Insertion in an AVL Tree

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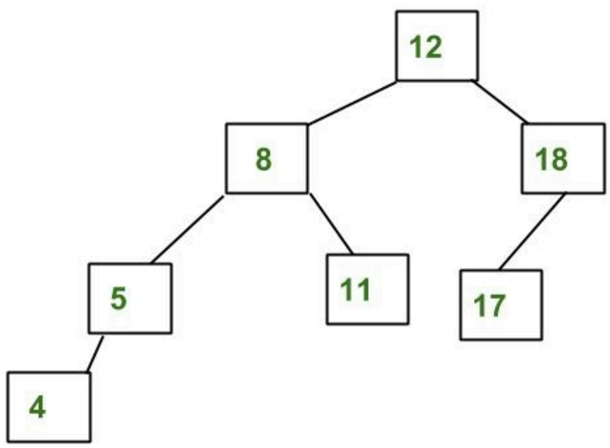
AVL tree is a self-balancing Binary Search Tree (**BST**) where the difference between heights of left and right subtrees cannot be more than **one** for all nodes.

Example of AVL Tree:



The above tree is AVL because the differences between the heights of left and right subtrees for every node are less than or equal to 1.

Example of a Tree that is NOT an AVL Tree:

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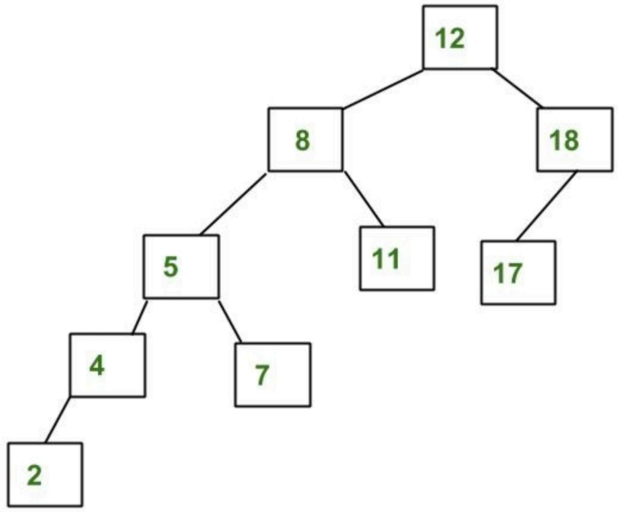
Got It !



The above tree is not AVL because the differences between the heights of the left and right subtrees for 8 and 12 are greater than 1.

Why AVL Trees? Most of the BST operations (e.g., search, max, min, insert, delete, floor and ceiling) take **O(h)** time where **h** is the height of the BST. The cost of these operations may become **O(n)** for a **skewed Binary tree**. If we make sure that the height of the tree remains **O(log(n))** after every insertion and deletion, then we can guarantee an upper bound of **O(log(n))** for all these operations. The height of an AVL tree is always **O(log(n))** where **n** is the number of nodes in the tree.

Insertion in AVL Tree:

To make sure that the given tree remains AVL after every insertion, we must augment the standard BST insert operation to perform some re-balancing. Following are two basic operations that can be performed to balance a BST without violating the BST property (keys(left) < key(root) < keys(right)).

- Left Rotation
- Right Rotation

```
T1, T2 and T3 are subtrees of the tree, rooted with y (on the left
side) or x (on the right side)
```

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```
     / \     Right Rotation          /  \
    x   T3   - - - - - - - >        T1   y
   / \       < - - - - - - -            / \
  T1  T2     Left Rotation            T2  T3
```

```
Keys in both of the above trees follow the following order
keys(T1) < key(x) < keys(T2) < key(y) < keys(T3)
So BST property is not violated anywhere.
```

Steps to follow for insertion:

Let the newly inserted node be **w**

- Perform standard **BST** insert for **w**.
- Starting from **w**, travel up and find the first **unbalanced node**. Let **z** be the first unbalanced node, **y** be the **child** of **z** that comes on the path from **w** to **z** and **x** be the **grandchild** of **z** that comes on the path from **w** to **z**.
- Re-balance the tree by performing appropriate rotations on the subtree rooted with **z.** There can be 4 possible cases that need to be handled as **x, y** and **z** can be arranged in 4 ways.
- Following are the possible 4 arrangements:
    - y is the left child of z and x is the left child of y (Left Left Case)
    - y is the left child of z and x is the right child of y (Left Right Case)
    - y is the right child of z and x is the right child of y (Right Right Case)
    - y is the right child of z and x is the left child of y (Right Left Case)

*Following are the operations to be performed in above mentioned 4 cases. In all of the cases, we only need to **re-balance** the subtree rooted with **z** and the complete tree becomes balanced as the height of the subtree (After appropriate rotations) rooted with **z** becomes the same as it was before insertion.*

1. Left Left Case

```
T1, T2, T3 and T4 are subtrees.
```

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```
         y   T4      Right Rotate (z)          x      z
        / \          - - - - - - - - ->       /  \    /  \
       x   T3                               T1  T2  T3  T4
      / \
    T1   T2
```

2. Left Right Case

```
       z                               z                           x
      / \                            /   \                        /
\
     y   T4  Left Rotate (y)        x    T4  Right Rotate(z)    y
z
    / \      - - - - - - - - ->    /  \      - - - - - - - ->  / \
/ \
T1   x                            y    T3                    T1  T2
T3  T4
    / \                          / \
  T2   T3                      T1   T2
```

3. Right Right Case

```
   z                                y
 /  \                             /   \
T1   y     Left Rotate(z)       z      x
    /  \   - - - - - - - ->    / \    / \
   T2   x                     T1  T2 T3  T4
       / \
     T3  T4
```

4. Right Left Case

```
   z                            z                            x
  / \                          / \                          /  \
T1   y   Right Rotate (y)    T1   x      Left Rotate(z)   z      y
    / \  - - - - - - - - ->     /  \   - - - - - - - ->  / \    /
\
   x   T4                      T2   y                  T1  T2  T3
```

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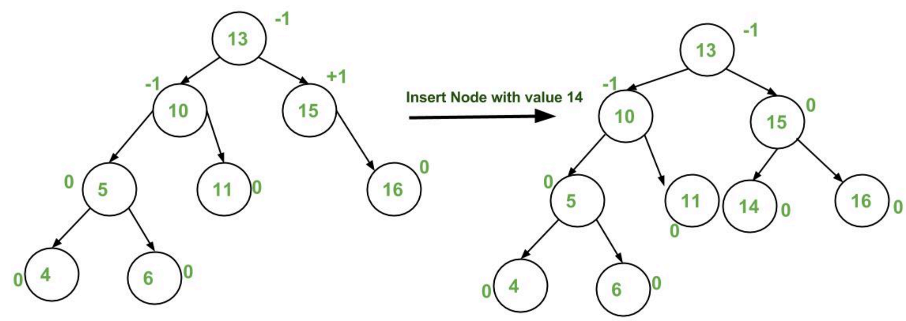
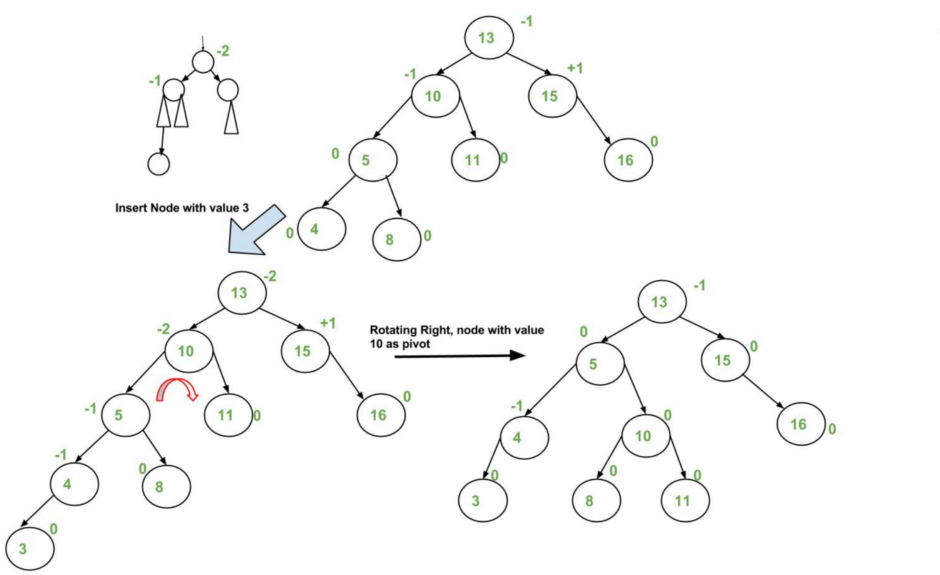
```
         / \                                      /   \
       T2   T3                                  T3    T4
```

Illustration of Insertion at AVL Tree





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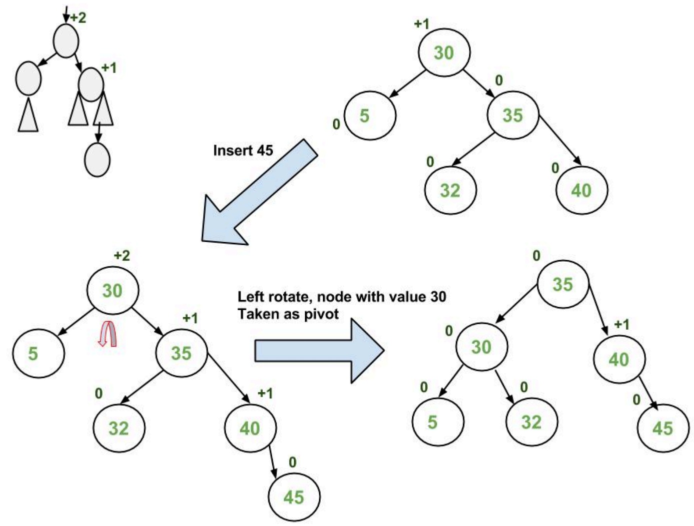

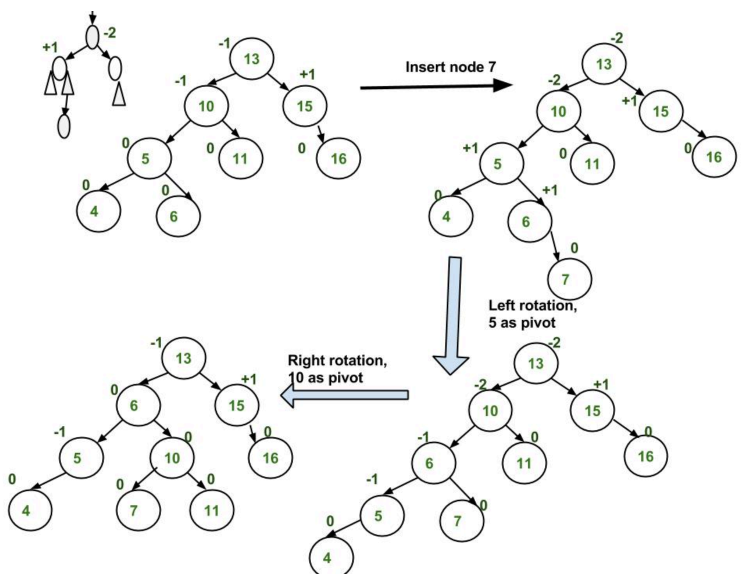

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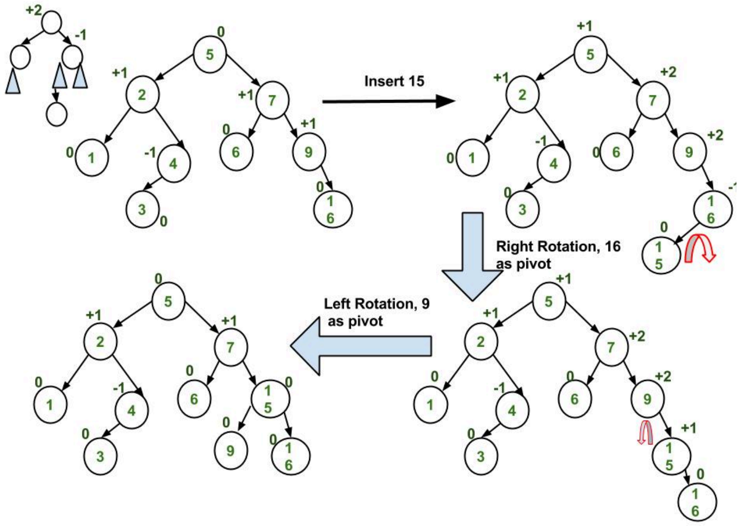

Approach: The idea is to use recursive BST insert, after insertion, we get pointers to all ancestors one by one in a bottom-up manner. So we don't need a parent pointer to travel up. The recursive code itself travels up and visits all the ancestors of the newly inserted node.

Follow the steps mentioned below to implement the idea:

- Perform the normal [BST insertion.](https://www.geeksforgeeks.org/binary-search-tree-set-1-search-and-insertion/)
- The current node must be one of the ancestors of the newly inserted node. Update the **height** of the current node.
- Get the balance factor **(left subtree height – right subtree height)** of the current node.
- If the balance factor is greater than **1,** then the current node is unbalanced and we are either in the **Left Left case** or **left Right case**. To check whether it is **left left case** or not, compare the newly inserted key with the key in the **left subtree root**.
- If the balance factor is less than **-1**, then the current node is unbalanced and we are either in the Right Right case or Right-Left case. To check whether it is the Right Right case or not, compare the newly inserted key with the key

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Below is the implementation of the above approach:

C++14 C Java Python C# JavaScript

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```
// An AVL tree node
struct Node {
    int key;
    Node *left;
    Node *right;
    int height;

    Node(int k) {
        key = k;
        left = nullptr;
        right = nullptr;
        height = 1;
    }
};

// A utility function to
// get the height of the tree
int height(Node *N) {
    if (N == nullptr)
        return 0;
    return N->height;
}

// A utility function to right
// rotate subtree rooted with y
Node *rightRotate(Node *y) {
    Node *x = y->left;
    Node *T2 = x->right;

    // Perform rotation
    x->right = y;
    y->left = T2;

    // Update heights
    y->height = 1 + max(height(y->left),
                    height(y->right));
    x->height = 1 + max(height(x->left),
                        height(x->right));

    // Return new root
    return x;
}

// A utility function to left rotate
// subtree rooted with x
Node *leftRotate(Node *x) {
    Node *y = x->right;
    Node *T2 = y->left;

    // Perform rotation
    y->left = x;
    x->right = T2;

    // Update heights
    x->height = 1 + max(height(x->left),
```

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```
    // Return new root
    return y;
}

// Get balance factor of node N
int getBalance(Node *N) {
    if (N == nullptr)
        return 0;
    return height(N->left) - height(N->right);
}

// Recursive function to insert a key in
// the subtree rooted with node
Node* insert(Node* node, int key) {

    // Perform the normal BST insertion
    if (node == nullptr)
        return new Node(key);

    if (key < node->key)
        node->left = insert(node->left, key);
    else if (key > node->key)
        node->right = insert(node->right, key);
    else // Equal keys are not allowed in BST
        return node;

    // Update height of this ancestor node
    node->height = 1 + max(height(node->left),
                           height(node->right));

    // Get the balance factor of this ancestor node
    int balance = getBalance(node);

    // If this node becomes unbalanced,
    // then there are 4 cases

    // Left Left Case
    if (balance > 1 && key < node->left->key)
        return rightRotate(node);

    // Right Right Case
    if (balance < -1 && key > node->right->key)
        return leftRotate(node);

    // Left Right Case
    if (balance > 1 && key > node->left->key) {
        node->left = leftRotate(node->left);
        return rightRotate(node);
    }

    // Right Left Case
    if (balance < -1 && key < node->right->key) {
        node->right = rightRotate(node->right);
        return leftRotate(node);
    }
```

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```
}

// A utility function to print
// preorder traversal of the tree
void preOrder(Node *root) {
    if (root != nullptr) {
        cout << root->key << " ";
        preOrder(root->left);
        preOrder(root->right);
    }
}

// Driver Code
int main() {
    Node *root = nullptr;

    // Constructing tree given in the above figure
    root = insert(root, 10);
    root = insert(root, 20);
    root = insert(root, 30);
    root = insert(root, 40);
    root = insert(root, 50);
    root = insert(root, 25);

    /* The constructed AVL Tree would be
              30
             /  \
           20    40
          /  \     \
        10   25    50
    */
    cout << "Preorder traversal : \n";
    preOrder(root);

    return 0;
}
```

Output

```
Preorder traversal :
30 20 10 25 40 50
```

Time Complexity: O(log(n)), For Insertion

Auxiliary Space: O(Log n) for recursion call stack as we have written a recursive method to insert

> *The rotation operations (left and right rotate) take constant time as only a few pointers are being changed there. Updating the height and getting the balance factor also takes constant time. So the time complexity of the*

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Comparison with Red Black Tree:

The AVL tree and other self-balancing search trees like Red Black are useful to get all basic operations done in O(log n) time. The AVL trees are more balanced compared to Red-Black Trees, but they may cause more rotations during insertion and deletion. So if your application involves many frequent insertions and deletions, then Red Black trees should be preferred. And if the insertions and deletions are less frequent and search is the more frequent operation, then the AVL tree should be preferred over Red Black Tree.

AVL Tree | Set 2 (Deletion)

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Insertion in an AVL Tree

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Insertion, Searching and Deletion in AVL trees containing a parent node pointer

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We have discussed AVL insertion in the previous post. In this post, we will follow a similar approach for deletion. Steps to follow for deletion. To make sure that the given tree remains AVL after every deletion, we...

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How is an AVL tree different from a B-tree?

AVL Trees: AVL tree is a self-balancing binary search tree in which each node maintain an extra factor which is called balance factor whose value is either -1, 0 or 1. B-Tree: A B-tree is a self - balancing tree data structure...

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AVL tree is binary search tree with additional property that difference between height of left sub-tree and right sub-tree of any node canâ€™t be more than 1. Here are some key points about AVL trees: If there are n...

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Please refer below post before reading about AVL tree handling of duplicates. How to handle duplicates in Binary Search Tree?This is to augment AVL tree node to store count together with regular fields like key, left...

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Count greater nodes in AVL tree

In this article we will see that how to calculate number of elements which are greater than given value in AVL tree. Examples: Input : x = 5 Root of below AVL tree 9 / \ 1 10 / \ \ 0 5 11 / / \ -1 2 6 Output : 4 Explanation:...

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Difference between Binary Search Tree and AVL Tree

Binary Search Tree:A binary Search Tree is a node-based binary tree data structure that has the following properties: The left subtree of a node contains only nodes with keys lesser than the nodeâ€™s key.The right...

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