

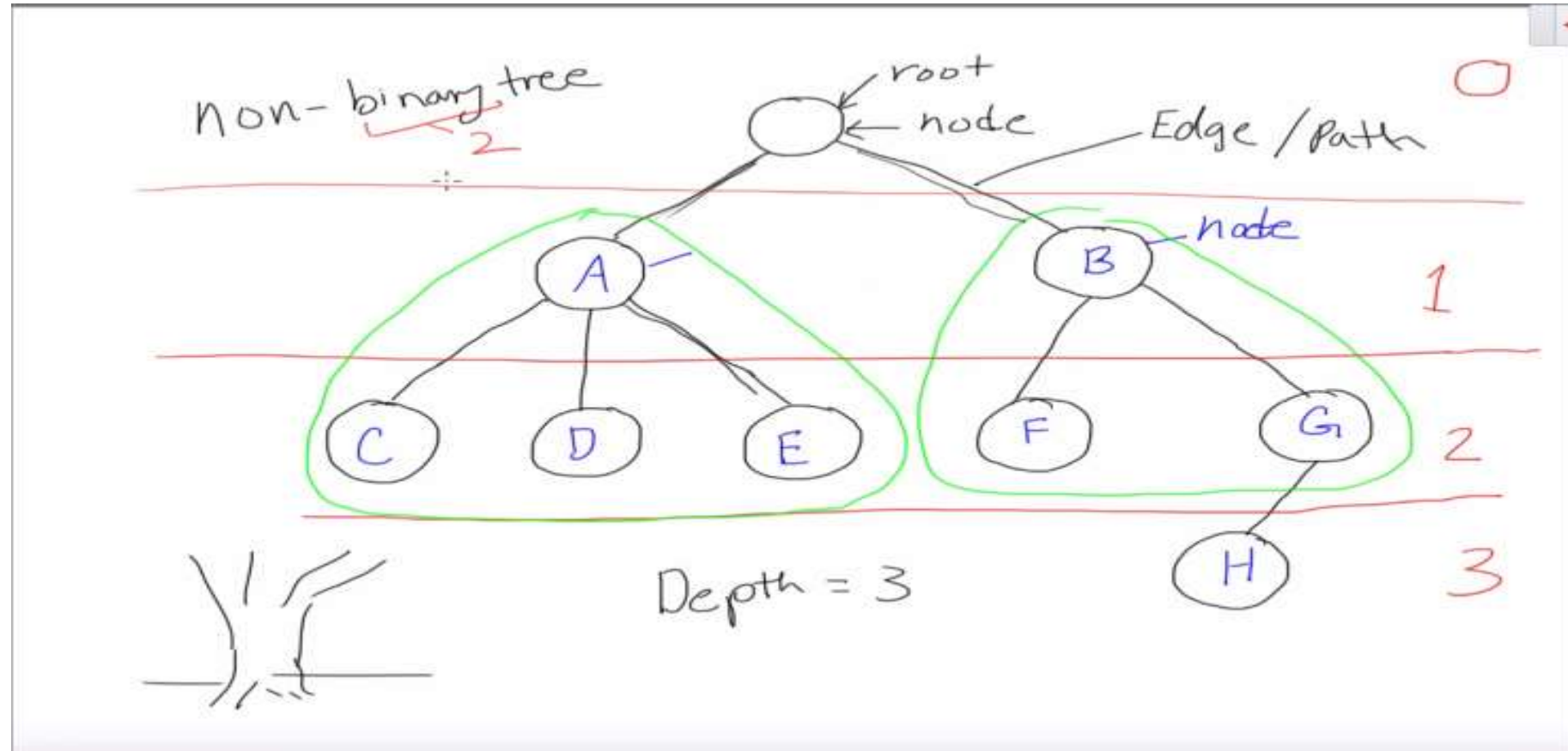
Binary Search Tree

- In computer science, a binary search tree (BST), also called an ordered or sorted binary tree, is a rooted binary tree whose internal nodes each store a key greater than all the keys in the node's left subtree and less than those in its right subtree. A binary tree is a type of data structure for storing data such as numbers in an organized way. Binary search trees allow binary search for fast lookup, addition and removal of data items . The order of nodes in a BST means that each comparison skips about half of the remaining tree, so the whole lookup takes time proportional to the binary logarithm of the number of items stored in the tree. This is much better than the linear time required to find items by key in an (unsorted) array

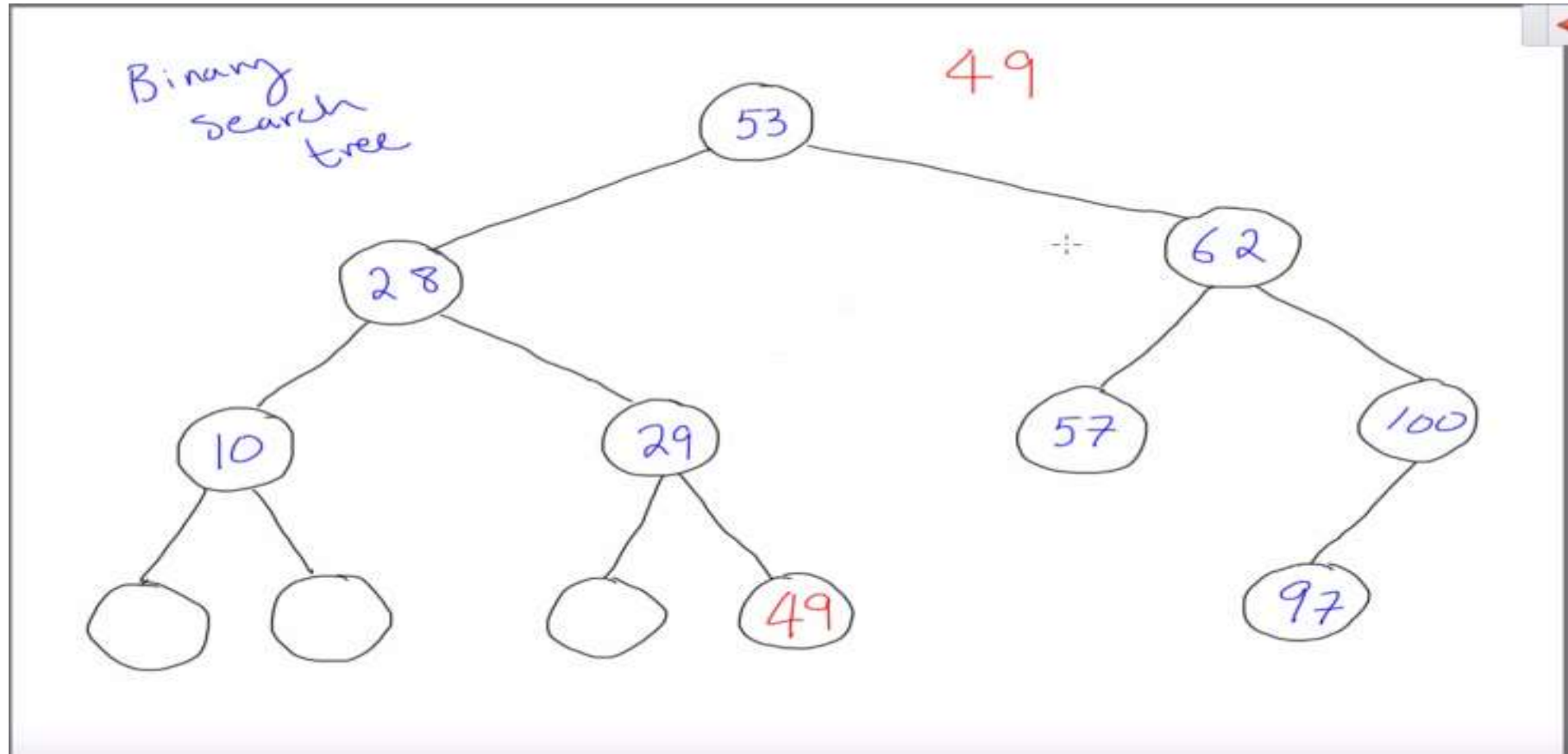
Complexity

Algorithm	Average	Worst case
Space	$O(n)$	$O(n)$
Search	$O(\log n)$	$O(n)$
Insert	$O(\log n)$	$O(n)$
Delete	$O(\log n)$	$O(n)$

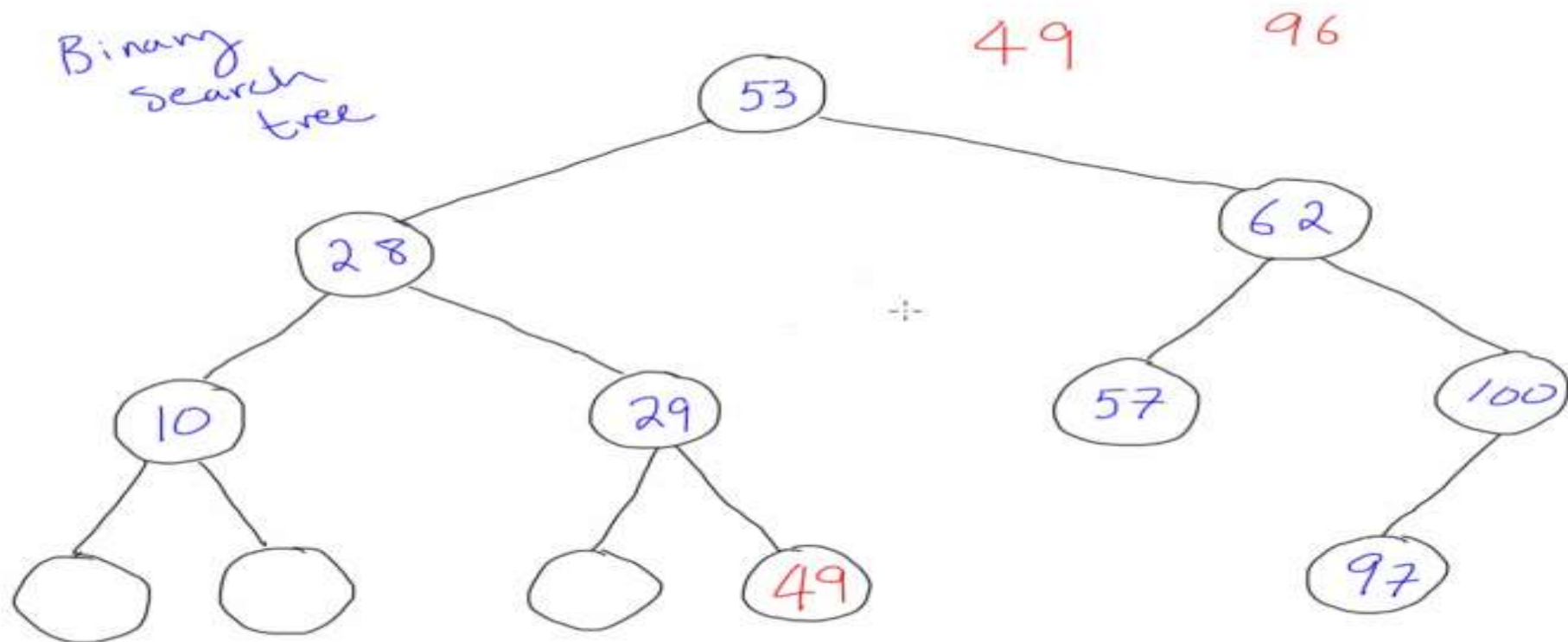
Non-Binary Tree Example



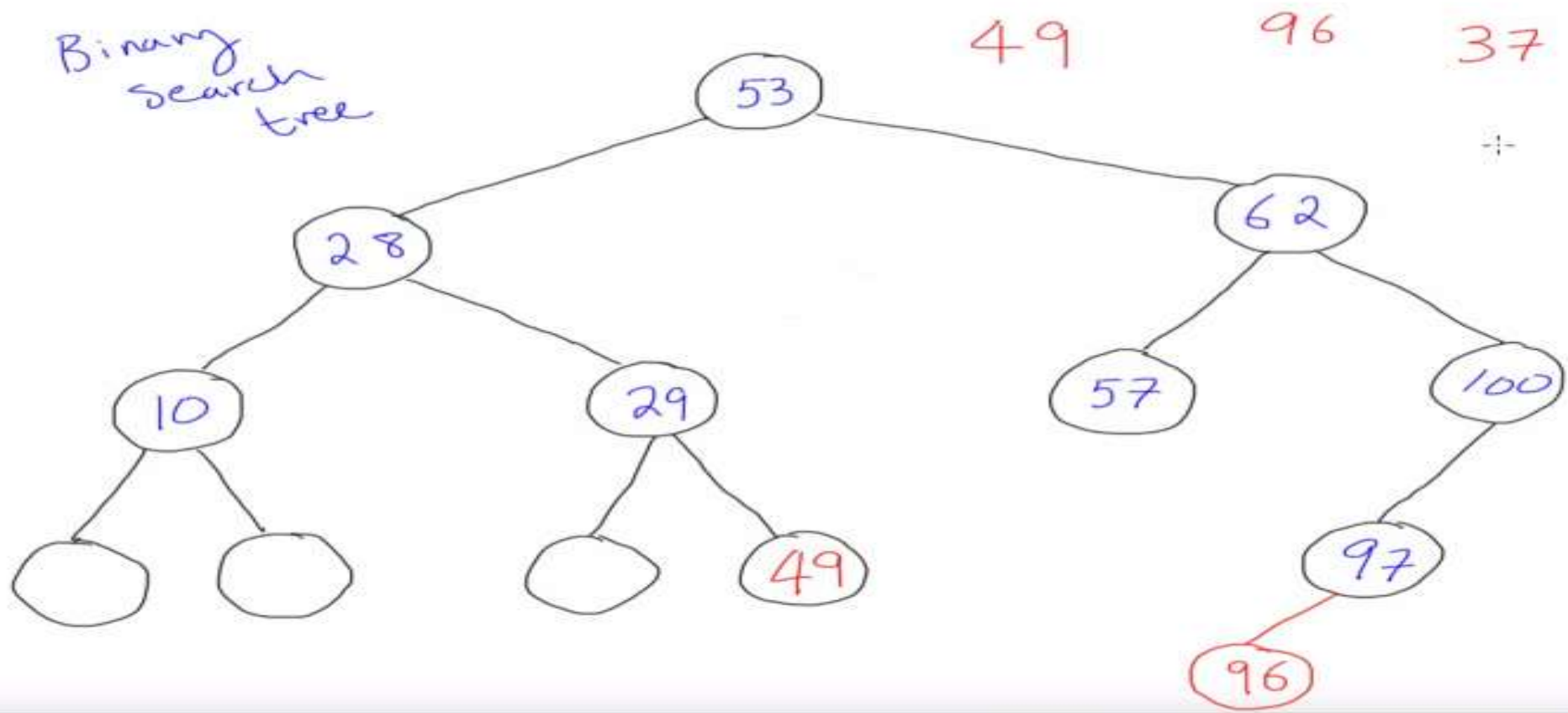
Binary Tree Example



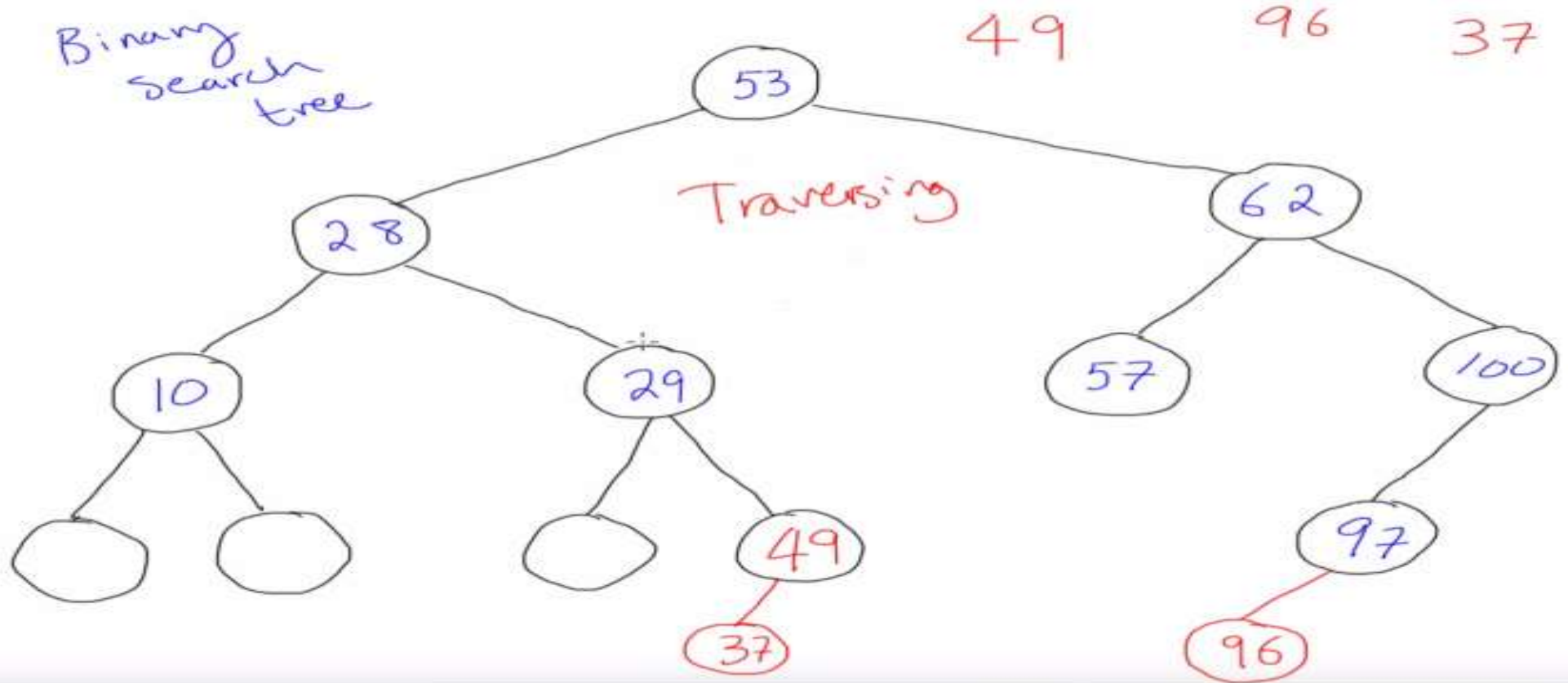
Binary
search
tree



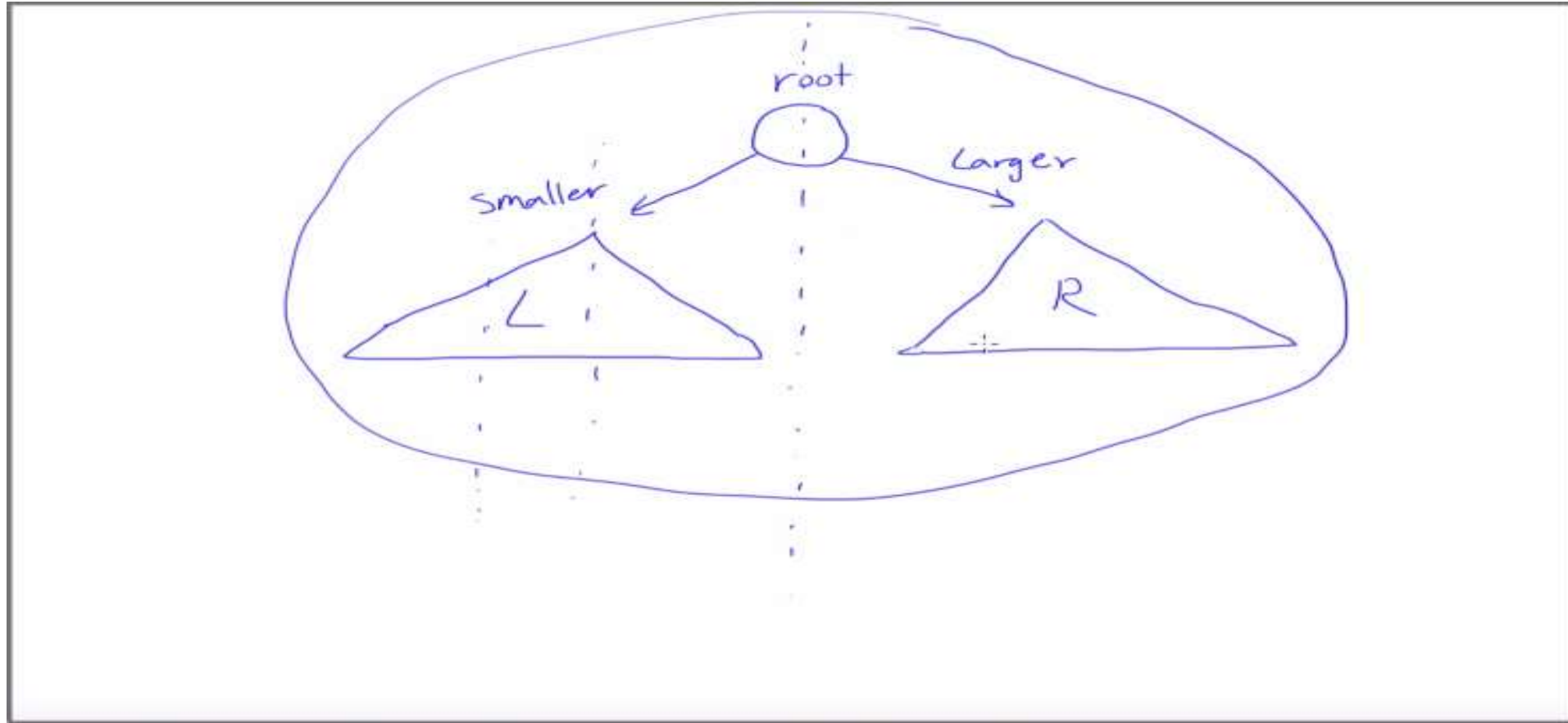
Binary
search
tree



Binary
search
tree



Overview



Worse

Search(x) $O(n)$

Insert(x) $O(1)$

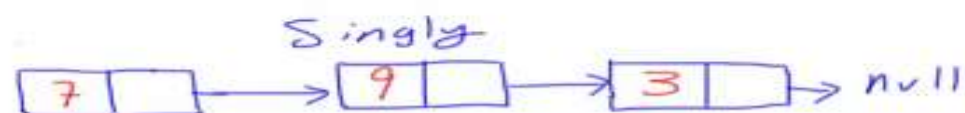
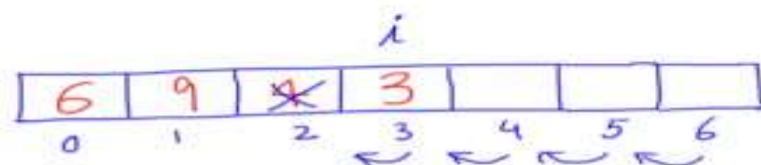
remove(x) $O(n)$

Search(x) $O(n)$

insert(x) $O(1)/O(n)$

remove(x) $O(n)$

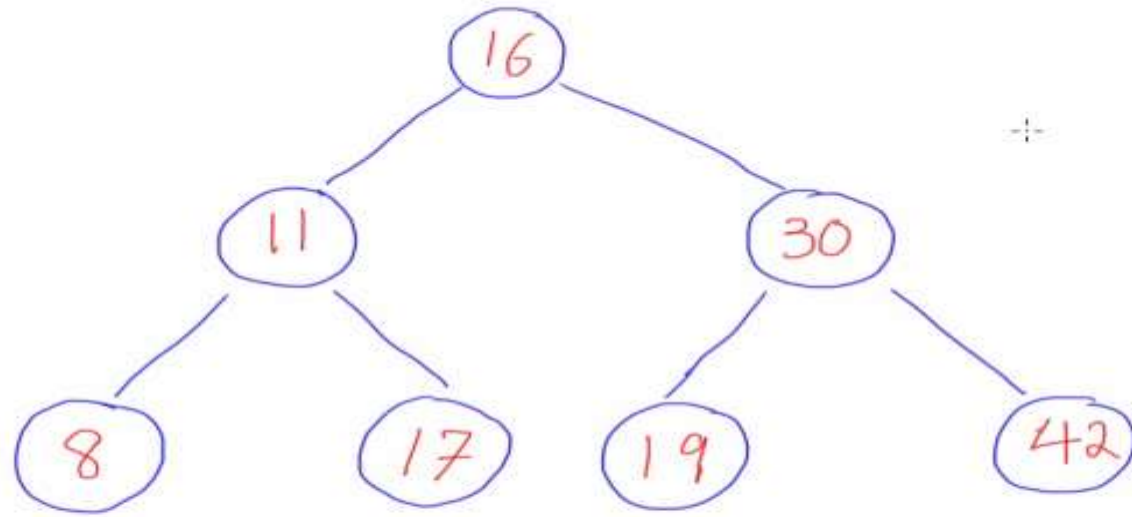
$$a[i+1] = x$$



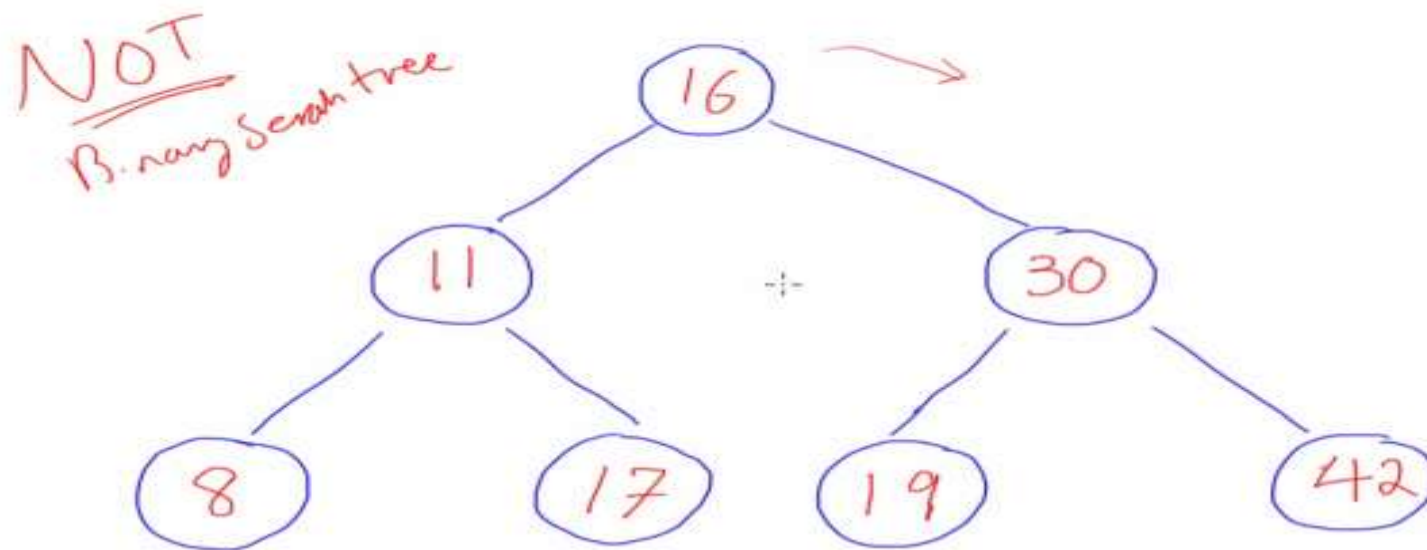
$$O(\log n)$$

Balanced ✓

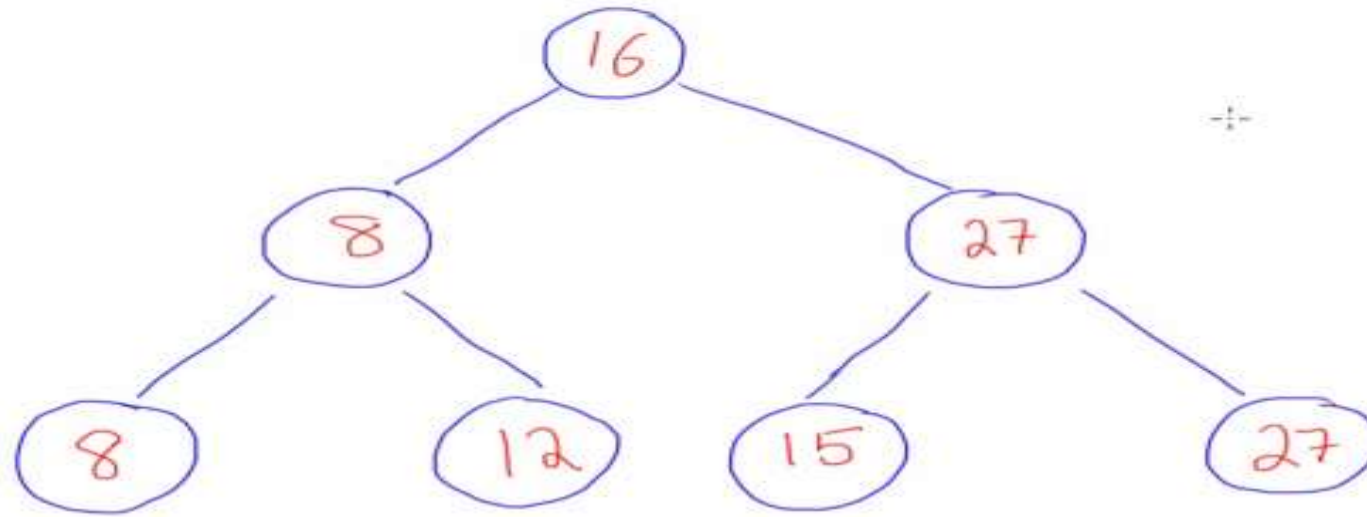
Q) Is it a Binary Search Tree ?



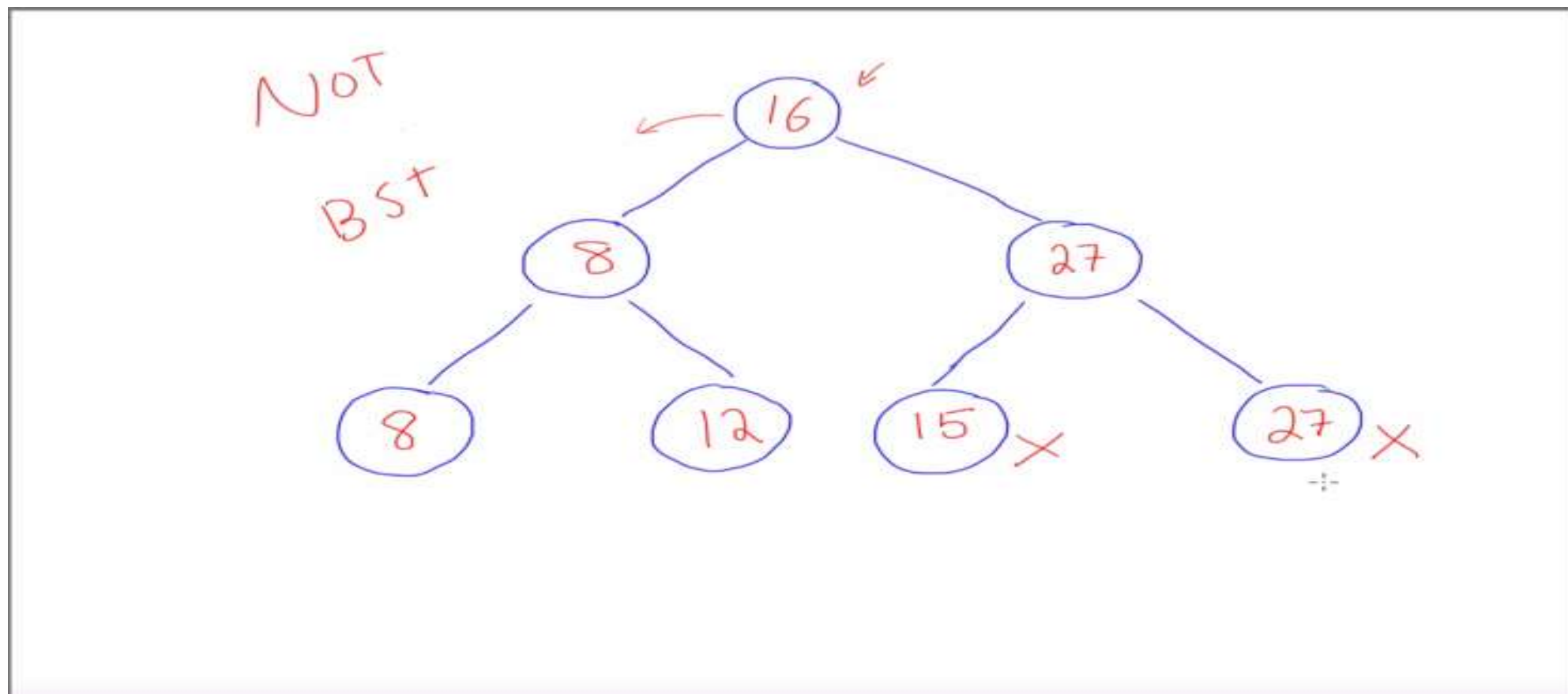
Answer



Q) Is it a Binary Search Tree ?

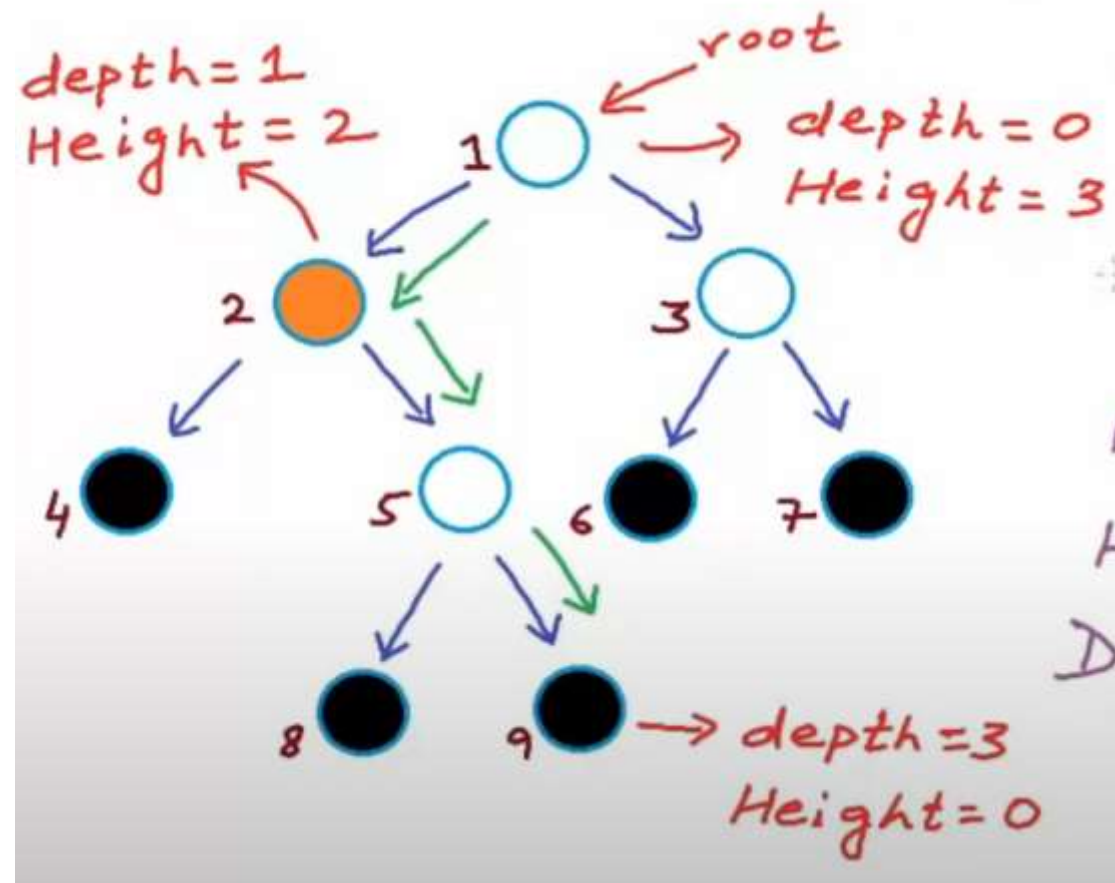


Answer

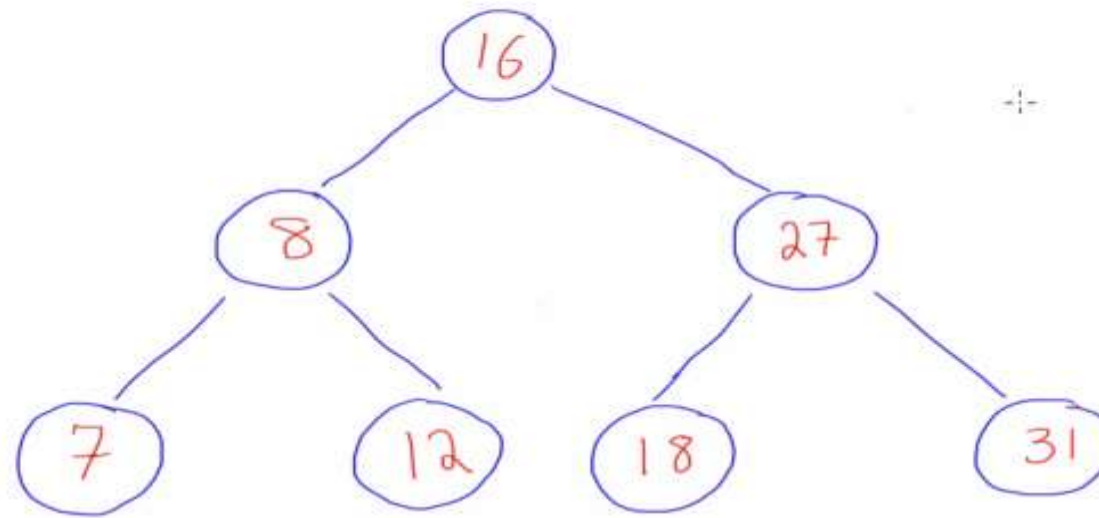


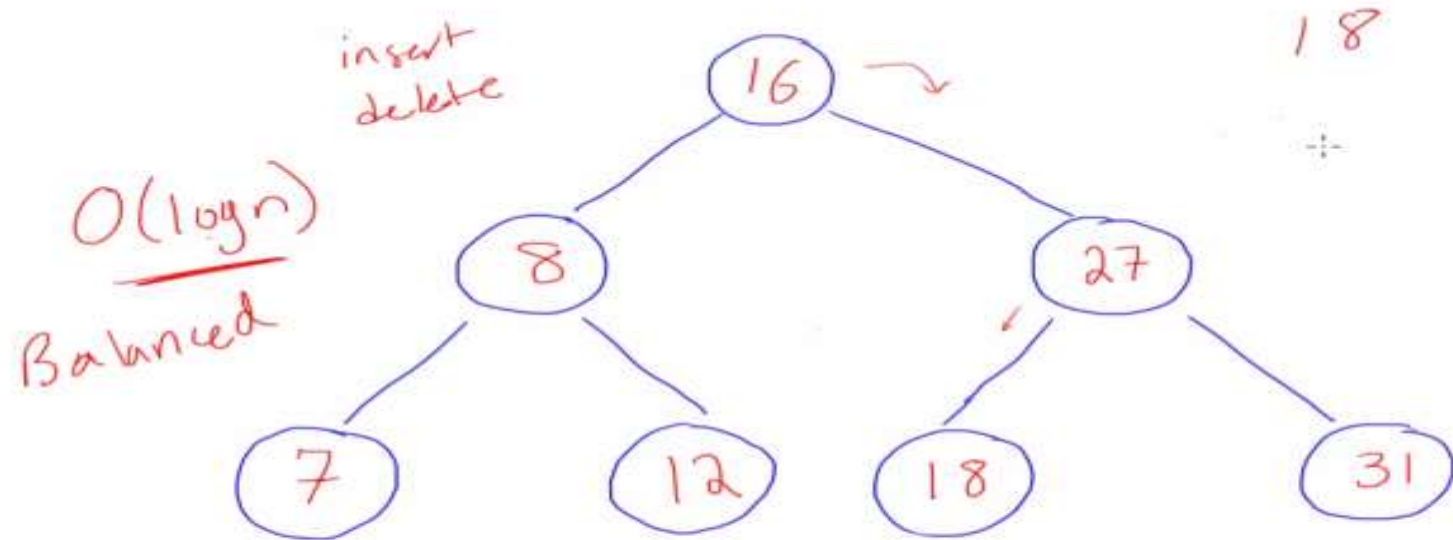
Balanced Binary Search Tree

- For all the nodes , the difference between the heights of the left and right subtrees must not be greater than one.
- Height of Binary Search Tree can be calculated by counting number of edges in longest path from the root to the leaf node.
 - *Height of Tree = Height of Root
 - *Height of Tree with 1 Node (Leaf Node) = 0
- Depth of a Node = No of edges in path from root to that Node.

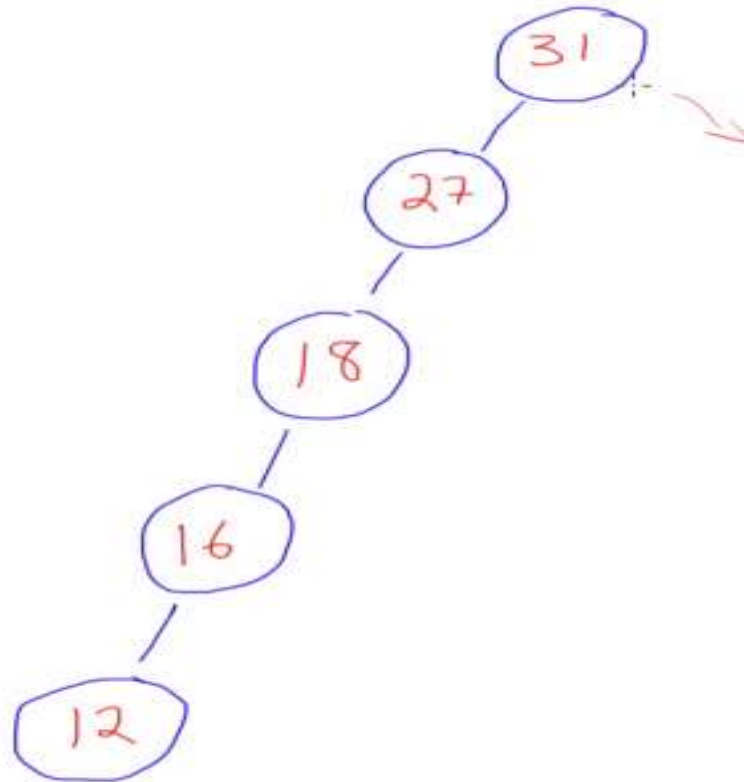


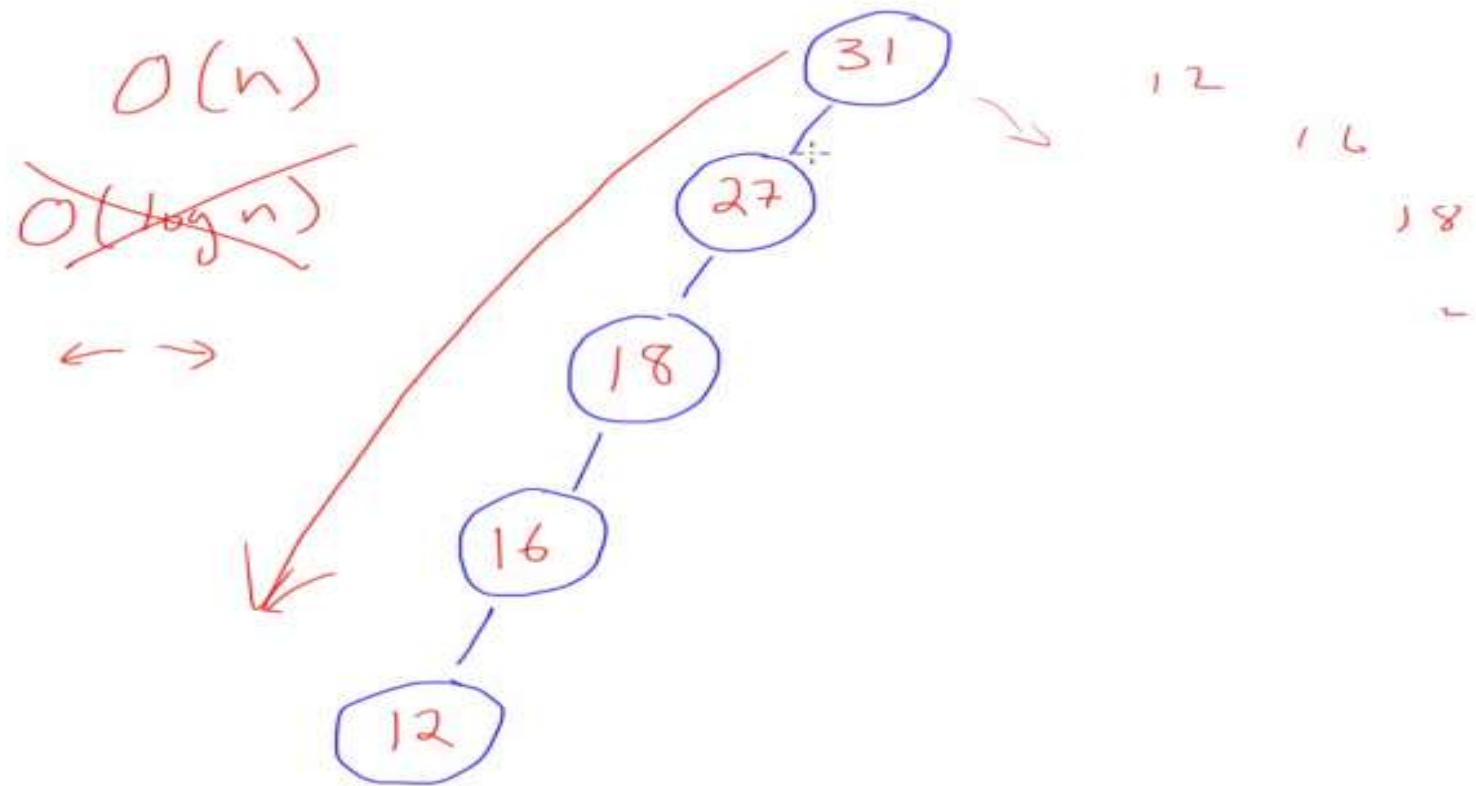
Balanced Binary Search Tree



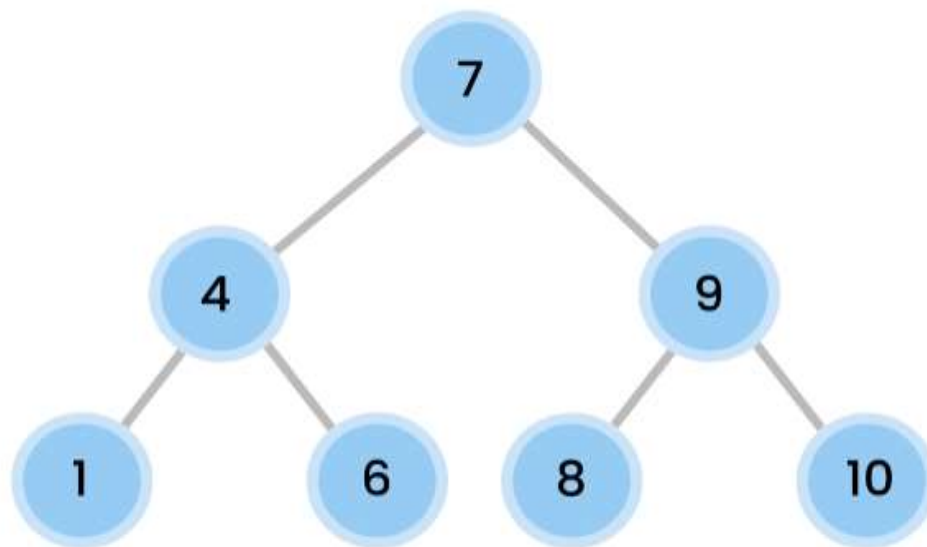


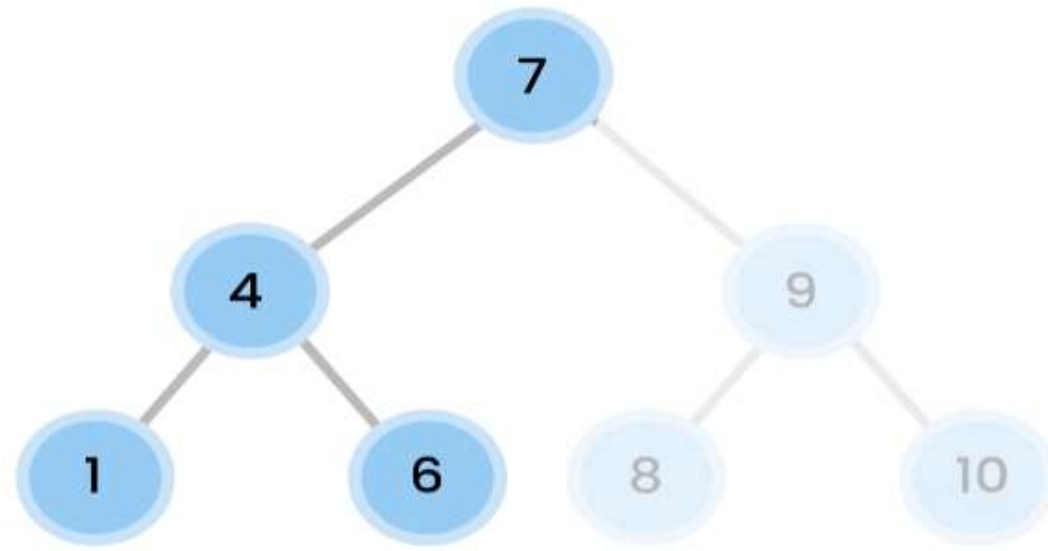
Unbalanced Binary Tree

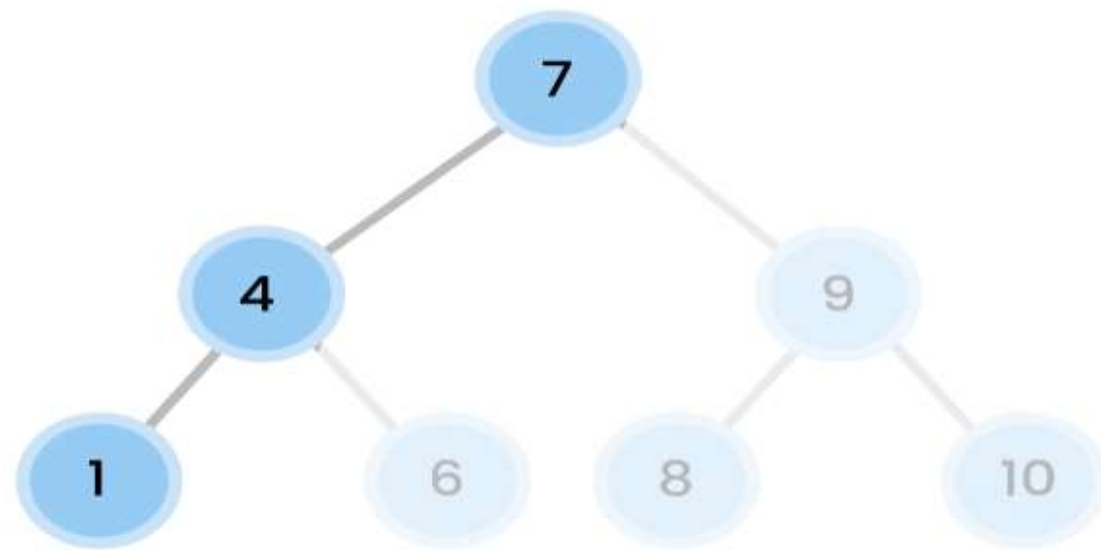




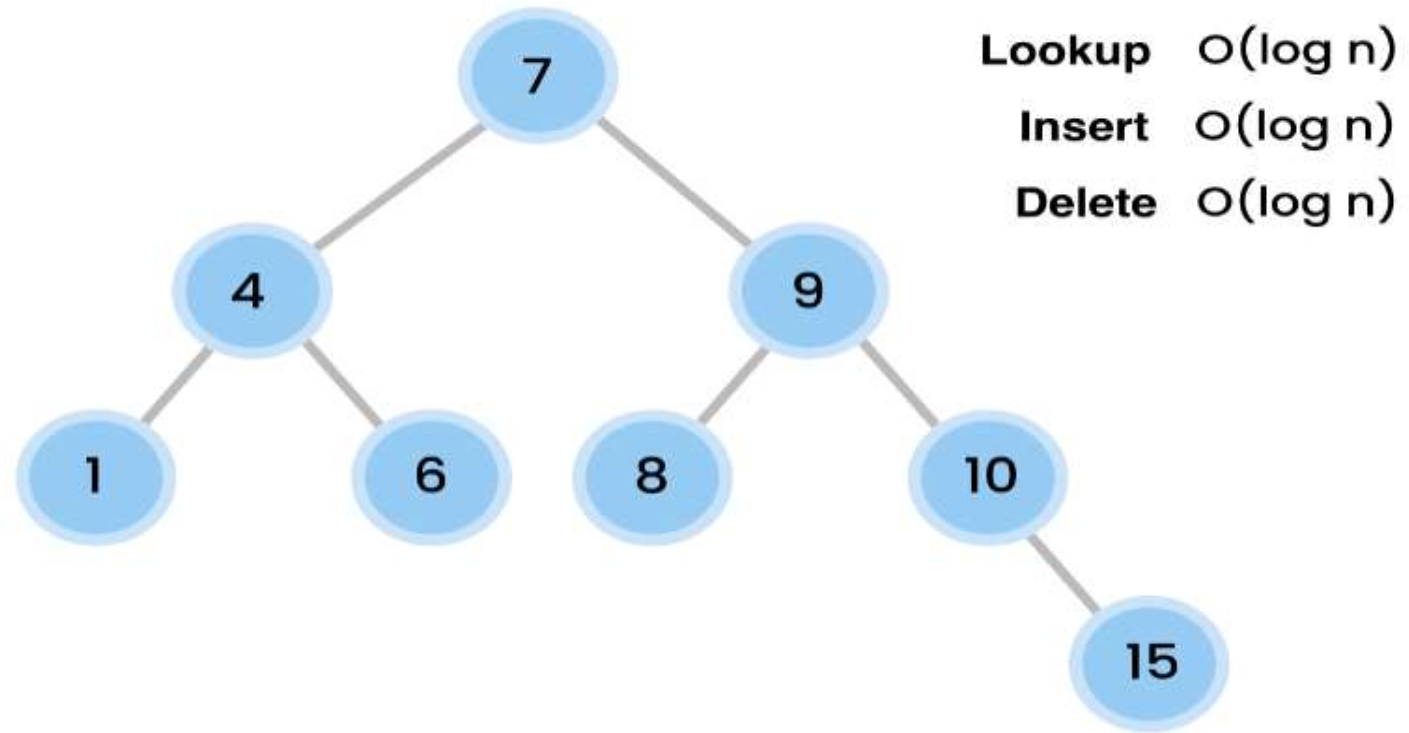
Searching 1







Runtime Complexity BST

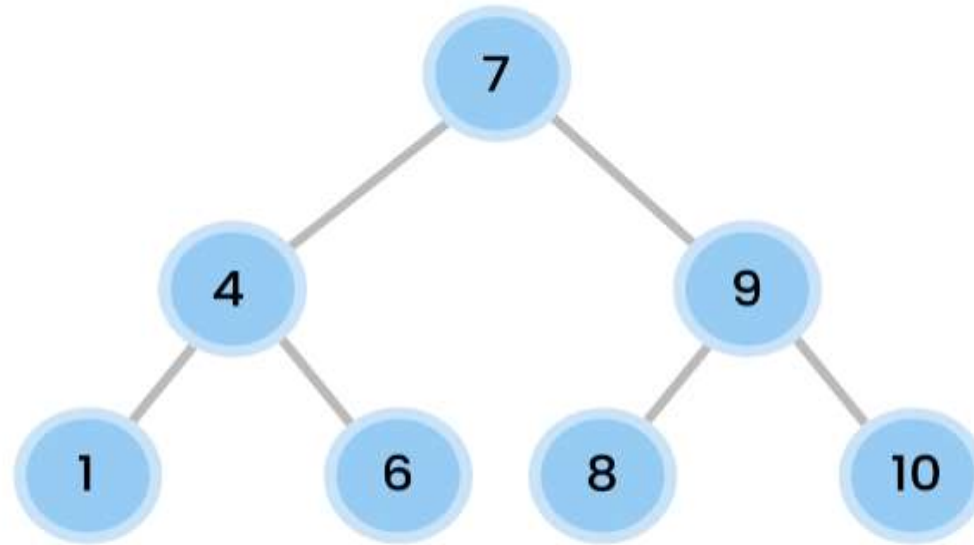


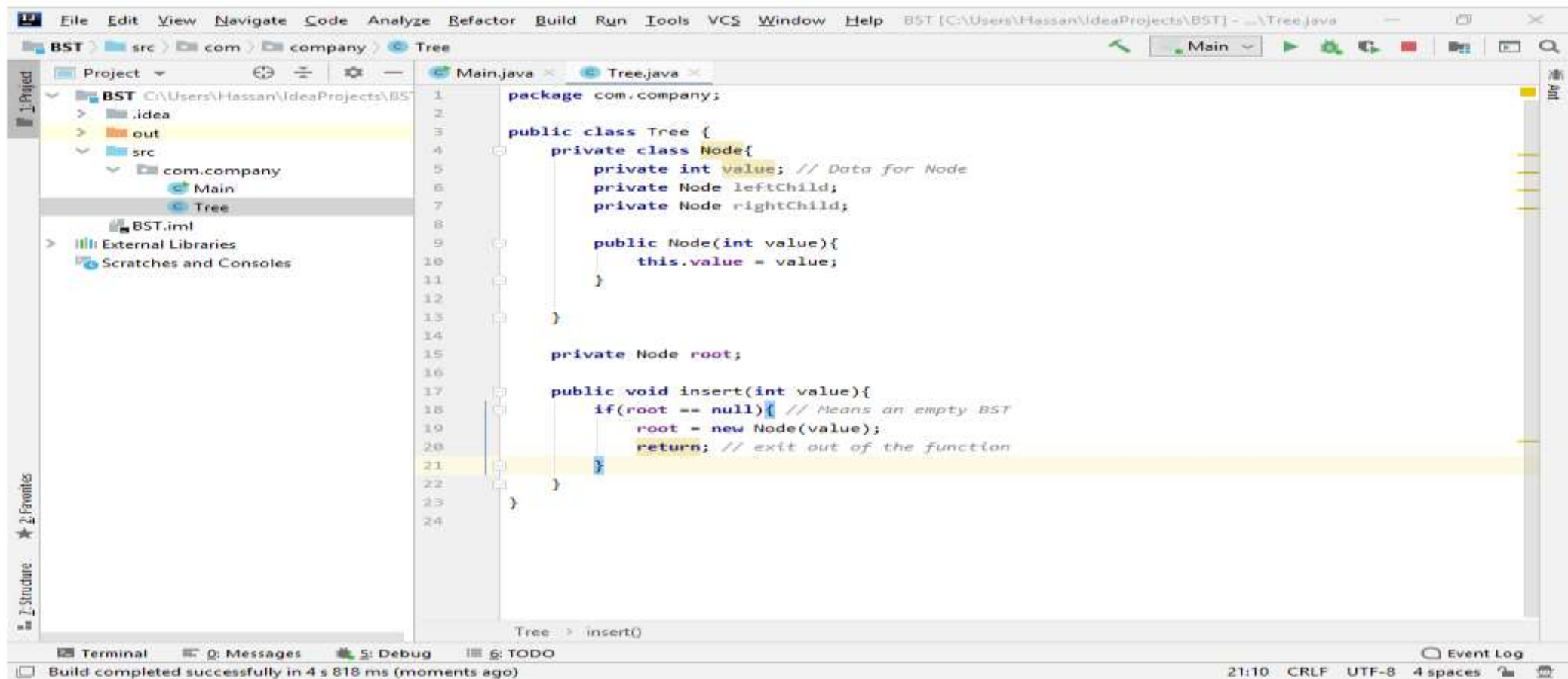
Applications

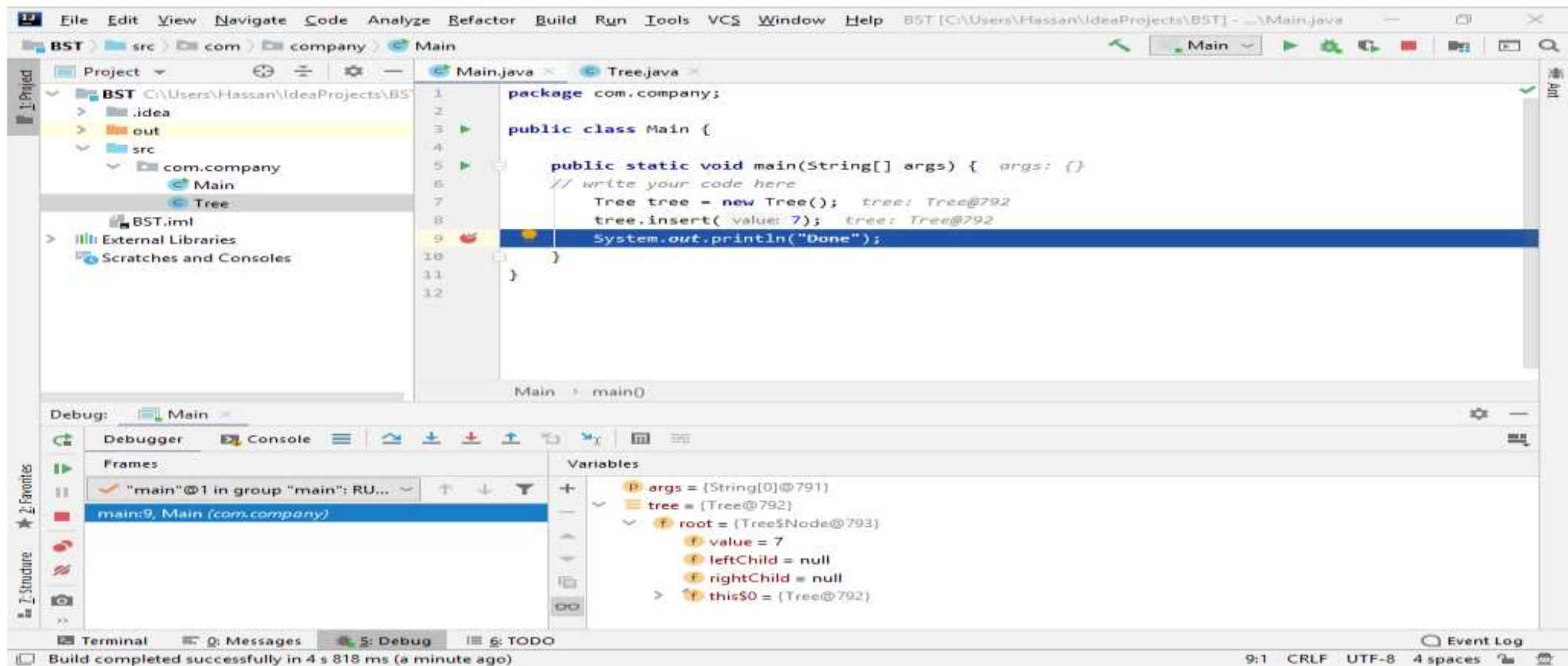
TREES

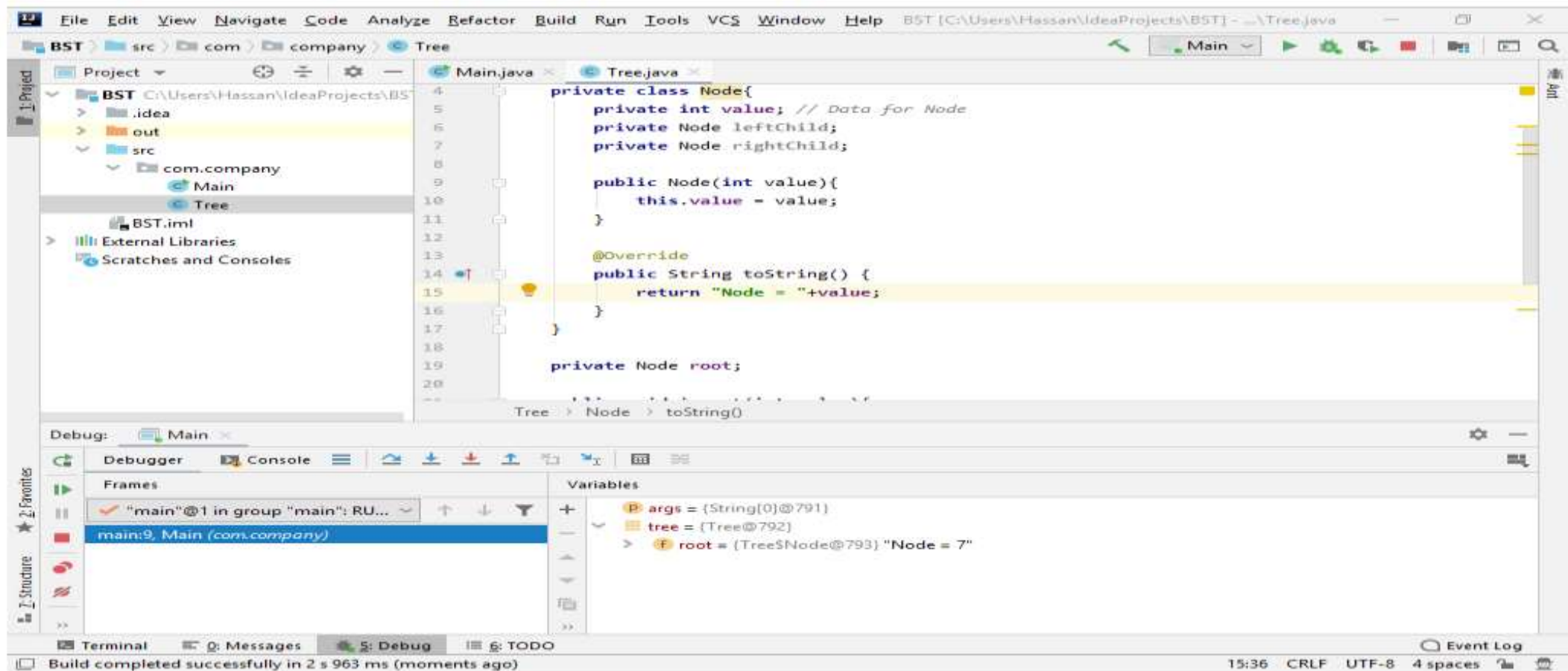
- Represent hierarchical data
- Databases
- Autocompletion
- Compilers
- Compression (JPEG, MP3)

Implementation of Following BST.

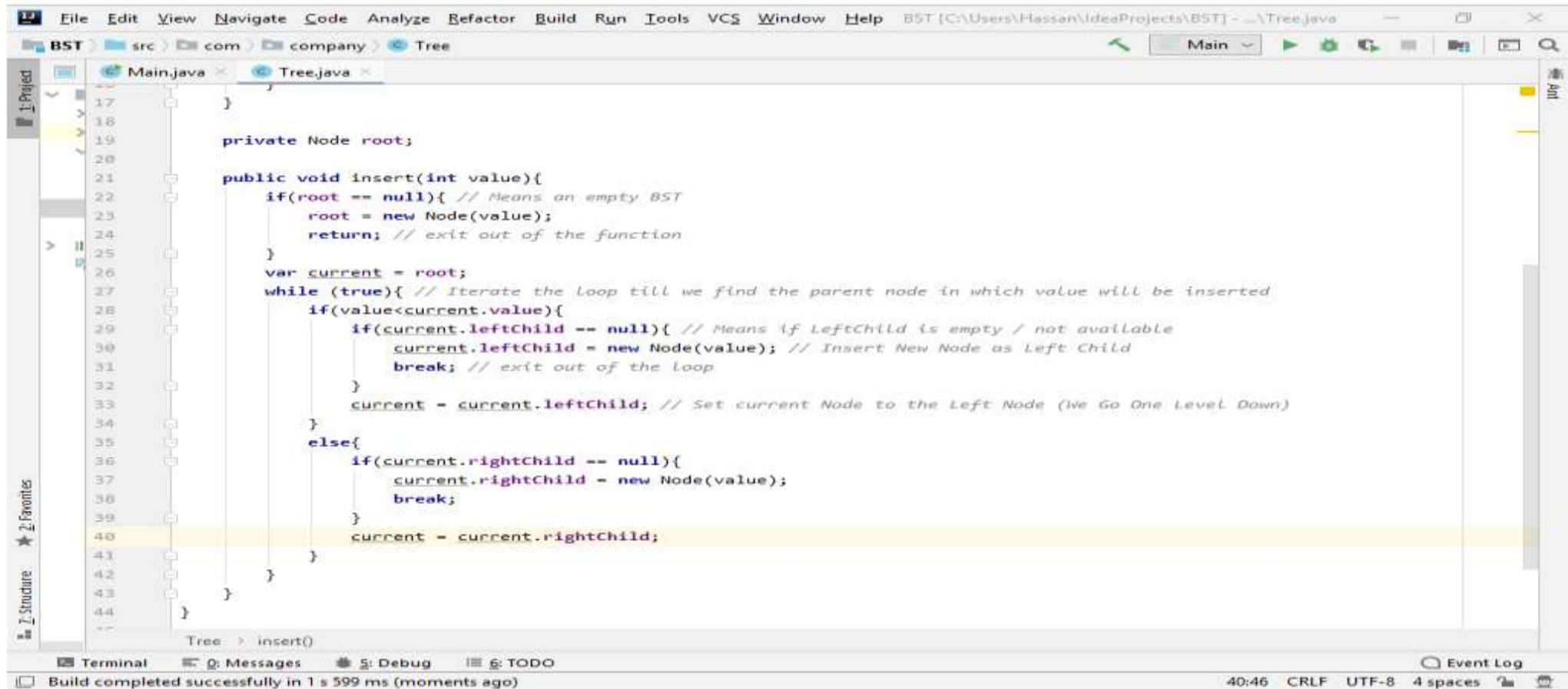








Insert Function

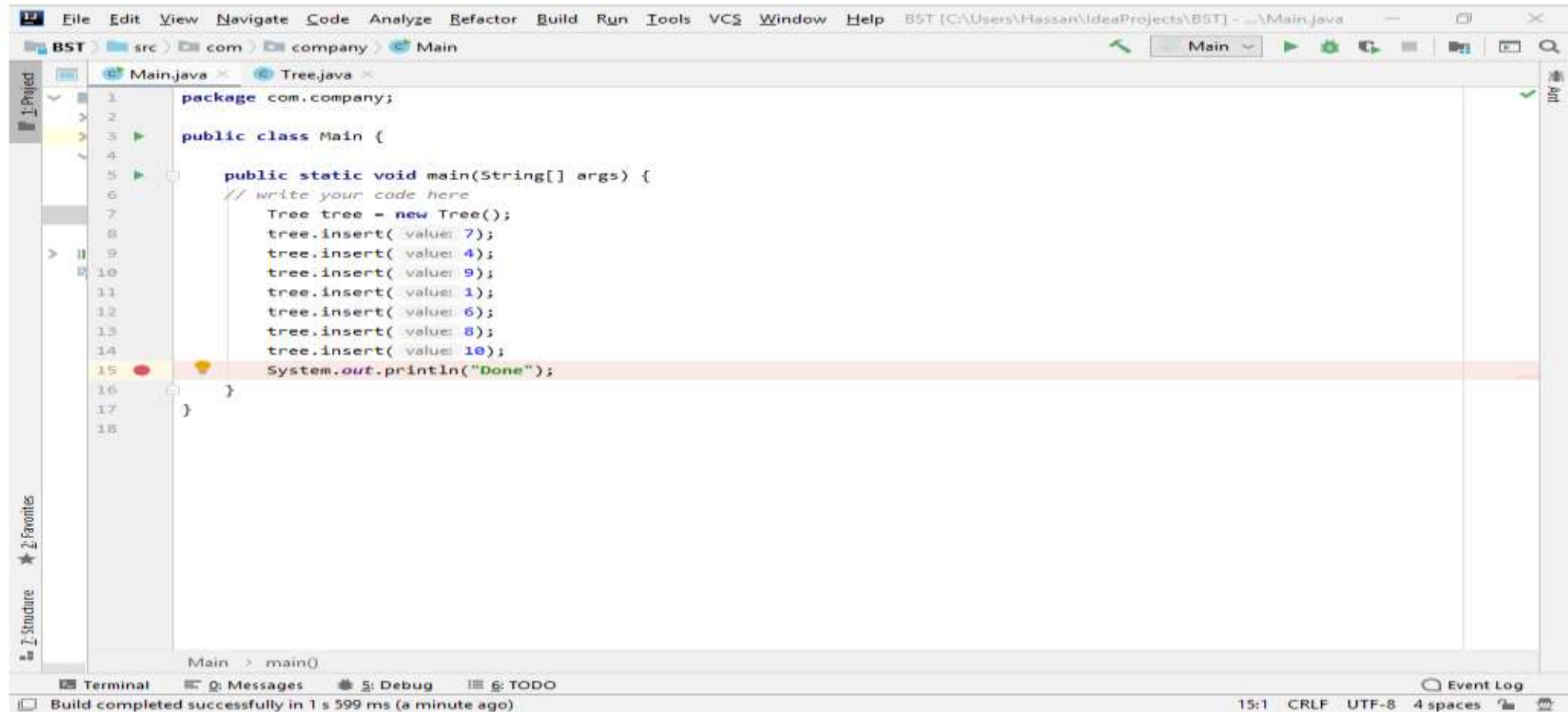


The screenshot shows an IDE window with the following components:

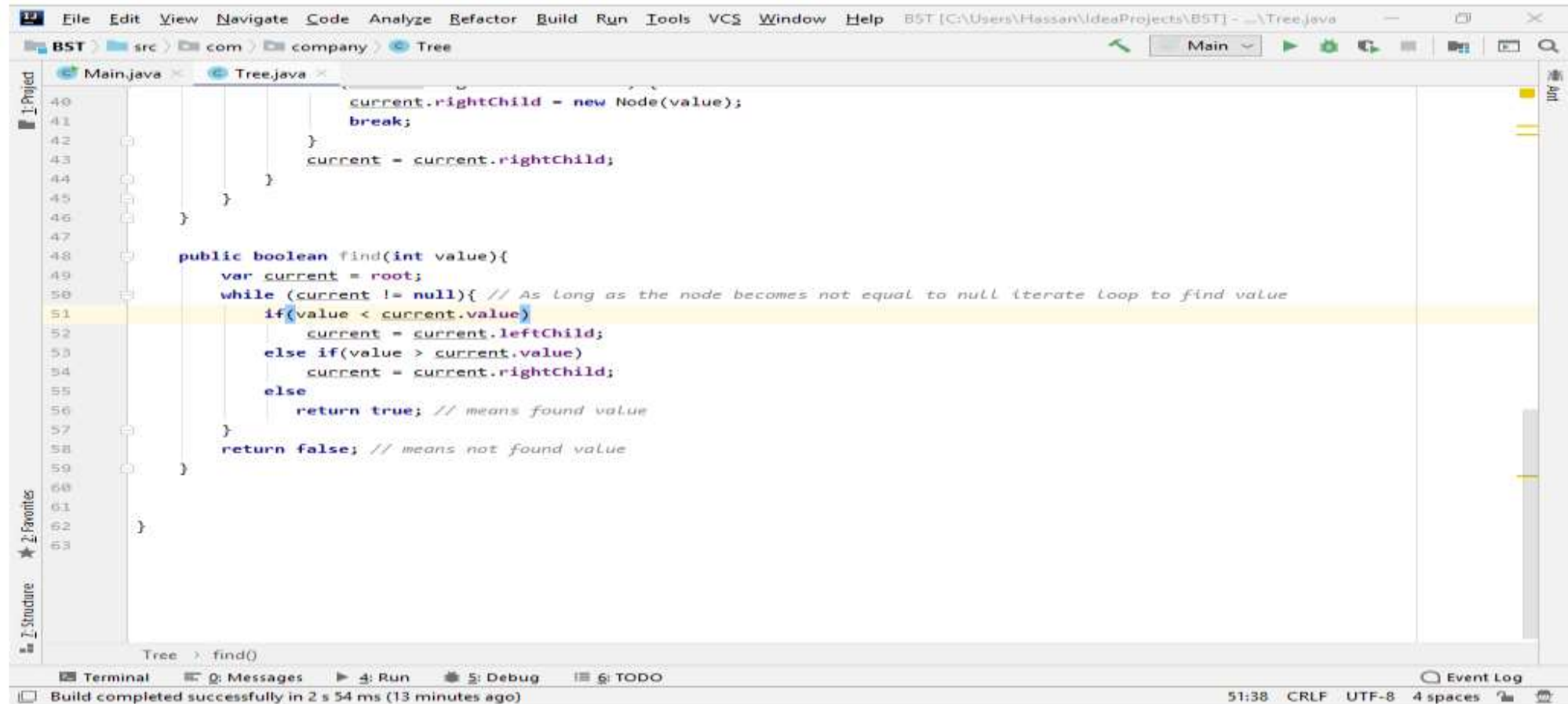
- Menu Bar:** File, Edit, View, Navigate, Code, Analyze, Refactor, Build, Run, Tools, VCS, Window, Help.
- Toolbar:** Includes icons for file operations, running, and searching.
- Project View (Left):** Shows the project structure: BST > src > com > company > Tree.
- Editor:** Displays the `Tree.java` file with the following code:

```
17 }
18
19 private Node root;
20
21 public void insert(int value){
22     if(root == null){ // Means an empty BST
23         root = new Node(value);
24         return; // exit out of the function
25     }
26     var current = root;
27     while (true){ // Iterate the loop till we find the parent node in which value will be inserted
28         if(value < current.value){
29             if(current.leftChild == null){ // Means if LeftChild is empty / not available
30                 current.leftChild = new Node(value); // Insert New Node as Left Child
31                 break; // exit out of the loop
32             }
33             current = current.leftChild; // Set current Node to the Left Node (We Go One Level Down)
34         }
35         else{
36             if(current.rightChild == null){
37                 current.rightChild = new Node(value);
38                 break;
39             }
40             current = current.rightChild;
41         }
42     }
43 }
44 }
```
- Bottom Panel:** Includes tabs for Terminal, Messages, Debug, and TODO. The status bar at the bottom shows: "Build completed successfully in 1 s 599 ms (moments ago)", "40:46", "CRLF", "UTF-8", and "4 spaces".

Test

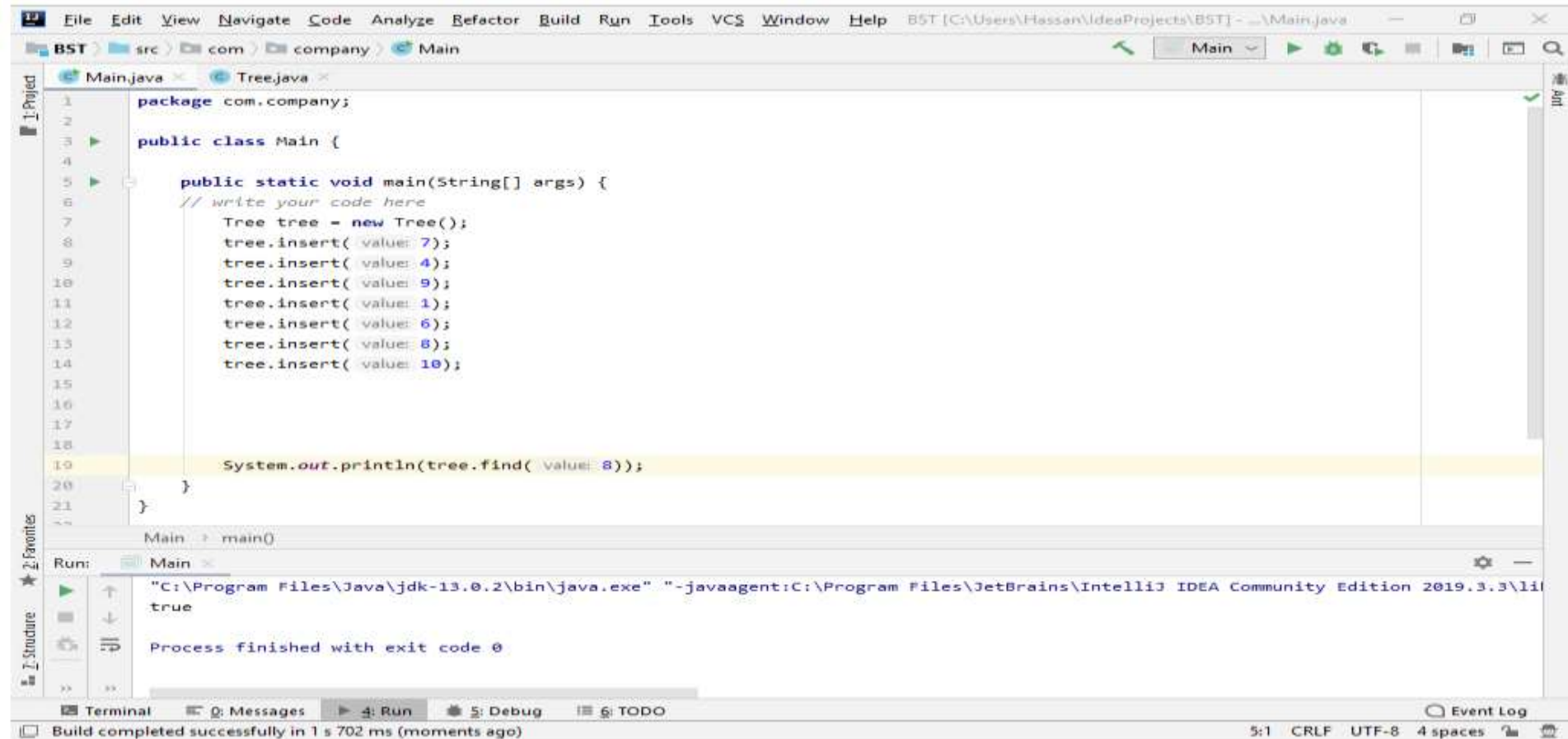


Find function



```
File Edit View Navigate Code Analyze Refactor Build Run Tools VCS Window Help BST [C:\Users\Hassan\IdeaProjects\BST] - ...Tree.java
BST src com company Tree
Main.java Tree.java
40         current.rightChild = new Node(value);
41         break;
42     }
43     current = current.rightChild;
44 }
45 }
46 }
47
48 public boolean find(int value){
49     var current = root;
50     while (current != null){ // As long as the node becomes not equal to null iterate loop to find value
51         if(value < current.value)
52             current = current.leftChild;
53         else if(value > current.value)
54             current = current.rightChild;
55         else
56             return true; // means found value
57     }
58     return false; // means not found value
59 }
60
61 }
62
63
Tree > find()
Terminal Messages Run Debug TODO
Build completed successfully in 2 s 54 ms (13 minutes ago) 51:38 CRLF UTF-8 4 spaces Event Log
```

Test



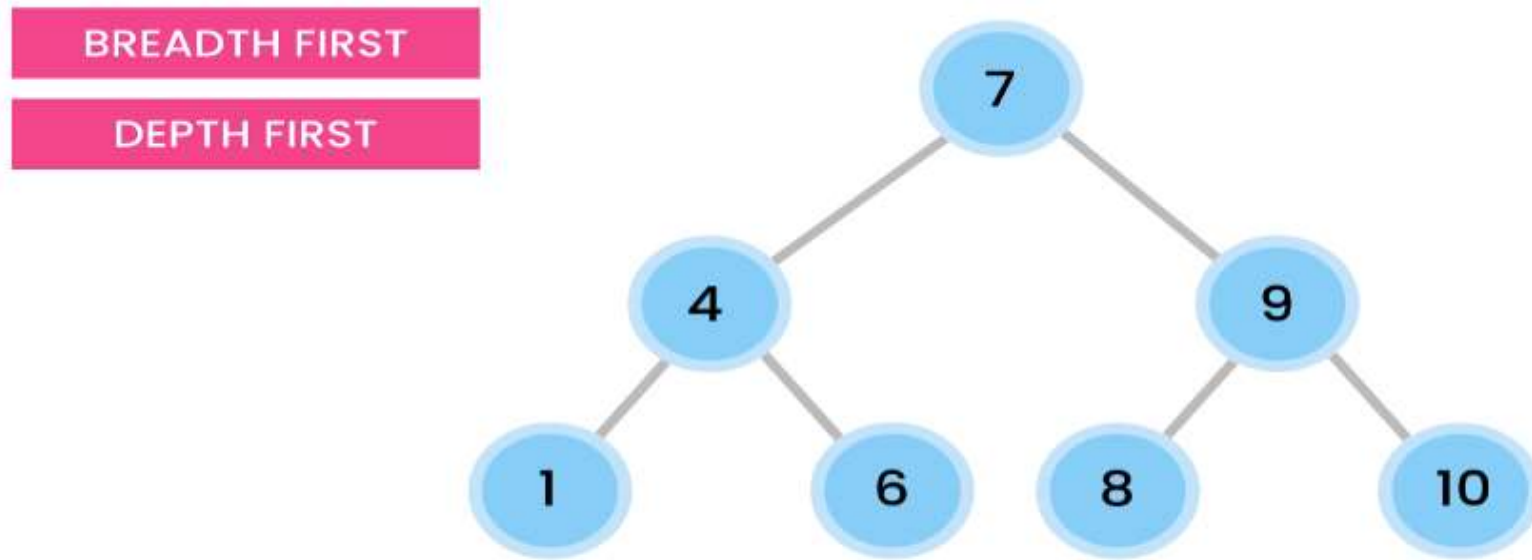
```
1 package com.company;
2
3 public class Main {
4
5     public static void main(String[] args) {
6         // write your code here
7         Tree tree = new Tree();
8         tree.insert( value: 7);
9         tree.insert( value: 4);
10        tree.insert( value: 9);
11        tree.insert( value: 1);
12        tree.insert( value: 6);
13        tree.insert( value: 8);
14        tree.insert( value: 10);
15
16
17
18
19        System.out.println(tree.find( value: 8));
20    }
21 }
```

Run: Main

```
"C:\Program Files\Java\jdk-13.0.2\bin\java.exe" "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA Community Edition 2019.3.3\lib\idea_rt.jar=5000:C:\Program Files\JetBrains\IntelliJ IDEA Community Edition 2019.3.3\bin" -Dfile.encoding=UTF-8
true
Process finished with exit code 0
```

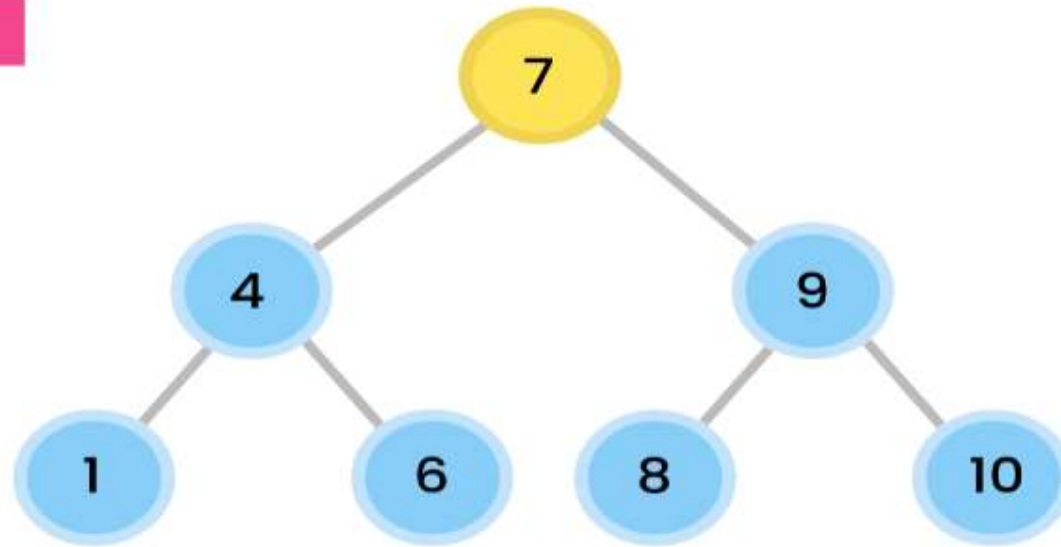
Build completed successfully in 1 s 702 ms (moments ago)

Two Types Of Traversal



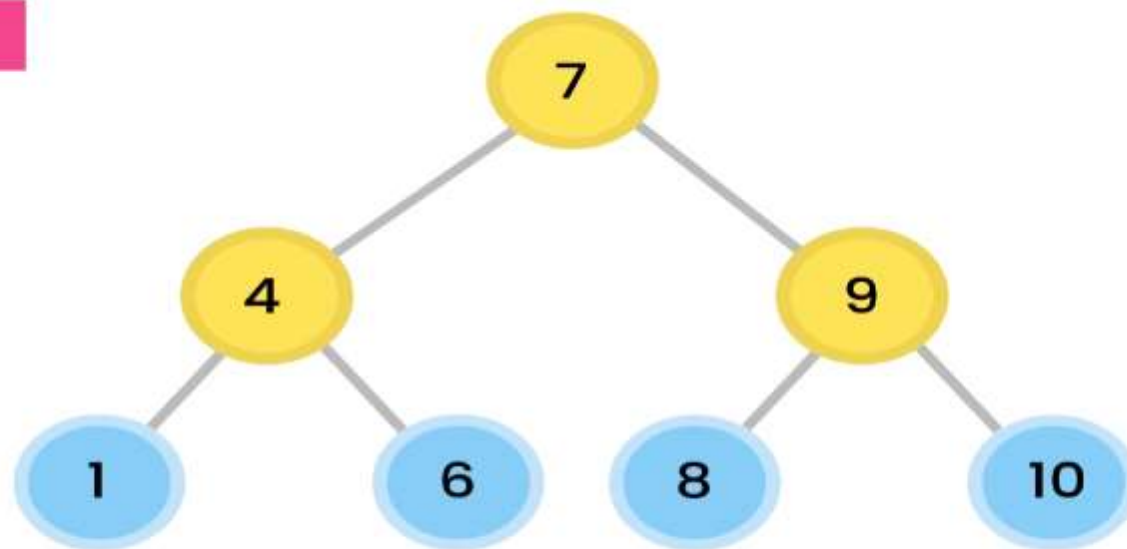
BREADTH FIRST

Level Order



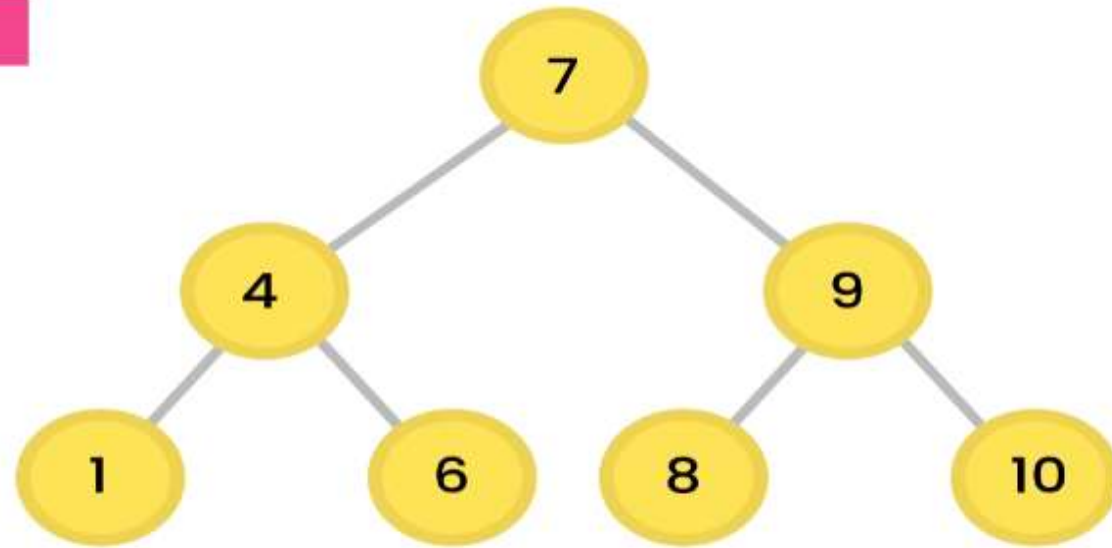
BREADTH FIRST

Level Order



BREADTH FIRST

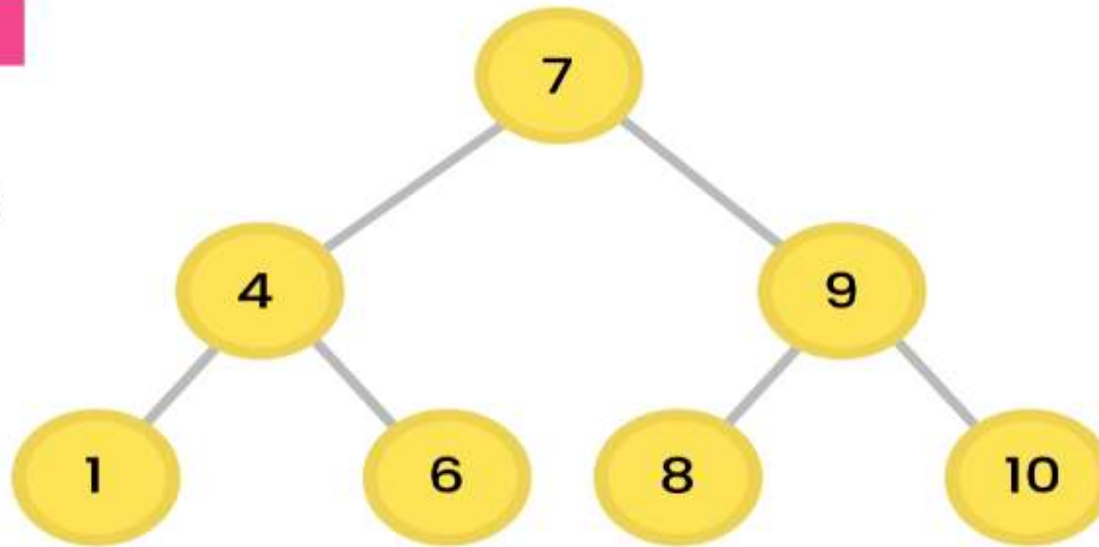
Level Order



BREADTH FIRST

Level Order

7, 4, 9, 1, 6, 8, 10



Three Types Of Depth First Traversal

DEPTH FIRST

Pre-order **Root**, Left, Right

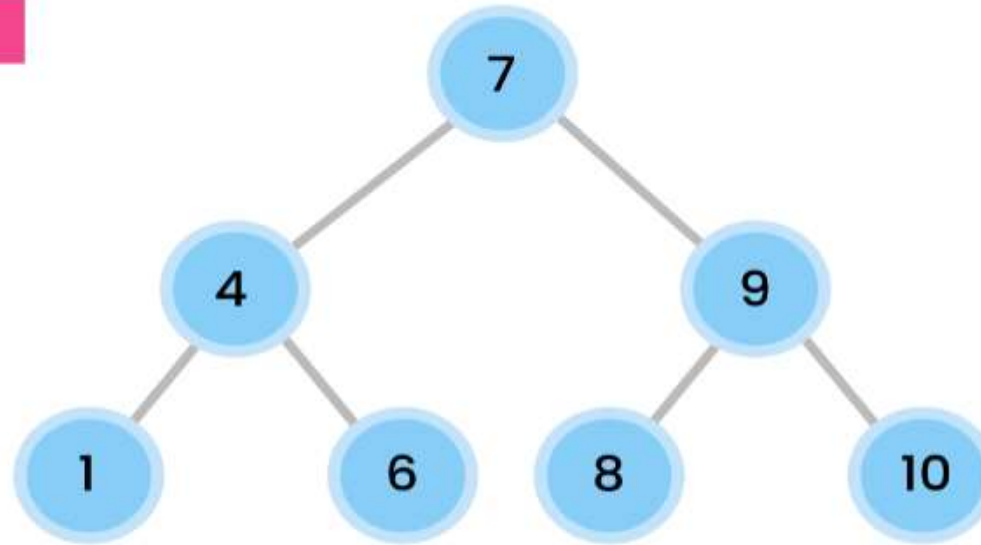
In-order Left, **Root**, Right

Post-order Left, Right, **Root**

Pre-Order Traversal

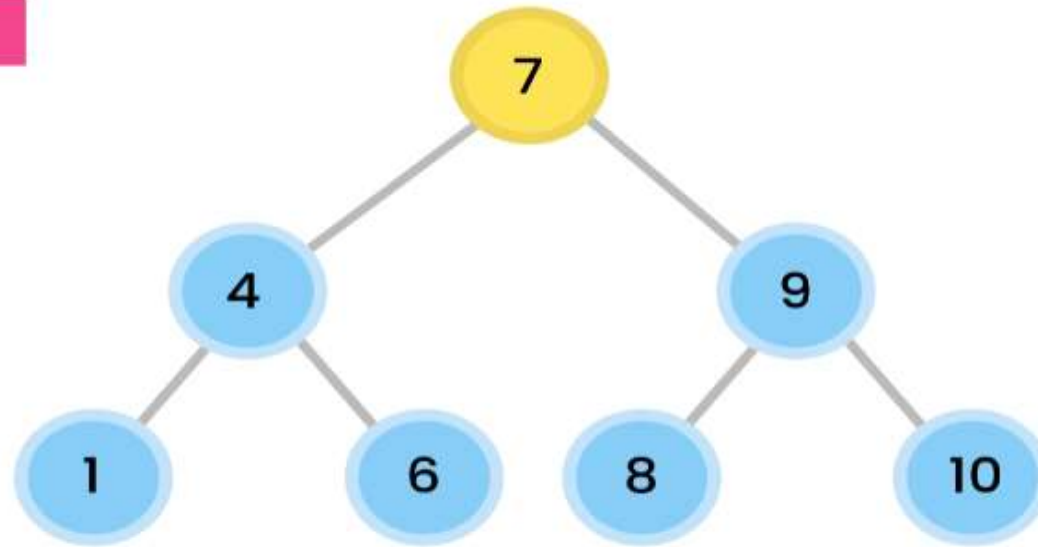
PRE-ORDER

Root, Left, Right



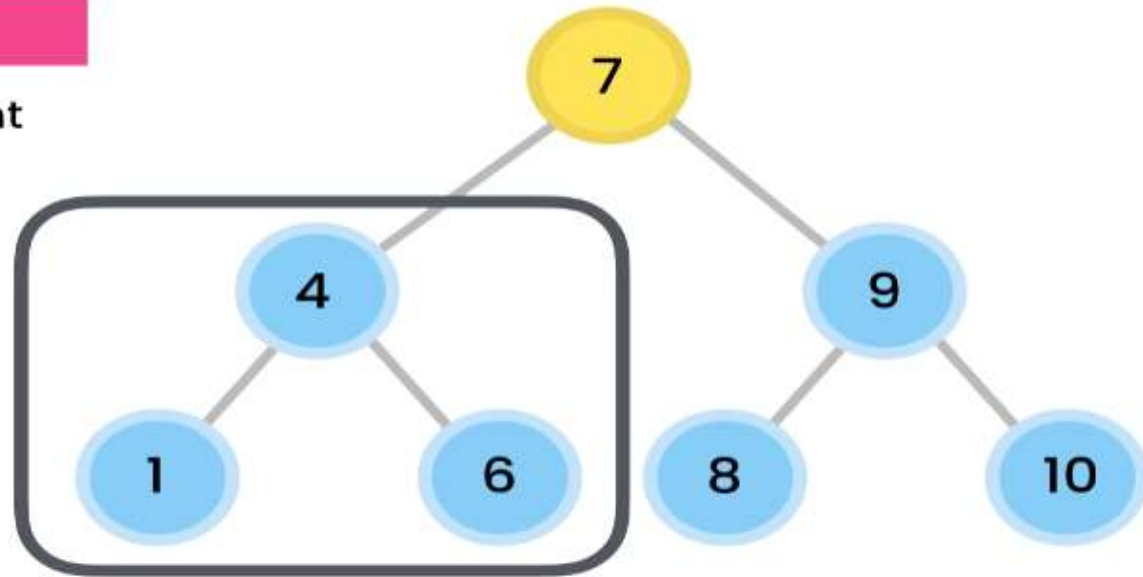
PRE-ORDER

Root, Left, Right



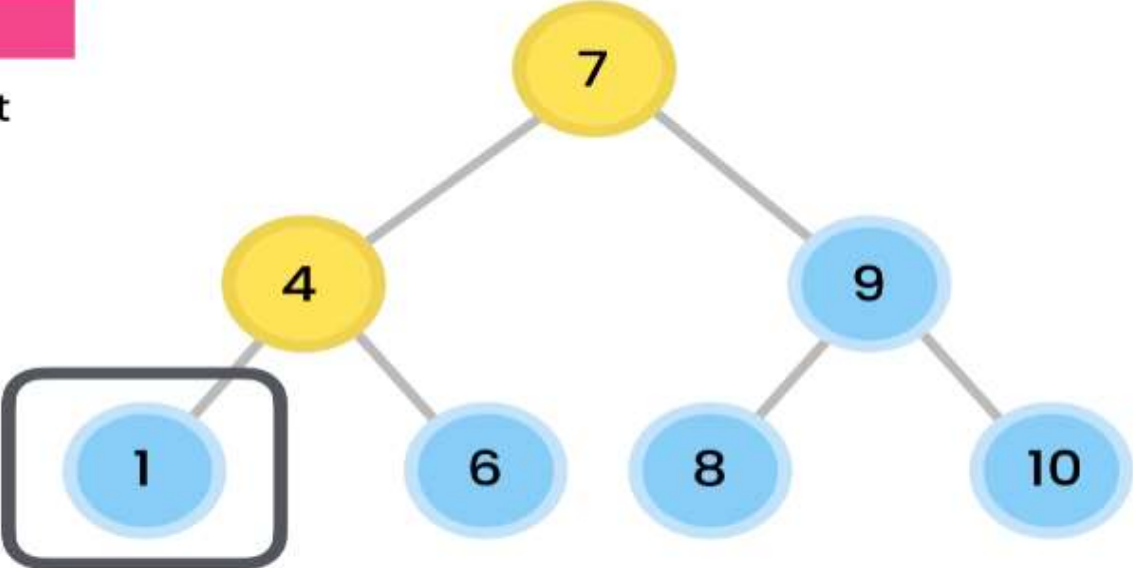
PRE-ORDER

Root, Left, Right



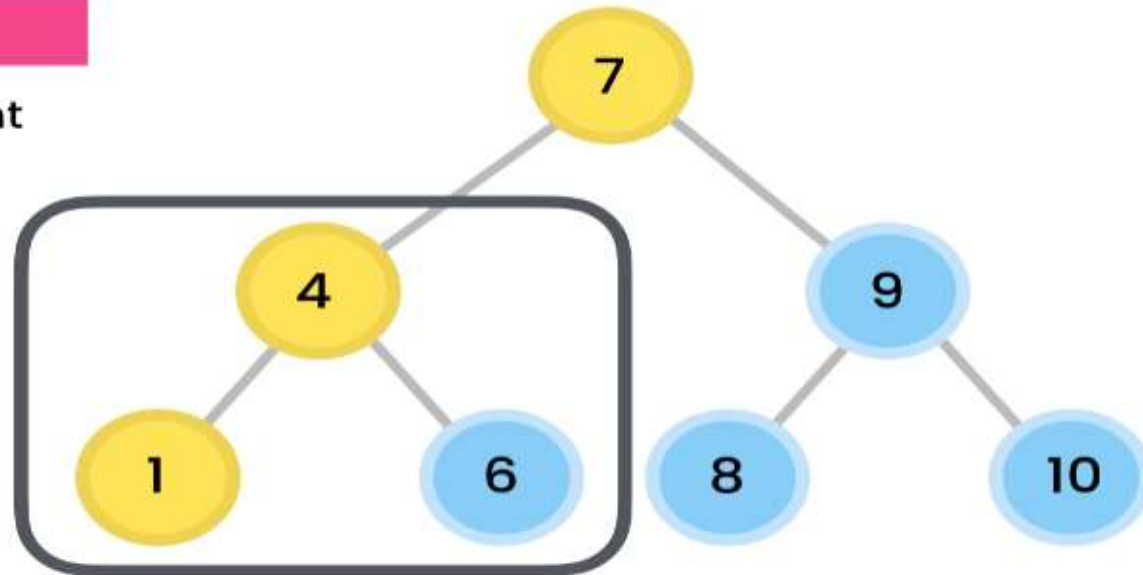
PRE-ORDER

Root, Left, Right



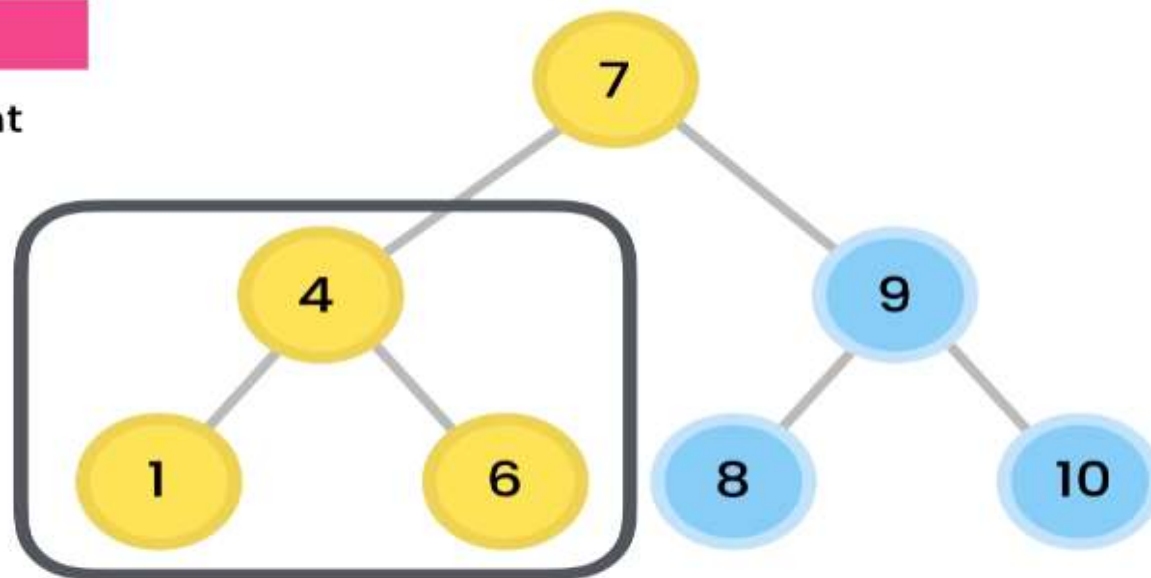
PRE-ORDER

Root, Left, Right



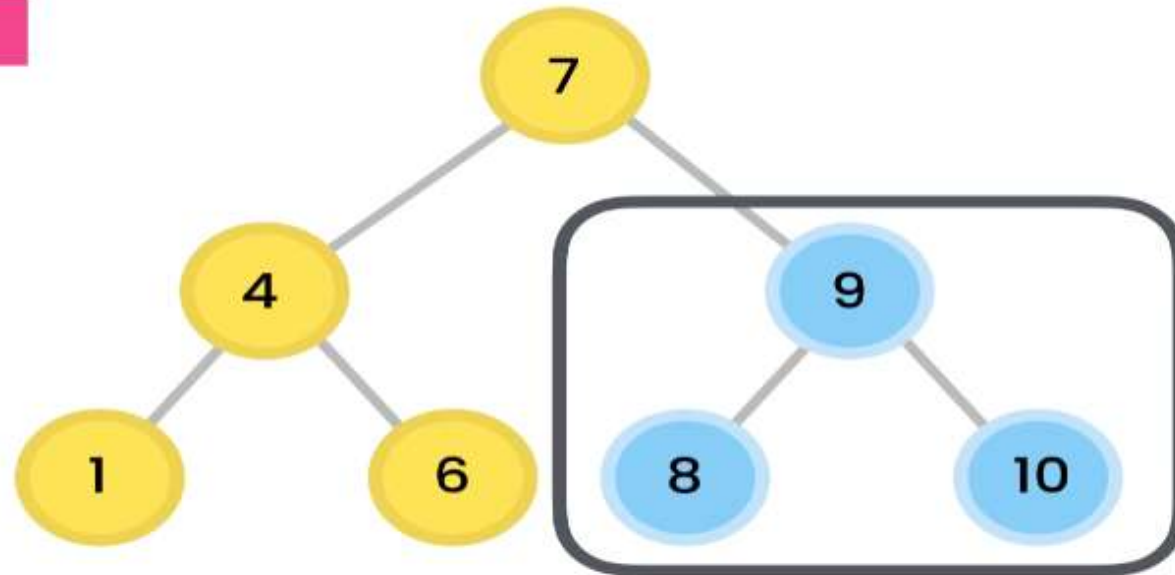
PRE-ORDER

Root, Left, Right



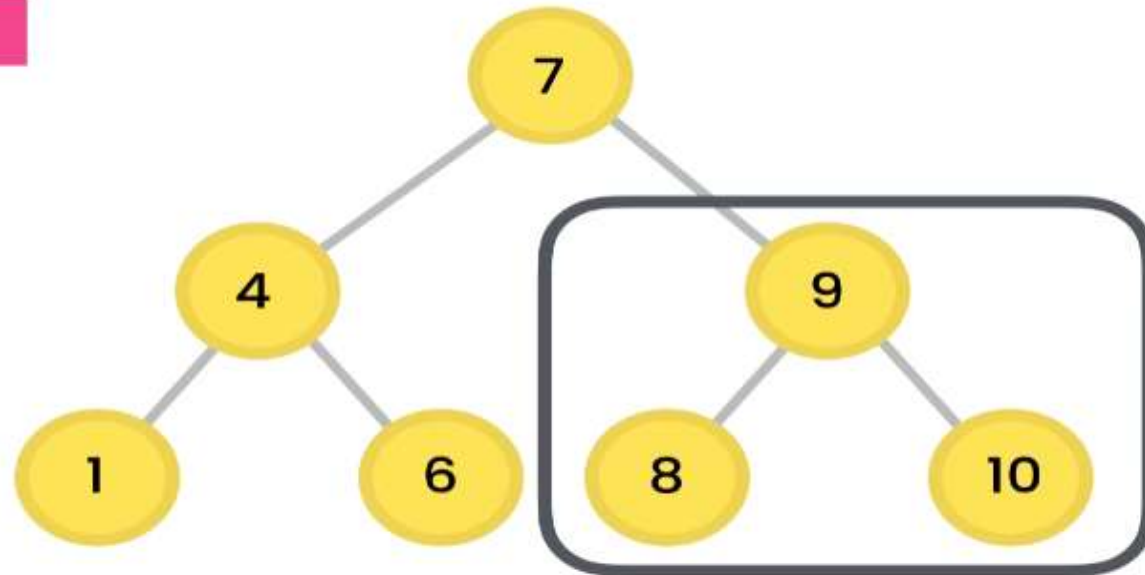
PRE-ORDER

Root, Left, Right



PRE-ORDER

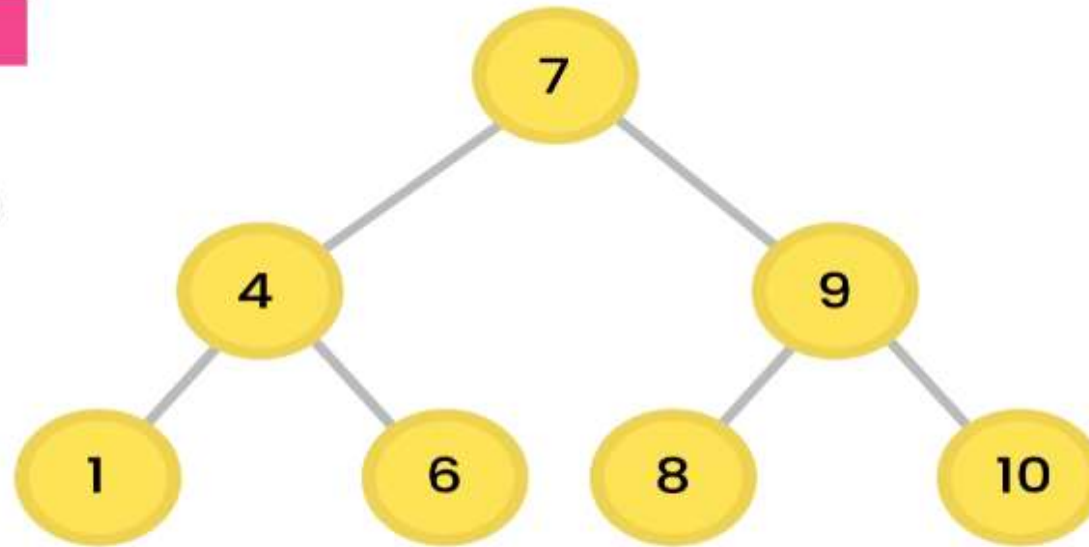
Root, Left, Right



PRE-ORDER

Root, Left, Right

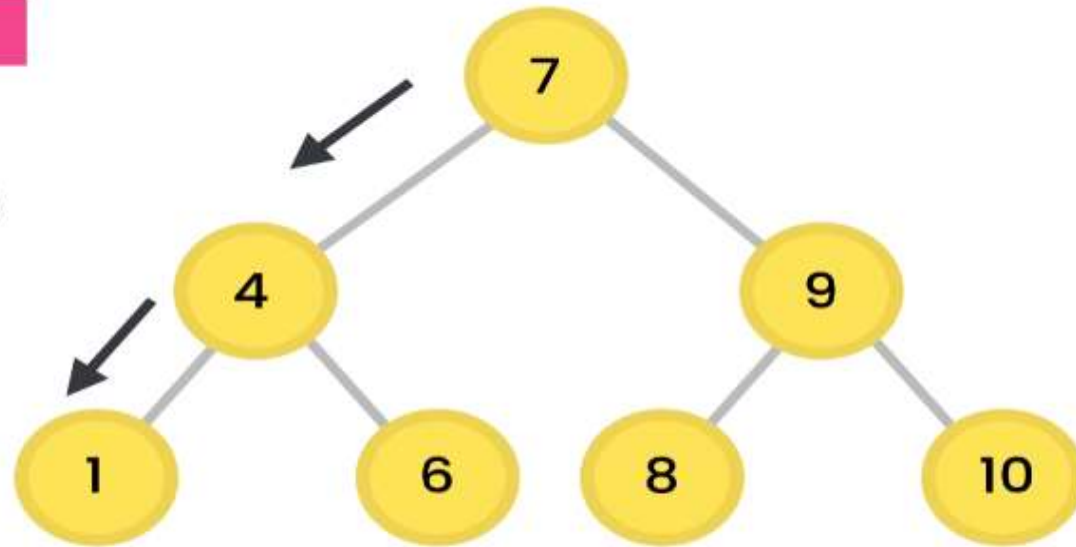
7, 4, 1, 6, 9, 8, 10



PRE-ORDER

Root, Left, Right

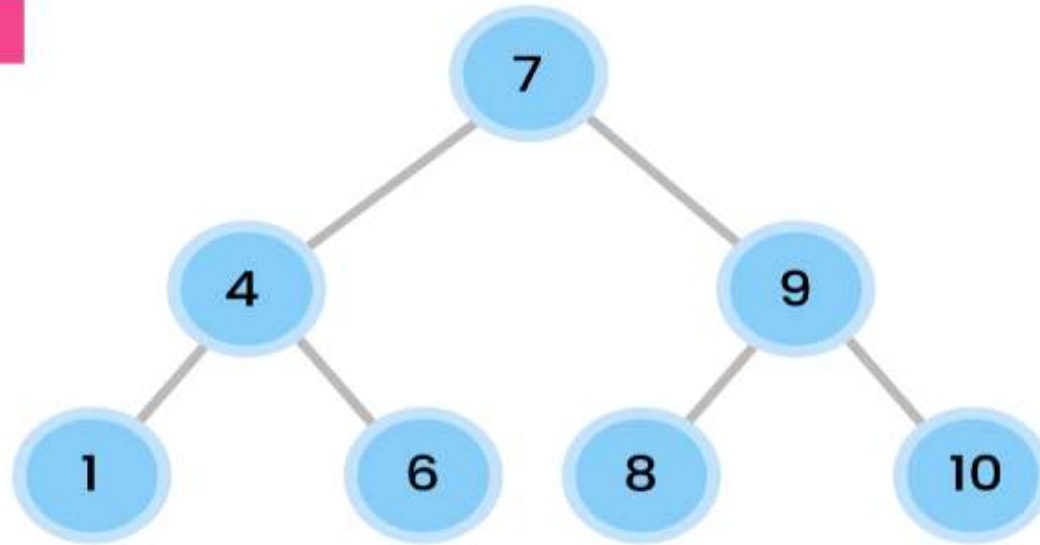
7, 4, 1, 6, 9, 8, 10



In-Order Traversal

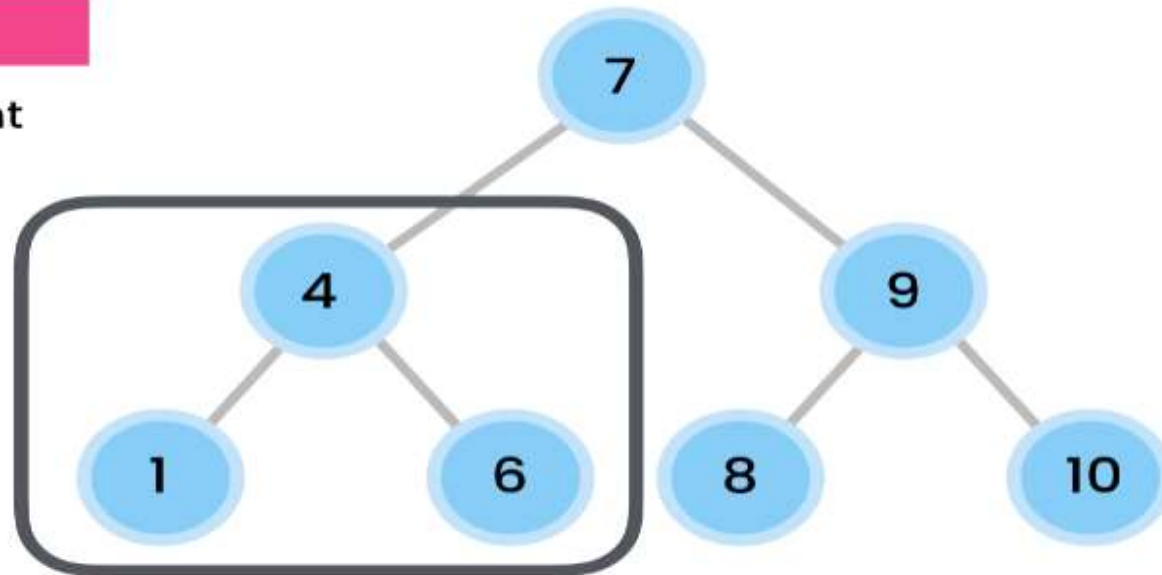
IN-ORDER

Left, Root, Right



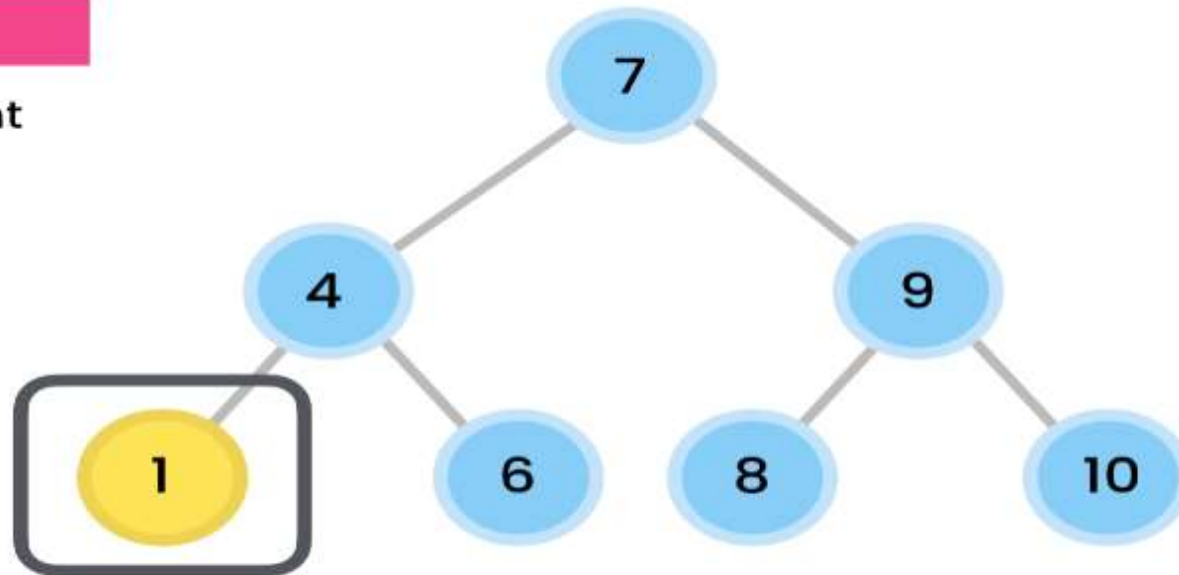
IN-ORDER

Left, Root, Right



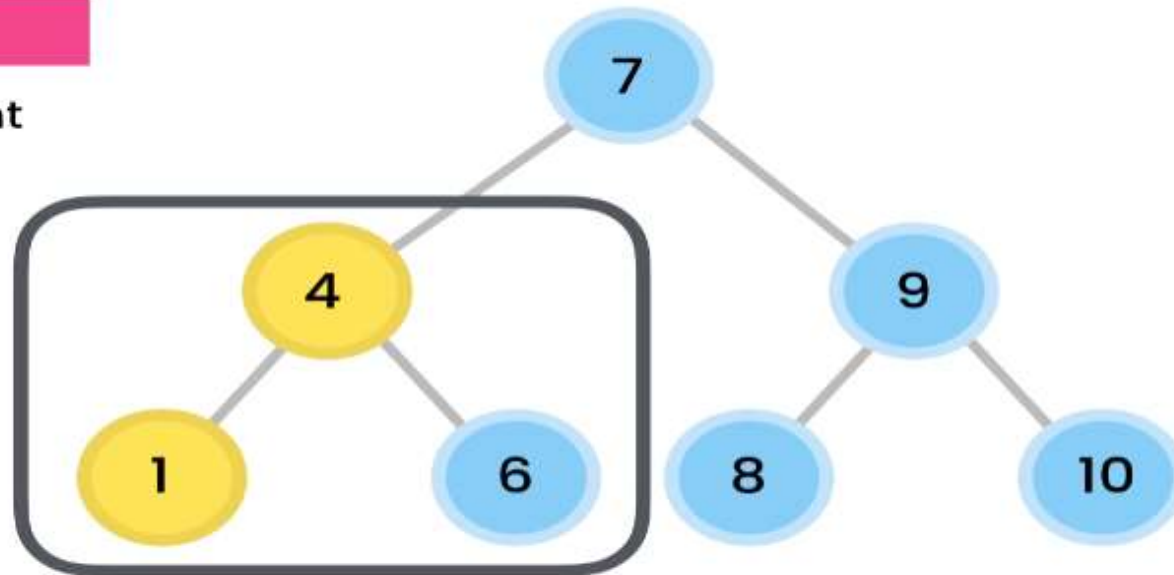
IN-ORDER

Left, Root, Right



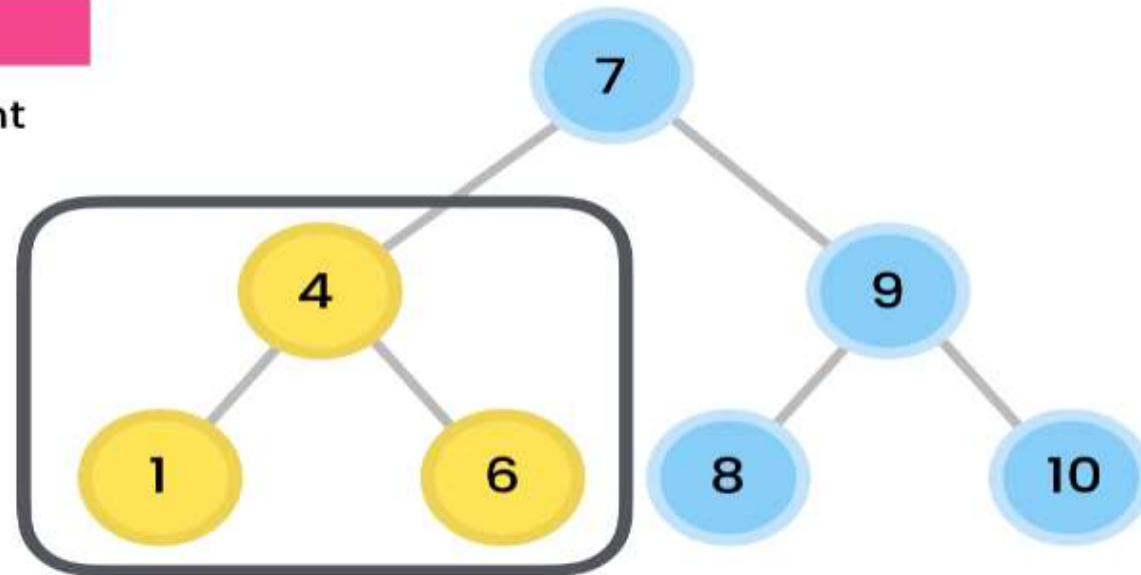
IN-ORDER

Left, Root, Right



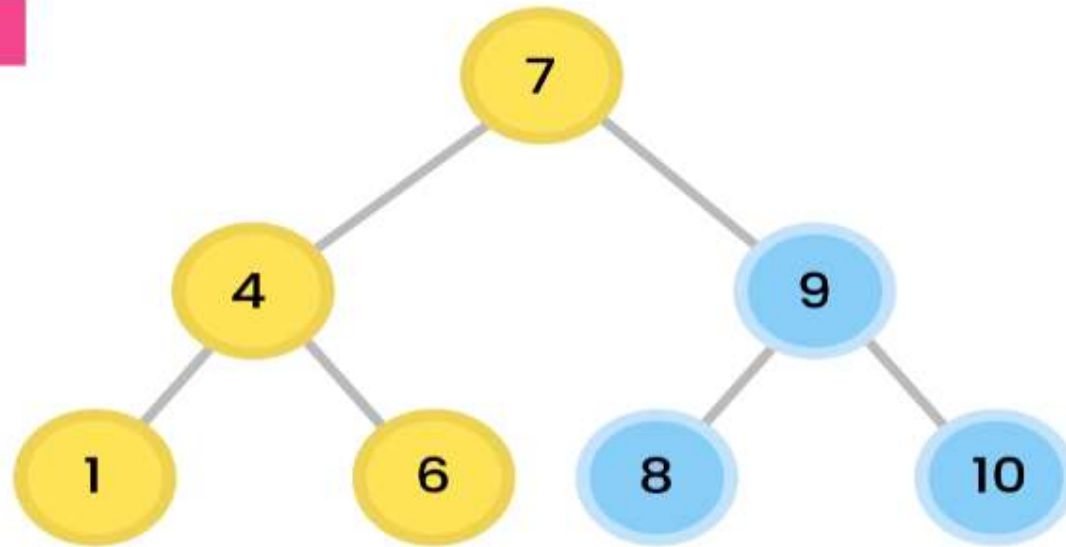
IN-ORDER

Left, Root, Right



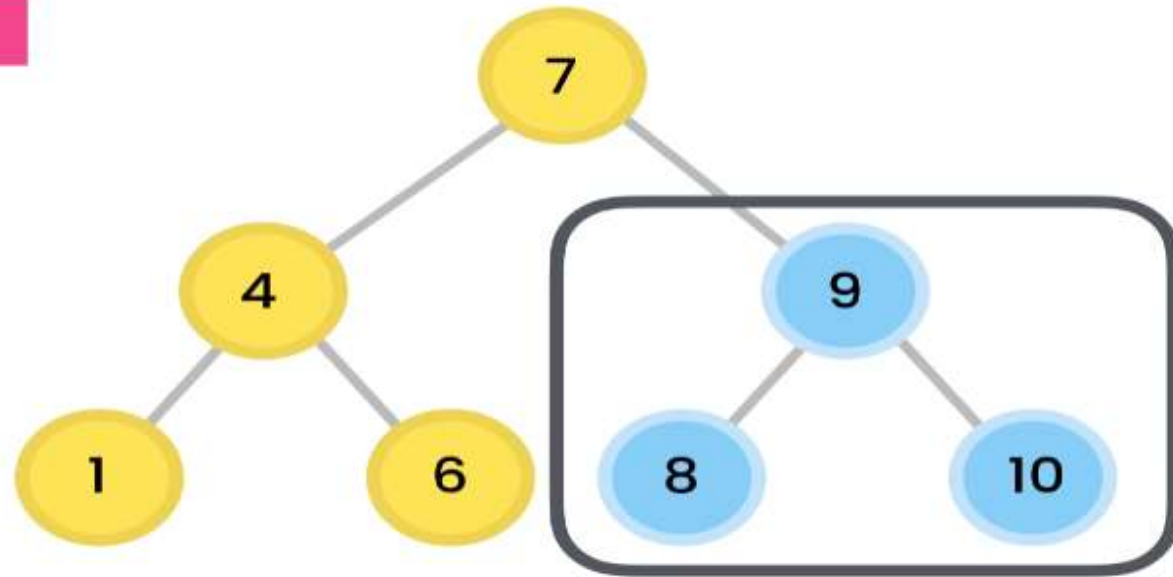
IN-ORDER

Left, Root, Right



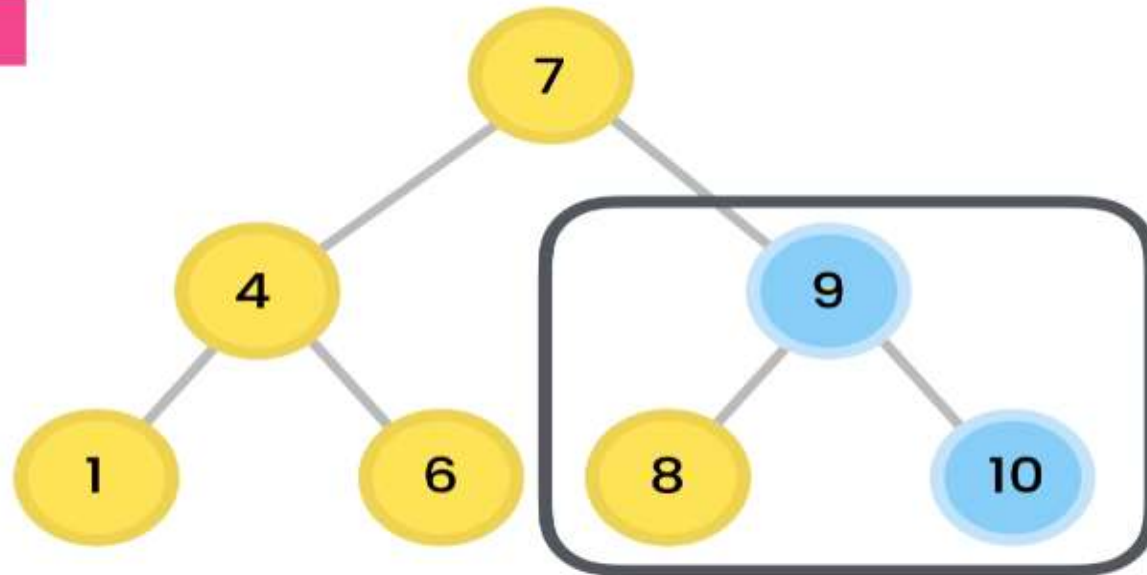
IN-ORDER

Left, Root, Right



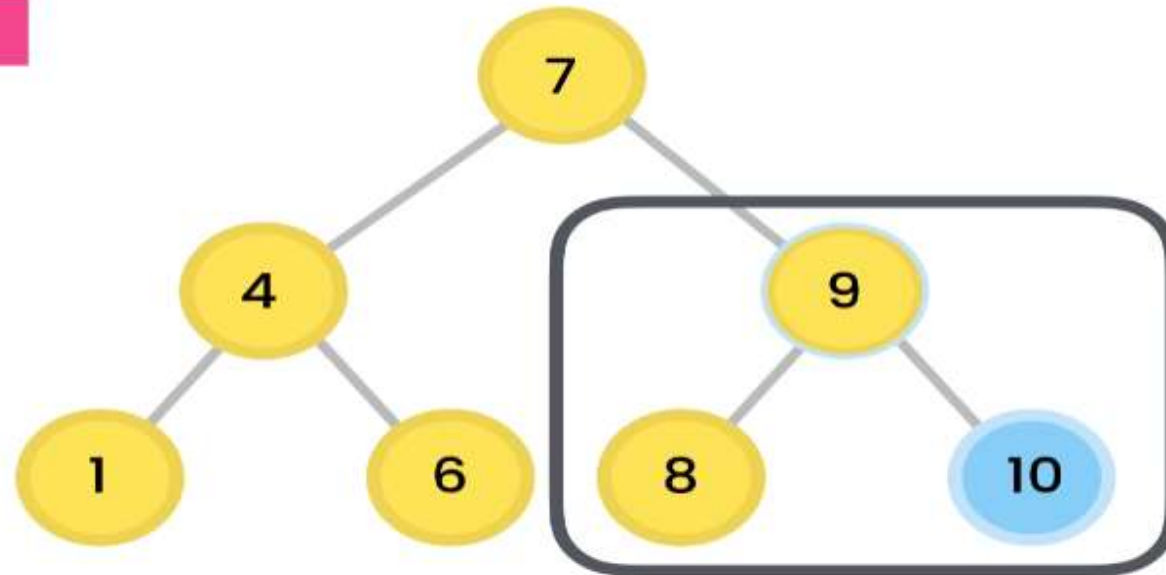
IN-ORDER

Left, Root, Right



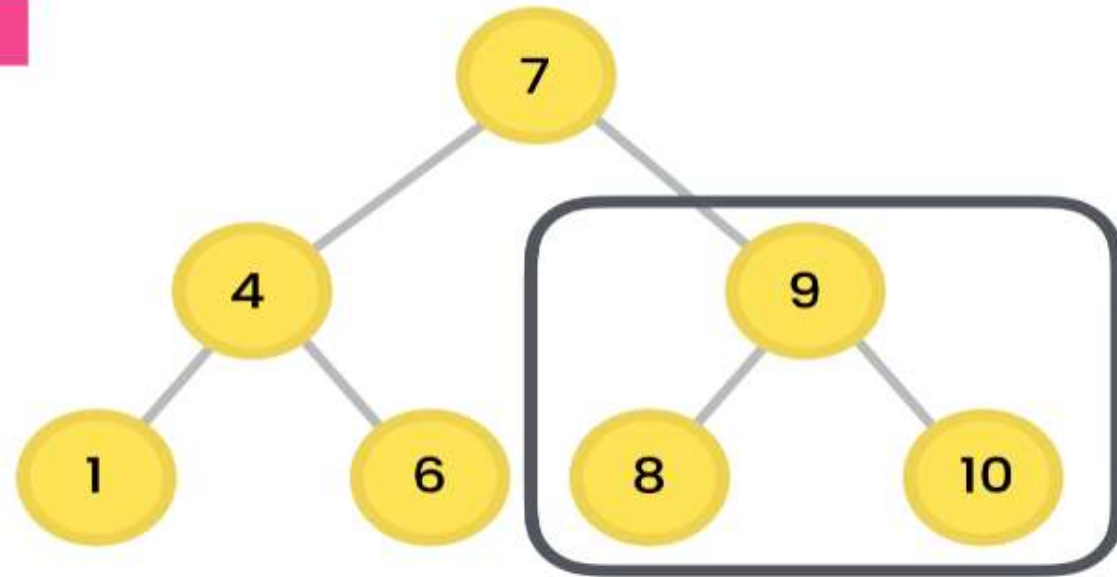
IN-ORDER

Left, Root, Right



IN-ORDER

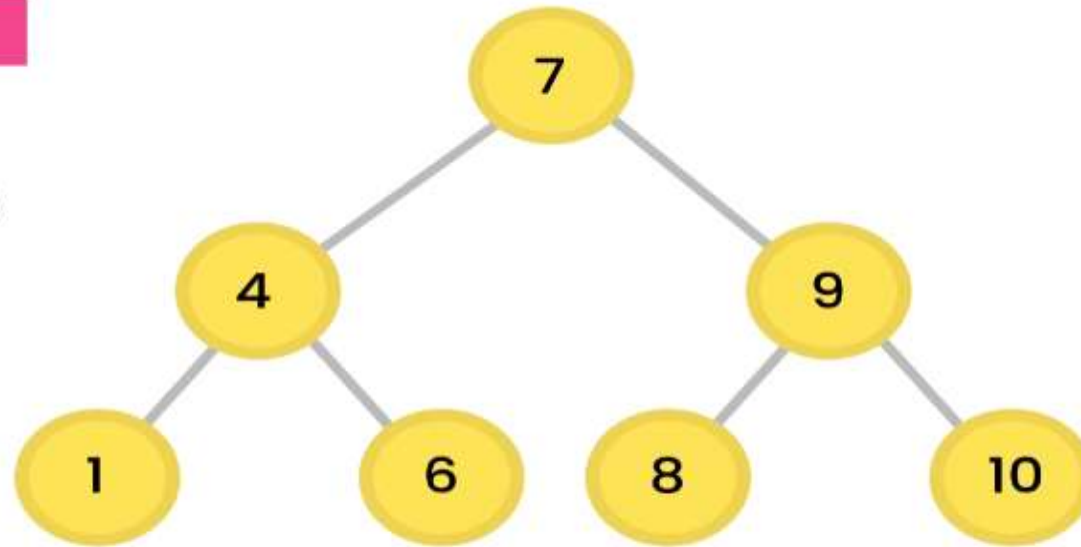
Left, Root, Right



IN-ORDER

Left, Root, Right

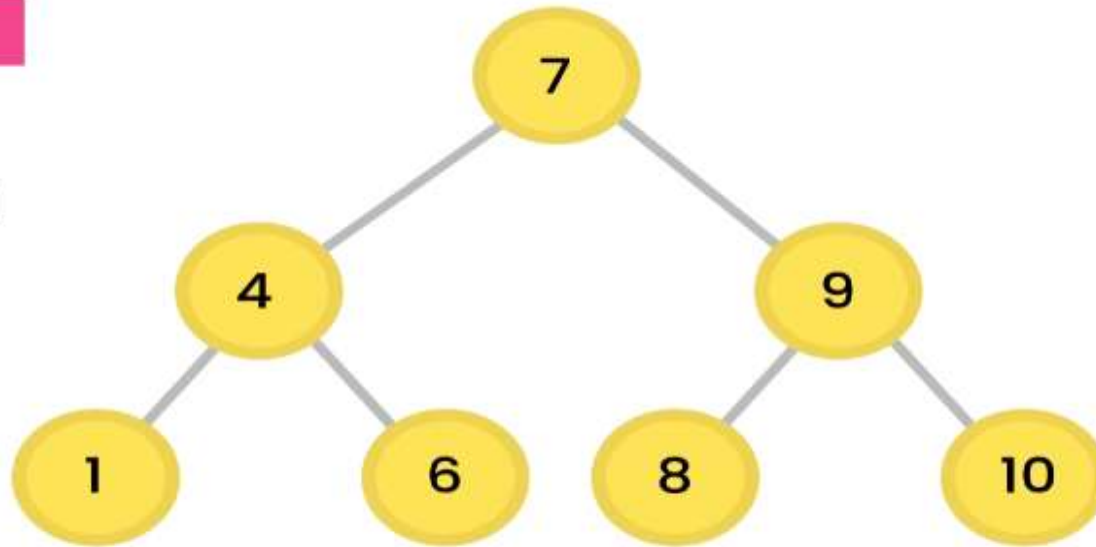
1, 4, 6, 7, 8, 9, 10



IN-ORDER

Right, Root, Left

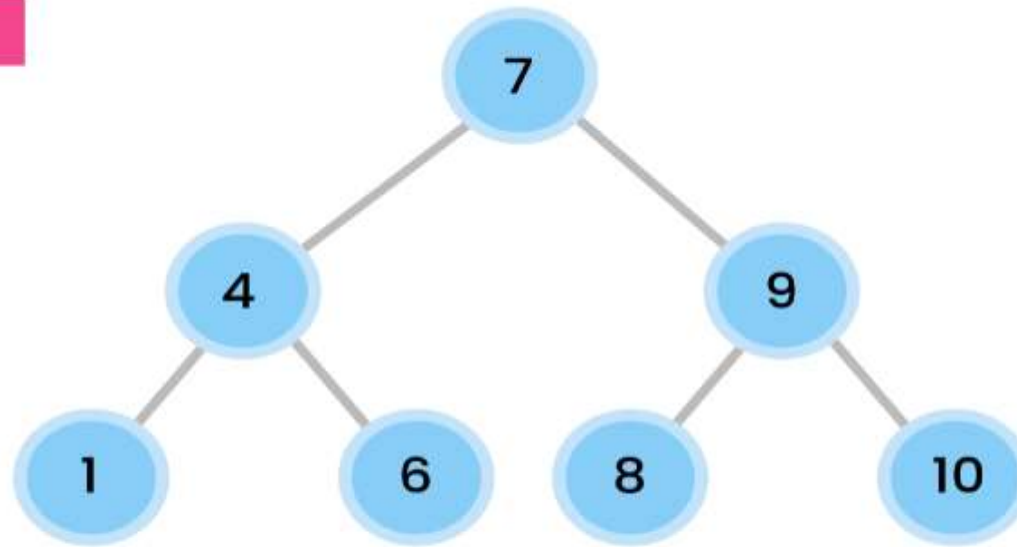
10, 9, 8, 7, 6, 4, 1



Post-Order Traversal

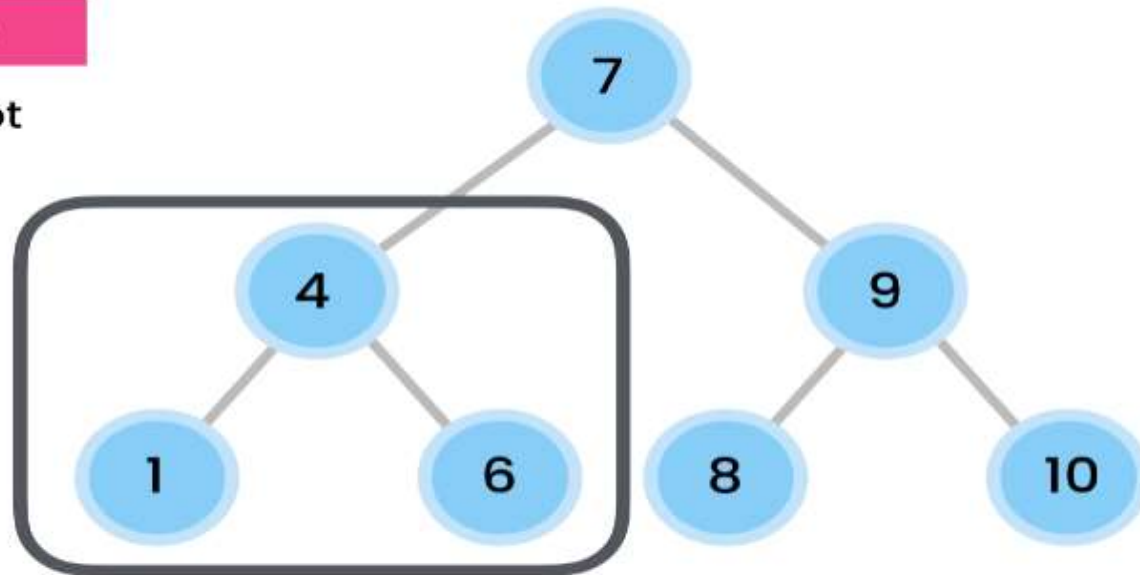
POST-ORDER

Left, Right, Root



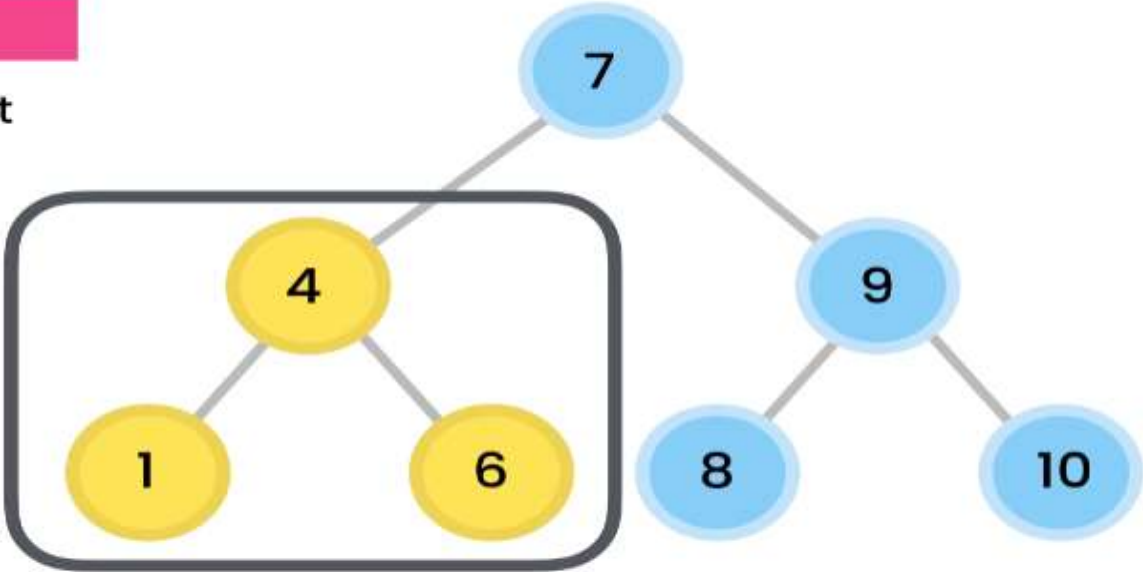
POST-ORDER

Left, Right, Root



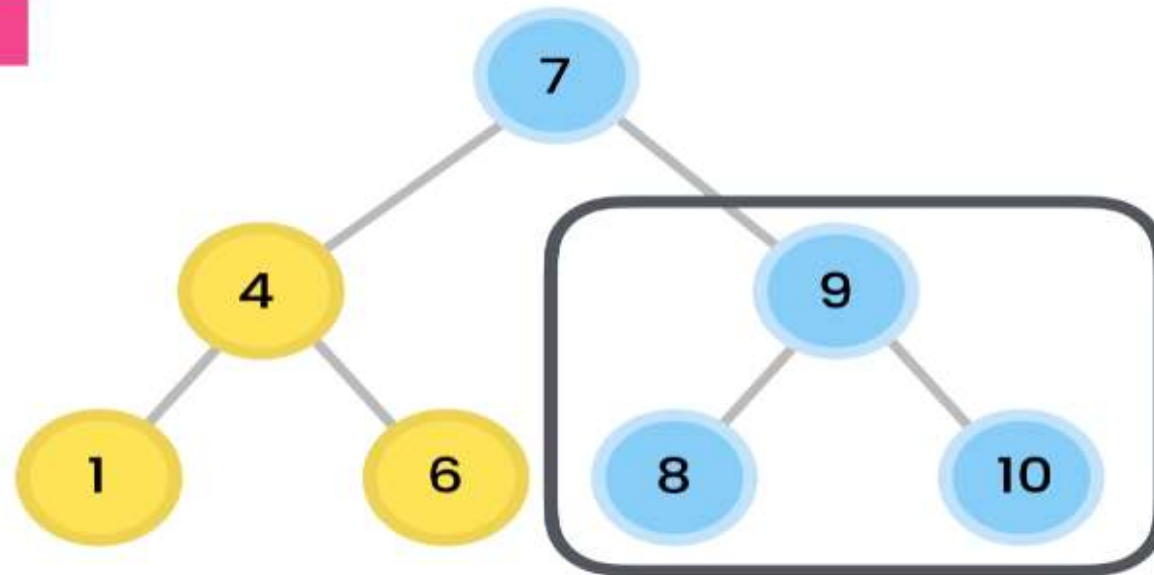
POST-ORDER

Left, Right, Root



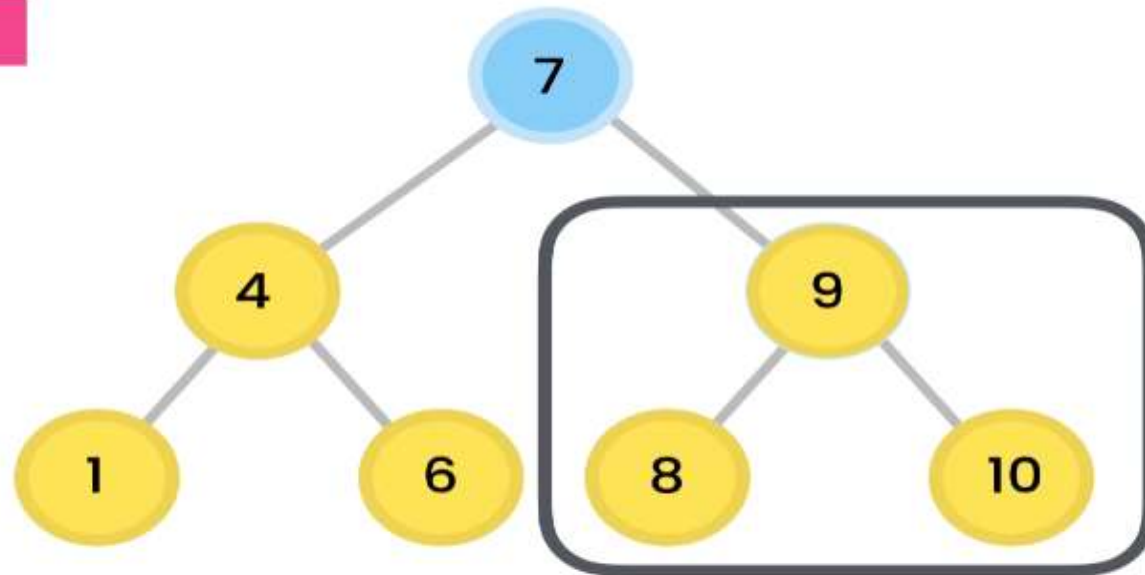
POST-ORDER

Left, Right, Root



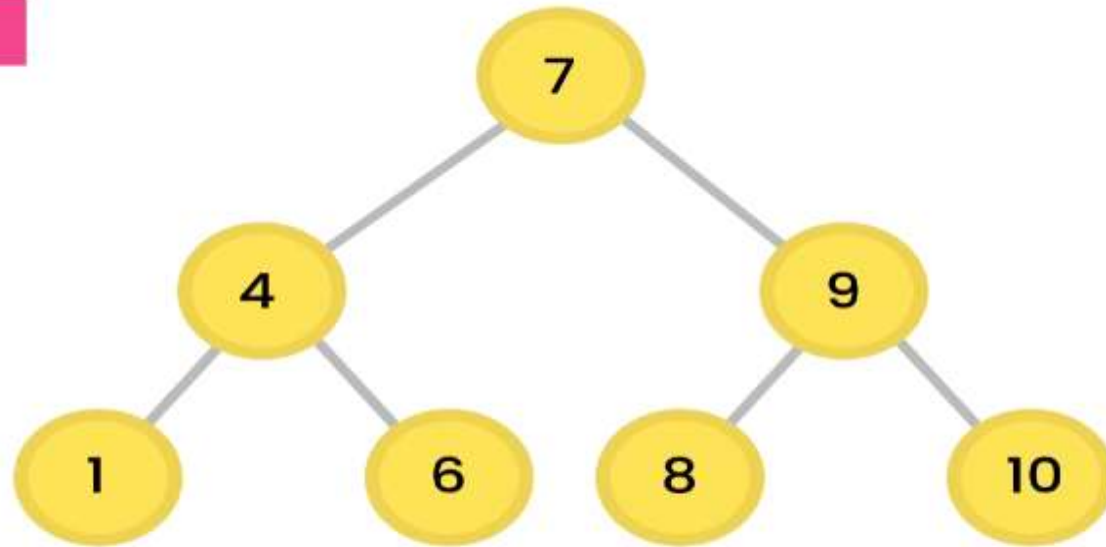
POST-ORDER

Left, Right, Root



POST-ORDER

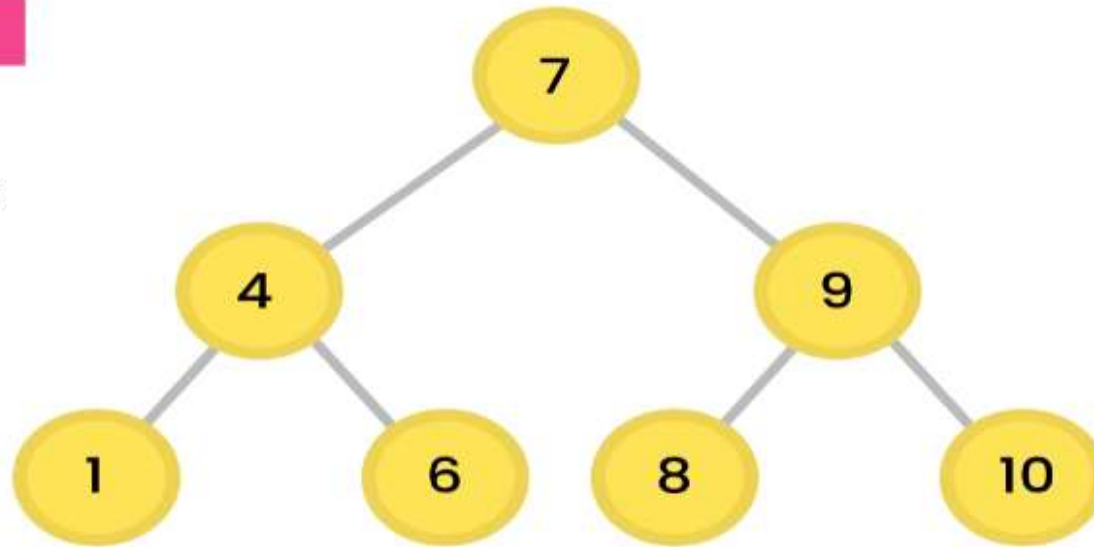
Left, Right, Root



POST-ORDER

Left, Right, Root

1, 6, 4, 8, 10, 9, 7

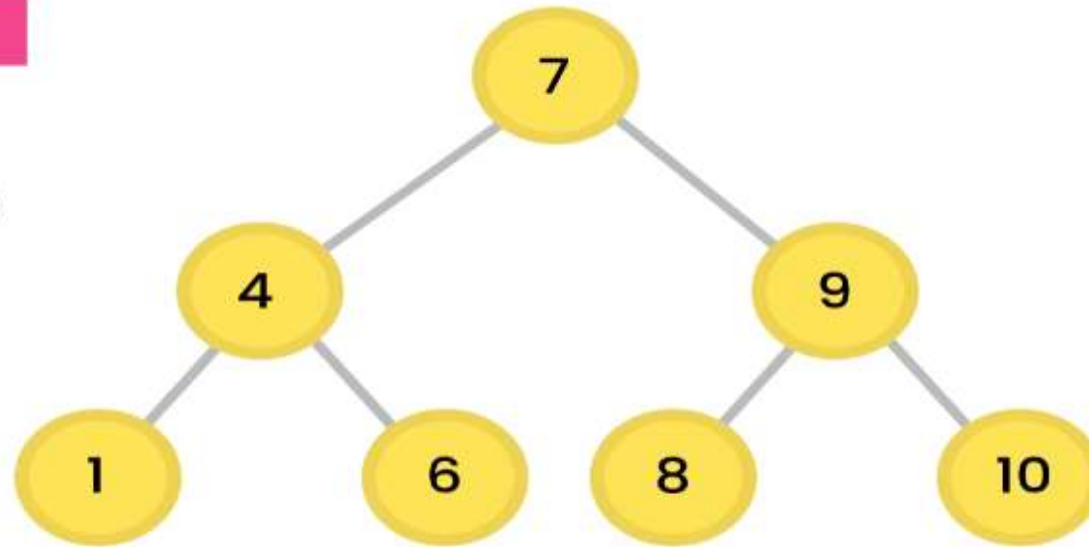


Implementation Of Following Algorithm

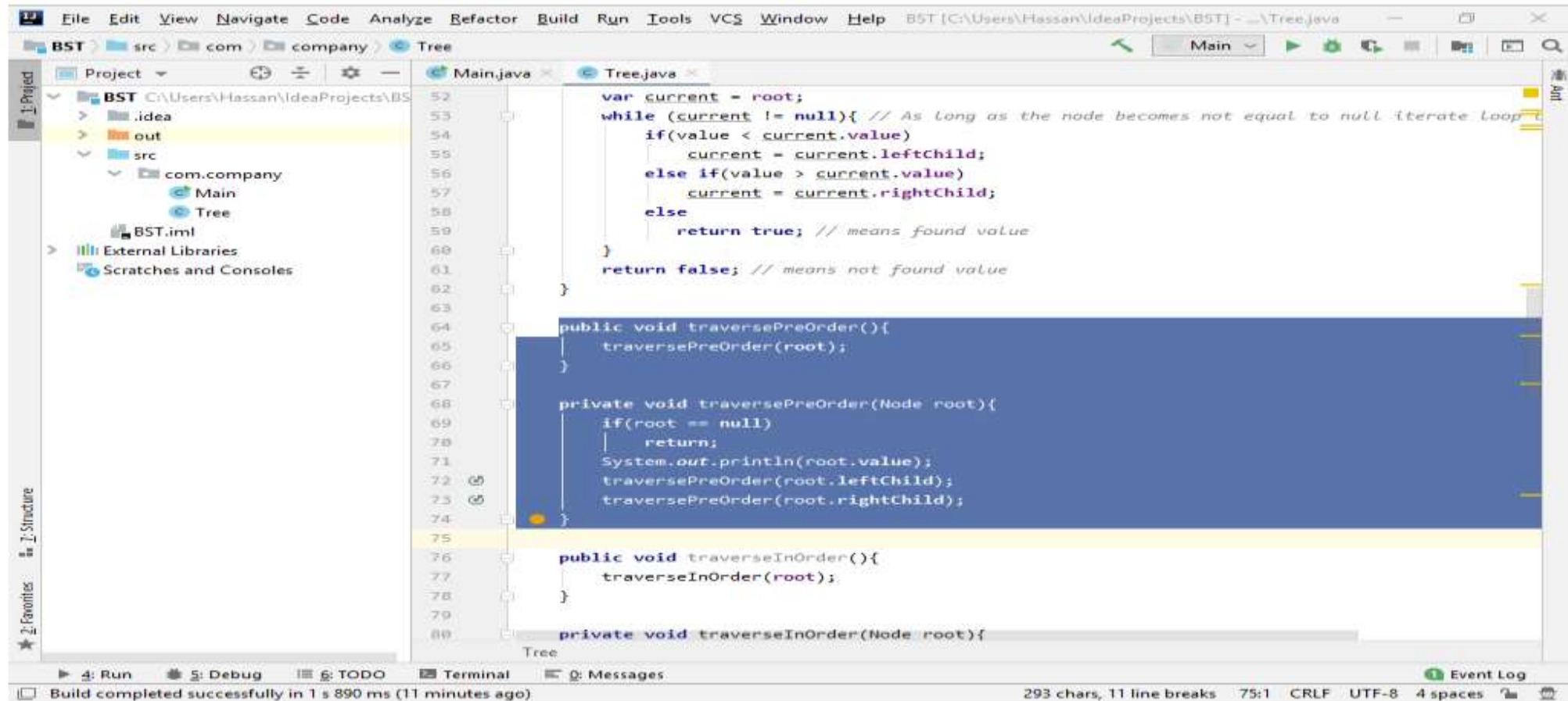
PRE-ORDER

Root, Left, Right

7, 4, 1, 6, 9, 8, 10



Pre-Order Using Recursion



The screenshot shows an IDE window with the following components:

- Project Structure:** A tree view on the left showing the project hierarchy: `BST` (root) → `src` → `com` → `company` → `Tree`. Other files like `Main.java` and `BST.iml` are also visible.
- Code Editor:** The main area displays the `Tree.java` file. The code includes:
 - A `while` loop for searching a value in the BST, comparing it with the current node's value and moving to the left or right child.
 - A `traversePreOrder()` method that calls a private recursive method `traversePreOrder(Node root)`.
 - The recursive method `traversePreOrder(Node root)` which prints the root's value, then recursively traverses the left and right subtrees.
 - A `traverseInOrder()` method that calls a private recursive method `traverseInOrder(Node root)`.
- Bottom Panel:** Contains tabs for `Run`, `Debug`, `TODO`, `Terminal`, and `Messages`. The `Run` tab is active, showing a message: "Build completed successfully in 1 s 890 ms (11 minutes ago)".

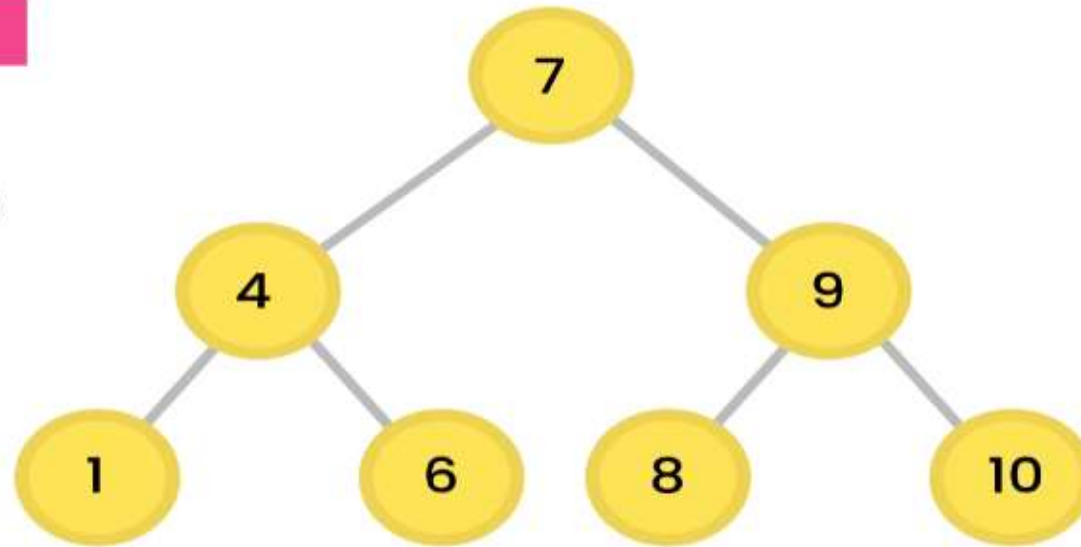
```
52 var current = root;
53 while (current != null){ // As long as the node becomes not equal to null iterate loop
54     if(value < current.value)
55         current = current.leftChild;
56     else if(value > current.value)
57         current = current.rightChild;
58     else
59         return true; // means found value
60 }
61 return false; // means not found value
62 }
63
64 public void traversePreOrder(){
65     traversePreOrder(root);
66 }
67
68 private void traversePreOrder(Node root){
69     if(root == null)
70         return;
71     System.out.println(root.value);
72     traversePreOrder(root.leftChild);
73     traversePreOrder(root.rightChild);
74 }
75
76 public void traverseInOrder(){
77     traverseInOrder(root);
78 }
79
80 private void traverseInOrder(Node root){
```

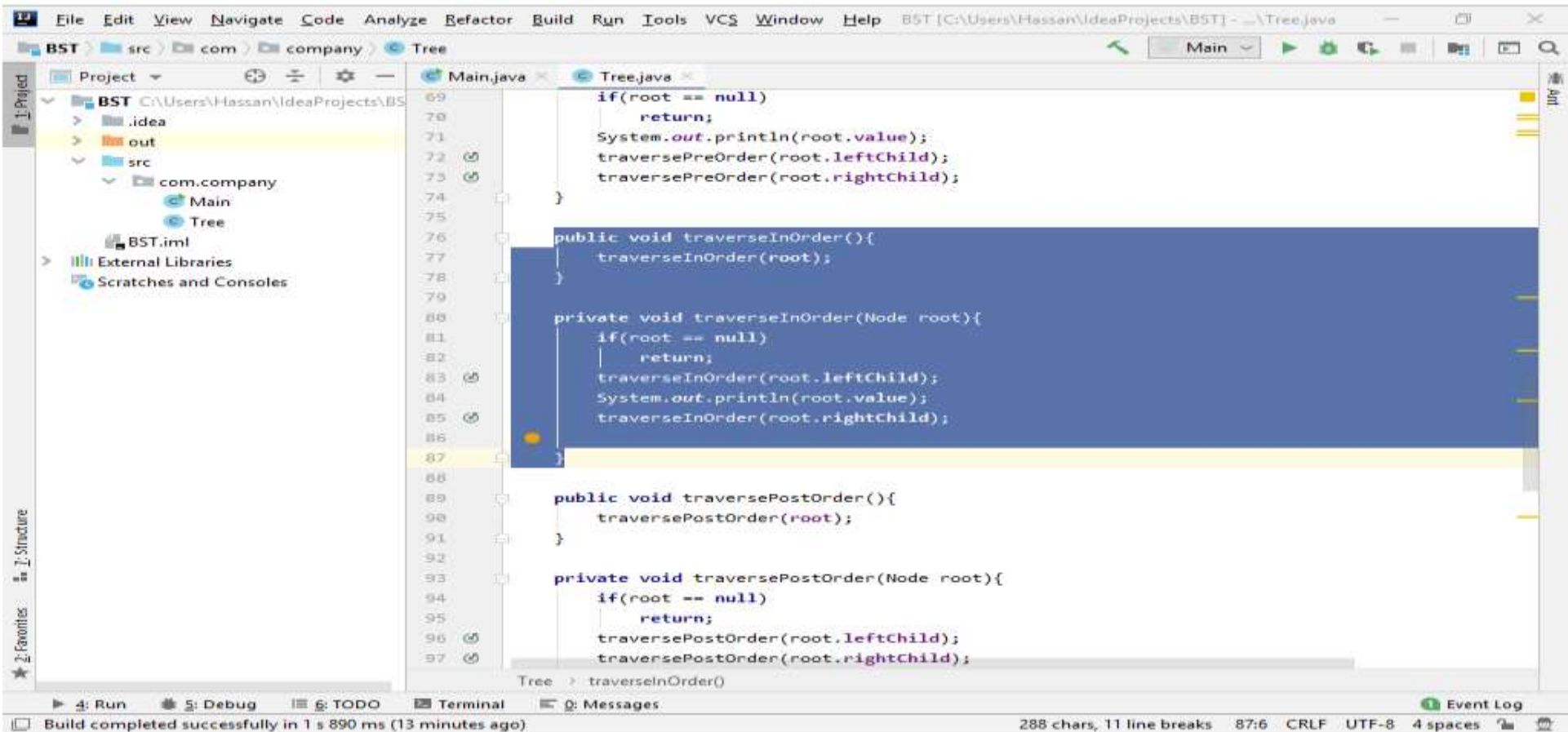
Implementation Of Following Algorithm

IN-ORDER

Left, Root, Right

1, 4, 6, 7, 8, 9, 10



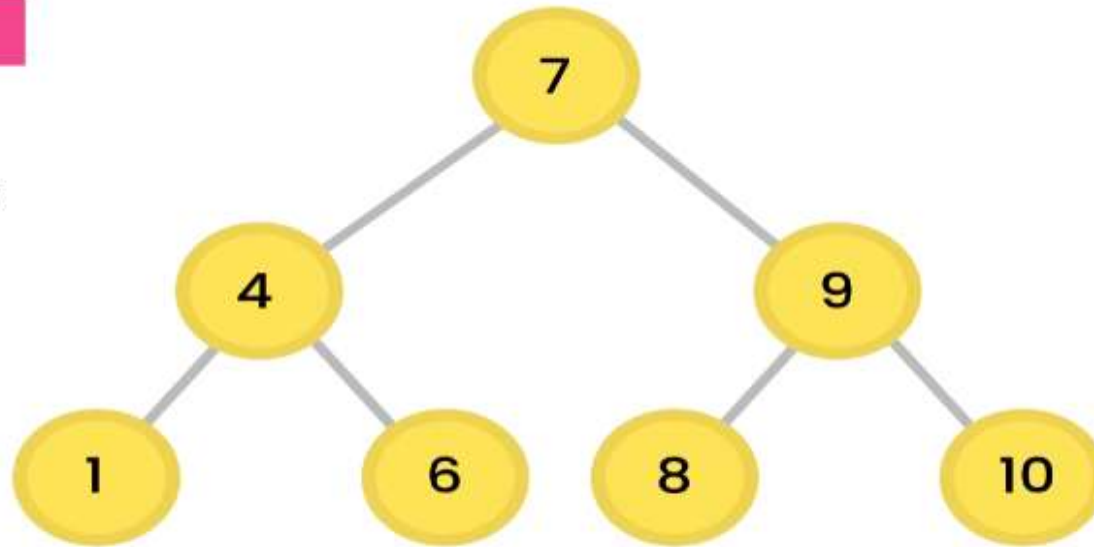


Implementation Of Following Algorithm

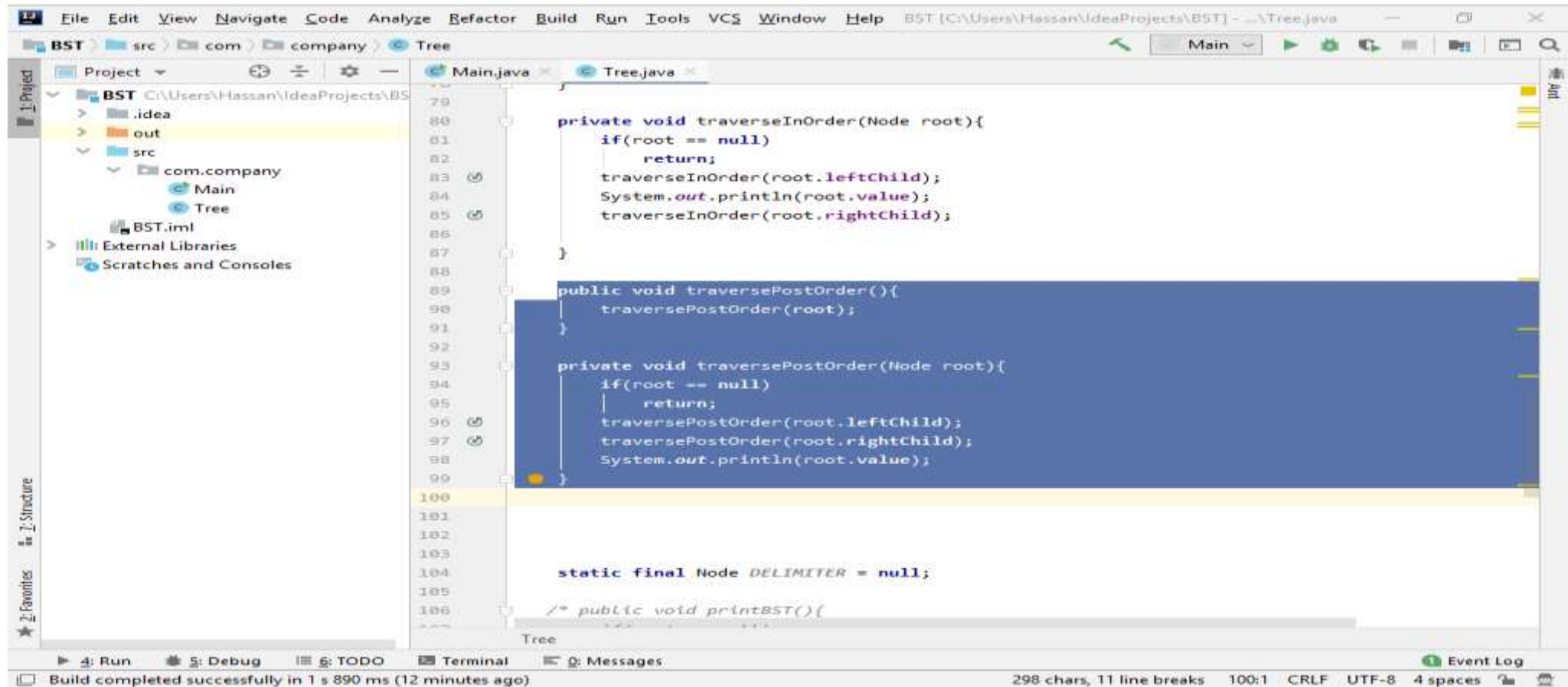
POST-ORDER

Left, Right, Root

1, 6, 4, 8, 10, 9, 7



Post-Order Using Recursion

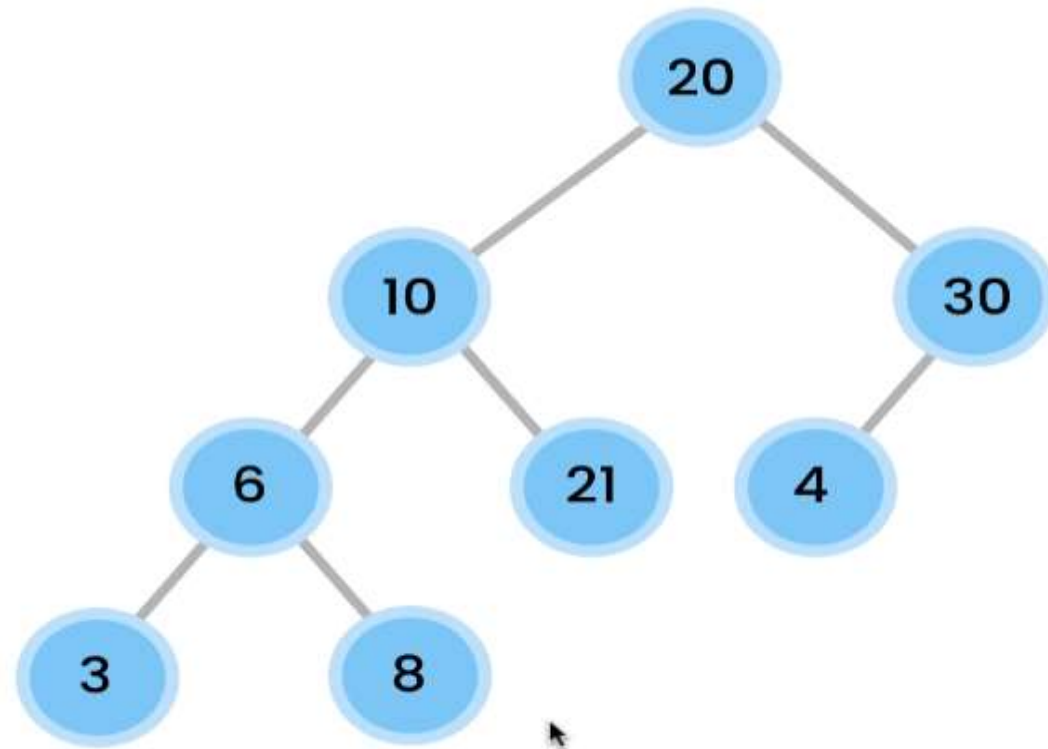


The screenshot shows an IDE window for a project named 'BST'. The file explorer on the left shows the project structure: 'BST' (root) contains '.idea', 'out', 'src', 'BST.iml', and 'External Libraries'. The 'src' directory contains 'com' (company) which has 'Main' and 'Tree' classes. The 'Tree.java' file is open in the editor, showing the following code:

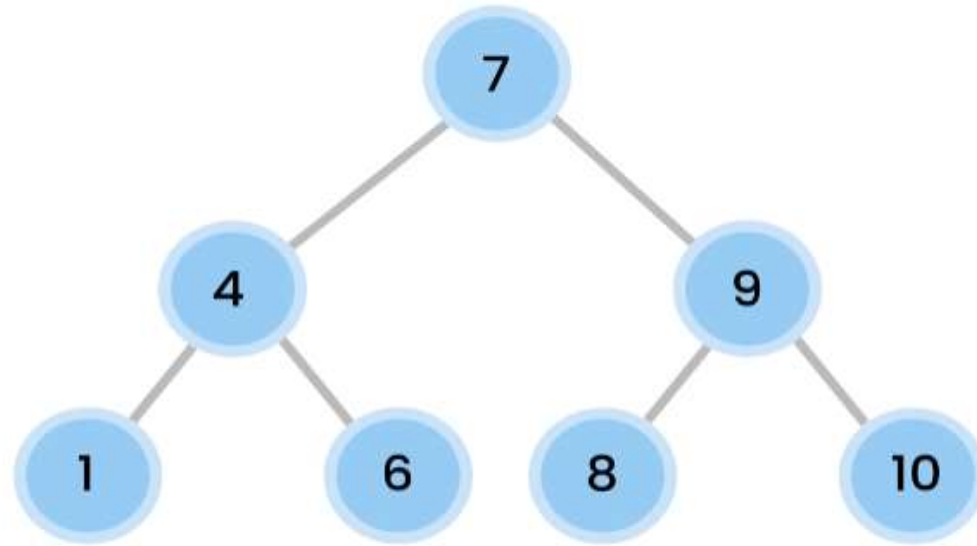
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Height & Depth of BT

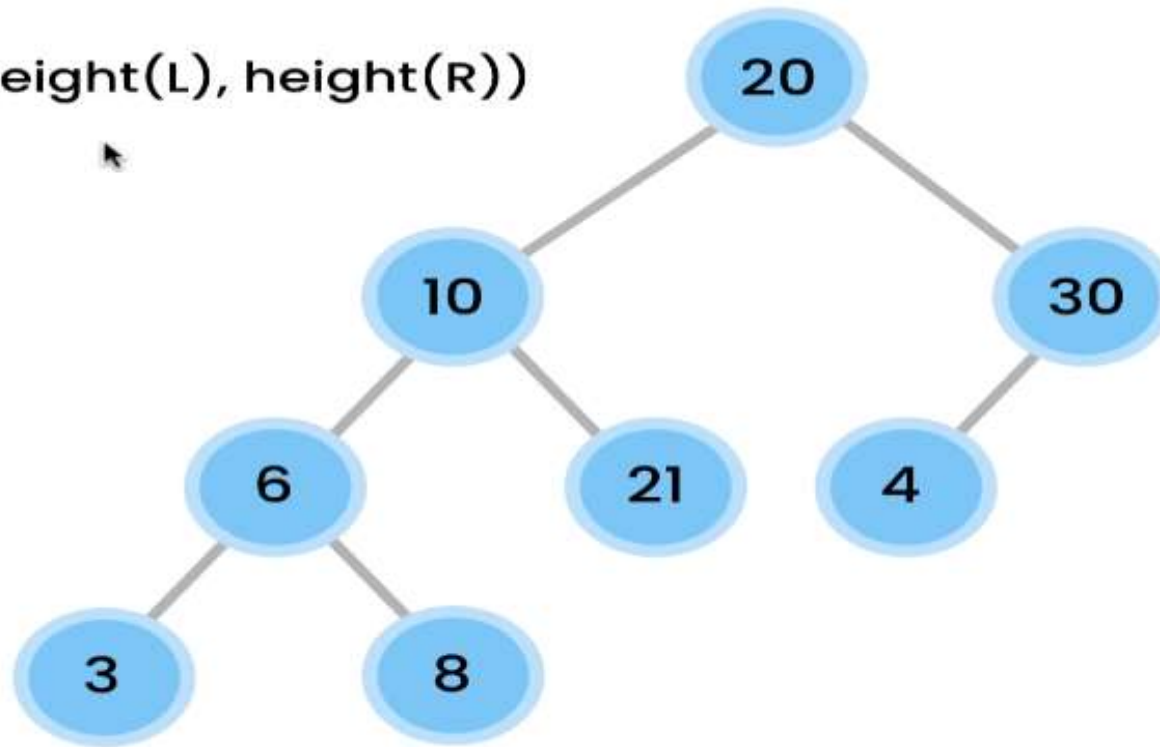


Height & Depth of BT.

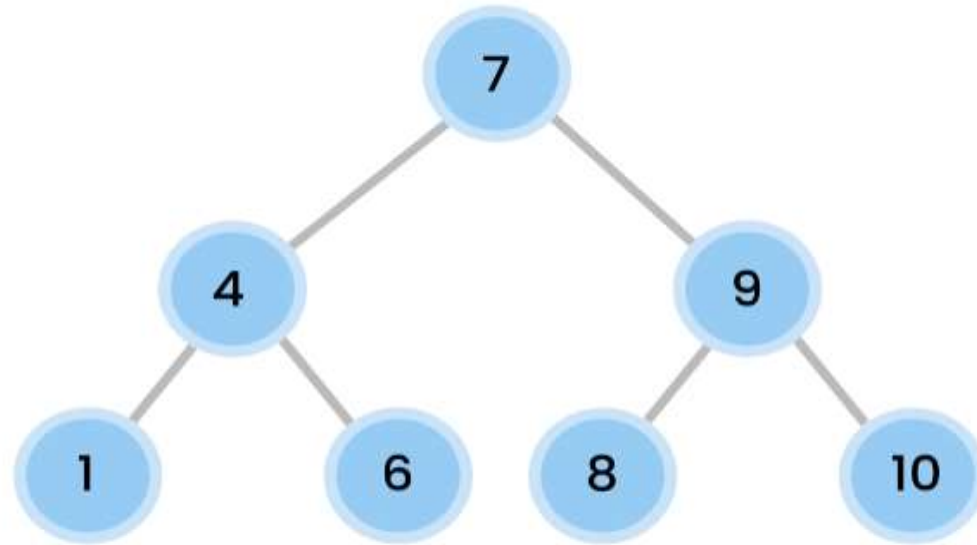


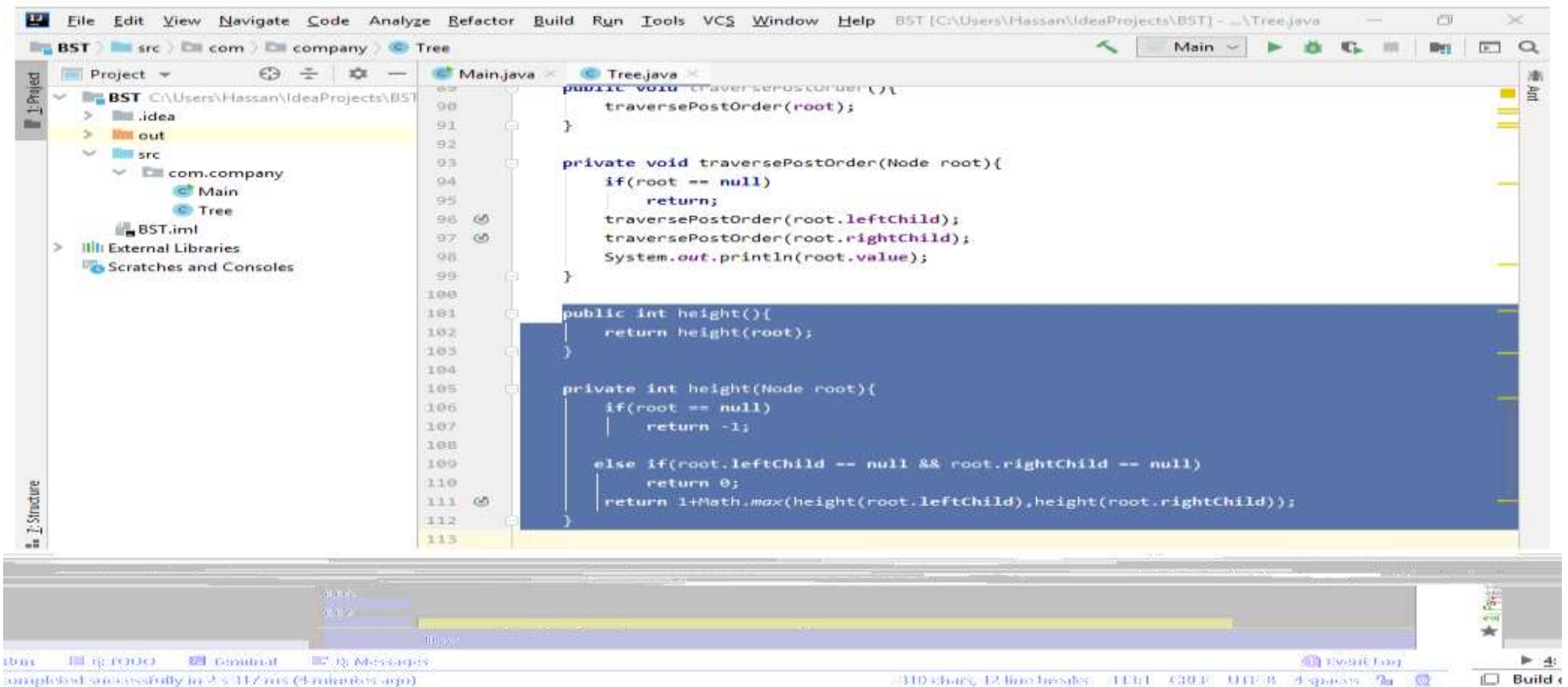
Height Formula (Recursive)

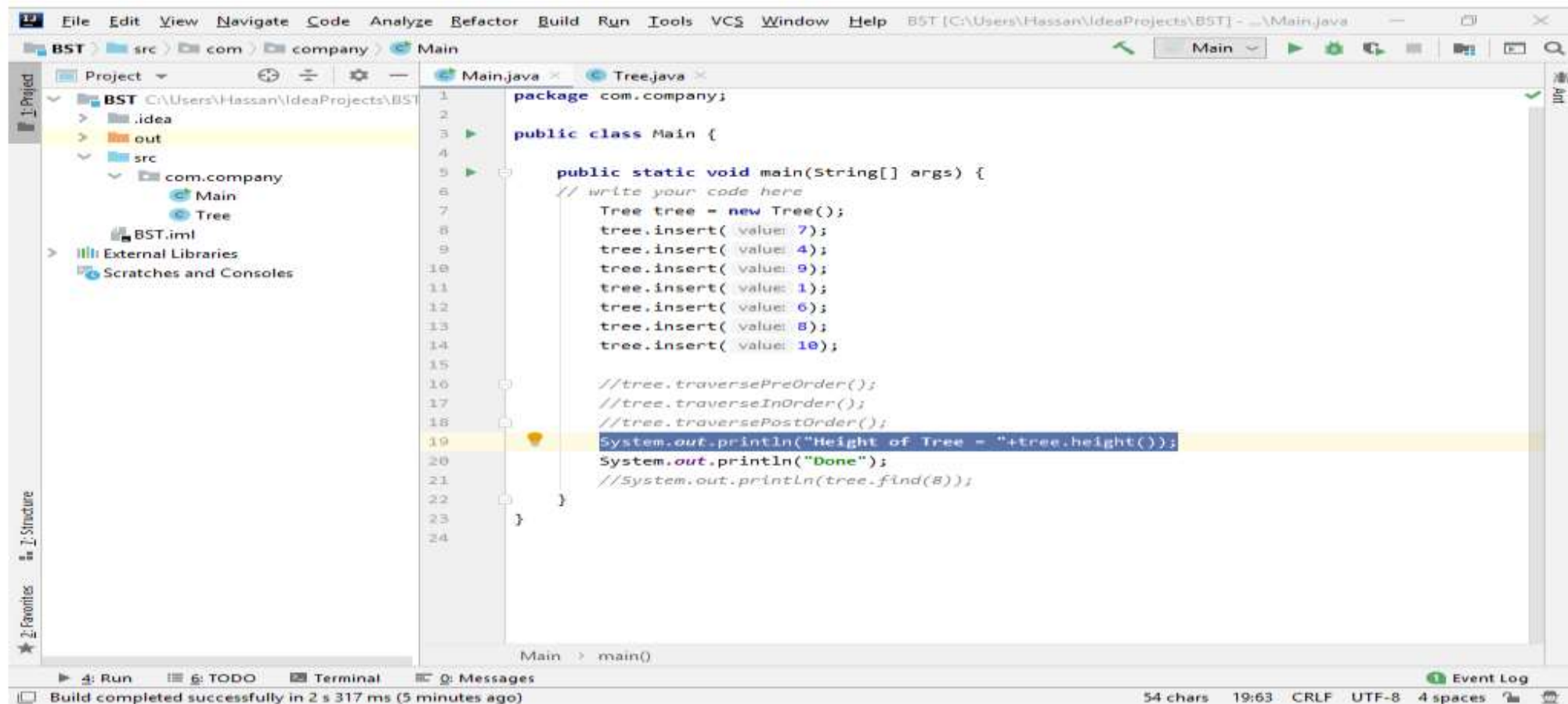
$1 + \max(\text{height}(L), \text{height}(R))$



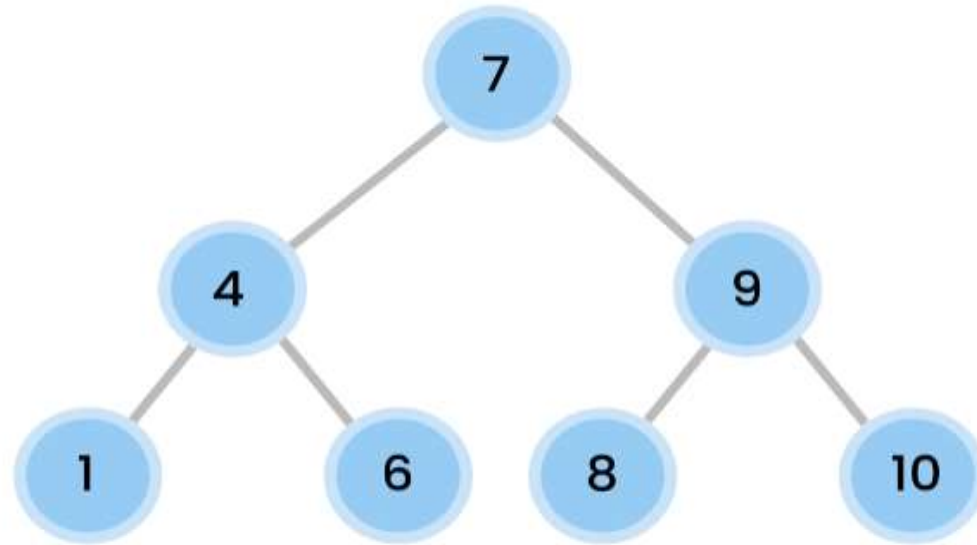
Implementation To Find Height Of BST

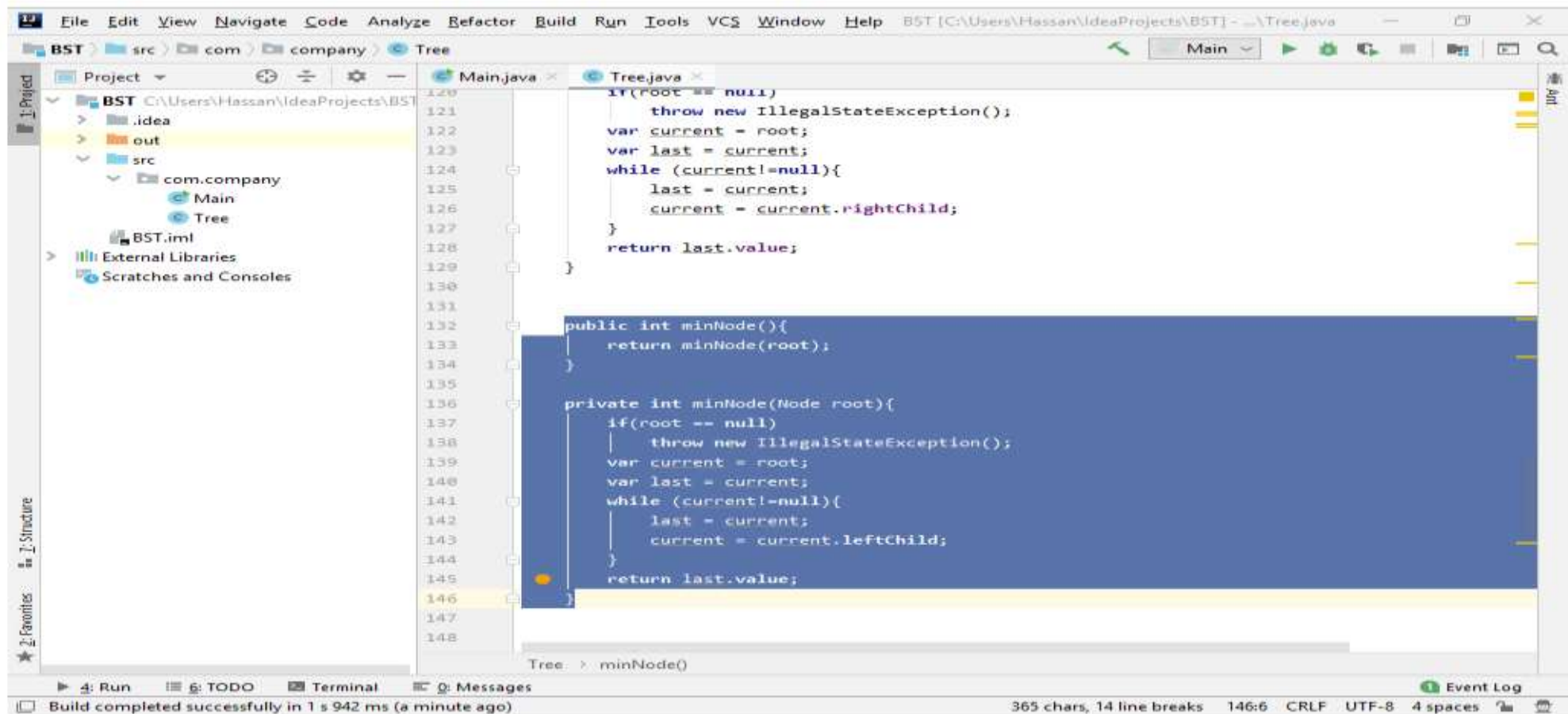




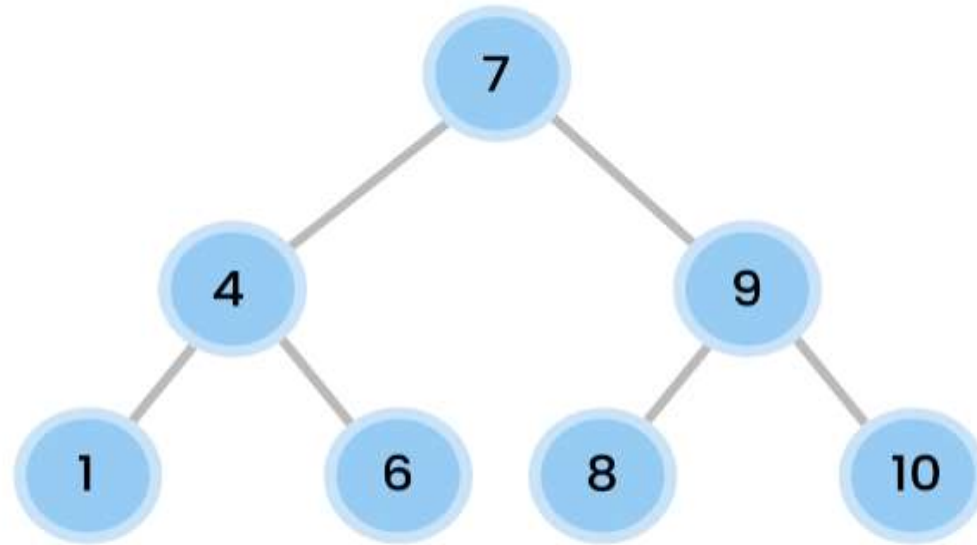


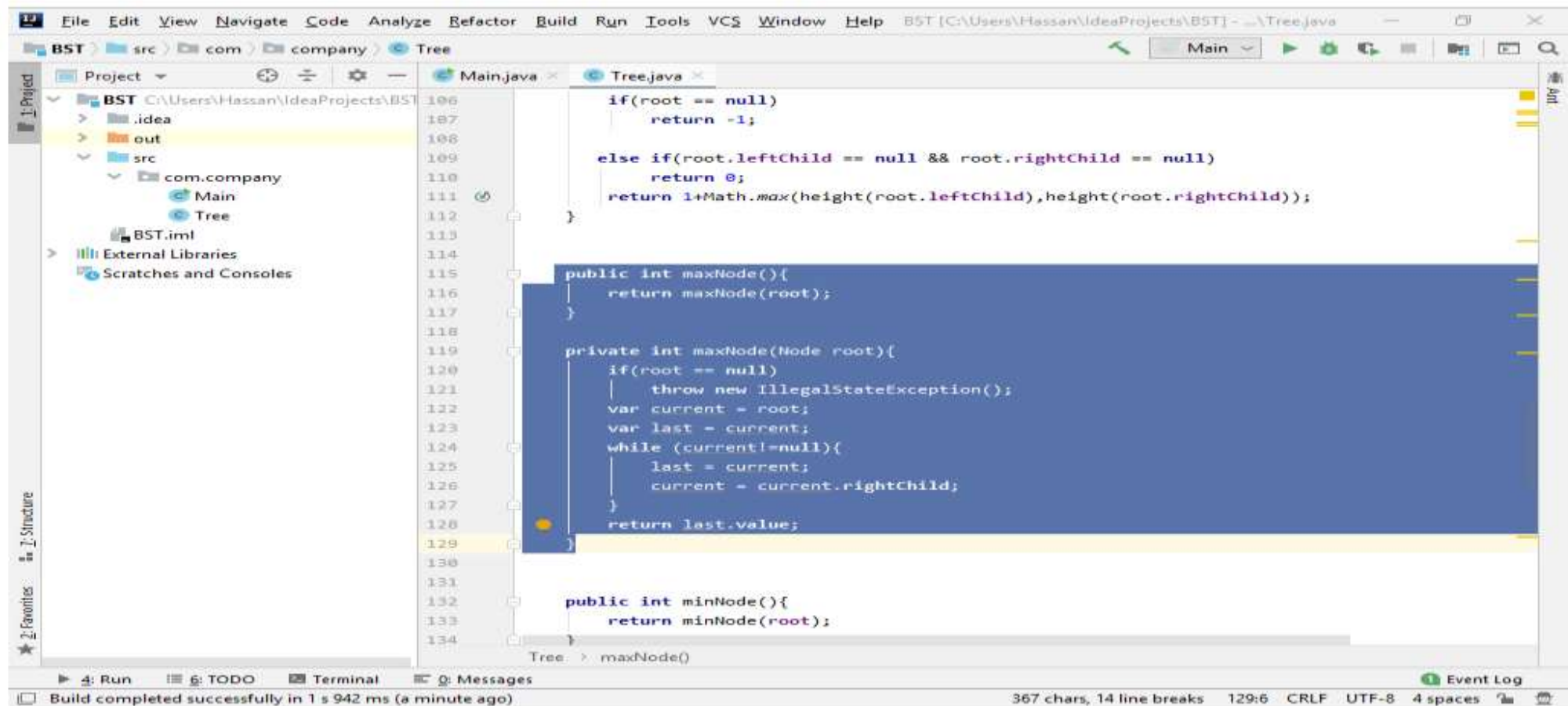
Implementation To Find Min Node Of BST



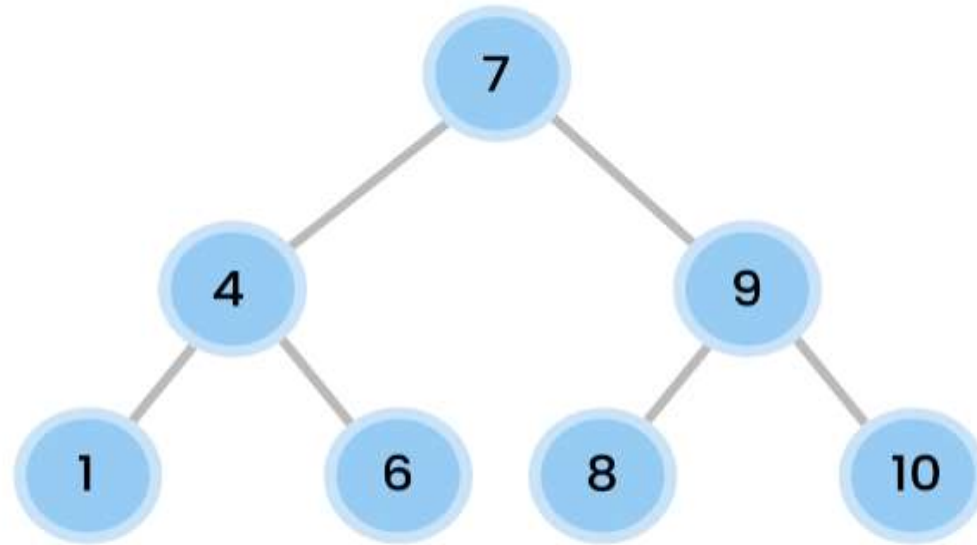


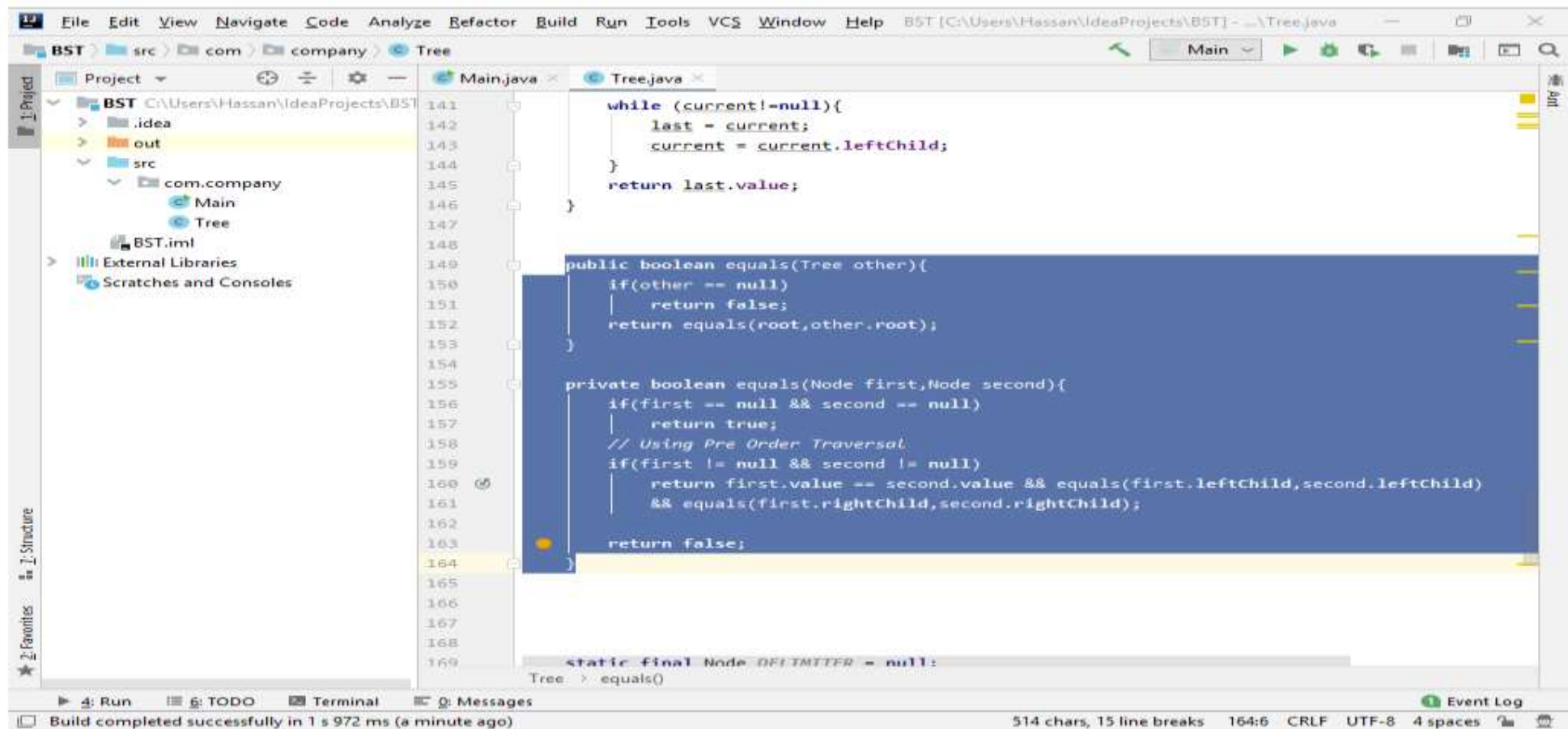
Implementation To Find Max Node Of BST

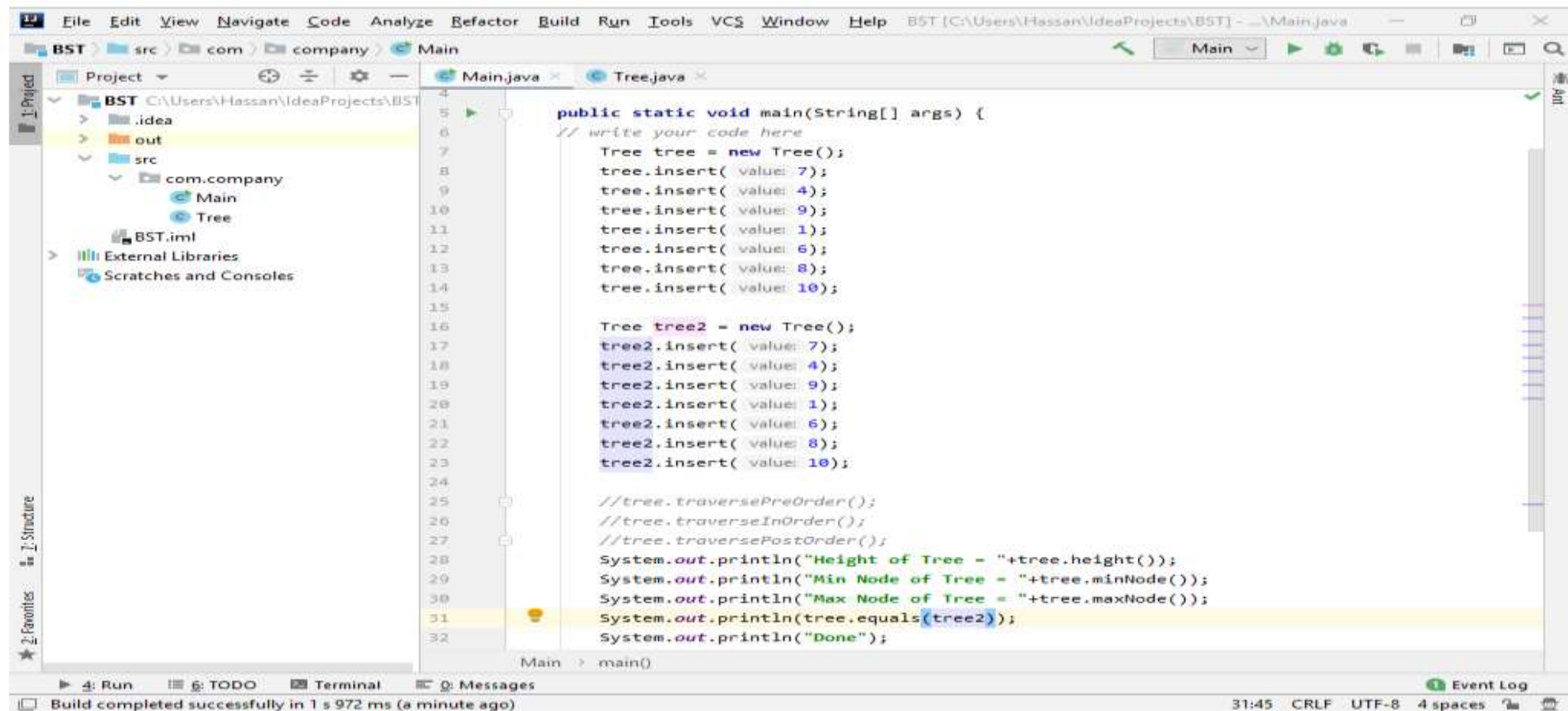




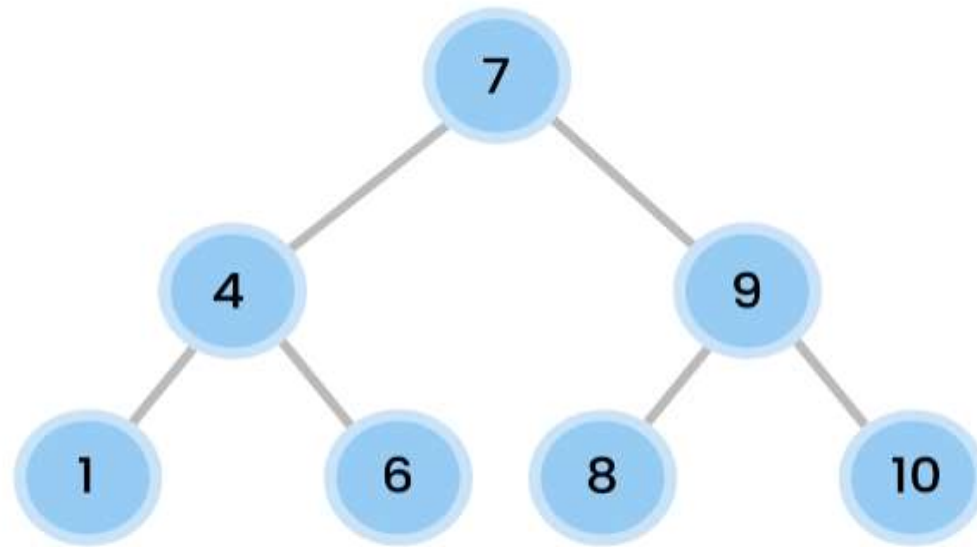
Implementation To Find Equality of BST



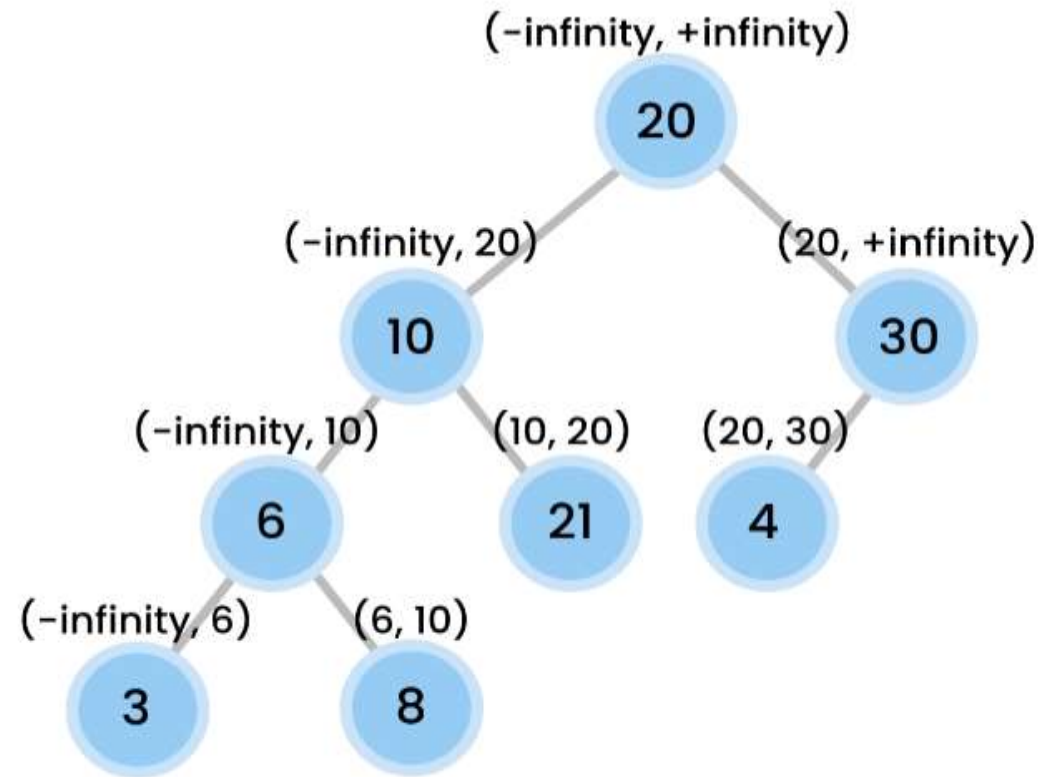


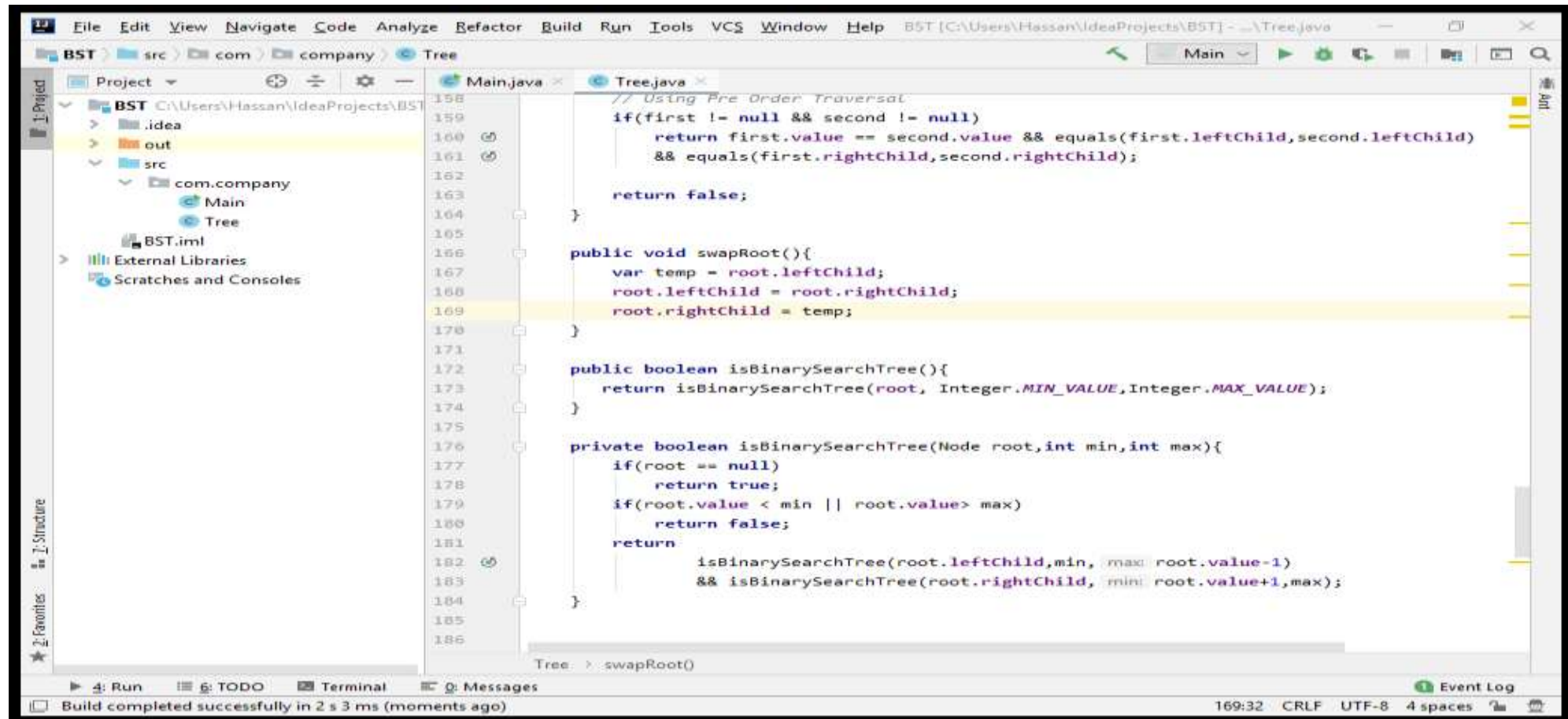


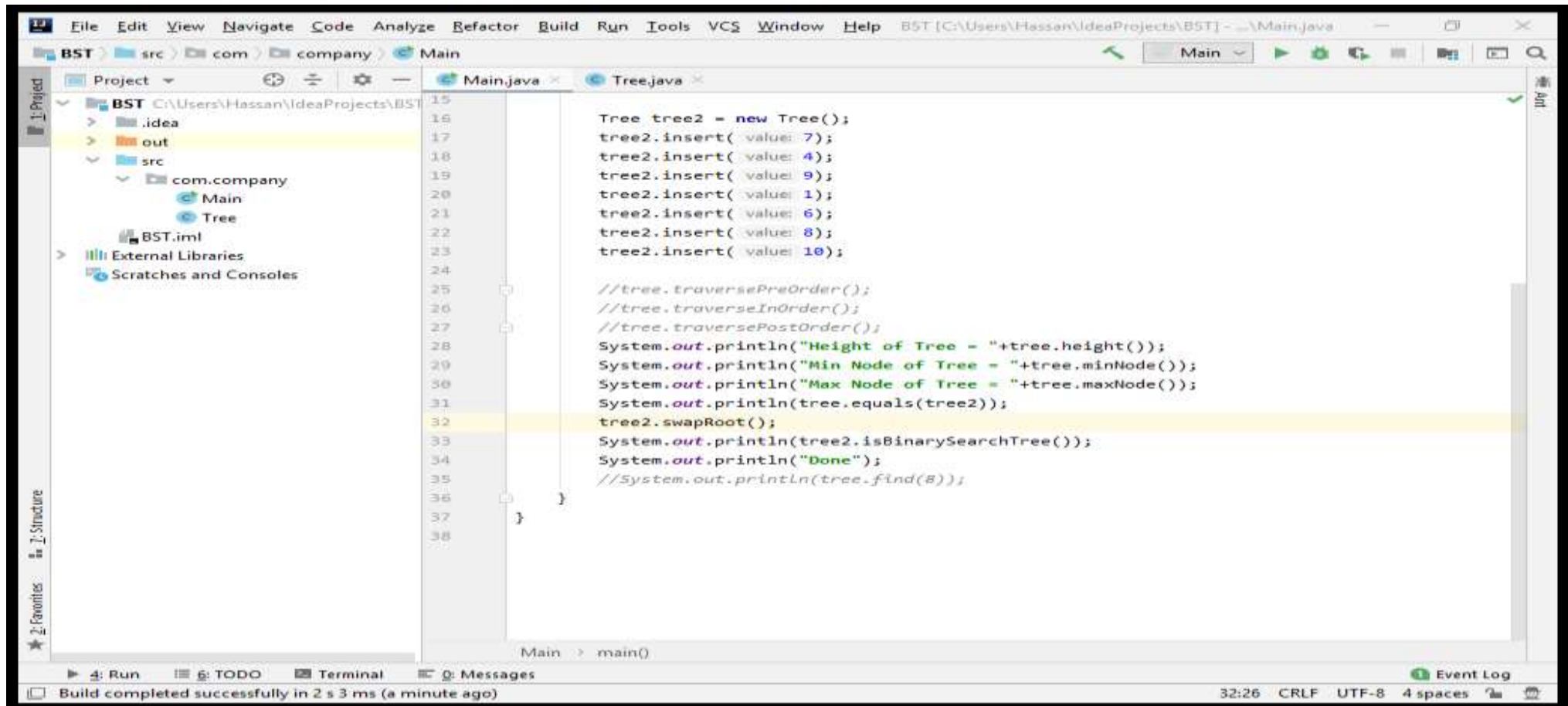
Validating BST



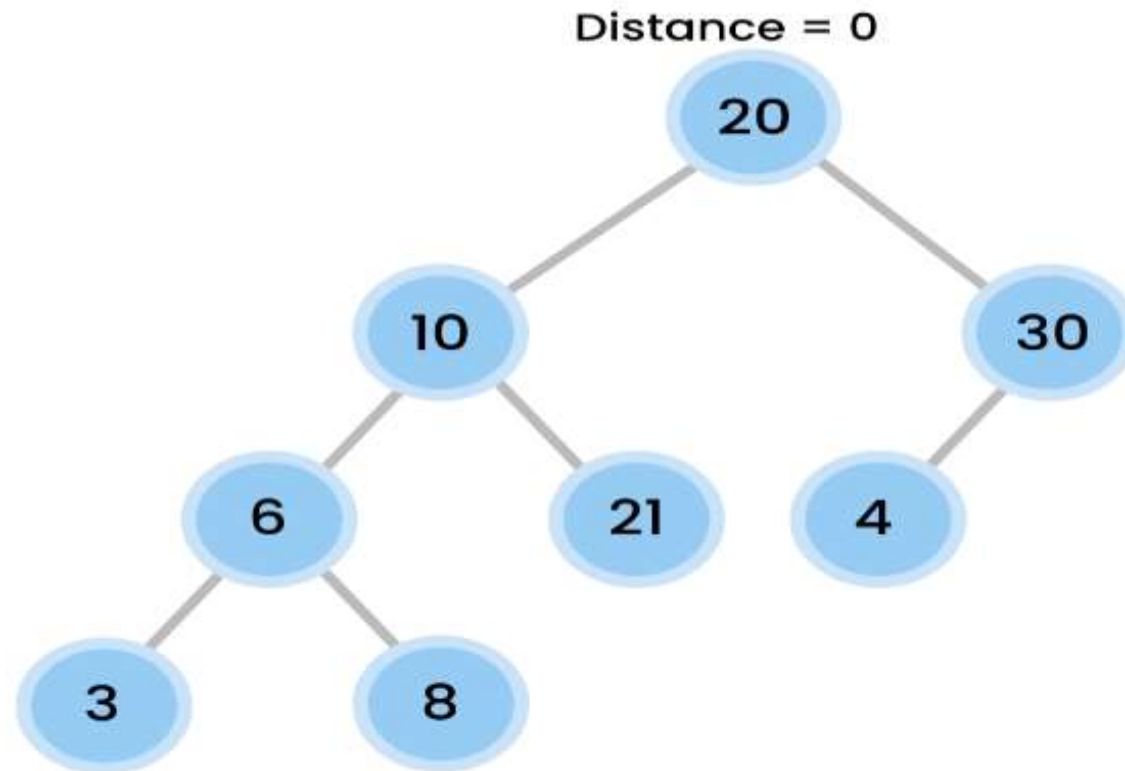
Validating By Checking Range of Nodes



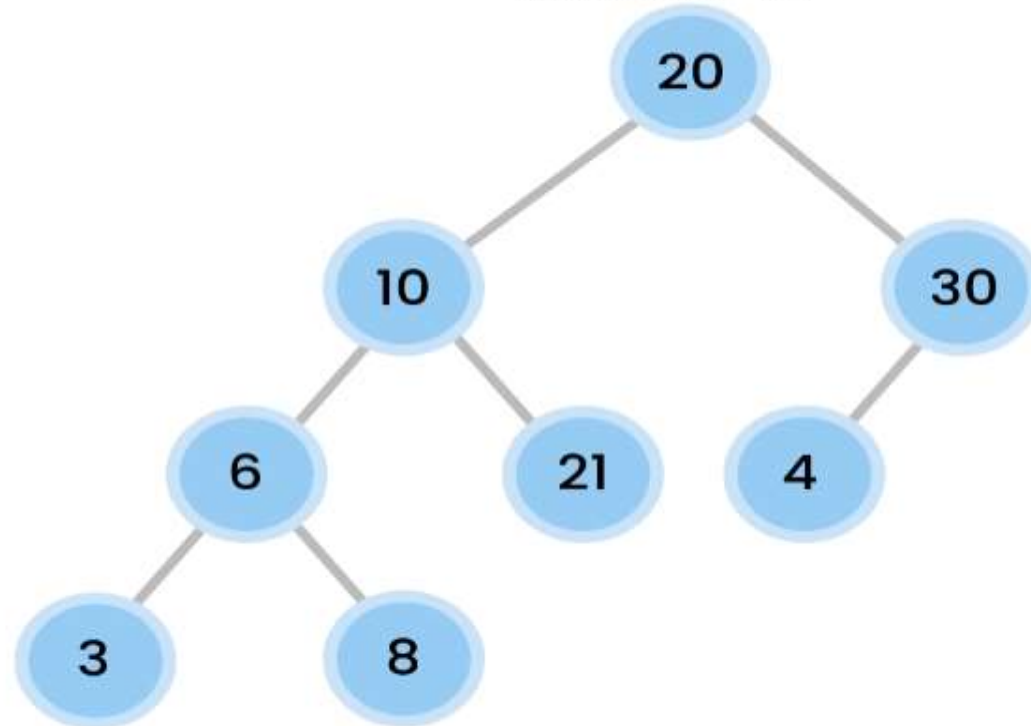


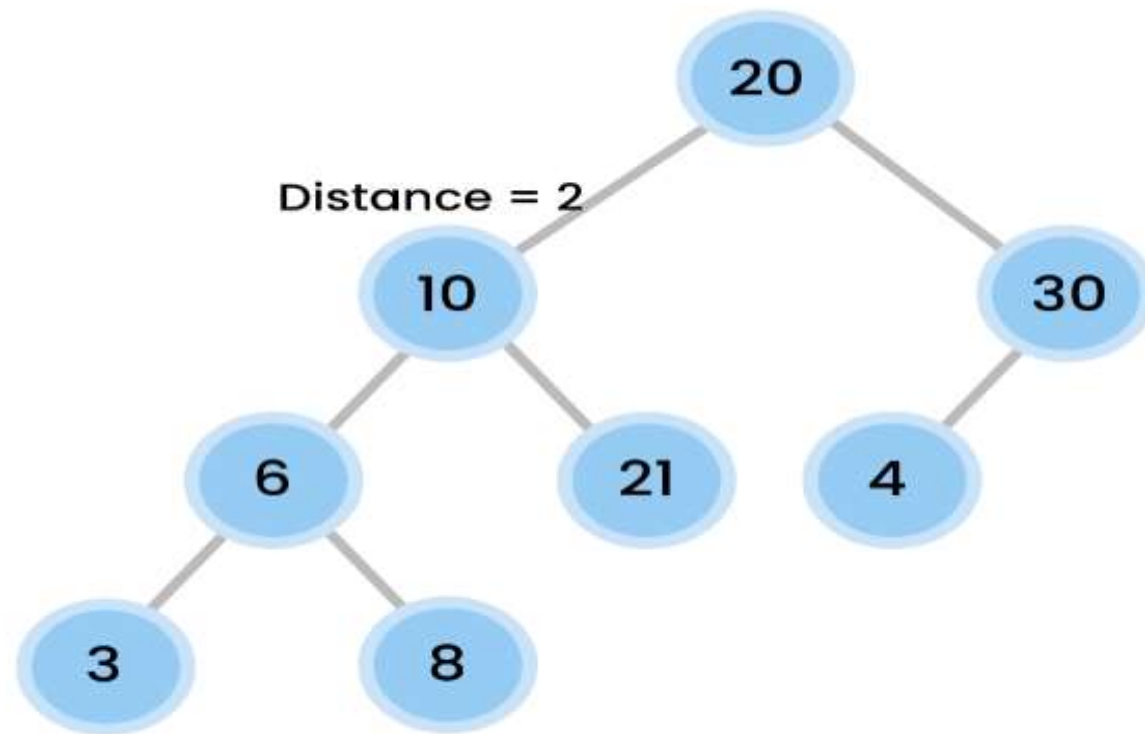


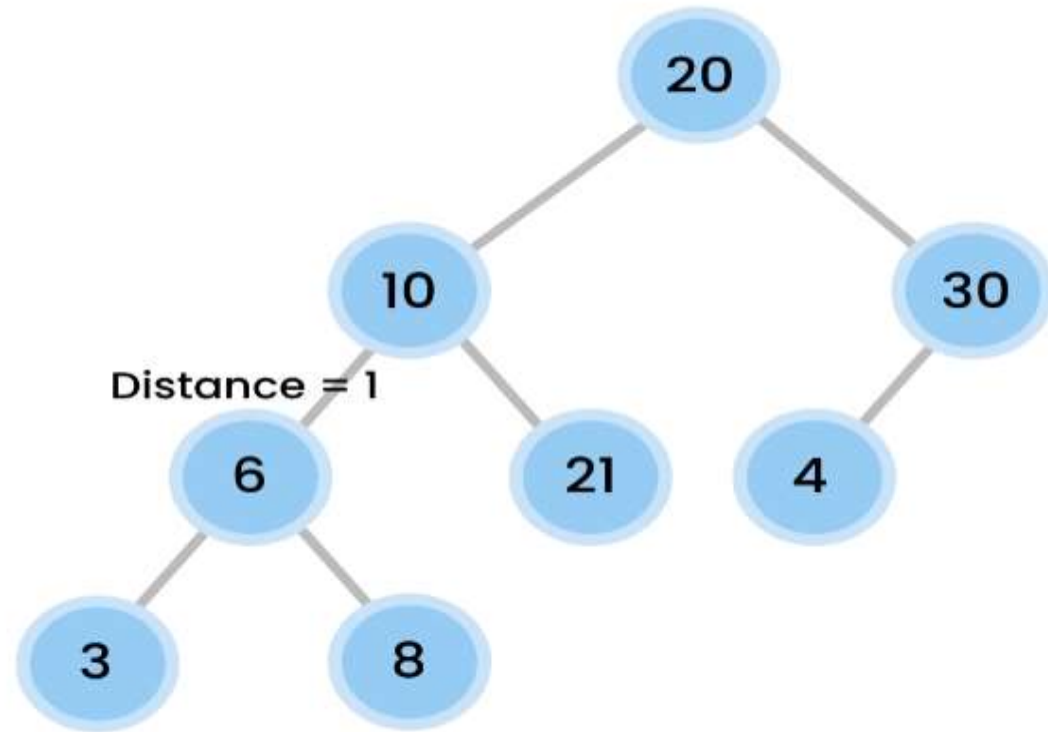
Nodes at K Distance from the Root Node

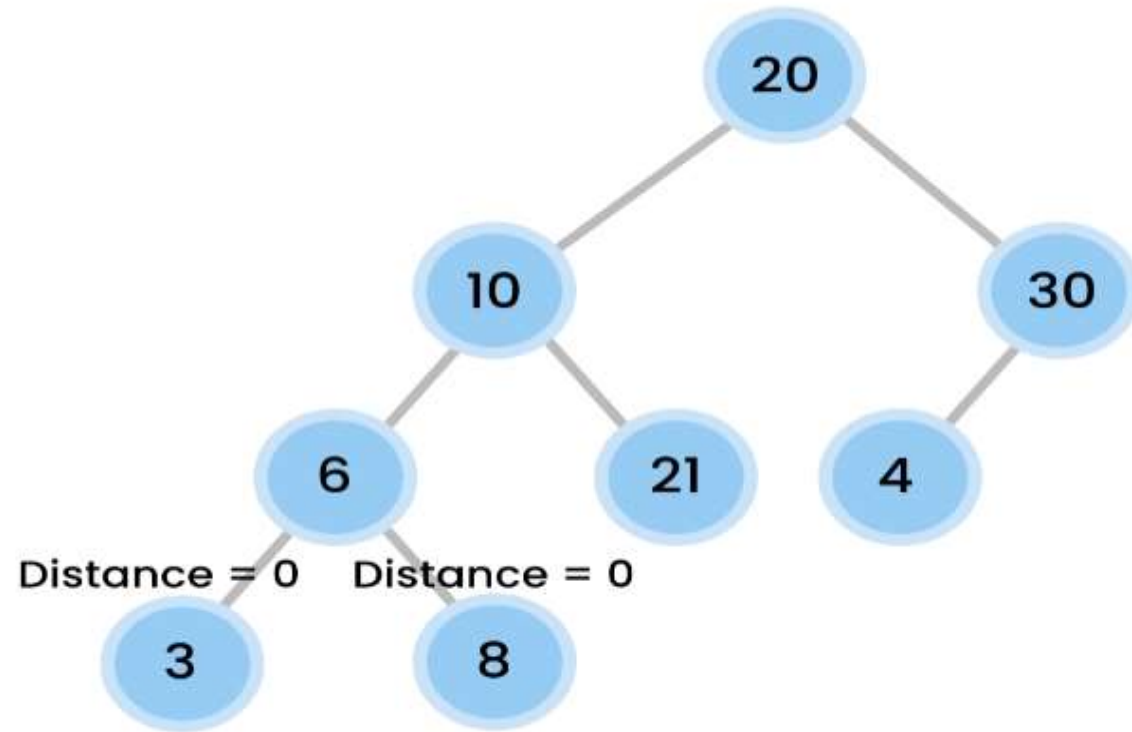


Distance = 3









Implementation To Find K Distance of Nodes In Following BST

