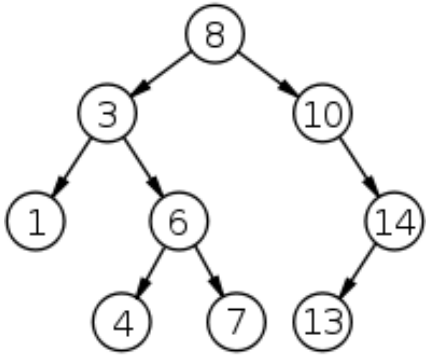



Q1-3

# CSSE 230 Day 7

## More BinaryTree methods
## Tree Traversals

After today, you should be able to…
… traverse trees on paper & in code

# Announcements

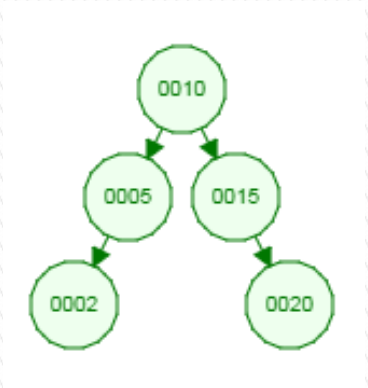
- ~~Please complete the StacksAndQueues partner evaluation in Moodle after you submit your final code.~~
  - ~~Due Friday~~
- Doublets is next programming assignment.
  - ~~Solve it with a partner – meet later during today's class.~~
  - Instructor demo later too.
- Questions (Exam, Stacks & Queues, HW3)?

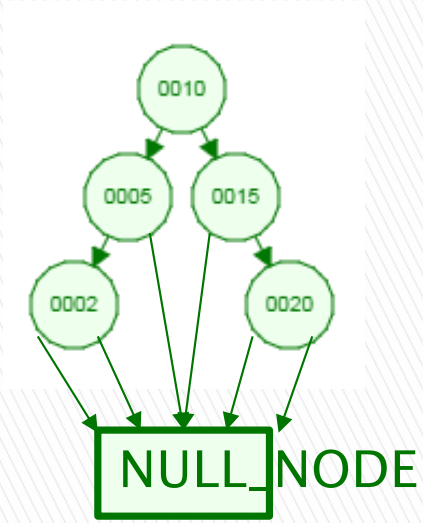
# Questions?

Quiz question: What became clear to you as a result of class?

CSSE230 student: I was **TREE**ted to some good knowledge by the time I **LEAF**t the classroom.

# A dummy NULL_NODE lets you recurse to a simpler base case while avoiding null pointer exceptions




4 possibilities for children (leaf, Left only, Right only, Both)

1 possibility for children: Both (which could be NULL_NODE)

# A dummy NULL_NODE lets you recurse to a simpler base case while avoiding null pointer exceptions

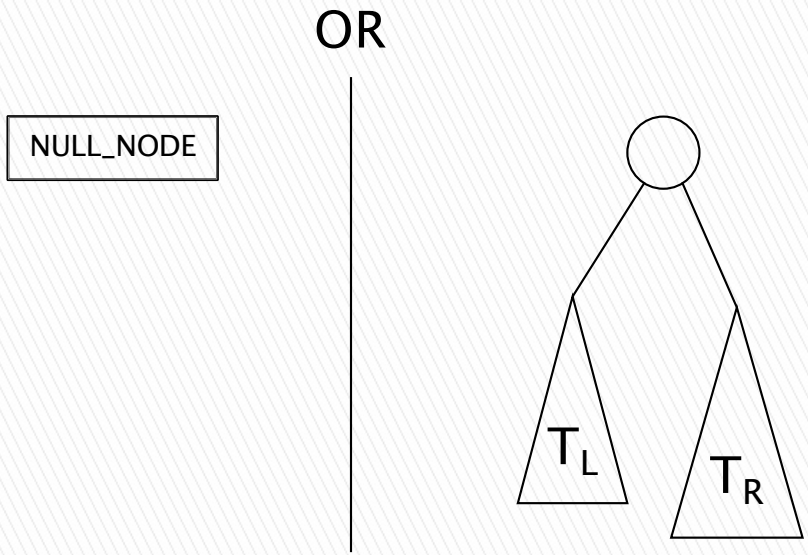
```java
public class BinarySearchTree<T> {
    private BinaryNode root;

    public BinarySearchTree() {
        root = null;
    }

    public int size() {
        if (root == null) {
            return 0;
        }
        return root.size();
    }

    class BinaryNode {
        private T data;
        private BinaryNode left;
        private BinaryNode right;

        public int size() {
            if (left == null && right == null) {
                return 1;
            } else if (left == null) {
                return right.size() + 1;
            } else if (right == null) {
                return left.size() + 1;
            } else {
                return left.size() + right.size() + 1;
            }
        }
```

```java
public class BinarySearchTree<T> {
    private BinaryNode root;

    private final BinaryNode NULL_NODE = new BinaryNode();

    public BinarySearchTree() {
        root = NULL_NODE;
    }

    public int size() {
        return root.size();
    }

    class BinaryNode {
        private T data;
        private BinaryNode left;
        private BinaryNode right;

        public BinaryNode(T element) {
            this.data = element;
            this.left = NULL_NODE;
            this.right = NULL_NODE;
        }

        public int size() {
            if (this == NULL_NODE) {
                return 0;
            }
            return left.size() + right.size() + 1;
        }
```

Simpler

Simpler

# Definition of Binary Tree, NULL_NODE version



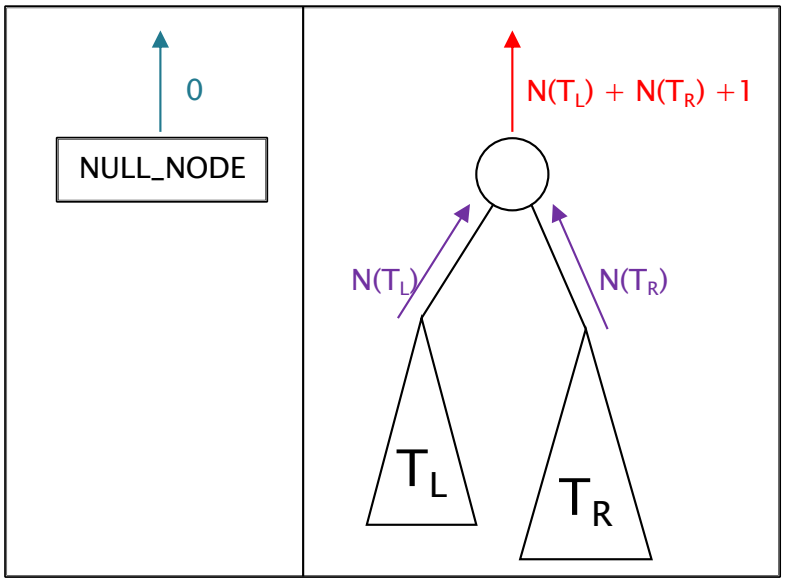
# More Trees

Comment out unused tests and uncomment as you go

Write `containsNonBST(T item)` now.

# Notice the pattern: size

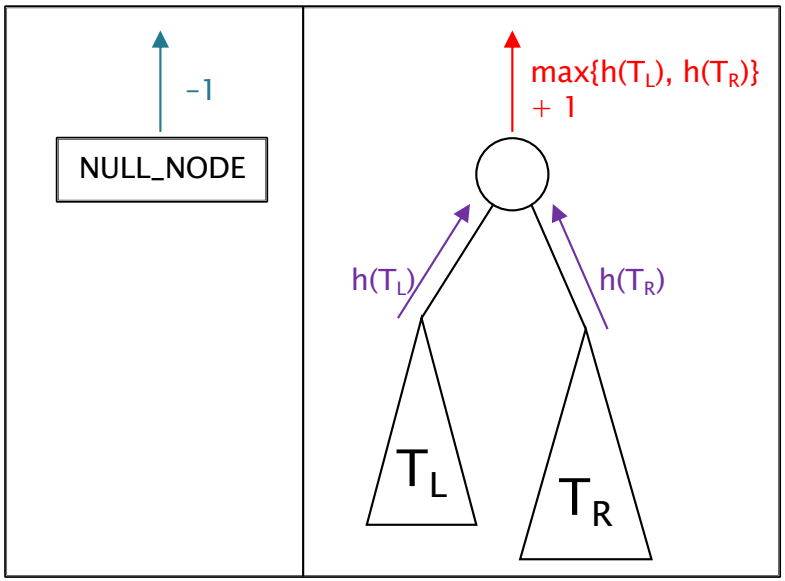
- If (node is null)
  - Return something simple
- Recurse to the left
- Recurse to the right
- Combine results with this node




```
1  public class BinarySearchTree<T> {
2      private BinaryNode root;
3
4      private final BinaryNode NULL_NODE = new BinaryNode();
5
6      public BinarySearchTree() {
7          root = NULL_NODE;
8      }
9
10     public int size() {
11         return root.size();
12     }
13
14     class BinaryNode {
15         private T data;
16         private BinaryNode left;
17         private BinaryNode right;
18
19         public BinaryNode() {
20             this.data = null;
21             this.left = null;
22             this.right = null;
23         }
24
25         public int size() {
26             if (this == NULL_NODE) {
27                 return 0;
28             }
29             return left.size() + right.size() + 1;
30         }
31     }
32 }
```

# Notice the pattern: height

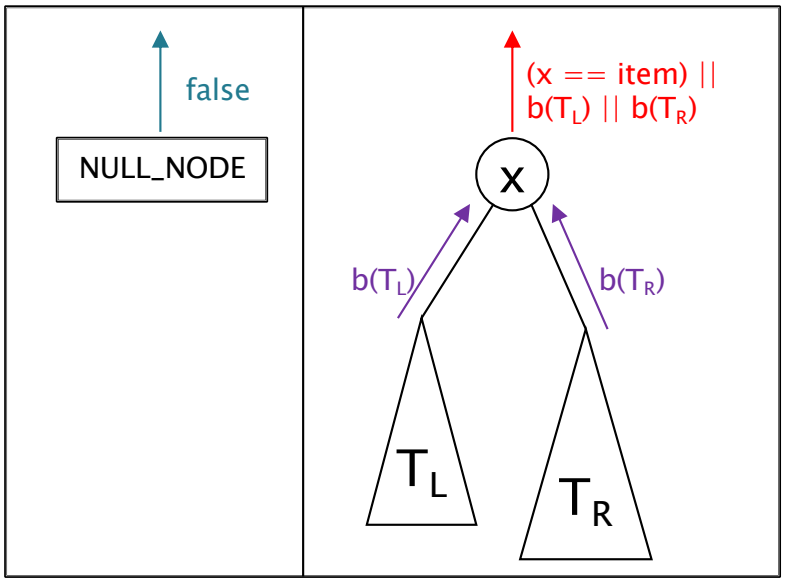
- If (node is null)
  - Return something simple
- Recurse to the left
- Recurse to the right
- Combine results with this node




```
1  public class BinarySearchTree<T> {
2      private BinaryNode root;
3
4      private final BinaryNode NULL_NODE = new BinaryNode();
5
6      public BinarySearchTree() {
7          root = NULL_NODE;
8      }
9
10     public int height() {
11         return root.height();
12     }
13
14     class BinaryNode {
15         private T data;
16         private BinaryNode left;
17         private BinaryNode right;
18
19         public BinaryNode() {
20             this.data = null;
21             this.left = null;
22             this.right = null;
23         }
24
25         public int height() {
26             if (this == NULL_NODE) {
27                 return -1;
28             }
29             return Math.max(left.height(), right.height()) + 1;
30         }
31     }
```

# Notice the pattern: contains

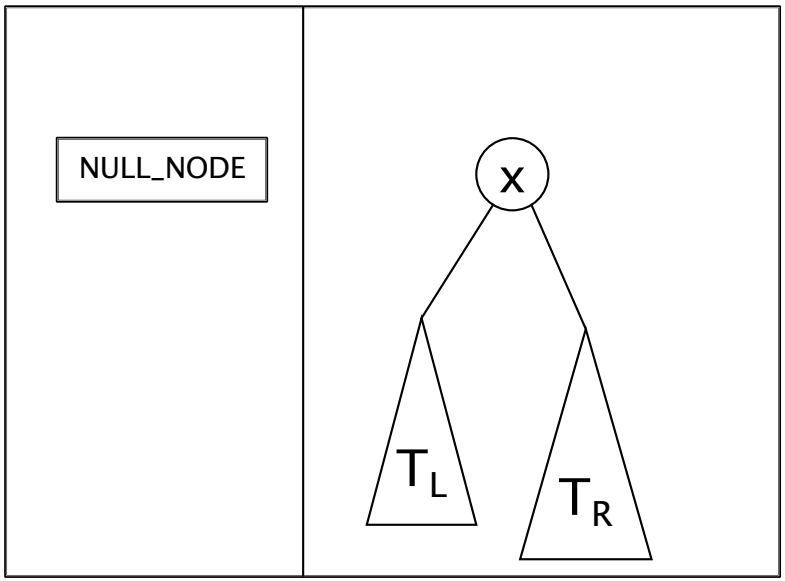
- If (node is null)
  - Return something simple
- Recurse to the left
- Recurse to the right
- Combine results with this node




```
1  public class BinarySearchTree<T> {
2      private BinaryNode root;
3
4      private final BinaryNode NULL_NODE = new BinaryNode();
5
6      public BinarySearchTree() {
7          root = NULL_NODE;
8      }
9
10     public boolean containsNonBST(T item) {
11         return root.containsNonBST(item);
12     }
13
14     class BinaryNode {
15         private T data;
16         private BinaryNode left;
17         private BinaryNode right;
18
19         public BinaryNode() {
20             this.data = null;
21             this.left = null;
22             this.right = null;
23         }
24
25         public boolean containsNonBST(T item) {
26             if (this == NULL_NODE) {
27                 return false;
28             }
29             return this.data.equals(item) ||
30                    left.containsNonBST(item) ||
31                    right.containsNonBST(item);
32         }
33     }
34 }
```

# What else could you do with this recursive pattern?

- If (node is null)
  - Return something simple
- Recurse to the left
- Recurse to the right
- Combine results with this node

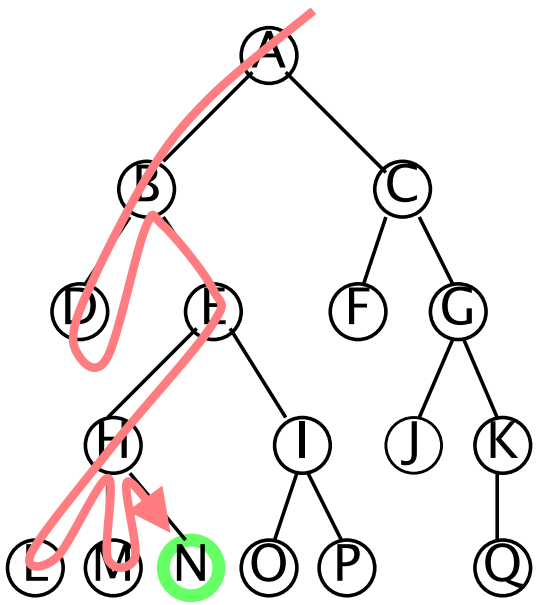


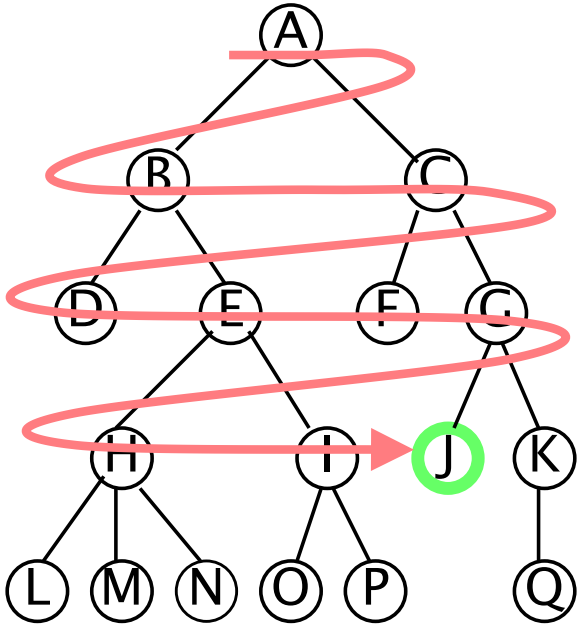

- Print the tree contents
- Sum the values of the nodes
- Dump the contents to an array list
- …

- All involve a *recursive traversal* of the tree.
- Question: in what *order* to visit nodes?

# Binary tree traversals

- Depth-first
  - PreOrder ("top-down")
    - root, left, right
  - InOrder ("left-to-right")
    - left, root, right
  - PostOrder ("bottom-up")
    - left, right, root
- Breadth-first / LevelOrder
  - Level-by-level, left-to-right



# Depth-first traversals using recursion

```
public void printPreOrder() {
        if (this == NULL_NODE) return;
        System.out.println(this.data.toString());
        left.printPreOrder();
        right.printPreOrder();
}

public void printInOrder() {
        if (this == NULL_NODE) return;
        left.printInOrder();
        System.out.println(this.data.toString());
        right.printInOrder();
}

public void printPostOrder() {
        if (this == NULL_NODE) return;
        left.printPostOrder();
        right.printPostOrder();
        System.out.println(this.data.toString());
}
```

If the tree has N nodes, what's the big-O run-time of each traversal?

# Converting the tree to an ArrayList gives an easy solution for toString()

- Brainstorm how to write:

```
public ArrayList<T> toArrayList()
```

- Then BST toString() will simply be:

```
return toArrayList().toString();
```

# Efficiency of toArrayList()

- **`toArrayList()`** is most efficient if we
  - Create the list only once, in the header
  - Pass (a reference to) the list down the recursion
    - All the "communication" is top-down (parent-to-child)

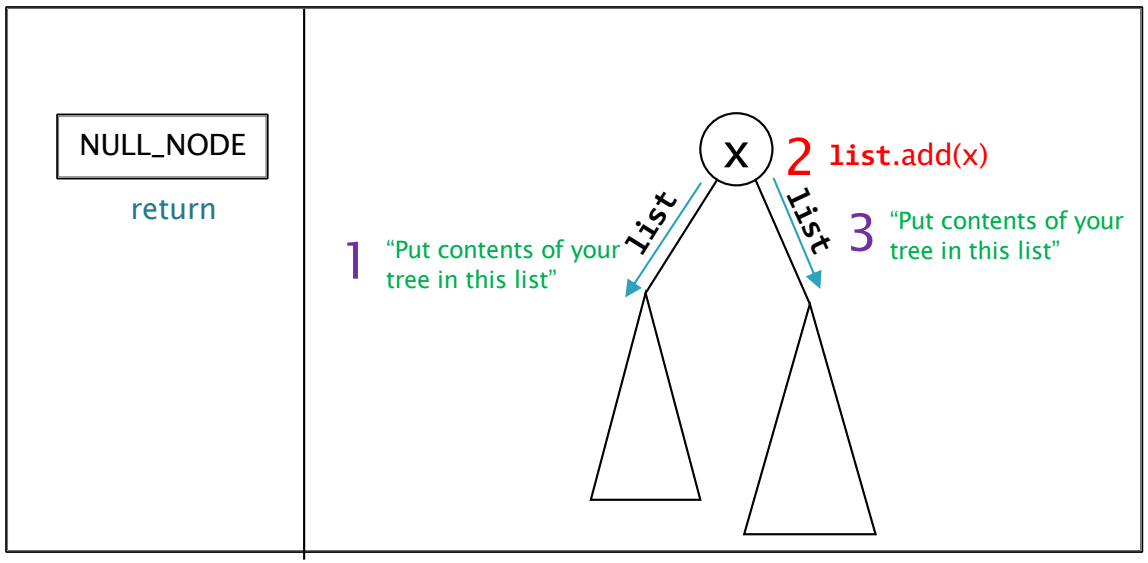
Tree level (header)

```
ArrayList list
        = new ArrayList();
```

**`list`**

"Put contents of your tree in this list"

Node level (recursion)



# Use the recursive pattern when you want to process the whole tree at once

Size(), height(), contains(), toArrayList(), toString(), etc.

What if we want an iterator (one element at a time)?

Next class

# Doublets Intro