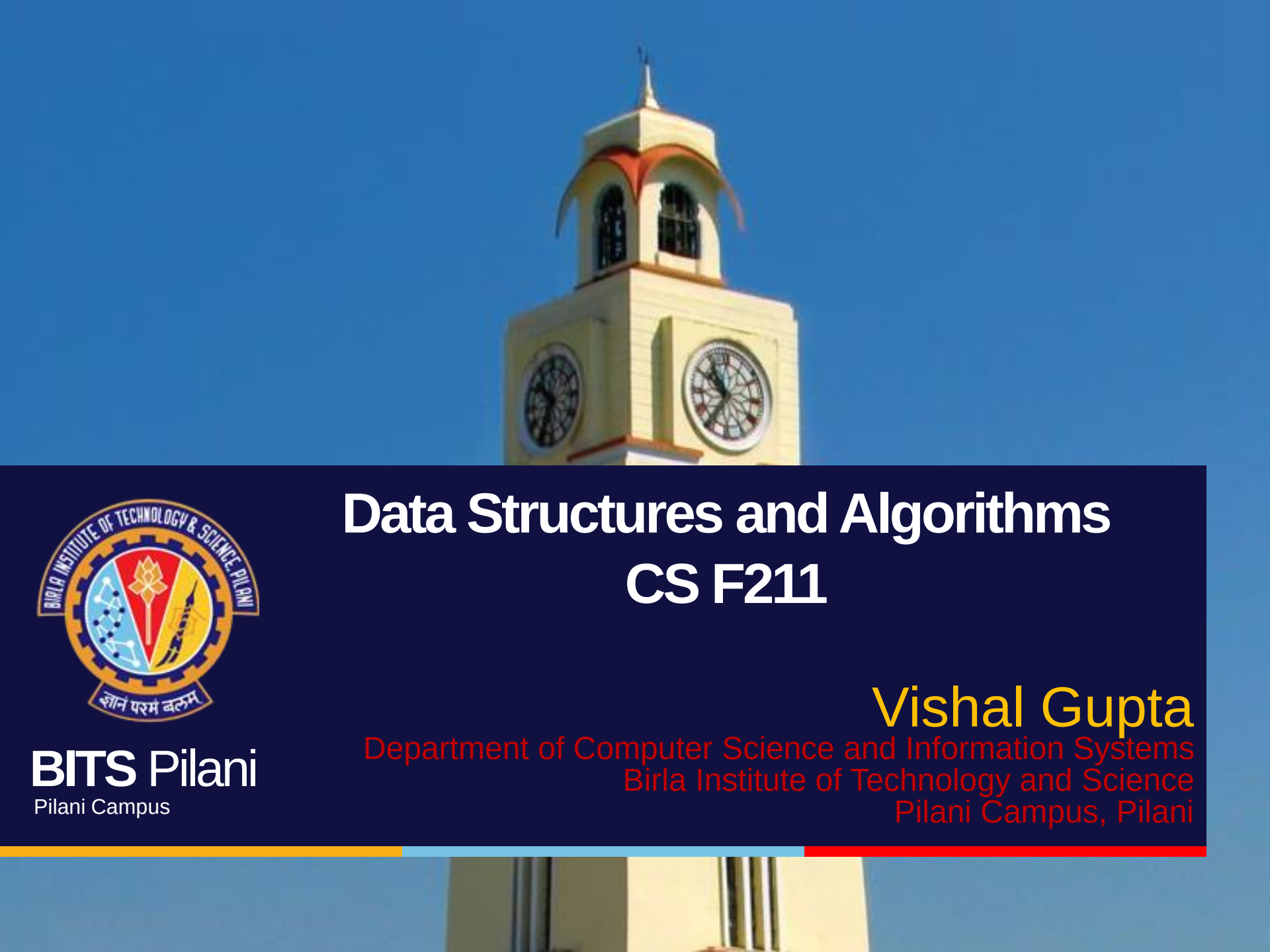

Data Structures and Algorithms
CS F211

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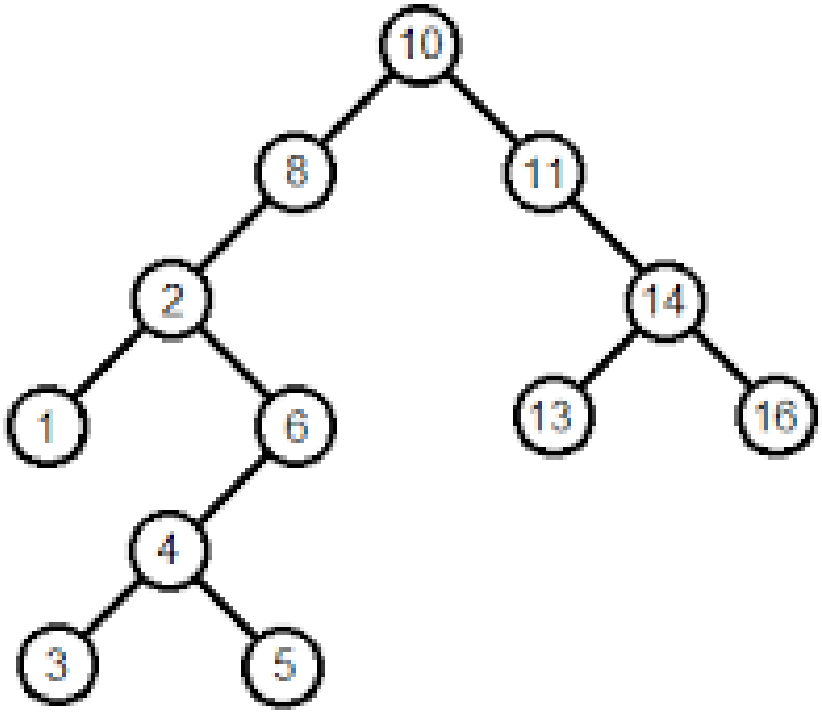
Binary Search trees

Pseudo code for INORDER

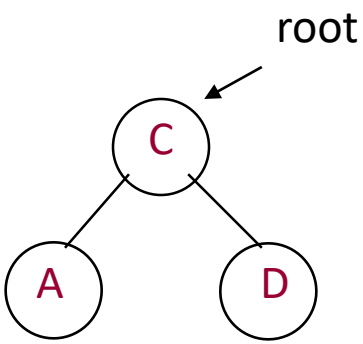


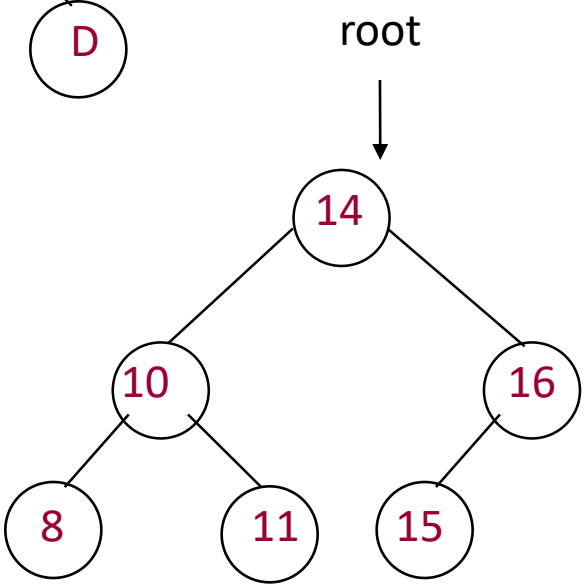
Binary Search Trees

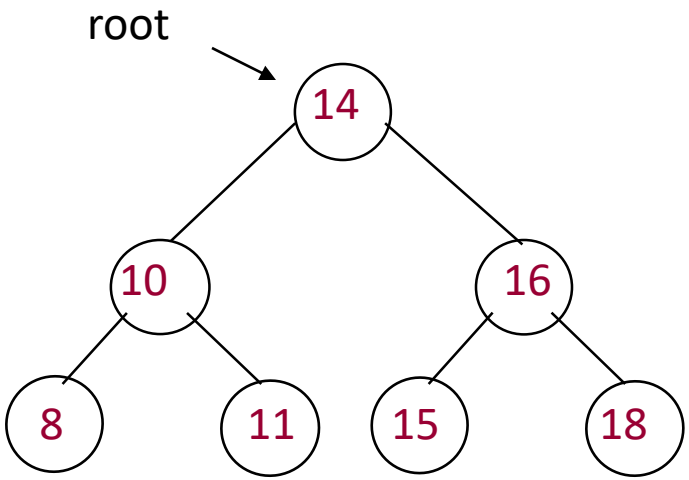
A **Binary Search Tree (BST)** is a binary tree with the following properties:

- The key of a node is *always greater* than the keys of the nodes in its left subtree
- The key of a node is *always smaller* than the keys of the nodes in its right subtree

Binary Search Trees: Examples





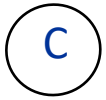


Building a BST

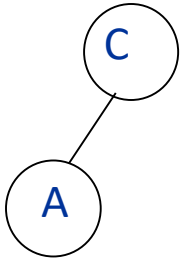
Build a BST from a sequence of nodes read one a time

Example: Inserting **C A B L M** **(in this order!)**

1) Insert C

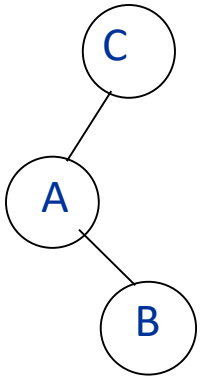


2) Insert A

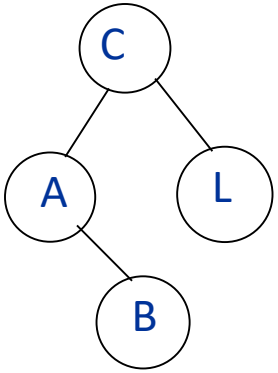


Building a BST

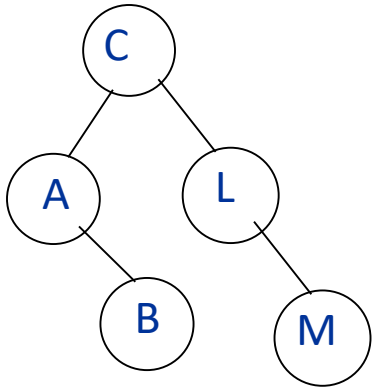
3) Insert B



4) Insert L



5) Insert M

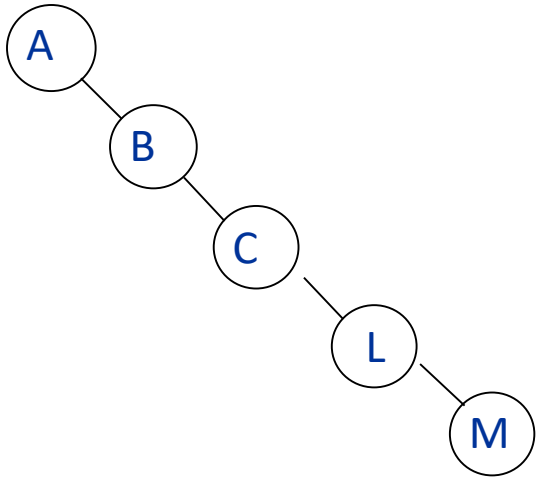


Building a BST

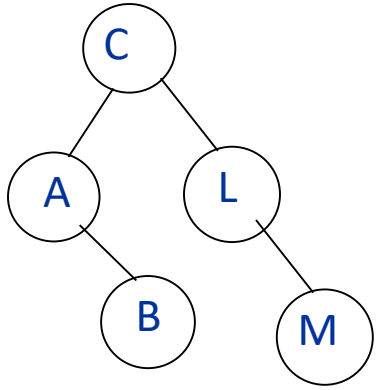
Is there a unique BST for letters A B C L M ?

NO! Different input sequences result in different trees

Inserting: A B C L M

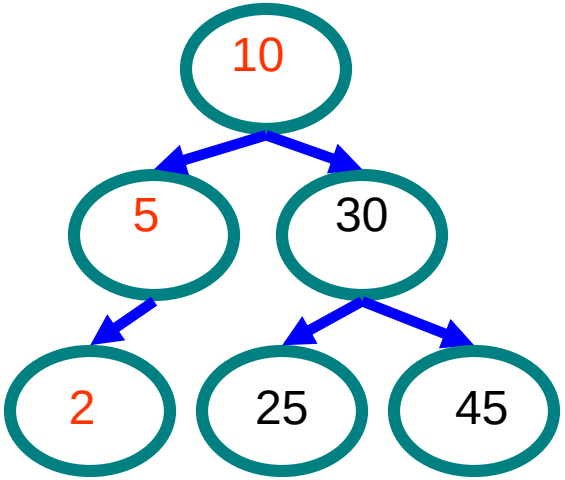


Inserting: C A B L M



Example Binary Searches

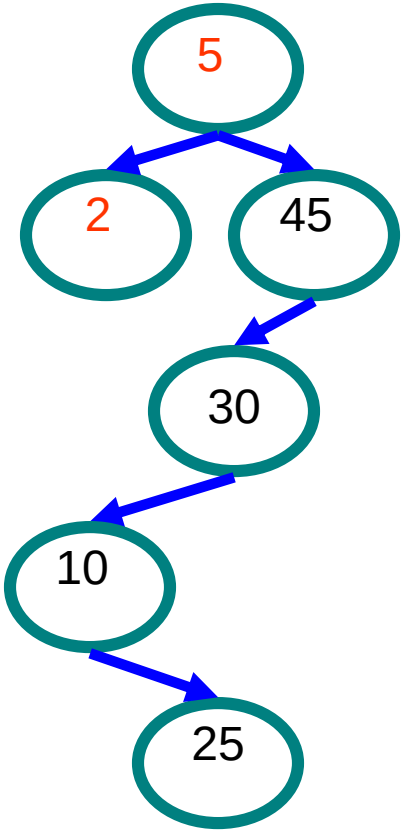
- **Find (2)**



10 > 2, left

5 > 2, left

2 = 2, found



5 > 2, left

2 = 2, found

Recursive Search of Binary Tree

```
Node Find( Node n, Value key) {
    if (n == null)                  // Not found
        return( n );
    else if (n.data == key)         // Found it
        return( n );
    else if (n.data > key)          // In left subtree
        return Find( n.left );
    else                            // In right subtree
        return Find( n.right );
}
```

Complexity of Search

- Running time of searching in a BST is proportional to the height of the tree.

If n is the number of nodes in a BST, then

- **Best Case** – O(logn)
- **Worst Case** – O(n)

Binary Search Tree - Insertion

Insert Algorithm

- If value we want to insert < key of current node, we have to go to the left subtree
- Otherwise we have to go to the right subtree
- If the current node is empty (not existing) create a node with the value we are inserting and place it here.

Insertion - Example

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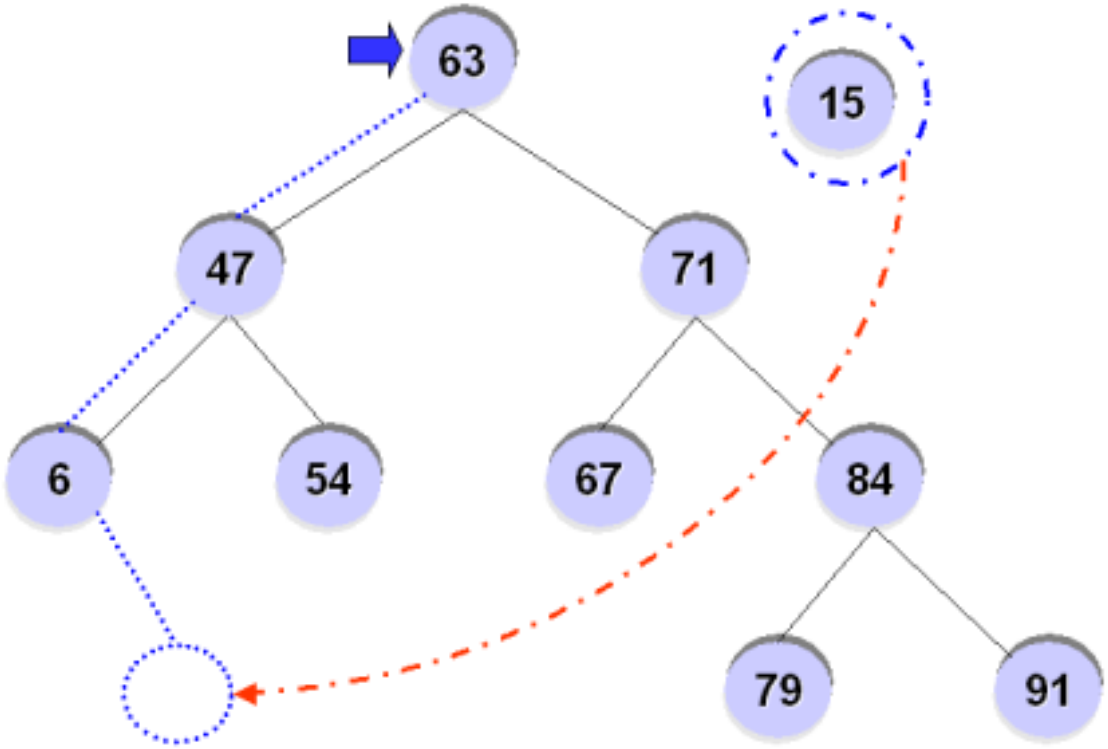
For example, inserting ’15’ into the BST?



Binary Search Tree - Deletion

There are 3 possible cases

Case1 : Node to be deleted has no children

→ **We just delete the node.**

Case2 : Node to be deleted has only one child

→ **Replace the node with its child and make the parent of the deleted node to be a parent of the child of the deleted node**

Case3 : Node to be deleted has two children

Binary Search Tree - Deletion

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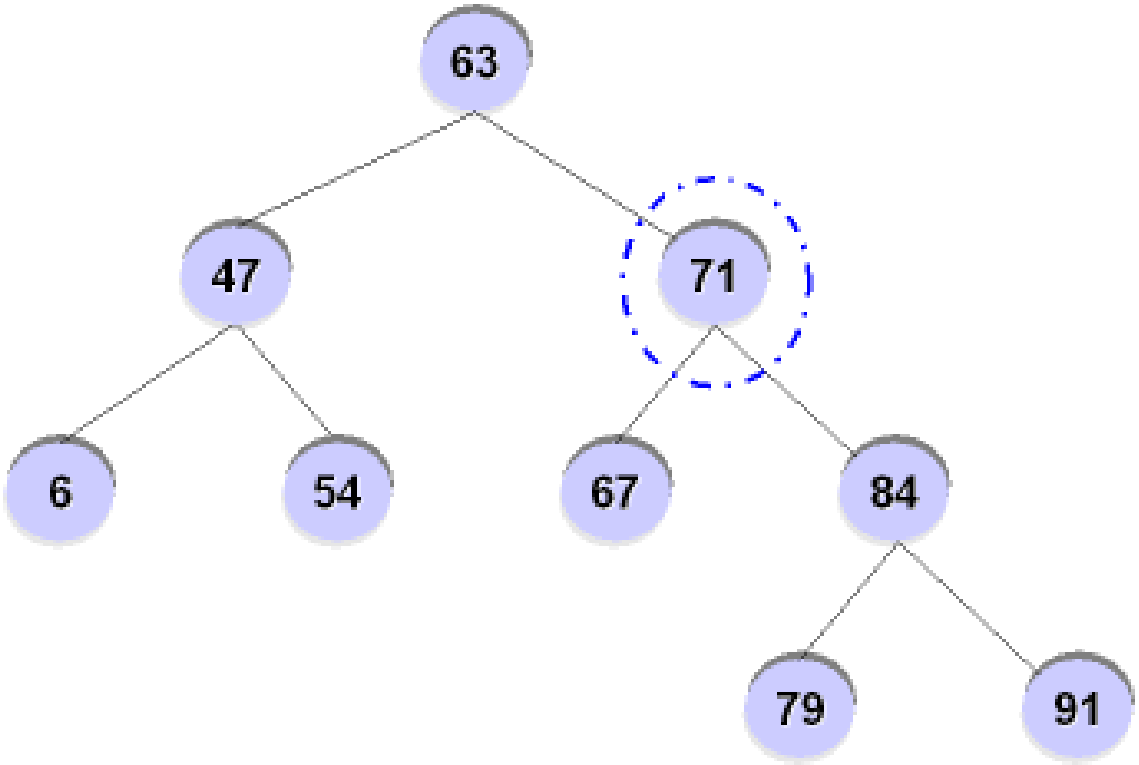
Node to be deleted has two children



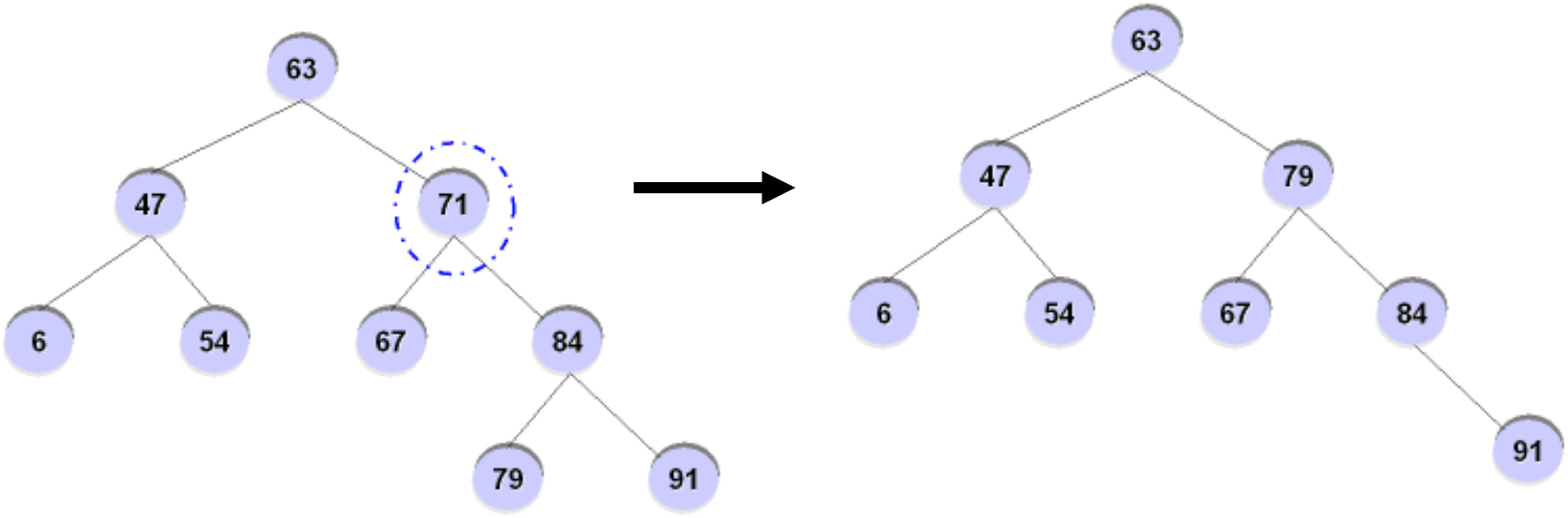
Binary Search Tree - Deletion

Node to be deleted has two children

Steps:

- Find minimum value of right subtree
- Delete minimum node of right subtree but keep its value
- Replace the value of the node to be deleted by the minimum value whose node was deleted earlier.

Binary Search Tree - Deletion



Convert the following into a pseudo code.


```
Node deleteNode(Node root, int valueToDelete) {
  if root = null
    return node
  if root.value < valueToDelete
    deleteNode(root.right, valueToDelete)
  if root.value > valueToDelete
    deleteNode(root.left, valueToDelete)
  else
    if (isLeafNode(root))
      return null

    if (root.right == null)
      return root.left
    if (root.left == null)
      return root.right

    else
      minValue = findMinInRightSubtree(root)
      root.value = minValue
      removeDuplicateNode(root)
      return root
```