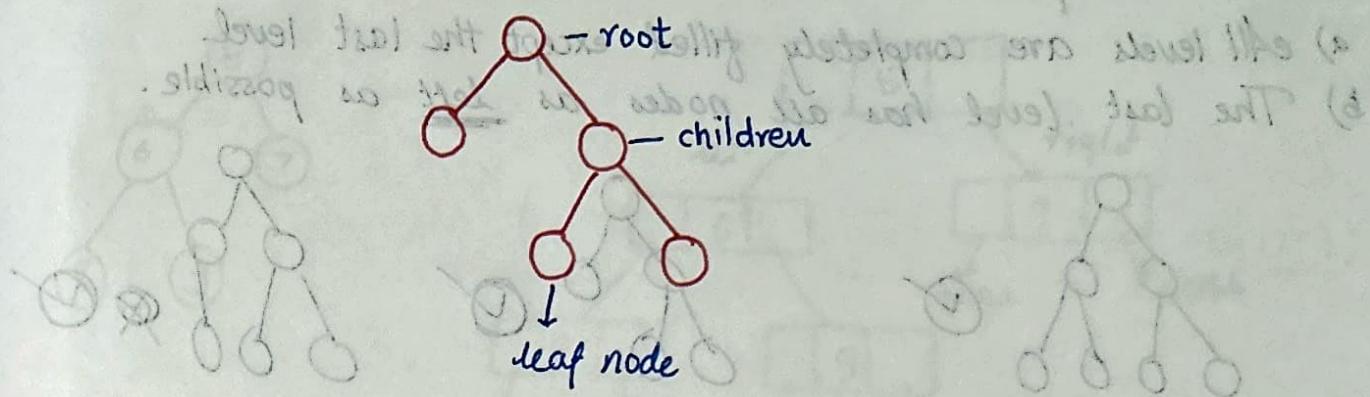
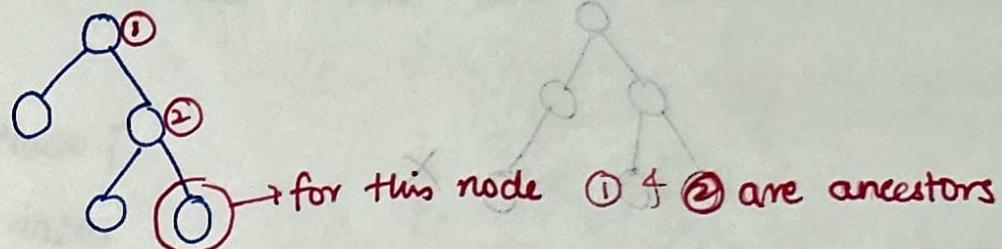


Introduction to trees :-

:- sort pyramid diagram

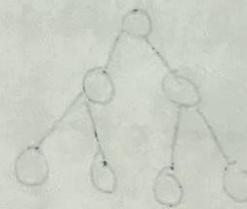


Ancestors:-



Types of binary trees :-

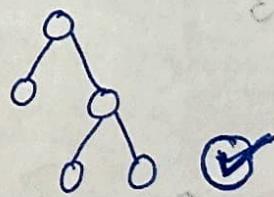
- ① Full binary tree
- ② Complete binary tree
- ③ Perfect binary tree
- ④ Balanced binary tree
- ⑤ Degenerate tree



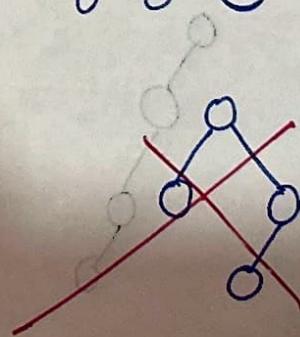
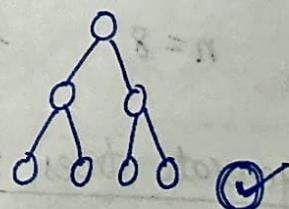
① Full binary tree :-

(n) pal xam to sort to nish.

Either have zero or two childrens.



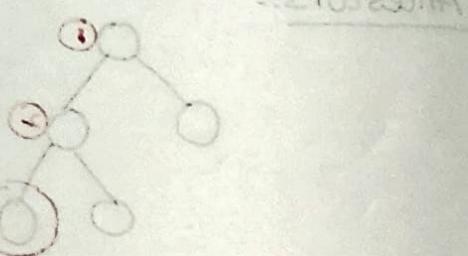
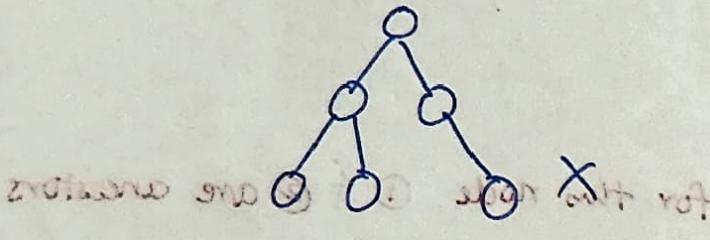
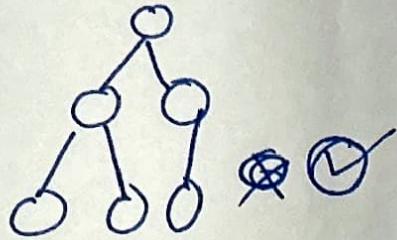
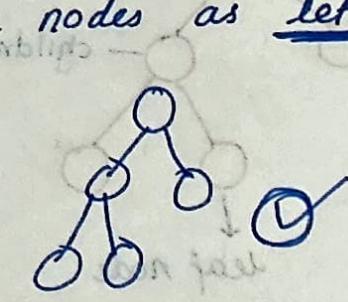
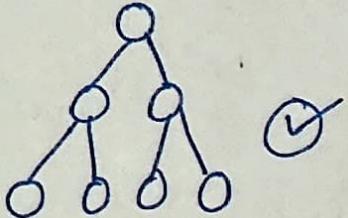
$E = 8, \text{pal}$



is not

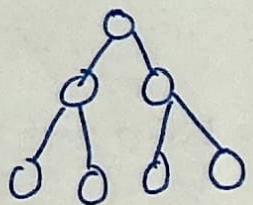
② Complete binary tree :-

- a) All levels are completely filled except the last level.
- b) The last level has all nodes as left as possible.



③ Perfect binary tree :-

All leaf nodes are at same level

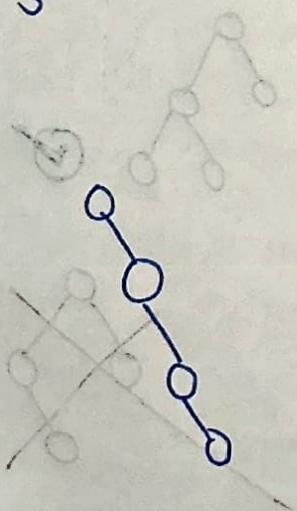
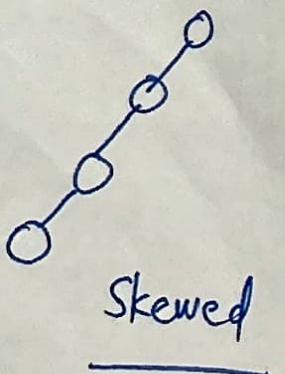


④ Balanced binary tree :-

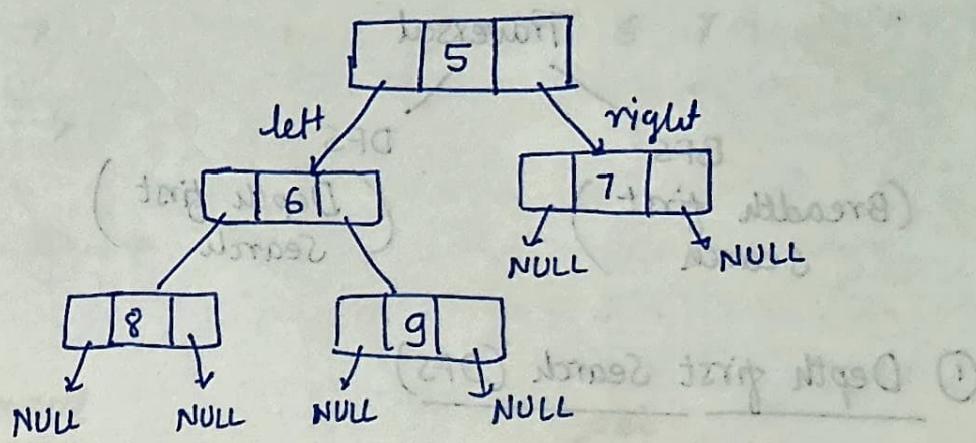
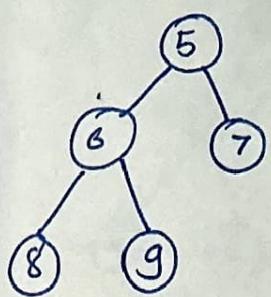
Height of tree at max $\log(n)$

$$n=8 \quad \log_2 8 = 3$$

⑤ Degenerate trees :-



Binary tree representation in C++ :-

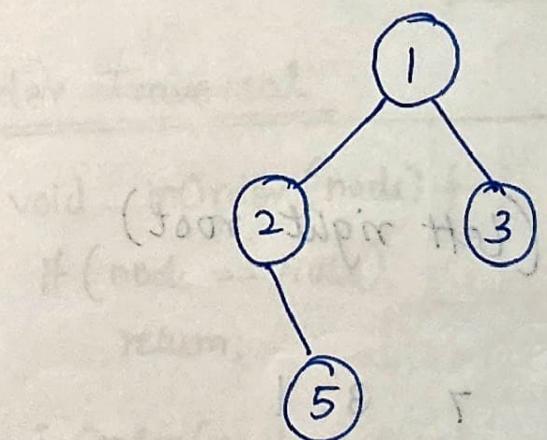


```

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

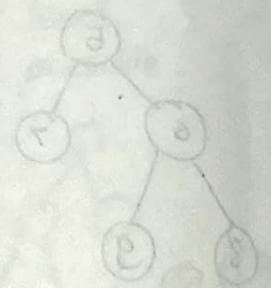
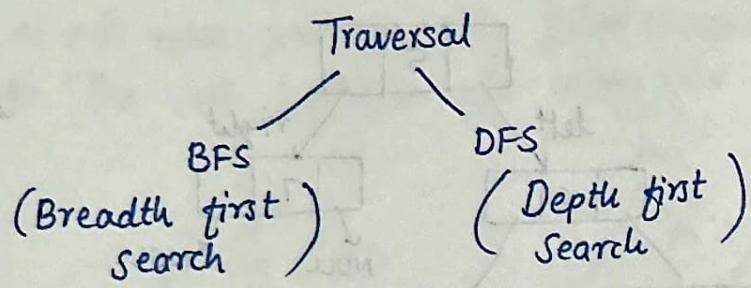
```

int main() {
    struct Node* root = new Node(1);
    root->left = new Node(2);
    root->right = new Node(3);
    root->left->right = new Node(5);
}
  
```



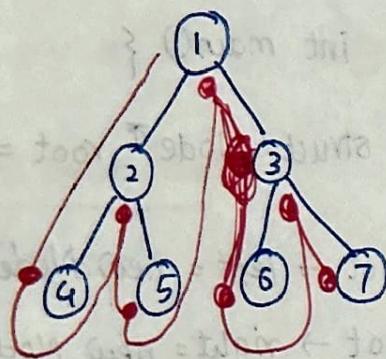
Locksworit rebro - tag

Traversal Techniques



① Depth first Search (DFS)

① Inorder traversal :- (Left - Root - right)



4 2 5 1 6 3 7

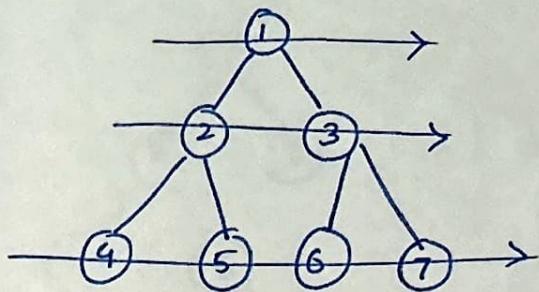
② preorder traversal (root left right)

1 2 4 5 3 6 7

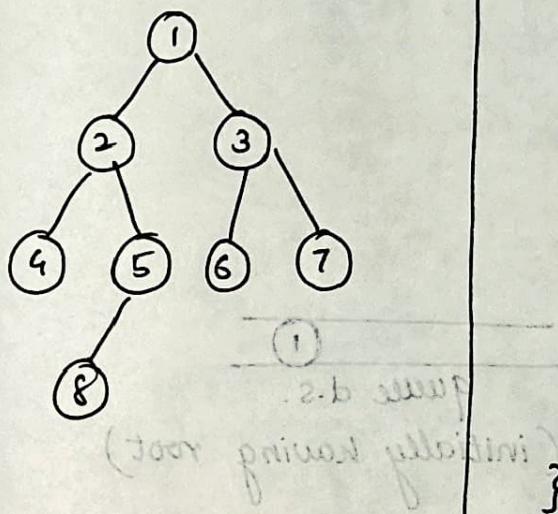
③ post-order traversal (left right root)

4 5 2 6 7 3 1

② Breadth First Search



① Pre-Order Traversal



```

void preOrder(node) {
    if (node == NULL)
        return;
    print(node → data);
    preOrder(node → left);
    preOrder (node → right);
}
  
```

$$T.C = O(N)$$

$$S.C = O(N)$$

② Inorder Traversal

```

void inOrder(node) {
    if (node == NULL)
        return;
    inOrder(node → left);
    print(node → data);
    inOrder(node → right);
}
  
```

$$T.C = O(N)$$

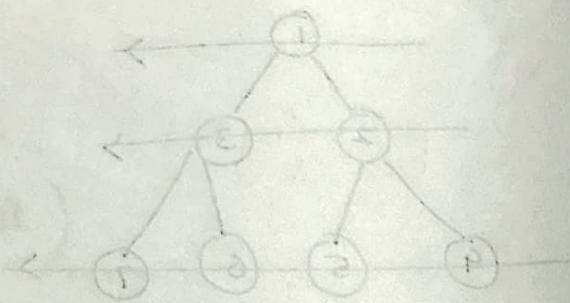
$$S.C = O(N)$$

③ Post Order Traversal

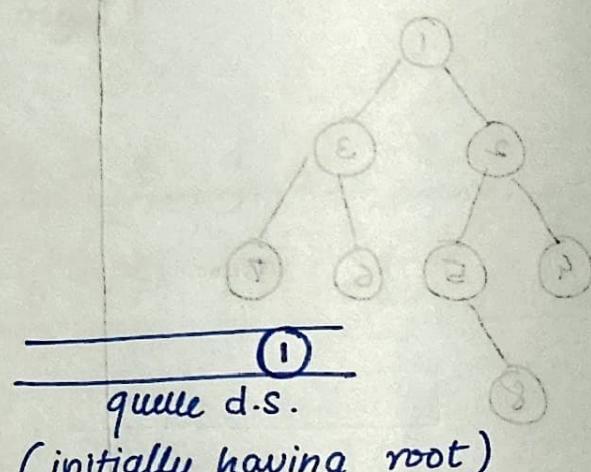
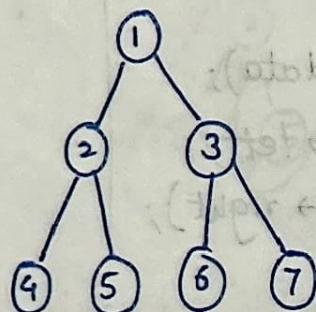
```

void postOrder(node) {
    if (node == NULL)
        return;
    postOrder (node → left);
    postOrder (node → right);
    print (node → data)
}
    
```

↑ or



Level-Order traversal:



Start

(1) 0 = 0.T
Take out = 0 \Rightarrow

① Now check left side exists for this 1

Yes! put in queue

(1) 0 = 0.T

(1) 0 = 22

[4, 5, 6, 7]

[2, 3]

[1]

vector

3
2
1
Q

Now do same for 2 4 3

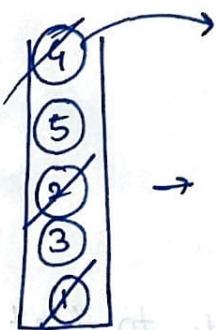
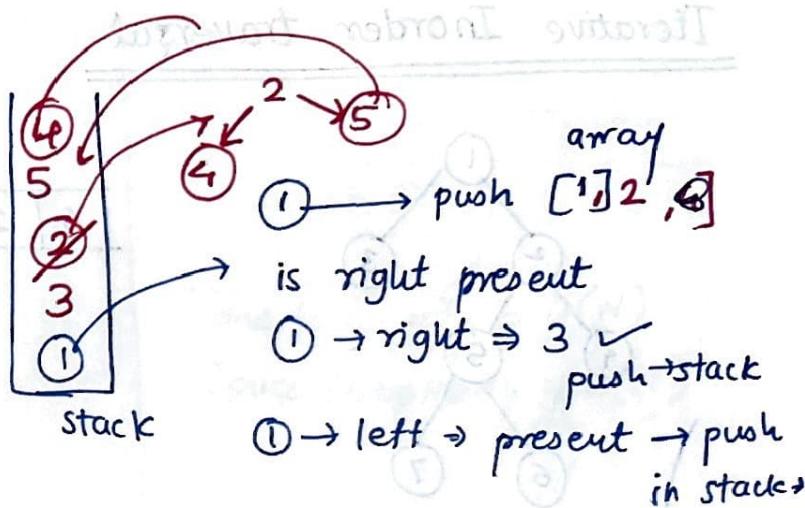
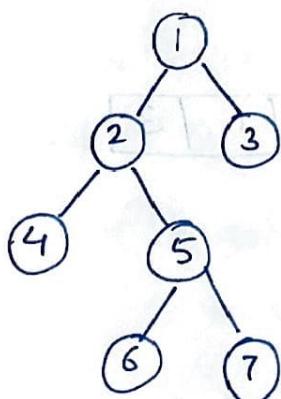
for ②

7
6
5
4



Whenever empty \rightarrow Completed !!

Pre-Order traversal (Iterative)



→ pop this and
push into array

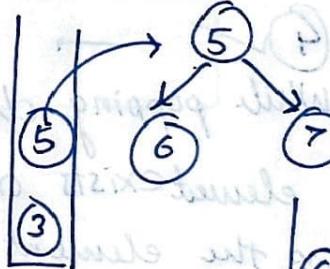
[1, 2, 4]



lun = 5011

⇒ push 5 in ans.

[1, 2, 4, 5]



While doing the level-order traversal

→ we have to iterate over the size of the queue and push left and then right

But in preorder iterative traversal,

Use stack and

push the RIGHT node first and then left node.

vector<int> ans;

stack<TreeNode*> st;

st.push(root)

while(!st.empty()) {

root = st.top();

st.pop();

ans.push_back(root->val);

if (root->right) → push into st.

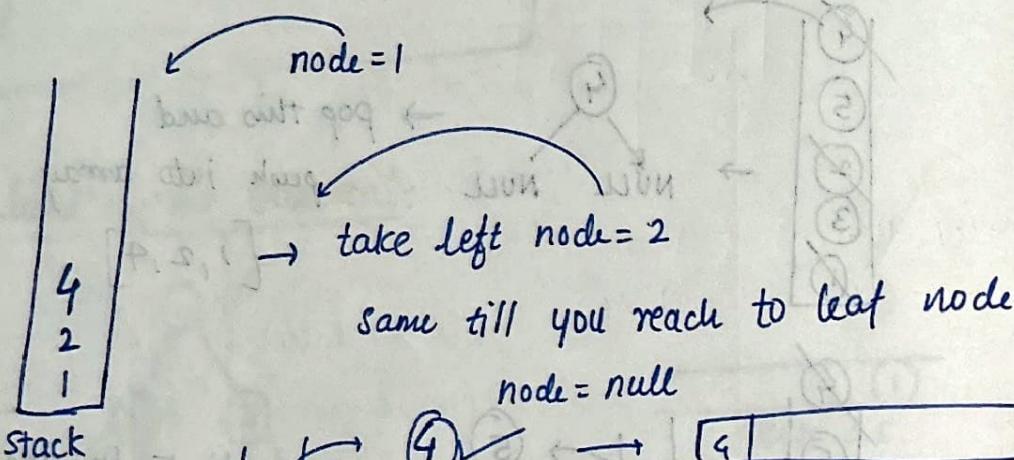
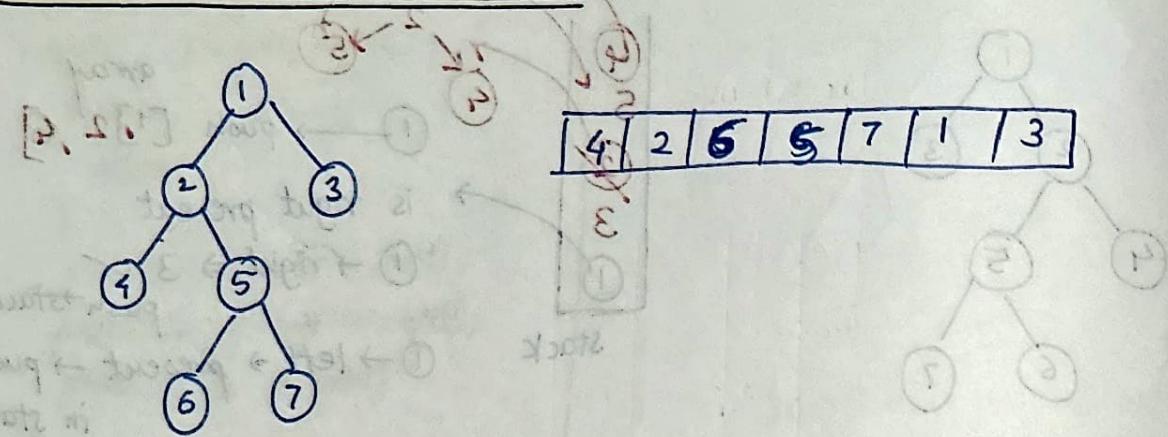
if (root->left) → push into st,

}

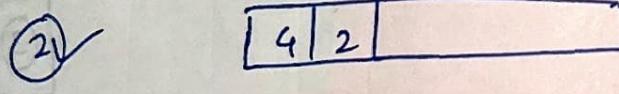
return ans;

Iterative Inorder traversal

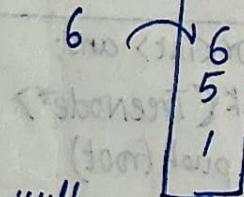
(written II) Learning notes 0-99



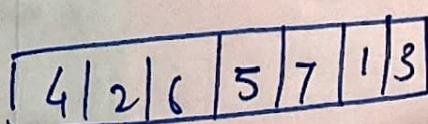
⇒ Stack: 4 2 1 → 4 → 4
while popping check whether right element exists or not if it is then pop the element and assign the right to node = 5



node = 5 → 6 → 6 → 5 → 4 | 2 | 6 | 5 |



node = 7



likethis.

```

stack <TreeNode*> st;
vector <int> result;
TreeNode* node = root; // -> node

```

```
while(true) {
```

```
    if(node == NULL) {
```

```
        st.push(node);
```

```
        node = node->left;
```

```
    } else {
```

```
        if(st.empty()) break;
```

```
        node = st.top();
```

```
        st.pop(); result.push_back(node->val);
```

```
        node = node->right;
```

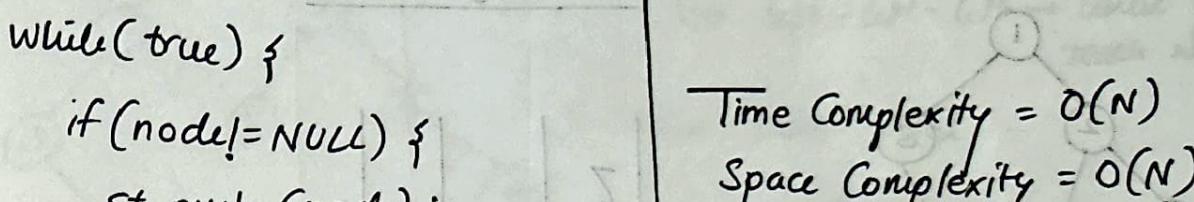
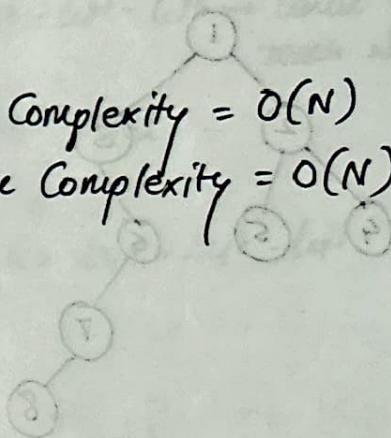
```
    }
```

```
}
```

```
return result;
```

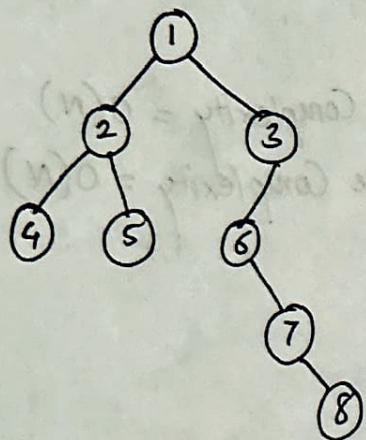
Time Complexity = $O(N)$

Space Complexity = $O(N)$

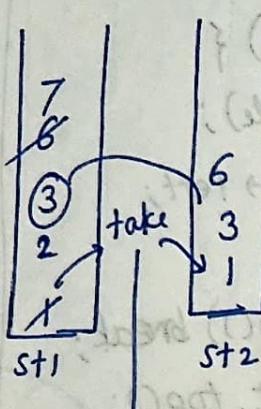


• Iterative post-order traversal

① Using Two-stacks



Left - Right - Root

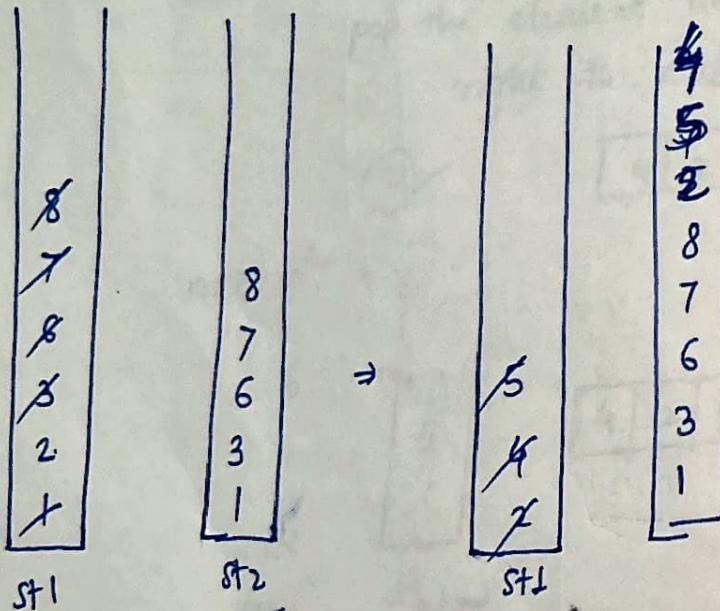


Check if '1' has left \rightarrow yes push into 'St1'
check if '1' has right \rightarrow _____

$\Rightarrow 3 \rightarrow \text{left} \rightarrow 6 \rightarrow \text{push in } St1$

$\Rightarrow 6 \rightarrow \text{right} \rightarrow 7 \rightarrow \text{push in } St1$

Perform this



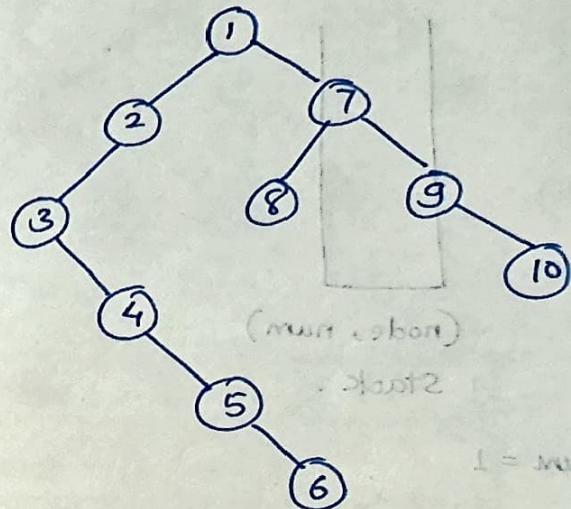
4	5	2	8	7	6	3	1
---	---	---	---	---	---	---	---

This is post order

```

vector<int> postorder;
if (root == NULL) return postorder;
Stack<Node*> St1, St2;
St1.push (root);
while (!St1.empty()) {
    root = St1.pop();
    St1.pop();
    St2.push (root);
    if (root->left)
        St1.push (root->left);
    if (root->right)
        St1.push (root->right);
}
while (!St2.empty()) {
    postorder.push_back (St2.top()->data);
    St2.pop();
}
  
```

② Using One stack



Go left - left - left → until you reach Null
 then take right
 AGAIN Go left - left - left

curr = 1 ← root

while (curr != NULL || !st.isEmpty()) {

if (curr == NULL) {

st.push(curr);

curr = curr → left;

} if of return <

else {

temp = st.top() → right; i →

if (temp == NULL) {

temp = st.top();

st.pop();

dup or not
postOrder.push_back(temp → val);

while (!st.isEmpty() && temp == st.top() → right) {

temp = st.top();

st.pop();

} postOrder.push_back(temp → val);

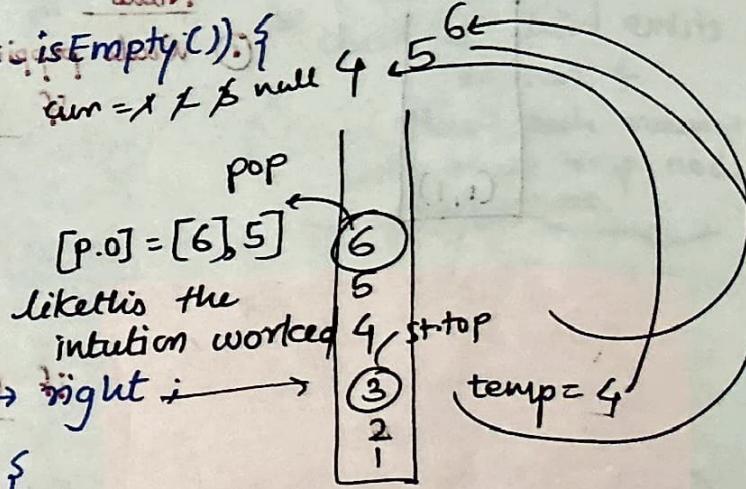
}

else

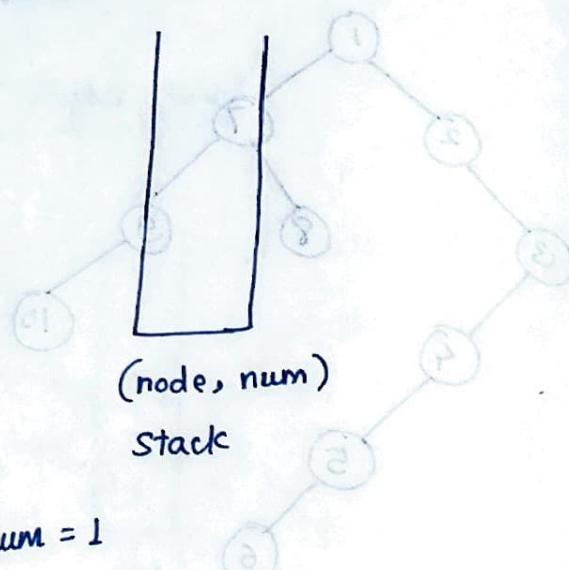
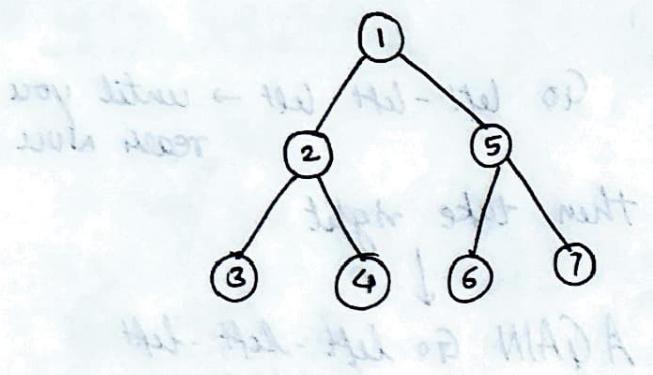
curr = temp;

}

}



PreOrder | InOrder | PostOrder in One traversal



At first push the root node with num = 1

(1, 1)

Rules

① While popping the element from stack

if num == 1

↳ **PRE-ORDER**

push that num++
if (left) exists

↳ enter to left

if (num == 2)

↳ **IN-ORDER**

Increment num++

if (right)

↳ enter to right

While ~~skipping~~ the num (1/2/3)

```

if (num == 1) {
    push (into preOrder)
    do num++;
    push again into stack
    check if (left is present)
    push (left, 1)
    ↳ num
}
  
```

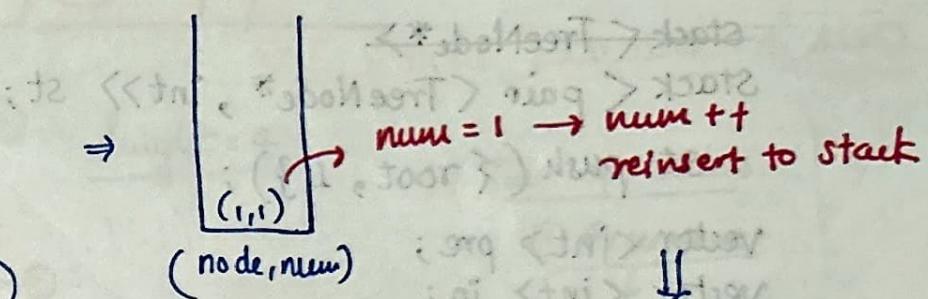
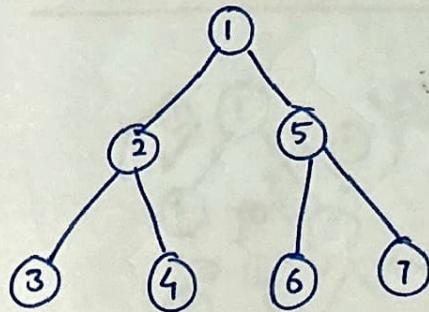
Same for num == 2

```

push it into inOrder
do num++;
push again into stack
check if right is present
→ push (right, 1)
  
```

else simply push-back
to the postOrder <>

DRY RUN



PreOrder : 1 2 3 4 5 6 7

InOrder : 3 2 4 1 6 5 7

PostOrder: 3 4 2 1 6 7 5

$\text{num} = 2$
INORDER
 $\text{num}++ = 3$
 check right
 \downarrow
 No

(3, 1)
(2, 2)
(1, 2)

(5, 1)
(2, 2)
(1, 2)

! pop-it \rightarrow check num
 increment it
 check if child exists
 or not &
 then push num=1
 with their resp. node
~~add it to~~

(3, 3)
(2, 2)
(1, 2)

(3, 2)
(2, 2)
(1, 2)

POST ORDER

pop the element
& node

$\text{num} = 3$

(4, 1)
(2, 2)
(1, 2)

INORDER $\therefore 2$
 \downarrow
 $\text{num}++ = 3$
 check right
 \downarrow
(4, 1)

(4, 1)
(2, 3)
(1, 2)

$\Rightarrow \text{num} 2$

INORDER

post order

\downarrow
 $\text{num} + +$
 $\Rightarrow (4, 3)$

likewise
you have
to
perform

(1, 3)

post post \rightarrow pop
Inorder

(5, 1)
(1, 2)

\rightarrow post \rightarrow pop
 \Rightarrow
(2, 3)
(1, 2)

Time Complexity = $O(N)$

Space Complexity = $O(N)$

```
stack <TreeNode*>
```

```
Stack < pair <TreeNode*, int>> st;
```

$\dagger \text{num} \leftarrow 1 = \text{num}$

root or root.push({root, 1});

```
vector <int> pre;
```

```
vector <int> in;
```

```
vector <int> post;
```

```
if (root == NULL) return;
```

```
while (!st.empty()) {
```

auto it
~~TreeNode*~~ top = st.top();

were here <= st.pop();

\dagger traversal

time block for

\dagger far to

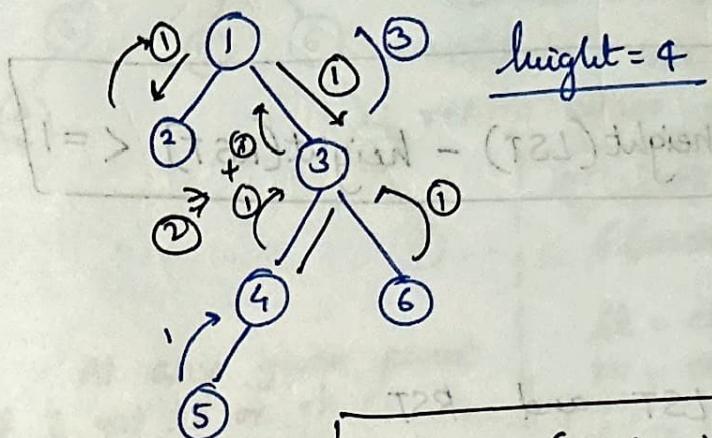
\dagger num next
more long next
more que next via
 \dagger time

```
if (top
```

\dagger num

Maximum Depth of Binary Tree

Question for 2nd year IT students



height = 4

Two approaches

① Recursive

Auxiliary Space $O(N)$

② Iterative

Queue D.S.

$S.C. \Rightarrow O(N)$

$$1 + \max(\text{left}, \text{right})$$

At ④ $\rightarrow 1 + \max(1, 0)$

$\Rightarrow 1 + 1 = 2 \rightarrow$ for 4 $\rightarrow \text{height} = 2$

for ⑥ $\rightarrow 1 + \max(0, 0) \rightarrow 1$

for ③ $\rightarrow 1 + \max(\text{left}, \text{right})$

$(1) + \max(2, 1) \Rightarrow 1 + 2 = 3$

```

int maxDepth(TreeNode* root) {
    if (root == NULL) return;
    int leftHeight = maxDepth(root->left);
    int rightHeight = maxDepth(root->right);
    return 1 + max(leftHeight, rightHeight);
}
  
```

~~sort priority to height maximum~~

• Check for balanced binary Tree :-

Balanced binary Tree :-

$$\text{height(LST)} - \text{height(RST)} \leq 1$$

Naive solution :-

Compute the height of LST and RST
and check the difference.

pseudo code

```
check(node) {
    if (node == null) return true;
```

$Lh = \text{findHeight}(\text{node} \rightarrow \text{left});$ $O(n)$
 $Rh = \text{findHeight}(\text{node} \rightarrow \text{right});$ $O(n)$ $\Rightarrow O(n^2)$

```
    if ( $|\text{abs}(Lh - Rh)| > 1$ ) return false;
```

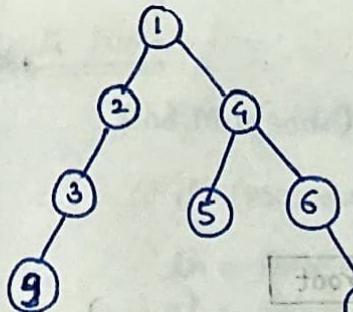
```
    Bool left = check(\text{node} \rightarrow \text{left});
    Bool right = check(\text{node} \rightarrow \text{right}),
}
```

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

```
    return true;
```

}

we have to
check for
every node.



Optimal code

~~lets dry run~~ The idea is to add the conditions. So before we were returning the true/false. but now instead of this we will return either -1 or height.

(using tree from previous slide)

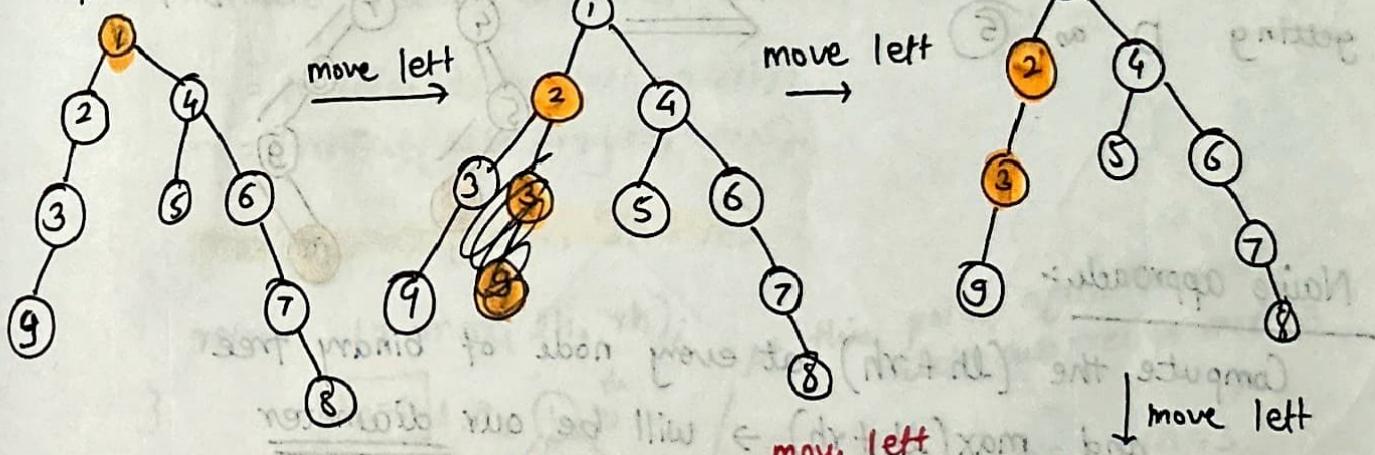
At any given point
if I got lh or rh as
-1 return -1

return -1 if
absolute diff exceeds

```
int check(node) {
    if (node == null) return 0;
    lh = check(node->left);
    rh = check(node->right);
    if (lh == -1 || rh == -1) return -1;
    if (abs(lh - rh) > 1) return -1;
    return max(lh, rh) + 1
}
```

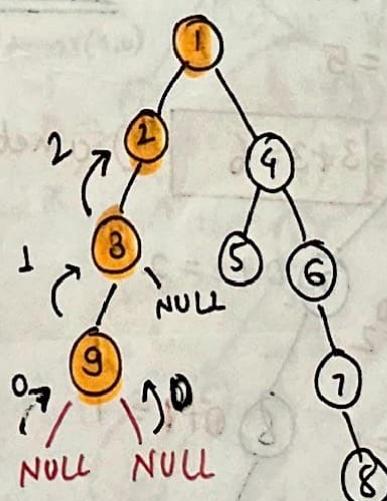
T.C = O(N) → Recursive traversal
S.C = O(N) → Auxiliary space for skewed tree

Dry run :-



At ③
from left = 1
from right = 0

$$\max(1, 0) + 1 = 1 + 1 = 2$$

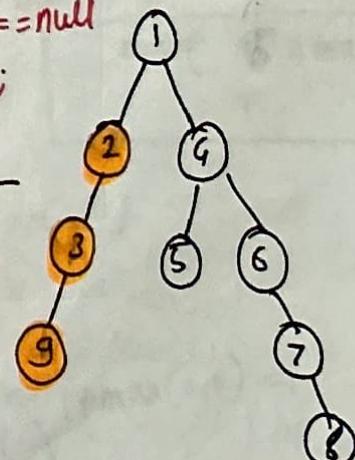


move leftt
here, node == null
return 0;

$$\Rightarrow lh = 0$$

$$\Rightarrow rh = 0$$

$$\text{return } \max(0, 0) + 1 = 1$$



At ② → the height

$$lh = 2 \\ rh = 1$$

$\rightarrow \text{if } (\text{abs}(lh - rh) > 1) \text{ return -1}$
This condition is executed!

Tree is ~~not~~ not a balanced binary tree!

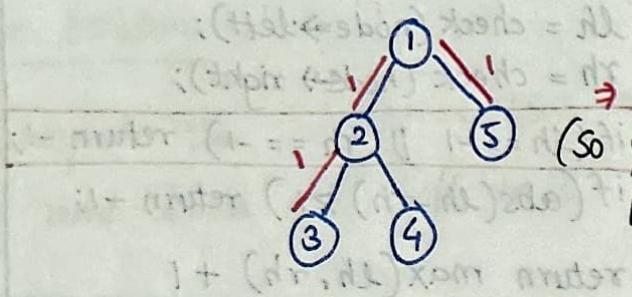
Diameter of binary tree

Diameter :-

→ Longest path between 2 nodes.

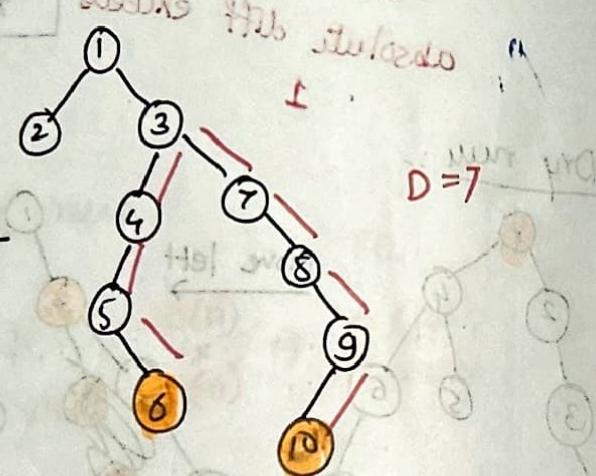
→ Path does not need to pass via root
optional (It can pass or may not pass)

This is tricky I'll show you How?



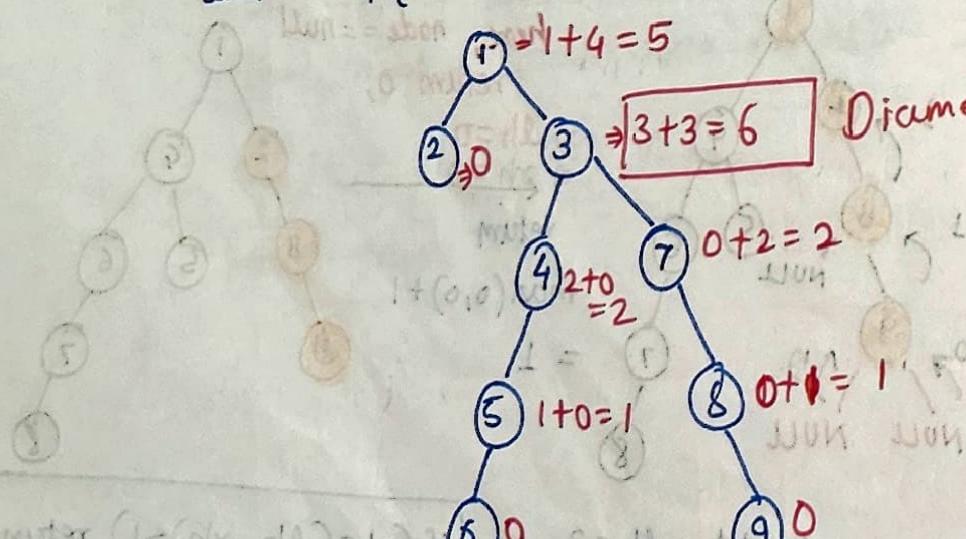
(Height of left node = 3)
(Height of right node = 1) $\Rightarrow 3$
(So you might think we should always pass through root node)

If I would have chosen the path which passes through root then I would have ended up getting D as 5



Naive approach :-

Compute the $(lh + rh)$ at every node of binary tree and $\max(lh + rh) \rightarrow$ will be our diameter



Diameter = 6

sort priority bounded to tail of array

Brute Force:-

findMax(node) {

 if (root == null) return 0;

 lh = findLeftH(node → left);

 rh = findRightH(node → right);

 maxi = max(maxi, lh + rh);

 findMax(node → left);] → Go to left and right

 findMax(node → right); and compute the max height
 EVERYTIME!!

now think about to sing you my song

T.C = O(N²)

Optimal ⇒

int findMax(node, maxi) {

 if (node == null) return 0; ← to below

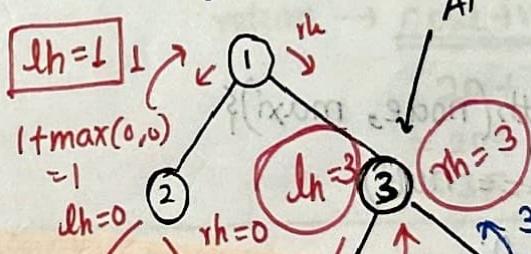
 int lh = findMax(node → left, maxi); ← to above

 rh = findMax(node → right, maxi); ← to above

 maxi = max(maxi, lh + rh); ← to above

 return 1 + max(lh, rh); ← to above

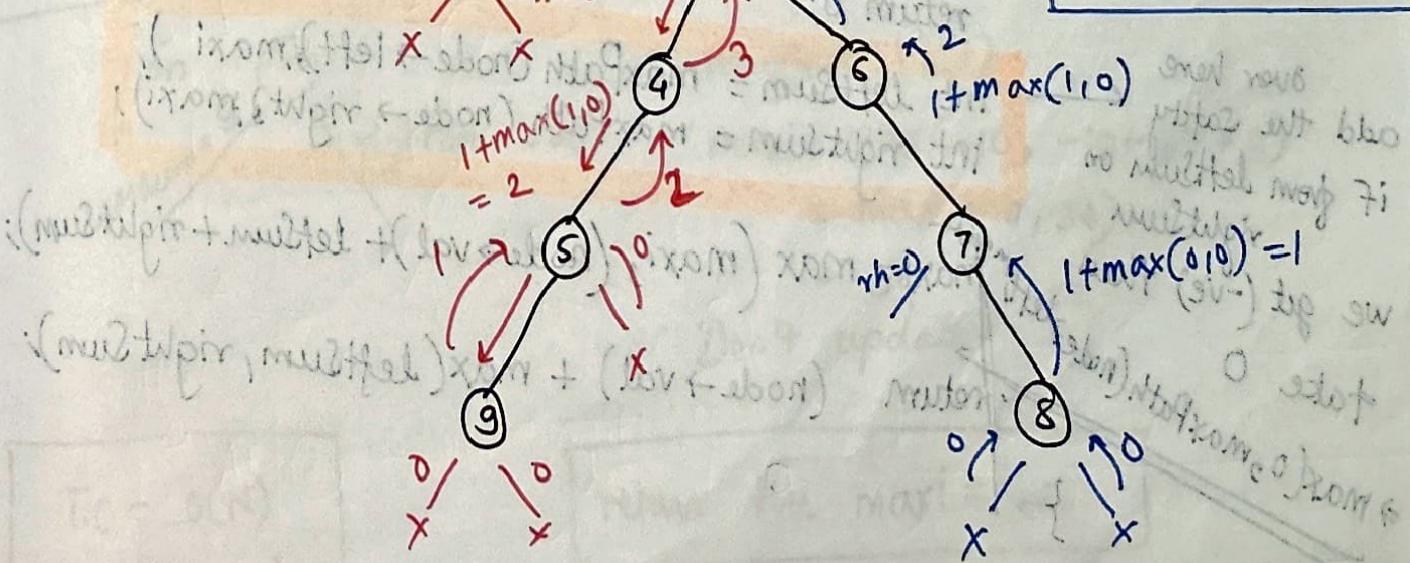
}



At this point after traversal
left sub tree \Rightarrow maxi = 3

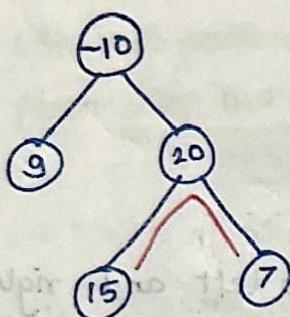
lh = 3, rh = 3

maxi = 6 \Rightarrow maximum



• Maximum Path Sum :-

Any node appears once while traversing through tree



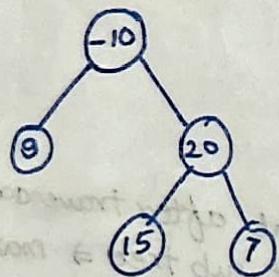
$$15 + 20 + 7 = 42 \text{ (Maximum path sum)}$$

Brute force :-

Find the path sum of for every pair of nodes which can cost $> O(n^2)$

prerequisite \Rightarrow **Maximum Height (BST)**
Width of BST

for every node, we need to compute the left sum and right sum



$$\text{formula} \rightarrow (\text{node} \rightarrow \text{val}) + (\text{rightSum} + \text{leftSum})$$

Dry run :-

```
int maxPath(node, maxi){
```

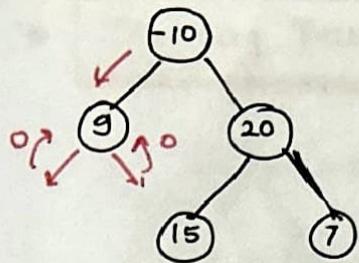
```
    if (node == null)
        return 0;
```

```
    int leftSum = maxPath(node->left), maxi);
    int rightSum = maxPath(node->right), maxi);
```

over here
add the safety
if from leftSum or
rightSum we get (-ve) then
take 0
 $\Rightarrow \max(0, \maxPath(\text{node} \rightarrow \text{left}), \text{right}))$

```
maxi = max(maxi, (node->val) + leftSum + rightSum);
```

```
return (node->val) + max(leftSum, rightSum);
```



At ⑨

$$\text{maxi} = \max(0, 9 + 0 + 0)$$

$$= \max(0, 9)$$

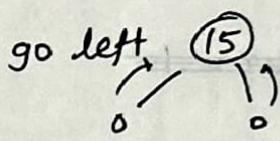
$$\text{maxi} = 9$$

$$\text{return } \rightarrow 9 + \max(0, 0) = 9$$

return to -10

At ⑩ → leftSum = 9

right, ⑯ → go left



$$\text{maxi} = 9 \text{ (old)}$$

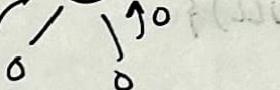
$$\text{maxi} = \max(9, 15 + 0 + 0)$$

$$= \max(9, 15)$$

$$\text{maxi} = 15 \rightarrow \text{returned } 15 \rightarrow ⑯$$

$$\text{return } 15 + \max(0, 0)$$

⑯ → right → ⑦



$$\text{maxi} = 15 \text{ (old)}$$

$$\text{maxi} = \max(15, 7 + 0 + 0)$$

$$= \max(15, 7)$$

$$= 15 \rightarrow \text{return to } ⑯$$

$$\text{return } \rightarrow 7 + \max(0, 0) \rightarrow \text{return to } ⑯$$

leftSum = 15
rightSum = 7

$$\text{maxi} = 15$$

$$\text{maxi} = \max(15, 20 + 15 + 7)$$

$$= \max(15, 42)$$

$$\text{return } \rightarrow \underline{\text{node}} + \underline{\text{val}} \rightarrow \dots$$

$$20 + \max(15, 7)$$

$$= 20 + 15$$

$$= 35 \rightarrow \text{return to } (-10)$$

on
leftSum = 9
rightSum = 35

$$\text{maxi} = 35 \text{ (old)}$$

$$\text{maxi} = \max(-10, -10 + 35 + 9)$$

$$= \max(-10, 34)$$

$$= 34$$

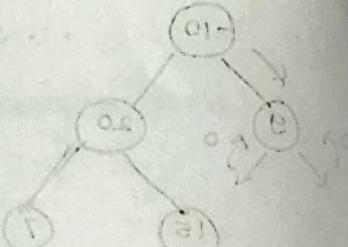
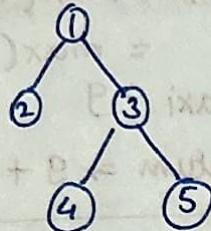
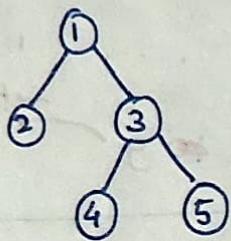
Don't update

T.C = O(N)
S.C = O(N)

return the maxi = 42

from main function

Same Tree or not :



preOrder = Traverse in both the ~~preOrder~~ trees at the same time

```

bool isSameTree(TreeNode* p, TreeNode* q) {
    if (p == NULL || q == NULL)
        return (p == q);
    if ((p->val) == (q->val))
        isSameTree (p->left, q->left);
    if ((p->right) == (q->right))
        isSameTree (p->right, q->right);
}
  
```

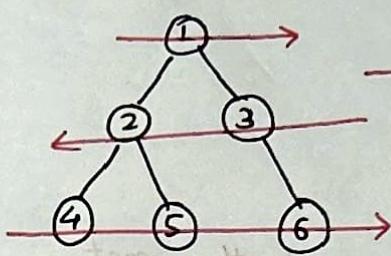
$SP = \text{ixom ant water}$

nothing more

$(H)O = 3T$

$(H)O = 3Z$

Zig-Zag Traversal

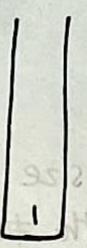


1 2 3 4 5 6 → This is zig-zag pattern

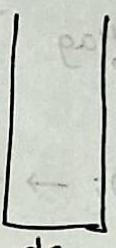


:

1 2 3 4 5 6 ← (1) 2 3 4 5 6 → (2) 3 4 5 6 1 2



Queue



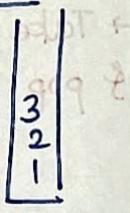
ds vector<vector>

direction = 0

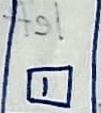
"0" → LEFT → RIGHT
"1" → RIGHT → LEFT

Dry Run ::

1 → left → 2 → push into Q
1 → right → 3 → push into Q

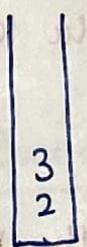


Once done
remove 1 from Q and put it into ds

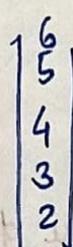


Now reverse the direction → 1

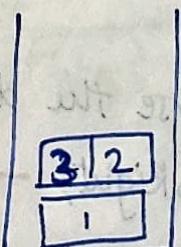
2 → 2 → left → 4 → push → Q
2 → right → 5 → push → Q



3 ⇒ 3 → left → NULL
3 → right → 6 → push → Q



Once done → from right to left



Likewise

$$(1) O = 3T$$

$$(2) O = 3Z$$

```
vector<vector<int>> zigZagLevelOrder(TreeNode* root) {
```

```
    vector<vector<int>> result;
```

```
    if (root == NULL) {  
        return result;  
    }
```

```
    queue<TreeNode*> nodesQueue;
```

nodesQueue.push(root); \rightarrow Initially push the root

```
    bool leftToRight = true;  $\rightarrow$  flag
```

```
    while (!nodesQueue.empty()) {
```

```
        int size = nodesQueue.size();  $\rightarrow$  find the size E.g.
```

```
        vector<int> row(size);
```

```
        for (int i=0; i<size; i++) {
```

```
            TreeNode* node = nodesQueue.front();  $\rightarrow$  Take front
```

```
            nodesQueue.pop();
```

ab

// find position to fills node value

int index = leftToRight ? i : (size - i - 1); \rightarrow Check direction

row[index] = node \rightarrow val \rightarrow push basic on direction

```
if (node  $\rightarrow$  left) {
```

nodesQueue.push(node \rightarrow left); $\boxed{}$ push the left node

```
}
```

```
if (node  $\rightarrow$  right) {
```

nodesQueue.push(node \rightarrow right); $\boxed{}$ push the right node

```
}
```

// after this level, reverse the direction

leftToRight = !leftToRight; \rightarrow Reverse the direction

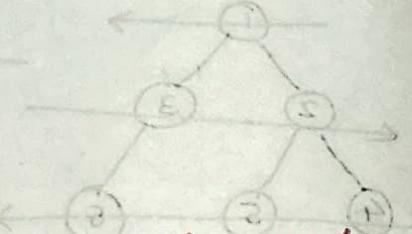
result.push_back(row); \rightarrow put the row in result

```
}
```

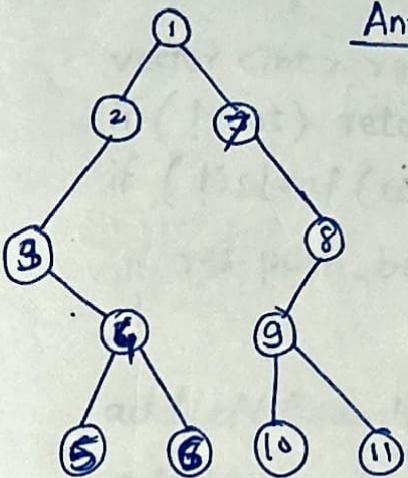
```
return result;
```

3

T.C = O(N)
S.C = O(N)



• Boundary Traversal :-



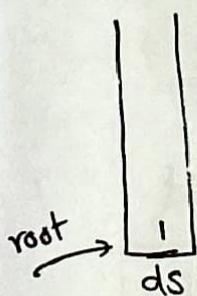
Anticlockwise

~~+ 2 4 5 6 7~~

Left Boundary (Excluding leaves)

Leaves (prefer Inorder)

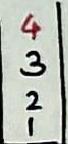
Right Boundary in the reverse + Exclude leaf nodes



Start with left boundary

node → left → put it into ds ⇒

check again node → left



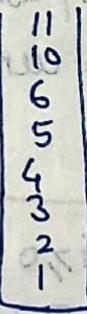
If there doesn't exist left → go to right

then check the node → left ⇒ 5 but this

is leaf nod
so SKIP

for leaf nodes
(INORDER TRAVERSAL)

Root left Right ⇒ 5 6 10 11



Right Boundary In Reverse



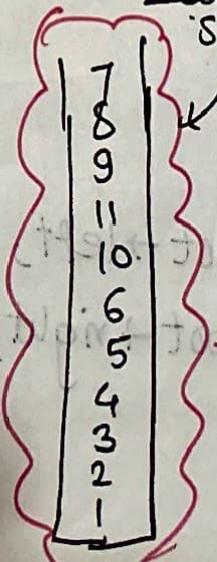
→ go to right 8 ⇒ does right exist ??

No

If right doesn't exist

Then move to LEFT

Again check for right node



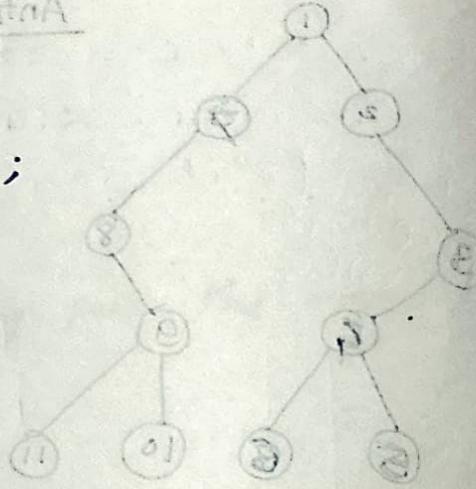
Take from last

→ This is the boundary traversal.

```

void addLeftBoundary(Node* root, vector<int>& res) {
    Node* curr = root->left;
    while (curr) {
        if (!isLeaf(curr)) {
            res.push_back(curr->val);
        }
        if (curr->left) {
            curr = curr->left;
        } else {
            curr = curr->right;
        }
    }
}

```



```
void addRightBoundary(Node* root, vector<int>& res) {
```

```
    Node* curr = root->right;
```

```
    vector<int> tmp;
```

```
    while (curr) {
```

```
        if (!isLeaf(curr)) tmp.push_back(curr->val);
        if (curr->right) curr = curr->right;
        else curr = curr->left;
    }
```

```
    for (int i = tmp.size() - 1; i >= 0; i--) {
        res.push_back(tmp[i]);
    }
}
```

Reversing

```
void addLeaves(Node* root, vector<int>& res) {
```

```
    if (isLeaf(root)) {
```

```
        res.push_back(root->val);
        return;
    }
```

```
}
```

```
if (root->left) { addLeaves(root->left, res); }
```

```
if (root->right) { addLeaves(root->right, res); }
```

Inorder traversal

Root

Left

Right

```
vector<int> printBoundary (Node *root) {
```

```
    vector<int> res;
```

```
    if (!root) return res;
```

```
    if (!isLeaf (root)) {
```

```
        res.push_back (root->val);
```

```
}
```

```
    addLeftBoundary (root->left, res);
```

```
    addLeaves (root->right, res);
```

```
    addRightBoundary (root->right, res);
```

```
    return res;
```

```
}
```

$$T.C. = O(H) + O(H) + O(N) \approx O(N)$$

height of tree height of tree Inorder traversal

$$S.C = O(N)$$



01 \rightarrow (0,0) to see why it is

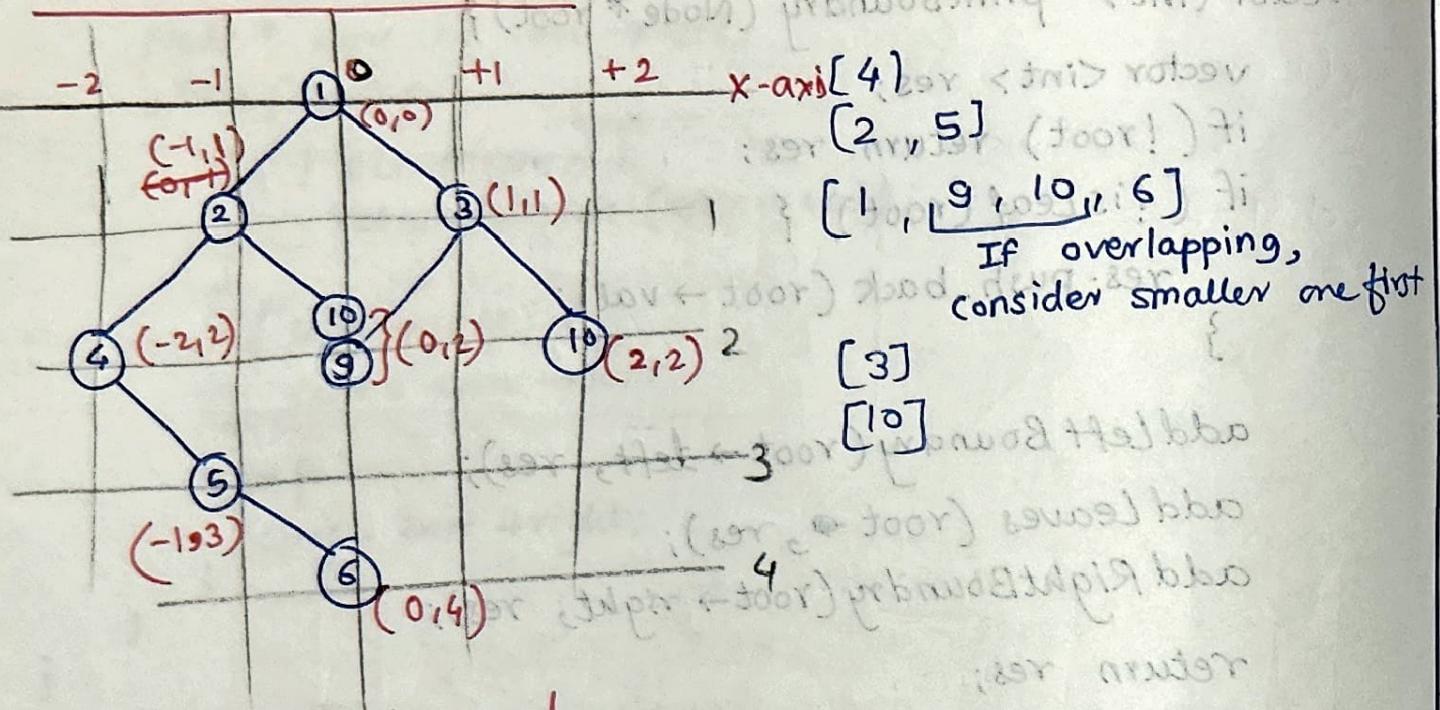
leftmost child
child is left

leftmost child

because it comes first

no other son exists

• Vertical Order traversal



Data Structures to be used :-

Queue

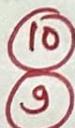
Q<node, vertical, level>

map<int, vector<int>>

represent vertical

for every vertical → Why I'm taking
map!!

so if you see at (0,2) →



At every level there can be multiple nodes I need them into sorted order that is why multiset

Why multiset

Because at each level duplicate node values can present.

node = 1

(1, 0, 0)

Q (node, vertical, level)

ds

map<int, map<>>

Insert into ds

0 → {0} → {1}

ds

This is the form

↓

node = 2 (moved left) → vertical -
level + 1;

(1, 0, 0), (2, -1, 1),

Q

↓

move ~~left~~ right

~~node~~

node = 3

(2, -1, 1), (3, 1, 1)

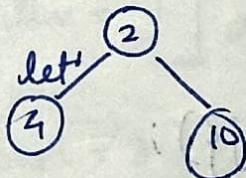
Q

vertical ++;
level ++;

node = 2
vertical = -1
level = 1

→ store into ds

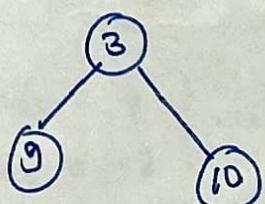
-1 → 1 → {2}
0 → 0 → {1}



(3, 1, 1), (4, -2, 2), (10, 0, 2)

Q

-1 → 1 → {3}
-1 → 1 → {2}
0 → 0 → {1}



(4, -2, 2), (10, 0, 2), (9, 0, 2), (10, 2, 2)

; like this

left

Right

(-1, +1)

(+1, +1)

Level order traversal used :

```
vector<vector<int>> verticalTraversal(TreeNode* root) {
    map<int, map<int, multiset<int>> nodes;
```

queue < pair<TreeNode*, pair<int, int>> todo;
 todo.push({root, {0, 0}});
 while (!todo.empty()) {
 (vertical, level)

auto p = todo.front();

todo.pop();

TreeNode* node = p.first;

int x = p.second.first; → vertical

int y = p.second.second; → level

nodes[x][y].insert(node → val);

if (node → left) {

todo.push({node → left, {x-1, y+1}});

}

if (node → right) {

todo.push({node → right, {x+1, y+1}});

}

}

vector<vector<int>> ans;

for (auto p: nodes) {

vector<int> col;

for (auto q: p.second) {

col.insert(col.end(), q.second.begin(),

q.second.end());

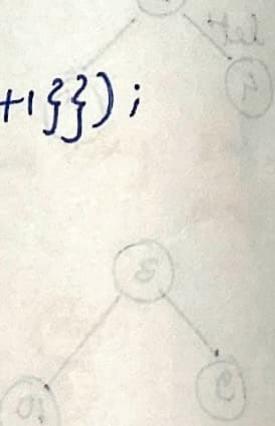
}

ans.push-back(col);

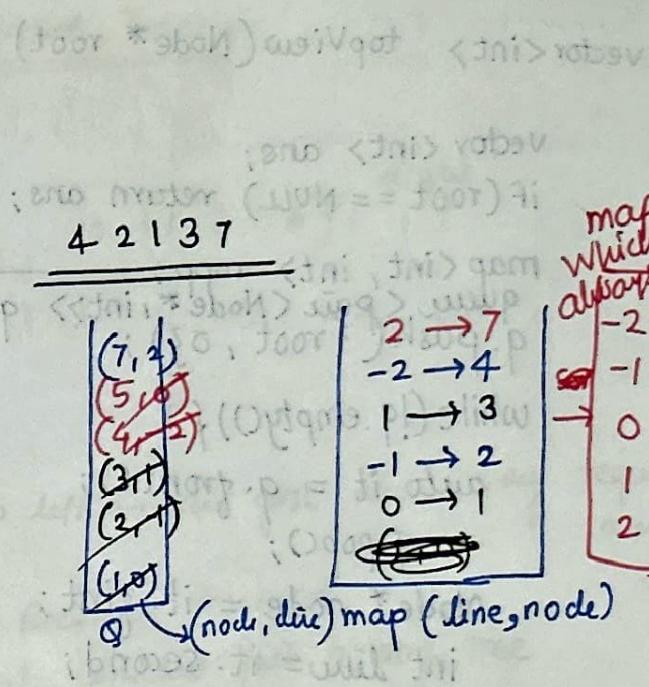
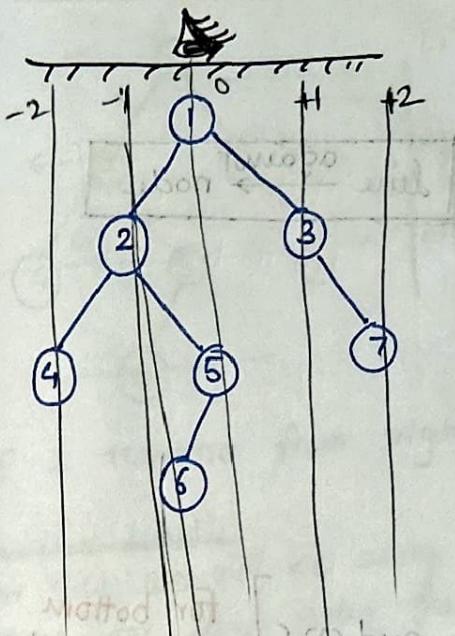
}

return ans;

}



Top view of Binary tree



node = 1 left ② → present on the -1 line
 line = 0 and on right ③ → +1 to line

node = 2 left ④ → do line -1 → -1 -1 = -2
 line = -1 and right ⑤ → do line +1 → -1 +1 = 0

node = 3 left → NULL
 line = 1 right → ⑦ → do line ++ → 1 + 1 = 2

node = 4 left → NULL
 line = -2 right → NULL

node = 5 Now on line = 0 → (0 → 1) "1" is already present hence don't consider
 line = 0 (0 → 5) ×

node = 7 left = NULL → push (2 → 7) in map
 line = 2 Right = NULL

(2, 1) above level will come in 2nd

1st level need to wait below

```
vector<int> topView(Node* root) {
```

```
    vector<int> ans;  
    if (root == NULL) return ans;  
    map<int, int> mpp;  
    queue<pair<Node*, int>> q;  
    q.push({root, 0});
```

```
    while (!q.empty()) {  
        auto it = q.front();  
        q.pop();  
        Node* node = it.first;  
        int line = it.second;  
        if (mpp.find(line) == mpp.end()) {  
            mpp[line] = node->val;  
        }
```

```
        if (node->left != NULL) q.push({node->left, line - 1});  
        if (node->right != NULL) q.push({node->right, line + 1});
```

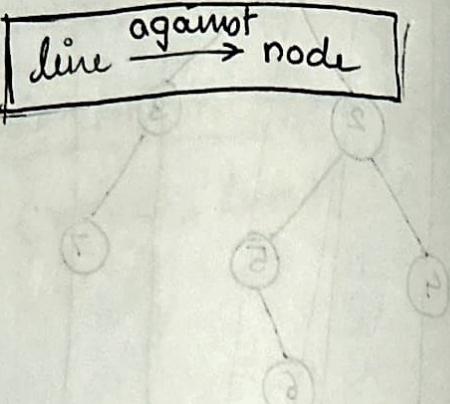
```
}
```

```
for (auto it: mpp){  
    ans.push_back(it.second);
```

```
}
```

```
return ans;
```

line $\xrightarrow{\text{against}}$ node



For bottom view of the tree we can remove the if block and override the values.

TC = O(N)
SC = O(N)

Notes to be discussed

Why the recursive approach is not used?

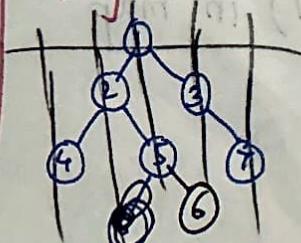
Why the level-order traversal is used.

→ If you've used inorder traversal then you would have visited

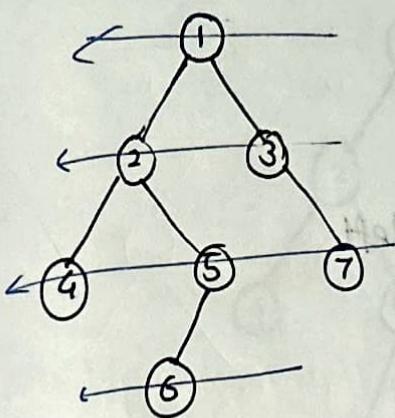
1 2 4 5 6 → This node is at (+1)

so in map the desired node (i.e. 3)

would have not been pushed!!



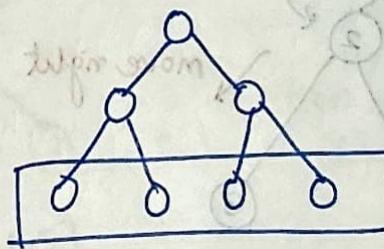
Right / Left View of Binary Trees :-



(Right view) $\rightarrow [1, 3, 7]$ (Left view) $\rightarrow [1, 3, 6]$

If I traverse from right to left \rightarrow the first node is my required ans.

In the level for this we will be using $\&$ Recursive traversal cause for level order traversal, consider full binary tree



In the worst case you will need to maintain 4 nodes and due to this space complexity can be very much.

Hence we will be using "RECURSIVE TRAVERSAL".

but in recursive the T.C = $O(N)$ but S.C = $O(H)$ \rightarrow Height of the tree.

preOrder \rightarrow Root, left, right

But for this \rightarrow [Root, right, left]

```

root, o
f(node, level) {

```

```

    if (node == NULL) return;

```

```

    if (level == ds.size) {

```

```

        ds.push_back(node->val);
    }

```

```

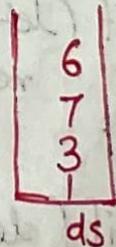
    if (node->right, level+1);

```

```

    if (node->left, level+1);
}

```



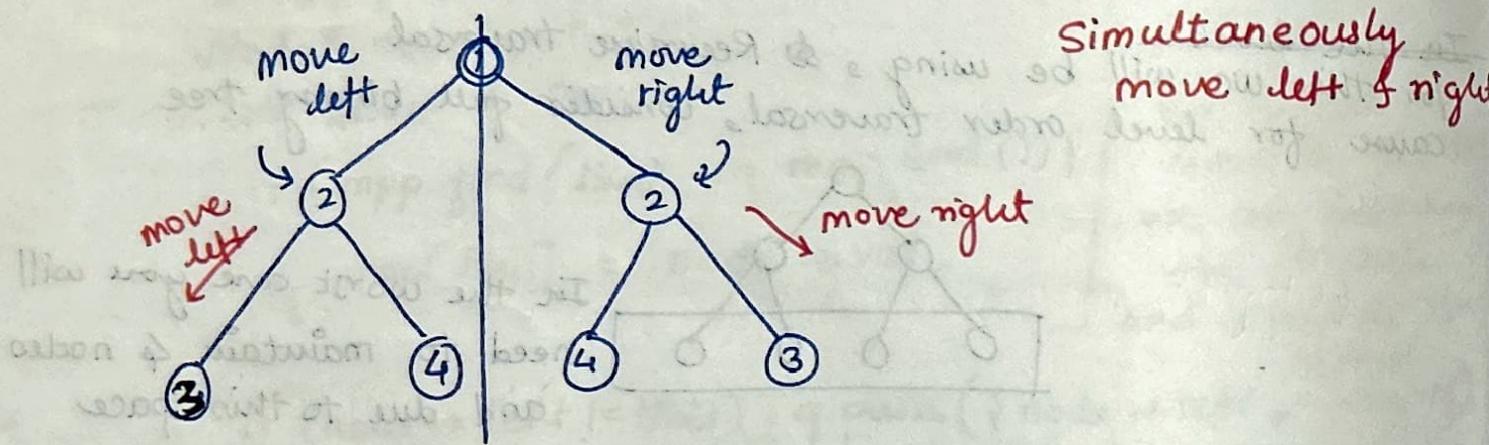
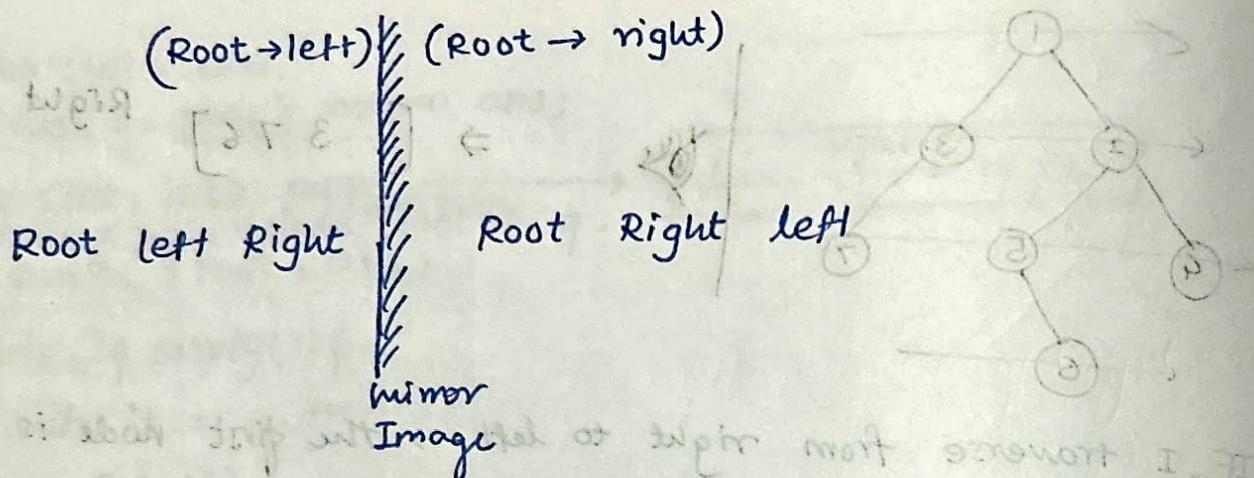
Check the ds size at each traversal.

(H.O = 3.7)
(L.O = 3.2)

for left view \Rightarrow Traverse

(R L Right)

Symmetric Binary Tree:-



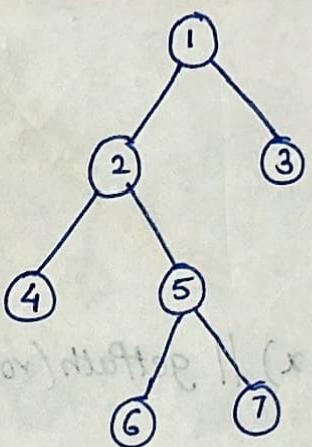
```
bool isSymmetricTree(TreeNode* node) {
    return root == NULL || isSymmetricHelper(node->left, node->right);
}
```

```
bool isSymmetricHelper(TreeNode* left, TreeNode* right) {
    if (left == NULL || right == NULL) {
        return left == right;
    }
    if (left->val != right->val) return false;
    return isSymmetricHelper(left->left, right->right) && isSymmetricHelper(left->right, right->left);
}
```

$$T.C = O(N)$$

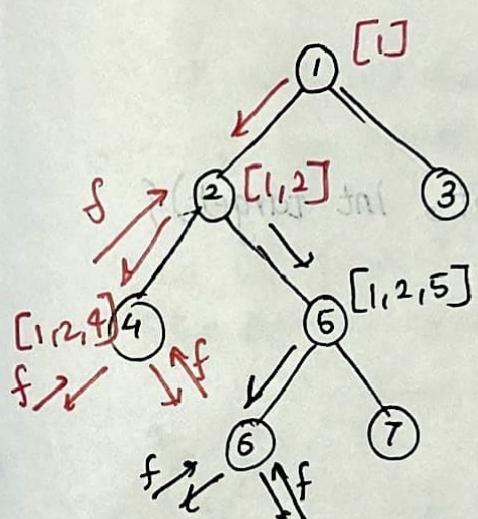
$$S.C = O(N)$$

• Print Root to Node path in Binary Tree:



node = 7
path from '1' to '7'
 $\Rightarrow [1, 2, 5, 7]$

Traversal \Rightarrow Inorder traversal



first move to left & come back

then

right and come back

At ② \rightarrow is 2 == 7 No! \rightarrow push [1, 2]

move left ④ \rightarrow is 4 == 7 No! \rightarrow push [1, 2, 4]

move left \Rightarrow NULL \Rightarrow return false

move right \Rightarrow NULL \Rightarrow return false

so from node ④ \rightarrow false is returned hence pop the last element (4) \Rightarrow [1, 2, 4] will become [1, 2]

move right from ② \rightarrow 5 == 7 No! \rightarrow push [1, 2, 5]

move left \Rightarrow ⑥ \rightarrow 6 == 7 No! \rightarrow push [1, 2, 5, 6]

move left of ⑥ \rightarrow NULL \rightarrow return false.

move right of ⑥ \rightarrow NULL \rightarrow return false \Rightarrow pop the ⑥

Array is [1, 2, 5]

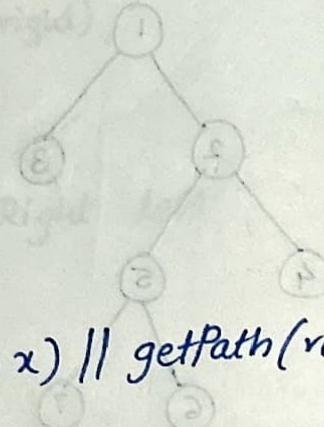
Now move right of ⑤ \rightarrow 7 is 7 == 7 \Rightarrow True \rightarrow push [1, 2, 5, 7]
return True.

The moment you get true from any of the left call or right call you've got the answer.

```

bool getPath(TreeNode* 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;
    arr.pop_back();
    return false;
}

```

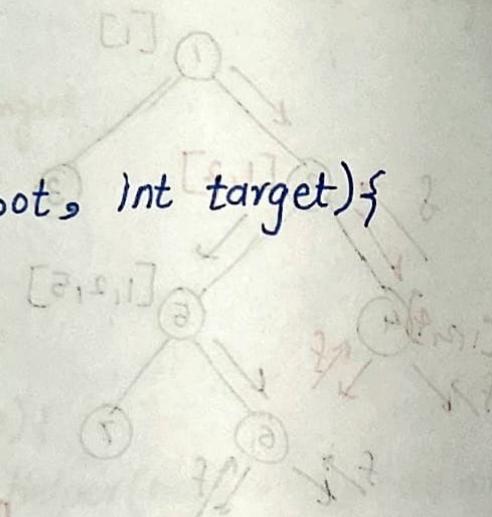


last visit reborn ← last visit

```

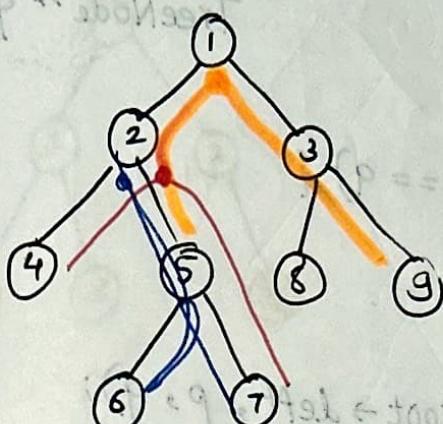
vector<int> pathToNode(TreeNode* root, int target) {
    vector<int> arr;
    if (root == NULL)
        return arr;
    getPath(root, arr, target);
    return arr;
}

```



Max height of max depth way from int
maximal int top always no tups to

Lowest Common Ancestor in Binary Trees



$$\text{dca}(4,7) = 2$$

$$\text{lca}(5, 9) = 1$$

$$\text{lca}(2,6) = 2$$

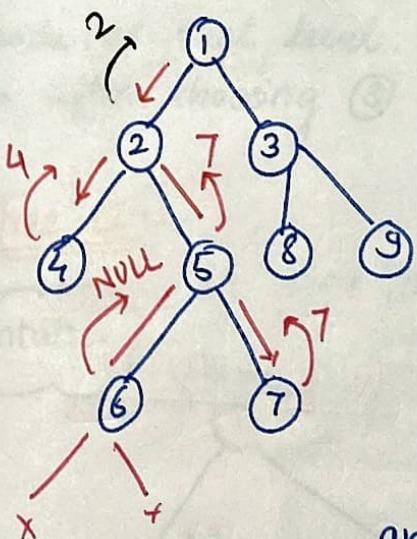
node = 4 path (1, 2, 7)
node = 7 Path (1, 2, 5, 7)

⇒ Whatever the last element is matched in path that is our lowest common ancestor.

T.C = O(N) → To find the path

S.C = $O(N)$ → Extra use of time complexity

$\text{lca}(4,7)$



- We will recursively traverse
- go to left \Rightarrow DFS → and whenever you encounter any of the node (4 / 7) then you have to return (node ~~marked~~) **IMPORTANT!**

⇒ At ⑤ from left → NULL
and ↑
Right

and now ⑤ will return 7

At $\textcircled{2}$ left $\xrightarrow{4}$ $\textcircled{2}$ \nearrow Right \Rightarrow This signifies you have figured out both the nodes

If left != NULL & right != NULL then

At this point, means whenever you encounter any node whose left & right both have valid values then return the (node ~~value~~) \Rightarrow And this is LCA.

`TreeNode* LowestCommonAncestor(TreeNode* root, TreeNode* p, TreeNode* q);`

// base case :-

```
// base case:  
if (root == NULL || root == p || root == q) {  
    return root;  
}  
}
```

`TreeNode* left = lowestCommonAncestor (root → left, p, q);`
`TreeNode* right = lowestCommonAncestor (root → right, p, q);`

if (left == NULL) return right;

if (right == NULL) return left;

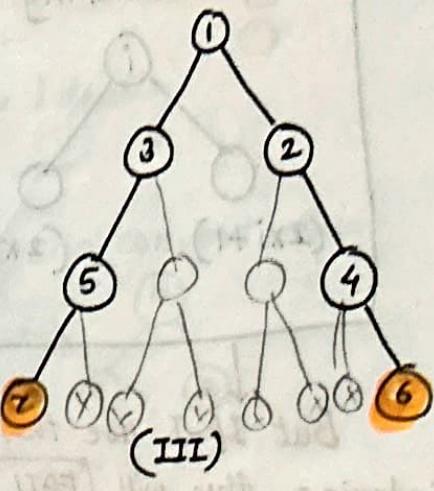
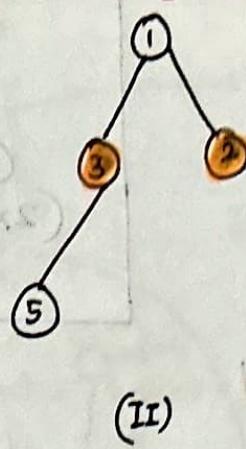
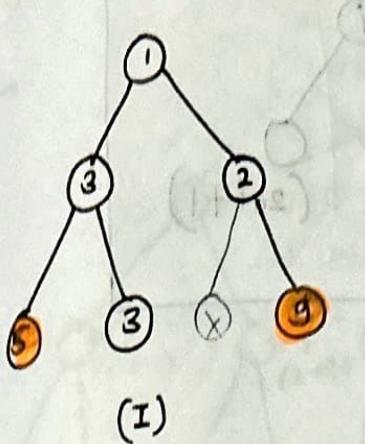
else return root; returns normal tree if no si

3

I understand now (2) with how

ADJ: si $a \in B$ $\in (\text{Folge ab})$ mit $a_n \rightarrow a$

Maximum width of Binary Tree :-



Width of Binary tree :- No. of nodes in a level betn any two nodes.

(I) Tree :-

⑤ and ⑨ are on the same level and if ② would have the left node then the maximum width of tree ≥ 4

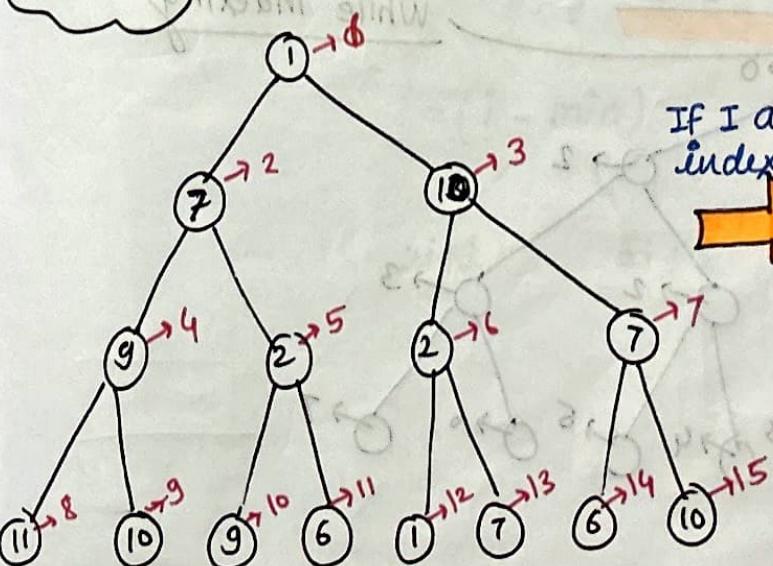
Tree - II :-

we can't take ⑤ because we don't have any other node at that level.
so after choosing ③ and ② \Rightarrow maximum width = 2

Tree - III :-

In third tree \Rightarrow Maximum width = 8

Intuition



If I assign the index at each level.

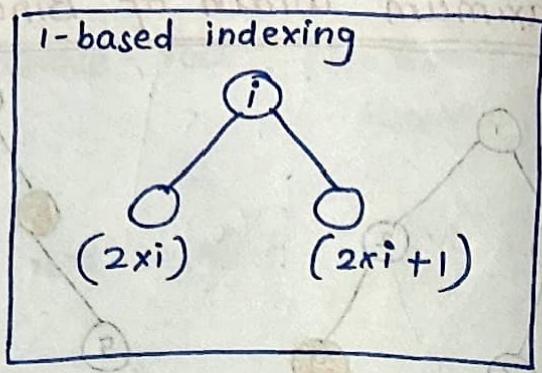
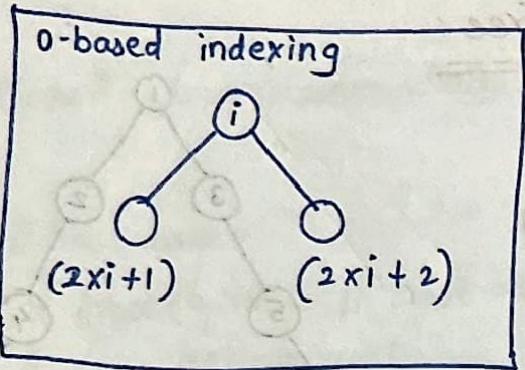
Then at each level
I just have to subtract
the (last idx - first idx + 1)

I will get the width

$$\text{EX: } ① 3 - 2 + 1 = \frac{2}{2}$$

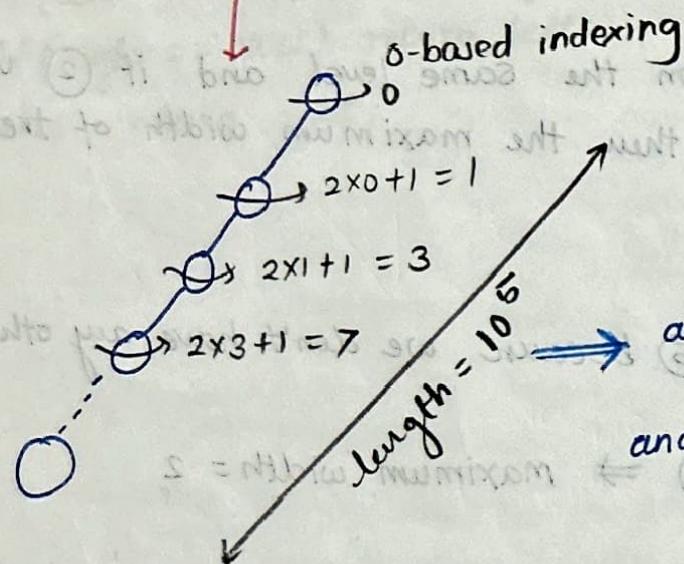
$$② 7 - 4 + 1 = \frac{4}{4}$$

$$③ 15 - 8 + 1 = \frac{8}{8}$$



But If I use this 0-based indexing this will FAIL

Why??



skew-tree

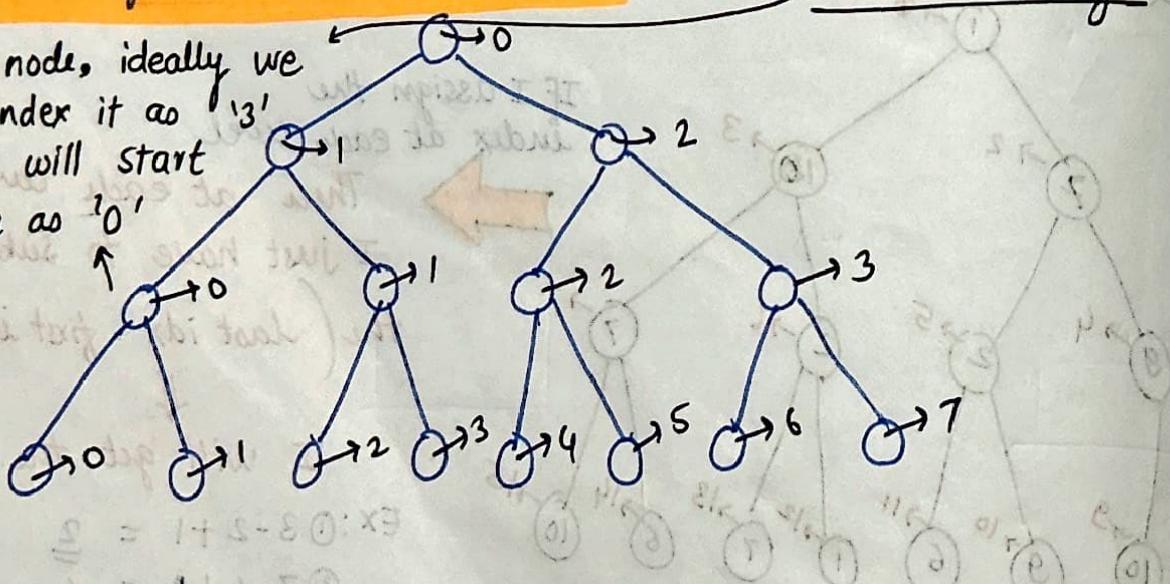
and At each step we are doing $(2xi+1)$
and $2 \times 10^5 + 1 \Rightarrow$ will overflow!!!

Hence this will fail!!

How will you prevent this overflow \Rightarrow

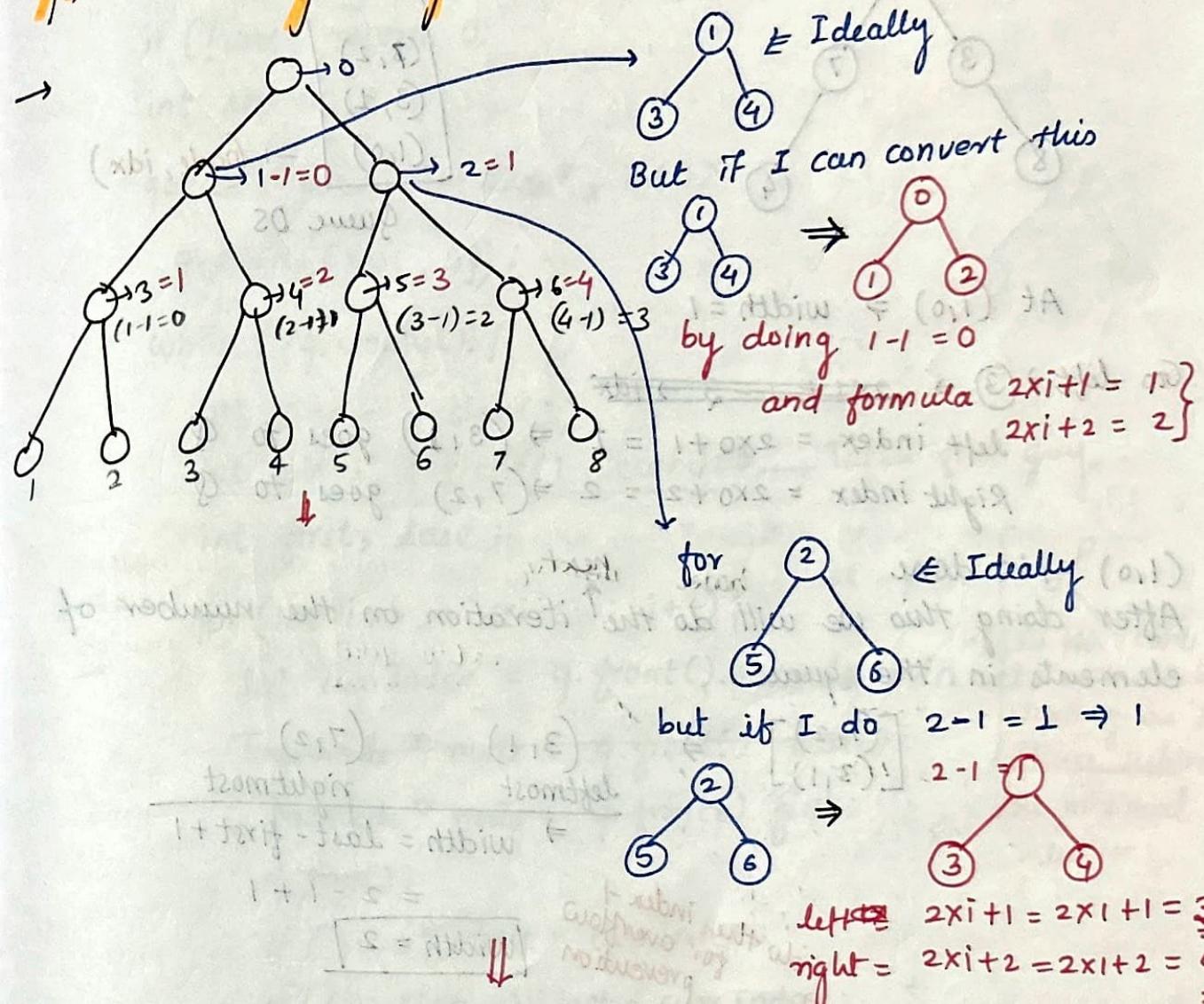
At this node, ideally we should index it as '3'
but we will start indexing as '0'

while indexing



Same here

How will you get those indexes?



THIS IS HOW IT WILL GET SIMPLIFIED TILL THE DEPTH OF TREE!

This is how it will get prevented from OVERFLOW!!

$$i = (i - \min)$$

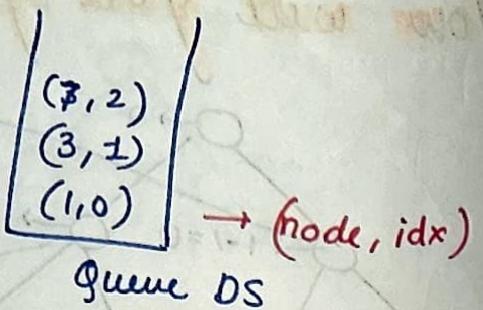
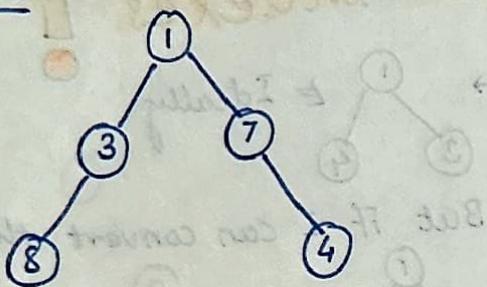
$$2i+1$$

$$2i+2$$

$$\begin{array}{|c|} \hline i+1-\Delta = w \\ p = w \\ \hline \end{array}$$

$$(1, 8)$$

Dry Run



At $(1, 0) \Rightarrow \text{width} = 1$

Go left $\Rightarrow 3 \Rightarrow$ ~~2x0 + 2 > idx~~
 left index $= 2 \times 0 + 1 = 1 \Rightarrow (3, 1)$ goes to Q
 Right index $= 2 \times 0 + 2 = 2 \Rightarrow (7, 2)$ goes to Q

$(1, 0) \rightarrow$ is done next
 After doing this we will do the iteration on the number of elements in the queue.

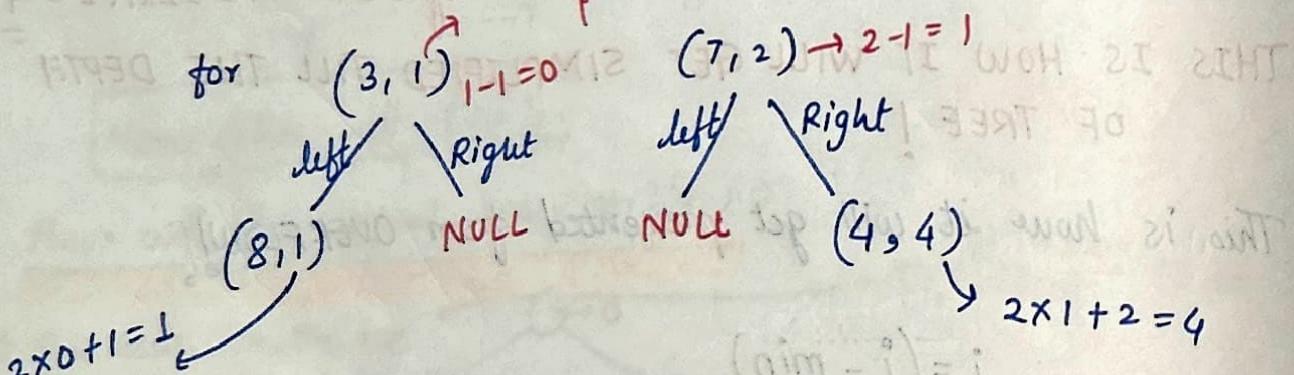
$$\begin{bmatrix} (7, 2) \\ (3, 1) \end{bmatrix} \Rightarrow \begin{array}{c} (3, 1) \\ \text{leftmost} \end{array} \quad \begin{array}{c} (7, 2) \\ \text{rightmost} \end{array}$$

$\Rightarrow \text{width} = \text{last} - \text{first} + 1$

$$= 2 - 1 + 1$$

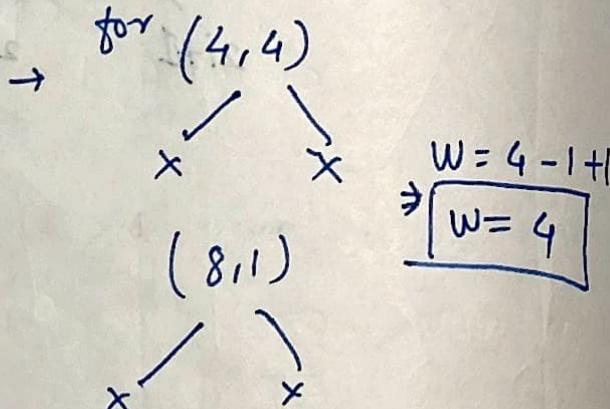
do the index-1
for overflow
prevention

$$\boxed{\text{width} = 2}$$



push these in Queue

$$\begin{bmatrix} (4, 4) \\ (8, 1) \end{bmatrix} \quad Q$$



```

int widthOfBinaryTree(TreeNode* root) {
    if (!root) return 0;
    int ans = 0;
    queue<pair<TreeNode*, int>> q;
    q.push({root, 0});
    while (!q.empty()) {
        int size = q.size();
        int min = q.front().second; → Taken first guy
        int first, last;
        for (int i=0; i<size; i++) {
            int curIndex = q.front().second - min;
            TreeNode* node = q.front().first;
            q.pop();
            if (i==0) first = curIndex;
            if (i==size-1) last = curIndex;
            if (node->left) {
                q.push({node->left, 2*curIndex + 1});
            }
            if (node->right) {
                q.push({node->right, 2*curIndex + 2});
            }
        }
        ans = max(ans, last - first + 1);
    }
    return ans;
}

```

In this case
It will not be
starting as '1'
Hence subtract
the minimal
index

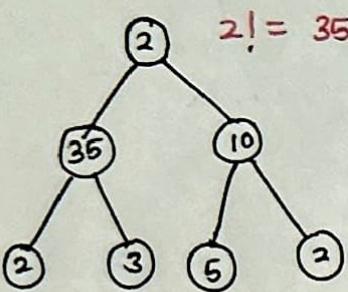
<img alt="A binary tree diagram with root 1. Root 1 has left child 2 and right child 3. Node 2 has left child 4 and right child 5. Node 3 has left child 6 and right child 7. Node 4 has left child 8 and right child 9. Node 5 has left child 10 and right child 11. Node 6 has left child 12 and right child 13. Node 7 has left child 14 and right child 15. Node 8 has left child 16 and right child 17. Node 9 has left child 18 and right child 19. Node 10 has left child 20 and right child 21. Node 11 has left child 22 and right child 23. Node 12 has left child 24 and right child 25. Node 13 has left child 26 and right child 27. Node 14 has left child 28 and right child 29. Node 15 has left child 30 and right child 31. Node 16 has left child 32 and right child 33. Node 17 has left child 34 and right child 35. Node 18 has left child 36 and right child 37. Node 19 has left child 38 and right child 39. Node 20 has left child 40 and right child 41. Node 21 has left child 42 and right child 43. 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Node 304 has left child 608 and right child 609. Node 305 has left child 610 and right child 611. Node 306 has left child 612 and right child 613. Node 307 has left child 614 and right child 615. Node 308 has left child 616 and right child 617. Node 309 has left child 618 and right child 619. Node 310 has left child 620 and right child 621. Node 311 has left child 622 and right child 623. Node 312 has left child 624 and right child 625. Node 313 has left child 626 and right child 627. Node 314 has left child 628 and right child 629. Node 315 has left child 630 and right child 631. Node 316 has left child 632 and right child 633. Node 317 has left child 634 and right child 635. Node 318 has left child 636 and right child 637. Node 319 has left child 638 and right child 639. Node 320 has left child 640 and right child 641. Node 321 has left child 642 and right child 643. Node 322 has left child 644 and right child 645. Node 323 has left child 646 and right child 647. 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Node 344 has left child 688 and right child 689. Node 345 has left child 690 and right child 691. Node 346 has left child 692 and right child 693. Node 347 has left child 694 and right child 695. Node 348 has left child 696 and right child 697. Node 349 has left child 698 and right child 699. Node 350 has left child 700 and right child 701. Node 351 has left child 702 and right child 703. Node 352 has left child 704 and right child 705. Node 353 has left child 706 and right child 707. Node 354 has left child 708 and right child 709. Node 355 has left child 710 and right child 711. Node 356 has left child 712 and right child 713. Node 357 has left child 714 and right child 715. Node 358 has left child 716 and right child 717. Node 359 has left child 718 and right child 719. Node 360 has left child 720 and right child 721. Node 361 has left child 722 and right child 723. Node 362 has left child 724 and right child 725. Node 363 has left child 726 and right child 727. Node 364 has left child 728 and right child 729. Node 365 has left child 730 and right child 731. Node 366 has left child 732 and right child 733. Node 367 has left child 734 and right child 735. Node 368 has left child 736 and right child 737. Node 369 has left child 738 and right child 739. Node 370 has left child 740 and right child 741. Node 371 has left child 742 and right child 743. Node 372 has left child 744 and right child 745. Node 373 has left child 746 and right child 747. Node 374 has left child 748 and right child 749. Node 375 has left child 750 and right child 751. Node 376 has left child 752 and right child 753. Node 377 has left child 754 and right child 755. Node 378 has left child 756 and right child 757. Node 379 has left child 758 and right child 759. Node 380 has left child 760 and right child 761. Node 381 has left child 762 and right child 763. Node 382 has left child 764 and right child 765. Node 383 has left child 766 and right child 767. Node 384 has left child 768 and right child 769. Node 385 has left child 770 and right child 771. Node 386 has left child 772 and right child 773. Node 387 has left child 774 and right child 775. Node 388 has left child 776 and right child 777. Node 389 has left child 778 and right child 779. Node 390 has left child 780 and right child 781. Node 391 has left child 782 and right child 783. Node 392 has left child 784 and right child 785. Node 393 has left child 786 and right child 787. Node 394 has left child 788 and right child 789. Node 395 has left child 790 and right child 791. Node 396 has left child 792 and right child 793. Node 397 has left child 794 and right child 795. Node 398 has left child 796 and right child 797. Node 399 has left child 798 and right child 799. Node 400 has left child 800 and right child 801. Node 401 has left child 802 and right child 803. Node 402 has left child 804 and right child 805. Node 403 has left child 806 and right child 807. Node 404 has left child 808 and right child 809. Node 405 has left child 810 and right child 811. Node 406 has left child 812 and right child 813. Node 407 has left child 814 and right child 815. Node 408 has left child 816 and right child 817. Node 409 has left child 818 and right child 819. Node 410 has left child 820 and right child 821. Node 411 has left child 822 and right child 823. Node 412 has left child 824 and right child 825. Node 413 has left child 826 and right child 827. Node 414 has left child 828 and right child 829. Node 415 has left child 830 and right child 831. Node 416 has left child 832 and right child 833. Node 417 has left child 834 and right child 835. Node 418 has left child 836 and right child 837. Node 419 has left child 838 and right child 839. Node 420 has left child 840 and right child 841. Node 421 has left child 842 and right child 843. Node 422 has left child 844 and right child 845. Node 423 has left child 846 and right child 847. Node 424 has left child 848 and right child 849. Node 425 has left child 850 and right child 851. Node 426 has left child 852 and right child 853. Node 427 has left child 854 and right child 855. Node 428 has left child 856 and right child 857. Node 429 has left child 858 and right child 859. Node 430 has left child 860 and right child 861. Node 431 has left child 862 and right child 863. Node 432 has left child 864 and right child 865. Node 433 has left child 866 and right child 867. Node 434 has left child 868 and right child 869. Node 435 has left child 870 and right child 871. Node 436 has left child 872 and right child 873. Node 437 has left child 874 and right child 875. Node 438 has left child 876 and right child 877. Node 439 has left child 878 and right child 879. Node 440 has left child 880 and right child 881. Node 441 has left child 882 and right child 883. Node 442 has left child 884 and right child 885. Node 443 has left child 886 and right child 887. Node 444 has left child 888 and right child 889. Node 445 has left child 890 and right child 891. Node 446 has left child 892 and right child 893. Node 447 has left child 894 and right child 895. Node 448 has left child 896 and right child 897. Node 449 has left child 898 and right child 899. Node 450 has left child 900 and right child 901. Node 451 has left child 902 and right child 903. Node 452 has left child 904 and right child 905. Node 453 has left child 906 and right child 907. Node 454 has left child 908 and right child 909. Node 455 has left child 910 and right child 911. Node 456 has left child 912 and right child 913. Node 457 has left child 914 and right child 915. Node 458 has left child 916 and right child 917. Node 459 has left child 918 and right child 919. Node 460 has left child 920 and right child 921. Node 461 has left child 922 and right child 923. Node 462 has left child 924 and right child 925. Node 463 has left child 926 and right child 927. Node 464 has left child 928 and right child 929. Node 465 has left child 930 and right child 931. Node 466 has left child 932 and right child 933. Node 467 has left child 934 and right child 935. Node 468 has left child 936 and right child 937. Node 469 has left child 938 and right child 939. Node 470 has left child 940 and right child 941. Node 471 has left child 942 and right child 943. Node 472 has left child 944 and right child 945. Node 473 has left child 946 and right child 947. Node 474 has left child 948 and right child 949. Node 475 has left child 950 and right child 951. Node 476 has left child 952 and right child 953. Node 477 has left child 954 and right child 955. Node 478 has left child 956 and right child 957. Node 479 has left child 958 and right child 959. Node 480 has left child 960 and right child 961. Node 481 has left child 962 and right child 963. Node 482 has left child 964 and right child 965. Node 483 has left child 966 and right child 967. Node 484 has left child 968 and right child 969. Node 485 has left child 970 and right child 971. Node 486 has left child 972 and right child 973. Node 487 has left child 974 and right child 975. Node 488 has left child 976 and right child 977. Node 489 has left child 978 and right child 979. Node 490 has left child 980 and right child 981. Node 491 has left child 982 and right child 983. Node 492 has left child 984 and right child 985. Node 493 has left child 986 and right child 987. Node 494 has left child 988 and right child 989. Node 495 has left child 990 and right child 991. Node 496 has left child 992 and right child 993. Node 497 has left child 994 and right child 995. Node 498 has left child 996 and right child 997. Node 499 has left child 998 and right child 999. Node 500 has left child 1000 and right child 1001.
</pre>

Children sum property :-

$\text{node} = \text{left node} + \text{right node}$ \Rightarrow children sum property

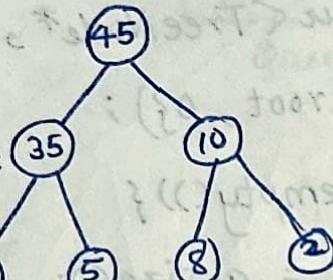
→ If this condition is not satisfying

- (i) you can add +1 to any node to any number of times

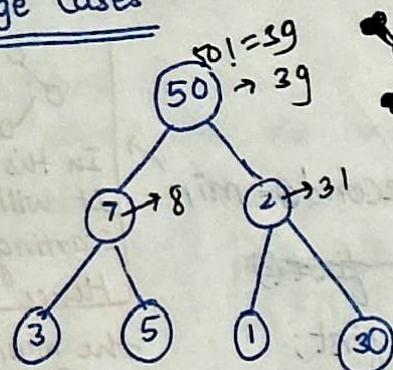


$$2 = 35 + 10$$

You can increment any node. However you want.



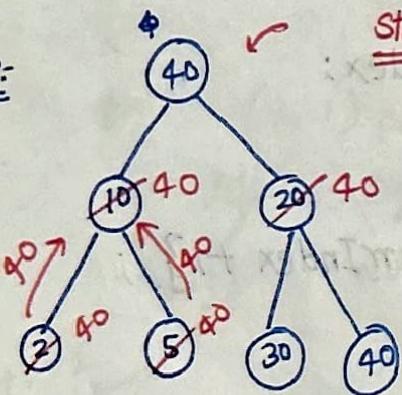
Edge Cases -



In this problem, ~~the~~ you can simply add the nodes and put up the sum into parent node cause it won't guarantee you that as you go up you will get that sum !!

→ We will be using recursive traversal

Ex:-



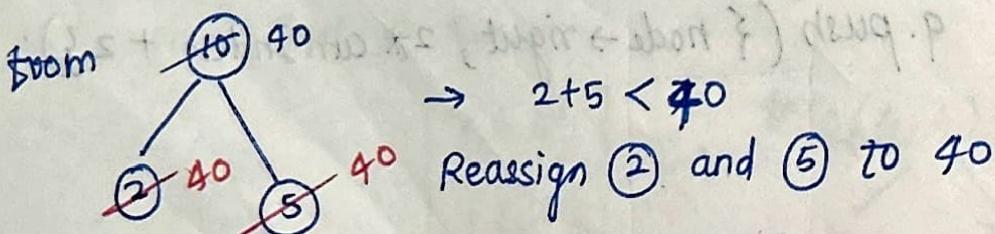
Start →

$\text{root} \rightarrow \text{left} = 10$

$\text{root} \rightarrow \text{right} = 20$

$$10 + 20 = 30 < 40$$

Got the sum less than 40 then I'll assign the left node as 40 and right node as 40



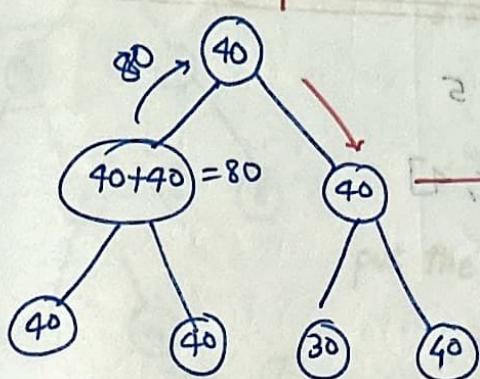
$$\rightarrow 2 + 5 < 40$$

Reassign (2) and (5) to 40

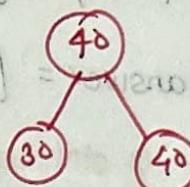
Now from (2) → No other nodes are present here

return 40 from (2) and same, return 40 from 5

→ Add them up



$2 = \text{parent}, 2 = 3$



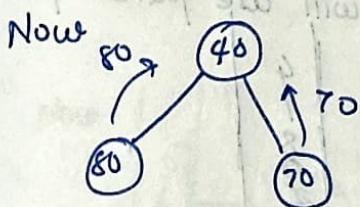
$$30 + 40 = 70$$

$$70 > 40$$

so make the node 40 (parent) as 70.

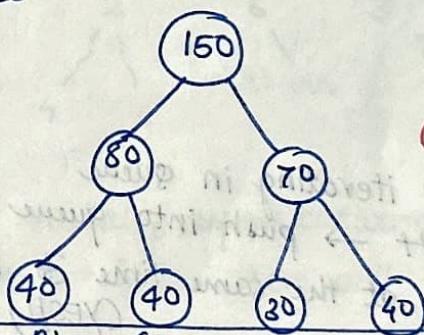
move left \rightarrow return 30

move right \rightarrow return 40



Now update the root by $80 + 170 = 150$

∴ Hence the tree



Children sum property Satisfied ✓

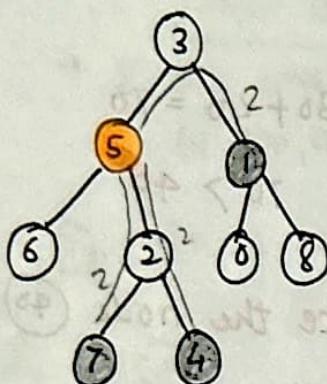
```
void ChangeTreeBinary(BinaryTreeNode<int>* root) {
    if (root == NULL) return;
    int child = 0;
    if (root->left) child += root->left->data;
    if (root->right) child += root->right->data;
    if (child >= root->data) root->data = child;
    else {
        if (root->left) root->left->data = root->data;
        if (root->right) root->right->data = root->data;
    }
    ChangeTreeBinary(root->left);
    ChangeTreeBinary(root->right);
}
```

T.C = O(N)

While coming back to parent

```
int total = 0;
if (root->left) total += root->left->data;
if (root->right) total += root->right->data;
if (root->left || root->right) root->data = total;
```

- Print all the Nodes at a distance of "k" in Binary Tree

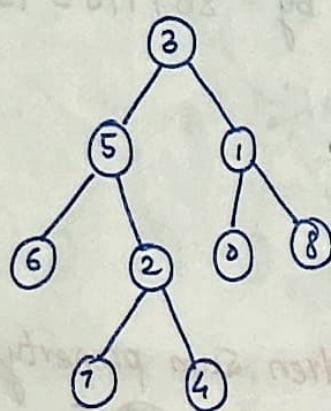


$k=2$, target = 5

answer = [1, 7, 4]

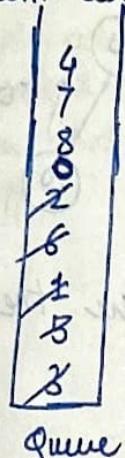
→ IF we want to get all the nodes from node 5 at a distance "2" then we have to move downward + upward in both the direction AND This is the main concern.

→ In order to move in upward direction, we will use parent pointer



$k=2$, target = 5

(BFS)



Start iterating in queue

if $3 \rightarrow \text{left} \rightarrow$ push into queue (5)

and at the same time 3 is a parent of 5
(YES!!)

Now $3 \rightarrow \text{right} \Rightarrow$ push into queue (1)

and say hey! ① your parent is 3 → YES!!

This is how we can map the parent nodes.

$5 \rightarrow \text{left} \rightarrow 6 \rightarrow$ push q

$5 \rightarrow \text{right} \rightarrow 2 \rightarrow$ push into q

$1 \rightarrow \text{left} \rightarrow 0 \rightarrow$ push into q

$1 \rightarrow \text{right} \rightarrow 8 \rightarrow$ push into q

$6 \rightarrow \text{left} \Rightarrow \text{NULL}$

$6 \rightarrow \text{right} \Rightarrow \text{NULL}$

$2 \rightarrow \text{left} \rightarrow 7 \rightarrow$ push into q

$2 \rightarrow \text{right} \rightarrow 4 \rightarrow$ push into q

like this

parent child map
↳ child → parent

5 → 3

1 → 3

6 → 5

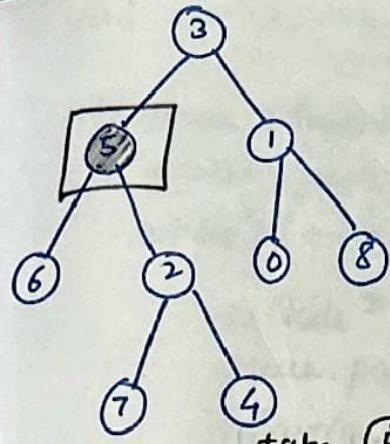
2 → 5

7 → 2

4 → 2

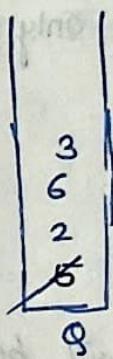
0 → 1

8 → 4



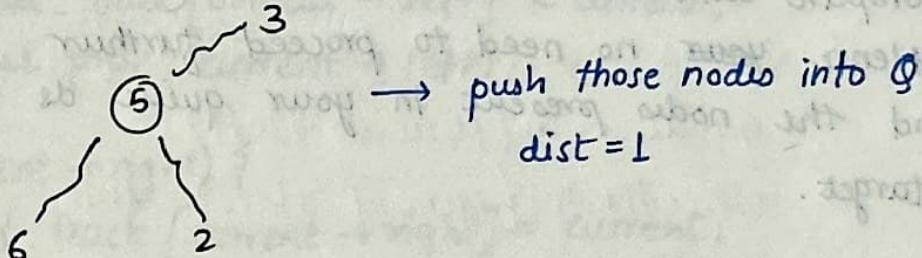
$\text{dist} = 0$

put the target into $\emptyset \rightarrow$

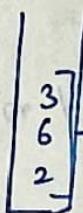


Carry a visited hash

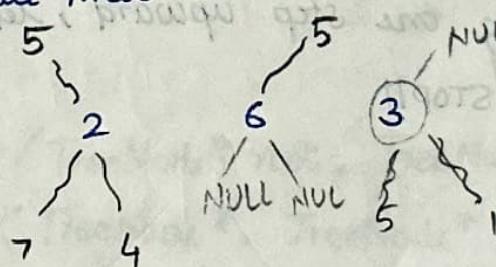
take 5 check upward, left and right



Now

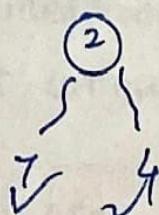


Take all these three nodes and try to move radially outwards

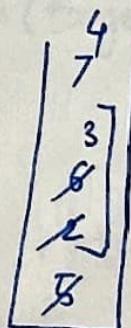


Now think!!

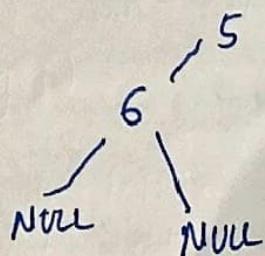
→ If we move radially outwards from 2 we will have 5 which is visited → hence there will help our visited hashmap
from 2 to 5 → you will not go cause 5 is already visited



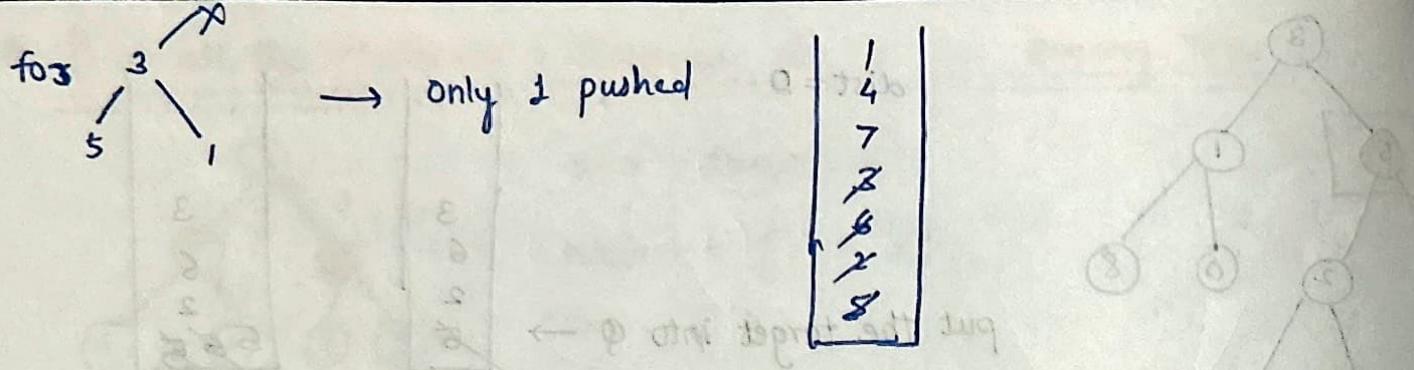
push into \emptyset
(7 and 4)



Now for 6 →



Nothing will be pushed into Queue



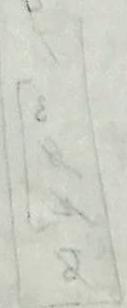
Now distance will be updated to 2
and compare with this distance to k ($k == \text{distance}$)

Hence ~~your~~ no need to proceed further
and the nodes present in your queue de is at ' k ' distance
from target.

→ Summary:-

- Have parent pointers.
- keep on moving one step upward, leftward and rightward
- at $\text{dist} == k$ STOP!!

② ~~start from a very large edge number sum of all edges + common between two given trees credit with - window size initially parent pointers in a queue of ten trees now ← ② at ③ mark~~



Q. other ways
(P. how?)



looking at the problem
and the

→ 2 not work

```

void markParents(TreeNode* root, unordered_map<TreeNode*, TreeNode*>
    &parent_track, TreeNode* target) {
    queue<TreeNode*> queue;
    queue.push(root);
    while (!q.empty()) {
        TreeNode* current = queue.front();
        queue.pop();
        if (current->left) {
            parent_track[current->left] = current;
            queue.push(current->left);
        }
        if (current->right) {
            parent_track[current->right] = current;
            queue.push(current->right);
        }
    }
}

vector<int> distanceK(TreeNode* root, TreeNode* target, int k) {
    unordered_map<TreeNode*, TreeNode*> parent_track;
    markParents(root, parent_track, target); → mapping done!
    unordered_map<TreeNode*, bool> visitedNodes;
    queue<TreeNode*> queue;
    queue.push(target);
    visitedNodes[target] = true;
    int currentLevel = 0;
}

```

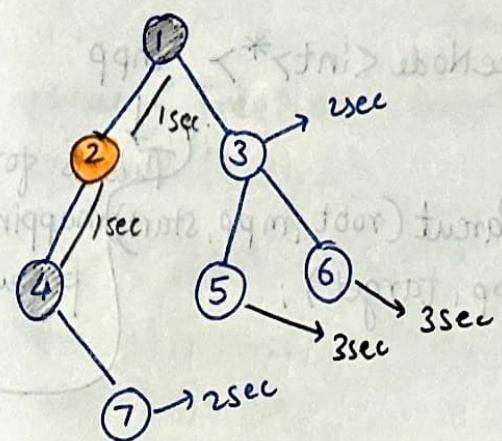
// → PTO.

```

while (!queue.empty()) {
    int size = queue.size();
    if (currentLevel++ == k) break; → reached k distance.
    for (int i=0 ; i<size ; i++) {
        TreeNode* current = queue.front();
        queue.pop();
        if (current->left && !visitedNodes[current->left]) {
            queue.push(current->left);
            visitedNodes[current->left] = true;
        }
        if (current->right && !visitedNodes[current->right]) {
            queue.push(current->right);
            visitedNodes[current->right] = true;
        }
        if (parent_track[current] && !visitedNodes[parent_track[current]]) {
            queue.push(parent_track[current]);
            visitedNodes[parent_track[current]] = true;
        }
    }
    vector<int> result;
    while (!queue.empty()) {
        TreeNode* x = queue.front();
        queue.pop();
        result.push_back(x->val);
    }
    return result;
}

```

• Minimum time taken to burn the binary tree from a node:-



node = 2

Total Time = 3 seconds

BFS Traversal :-

Step 1:- Have the parents pointers ready.

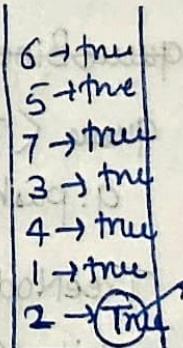
(Refer the code for markParents function of last question)

time = 0

→ node = 2 (above, left, right)

↳ it can burn above(1)

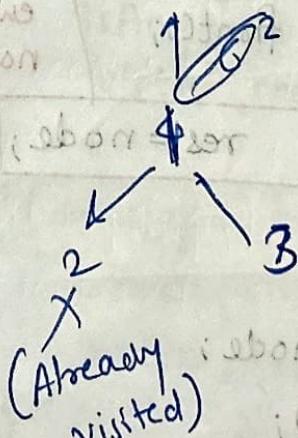
↳ It can burn left (4)



Now pick both the nodes

time = 1

NULL



Now perform the operation on this
⇒ time = 3

time = 2

{ (More - abon) }

Here don't update
5 the time

doesn't
burns anyone
and so 6
also don't burn

```

int findMinTimeToBurn(TreeNode<int>* root, int start) {
    map<TreeNode<int>*, TreeNode<int>*> mpp
    This is for
    mapping of
    parents
}

TreeNode<int>* target = bfsToMapParent(root, mpp, start);
int time = findTimeToBurn(mpp, target);
return time;
}

```

```

TreeNode<int>* bfsToMapParent(
    TreeNode<int>* root,
    map<TreeNode<int>*, TreeNode<int>*> mpp,
    int start);

```

~~queueBinary~~

```
queue<TreeNode<int>> q;
```

```
q.push(root);
```

```
TreeNode<int>* res;
```

```
while (!q.empty()) {
```

```
TreeNode<int>* node = q.front();
```

```
q.pop();
```

```
if (node->data == start) res = node;
```

```
q.pop();
```

```
if (node->left) {
```

```
mpp[node->left] = node;
```

```
q.push(node->left);
```

```
}
```

```
if (node->right) {
```

```
mpp[node->right] = node;
```

```
q.push(node->right);
```

```
}
```

```
return res; }
```

Since in question
is given they did
not give us the
address of the node

Hence whenever we
encounter the
node->data == star

store the addm
(node)
and return
that;

```
int findTimeToBurn (map<TreeNode<int>*, &TreeNode<int>> mpp,
```

```
    TreeNode<int>* target) {
```

```
queue<TreeNode<int>*> q;
```

```
q.push(target);
```

```
map<TreeNode<int>*, bool> visited;
```

```
visited[target] = true;
```

```
int time = 0;
```

```
while (!q.empty()) {
```

```
    int size = q.size();
```

```
    bool bool isAnyNodeBurnt = false;
```

```
    for (int i=0 ; i < size ; i++) {
```

```
        auto node = q.front();
```

```
        q.pop();
```

```
        if (node->left && !visited[node->left]) {
```

```
            isAnyNodeBurnt = true;
```

```
            visited[node->left] = true;
```

```
        if (node->right && !visited[node->right]) {
```

```
            isAnyNodeBurnt = true;
```

```
            visited[node->right] = true;
```

```
}
```

```
        if (mpp[node] && !visited[mpp[node]]) {
```

```
            isAnyNodeBurnt = true;
```

```
            visited[mpp[node]] = true;
```

```
}
```

```
}
```

```
        if (isAnyNodeBurnt) {
```

```
            time++;
```

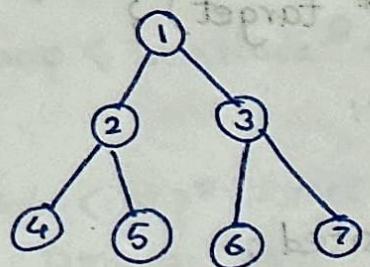
```
}
```

```
}
```

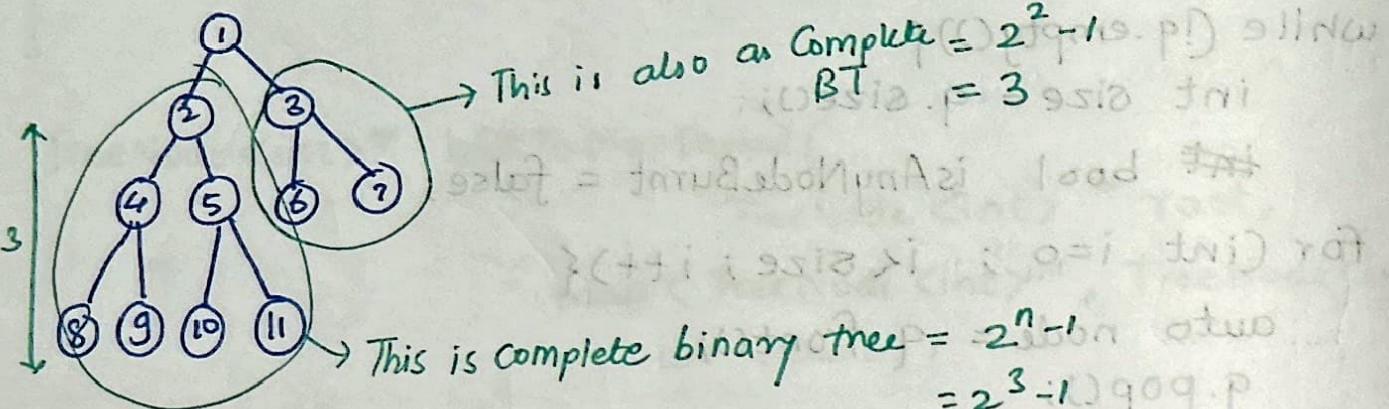
```
return time;
```

```
}
```

Count total number of nodes in a complete binary tree



$$\text{No. of nodes} = 2^3 - 1$$



$$\text{This is complete binary tree} = 2^n - 1$$

$$= 2^3 - 1$$

$$= 7$$

([Height] \leq [Level] + 1) \Rightarrow 3 \leq 3 + 1

$$7 + 3 + 1 = \underline{\underline{11}}$$

$lh = 4$ ($lh \neq rh$) \rightarrow hence it's not complete binary tree \rightarrow can't apply 2^{n-1} formula directly

$$rh = 3$$

$$1 + (\text{ans from left}) + (\text{ans from right})$$

```

int countNodes(TreeNode* root) {
    if (root == NULL) return 0;
    int lh = findLeftHeight(root->left);
    int rh = findRightHeight(root->right);
    if (lh == rh) {
        return (pow(2, lh) - 1);
    }
    return 1 + countNodes(root->left) + countNodes(root->right);
}

```

```

int findLeftHeight(TreeNode* node) {
    int height = 0;
    while (node) {
        height++;
        node = node->left;
    }
    return height;
}

```

$$S.C = O(\log N)$$

$$T.C = O((\log N)^2)$$

At the worst case you will end up traversing the height of the tree $\Rightarrow \log N$

and every time compute the height

$$\log N * \log N = (\log N)^2$$

```

int findRightHeight(TreeNode* node) {
    int height = 0;
    while (node) {
        height++;
        node = node->right;
    }
}

```

```

return height;
}

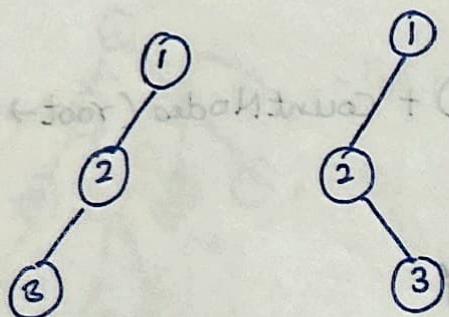
```

- Requirements needed to construct a unique binary tree :-

Q.1) You will be given a preOrder and post-order traversal and you have to create a unique binary tree? Can you?

Example :-

① preOrder :- 1 2 3 (Root - Left - Right)
postOrder :- 3 2 1 (Left - Right - Root)

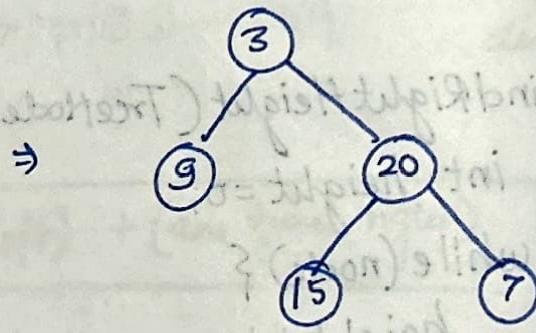
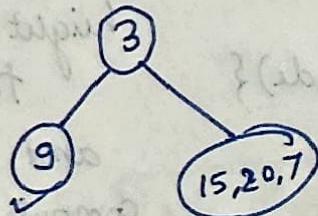


so if you check in this example, we have constructed two binary trees
Hence with preOrder & postOrder we can't create **UNIQUE** binary tree.

Q.2) What if preOrder & InOrder is given

InOrder = [^{Left} 9 ^{Root} 3 ^{Right} 15 20 7] - (Left - Root - Right)

PreOrder = [3 ^{Root} 9 20 15 7] - (Root - Left - Right)

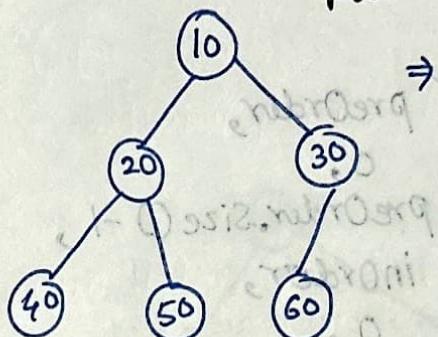


⇒ And this is unique binary tree!

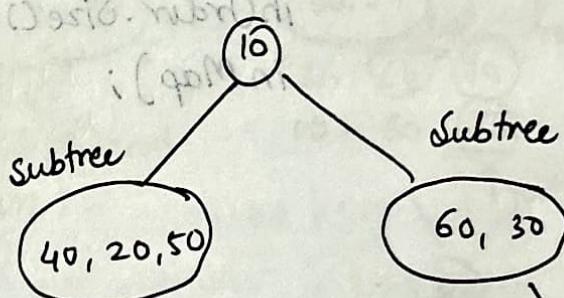
⇒ We can create the unique binary tree only if the
 ⇒ InOrder + PreOrder
 ⇒ InOrder + PostOrder
 is given

Create Binary tree from InOrder & preOrder :-

InOrder = [40, 20, 50, 10, 60, 30] → (Left - Root - Right)
 preOrder = [10, 20, 40, 50, 30, 60] → (Root - Left - Right)



⇒ This is the tree



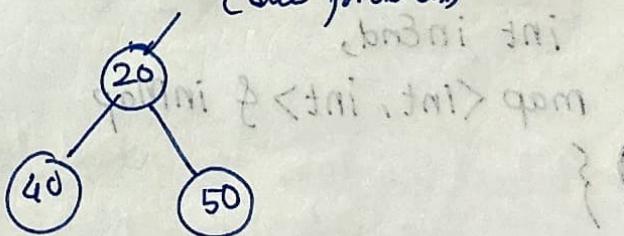
find the InOrder & preOrder

InOrder = 40, 20, 50

preOrder = 20, 40, 50

This is a new problem

(sub problem)



InOrder = 40

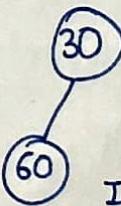
pre: 40

In: 50

pre: go

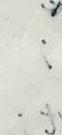
(New Subproblem)

(New Subprob.)



In: 60
pre: 60

(New Subproblem)



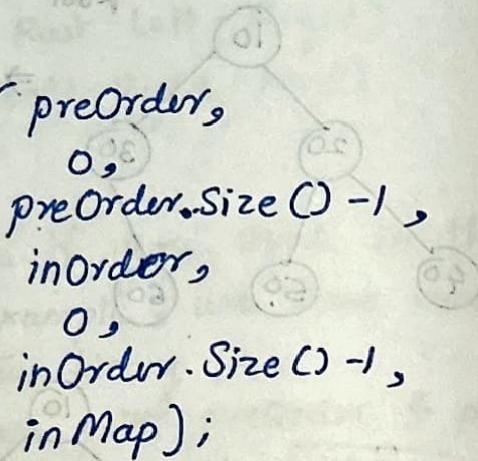
if (you find the both child as null then attach the node)

```
TreeNode* buildTree(vector<int>& preOrder, vector<int>& inOrder)
```

```
map<int, int> inMap;
```

```
for(auto i: inOrder) {  
    for(int j=0; j< inOrder.size(); j++) {  
        if(inOrder[j] == i) {  
            inMap[i] = j;  
        }  
    }  
}
```

```
TreeNode* root = buildTree(preOrder,
```



```
preOrder.size() - 1,  
inOrder,  
0,  
inOrder.size() - 1,  
inMap);
```

```
return root;
```

```
}
```

```
T.C = O(N)  
S.C = O(N)
```

```
TreeNode* buildTree(vector<int>& preOrder,  
int preStart,  
int preEnd,  
vector<int>& inOrder,  
int inStart,  
int inEnd,  
map<int, int> & inMap)
```

```
) {
```

```
if (preEnd
```

```
if (preStart > preEnd || inStart > inEnd) return NULL;
```

```
TreeNode* root = new TreeNode(preOrder[preStart]);
```

```
int inRoot = inMap[root->val];
```

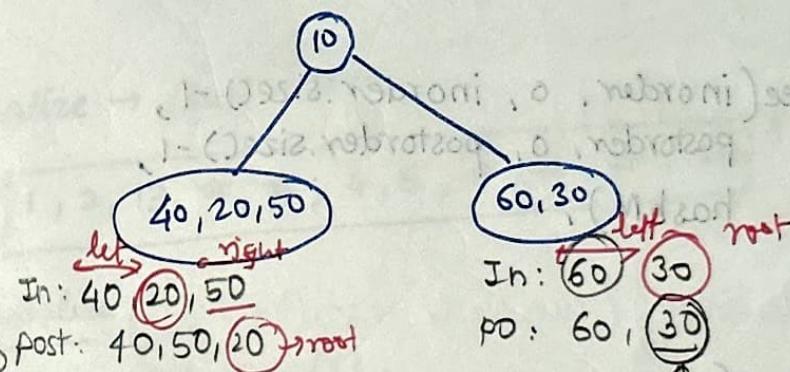
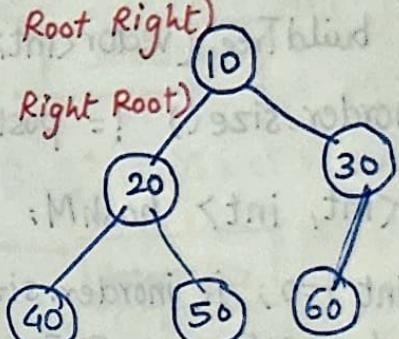
```
int numsLeft = inRoot - inStart;
```

```
root->left = buildTree(preOrder, preStart+1, preStart+numsLeft,  
inOrder, inStart, inRoot-1, inMap);
```

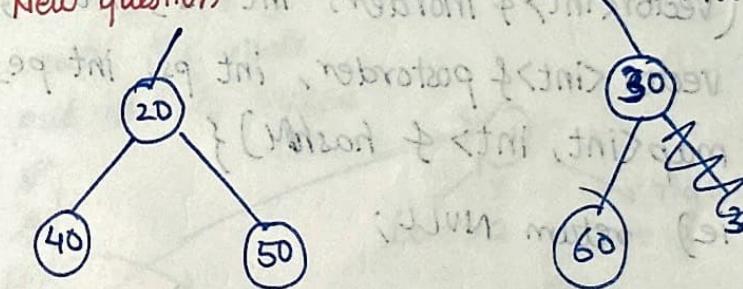
```
root->right = buildTree(preOrder, preStart+numsLeft+1, preEnd,  
inOrder, inRoot+1, inEnd, inMap);
```

```
return root;
```

- Construct the binary tree from PostOrder and Inorder :-
- Inorder = [40, 20, 50, 10, 60, 30] (Left Root Right)
PostOrder = [40, 50, 20, 60, 30, 10] (Left Right Root)



In: 60, 30
Post: 60, 30 \rightarrow root



\rightarrow In: 50
Post: 50

\rightarrow [In: 60, Post: 60] \leftrightarrow [In: 30, Post: 30]

\rightarrow 20 -> 40, 50

\rightarrow 30 -> 60

\rightarrow 20 -> 30

\rightarrow 20 -> 30

\rightarrow 20 -> 30

\rightarrow 20 -> 30

Whatever postOrder is given the last element is root.

```
TreeNode* buildTree (vector<int>& inorder, vector<int>& postOrder){  
    if (inorder.size() != postOrder.size()) return NULL;  
  
    map<int, int> hashM;  
    for (int i=0; i < inorder.size(); i++) {  
        hashM[inorder[i]] = i;  
    }  
  
    return buildPostInTree(inorder, 0, inorder.size() - 1,  
                           postOrder, 0, postOrder.size() - 1,  
                           hashM);  
}
```

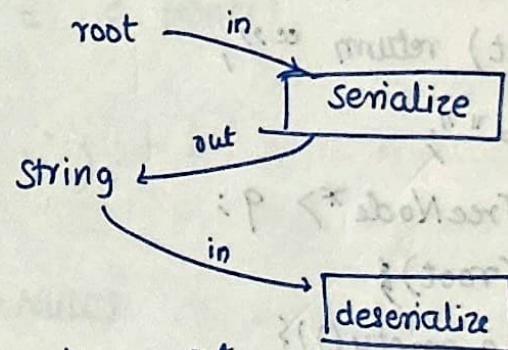
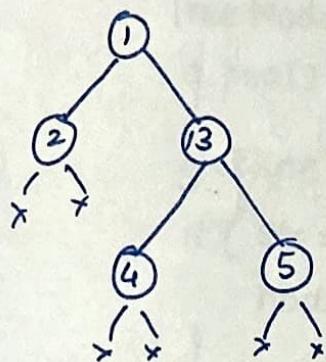
TreeNode* buildPostInTree (vector<int>& inorder, int is, int ie,
 vector<int>& postorder, int ps, int pe,
 map<int, int> &hashM) {
 if (ps > pe || is > ie) return NULL;

 TreeNode* root = new TreeNode(postOrder[pe]);
 int inRoot = hashM[postOrder[pe]];
 int numsleft = inRoot - is;

 root->left = buildPostInTree(inorder, is, inRoot - 1,
 postOrder, ps, ps + numsleft - 1, hashM);

 root->right = buildPostInTree(inorder, inRoot + 1, ie,
 postOrder, ps + numsleft, pe - 1, hashM);
}

Serialize and deserialize binary Tree



serialize → Level order

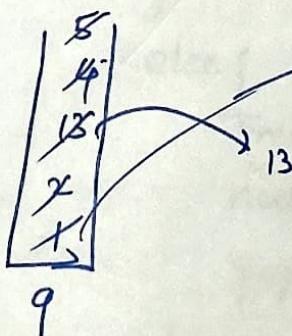
s = "1, 2, 13, #, #, 4, 5, #, #, #, #"

deserialize

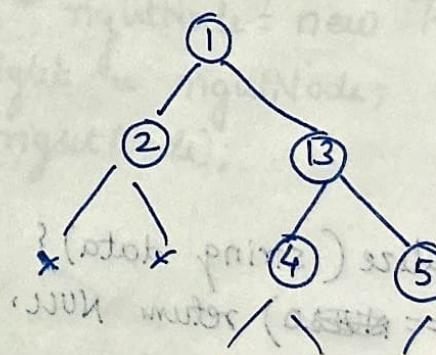
take the first guy (1)

and create the node

and put it into queue



left = 2
right = 13



q.is empty

to normal int dsg[]
int top prev sd
t1 ← Unfilled ab very small
elements on int dsg[]

i ((rt2).data) ablserT cur = root * ablserT

if p < * ablserT > wmp

(root) dsg.p

```
string serialize(TreeNode* root) {
```

```
    if (!root) return "##";
```

```
    string s = "#";
```

```
    queue<TreeNode*> q;
```

```
    q.push(root);
```

```
    while (!q.empty()) {
```

```
        TreeNode* currNode = q.front();
```

```
        q.pop();
```

```
        if (currNode == NULL) s += "#";
```

```
        else {
```

```
            s += (to_string(currNode->val) + ", ");
```

```
}
```

```
        if (currNode != NULL) {
```

```
            q.push(currNode->left);
```

```
            q.push(currNode->right);
```

```
}
```

```
    }
```

```
}
```

```
    return s;
```

```
}
```

```
TreeNode* deserialize(string data) {
```

```
    if (data.size() == 0) return NULL;
```

```
    stringstream s(data);
```

1, 13, 2, #, #, ---

```
    string str;
```

```
    getline(s, str, ',');
```

by using getline it will automatically
pick the element

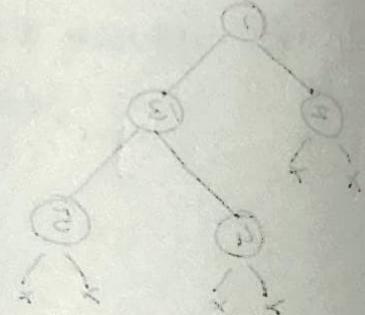
```
    TreeNode* root
```

delimiter Whenever you do getline() → it
will pick the ~~the~~ elements

```
    TreeNode* root = new TreeNode(stoi(str));
```

```
    queue<TreeNode*> q;
```

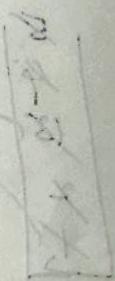
```
    q.push(root);
```



#, #, #, #, 2, #, #, ., #, ., #, ., 1;

(1) just start with root

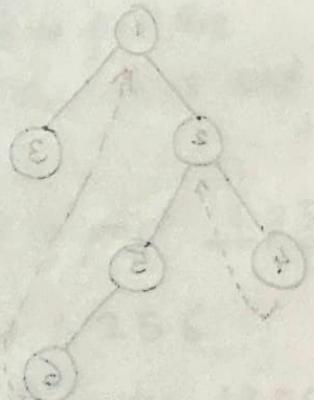
then left then right



```

while (!q.empty()) {
    TreeNode* node = q.front();
    q.pop();
    getline(s, str, ',');
    if (str == "#") {
        node->left = NULL;
    } else {
        TreeNode* leftNode = new TreeNode(stoi(str));
        node->left = leftNode;
        q.push(leftNode);
    }
    getline(s, str, ',');
    if (str == "#") {
        node->right = NULL;
    } else {
        TreeNode* rightNode = new TreeNode(stoi(str));
        node->right = rightNode;
        q.push(rightNode);
    }
}
return root;
}

```



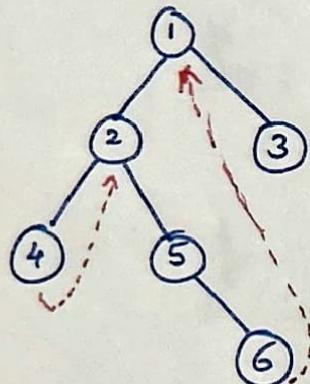
Morris Traversal

Why morris traversal ?

→ In the recursive traversal $T.C = O(N)$ & $S.C = O(N)$
but in morris traversal $T.C = O(N)$ & $S.C = O(1)$

It Only takes $O(1)$ space for traversal
cause morris traversal uses

Threaded binary tree



Inorder = 4 2 5 6 1 3

last node of any
subtree and if you go back \Rightarrow root

Case 1:-

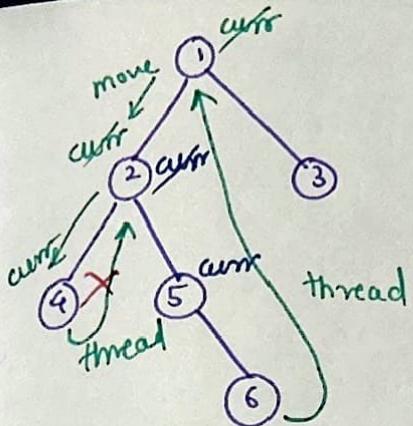
If the left \rightarrow NULL
 \Rightarrow print the current node
 \Rightarrow move to right

Case 2:-

Before going to left \rightarrow whichever the rightmost guy
of the left sub tree
will be connected to the current

Case 3:-

If the rightmost guy is already point to current
then remove the thread.



? (for \leftarrow absent) retrace < \rightarrow robust
At ④ → if you consider this as subtree
This will never have left so consider this
as root and print 4

4 ? ($\text{mwo} = 1 \leftarrow \text{mwo}$)
Now use the thread and go to ②
print \Rightarrow 4 2

Now on ② curr says

when I go to left → the last guy on left
sub tree ~~itself~~ is already pointing
to himself (means 2)

{ ($\text{mwo} = 1 \leftarrow \text{mwo}$)
so in this case go to the left → find the
rightmost guy and cut off the link take the curr and
move right \Rightarrow ⑤

⑤ does not have left → so its already a root → print 4 2 5
root is printed → go to the right → print → 4 2 5 6
and through the curr you came back to ① print \Rightarrow 4 2 5 6 1

Now on ①'s left already has a thread which is already
visited the left arena.

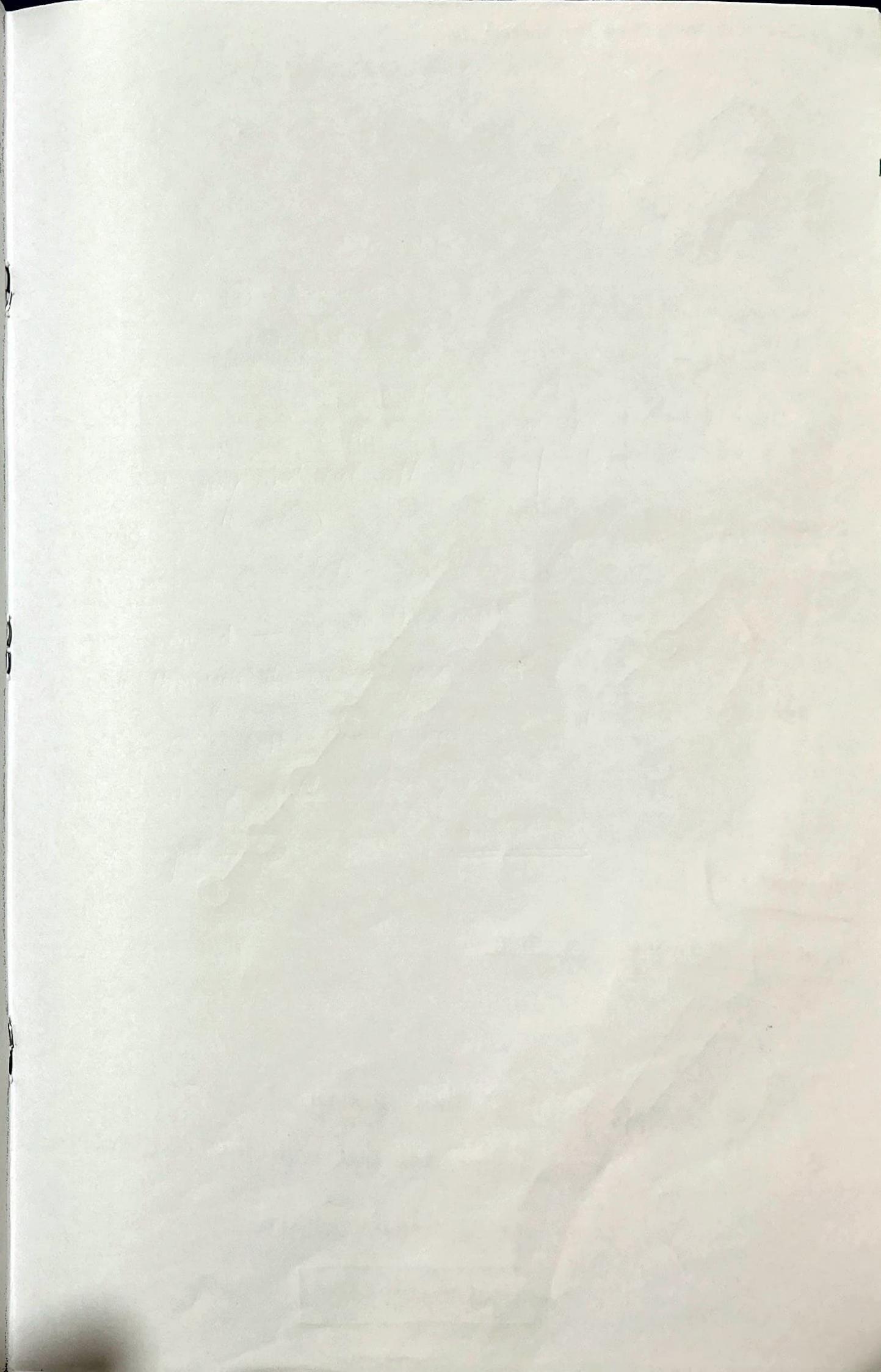
move right → ③ ⇒ print 4 2 5 6 1 3

{ mwo mwo

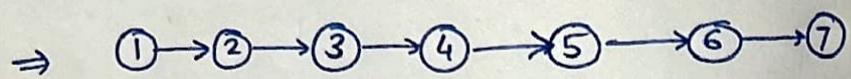
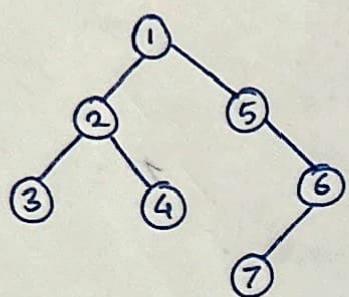
```

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

```



Flatten a binary tree to Linked List :-



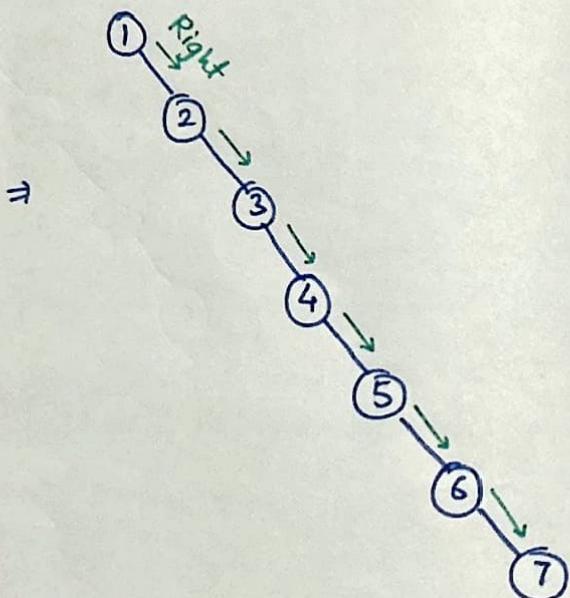
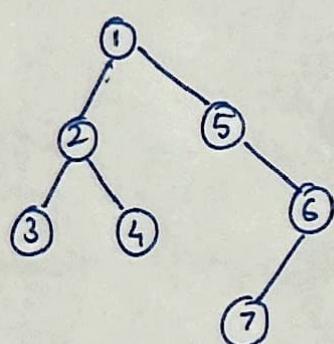
preorder $\Rightarrow 1 2 3 4 5 6 7$

Whatever is the preorder \rightarrow you might think like this
create a node and
generate LL

BUT THIS IS NOT ACCEPTABLE!!

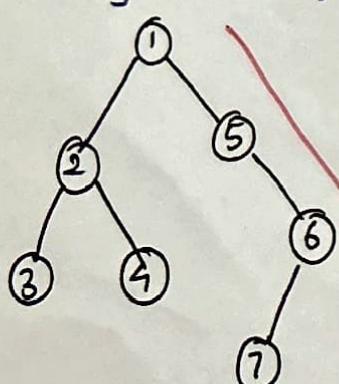
Because we have to flatten the BT

EX:-



Approach : I

basically rearrange the tree



go till ⑥ then arrange 7

& After that deal with the left subtree

so the traversal will be

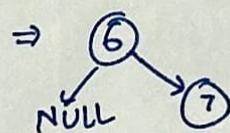
Right - Left - Root

```

prev = null;
flatten(node) {
    if(node == null) return;
    flatten(node->right);
    flatten(node->left);
    node->right = prev;
    node->left = null;
    prev = node
}

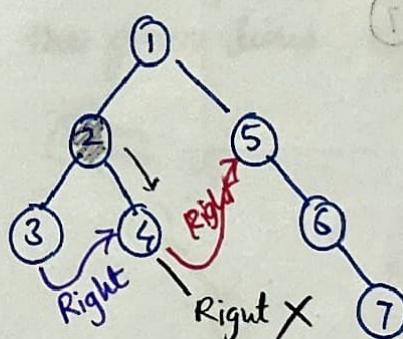
```

next step → ⑥ Right ⇒ prev



prev = 6

Now the tree is looking like this after traversal till ① and prev=5



Hence prev=5 and at ④

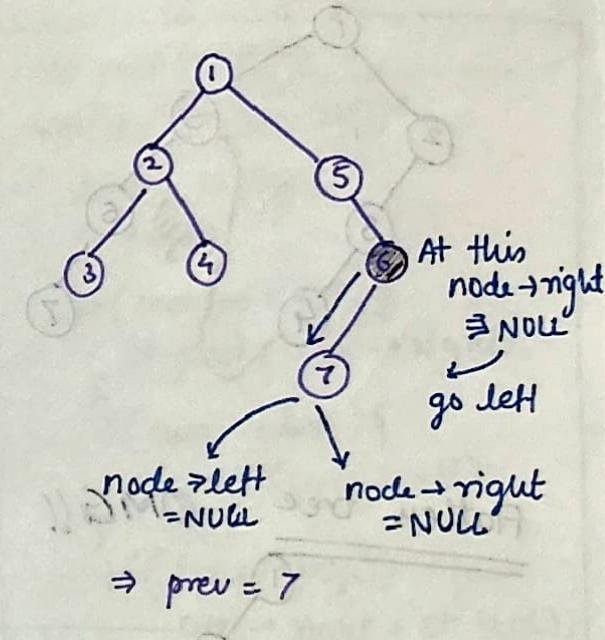
$\text{node} \rightarrow \text{right} = \text{prev}$
means ④ Right ⑤

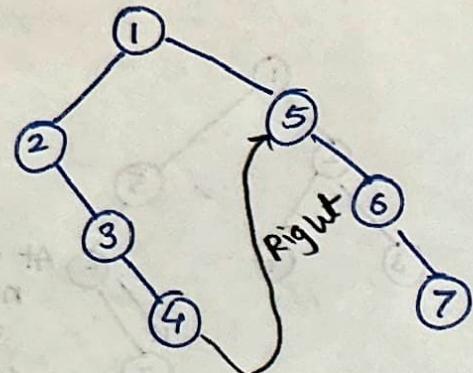
Now prev = 4

come to 2, and then come to ③ Now at ③ Right X

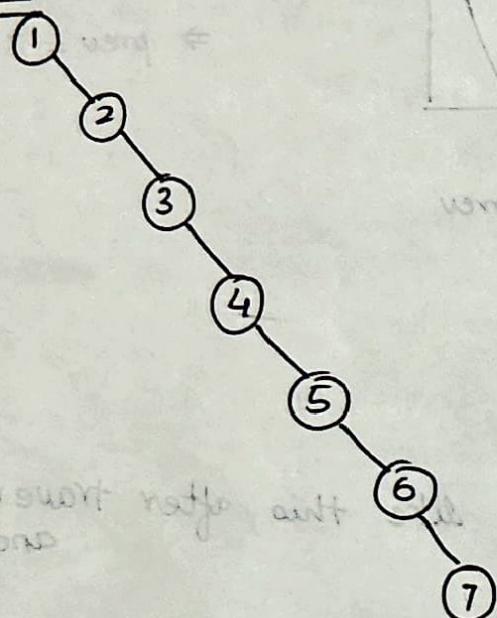
and ③ $\text{node} \rightarrow \text{right} = \text{prev}$
means ③ Right ④
prev = 3

Now comes back to ②, It's right → DONE }
left → DONE } point ② right prev
② right ③





Flatten tree **OMG!!**

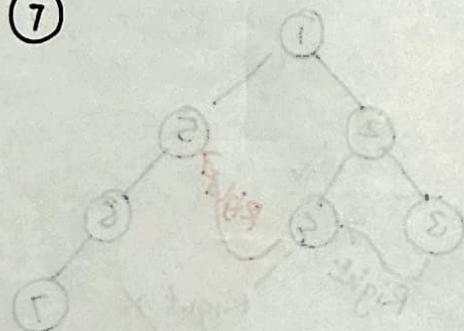


① No leaf node will be present in the final list since now

$$\boxed{T.C = O(N) \\ S.C = O(N)}$$



$\alpha = \text{wrong}$



② $\text{using} = \text{tuplr} \leftarrow \text{abon}$

③ tuplr

④ abon

$\beta = \text{wrong}$

X \checkmark ⑤ to work ⑥ at some next bus & ⑦ at some coming

$\text{wrong} = \text{tuplr} \leftarrow \text{abon}$ ⑧ bus

⑨ tuplr

⑩ abon

$\beta = \text{wrong}$

⑪ tuplr ⑫ abon { $\text{tuplr} \leftarrow \text{abon}$ } ⑬ $\text{at some point when}$

⑭ tuplr ⑮ abon

⑯ tuplr ⑰ abon

after pointing the $\text{②} \xrightarrow{\text{right}} \text{③}$
 $\Rightarrow \text{prev} = 2$
 Come back to 1
 Now its left and right is done!
 hence $\text{①} \xrightarrow{\text{Right}} \text{prev}$

$\text{①} \xrightarrow{\text{Right}} \text{②}$
 $\text{abon} = \text{tuplr} \leftarrow \text{abon}$
 $\text{abon} = \text{wrong}$

wrong \leftarrow tuplr

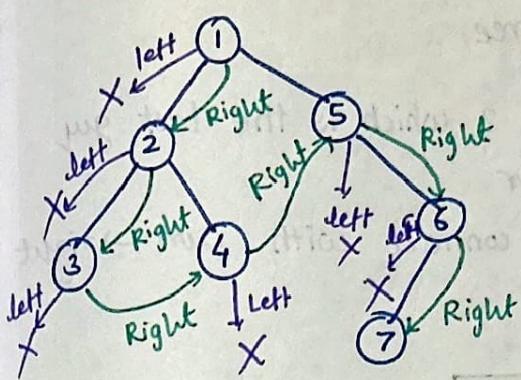


$\alpha = \text{wrong}$

④ to bus $\beta = \text{wrong}$ hence

Approach : II

Using stack!



(1) o = 0
(1) o = 0.2

due to this line

1 → Right = st. top()

1 → leftt = NULL

st
2
5
()

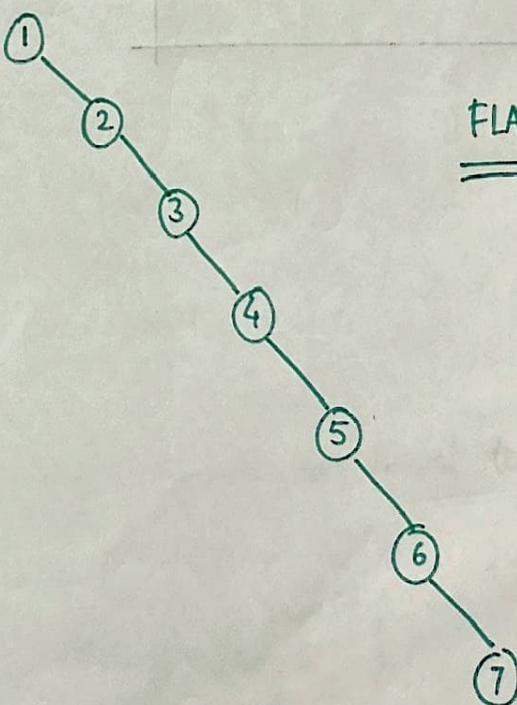
pick
2
3
4

curr

4 → put it into st.

3
4
2
5

Now join the green lines



FLATTEN!!

T.C = O(N)
S.C = O(N)

st.push(root);
while (!st.empty()) {

curr = st.top();

st.pop();

if (curr → right) {

st.push(curr → right);

}

if (curr → left) {

st.push(curr → left);

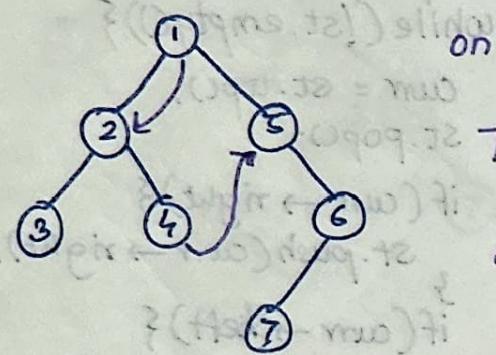
}

if (!st.empty())

curr → right = st.top();

curr → left = NULL;

Approach : III



on the left subtree

Try to figure out ? which is the last guy
in the preorder
and if found connect with curr → right

```

curr = root;
while (curr != NULL) {
    if (curr->left != NULL) {
        prev = curr->left;
        while (prev->right) {
            prev = prev->right;
        }
        prev->right = curr->right;
        curr->right = curr->left;
        curr->left = nullptr;
    }
    curr = curr->right;
}
  
```

T.C = O(N)
S.C = O(1)

(4) O = O.T
(4) O = O.B

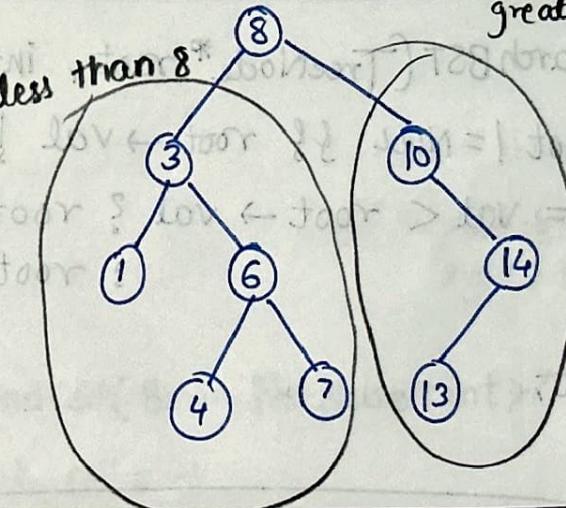
Binary Search Tree

alt prntwrd for bnd nodes
sort strings

(mgd) O = O.T

~~→ O(1)~~

BST signifies $\Rightarrow L < N < R$



- (1) Left Subtree should be BST
- (2) Right Subtree should be BST

Are duplicates allowed?

→ it depends and if so then $L < N < R$ will be modified.

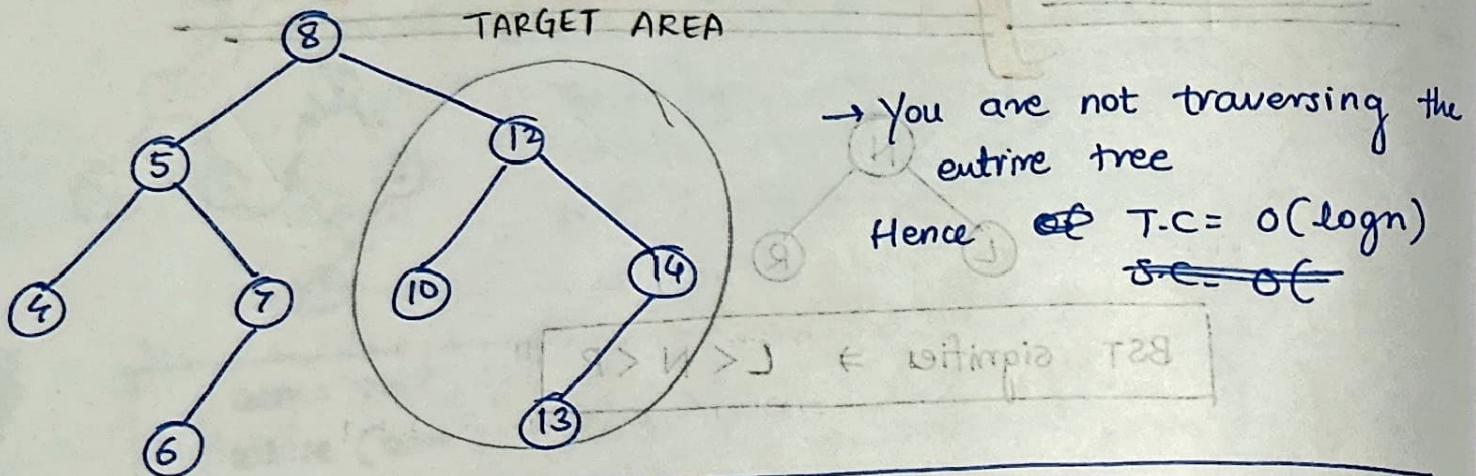
Why BST?

In binary tree, if we want to search any node

$\hookrightarrow O(N)$

but in BST $\rightarrow O(\log N)$

• Search in BST :-



```

TreeNode* searchBST(TreeNode* root, int val) {
    while (root != NULL && root->val != val) {
        if (root->val < val) root = root->left;
        else root = root->right;
    }
    return root;
}

```

T2B ad blwrdz sortdz thd (1)
T2B ad blwrdz sortdz twgt (2)

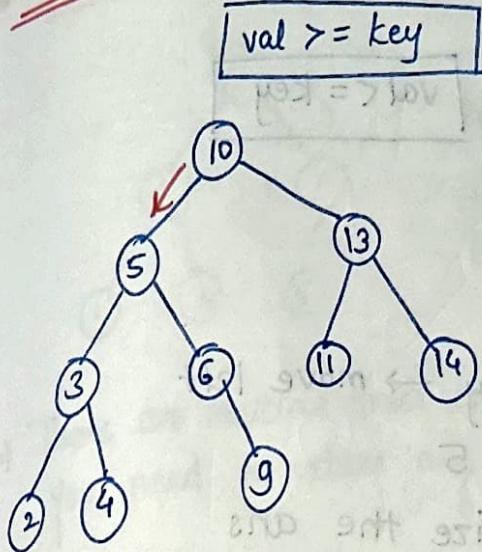
ad hia g>N>J next & 77 bnd abnqet fir
. bsifibom

? T2B jntw

abon jntw nboez of thow sw fi sort monid nT
(1)0 ✓

(Input) o f T2B ni jnd

• Ceil in a BST :-



val \geq key

key = 8

root = 10 \Rightarrow

10 \geq 8

But we need to reduce this as much as possible.

Now, key $<$ root \rightarrow move left

from 5 \rightarrow go to right \Rightarrow 6 is possible

from 6 \rightarrow go to right \Rightarrow 9

↓

is 9 possible?

YES!

update the ans

go to left \Rightarrow NULL

Right \Rightarrow NULL

```
int findCeil(BinaryTreeNode<int>* root, int key) {
```

int ceil = -1;

while (root) {

if (root->data == key) {

return root->data;

}

if (key > root->data) root = root->right;

else {

ceil = root->data;

root = root->left;

}

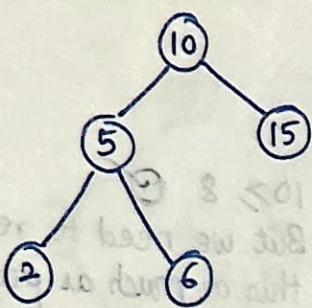
}

return ceil;

}

T.C = O(N)

Floor in Binary Search Tree



key = 7

8 = key

6 < 7

val <= key

root = 10 → root > key → move left

root → data = 5 → ans = 5

Now you have to maximize the ans
So you have to move right

6 → 6 <= 7 → True ans = 6

move left → NULL

move right → NULL

return 6

```
int findFloor (BinaryTreeNode<int>* root, int key) {
```

int floor = -1;

while (root != NULL) {

if (root → data == key) return root → data;

if (root → data < key) {

// move right

~~root~~ = floor = root → data;

root = root → right;

}

else {

root = root → left;

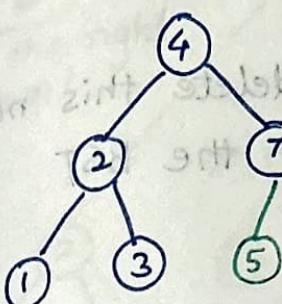
}

}

return floor;

}

Insert a given node in Binary Search Tree



node = 5

Now you have to insert this node in such a way that all conditions for binary search tree will be satisfied.

⇒ There are multiple trees are possible.
you need to return any of them.

Try to find out the place for the node.

Find where it can be inserted
and its always on the leaf

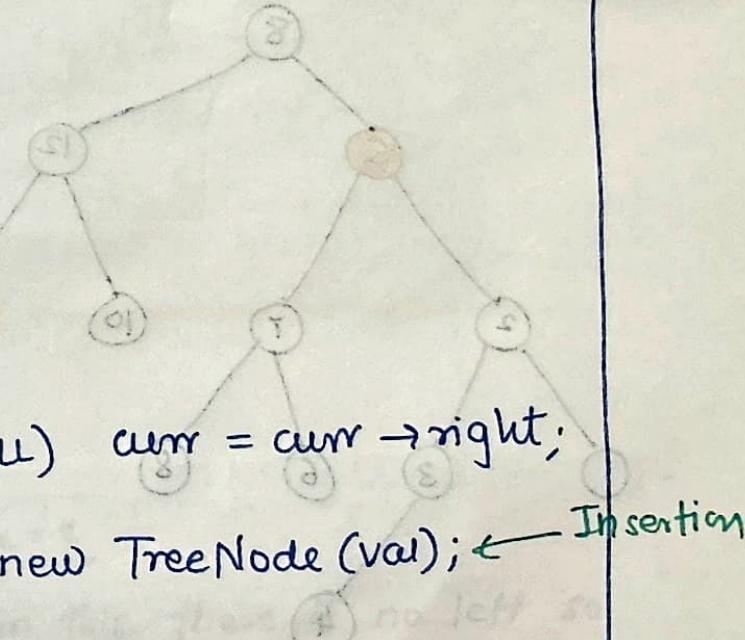
For simplicity.

```

TreeNode* insertIntoBST(TreeNode* root, int val) {
    if (root == NULL) { return newTree
        return new TreeNode(val);
    }
}
  
```

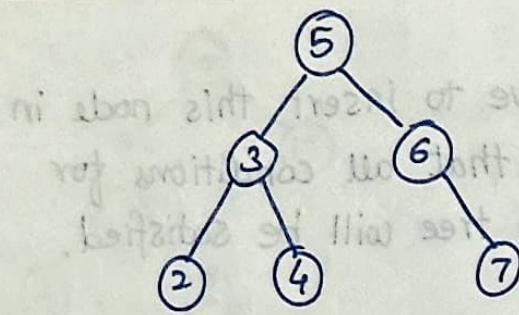
```

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



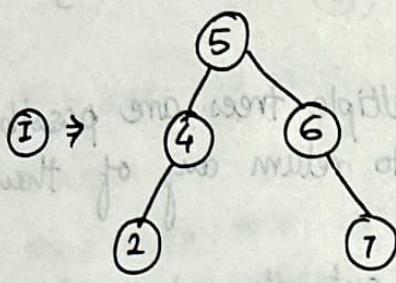
3 3 3
3 return root;

• Delete a Node in Binary Search Tree:-

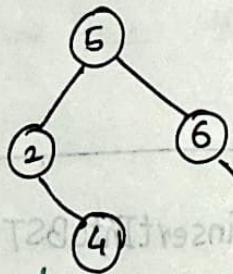


node = 3

You have to delete this node
and rearrange the BST



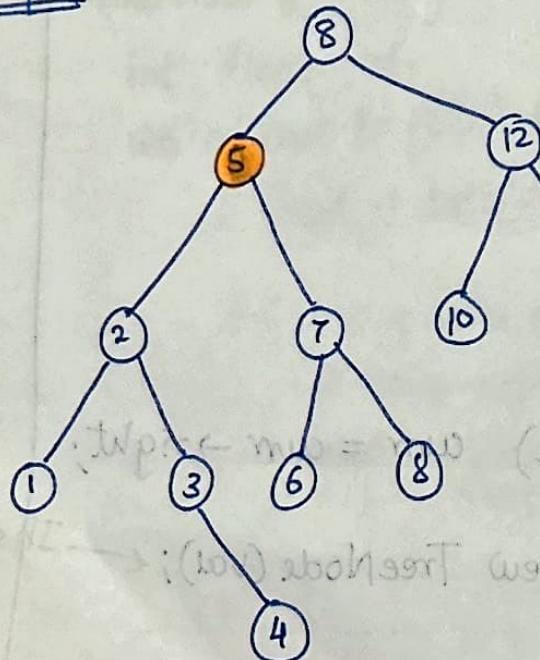
① =>



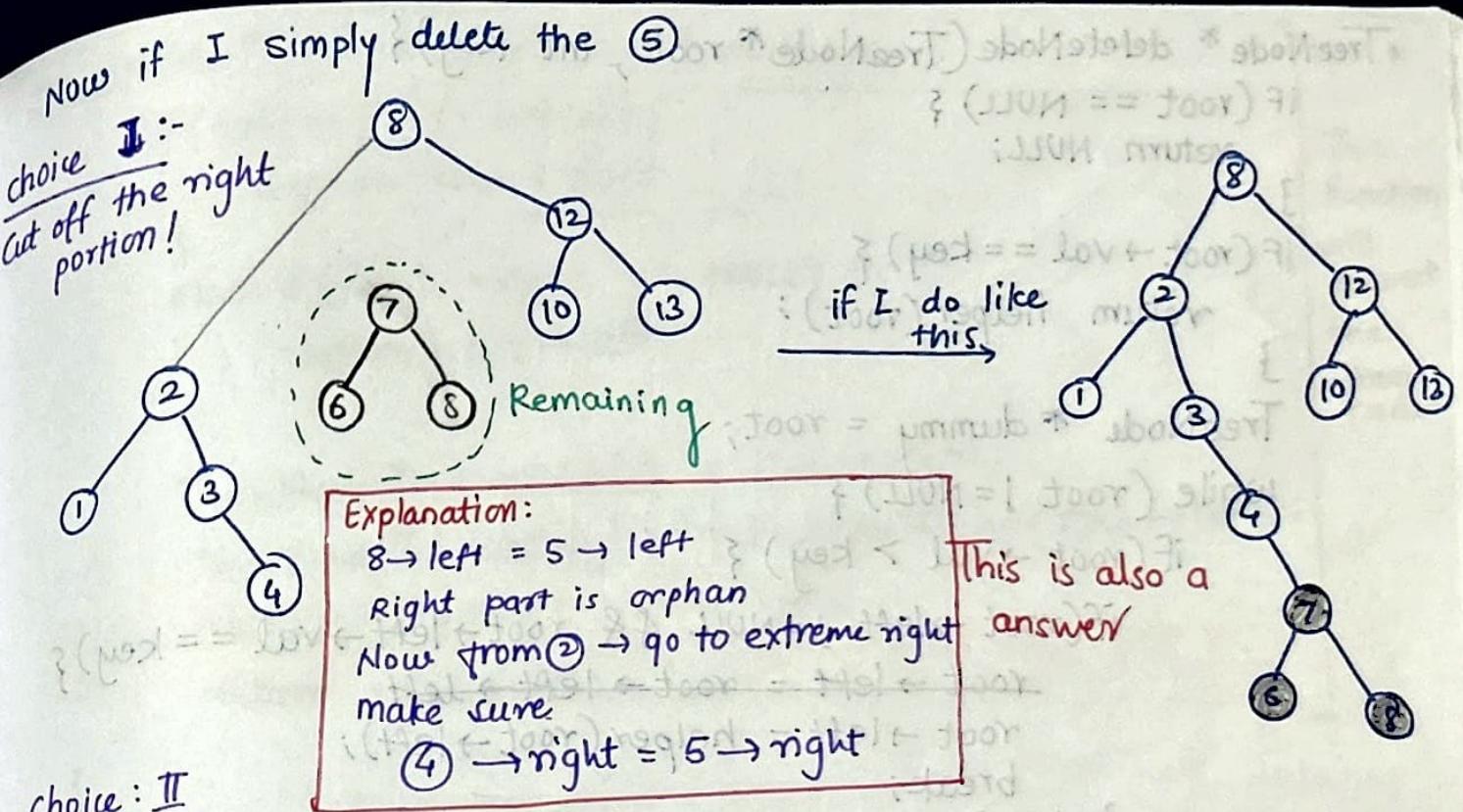
② =>

There are multiple solutions present

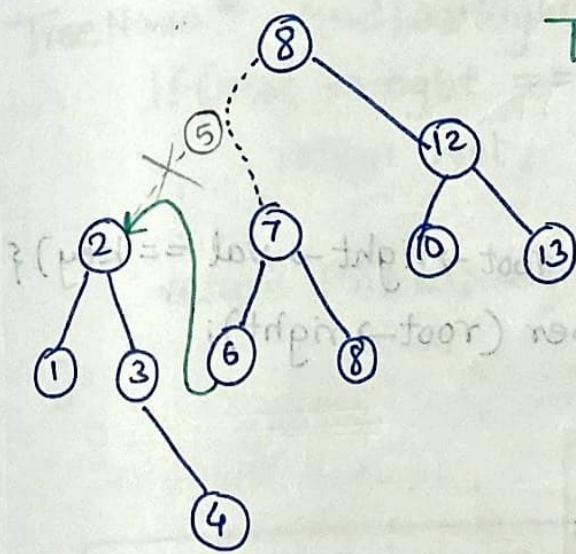
Example :-



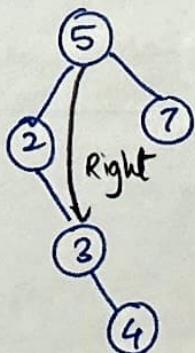
node = 5



The smallest number on the right subtree = 6
connect to this to 2

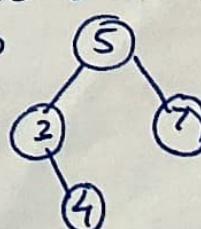


EDGE CASE



node = 2

So in this there is no left so simply attach



```
TreeNode* deleteNode(TreeNode* root, int key) {
    if (root == NULL) {
        return NULL;
    }
    if (root->val == key) {
        return helper(root);
    }
    TreeNode *dummy = root;
    while (root != NULL) {
        if (root->val > key) {
            if (root->left != NULL && root->left->val == key) {
                root->left = root->left->left
                root->left = helper(root->left);
                break;
            } else {
                root = root->left;
            }
        } else {
            if (root->right != NULL && root->right->val == key) {
                root->right = helper(root->right);
                break;
            } else {
                root = root->right;
            }
        }
    }
    return dummy;
}
```

```

TreeNode* helper(TreeNode* root) {
    if (root->left == NULL) {
        return root->right;
    }
    else if (root->right == NULL) {
        return root->left;
    }
}

```

This function will connect the linear nodes

```

TreeNode* rightChild = root->right;
TreeNode* lastRight = findLastRight(root->left);
lastRight->right = rightChild;
return root->left;
}

```

```

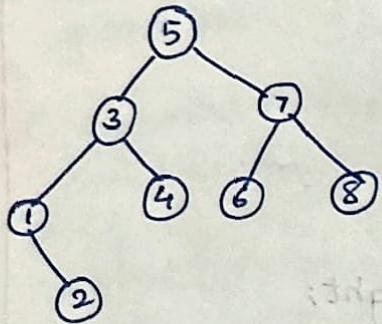
TreeNode* findLastRight(TreeNode* root) {
    if (root->right == NULL) {
        return root;
    }
    return findLastRight(root->right);
}
}

```

Time Complexity $\Rightarrow O(H)$
Space Complexity $\Rightarrow O(1)$

$$\text{Time Complexity} (H) = O(H)$$

- K^{th} smallest element in BST :-



Write down the inorder :-

1	2	3	4	5	6	7	8
---	---	---	---	---	---	---	---

Impl!!

Inorder of binary Search tree is always in the sorted order

Maintain the count as "0"

and whenever you encounter the node \rightarrow count++;

Three Approaches :-

① Recursive :- $T.C = O(N)$
 $S.C = O(N)$

② Iterative : $T.C = O(N)$
 $S.C = O(N)$

③ Morris traversal : $T.C = O(N)$
 $S.C = \cancel{O(N)} O(1)$

→ preferred solution

- k^{th} largest element in BST

logic \Rightarrow

$$k^{th} \text{ largest} = \frac{(N - k + 1)^{th} \text{ smallest element}}{(N - k + 1)^{th} \text{ smallest element}}$$

```

int KthSmallest(TreeNode* root, int k) {
    int count = 0, result = 0;
    traverse(root, k, count, result);
    return result;
}

void traverse(TreeNode* node, int k, int& count, int& result) {
    if (node == NULL) return; result,
    traverse(node->left, k, count, result);
    count++;
    if (count == k) {
        result = node->val;
        return;
    }
    traverse(node->right, k, count, result);
}

```

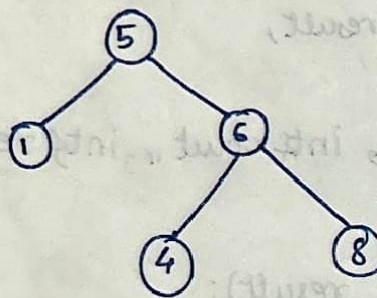
```

int KthLargest(TreeNode* root, int k) {
    int count = 0, result = 0;
    traverse(node, k, count, result);
    return result;
}

void traverse(TreeNode* node, int k, int& count, int& result) {
    if (node == NULL) return;
    traverse(node->right, k, count, result); Opposite Traversal
    count++;
    if (count == k) {
        result = node->val;
        return;
    }
    traverse(node->left, k, count, result);
}

```

- Check if tree is a BST or BT
- for satisfying the condition of BST \Rightarrow



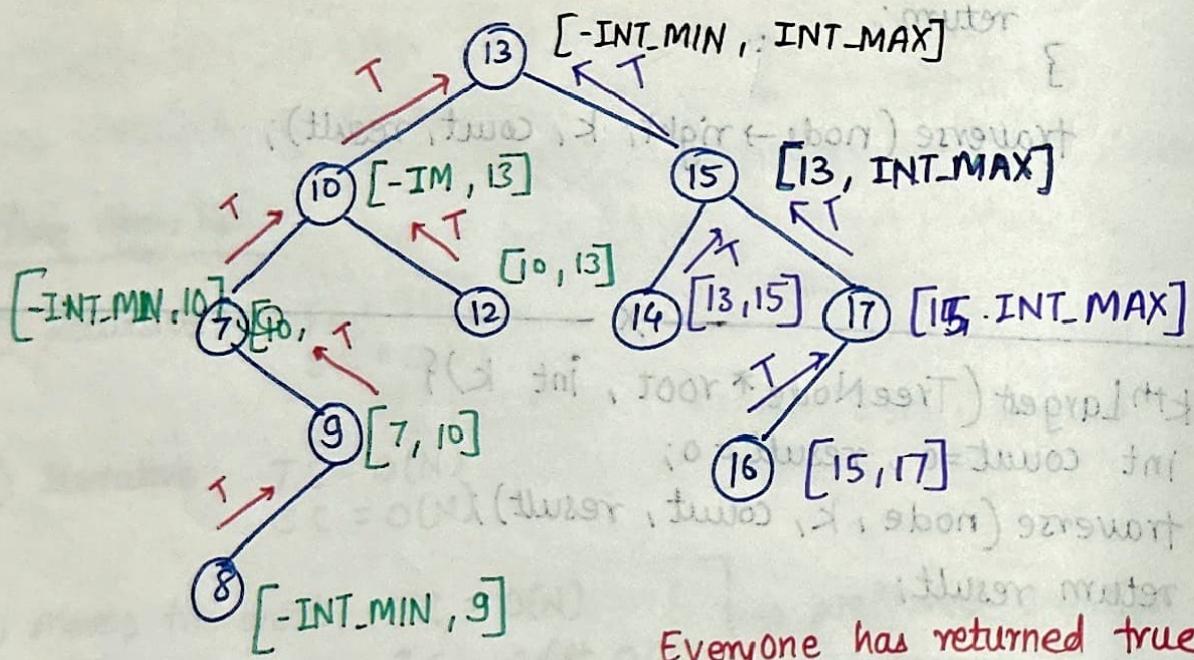
for ④ It should be lesser than ⑥
AND should be greater than ⑤

Hence we need to consider the scenario

Intuition:-

$$\text{node} = [L, H]$$

Example :- for ④ it should lie b/w $[5, 6]$ \Rightarrow false



Everyone has returned true

\Rightarrow Hence its a valid BST

$$T.C = O(N)$$

$$S.C = O(1)$$

bool isValidBST(TreeNode* root) {

 return isValid(root, INT_MIN, INT_MAX);

}

bool isValid(TreeNode* root, long minValue, long maxValue) {

 if (root == NULL) return true;

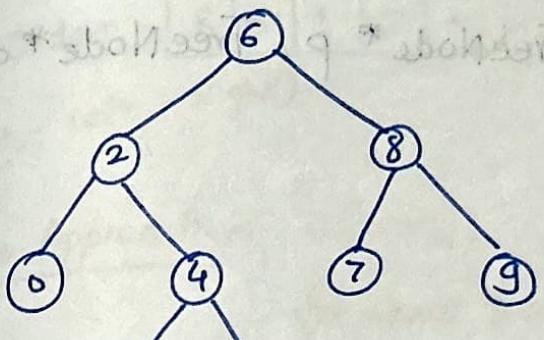
 if (root->val >= maxValue || root->val <= minValue) return false;

 return isValid(root->left, minValue, root->val);

 if (isValid(root->right, root->val, maxValue))

 return true;

Lowest Common Ancestor in Binary Search Tree :-

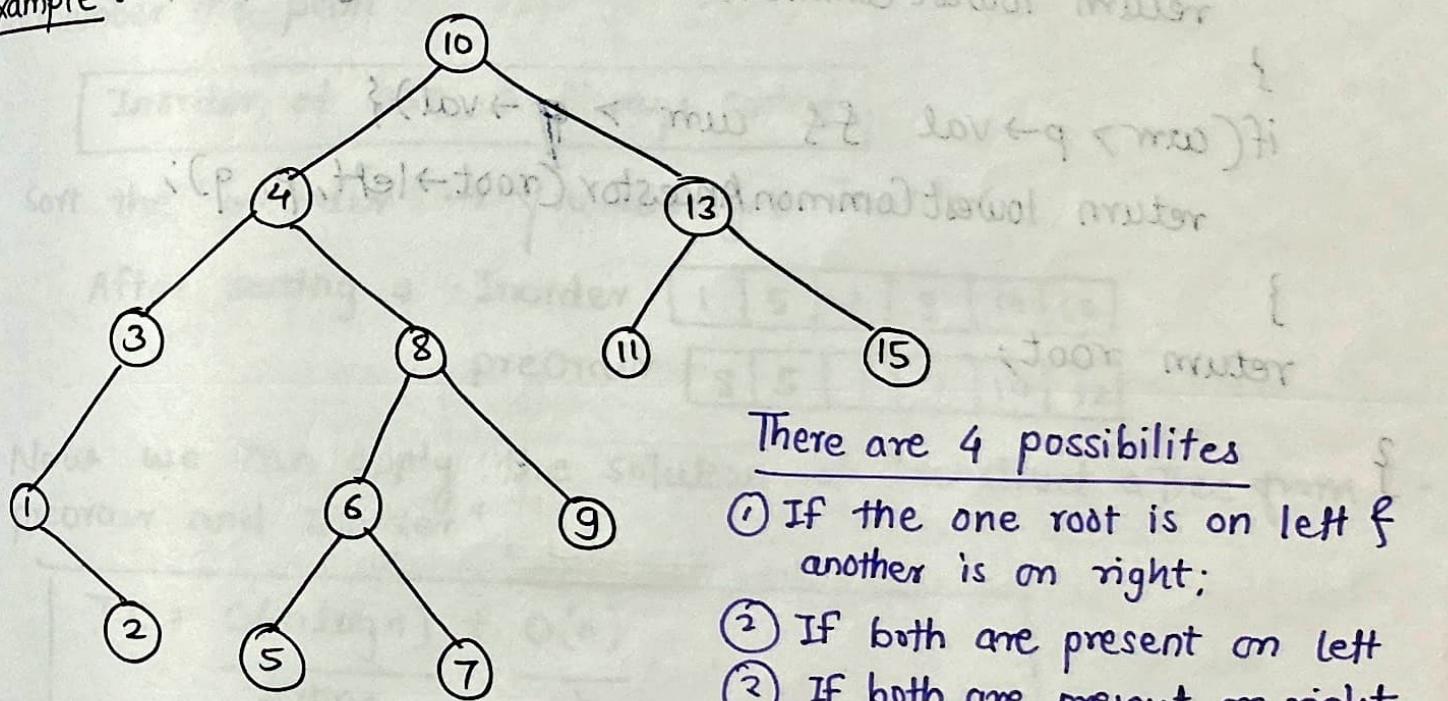


$$LCA(2, 5) = 2$$

$$LCA(0, 5) = 2$$

first intersection path (from bottom)

Example :-



There are 4 possibilities

- ① If the one root is on left & another is on right;
- ② If both are present on left
- ③ If both are present on right
- ④ If there is a root node from one amongst them.

let's discuss $L(5, 9)$

Now 5 & 9 both are lesser than 10. move to left \Rightarrow 4

④ \rightarrow 5 & 9 are greater \rightarrow move to right \Rightarrow 8

on ⑧ \rightarrow 5 is on left and 9 is on right \rightarrow This is where the path has been split so this is my LCA

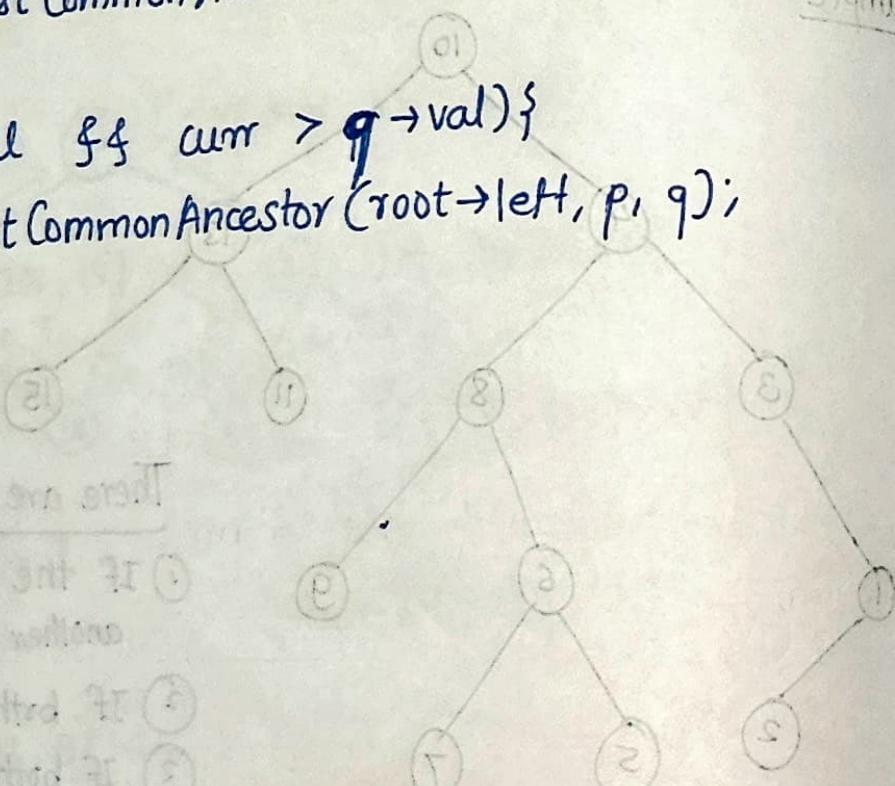
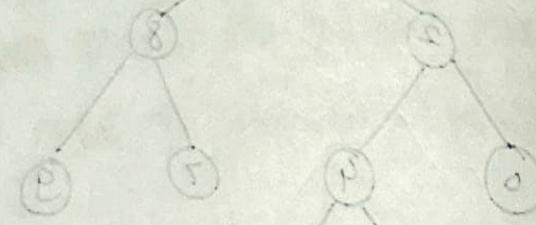
$$T.C = O(H)$$

$$S.C = O(1)$$

```

TreeNode* LowestCommonAncestor(TreeNode* root,
                                TreeNode* p, TreeNode* q) {
    if (root == NULL) {
        return NULL;
    }
    int curr = root->val;
    if (curr < p->val && curr < q->val) {
        return lowestCommonAncestor(root->right, p, q);
    }
    if (curr > p->val && curr > q->val) {
        return lowestCommonAncestor(root->left, p, q);
    }
    return root;
}

```



(p, q) = lowest common ancestor

p ∈ left of 8 and q ∈ right of 8

8 ∈ right of 8 and p ∈ left of 8

need to check if p is in right of 8

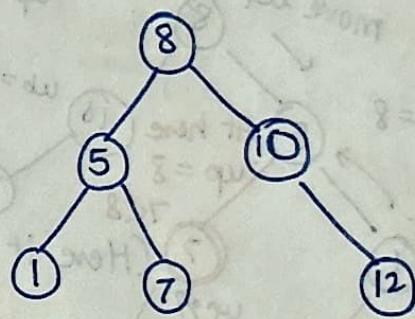
ADJ sum is right or left

$$(H)O = OT$$

Construct a BST from preOrder traversal :-

preOrder
(Root - Left - Right)

8	5	1	7	10	12
---	---	---	---	----	----



Naive Approach :- $O(N \times N)$
for skew tree

Better Method :-

Remember the point

Inorder of BST \Rightarrow Always sorted

sort the preorder \rightarrow you will get Inorder

After sorting \Rightarrow Inorder

1	5	7	8	10	12
---	---	---	---	----	----

preOrder

8	5	1	7	10	12
---	---	---	---	----	----

Now we can apply the solution of "construct a Tree from preOrder and Inorder".

$$T.C = \frac{O(n \log n)}{\text{sorting}} + O(n) \quad \downarrow \text{construct the tree}$$

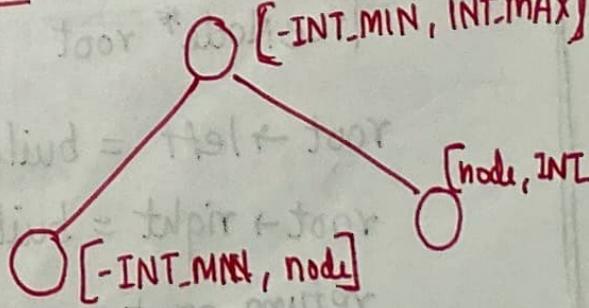
$$S.C = O(n)$$

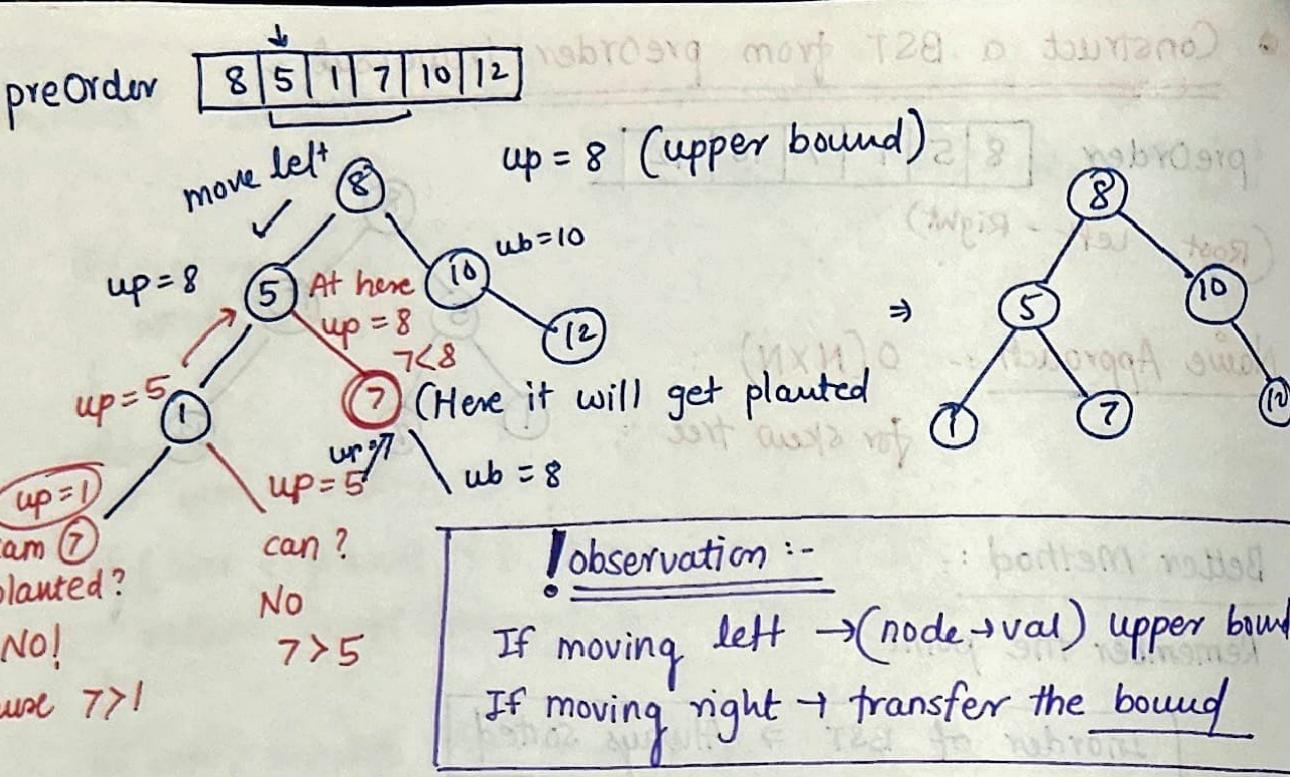
Efficient Method :-

preOrder

8	5	1	7	10	12
---	---	---	---	----	----

Ref: check if tree is BST or not





$$T.C = O(3N)$$

You are visiting 3 times a single node

$$T.C \approx O(N)$$

$$S.C = O(1)$$

TreeNode* bstFromPreOrder(~~TreeNode*~~ vector<int>& A) {

 int i = 0;

 return build(A, i, INT_MAX);

}

TreeNode* build(vector<int>& A, int i, int bound) {

 if (i == A.size() || A[i] > bound) return NULL;

 TreeNode* root = new TreeNode(A[i++]);

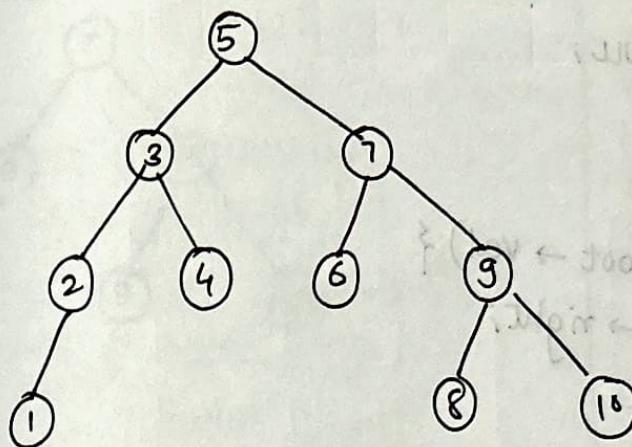
 root->left = build(A, i, root->val);

 root->right = build(A, i, bound);

 return root;

}

Inorder Successor in Binary Search Tree :-



Inorder $\Rightarrow 1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9 \ 10$

\uparrow
Inorder Successor

If the no successor is present \rightarrow return NULL.

Efficient Approach :-

successor = NULL val = 8

At root $\rightarrow 5 \rightarrow$ I should move to right

Now at 7 \rightarrow I should move to right

at 9 \rightarrow Here we can say 9 is the successor
But are we sure?

NOT \rightarrow cause there might be a possibility
that the successor (min) would
present at left

I know 9 $\xrightarrow{\text{Right}}$ 10 will not be my successor

Hence I need someone who is > 8 and ≤ 9

move left \rightarrow 8 found

Now move right we reach NULL.

Hence our successor is 9.

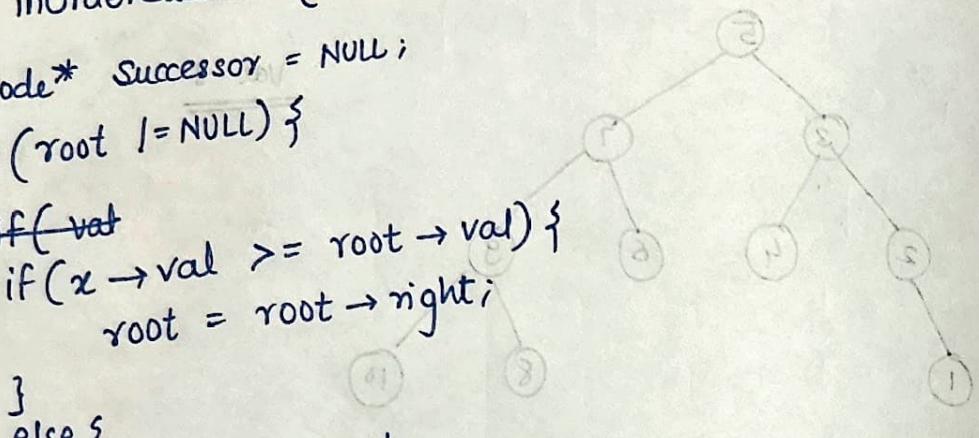
Time Complexity = $O(H)$

Space Complexity = $O(1)$

```

TreeNode* inOrderSuccessor(TreeNode* root, TreeNode* x) {
    TreeNode* successor = NULL;
    while (root != NULL) {
        if (x->val <= root->val) {
            if (x->val >= root->val) {
                root = root->right;
            } else {
                successor = root;
                root = root->left;
            }
        }
        return successor;
    }
}

```



predecessor :-

```

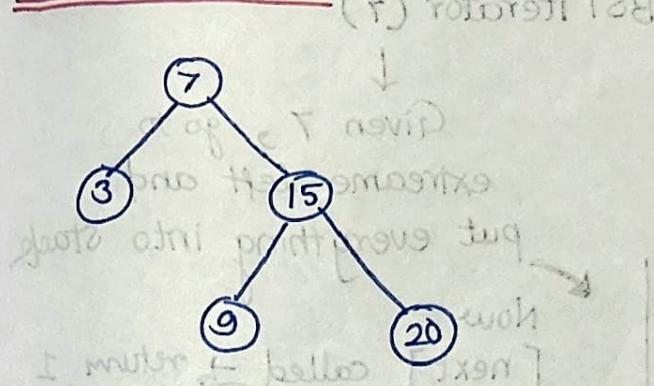
TreeNode* inOrderPredecessor(TreeNode* root, TreeNode* x) {
    TreeNode* predecessor = NULL;
    while (root != NULL) {
        if (x->val >= root->val) {
            predecessor = root;
            root = root->left;
        } else {
            predecessor = root;
            root = root->right;
        }
    }
    return predecessor;
}

```

$$(H)_O = \text{prefix sum}$$

$$(D)_O = \text{suffix sum}$$

BST Iterator :-



Inorder

3	7	9	15	20
---	---	---	----	----

Initially pointer will be pointing to a NULL

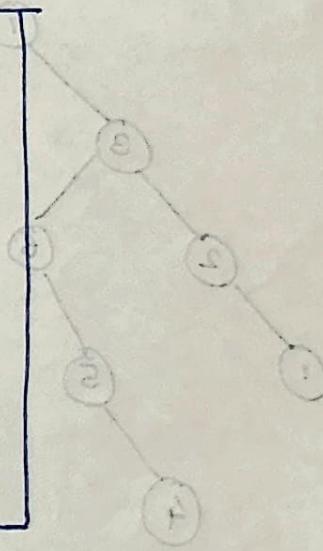
- next → return 3
- next → return 7
- hasnext → return True
- next → 9
- hasnext → return True
- next → 15
- hasnext → True
- Next → 20
- hasnext → false.

Inorder \Rightarrow Left \leftrightarrow Root - Right

$$\begin{aligned} (4) O &= O.H \\ (1) O &= O.T \end{aligned}$$

BST iterator(7)

next
next
hasnext
next
hasnext
next.
hasnext
next.
hasnext



for returning the

T.C = O(1)

S.C = O(N)

for storing the inorder

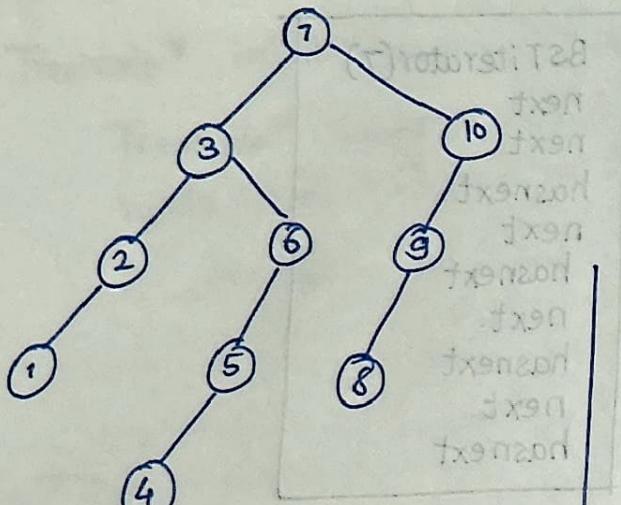
This question is easy if we are allowed to store the inorder but if they don't then its a tricky question

The constraint \Rightarrow O(H)

T.C

$$(X)(A)O \leftarrow O.T = O.O [O.O]$$

$$(1)O = O.T$$



BST iterator (7)

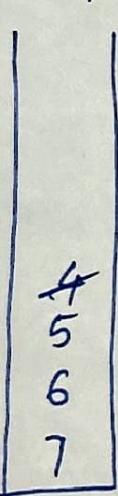
Given 7, go to extreme left and put everything into stack

Now [next] called → return 1
check for right

[next] called → return 2
check for right x

[next] called → return 3
check for right ⇒ yes!

Now go to right & put everything into stack (~~left~~) element



[hasnext] → if stack empty?
→ No → return true

next → 4 → return 4
If 4 has right → x

next → 5 → return 5

↓
|
|
|
↓

This is how this will work!

$$\begin{aligned} S.C &= O(H) \\ T.C &= O(1) \end{aligned}$$

pushing n elements into stack → N

& there might be N

[next] calls = T.C ⇒ $O(N/N)$

$$T.C = O(1)$$

```
class BSTIterator {
```

```
    stack<TreeNode*> myStack;
```

```
public:
```

```
    BSTIterator(TreeNode* root) {
```

```
        myStack.push(
```

```
            pushAll(root);
```

```
}
```

```
    bool hasNext() {
```

```
        return !myStack.empty();
```

```
}
```

```
    int next() {
```

```
        TreeNode* tmpNode = myStack.top();
```

```
        myStack.pop();
```

```
        pushAll(tmpNode->right);
```

```
        return tmpNode->val;
```

```
;--x } = 2 <= i <= s
```

```
private:
```

```
    void pushAll(TreeNode* node) {
```

```
        for(; node != NULL;
```

```
            while (node != NULL) {
```

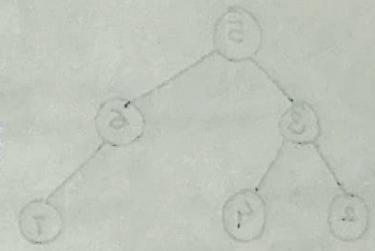
```
                myStack.push(node);
```

```
                node = node->left;
```

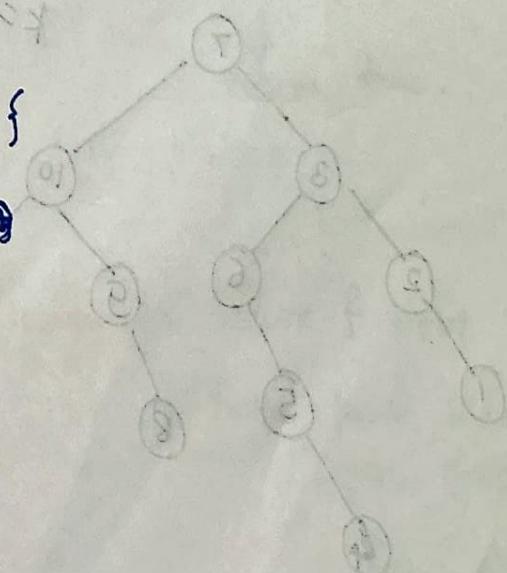
```
}
```

```
}
```

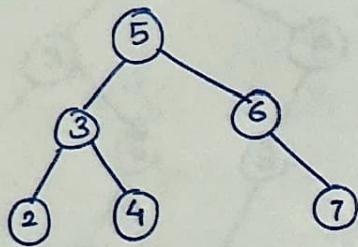
```
}
```



$$(n)O + (n)O = O.T$$
$$(n)O = O.2$$



Two Sum IV in BST



return true if pair exists, return false

Brute force :-

why inorder have taken? cause its always sorted!

find the inorder \Rightarrow

2	3	4	5	6	7
↑	↑				↑
l	r				r

 GOT IT!! r

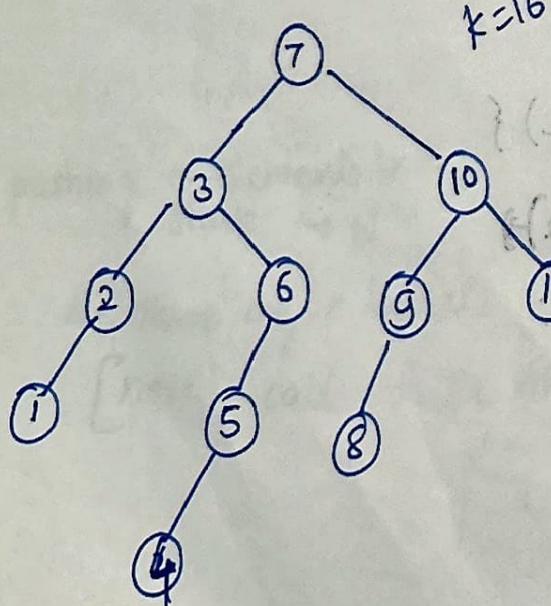
then take $l=0$
 $r = \text{size} - 1$ if $2 + 7 = k \rightarrow \text{No} \Rightarrow 9 > 5$
 then reduce the greater no. index

$T.C = O(N) + O(N)$
 $S.C = O(N)$

$2 + 5 = 7 > 5 \Rightarrow r--;$

$2 + 4 = 6 > 5 \Rightarrow r--$

$2 + 3 = (5 = 5) \Rightarrow \text{return true}$



$k=16$

We will try to reduce the space complexity, cause in the worst case we need to travel each node.

Now you can take a help from the concept BST Iterator
for before concept

Now If you iterate DFS \Rightarrow Right - Node - Left

\Downarrow
resulting in descending
order sort

In next() concept we pushed everything which is present on left
but In before() concept we push everything which is present on RIGHT

Initially my i^{th} pointer stands at $i = \text{next}()$
and j^{th} pointer $= j = \text{before}()$

next will be the smallest element $\Rightarrow i=1$

before will be the largest element $\Rightarrow j=11$

$1+11 = 12 \rightarrow$ less than $k=16 \rightarrow$ increase the i
(move upward)

$2+11 = 13$ (move upward)

$3+11 = 14$ increase

Now i is moved to ④ $\Rightarrow 4+11 = 15$ (increase)
 $5+11 = 16$ MATCHED

\downarrow
return true.

$$T.C = O(N)$$

$$S.C = 2 \times O(H)$$

because storing for before & next
hence twice is the
space complexity

```

class BSTIterator {
    stack<TreeNode*> myst;
    // Reverse → true ⇒ before
    // Reverse → false ⇒ next
    bool reverse = true;
public:
    BSTIterator(TreeNode* root, bool isReverse) {
        reverse = isReverse;
        pushAll(root);
    }
    // Returns whether we have a next smallest number
    bool hasNext() {
        return !myst.empty();
    }
    // Returns the next smallest number
    int next() {
        TreeNode* tmpNode = myst.top();
        myst.pop();
        if (!reverse) {
            pushAll(tmpNode->right);
        } else {
            pushAll(tmpNode->left);
        }
        return tmpNode->val;
    }
}

```

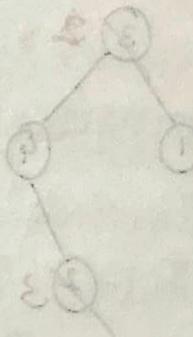
private:
 void pushAll(TreeNode* node){
 while (node != NULL) {
 mySt.push(node);
 if (reverse == true) {
 node = node->right;
 } else {
 node = node->left;
 }
 }

class Solution {

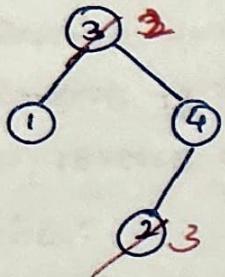
public:
 bool findTarget(TreeNode* root, int k) {
 if (root == NULL) return false;
 BSTIterator left(root, false);
 BSTIterator right(root, true);

 int i = left.next();
 int j = right.next();

 while (i < j) {
 if (i + j == k) return true;
 else if (i + j < k) i = left.next();
 else {
 j = right.next();
 }
 }
 }



• Recover BST :-



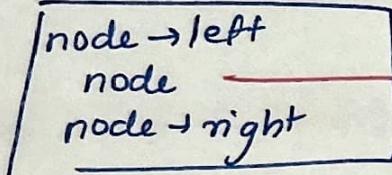
In the given tree, two nodes are swapped
you have to recover the BST

If you swap 2 & 3 then the BST will
be recovered.

Brute :-

get \Rightarrow Inorder traversal and sort it

and while going to

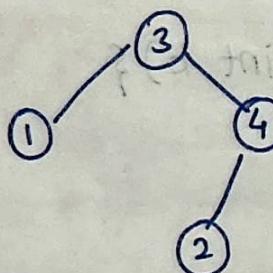


when it comes to
"node" check
if the node is in
inorder(idx)

sorted inorder:-

1	2	3	4
---	---	---	---

idx = 0



node \Rightarrow 1 \rightarrow inorder[idx] = 1 ✓ idx++
and then at 3 - inorder[idx] = 2

\downarrow swap

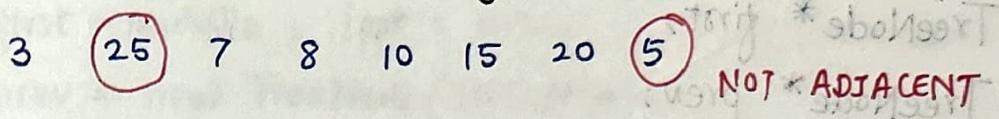
this is how you can process.

$$T.C = 2N + N \log N$$

$$S.C = O(N)$$

Better Approach

i) Swapped nodes are not adjacent



ii) Swapped nodes are adjacent.

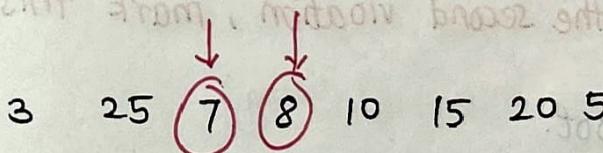


Case I)

while traversal from 25 if we move to 7 It decreased
(Inorder) \rightarrow Hence this is the first
violation

Now from 20 \rightarrow 5 the Again violation second violation
 \rightarrow swap(first & last)

Case II)



first = 7

middle = 8

No second violation found \Rightarrow swap(middle, first)

$$T.C = O(N)$$

$$S.C = O(1)$$

Class Solution;

private:

TreeNode* first;

TreeNode* prev;

TreeNode* middle;

TreeNode* last;

private:

void inorder(TreeNode* root) {

if (root == NULL) return;

inorder(root->left);

if (prev != NULL && (root->val < prev->val)) {

// If this is the first violation, mark these two nodes

// as 'first' and 'middle'

if (first == NULL) {

first = prev;

middle = root;

}

// If this is the second violation, mark this node as

else {

last = root.

}

}

// mark this node as previous

prev = root;

inorder(root->right);

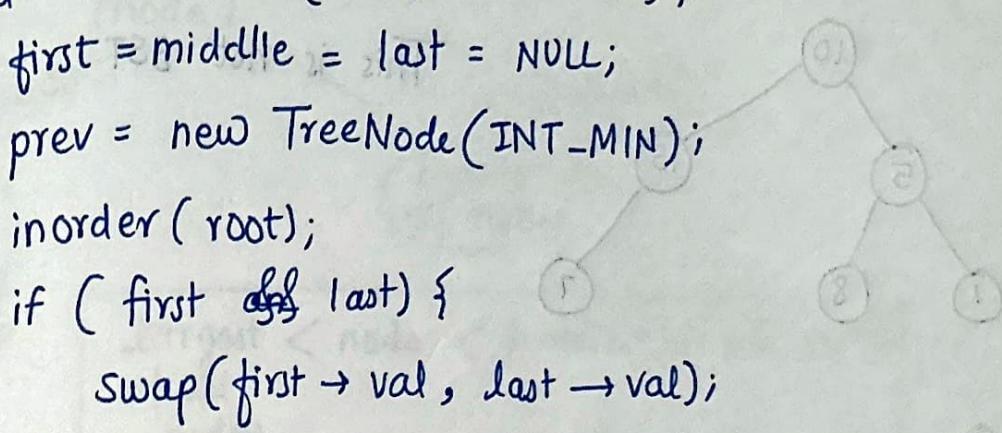
}

(1) O = O.T
(2) O = O.Z

```

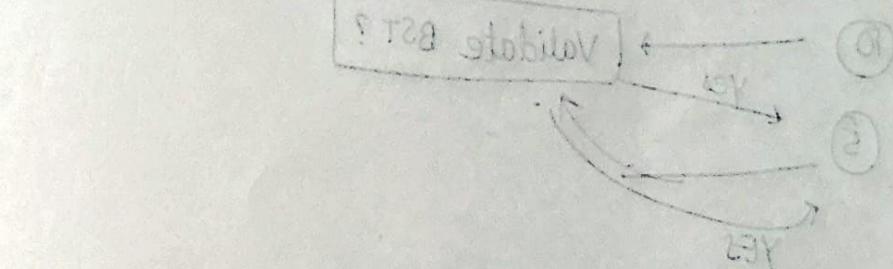
public:
    void recoverTree(TreeNode* root) {
        first = middle = last = NULL;
        prev = new TreeNode(INT_MIN);
        inorder(root);
        if (first && last) {
            swap(first->val, last->val);
        } else if (first && middle) {
            swap(first->val, middle->val);
   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

```



: sort start

T2B stabilitv : best

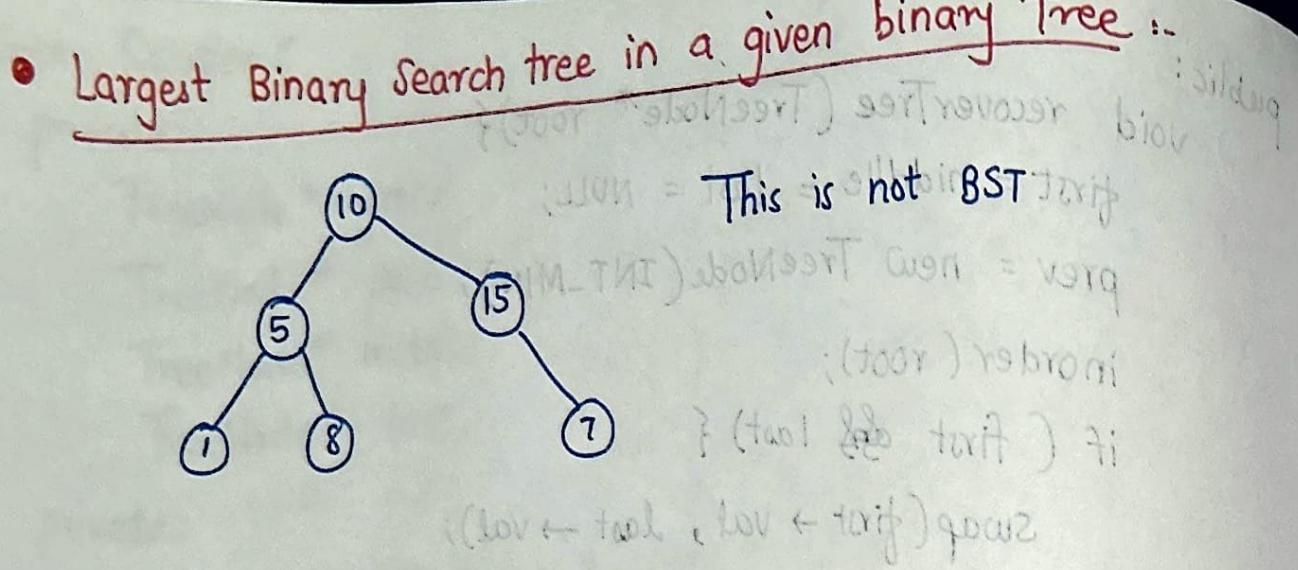


(pre) lernwork ~~best~~ next 23 91

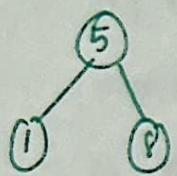
$$(n)O * (n)O = O(n^2)$$

\uparrow \uparrow
 num of pairwise stabilitv
 swap T2B

(sw)O = O(n)

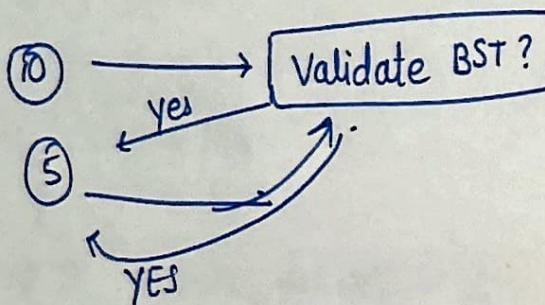


\Rightarrow BST



Brute force :-

Ref: Validate BST



If YES then ~~any~~ traversal (any)

$$T.C = O(N) * O(N)$$

\uparrow \uparrow
 Validate reading to every
 a BST Node

$T.C = O(N^2)$

Optimal :-

