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Mohammed Abu-Hadhoud
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Algorithms & Problem Solving
Level 6
Types of Violations Post-Deletion
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Remember..

- A Red-Black Tree is a type of self-balancing binary search tree
- When insert new node we must make sure the tree is rebalanced if needed and all red black tree properties are met:
  - Color Property: Every node is either red or black.
  - Root Property: The root of the tree is always black.
  - All leaves (NIL nodes) are black.
  - Red Property: If a red node has children, then both are black (no two red nodes appear in a sequence).
  - Depth (Black-Height) Property: Every path from a node to its descendant NULL nodes has the same number of black nodes.

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Quick Review

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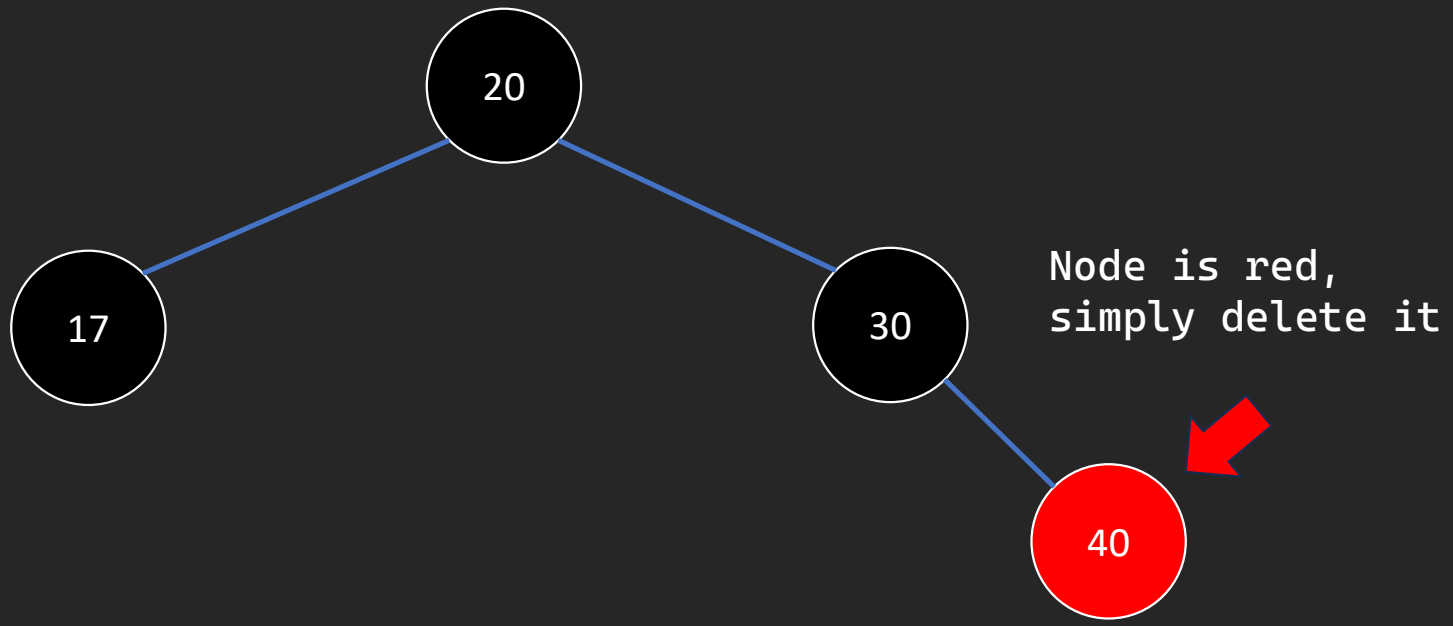
Case 1: No children.



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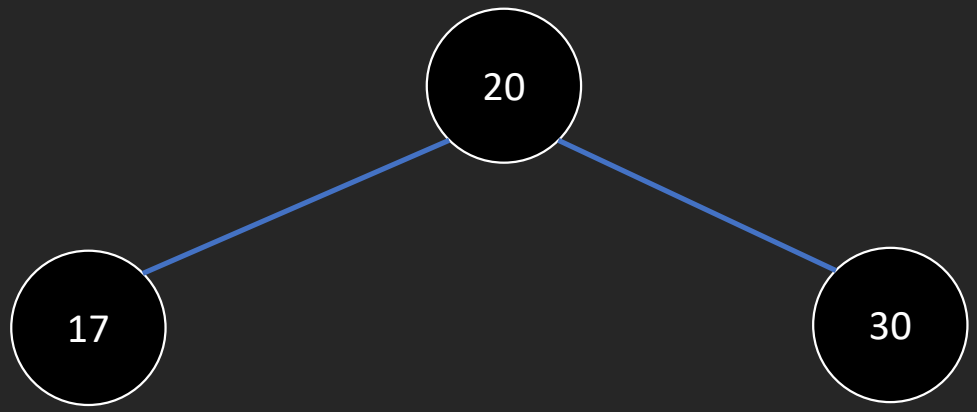

Red Black Tree Properties
are maintained, no fixes.

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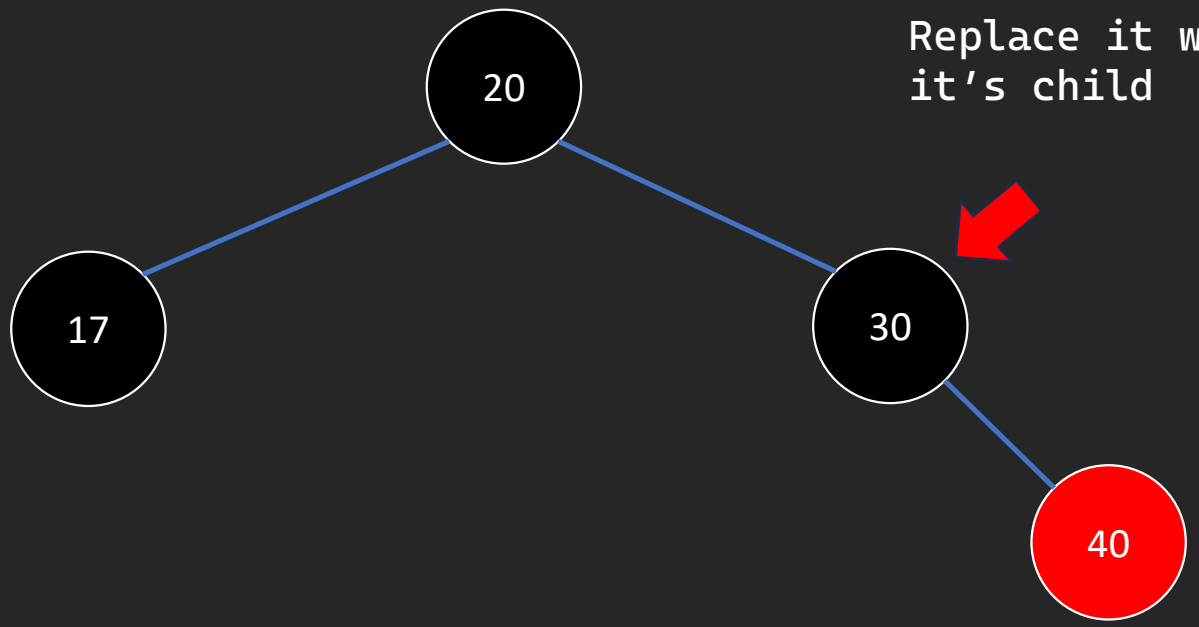
Case 2: one child

We don’t delete internal node
Replace it with
it’s child



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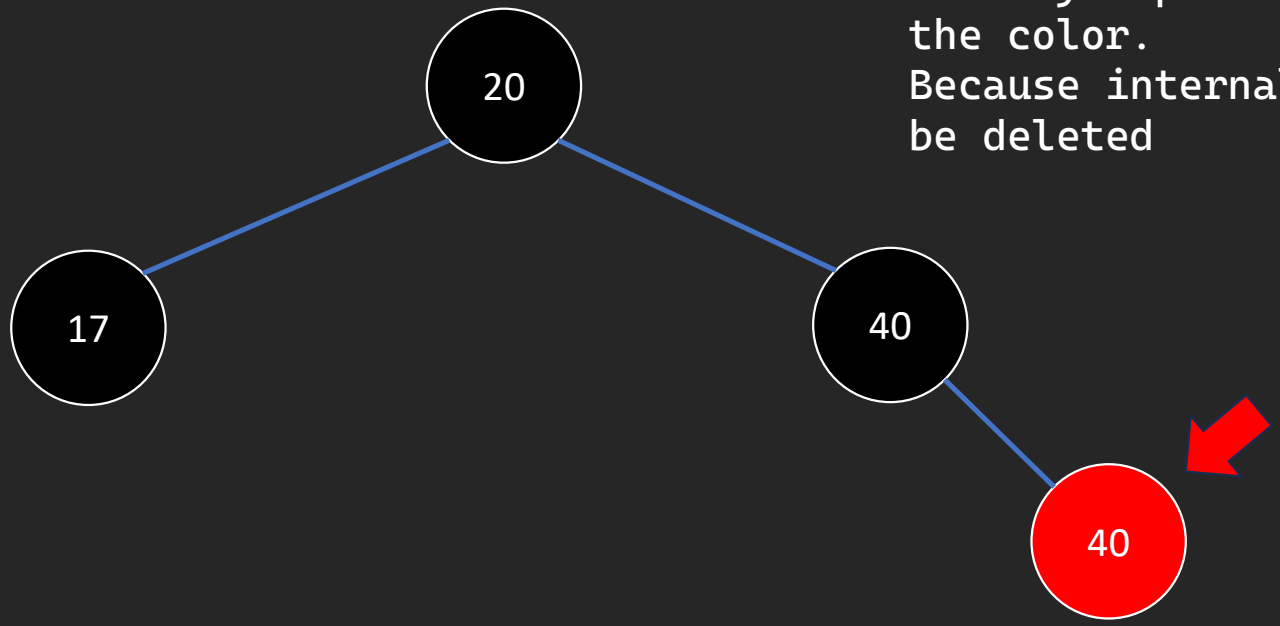

We only replace the value not the color.
Because internal node will not be deleted

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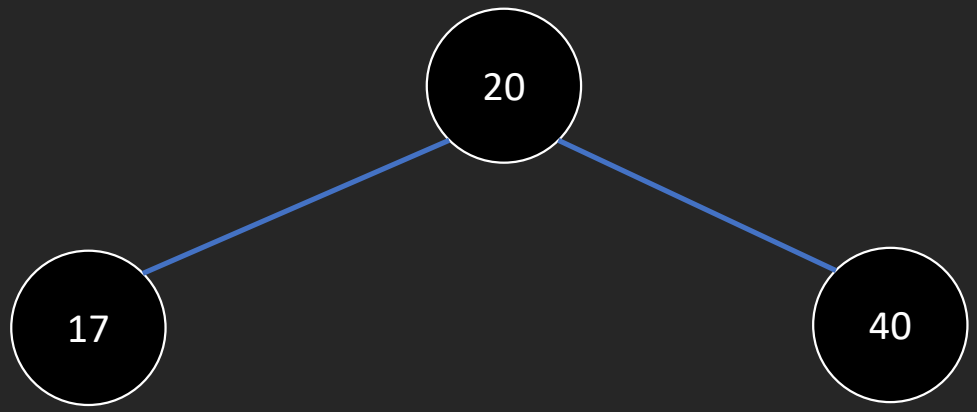

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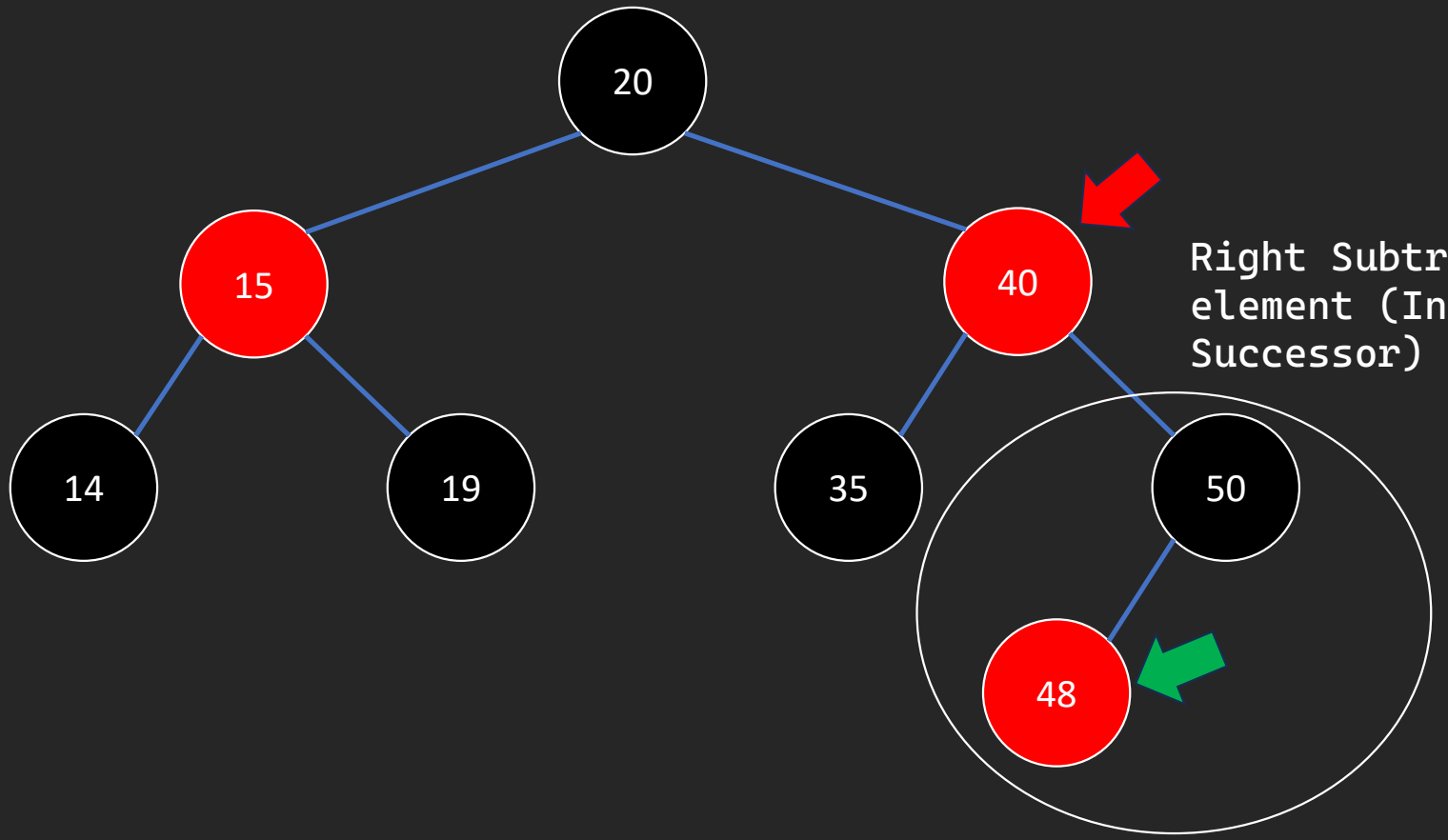
Case 3: Two Children.



Right Subtree, smallest element (In-Order Successor)

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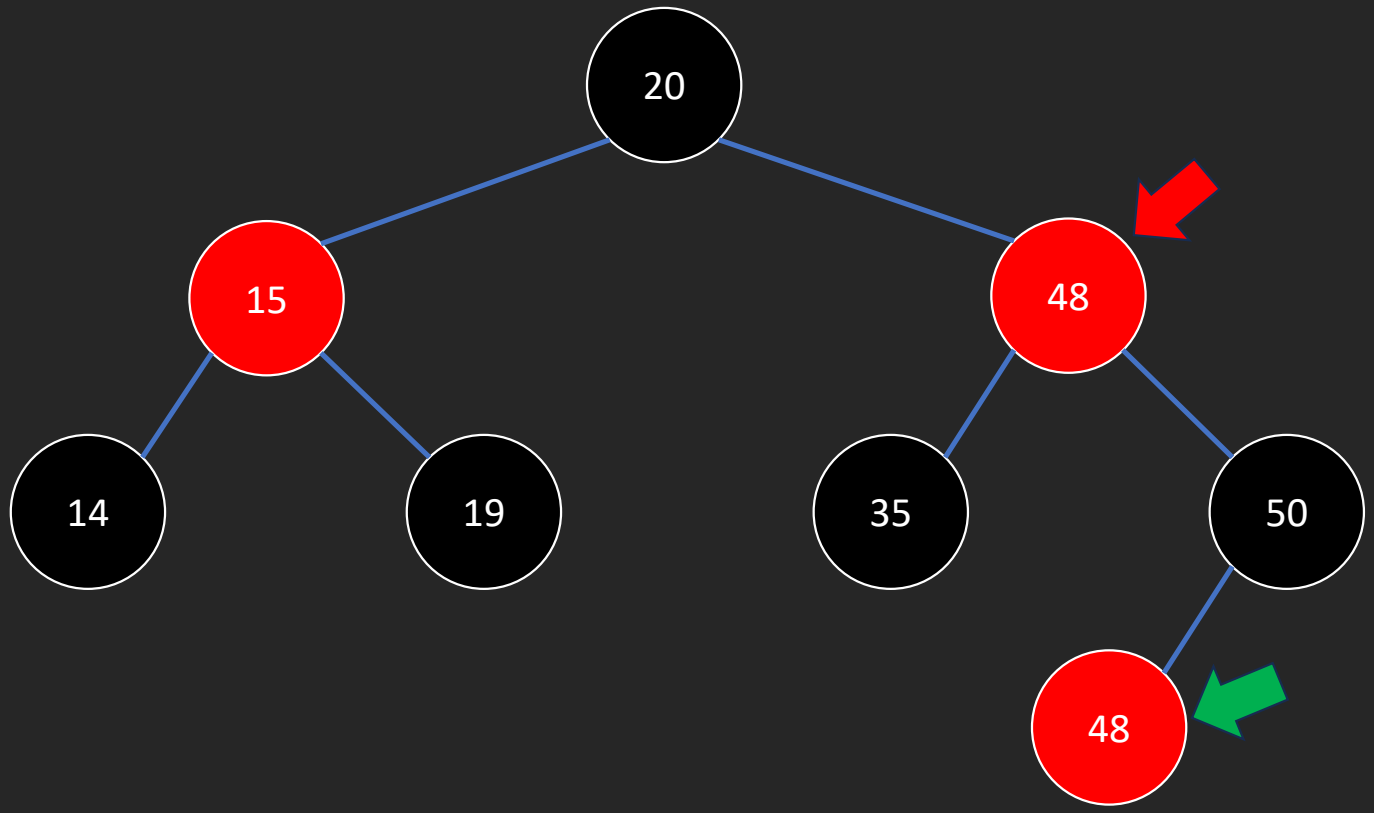

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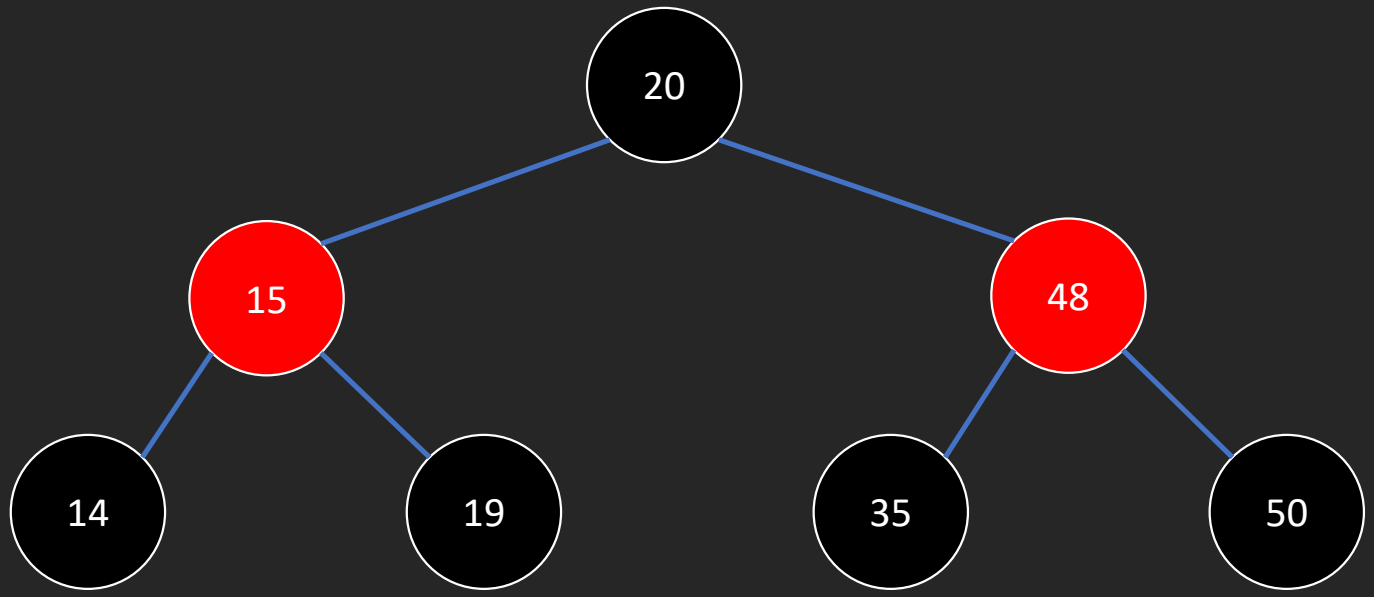

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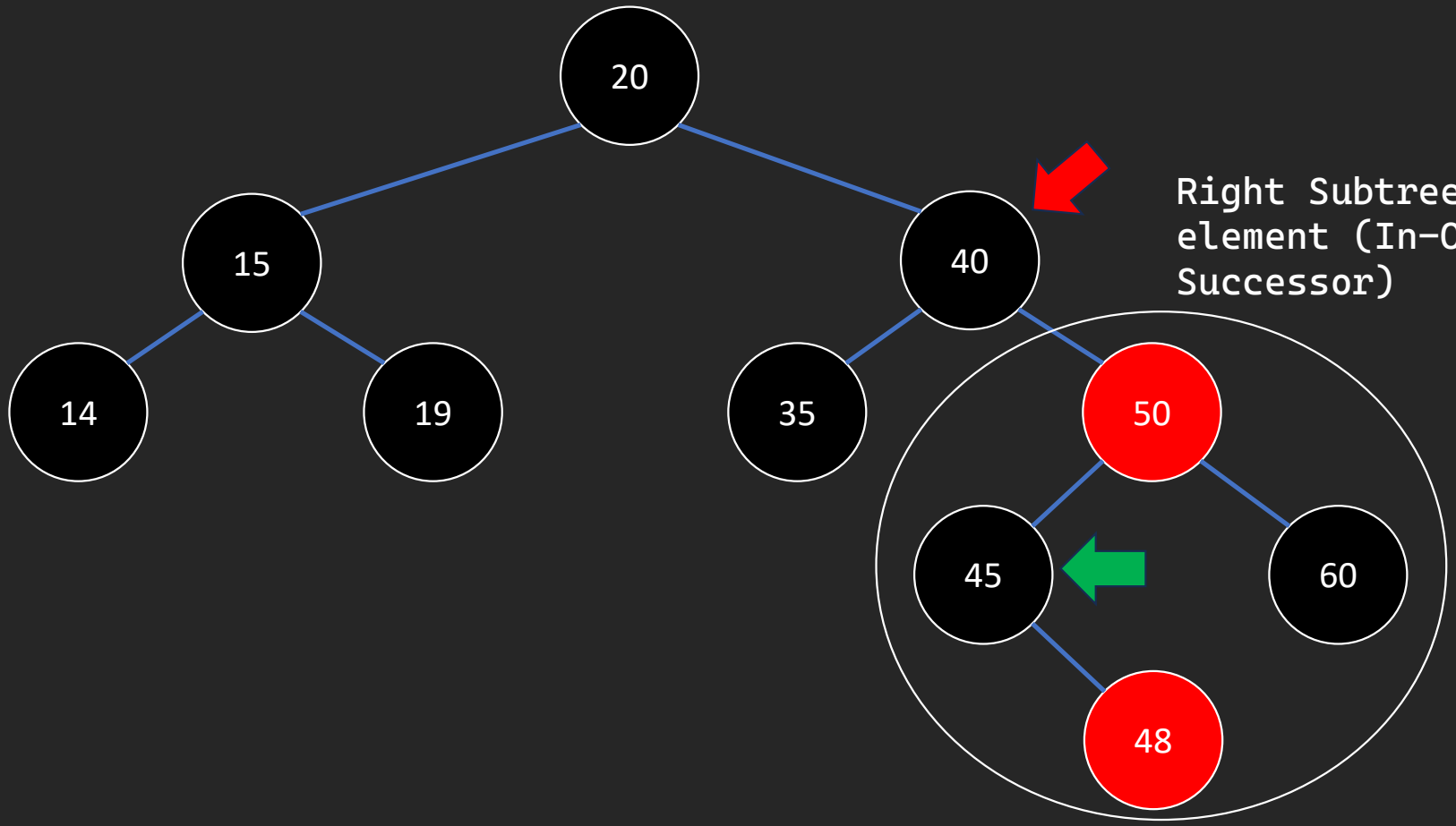
Case 3: Example 2, Two Children.



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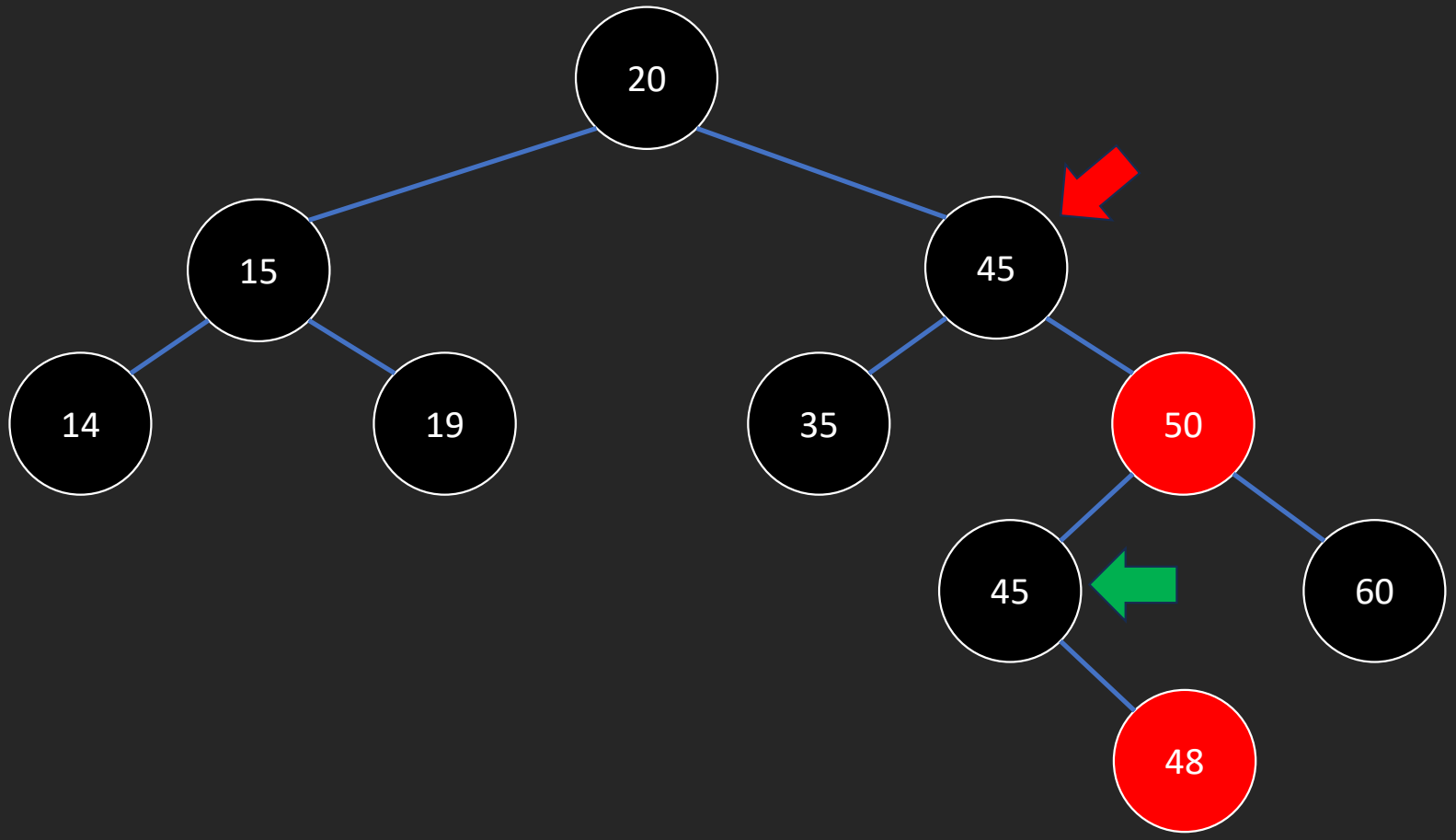

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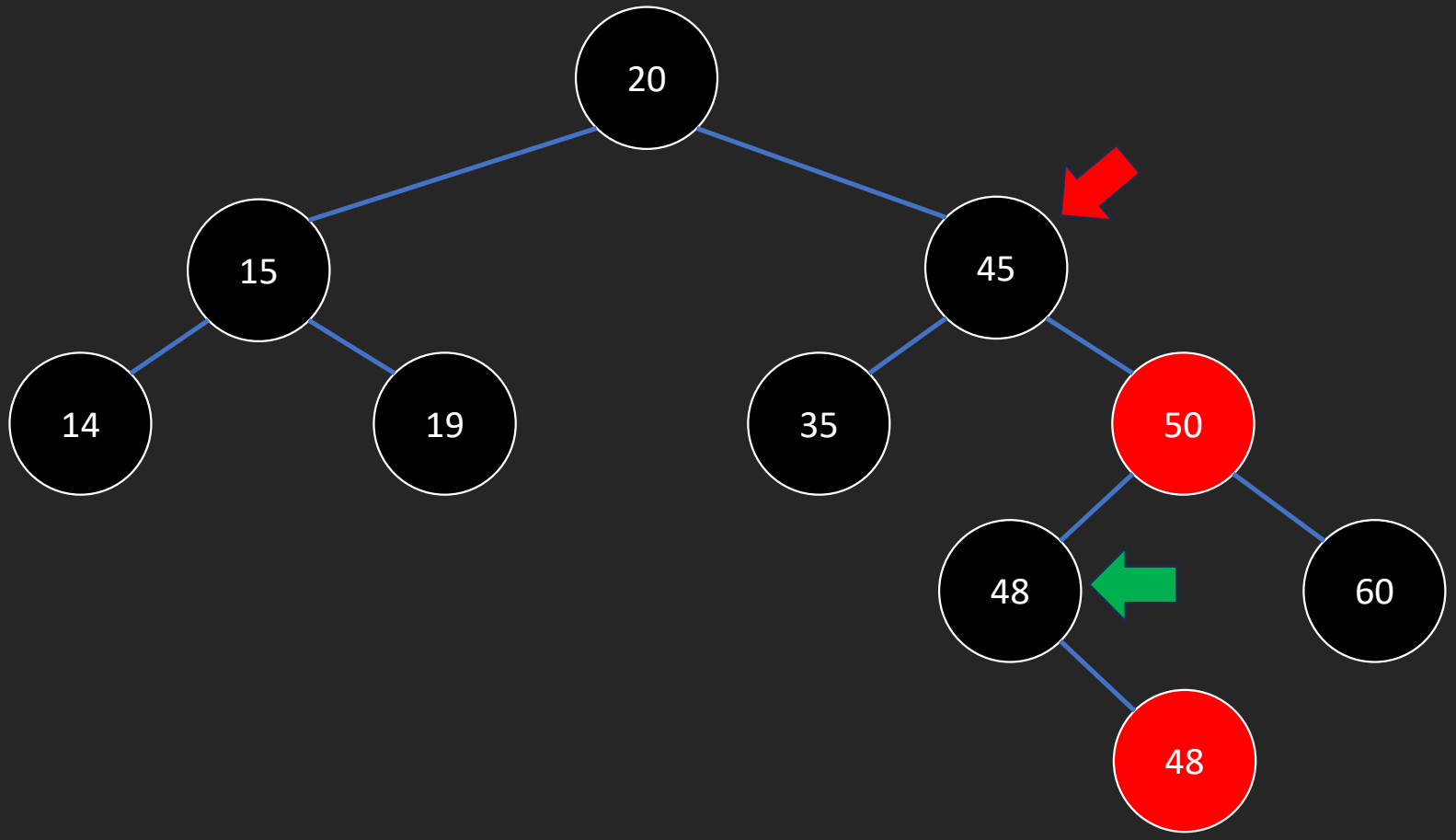

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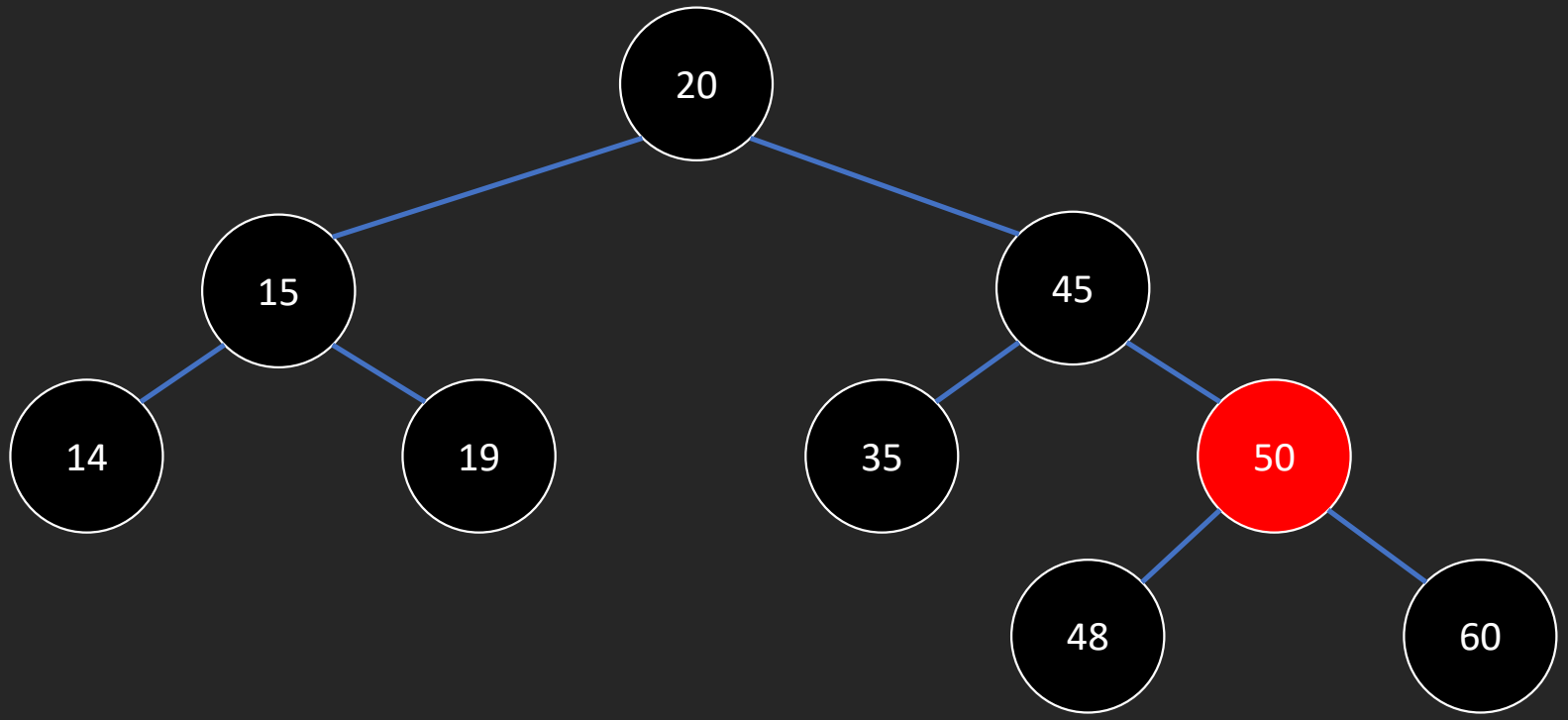

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What if RB Properties are not maintained? We need to Fix. In the next lesson.

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Types of Violations Post-Deletion

After deletion, there are two primary cases to consider:

- **Deleting a Red Node**: This is relatively simple because it does not disrupt the Black-Height Property. Red nodes do not contribute to the black height, so the tree remains balanced.
- **Deleting a Black Node**: This is more complex. The removal of a black node can cause a violation of the Black-Height Property, leading to an imbalance. Specifically, the paths from the root to some leaves might have fewer black nodes than others, resulting in a condition known as Double Black.

The Double Black condition is a concept used to track this imbalance and the extra blackness that must be resolved.

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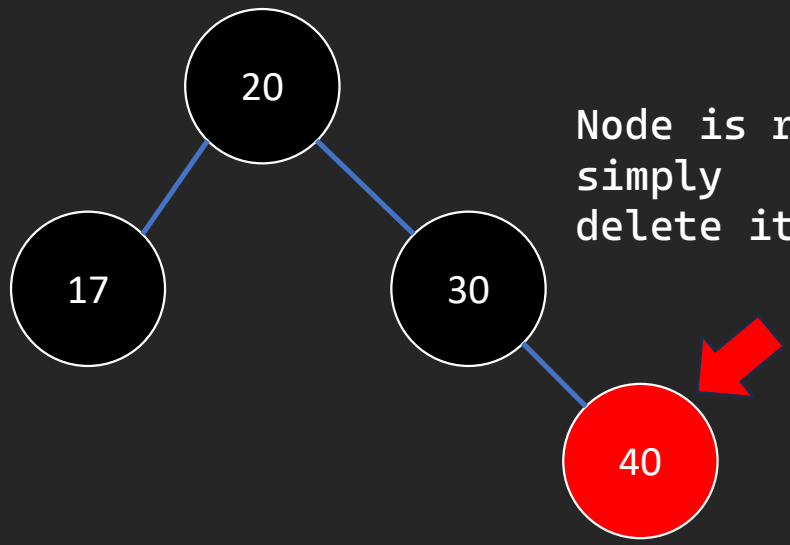
Why it’s called Double Black?



Node is red,
simply
delete it

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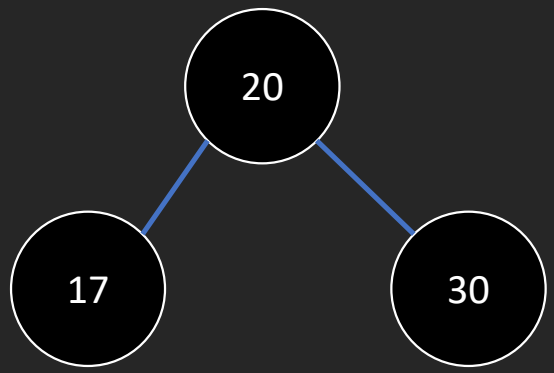

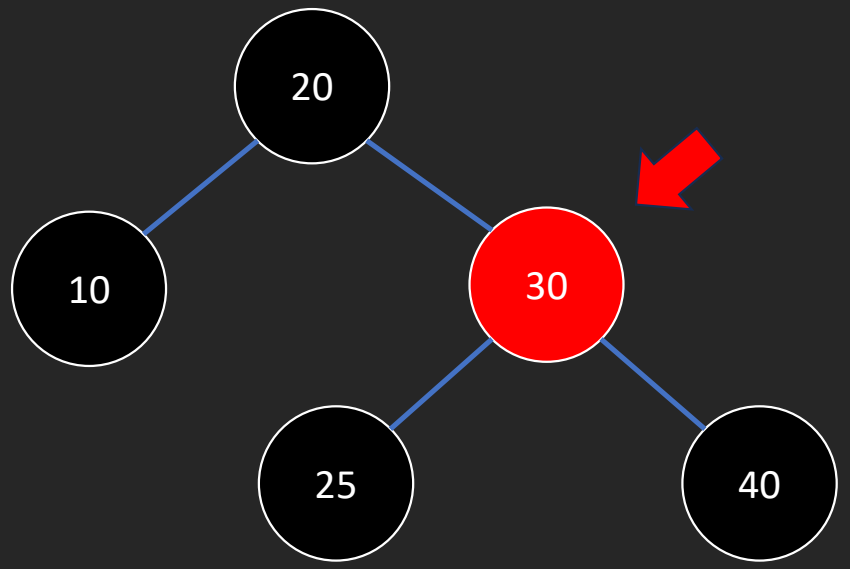

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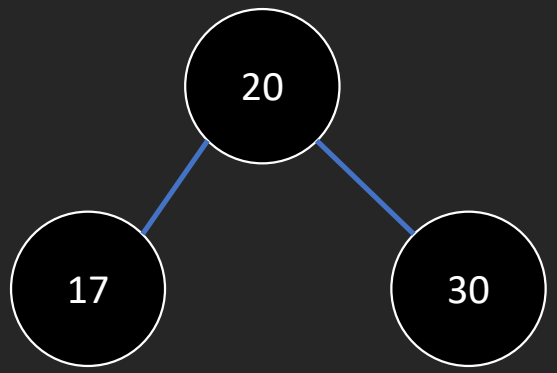

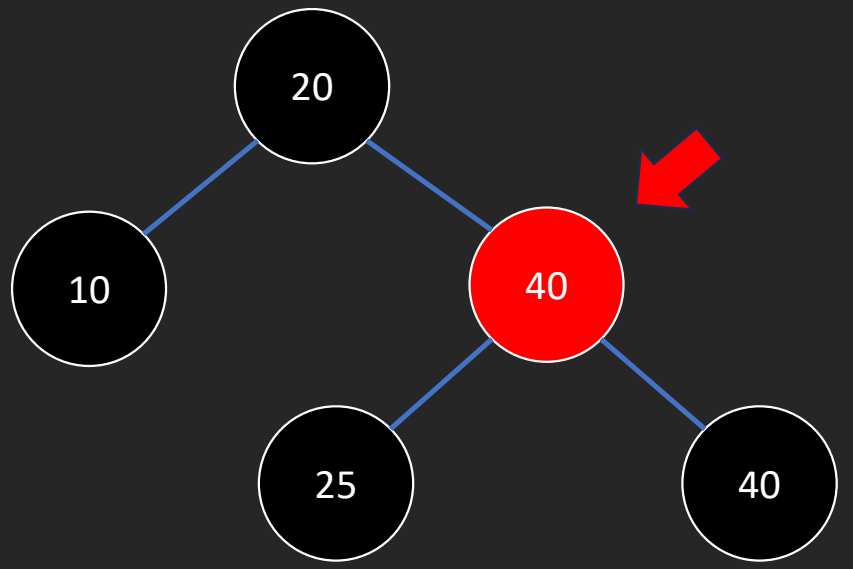

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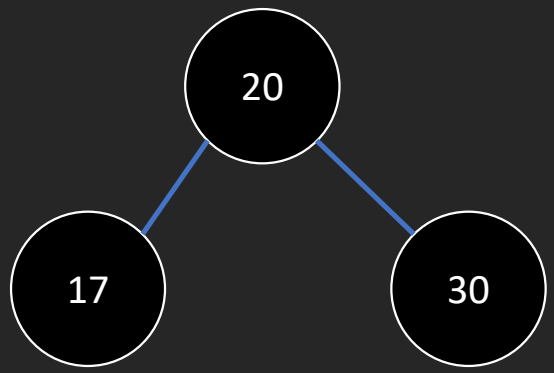

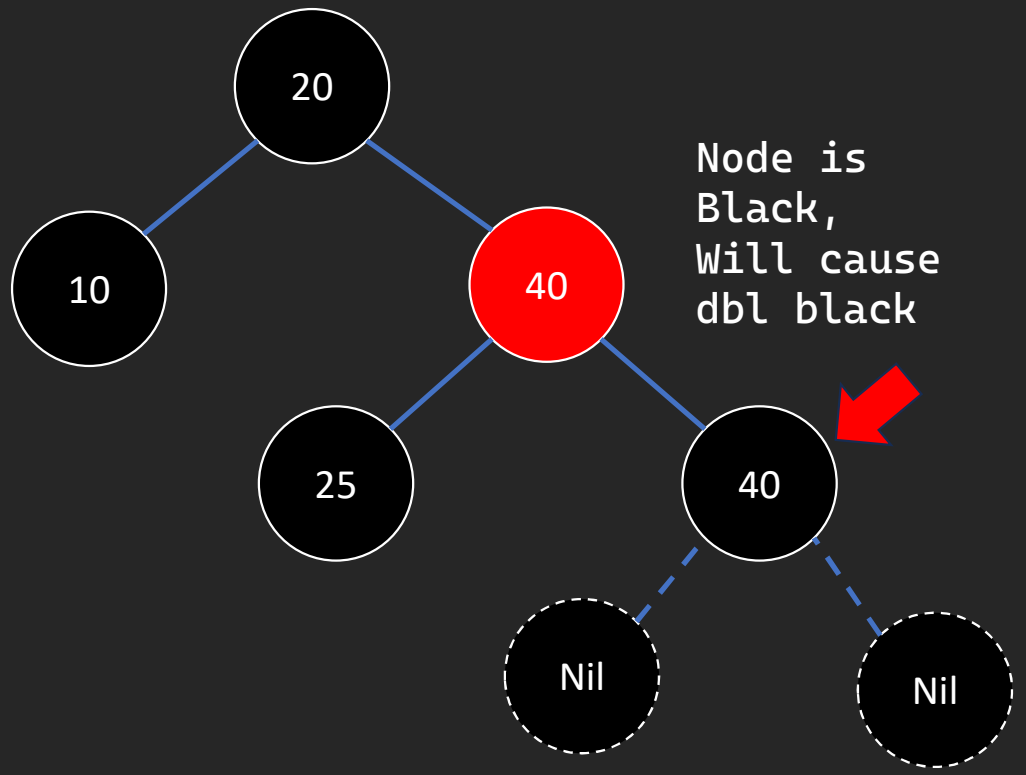

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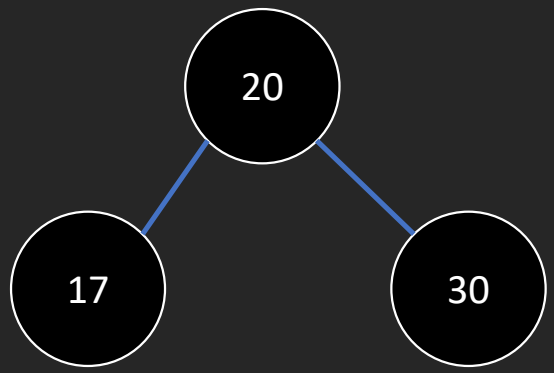

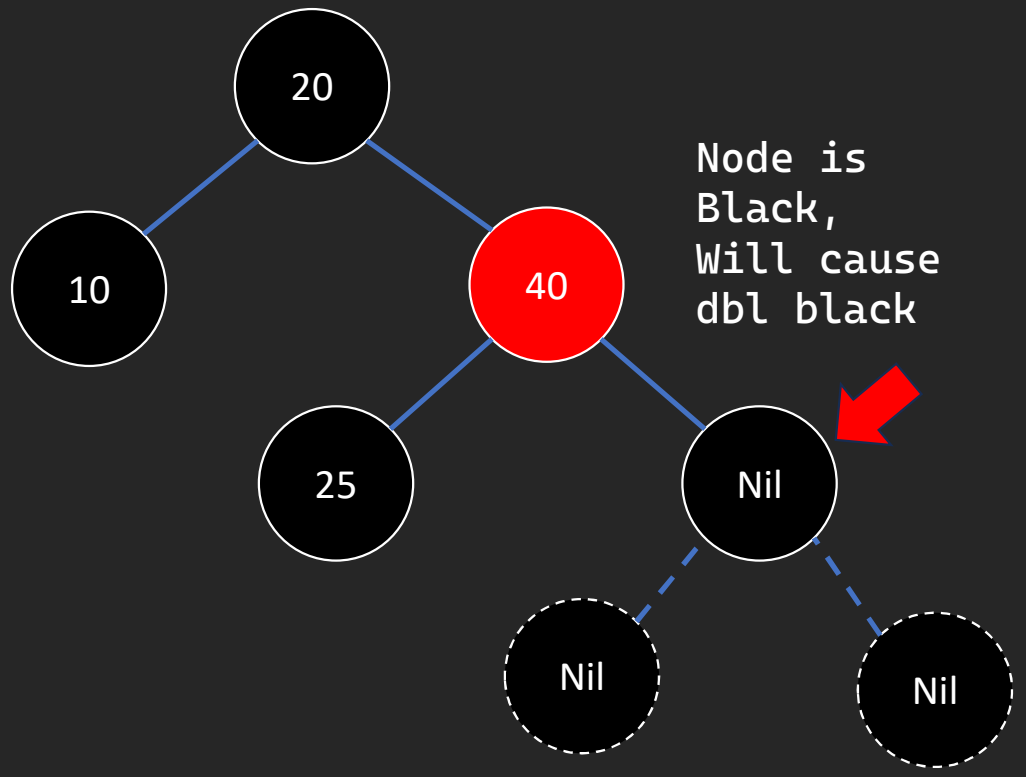

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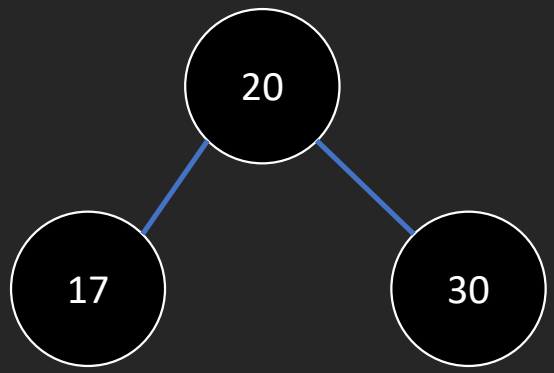

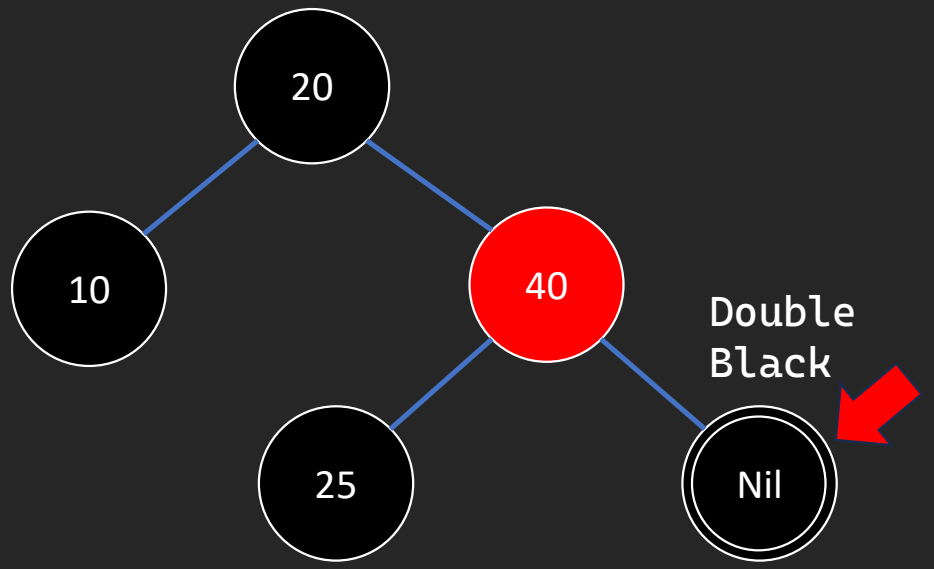

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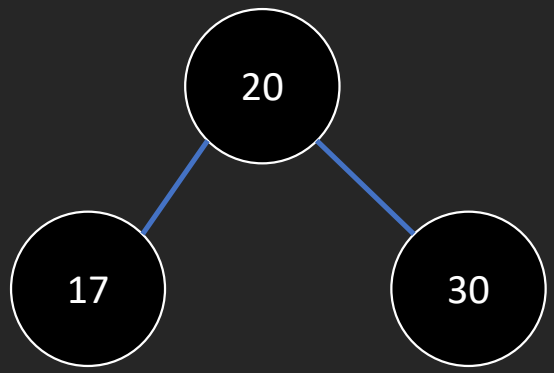

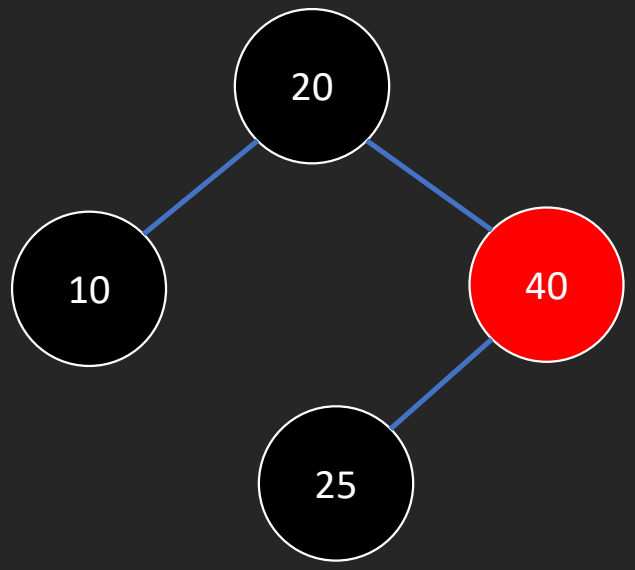

Double Black Problem

Depth (Black-Height) Property: Every path from a node to its descendant NULL nodes has the same number of black nodes.

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Understanding Double Black:

- Black-Height Property: One of the key properties of a Red-Black Tree is that every path from a given node to its descendant NIL nodes must have the same number of black nodes. This is called the black height.
- Violation After Deletion: When a black node is deleted, the black height property may be violated because the paths that previously included the deleted node might now have one fewer black node.
- Double Black Representation: To manage this violation, we conceptually treat the node that replaced the deleted node as "double black." This is not a real color but a representation that this node is over-counted as black (because we lost one black node). The goal is to resolve this double black condition so that the tree's black-height property is restored.

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Fixing Double Black:

The process of resolving a double black node typically involves:

- Recoloring: Adjusting the colors of the sibling and parent nodes to redistribute the black height properly.
- Rotations: Performing tree rotations to rebalance the tree and eliminate the double black condition.
- Propagation: Sometimes, resolving a double black condition at one node causes another double black condition at the parent node, requiring the process to be repeated higher up the tree.

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