CSCI 232:
Data Structures and Algorithms

Binary Search Trees (BST) Part 2

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Spring 2024

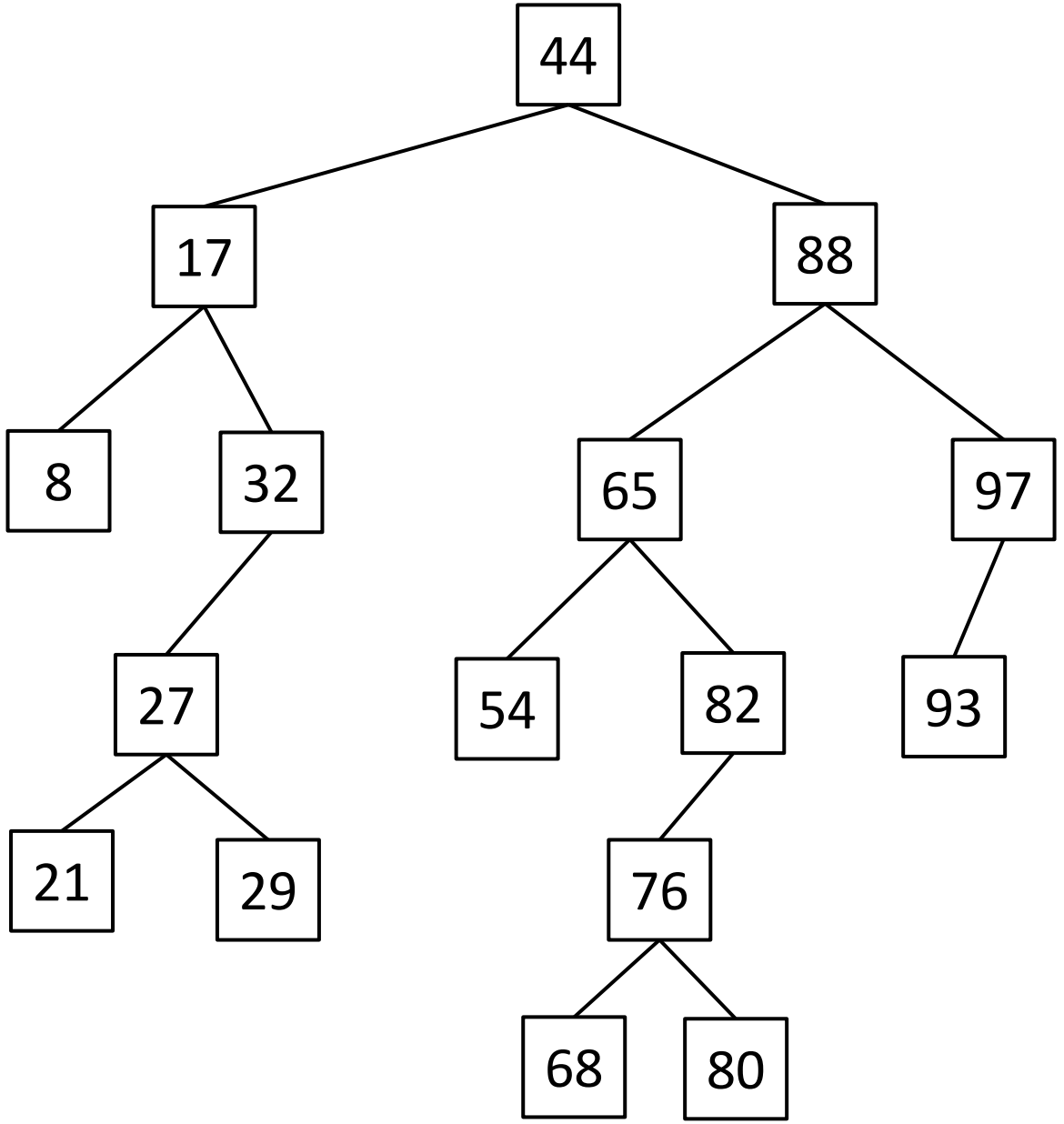
Announcements

Program 1 posted, due Feb 27

Binary Search Tree

Properties of a BST:

- Composed of **`Comparable`** data elements
- Each node as at most two children
- For a given node, all left-hand descendants have values that are less than the node
- For a given node, all right-hand descendants have values that are greater than the node
- No duplicate values



Binary Search Tree - Insertion

```
public void insert(int newValue) {
    if(root == null) {
        root = new Node(newValue);
    }
    else {
    Node currentNode = root;
    boolean placed = false;
    while(!placed) {
         if(currentNode.getValue() == newValue) {
              placed = true;
              System.out.println("No duplicate values allowed");
         }
         else if(newValue < currentNode.getValue()) {
              if(currentNode.getLeft() == null) {
                   currentNode.setLeft(new Node(newValue));
                   currentNode.getLeft().setParent(currentNode);
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              }
              else {
                   currentNode = currentNode.getLeft();
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        }
        else {
             if(currentNode.getRight() == null) {
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             else {
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We repeatedly move left or right until we find the correct spot for our new node

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Once we find the correct spot, we update some pointers

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Running time?

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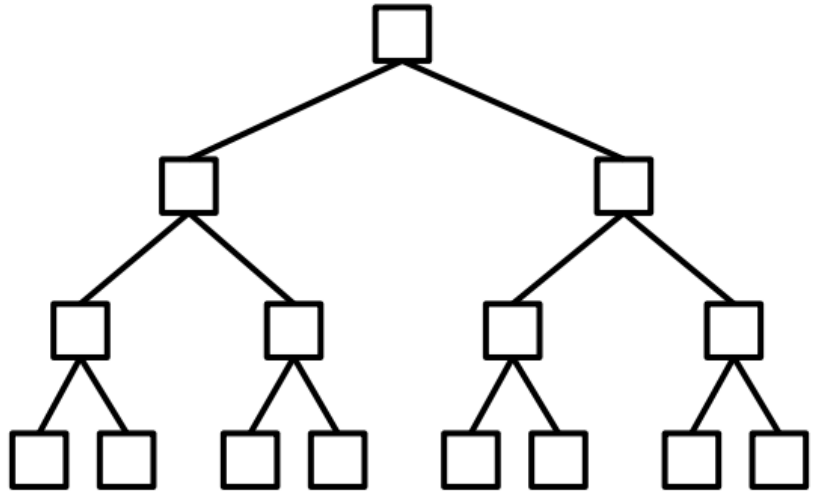
Running time?

We will always be inserting a leaf node, so worst cast scenario we will need to travel the **height** of the tree

If we have a “balanced tree” the height of the tree, is log(n) n = # of nodes



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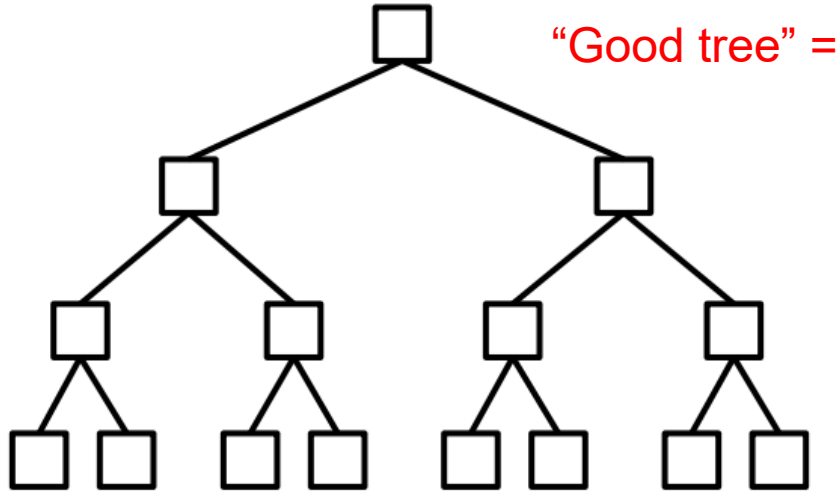

“Good tree” = **O(logn)**

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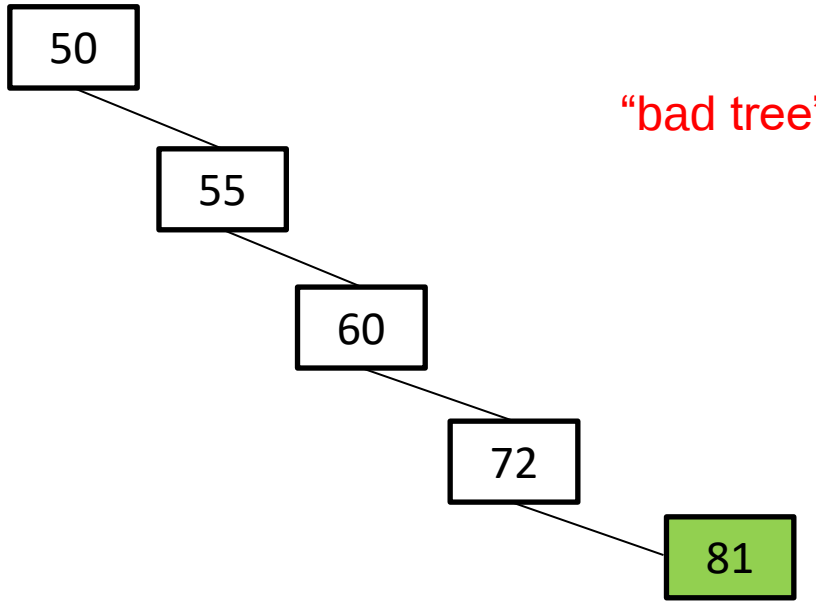
Running time?

We will always be inserting a leaf node, so worst cast scenario we will need to travel the **height** of the tree

If we have a “bad tree” the height of the tree, is O(n-1) n = # of nodes



“bad tree” = **O(n)**

Binary Search Tree - Insertion

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```

Running time?

We will always be inserting a leaf node, so worst cast scenario we will need to travel the **height** of the tree

"Bad" tree → O(n)
"Good" tree → O(logn)

O(h) → h = height of tree

Running time for adding to an array?

O(n)

Binary Search Tree - Insertion

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public void insert(int newValue) {
    if(ro
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    while
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}
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If we can find a way to keep a tree “balanced”, we can achieve **O(logn)** insertion time, and **O(logn)** searching time

Running time?

We will always be inserting a leaf node, so worst cast scenario we will need to travel the **height** of the tree

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If we can find a way to keep a tree "balanced", we can achieve **O(logn)** insertion time, and **O(logn)** searching time

There is a way! Coming soon

Running time?

We will always be inserting a leaf node, so worst cast scenario we will need to travel the **height** of the tree

"Bad" tree → O(n)
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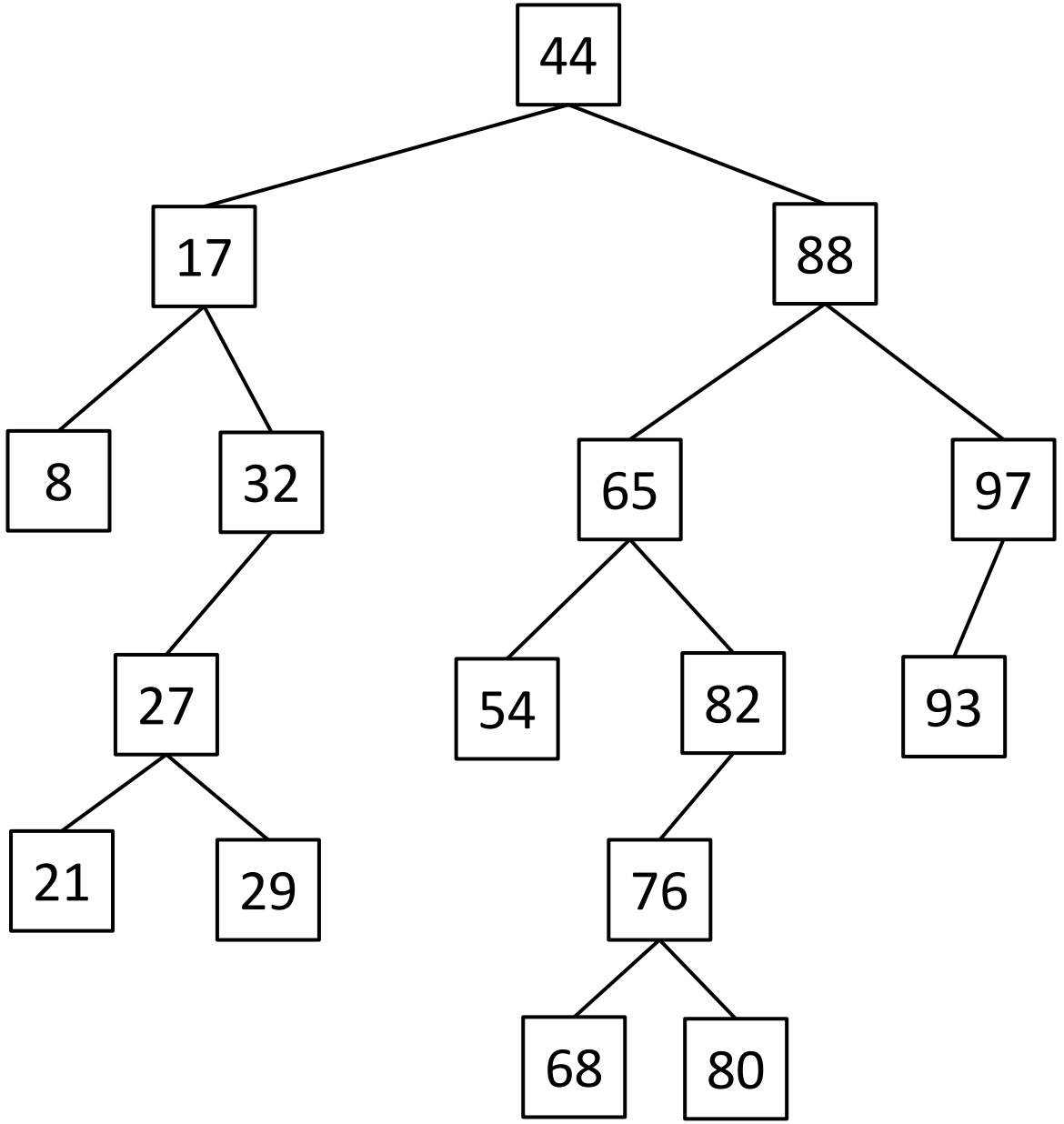
O(h) → h = height of tree

Running time for adding to an array?

O(n)

Binary Search Tree- Removal

```
remove(68);
```



Binary Search Tree- Removal

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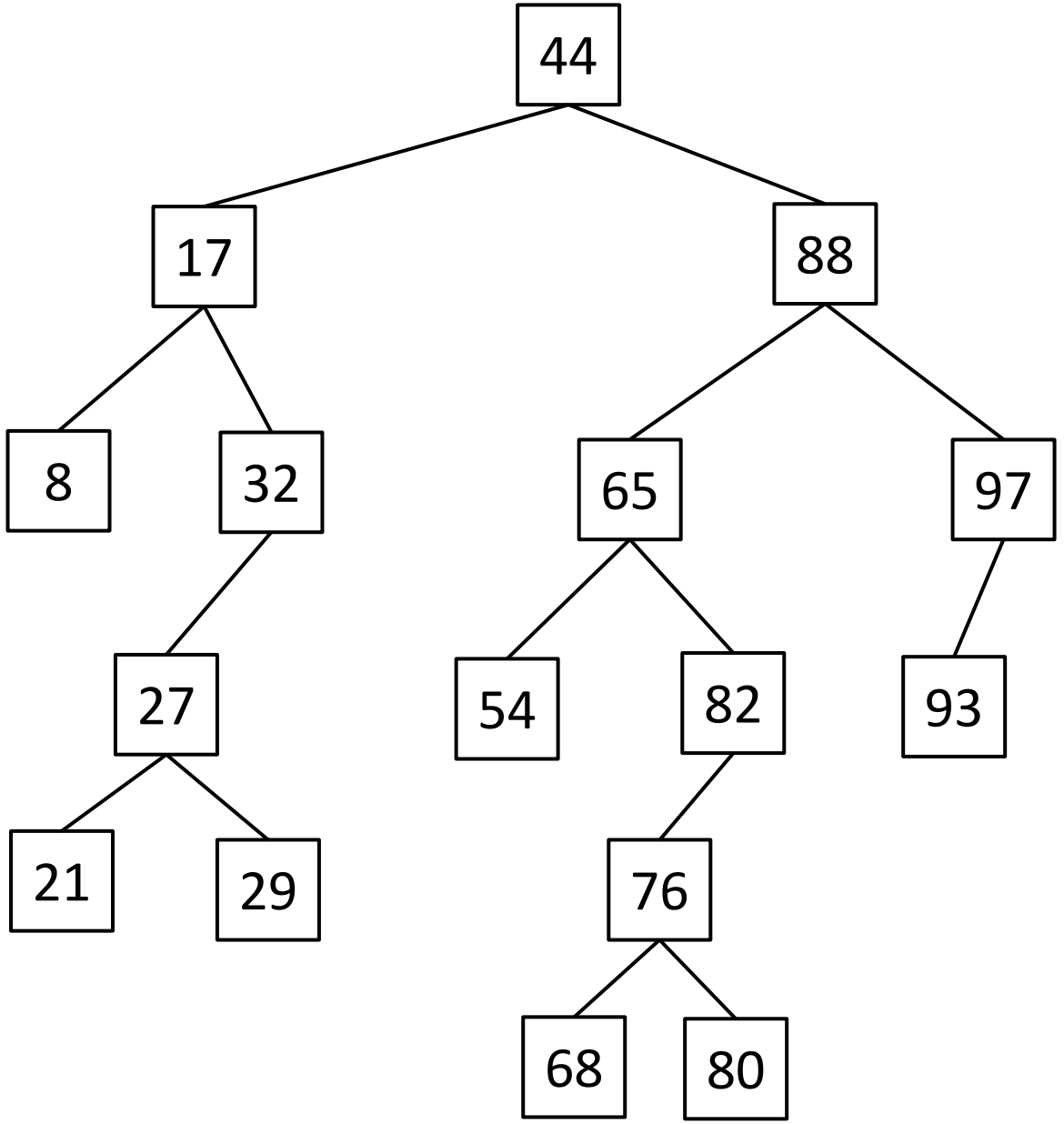
Step 1: Find the node in the tree



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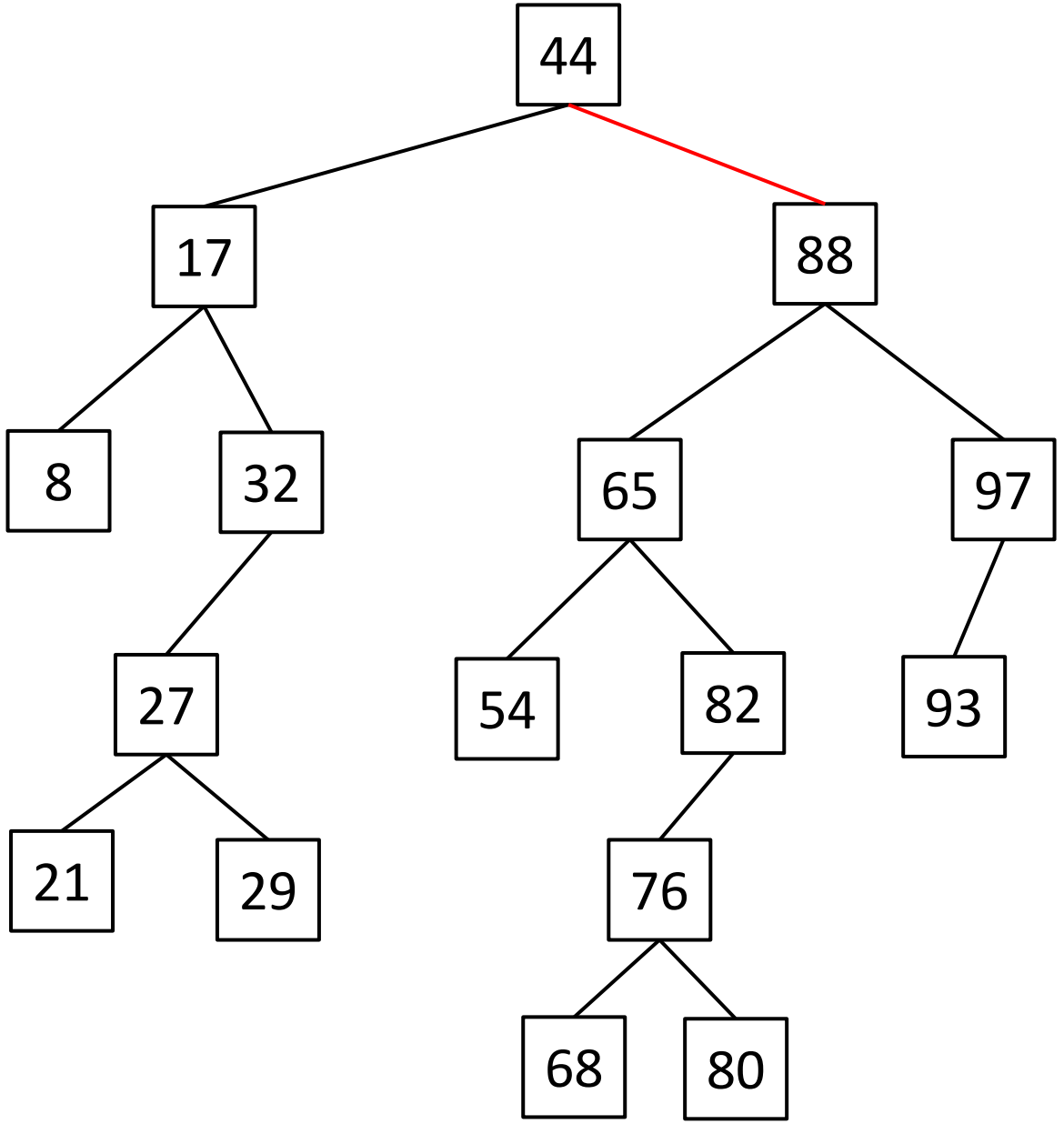

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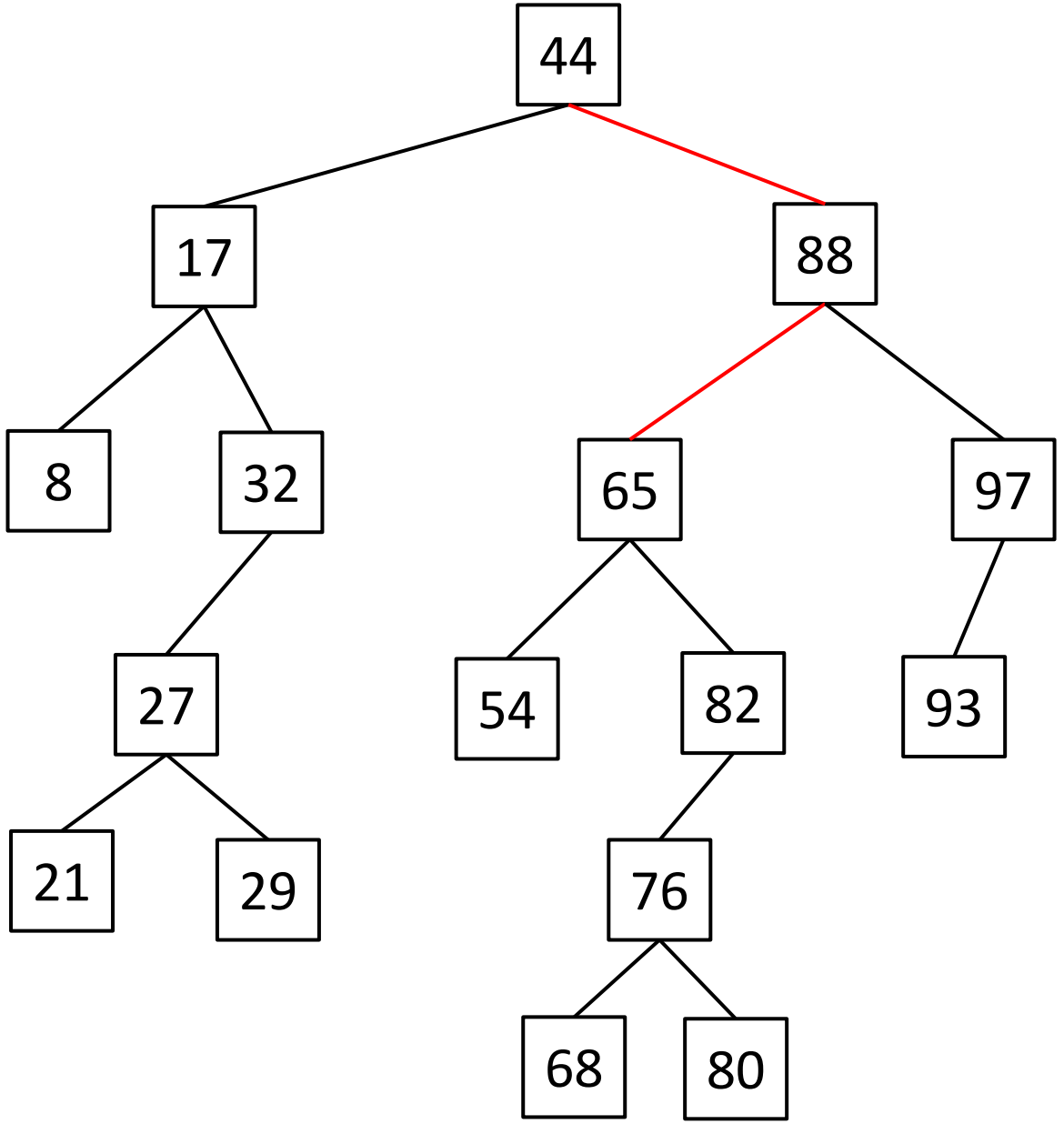

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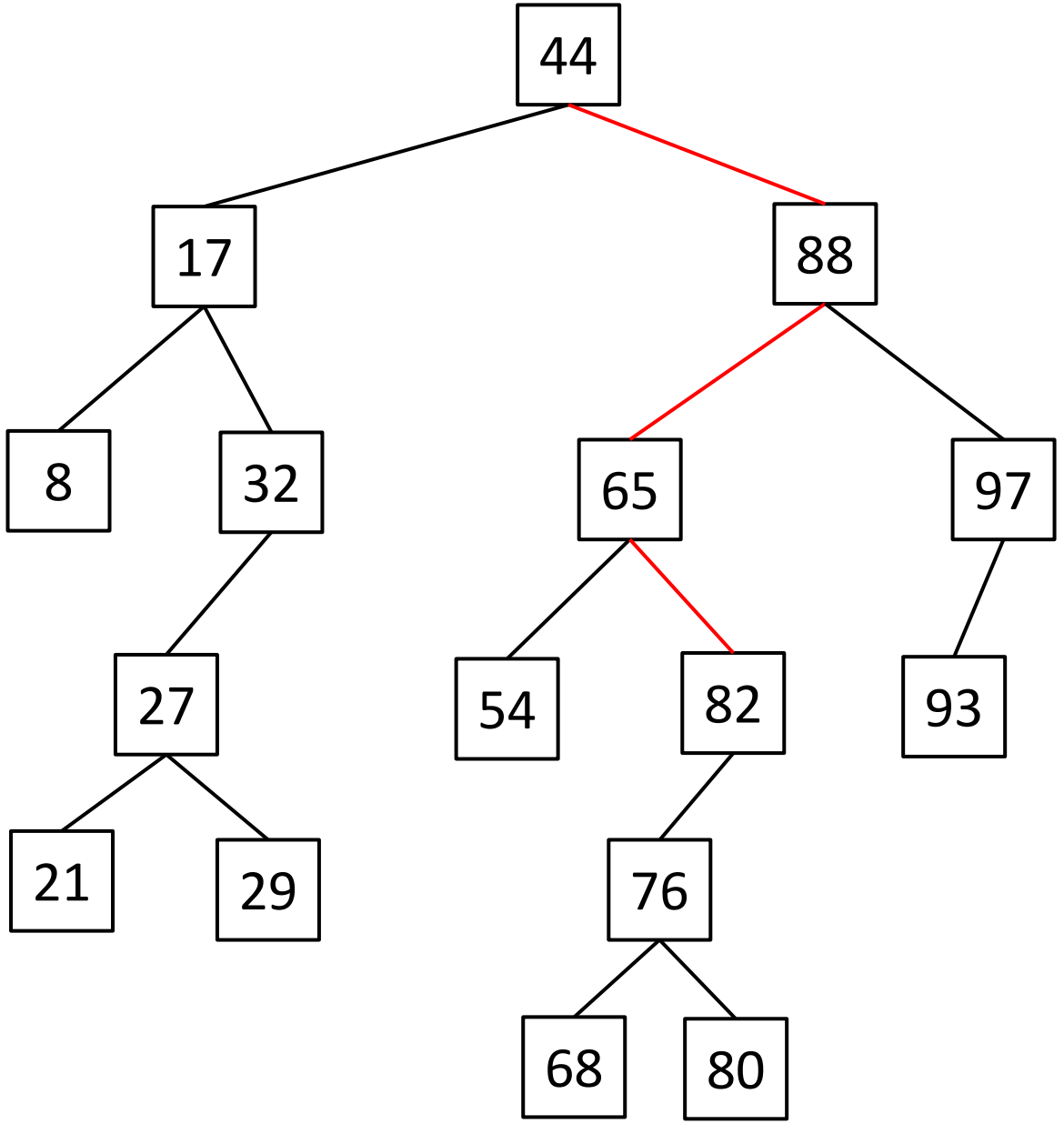

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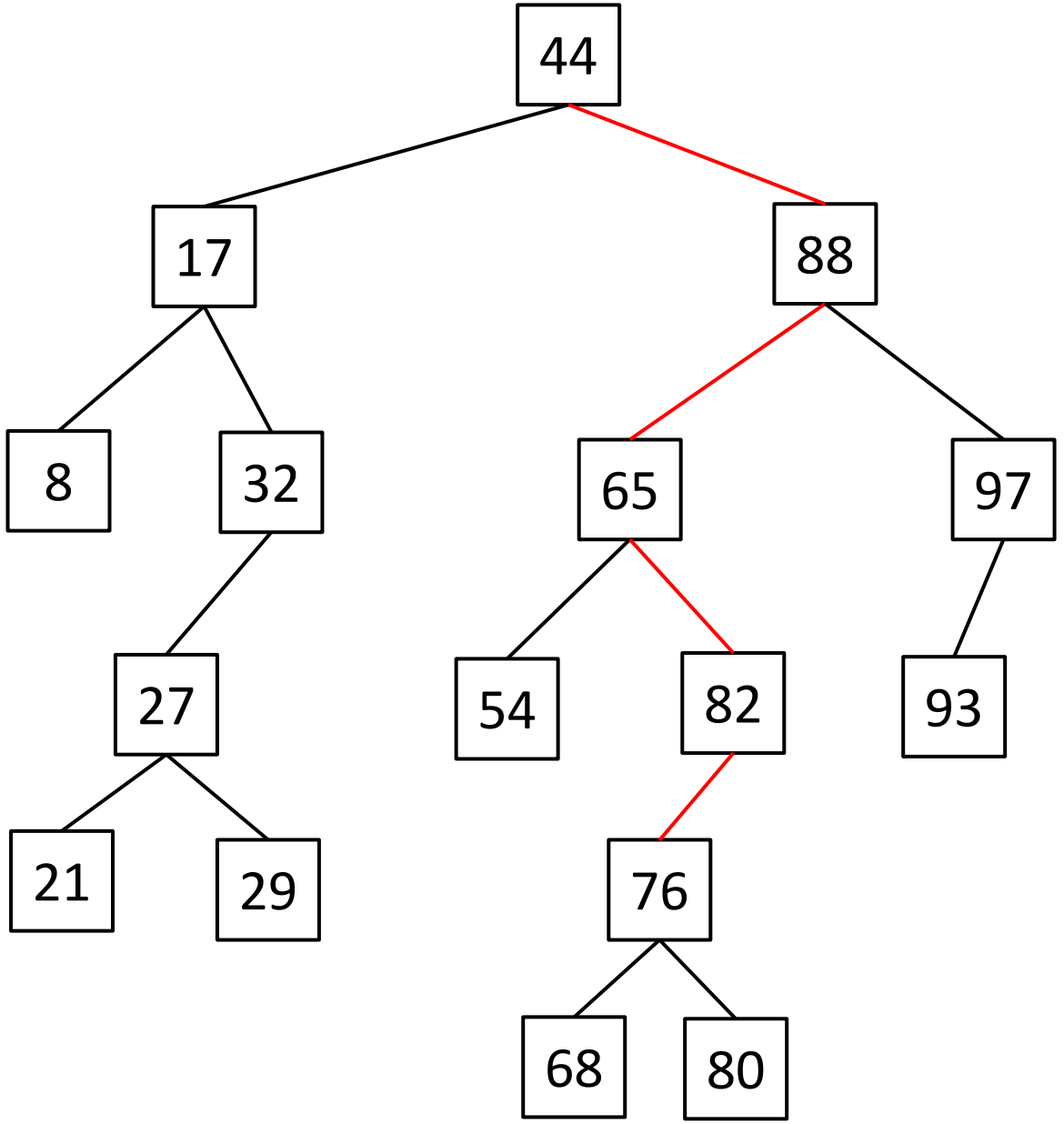

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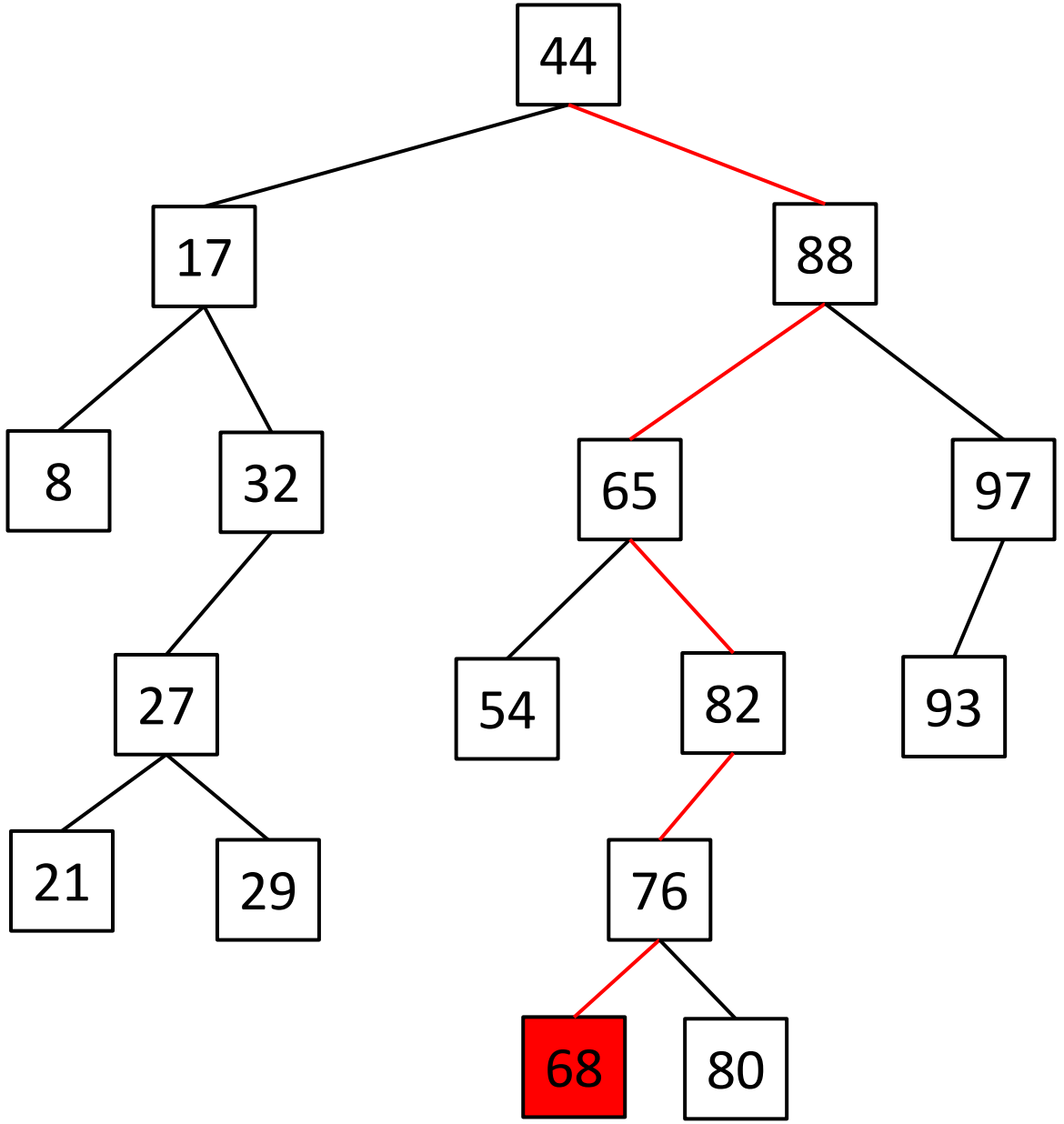

Binary Search Tree- Removal

```
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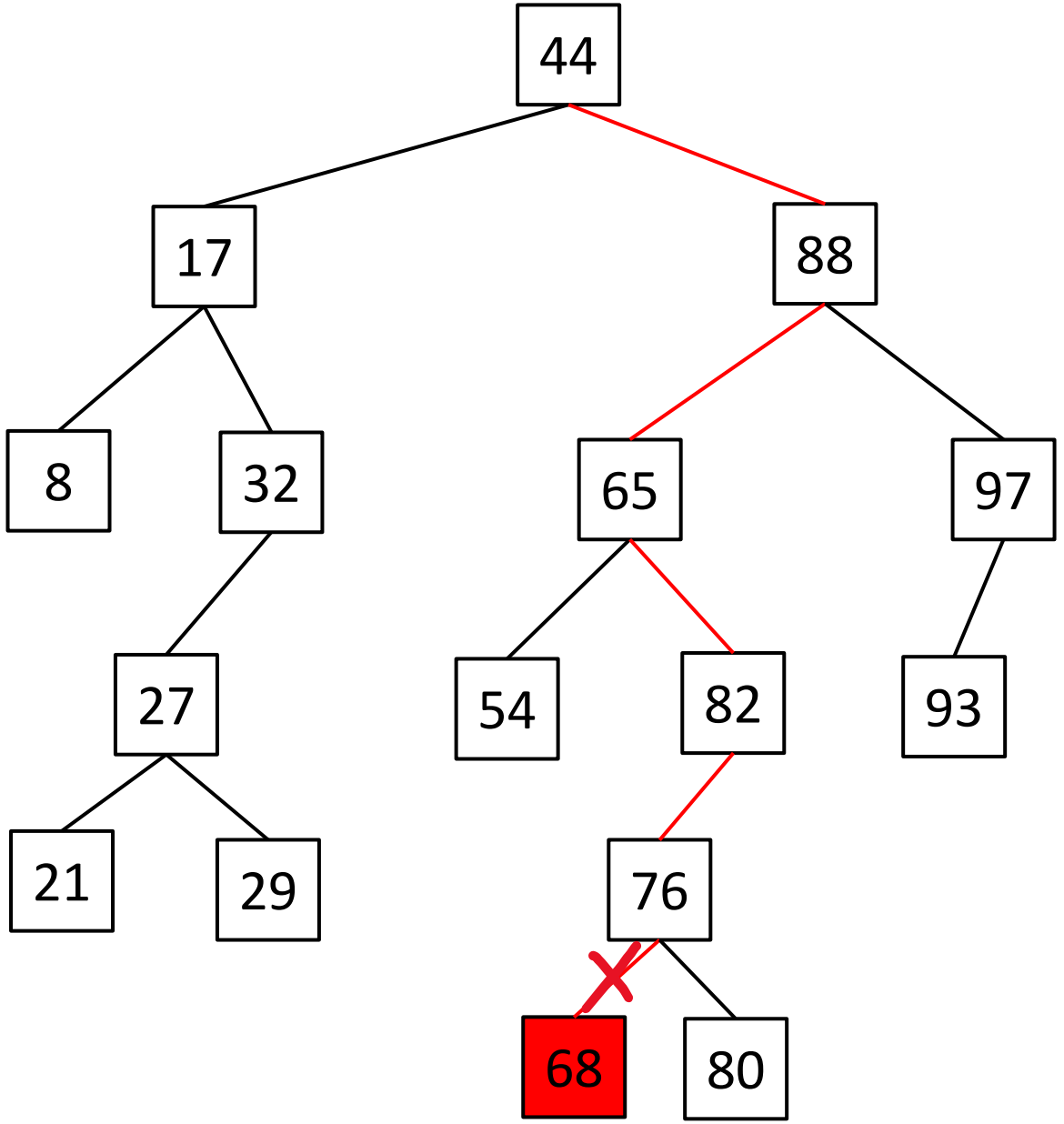
Step 1: Find the node in the tree
Step 2: Change parent to point to `null`



Binary Search Tree- Removal

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Step 1: Find the node in the tree
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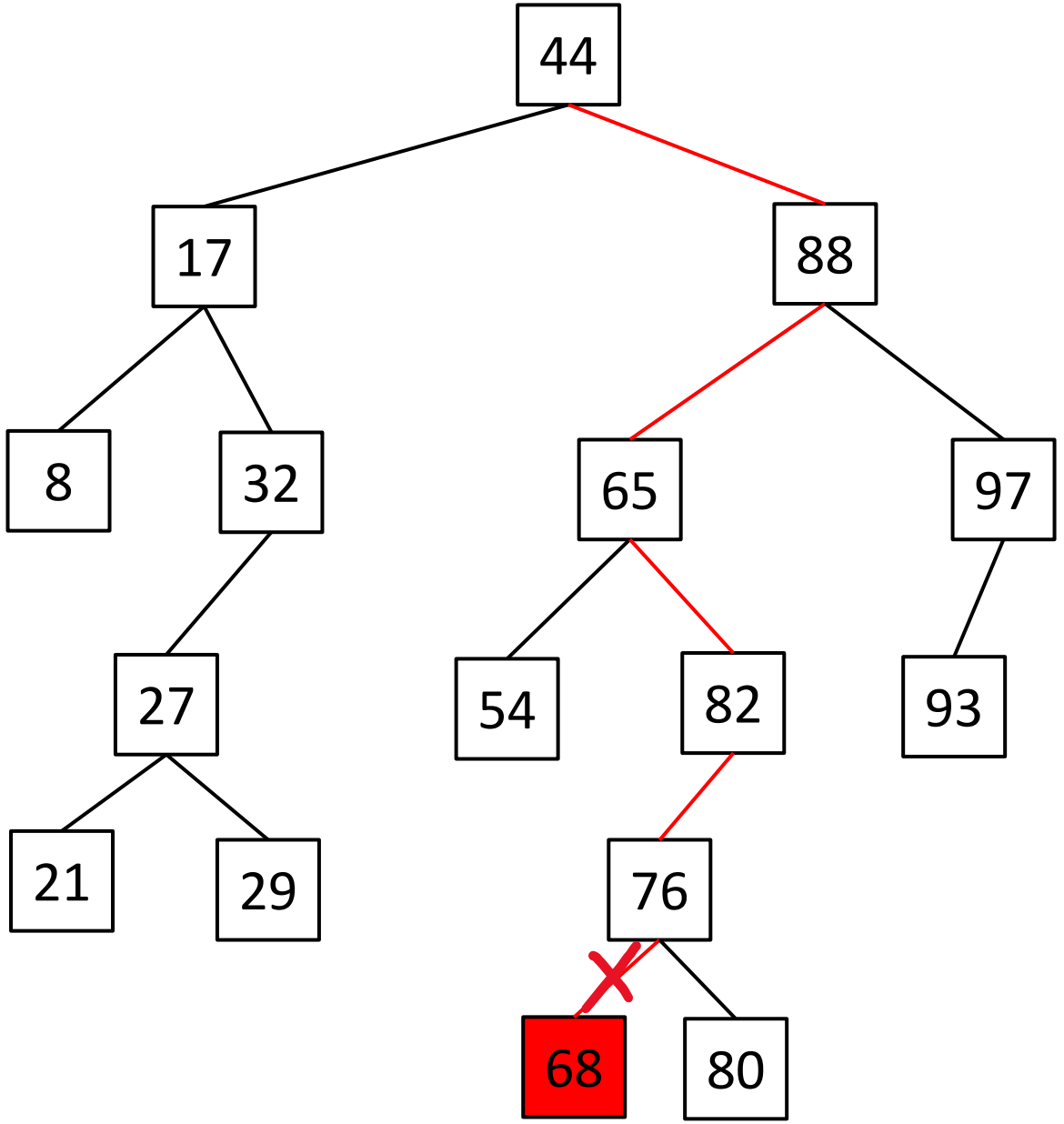
Does this always work?

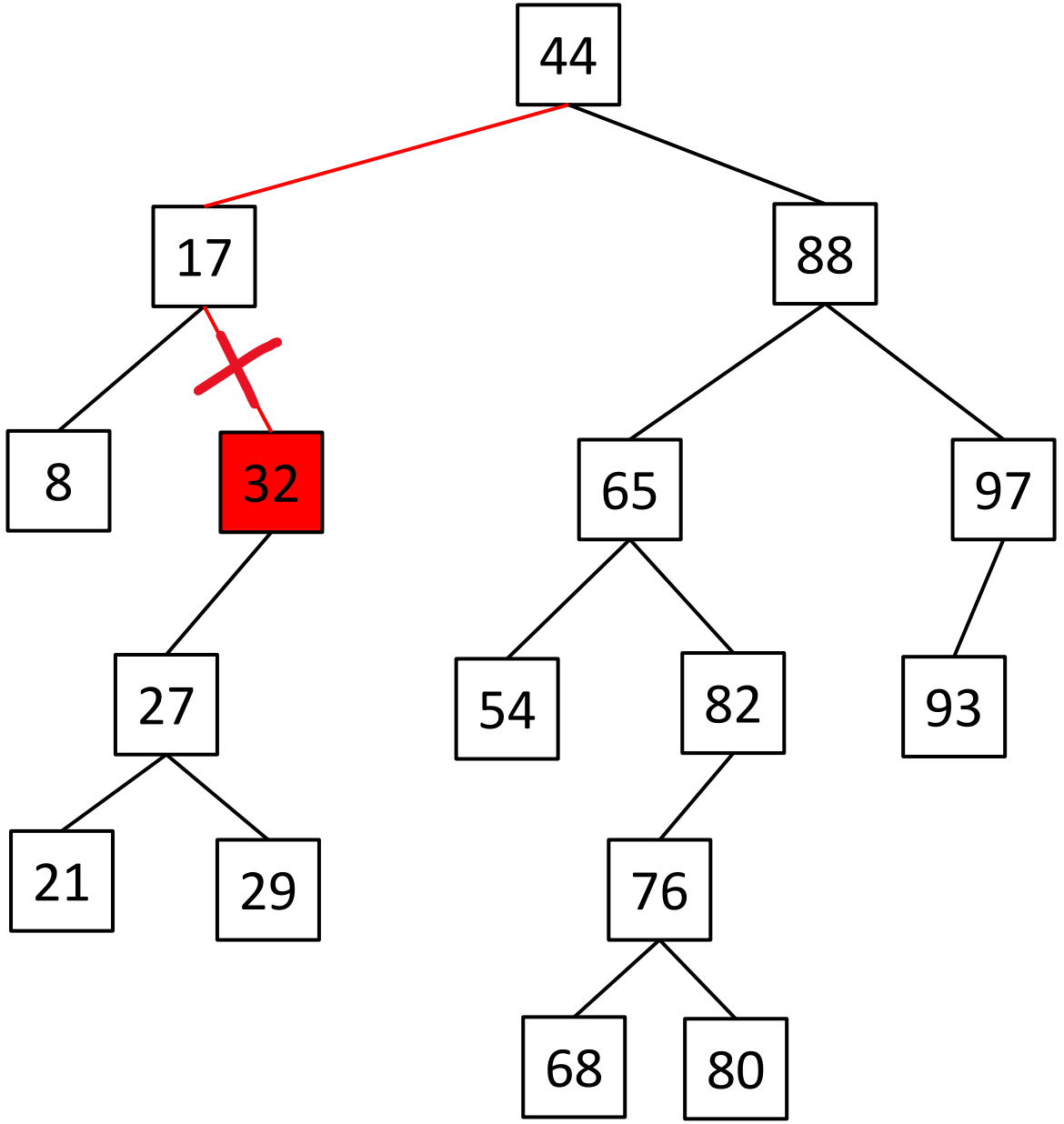


Binary Search Tree- Removal

```
remove(32);
```

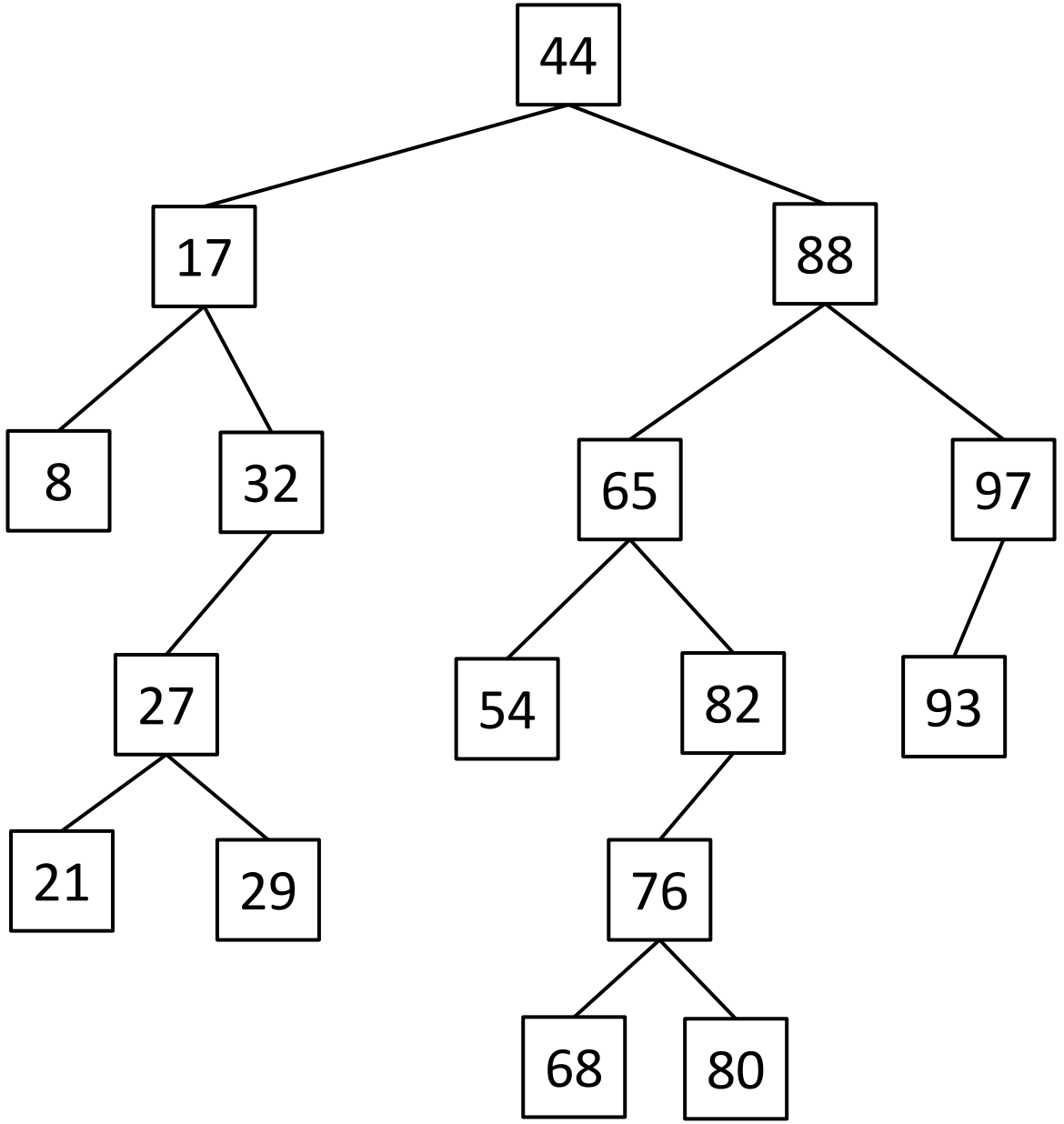
Step 1: Find the node in the tree
Step 2: Change parent to point to `null`

This does not always work



Binary Search Tree- Removal

Case 1: Node has no children
Case 2: Node has one child
Case 3: Node has two children

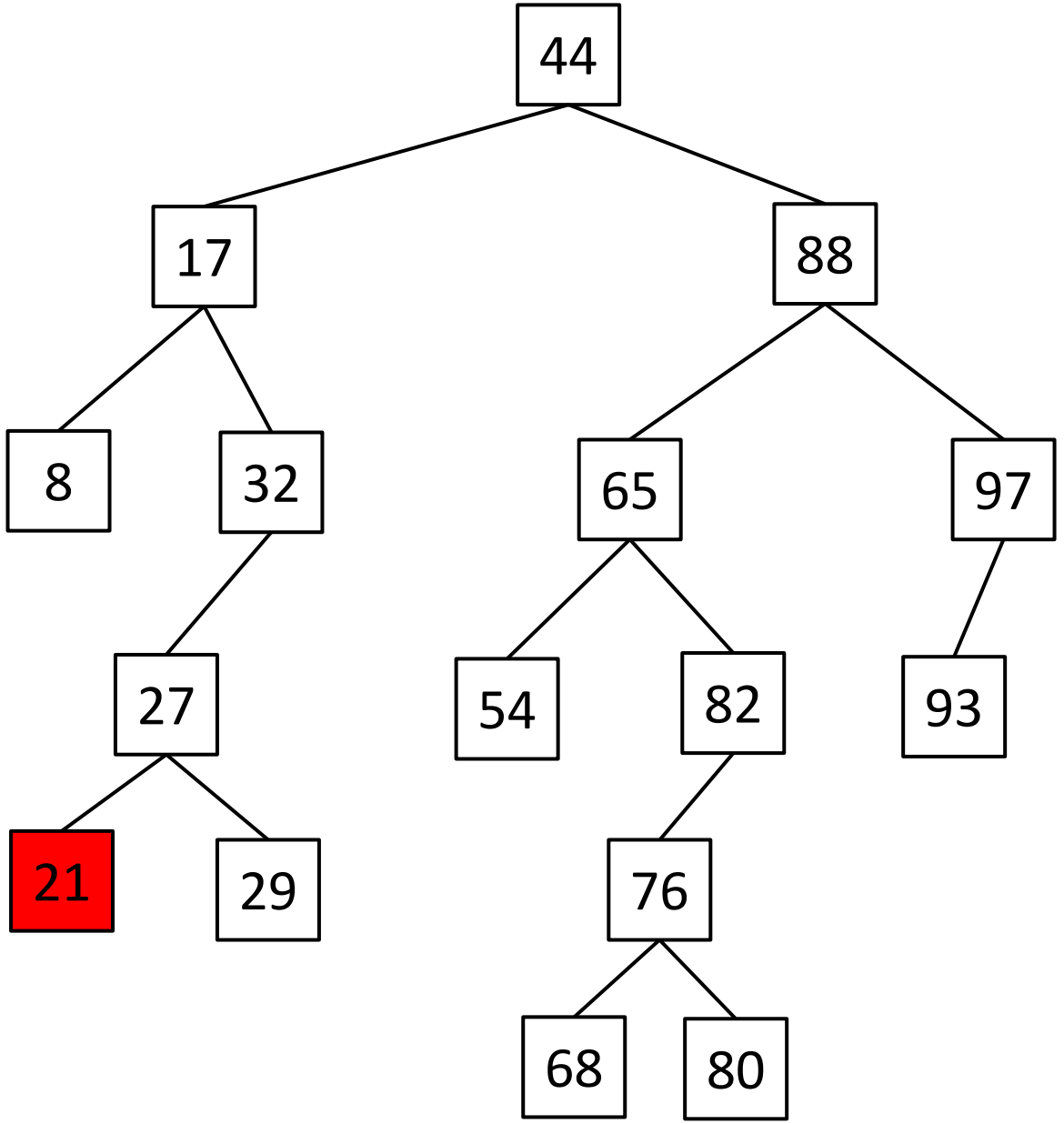


Binary Search Tree- Removal

Case 1: Node has no children
Case 2: Node has one child
Case 3: Node has two children

```
remove(21);
```

How do we know it has no children?



Binary Search Tree- Removal

Case 1: Node has no children
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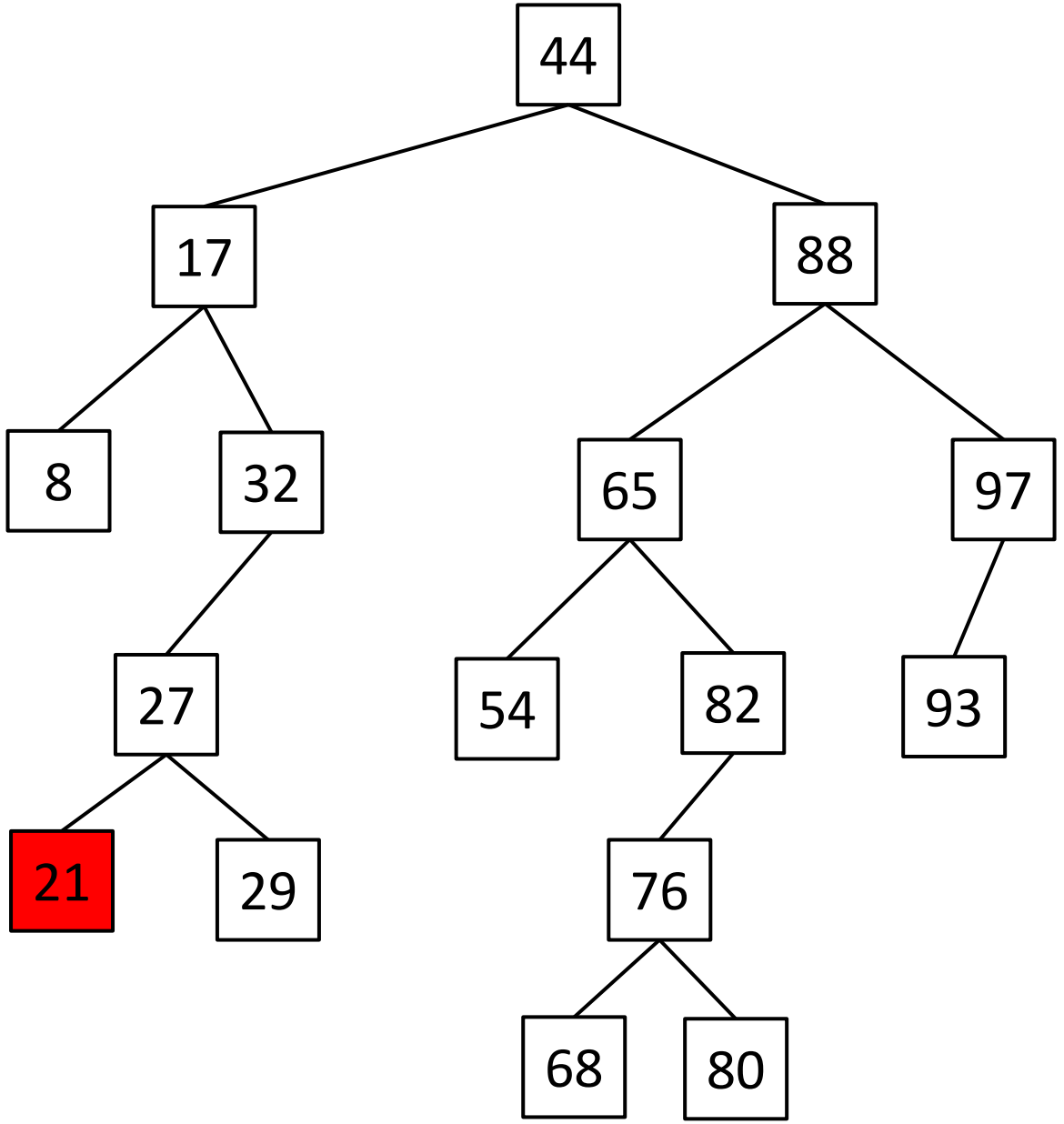
How do we know it has no children?
If its left and right child are both null



Binary Search Tree- Removal

Case 1: Node has no children
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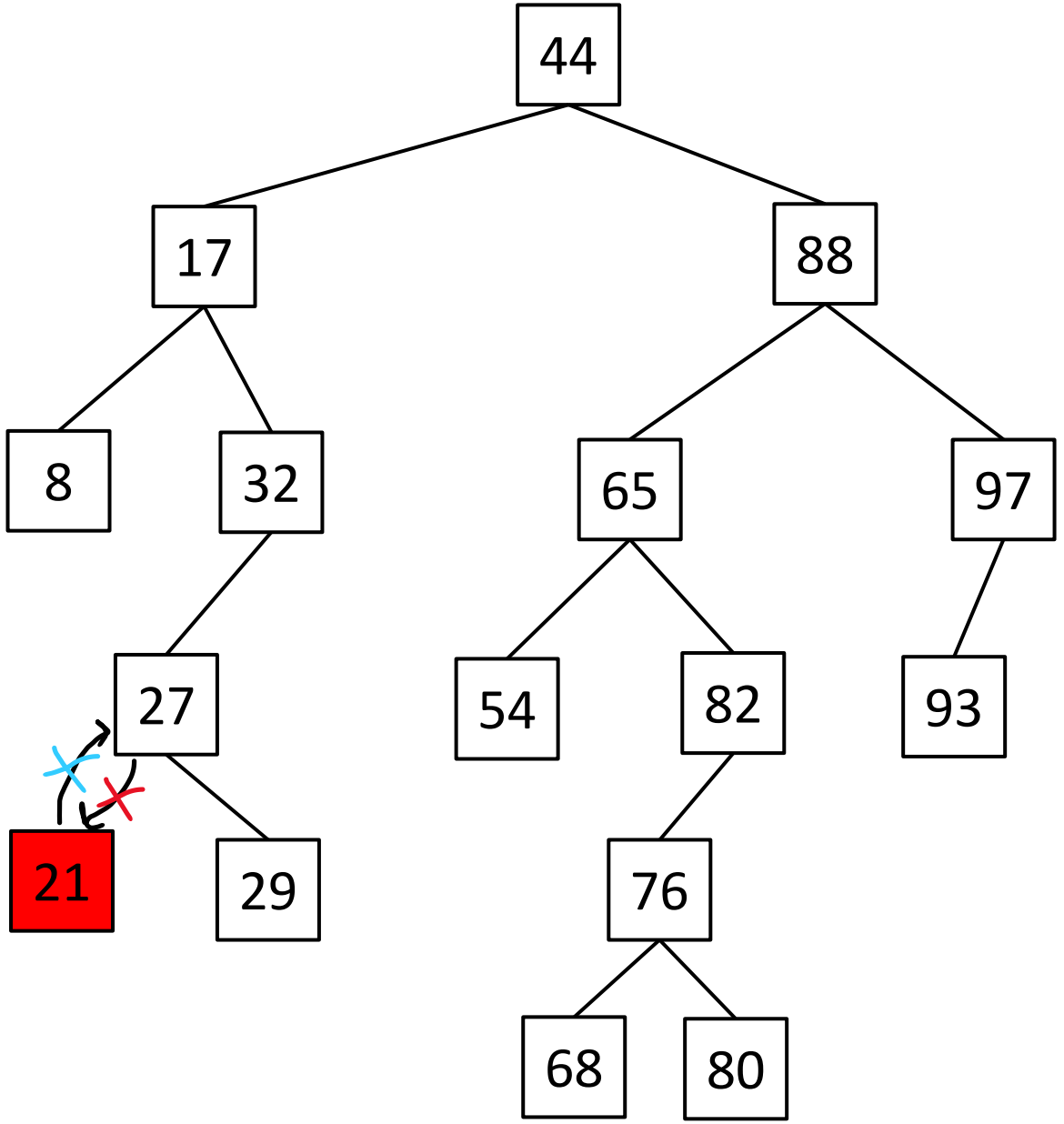
```

1. Update parent's **`child`** to point to **`null`**
2. Update Node's **`parent`** to point to **`null`**



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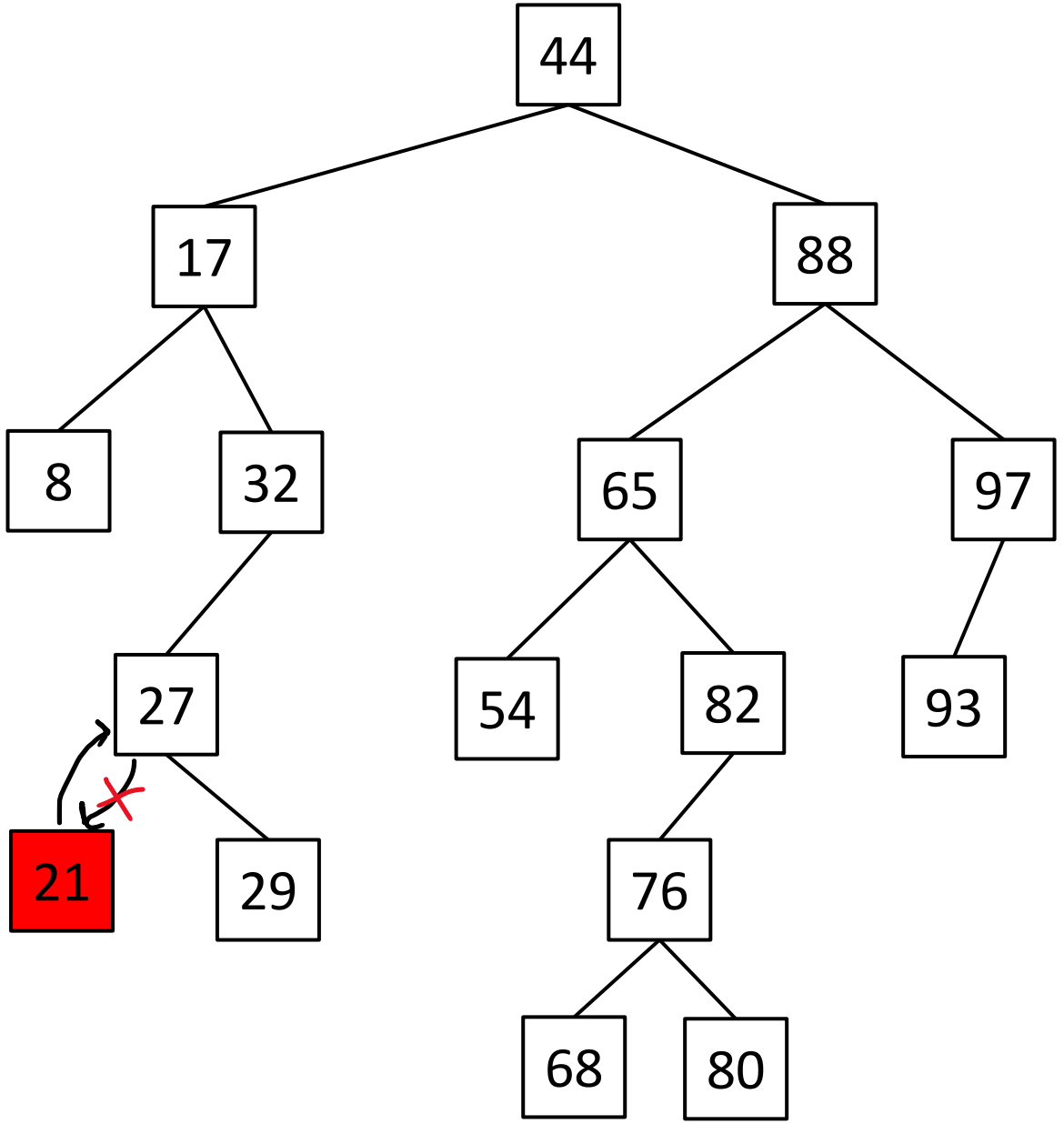

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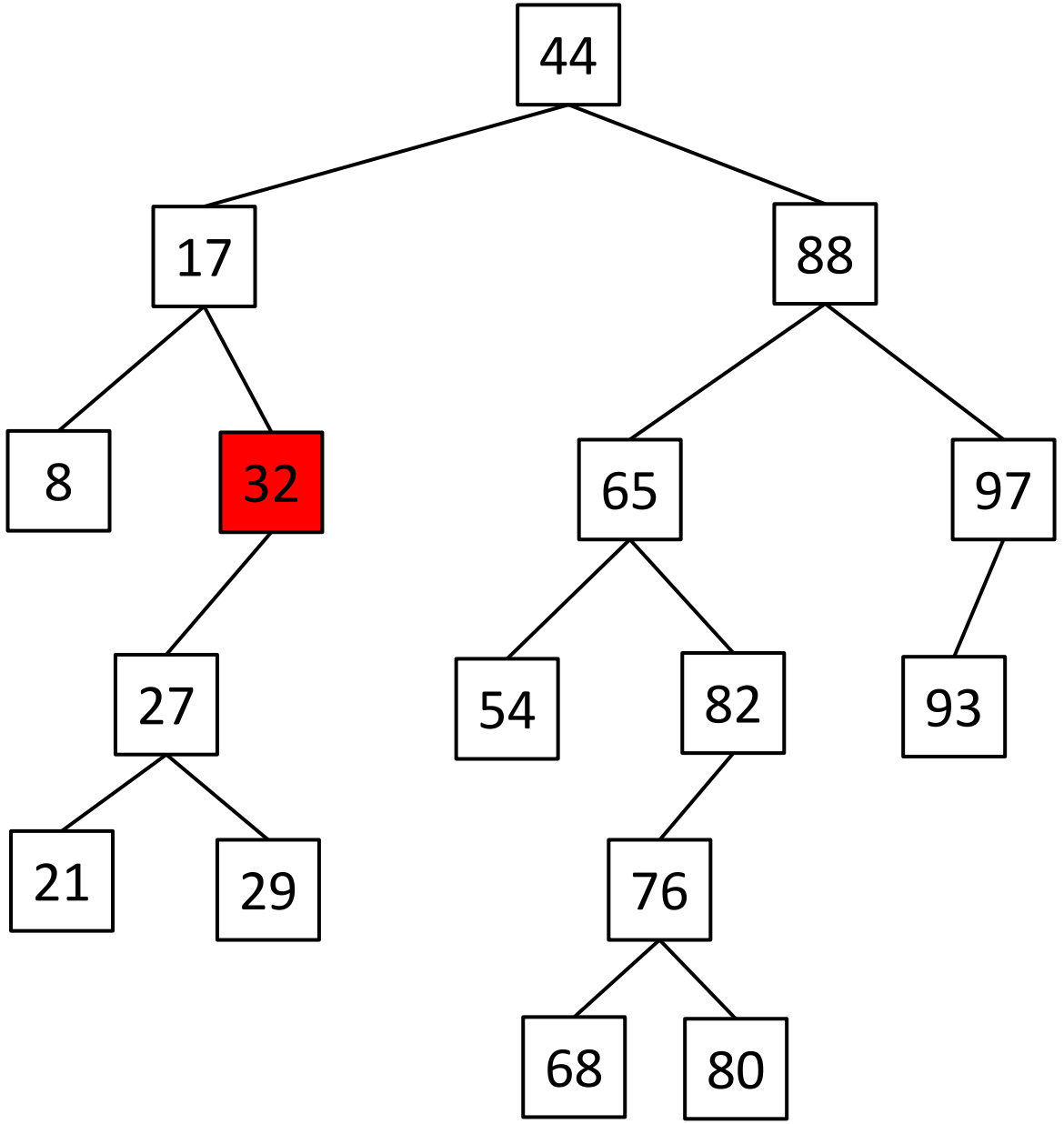

Binary Search Tree- Removal

Case 1: Node has no children
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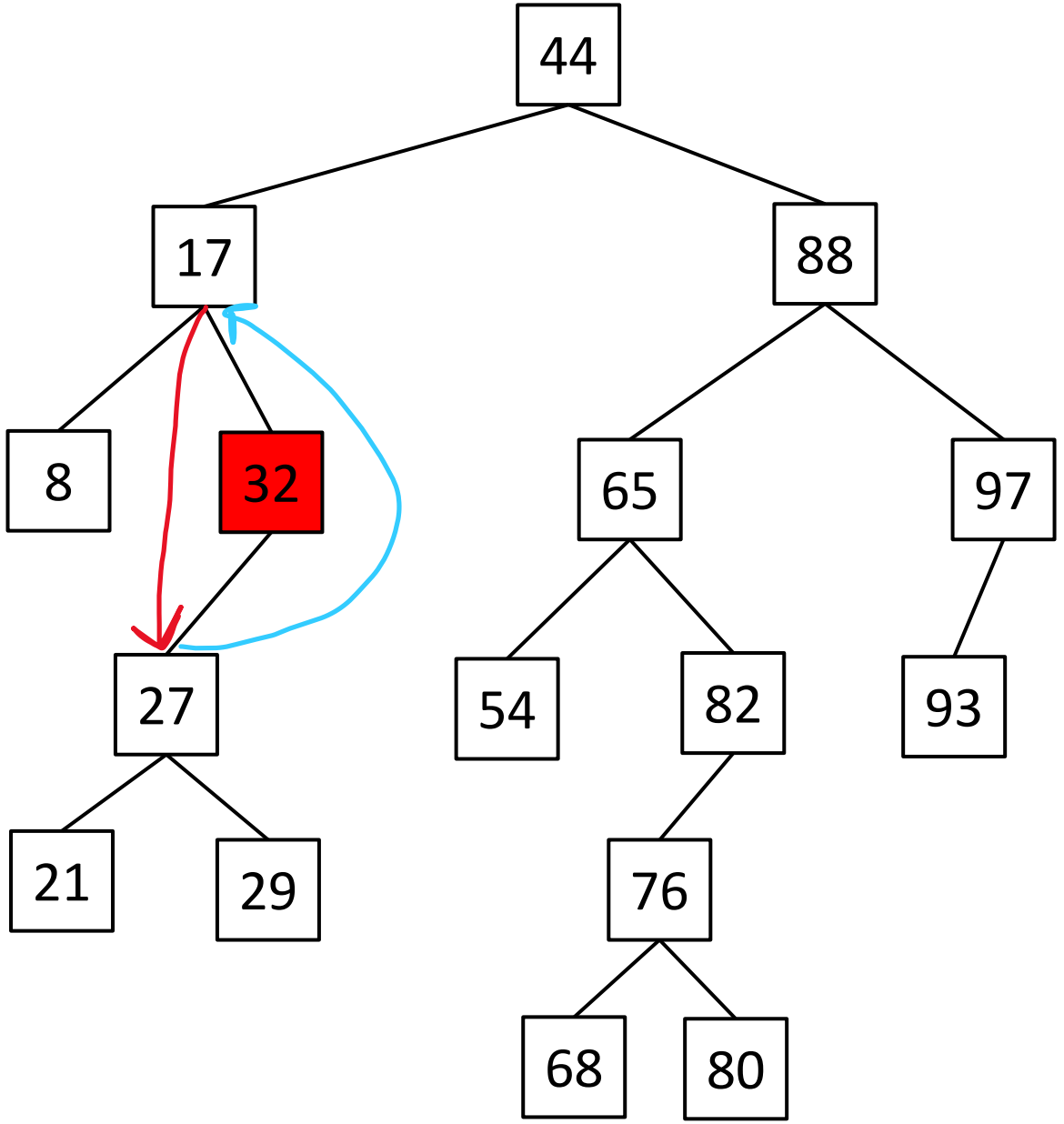
- Change the Node's `parent` to point to the only child
- Update the Node's only child `parent` to point to the Node's Parent



Binary Search Tree- Removal

Case 1: Node has no children
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remove(88);
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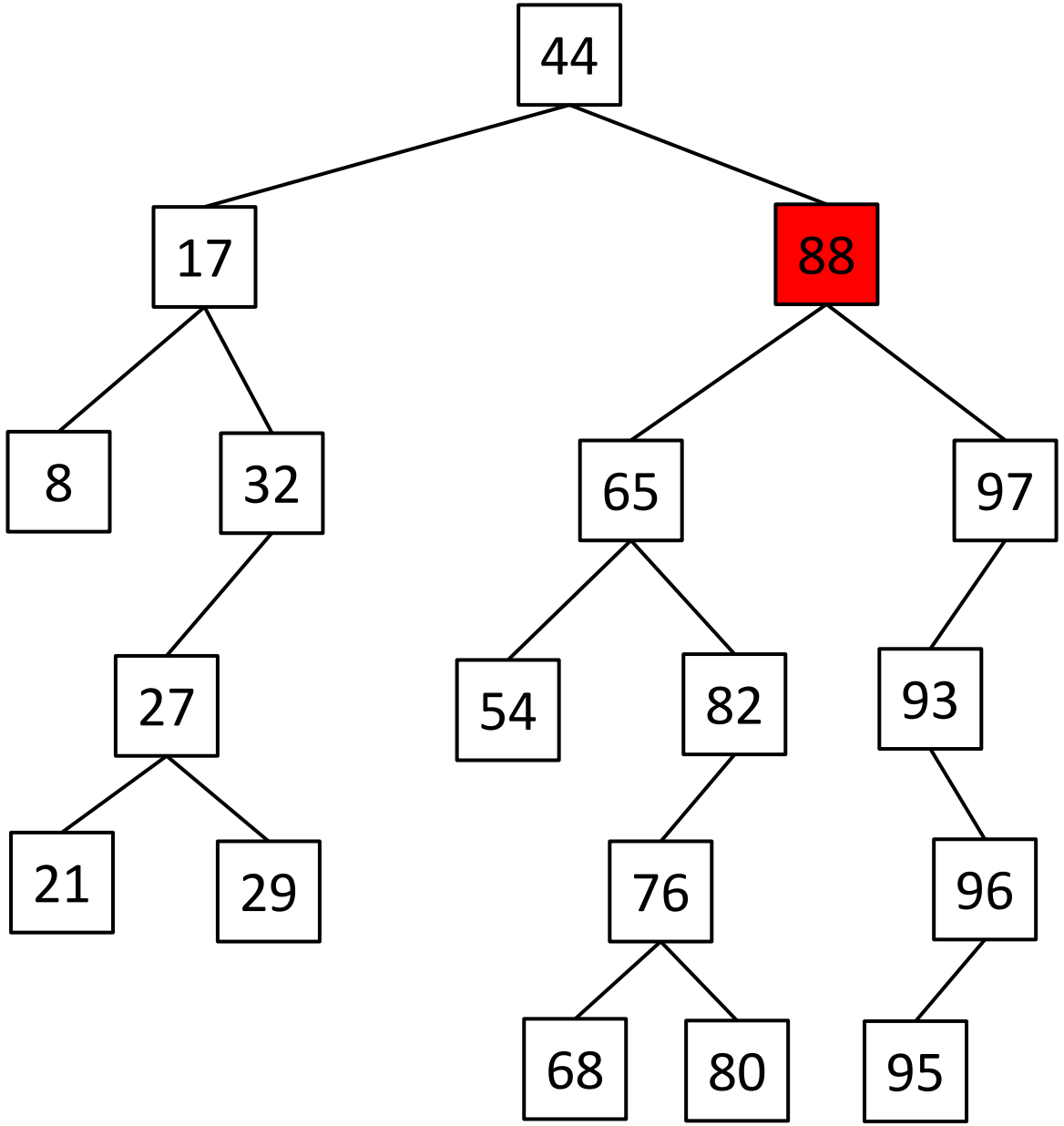

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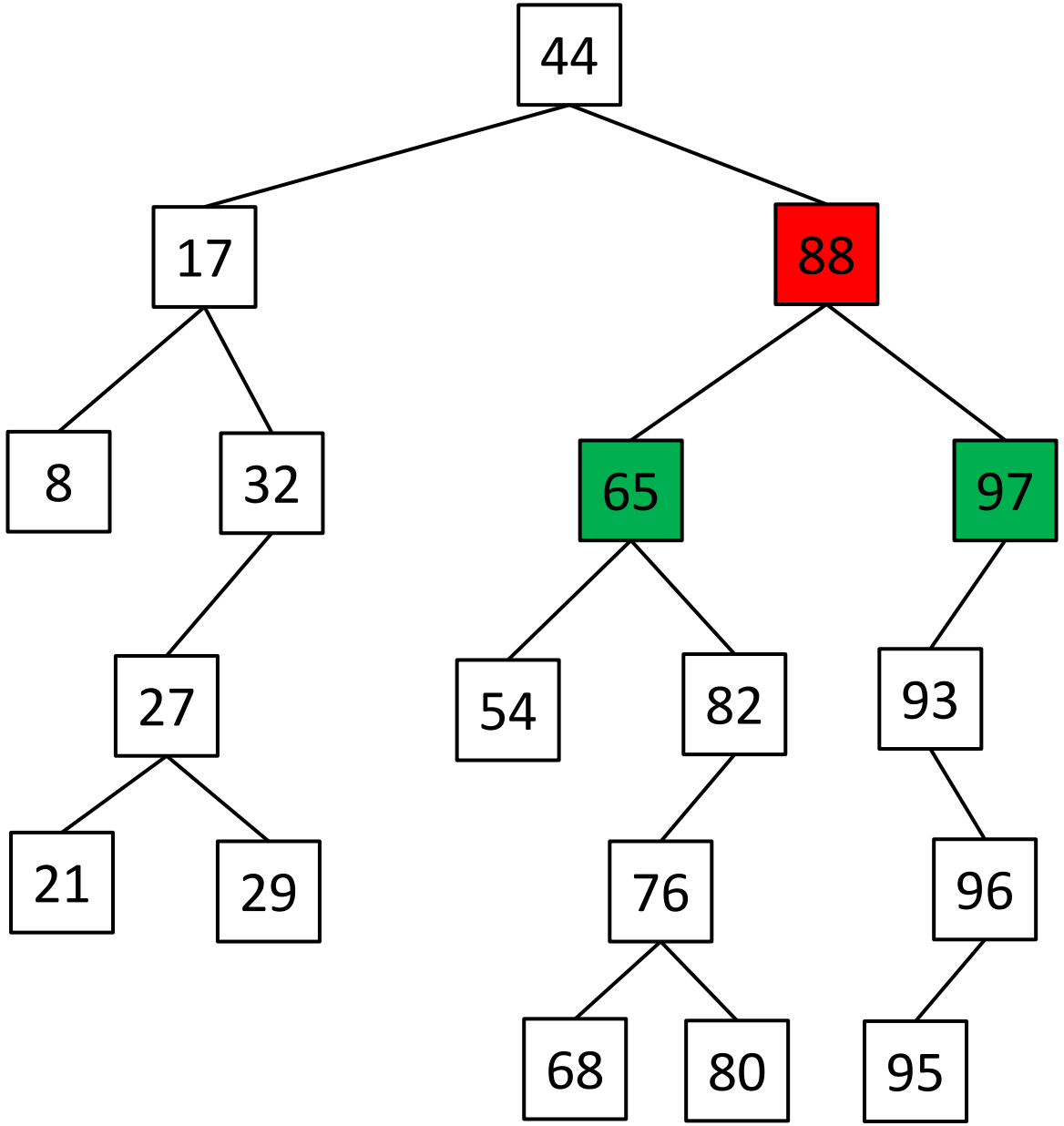
Which child to use?



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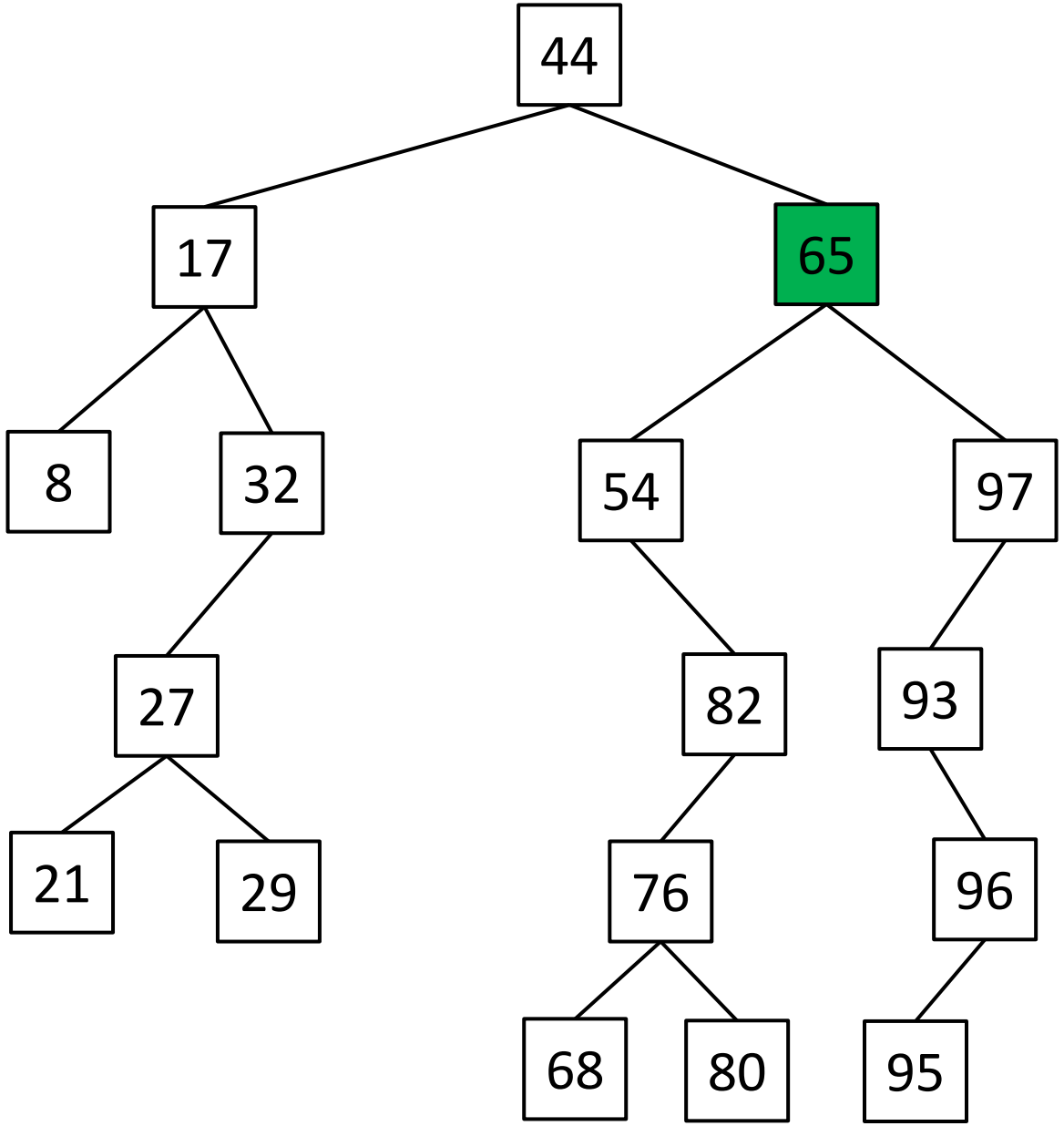

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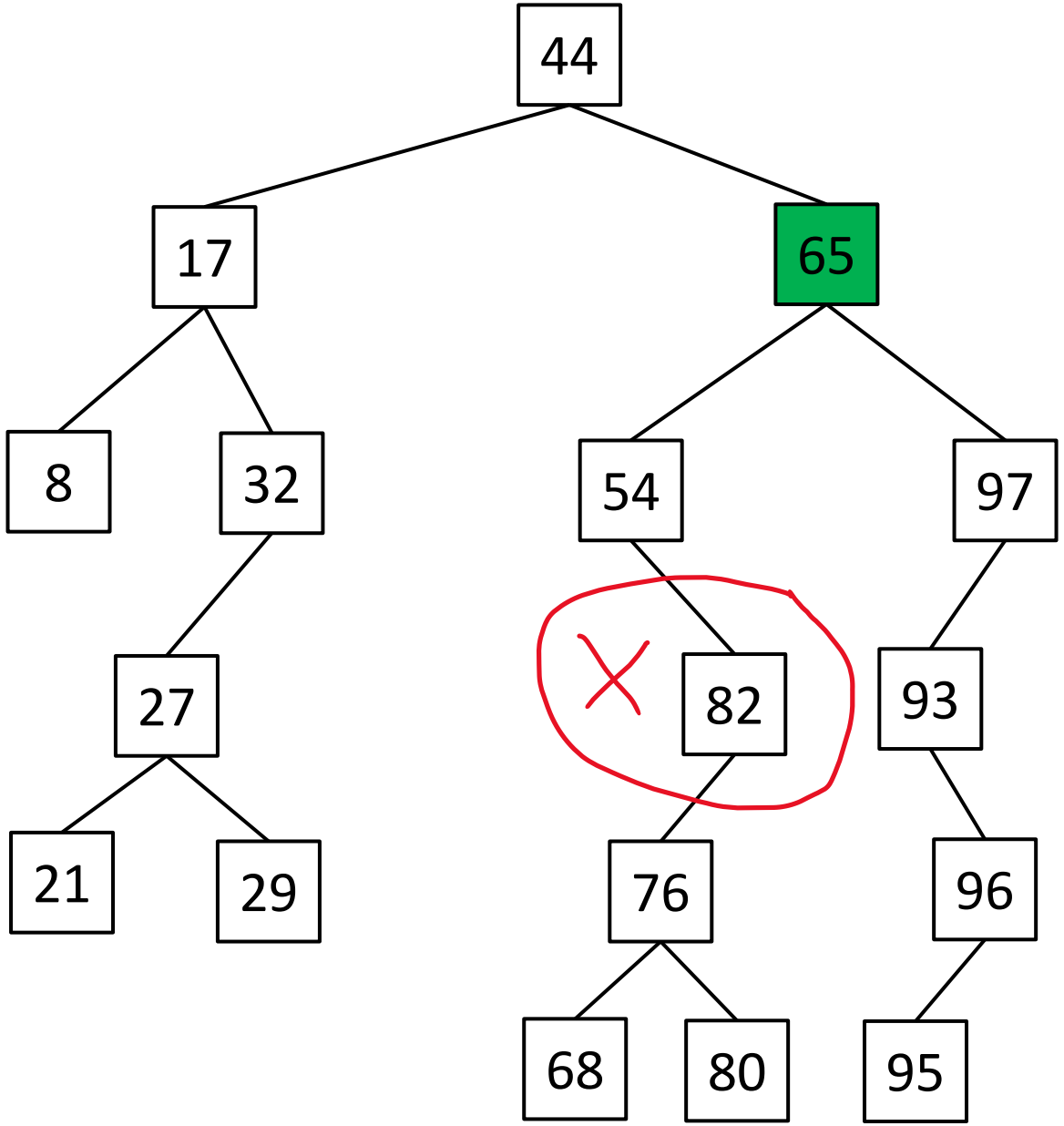

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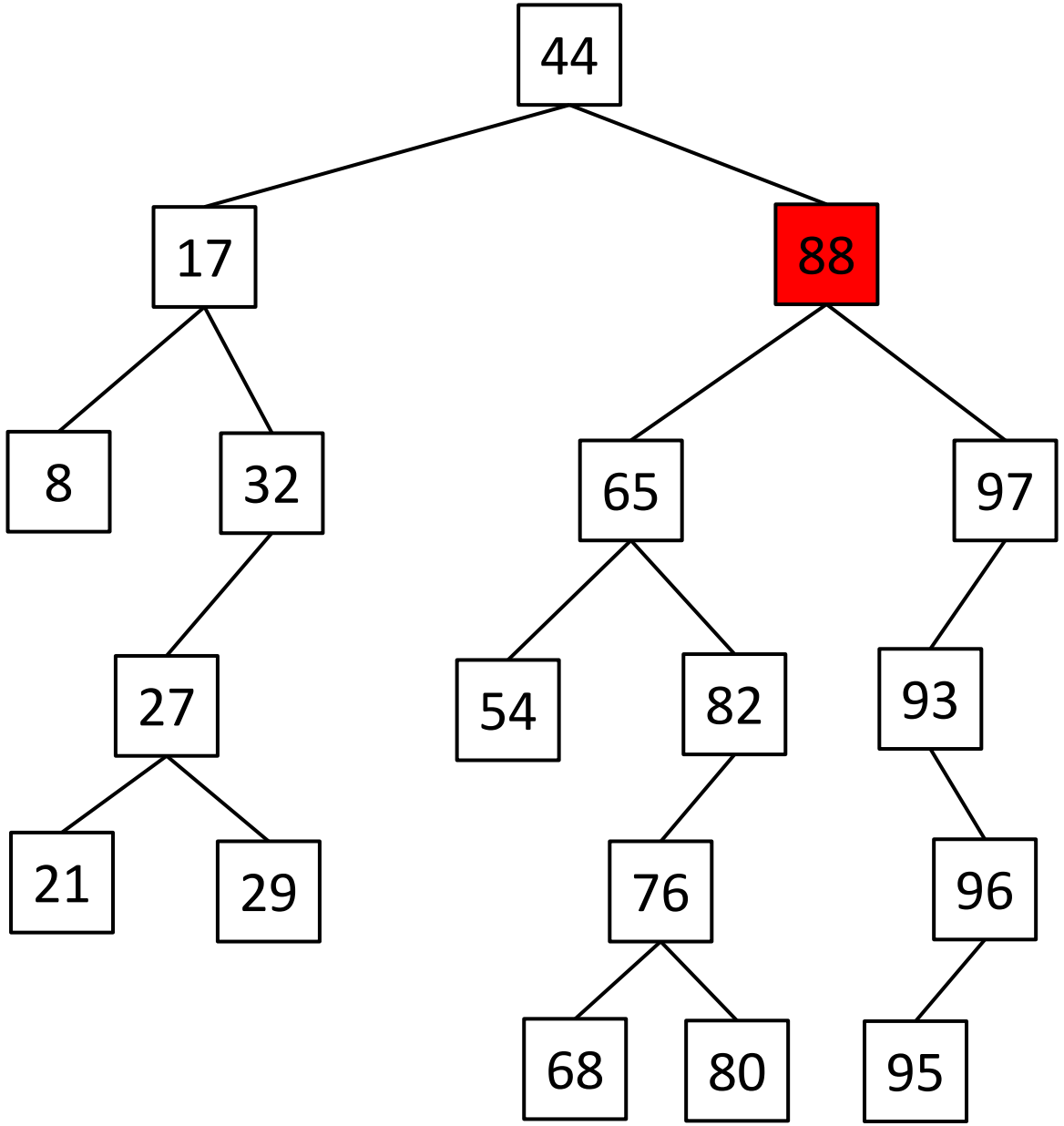

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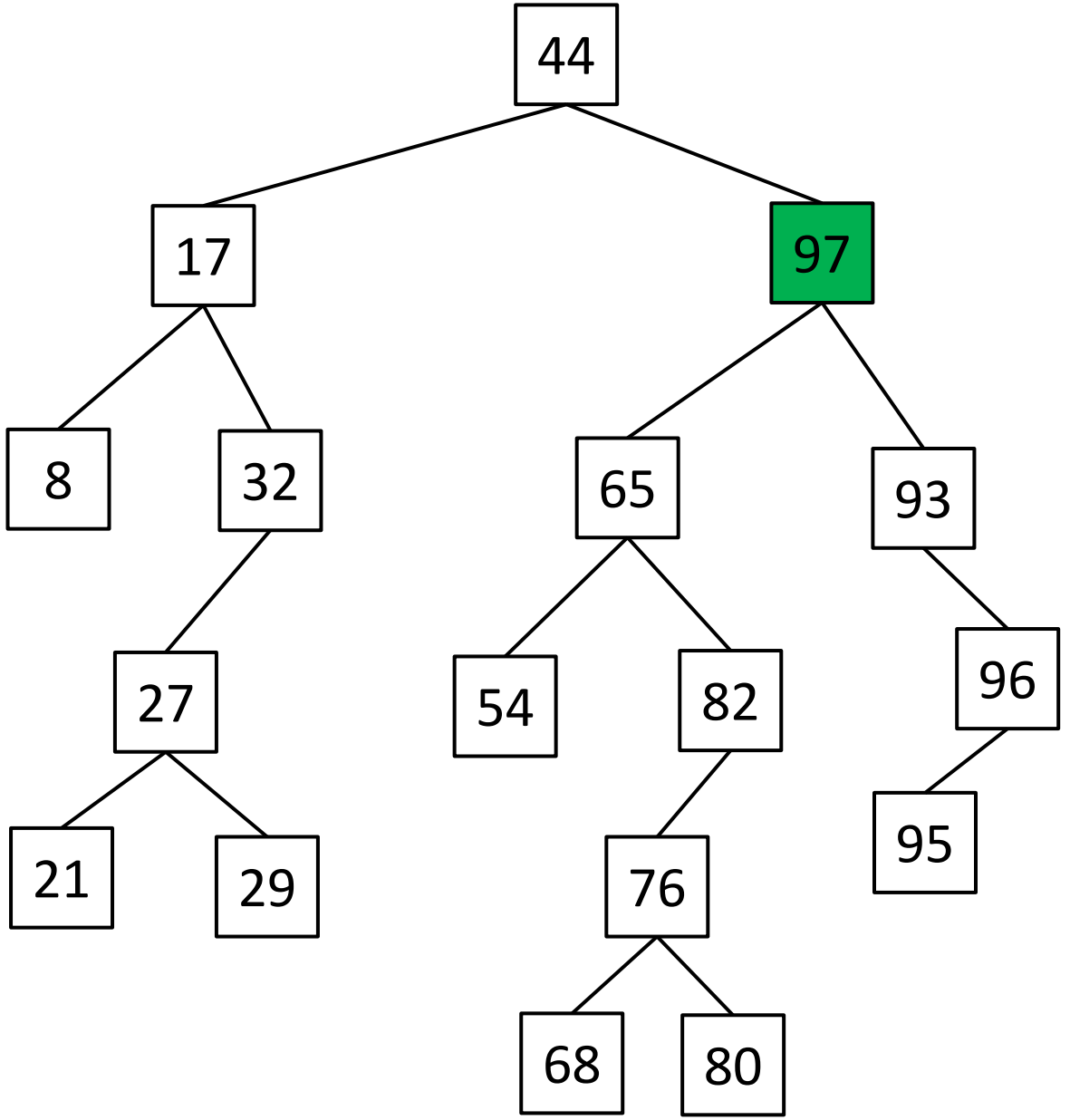
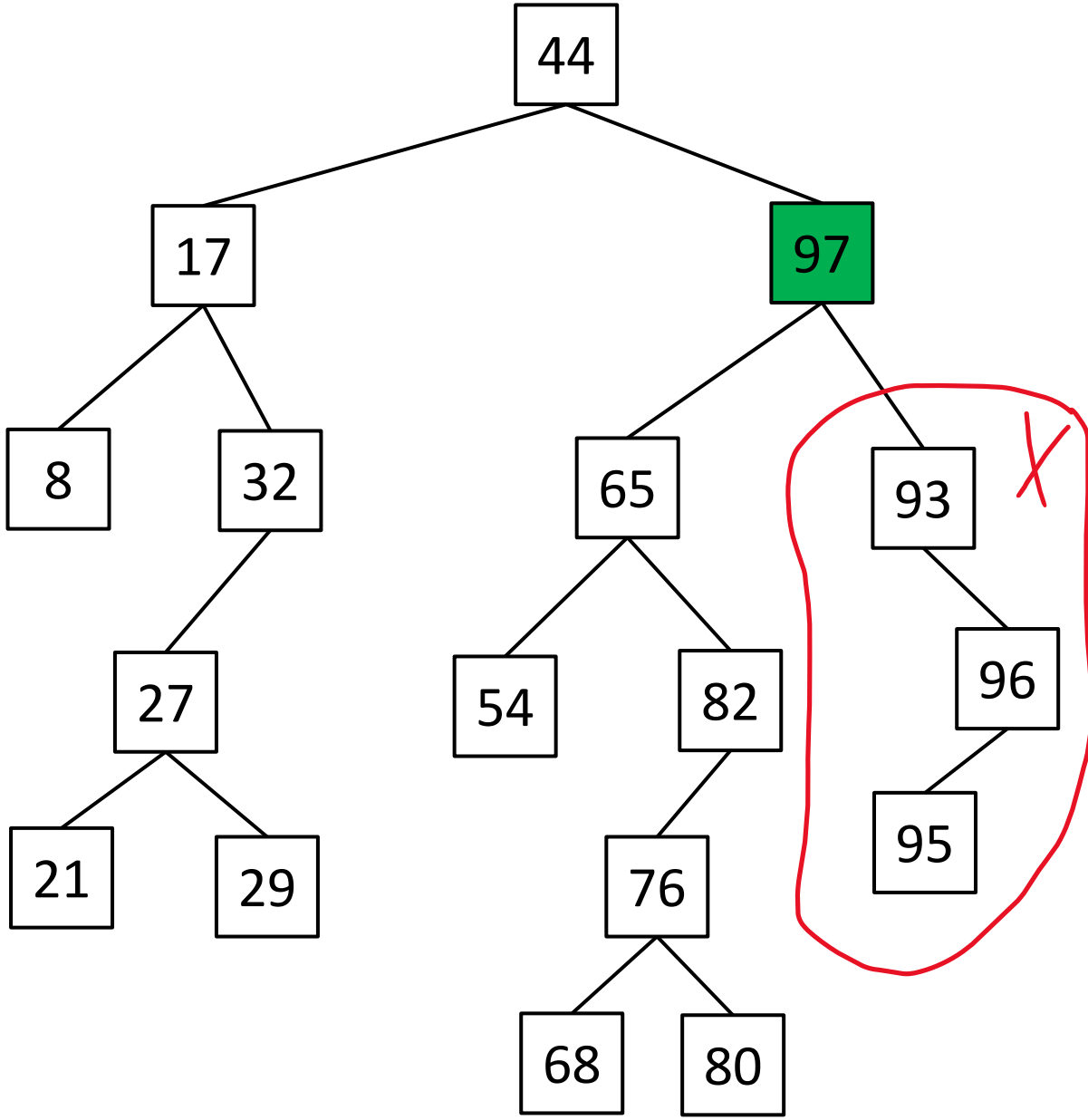


Binary Search Tree- Removal

Case 1: Node has no children
Case 2: Node has one child
Case 3: Node has two children

```
remove(88);
```



Binary Search Tree- Removal

Case 1: Node has no children
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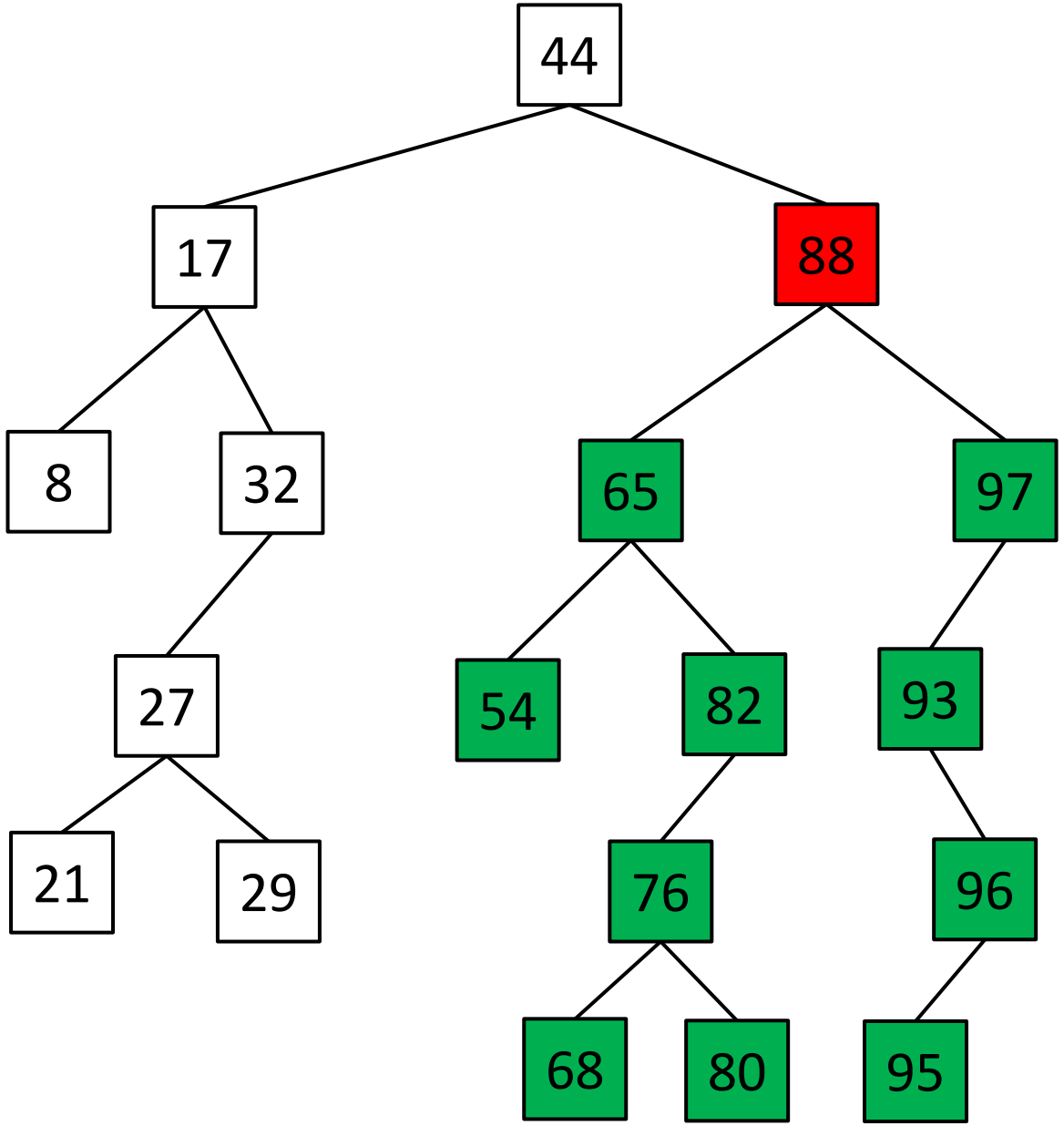
Case 3: Node has two children

```
remove(88);
```

Which ~~child~~ **descendant** to use?



Binary Search Tree- Removal

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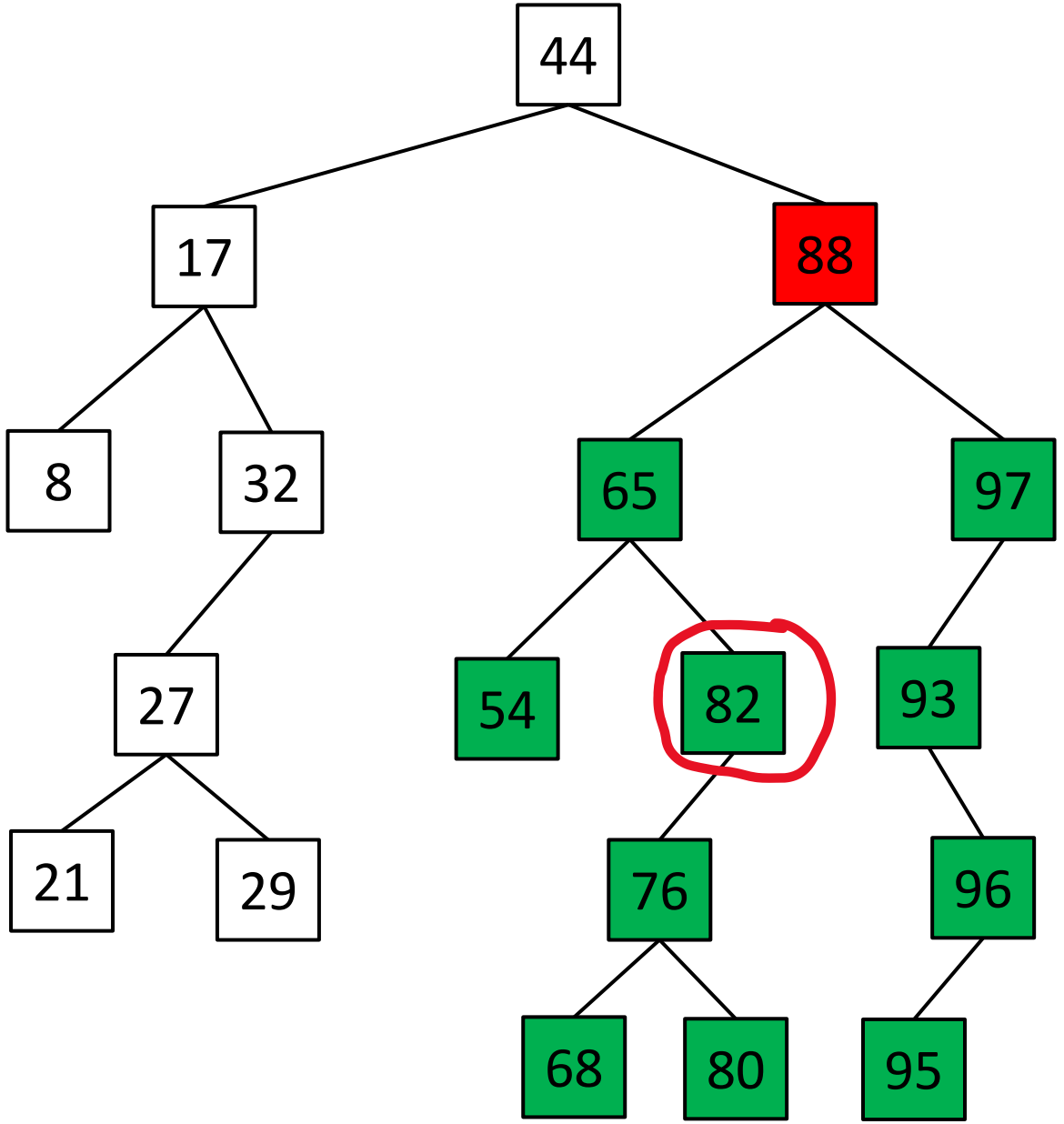

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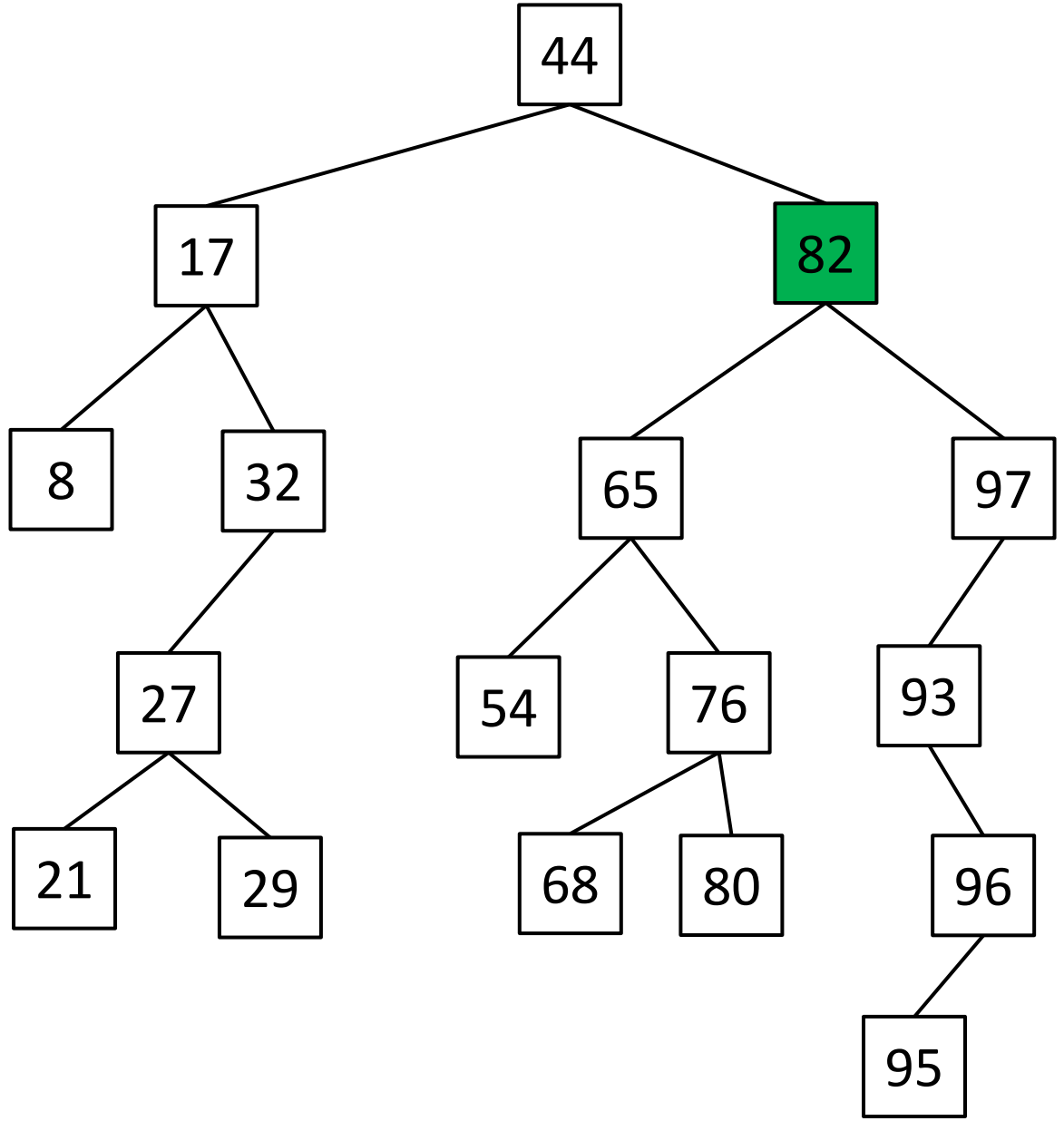

Binary Search Tree- Removal

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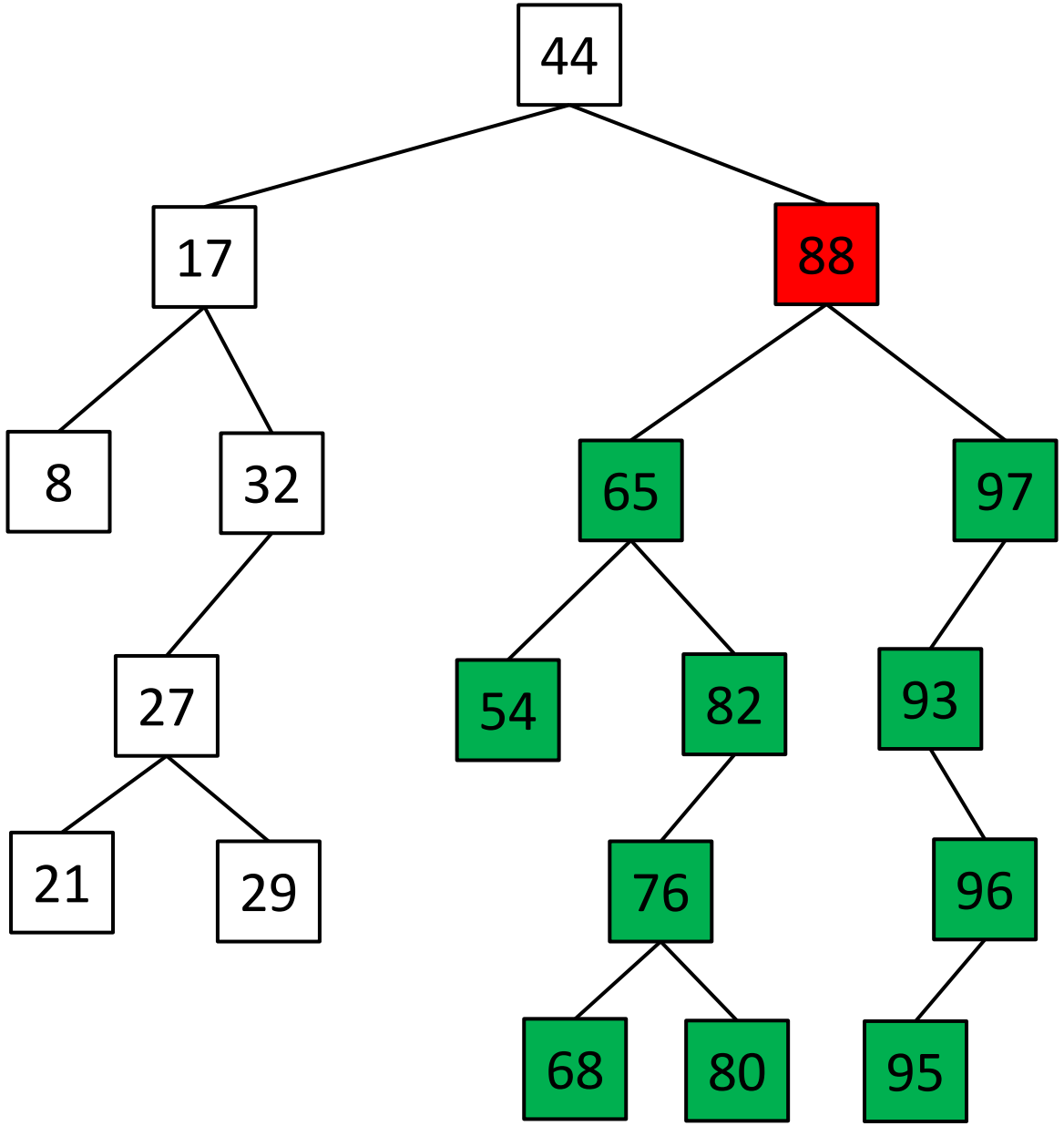

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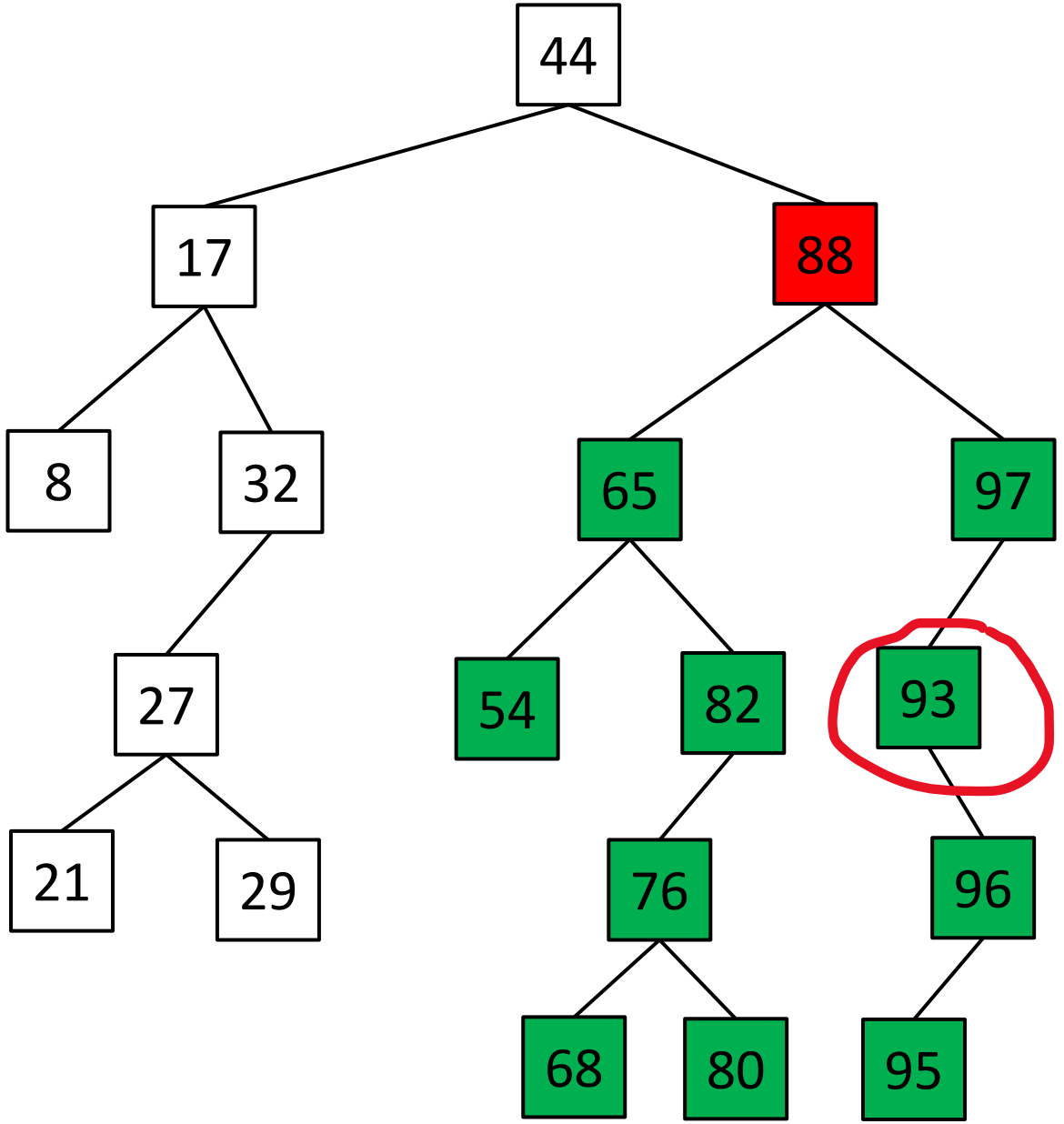

Binary Search Tree- Removal

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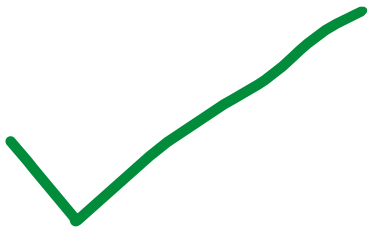
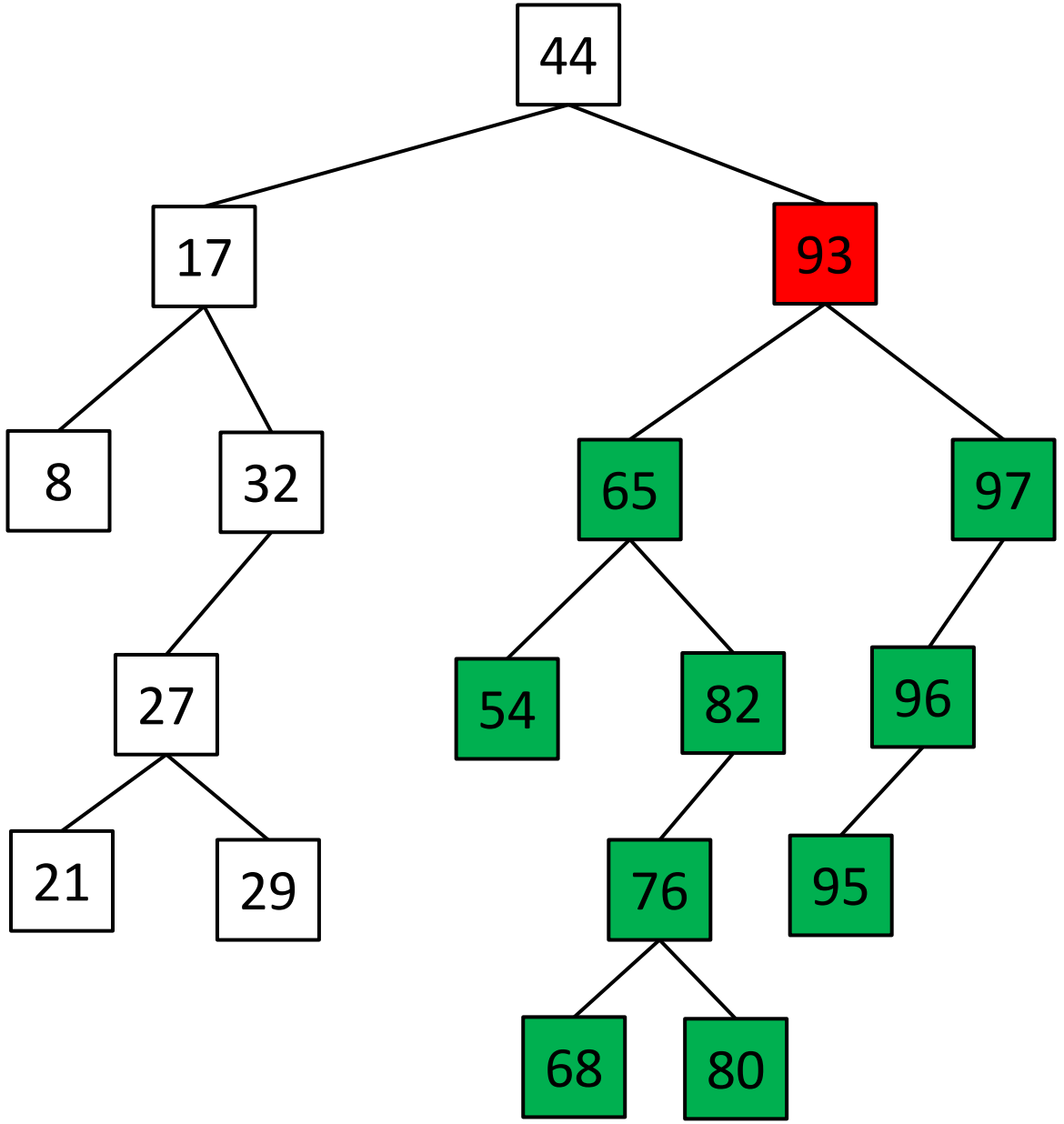




Binary Search Tree- Removal

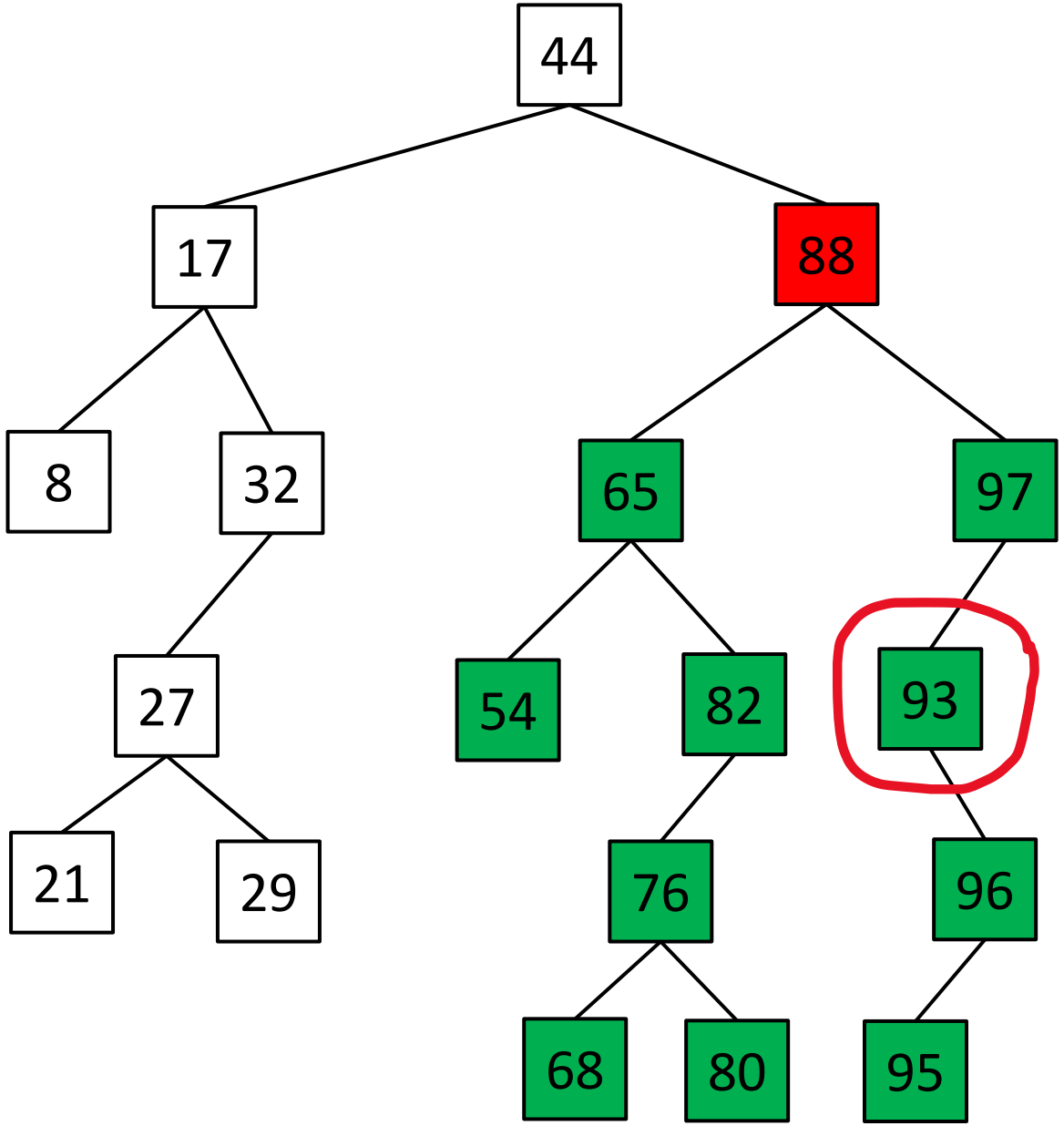
Case 1: Node has no children
Case 2: Node has one child
Case 3: Node has two children

```
remove(88);
```

Which ~~child~~ **descendant** to use?

The lowest value in the right subtree

or the highest value in the left subtree



Binary Search Tree- Removal

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remove(88);
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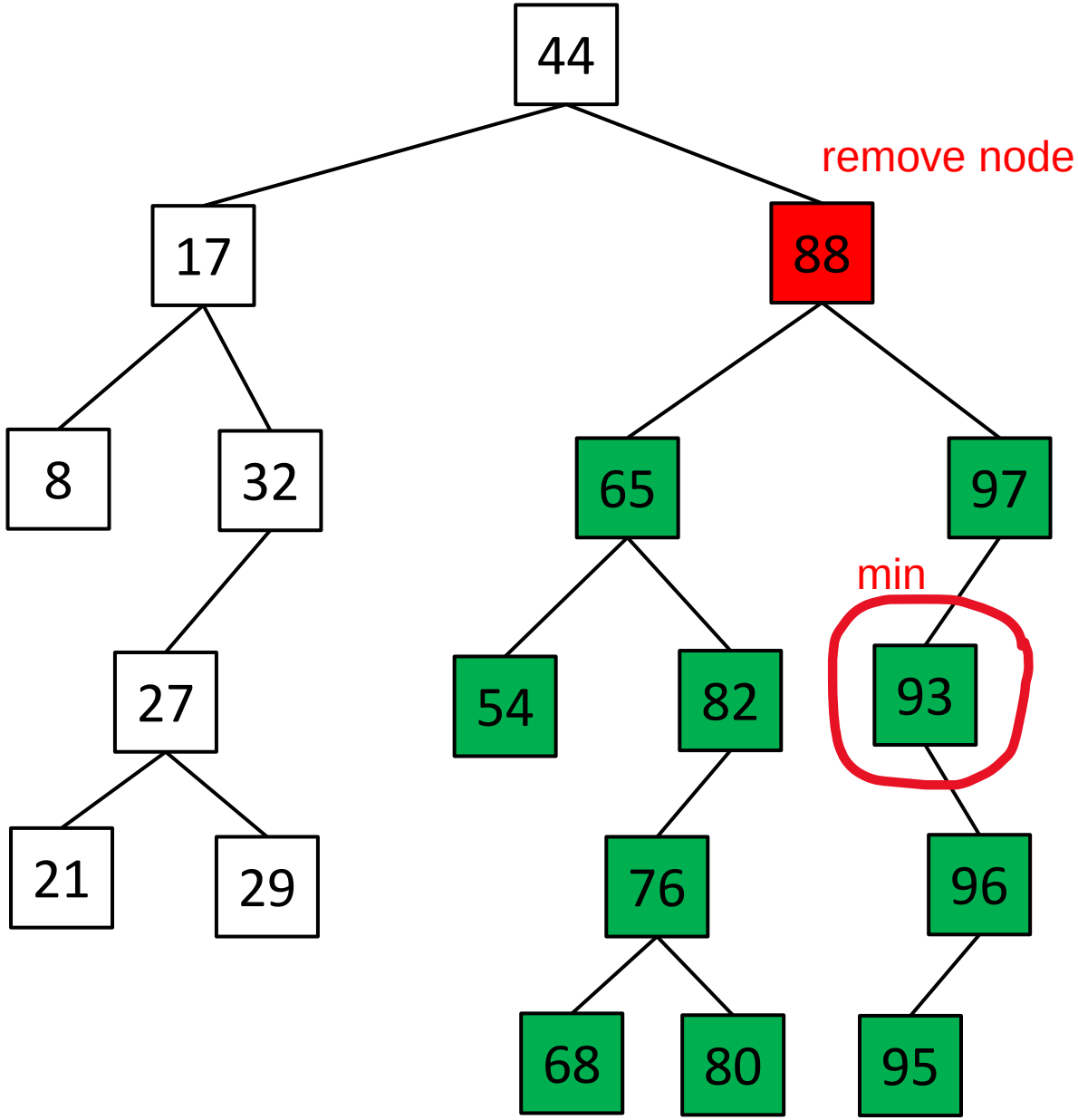


1. Find smallest node in right sub tree (min)
2. Update the of remove node to be the value of min
3. Update the parents of min
4. Update children on remove node

Binary Search Tree- Removal

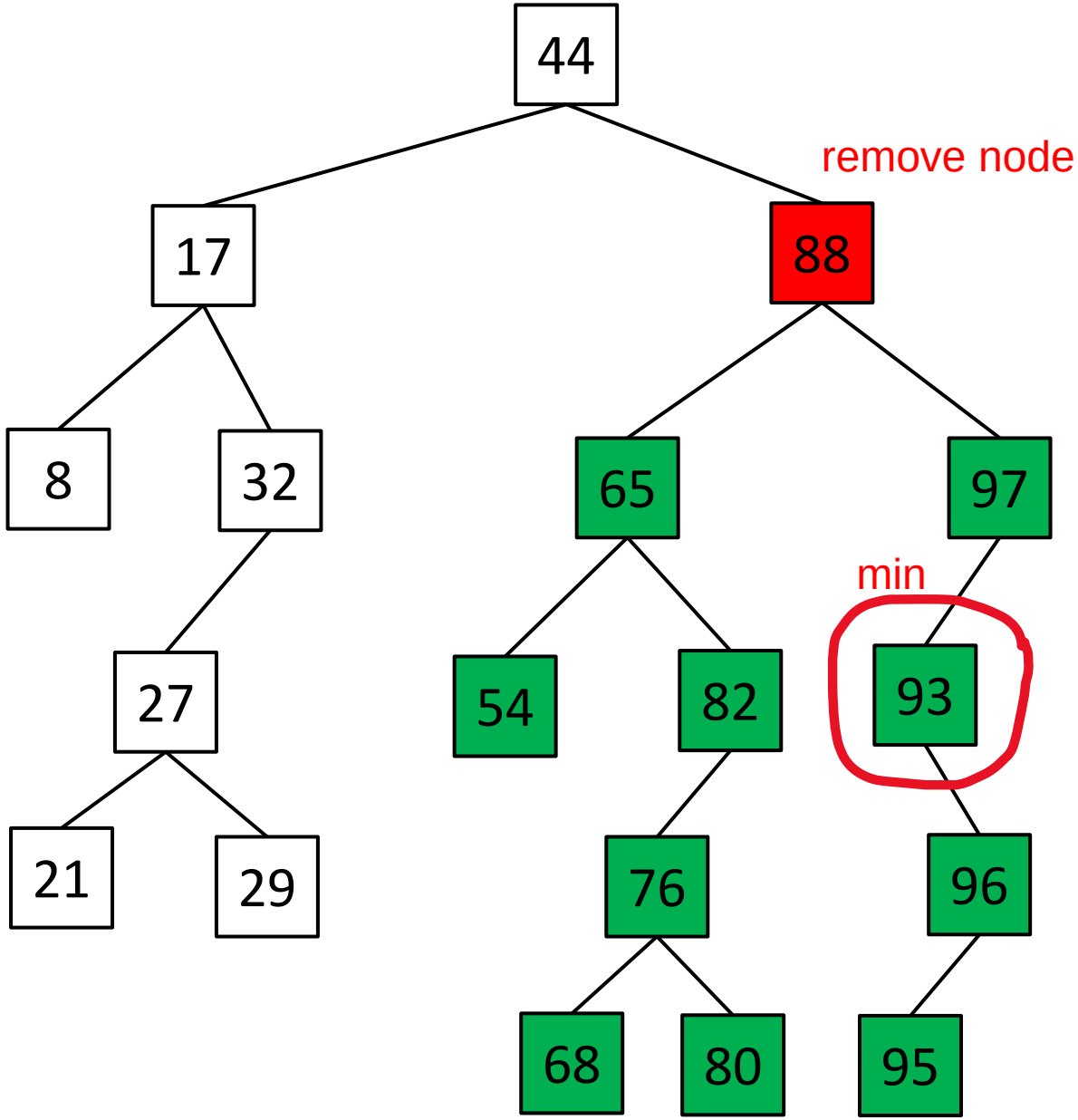
Case 1: Node has no children
Case 2: Node has one child
Case 3: Node has two children

```
remove(88);
```

Running time?

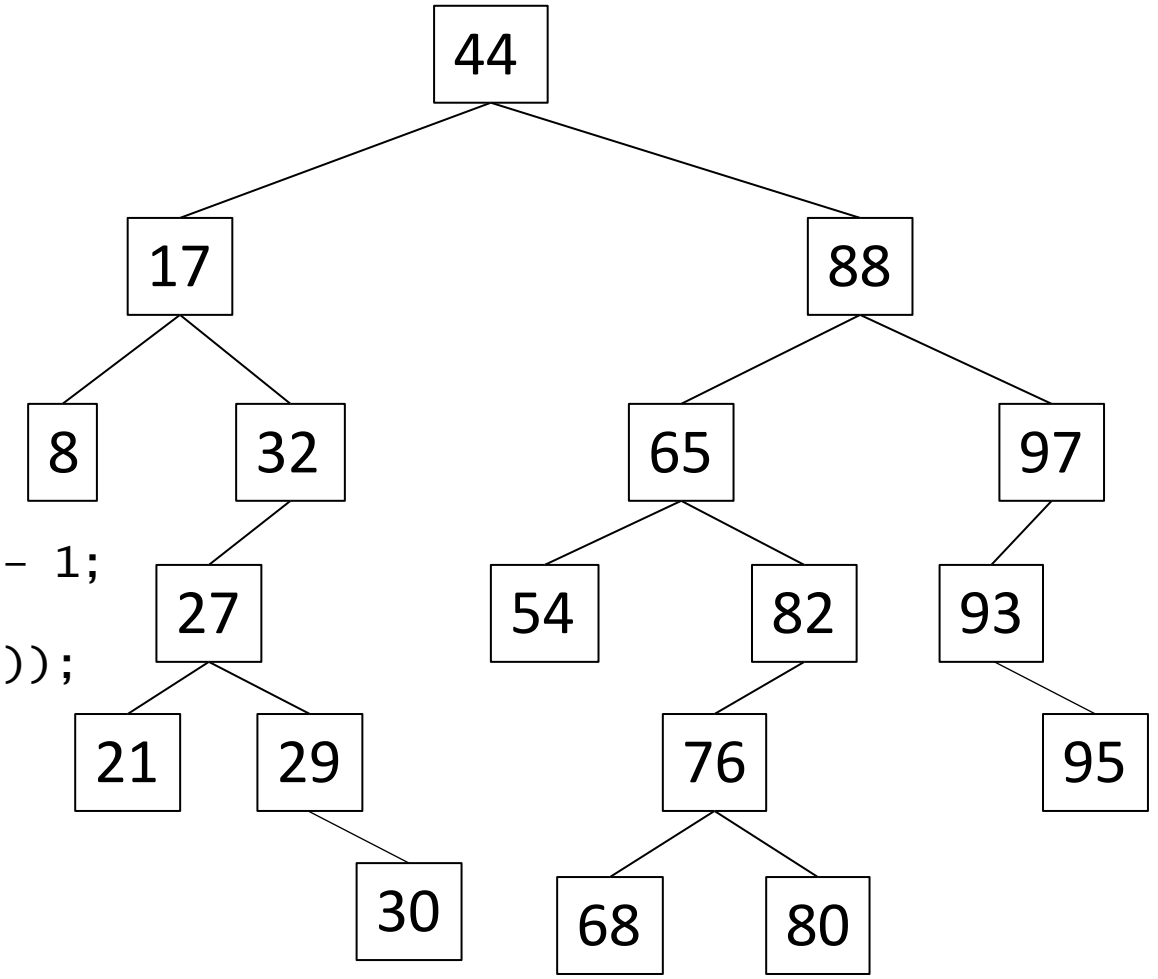
"Bad" tree → O(n)
"Good" tree → O(logn)

O(h) → h = height of tree



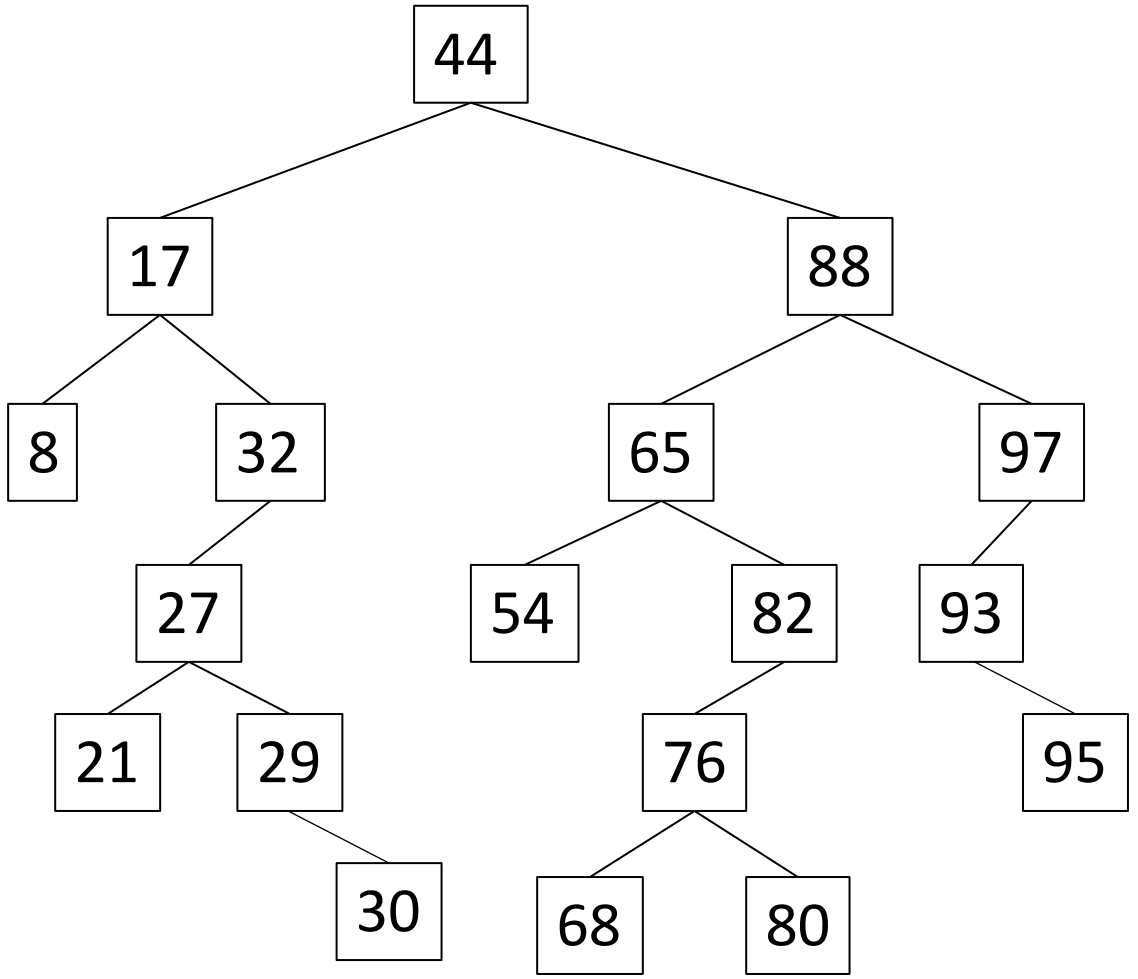
Binary Search Tree - Traversal

```
public void depthFirst() {
    Stack<Node> stack = new Stack<>();
    if (root != null) {
        stack.add(root);
        while(!stack.isEmpty()) {
            Node node = stack.pop();
            System.out.println(node.getName());
            for (int i = node.getChildren().size() - 1;
                 i >= 0; i--) {
                stack.push(node.getChildren().get(i));
            }
        }
    }
}
```



Binary Search Tree - Traversal

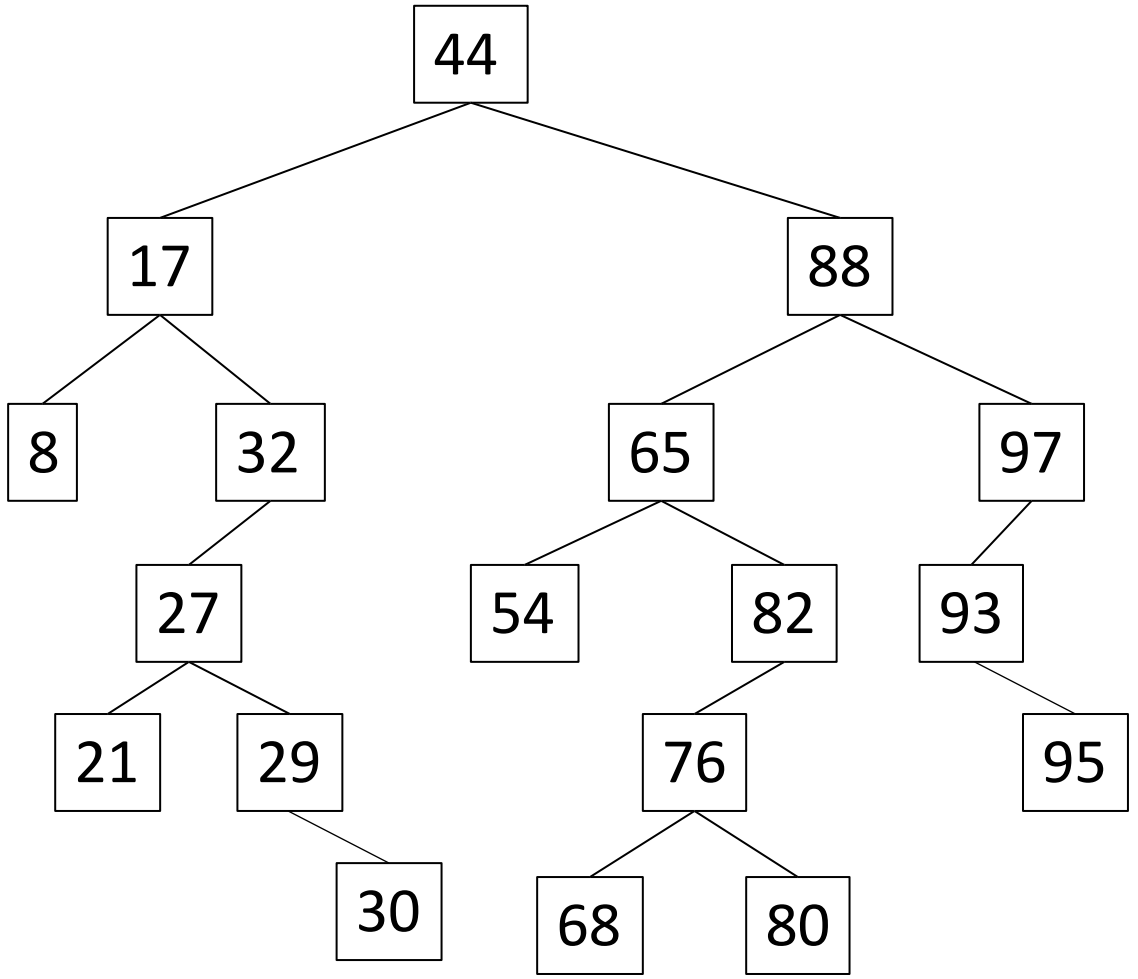
Recursion:



Binary Search Tree - Traversal

Recursion:

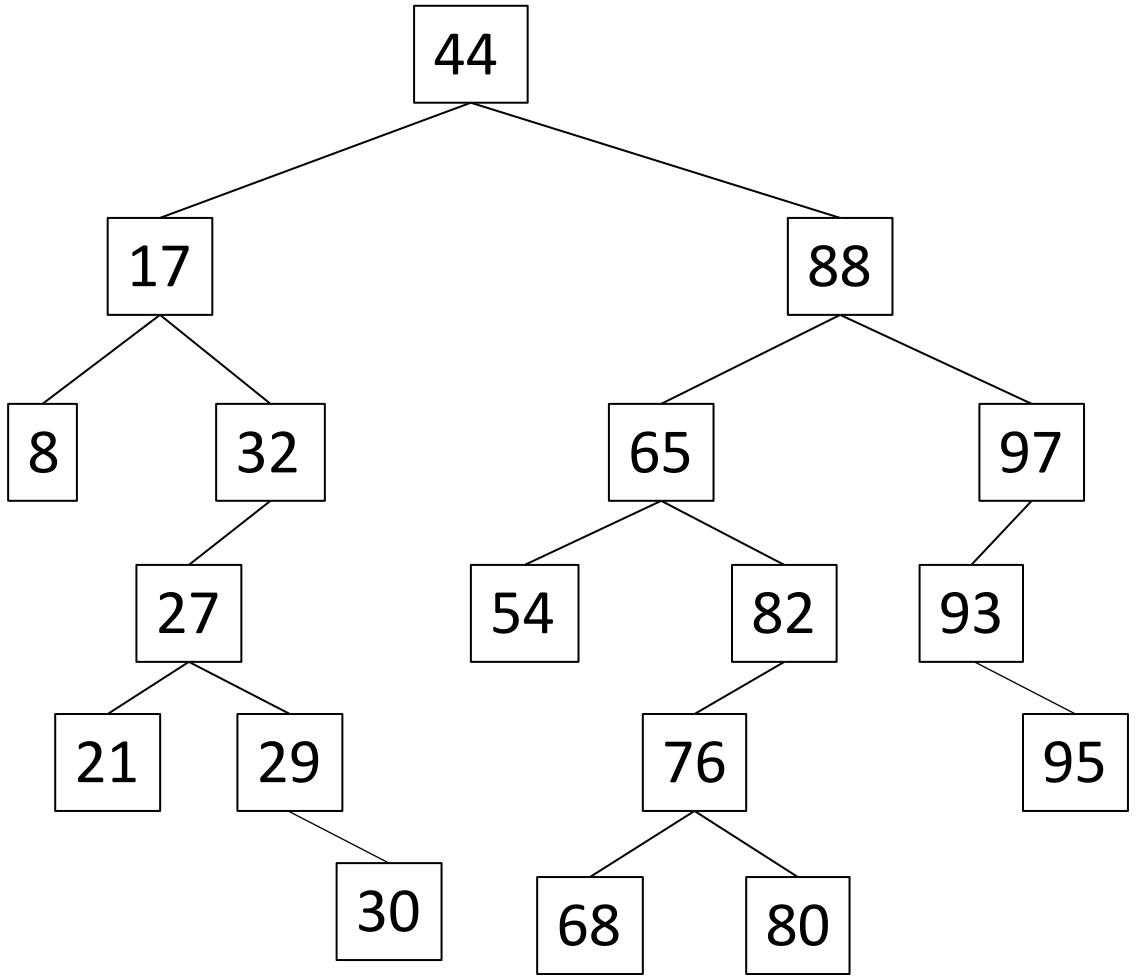
- **Calling a method from inside itself.**



Binary Search Tree - Traversal

Recursion:

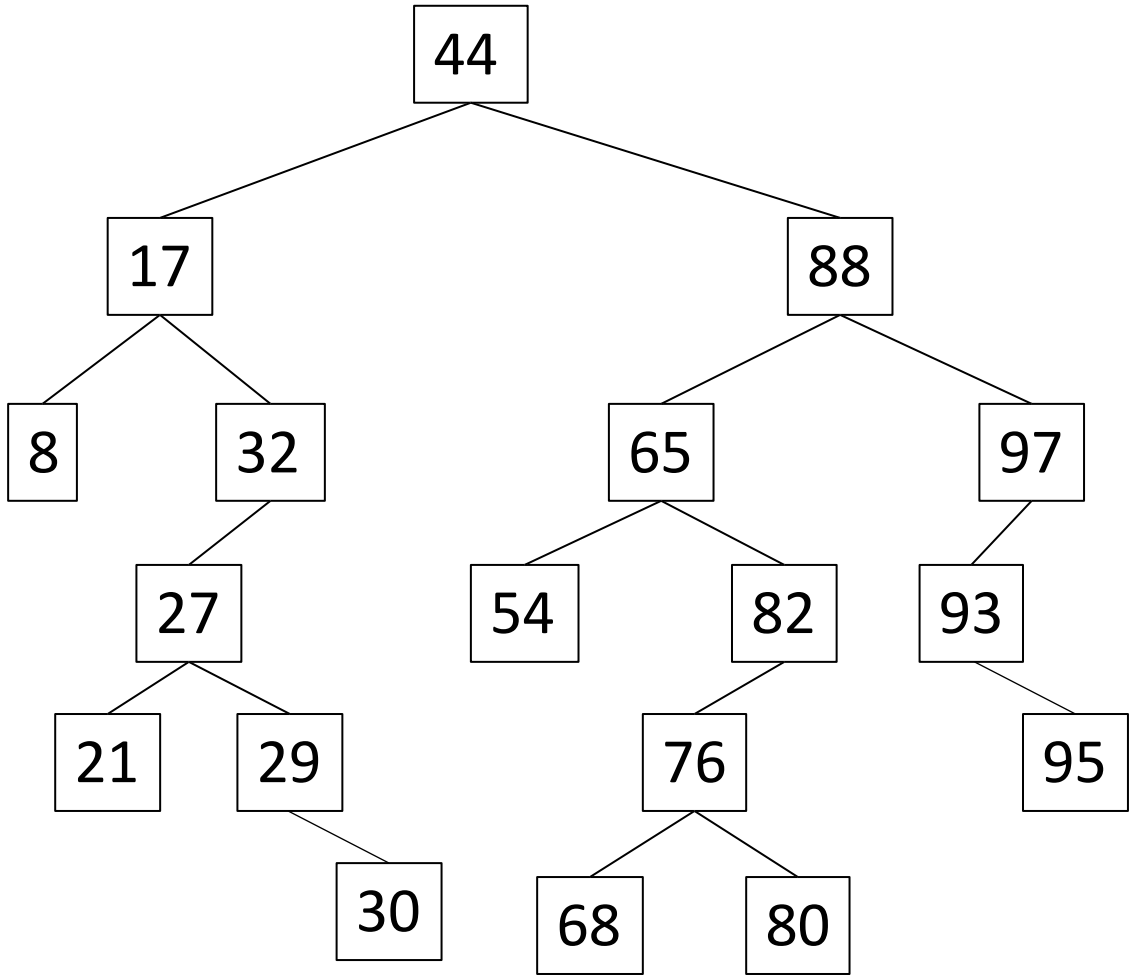
- **Calling a method from inside itself.**
- **Solve the problem by solving identical smaller problems.**



Binary Search Tree - Traversal

Recursion:

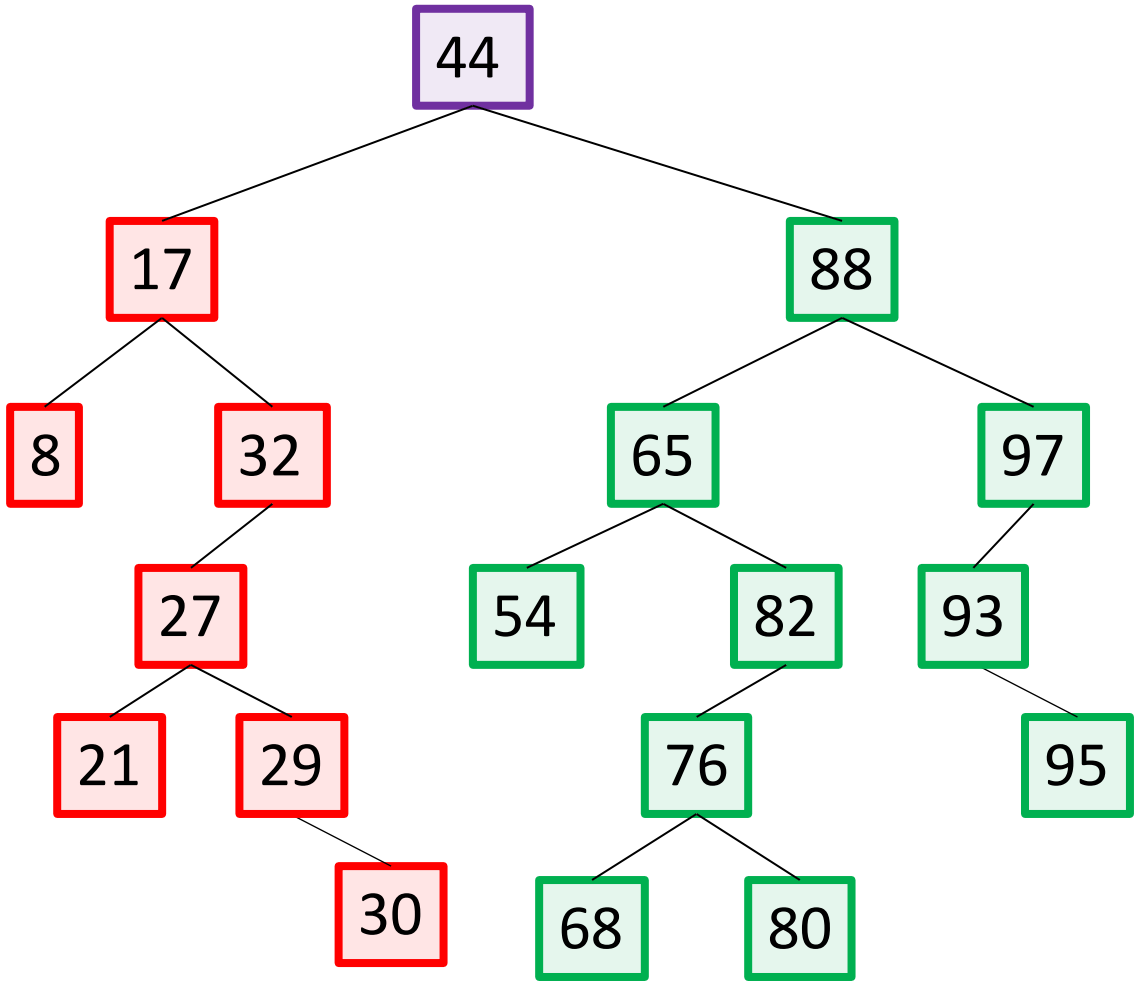
- **Calling a method from inside itself.**
- **Solve the problem by solving identical smaller problems.**
- **What is the “smaller problem”?**



Binary Search Tree - Traversal

Recursion:

- **Calling a method from inside itself.**
- **Solve the problem by solving identical smaller problems.**
- **What is the "smaller problem"?**
  - **Process the left side, then process the right side.**



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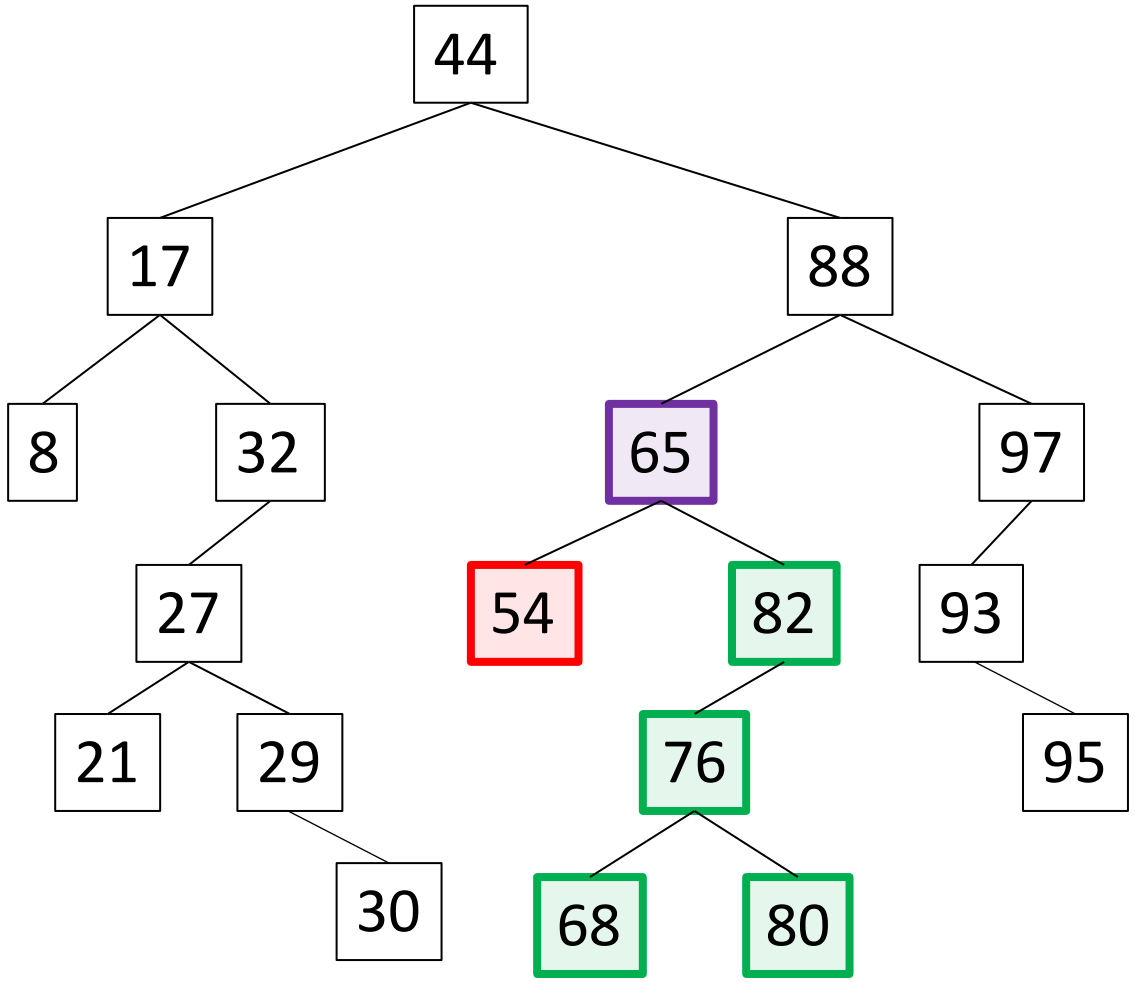
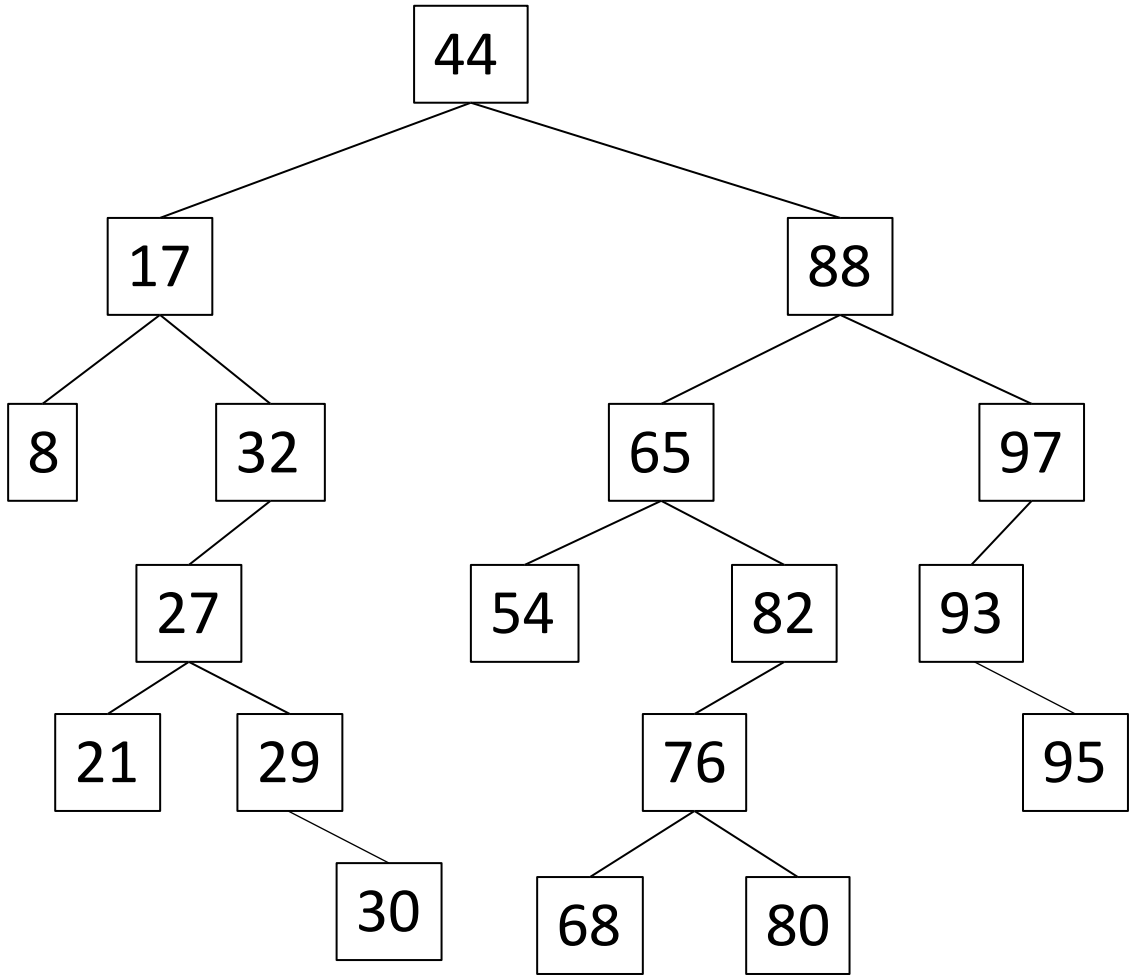


Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



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Output:

Binary Search Tree - Traversal

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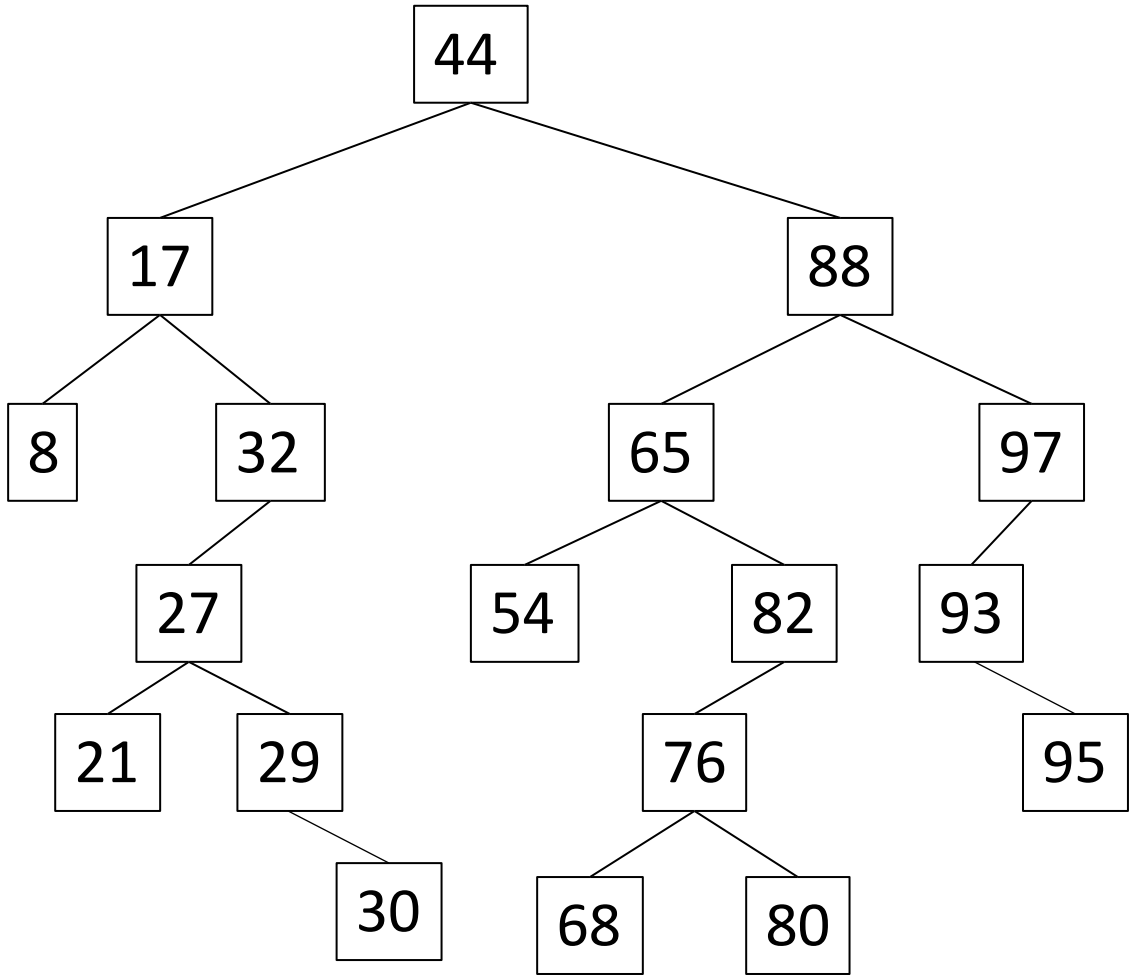
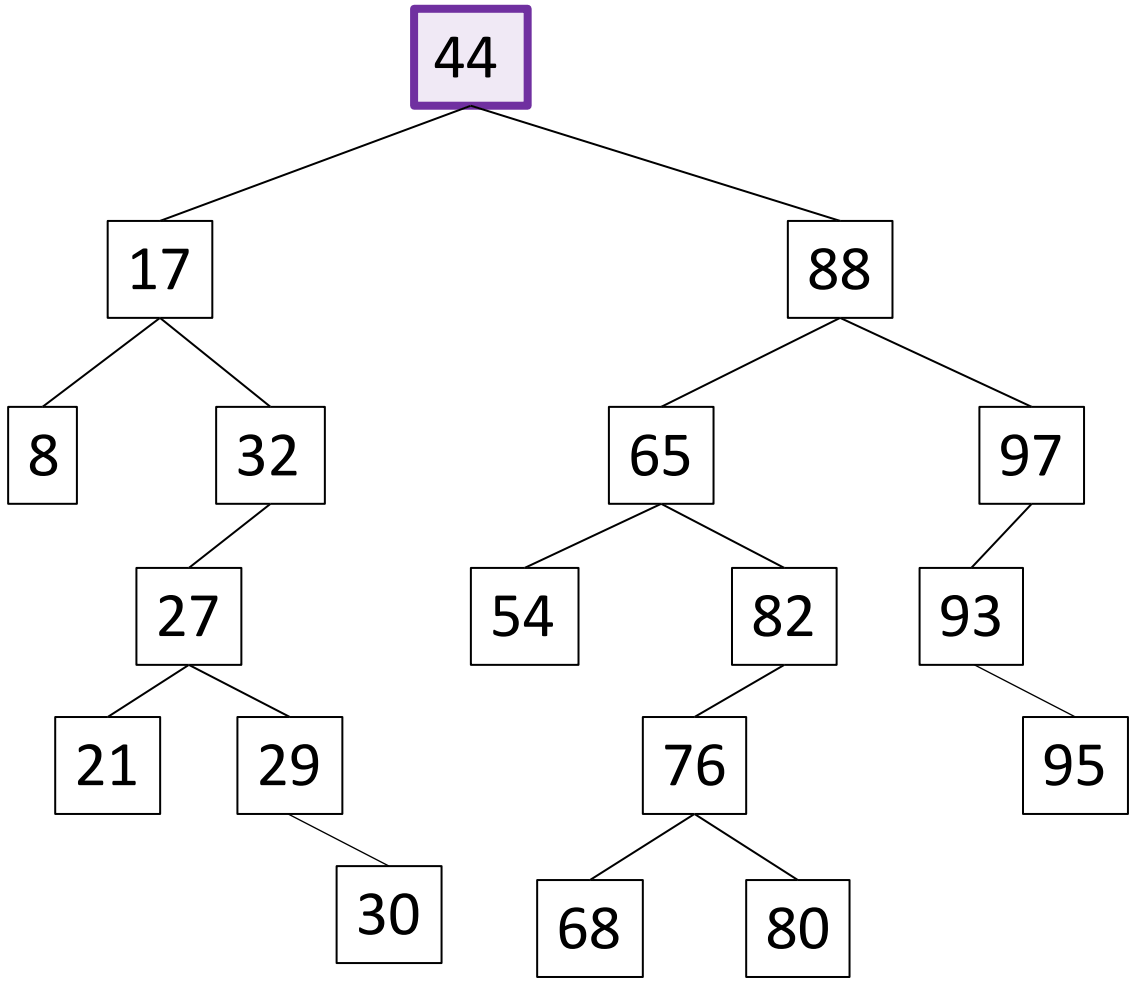


Output:

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:
44

Binary Search Tree - Traversal

```
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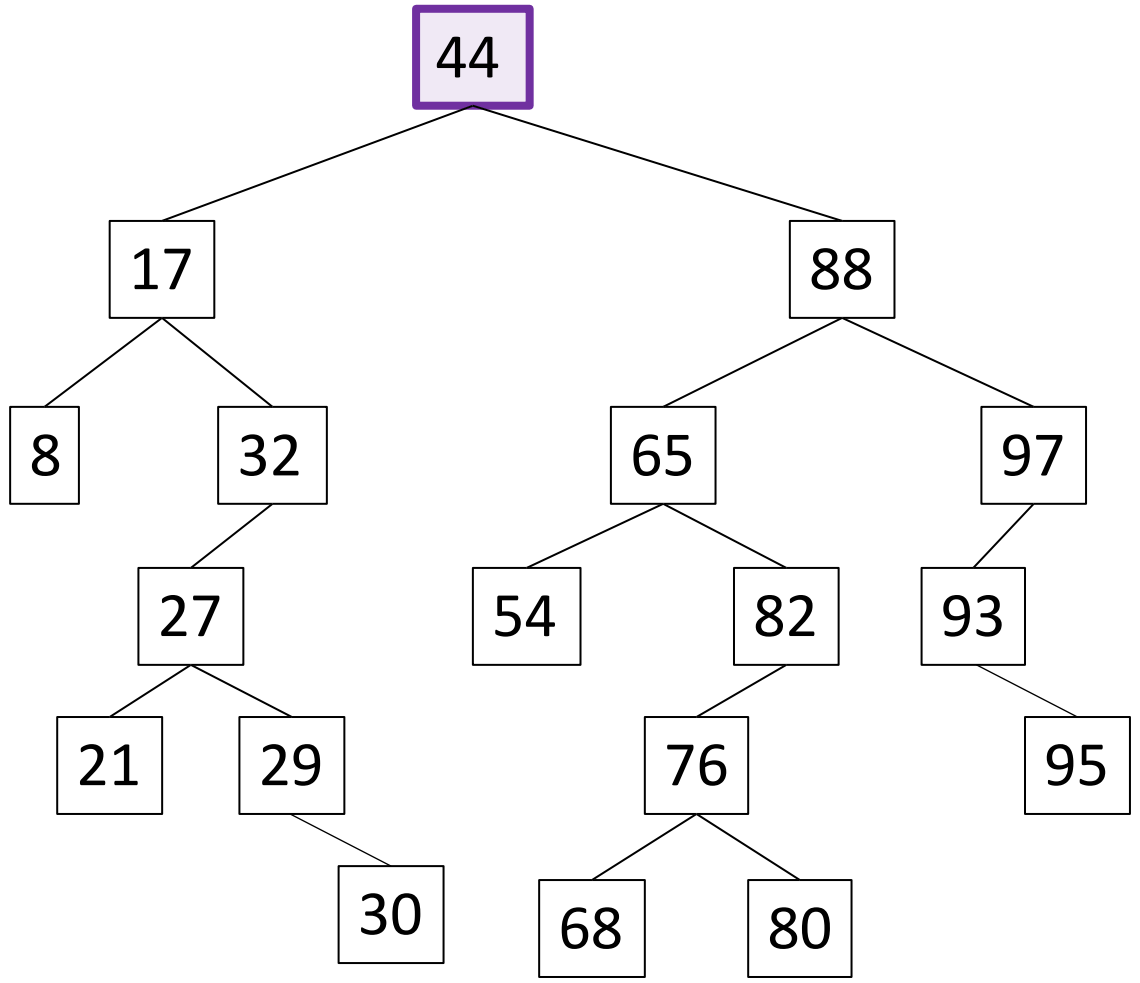

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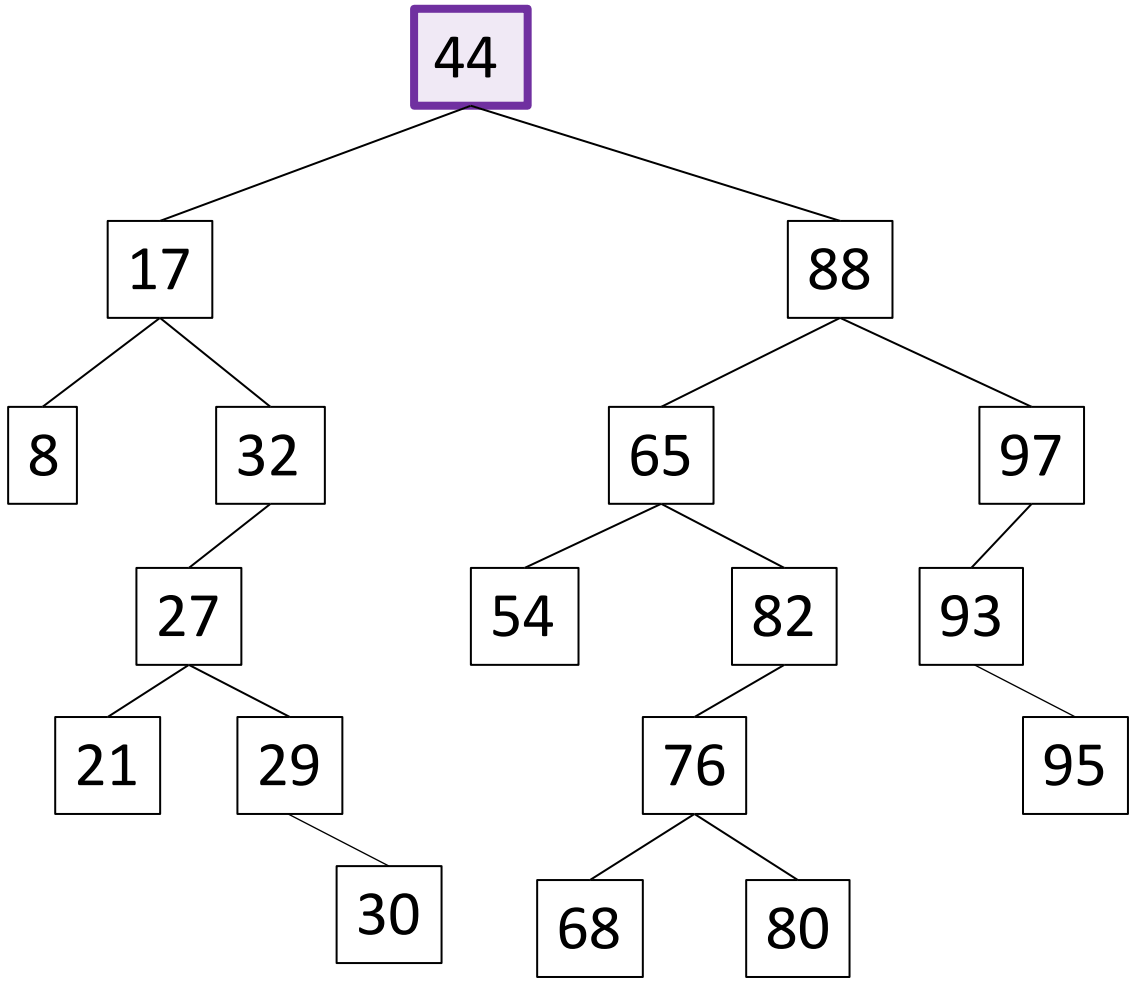

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```
public void depthFirst(17) {
    if (n != null) {
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}
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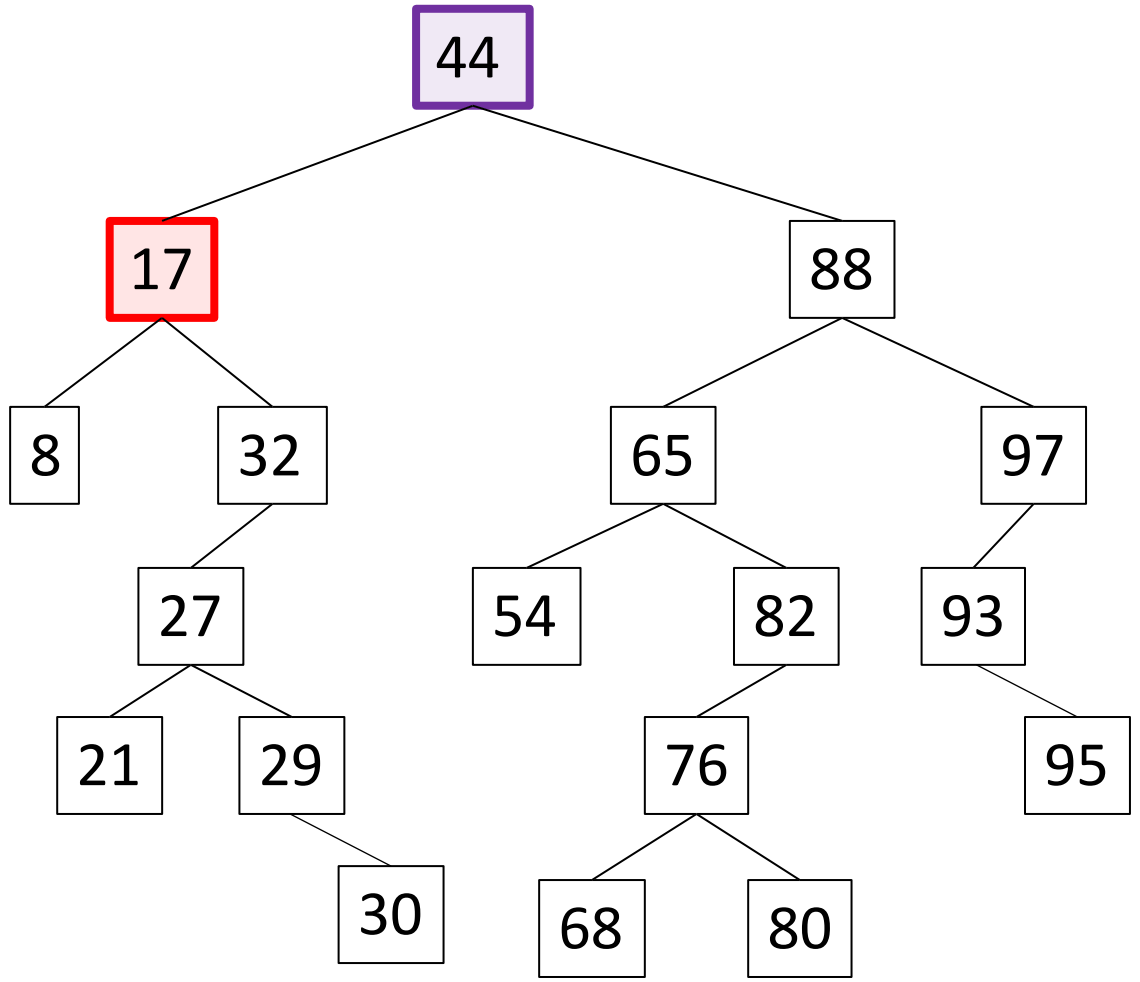

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Output:

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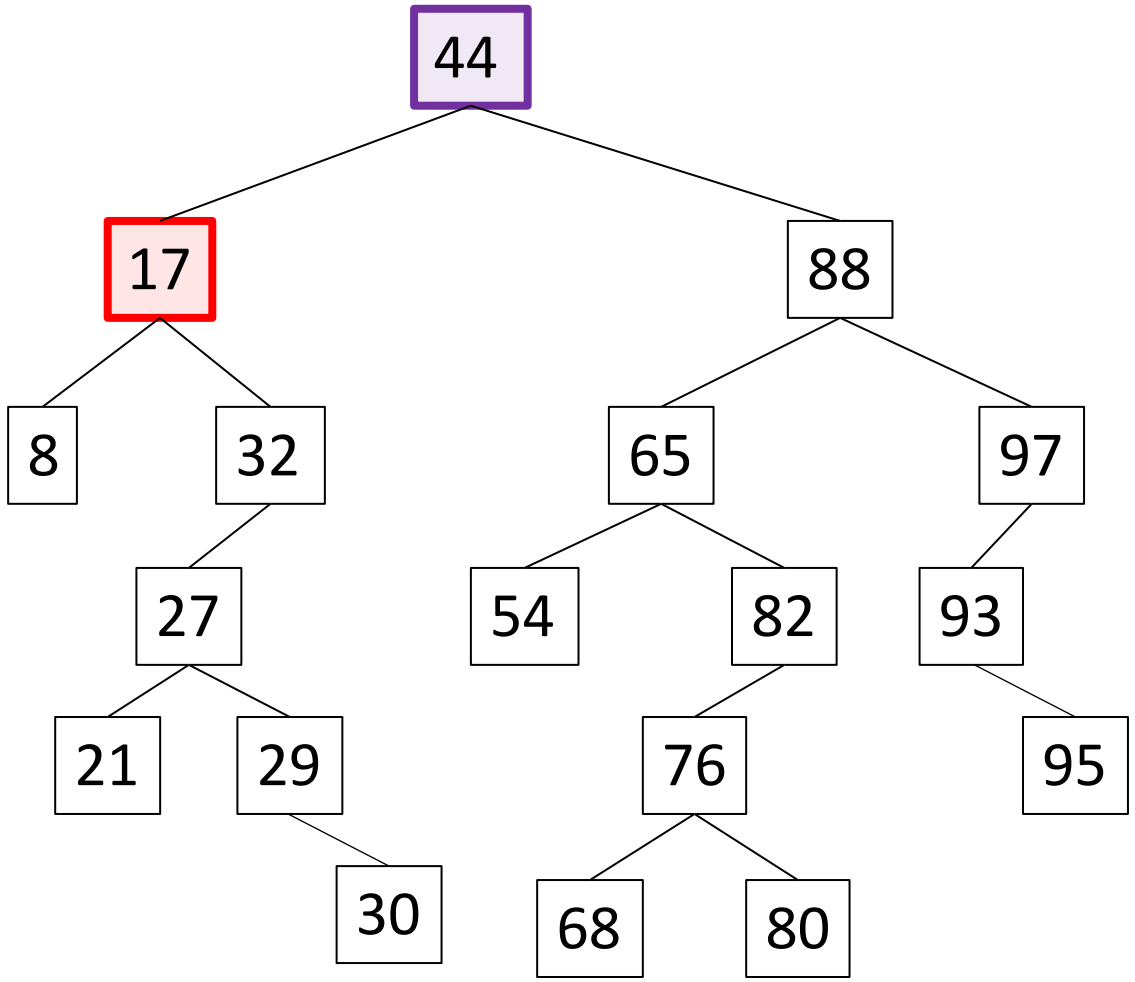

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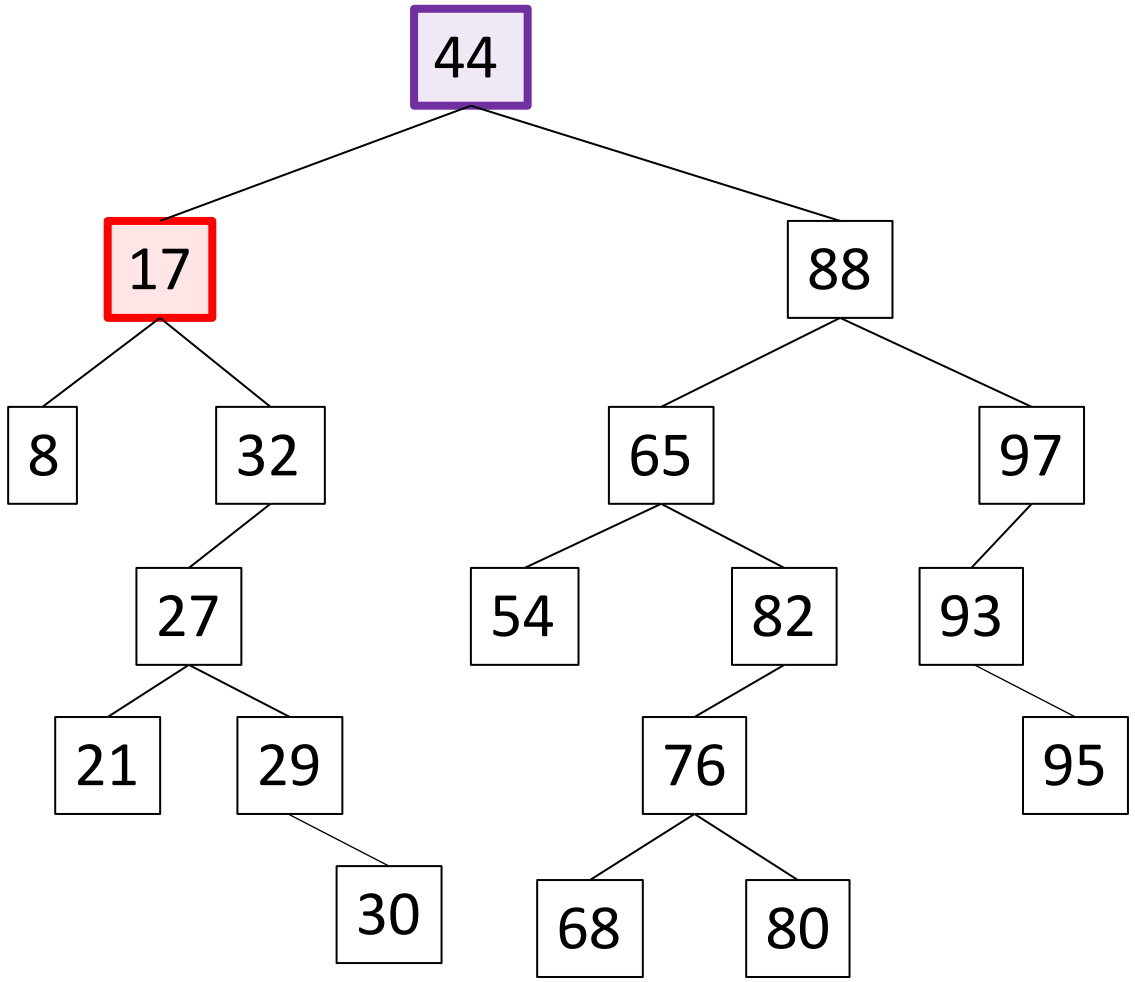

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```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
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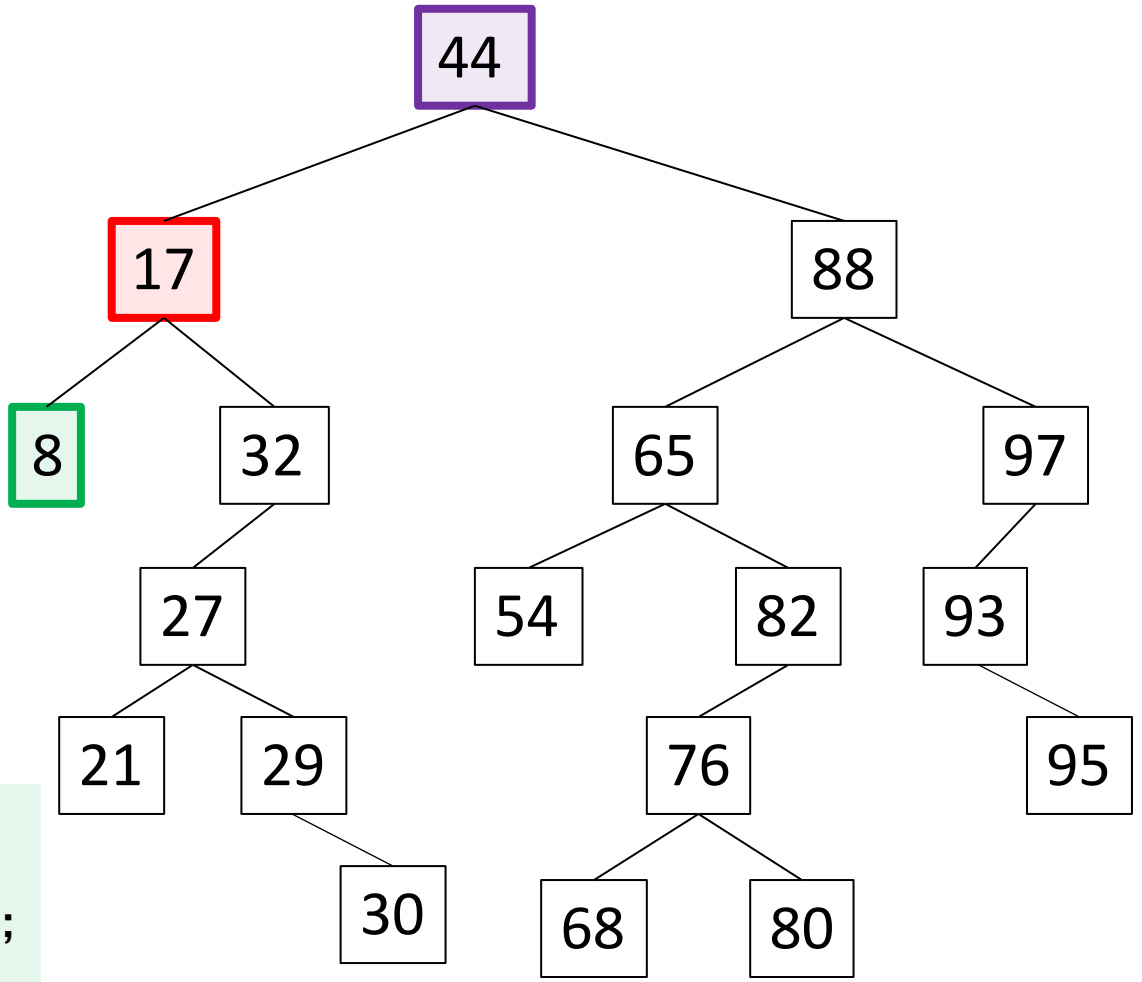
    }
}
```



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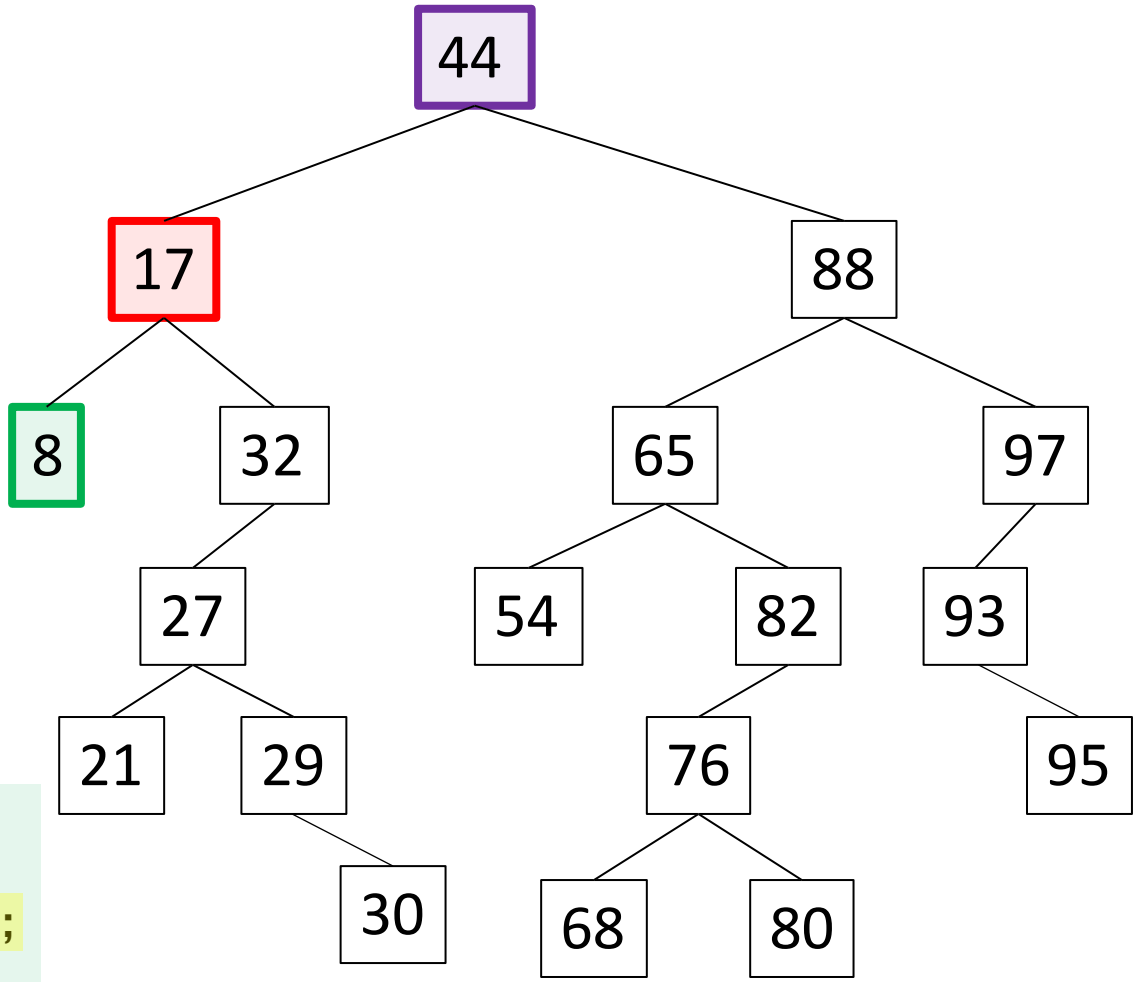

Output:

44

17

8

Binary Search Tree - Traversal

Output:

44

17

8

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}
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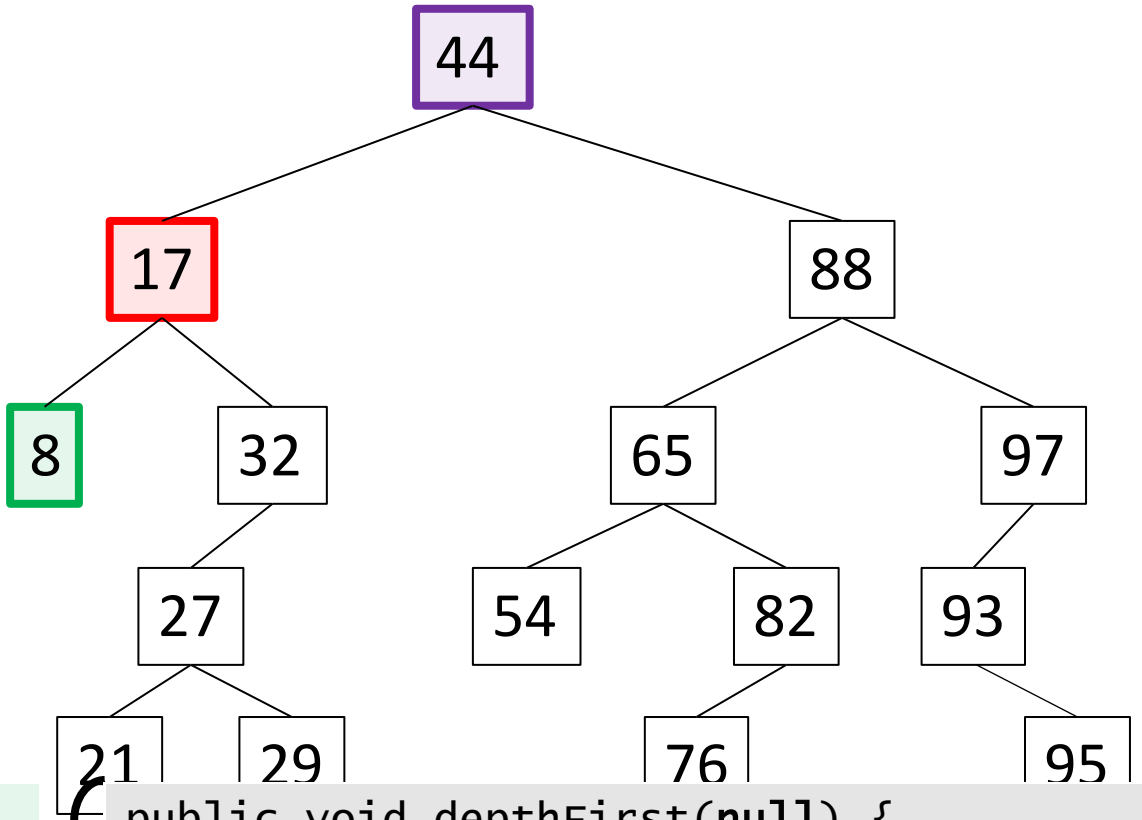

Binary Search Tree - Traversal

Output:

44

17

8

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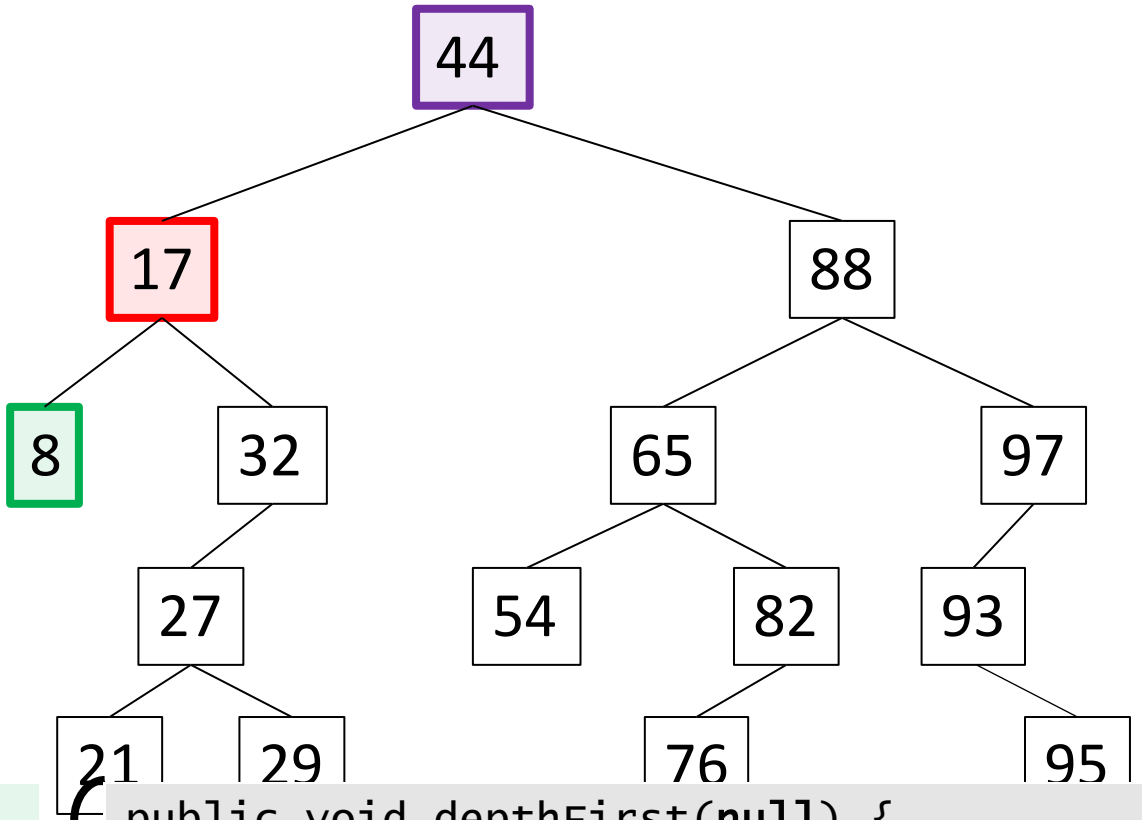

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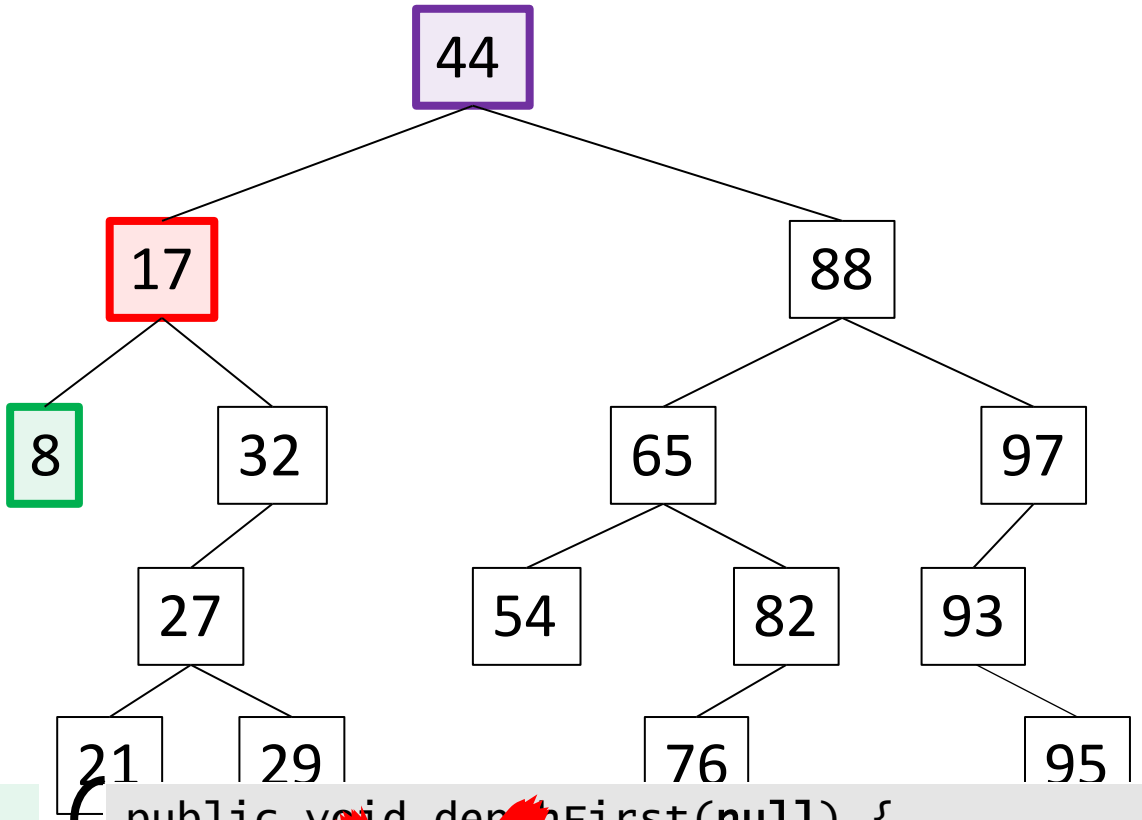

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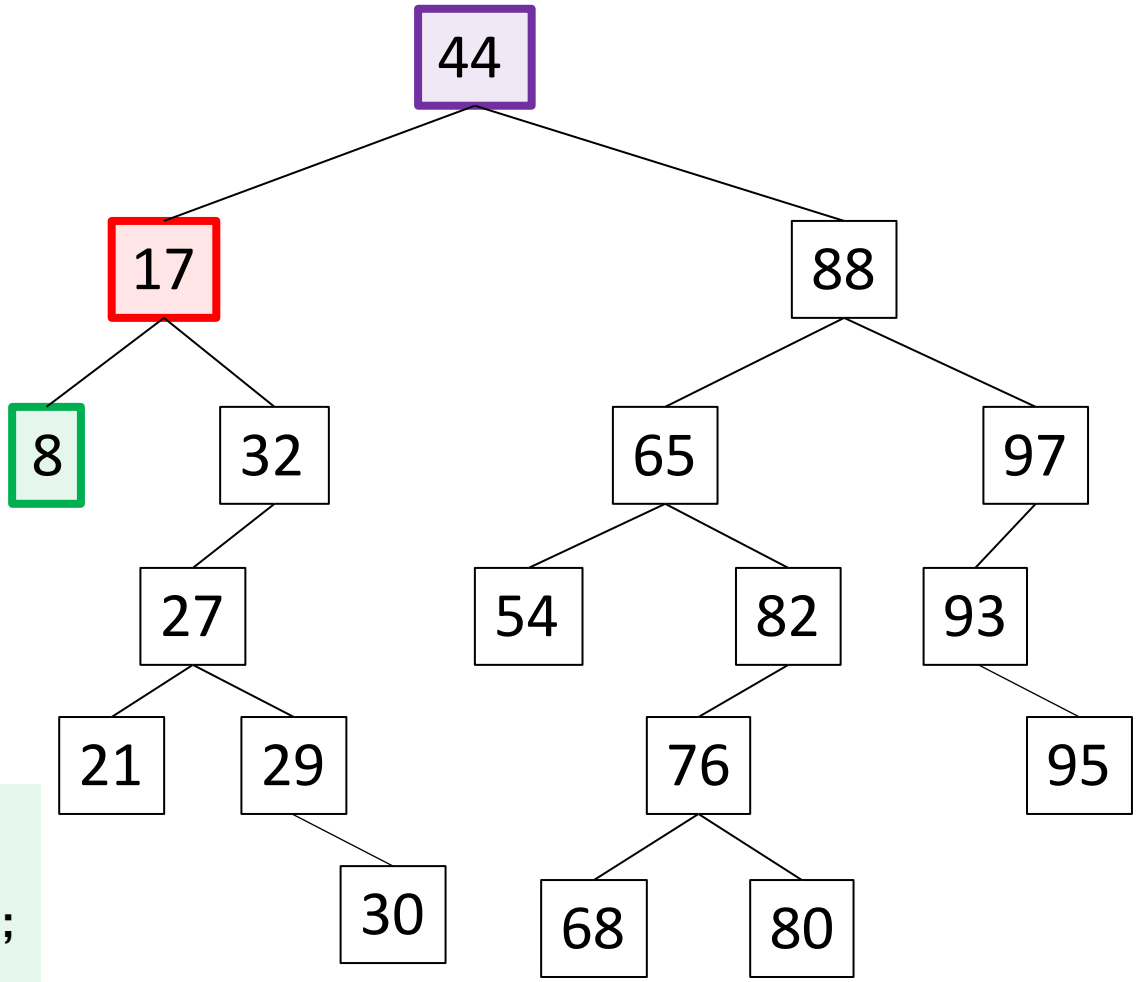
}
```



Output:

44

17

8

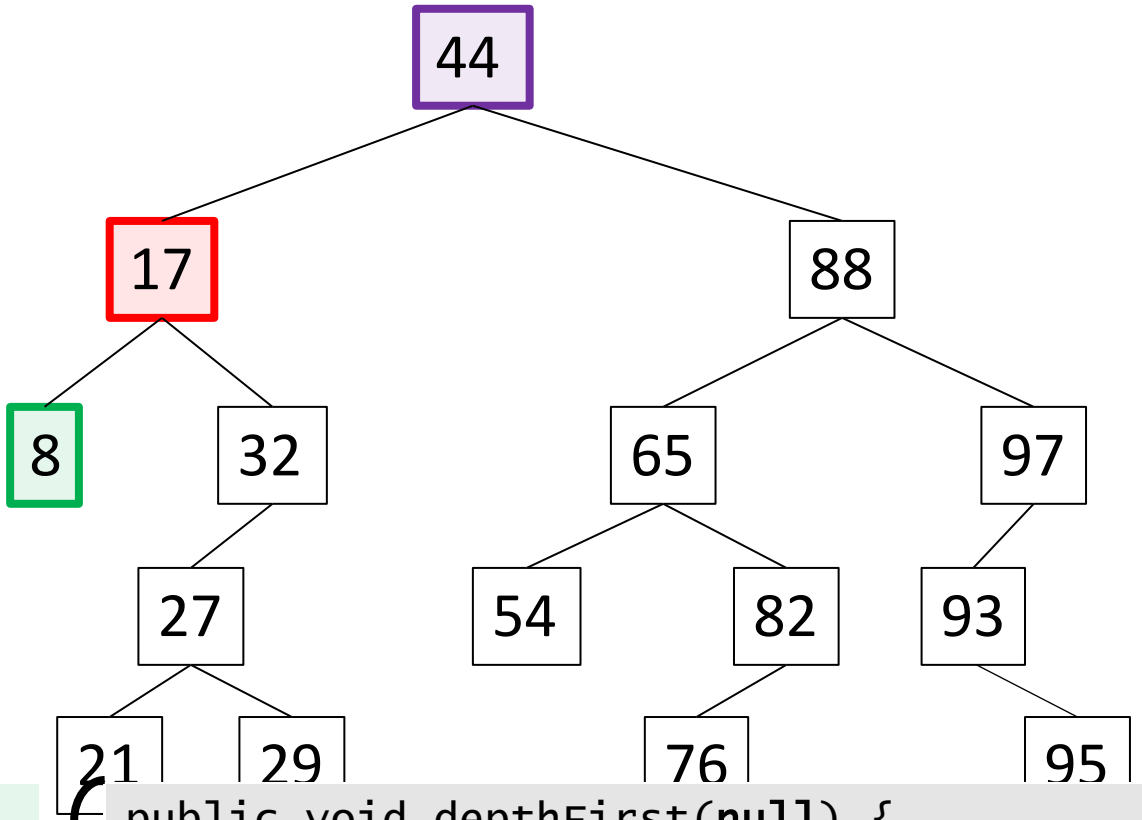
Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(null) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

8

Binary Search Tree - Traversal

Output:

44

17

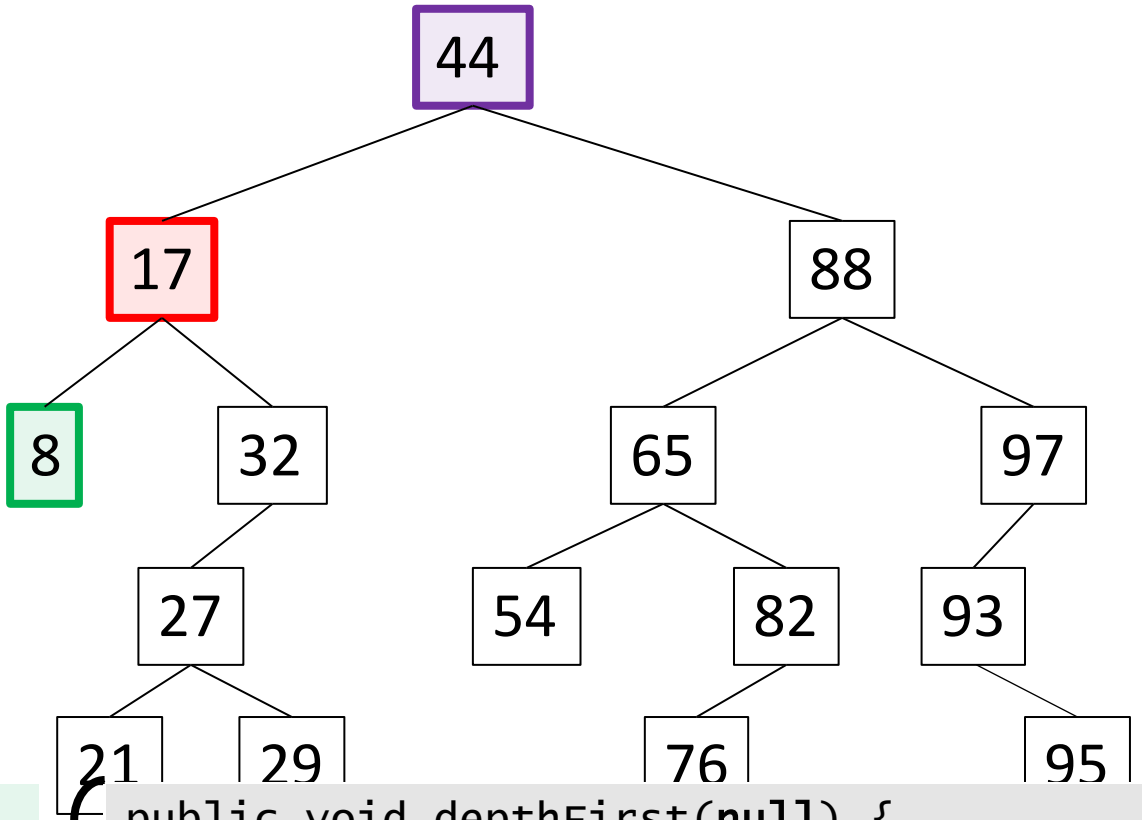
8

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(null) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Binary Search Tree - Traversal

Output:

44

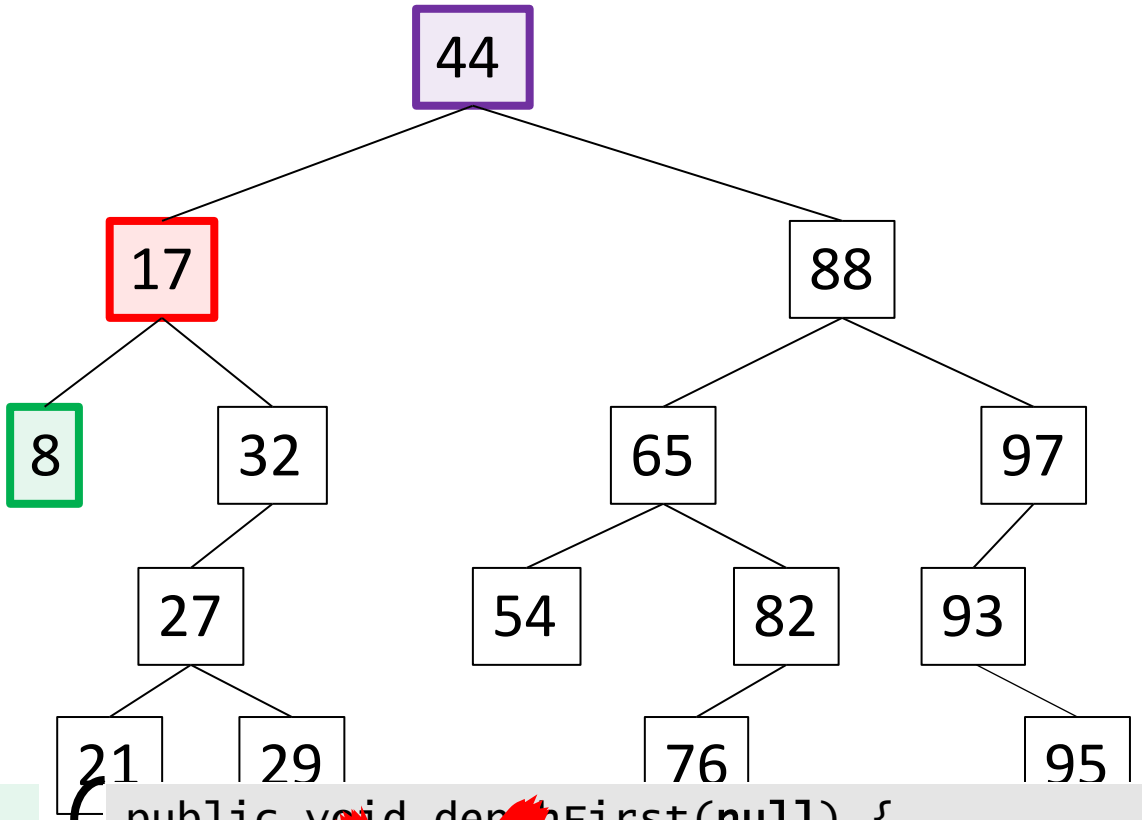
17

8

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



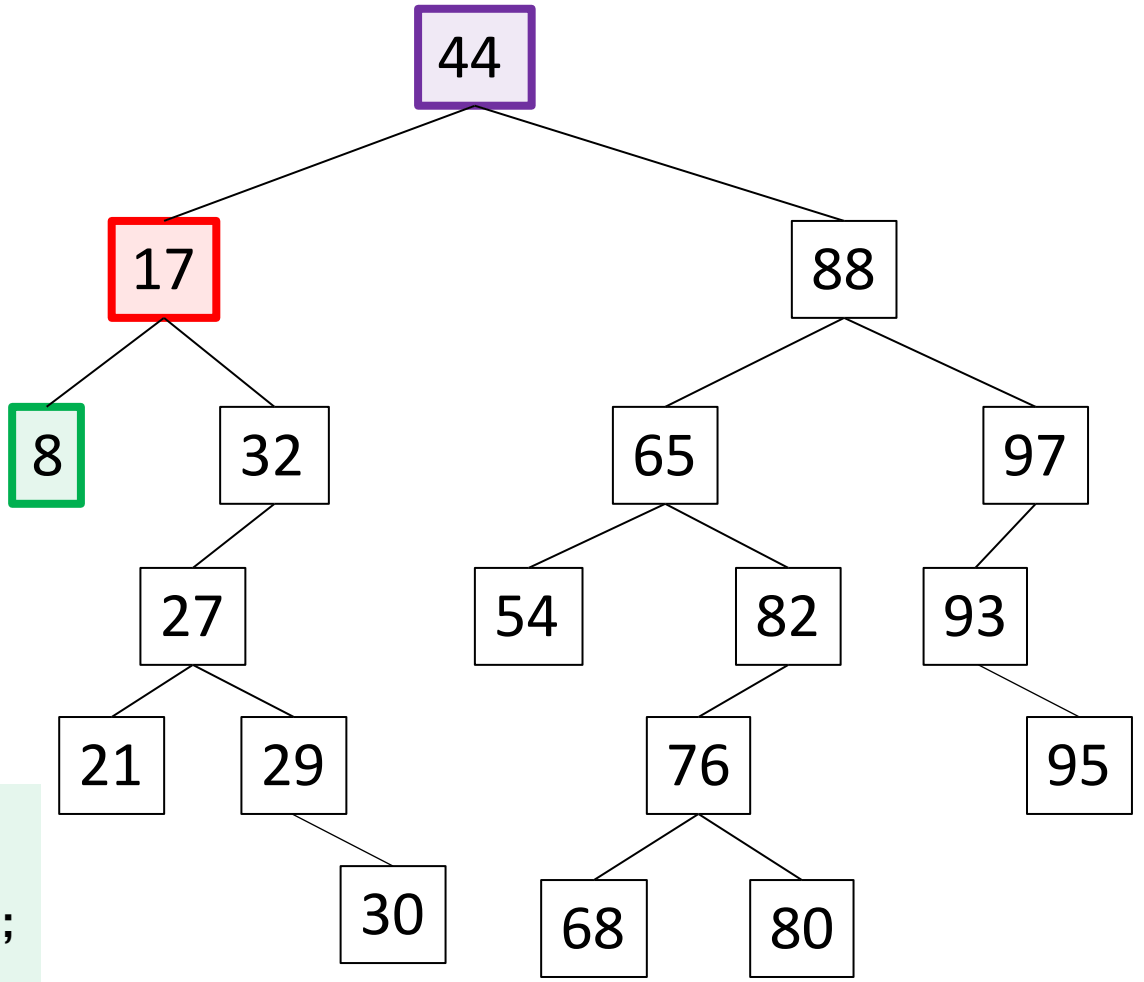

```
public void depthFirst(null) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

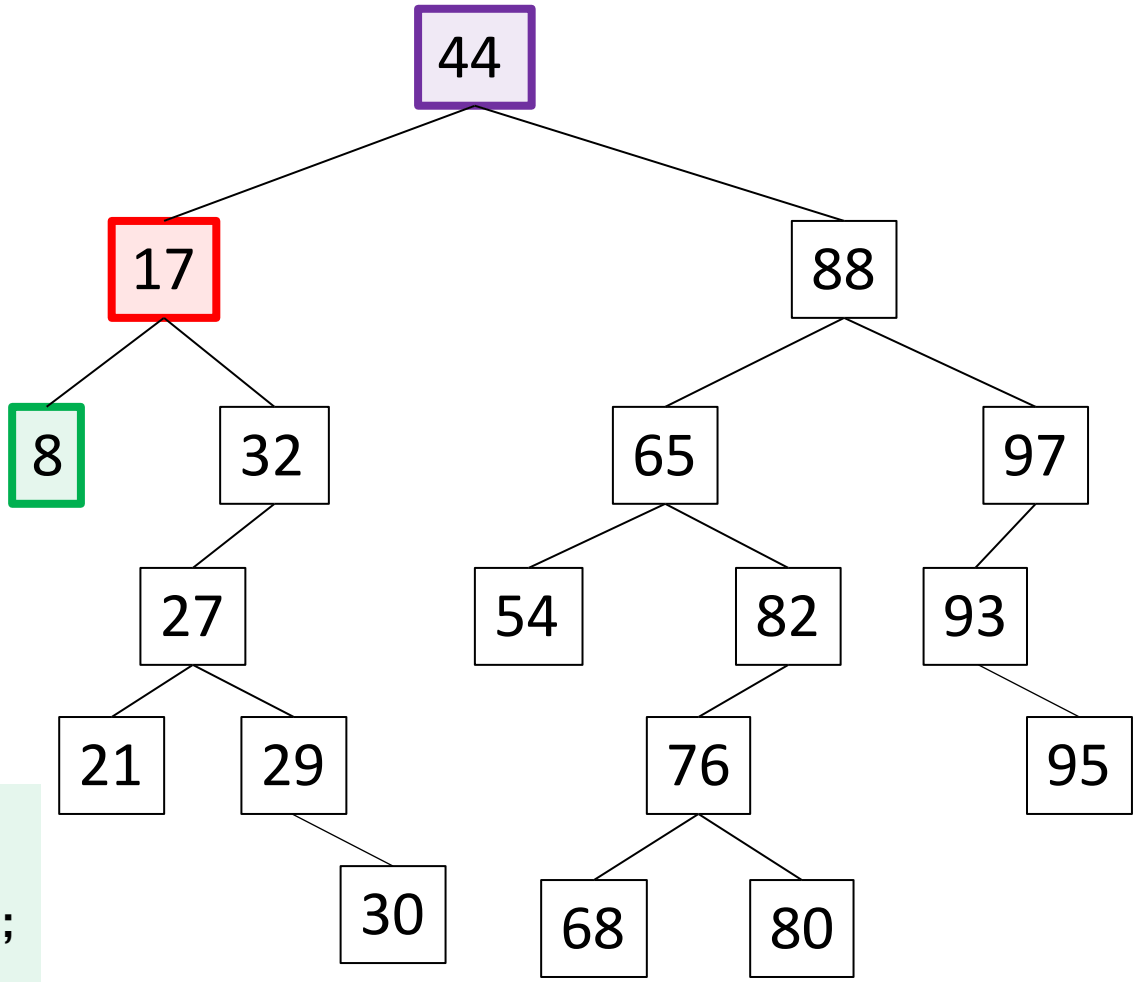
8

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

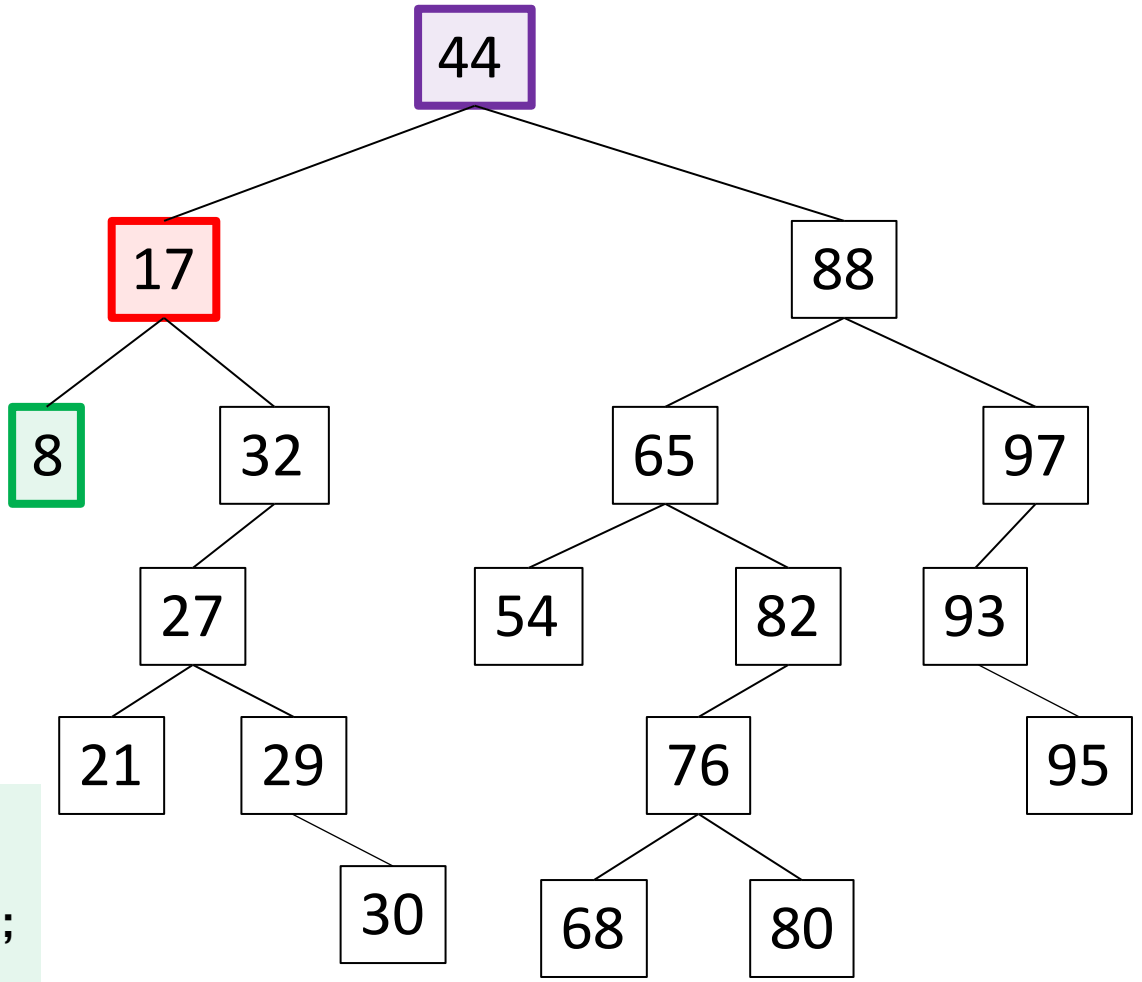
8

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

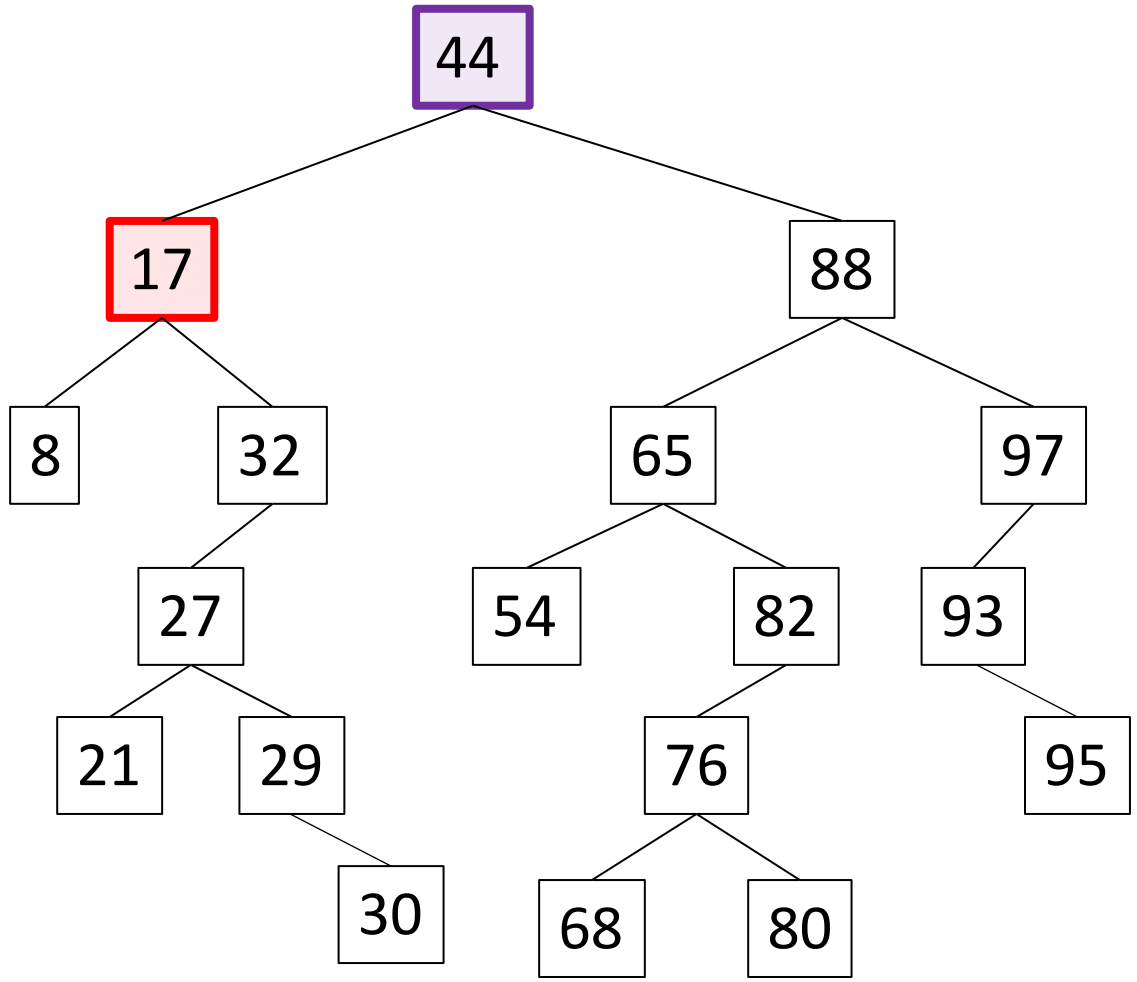
17

8

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

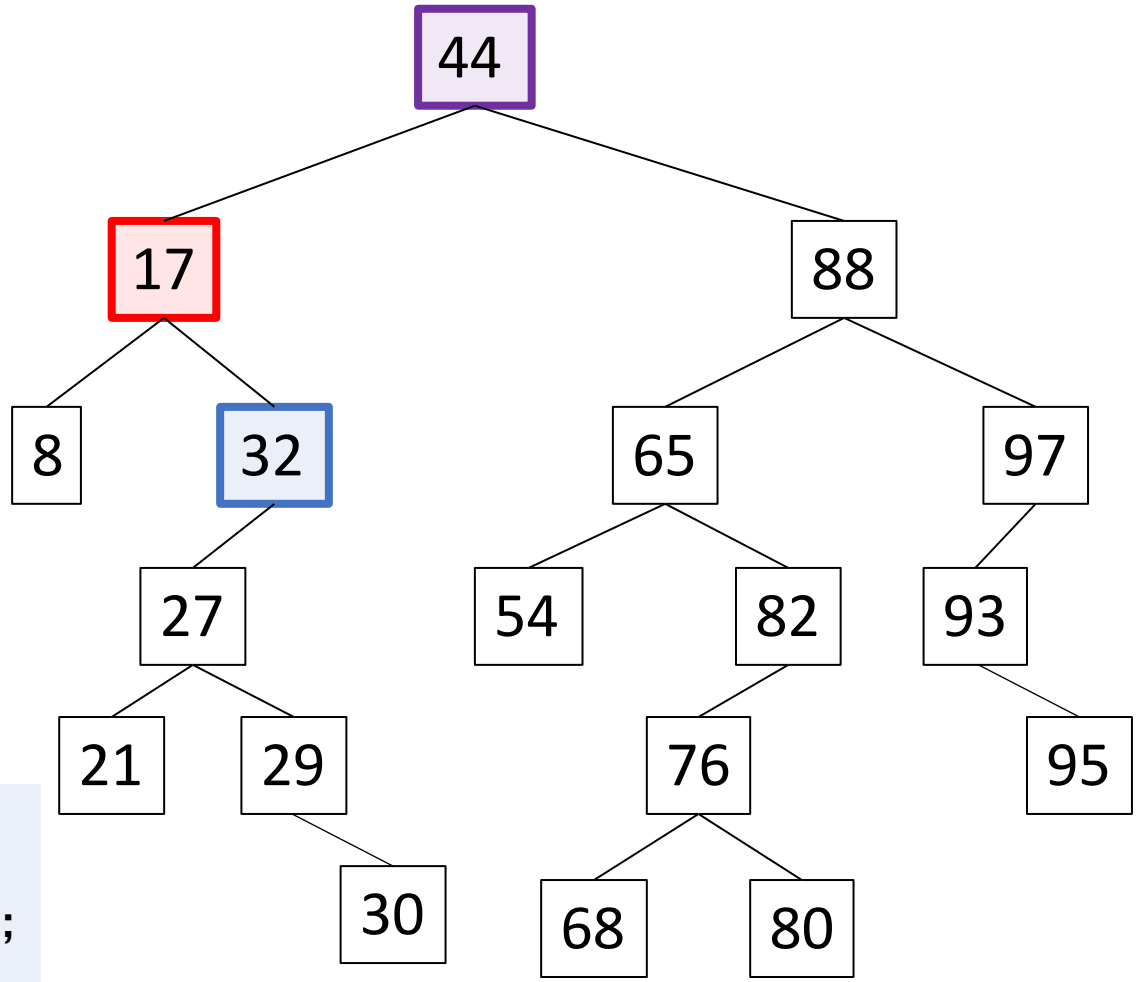
8

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

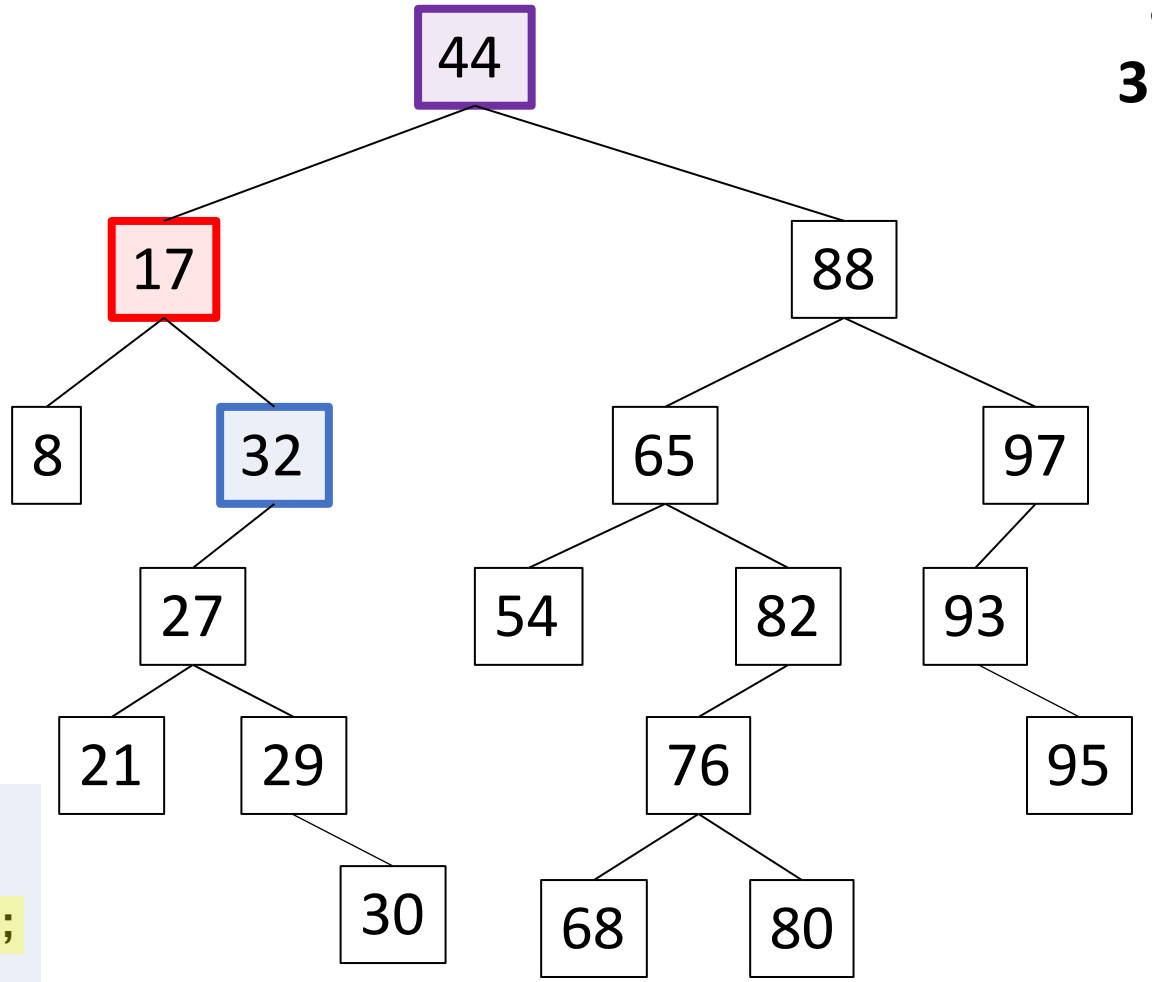
8

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

8

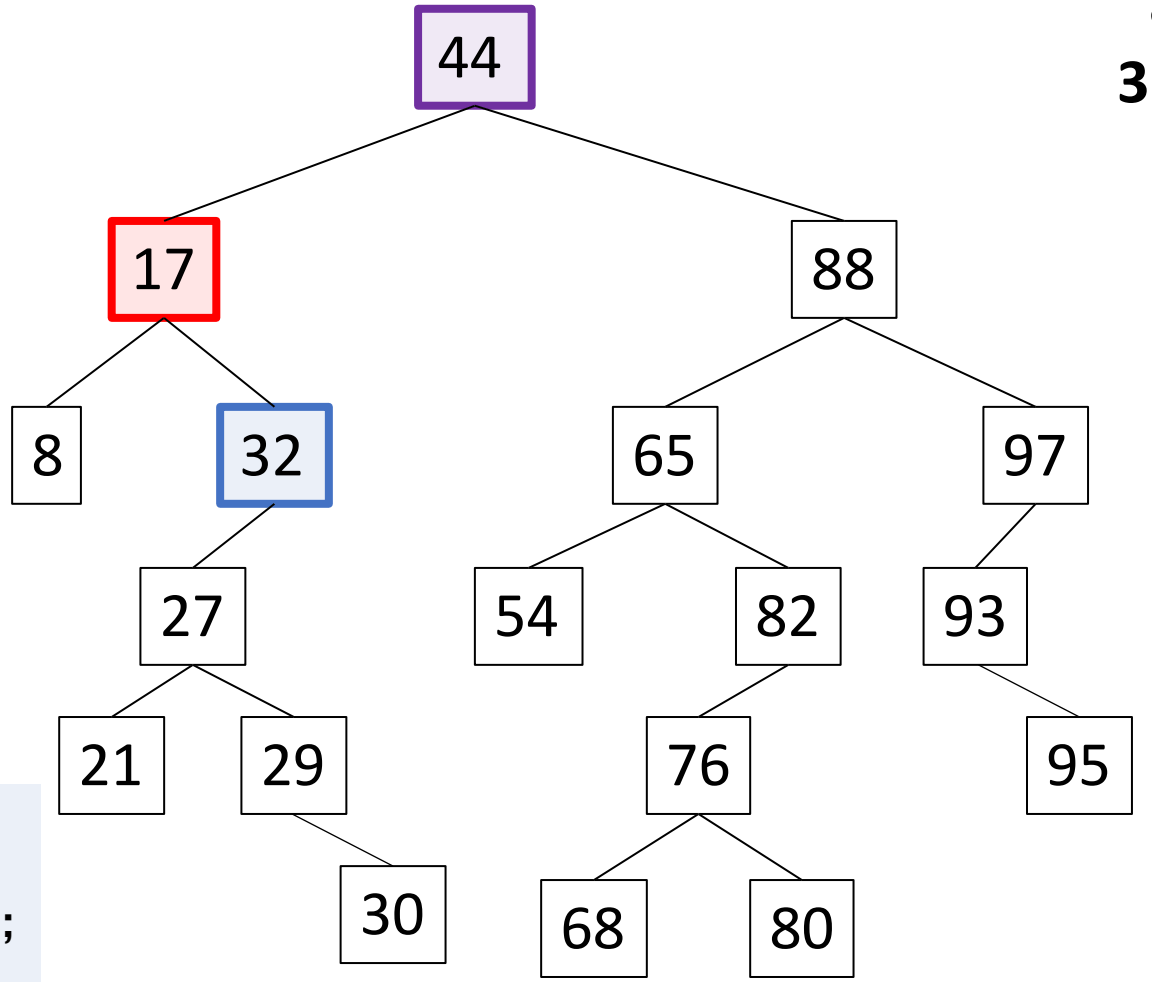
32

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44

17

8

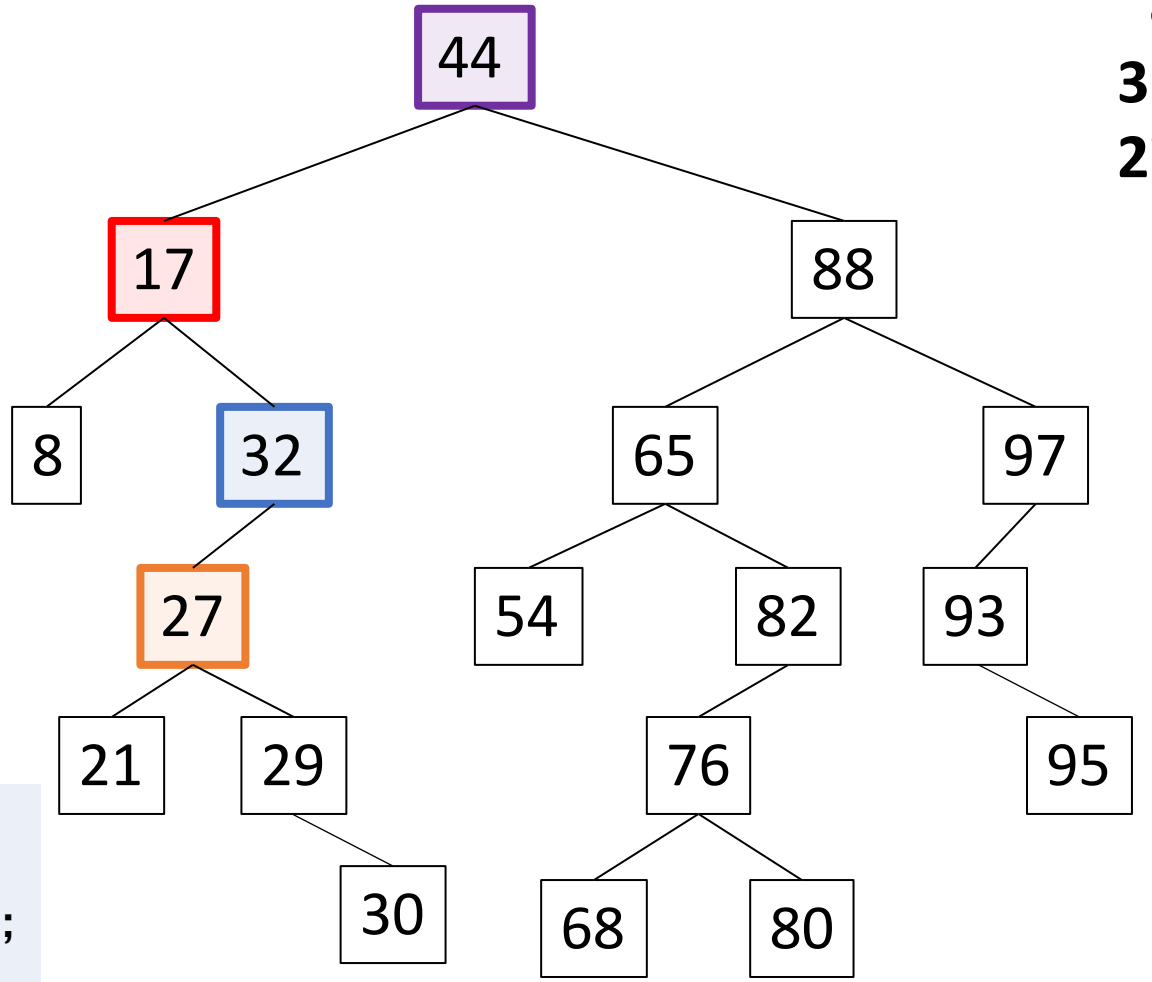
32

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

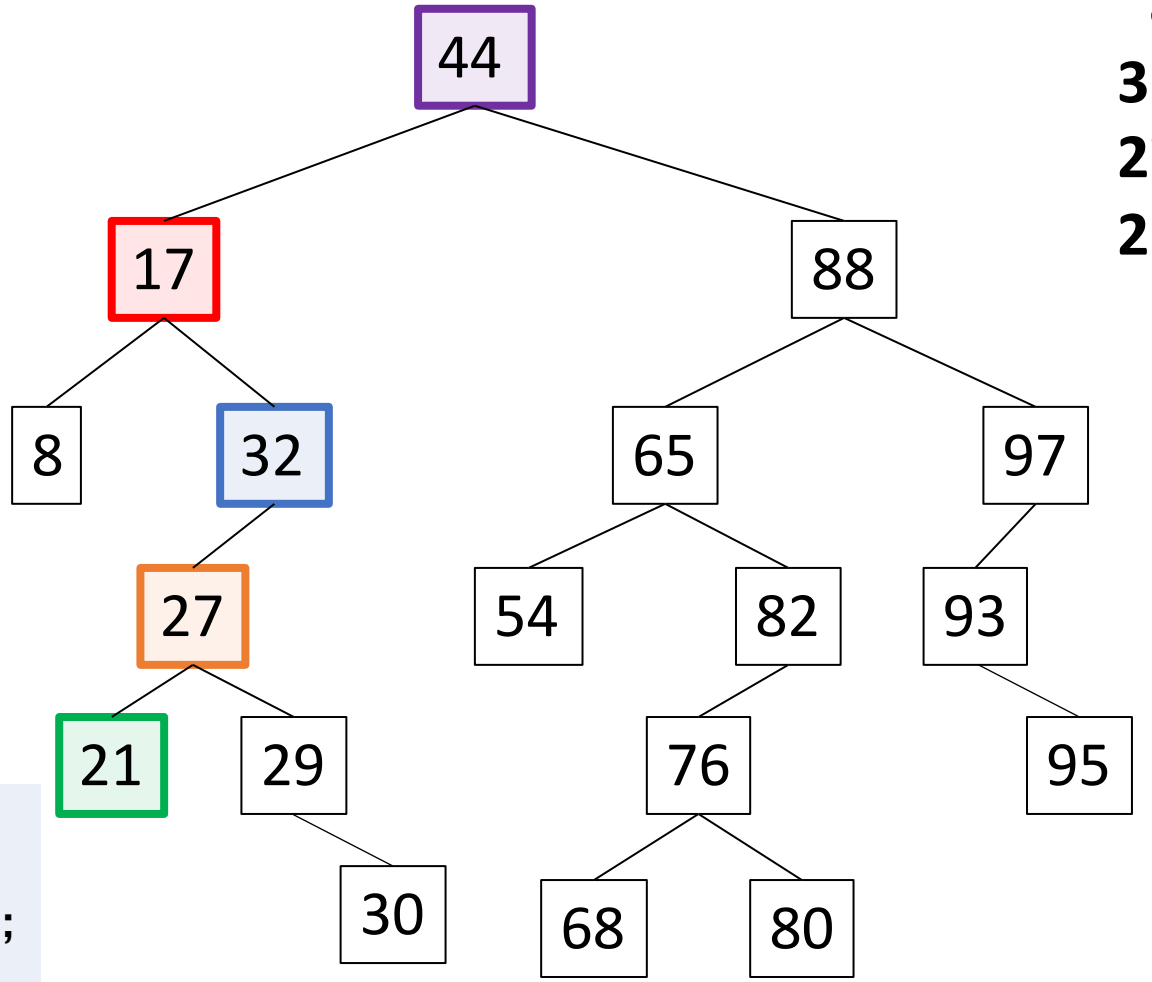
44
17
8
32
27

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

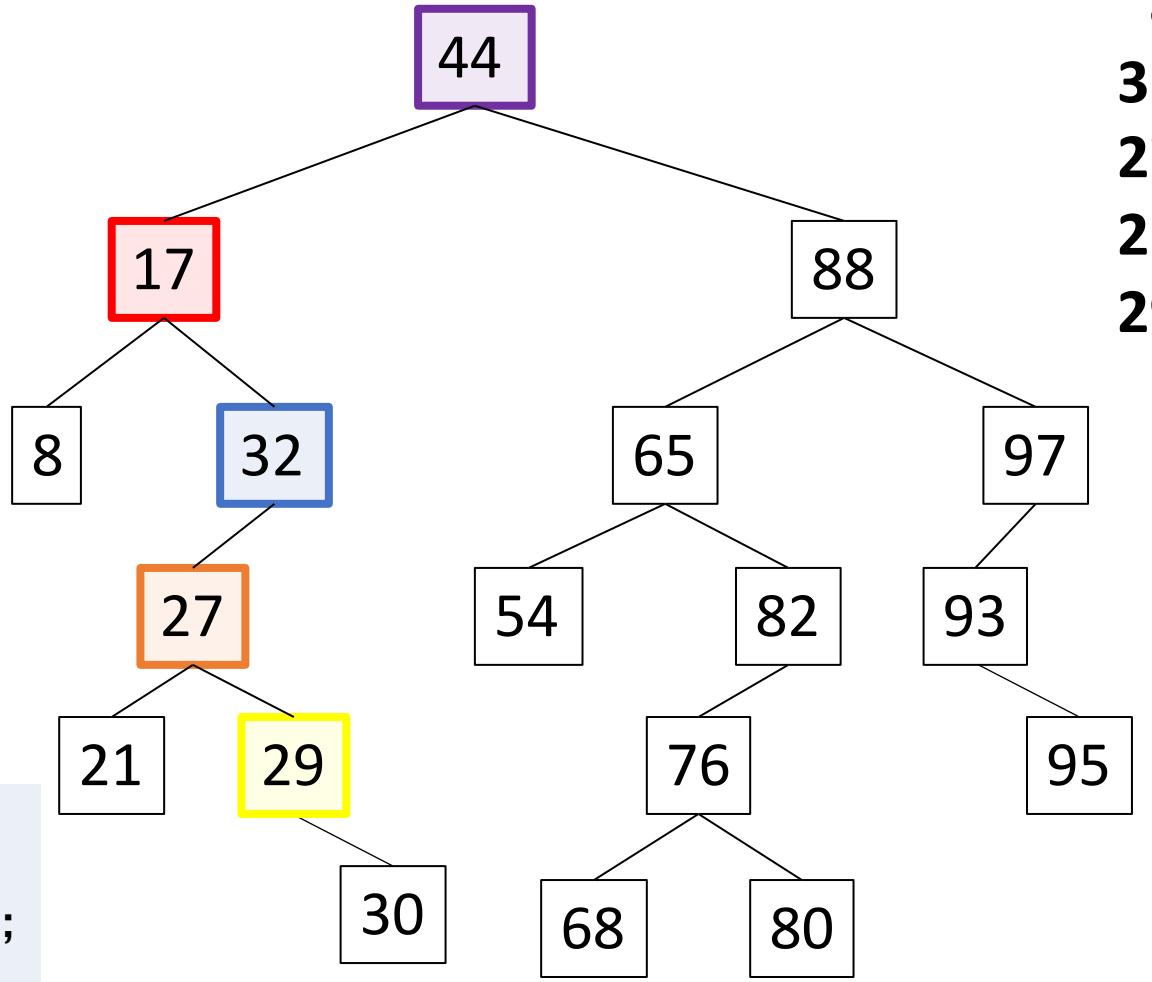
44
17
8
32
27
21

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

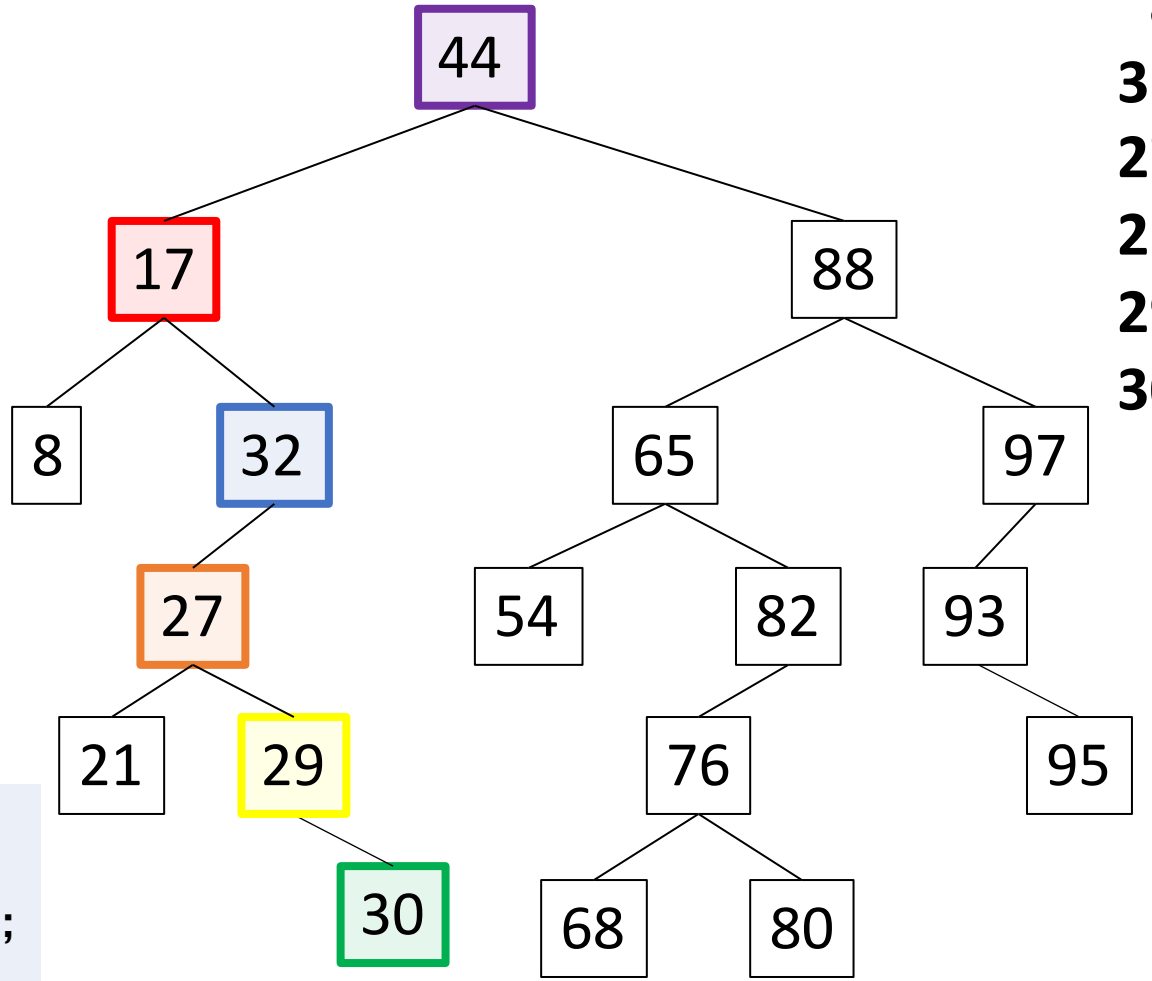
44
17
8
32
27
21
29

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

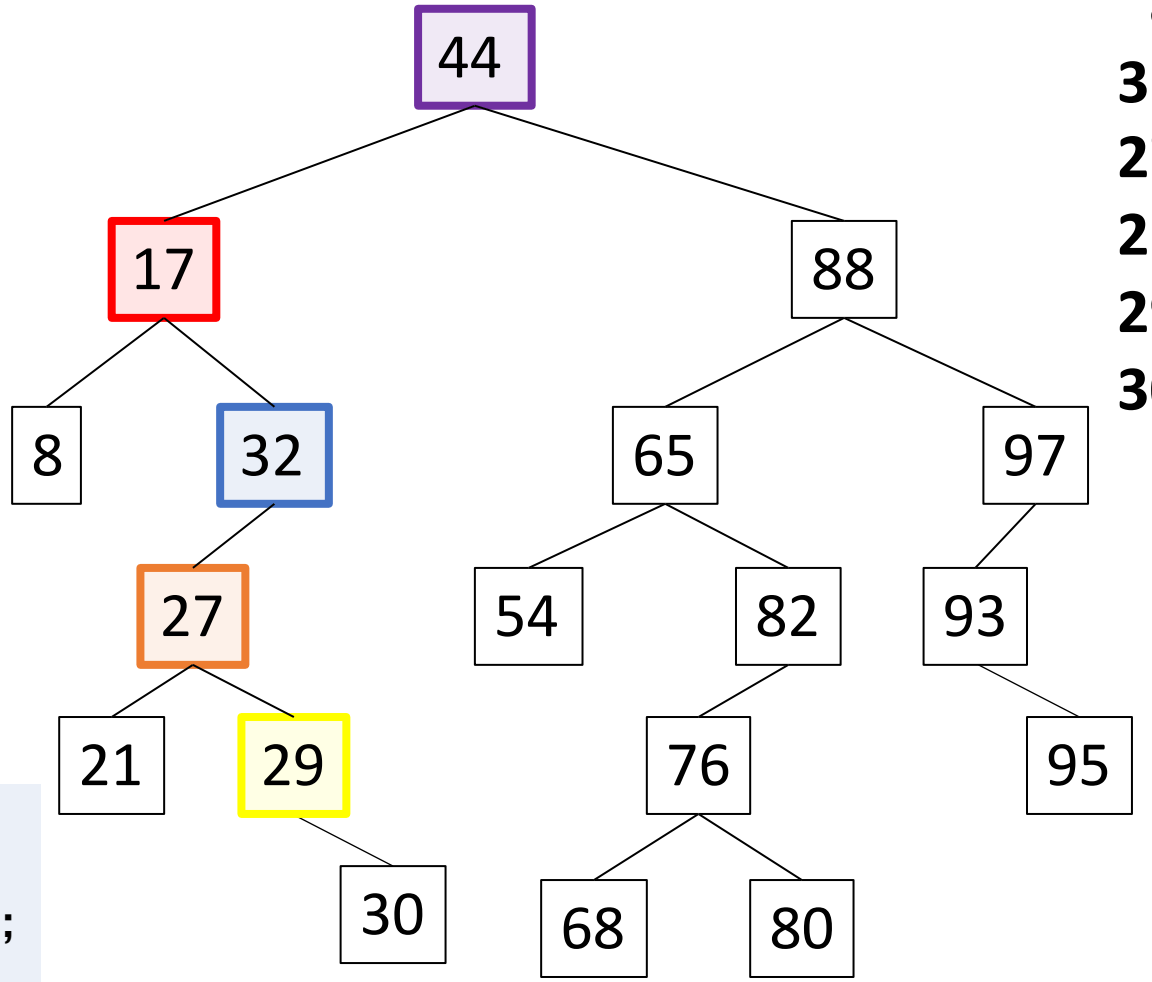
44
17
8
32
27
21
29
30

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44
17
8
32
27
21
29
30

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
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    if (n != null) {
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        depthFirst(n.getRight());
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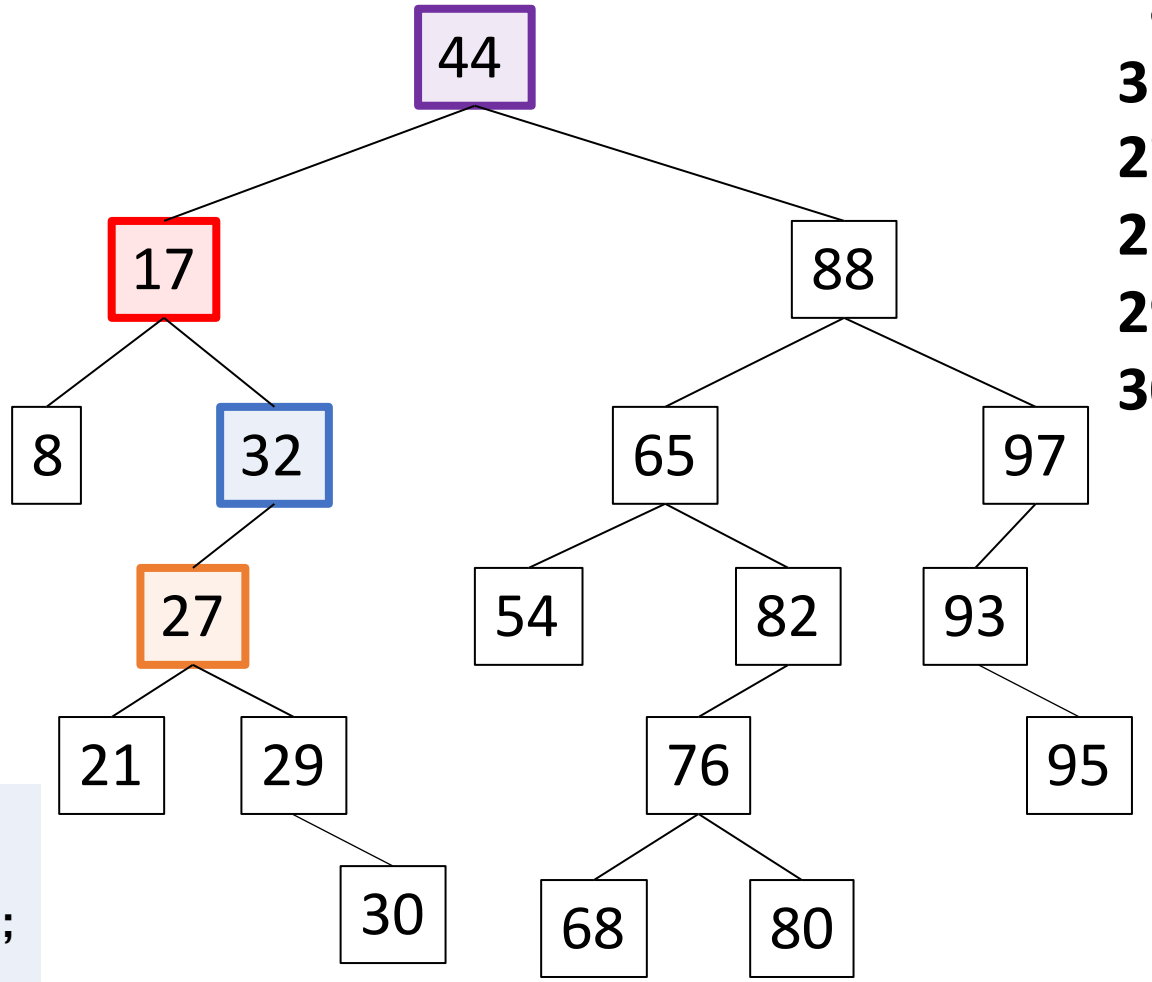
```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44
17
8
32
27
21
29
30

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
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```
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        System.out.println(n.getValue());
        depthFirst(n.getLeft());
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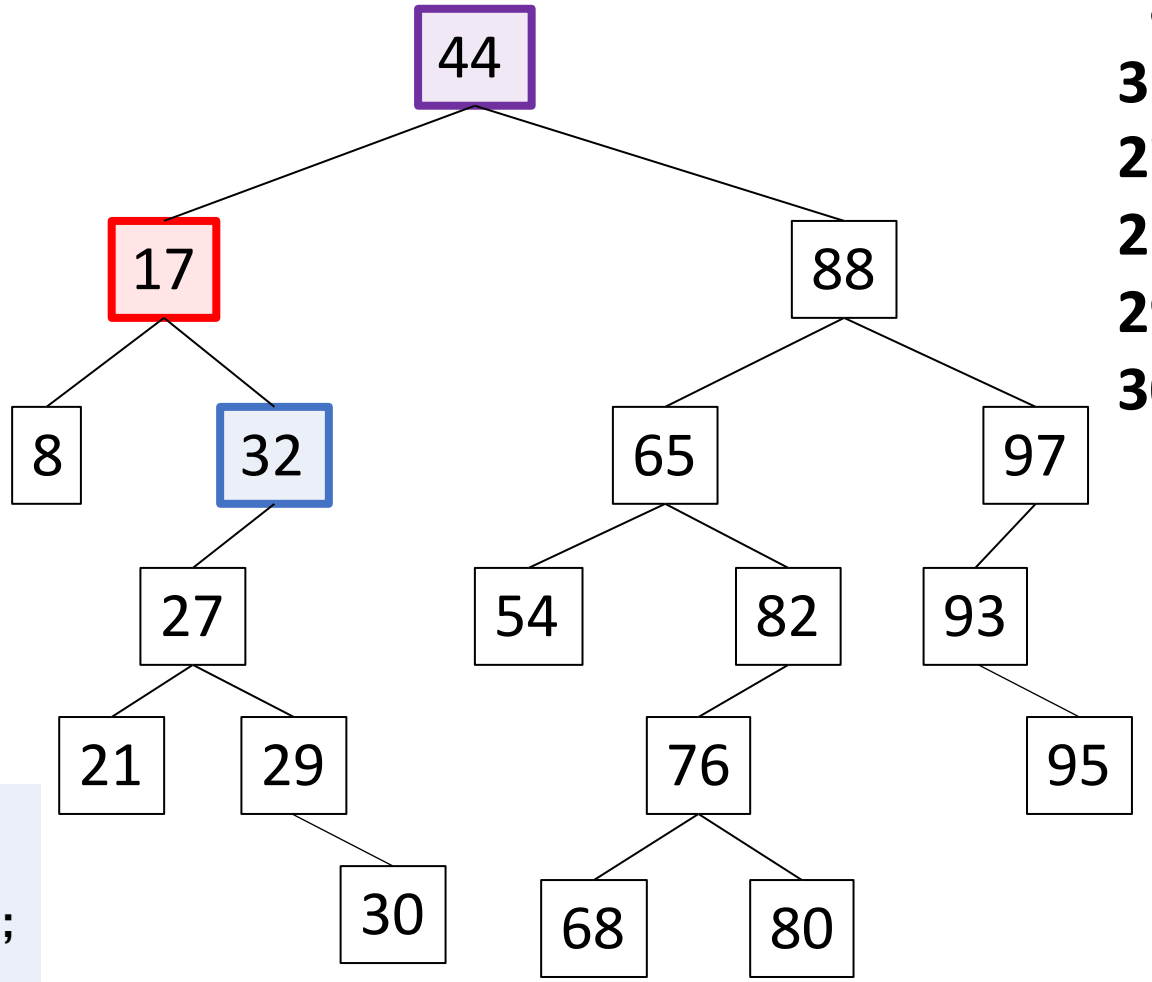
    }
}
```

```
public void depthFirst(32) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44
17
8
32
27
21
29
30

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
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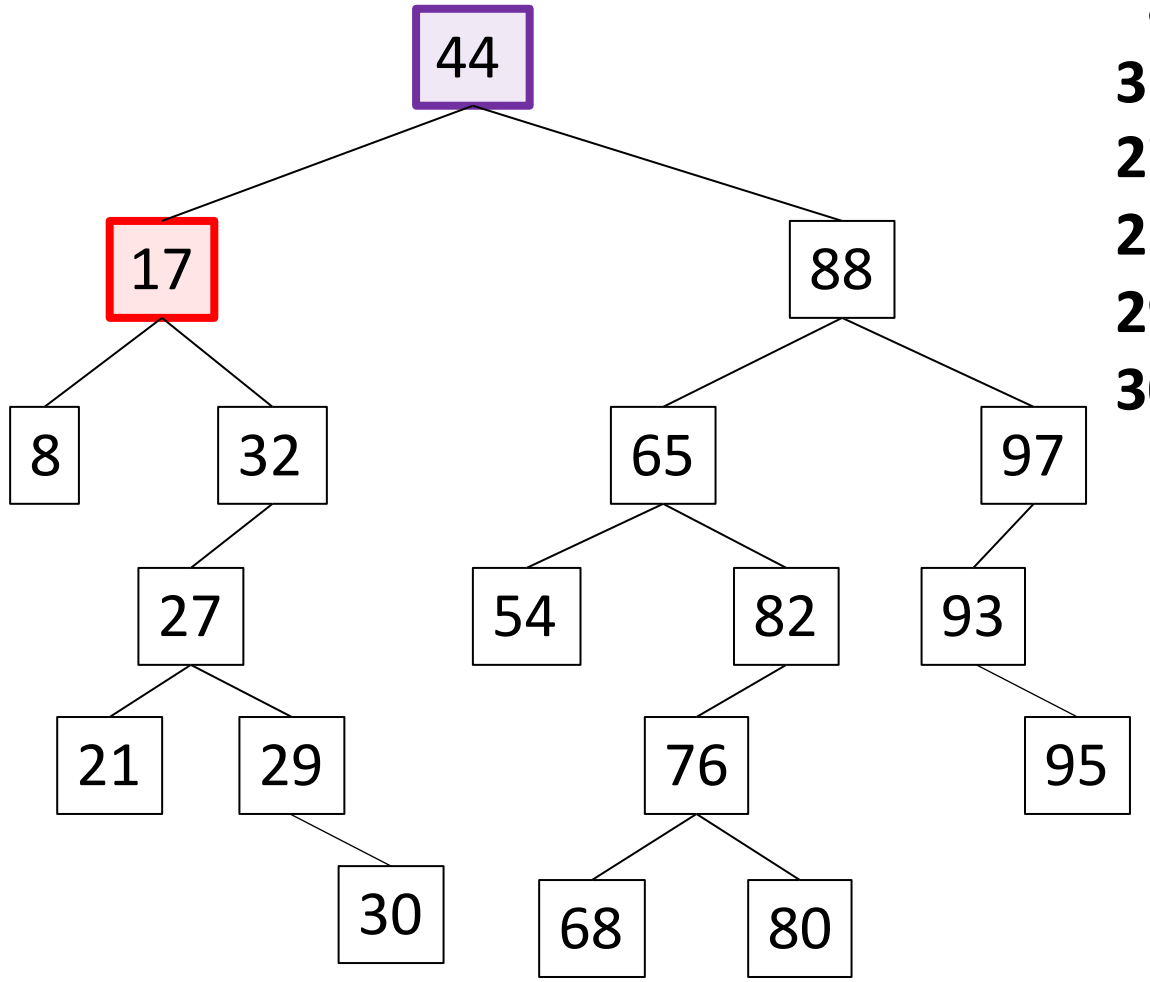
```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

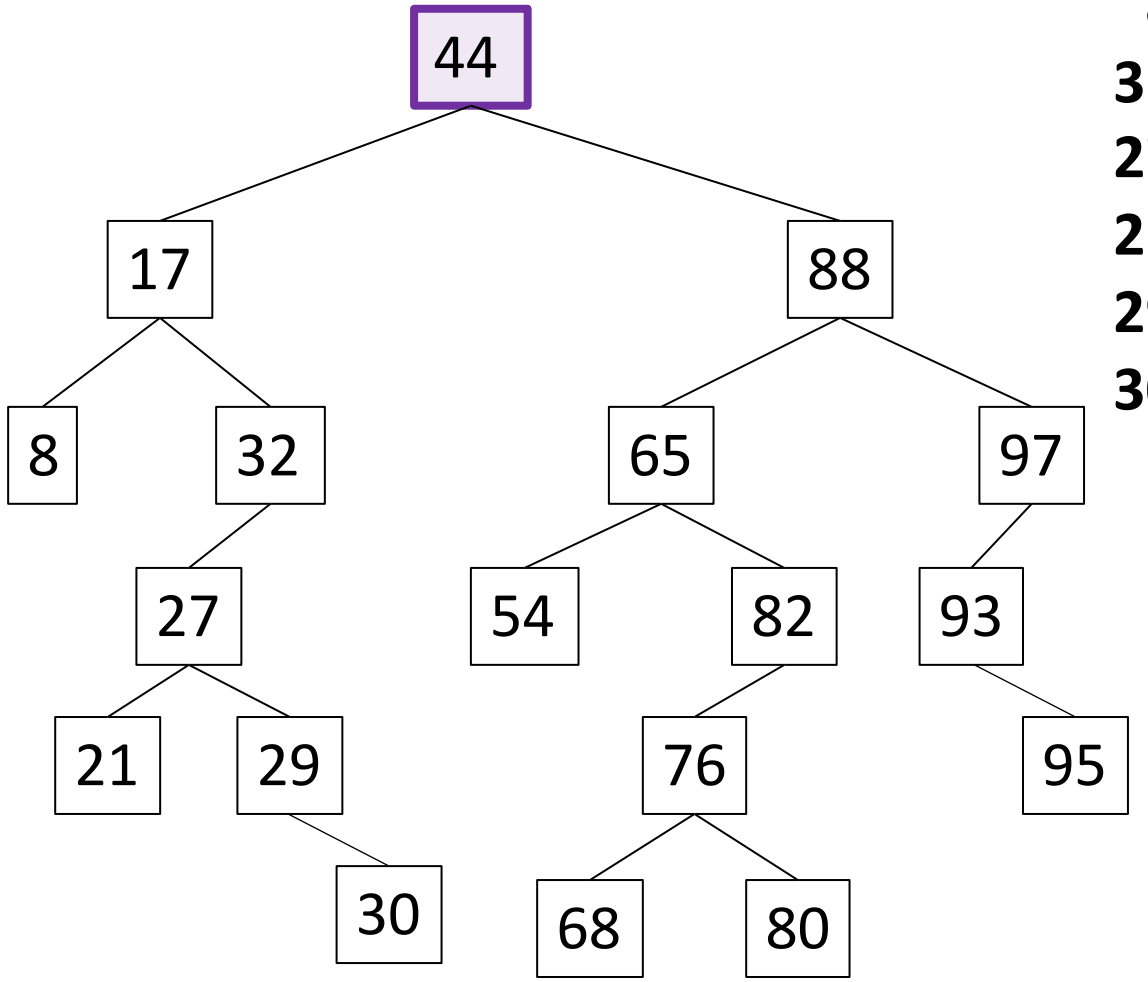


Output:

44
17
8
32
27
21
29
30

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

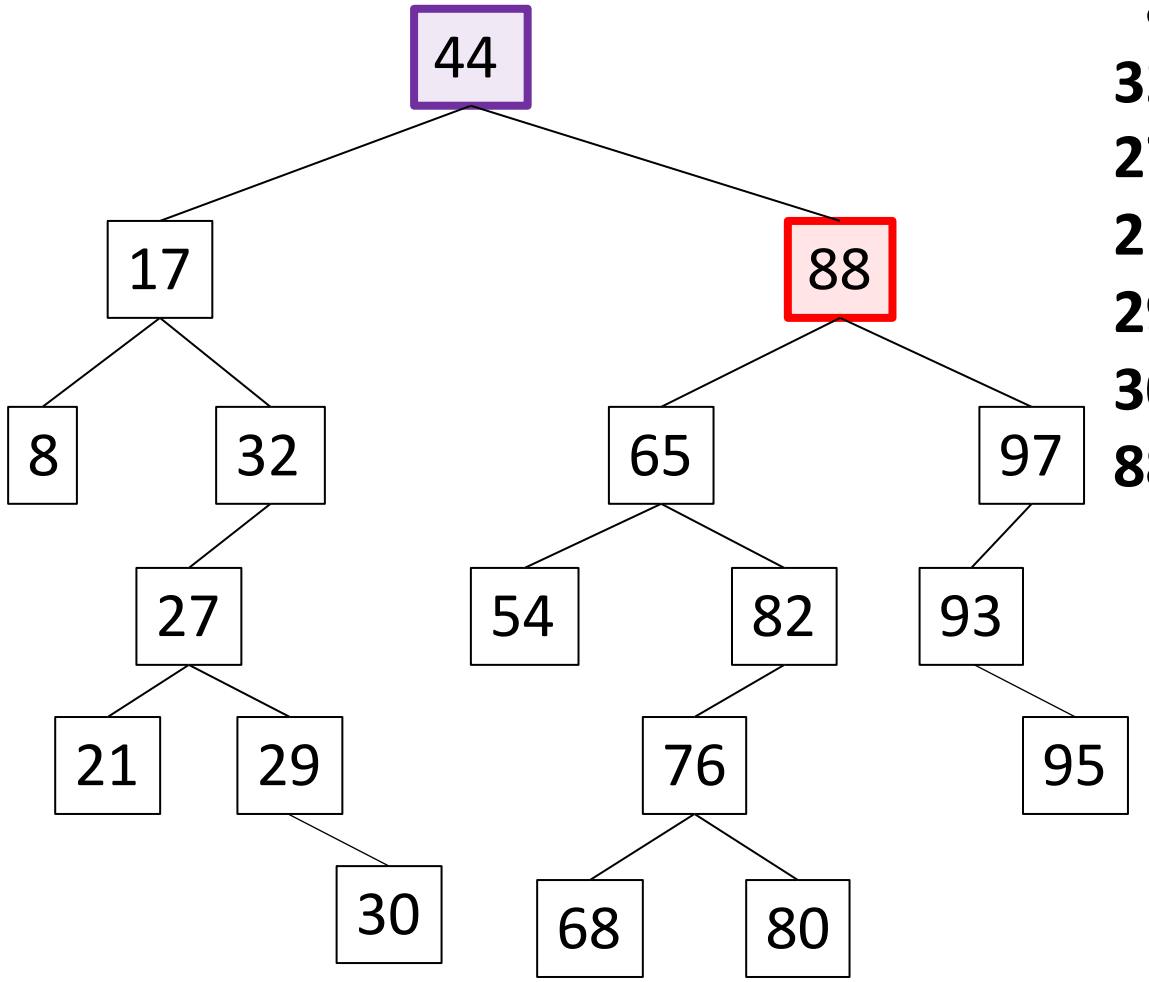


Output:

44
17
8
32
27
21
29
30

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

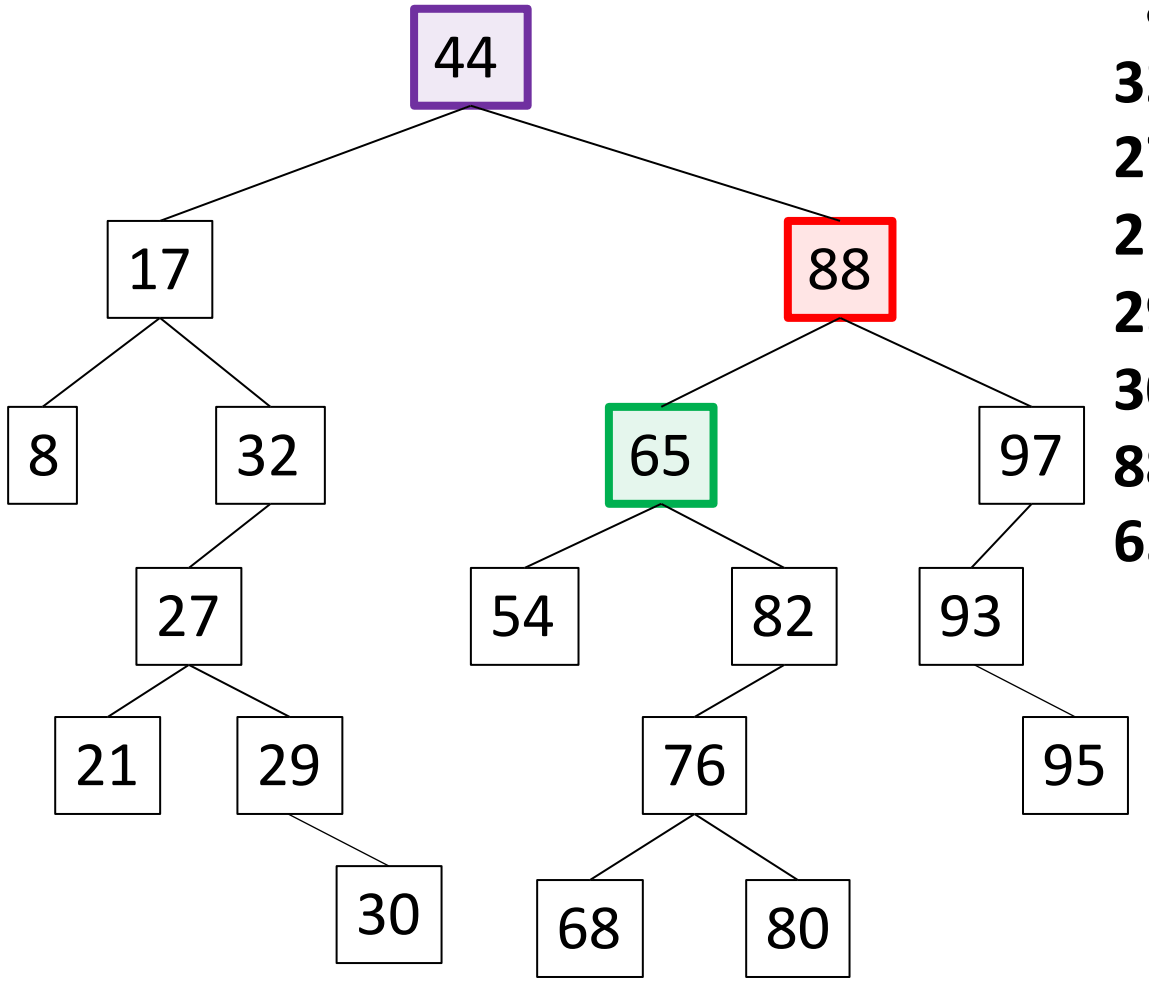


Output:

44
17
8
32
27
21
29
30
88

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

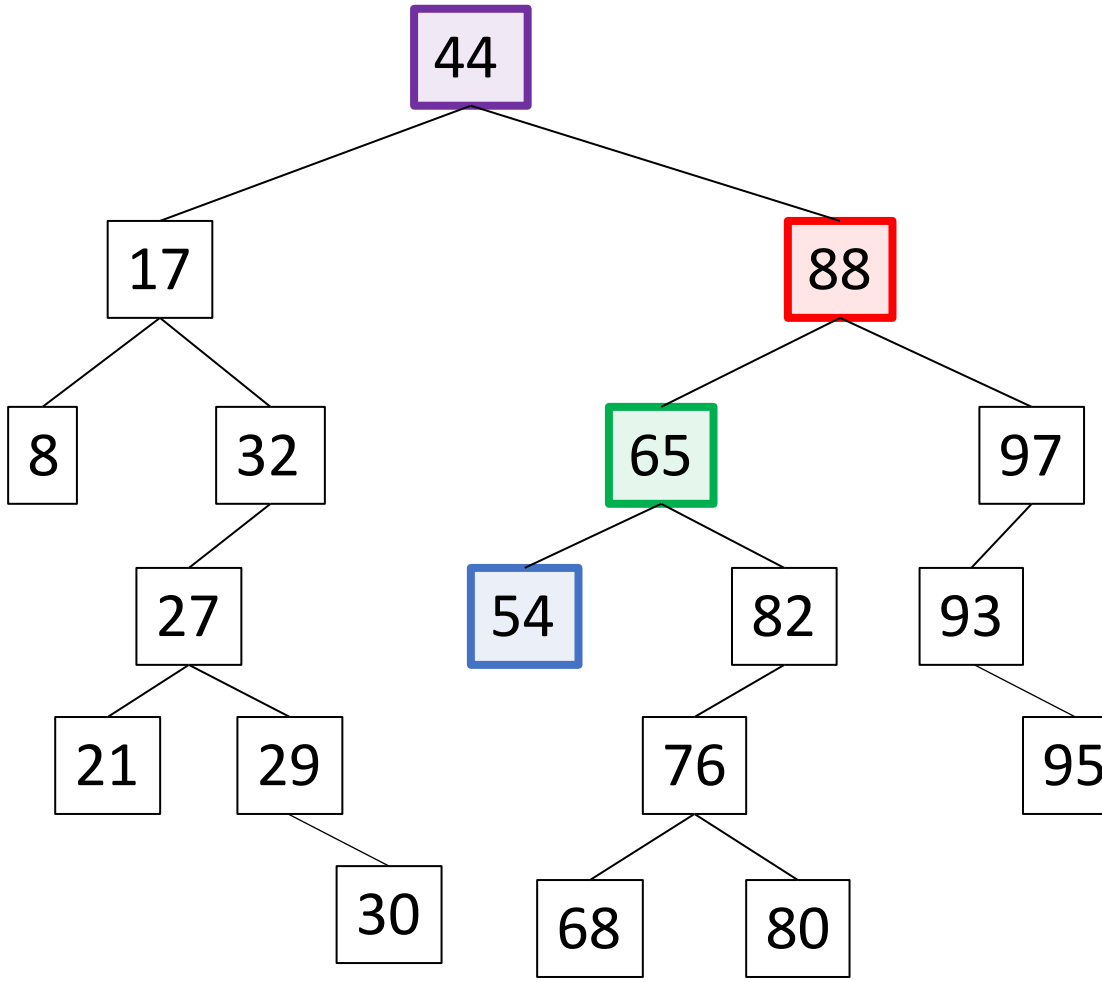


Output:

44
17
8
32
27
21
29
30
88
65

Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Output:

44
17
8
32
27
21
29
30
88
65
54

Binary Search Tree - Traversal

Output:

44

17

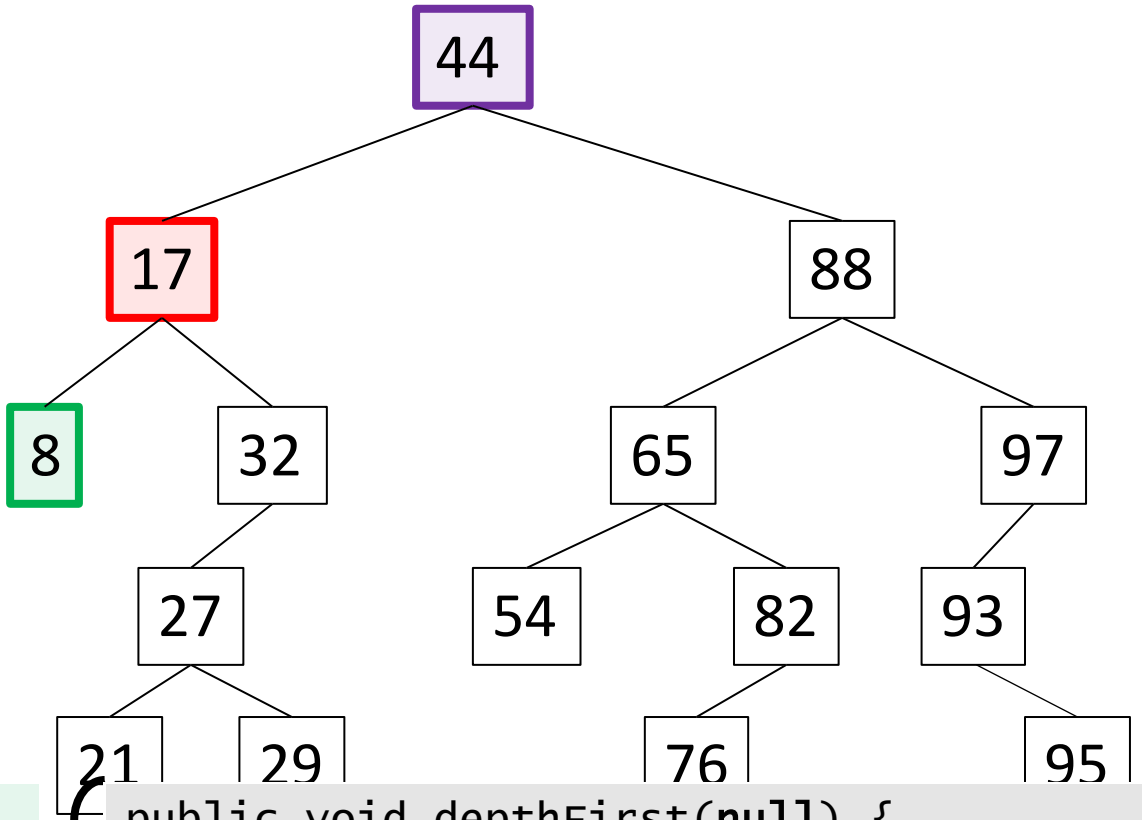
8

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(17) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

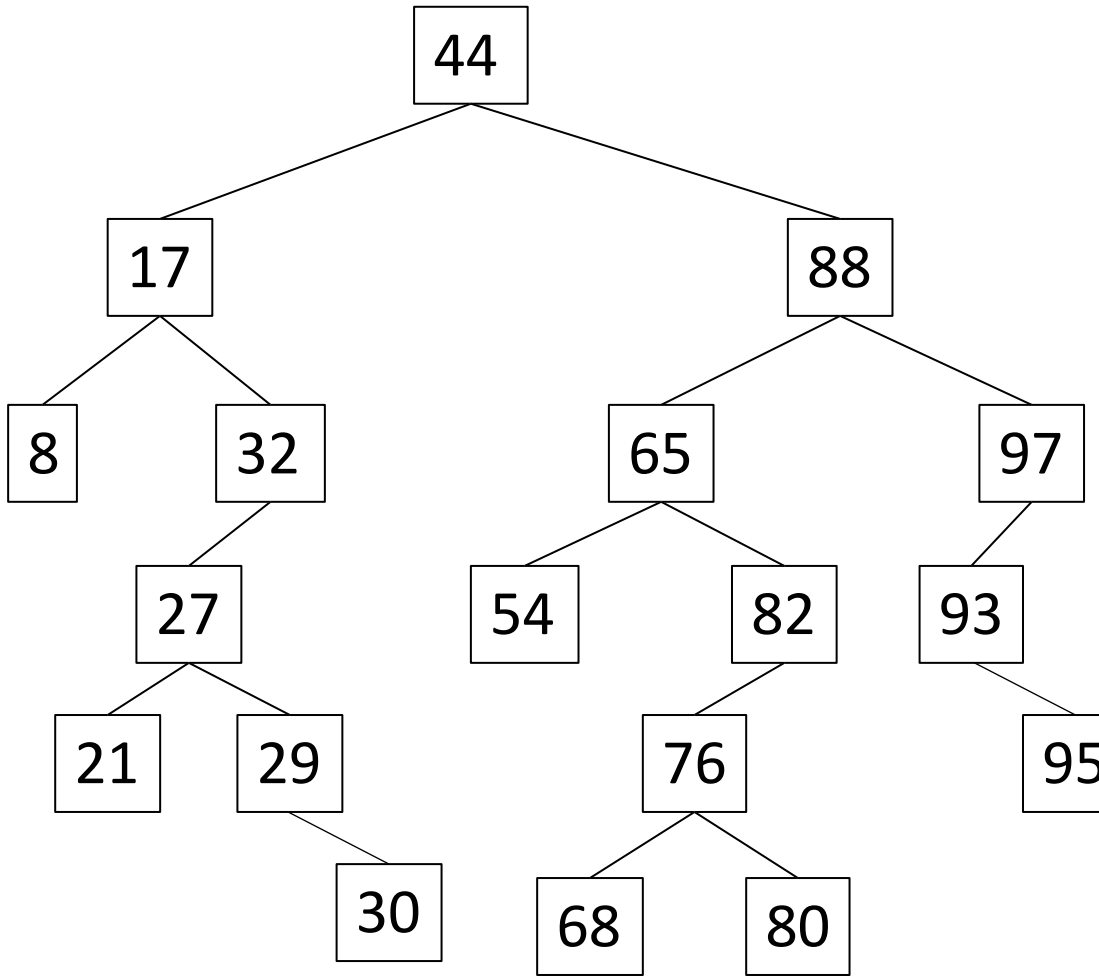
```
public void depthFirst(8) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

```
public void depthFirst(null) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



Binary Search Tree - Traversal

```
public void depthFirst(44) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```



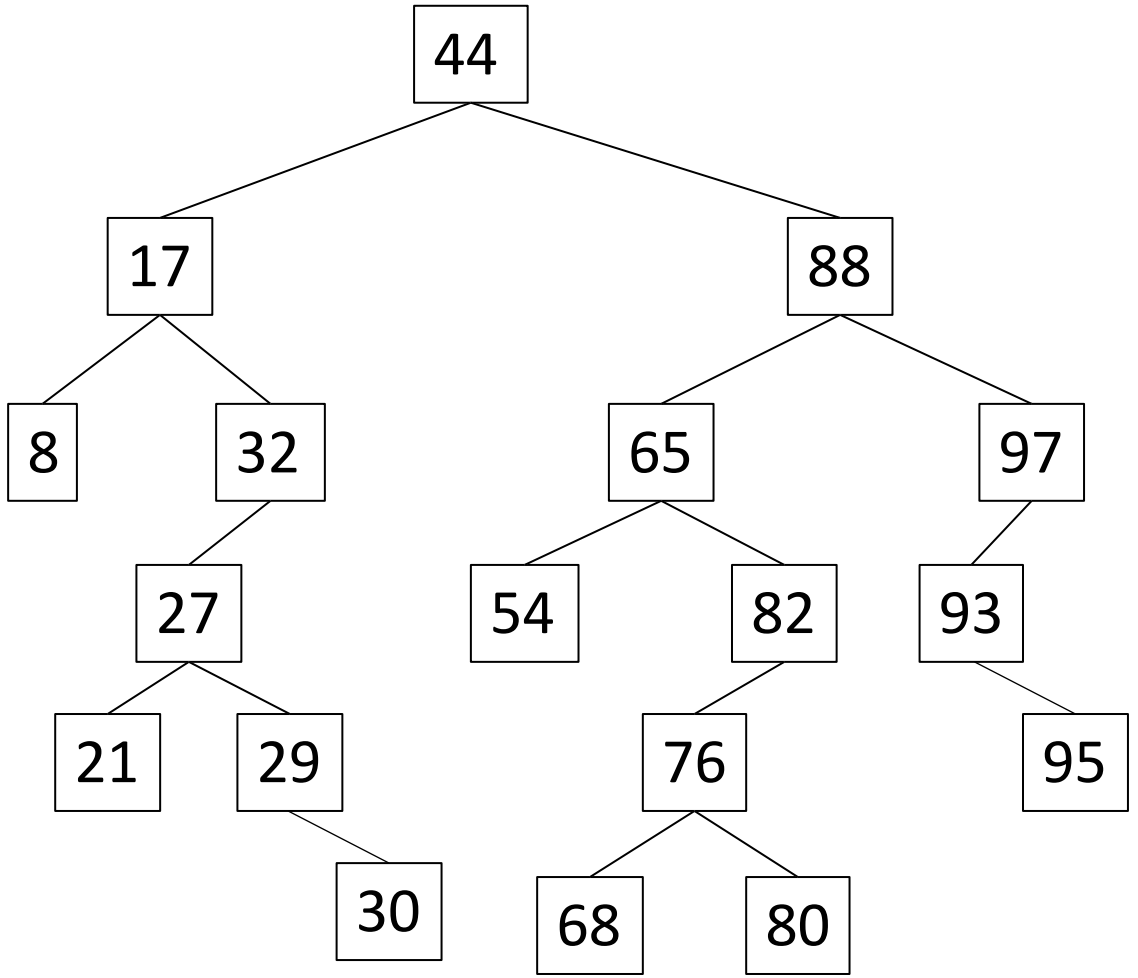
Output:

44
17
8
32
27
21
29
30
88
65
54
…

Output:

Binary Search Tree - Traversal

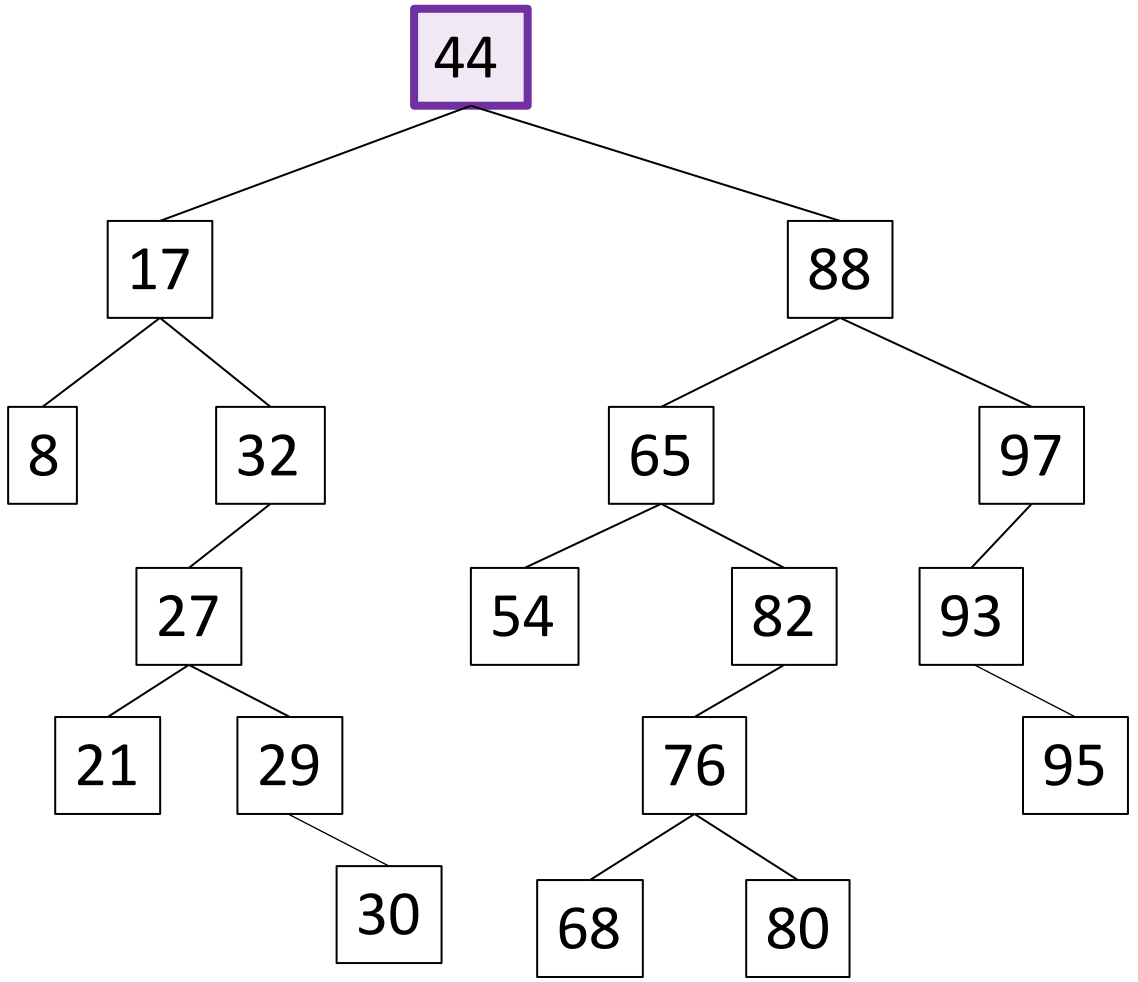
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



Output:

Binary Search Tree - Traversal

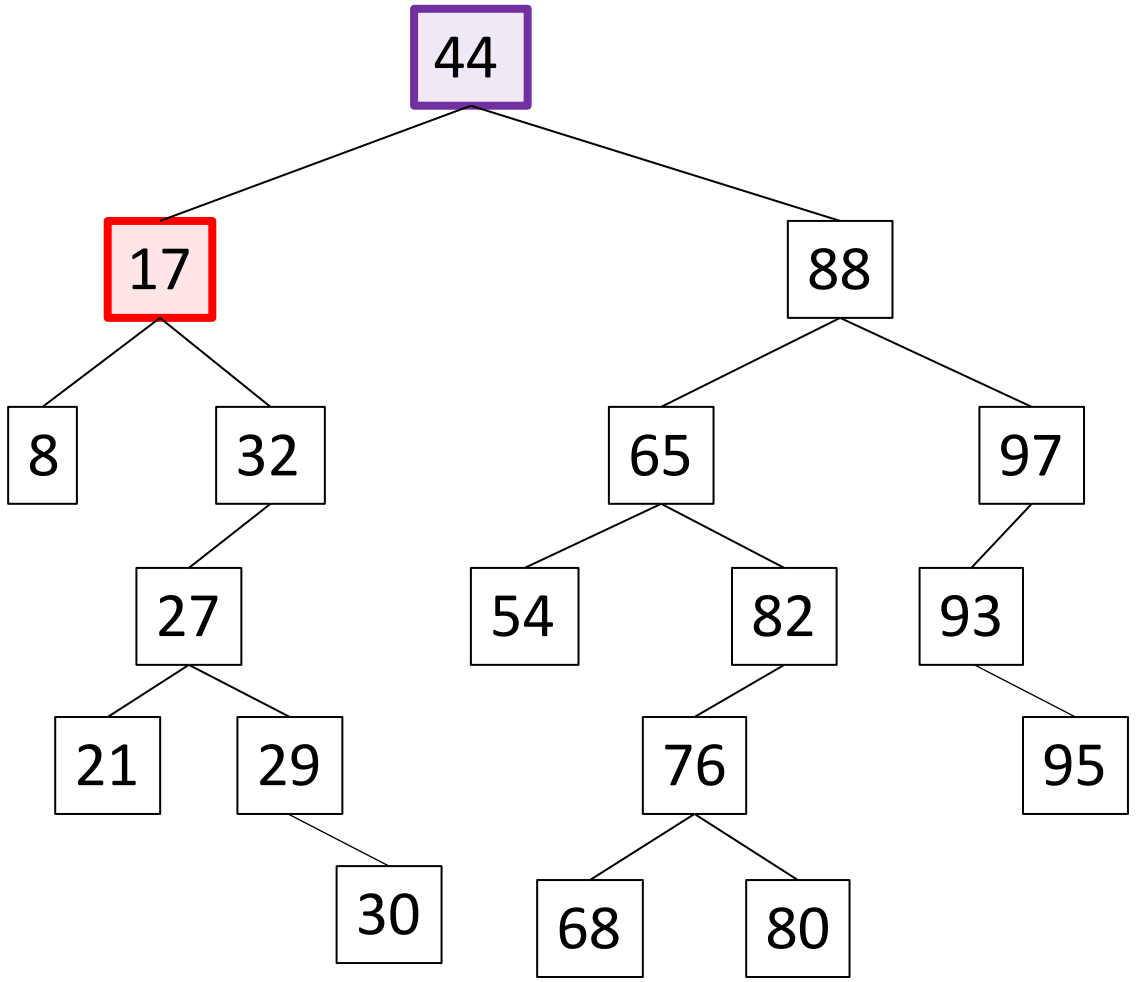
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



Output:

Binary Search Tree - Traversal

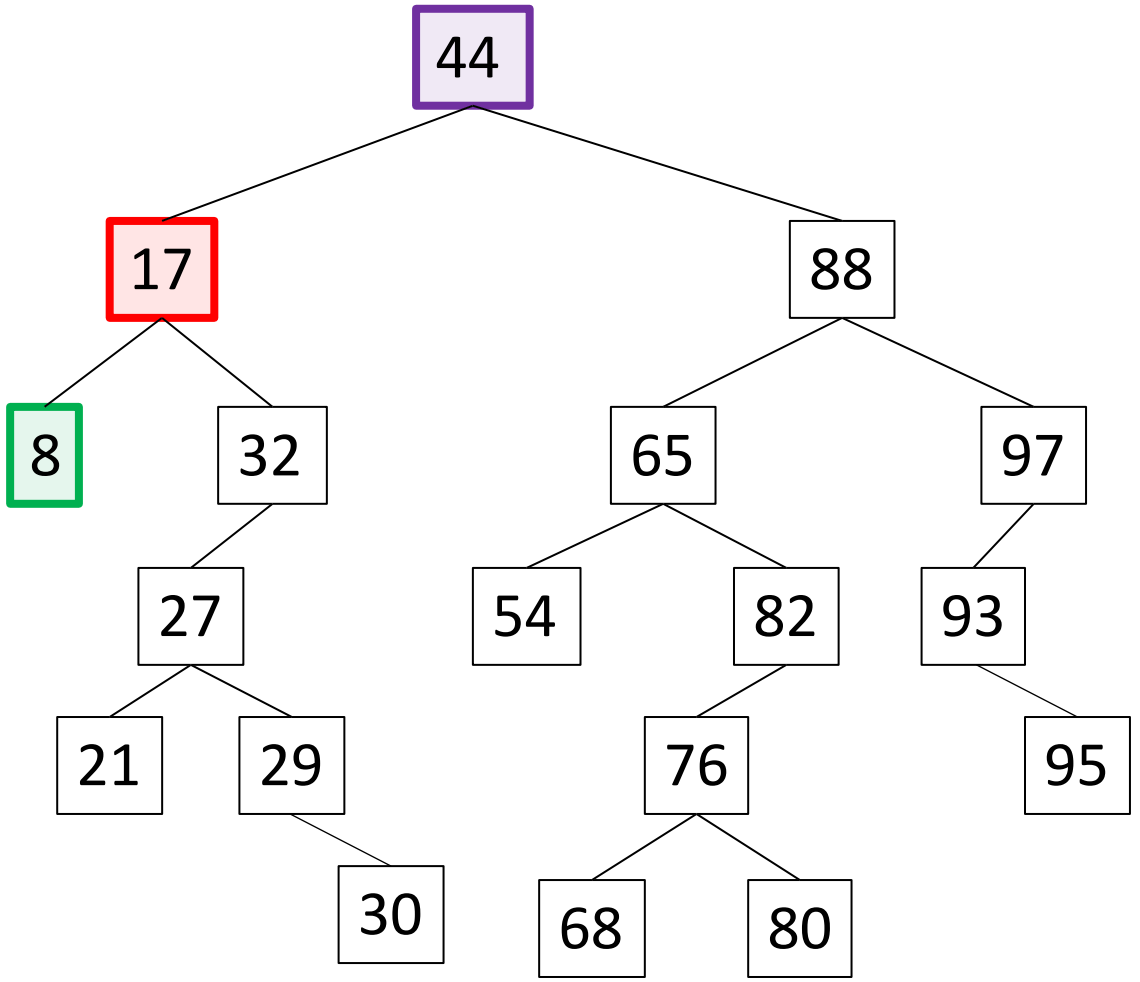
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



Output:

Binary Search Tree - Traversal

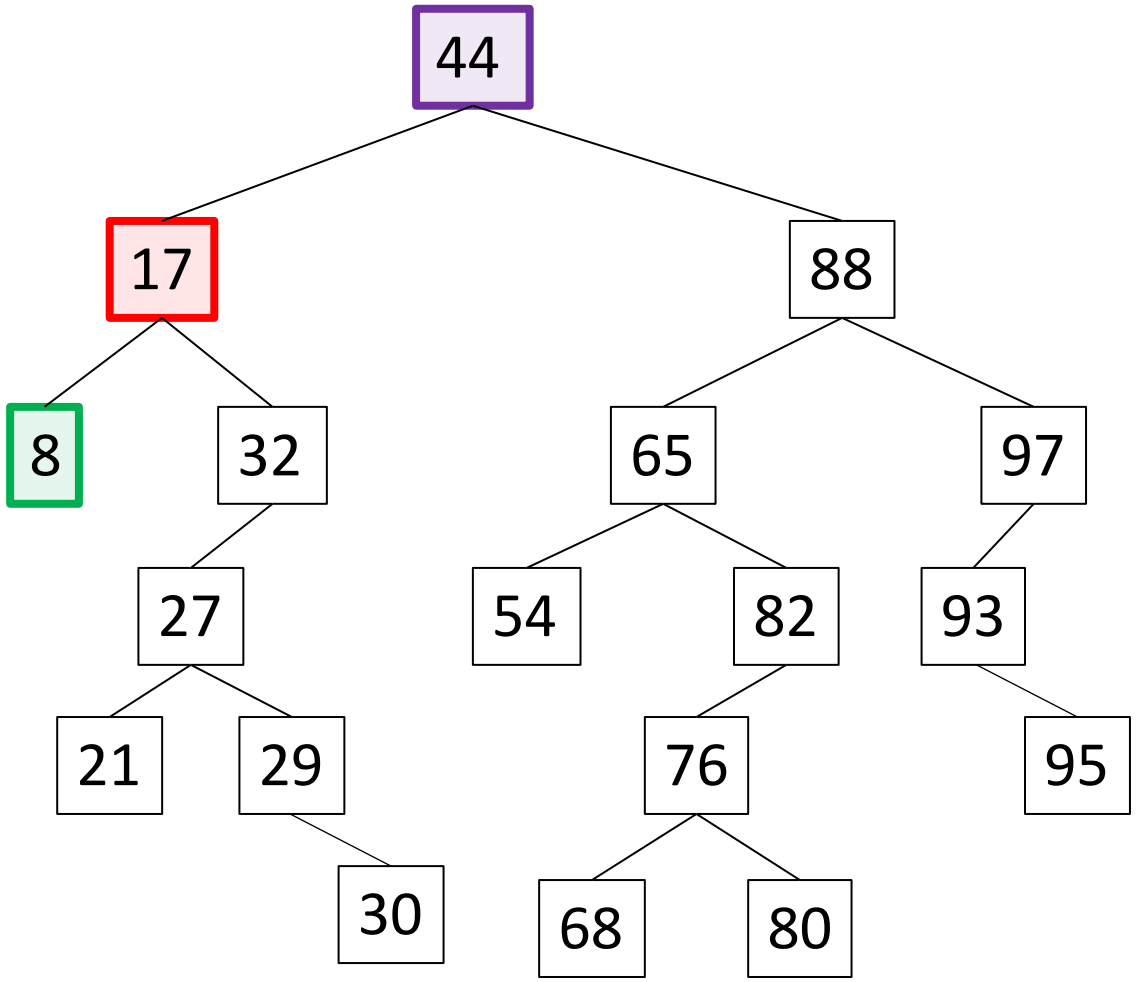
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



Output:
8

Binary Search Tree - Traversal

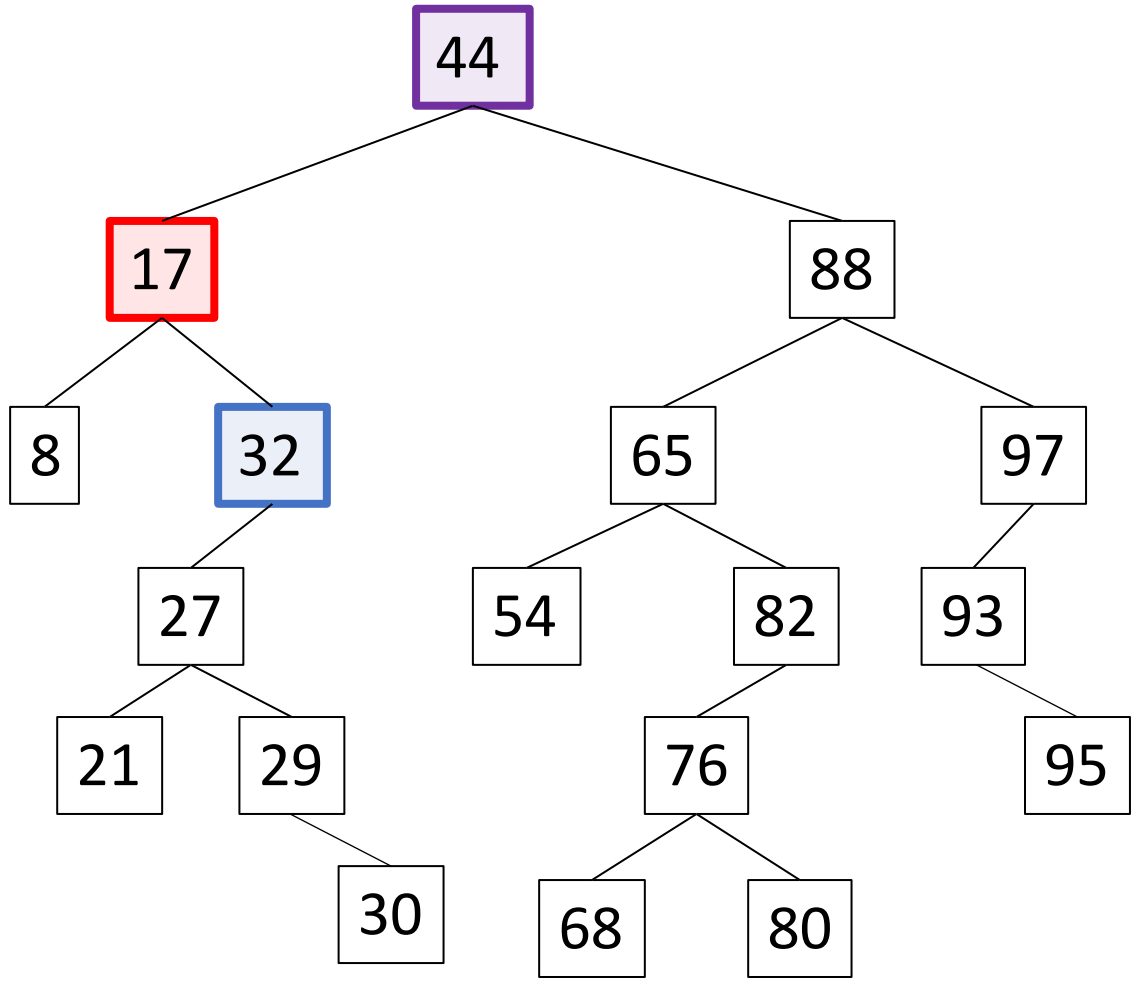
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



Output:
8

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

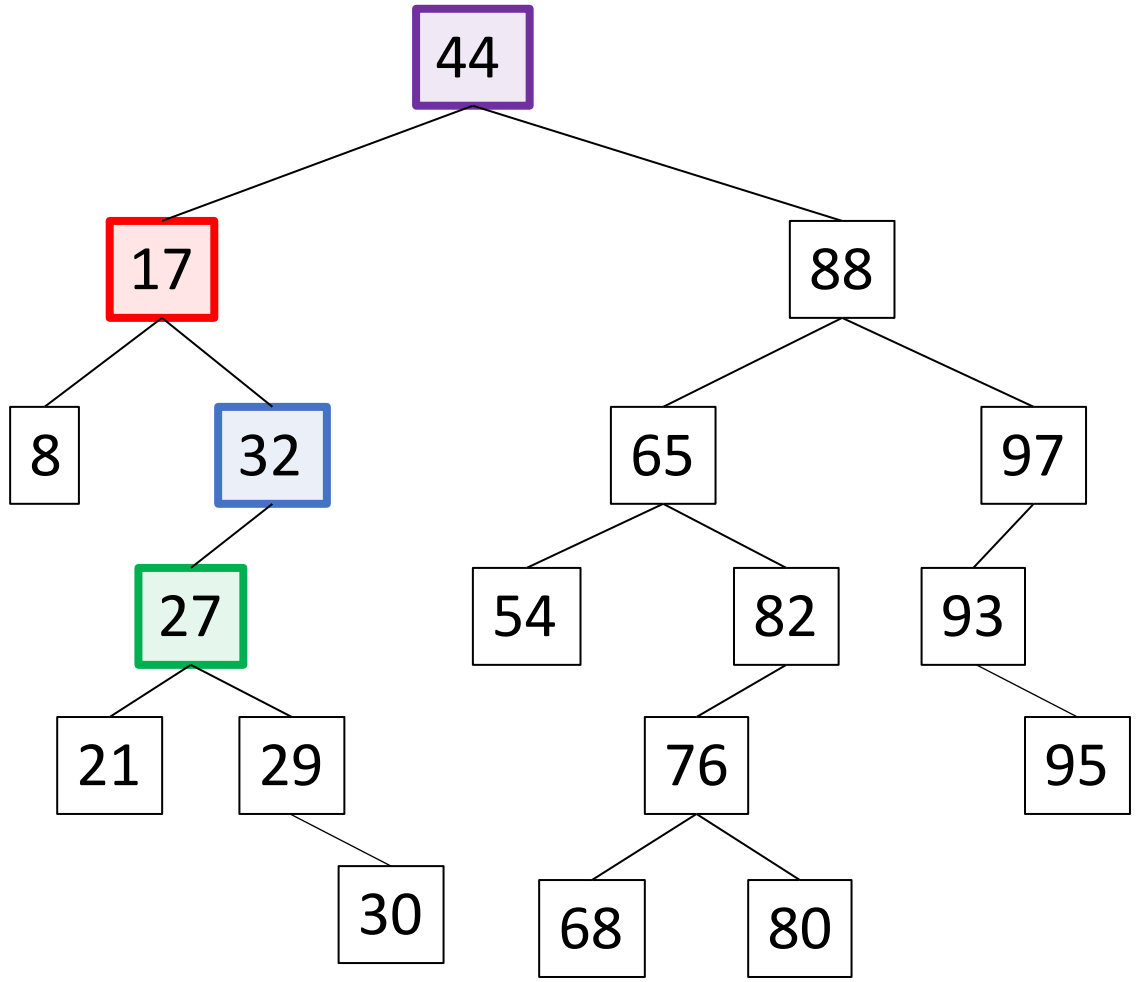


Output:

8

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

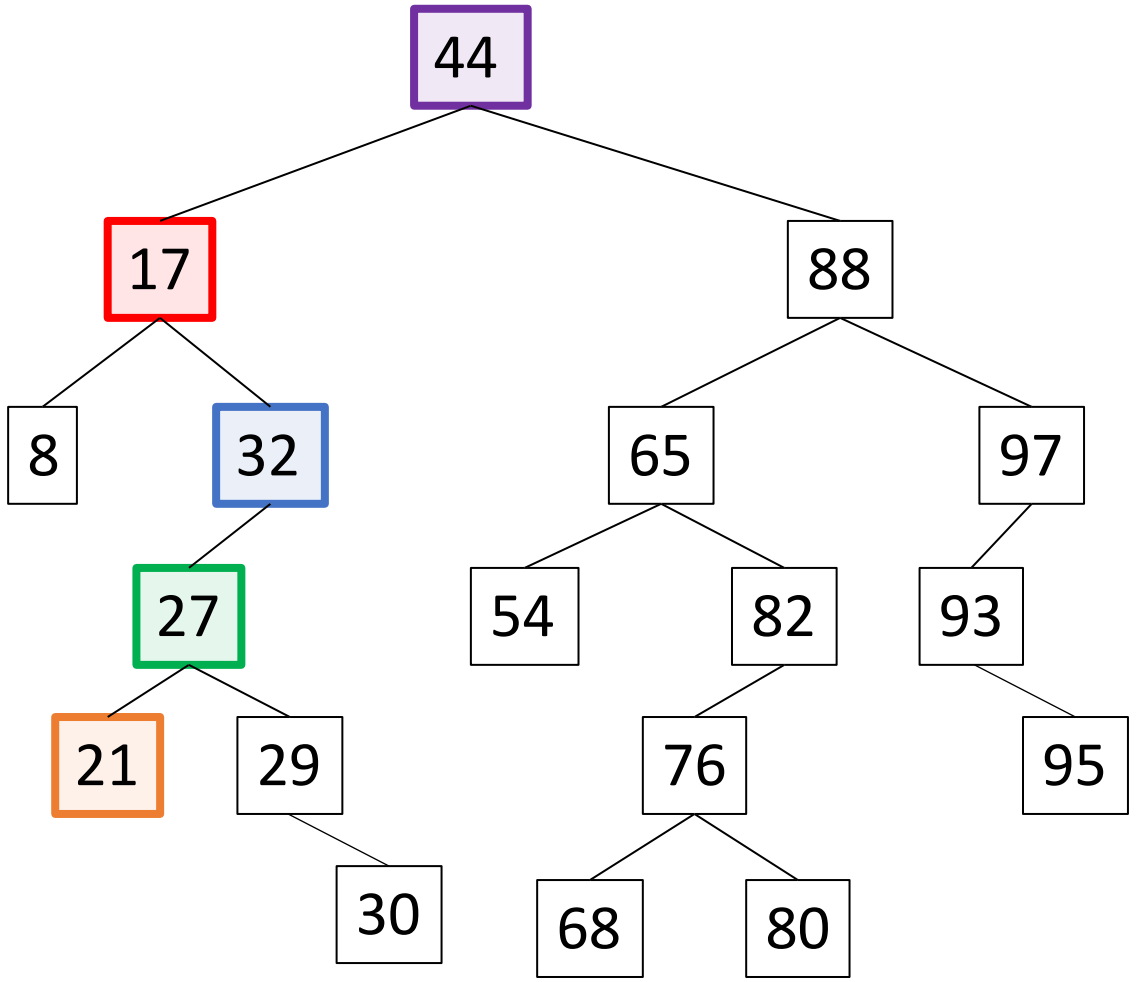


Output:

8

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



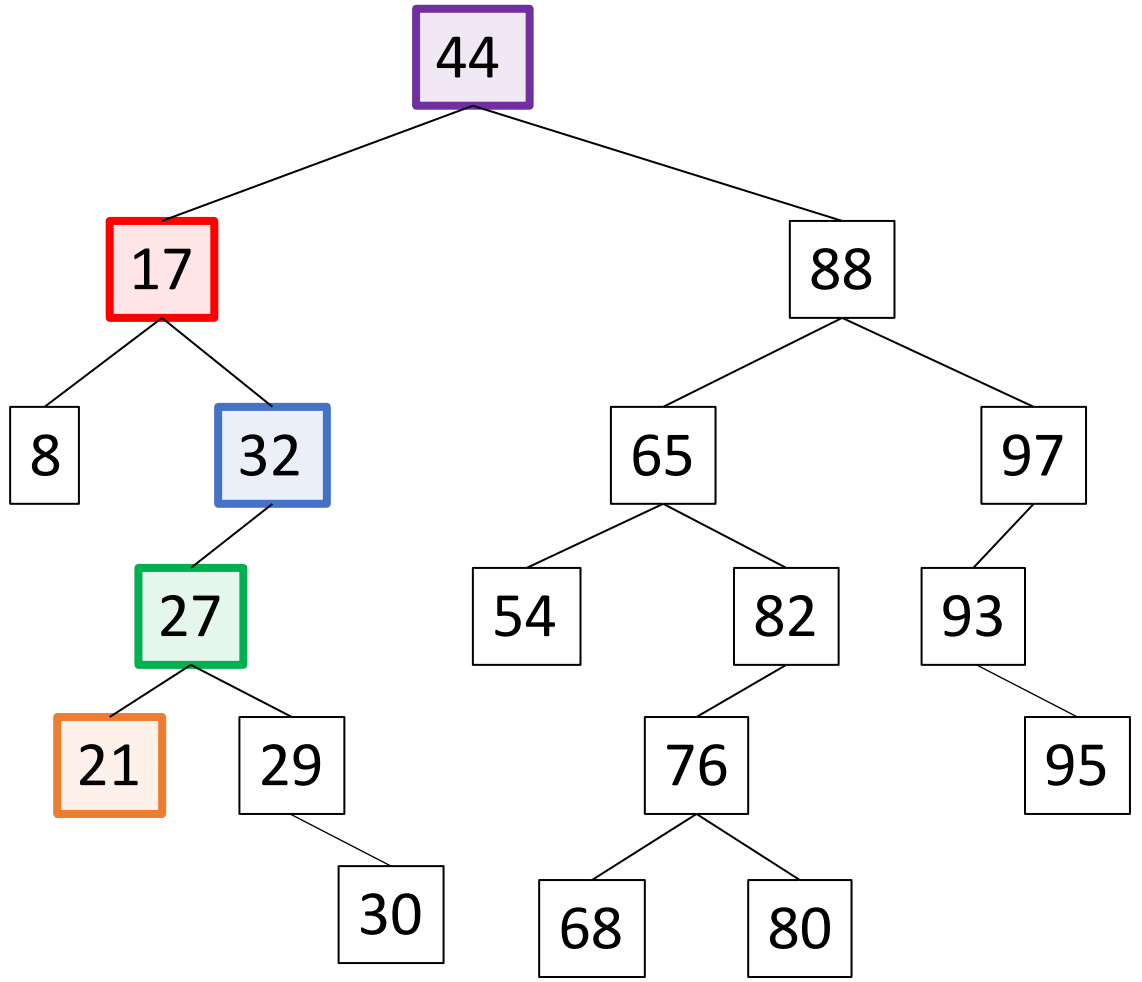
Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Output:

8

21



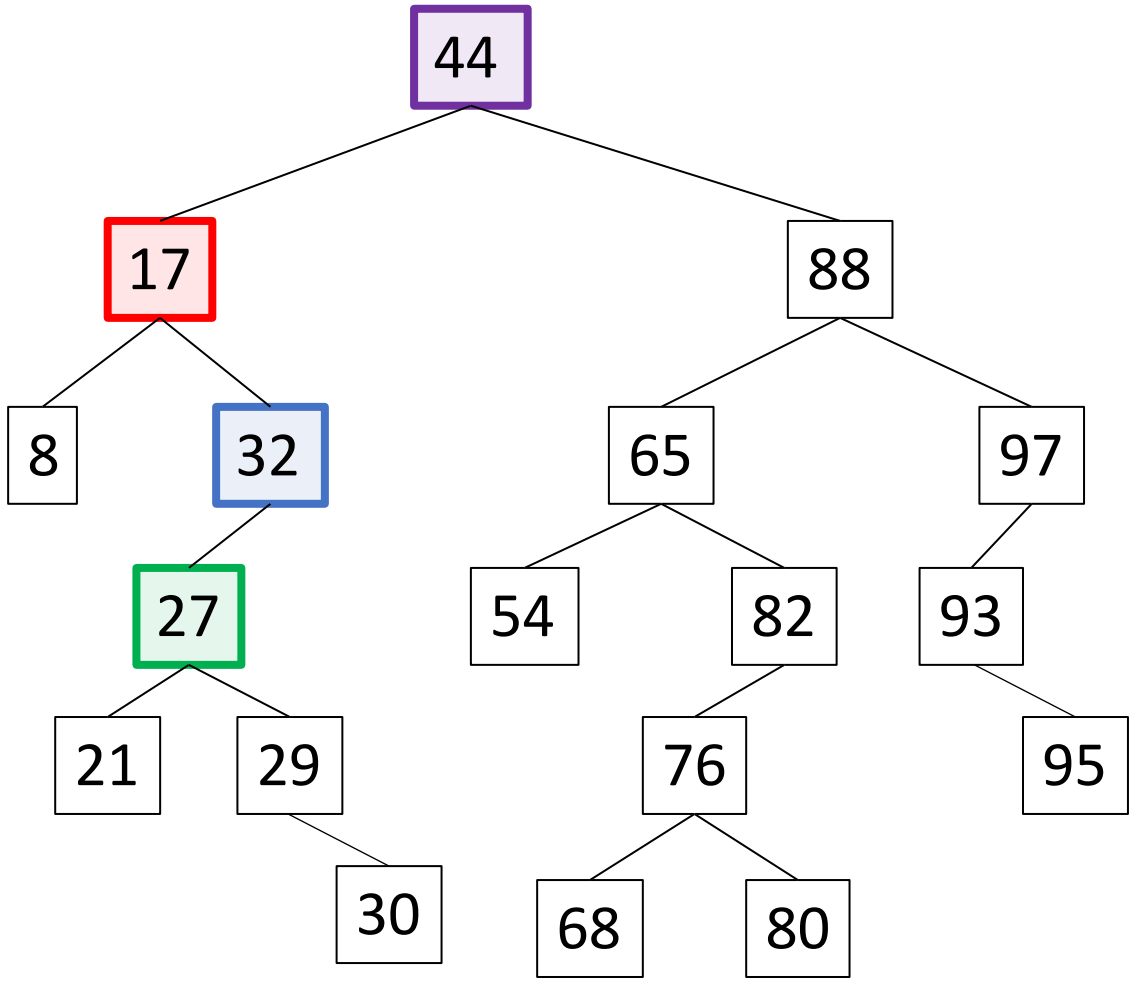
Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Output:

8

21



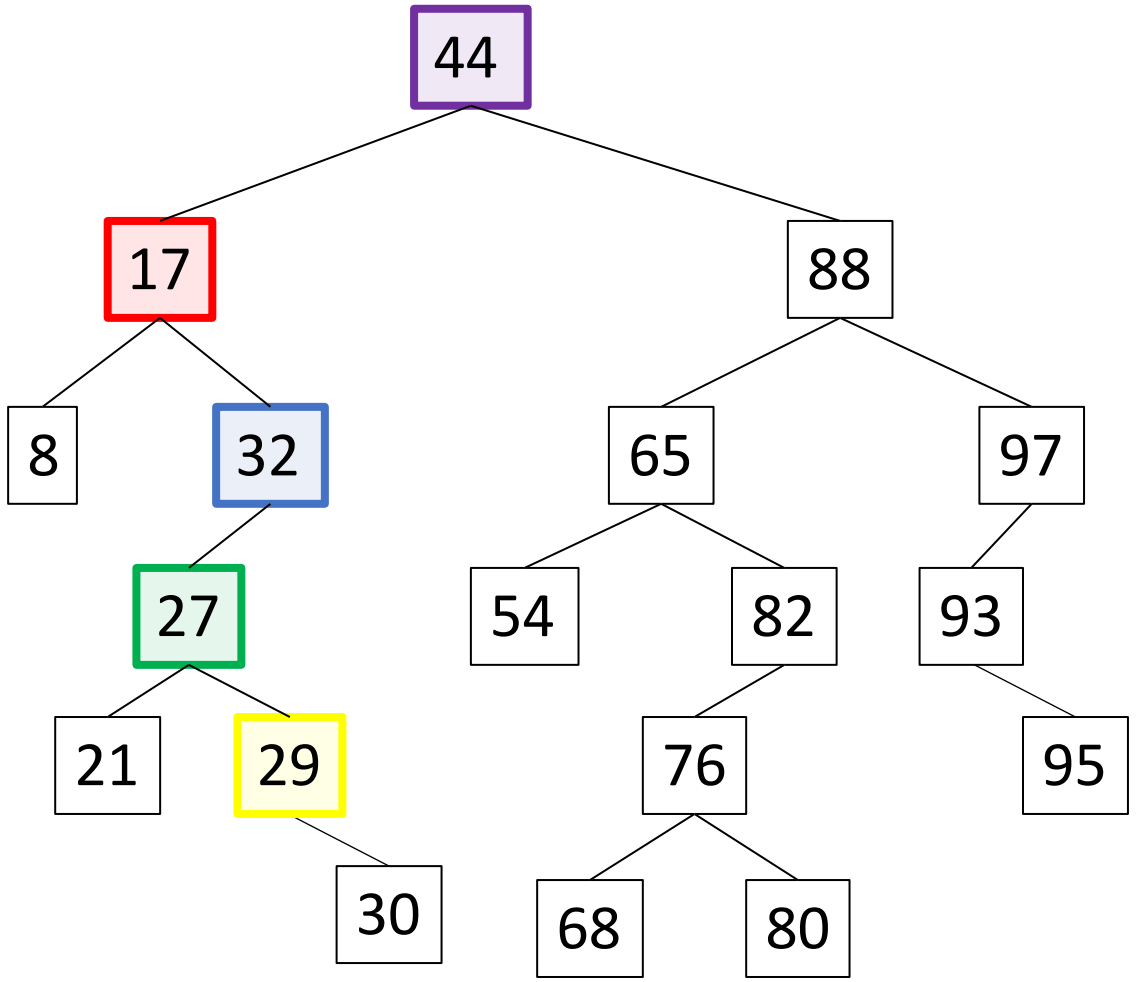
Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Output:

8

21



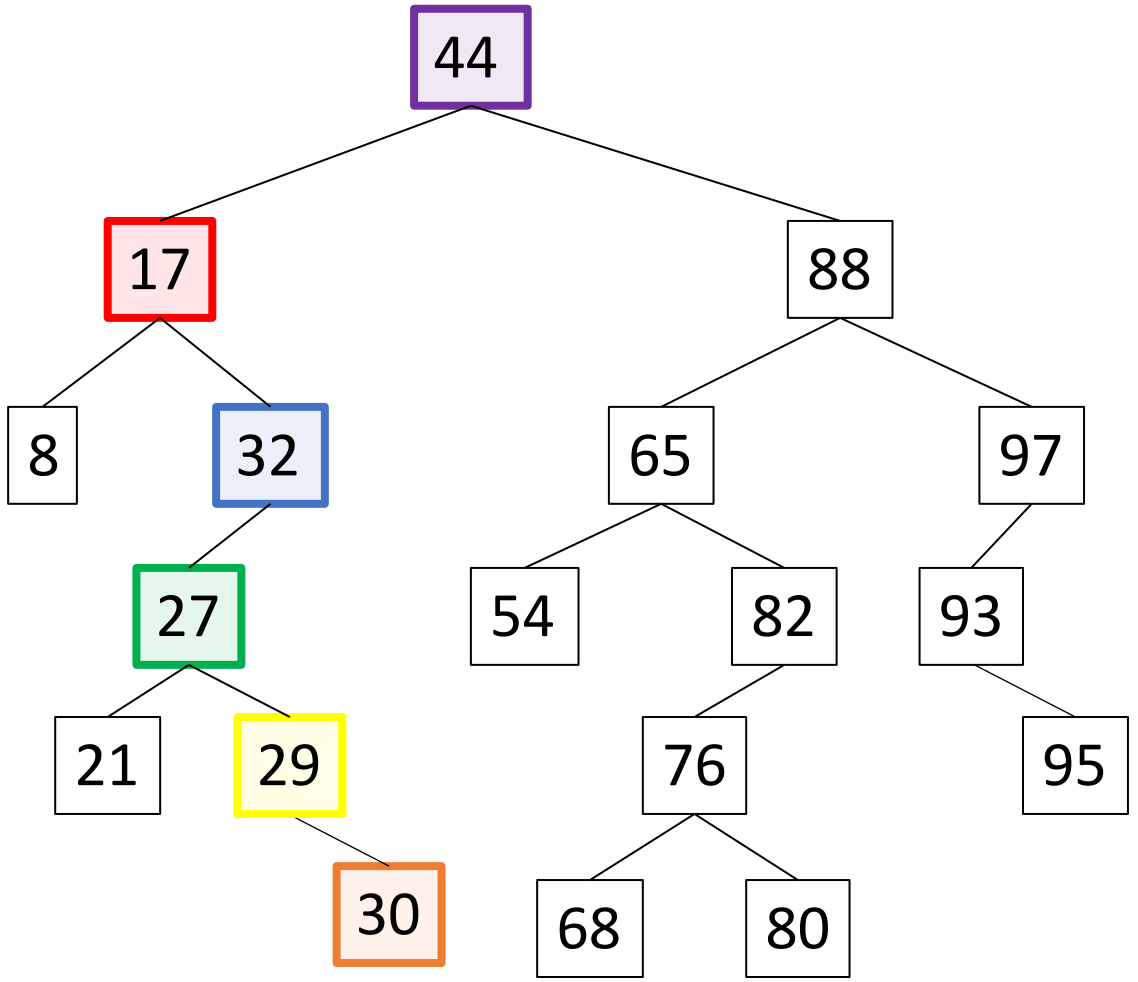
Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Output:

8

21



Binary Search Tree - Traversal

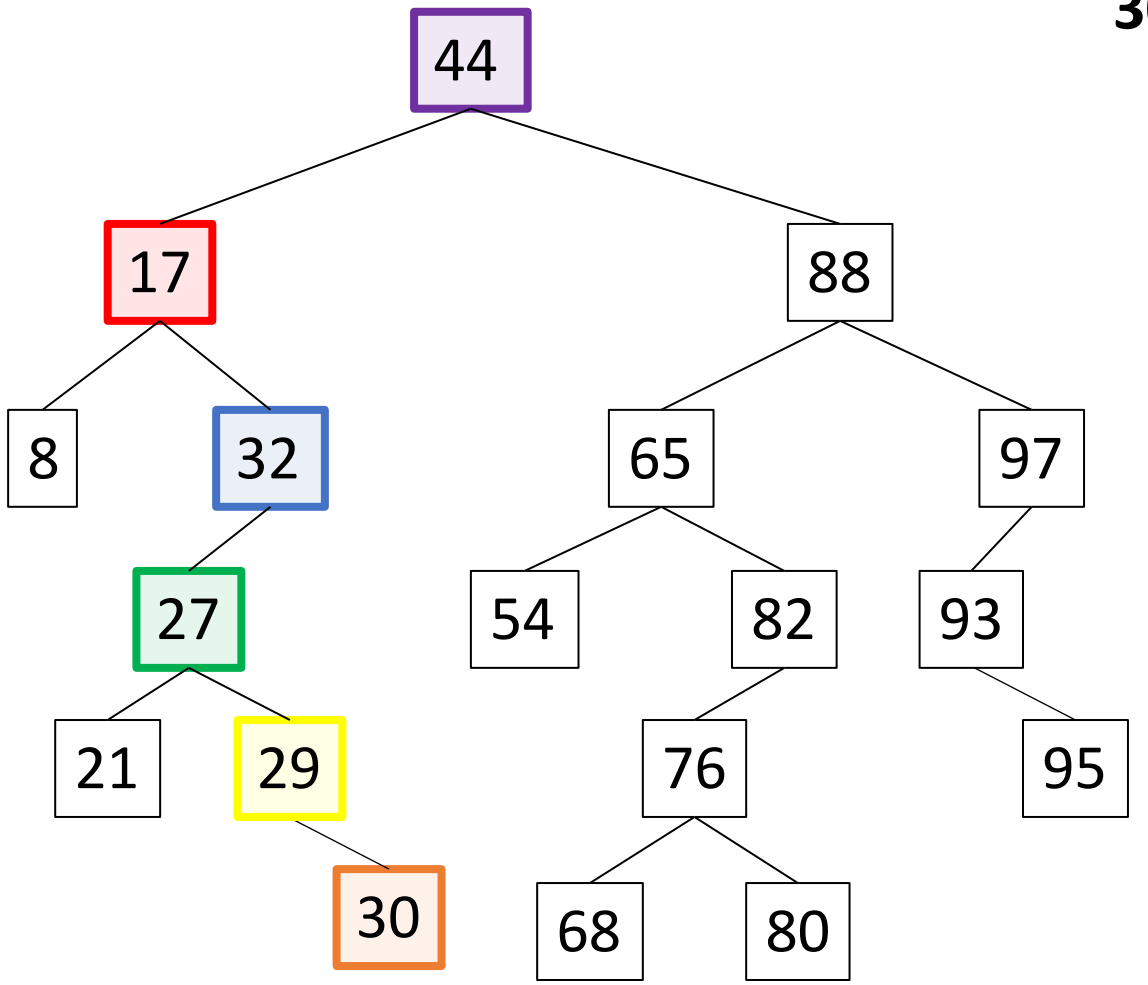
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Output:

8

21

30



Binary Search Tree - Traversal

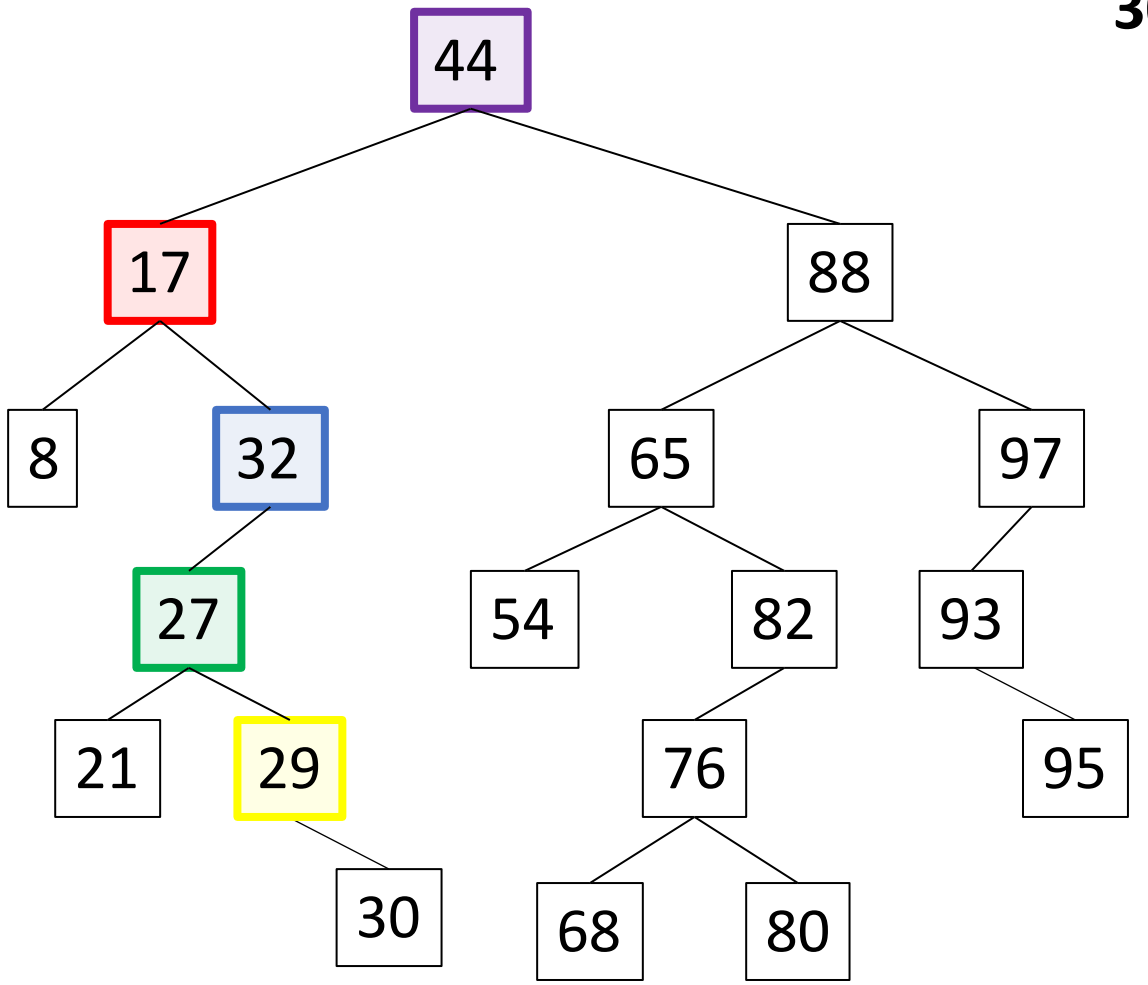
```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Output:

8

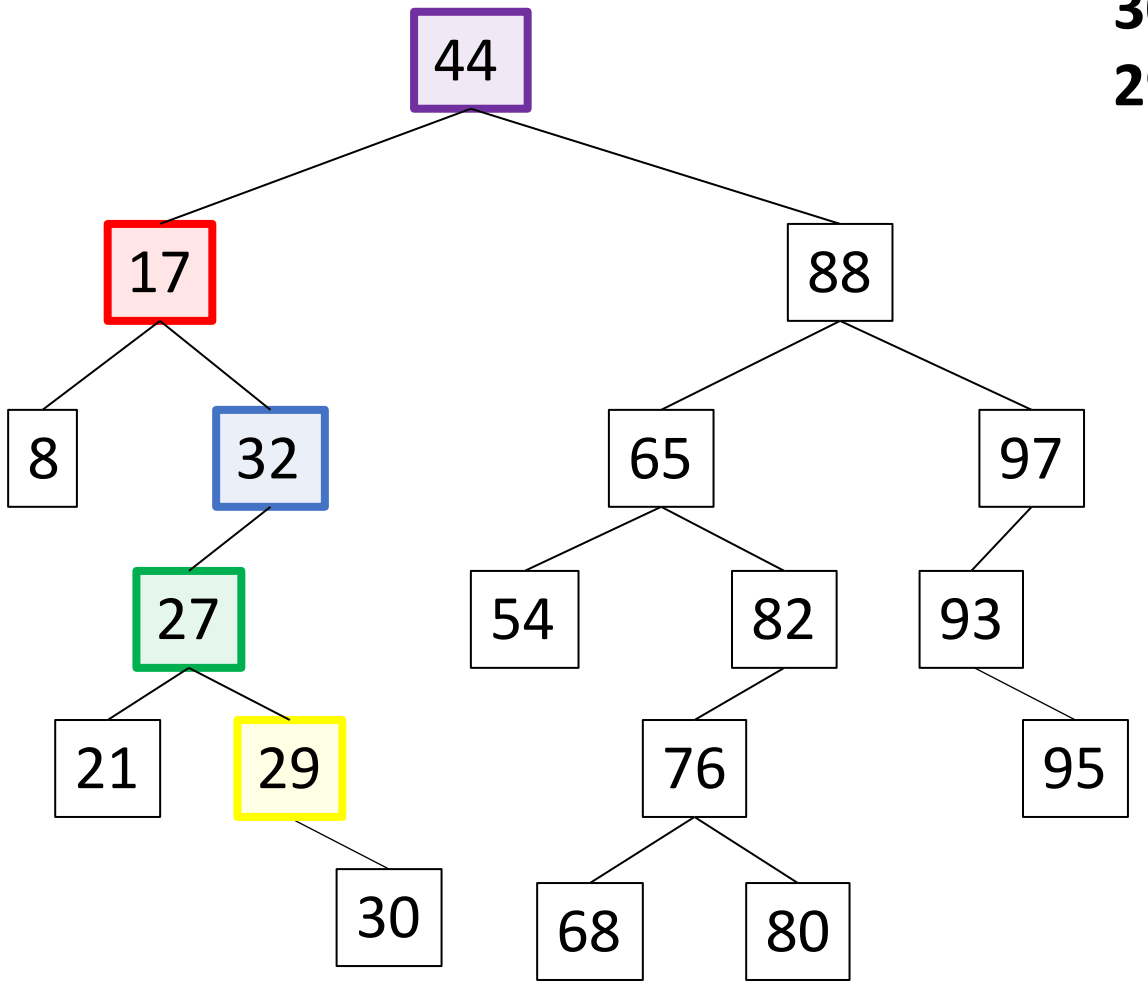
21

30



Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



Output:

8

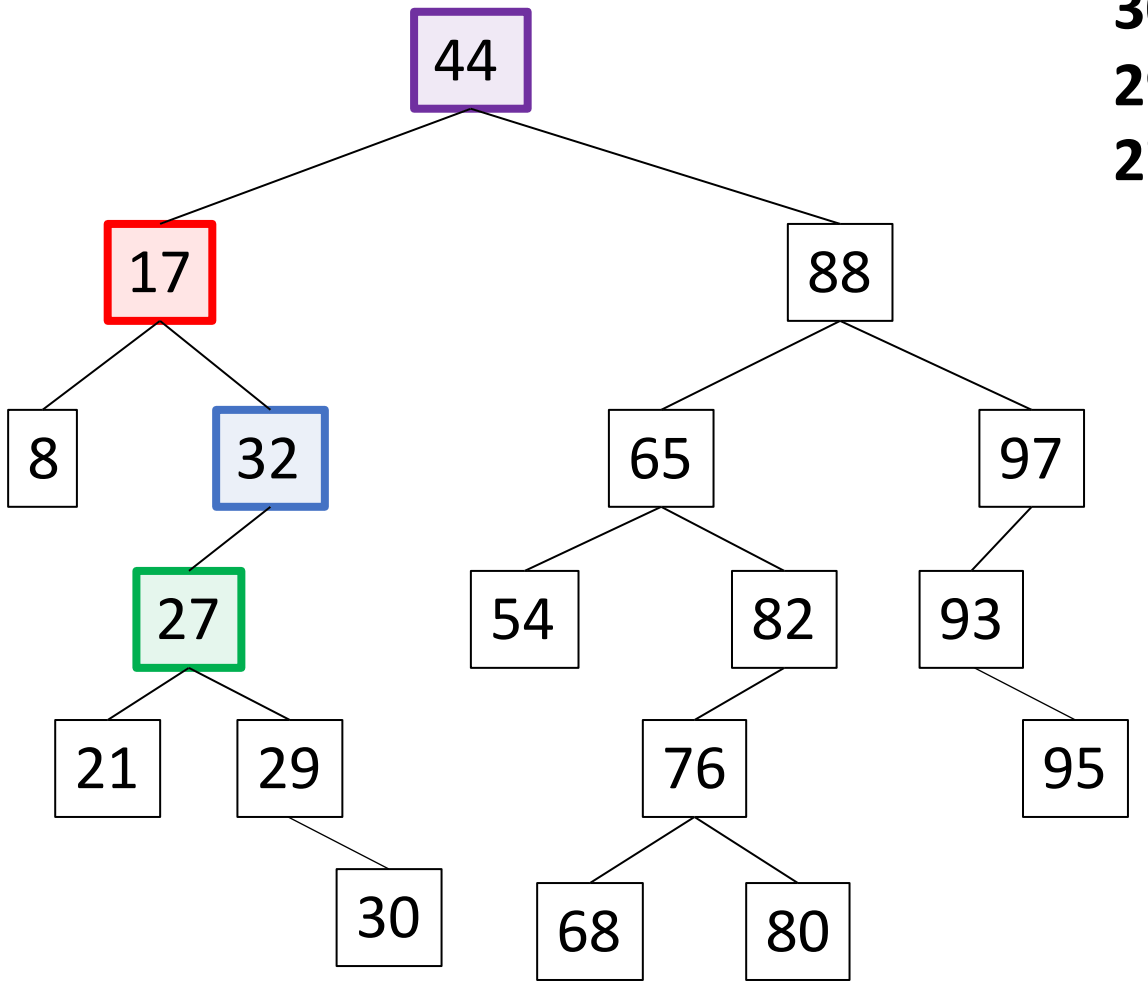
21

30

29

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

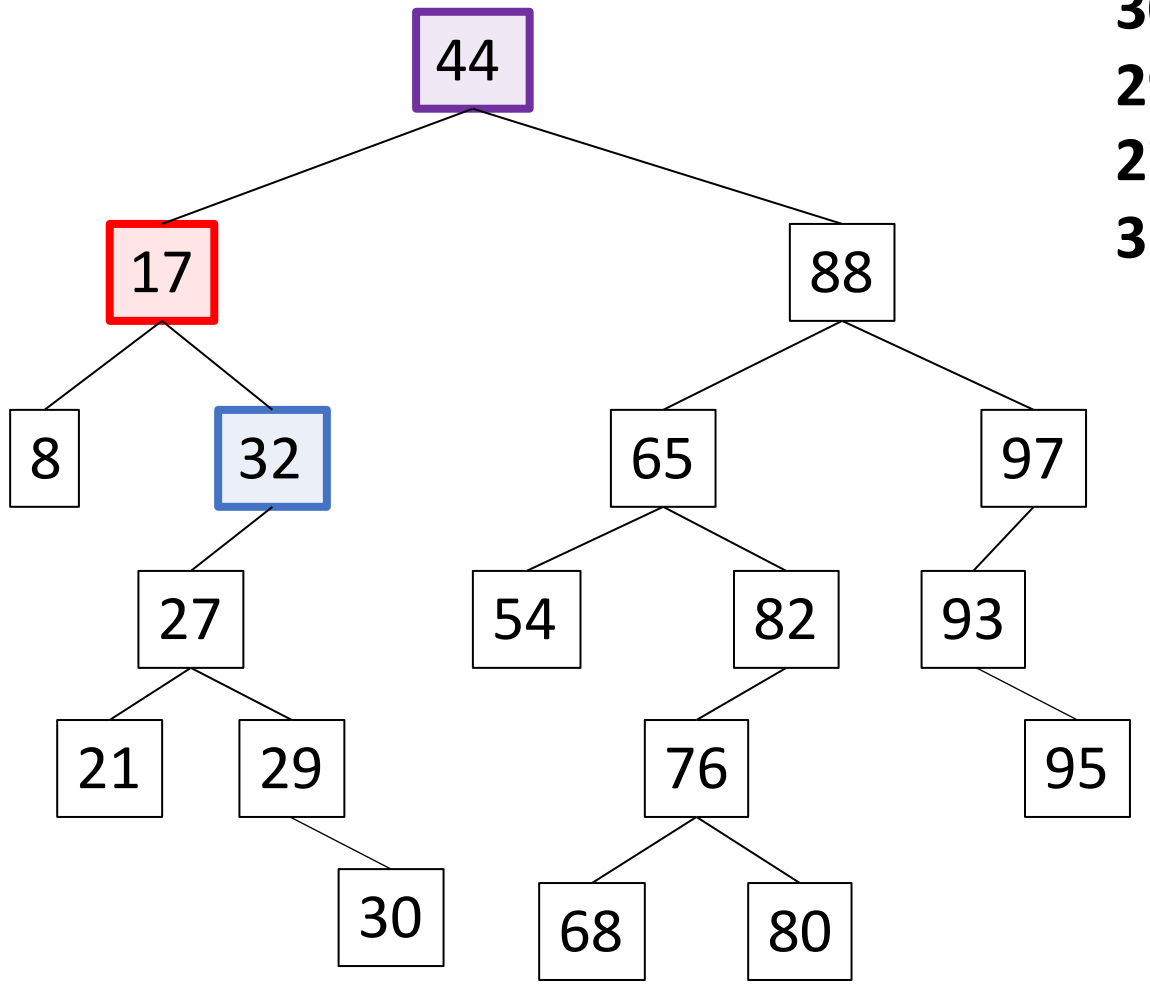


Output:

8
21
30
29
27

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

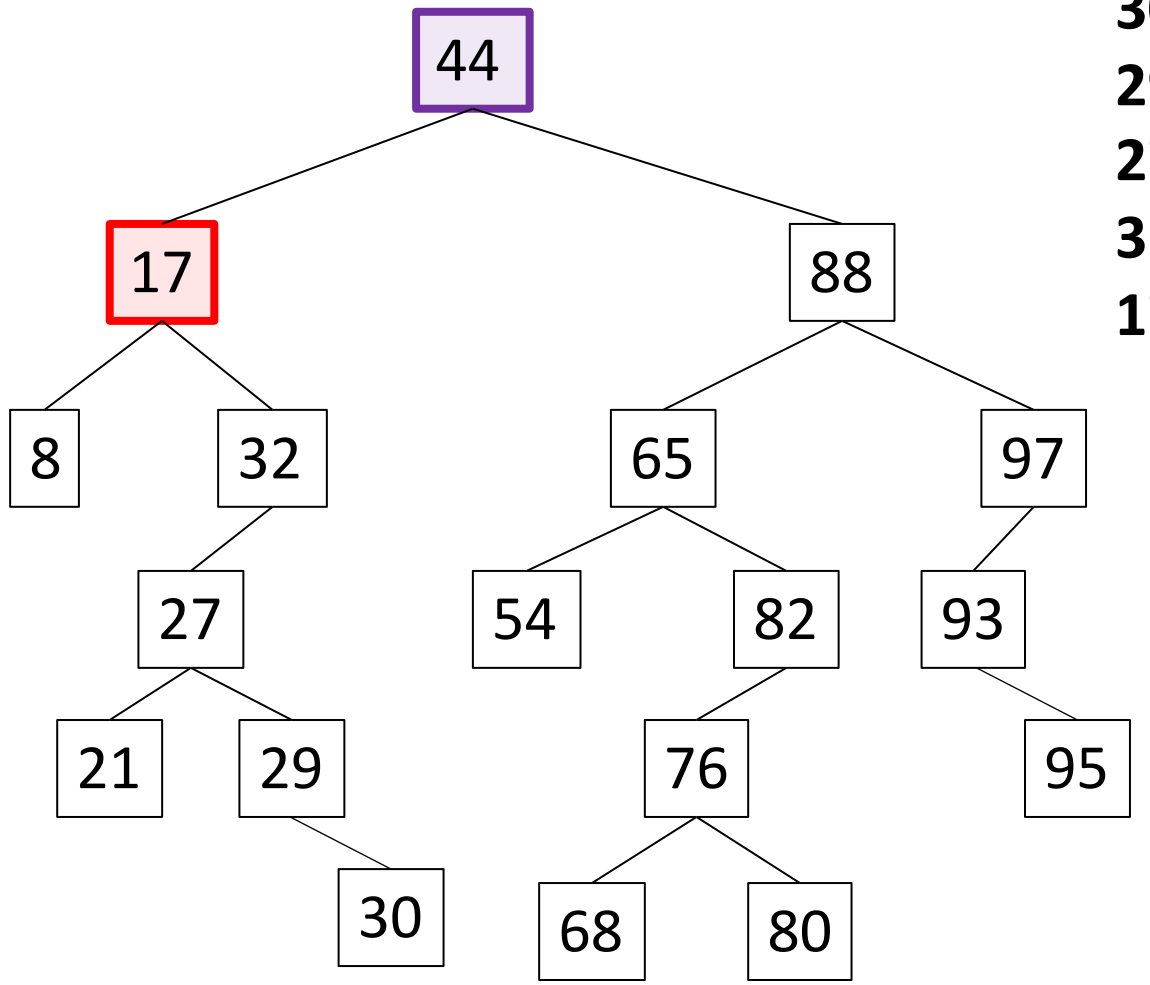


Output:

8
21
30
29
27
32

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

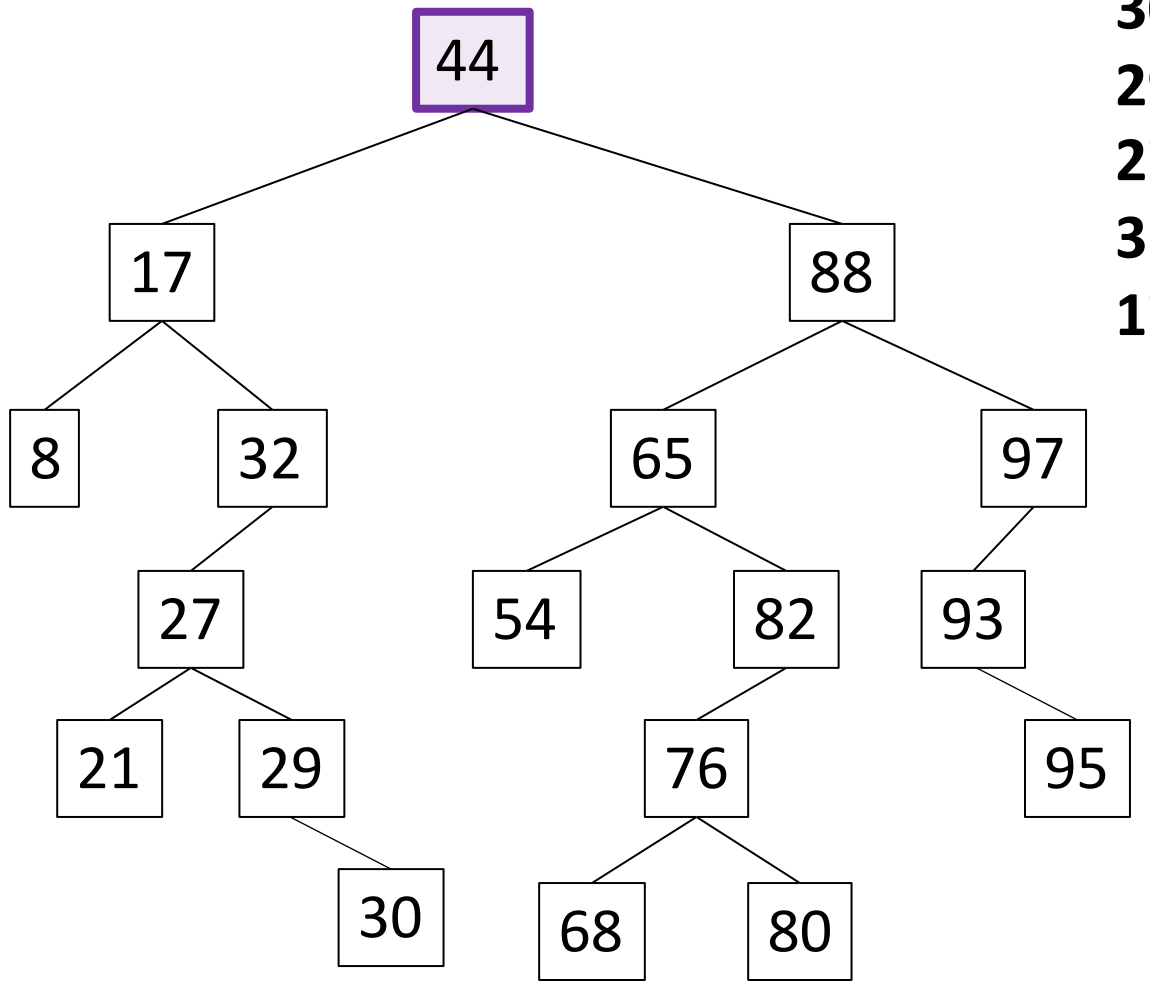


Output:

8
21
30
29
27
32
17

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

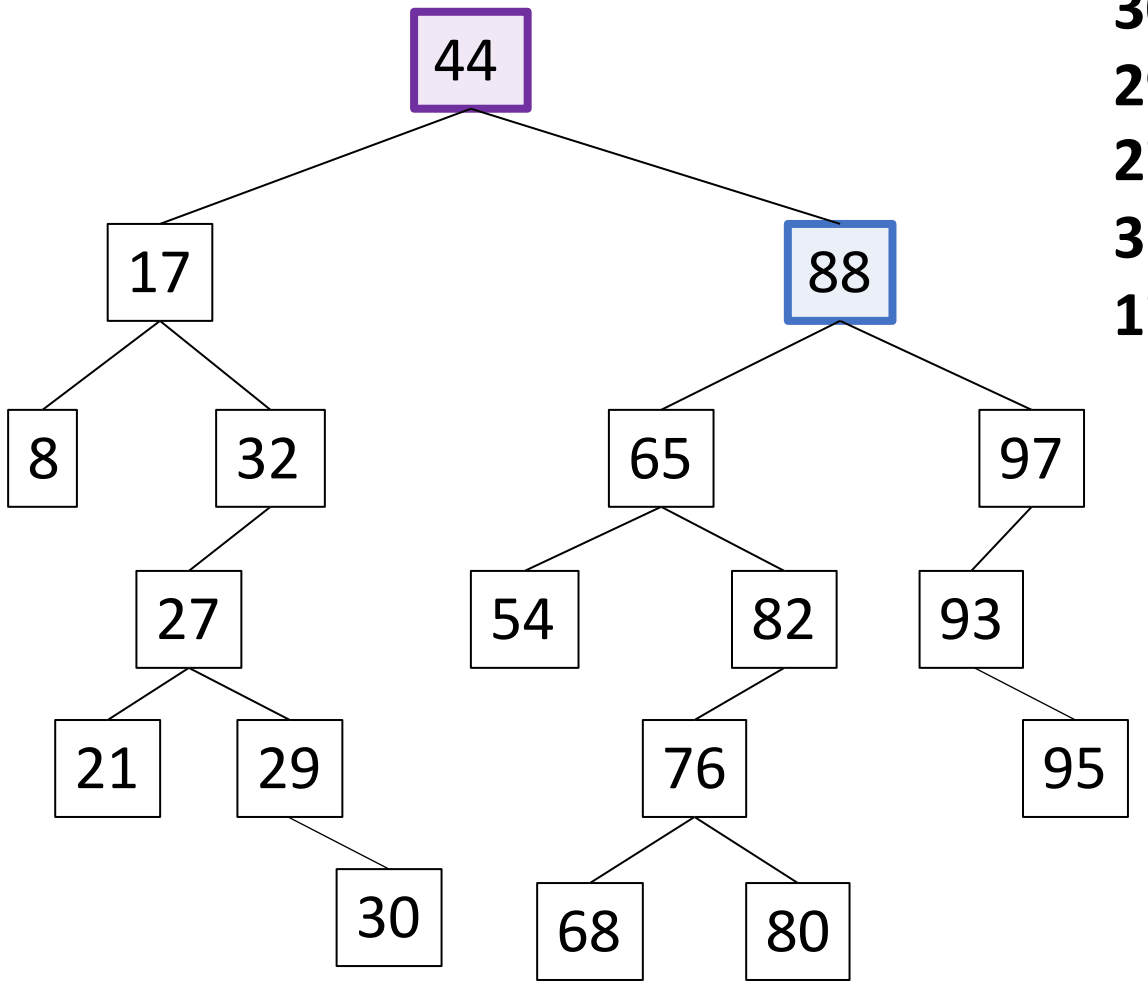


Output:

8
21
30
29
27
32
17

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

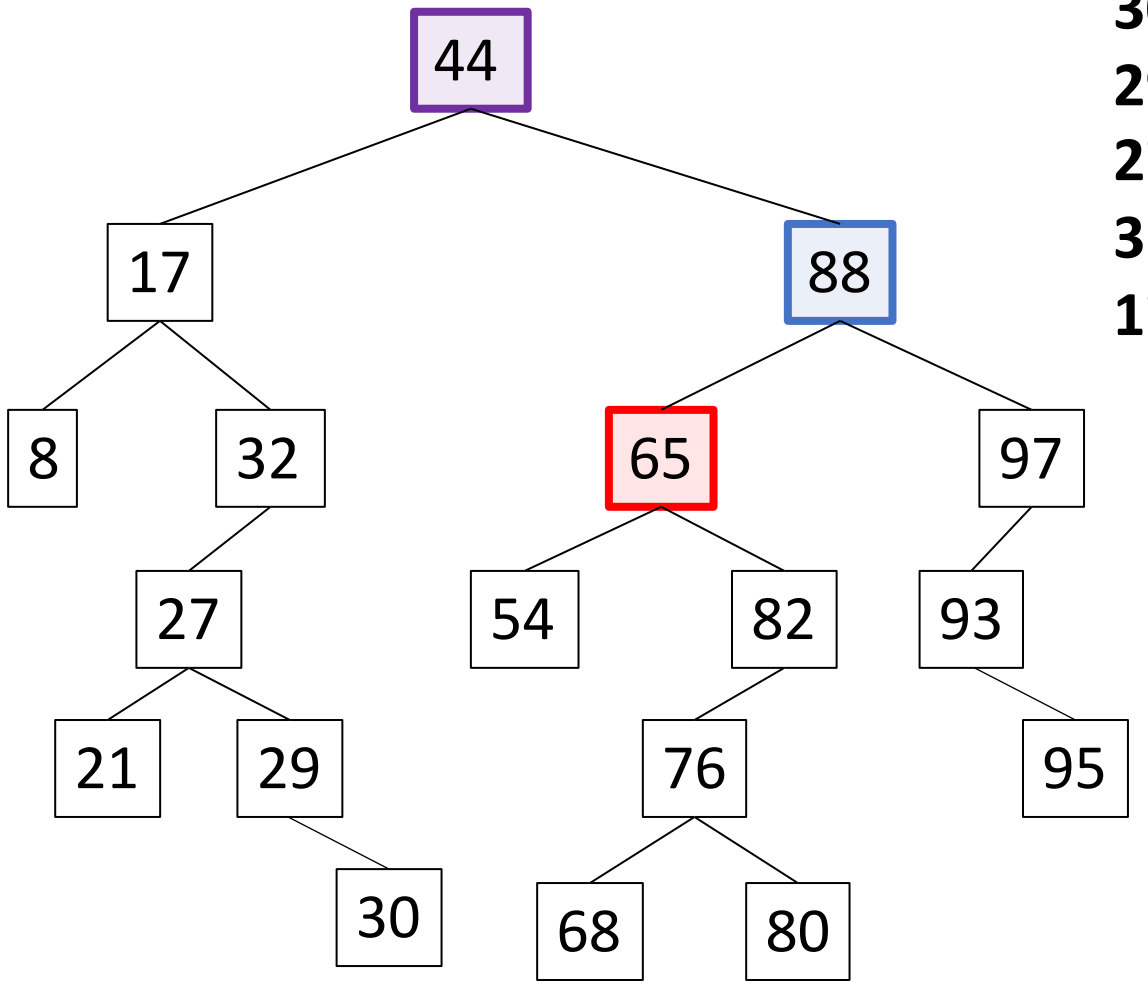


Output:

8
21
30
29
27
32
17

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

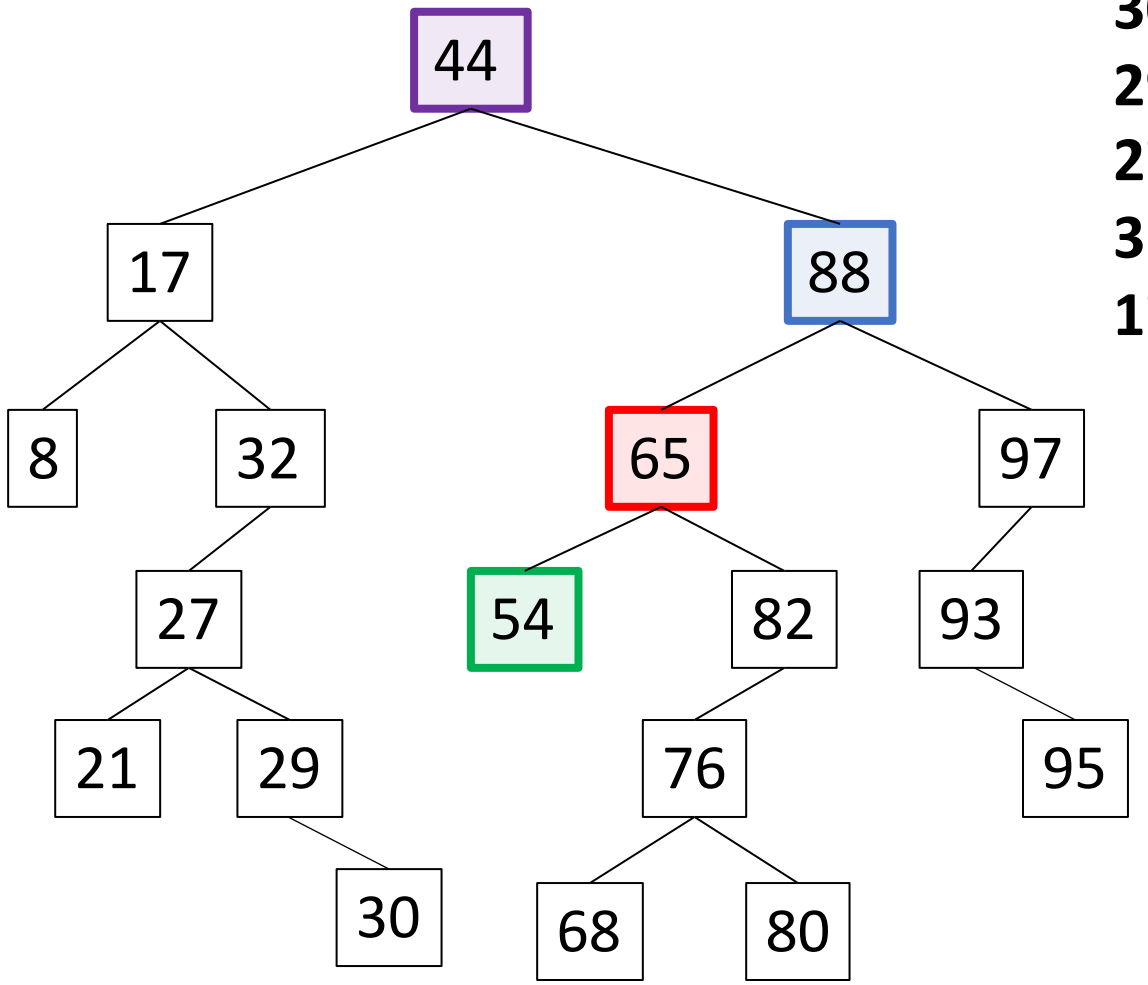


Output:

8
21
30
29
27
32
17

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

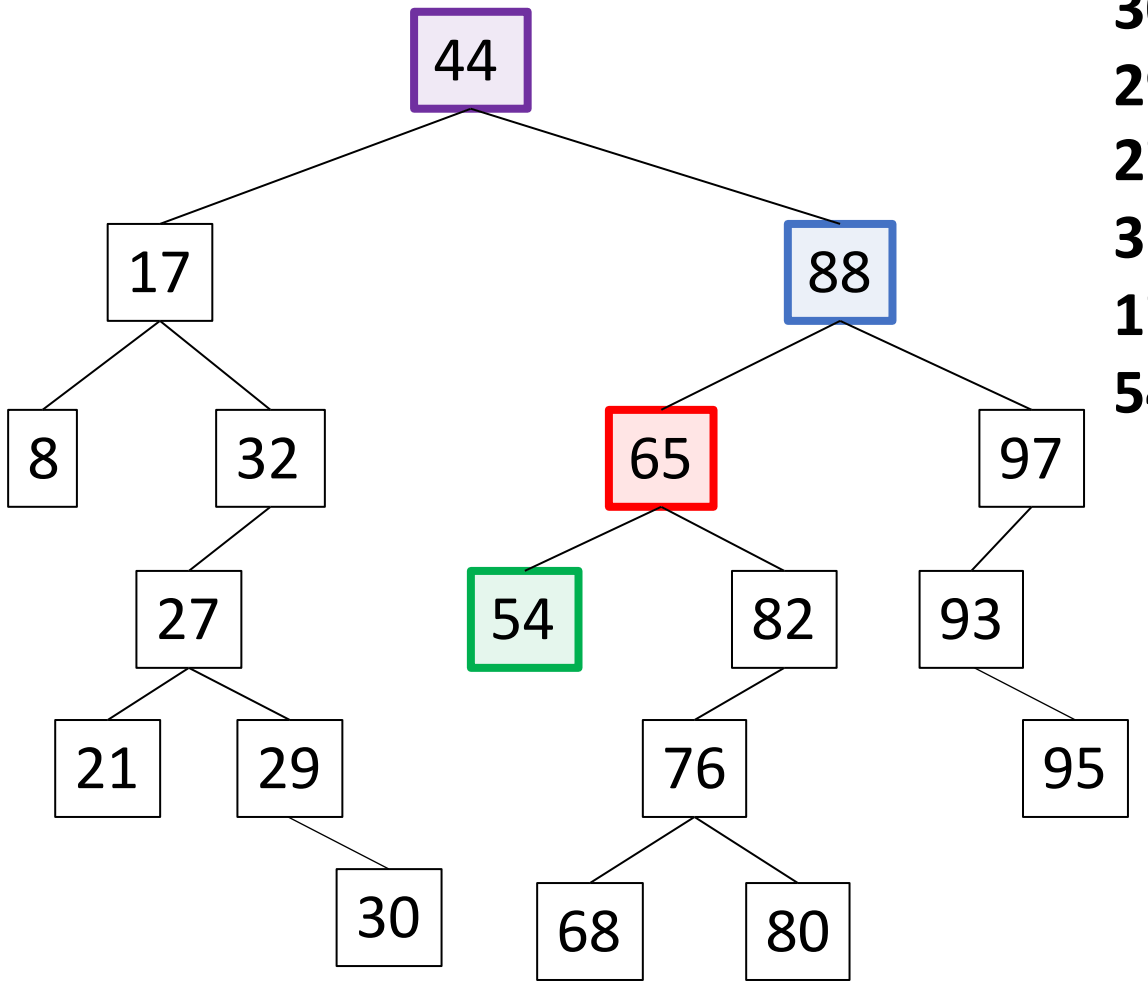


Output:

8
21
30
29
27
32
17

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

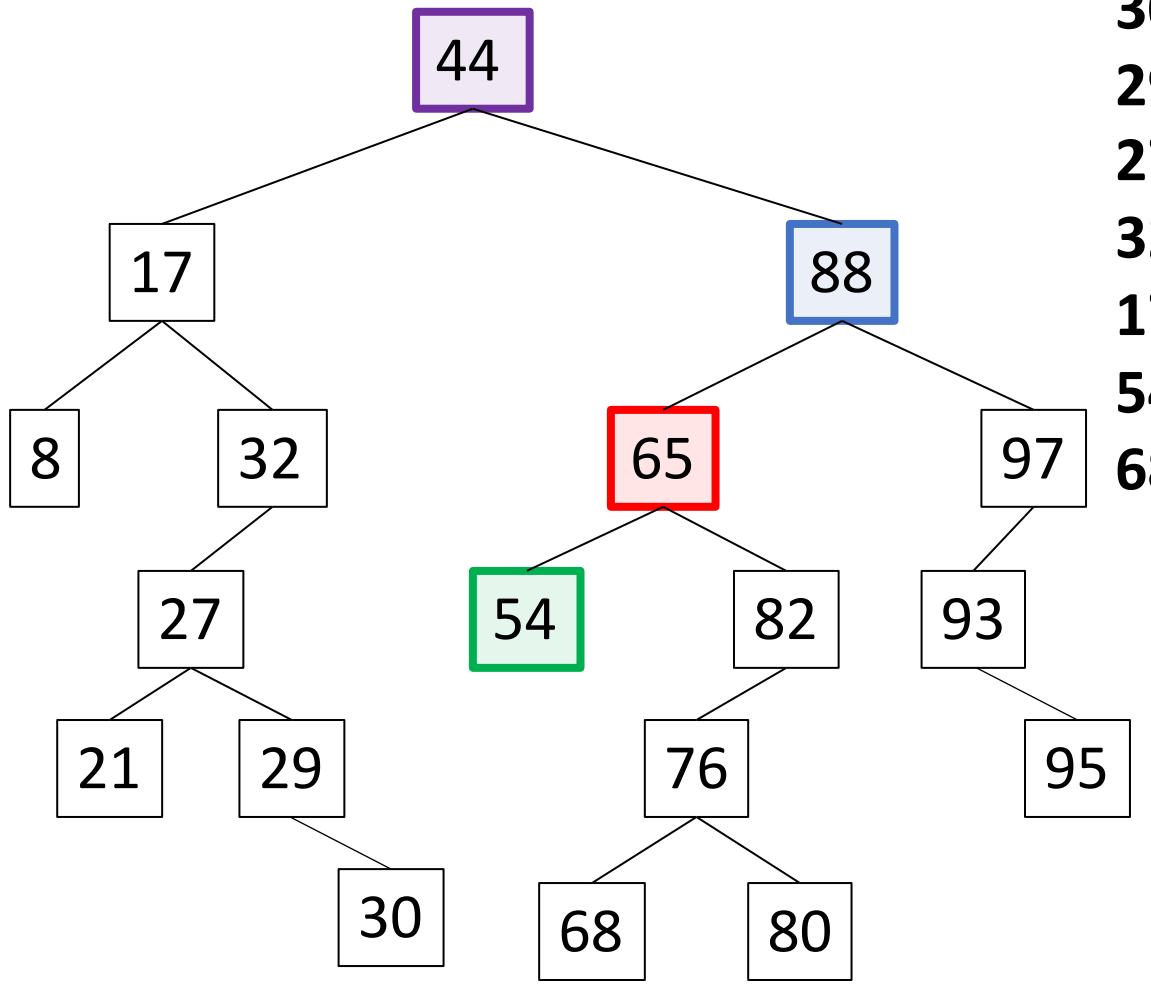


Output:

8
21
30
29
27
32
17
54

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

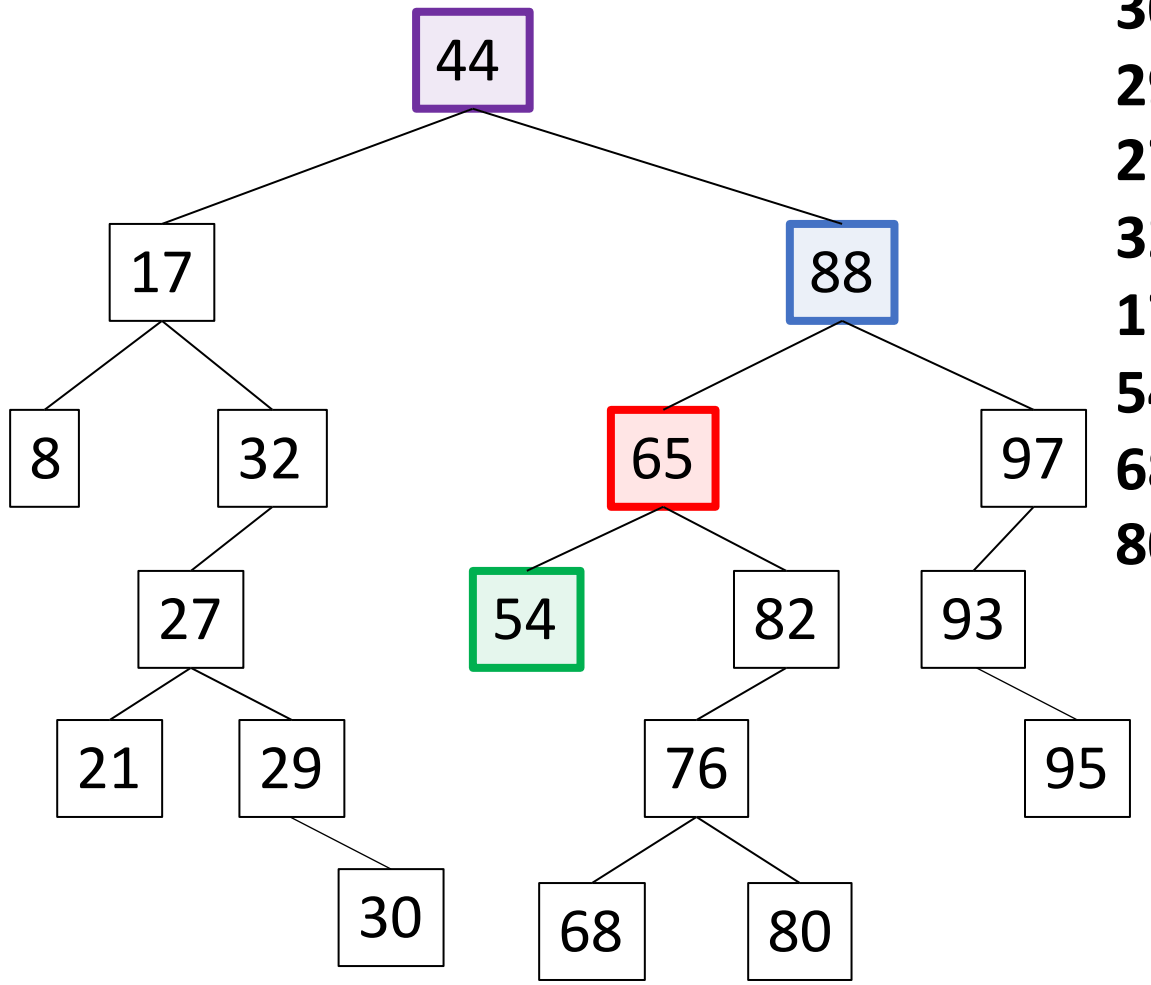


Output:

8
21
30
29
27
32
17
54
68

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

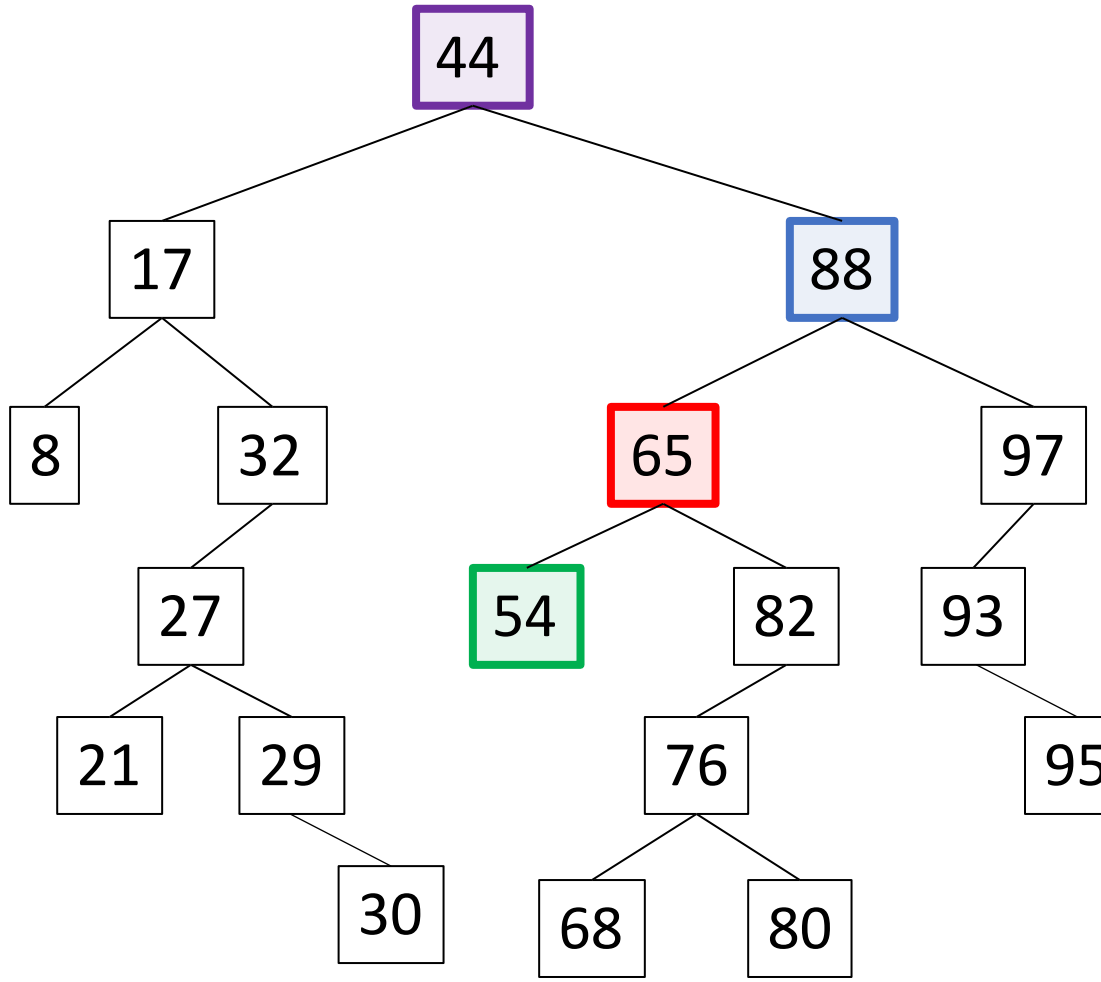


Output:

8
21
30
29
27
32
17
54
68
80

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```



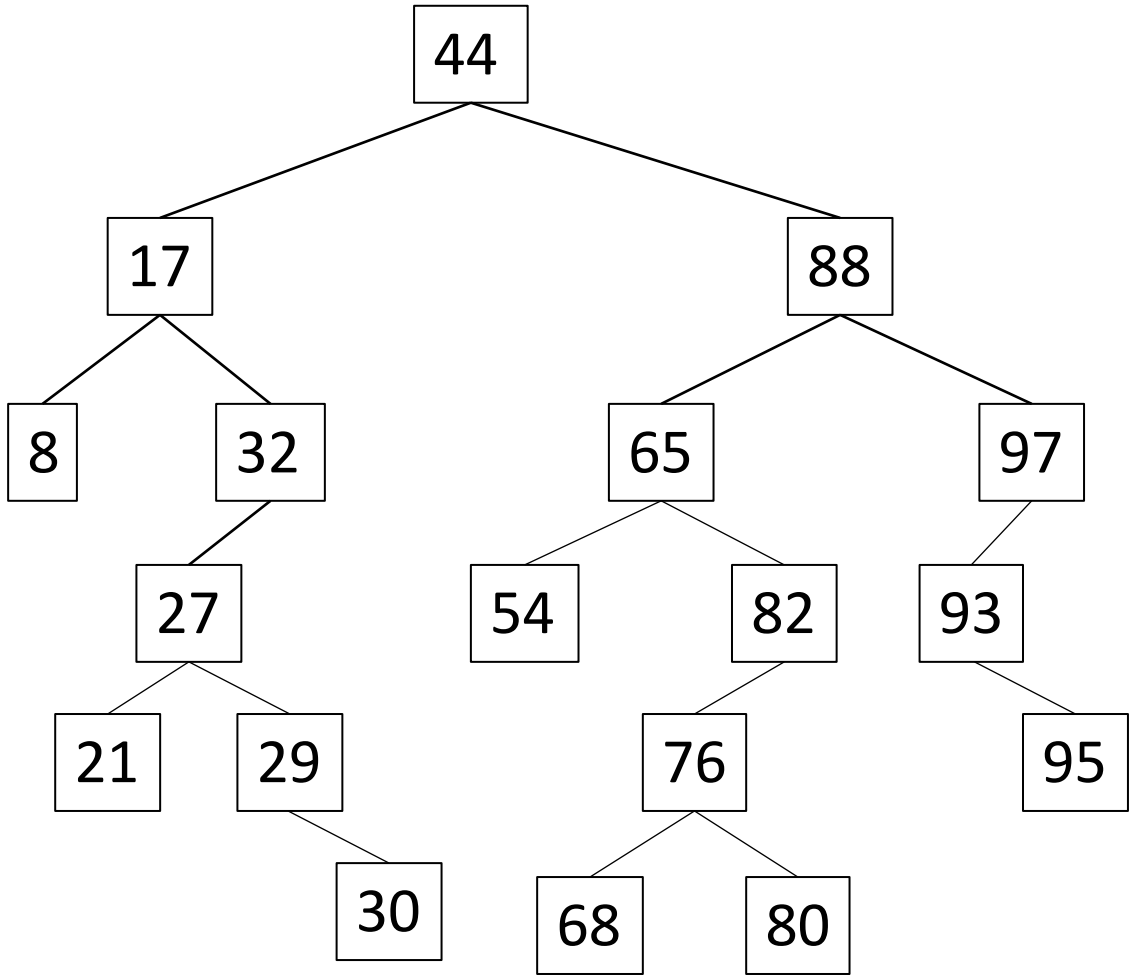
Output:

8
21
30
29
27
32
17
54
68
80
76
…

Output:

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

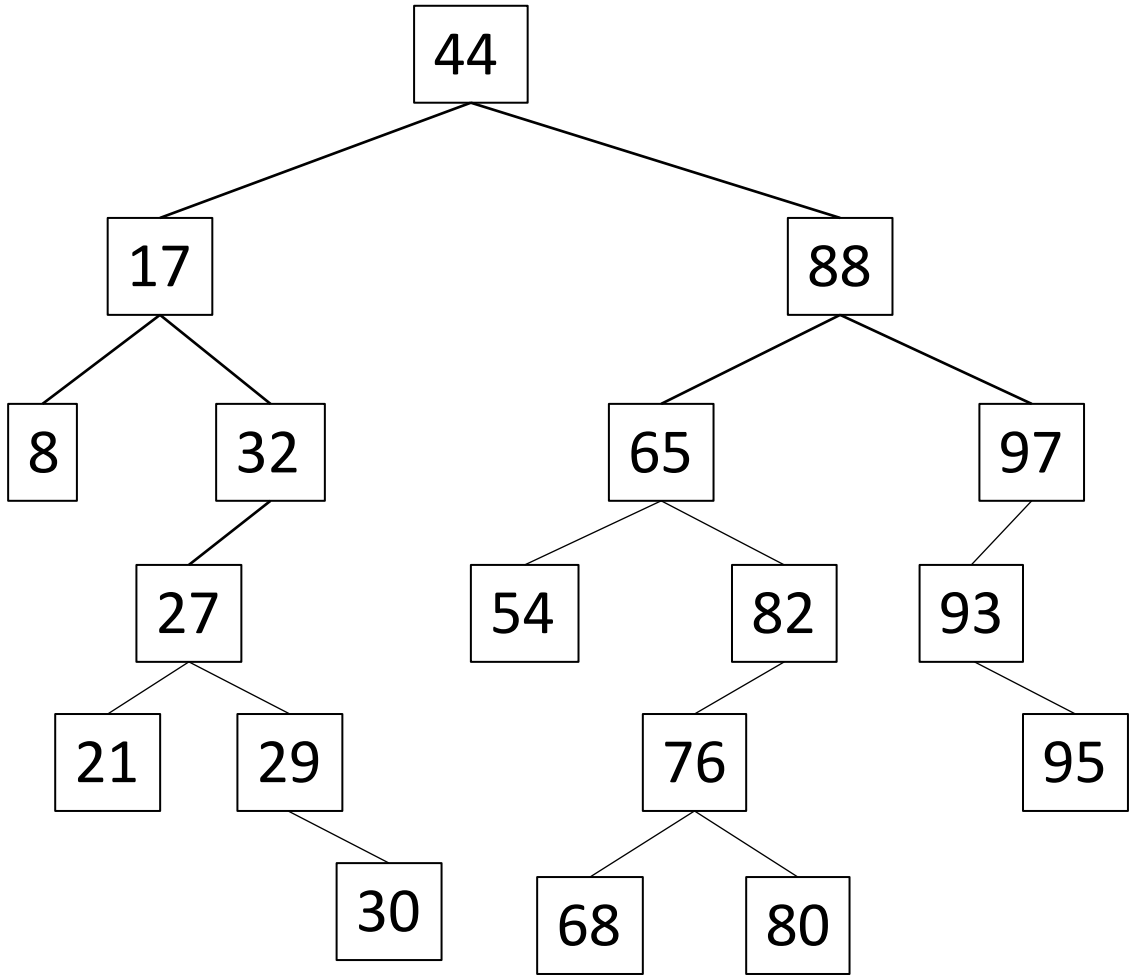


Output:

8

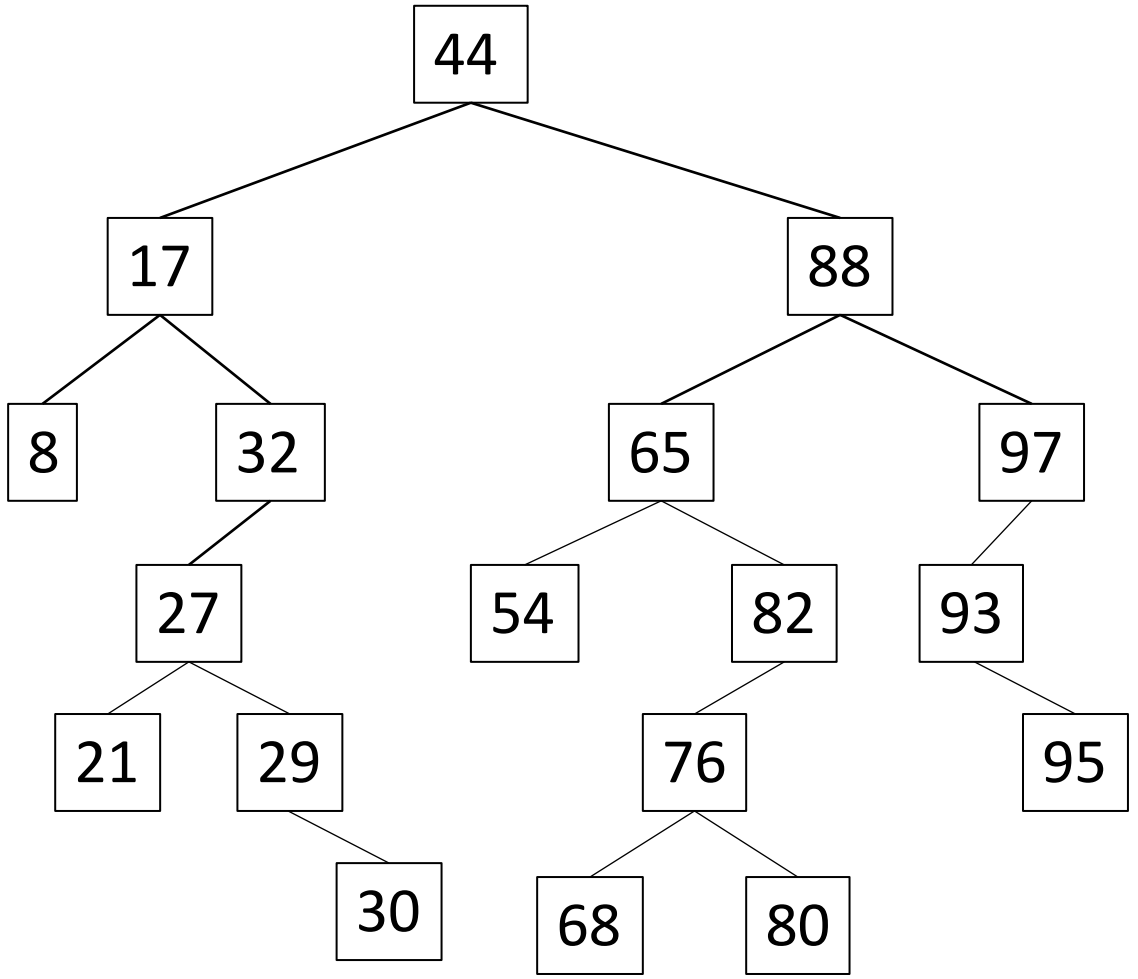
Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```



Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```



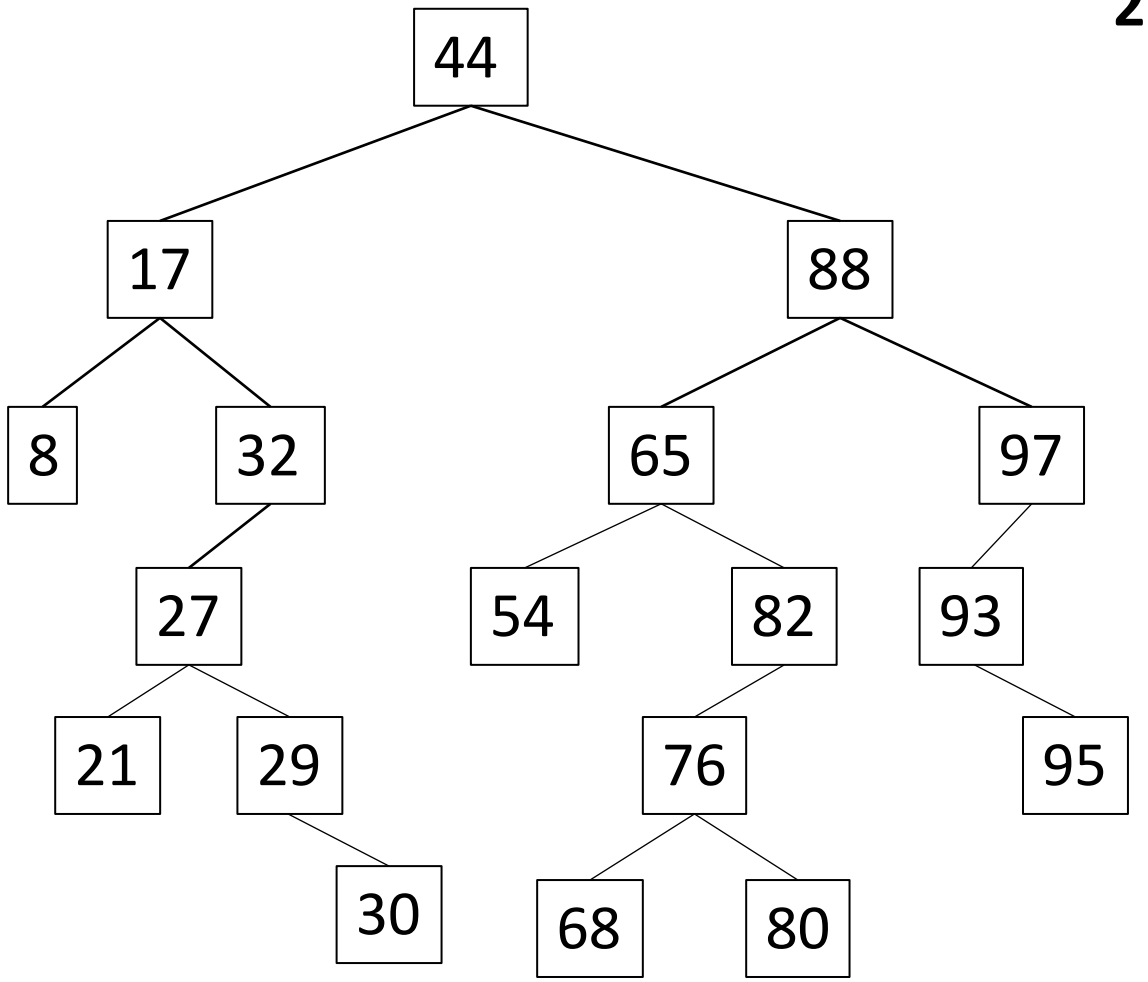
Output:

8

17

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```



Output:

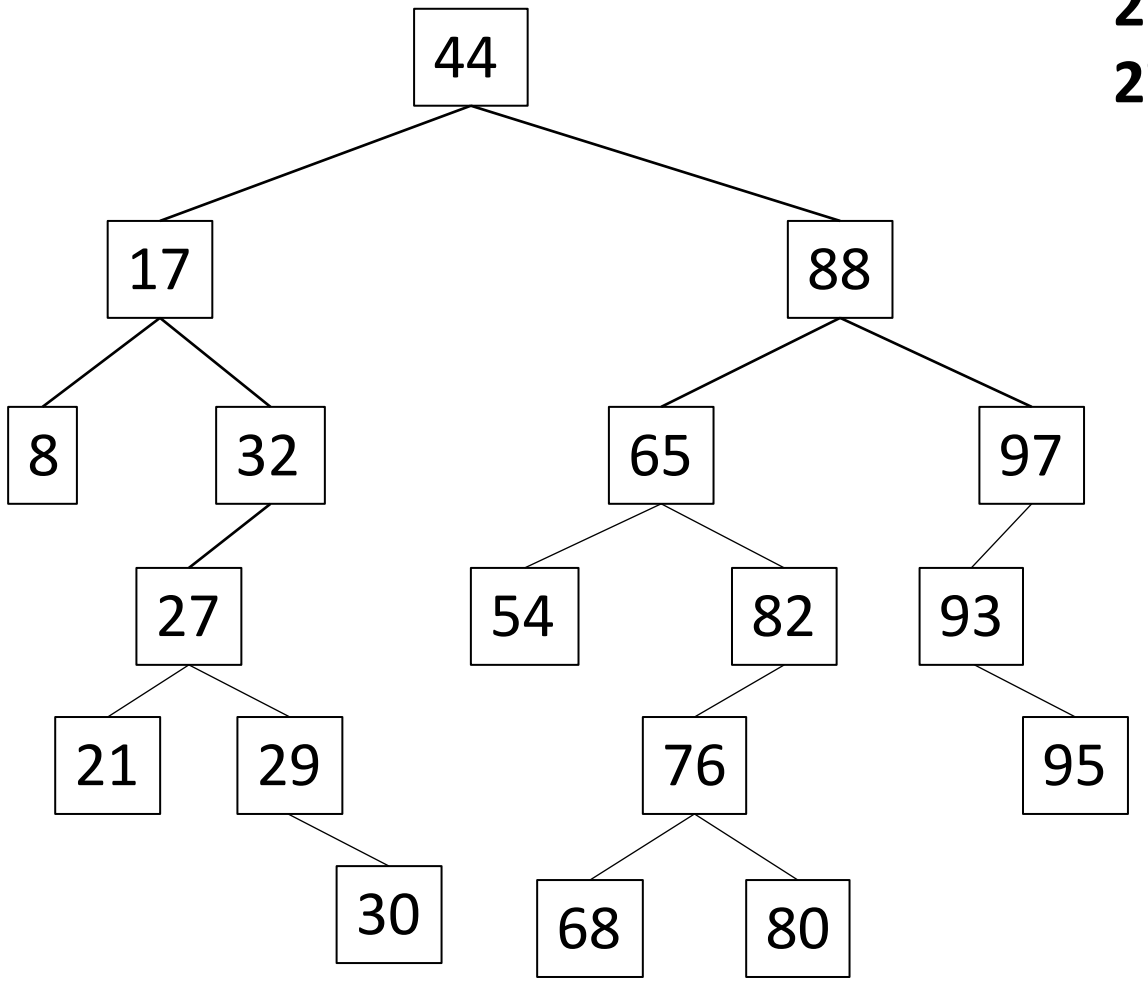
8

17

21

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```



Output:

8

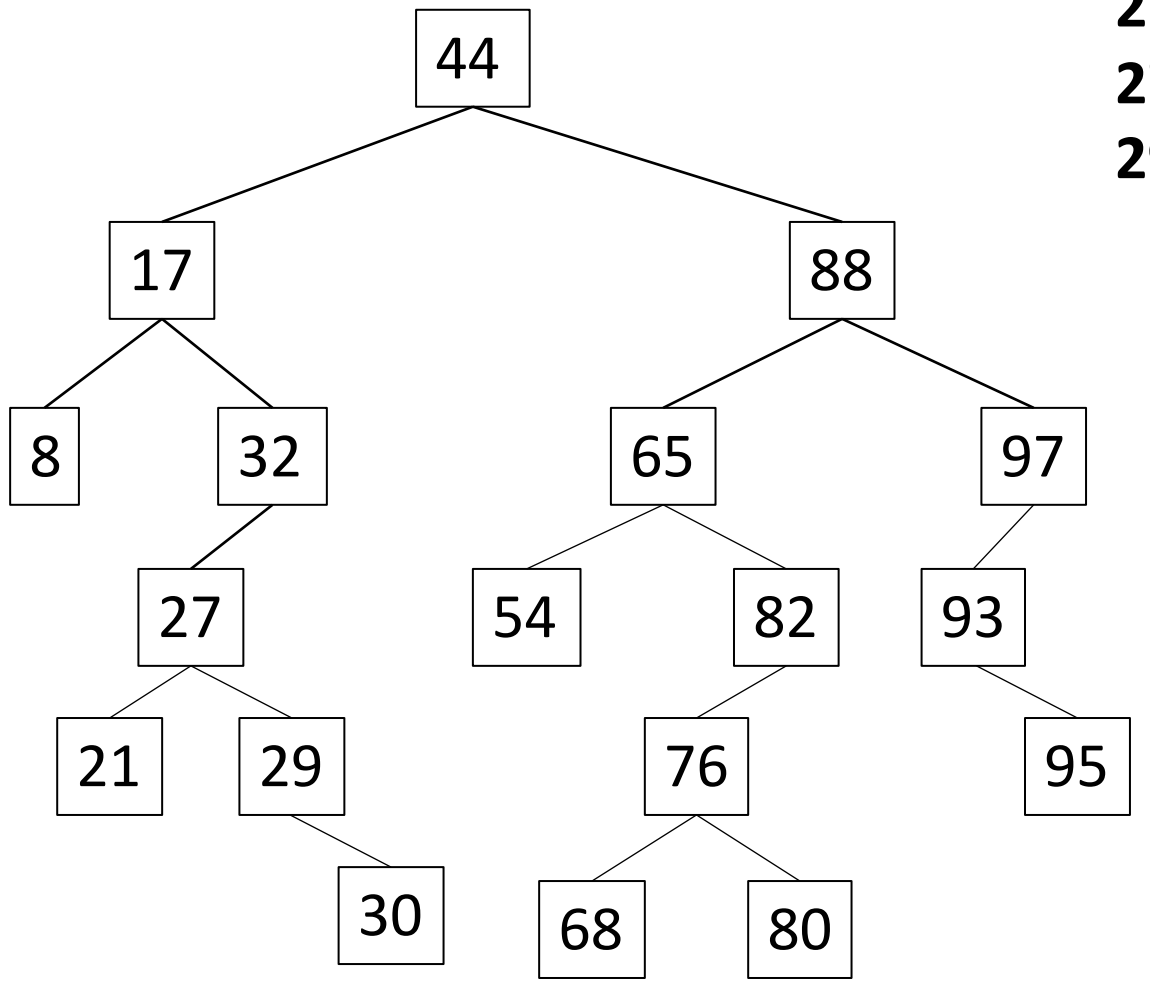
17

21

27

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

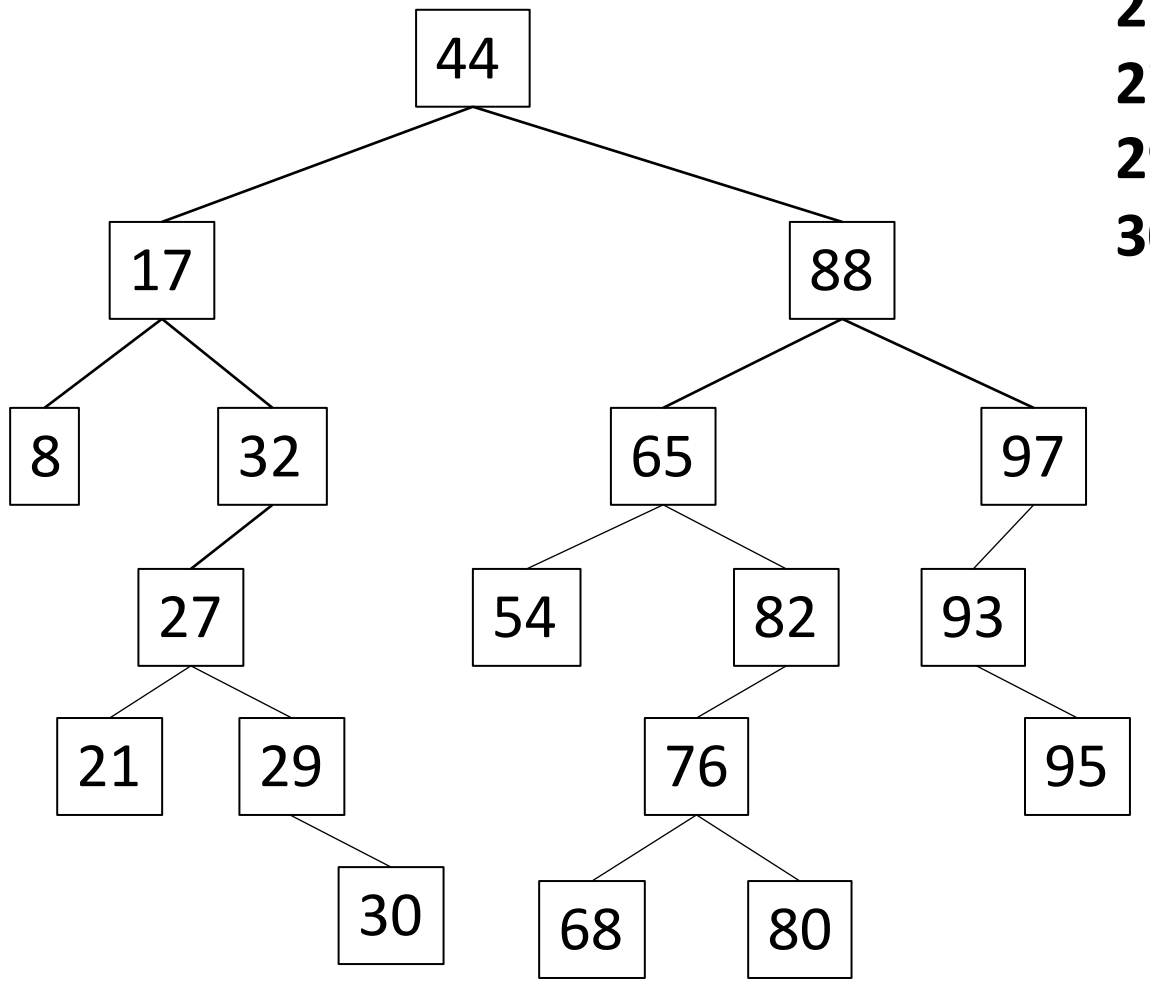


Output:

8
17
21
27
29

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

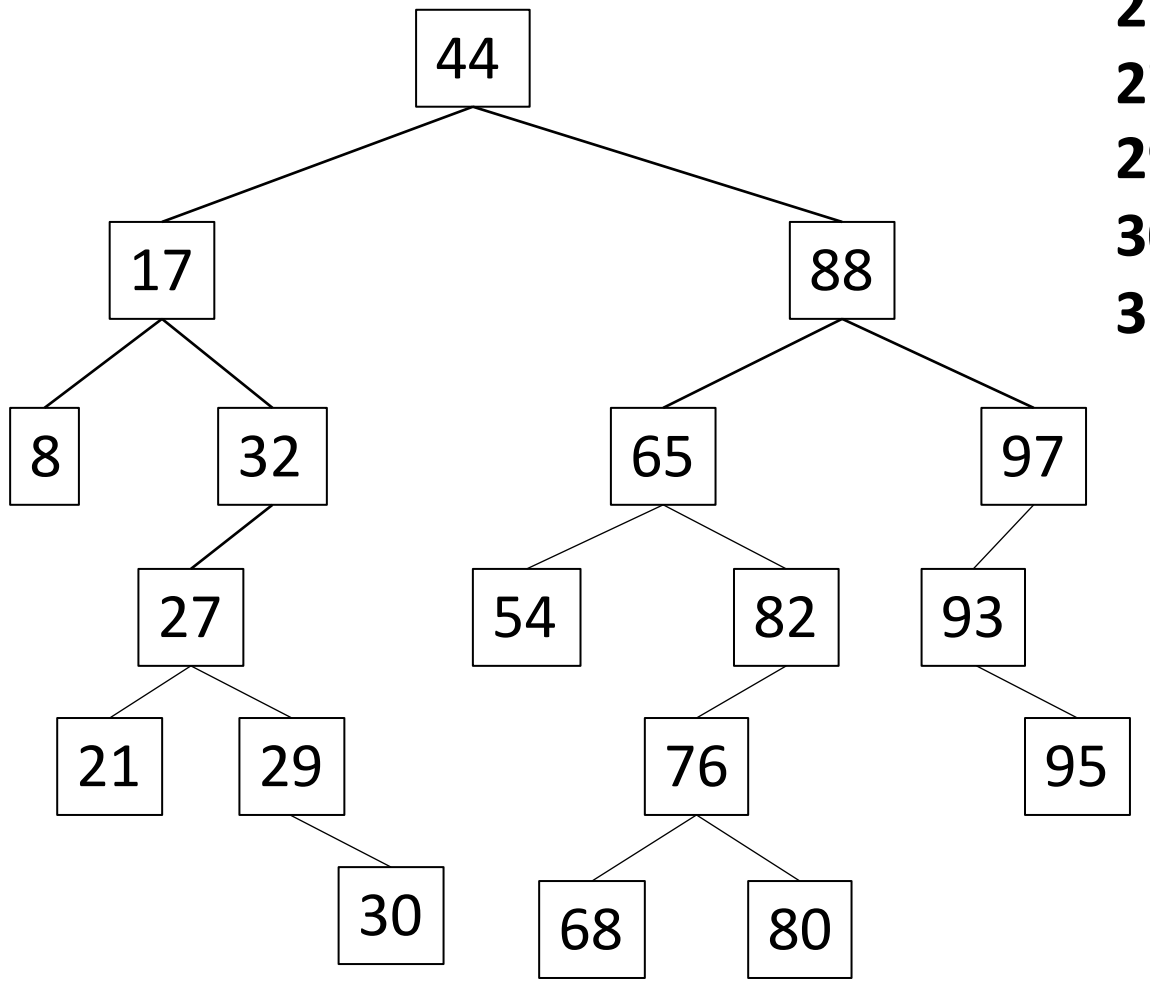


Output:

8
17
21
27
29
30

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

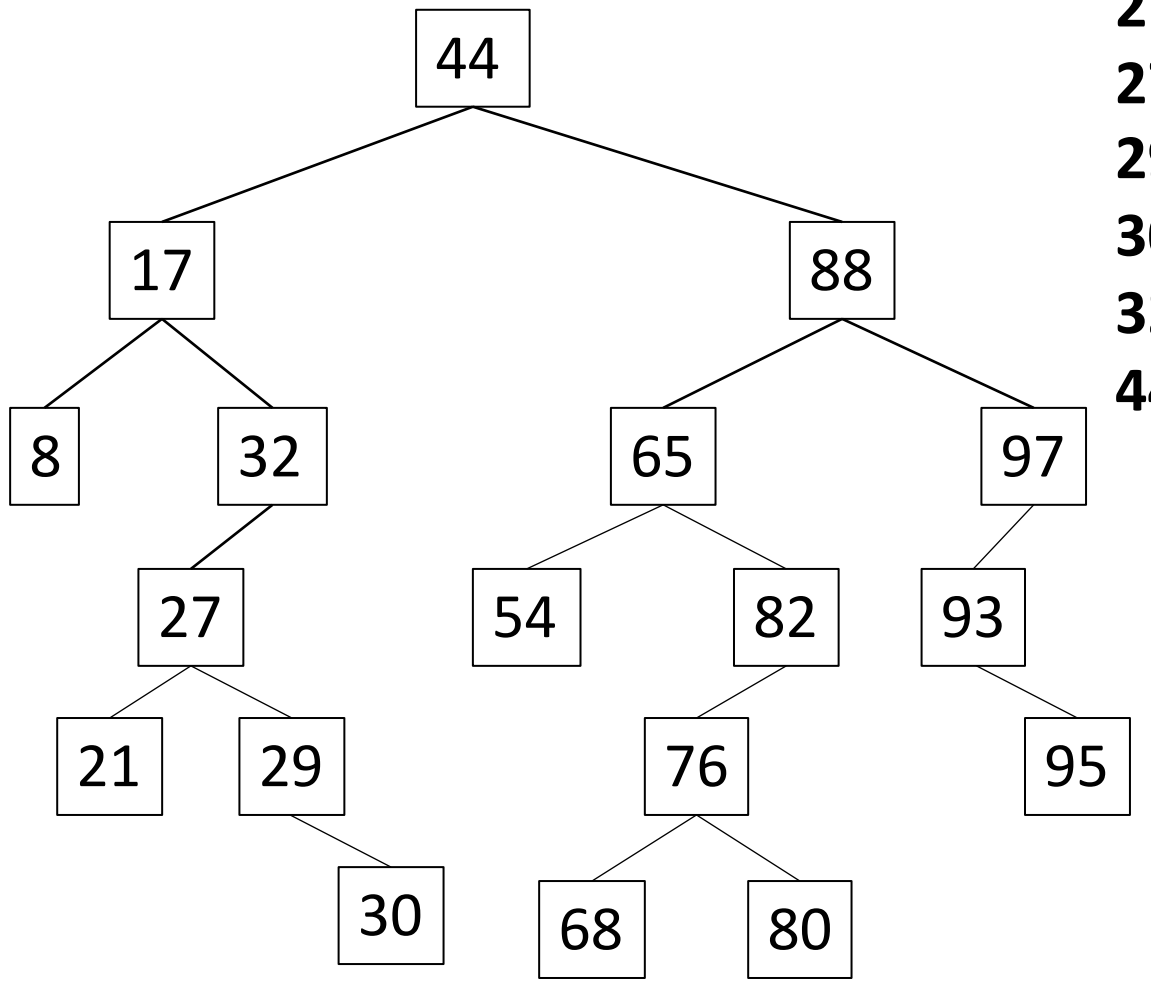


Output:

8
17
21
27
29
30
32

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

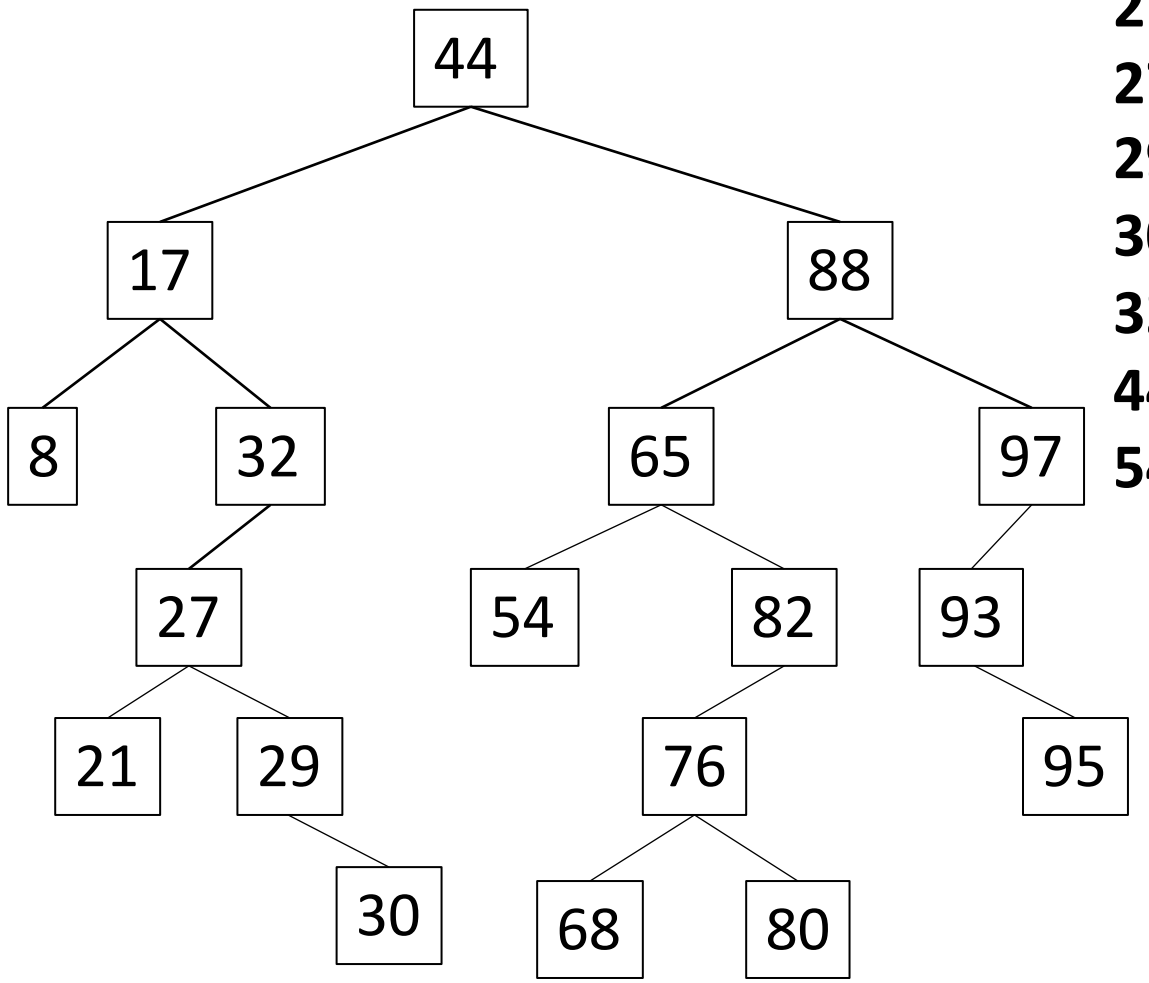


Output:

8
17
21
27
29
30
32
44

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

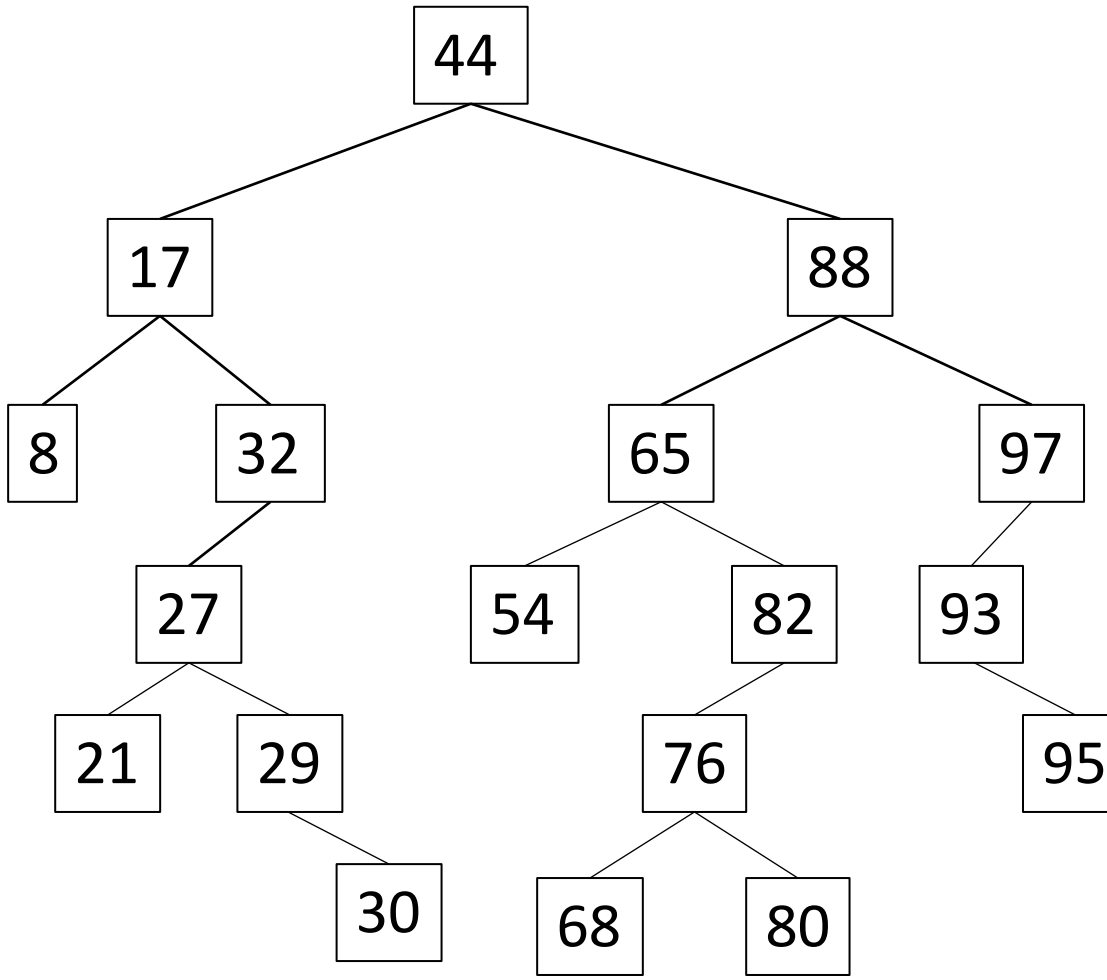


Output:

8
17
21
27
29
30
32
44
54

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

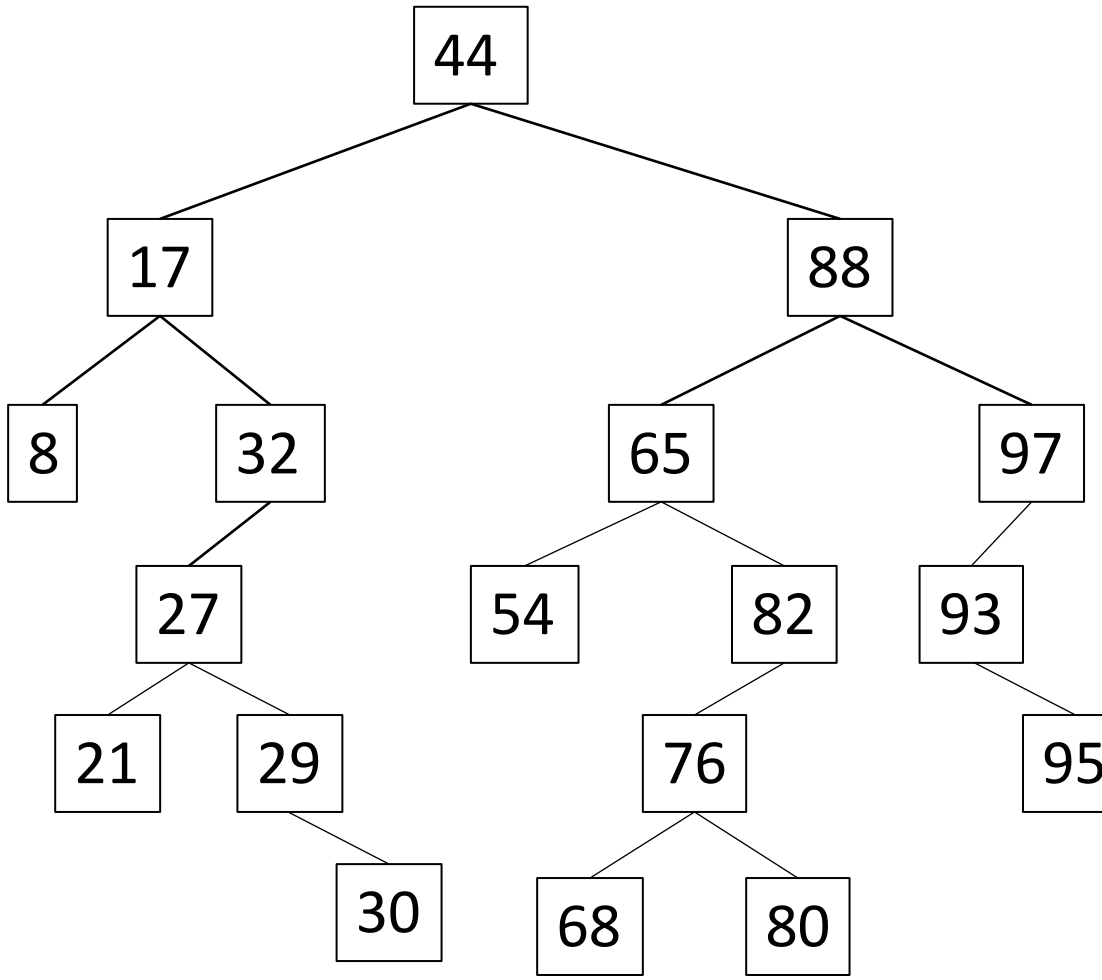


Output:

8
17
21
27
29
30
32
44
54
65

Binary Search Tree - Traversal

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```



Output:

8
17
21
27
29
30
32
44
54
65
68
…

Binary Search Tree - Traversal

Preorder

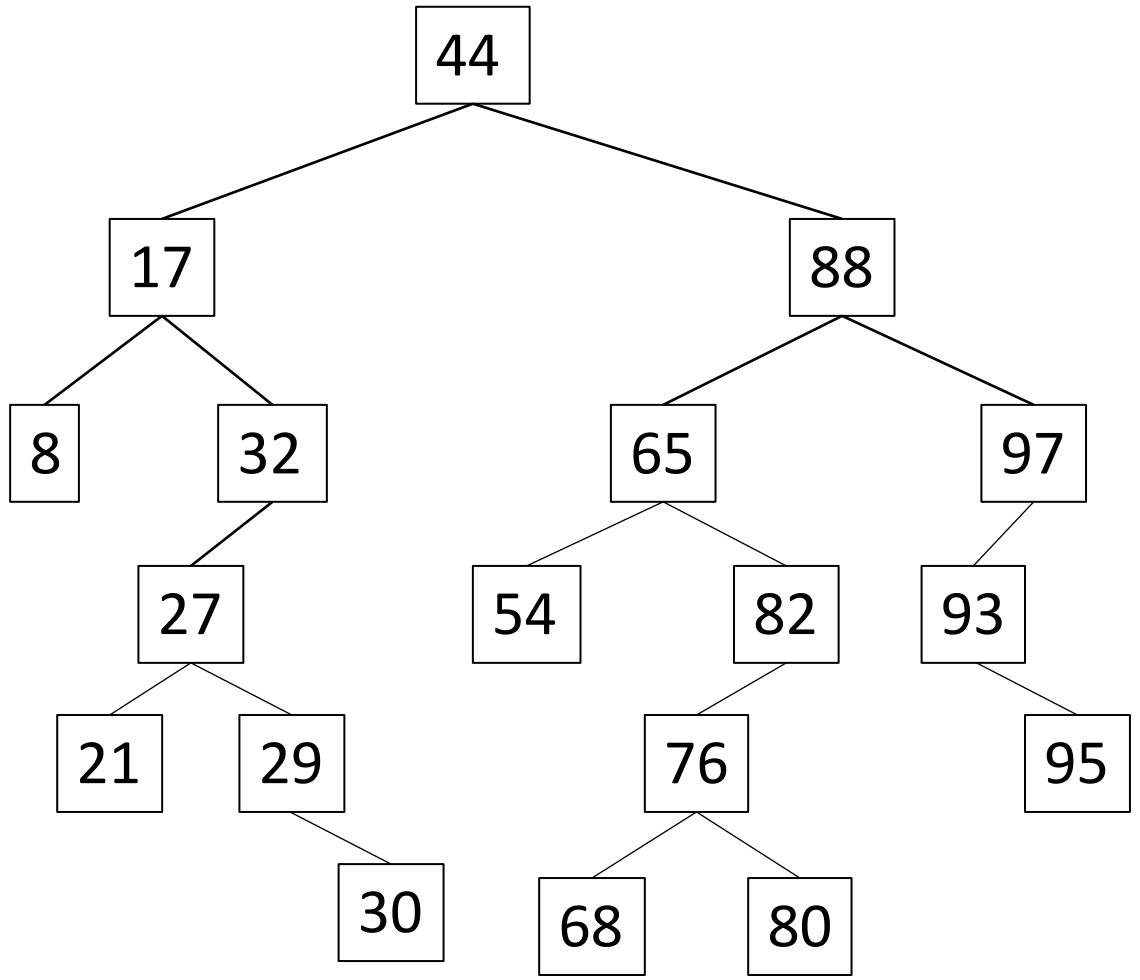
```
public void depthFirst(Node n) {
    if (n != null) {
        System.out.println(n.getValue());
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
    }
}
```

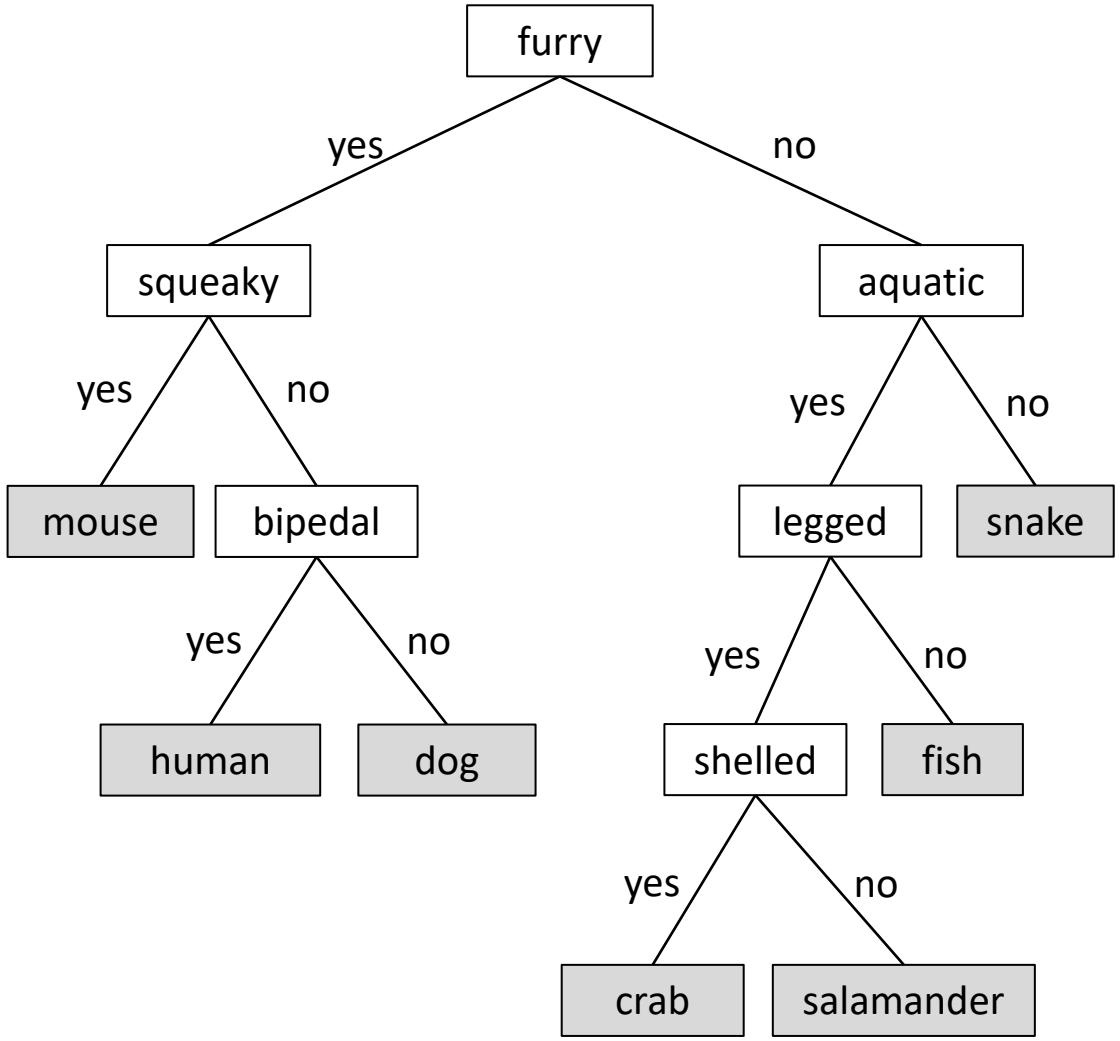
Postorder

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        depthFirst(n.getRight());
        System.out.println(n.getValue());
    }
}
```

Inorder

```
public void depthFirst(Node n) {
    if (n != null) {
        depthFirst(n.getLeft());
        System.out.println(n.getValue());
        depthFirst(n.getRight());
    }
}
```

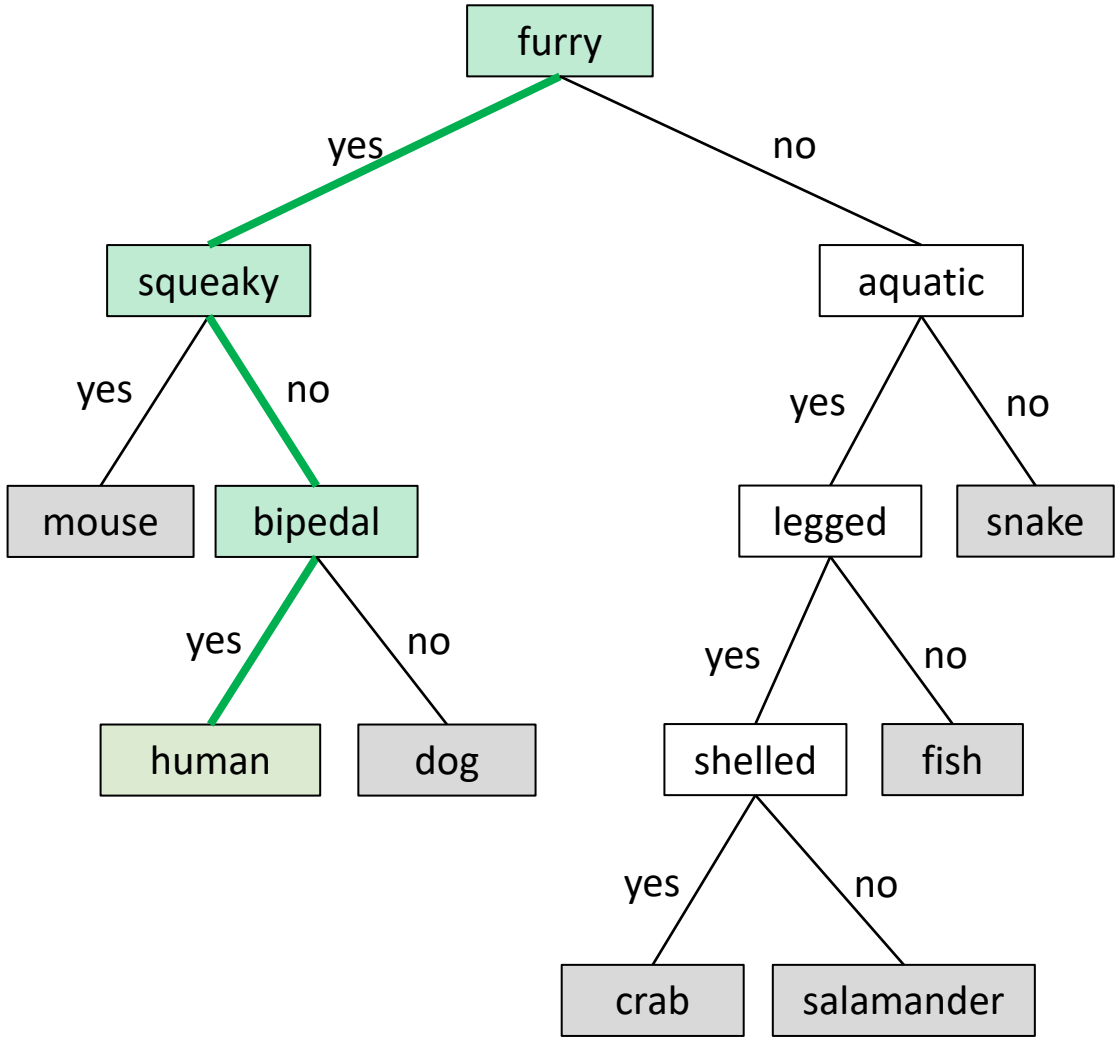




Do you have another animal to identify? (Y/N) > Y
Is this animal furry? (Y/N) > Y
Is this animal squeaky? (Y/N) > N
Is this animal bipedal? (Y/N) > Y
Is this animal a human? (Y/N) > N
I don't know any furry, not squeaky, bipedal animals that aren't a human.
What is the new animal? > bigfoot
What characteristic does a bigfoot have that a human does not? > reclusive

Program Execution:

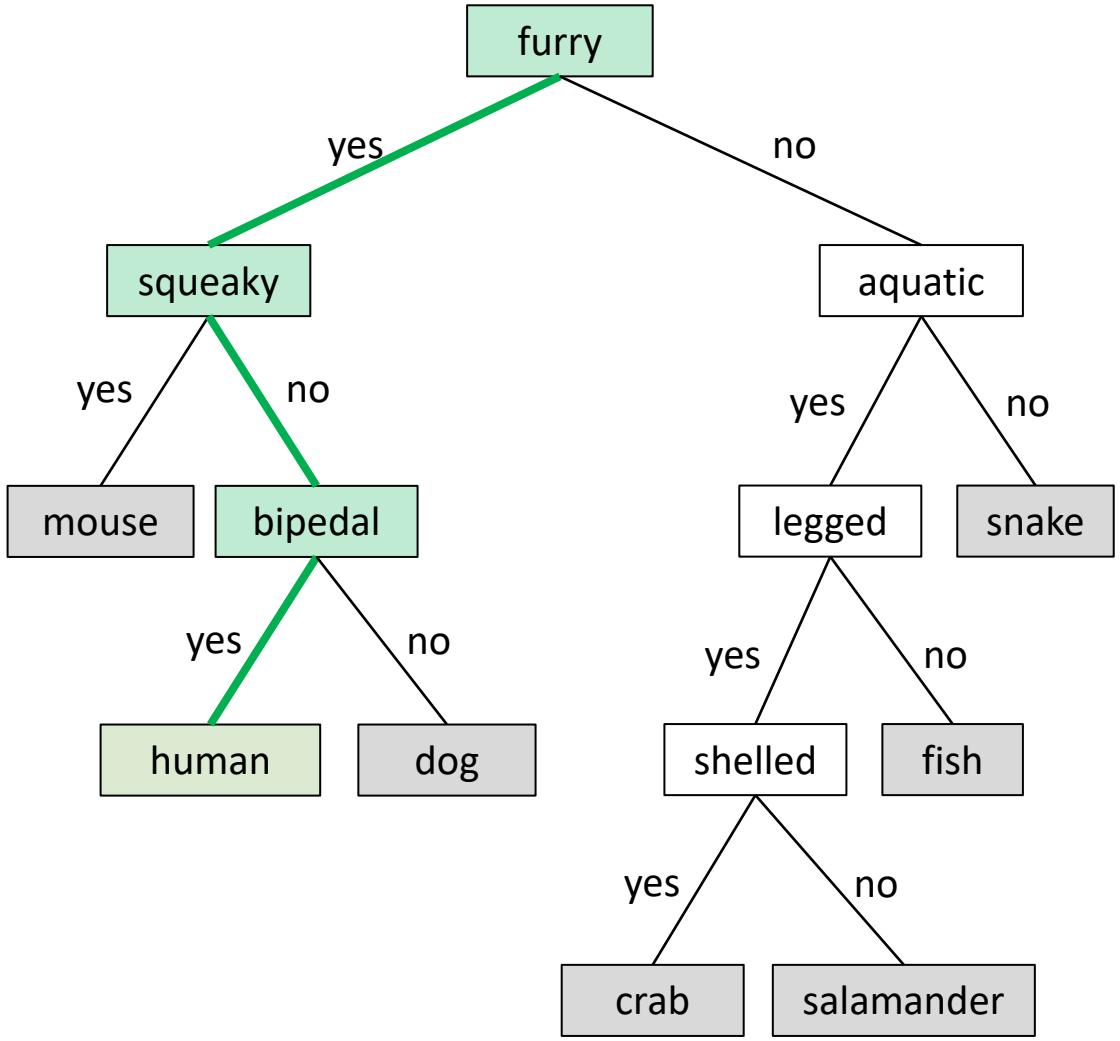
1.



Do you have another animal to identify? (Y/N) > Y
Is this animal furry? (Y/N) > Y
Is this animal squeaky? (Y/N) > N
Is this animal bipedal? (Y/N) > Y
Is this animal a human? (Y/N) > N
I don't know any furry, not squeaky, bipedal animals that aren't a human.
What is the new animal? > bigfoot
What characteristic does a bigfoot have that a human does not? > reclusive

Program Execution:

1. Yes/No questions to navigate to a leaf (animal).
2. Is animal correct?
3.



Do you have another animal to identify? (Y/N) > Y
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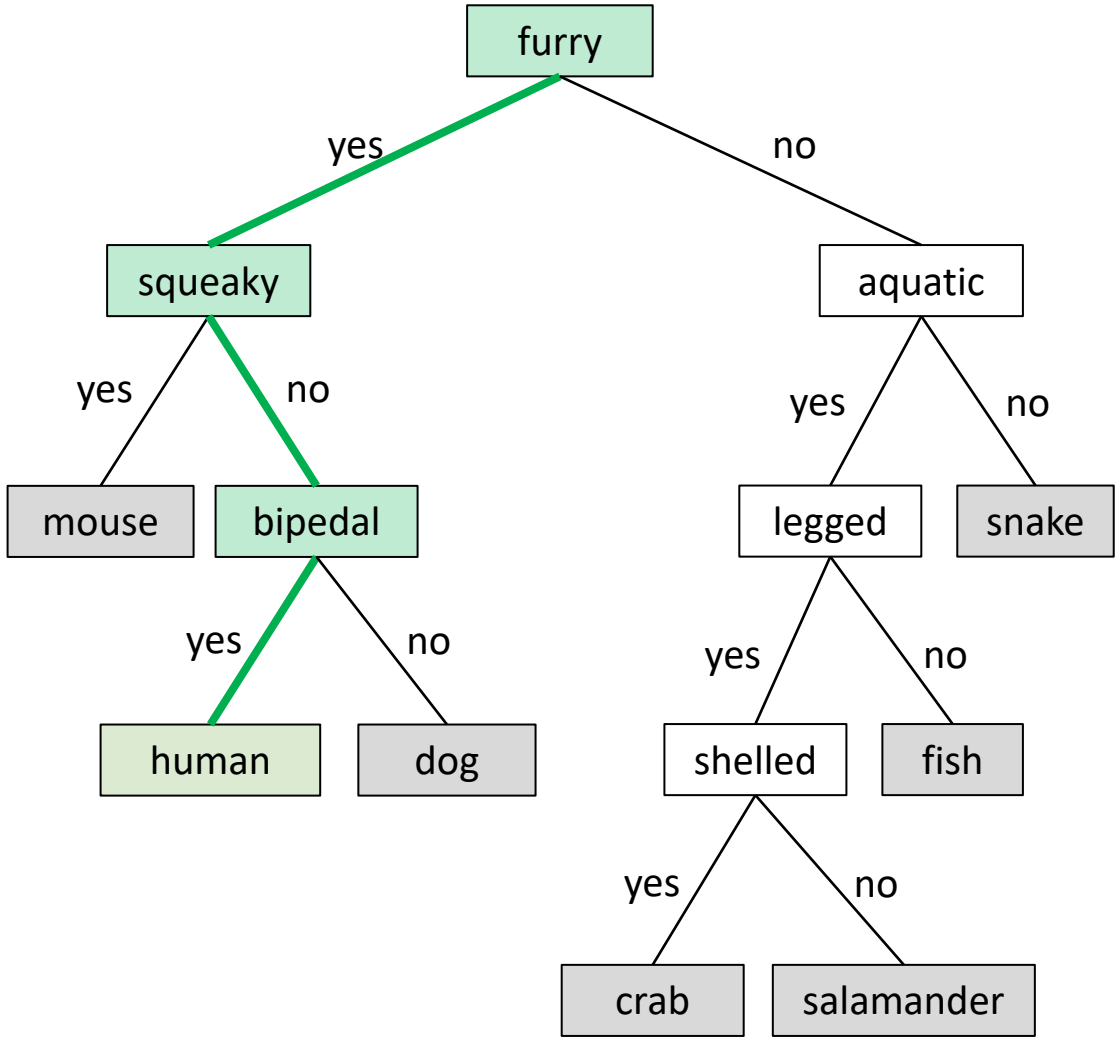
Program Execution:

1. Yes/No questions to navigate to a leaf (animal).
2. Is animal correct?
3. If not:
   - 3.1. Print location in tree.
   - 3.2.



Do you have another animal to identify? (Y/N) > Y
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Is this animal squeaky? (Y/N) > N
Is this animal bipedal? (Y/N) > Y
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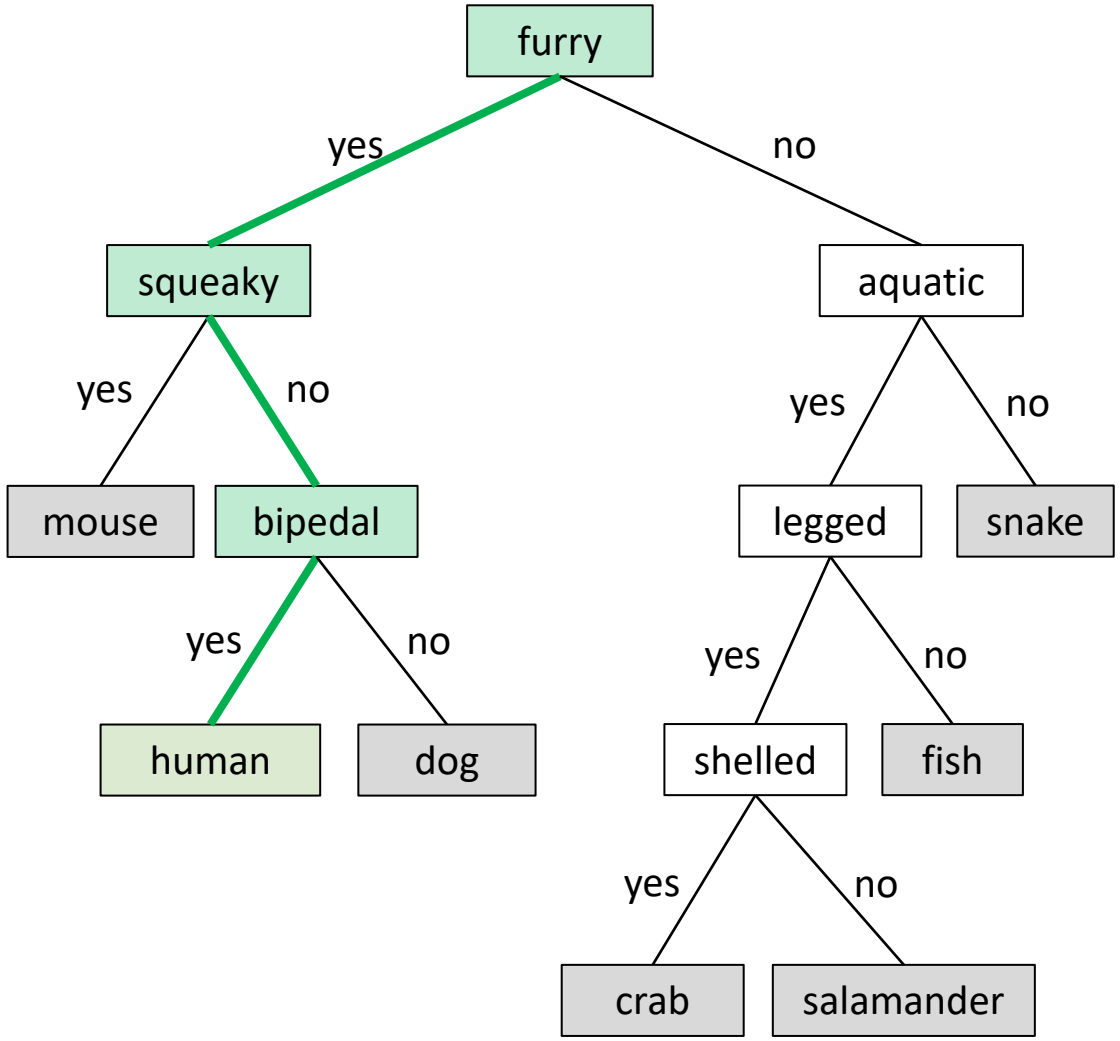
I don't know any furry, not squeaky, bipedal animals that aren't a human.
What is the new animal? > bigfoot
What characteristic does a bigfoot have that a human does not? > reclusive

Program Execution:

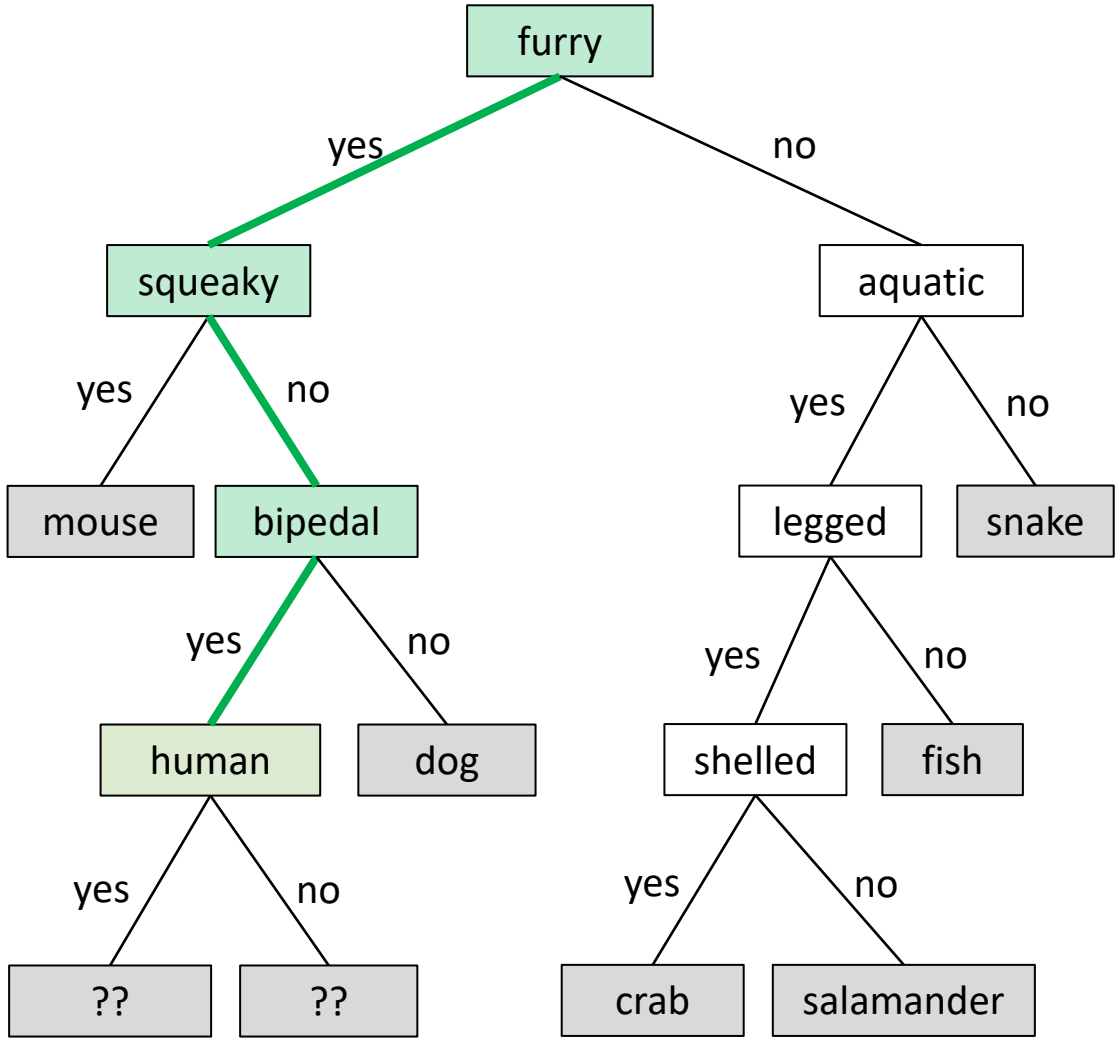
1. Yes/No questions to navigate to a leaf (animal).
2. Is animal correct?
3. If not:
   - 3.1. Print location in tree.
   - 3.2. Get name of new animal.
   - 3.3. Get distinguishing characteristic.
   - 3.4.



Do you have another animal to identify? (Y/N) > Y
Is this animal furry? (Y/N) > Y
Is this animal squeaky? (Y/N) > N
Is this animal bipedal? (Y/N) > Y
Is this animal a human? (Y/N) > N
I don't know any furry, not squeaky, bipedal animals that aren't a human.
What is the new animal? > bigfoot
What characteristic does a bigfoot have that a human does not? > reclusive

Program Execution:

1. Yes/No questions to navigate to a leaf (animal).
2. Is animal correct?
3. If not:
   - 3.1. Print location in tree.
   - 3.2. Get name of new animal.
   - 3.3. Get distinguishing characteristic.
   - 3.4. Modify tree:
     - 3.4.1.



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Is this animal furry? (Y/N) > Y
Is this animal squeaky? (Y/N) > N
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Program Execution:

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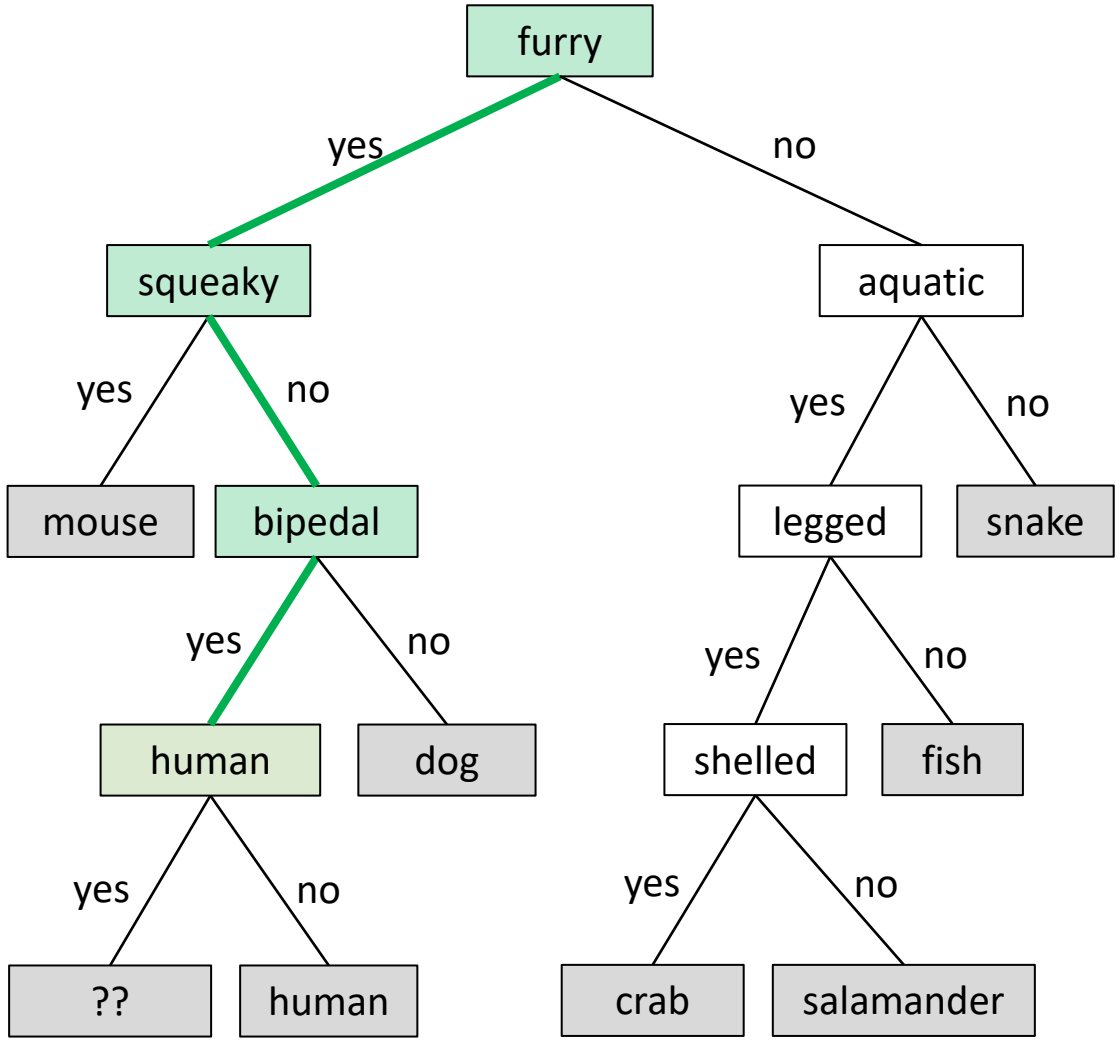
   - 3.1. Print location in tree.
   - 3.2. Get name of new animal.
   - 3.3. Get distinguishing characteristic.
   - 3.4. Modify tree:
     - 3.4.1. Create two new child nodes at current leaf.
     - 3.4.2.



Do you have another animal to identify? (Y/N) > Y
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Is this animal squeaky? (Y/N) > N
Is this animal bipedal? (Y/N) > Y
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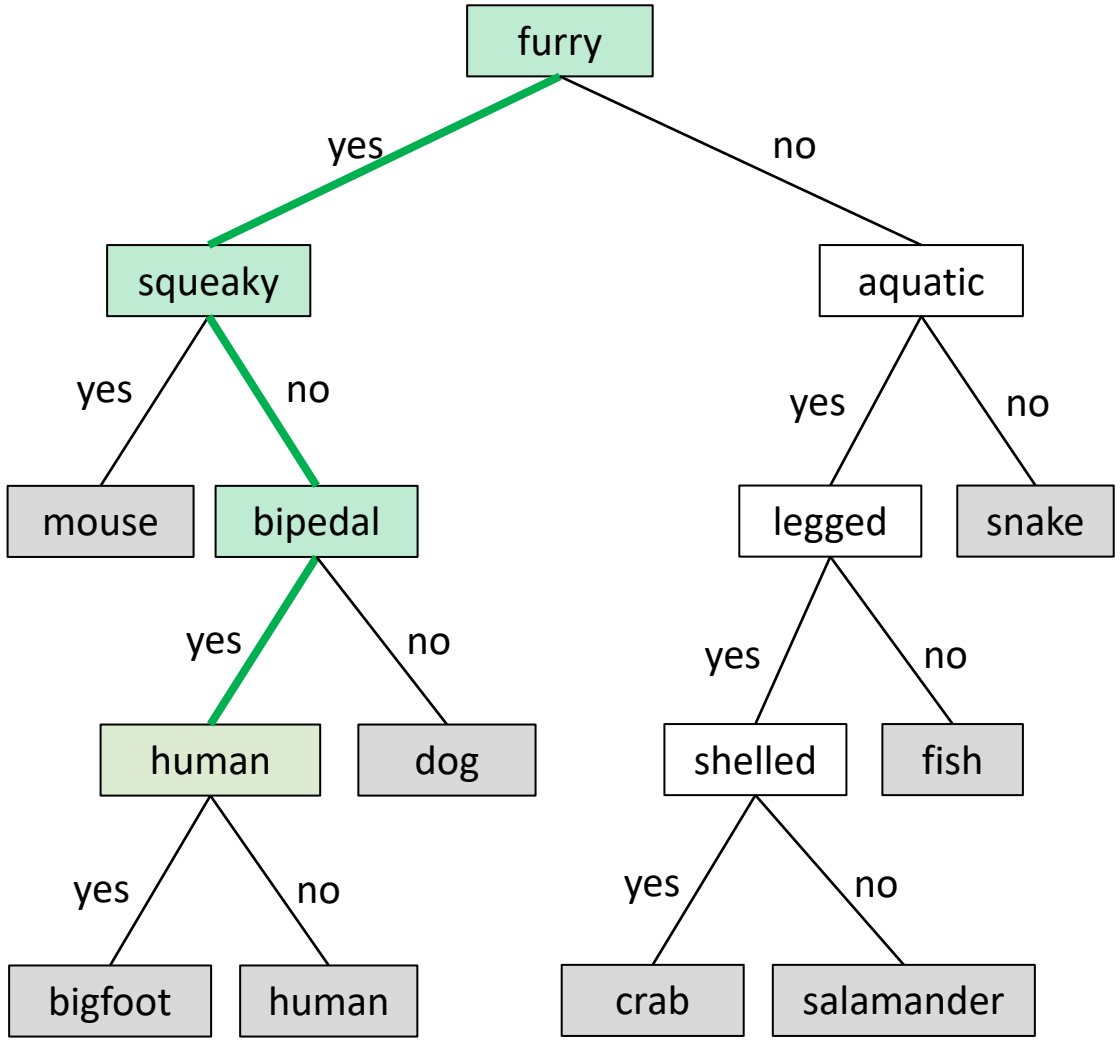
Program Execution:

1. Yes/No questions to navigate to a leaf (animal).
2. Is animal correct?
3. If not:
   - 3.1. Print location in tree.
   - 3.2. Get name of new animal.
   - 3.3. Get distinguishing characteristic.
   - 3.4. Modify tree:
     - 3.4.1. Create two new child nodes at current leaf.
     - 3.4.2. Make "no" child node animal be old leaf.
     - 3.4.3.



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Is this animal furry? (Y/N) > Y
Is this animal squeaky? (Y/N) > N
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Program Execution:

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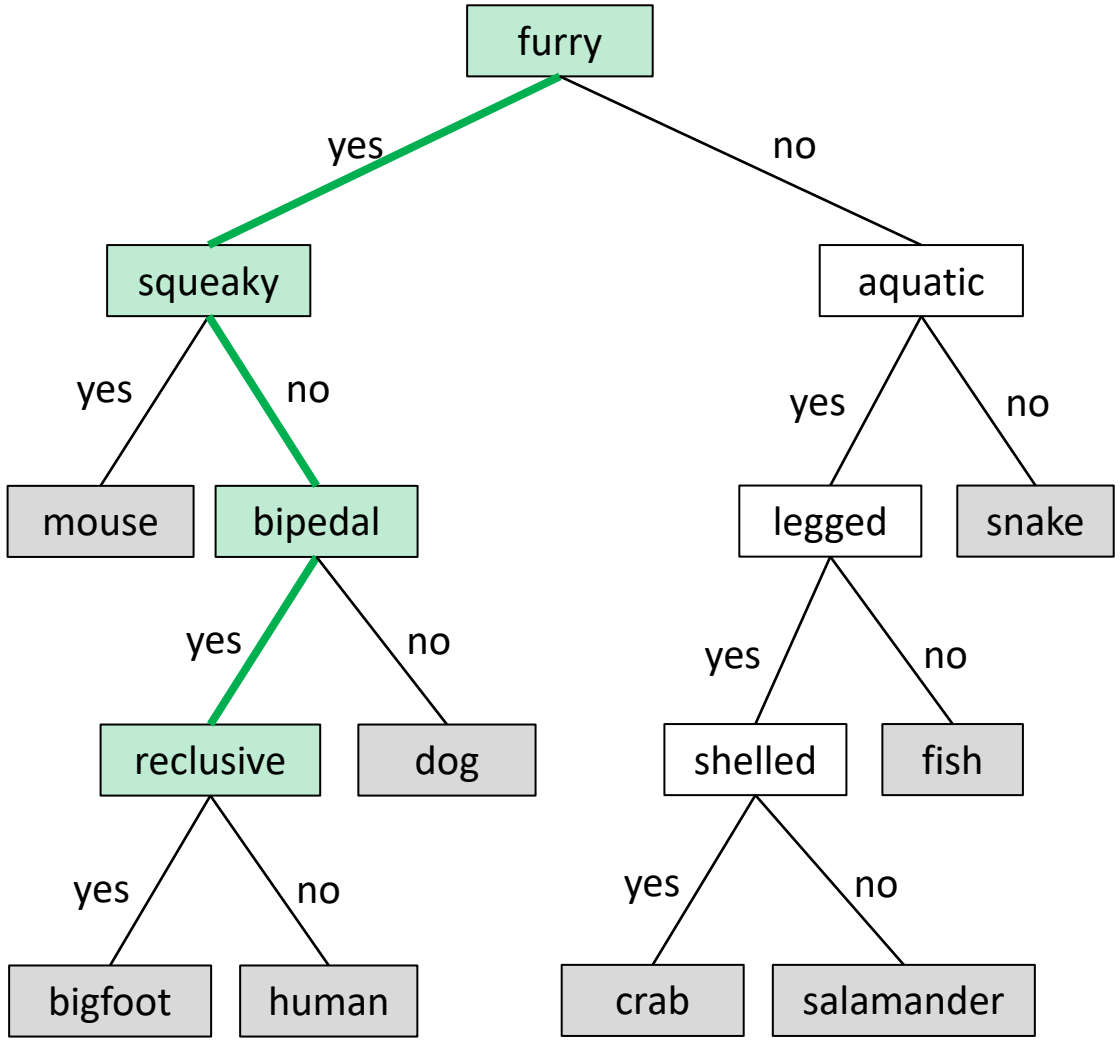
   - 3.1. Print location in tree.
   - 3.2. Get name of new animal.
   - 3.3. Get distinguishing characteristic.
   - 3.4. Modify tree:
     - 3.4.1. Create two new child nodes at current leaf.
     - 3.4.2. Make "no" child node animal be old leaf.
     - 3.4.3. Make "yes" child node animal be new animal.
     - 3.4.4.



Do you have another animal to identify? (Y/N) > Y
Is this animal furry? (Y/N) > Y
Is this animal squeaky? (Y/N) > N
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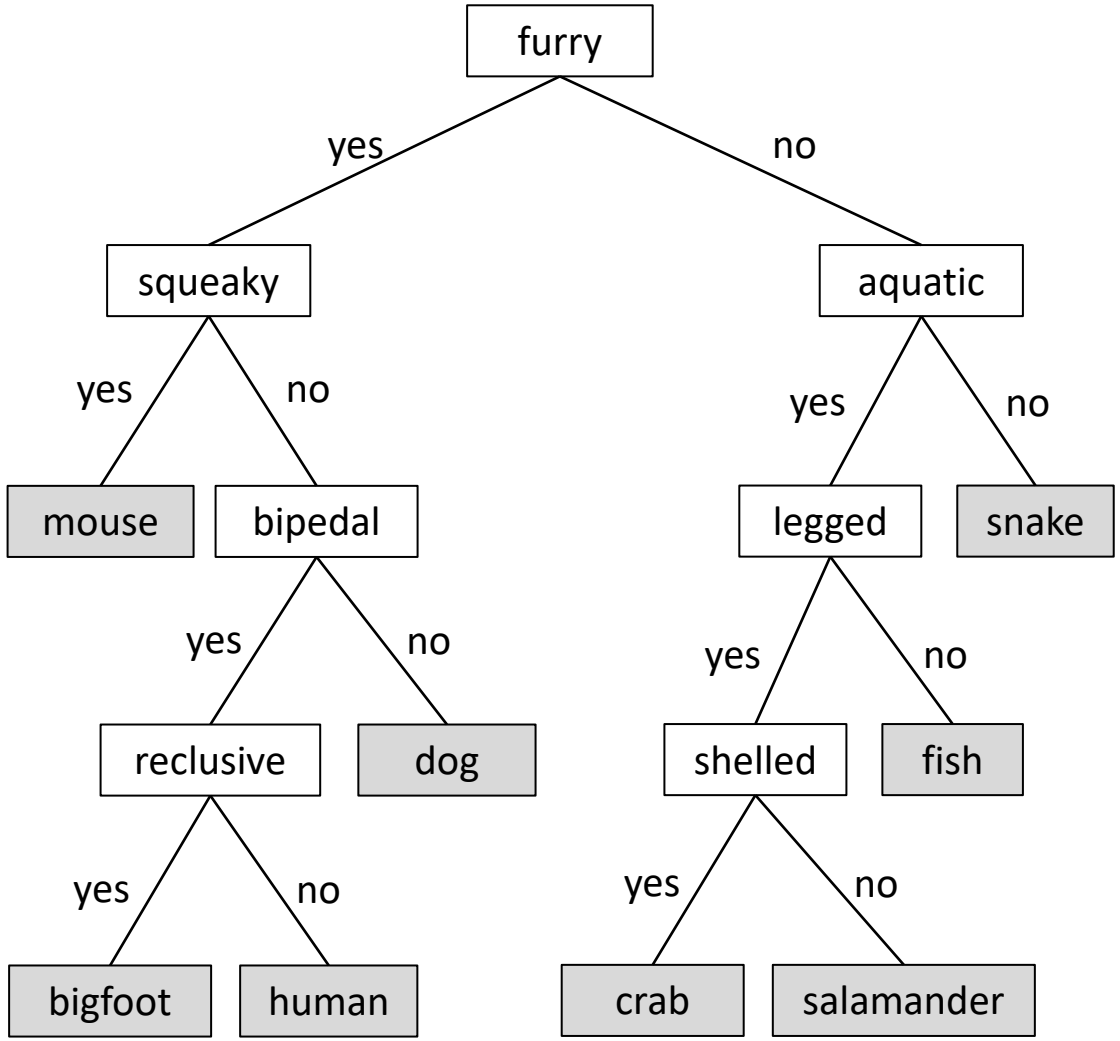
     - 3.4.1. Create two new child nodes at current leaf.
     - 3.4.2. Make "no" child node animal be old leaf.
     - 3.4.3. Make "yes" child node animal be new animal.
     - 3.4.4. Make old leaf be distinguishing characteristic.



Do you have another animal to identify? (Y/N) > Y
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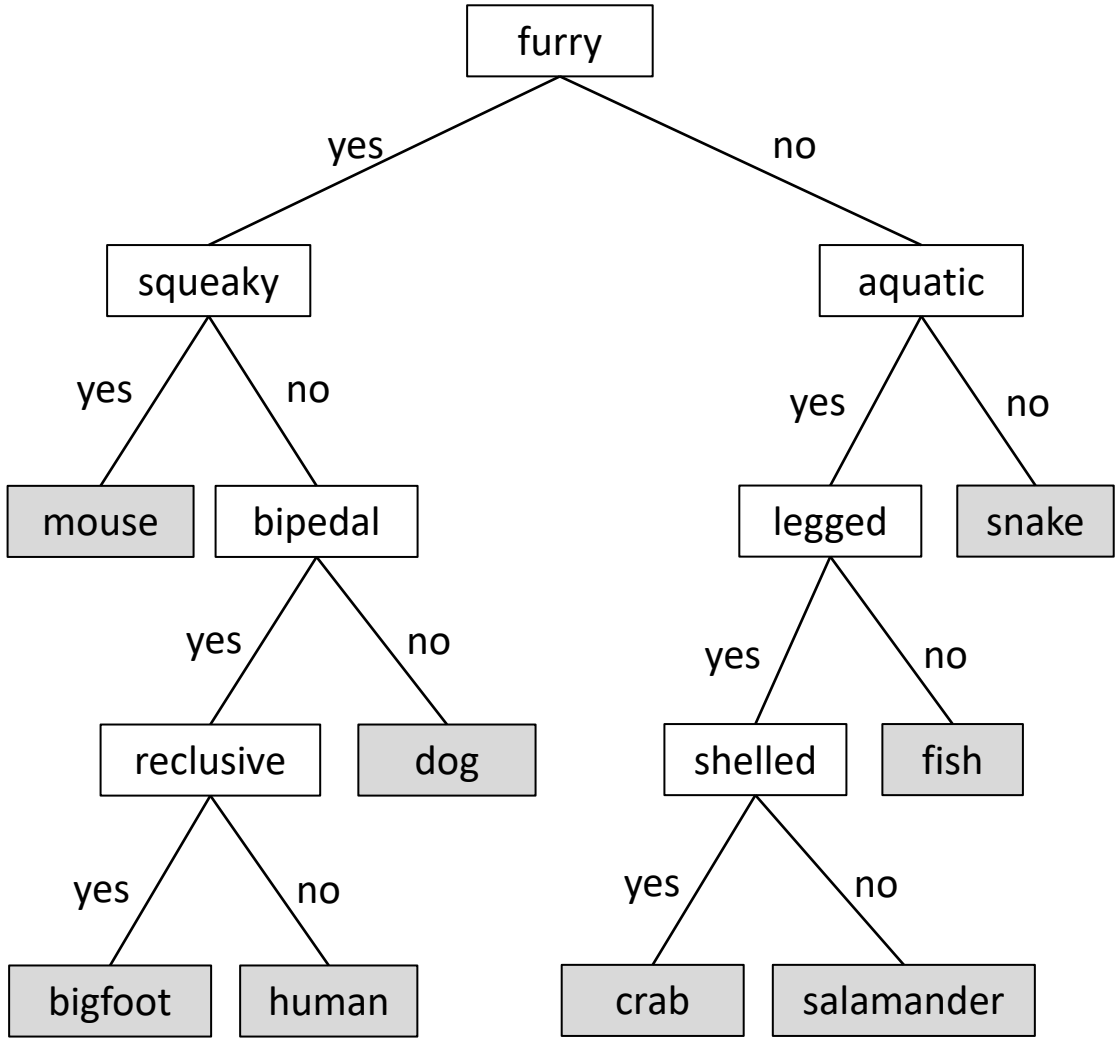
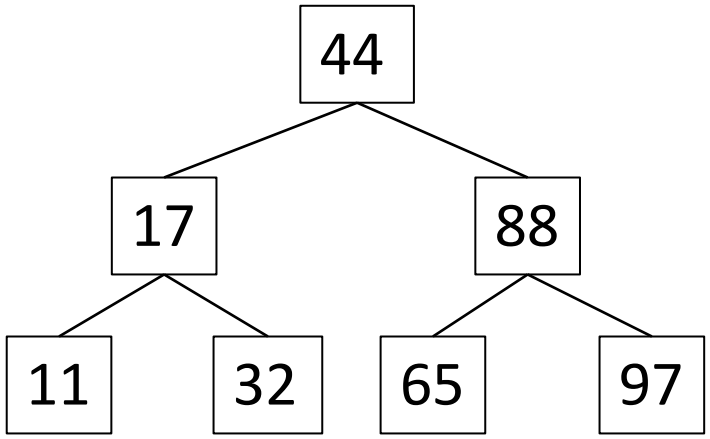



```
public class Node {
    private String text;
    private Node yesChild;
    private Node noChild;
    private Node parent;


    ...
}
```

File read/writing

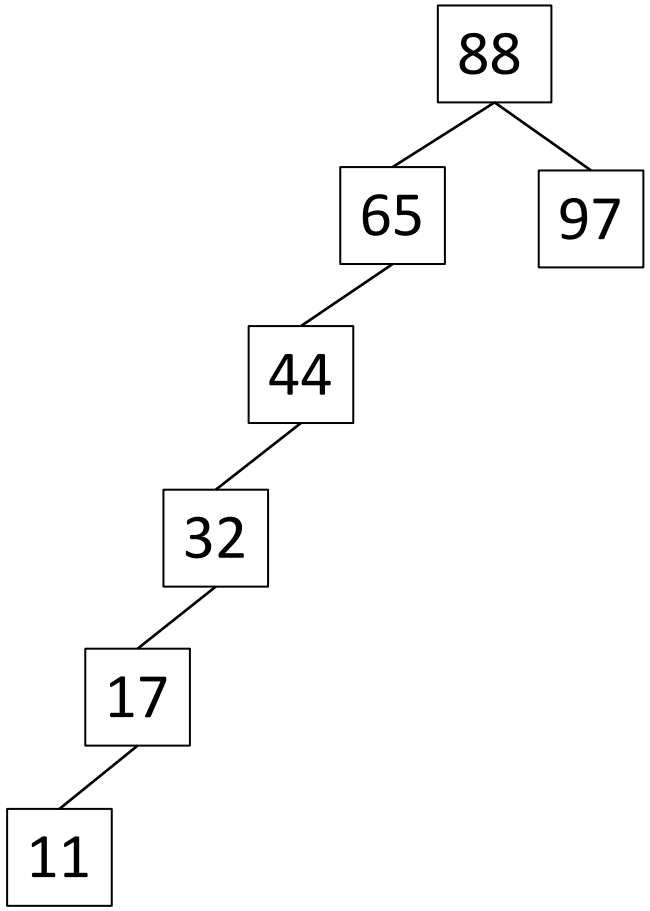
Order Matters



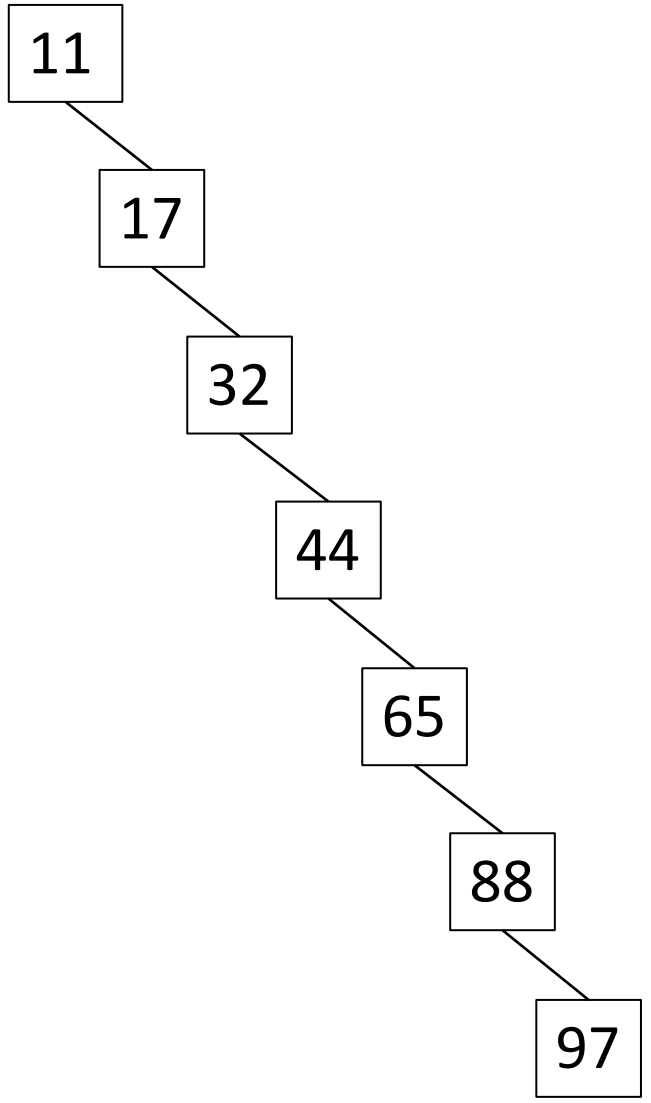
44, 17, 88, 11, 32, 65, 97

44, 17, 32, 88, 11, 97, 65

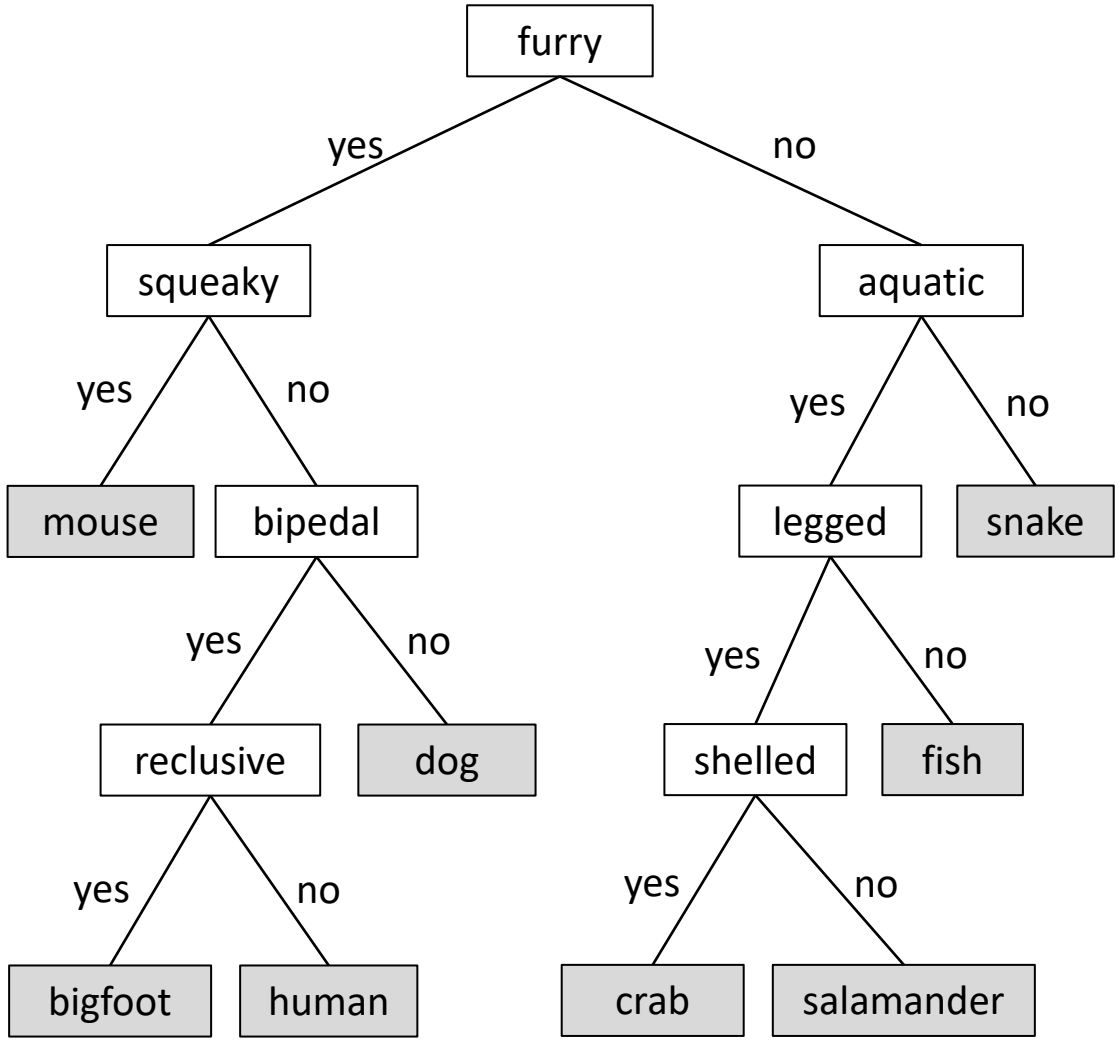
44, 88, 65, 97, 17, 32, 11



88, 65, 44, 32, 97, 17, 11



11, 17, 32, 44, 65, 88, 97




```
public class Node {
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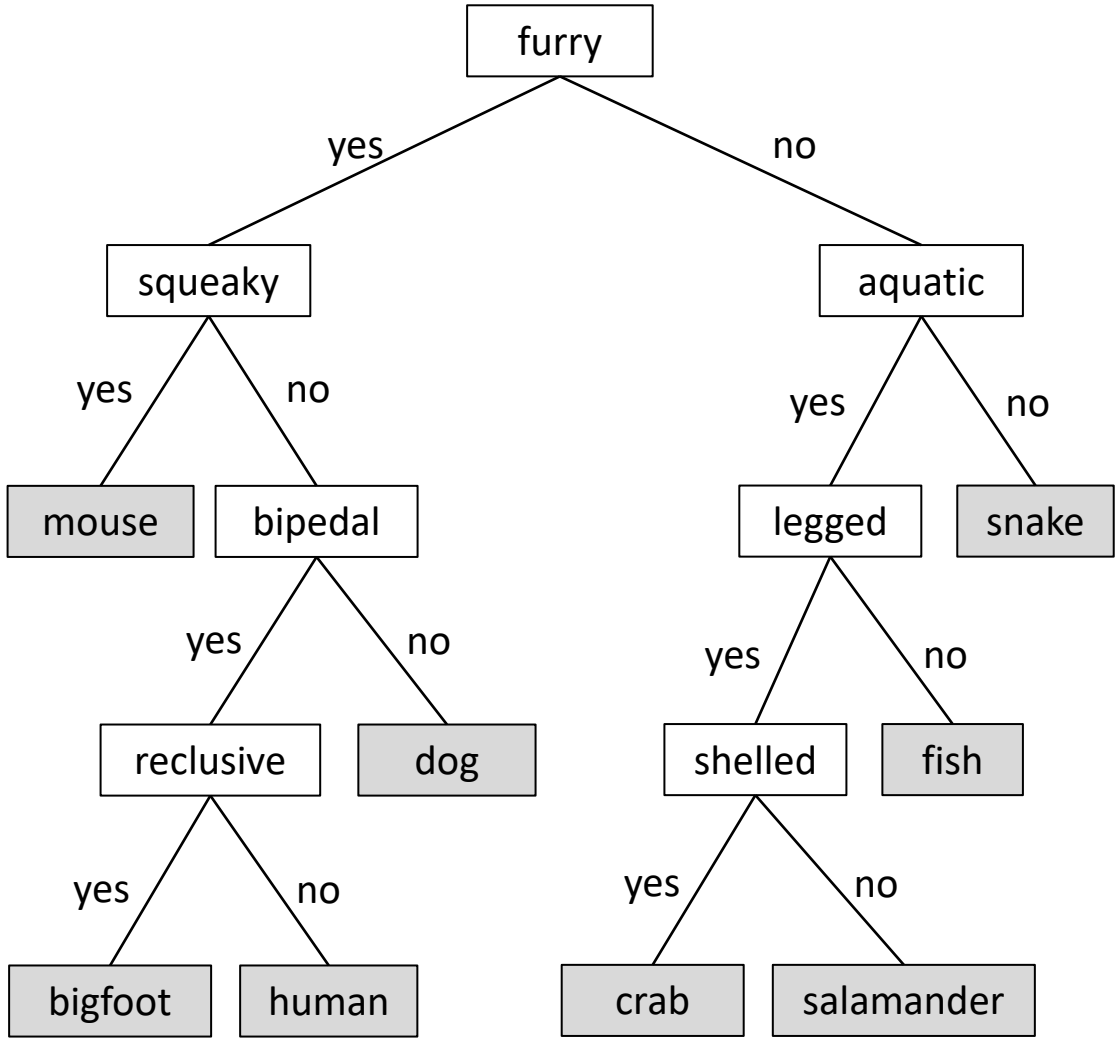
    private Node parent;

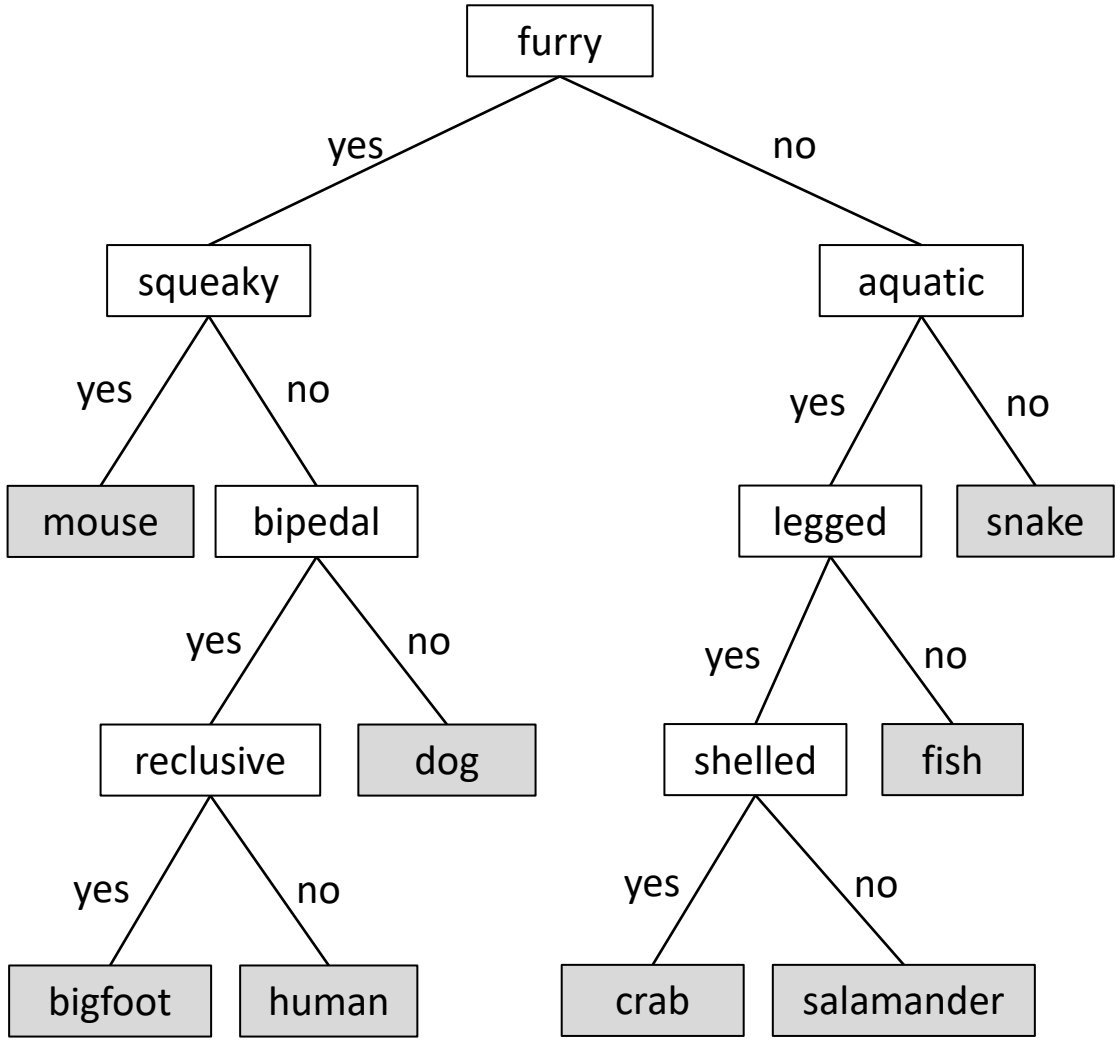

    ...
}
```

File read/writing




```
public class Node {
    private String text;
    private Node yesChild;
    private Node noChild;
    private Node parent;
    private int tag;
    ...
}
```

File read/writing

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    private Node parent;
    private int tag;
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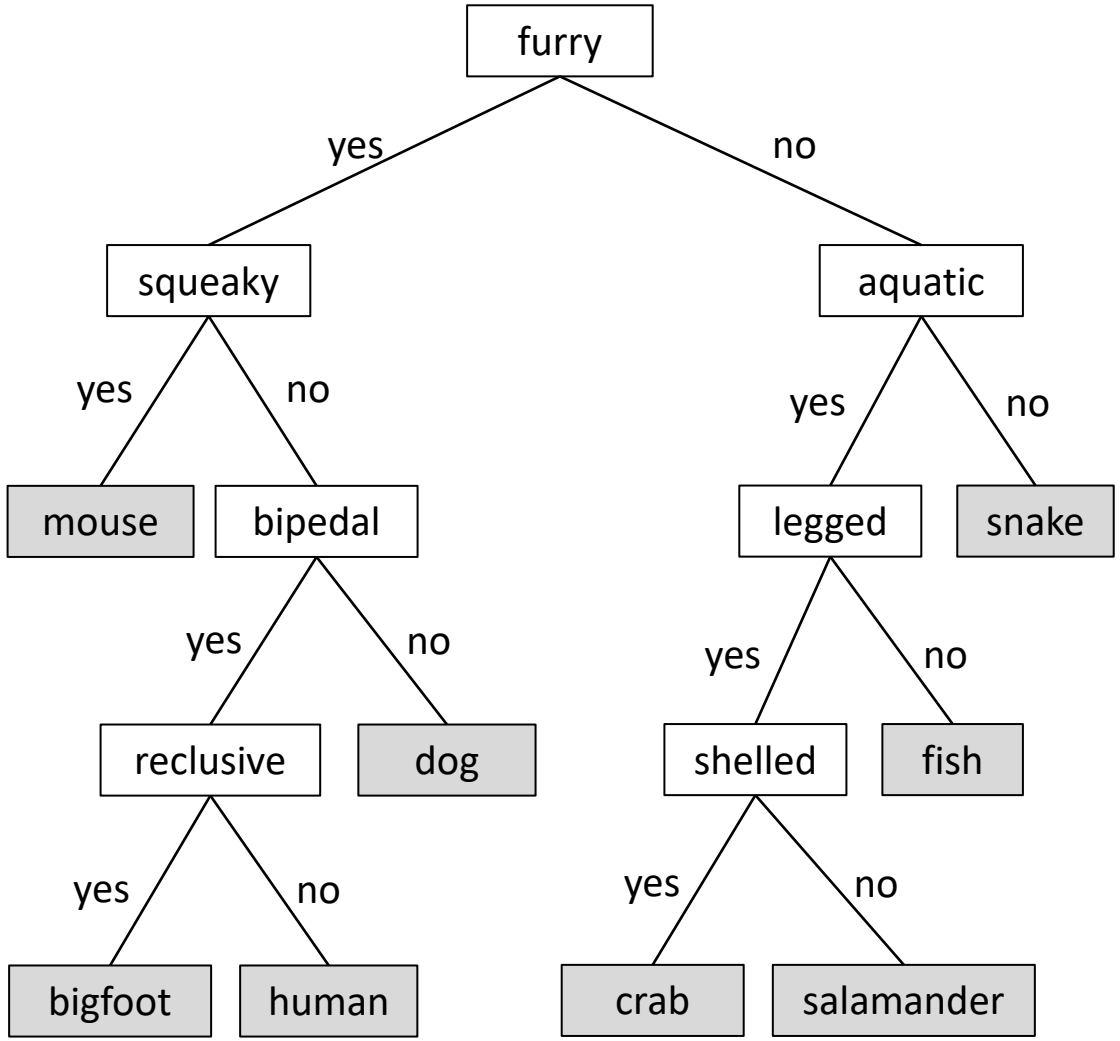
}
```

Save to file:

File read/writing

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    ...
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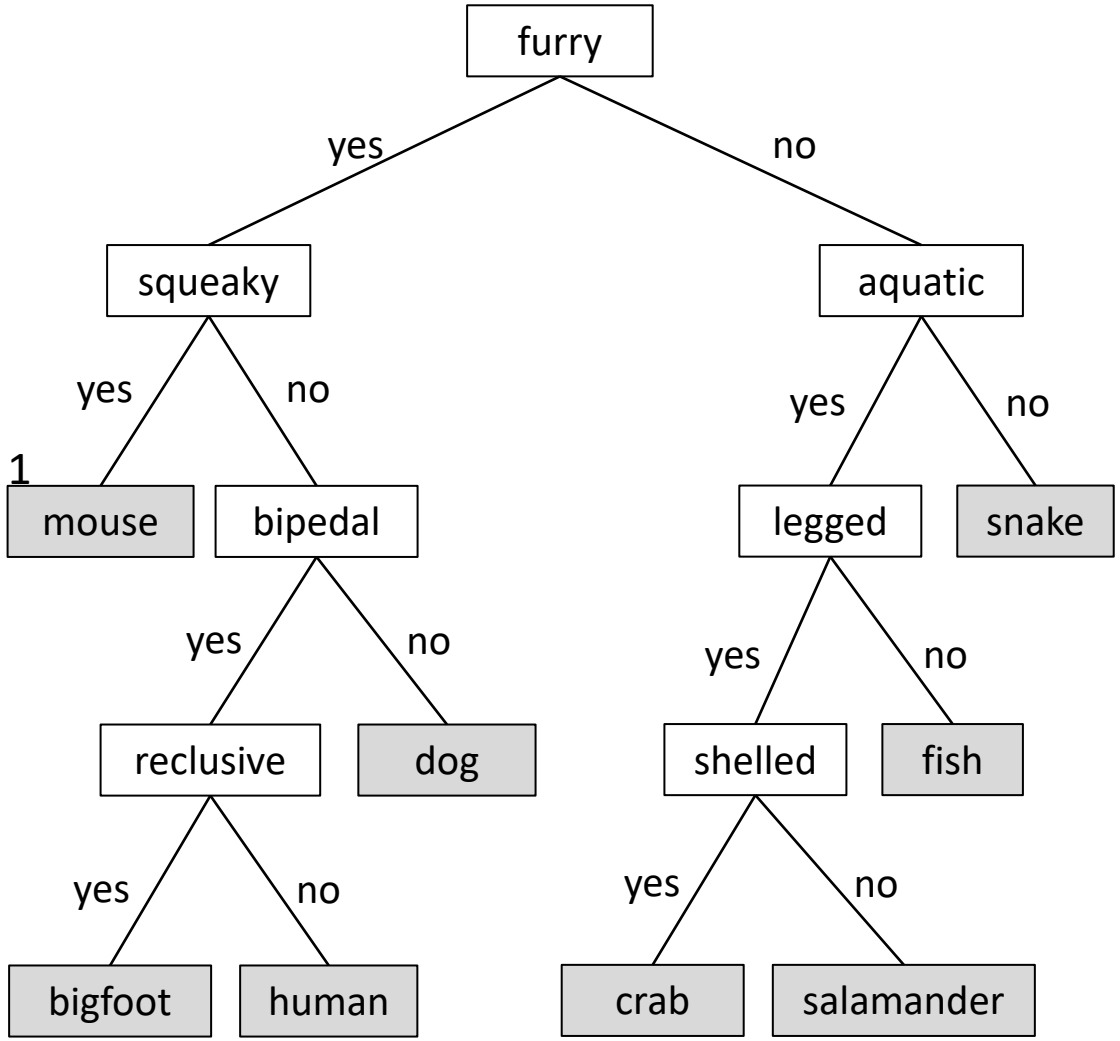
```

Save to file:

1. Do inorder traversal of tree and assign sequential integer tag values.

File read/writing

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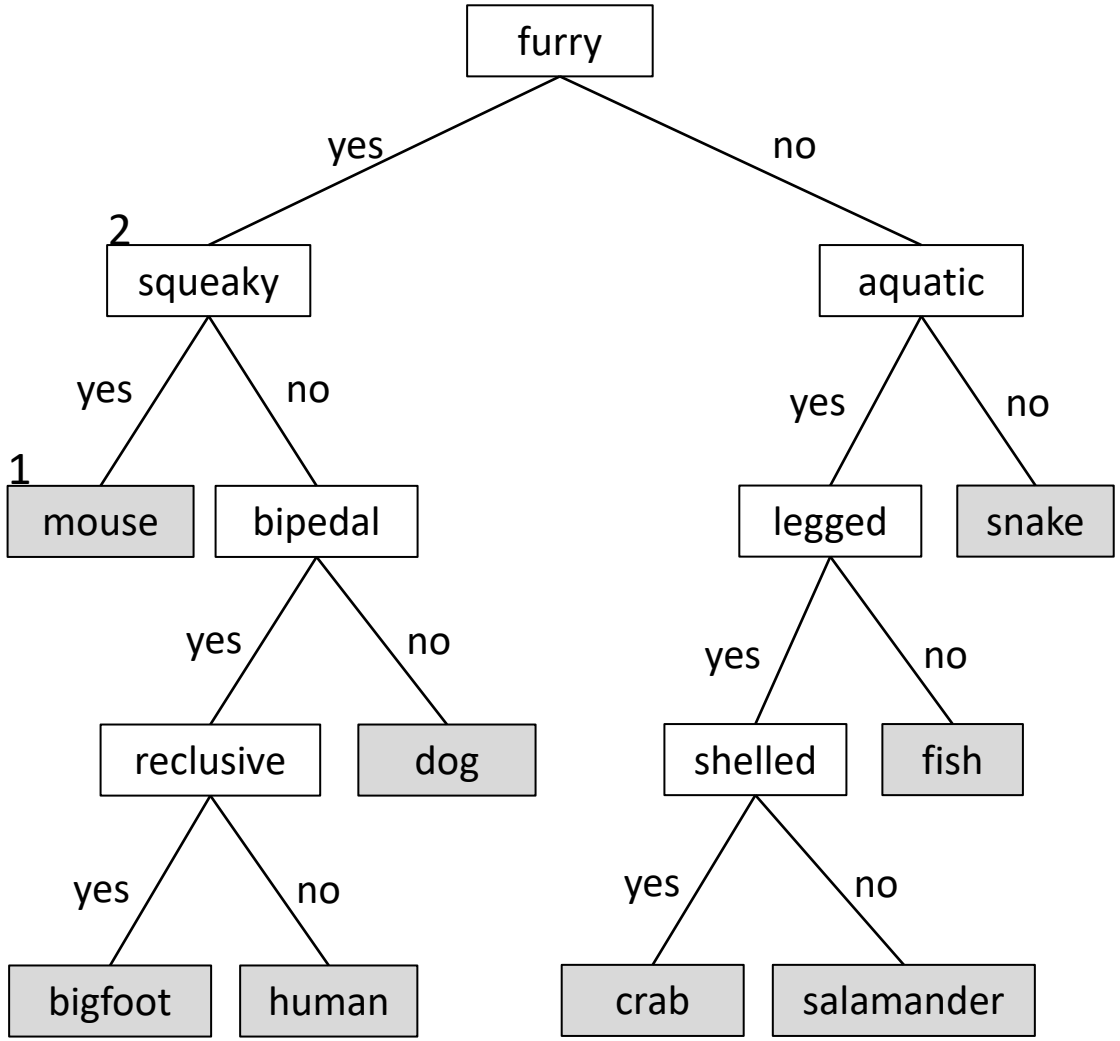
Save to file:

1. Do inorder traversal of tree and assign sequential integer tag values.

File read/writing




```
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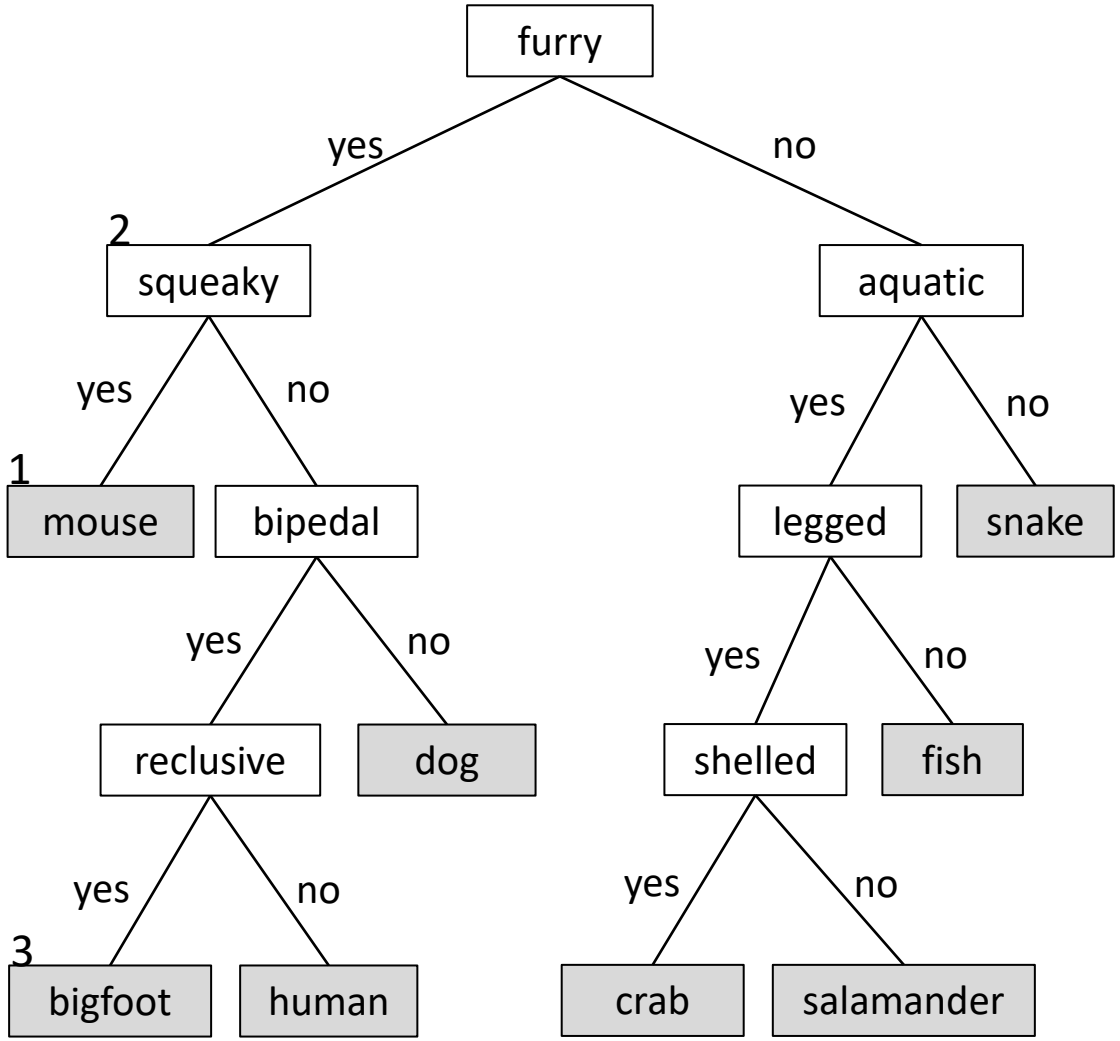
    private Node noChild;
    private Node parent;
    private int tag;
    ...
}
```

Save to file:

1. Do inorder traversal of tree and assign sequential integer tag values.

File read/writing

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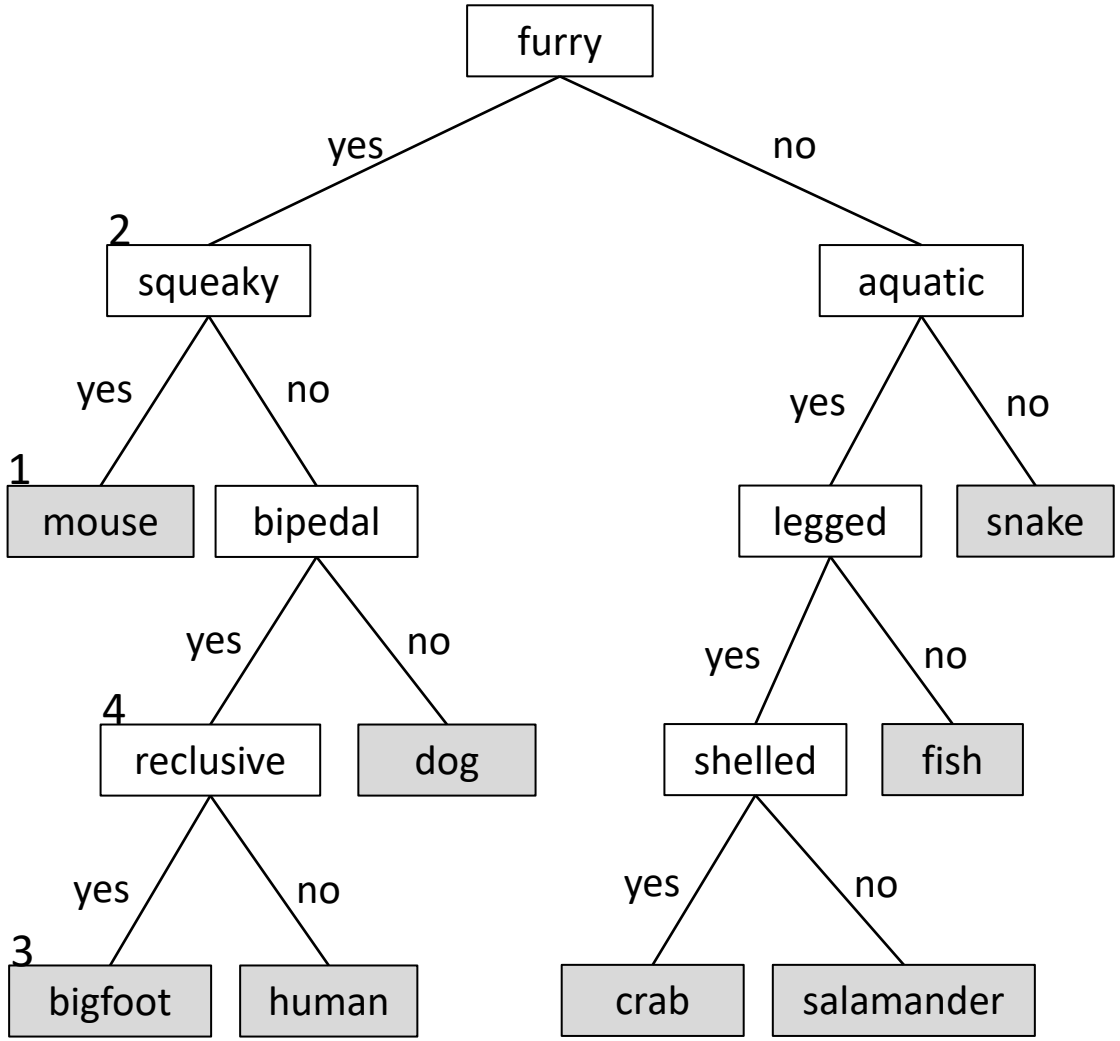
Save to file:

1. Do inorder traversal of tree and assign sequential integer tag values.

File read/writing

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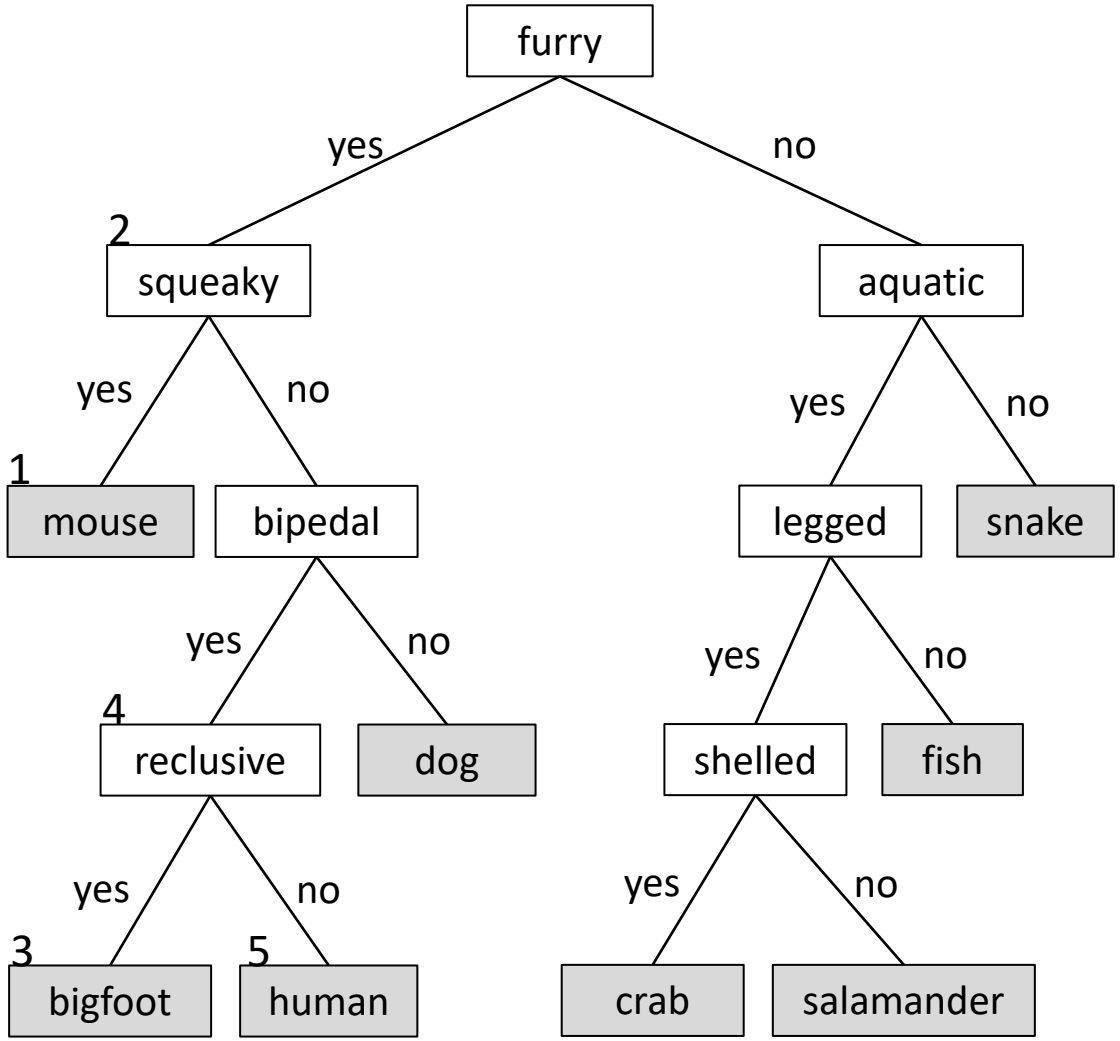
    private Node parent;
    private int tag;
    ...
}
```

Save to file:

1. Do inorder traversal of tree and assign sequential integer tag values.

File read/writing




```
public class Node {
    private String text;
    private Node yesChild;
    private Node noChild;
    private Node parent;
    private int tag;
    ...
}
```

Save to file:

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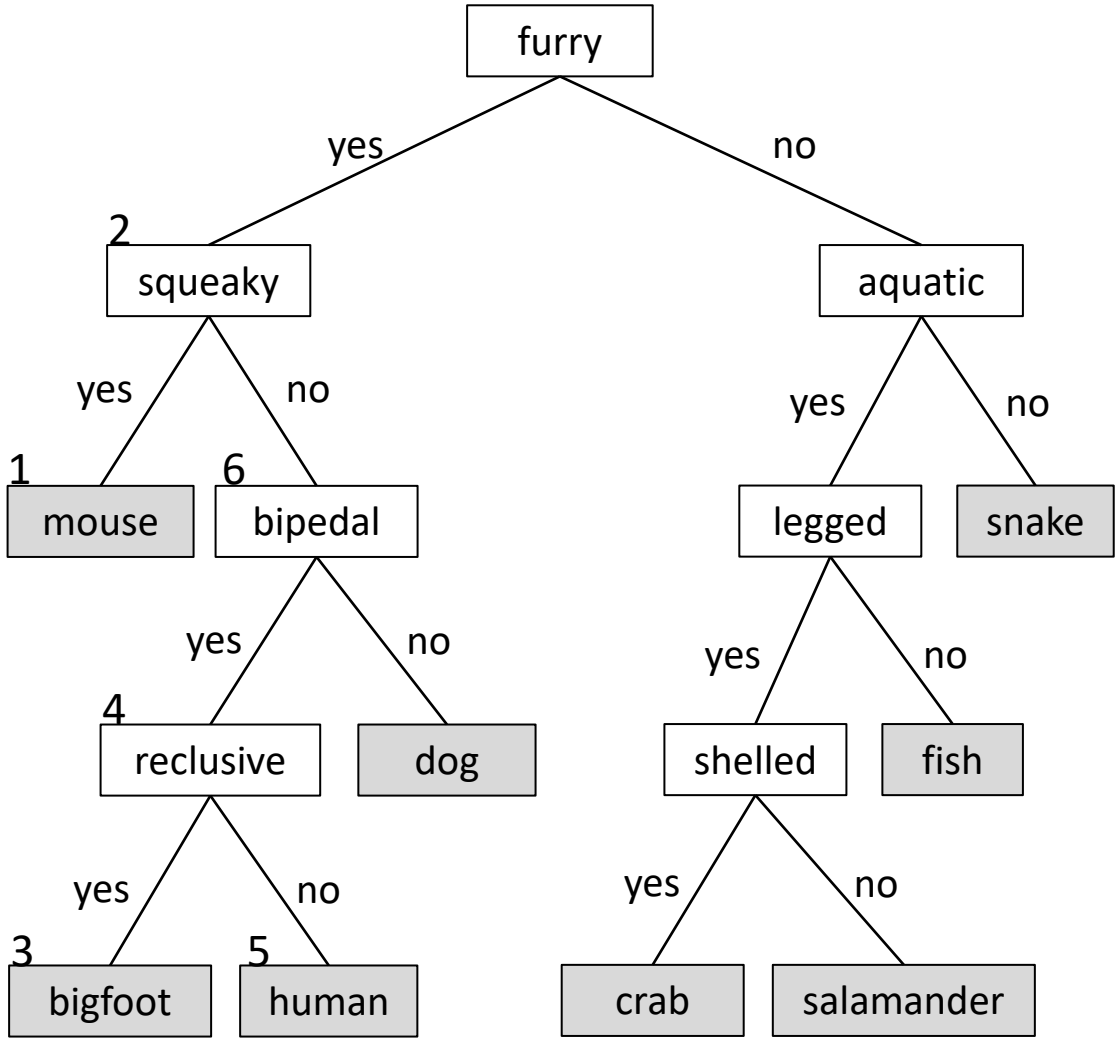


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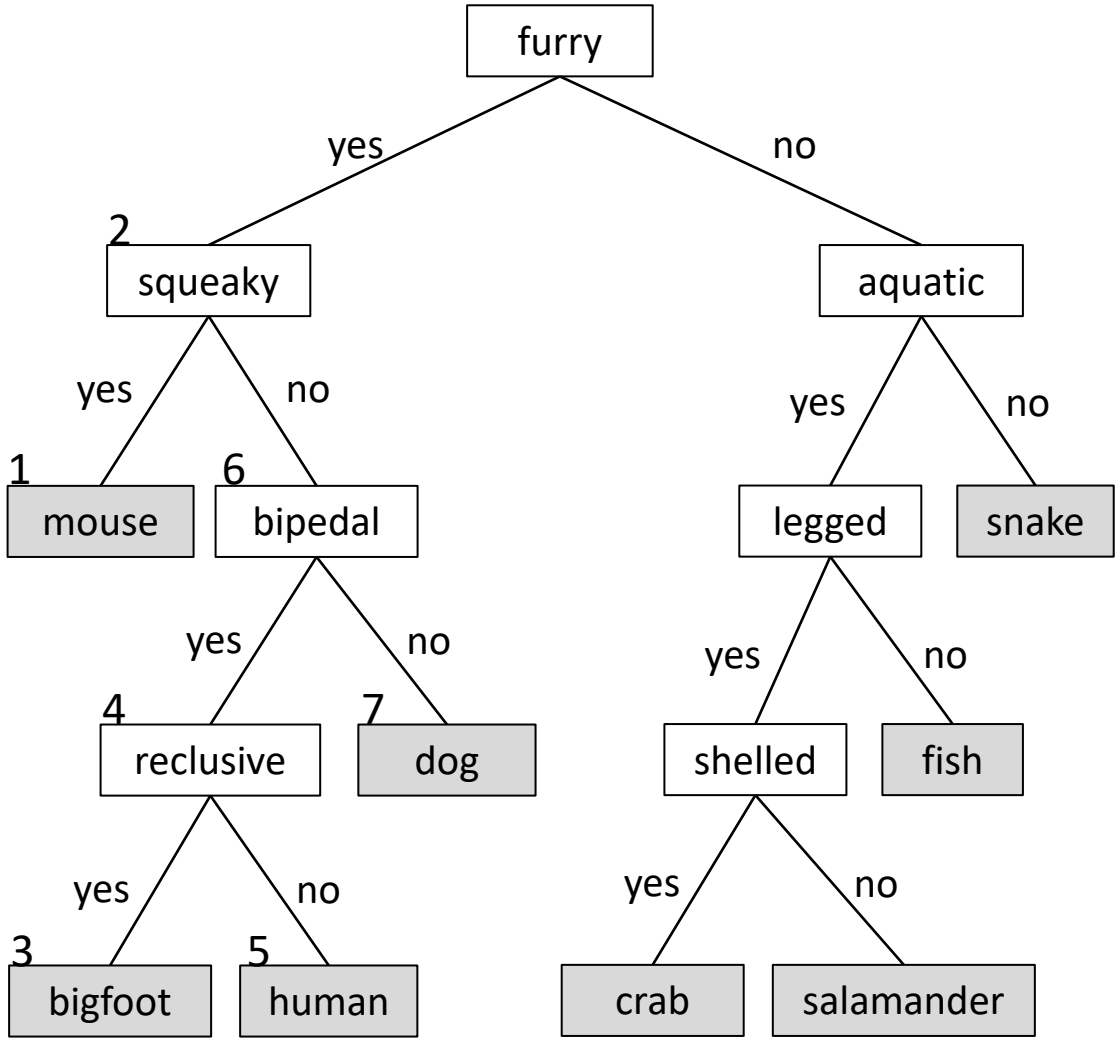


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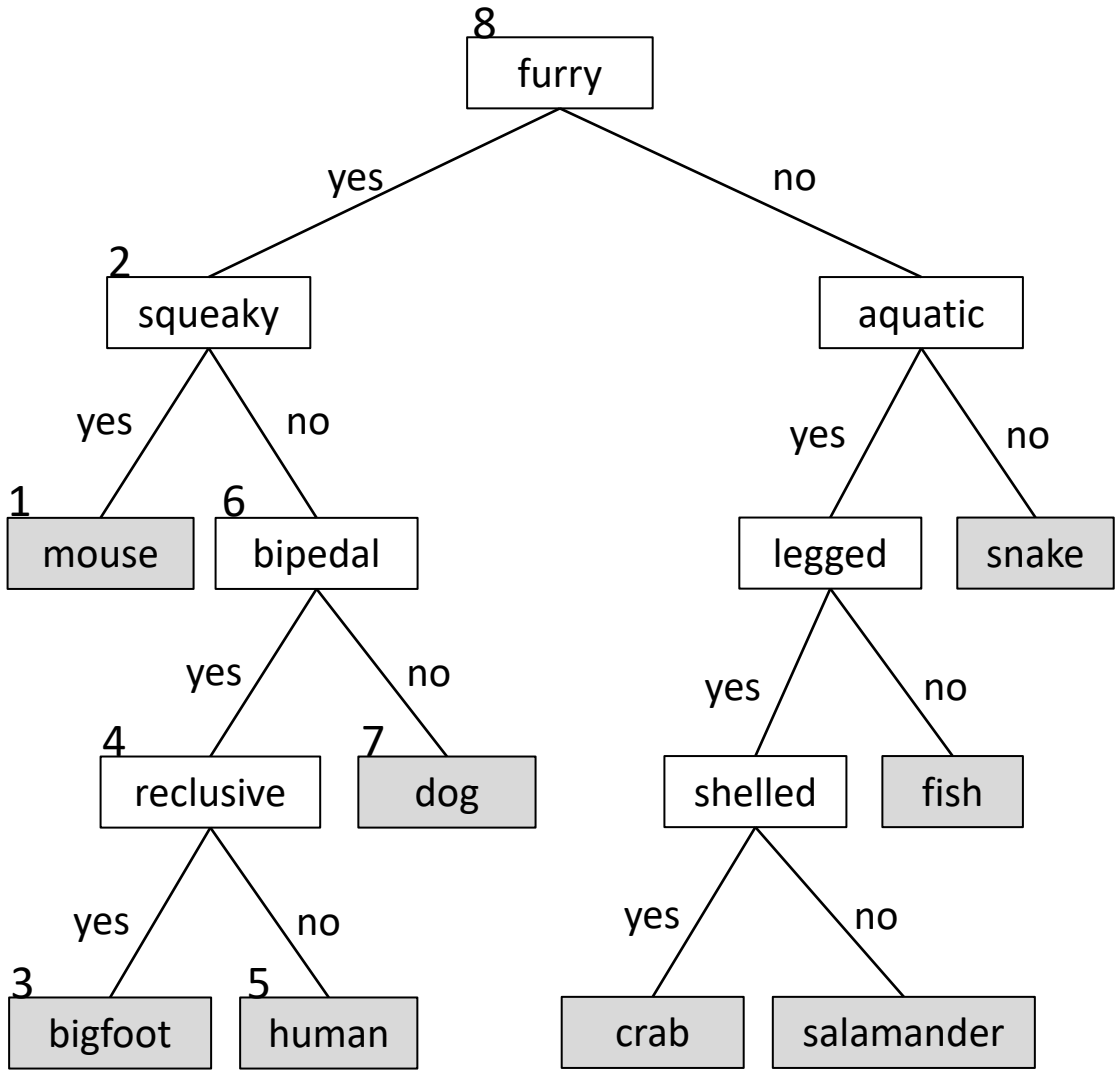


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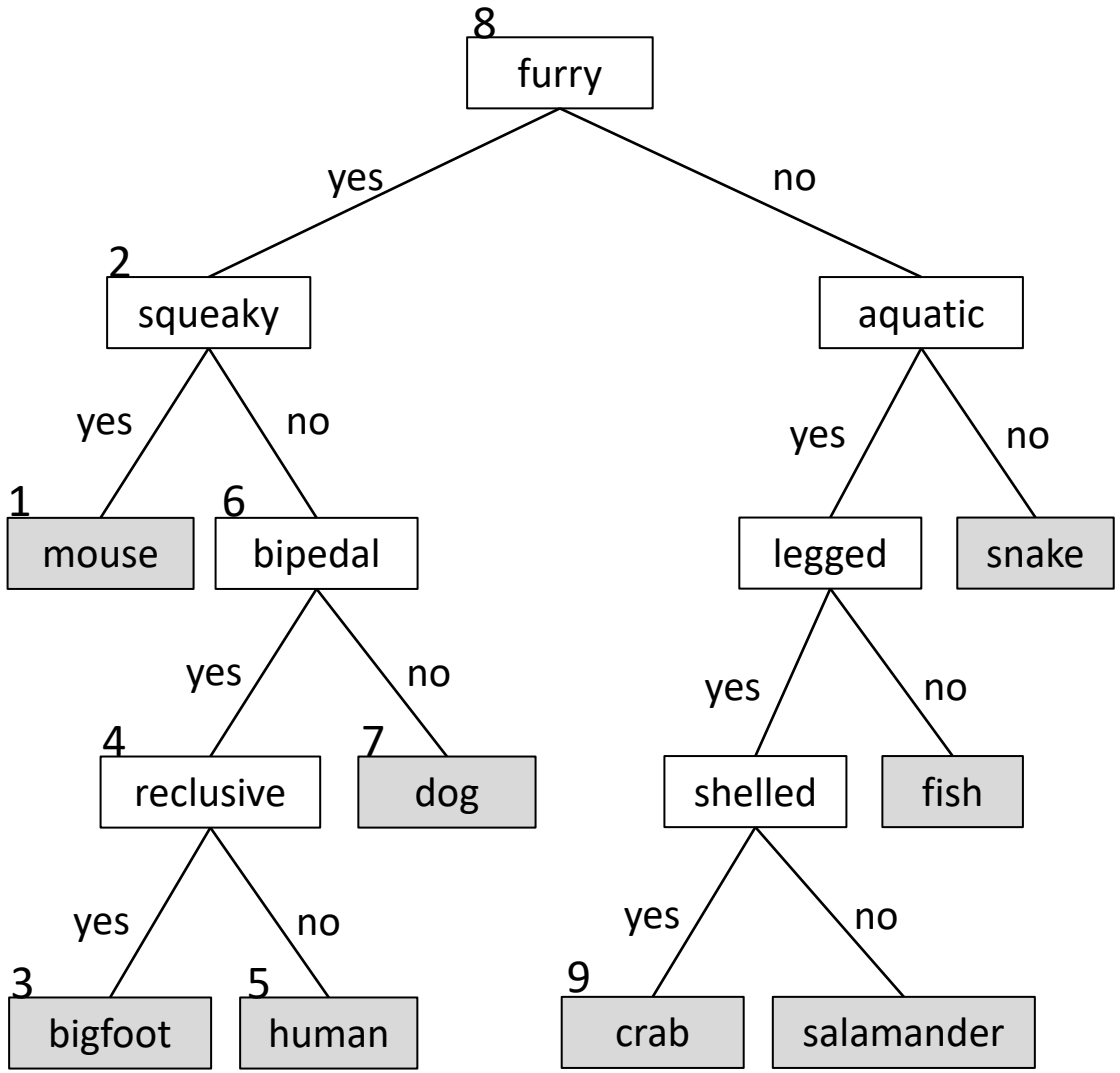


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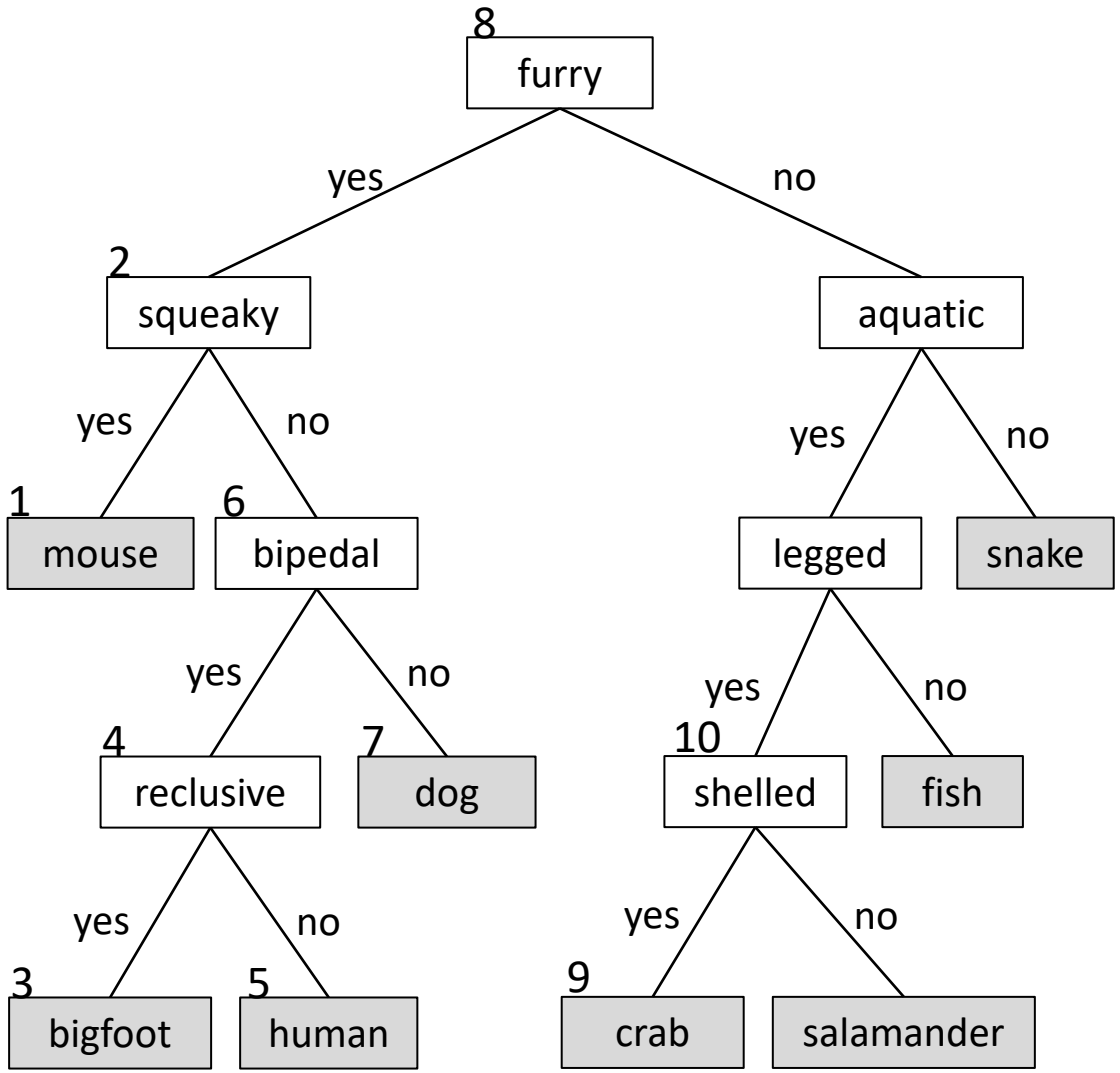


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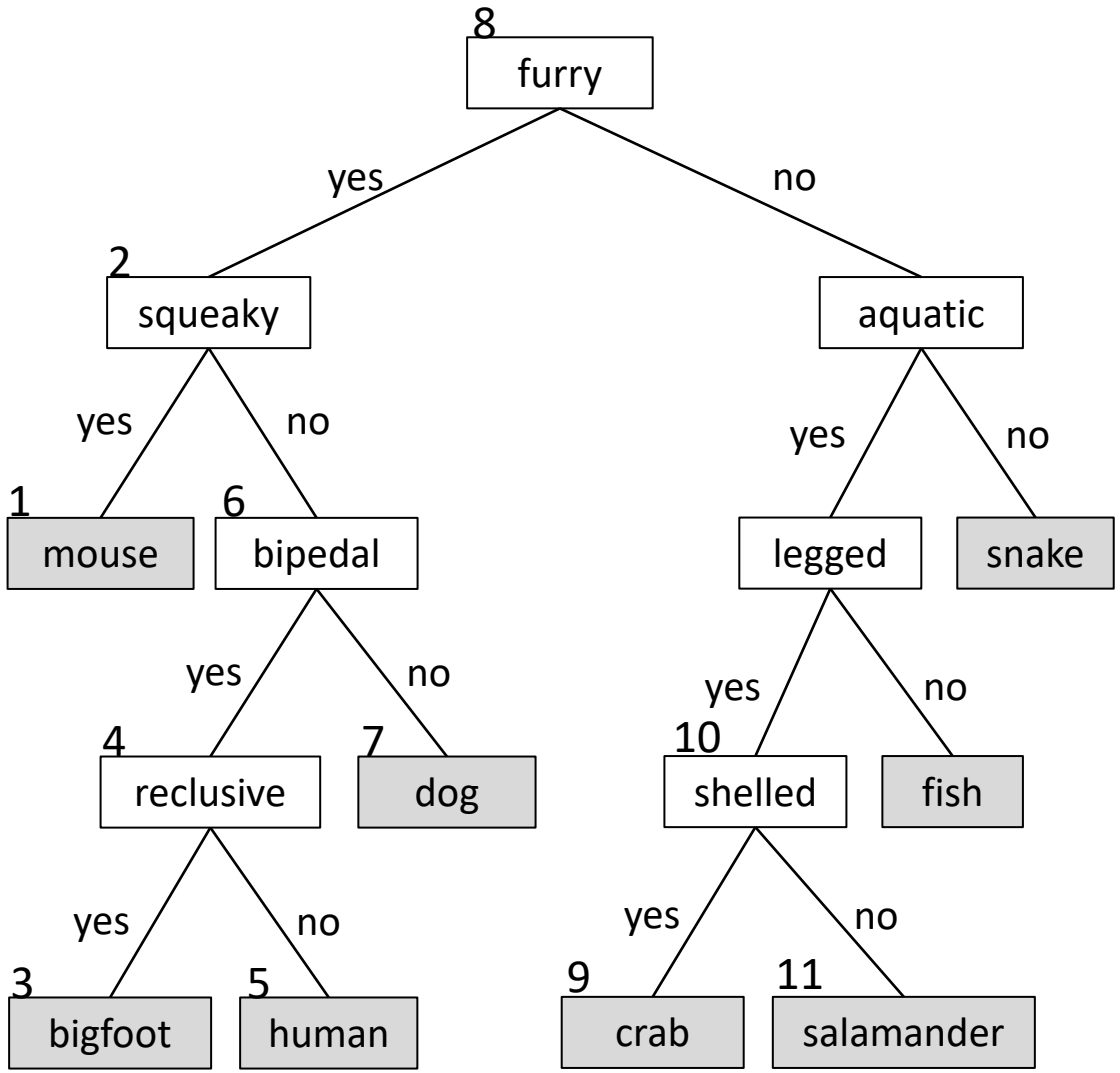


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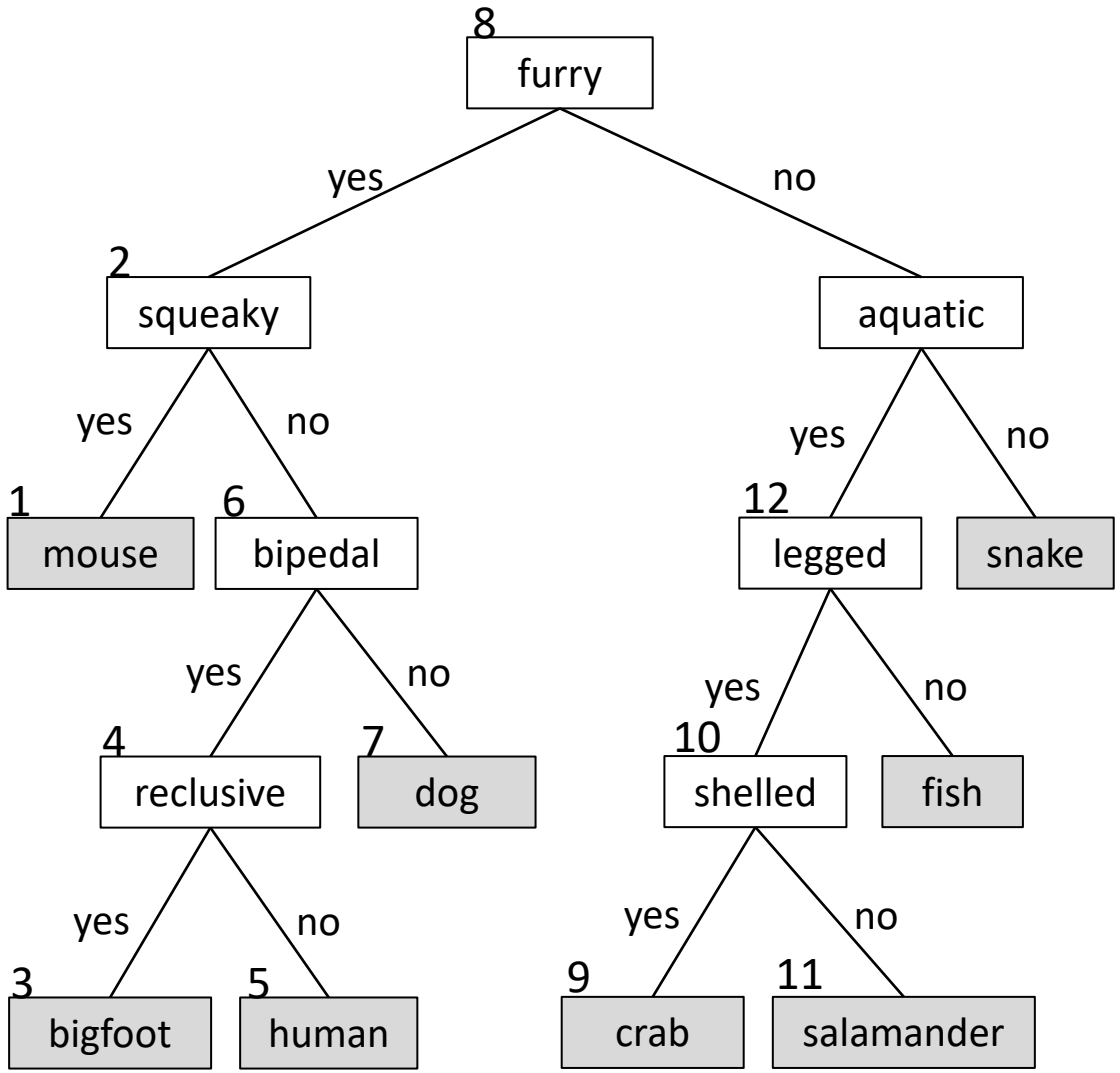


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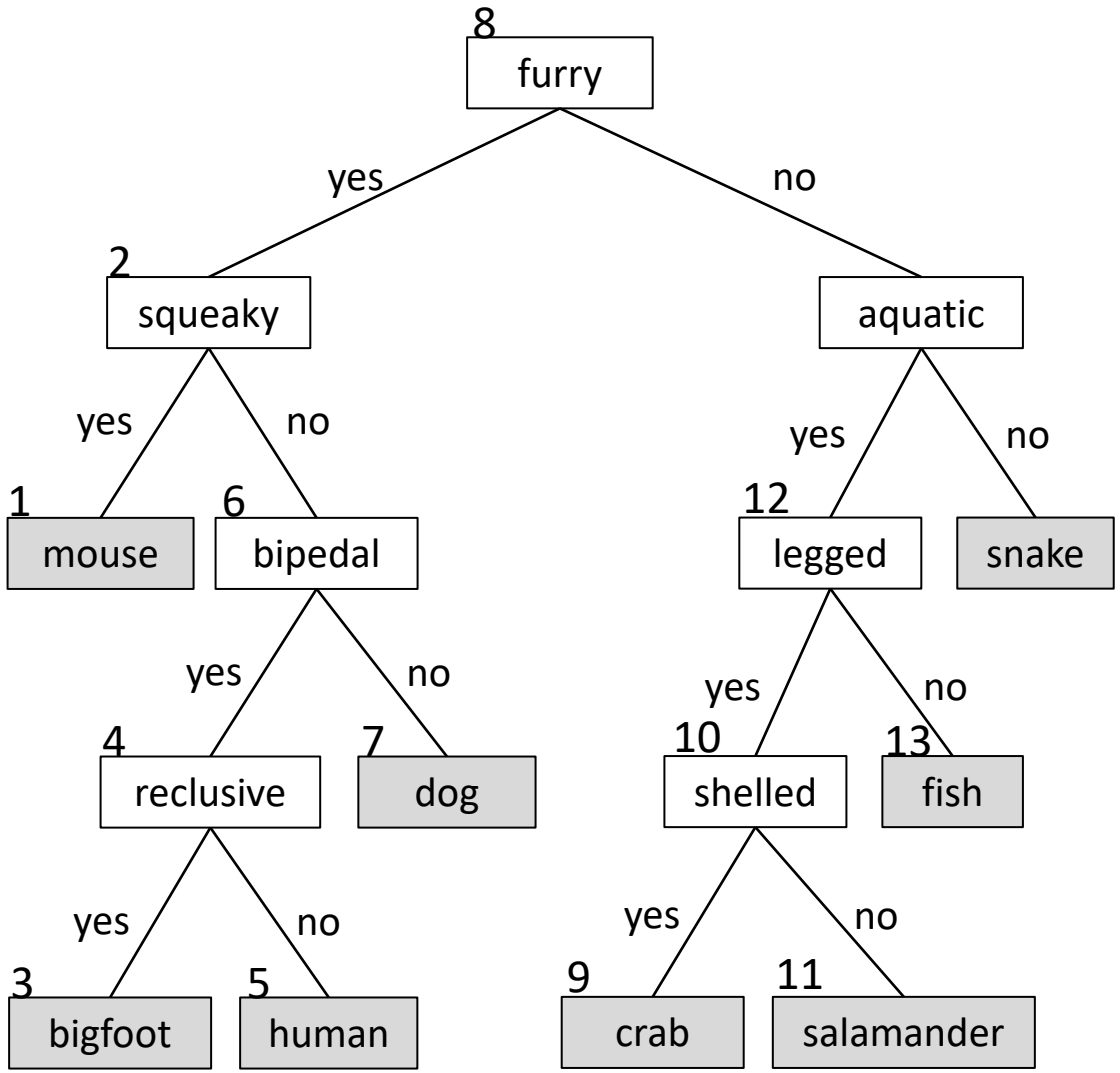


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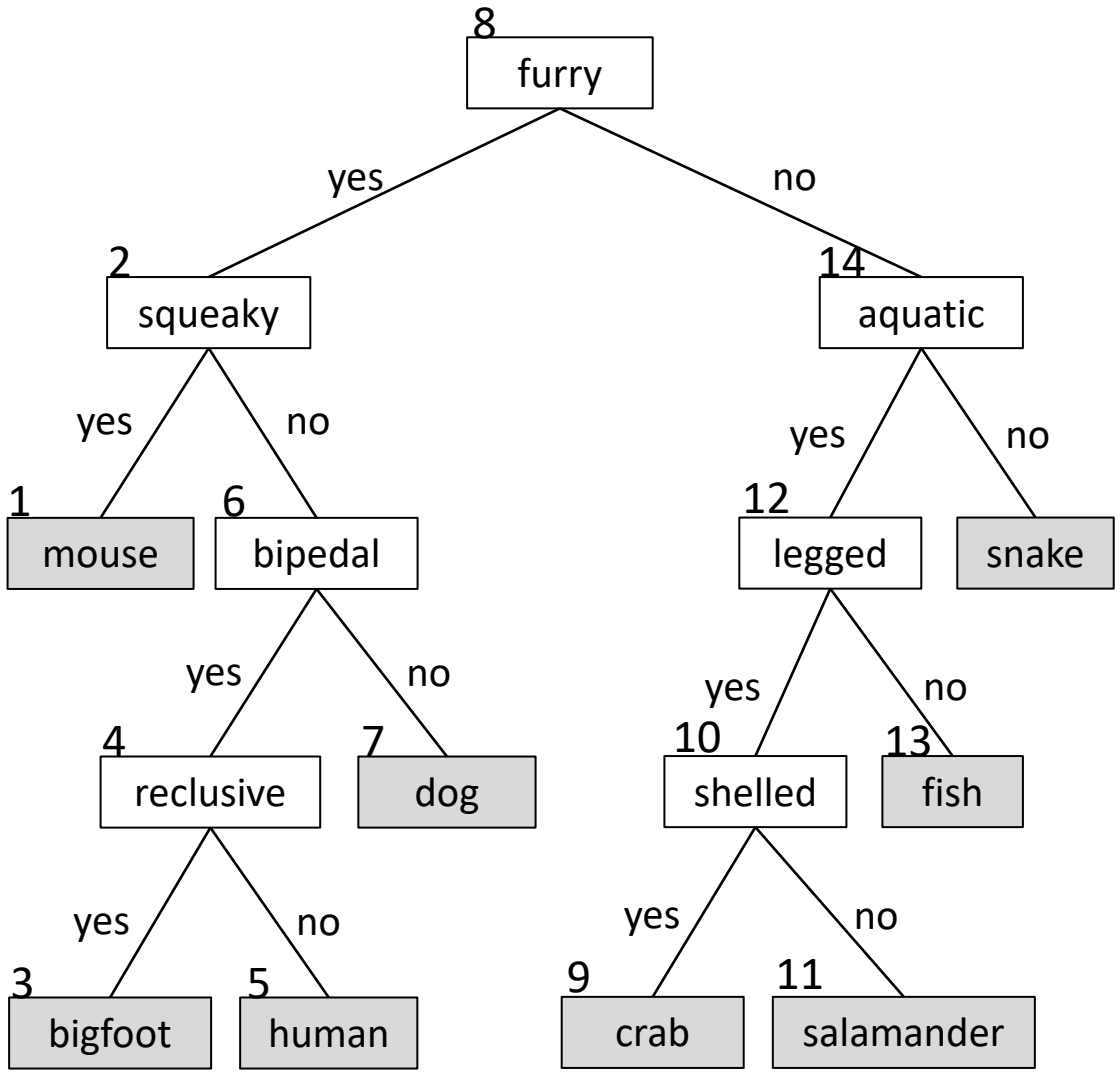


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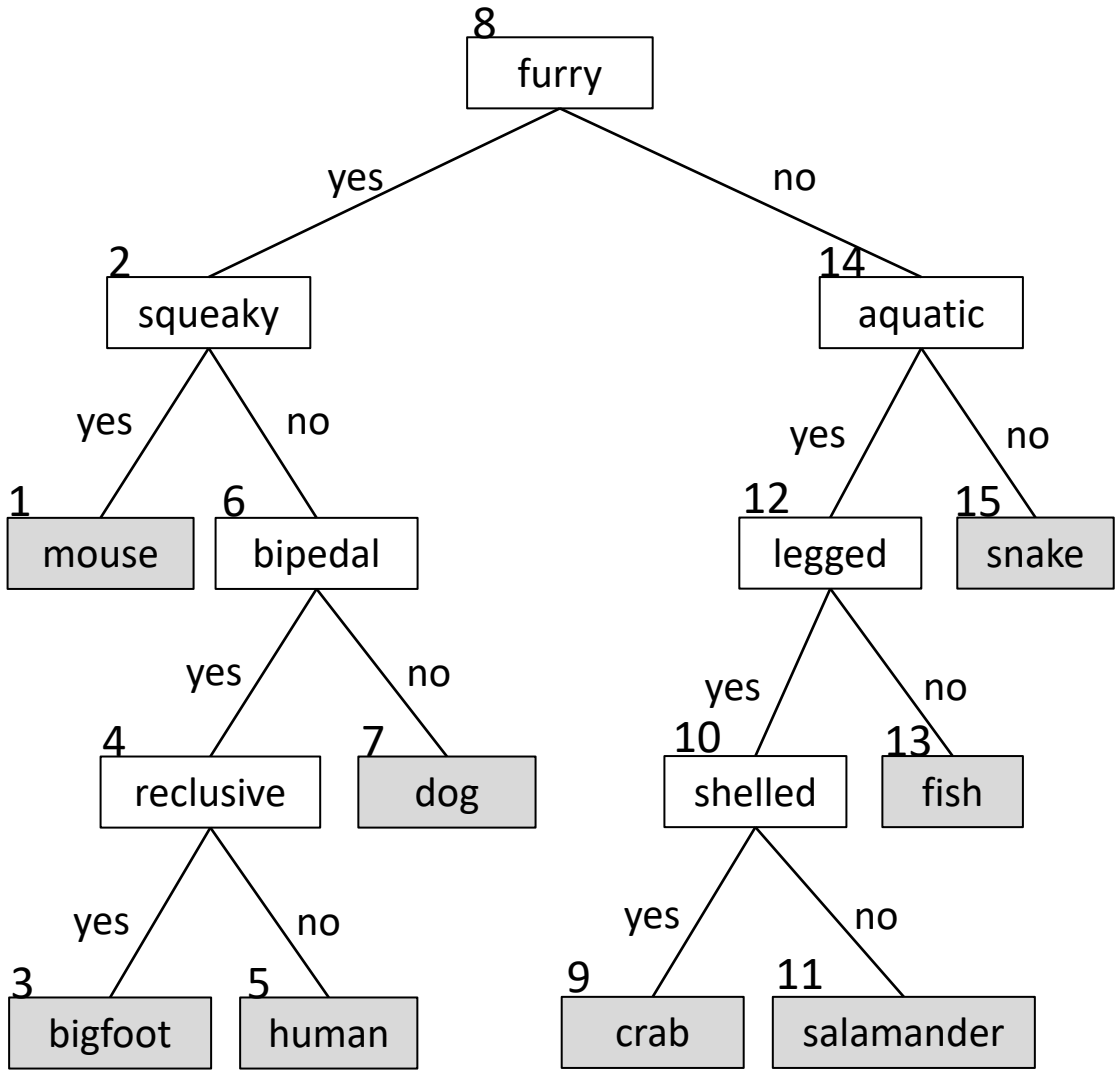


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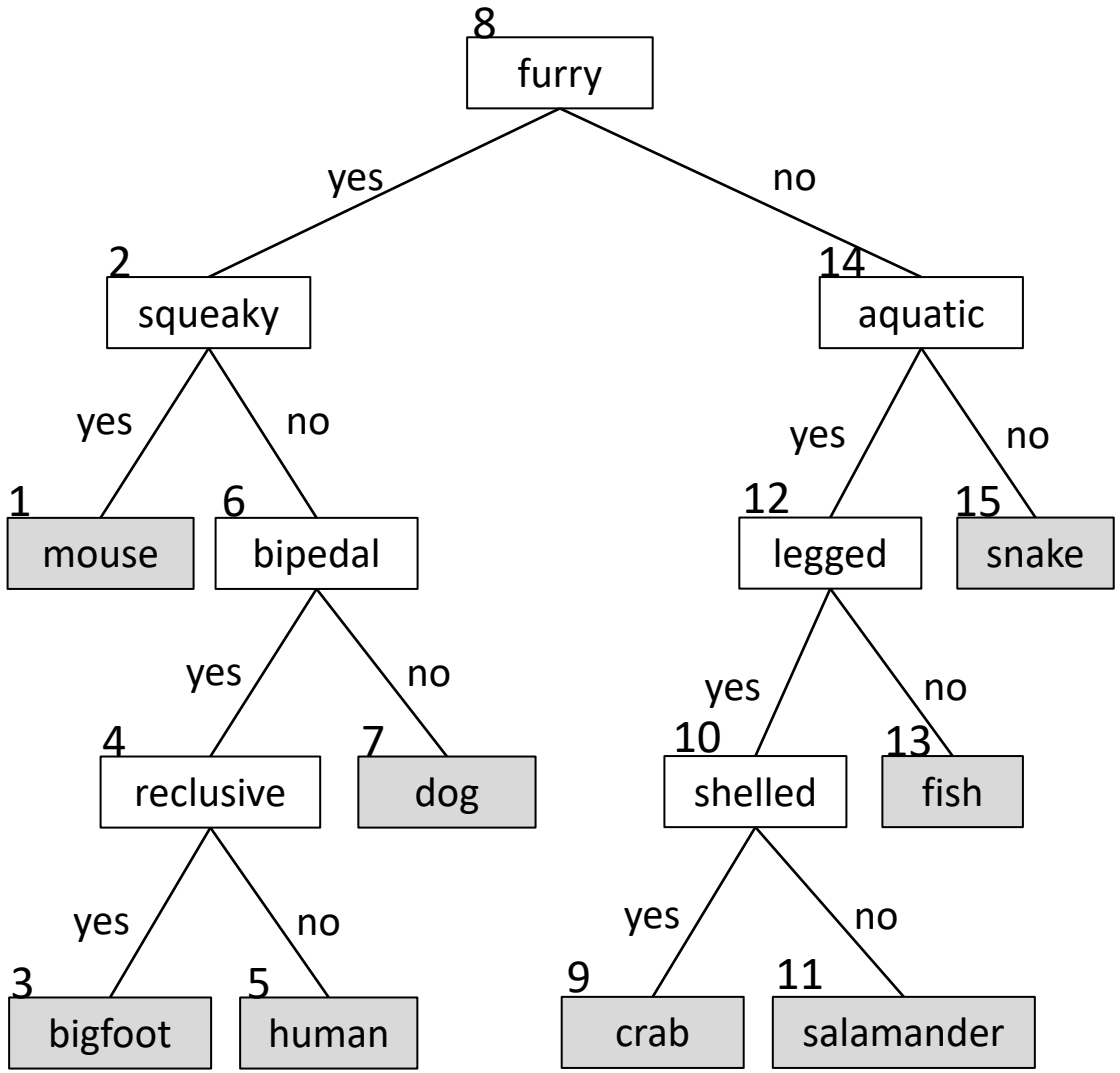


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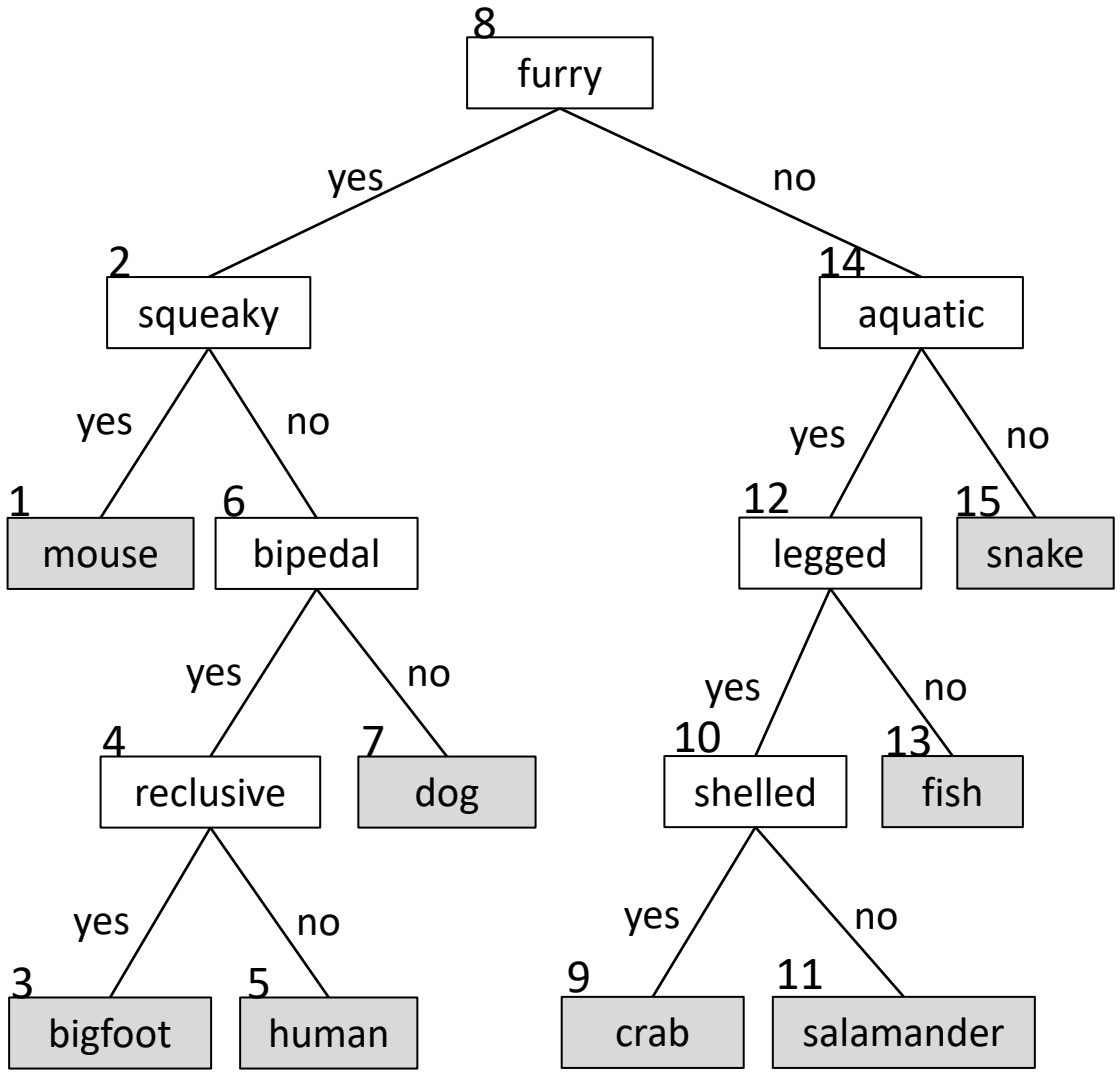
Save to file:

1. Do inorder traversal of tree and assign sequential integer tag values.
2. Do breadth first traversal and write tag and text values to file. E.g. 8-furry,2-squeaky,14-aquatic,1-mouse,6-bipedal,…

File read/writing

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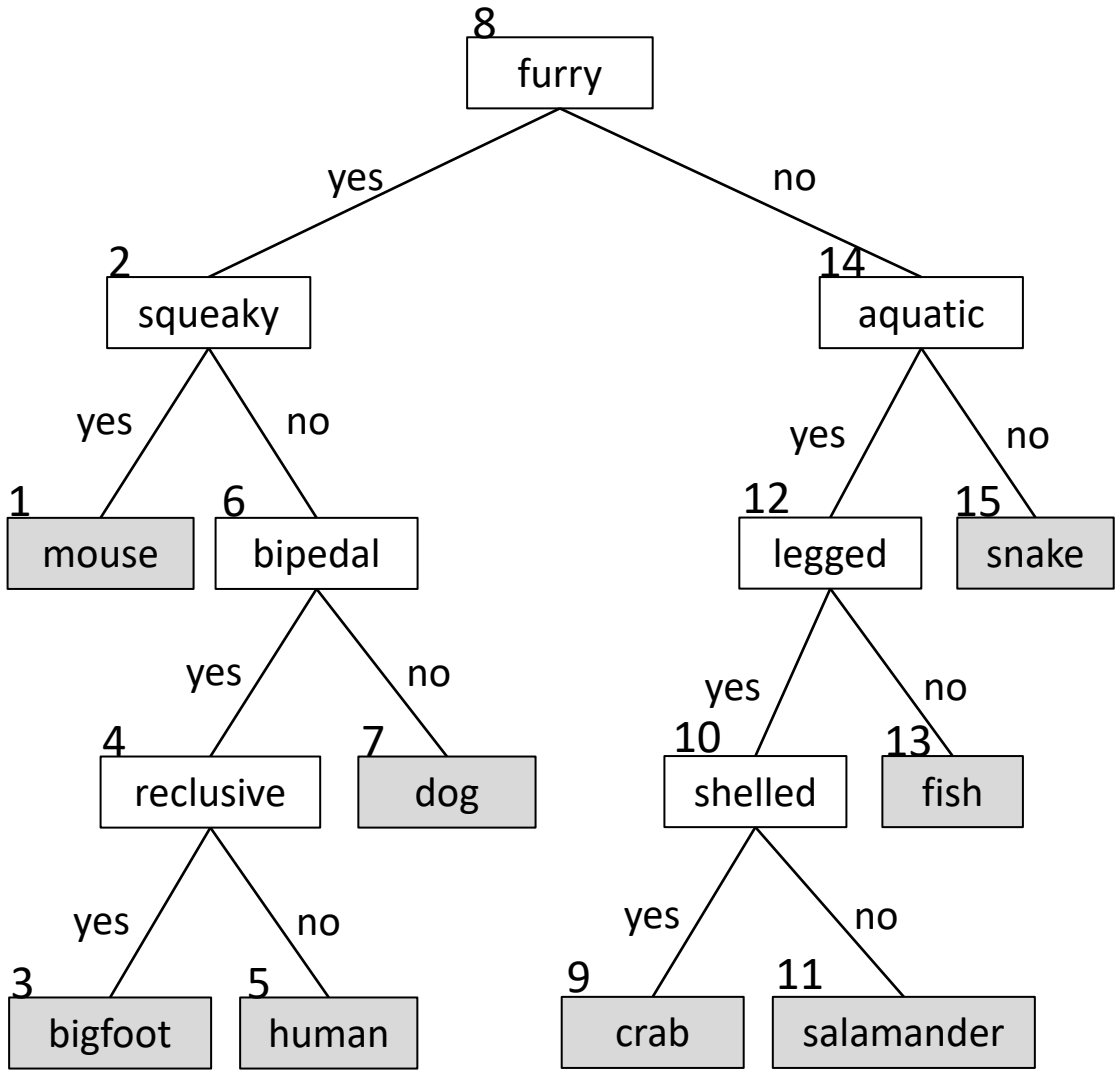
Build from file:

File read/writing

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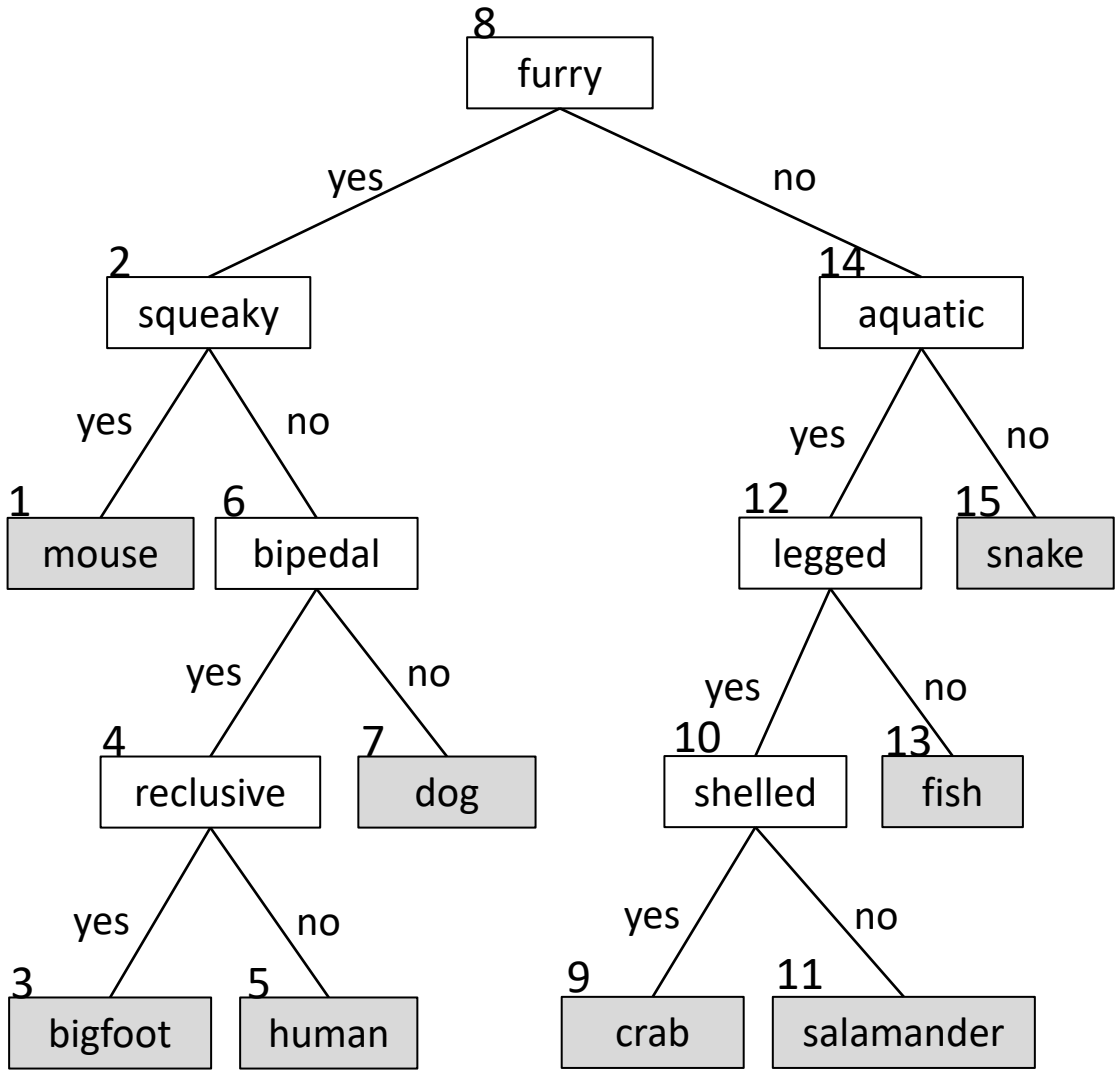
Build from file:

1. Parse input on commas to get each entry.
2. Parse each entry on dash to get tag value and text value.

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Build from file:

1. Parse input on commas to get each entry.
2. Parse each entry on dash to get tag value and text value.
3. Use BST insert method to put tag/text where it should be.