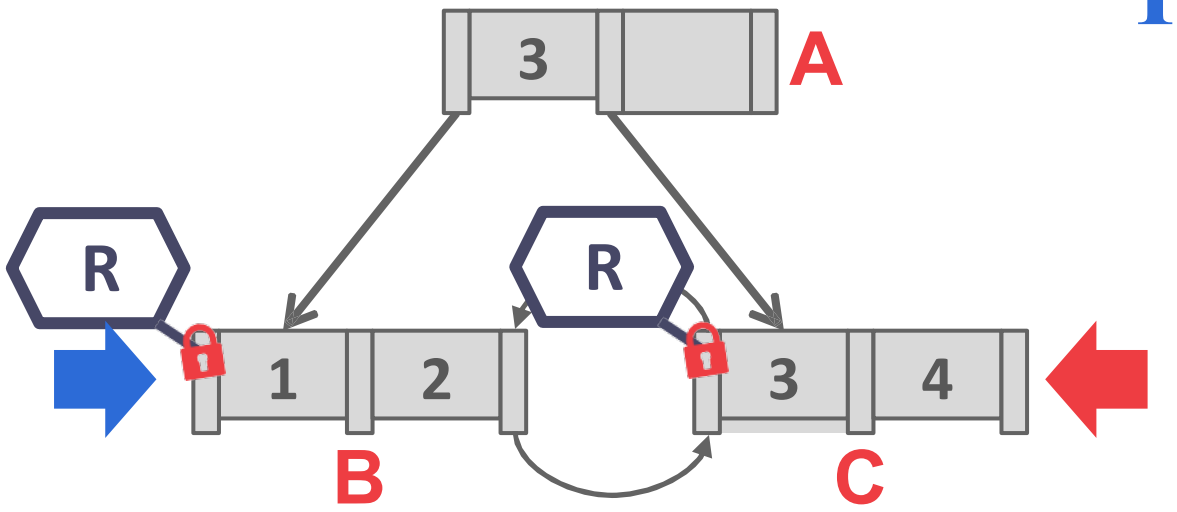
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #2

T_1: Find Keys < 4

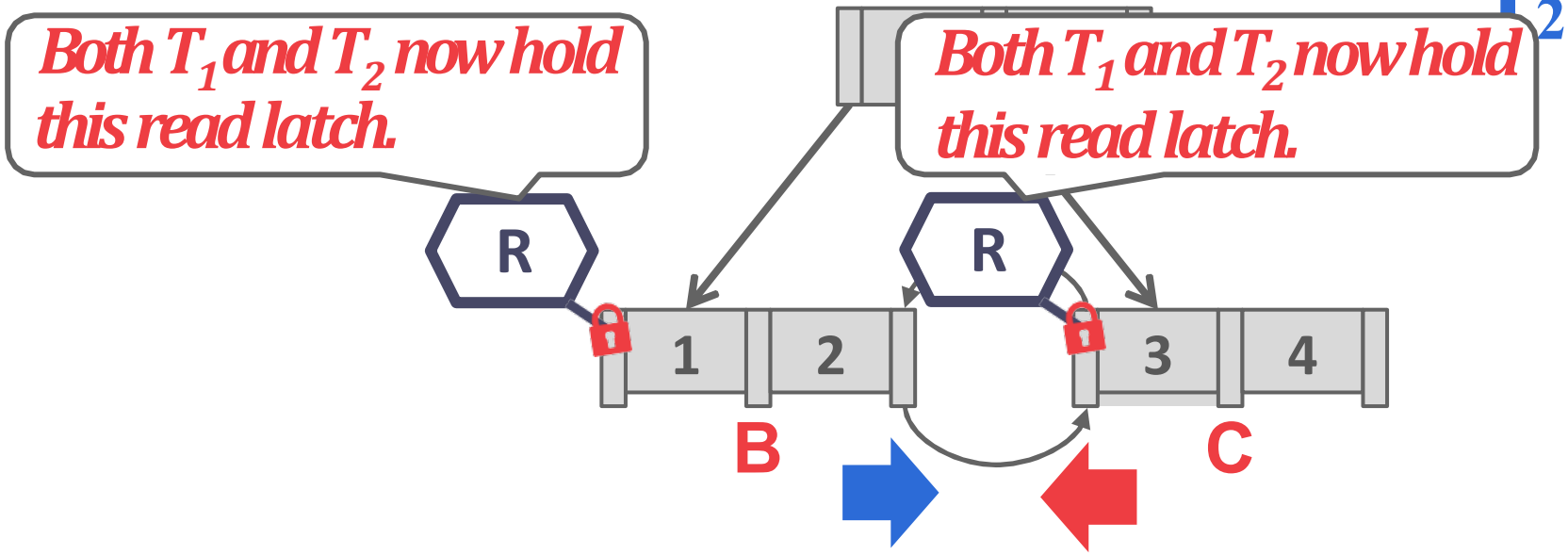
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #2

T_1: Find Keys < 4

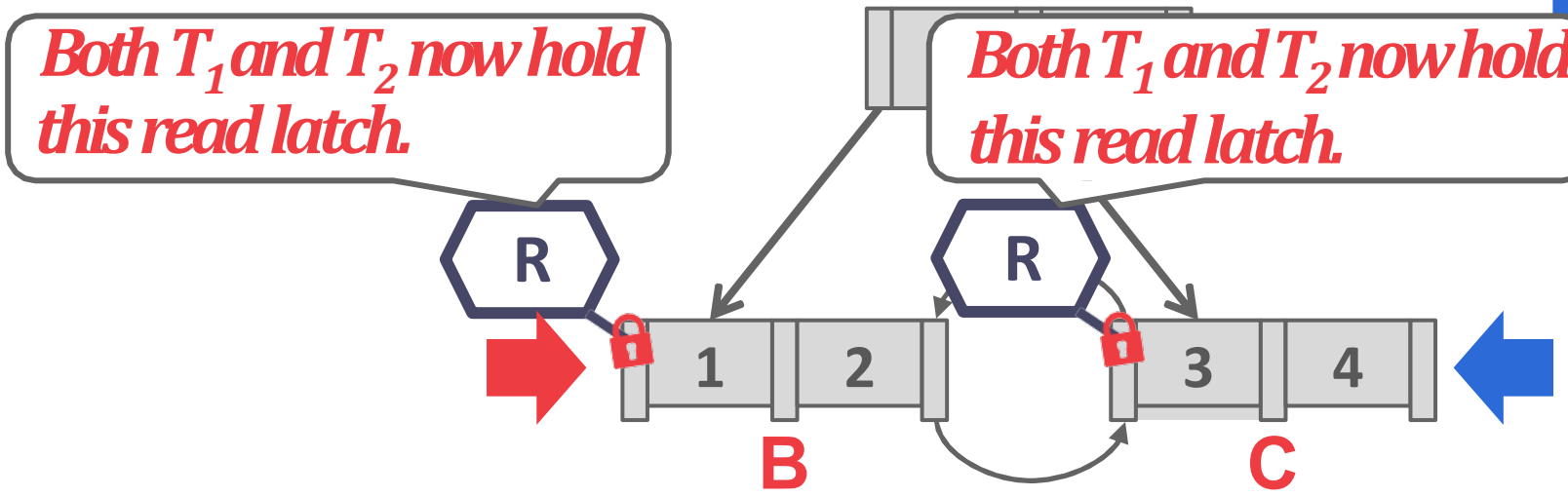
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #2

T_1: Find Keys < 4

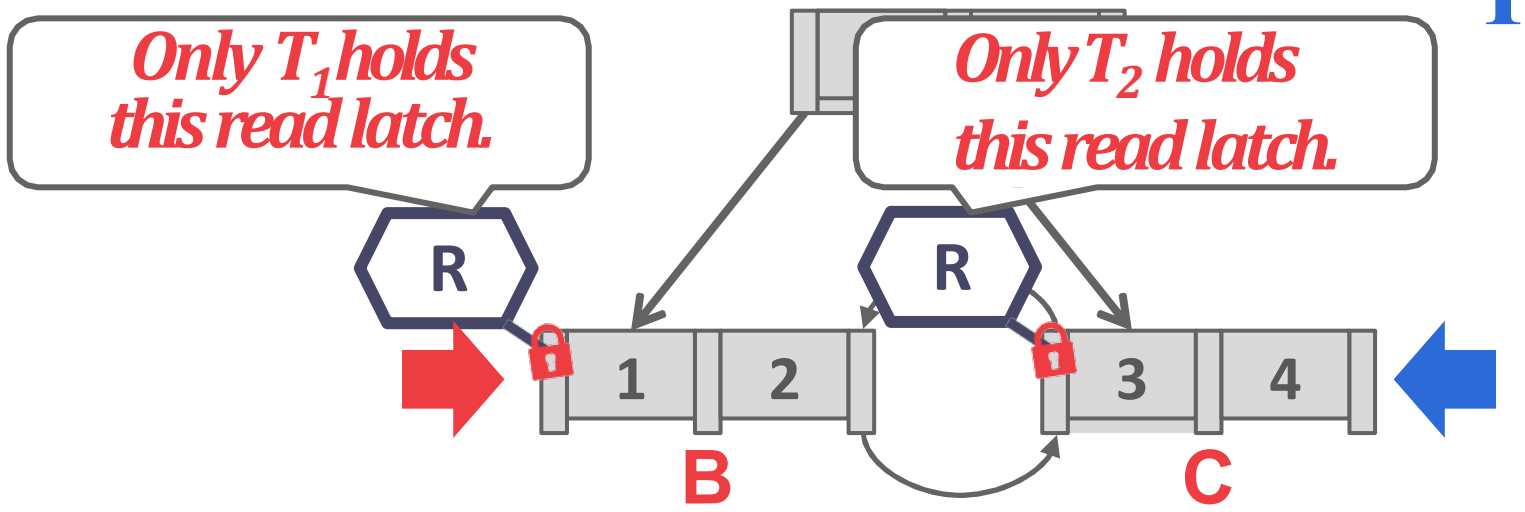
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #2

T_1: Find Keys < 4

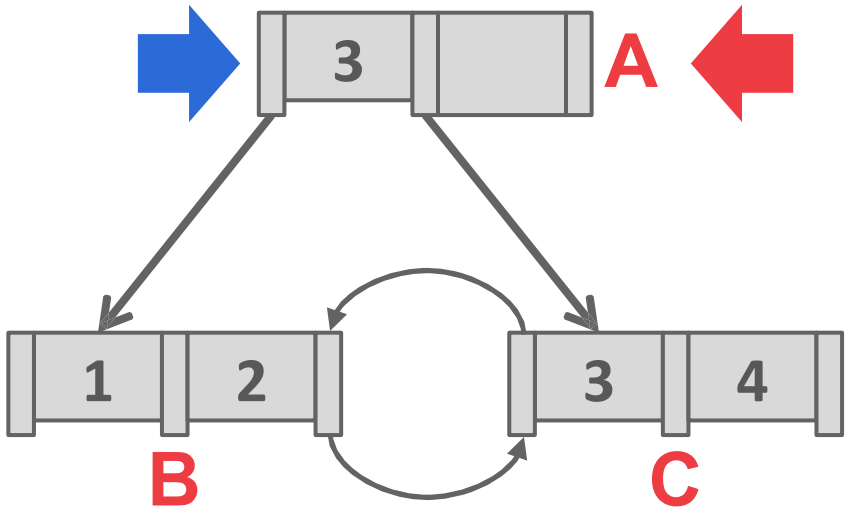
T_2: Find Keys > 1



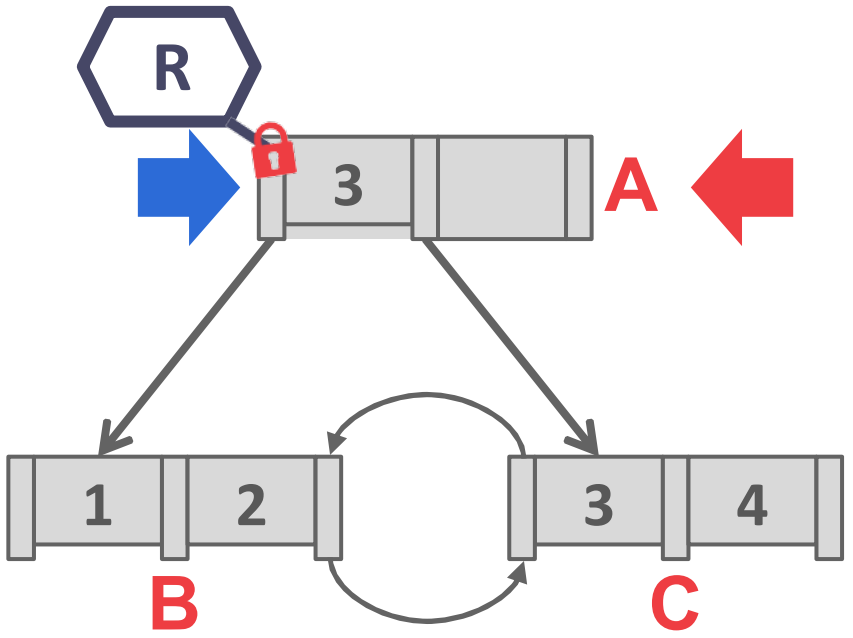
LEAF NODE SCAN EXAMPLE #3

T_1: Delete 4

T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #3



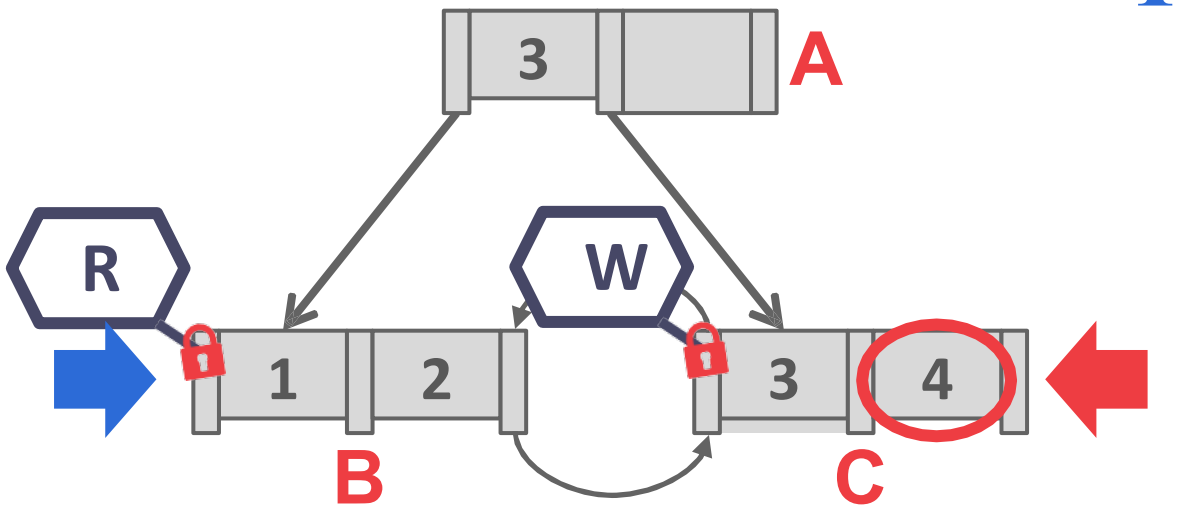
T_1: Delete 4

T_2: Find Keys > 1

LEAF NODE SCAN EXAMPLE #3

T_1: Delete 4

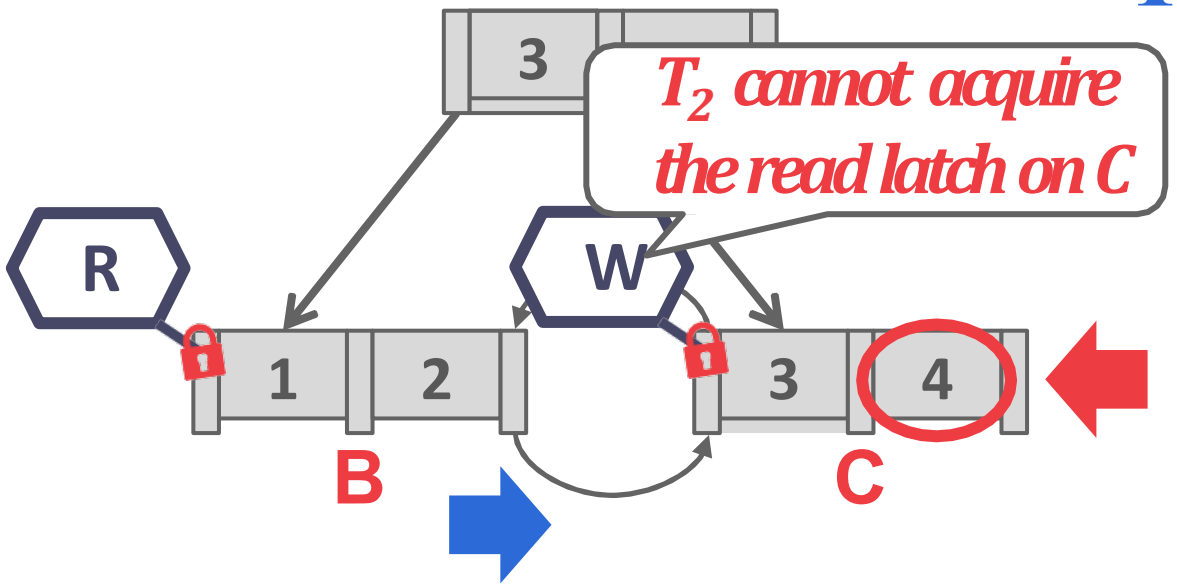
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #3

T_1: Delete 4

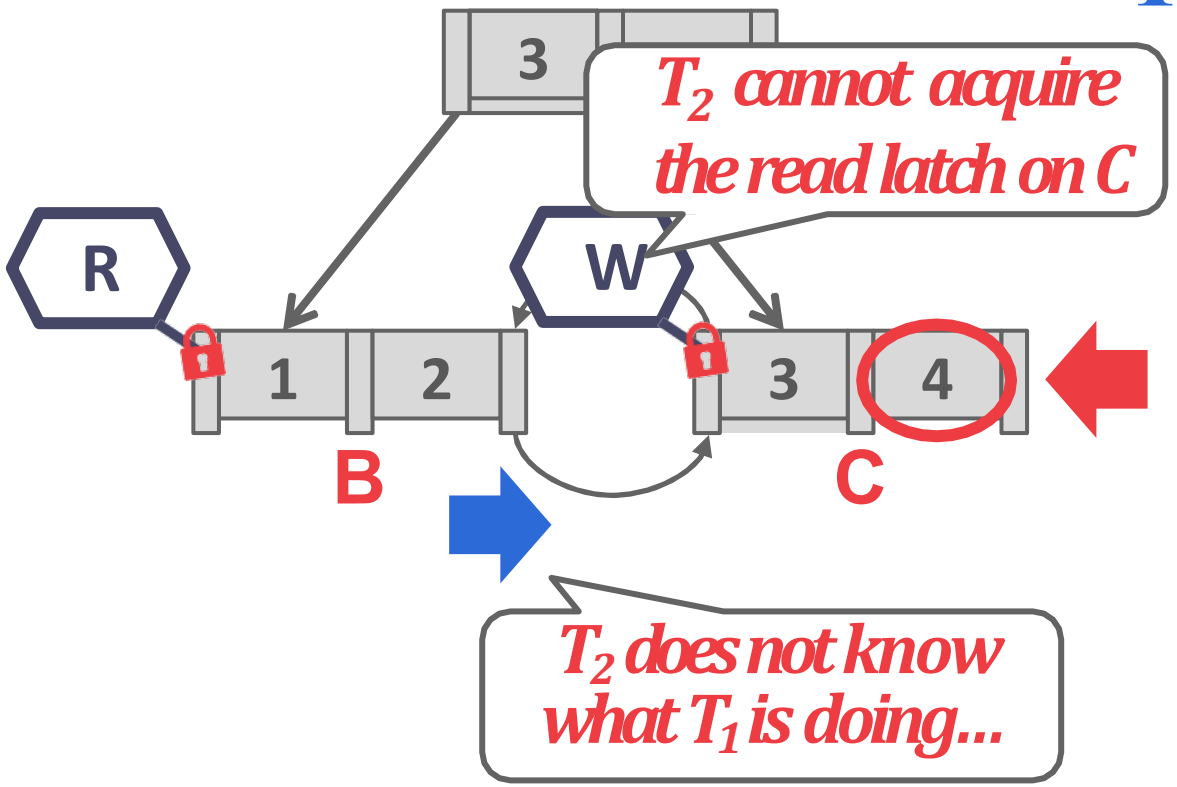
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #3

T_1: Delete 4

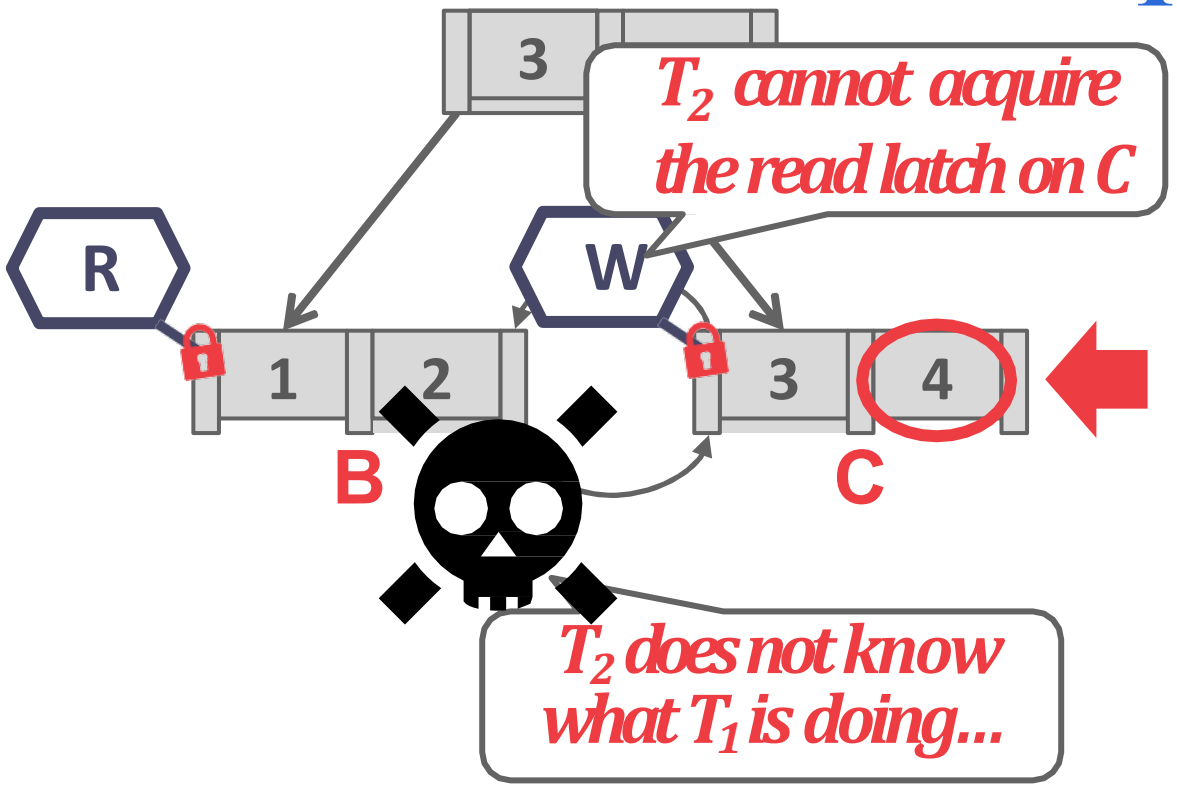
T_2: Find Keys > 1



LEAF NODE SCAN EXAMPLE #3

T_1: Delete 4

T_2: Find Keys > 1



LEAF NODE SCANS

Latches do not support deadlock detection or avoidance. The only way we can deal with this problem is through coding discipline.

The leaf node sibling latch acquisition protocol must support a "no-wait" mode.

The DBMS's data structures must cope with failed latch acquisitions.

DELAYED PARENT UPDATES

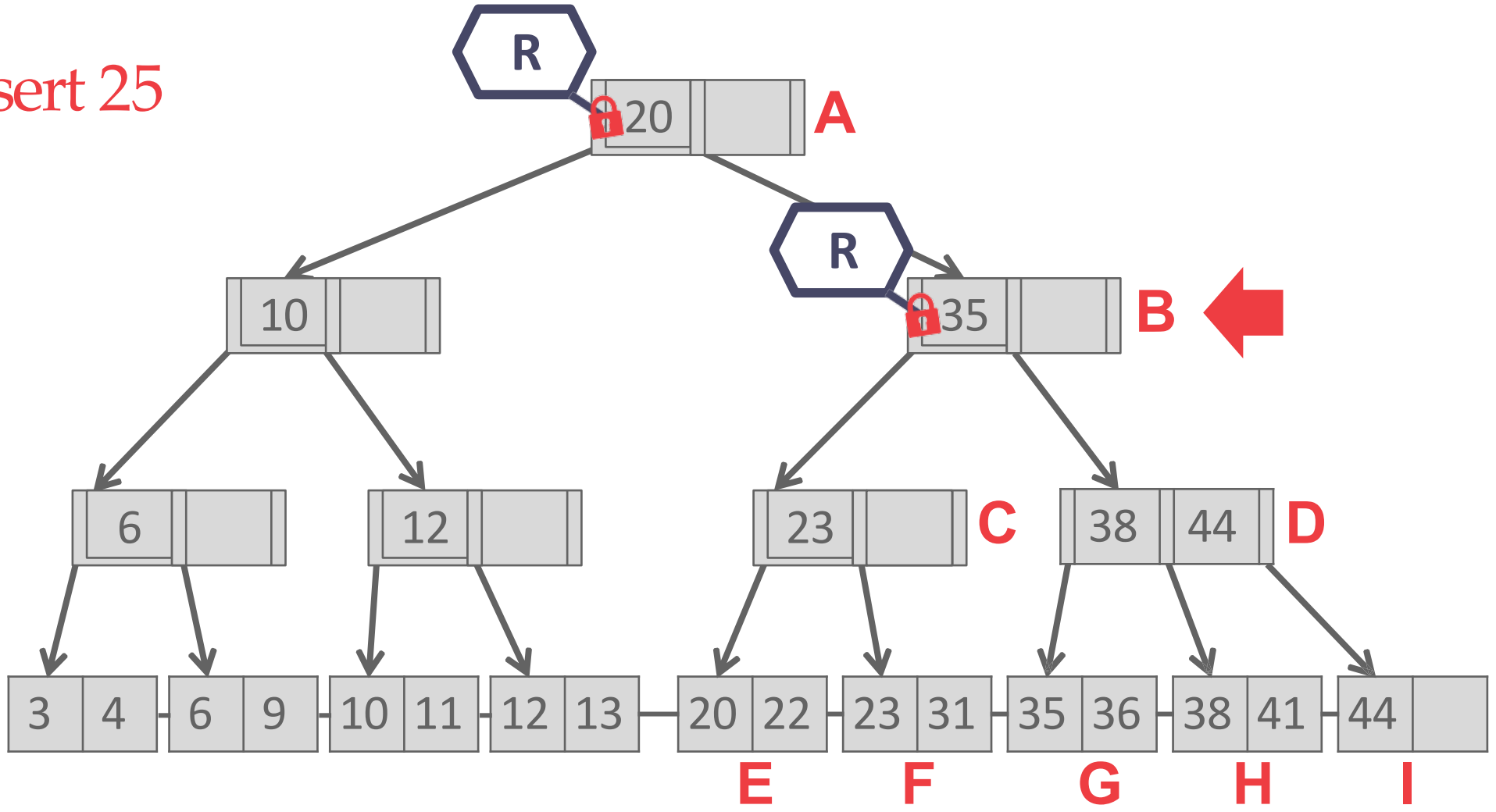
Every time a leaf node overflows, we must update at least three nodes.

→ The leaf node being split.
→ The new leaf node being created.
→ The parent node.

B$^+$-Tree Optimization: When a leaf node overflows, delay updating its parent node.

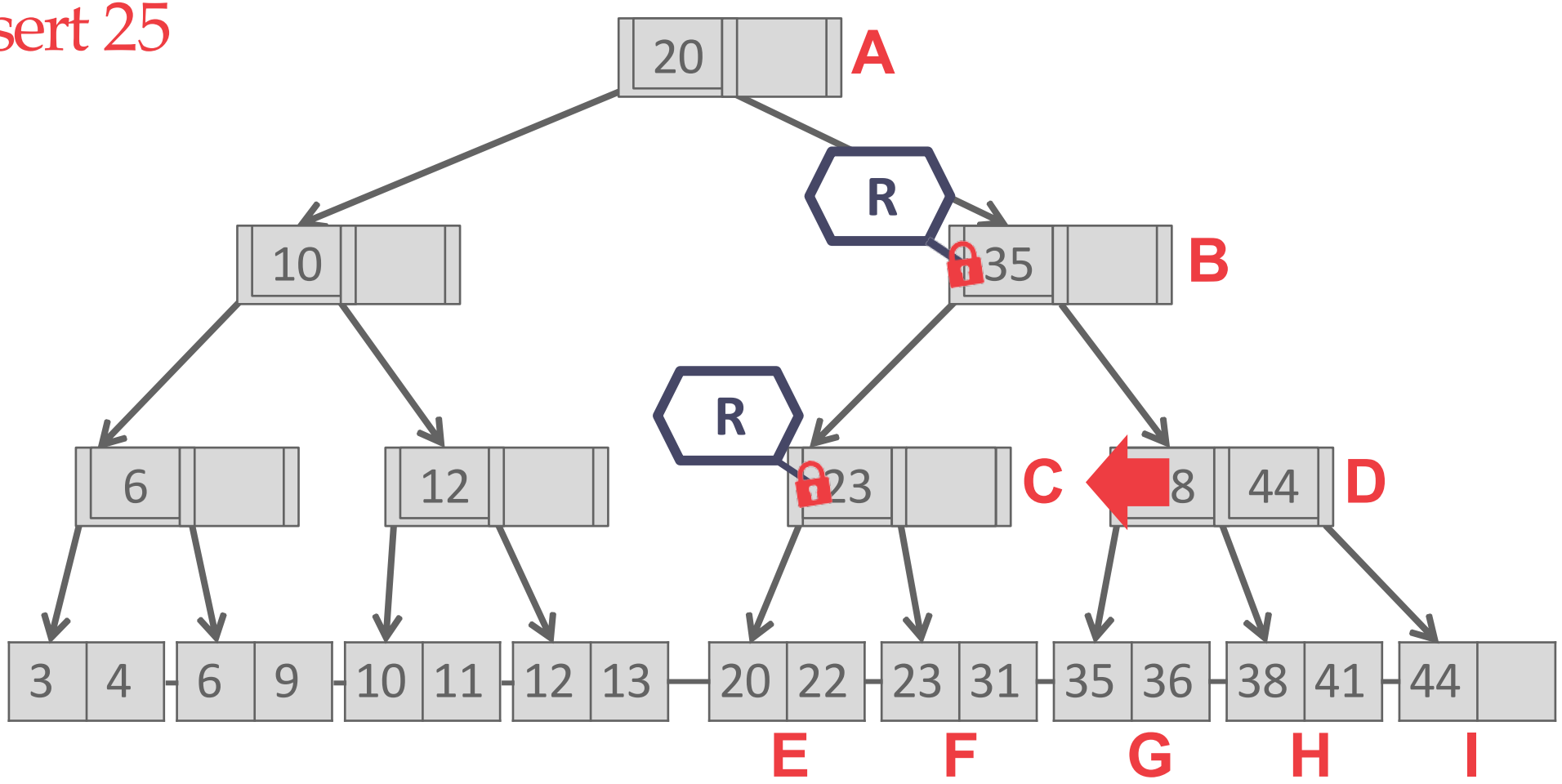
EXAMPLE #4 – INSERT 25

T_1: Insert 25



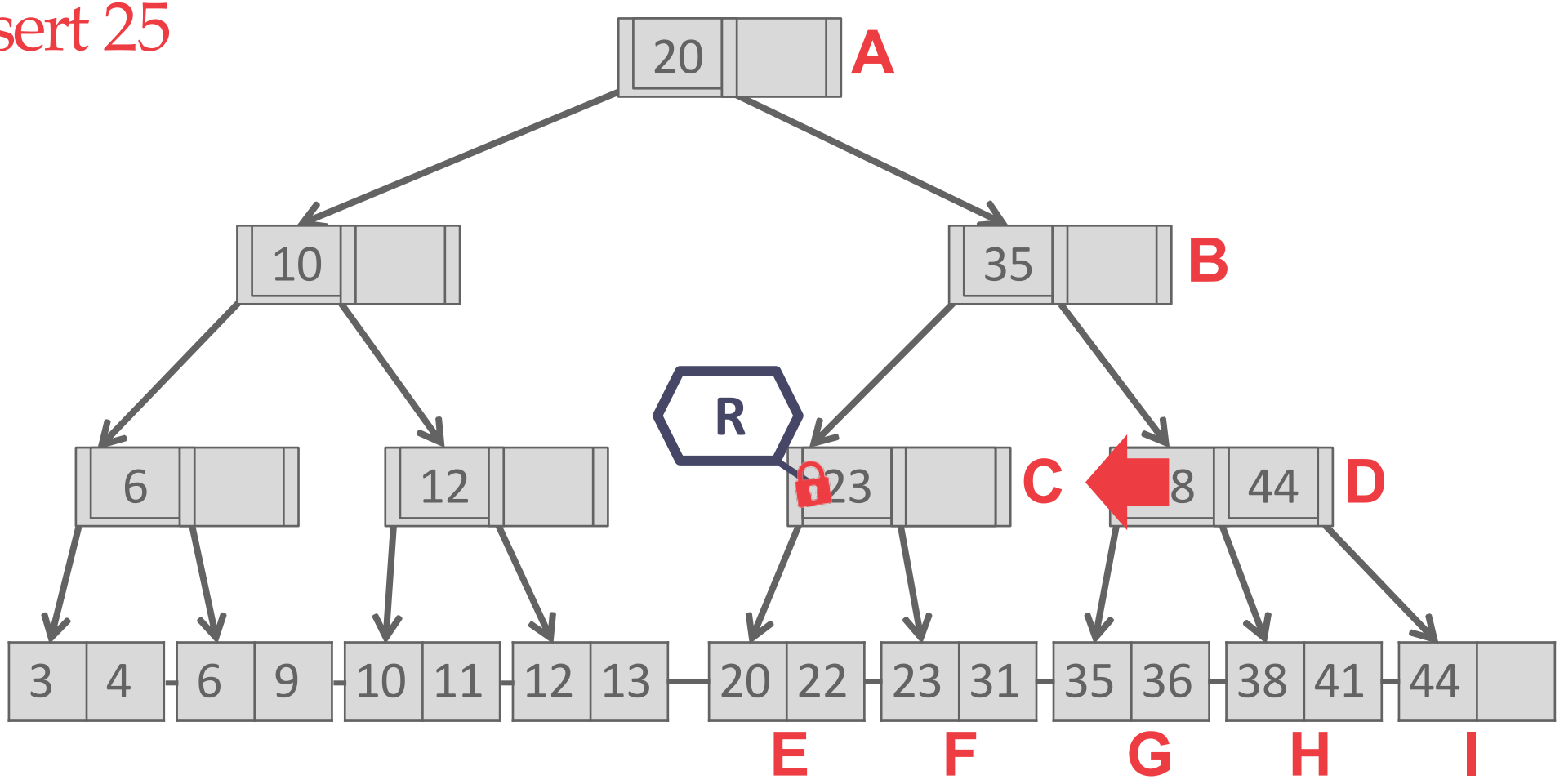
EXAMPLE #4 – INSERT 25

T_1: Insert 25



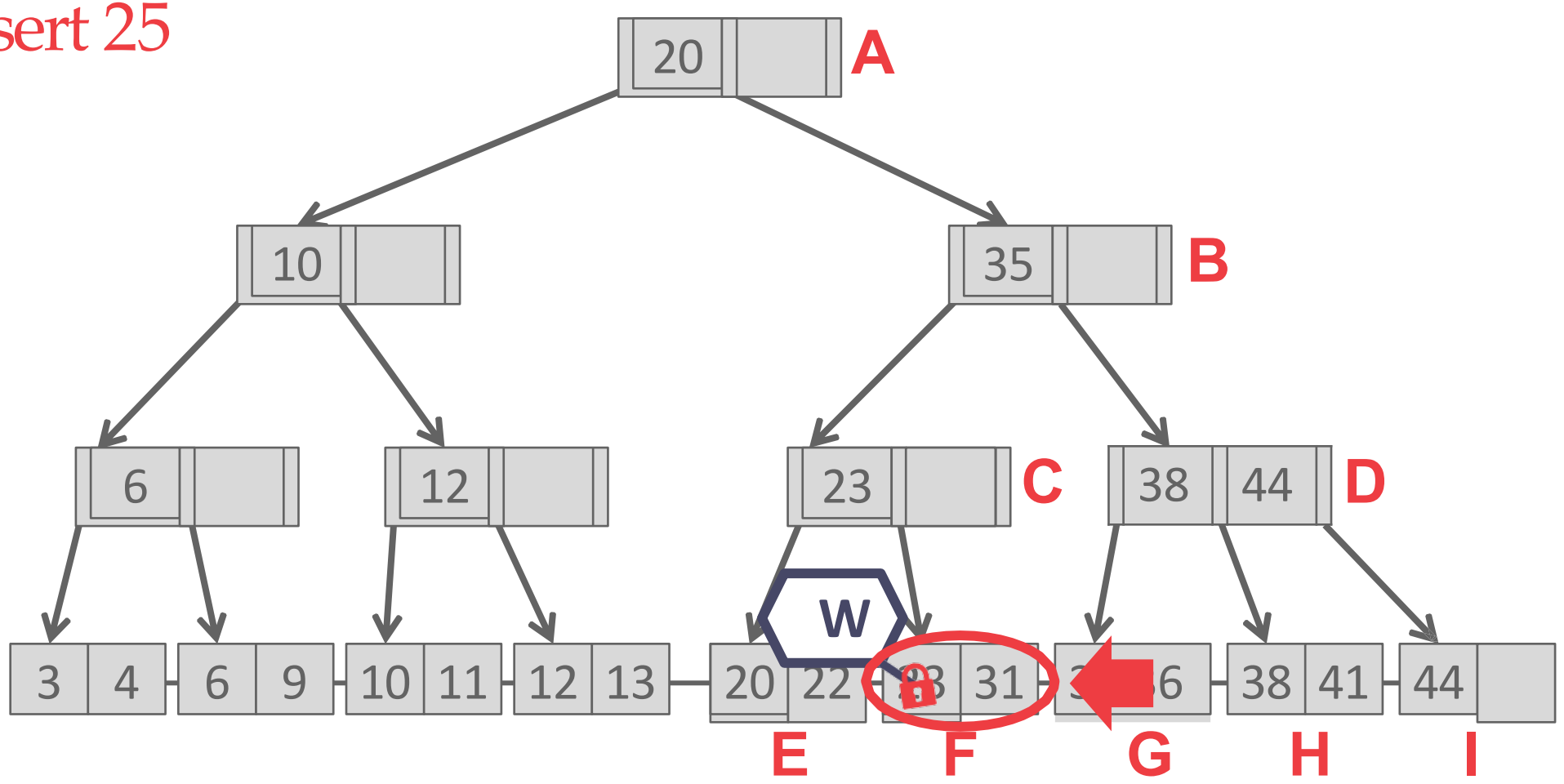
EXAMPLE #4 – INSERT 25

T_1: Insert 25



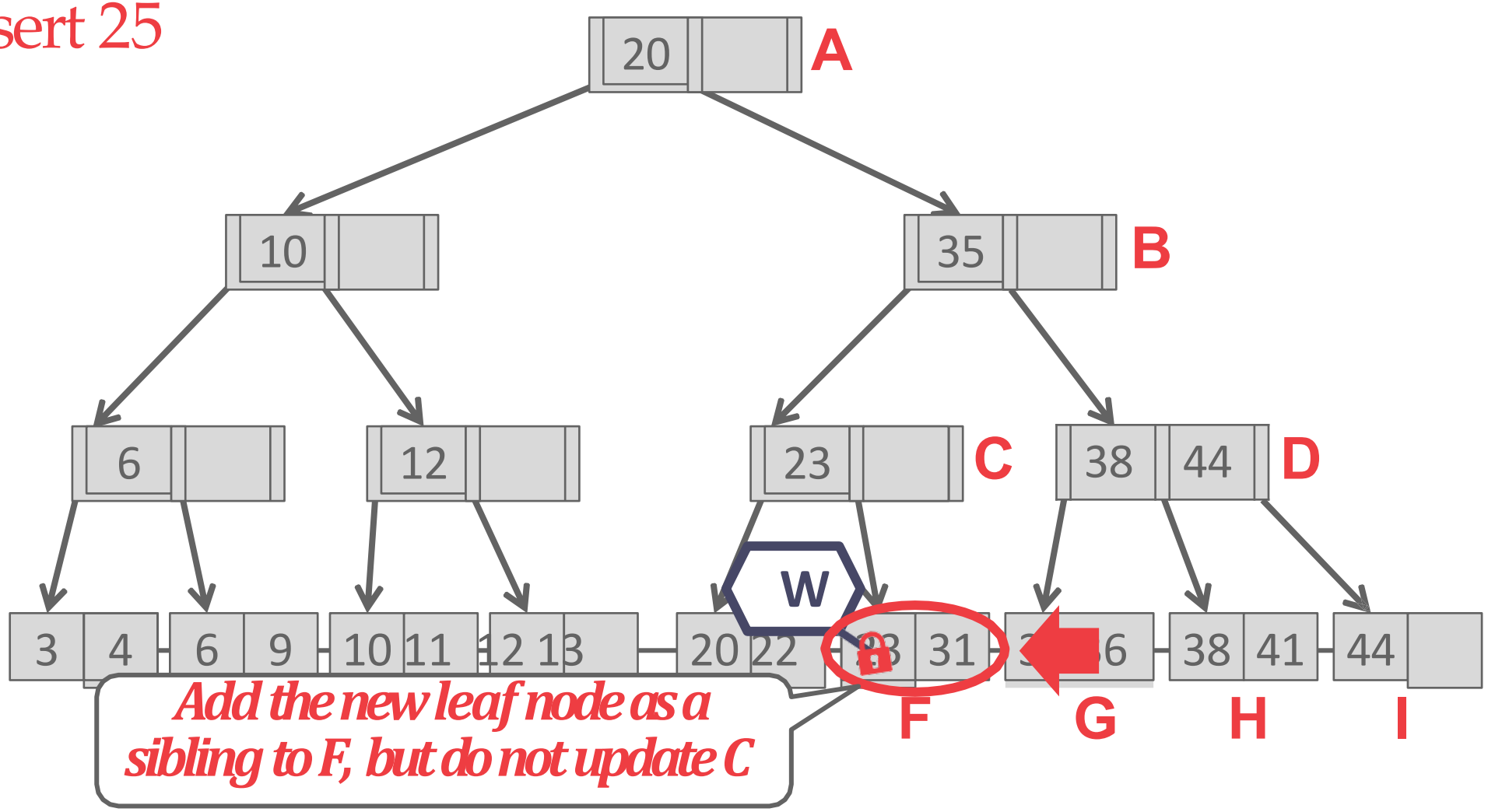
EXAMPLE #4 – INSERT 25

T_1: Insert 25



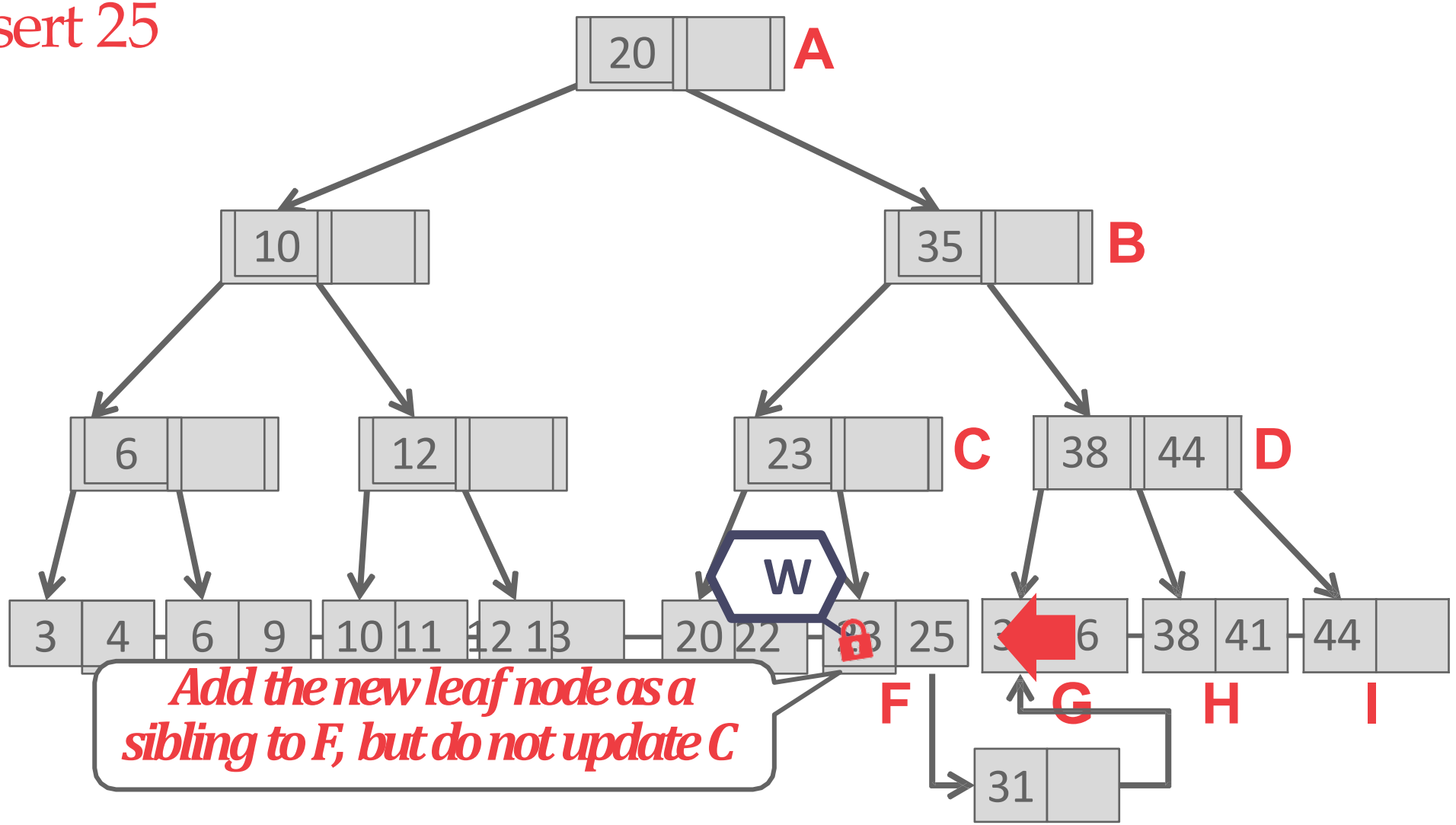
EXAMPLE #4 – INSERT 25

T_1: Insert 25

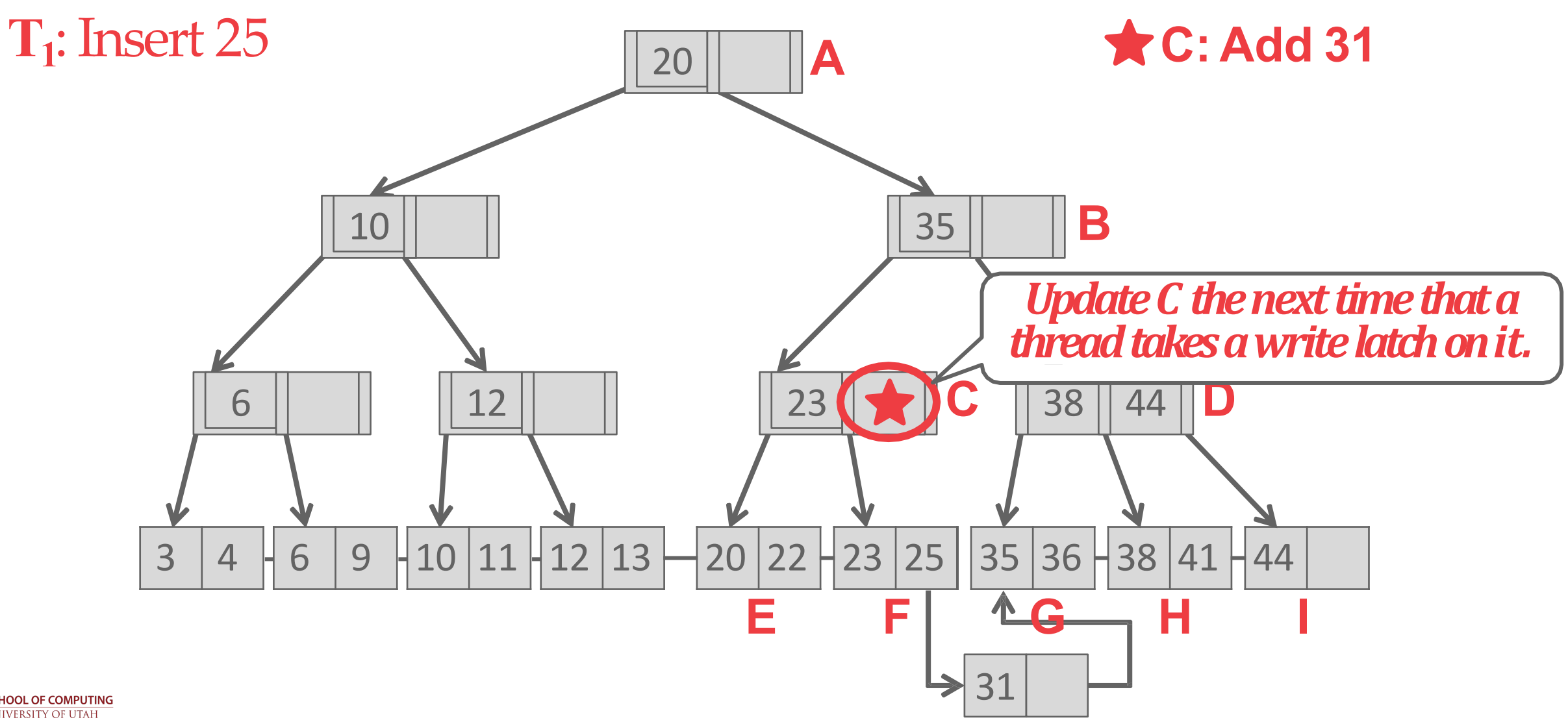


EXAMPLE #4 – INSERT 25

T_1: Insert 25



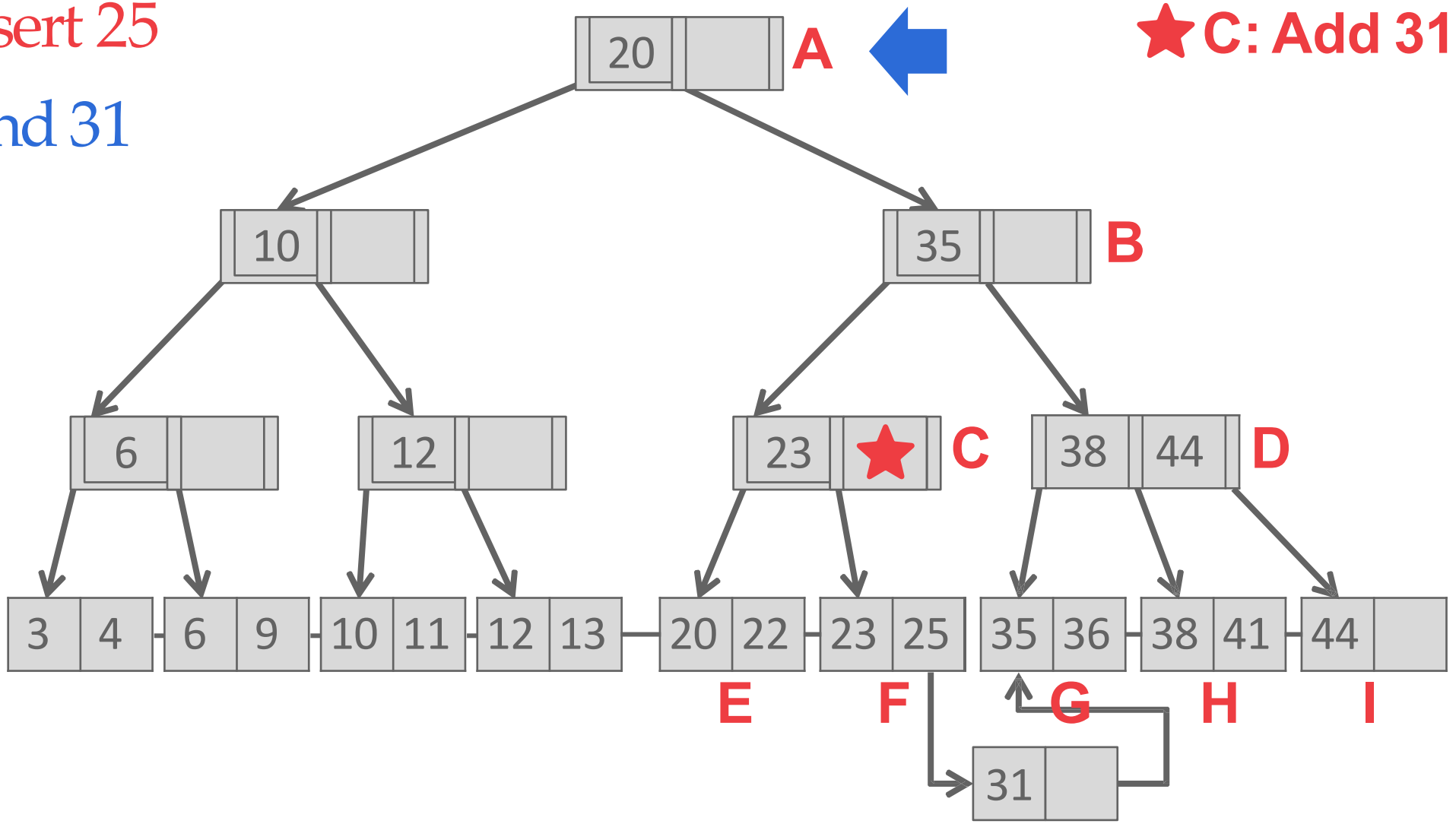
EXAMPLE #4 – INSERT 25



EXAMPLE #4 – INSERT 25

T_1: Insert 25

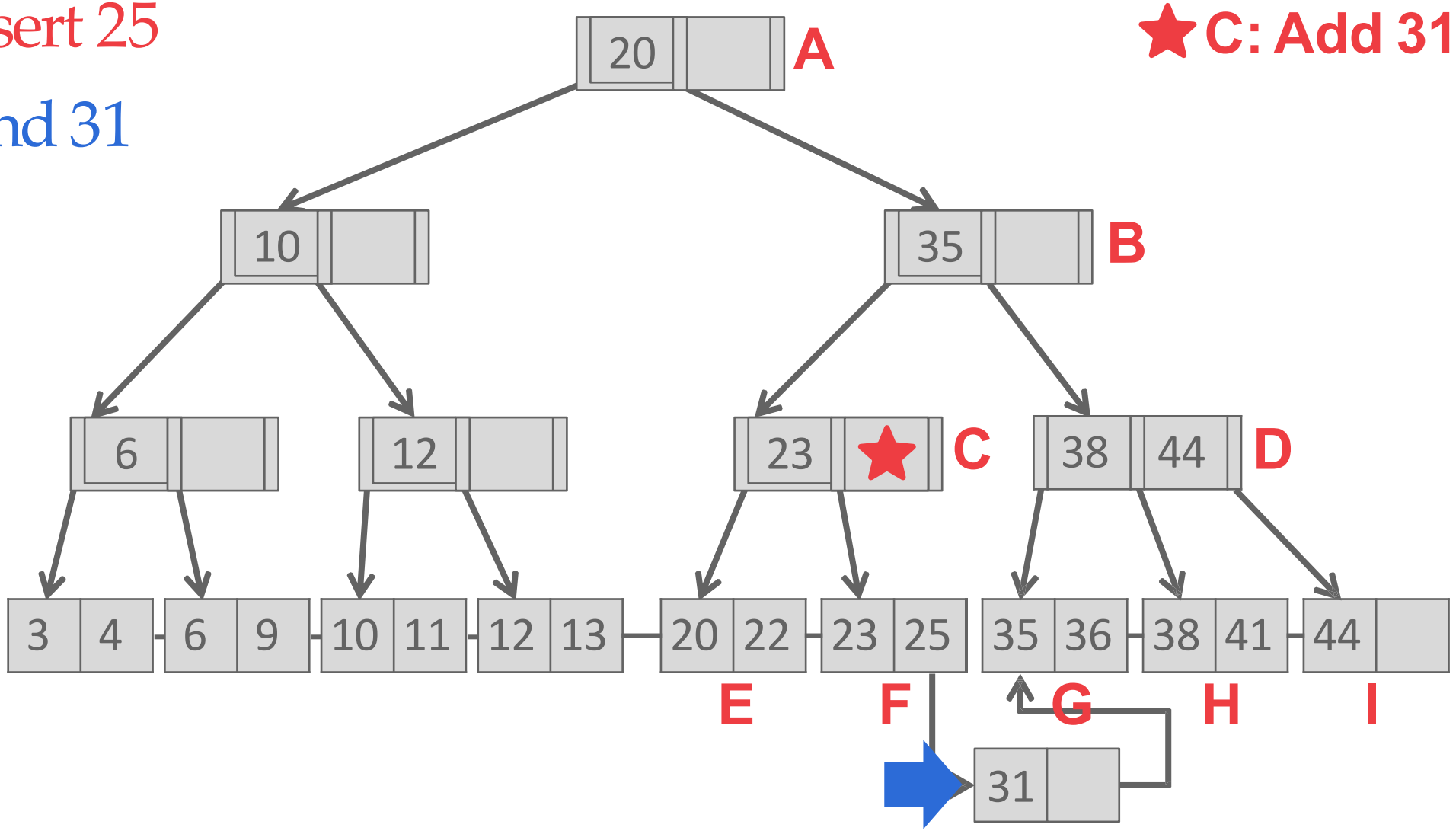
T_2: Find 31



EXAMPLE #4 – INSERT 25

T_1: Insert 25

T_2: Find 31

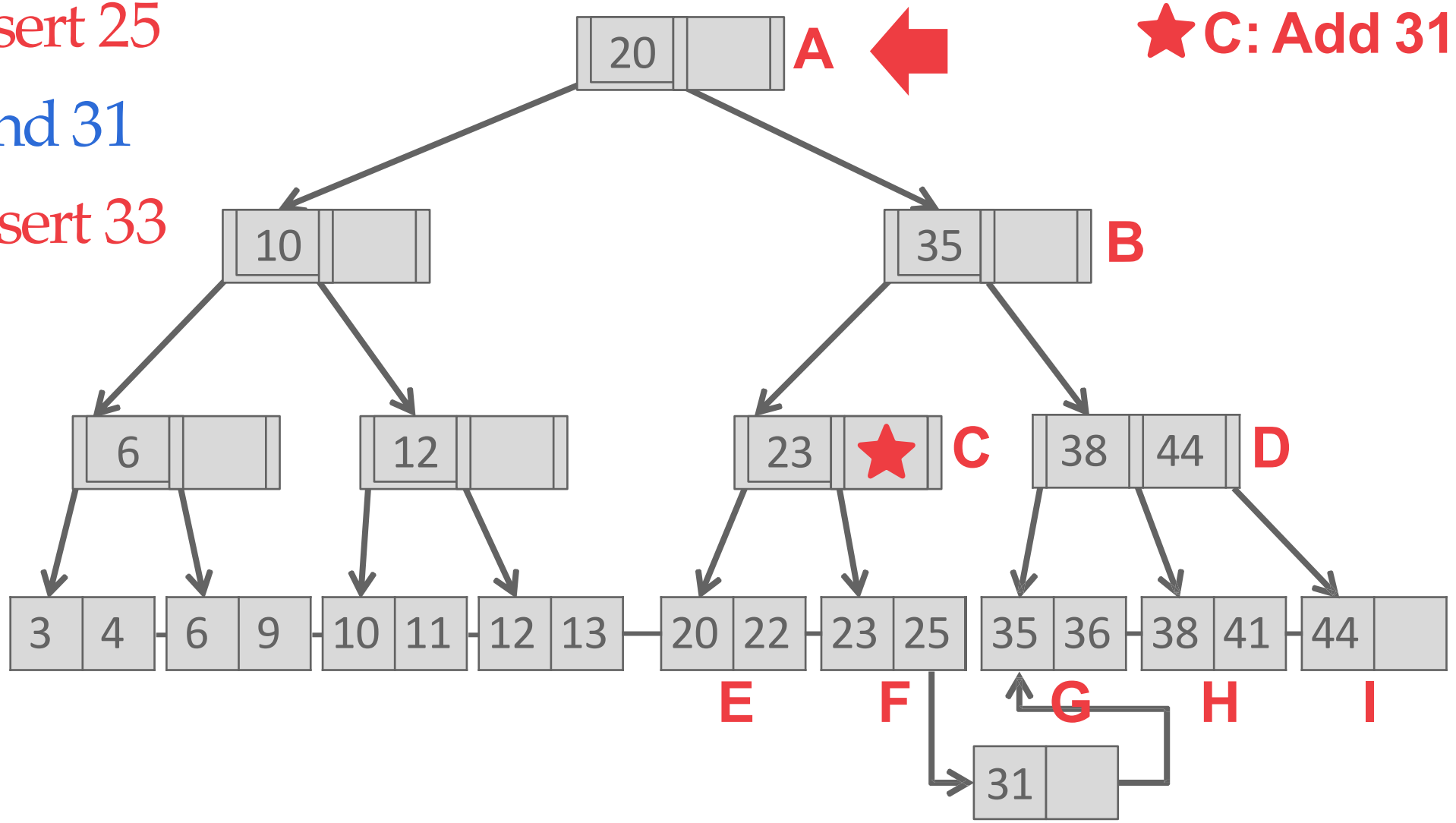


EXAMPLE #4 – INSERT 25

T_1: Insert 25

T_2: Find 31

T_3: Insert 33

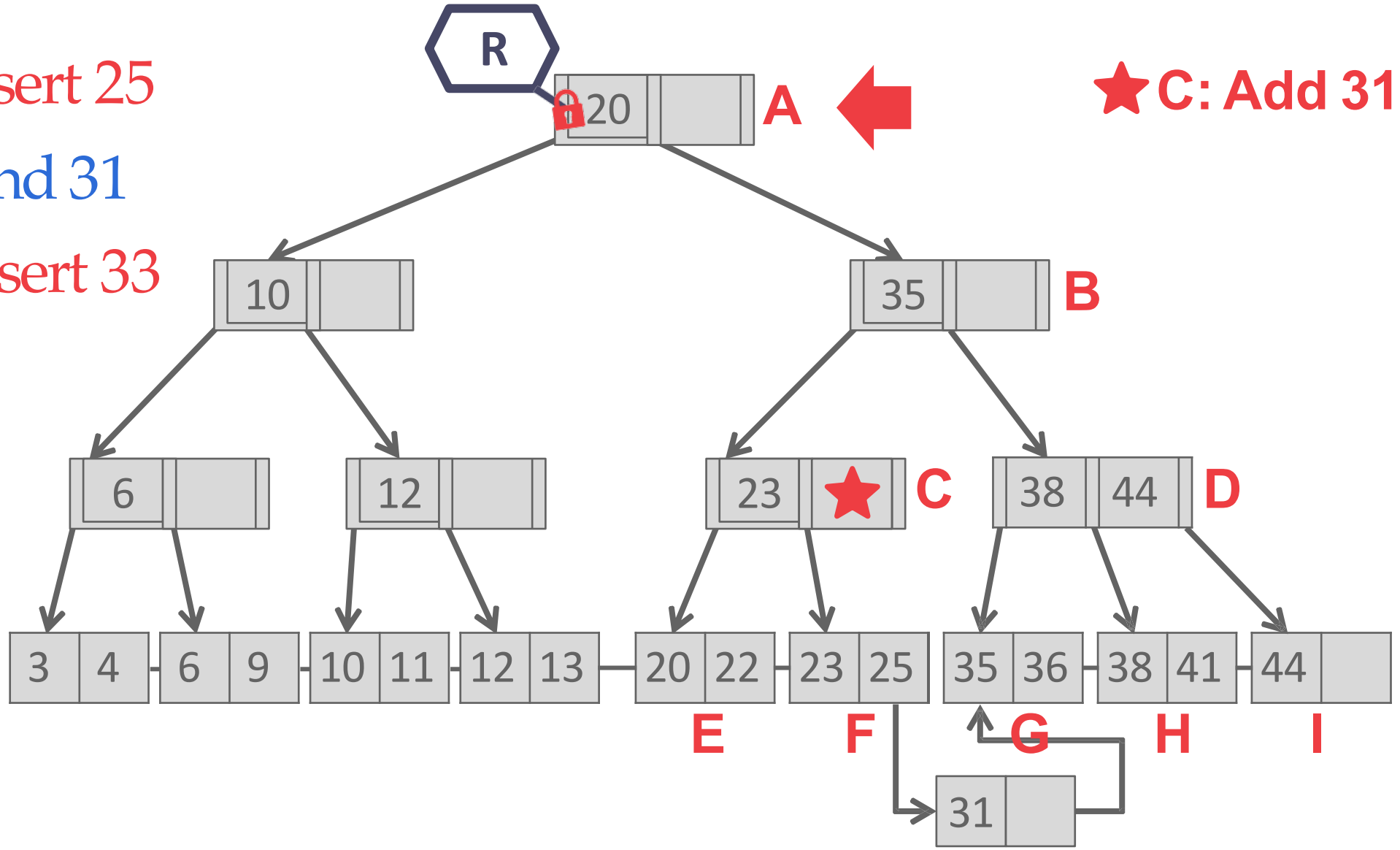


EXAMPLE #4 – INSERT 25

T_1: Insert 25

T_2: Find 31

T_3: Insert 33

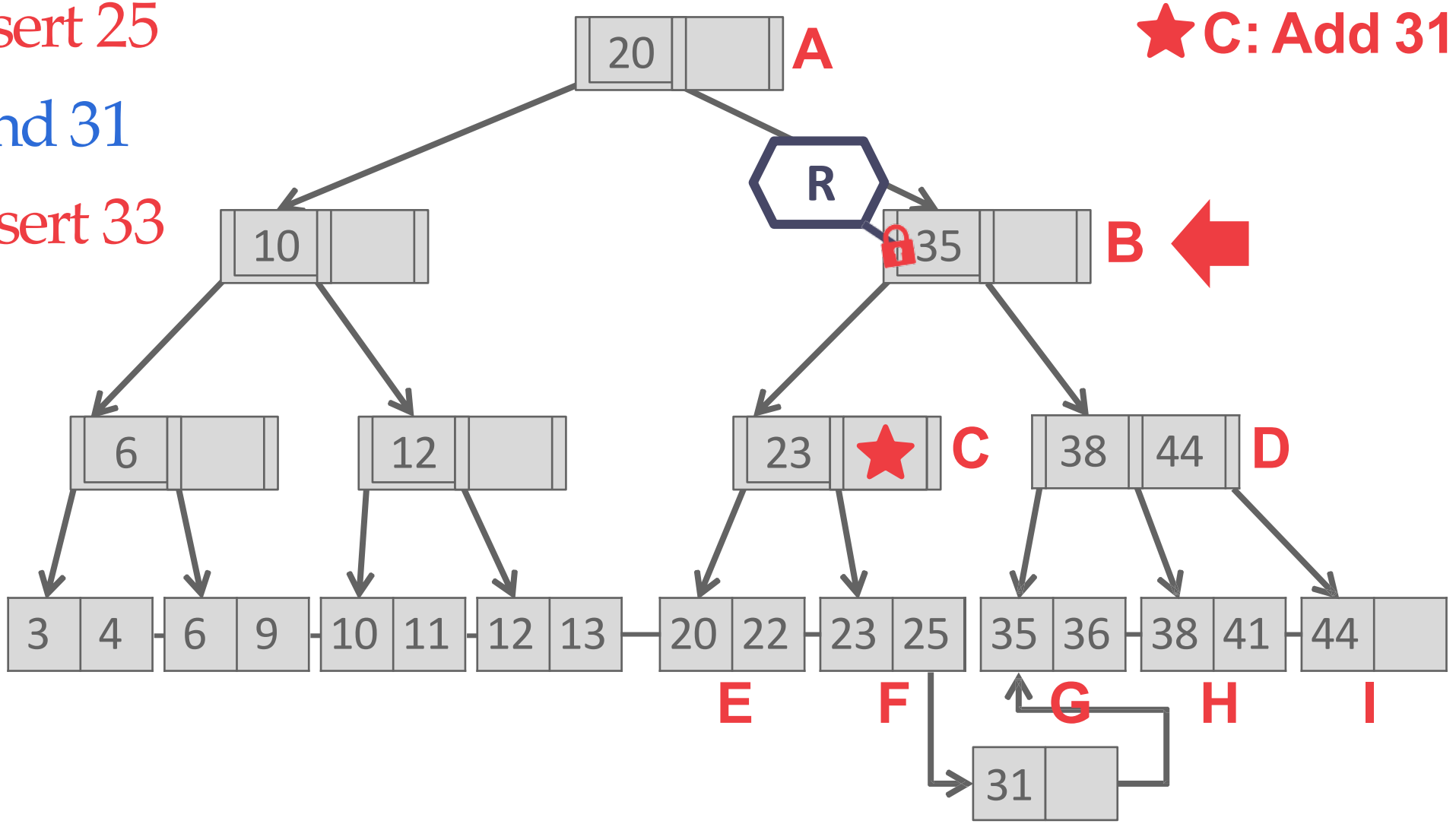


EXAMPLE #4 – INSERT 25

T_1: Insert 25

T_2: Find 31

T_3: Insert 33

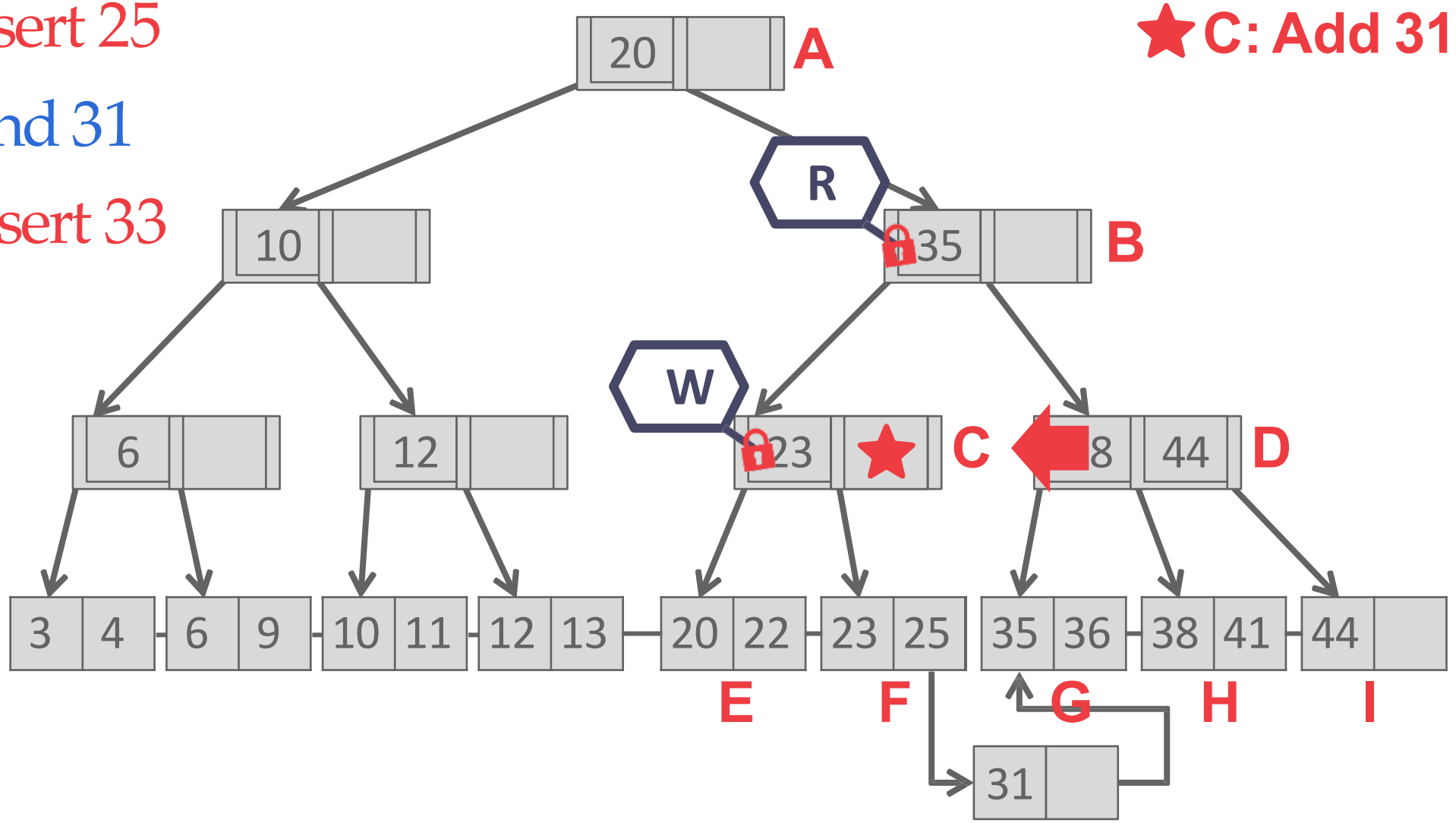


EXAMPLE #4 – INSERT 25

T_1: Insert 25

T_2: Find 31

T_3: Insert 33

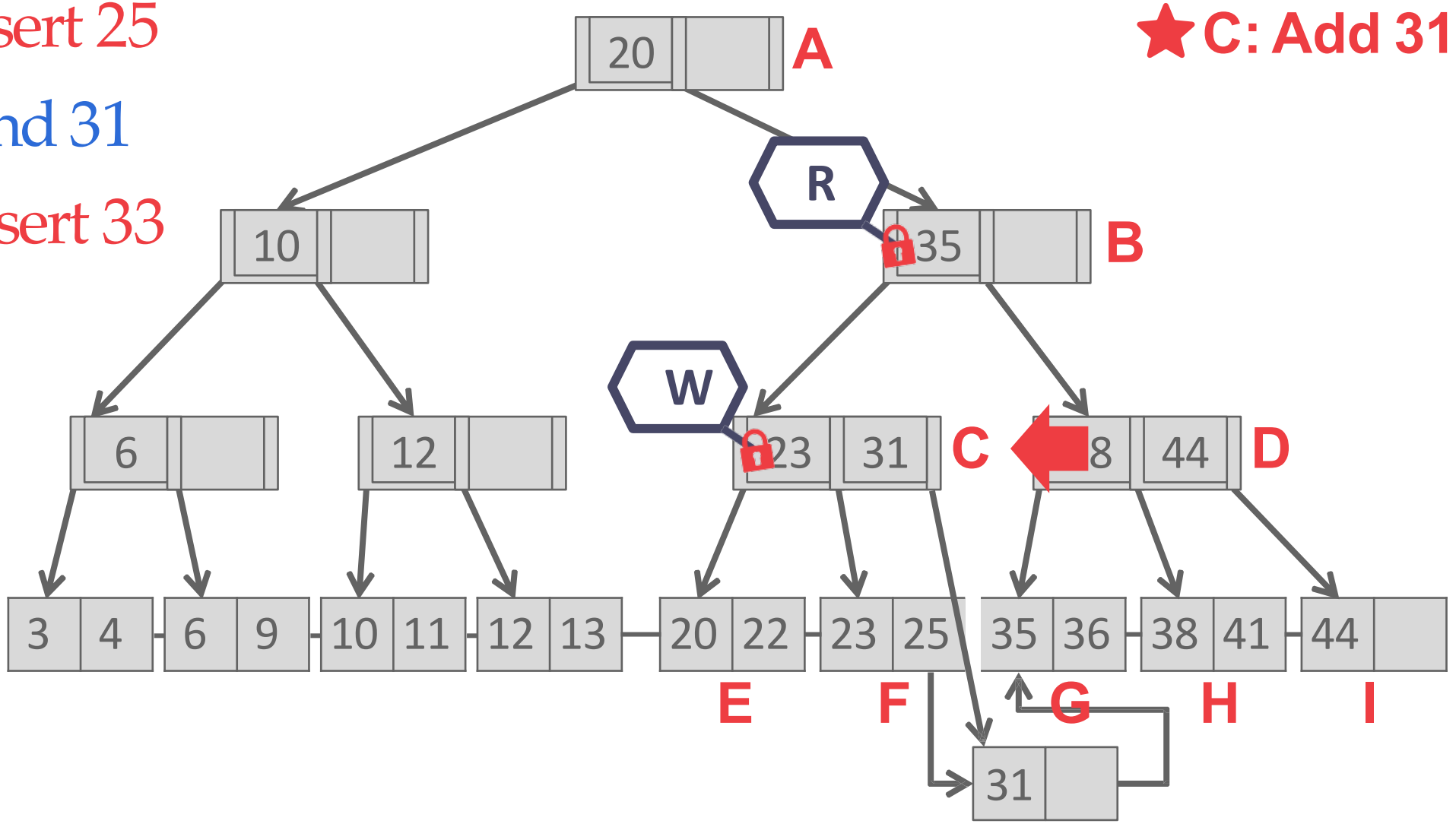


EXAMPLE #4 – INSERT 25

T_1: Insert 25

T_2: Find 31

T_3: Insert 33



EXAMPLE #4 – INSERT 25

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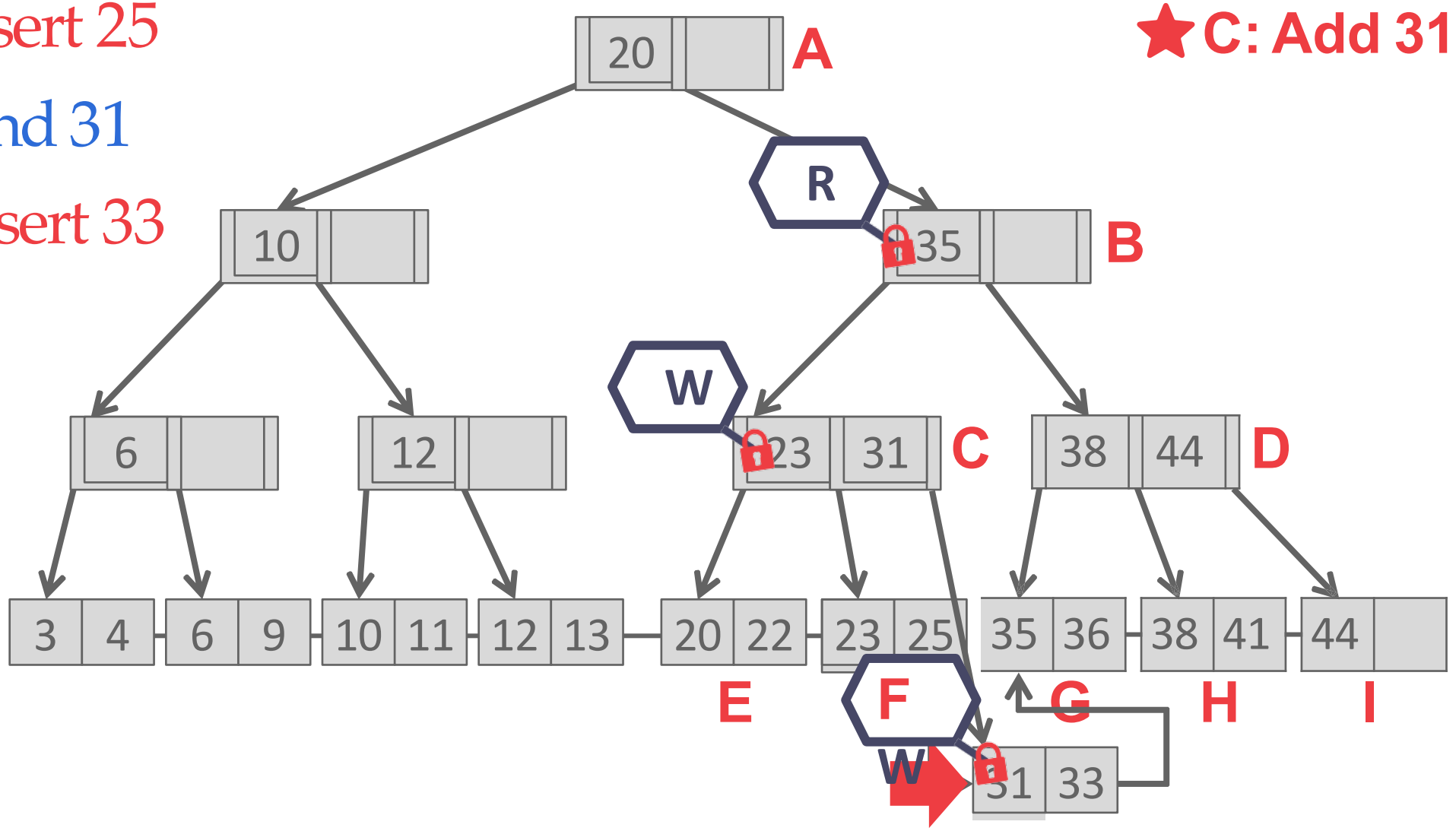
T_2: Find 31

T_3: Insert 33



Next lecture

- Locking and transactions
- MVCC