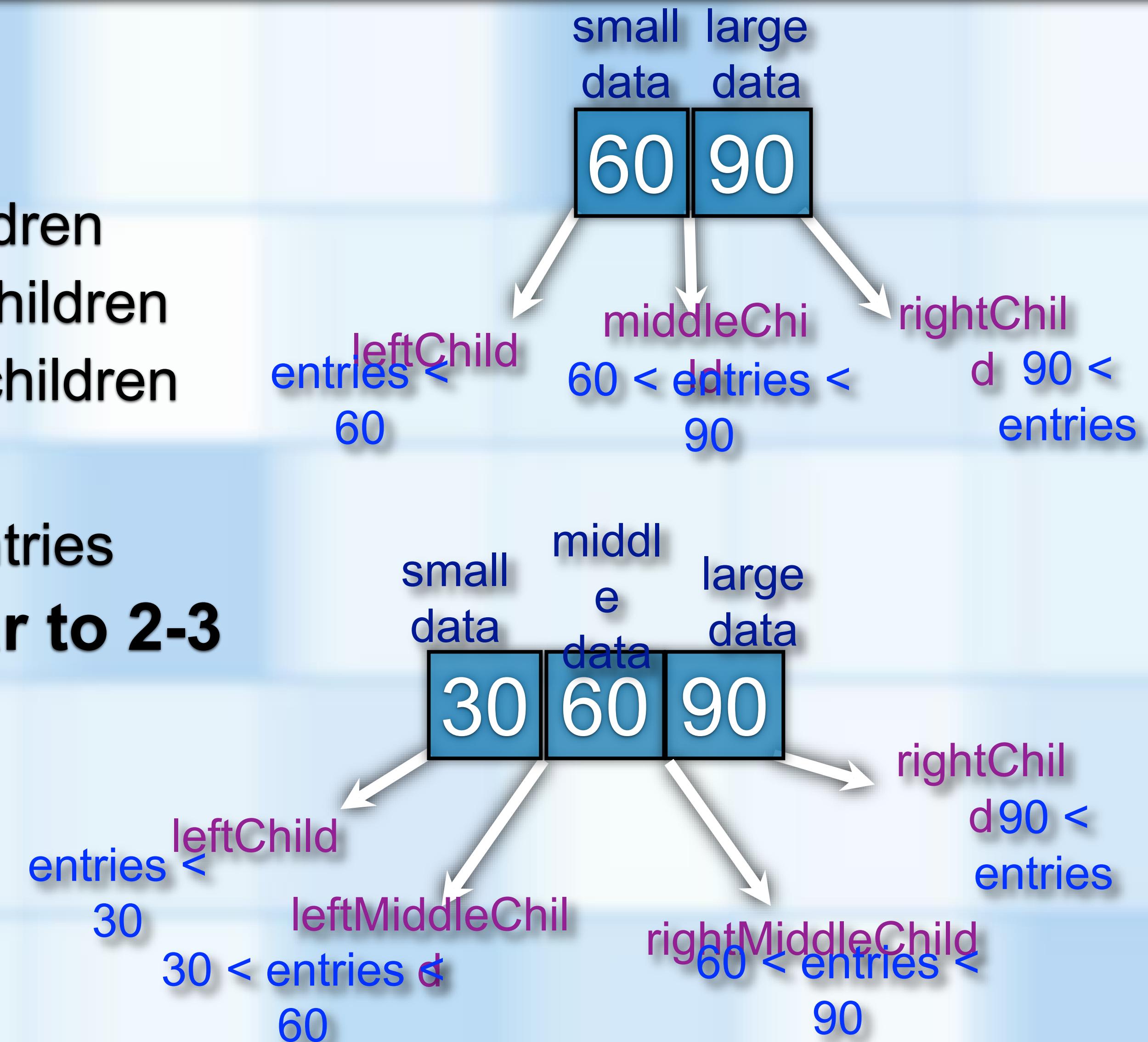
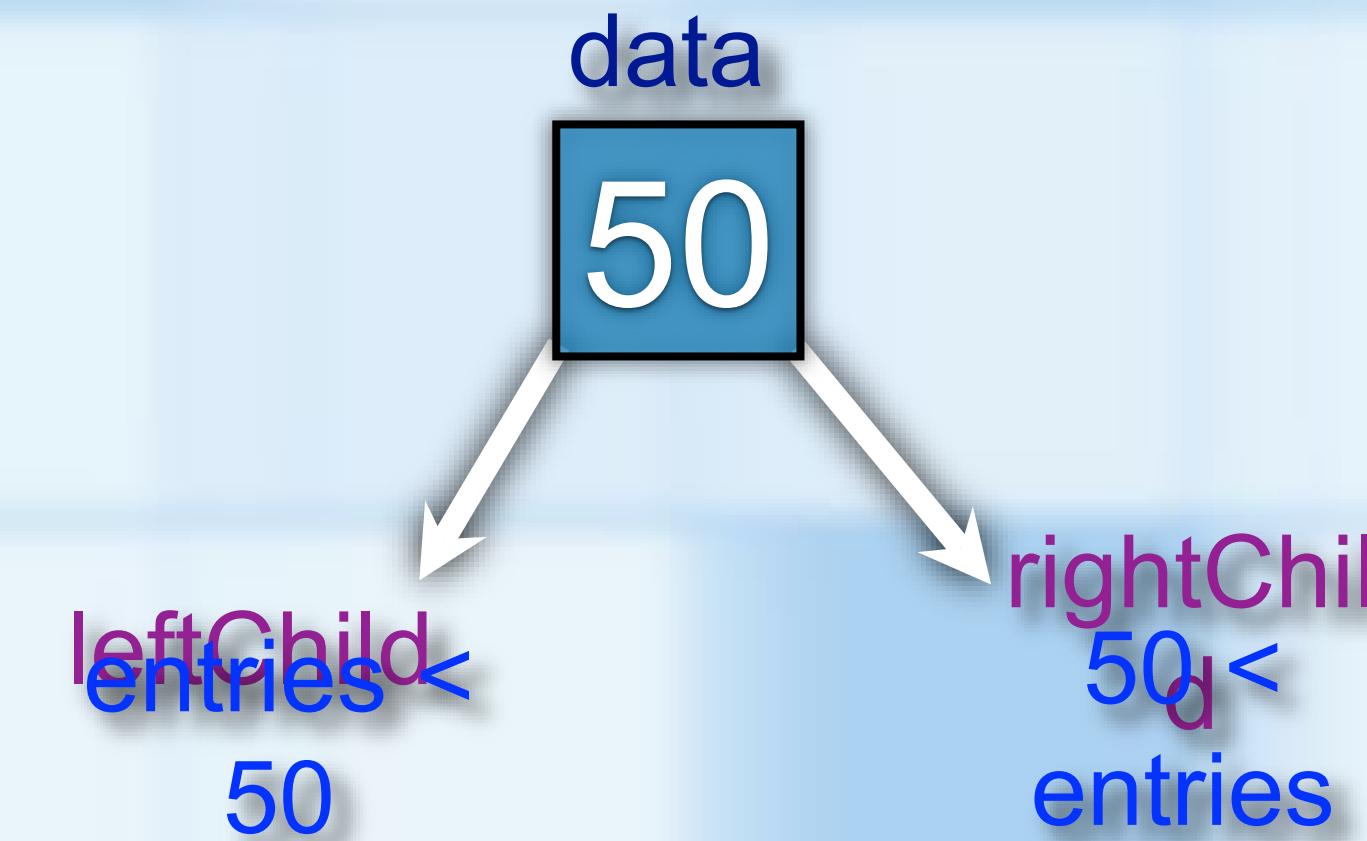


2-3-4 TREES

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- **General Search Tree**
- **Interior nodes are a**
 - **2-node** with one data item **and** two children
 - **3-node** with two data items **and** three children
 - **4-node** with three data items **and** four children
- **All leaves are at the same level**
- Leaf nodes contain one, two or three entries
- **Searching and traversing is similar to 2-3 trees**

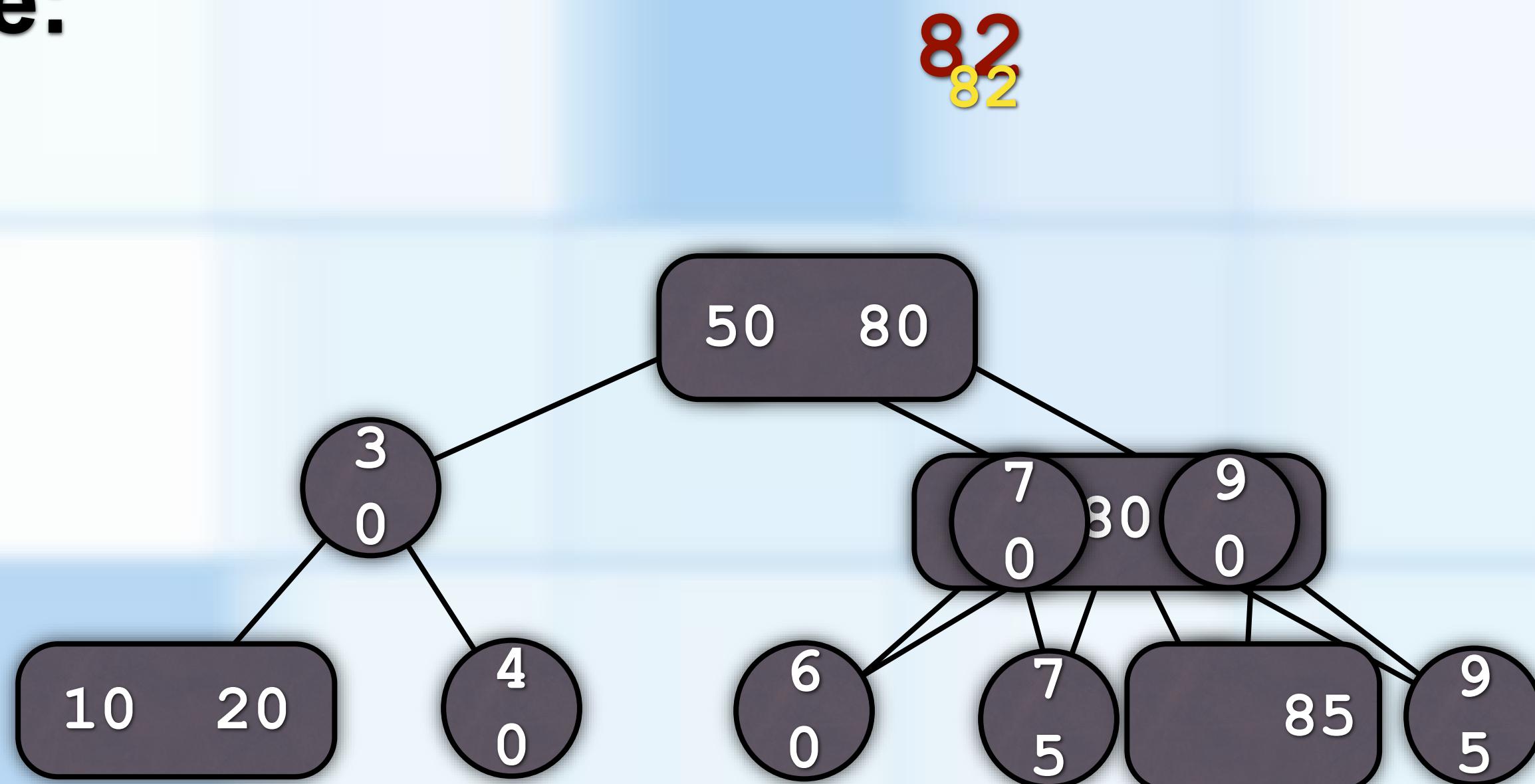


ADDING TO A 2-3-4 TREE

- The insertion algorithm for a 2-3-4 tree:

- Splitting 4-nodes During Insertion

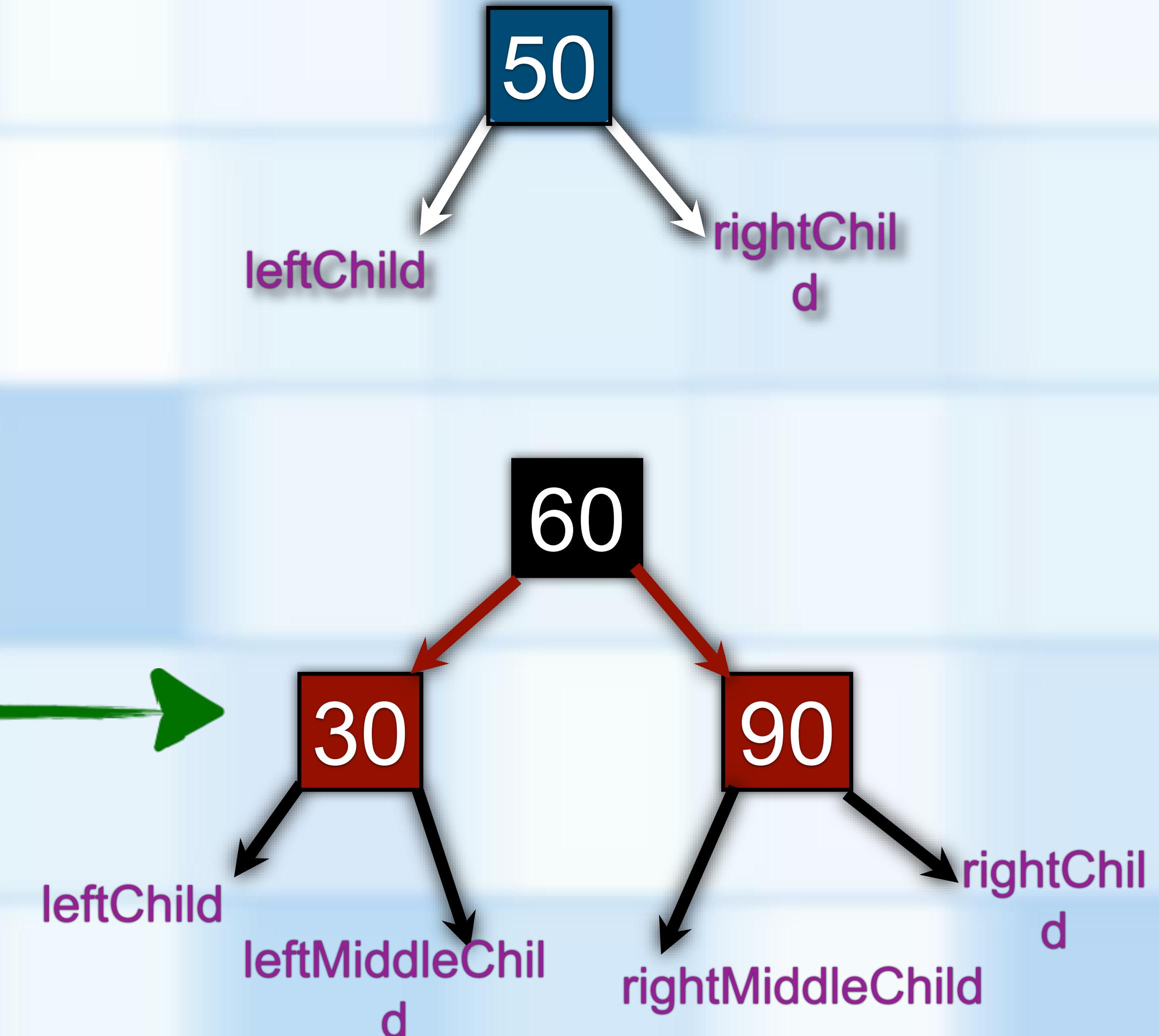
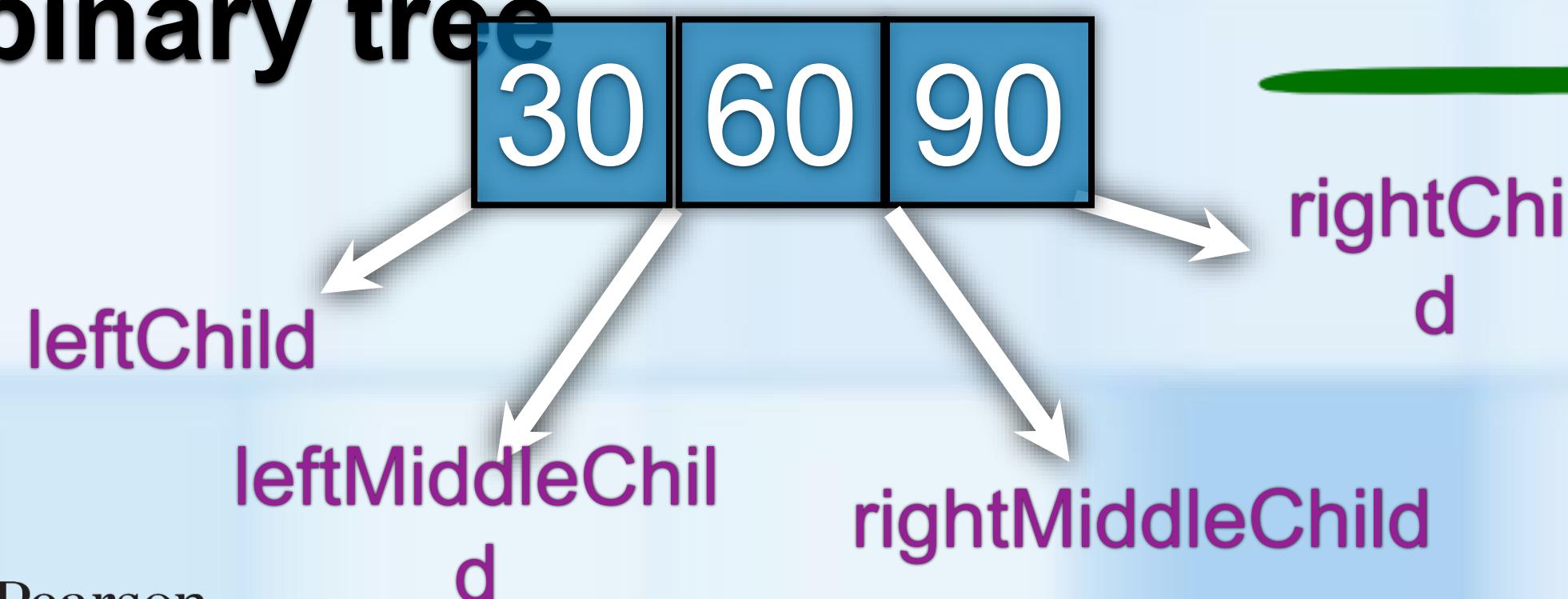
- Split 4-nodes when encountered during a search
 - when traveling from root to leaf
- Split a 4-node by
 - moving one of its items up to its parent node
- A 4-node that is split will
 - Be the root, or have a 2-node or 3-node parent
 - When a 4-node is split, its parent cannot be a 4-node,
 - (because it would have been split before the current node)
 - so it can accommodate item moved up from the 4-node



RED-BLACK TREES

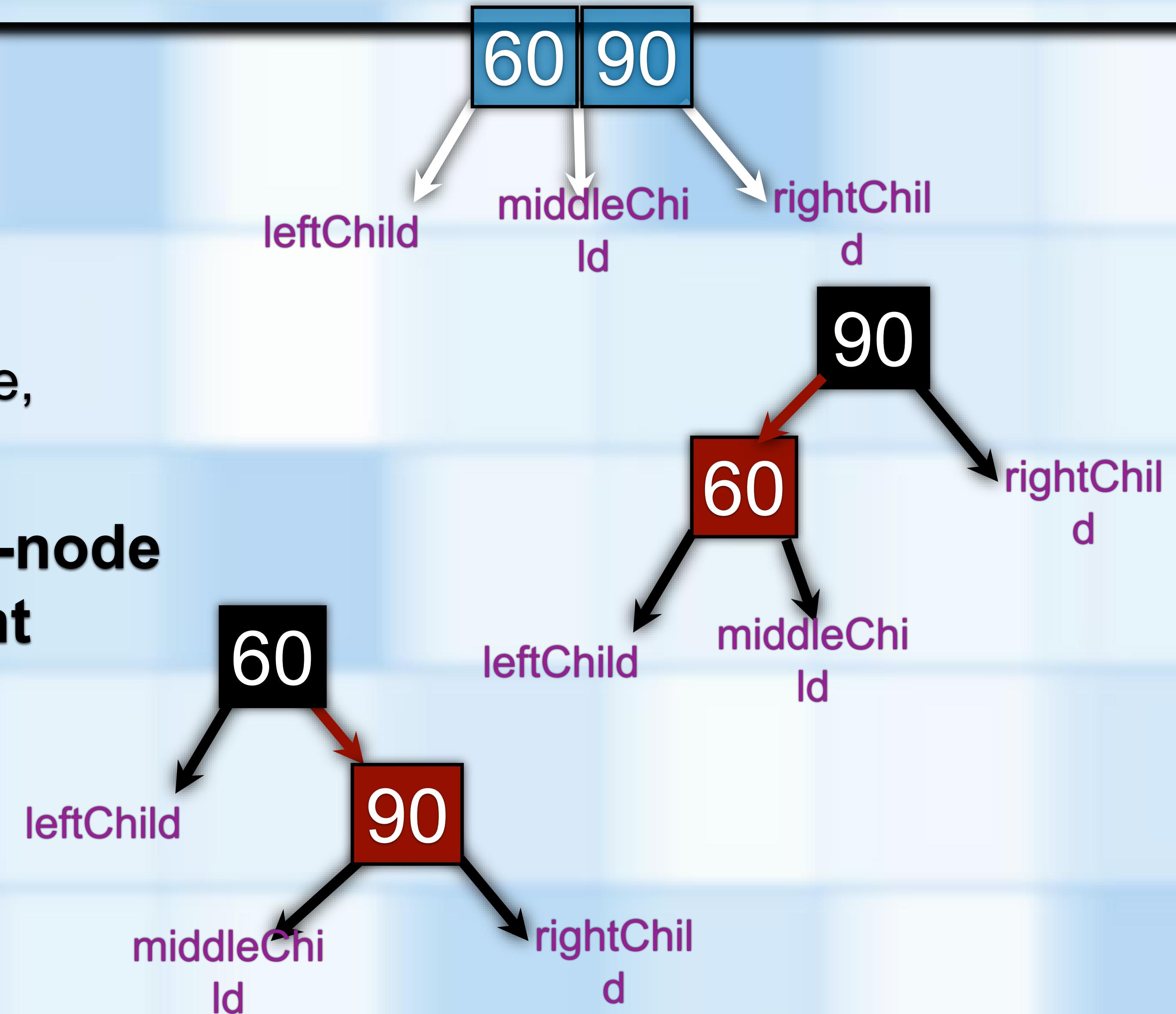
RED-BLACK TREES

- A red-black tree
 - A special binary search tree
 - Used to represent a 2-3-4 tree
 - Has the advantages of a 2-3-4 tree, without the storage overhead
- Represent each 3-node and 4-node in a 2-3-4 tree as an equivalent binary tree



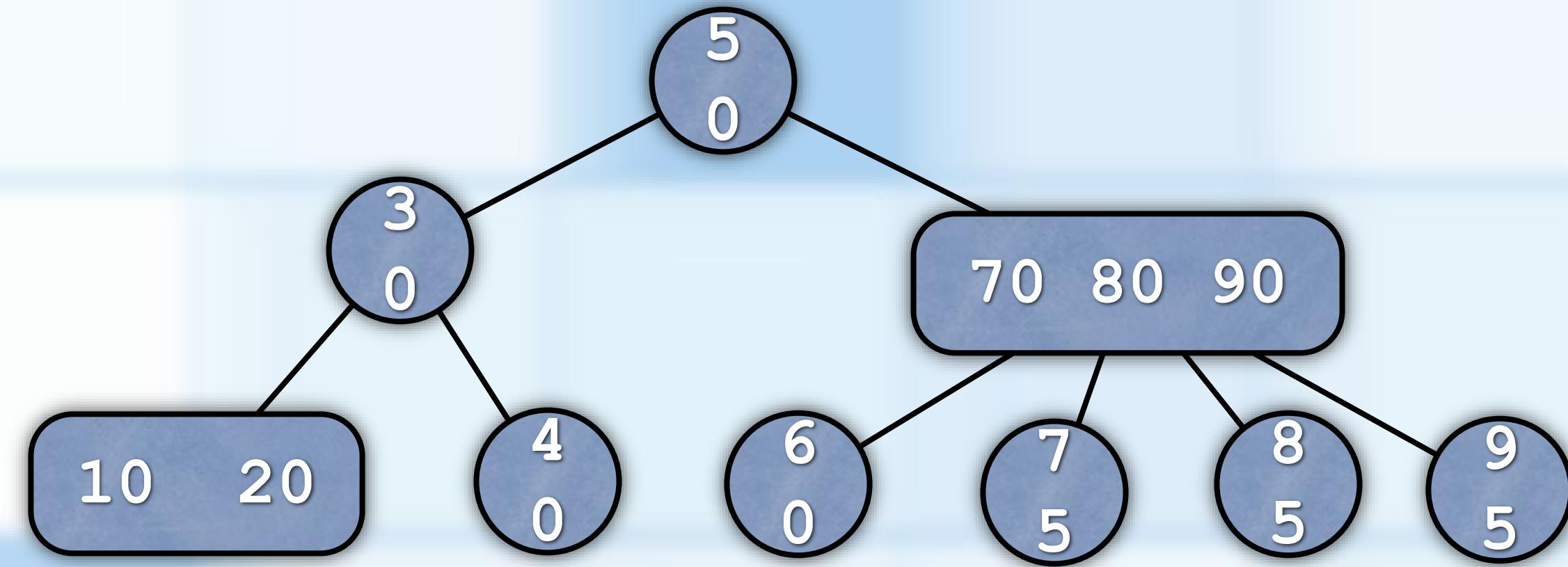
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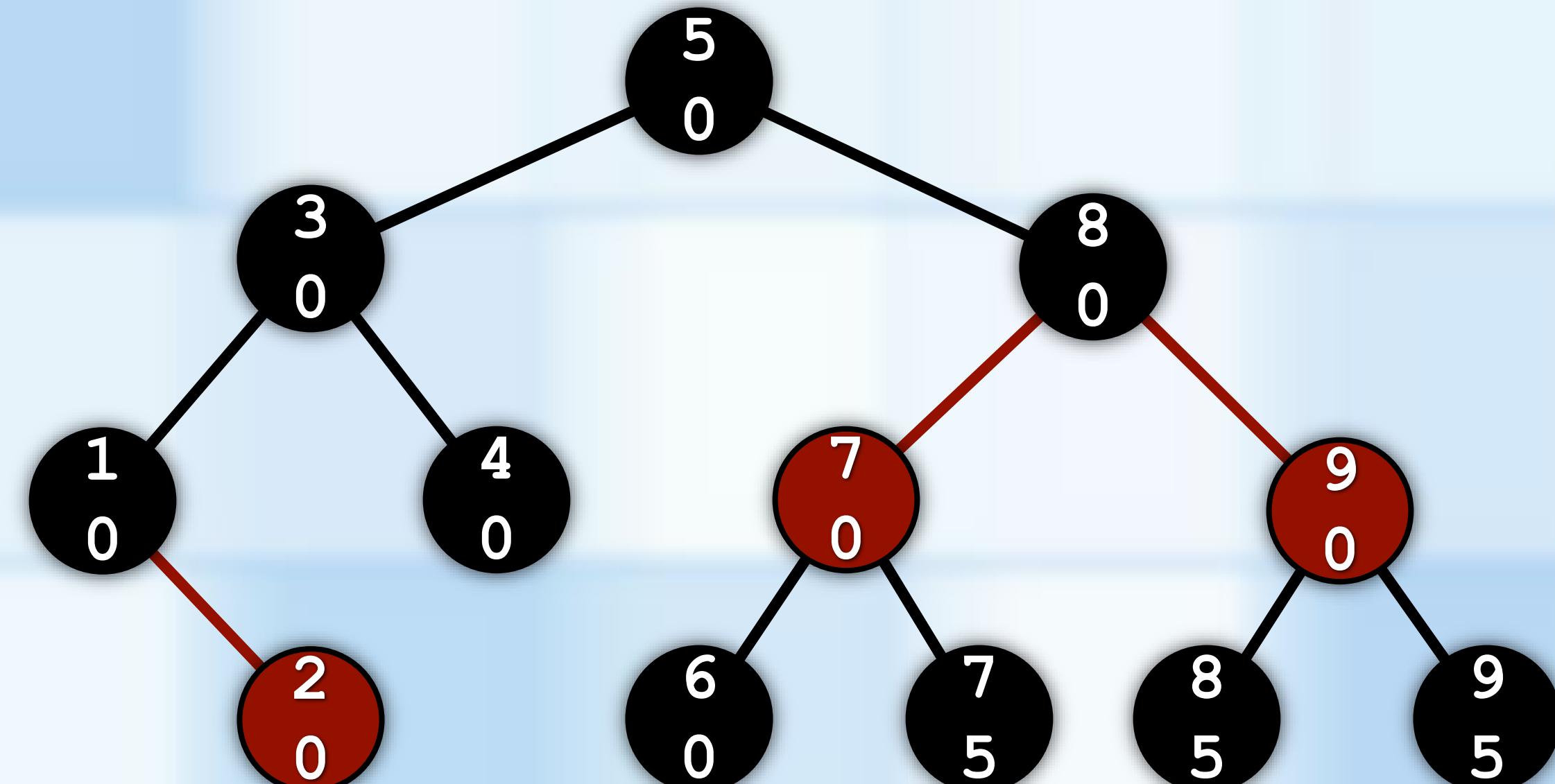
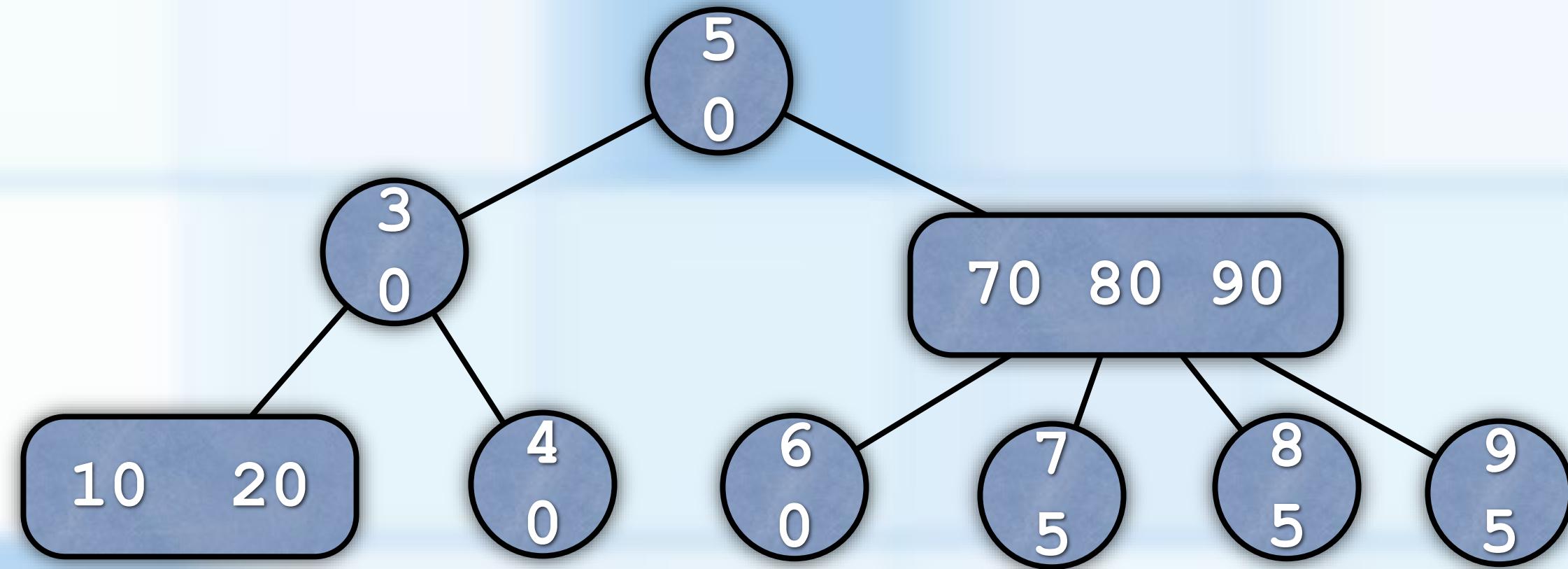
PROPERTIES OF A RED-BLACK TREE

- The root of every red-black tree is black
- Every **red node** has a black parent
 - Red nodes are only created from 3- or 4 nodes
- Children of a **red node** are black
- All paths from the root to a leaf have the same number of black nodes
- Two ways to indicate color
 - Nodes are flagged as red or black
 - Child pointers or a node data field indicate red and black children



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PROPERTIES OF A RED-BLACK TREE

- Splitting a 4-node only requires flipping the color the corresponding 2-nodes

