CSE 143
Lecture 21

Binary Search Trees, continued

read 17.3 - 17.5

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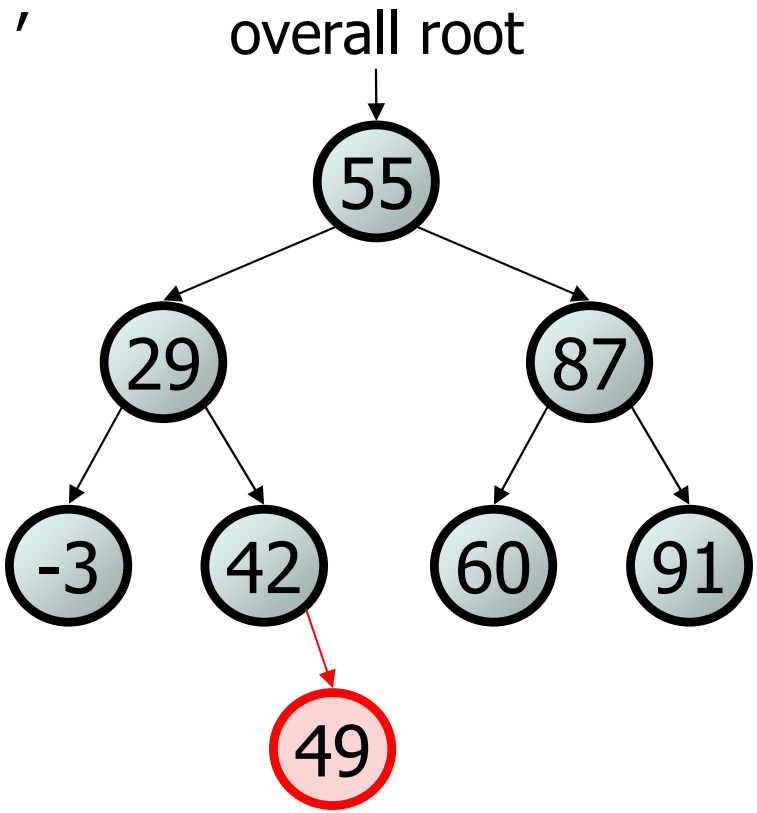
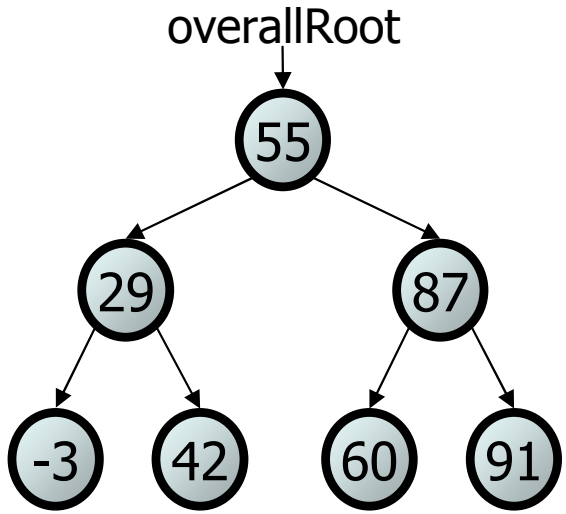
Exercise

- Add a method `add` to the `SearchTree` class that adds a given integer value to the tree. Assume that the elements of the `SearchTree` constitute a legal binary search tree, and add the new value in the appropriate place to maintain ordering.
  - `tree.add(49);`



An incorrect solution

```
// Adds the given value to this BST in sorted order.
public void add(int value) {
    add(overallRoot, value);
}

private void add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    } else if (node.data > value) {
        add(node.left, value);
    } else if (node.data < value) {
        add(node.right, value);
    }
    // else node.data == value, so
    // it's a duplicate (don't add)
}
```

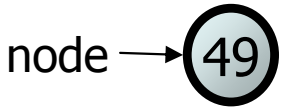


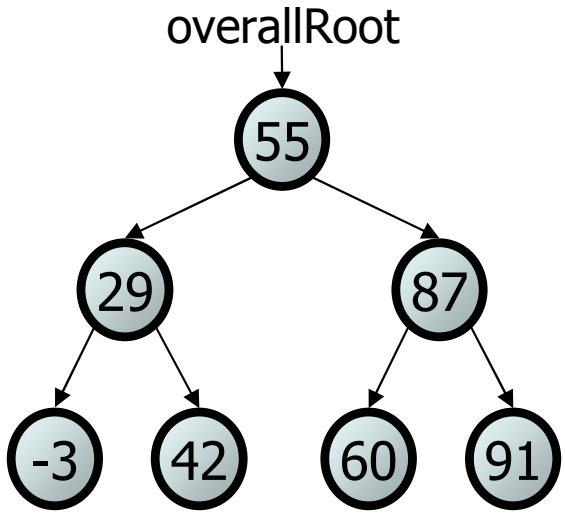
- Why doesn't this solution work?

The problem

- Much like with linked lists, if we just modify what a local variable refers to, it won't change the collection.

```
public void add(int value) {
    add(overallRoot, value);
}

private void add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    } ...
```





  - In the linked list case, how did we actually modify the list?
    - by changing the `front`
    - by changing a node's `next` field

A poor correct solution

```
// Adds the given value to this BST in sorted order. (bad style)
public void add(int value) {
    if (overallRoot == null) {
        overallRoot = new IntTreeNode(value);
    } else if (overallRoot.data > value) {
        add(overallRoot.left, value);
    } else if (overallRoot.data < value) {
        add(overallRoot.right, value);
    }
    // else overallRoot.data == value; a duplicate (don't add)
}

private void add(IntTreeNode root, int value) {
    if (root.data > value) {
        if (root.left == null) {
            root.left = new IntTreeNode(value);
        } else {
            add(overallRoot.left, value);
        }
    } else if (root.data < value) {
        if (root.right == null) {
            root.right = new IntTreeNode(value);
        } else {
            add(overallRoot.right, value);
        }
    }
    // else root.data == value; a duplicate (don't add)
}
```

x = change(x);

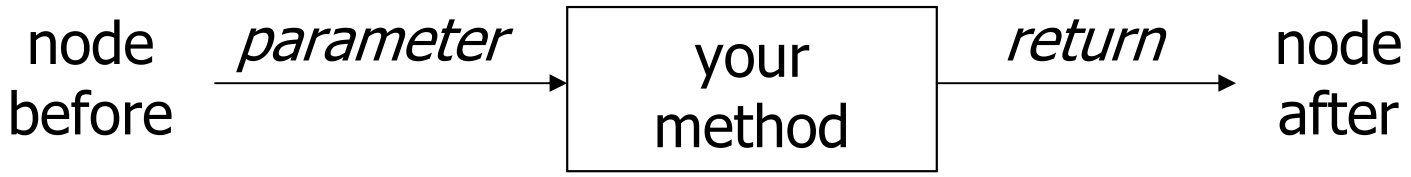
- If you want to write a method that can change the object that a variable refers to, you must do three things:
  1. **pass** in the original state of the object to the method
  2. **return** the new (possibly changed) object from the method
  3. **re-assign** the caller's variable to store the returned result

```
p = change(p);     // in main

public static Point change(Point thePoint) {
    thePoint = new Point(99, -1);
    return thePoint;
```

- We call this general algorithmic pattern **x = change(x);**

Applying x = change(x)

- Methods that modify a tree should have the following pattern:
  - input (parameter): old state of the node
  - output (return): new state of the node

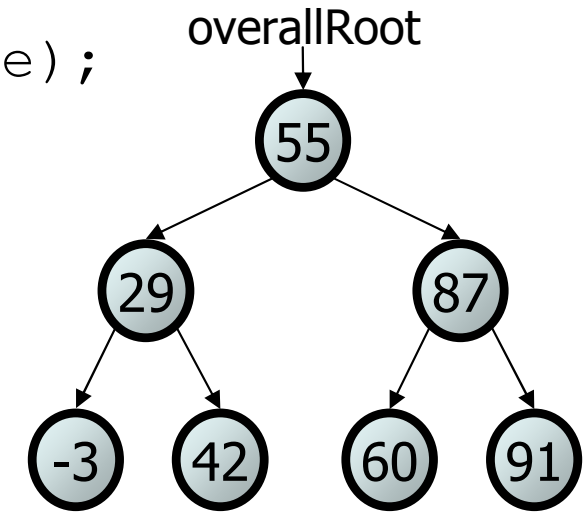


- In order to actually change the tree, you must reassign:

```
node      = change(node, parameters);
node.left = change(node.left, parameters);
node.right = change(node.right, parameters);
overallRoot = change(overallRoot, parameters);
```

A correct solution

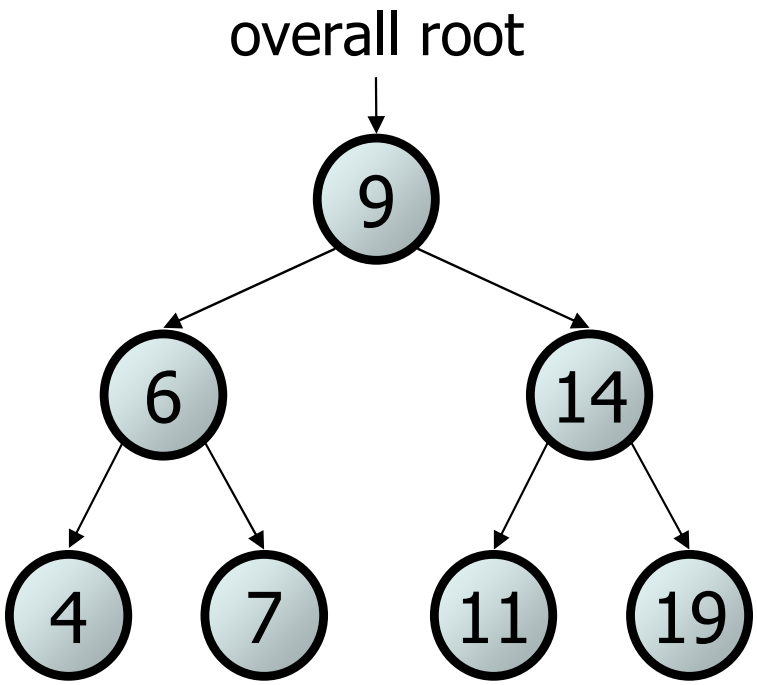
```
// Adds the given value to this BST in sorted order.
public void add(int value) {
    overallRoot = add(overallRoot, value);
}

private IntTreeNode add(IntTreeNode node, int value) {
    if (node == null) {
        node = new IntTreeNode(value);
    } else if (node.data > value) {
        node.left = add(node.left, value);
    } else if (node.data < value) {
        node.right = add(node.right, value);
    } // else a duplicate

    return node;
}
```

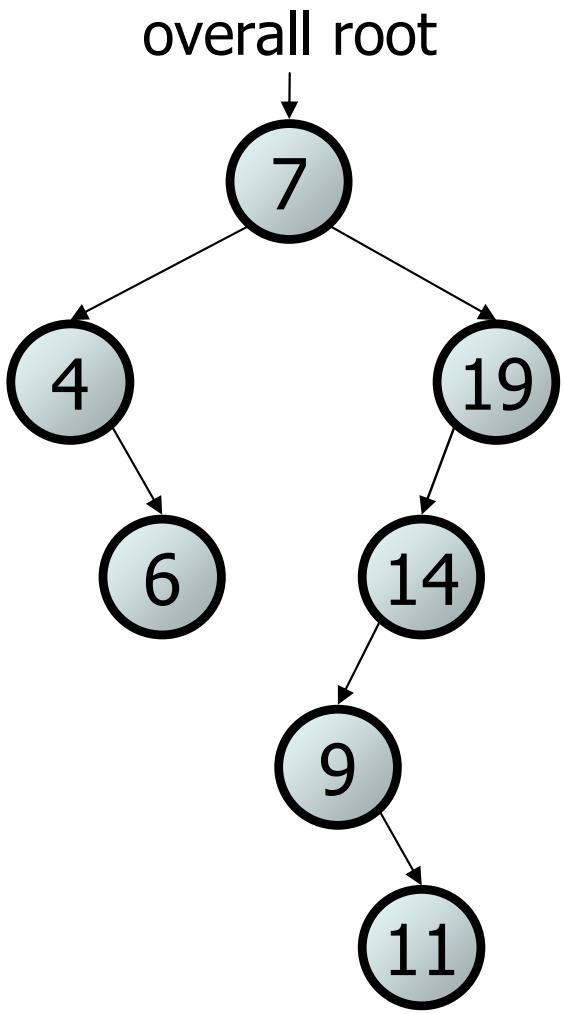


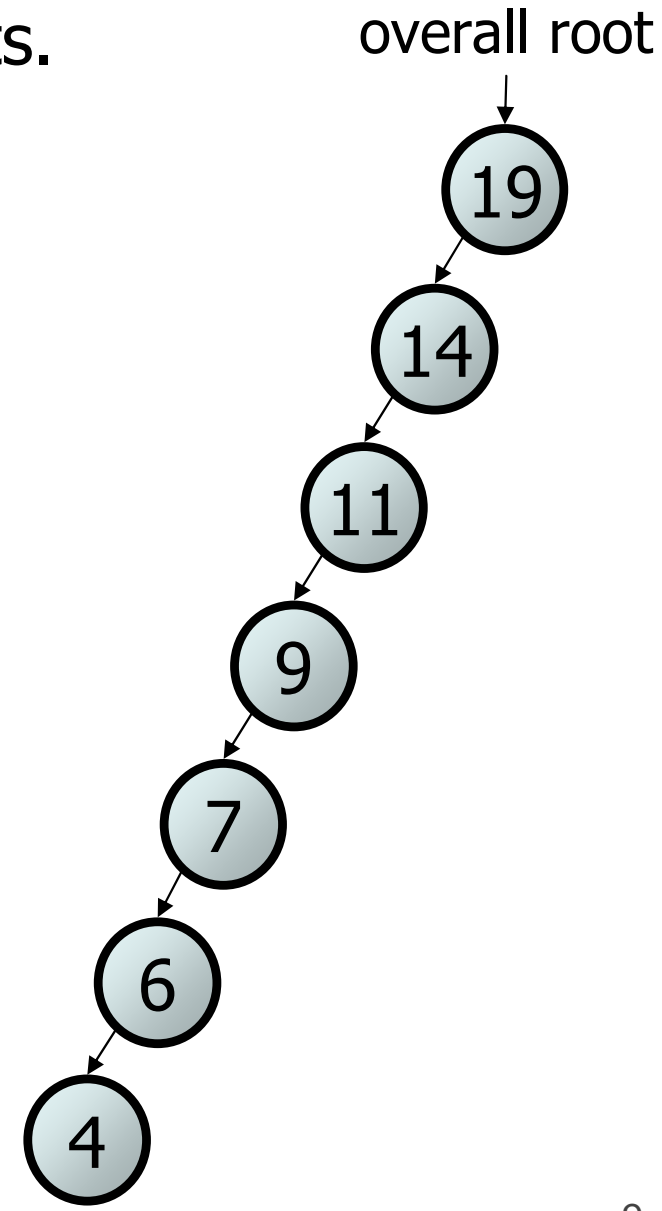
- Think about the case when `node` is a leaf...

Searching BSTs

- The BSTs below contain the same elements.
  - What orders are "better" for searching?



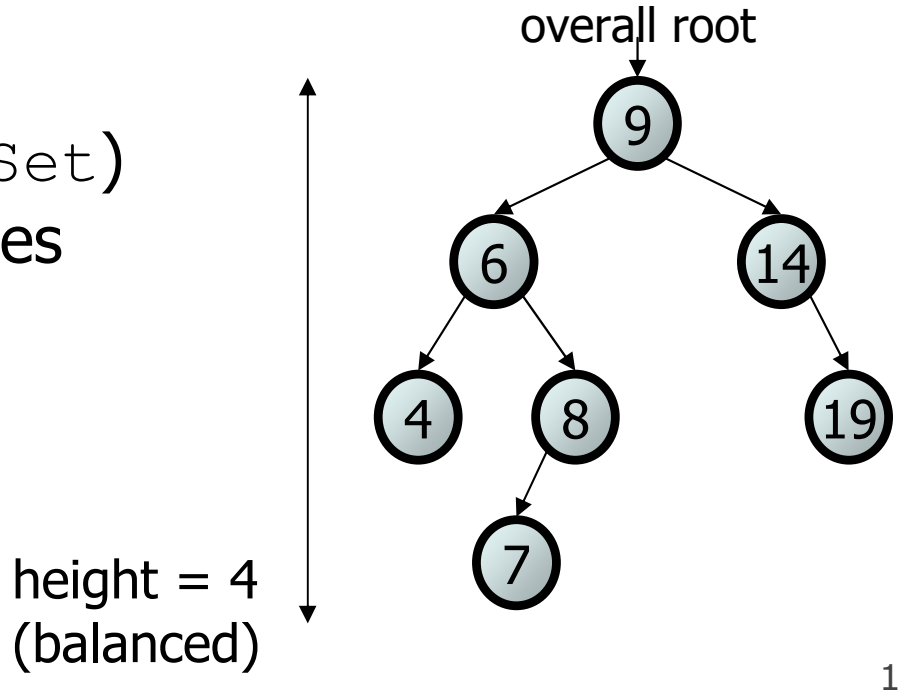




Trees and balance

- **balanced tree**: One whose subtrees differ in height by at most 1 and are themselves balanced.
  - A balanced tree of N nodes has a height of ~ $\log_2$ N.
  - A very unbalanced tree can have a height close to N.

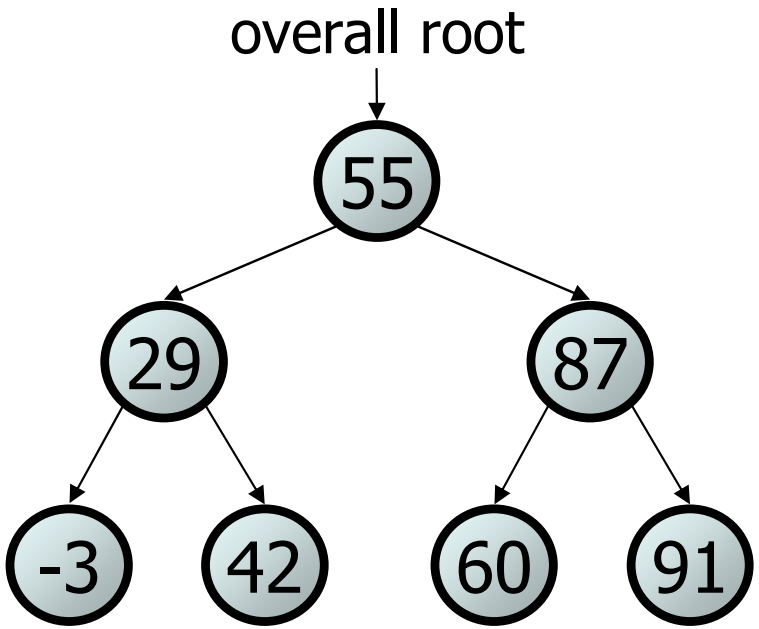
  - The runtime of adding to / searching a BST is closely related to height.
  - Some tree collections (e.g. `TreeSet`) contain code to balance themselves as new nodes are added.



Exercise

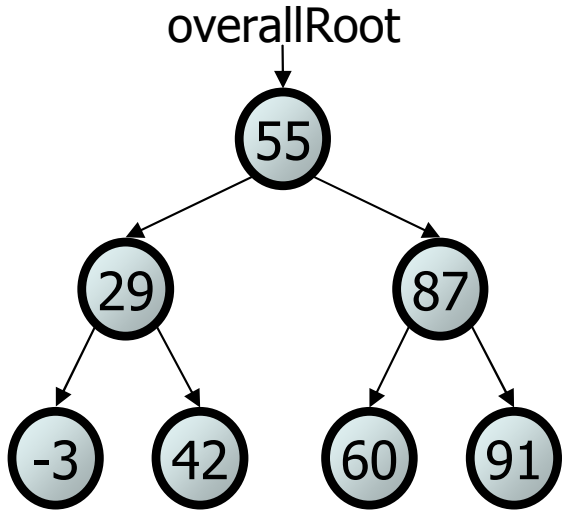
- Add a method `getMin` to the `IntTree` class that returns the minimum integer value from the tree. Assume that the elements of the `IntTree` constitute a legal binary search tree. Throw a `NoSuchElementException` if the tree is empty.

```
int min = tree.getMin();  // -3
```



Exercise solution

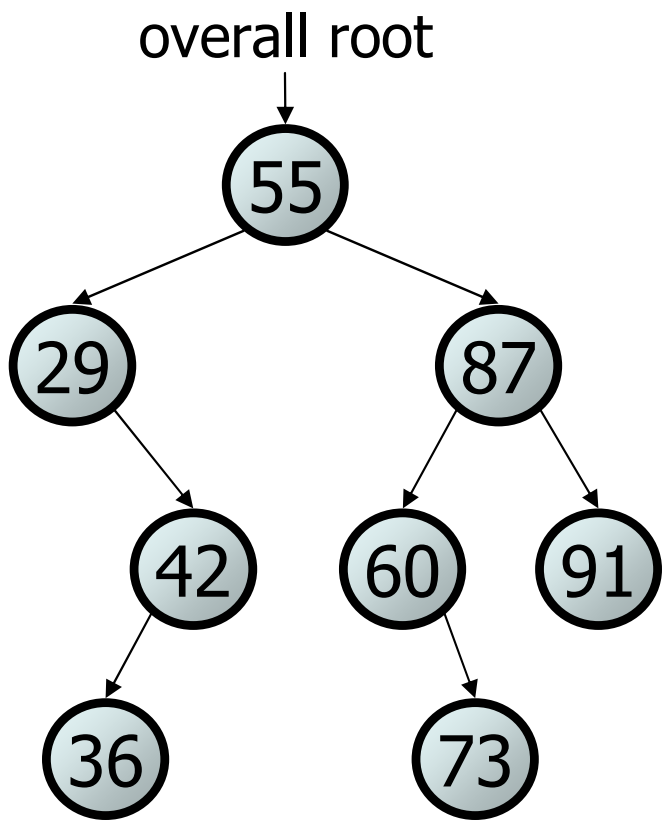
```
// Returns the minimum value from this BST.
// Throws a NoSuchElementException if the tree is empty.
public int getMin() {
    if (overallRoot == null) {
        throw new NoSuchElementException();
    }
    return getMin(overallRoot);
}

private int getMin(IntTreeNode root) {
    if (root.left == null) {
        return root.data;
    } else {
        return getMin(root.left);
    }
}
```



Exercise

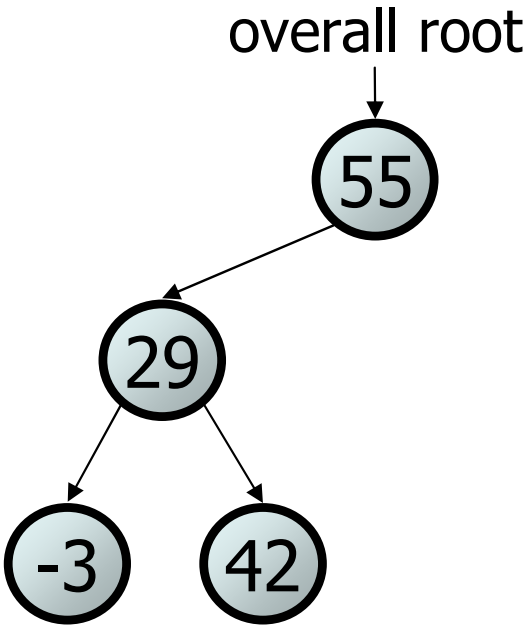
- Add a method `remove` to the `IntTree` class that removes a given integer value from the tree, if present. Assume that the elements of the `IntTree` constitute a legal binary search tree, and remove the value in such a way as to maintain ordering.

```
•tree.remove(73);
•tree.remove(29);
•tree.remove(87);
•tree.remove(55);
```

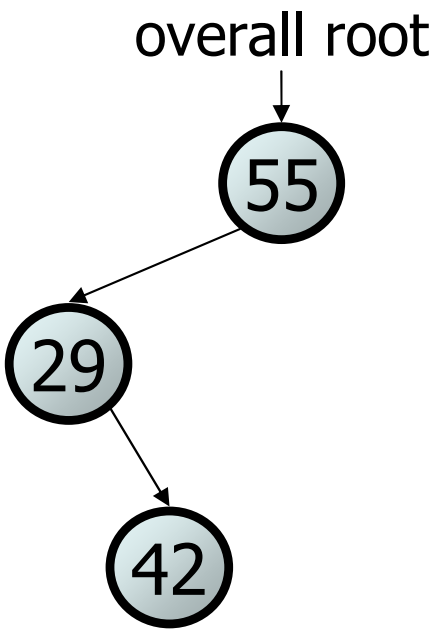


Cases for removal 1

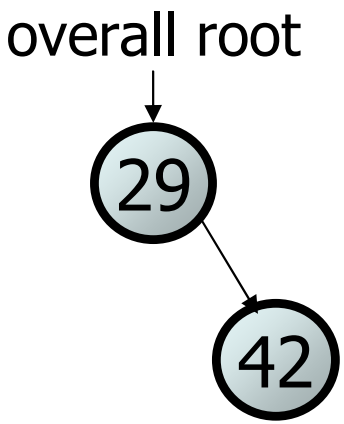
1. a **leaf**: replace with `null`
2. a node with a **left child only**: replace with left child
3. a node with a **right child only**: replace with right child



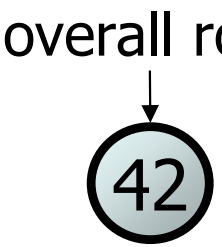
`tree.remove(-3);`



`tree.remove(55);`

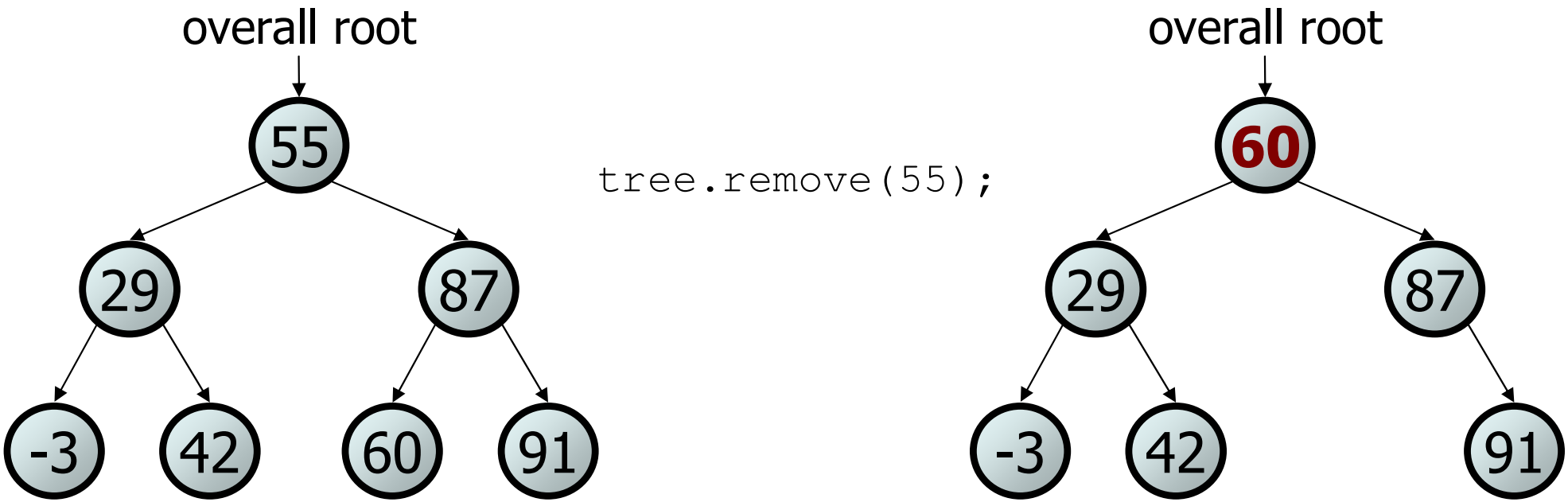


`tree.remove(29);`



Cases for removal 2

4. a node with **both** children: replace with **min from right**



Exercise solution

```
// Removes the given value from this BST, if it exists.
public void remove(int value) {
    overallRoot = remove(overallRoot, value);
}

private IntTreeNode remove(IntTreeNode root, int value) {
    if (root == null) {
        return null;
    } else if (root.data > value) {
        root.left = remove(root.left, value);
    } else if (root.data < value) {
        root.right = remove(root.right, value);
    } else {  // root.data == value; remove this node
        if (root.right == null) {
            return root.left;    // no R child; replace w/ L
        } else if (root.left == null) {
            return root.right;   // no L child; replace w/ R
        } else {
            // both children; replace w/ min from R
            root.data = getMin(root.right);
            root.right = remove(root.right, root.data);
        }
    }
    return root;
}
```