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FREE KA TREE SERIES

Notes:

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take U forward

Trees

- Binary Tree :- Hierarchical data structure in which each node can have atmost two childrens

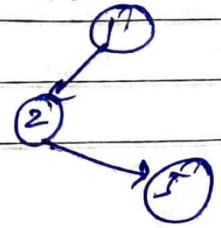
1. Full Binary Tree :- either 0 or 2 childrens
2. Complete Binary Tree :- all levels are completely filled except the last level which has all nodes in left only.
3. Perfect BT: all leaf nodes are at same level
4. Balanced BT: height of tree can be atmost $\log n$.
5. Degenerated Tree :- skewed trees (linked list)

- Representation in C++ :-

```
struct Node {
    int data;
    struct Node *left;
    struct Node *right;

    Node(int val) {
        data = val;
        left = right = NULL;
    }
};

main() {
    struct Node *root = new Node(1);
    root->left = new Node(2);
    root->left->right = new Node(5);
}
```



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Traversals

DFS

→ Inorder (left, root, right)
→ preorder (root, left, right)
→ post order (left, right, root)

BFS (level wise)

① void preorder (node) {
if (node == NULL) return;

cout << node → data;
preorder (node → left);
preorder (node → right);
}

② void bfs (node * root) {
queue <node *> q;
q.push (root);
while (! q.empty())
{
node *f = q.front();
cout << f → data;
if (f → left) q.push (f → left);
if (f → right) q.push (f → right);
q.pop();
}
}

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③ Iterative Preorder:-

→ 1) push root on stack
2) while stack is not empty:
   a) pop the top & print it
   b) push its RIGHT in stack
   c) push its LEFT in stack

Code:
```
stack<node*> st;
st.push(root);
while(!st.empty()) {
    root = st.top();
    st.pop();
    cout<<root->data<<" ";
    if(root->right)
        st.push(root->right);
    if(root->left)
        st.push(root->left);
}
```

④ Iterative Inorder:-

→ 1) keep going left & pushing into stack until you get null
2) as null comes, print & pop top & then go right & push on the stack.
3) repeat.

Code:
```
Stack<Node*> st;
Node* node = root;
while(true) {
    if(node!=NULL) {
        st.push(node);
        node = node->left;
    }
```

```
else {
        if(st.empty()) break;
        node = st.top();
        st.pop();
        cout << node -> data << " ";
        node = node -> right;
      }
}
```

(2) Iterative Postorder using 2 stacks:-

1) push root in stack 1
2) pop top of the stack 1, push it in stack 2 and then push its left & right in stack 1.
3) repeat the step 2 until stack 1 is not empty
4) postorder will be available in stack 2

Code:

```
stack<Node*> st1, st2;
st1.push(root);
while(!st1.empty()) {
    root = st1.top();
    st1.pop();
    st2.push(root);
    if(root->left) st1.push(root->left);
    if(root->right) st1.push(root->right);
                }
while(!st2.empty()) {
    cout << st2.top()->data << " ";
    st2.pop();
                }
```

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⑥ Iterative Postorder using 1 stack:

1) go left until null
2) go one time right
3) go again left until null

} recursive idea

Code:

```
curr = root;  stack<Node*> st;
while(curr != NULL || !st.empty())
{
    if(curr != NULL){
        st.push(curr);
        curr = curr->left;
    }
    else {
        temp = st.top()->right;
        if(temp == NULL){
            temp = st.top();
            st.pop();
            cout<<temp->data<<" ";
            while(!st.empty() && temp==st.top()->right)
            {
                temp = st.top();
                st.pop();
                cout<<temp->data<<" ";
            }
        }
        else
            curr = temp;
    }
}
```

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④ Pre, In & Post order Traversals in one traversal:-

Idea: Maintain three vectors pre, in & post.
push a pair {root, 1} onto the stack
(1 ↑ number)

i) if num = 1:
   a) push root's value in pre vector & pop in st
   b) increment num, i.e. push {root, 2} in stack.
   c) if root's left exist, push {root→left, 1} in stack

ii) if num = 2:
   a) push in in vector & pop from stack
   b) increment num & push
   c) push right

iii) if num = 3;
   a) push in post vector
   b) pop from stack

Code:

```
stack < pair < Node *, int > > st;
st.push ( {root, 1} );
vector < int > pre, in, post;
if (root == NULL) return;
while ( ! st.empty() ) {
    auto it = st.top();
    st.pop();

    if (it.second == 1) {
        pre.push_back (it.first → val);
        it.second ++;
```

```
st.push(it);
if(it.first->left != NULL) {
        st.push({it.first->left, 1});
}
else if(it.second == 2) {
    in.push_back(it.first->val);
    it.second++;
    st.push(it);

    if(it.first->right != NULL) {
        st.push({it.first->right, 1});
    }

}
else {
    post.push_back(it.first->val);
}
}
```

(3) Maximum Depth (Height) of Binary Tree :-

Code:

```
int Height(Node * root) {
    if(root == NULL) return 0;

    int left = Height(root->left);
    int right = Height(root->right);

    return 1 + max(left, right);
}
```

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(1) Check for Balanced Binary Tree :-
for every node : height(left) - height(right) <= 1

→ Naive approach : (Time = O(n²))

```
Bool check(node) {
    if(node == NULL) return true;

    int left = Height(node->left);
    int right = Height(node->right);

    if(abs(left-right) > 1) return false;

    bool left = check(node->left);
    bool right = check(node->right);

    if(!left || !right) return false;

    return true;
}
```

→ O(N) approach : (same as finding height)

Code :

```
int check(node) {
    if(node==NULL) return 0;

    int left = check(node->left);
    int right = check(node->right);
    if(left==-1 or right==-1) return -1;
    if(abs(left-right) > 1) return -1;

    return max(left, right) + 1;
}
```

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(5) Diameter of B.T. :- (longest path b/w 2 nodes)

→ (1) O(N²):

```
int diameter(node * root) {
    if (root == NULL) return 0;

    int h1 = height(root -> left);
    int h2 = height(root -> right);

    int op1 = h1 + h2; //when passes through root
    int op2 = diameter(root -> left);
    int op3 = diameter(root -> right);
    return max({op1, op2, op3});
}
```

(2) O(N):

```
class Pair {
    public:
    int height;
    int diameter;
};

Pair diameter(node * root) {
    Pair p;
    if (root == NULL) {
        p.height = 0;
        p.diameter = 0;
        return p; }

    Pair left = diameter(root -> left);
    Pair right = diameter(root -> right);
    p.height = 1 + max(left.height, right.height);
```

```
p.diameter = max(left.height + right.height,
                 left.diameter,
                 right.diameter);
return p;
}
```

(11) Maximum path Sum in B.T. :-
find max sum of a path between any two nodes

code:
```
int maxPathSum(node * root) {
    int maxi = INT_MIN;
    maxSum(root, maxi);
    return maxi;
}
int maxSum(node * root, int &maxi) {
    if(root == NULL) return 0;

    int left = max(0, maxSum(root->left, maxi));
                    → to ignore negative path sums
    int right = max(0, maxSum(root->right, maxi));
    maxi = max(maxi, left + right + root->val);
    return max(left, right) + root->val;
}
```

(12) Check if two trees are identical

code
```
bool isSame(node * p, node * q) {
    if (p == NULL || q == NULL) {
        return (p == q); }

    return (p->val == q->val) &&
           isSame(p->left, q->left) &&
           isSame(p->right, q->right); }
```

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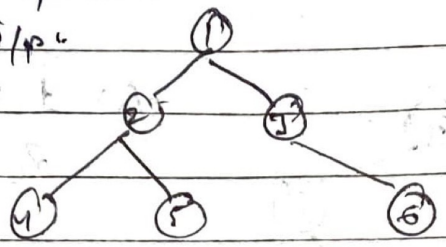
(3) Zig-zag / Spiral Traversal in a B.T. :-

eg. i/p:



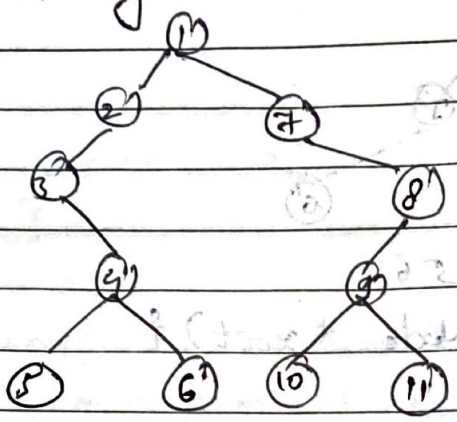
o/p: 1 3 2 4 5 6

Code:

```
vector<int> findSpiral(Node *root) {
    vector<int> ans;
    queue<Node*> q;
    if(root == NULL) return ans;
    q.push(root);
    bool rightToLeft = true;
    while(!q.empty()) {
        int size = q.size();
        vector<int> temp(size);
        for(int i=0; i<size; i++) {
            Node *f = q.front();
            q.pop();
            if(rightToLeft) temp[size-i-1] = f->data;
            else temp[i] = f->data;

            if(f->left) q.push(f->left);
            if(f->right) q.push(f->right);
        }
        rightToLeft = !rightToLeft;
        for(int i=0; i<size; i++)
            ans.push_back(temp[i]);
    }
    return ans;
}
```

(14) Boundary Traversal in B.T. :- (anticlockwise)

i/p:



o/p: 1 2 3 4 5 6 10 11 9 8 7

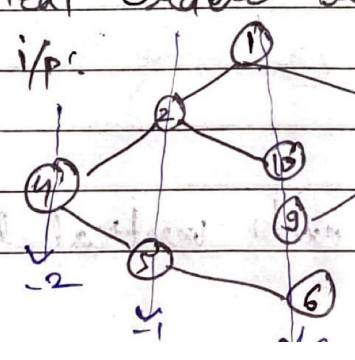
→ Left Boundary (excluding leaves) + leaf nodes + right boundary in reverse (excluding leaves)

Code:

```
bool isLeaf(Node *root)
    return (root->left==NULL && root->right==NULL);

void left(Node *root, vector<int> &ans) {
    root = root->left;
    if(!root) return;
    while(!isLeaf(root)) {
        ans.push_back(root->data);
        if(root->left) root = root->left;
        else root = root->right;
    }
}

void leaf(Node *root, vector<int> &ans) {
    if(root==NULL) return;
    if(isLeaf(root)) ans.push_back(root->data);
    leaf(root->left, ans);
    leaf(root->right, ans);
}
```

```
void right(Node *root, vector<int> &ans) {
    vector<int> temp;
    root = root->right;
    if(!root) return;
    while(!isLeaf(root)) {
        temp.push_back(root->data);
        if(root->right) root = root->right;
        else root = root->left;
    }
    for(int i = temp.size()-1; i>=0; i--)
        ans.push_back(temp[i]);
}

vector<int> boundary(Node *root) {
    vector<int> ans;
    if(!root) return ans;
    ans.push_back(root->data);
    if(isLeaf(root)) return ans;
    left(root, ans);
    leaf(root, ans);
    right(root, ans);
    return ans;
}
```

(15) Vertical Order Traversal of Binary Tree :-



o/p: 4 2 5 1 ~~9 10~~ 6 3 10

In case of overlap, write smaller value first.

(Left to right + Top to Bottom)

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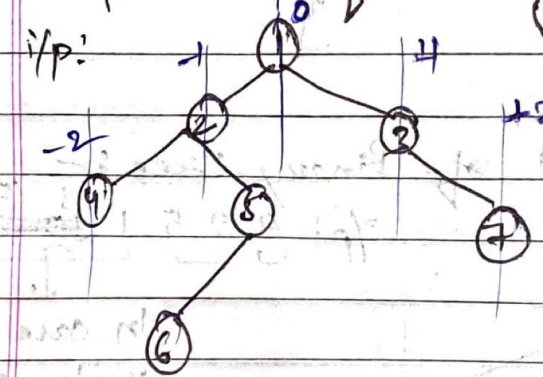
Code:
```
vector<int> verticalOrder(Node *root) {
    vector<int> ans;
    map<int, vector<int>> mp; // {verticalLevel, nodes}
    queue< pair<Node*, int>> q; // {root, verticalLevel}
    q.push({root, 0});

    while(!q.empty()) {
        Node *f = q.front().first;
        int vl = q.front().second;
        q.pop();
        mp[vl].push_back(f->data);
        if(f->left) q.push({f->left, vl-1});
        if(f->right) q.push({f->right, vl+1});
    }
    for(auto it: mp) {
        for(auto i: it.second)
            ans.push_back(i);
    }
    return ans;
}
```

(16) Top view of Binary Tree :-



o/p: 4 2 1 3 7

→ print the first node of each vertical line

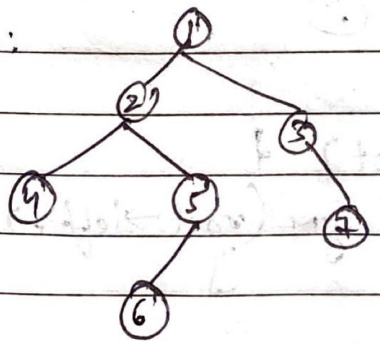
Code:

```
vector<int> topView(Node *root) {
    vector<int> ans;
    queue<pair<Node*, int>> q;
    map<int, int> mp;
    if(!root) return ans;
    q.push({root, 0});
    while(!q.empty()) {
        Node *f = q.front().first;
        int vl = q.front().second;
        q.pop();
        if(mp.find(vl) == mp.end())
            mp[vl] = f->data;
        if(f->left) q.push({f->left, vl-1});
        if(f->right) q.push({f->right, vl+1});
    }
    for(auto it: mp)
        ans.push_back(it.second);
    return ans;
}
```

By removing this line, you will get bottom view of B.T.

(7) Right view of Binary Tree :-

i/p:



o/p: 1 3 7 6

→ print last node of every level

Generally: Space in Iterative (level order) > Recursive O(Height)
O(n)

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→ if you traverse each level from right to left then first node of each level will be answer.
→ use recursive traversal as: root right left; and print when you visit a level for first time

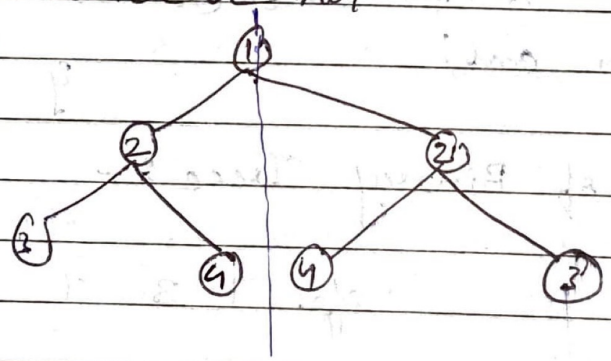
Code
```
void pre(Node * root, int level, vector<int> &ans){
    if(root == NULL) return;

    if(level == ans.size())
        ans.push_back(root->data);

    pre(root->right, level+1, ans);
    pre(root->left, level+1, ans);
}
```
swap these to get the left view.

(18) Check for Symmetrical Binary Trees :-
whether it forms a mirror image of itself around the center or not

i/p:



o/p: True

Code
```
bool isSymmetric(Node * root) {
    return root == NULL || sym(root->left, root->right);
}

bool sym(Node * left, Node * right) {
```

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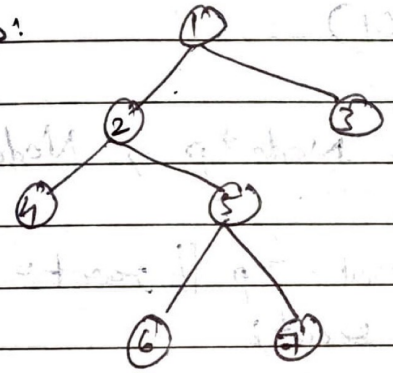
```
if(left == NULL || right == NULL)
        return left == right;

if(left->data != right->data) return false;

return sym(left->left, right->right)
        &&
       sym(left->right, right->left);
```

(19) Print Root to node path :-

i/p:



node = 7

o/p: {1, 2, 5, 7}

Code:

```
bool getPath(Node * root, vector<int> &arr, int x){
    if(!root) return false;

    arr.push_back(root->val);

    if(root->val == x) return true;

    if(getPath(root->left, arr, x) || getPath(root->right,
                                              arr, x))
        return true;
```

```
    ans.pop_back();
    return false;
}
```

(20) Lowest Common Ancestor (LCA) in BT :-

(m-1) find path from root to first node & root to second node, store in two vectors.
→ now find the last common element in both vectors.

time = space = O(n)

m-2 Time = O(n), Space = O(1)

Code

```
Node* LCA(Node* root, Node* p, Node* q) {
    //base case
    if(root==NULL || root==p || root==q)
        return root;

    Node* left = LCA(root->left, p, q);
    Node* right = LCA(root->right, p, q);

    //result
    if(left==NULL) return right;
    else if(right==NULL) return left;
    else {
        // we found our result
        return root;
    }
}
```

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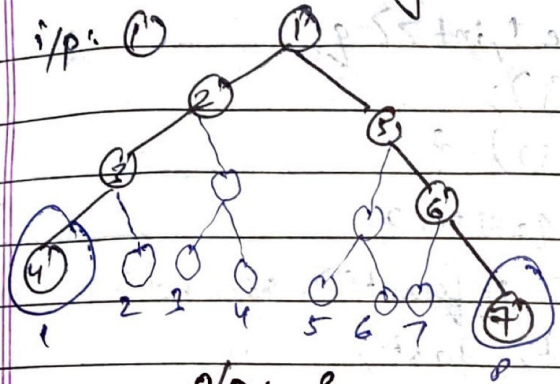
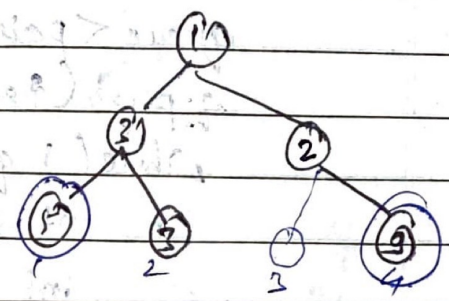
(21) Maximum width of Binary Tree :-

width : No. of nodes in a level between any 2 nodes including those 2 nodes

i/p :

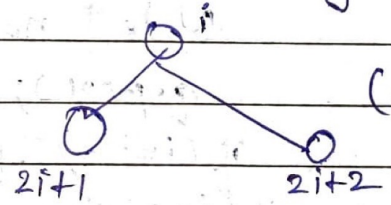


o/p : 8



o/p : 4

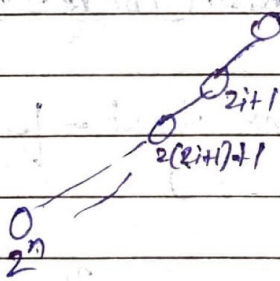
Idea : we can give index to every node.



(0 Based indexing)

and then width of a level = last index − first index + 1

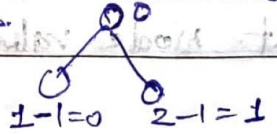
but if tree is skewed then we might get overflow



So, we will try that first node of each level will start with index 0

So, original index = current index − minimum index (i.e. index of first node)

eg.



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code

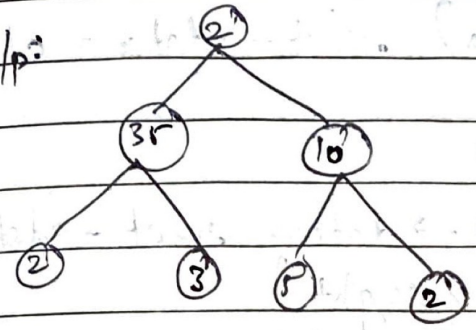
```
int width(Node* root) {
    if(!root) return 0;
    int ans = 0;
    queue<pair<Node*, int>> q;
    q.push({root, 0});
    while(!q.empty()) {
        int size = q.size();
        int mini = q.front().second;
        int first, last;
        for(int i=0; i<size; i++) {
            int curr_id = q.front().second - mini;
            Node* node = q.front().first;
            q.pop();
            if(i==0) first = curr_id;
            if(i==size-1) last = curr_id;
            if(node->left)
                q.push({node->left, curr_id*2+1});
            if(node->left)
                q.push({node->right, curr_id*2+2});
        }
        ans = max(ans, last-first+1);
    }
    return ans;
}
```

(24) Children Sum property

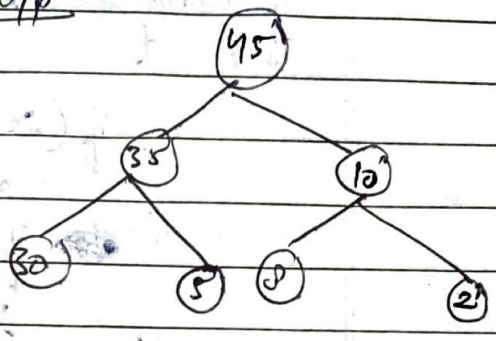
each node value should be equal to sum of its left & right node values

→ you can increment node value (you cant decrease)

i/p:

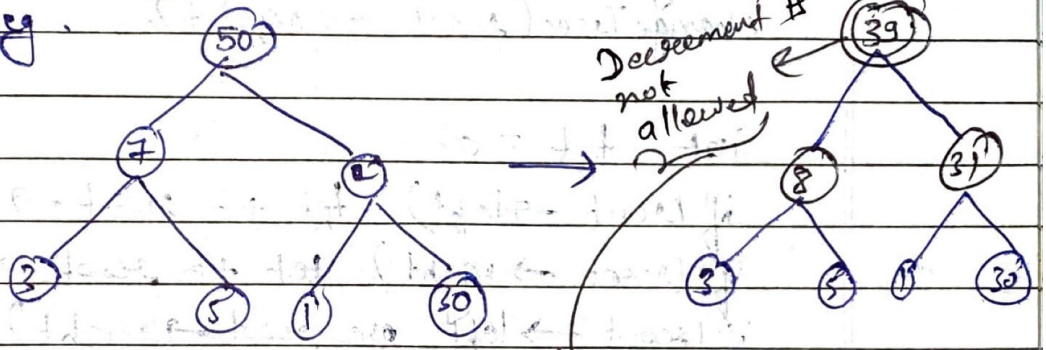


one of o/p:



→ We cant replace simply the addition of left & right child from bottom to up.

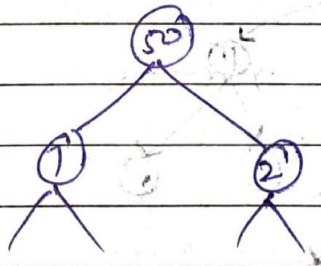
eg.



shortage of (50-39) = 11

→ So going from top to down, we will change the values in such a way that when we again go from bottom to up then there will not be any shortage.

eg.



→ 7+2 = 9 < 50
So we will make 7 & 2 as 50 only.

Code:

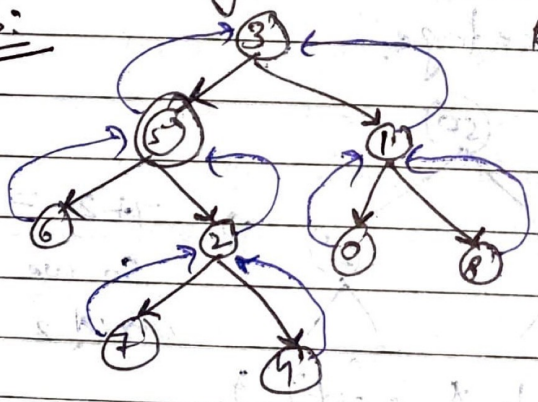
```
void changeTree(Node * root) {
    if (root == NULL) return;
    int child = 0;
    if (root->left) child += root->left->data;
    if (root->right) child += root->right->data;
```

```
if (child >= root->data) root->data = child;
else {
        if (root->left)
            root->left->data = root->data;
        if (root->right)
            root->right->data = root->data;
    }
changeTree(root->left);
changeTree(root->right);

int tot = 0;
if (root->left) tot += root->left->data;
if (root->right) tot += root->right->data;
if (root->left or root->right) root->data = tot;
}
```

(23) Print all the nodes at distance of k from the given target node.

i/p:



k = 2, target = 5 (add. given)

o/p: 7, 4, 1.

⇒ as we can't move backward so first store all the parents using BFS.

⇒ start BFS from target node & go to left, right & parent if they are not visited already &

increment the distance by 1, whenever distance = k, print the nodes

code:

```
void markParents(Node *root, unordered_map<Node*, Node*> &parents) {
    queue<Node*> q;
    q.push(root);
    while(!q.empty()) {
        Node* f = q.front();
        q.pop();
        if(f->left) {
            parent[f->left] = f;
            q.push(f->left);
        }
        if(f->right) {
            parent[f->right] = f;
            q.push(f->right);
        }
    }
vector<int> distanceK(Node* root, Node* target, int k) {
    unordered_map<Node*, Node*> parent;
    markParents(root, parent);

    unordered_map<Node*, bool> visited;
    queue<Node*> q;
    q.push(target);
    visited[target] = true;
    int curr_level = 0;
    while(!q.empty()) {
```

```
int size = q.size();
if (curr_level == k) break;
for(int i=0; i<size; i++) {
    Node* current = q.front();
    q.pop();
    if(current->left && !visited[current->left])
    {
        q.push(current->left);
        visited[current->left] = true;
    }
    if(current->right && !visited[current->right])
    {
        q.push(current->right);
        visited[current->right] = true;
    }
    if(parent[current] && !visited[parent[current]])
    {
        q.push(parent[current]);
        visited[parent[current]] = true;
    }
}
}
vector<int> result;
while(!q.empty()) {
    Node* curr = q.front();
    q.pop();
    result.push_back(curr->val);
}
return result;
}
```

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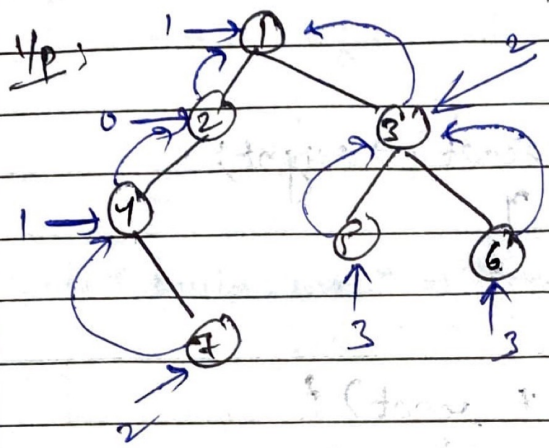
(24) Minimum time to burn a B.T. from a node.



node = 2 (node value is given)

o/p: 3

→ steps: (1) Mark parents & also get add. of target node.
(2) apply BFS. (same as previous)

(25) Count total nodes in a complete Binary Tree.

→ if height of CBT = h, then (in o(Logn))
#nodes = $2^h - 1$.

→ at a particular node, just find height of its left most & right most node, if both are equal then just return $2^h - 1$ otherwise $1 + left + right$.

code: int leftMost(Node * root) {
int h = 0;
while (root) {
h++;
root = root → left;
}
return h;
}

int rightMost (Node * root) {

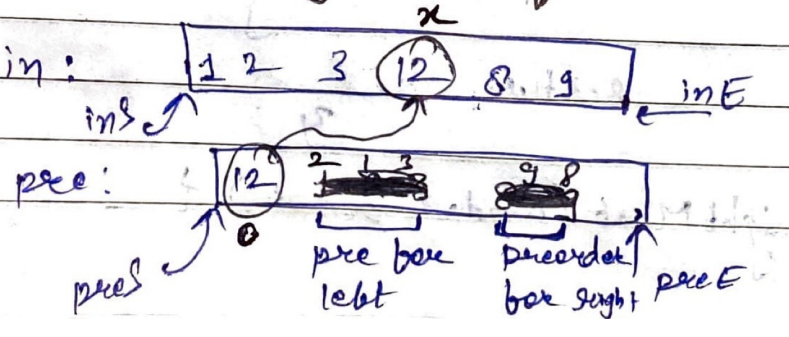
```
int h = 0;
while (root) {
        h++;
        root = root -> right;
    }
    return h;
}
int countNodes(Node * root) {
    if (root == NULL) return 0;

    int l = leftMost(root);
    int re = rightMost(root);

    if (l == re) return (1 << l) - 1;

    return 1 + countNodes(root -> left) +
               countNodes(root -> right);
}
```

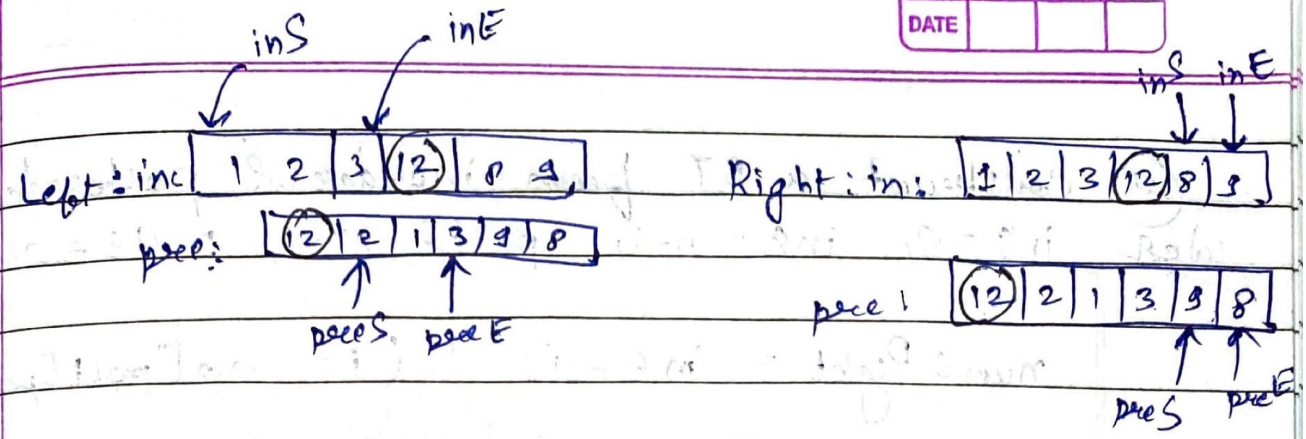
NOTE: 1) Given Preorder & postorder, many binary trees can be constructed.

2) To construct a unique binary tree, inorder must be given.

(26) Construct a binary Tree from Preorder & Inorder

Step 1






```
Node* build(int *in, int *pre, int preS, int preE,
            int inS, int inE, map<int, int> &mp)
{
    if(preS > preE or inS > inE) return NULL;

    int i = mp[pre[preS]];
    int numsLeft = i - inS;

    Node * root = new Node(pre[preS]);

    root->left = build(in, pre, preS+1, preS + numsLeft,
                       inS, i-1, mp);
    root->right = build(in, pre, preS + numsLeft + 1,
                        preE, i+1, inE, mp);

    return root;
}

Node * buildTree(int in[], int pre[], int n) {
    map<int, int> mp;
    for(int i=0; i<n; i++) mp[in[i]] = i;

    return build(in, pre, 0, n-1, 0, n-1, mp);
}
```

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(27) Construct a BT from inorder & postorder:-

idea: $inS = 0$, $inE = n-1$, $postS = n-1$, $postE = 0$.

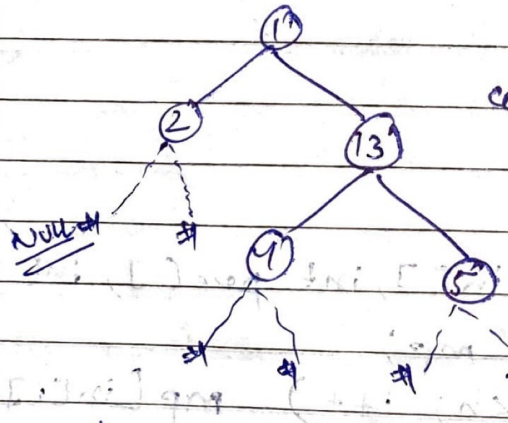
numsRight = $inE - i$; ($i = mp[post[postS]]$)

root->left = build(in, post, postS - numsRight - 1, postE, inS, i-1, mp);
root->right = build(in, post, postS-1, postS - numsRight, i+1, inE, mp);

(28) Serialize and Deserialize a Binary Tree:-
Serialization is to store tree in a file so that it can be restored later. The structure of tree must be maintained. Deserialization is reading tree back from file.

→ Task is to complete the function "Serialize" which stores the tree into an array A[] and "deSerialize" which deserializes the array to tree and returns it.

eg



store it level wise:
arr[] = 1, 2, 13, #, #, 9, 5, #, #, #, #

code:
```
vector<int> serialize(Node * root) {
    vector<int> v;
    if (root == NULL) return v;
```

```
queue<Node *> q;
q.push(root);

while(!q.empty()) {
    Node *f = q.front();
    q.pop();

    if(f==NULL) v.push_back(0);
    else {
        v.push_back(f->data);
        q.push(f->left);
        q.push(f->right);
    }
}
return v;
}

Node *deSerialize(vector<int> &v) {
    if(v.size()==0) return NULL;
    Node *root = new Node(A[0]);
    queue<Node*> q;
    q.push(root);
    int i=0;
    while(!q.empty()) {
        Node *f = q.front();
        q.pop();

        i++;
        if(v[i]!=0) {
            f->left = new Node(v[i]);
```

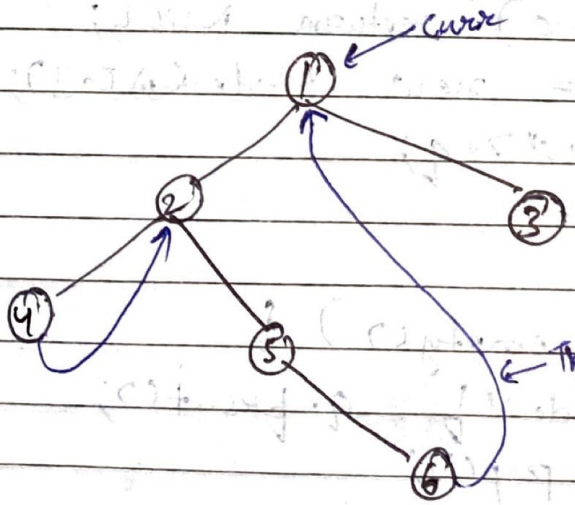
```
        q.push(f->left); }
    else {
        f->left = NULL;
    }
    i++;
    if(A[i]!=0) {
        f->right = new Node(A[i]);
        q.push(f->right);
    }
    else f->right = NULL;
}
return root;
}
```

(29) Morris Traversal (Inorder):

→ uses threaded binary tree

→ time = O(n), Space = O(1). (No stack/Queue)

eg



inorder: left Root Right

→ When curr is moved to left, then we will make a threaded path from the right most node of left subtree to the root, because after

completing left subtree, we need to go to root again

→ if left of curr is null then that means curr is root so just point it & go to right.

→ if you move to the right most node in left subtree & if there is already a thread then that means left part is completed so remove the thread & move curr to right & point the root too.

code:

```
vector<int> getInorder(Node * root) {
    vector<int> inorder;
    Node *curr = root;
    while(curr != NULL) {
        if(curr->left == NULL) {
            inorder.push_back(curr->val);
            curr = curr->right;
        }
        else {
            Node *prev = curr->left;
            While(prev->right && prev->right != curr)
                prev = prev->right;

            if(prev->right == NULL) {
//Create Thread// prev->right = curr;
                curr = curr->left; }
            else {
                prev->right = NULL; //Remove Thread
                inorder.push_back(curr->val);
            } curr = curr->right;
    } } }
```

if you shift this line then it will become pre order

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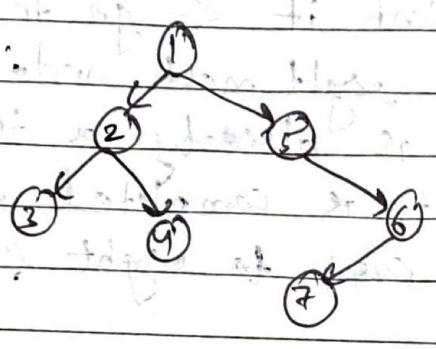
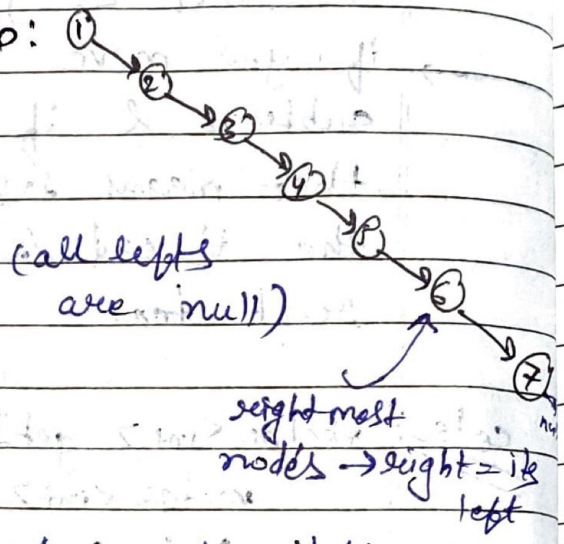
(30) Flatten a Binary Tree to Linked List :- (Preorder)

M-1: Recursive:

i/p:



o/p:



So reversal suitable is:
right left root

Code:

```
Node * prev = NULL;
void flatten(Node * root) {
    if (root == NULL) return;

    flatten(root → right);
    flatten(root → left);

    root → right = prev;
    root → left = NULL;
    prev = root;
}
```

M-2: Iterative:

1) push root into stack
2) curr = top of stack

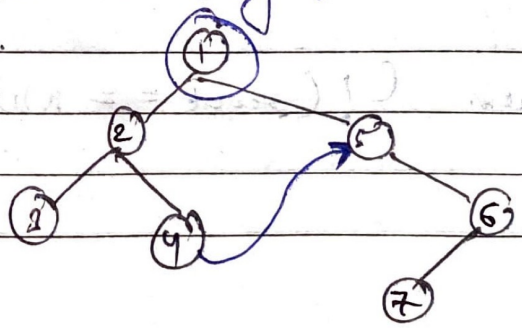
3) push curr's left & right in stack (reverse order) (right → left)
4) curr's right will be top of stack & curr's left = null
5) curr = pop()
6) repeat 3, 4, 5 until stack is not empty.

code:
```
void flatten(Node* root) {
    stack<Node*> st;
    st.push(root);
    Node* curr;
    while(!st.empty()) {
        curr = st.top(); st.pop();
        if(curr->right) st.push(curr->right);
        if(curr->left) st.push(curr->left);

        if(!st.empty()) curr->right = st.top();

        curr->left = NULL;
    }
}
```

M-3 : space = O(1) (similar to Morris Traversal)

Step (1) Connect the rightmost node in left subtree of the root to root's right.

eg.



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code:
```
void flatten(Node *root) {
    Node *curr = root;
    while (curr != NULL) {
        if (curr->left != NULL) {
            Node *prev = curr->left;
            while (prev->right != NULL)
                prev = prev->right;
            prev->right = curr->right;
            curr->right = curr->left;
            curr->left = NULL;
        }
        curr = curr->right;
    }
}
```

- Binary Search Tree :-
  → left < root, right > root ∀ roots
  left subtree = BST
  right subtree = BST

① Search a node in BST :-

code:
```
bool search(Node *root, int x) {
    while(root and root->data != x) {
        if (root->data > x) root = root->left;
        else root = root->right;
    }
    return (!(root == NULL));
}
```

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(2) Ceil in a BST

find lowest value >= key.

code

```
int findCeil (Node *root, int key) {
    int ceil = -1;
    while (root) {
        if (root->data == key) {
            ceil = root->data;
            return ceil;
        }
        if (key > root->data) {
            root = root->right;
        }
        else {
            ceil = root->data;
            root = root->left;
        }
    }
    return ceil;
}
```

(3) Floor in a BST

find greatest value <= key

code

```
int findFloor (Node *root, int key) {
    int floor = -1;
    while (root) {
        if (root->val == key) return key;
        if (key > root->val) {
            floor = root->val;
            root = root->right; }
        else { root = root->left; } }
    return floor;
}
```

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④ Insert a given node in BST :-

Code

```
Node* insert(Node *root, int val) {
    if(root==NULL) return new Node(val);
    Node *curr = root;
    while(true) {
        if(curr->val <= val) {
            if(curr->right!=NULL) curr=curr->right;
            else {
                curr->right = new Node(val);
                break;
            }
        }
        else {
            if(curr->left!=NULL)
                curr = curr->left;
            else {
                curr->left = new Node(val);
                break;
            }
        }
    }
    return root;
}
```

⑤ Delete a Node in BST :-

code:

```
Node *deleteNode(Node *root, int key) {
    if(root==NULL) return NULL;

    if(root->data < key) {
```

```
: root -> right = deleteNode(root -> right, key);
  return root;  }
else if (root -> data > key) {
    root -> left = deleteNode (root -> left, key);
    return root;          }
else
    {
        if (root -> left == NULL && root -> right == NULL)
            {
                delete (root);
                return NULL;
            }
        else if (root -> left == NULL && root -> right != NULL)
            {
                Node * temp = root -> right;
                delete root;
                return temp;
            }
        else if (root -> right == NULL && root -> left != NULL)
            {
                Node * temp = root -> left;
                delete root;
                return temp;
            }
        else {
            Node *prev = root -> left;
            while (prev -> right != NULL)
                prev = prev -> right;
            root -> data = prev -> data;
```

```
        root->left = deleteNode(root->left, prev->data);
        return root;
    }
}
```

(6) K^{th} smallest element in BST :-

Steps (1) count = 0
(2) do inorder traversal (as it will be sorted)
(3) instead of printing root, do count++.
(4) stop when count = K.

(7) Validate a BST :-

→ Give each node a range & check if the node's value lies in the range or not. (Pass in function)

initial range = $[-\infty, \infty]$
going left = $[-\infty, root]$
going right = $[root, \infty]$

(8) LCA in BST :- $(O(\log n)) \cong O(Height)$

→ to find LCA of u & v:
(1) if at node n, u lies left & v lies in right then n is LCA
(2) if both lies left ⇒ go left
if both lies right ⇒ go right
(3) if n is u or v then also n is LCA

(9) Construct a BST from a preorder traversal :-

(M-1)
1) get the inorder by sorting preorder — Time = $O(n \log n)$
2) construct unique BT.

M-2 Maintain upper bound at every node
→ & acc to upper bound, go to either left or right (i.e. use root left right traversal, if upcoming value is less than upper bound then place it otherwise go back)

Code:
```
Node * build (vector<int> &pre, int &i, int bound) {
    if (i == pre.size() || pre[i] > bound)
        return NULL;

    Node * root = new Node(pre[i++]);
    root -> left = build (pre, i, root -> val);
    root -> right = build(pre, i, bound);
    return root;
}

Node * bstFromPreorder (vector<int> &pre) {
    int i=0;
    return build(pre, i, INT_MAX);
}
```

⑩ Inorder Successor in BST :- O(log(H))
→ inorder successor of x is the first value which is greater than x

Code
```
Node * Succ (Node * root, Node * p) {
    Node * successor = NULL;
    while (root != NULL) {
        if (p -> val >= root -> val) root = root -> right;
        else { successor = root;
               root = root -> left; }
    }
    return successor;
}
```

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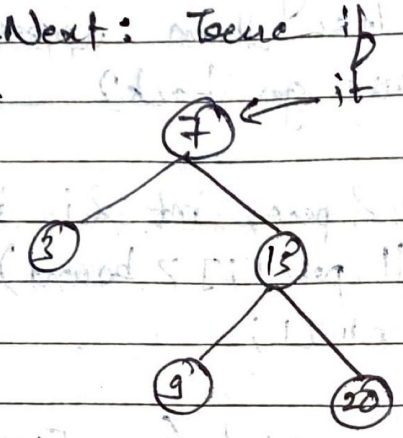
(11) BST Iterator

perform Given steps.

next : inorder successor of current iterator's node

hasNext : True if inorder successor is present

i/p :



BSTIterator(7)

Steps :

next → 3

next → 7

hasNext → True

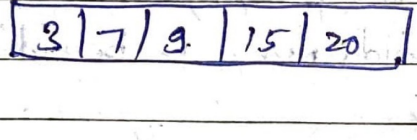
next → 9

hasNext → True

next → 15

next → 20

hasNext → False



Space = O(H)

Time ≈ O(1)

⇒ use a stack & follow inorder.

i) push all lefts in stack

ii) next : return top of stack & pop it, also if it have a right then push it along with all its lefts

iii) hasNext : return true if stack is non empty

code :

```
class BSTIterator {
    stack<Node *> myStack;
public:
    BSTIterator(Node *root) {
        pushAll(root);
    }
```

```
bool hasNext() {
    return !myStack.empty();
}

int next() {
    Node * temp = myStack.top();
    myStack.pop();
    pushAll(temp->right);
    return temp->val;
}

private:
    void pushAll(Node *node) {
        for(; node!=NULL; myStack.push(node),
                node = node->left);
    }
};
```

before() can be find out by using opposite logic. (i.e. go left & push all rights)

(12) Two Sum in BST :-

→ Given k, find two nodes whose sum is k.

Idea: M-1 : store inorder & then solve it using concept of 2 sum problem. (using 2 pointers)

M-2 : use BSTIterator

i = next() j = before()

if i+j < k ⇒ i = next()

else ⇒ j = before()

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(13) Recover BST :-

→ In a BST, 2 nodes are swapped now correct the BST.

Idea: as inorder traversal should be sorted, but if two numbers are swapped then there can be two cases:

(1) Swapped nodes are not adjacent

eg. 3, 25, 7, 8, 10, 15, 20, 5 ← last

first — 1st violation — 2nd violation

(2) swapped nodes are adjacent

eg. 3, 5, 8, 7, 10, 15, 20, 25

only one violation

Code:

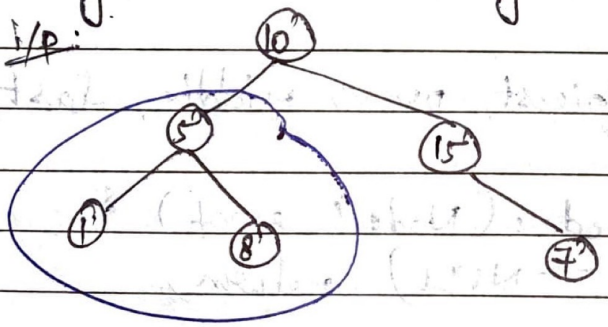
```
class Solution {
private:
    Node* first, prev, middle, last;
private:
    void inorder(Node* root) {
        if(root == NULL) return;

        inorder(root->left);
        if(prev != NULL && (root->val < prev->val))
        {
            // if its first violation
            if(first == NULL) {
                first = prev;
                middle = root;
            }
```

```
        else    last = root;
            }
        prev = root;
        inorder(root->right);
        }
public:
    void recoverTree(Node* root) {
        first = Middle = last = NULL;
        prev = new Node(INT_MIN);
        inorder(root);
        if(first && last) swap(first->val, last->val);
        else if(first && Middle)
            swap(first->val, middle->val);
            }
    };
```

(14) largest BST in given BT :-

i/p:



o/p : 3

m-1 : at each node, see if its valid BST, if its valid, then count no. of nodes $\Rightarrow O(n^2)$

(2) if a particular node is :
i) greater than the greatest element of its left subtree

ii) Smaller than the smallest element in right subtree.

then its a BST

→ to get the size of BST, follow Bottom up approach

→ at each node, maintain {size, smallest, largest}

code:

```
class NodeValue {
public:
    int maxNode, minNode, maxSize;

    NodeValue(int minNode, int maxNode, int maxSize)
    {
        this->maxNode = maxNode;
        this->minNode = minNode;
        this->maxSize = maxSize;
    }
};

class Solution {
private:
    NodeValue largestBSTSubtreeHelper(Node* root) {
        // An empty tree is a BST of size 0
        if (!root) return NodeValue(INT_MAX, INT_MIN, 0);

        auto left = largestBSTSubtreeHelper(root->left);
        auto right = largestBSTSubtreeHelper(root->right);

        if (left.maxNode < root->val && root->val < right.minNode)
        {
            return NodeVal(min(root->val, left.minNode),
                           max(root->val, right.maxNode),
                           left.maxSize + right.maxSize + 1); }
```

```
        return NodeVal(INT_MIN, INT_MAX,
                max(left.maxSize, right.maxSize));
    }
public:
    int largestBSTSubtree(Node *root) {
        return largestBSTSubtreeHelper(root).maxSize;
    }
};
```

THANK YOU :)

Keep Learning