Trees → Generic Tree, Binary Tree, Binary Search Tree

Level (2) Lecture (1) {Saturday, 12 Feb}

Maximum Height

Minimum Height

Is Tree Balanced?

Diameter of Binary Tree

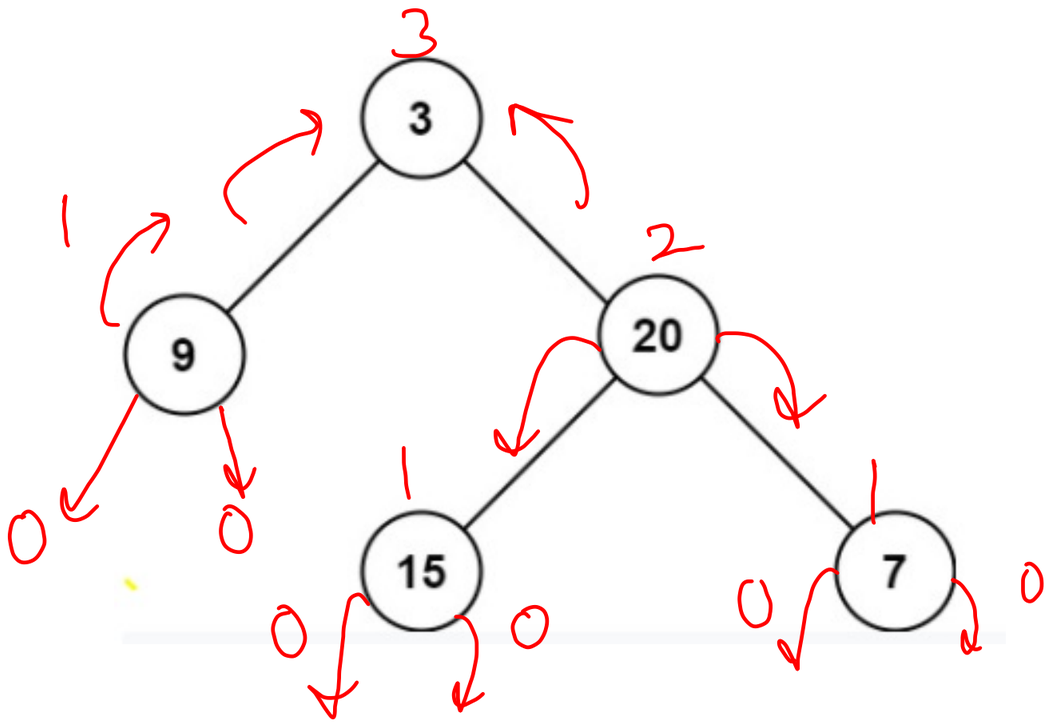
Diameter of NAry Tree

Maximum Depth of Binary Tree

LC 104

```java
class Solution {
    public int maxDepth(TreeNode root) {
        if(root == null) return 0;
        return 1 + Math.max(maxDepth(root.left), maxDepth(root.right));
    }
}
```

root.val



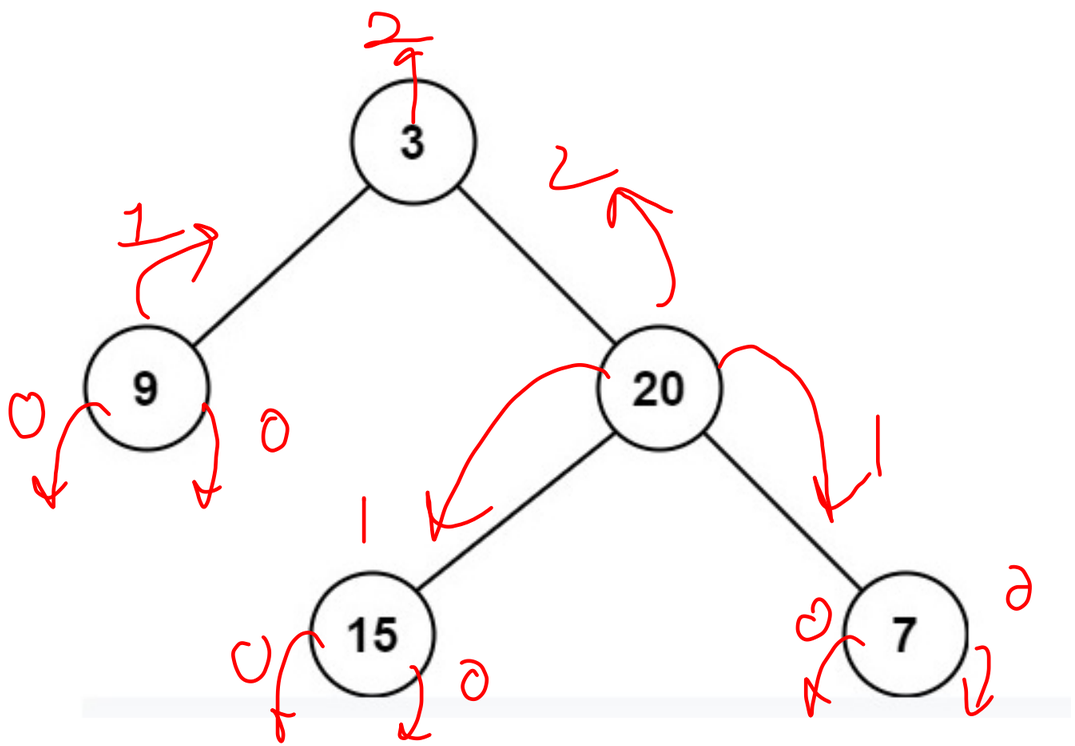
Follow up : Replace 1 with root.val

maximum path sum from root to any leaf node

Minimum Depth (111) LC

Minimum distance from root to any leaf node

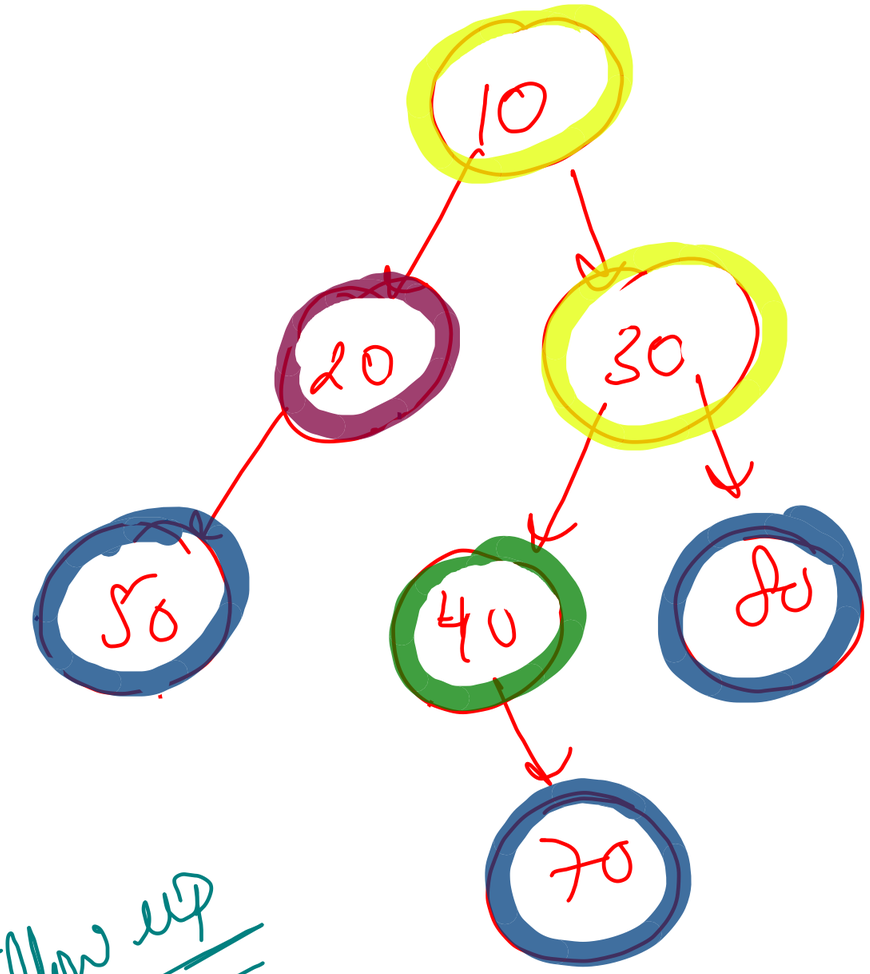
↳ children = 0




```java
class Solution {
    public int maxDepth(TreeNode root) {
        if(root == null) return 0;
        return 1 + Math.max(maxDepth(root.left), maxDepth(root.right));
    }
}
```

min

Code is wrong for single child



Follow up
e.g.

Minimum Path Sum from Root Node to any leaf node

Root == null → 0

Root.left == null && root.right == null

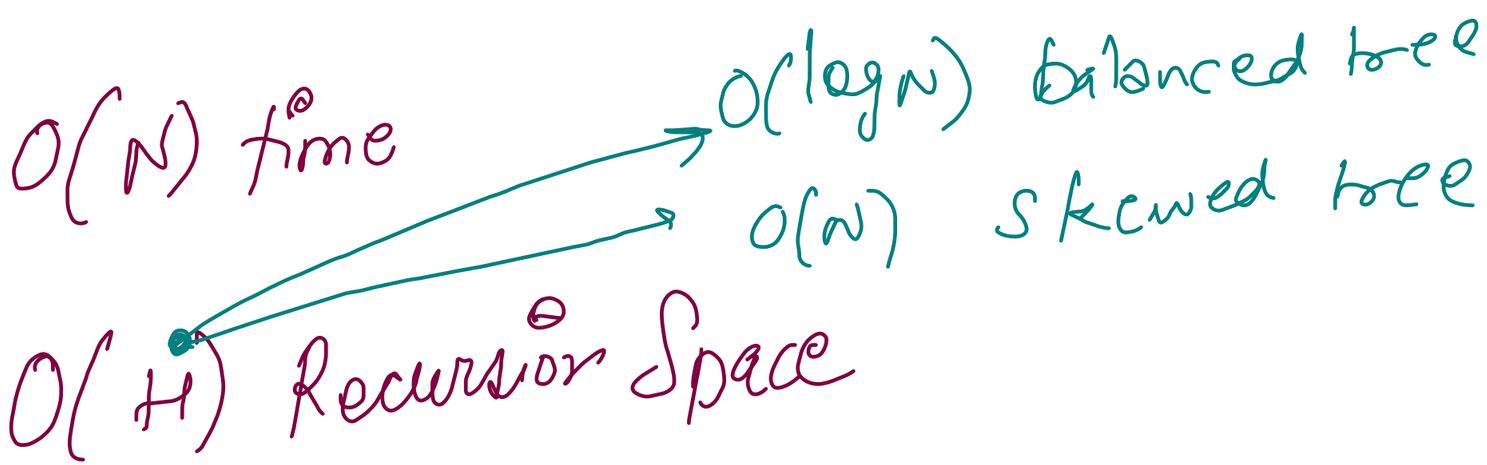
↳ leaf node → 1

Root.left == null → answer from right child +1

Root.right == null → answer from left child +1

2 child node → return (min(lm, rm) + 1)

```java
public int minDepth(TreeNode root) {
    if(root == null) return 0;

    if(root.left == null && root.right == null)
        return 1; // Leaf Node

    if(root.left == null) // Only Right Child
        return 1 + minDepth(root.right);

    if(root.right == null) // Only Left Child
        return 1 + minDepth(root.left);

    // Node with 2 Childs
    return 1 + Math.min(minDepth(root.left), minDepth(root.right));
}
```

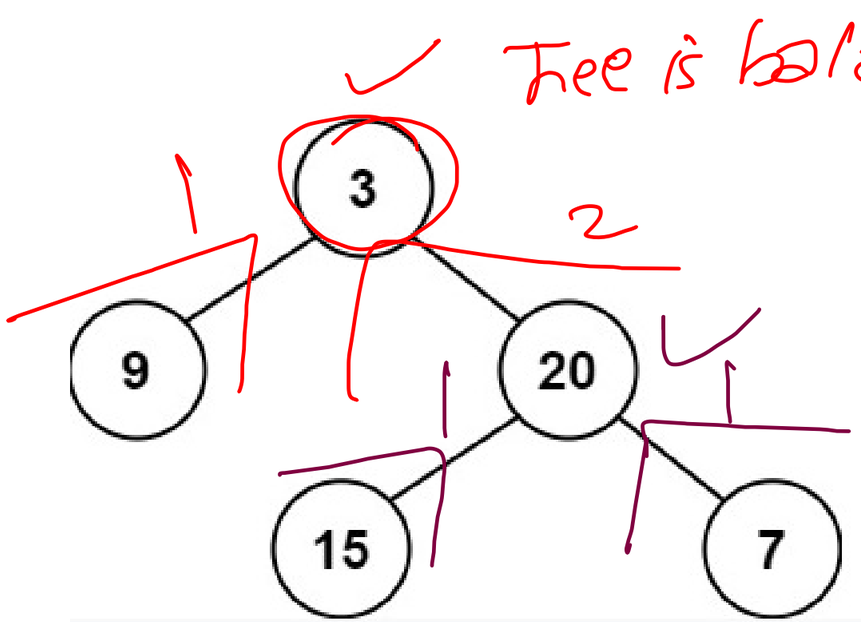


Is Tree Balanced?

110 LC

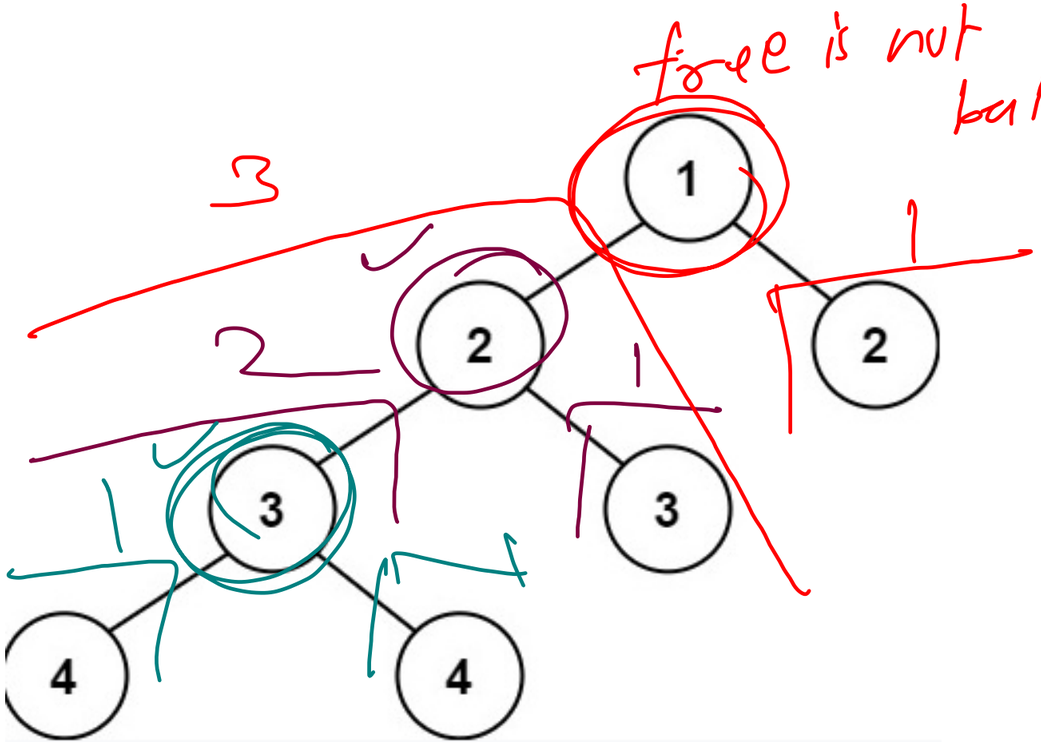
For each node { $|lh - rh| \leq 1$

$lh = rh + 1,\ lh = rh,\ lh = rh - 1$



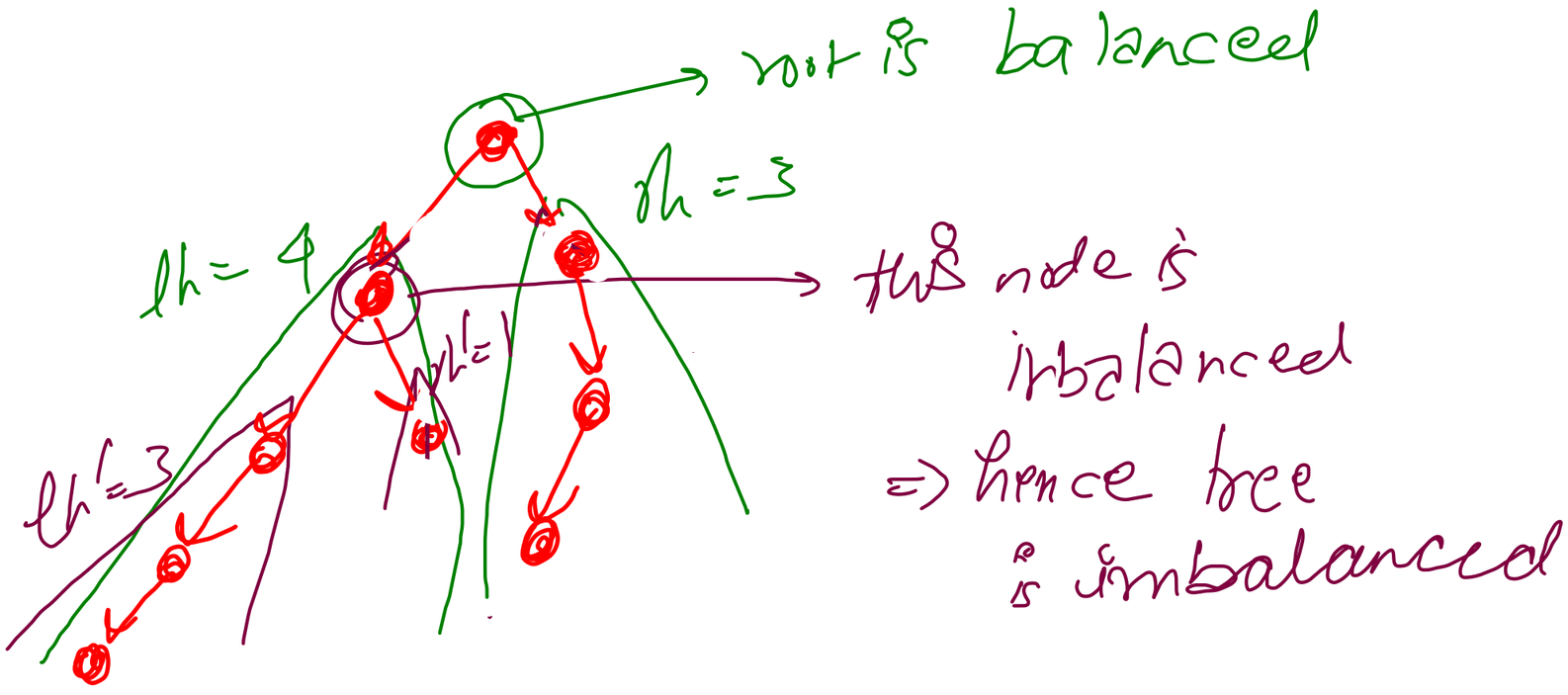
Tree is balanced

True



Tree is not balanced

False

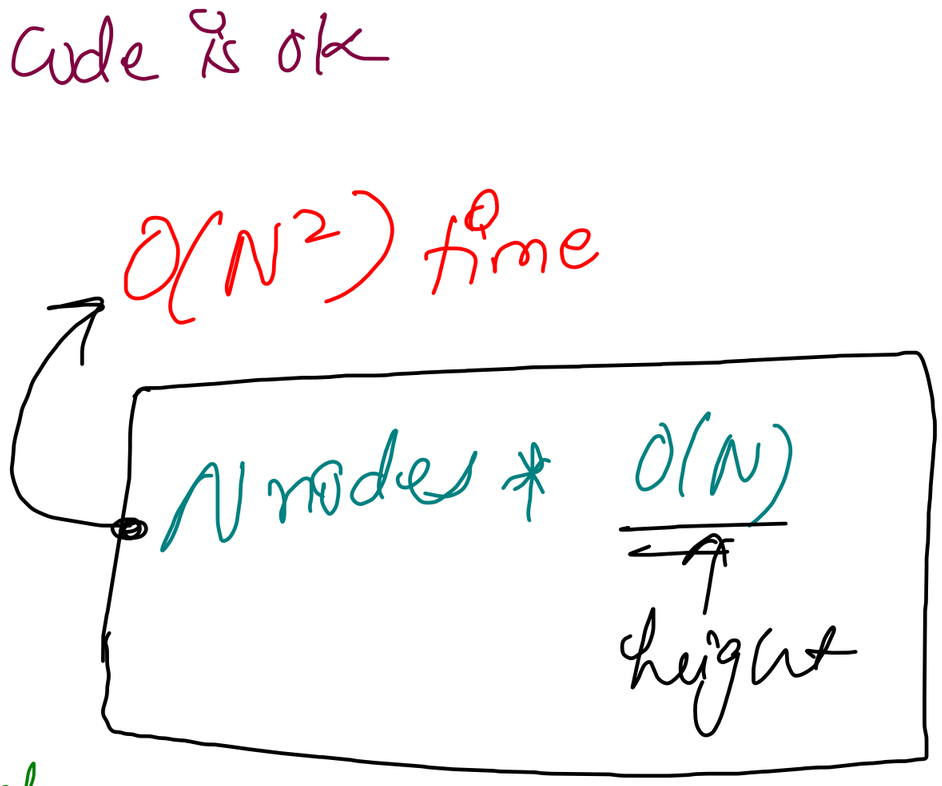


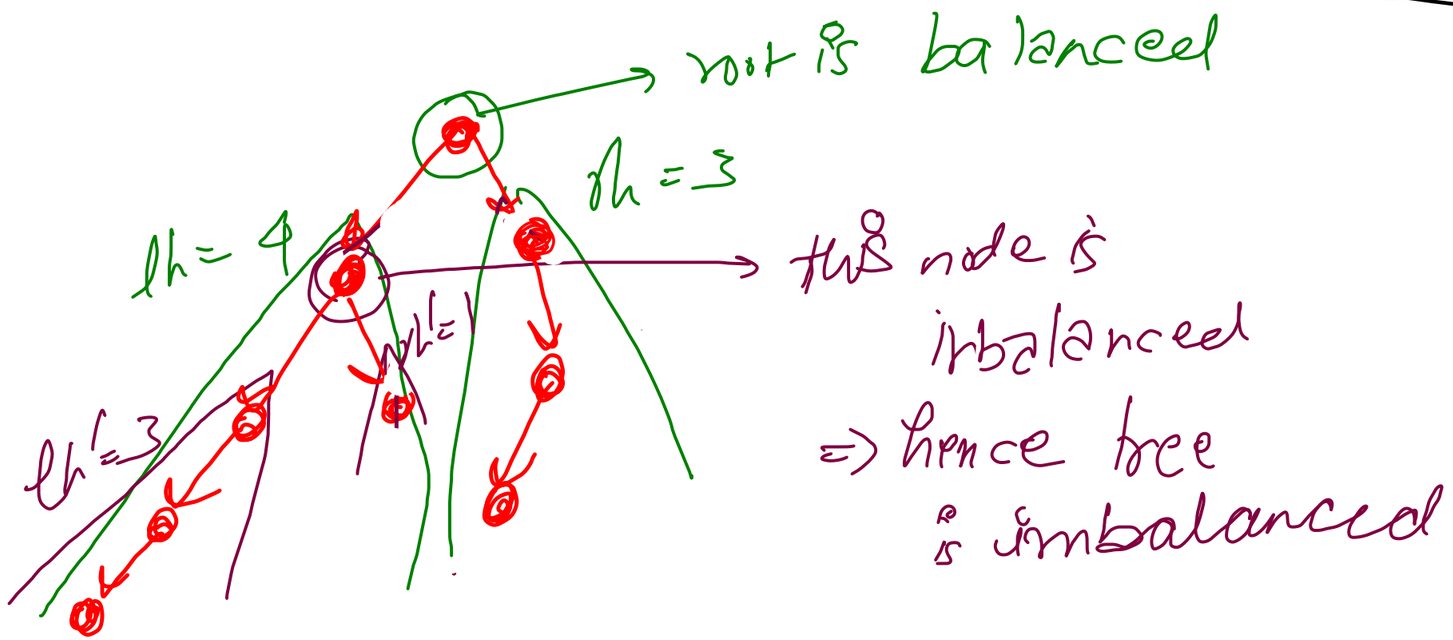

```java
public int height(TreeNode root){
    if(root == null) return 0;
    return 1 + math.max(height(root.left), height(root.right));
}

public boolean isBalanced(TreeNode root) {
    if(root == null) return true;

    int lheight = height(root.left);
    int rheight = height(root.right);

    if(lheight - rheight < -1 || lheight - rheight > 1) return false;
    return true;
}
```

code is wrong
⇓
You are only checking for root node

```java
public int height(TreeNode root){
    if(root == null) return 0;
    return 1 + Math.max(height(root.left), height(root.right));
}

public boolean isBalanced(TreeNode root) {
    if(root == null) return true;

    int lheight = height(root.left);
    int rheight = height(root.right);

    if(lheight - rheight < -1 || lheight - rheight > 1) return false;
    return isBalanced(root.left) && isBalanced(root.right);
}
```

Code is ok





Rerooting Technique (DP on Tree)

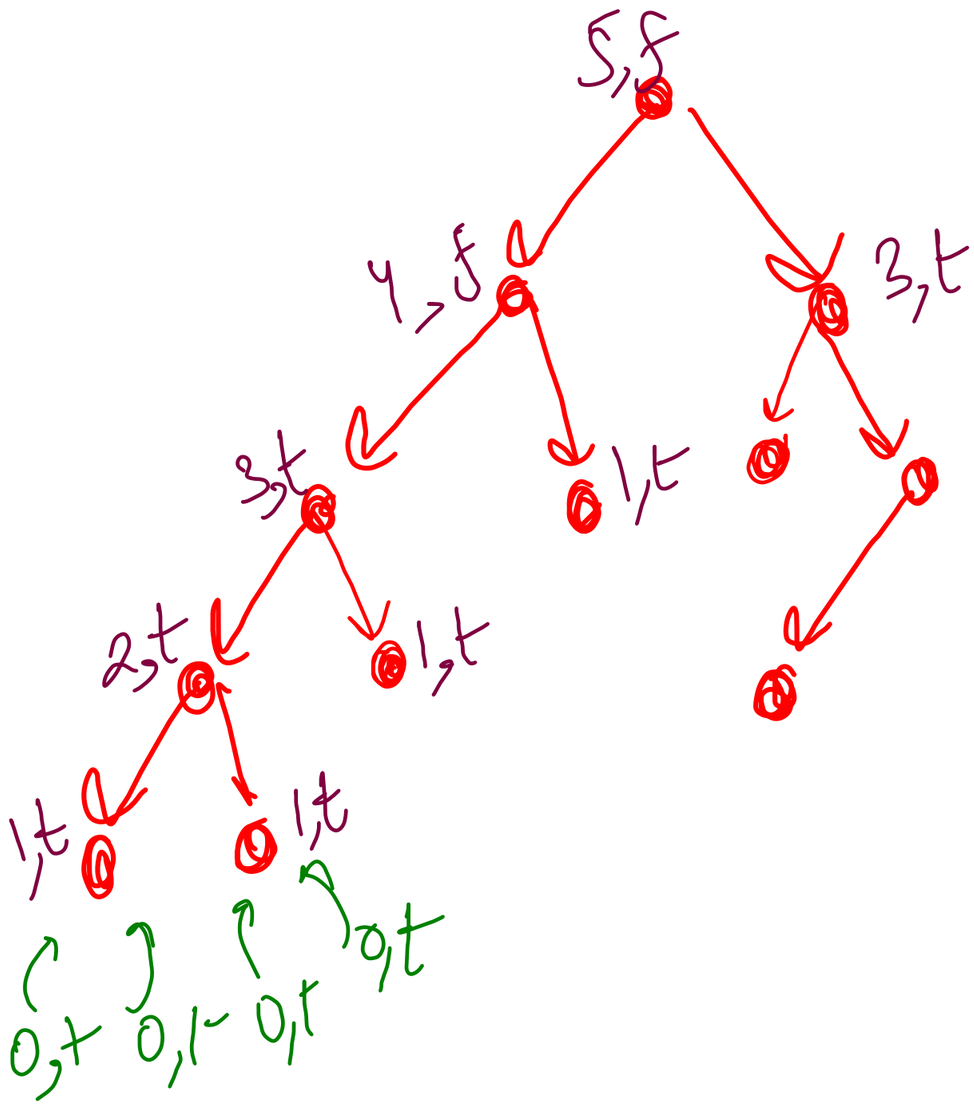
```java
static class Pair{
    boolean isBalanced = true;
    int height = 0;
}

public Pair helper(TreeNode root) {
    if(root == null) return new Pair();

    Pair left = helper(root.left);
    Pair right = helper(root.right);

    Pair curr = new Pair();
    curr.height = Math.max(left.height, right.height) + 1;
    curr.isBalanced = (left.isBalanced && right.isBalanced
        && (Math.abs(left.height - right.height) <= 1));
    return curr;
}

public boolean isBalanced(TreeNode root){
    return helper(root).isBalanced;
}
```

O(N) Time

O(H) Recursion Call Stack Space

O(N) Worst case (Skewed tree)

$O(\log_2 N)$ {balanced binary tree}



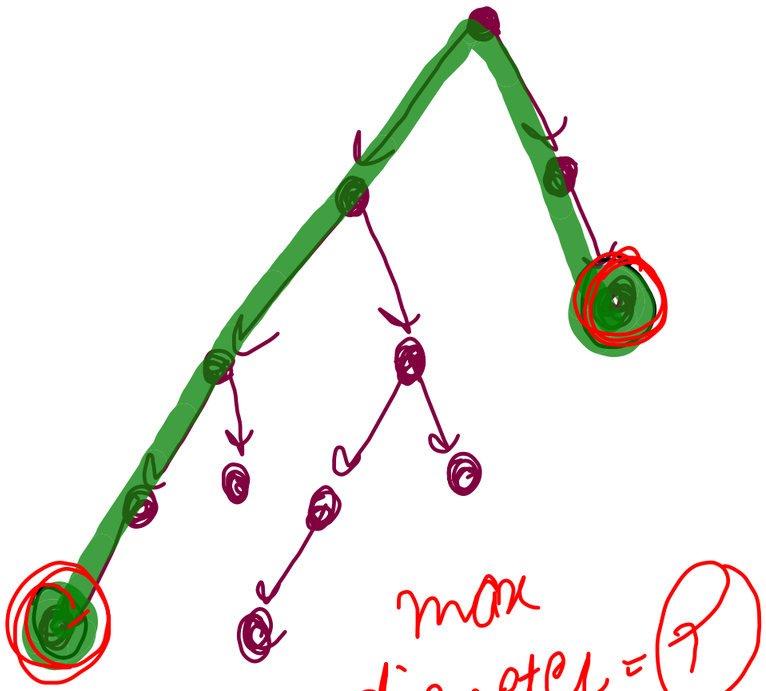

```java
static class Pair{
    boolean isBalanced = true;
    int height = 0;
}

public Pair helper(TreeNode root) {
    if(root == null) return new Pair();

    Pair left = helper(root.left);
    Pair right = helper(root.right);

    Pair curr = new Pair();
    curr.height = Math.max(left.height, right.height) + 1;
    curr.isBalanced = (left.isBalanced && right.isBalanced
        && (Math.abs(left.height - right.height) <= 1));
    return curr;
}

public boolean isBalanced(TreeNode root){
    return helper(root).isBalanced;
}
```

Diameter

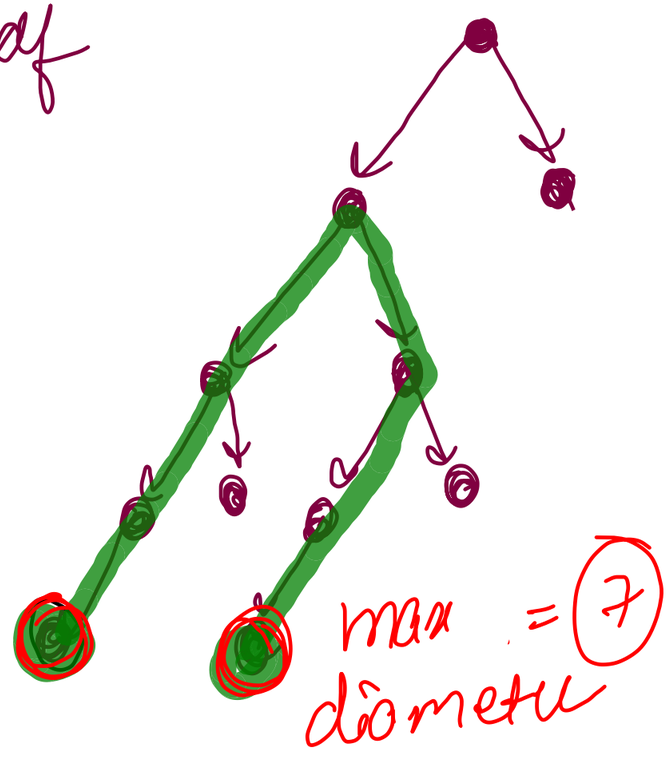
- Binary Tree
- Generic Tree

Longest distance b/w any node to any node

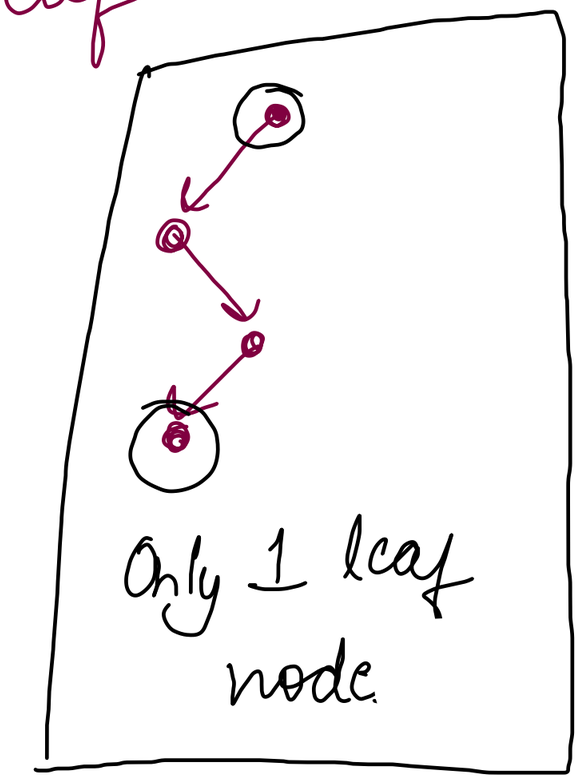
- any node → leaf
- any node → leaf



max diameter = 7



max diameter = 7



only 1 leaf node

```java
public int height(TreeNode root){
    if(root == null) return 0;
    return 1 + Math.max(height(root.left), height(root.right));
}

public int diameterOfBinaryTree(TreeNode root) {
    if(root == null) return 0;

    int lh = height(root.left);
    int rh = height(root.right);

    return 1 + lh + rh;
}
```

Diameter based on Root Node

This code is wrong because diameter may or may not pass through root

```java
public int height(TreeNode root){
    if(root == null) return 0;
    return 1 + Math.max(height(root.left), height(root.right));
}

public int diameter(TreeNode root) {
    if(root == null) return 0;

    int lh = height(root.left);
    int rh = height(root.right);

    int ld = diameter(root.left);
    int rd = diameter(root.right);
    return Math.max(lh + rh + 1, Math.max(ld, rd));
}

public int diameterOfBinaryTree(TreeNode root){
    if(root == null) return 0;
    return diameter(root) - 1;
    // Diameter in Terms of Edges = Diamater in Terms of Nodes - 1
}
```

$O(N^2)$ Time
$O(H)$ Space

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

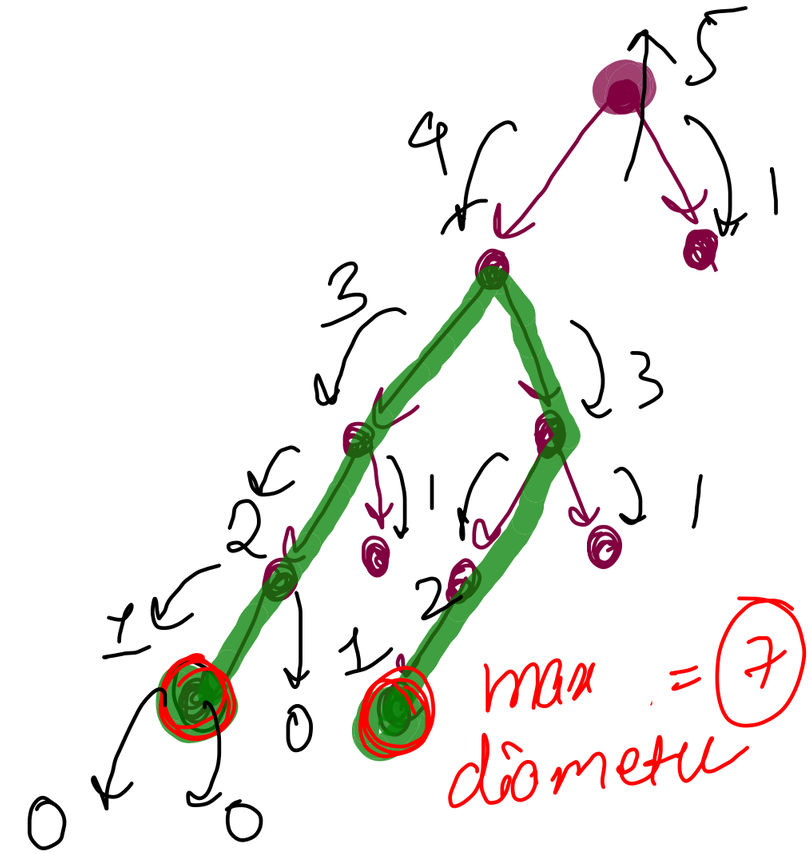
diameter Length.

This correct is but take more time
Correct

```java
public int globalDia = 0;
public int diameter(TreeNode root){
    if(root == null) return 0;

    int lh = diameter(root.left);
    int rh = diameter(root.right);

    // Global Variable Strategy or Travel & Change Strategy
    globalDia = Math.max(globalDia, lh + rh + 1);
    return Math.max(lh, rh) + 1;
}

public int diameterOfBinaryTree(TreeNode root){
    if(root == null) return 0;
    diameter(root);
    return globalDia - 1;
    // Diameter in Terms of Edges = Diamater in Terms of Nodes - 1
}
```

Postorder

globalDia = 0 1 7 4 7



Travel & Change

O(N) time

O(H) recursion stack

"heavy" → Travel & change

```java
public int diameter(TreeNode root, int[] globalDia){
    if(root == null) return 0;

    int lh = diameter(root.left, globalDia);
    int rh = diameter(root.right, globalDia);

    // Global Variable Strategy or Travel & Change Strategy
    globalDia[0] = Math.max(globalDia[0], lh + rh + 1);
    return Math.max(lh, rh) + 1;
}

public int diameterOfBinaryTree(TreeNode root){
    if(root == null) return 0;
    int[] globalDia = new int[1];

    diameter(root, globalDia);
    return globalDia[0] - 1;
    // Diameter in Terms of Edges = Diamater in Terms of Nodes - 1
}
```

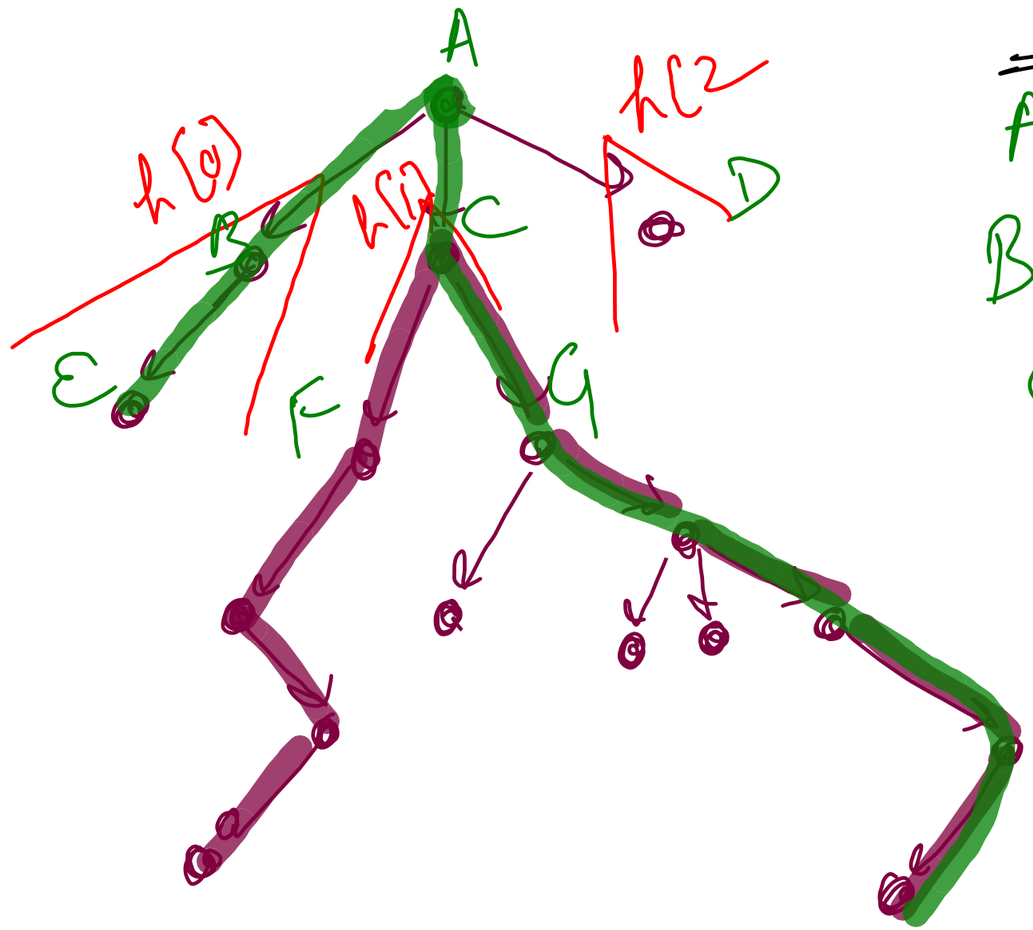
Same approach but without global variable

```java
public static class Pair{
    int height;
    int diameter; // Diameter is of entire subtree
}

public Pair diameter(TreeNode root){
    if(root == null) return new Pair();

    Pair left = diameter(root.left);
    Pair right = diameter(root.right);

    Pair curr = new Pair();
    curr.height = Math.max(left.height, right.height) + 1;
    curr.diameter = left.height + right.height + 1;
    curr.diameter = Math.max(curr.diameter, Math.max(left.diameter, right.diameter));
    return curr;
}

public int diameterOfBinaryTree(TreeNode root){
    if(root == null) return 0;
    // Diameter in Terms of Edges = Diamater in Terms of Nodes - 1
    return diameter(root).diameter - 1;
}
```

O(N) time
O(H) Recursion Call Stack

Diameter of Generic/N-Ary Tree

{ Largest Distance Bw 2 nodes in Tree }



Adjacency List

A → B, C, D

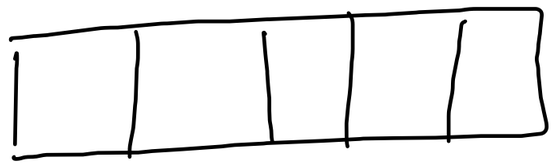
B → E

C → F, G

D → { }

!

!



par [i] → i

lh + rh + 1 (Children's height)

rh → second max

lh → max(height child)

```java
public int globalDia = 0;

public int dfs(ArrayList<Integer>[] adj, int root){
    int maxHeight = 0, secondMaxHeight = 0;
    for(Integer child: adj[root]){
        int height = dfs(adj, child);
        if(height > maxHeight){
            secondMaxHeight = maxHeight;
            maxHeight = height;
        }
        else if(height >= secondMaxHeight)
            secondMaxHeight = height;
    }

    globalDia = Math.max(globalDia, maxHeight + secondMaxHeight + 1);
    return 1 + maxHeight;
}
```

parent's array

```java
public int solve(int[] A) {
    ArrayList<Integer>[] adj = new ArrayList[A.length];
    for(int i=0; i<A.length; i++){
        adj[i] = new ArrayList<>();
    }

    int root = 0;
    for(int i=0; i<A.length; i++){
        if(A[i] == -1) root = i;
        else adj[A[i]].add(i);
    }

    dfs(adj, root);
    return globalDia - 1;
}
```

A[i] = j

if j == -1 ⇒ i is the root node

else j is the parent of i, i is child of j

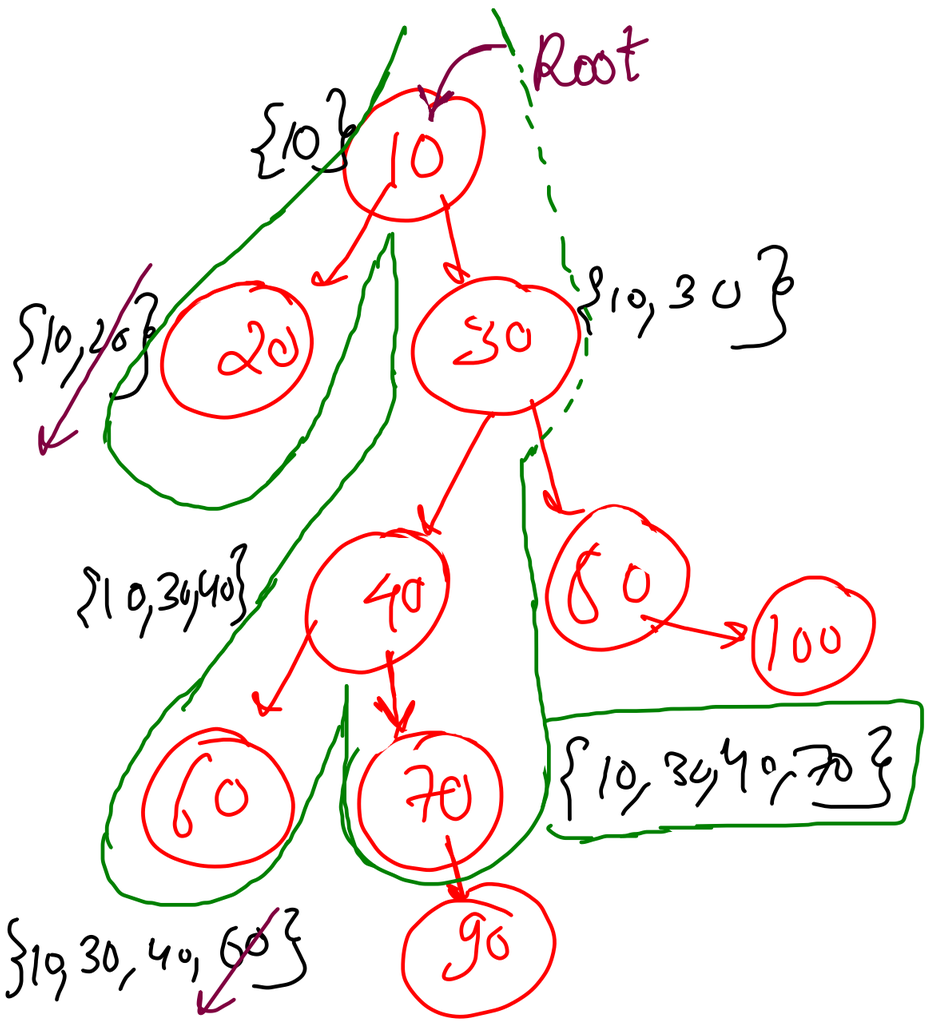
Level (2), Lecture (2) 13 Feb (3PM)

System Design → Static, final, etc.

(1) Node to Root Path
Root to leaf Path
linked List in Tree

(2) Max Sum Subtree
Tilt of Binary Tree

(3) Path Sum
→ Root to Leaf (1&11)
→ Node to Node (downwards)
→ Leaf to Leaf
→ Node to Node (Any)



target ⇒ 70

boolean Find (target, ArrInt> path)

Ancestors Node to Root Path

↳ 70, 40, 30, 10

Root to Node Path

↳ 10, 30, 40, 70

```java
public static boolean Ancestors(Node root, ArrayList<Integer> path, int target){
    if(root == null) return false;
    if(target == root.data) return true;

    path.add(root.data);
    if(Ancestors(root.left, path, target) == true)
        return true;

    if(Ancestors(root.right, path, target) == true)
        return true;

    path.remove(path.size() - 1); // backtrack
    return false;
}
```

Root to Node

O(N) Time

O(H) recursion

```java
public static ArrayList<Integer> Ancestors(Node root, int target)
{
    ArrayList<Integer> ancestors = new ArrayList<>();
    Ancestors(root, ancestors, target);
    Collections.reverse(ancestors);
    return ancestors;
}
```

Node to Root Path

257 Root to leaf Node

```java
public void helper(TreeNode root, String path, List<String> paths){
    if(root == null){
        // if any only if tree is of 0 nodes
        return;
    }

    if(root.left == null && root.right == null){
        // leaf node
        paths.add(path + root.val);
        return;
    }

    helper(root.left, path + root.val + "->", paths);
    helper(root.right, path + root.val + "->", paths);
}

public List<String> binaryTreePaths(TreeNode root) {
    List<String> paths = new ArrayList<>();
    helper(root, "", paths);
    return paths;
}
```

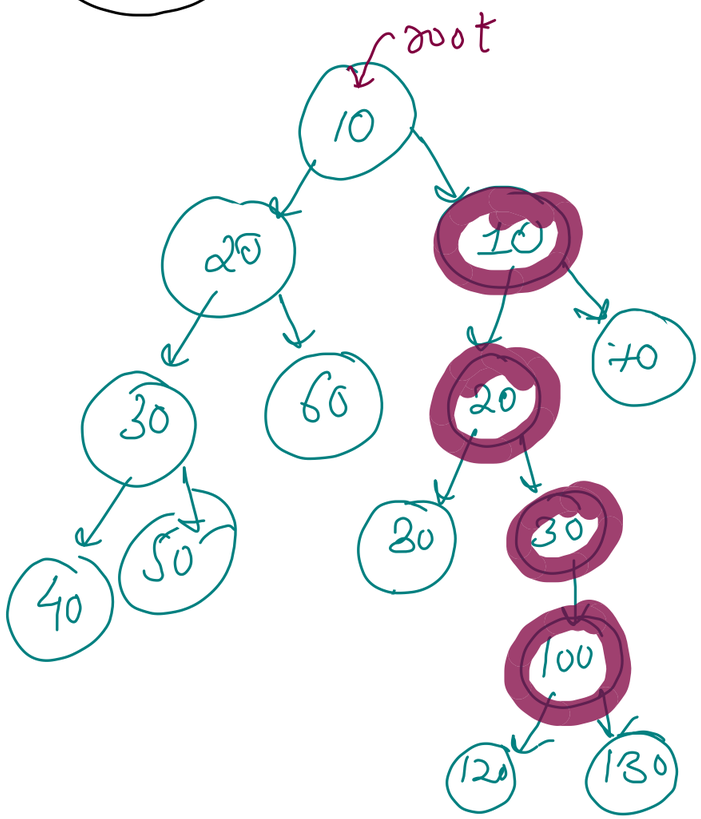
Variations
- # Nodes ⇒ Path to leaf in Range [L, R]
- # All paths dum print

O(N) Time

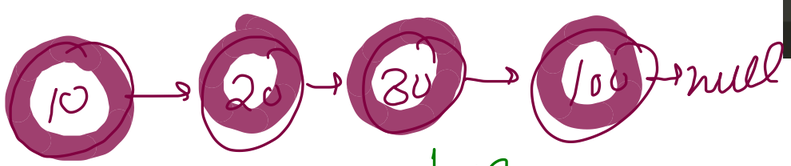
O(H) Recursion call Stack

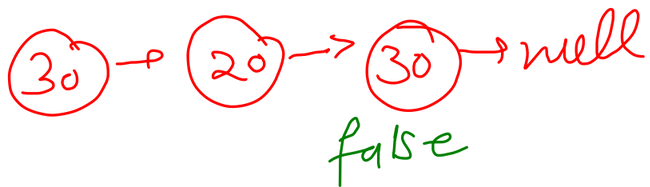
1367 Linked List in Binary Tree

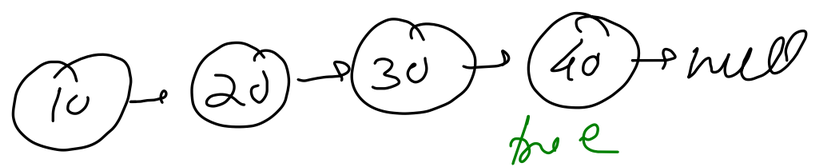
$O(N^2)$ time, $O(H)$ Recursion Space




```java
public boolean isSubPathHelper(ListNode head, TreeNode root){
    if(head == null) return true;
    // Linked List has all nodes present, return true

    if(root == null) return false;
    // Linked List is still remaining, but tree is empty

    if(root.val == head.val){
        if(isSubPathHelper(head.next, root.left) == true)
            return true;

        if(isSubPathHelper(head.next, root.right) == true)
            return true;
    }

    return false;
}

public boolean isSubPath(ListNode head, TreeNode root) {
    if(head == null) return true;
    if(root == null) return false;

    return isSubPathHelper(head, root) || isSubPath(head, root.left)
                                       || isSubPath(head, root.right);
}
```

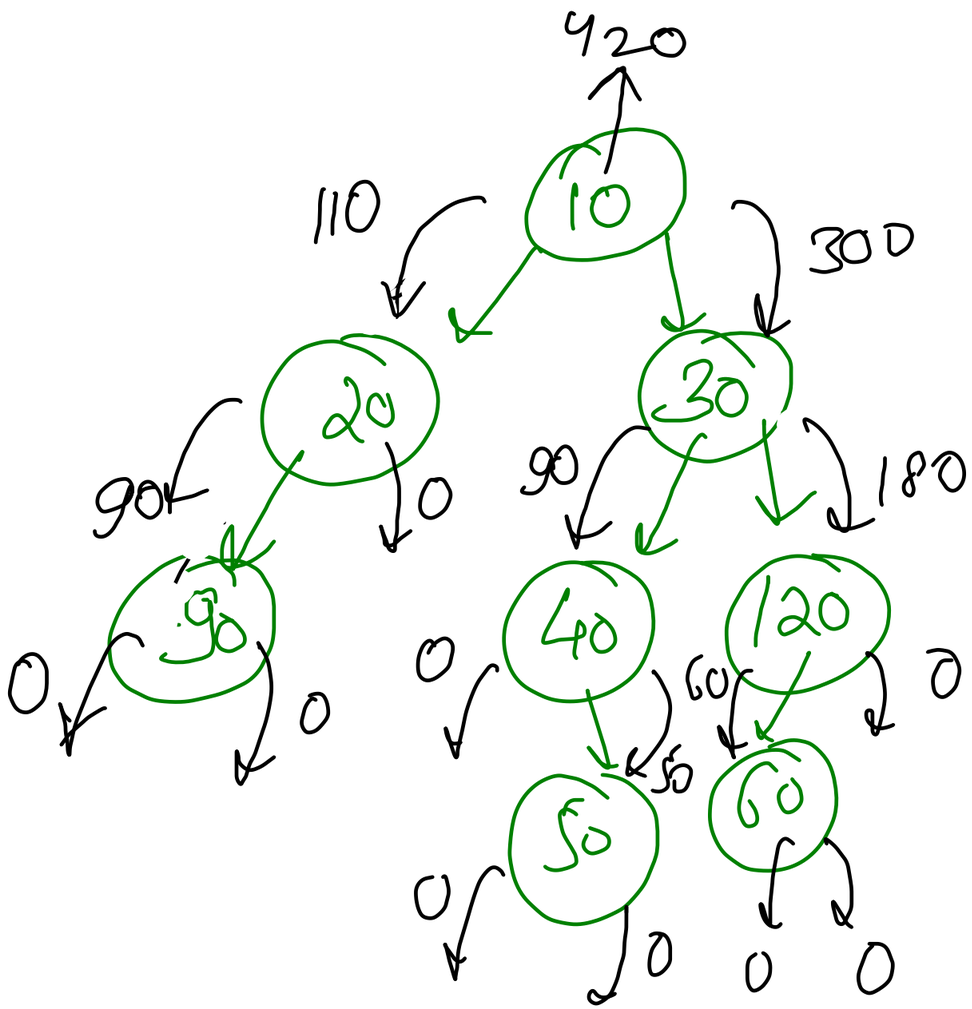






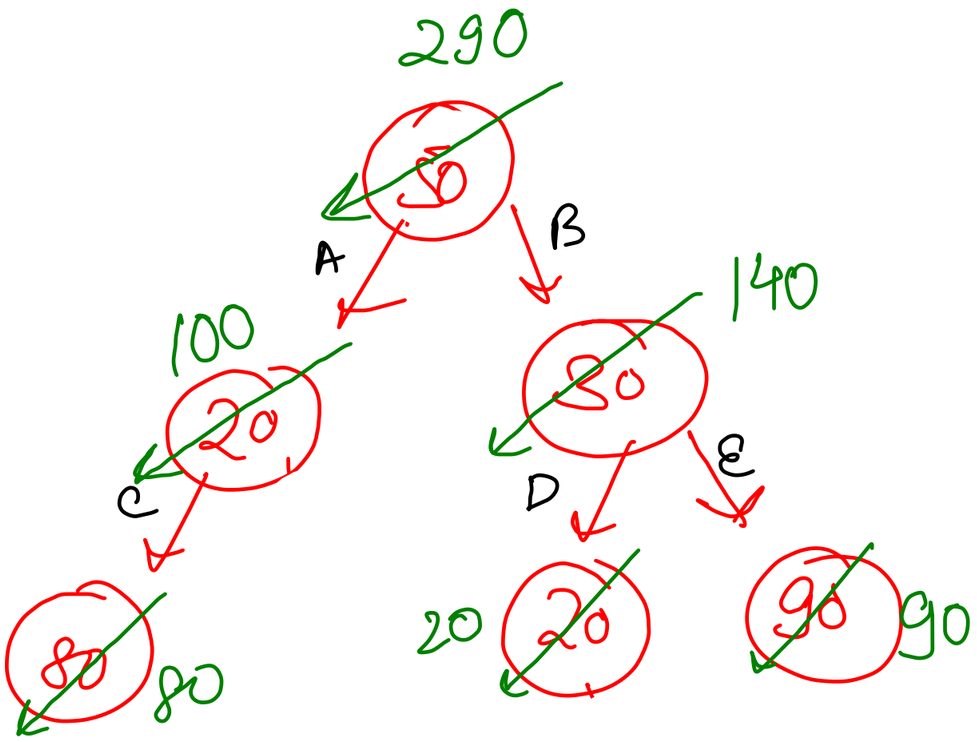
TCLF

SG 3



$$\text{Tilt} = 0+0+90+50+60+90+190$$

1339 Maximum Product Subtree



#1

$S1 = 290 - 100$

$S1 = 50 \to 30 \to 20, 90$

$S2 = 100$

$S2 = 20 \to 80$

B

$= 290 - 140$

$S1 = 50 \to 20 \to 80$

$S2 = 140$

$S2 = 30 \to 20, 90$

C

80 → 50 → 20, 30; 20, 90

S1 * S2

D

$S1 * S2$ → 20

50 → 20, 30; 20, 90; 80

E

50 → 90

50 → 20, 30; 20, 30; 80, 20

$S1 * S2$

$S = 20$

```java
public int sumTree(TreeNode root){
    if(root == null) return 0;
    root.val += sumTree(root.left) + sumTree(root.right);
    return root.val;
}

long maxProduct = 0;
long total = 0;
public void helper(TreeNode root){
    if(root == null) return;

    helper(root.left);
    helper(root.right);

    long leftSubtree = (root.left == null) ? 0l : root.left.val;
    long leftProduct = leftSubtree * (total - leftSubtree);

    long rightSubtree = (root.right == null) ? 0l : root.right.val;
    long rightProduct = rightSubtree * (total - rightSubtree);

    maxProduct = Math.max(maxProduct, Math.max(leftProduct, rightProduct));
}

public int maxProduct(TreeNode root) {
    if(root == null) return 0;
    total = sumTree(root);
    helper(root);
    return (int)(maxProduct % 10000000071);
}
```

converting tree into subtree

left edge removal

right edge removal

O(N) time

O(H) Recursion call stacks

```java
public boolean hasPathSum(TreeNode root, int targetSum) {
    if(root == null) return false;
    if(root.left == null && root.right == null){
        // Root to Leaf Path Sum = targetSum
        return (targetSum == root.val);
    }

    if(hasPathSum(root.left, targetSum - root.val) == true) return true;
    if(hasPathSum(root.right, targetSum - root.val) == true) return true;
    return false;
}
```

Path Sum - (1) [112] LC

Root to leaf Target

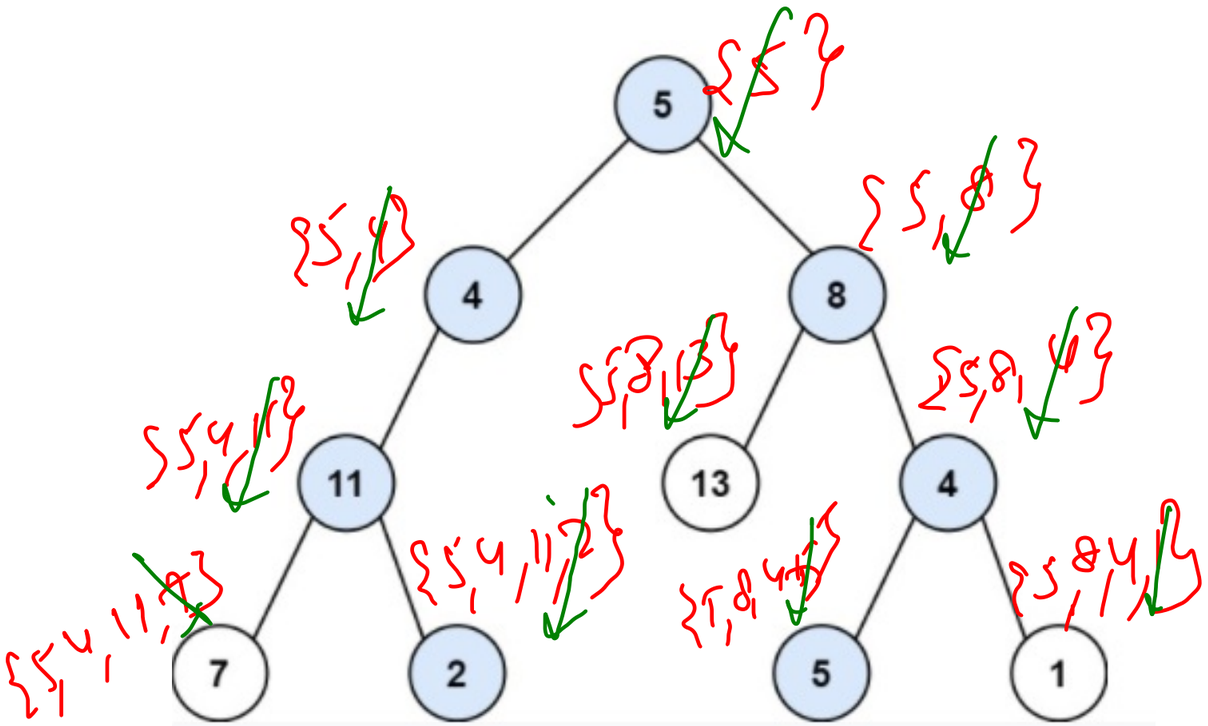
True False

```java
List<List<Integer>> paths;
public void helper(TreeNode root, List<Integer> path, int target){
    if(root == null) return;

    path.add(root.val);
    if(root.left == null && root.right == null){
        if(target == root.val)
            paths.add(new ArrayList<>(path)); // deep copy

        path.remove(path.size() - 1);
        return;
    }

    helper(root.left, path, target - root.val);
    helper(root.right, path, target - root.val);
    path.remove(path.size() - 1); // backtrack
}

public List<List<Integer>> pathSum(TreeNode root, int targetSum) {
    paths = new ArrayList<>();
    helper(root, new ArrayList<>(), targetSum);
    return paths;
}
```

Path Sum (11) [113] LC

Root-to-Leaf All paths

with given Target



target = 22

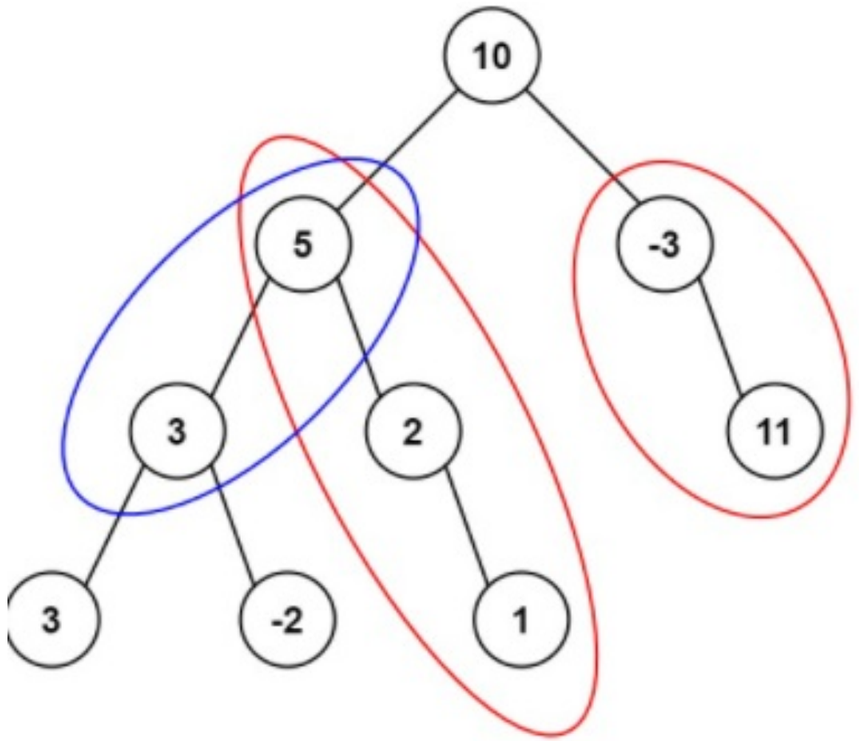
Root to leaf path
with given target-

{ {5, 4, 11, 2} {5, 8, 4, 5} }

base case {deep copy}

2d.add(new ArrayList(ld));

(437) Path Sum - III { Any node to Any node Downwards }

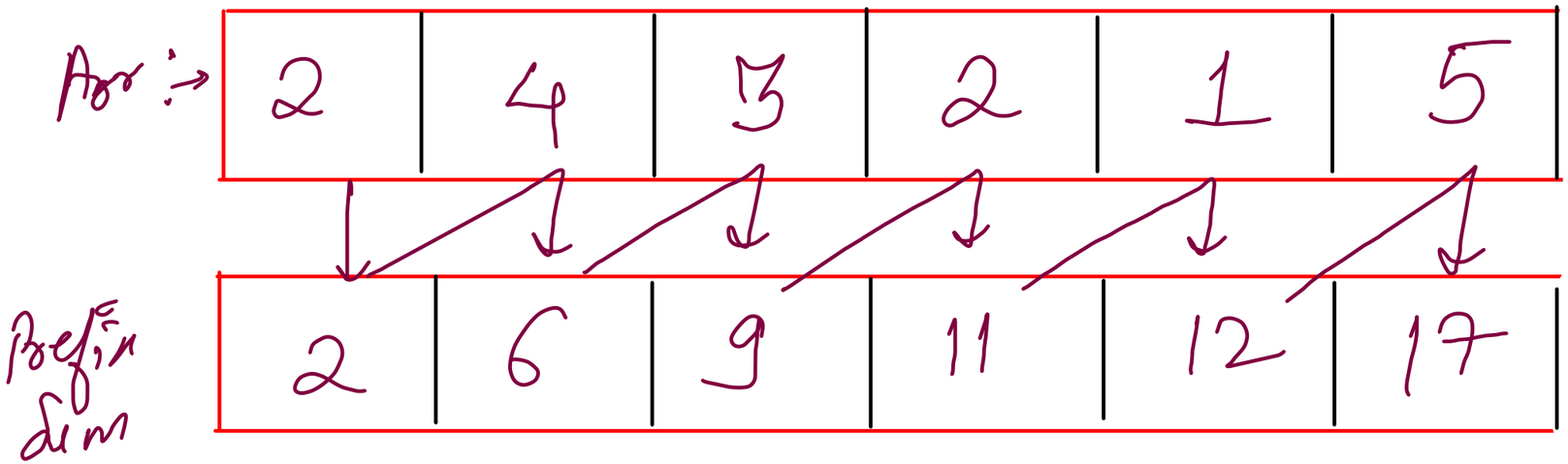


count of targetSum Path

target = 8

{ N * DFS ⇒ N * N ⇒ $O(N^2)$ }

```java
public int dfs(TreeNode root, int targetSum){
    if(root == null) return 0;

    targetSum -= root.val;

    int count = 0;
    if(targetSum == 0)
        count++;

    return count + dfs(root.left, targetSum) + dfs(root.right, targetSum);
}

public int pathSum(TreeNode root, int targetSum) {
    if(root == null) return 0;
    return dfs(root, targetSum) + pathSum(root.left, targetSum) +
        pathSum(root.right, targetSum);
}
```



SDE LC

K sum subarray

Count subarrays with given sum

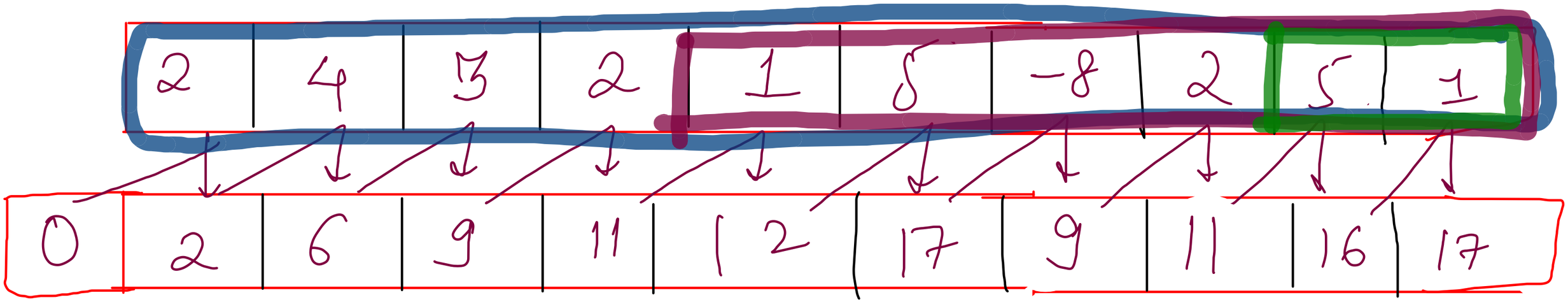
target ≠ 0

{2,4} {3,2,1} {1,5}

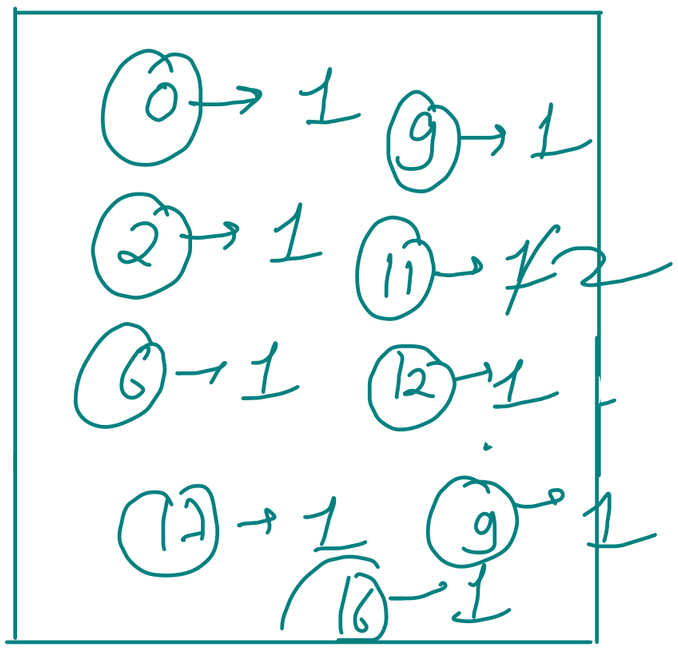
Brute force :→ $O(N^2)$

count of subarrays ending at i with sum target

= freq[prefixSum[i] − target]



target = 6 count = 1+1+1+1+2



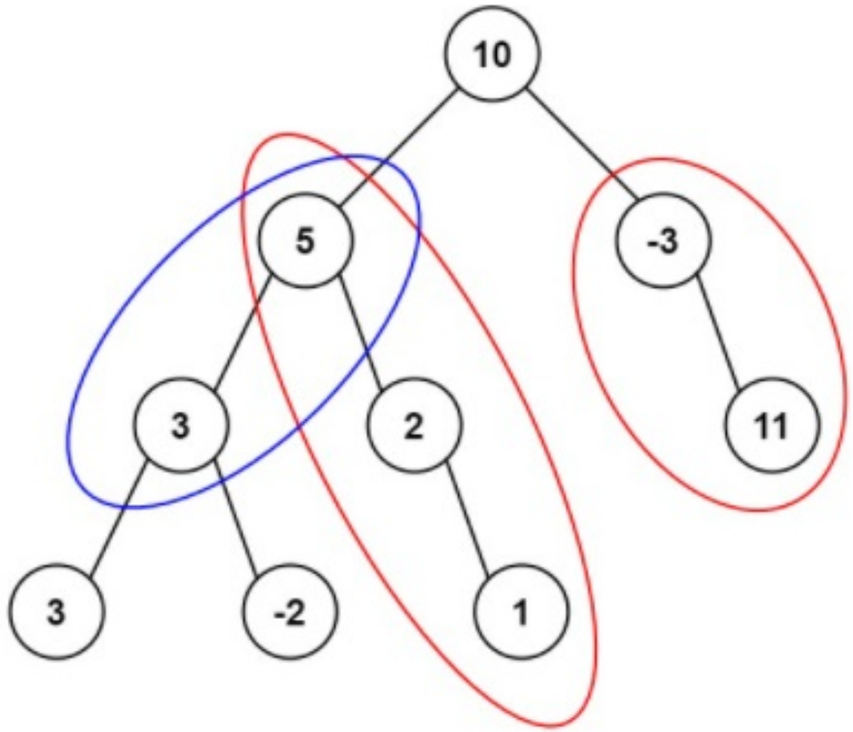
count of subarrays ending at i with sum target

= freq[prefixSum[i] - target]

```java
public int subarraySum(int[] nums, int k) {
    HashMap<Integer, Integer> freq = new HashMap<>();
    int prefSum = 0;
    freq.put(0, 1);

    int res = 0;
    for(int i=0; i<nums.length; i++){
        prefSum += nums[i];
        res += freq.getOrDefault(prefSum - k, 0);
        freq.put(prefSum, freq.getOrDefault(prefSum, 0) + 1);
    }

    return res;
}
```

O(N) time

O(N) hashmap extra space



target ⇒ 8

R2N	sum	Freq
0	10	1
10	15	1
15	18	1
18	21	1
21	16	1
16	17	1
17	18	1
18	7	1
7	18	1

count = 0 1 2 3

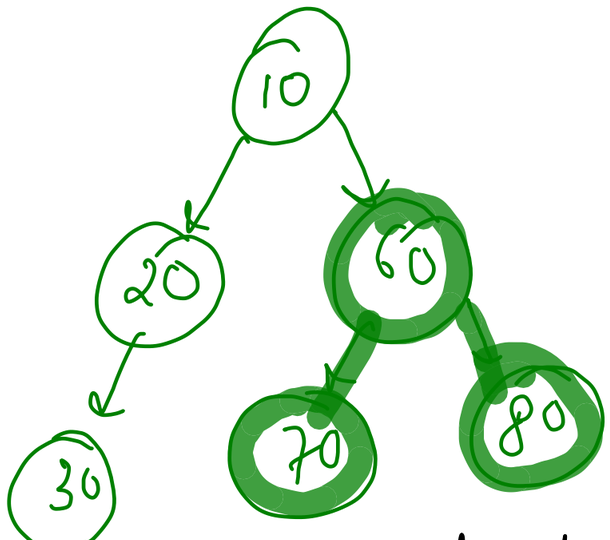
```java
// O(N) Approach
class Solution{
    HashMap<Integer, Integer> freq = new HashMap<>();

    public int helper(TreeNode root, int targetSum, int prefSum){
        if(root == null) return 0;

        prefSum += root.val;
        int count = freq.getOrDefault(prefSum - targetSum, 0);
        freq.put(prefSum, freq.getOrDefault(prefSum, 0) + 1);

        count += helper(root.left, targetSum, prefSum);
        count += helper(root.right, targetSum, prefSum);

        freq.put(prefSum, freq.getOrDefault(prefSum, 0) - 1); // Backtrack

        return count;
    }

    public int pathSum(TreeNode root, int targetSum){
        if(root == null) return 0;
        freq.put(0, 1);
        return helper(root, targetSum, 0);
    }
}
```

O(N) Time

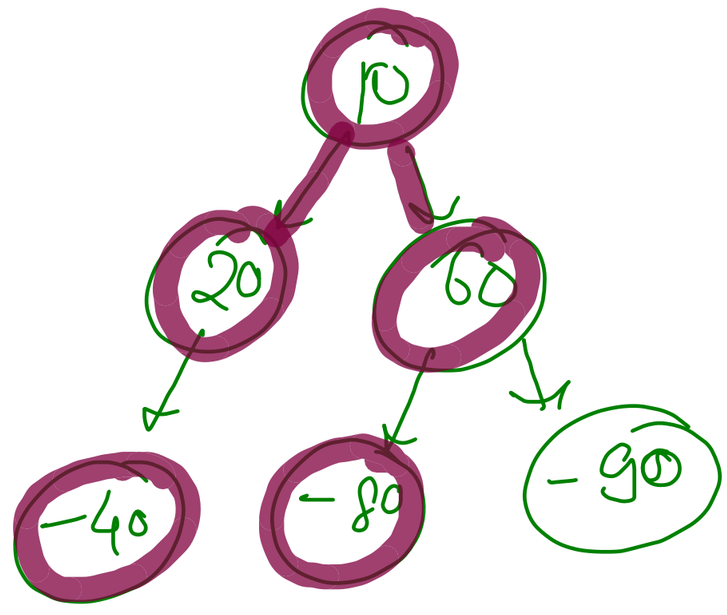
O(H) extra space (Hashmap)

O(H) Recursion call stack

Max Path Sum
b/w 2 leaf nodes



All +ve values



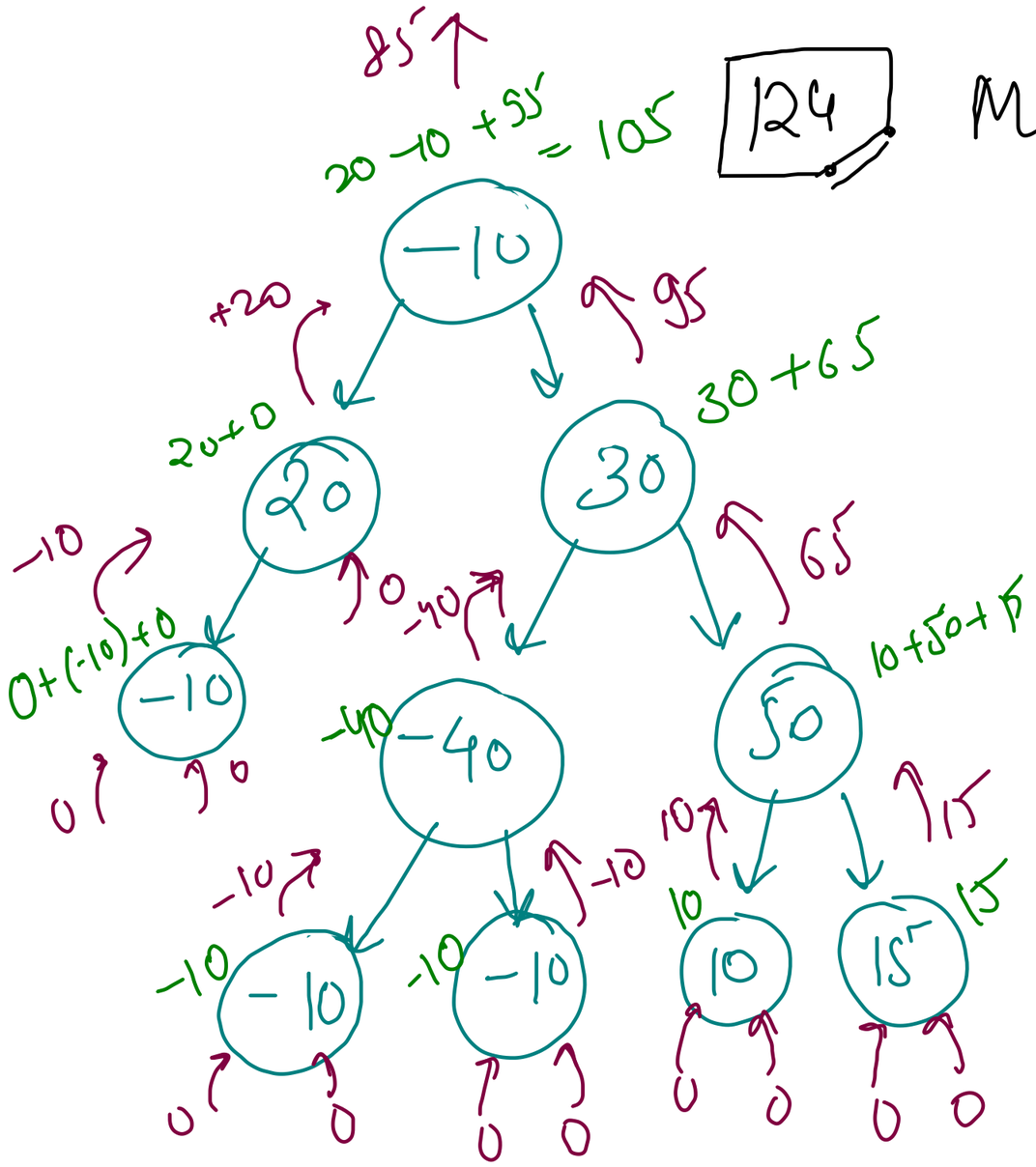
Max Path B/w Any 2 Nodes with all values as positive

```java
static long globalAns = Long.MIN_VALUE;
public long diameter(Node root){
    if(root == null) return 0l;
    if(root.left == null && root.right == null) return 1l * root.data;
    if(root.left == null) return 1l * root.data + diameter(root.right);
    if(root.right == null) return 1l * root.data + diameter(root.left);

    long left = diameter(root.left);
    long right = diameter(root.right);
    long diameter = left + right + 1l * root.data;
    if(diameter > globalAns) globalAns = diameter;
    return root.data * 1l + Math.max(left, right);
}

int maxPathSum(Node root)
{
    globalAns = Long.MIN_VALUE;
    long sum = diameter(root);
    if(root.left == null || root.right == null){
        globalAns = Math.max(globalAns, sum);
    }
    return (int)globalAns;
}
```

O(N) time

O(H) space

{ Diameter } variation



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Max Path Sum (HARD)

{Any Node to Any Node}

{If All values are positive

⇒ variation of diameter

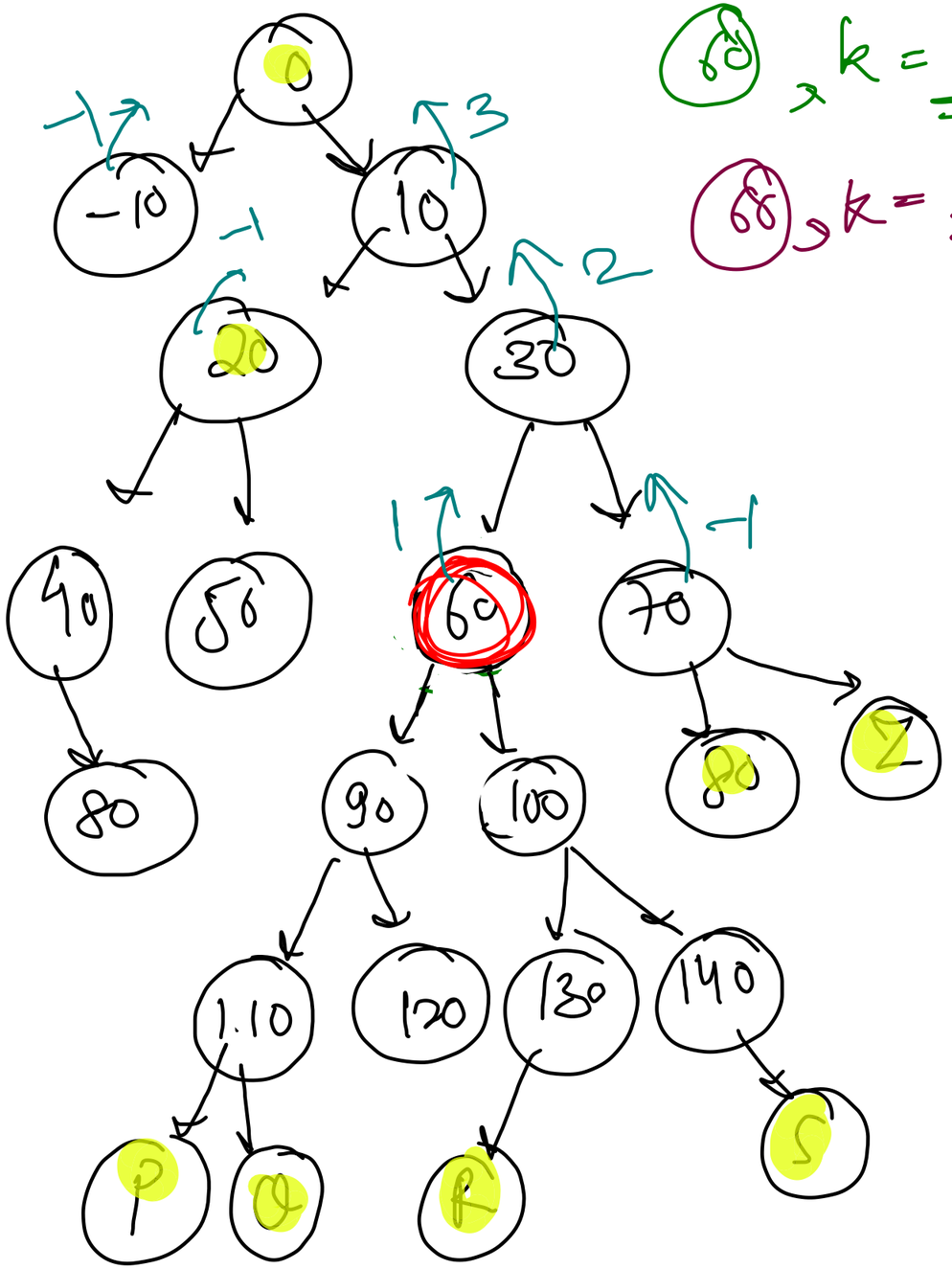
⇒ max Path Sum

Leaf to Leaf}

```java
class Solution {
    int maxPathSum = Integer.MIN_VALUE;

    public int helper(TreeNode root){
        if(root == null) return 0;

        int leftDownPath = helper(root.left);
        int rightDownPath = helper(root.right);

        int currPathSum = root.val + Math.max(0, leftDownPath) + Math.max(0, rightDownPath);
        maxPathSum = Math.max(maxPathSum, currPathSum);

        return Math.max(0, Math.max(leftDownPath, rightDownPath)) + root.val;
    }

    public int maxPathSum(TreeNode root) {
        helper(root);
        return maxPathSum;
    }
```

{ O(N) time
O(H) Recursion call stack }

using Travel & change { Global variable Strategy }



(60), k = 2

(68), k = 3

K Levels Down (GFG)

(2) 110, 120, 130, 140

(3) P, Q, R, S

K Nodes Away (LC-863)

2 → 110, 120, 130, 140

2 → 70

2 → 1

3 → P, Q, R, S

3 → 80, Z

3 → 20

3 → 0

```java
public boolean path(TreeNode root, TreeNode target, ArrayList<TreeNode> r2nPath){
    if(root == null) return false;
    if(root == target){
        r2nPath.add(root);
        return true;
    }

    r2nPath.add(root);
    if(path(root.left, target, r2nPath) == true) return true;
    if(path(root.right, target, r2nPath) == true) return true;
    r2nPath.remove(r2nPath.size() - 1);
    return false;
}
```

R2N Path O(H) Extra Space

```java
public void kLevelDown(TreeNode root, TreeNode blocker, int k, List<Integer> res){
    if(k < 0 || root == null || root == blocker)  return;
    if(k == 0){
        res.add(root.val);
        return;
    }

    kLevelDown(root.left, blocker, k - 1, res);
    kLevelDown(root.right, blocker, k - 1, res);
}
```

DFS from each node on R2N

```java
public List<Integer> distanceK(TreeNode root, TreeNode target, int k) {
    ArrayList<TreeNode> r2nPath = new ArrayList<>();
    if(path(root, target, r2nPath) == false) return new ArrayList<>();

    r2nPath.add(null);
    List<Integer> res = new ArrayList<>();
    for(int i=r2nPath.size()-2; i>=0; i--){
        TreeNode curr = r2nPath.get(i);
        TreeNode blocker = r2nPath.get(i + 1);
        kLevelDown(curr, blocker, k, res);
        k--;
    }
    return res;
}
```

O(n) time

10:11

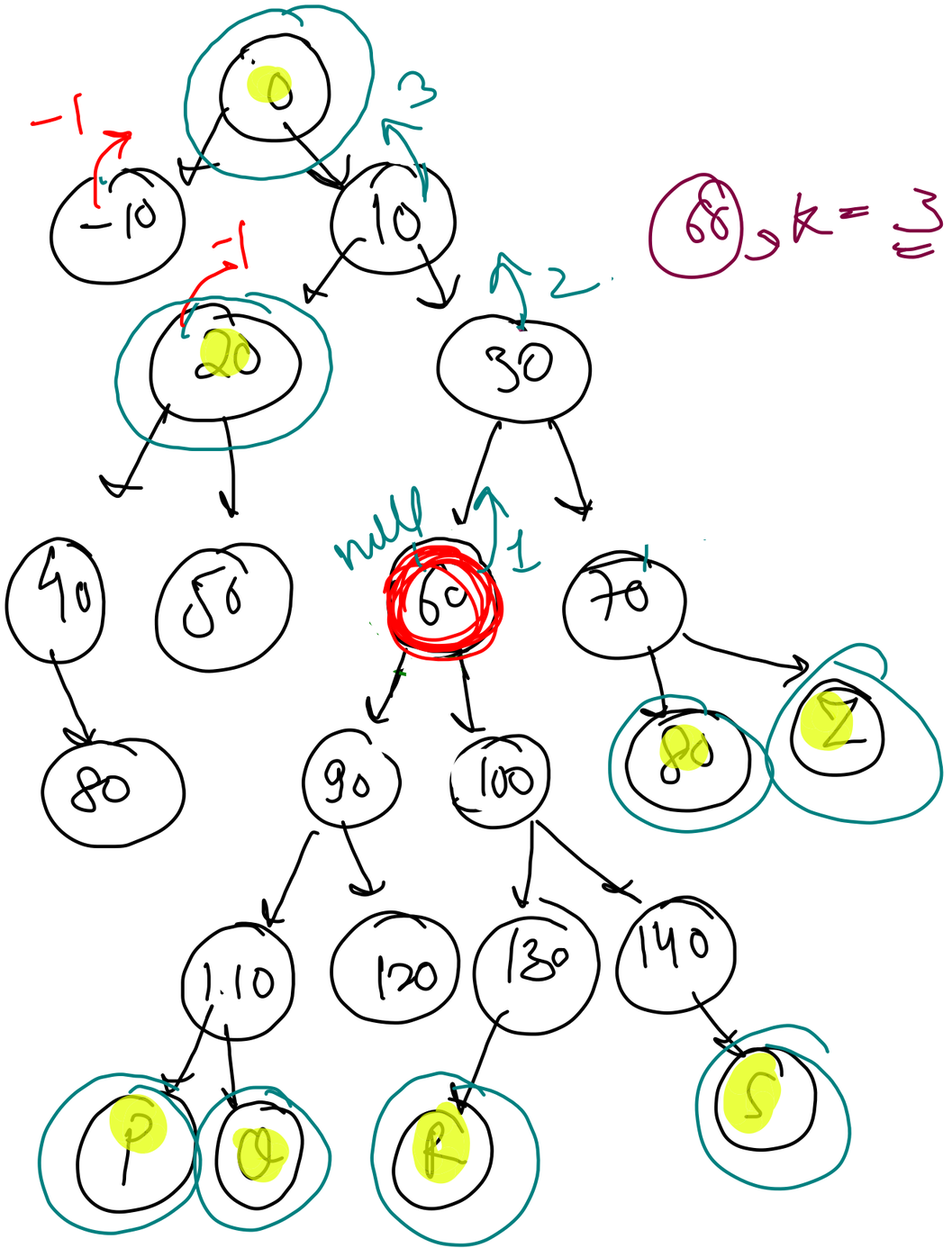
10:20

```java
public int DFS(TreeNode root, TreeNode target, int k, List<Integer> res){
    if(root == null) return -1;
    if(root == target){
        kLevelDown(root, null, k, res);
        return 1;
    }

    int left = DFS(root.left, target, k, res);
    if(left >= 0){
        kLevelDown(root, root.left, k - left, res);
        return left + 1;
    }

    int right = DFS(root.right, target, k, res);
    if(right >= 0){
        kLevelDown(root, root.right, k - right, res);
        return right + 1;
    }

    return -1;
}
```

O(n) time

{ without extra space

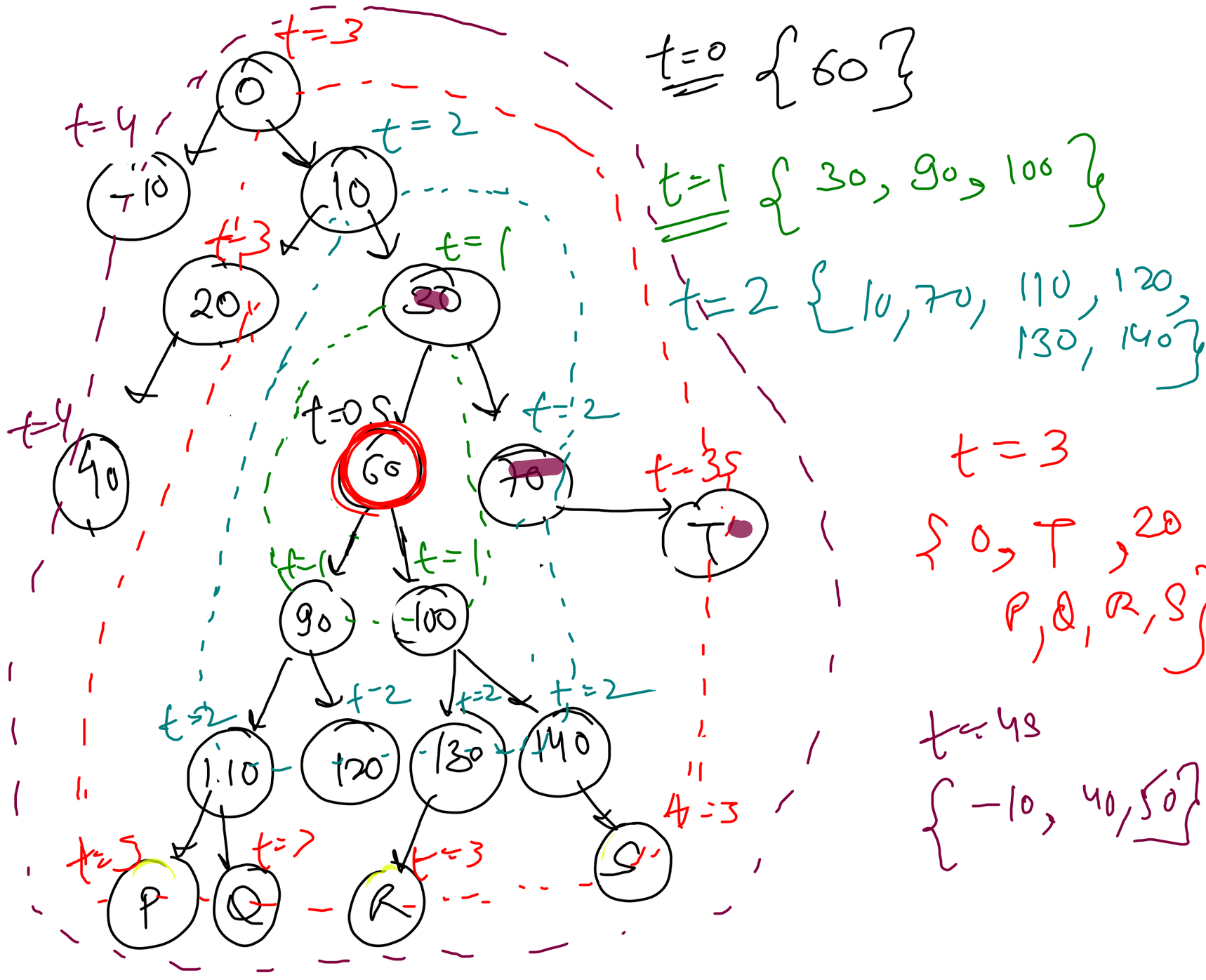
```java
public void kLevelDown(TreeNode root, TreeNode blocker, int k, List<Integer> res){
    if(k < 0 || root == null || root == blocker)  return;
    if(k == 0){
        res.add(root.val);
        return;
    }

    kLevelDown(root.left, blocker, k - 1, res);
    kLevelDown(root.right, blocker, k - 1, res);
}

public List<Integer> distanceK(TreeNode root, TreeNode target, int k) {
    List<Integer> res = new ArrayList<>();
    DFS(root, target, k, res);
    return res;
}
```



Burning Tree

BFS on graph

Infection Spread



```java
static int minTime = 0;
public static int DFS(Node root, int target){
    if(root == null) return -1;

    if(root.data == target){
        height(root, null, 0);
        return 1;
    }

    int left = DFS(root.left, target);
    if(left >= 0){
        height(root, root.left, left);
        return 1 + left;
    }

    int right = DFS(root.right, target);
    if(right >= 0){
        height(root, root.right, right);
        return 1 + right;
    }

    return -1;
}
```

```java
public static void height(Node root, Node blockage, int time){
    if(root == null || root == blockage) return;
    minTime = Math.max(minTime, time);
    height(root.left, blockage, time + 1);
    height(root.right, blockage, time + 1);
}

public static int minTime(Node root, int target)
{
    minTime = 0;
    DFS(root, target);
    return minTime;
}
```

O(N) Time

O(H) Recursion call stack

BFS

Level order Traversal & Variations

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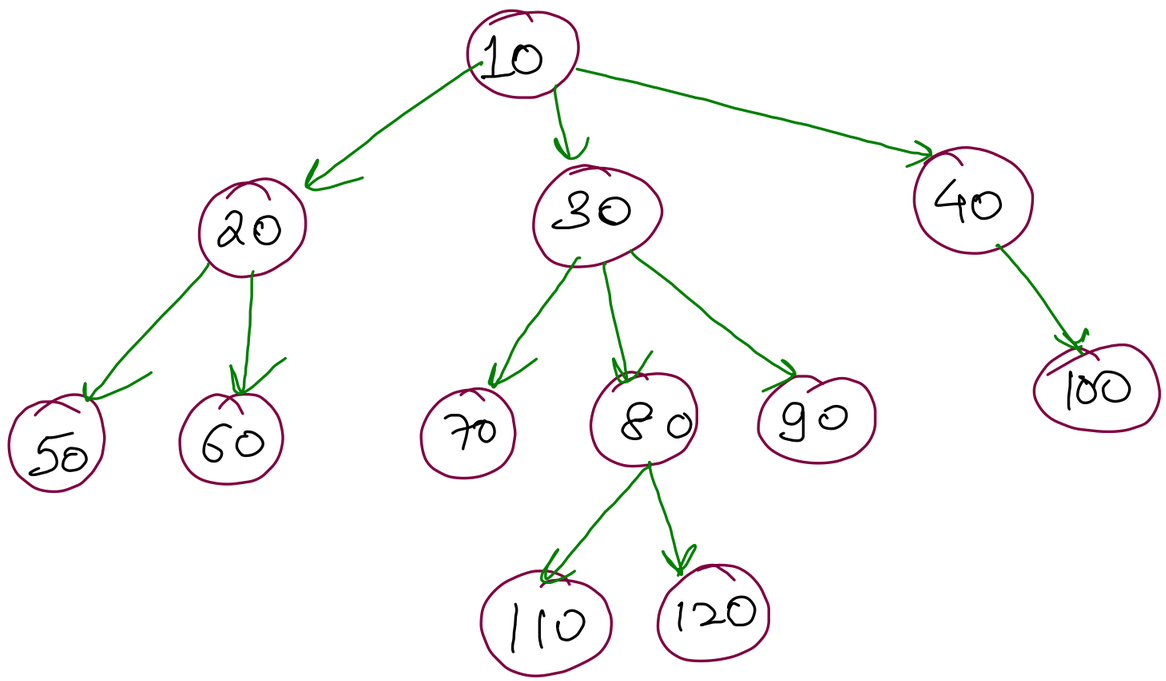
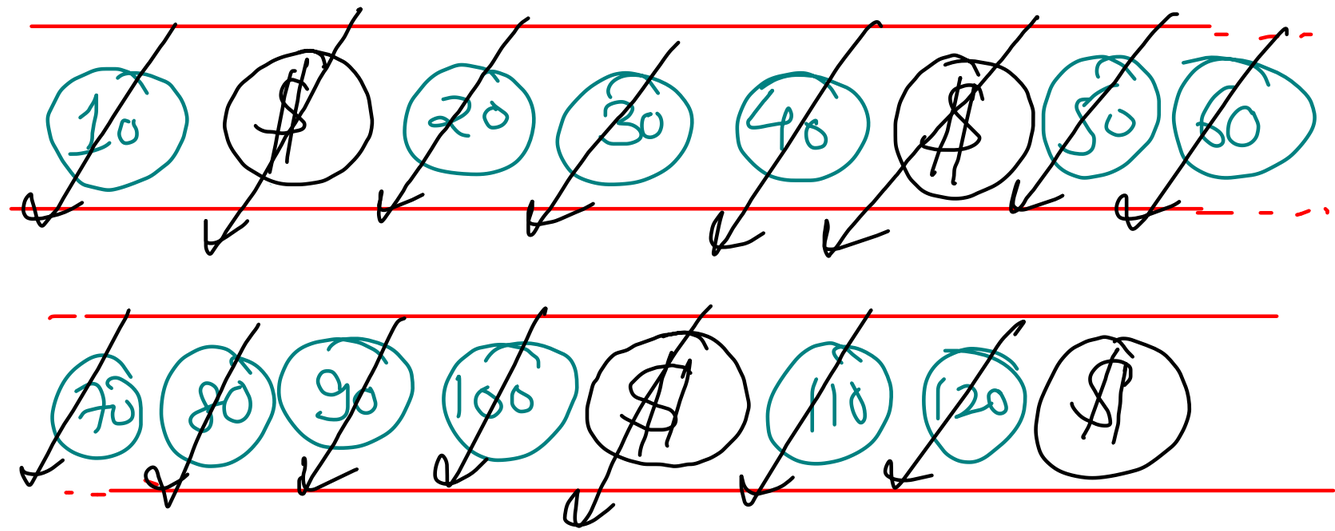




{ 10 }, { 20, 30, 40 }

{ 50, 60, 70, 80, 90, 100 }

{ 110, 120 }

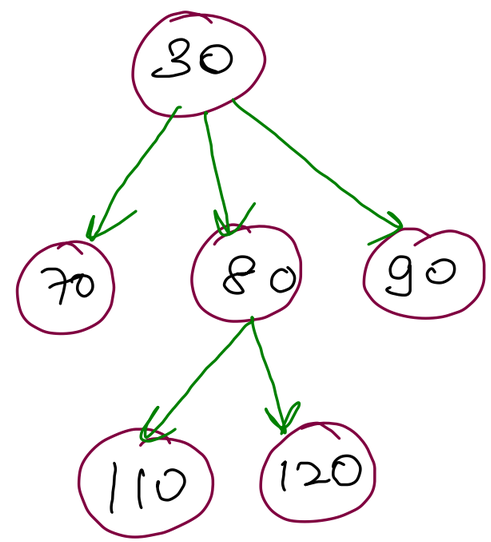
using marker node method

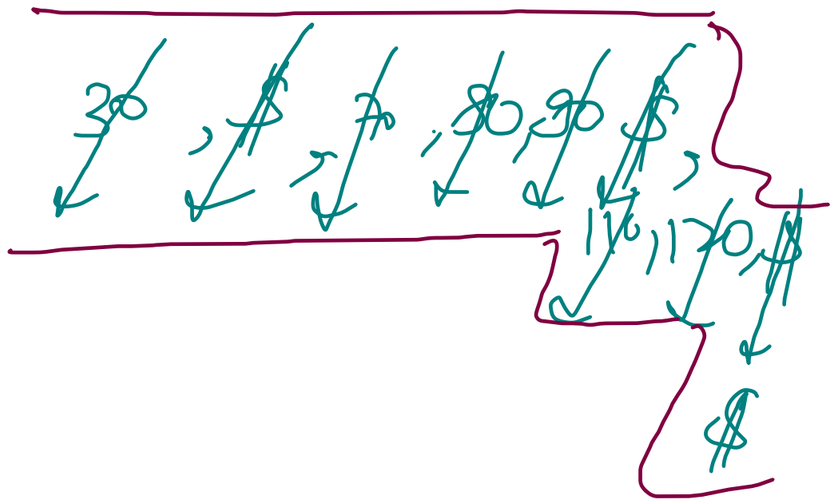
```java
public List<List<Integer>> levelOrder(Node root) {
    List<List<Integer>> res = new ArrayList<>();
    if(root == null) return res;

    Queue<Node> q = new ArrayDeque<>();
    q.add(root);
    Node marker = new Node(-1);
    q.add(marker);

    List<Integer> level = new ArrayList<>();
    while(q.size() > 1){
        Node curr = q.remove();
        if(curr == marker){
            res.add(level);
            level = new ArrayList<>();
            q.add(marker);
        }
        else {
            level.add(curr.val);
            for(Node child: curr.children){
                q.add(child);
            }
        }
    }
    if(level.size() > 0) res.add(level);
    return res;
}
```

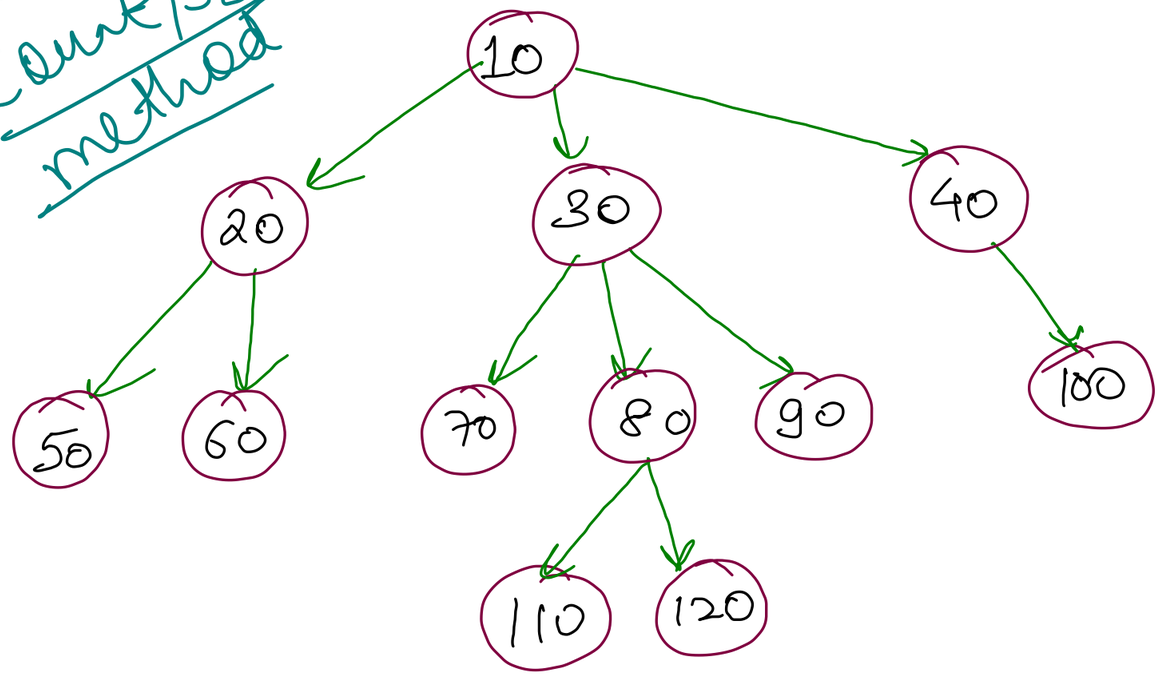
using marker node

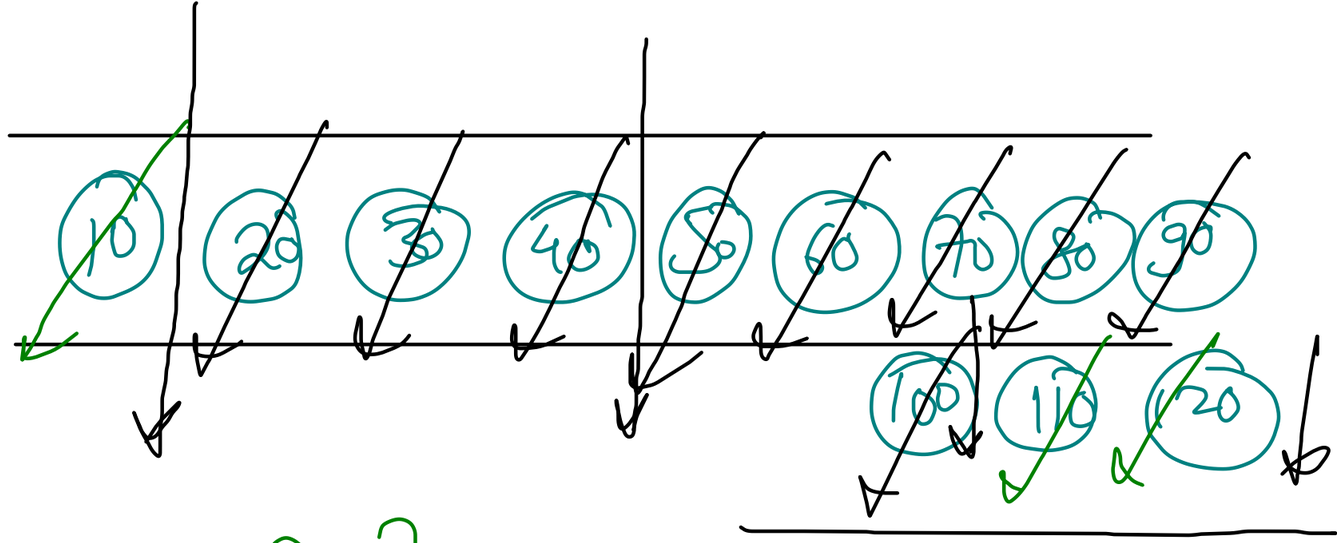




{{30} {70,80,90} {110,120}}

using count/size method





{10}

{20, 30, 40}

{50, 60, 70, 80, 90, 100}

{110, 120}

```
int count = q.size();
for(int i=0; i<count ; i++)
```

```java
public List<List<Integer>> levelOrder(Node root) {
    List<List<Integer>> res = new ArrayList<>();
    if(root == null) return res;

    Queue<Node> q = new ArrayDeque<>();
    q.add(root);

    while(q.size() > 0){
        int count = q.size();
        List<Integer> level = new ArrayList<>();
        while(count-- > 0){
            Node curr = q.remove();
            level.add(curr.val);
            for(Node child: curr.children){
                q.add(child);
            }
        }
        res.add(level);
    }

    return res;
}
```

using count method

O(N) time

O(breadth) extra space complexity

best case

worst case

O(N)

O(N)

{N/2}

even if tree is balanced

```java
public List<List<Integer>> levelOrder(TreeNode root) {
    List<List<Integer>> res = new ArrayList<>();
    if(root == null) return res;

    Queue<TreeNode> q = new ArrayDeque<>();
    q.add(root);

    while(q.size() > 0){
        int count = q.size();
        List<Integer> level = new ArrayList<>();
        while(count-- > 0){
            TreeNode curr = q.remove();
            level.add(curr.val);
            if(curr.left != null) q.add(curr.left);
            if(curr.right != null) q.add(curr.right);
        }
        res.add(level);
    }

    return res;
}
```

Binary Tree level order

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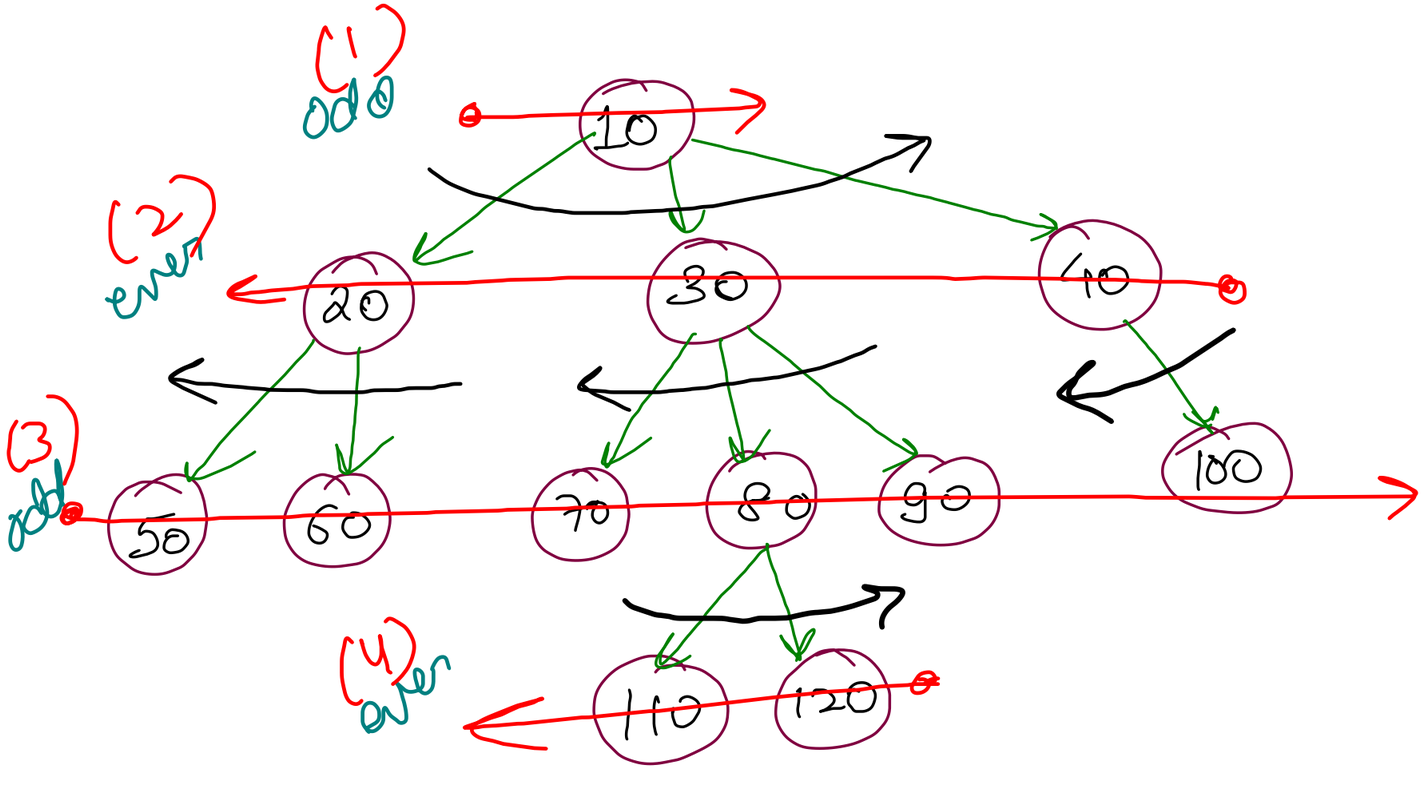
O(N) time

O(N) Queue extra space



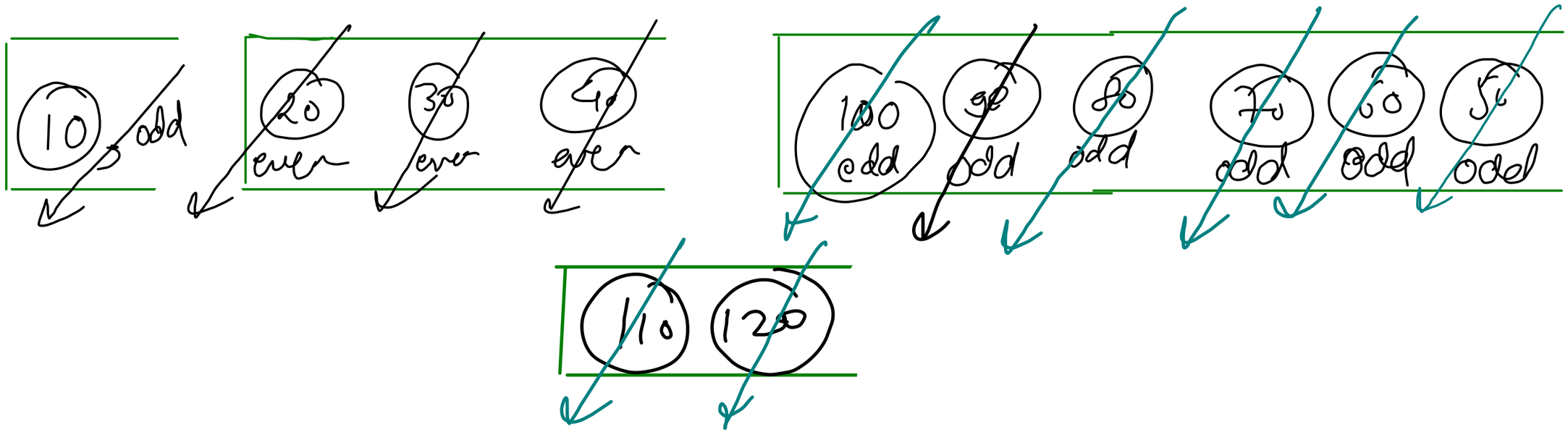
{10}

{40, 30, 20}

{50, 60, 70, 80, 90, 100}

{120, 110}

Zig Zag level order



```java
public List<List<Integer>> zigzagLevelOrder(TreeNode root) {
    List<List<Integer>> res = new ArrayList<>();
    if(root == null) return res;

    Stack<TreeNode> odd = new Stack<>();
    Stack<TreeNode> even = new Stack<>();
    odd.push(root);
    int level = 1;

    while(odd.size() > 0 || even.size() > 0){
        List<Integer> oned = new ArrayList<>();
        if(level % 2 == 1){
            while(odd.size() > 0){
                TreeNode curr = odd.pop();
                oned.add(curr.val);

                if(curr.left != null) even.push(curr.left);
                if(curr.right != null) even.push(curr.right);
            }
        }
        else {
            while(even.size() > 0){
                TreeNode curr = even.pop();
                oned.add(curr.val);

                if(curr.right != null) odd.push(curr.right);
                if(curr.left != null) odd.push(curr.left);
            }
        }

        level++;
        res.add(oned);
    }
    return res;
}
```

O(N) time

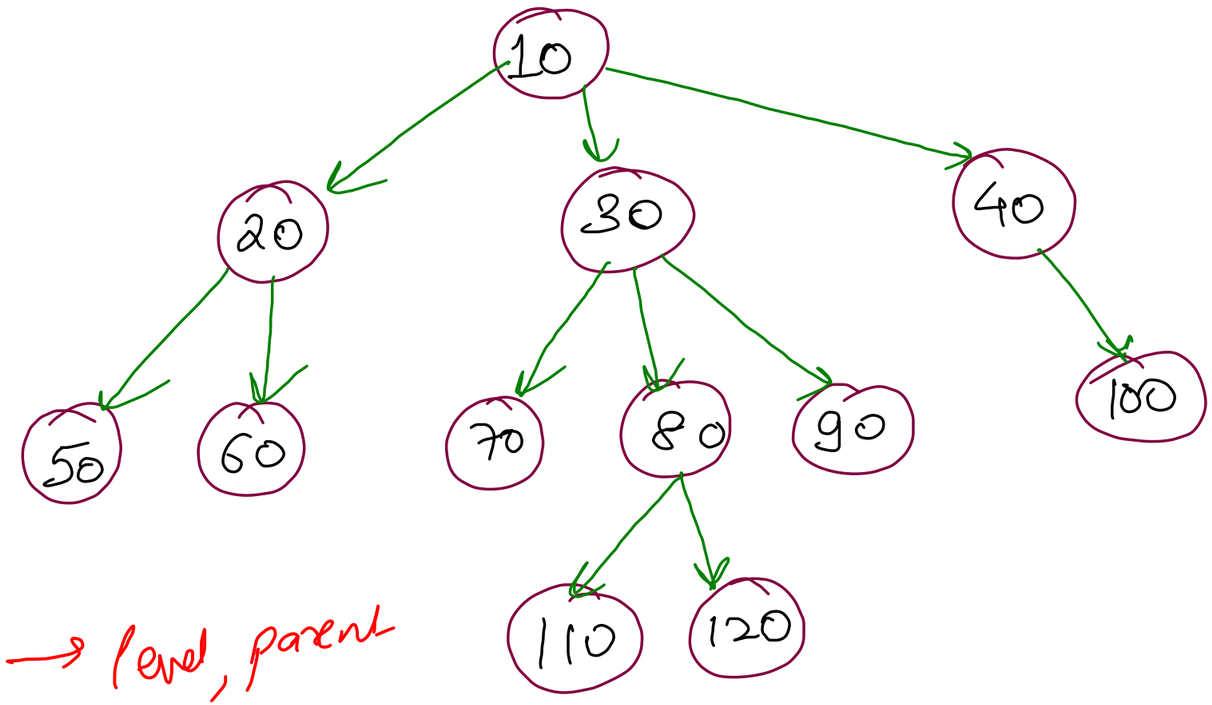
O(N) space

```java
public List<List<Integer>> zigzagLevelOrder(TreeNode root) {
    List<List<Integer>> res = new ArrayList<>();
    if(root == null) return res;

    Stack<TreeNode> odd = new Stack<>();
    Stack<TreeNode> even = new Stack<>();
    odd.push(root);
    int level = 1;

    while(odd.size() > 0 || even.size() > 0){
        List<Integer> oned = new ArrayList<>();
        if(level % 2 == 1){
            while(odd.size() > 0){
                TreeNode curr = odd.pop();
                oned.add(curr.val);

                if(curr.left != null) even.push(curr.left);
                if(curr.right != null) even.push(curr.right);
            }
        }
        else {
            while(even.size() > 0){
                TreeNode curr = even.pop();
                oned.add(curr.val);

                if(curr.right != null) odd.push(curr.right);
                if(curr.left != null) odd.push(curr.left);
            }
        }

        level++;
        res.add(oned);
    }
    return res;
}
```

O(N) time

O(N) space

Cousins in Binary Tree



A → level, parent

B → level, parent

```
// If X.level != Y.level return false (Neither Sibling Nor Cousin)
// Else If X.Parent == Y.Parent return false (Sibling but not Cousin)
// Else Return true (Same Level & Different Parent -> Cousin)
```

nodes with same parent

sibling → 70, 90

80

cousins → 50, 60, 100

same level, should not be sibling

cousin (10, 40) → false

cousin (30, 30) → false

cousin (20, 30) → false

cousin (70, 80) → false

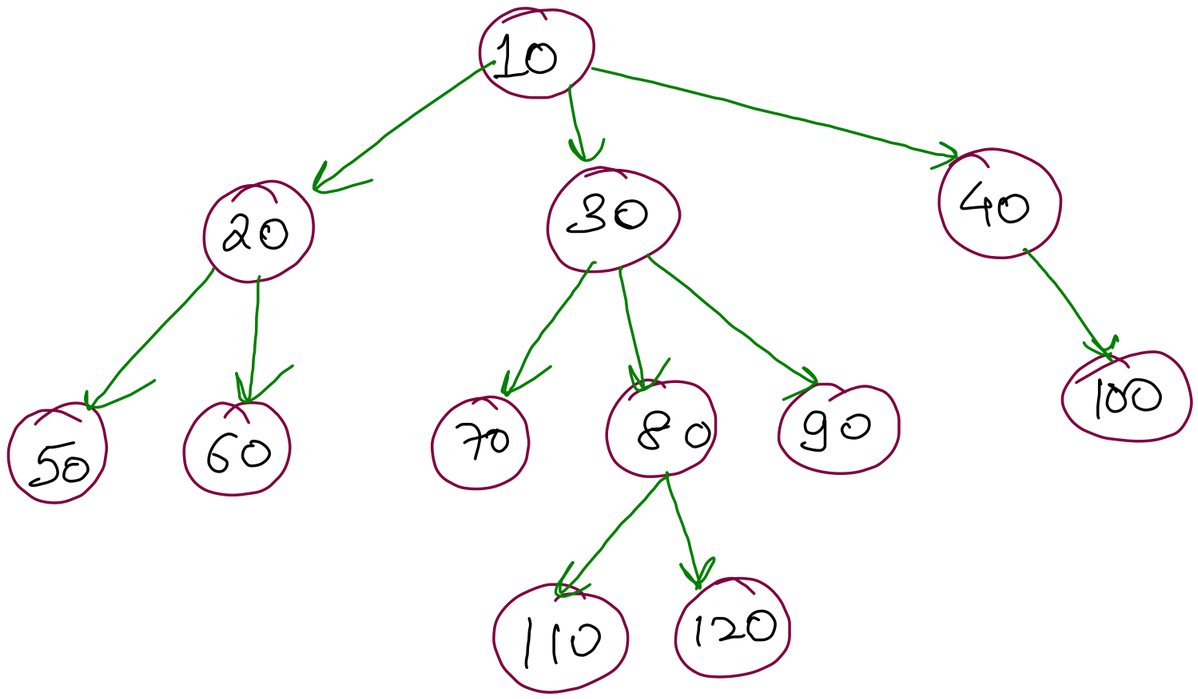
cousin (50, 80) → true

```
int xLevel = 0, yLevel = 0, xParent = -1, yParent = -1;

public void DFS(TreeNode root, int x, int y, int level){
    if(root == null) return;

    if(root.val == x) xLevel = level;
    if(root.val == y) yLevel = level;

    if(root.left != null){
        if(root.left.val == x) xParent = root.val;
        if(root.left.val == y) yParent = root.val;
    }

    if(root.right != null){
        if(root.right.val == x) xParent = root.val;
        if(root.right.val == y) yParent = root.val;
    }

    DFS(root.left, x, y, level + 1);
    DFS(root.right, x, y, level + 1);
}

public boolean isCousins(TreeNode root, int x, int y) {
    DFS(root, x, y, 0);

    if(x == y) return false;
    if(xLevel != yLevel) return false;
    if(xParent == yParent) return false;
    return true;
}
```

Approach 1

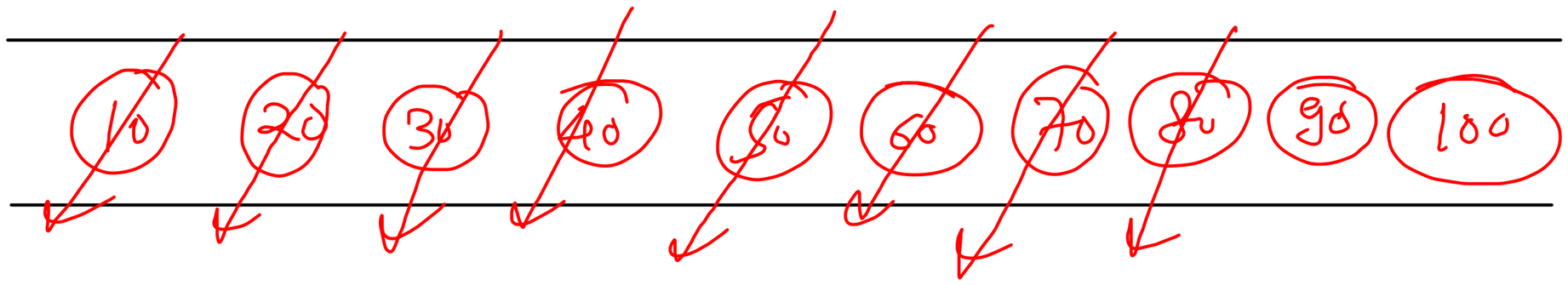
```
class Solution {
    int xLevel = 0, yLevel = 0, xParent = -1, yParent = -1;

    public void DFS(TreeNode root, int x, int y, int level, int parent){
        if(root == null) return;

        if(root.val == x) {
            xLevel = level;
            xParent = parent;
        }
        if(root.val == y){
            yLevel = level;
            yParent = parent;
        }

        DFS(root.left, x, y, level + 1, root.val);
        DFS(root.right, x, y, level + 1, root.val);
    }

    public boolean isCousins(TreeNode root, int x, int y) {
        DFS(root, x, y, 0, -1);

        if(x == y) return false;
        if(xLevel != yLevel) return false;
        if(xParent == yParent) return false;
        return true;
    }
}
```

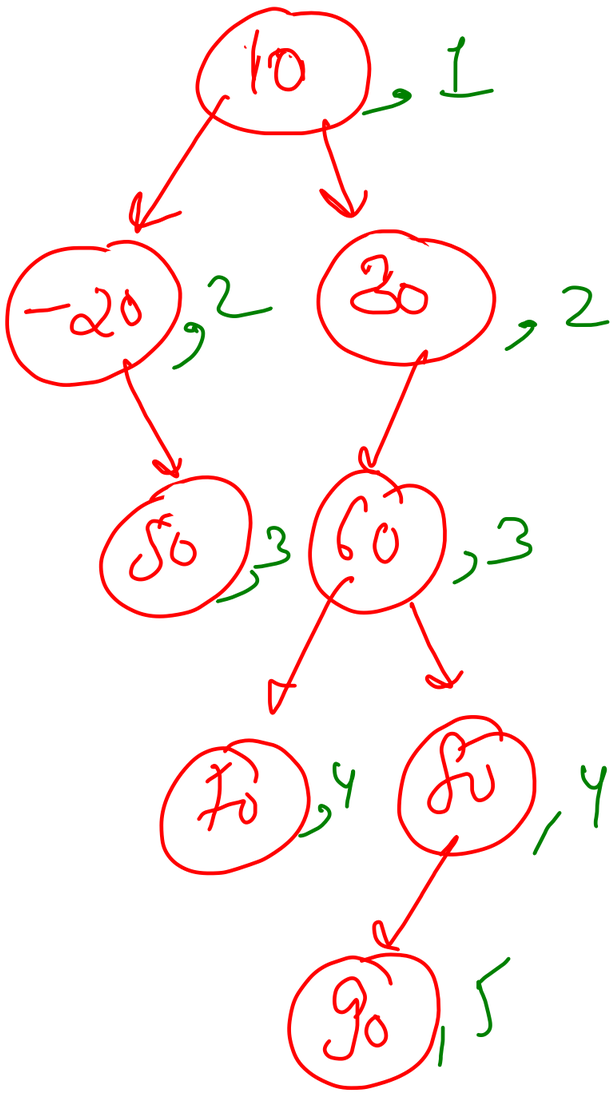
Approach (2)

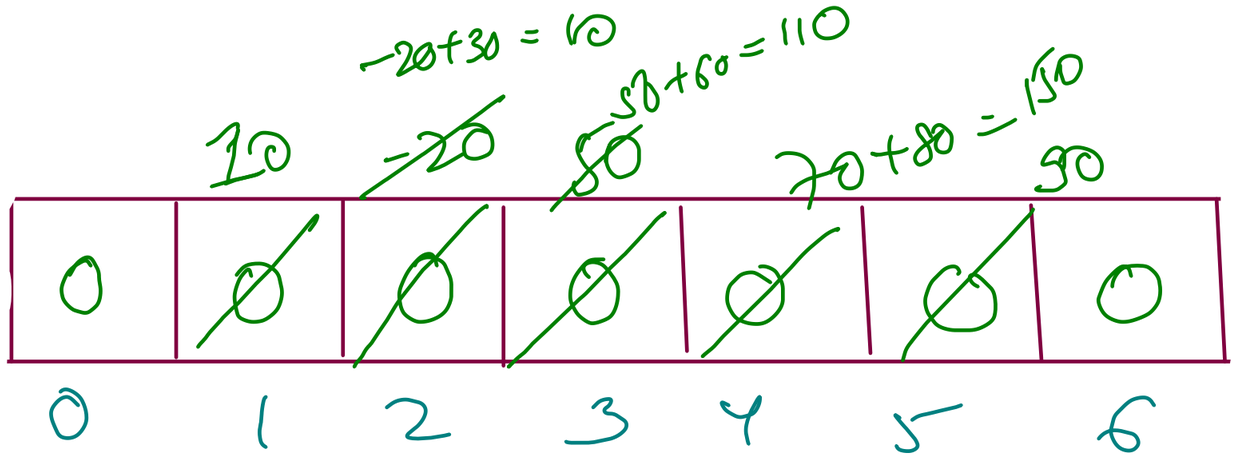


① $x = 50,\ y = 80 \rightarrow$ true

② $x = 70,\ y = 80 \Rightarrow$ false







O(N) time

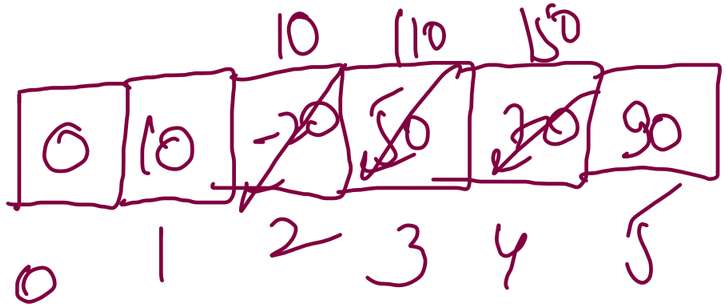
O(H) Extra Space (for ArrayList)

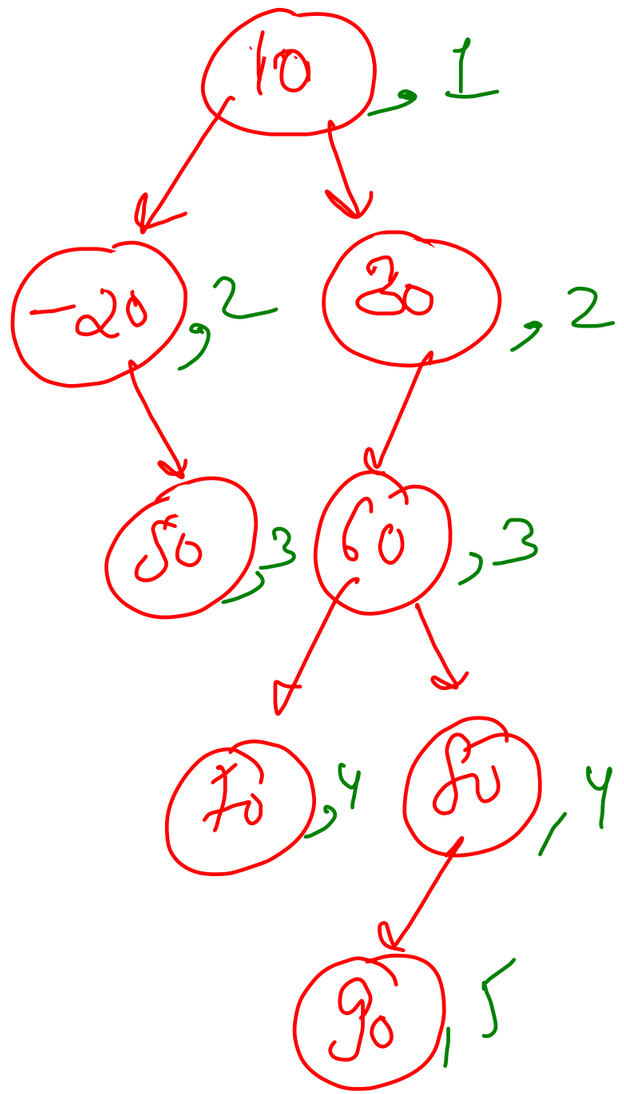
O(H) Recursion call stack

```java
public void DFS(TreeNode root, ArrayList<Integer> levelSum, int level){
    if(root == null) return;

    if(levelSum.size() > level)
        levelSum.set(level, levelSum.get(level) + root.val);
    else levelSum.add(root.val);

    DFS(root.left, levelSum, level + 1);
    DFS(root.right, levelSum, level + 1);
}
public int maxLevelSum(TreeNode root) {
    ArrayList<Integer> levelSum = new ArrayList<>();
    levelSum.add(0);
    DFS(root, levelSum, 1);

    int maxSumLevel = 1;
    for(int i=1; i<levelSum.size(); i++){
        if(levelSum.get(i) > levelSum.get(maxSumLevel)){
            maxSumLevel = i;
        }
    }
    return maxSumLevel;
}
```

O(H) height

smallest level with max^m level





Binary Tree - level (2)
lecture (6)

→ Next Right Pointer – I, II

→ Diagonal Order – I, II

→ Vertical order – I, II

→ left View, Right View

→ Top View, Bottom View

→ Boundary Traversal

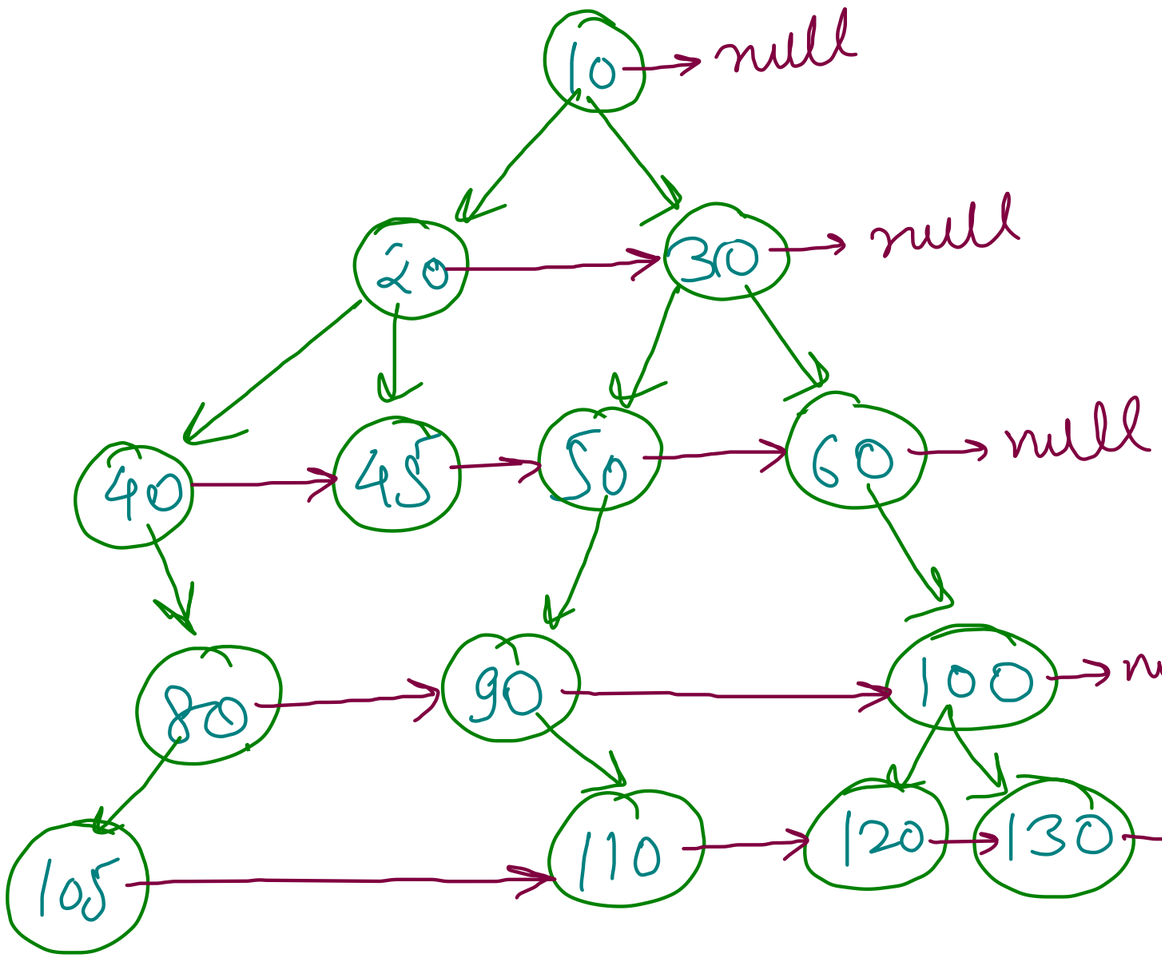
Pre-requisite

→ DFS (Preorder)

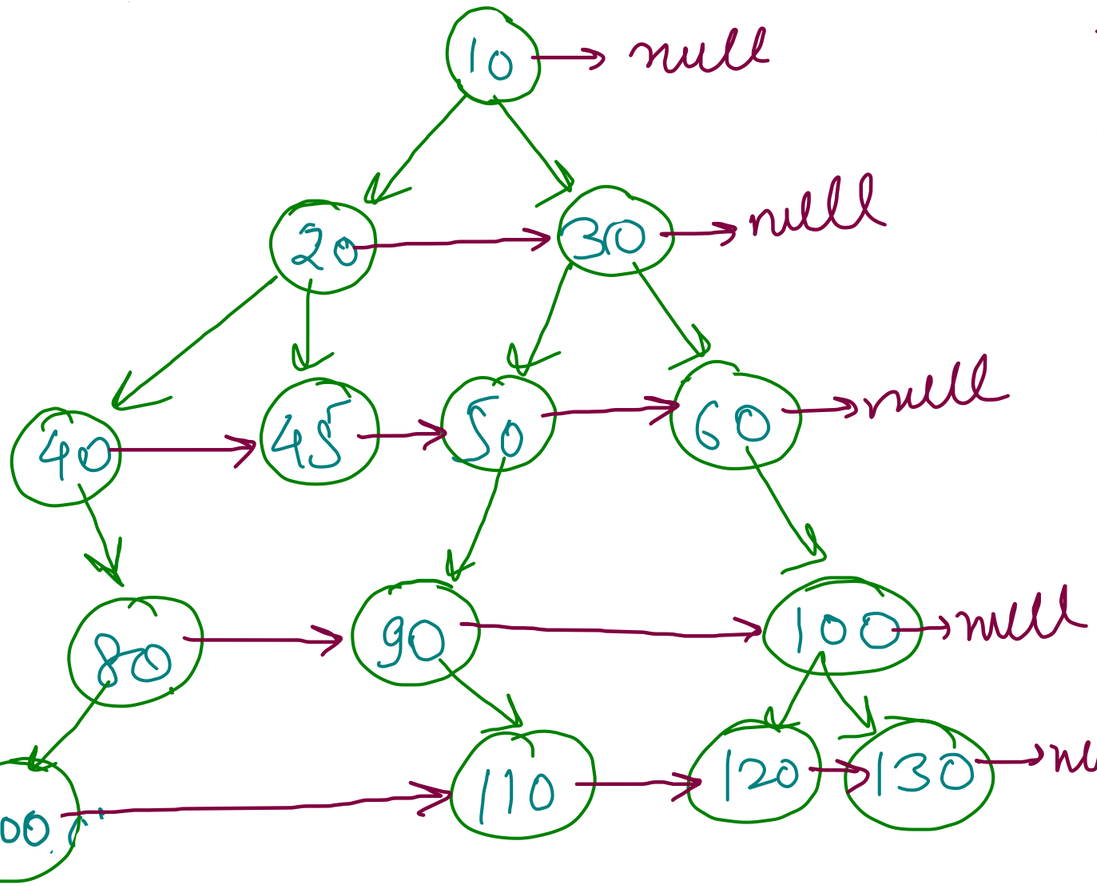
→ BFS (level Order)

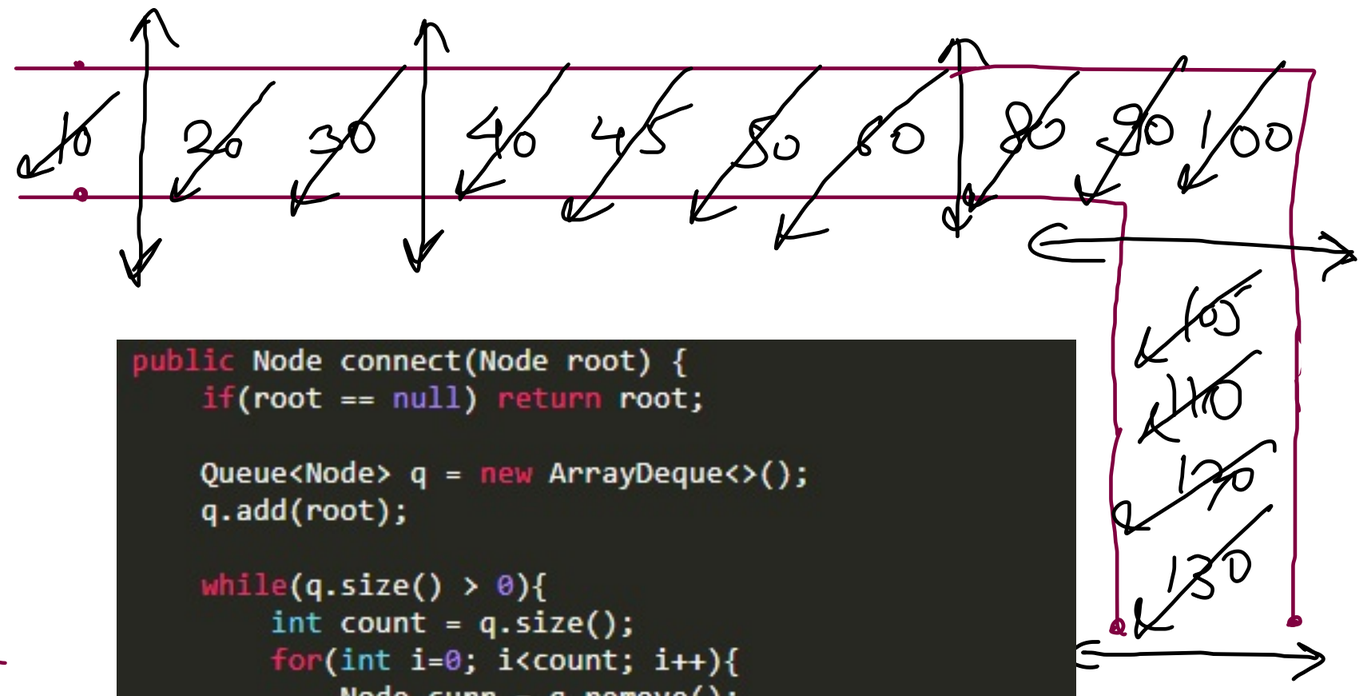
Populating Next Right Pointer

{ 116 and 117 }

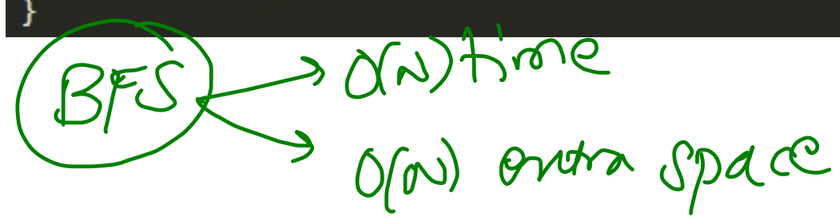


- data
- left
- right
- next



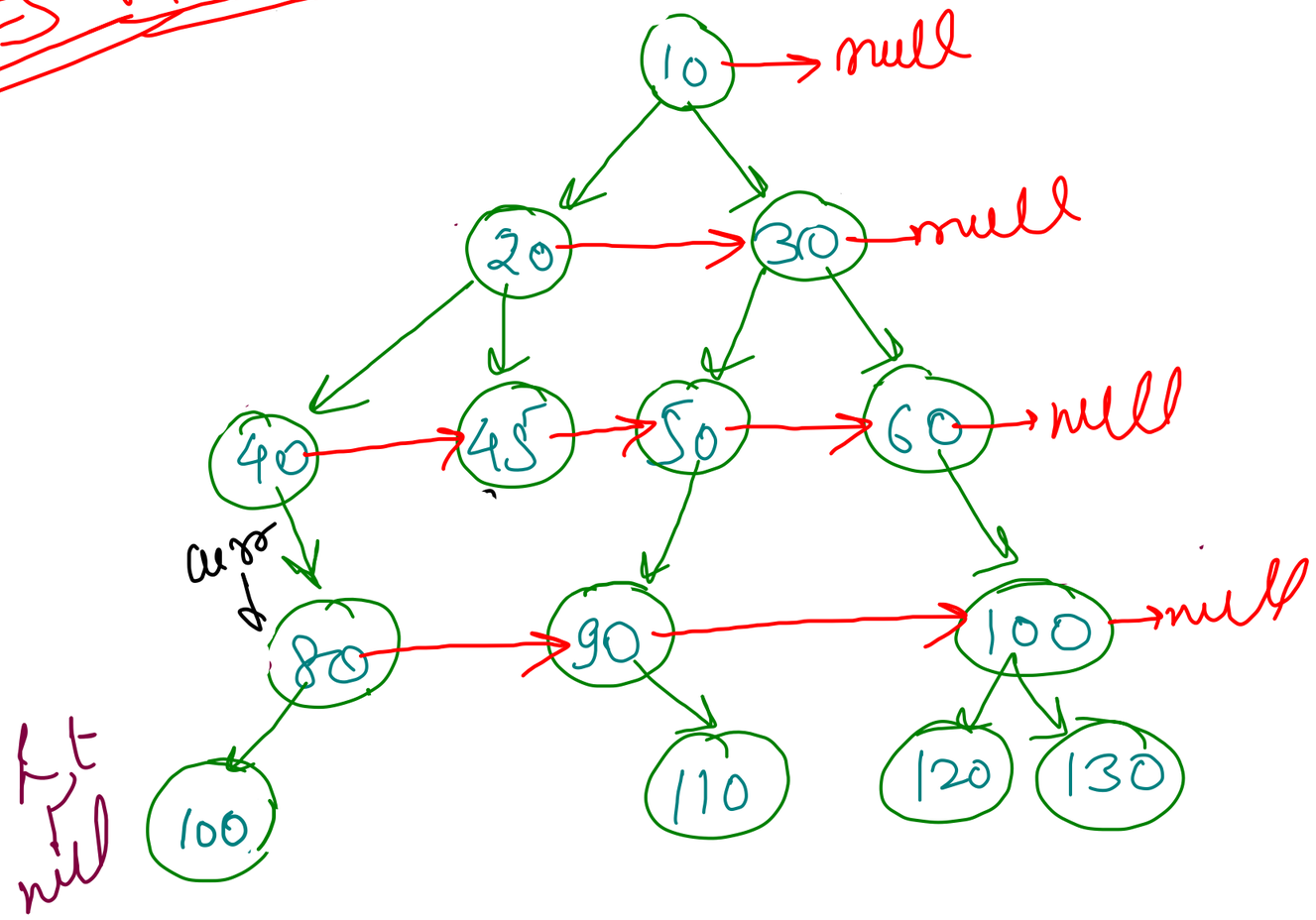


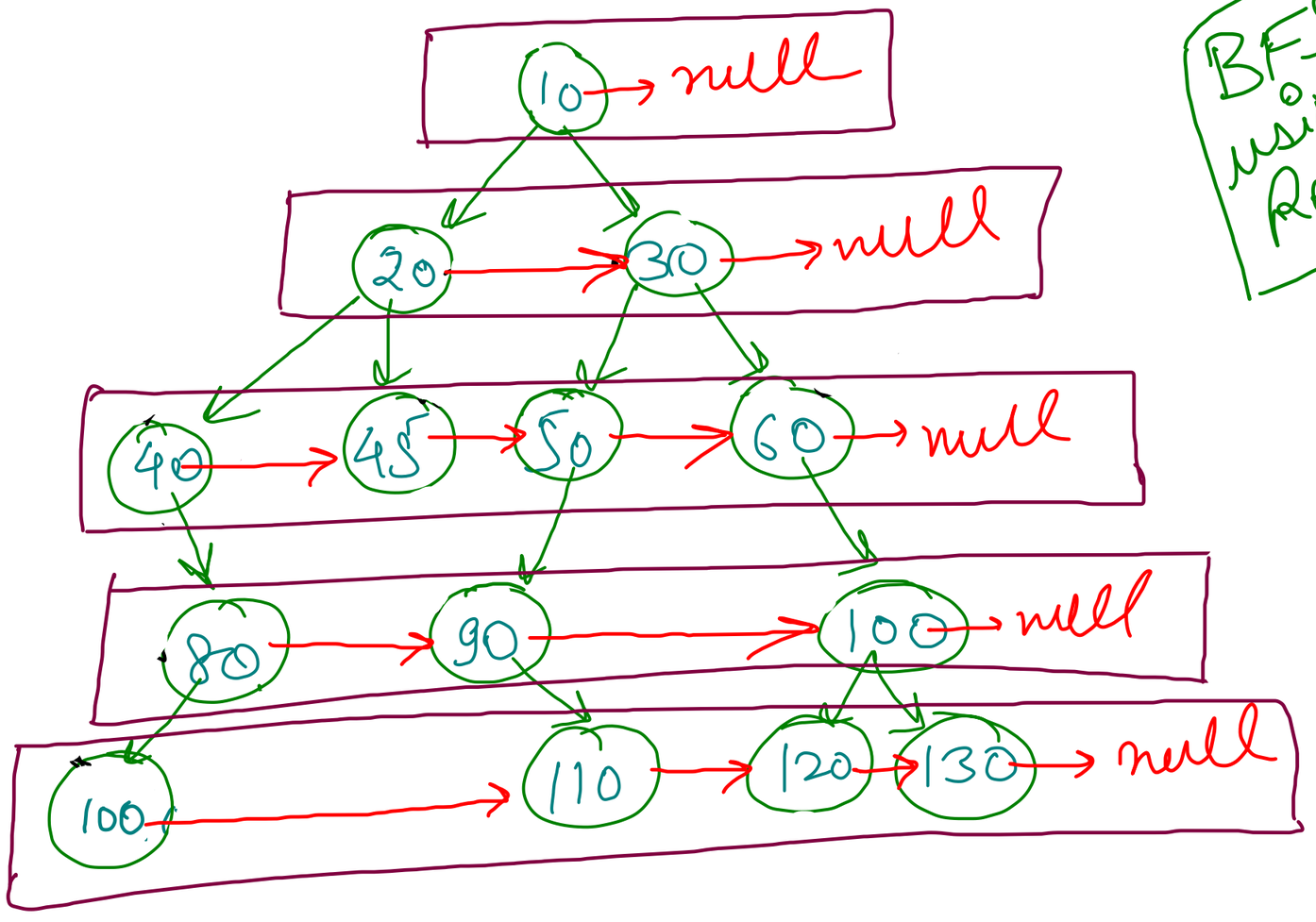

```java
public Node connect(Node root) {
    if(root == null) return root;

    Queue<Node> q = new ArrayDeque<>();
    q.add(root);

    while(q.size() > 0){
        int count = q.size();
        for(int i=0; i<count; i++){
            Node curr = q.remove();

            // Populate Next Right Pointer of Curr
            if(i < count - 1) curr.next = q.peek();
            if(curr.left != null) q.add(curr.left);
            if(curr.right != null) q.add(curr.right);
        }
    }

    return root;
}
```



BFS W/O Queue

```java
public Node connect(Node root){
    Node curr = root;
    while(curr != null){
        Node head = null, tail = null;

        // Travel on Current Level and Construct Next Level
        while(curr != null){
            if(curr.left != null){
                if(head == null)
                    head = tail = curr.left;
                else {
                    tail.next = curr.left;
                    tail = tail.next;
                }
            }
            if(curr.right != null){
                if(head == null)
                    head = tail = curr.right;
                else {
                    tail.next = curr.right;
                    tail = tail.next;
                }
            }

            curr = curr.next;
        }

        curr = head; // Update current as Head of Next Level
    }

    return root;
}
```





BFS using Recursion

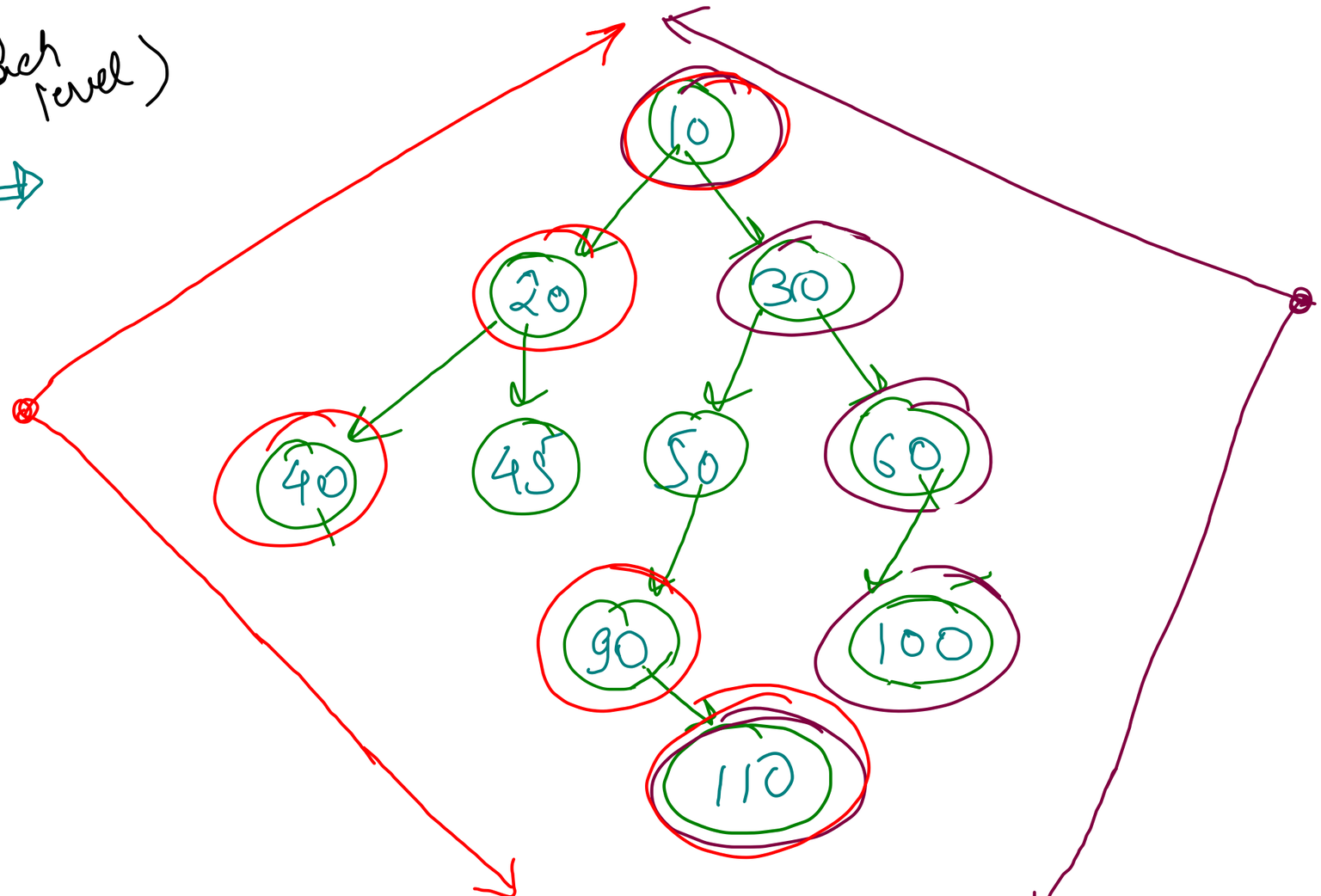
linked list type + level Order

{ on traversing ith level populate next pointers of $(i+1)^{th}$ level using head & tail strategy }

Left View, Right View

(first node of each level)

left view →



(last node of each level)

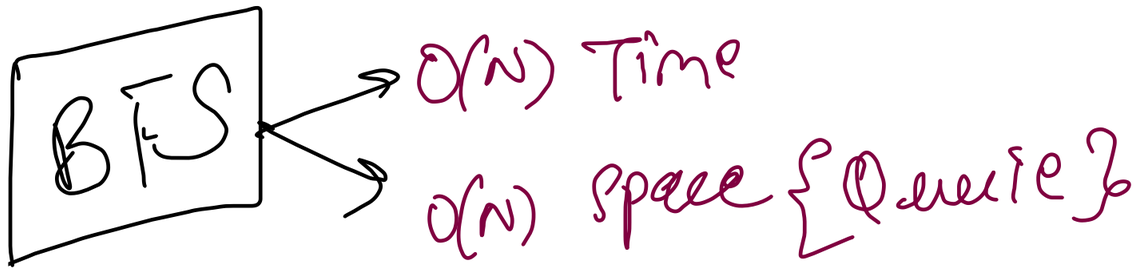
← right side

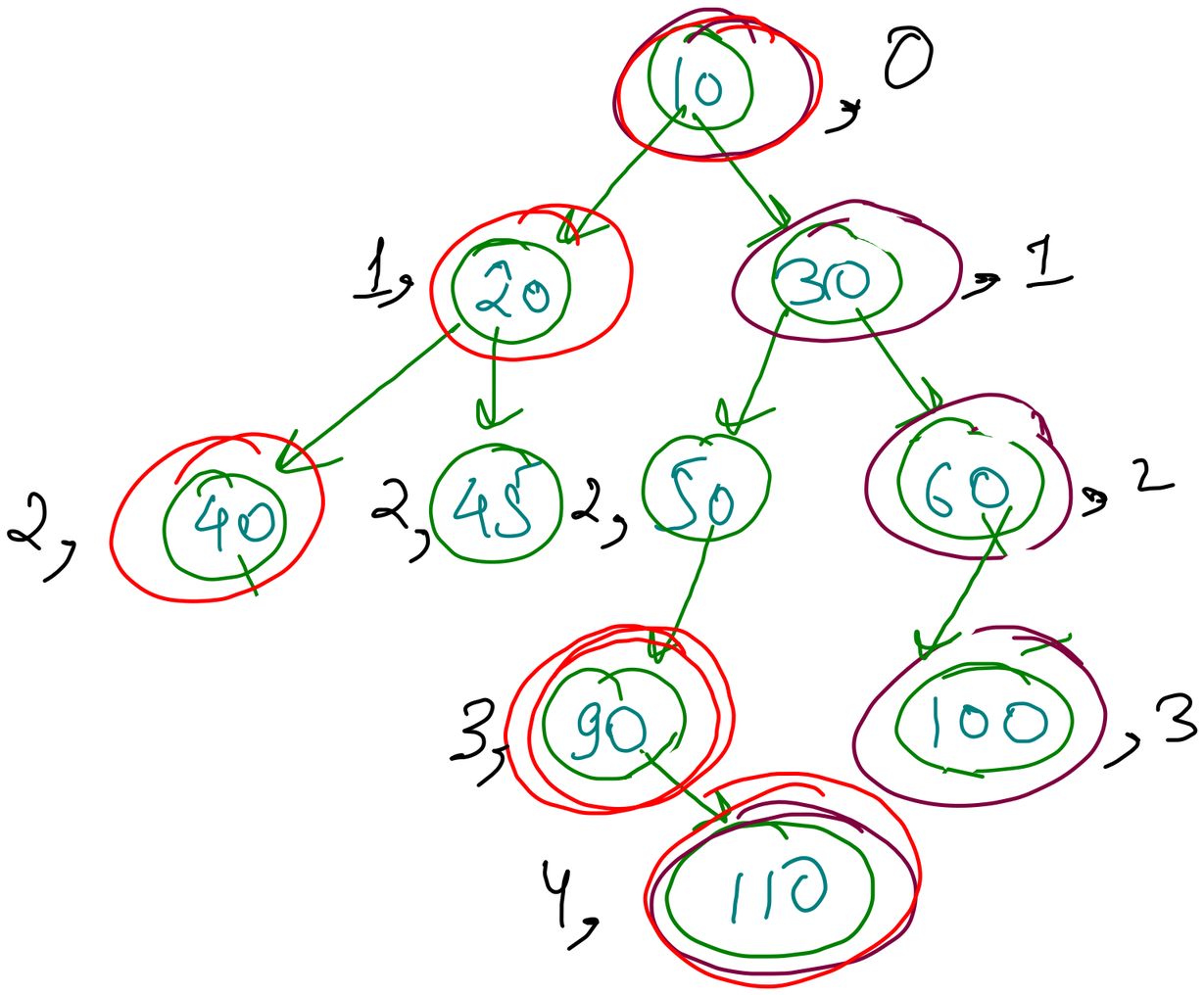
10
20
40
90
100

10
30
60
100
110

```java
ArrayList<Integer> leftView(Node root)
{
    ArrayList<Integer> leftView = new ArrayList<>();
    if(root == null) return leftView;

    Queue<Node> q = new ArrayDeque<>();
    q.add(root);

    while(q.size() > 0){
        int count = q.size();
        for(int i=0; i<count; i++){
            Node curr = q.remove();

            if(i == 0) leftView.add(curr.data);
            if(curr.left != null) q.add(curr.left);
            if(curr.right != null) q.add(curr.right);
        }
    }

    return leftView;
}
```

```java
public List<Integer> rightSideView(TreeNode root) {
    List<Integer> rightView = new ArrayList<>();
    if(root == null) return rightView;

    Queue<TreeNode> q = new ArrayDeque<>();
    q.add(root);

    while(q.size() > 0){
        int count = q.size();
        for(int i=0; i<count; i++){
            TreeNode curr = q.remove();

            if(i == count - 1) rightView.add(curr.val);
            if(curr.left != null) q.add(curr.left);
            if(curr.right != null) q.add(curr.right);
        }
    }

    return rightView;
}
```





10	20	40	90	110

Left view

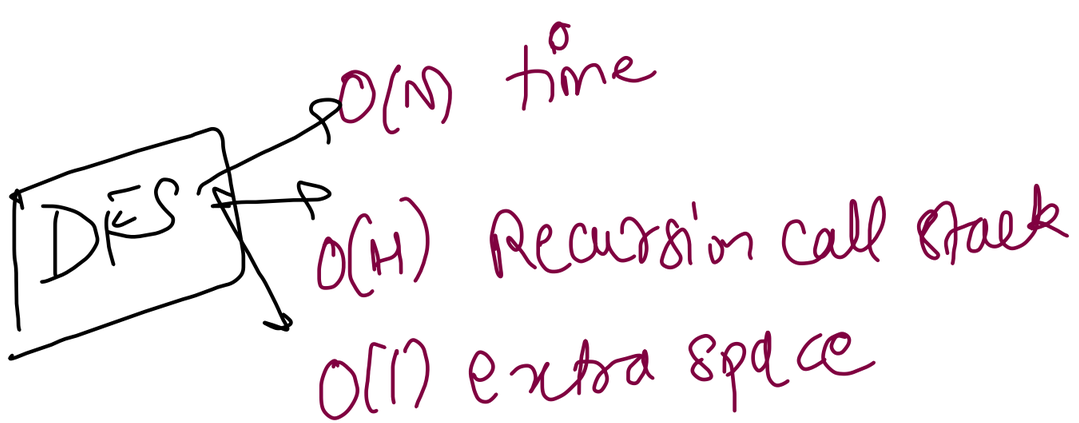
60
~~50~~
~~45~~
100

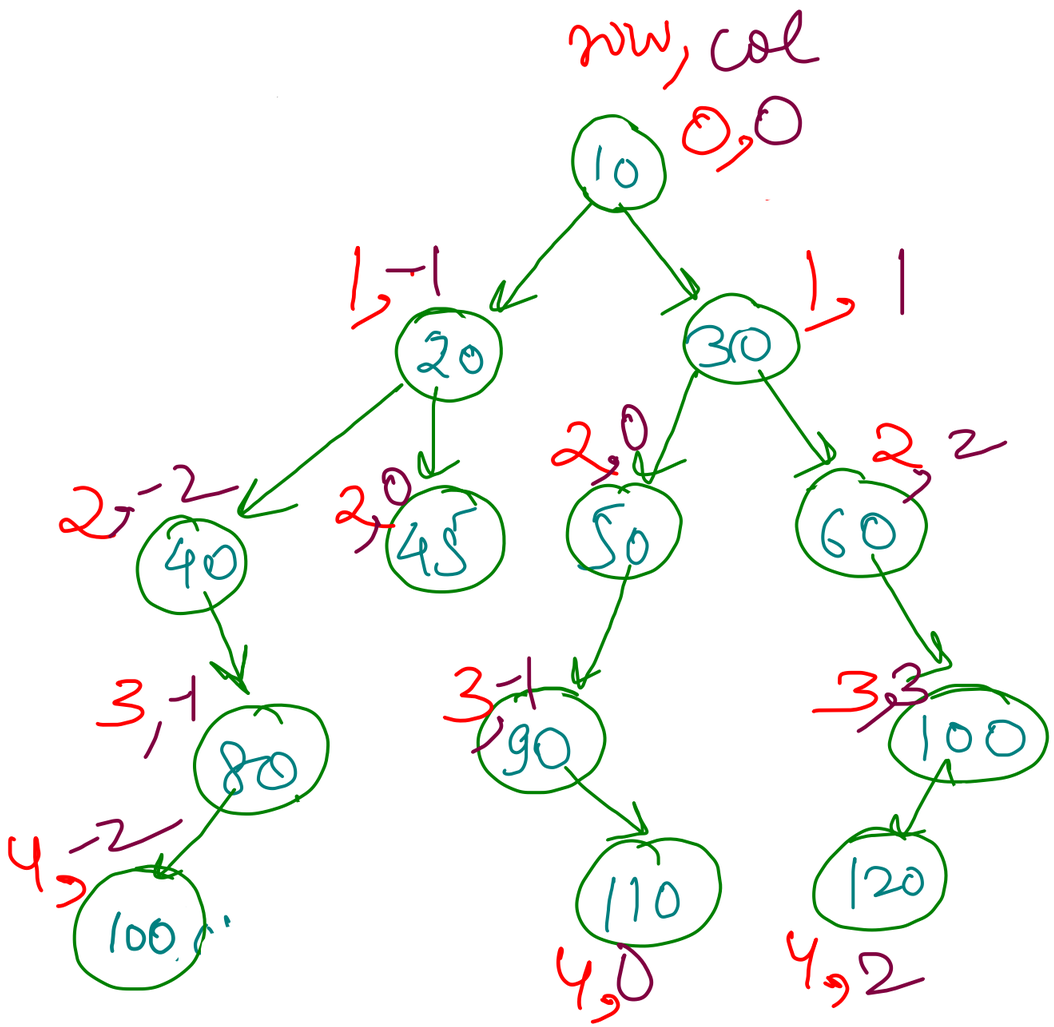
10	~~30~~ 20	~~40~~	~~90~~	110

right view

```java
public void DFS(TreeNode root, List<Integer> rightView, int level){
    if(root == null) return;

    if(level >= rightView.size())
        rightView.add(root.val);
    else rightView.set(level, root.val);

    DFS(root.left, rightView, level + 1);
    DFS(root.right, rightView, level + 1);
}

public List<Integer> rightSideView(TreeNode root) {
    List<Integer> rightView = new ArrayList<>();
    DFS(root, rightView, 0);
    return rightView;
}
```

```java
public void DFS(Node root, ArrayList<Integer> leftView, int level){
    if(root == null) return;

    if(level >= leftView.size())
        leftView.add(root.data);

    DFS(root.left, leftView, level + 1);
    DFS(root.right, leftView, level + 1);
}

ArrayList<Integer> leftView(Node root)
{
    ArrayList<Integer> leftView = new ArrayList<>();
    DFS(root, leftView, 0);
    return leftView;
}
```





level 0

level 1

level 2

level 3

level 4

col → vertical order

-2 ⇒ { 40, 100 }

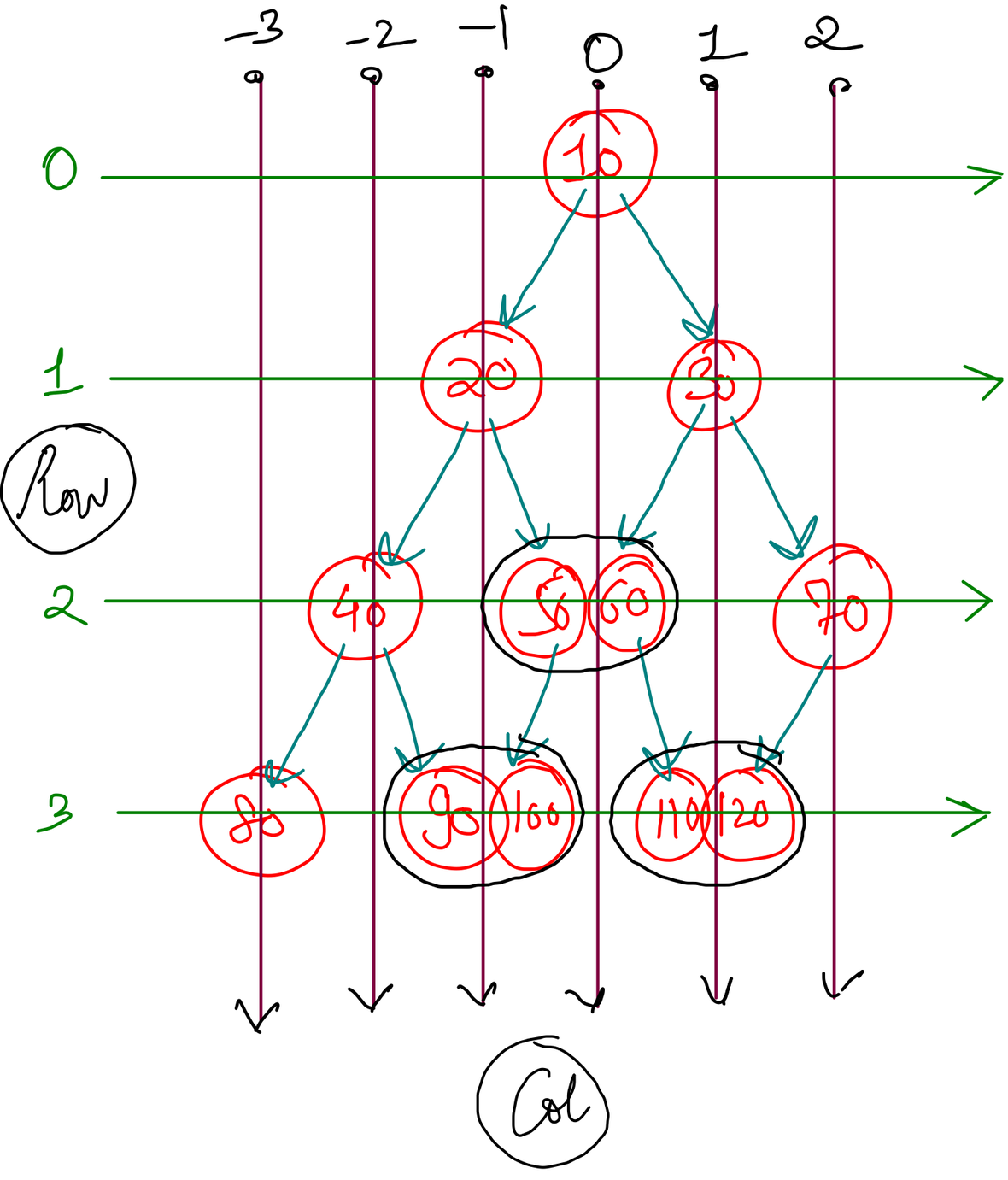
-1 ⇒ { 20, 80, 90 }

0 ⇒ { 10, 45, 50, 110 }

1 ⇒ { 30 }

2 ⇒ { 60, 120 }

3 ⇒ { 100 }



Key (Integer)

Value

{ ArrayList <Integer> }

-3 → { 80 }

-2 → { 40 }

-1 → { 20, 90, 100 }

0 → { 10, 50, 60 }

1 → { 30, 110, 120 }

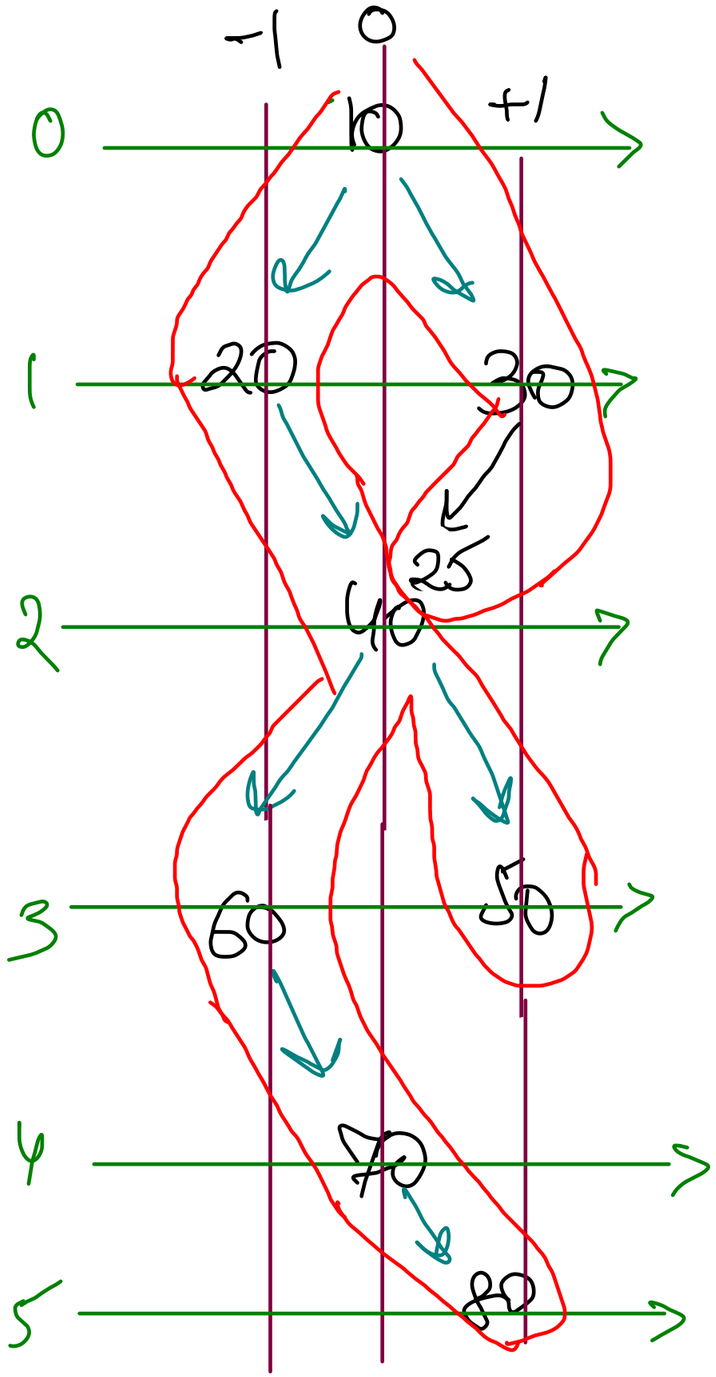
2 → { 70 }

Same Vertical order

↓

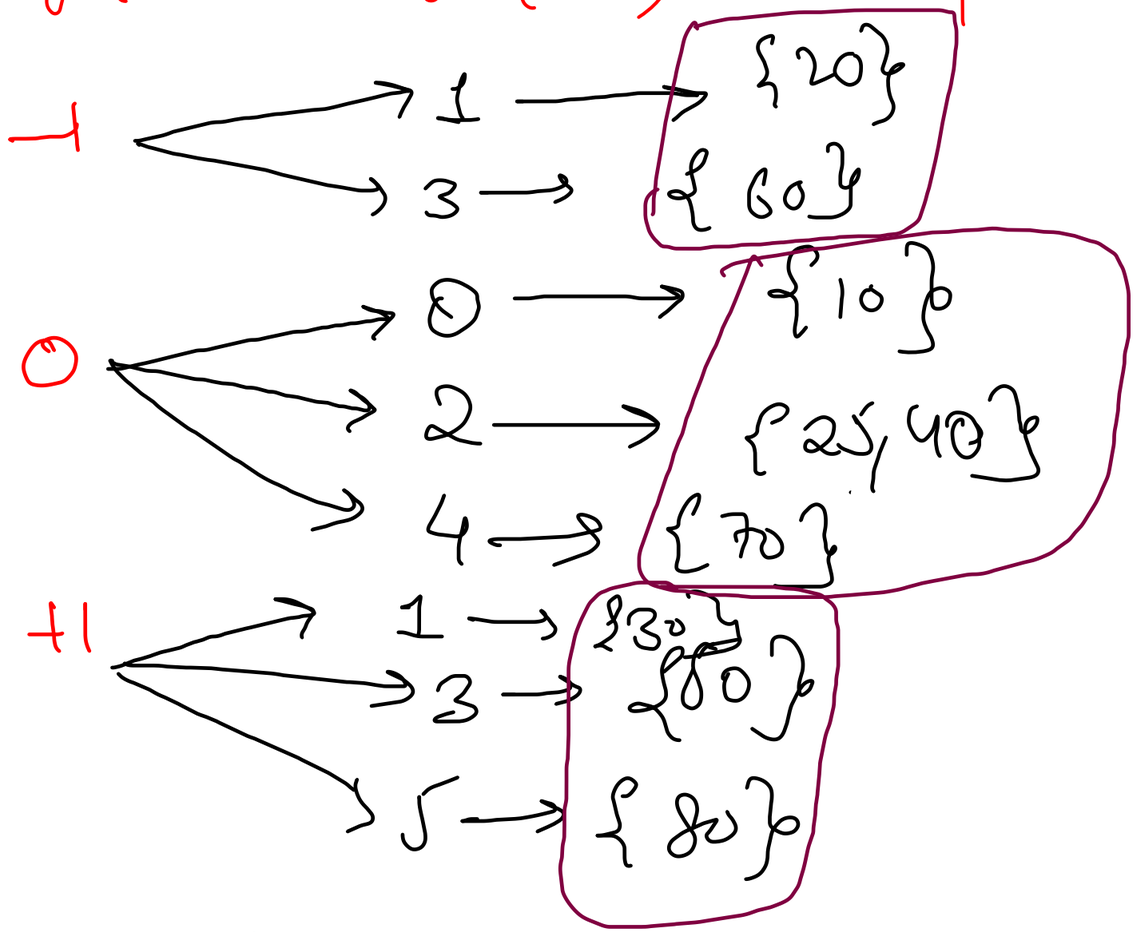
Elements in the level order

If k_0, v_0 is same, increasing set



2D (Nested) hashmap

key1(col) → key2(row) → value{TreeSet}



"Level order cannot be maintained in DFS"

```java
TreeMap<Integer, TreeMap<Integer, ArrayList<Integer>>> vertical;

public void DFS(TreeNode root, int row, int col){
    if(root == null) return;

    if(vertical.containsKey(col) == false)
        vertical.put(col, new TreeMap<>());

    if(vertical.get(col).containsKey(row) == false)
        vertical.get(col).put(row, new ArrayList<>());

    vertical.get(col).get(row).add(root.val);

    DFS(root.left, row + 1, col - 1);
    DFS(root.right, row + 1, col + 1);
}
```

```java
public List<List<Integer>> verticalTraversal(TreeNode root) {
    vertical = new TreeMap<>();
    DFS(root, 0, 0);

    List<List<Integer>> res = new ArrayList<>();
    for(Integer col: vertical.keySet()){
        TreeMap<Integer, ArrayList<Integer>> curr = vertical.get(col);
        List<Integer> res1d = new ArrayList<>();
        for(Integer row: curr.keySet()){
            ArrayList<Integer> oned = curr.get(row);
            Collections.sort(oned);
            for(Integer val: oned){
                res1d.add(val);
            }
        }
        res.add(res1d);
    }
    return res;
}
```

```cpp
class Solution {
public:
    map<int,map<int,set<int>>> m;
    void solve(TreeNode* root,int row,int col)
    {
        if(root == NULL)
            return;
        m[col][row].insert(root->val);
        solve(root->left,row + 1, col - 1);
        solve(root->right,row + 1, col + 1);
    }
    vector<vector<int>> verticalTraversal(TreeNode* root) {
        vector<vector<int>> res;
        if(root == NULL)
            return res;
        solve(root,0,0);
        for(auto i:m)
        {
            vector<int> arr;
            for(auto j: i.second)
            {
                for(auto k: j.second)
                    arr.push_back(k);
            }
            res.push_back(arr);
        }
        return res;
    }
};
```