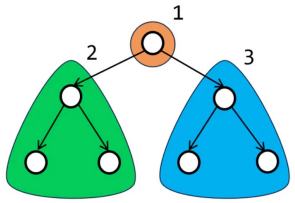
TREE

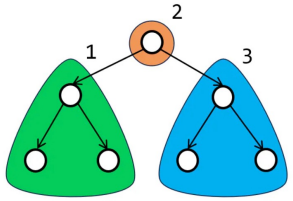
Tree Traversals

Depth-First Traversals

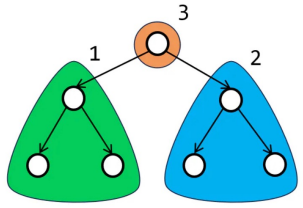
- **Pre-order**: Root – Left – Right



- **In-order**: Left – Root – Right



- **Post-order**: Left – Right – Root



Breadth-First Traversal (Level Order Traversal)

Visit every node on a level before moving to a lower level.

Image credits:
https://deriveit.org/coding/tree-dfs-113

Tree Traversals

Depth-First Traversals

Use a recursive algorithm to traverse according to the order

- **Pre-order**: Root – Left – Right

```
if (!root) return;
doSomething();
visit(node->left);
visit(node->right);
```

- **In-order**: Left – Root – Right

```
if (!root) return;
visit(node->left);
doSomething();
visit(node->right);
```

- **Post-order**: Left – Right – Root

```
if (!root) return;
visit(node->left);
visit(node->right);
doSomething();
```

Tree Traversals

Example of pre-order and in-order

```
struct TreeNode {
    int val;
    TreeNode *left, *right;
    TreeNode(int x) : val(x), left(nullptr), right(nullptr) {}
};

// Pre-order traversal
void preorderTraversal(TreeNode* root) {
    if (root == nullptr) return;
    cout << root->val << " ";
    preorderTraversal(root->left);
    preorderTraversal(root->right);
}

// In-order traversal
void inorderTraversal(TreeNode* root) {
    if (root == nullptr) return;
    inorderTraversal(root->left);
    cout << root->val << " ";
    inorderTraversal(root->right);
}
```

Tree Traversals

Example of post-order and level-order

```
struct TreeNode {
    int val;
    TreeNode *left, *right;
    TreeNode(int x) : val(x), left(nullptr), right(nullptr) {}
};

// Post-order traversal
void postorderTraversal(TreeNode* root) {
    if (root == nullptr) return;
    postorderTraversal(root->left);
    postorderTraversal(root->right);
    cout << root->val << " ";
}

// Level-order traversal using a queue
void levelOrderTraversal(TreeNode* root) {
    if (root == nullptr) return;
    queue<TreeNode*> q;
    q.push(root);
    while (!q.empty()) {
        TreeNode* current = q.front();
        q.pop();
        cout << current->val << " ";
        if (current->left != nullptr) q.push(current->left);
        if (current->right != nullptr) q.push(current->right);
    }
}
```

BFS Using Stack

BFS with std::stack

- This might be useful for problems when you want to return and resume (for example, 872. Leaf-Similar Trees)

```
struct TreeNode {
    int val;
    TreeNode *left, *right;
    TreeNode(int x) : val(x), left(nullptr), right(nullptr) {}
};

// Pre-order traversal
void bfs(std::stack<TreeNode*>& tree) {
    while(!tree.empty()) {
        TreeNode* root = tree.top();
        tree.pop();
        // do something ...
        if (root->right) tree.push(root->right);
        if (root->left) tree.push(root->left);
    }
}
```

Problem – Maximum Depth of Binary Tree

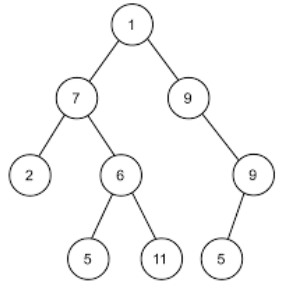
Easy

LeetCode https://leetcode.com/problems/maximum-depth-of-binary-tree

Problem Statement

- Given the root of a binary tree, find the *maximum depth*
- **Example:**

  root = [1,7,9,2,6,null,9,null,null,5,11,5,null]
- **Output**: 4



Solution – Maximum Depth of Binary Tree

Easy

LeetCode https://leetcode.com/problems/maximum-depth-of-binary-tree

Solution

- Perform **post-order** traversal: left - right - root
- Recursively go left and right to find each value
- Return the max of each one

Code – Maximum Depth of Binary Tree

Easy

LeetCode https://leetcode.com/problems/maximum-depth-of-binary-tree

```
int maxDepth(TreeNode* root) {
    if (!root) return 0;
    // find max left
    int maxLeft = maxDepth(root->left);
    // find max right
    int maxRight = maxDepth(root->right);
    // return max +1 (account for root)
    return std::max(maxLeft, maxRight) + 1;
}
```

Problem – Path Sum

Easy

LeetCode https://leetcode.com/problems/path-sum

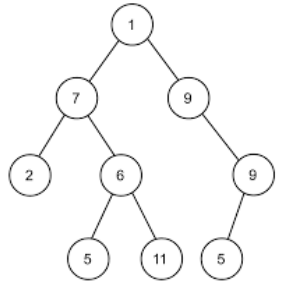
Problem Statement

- It is given the **root** of a binary tree and an integer **target sum**
- **Example:**

  root = [1,7,9,2,6,null,9,null,null,5,11,5,null]

  target sum = 10
- Return true if there is a path from root to leaf that adds up to 10
- **Output**: true

  Node 1 + Node 7 + Node 2 = 10



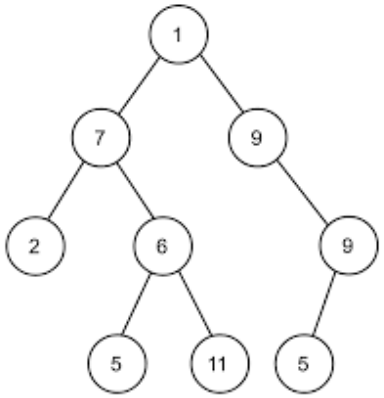
Solution – Path Sum

Easy

LeetCode https://leetcode.com/problems/path-sum

Solution

- Start from root node (1)
- Subtract from target number (example 10 – 1 = 9)
- Continue going down the tree, until the target is 0, return true
- After visiting all nodes, if the target is not zero, return false



Code – Path Sum

Easy

LeetCode https://leetcode.com/problems/path-sum

```
bool hasPathSum(TreeNode* root, int targetSum) {
    if (!root) {
        return false;
    }
    // we want targetSum to be zero
    targetSum -= root->val;
    // if there is no left, no right, we've reached the end of the path
    // so if the targetSum is zero, then the nodes summed up to the targetSum
    if (!root->left && !root->right && targetSum == 0) {
        return true;
    }
    // propagate to left and right
    return hasPathSum(root->left, targetSum) || hasPathSum(root->right, targetSum);
}
```

Also, a small performance tweak can be made by avoiding writing *targetSum*: *`targetSum -= root->val`*

This will avoid a memory write access, making the calculation directly in the CPU, but also at a cost of readability

```
    if (!root->left && !root->right && targetSum - root->val == 0) {
     …
    return hasPathSum(root->left, targetSum - root->val) || hasPathSum(root->right, targetSum - root->val);
```

Problem – 297. Serialize and Deserialize Binary Tree

Hard

LeetCode leetcode.com/problems/serialize-and-deserialize-binary-tree

Problem

- Design an algorithm to serialize and deserialize a binary tree
- You have to build two interfaces: serialize that returns a string, and deserialize that returns the whole tree as TreeNode pointer
- The string can be represented at any format (comma-separated, space separated etc)

Solution – 297. Serialize and Deserialize Binary Tree

Hard

LeetCode leetcode.com/problems/serialize-and-deserialize-binary-tree

Solution

- **Serialize**: traverse the tree pre-order, and append its value to a string

  Null value should also be represented

  Example: [1,2,null,null,3 ...]

  Call “traverse” to do it recursively

- **Deserialize**: split the string into tokens

  read each token and re-build the tree by adding a new node

  Call “buildTree” to do it recursively

Code – 297. Serialize and Deserialize Binary Tree

Hard

LeetCode leetcode.com/problems/serialize-and-deserialize-binary-tree

Code

Time: O() Space: O()

```
string serialize(TreeNode* root) {
    // traverse the tree in pre-order: root, left, right
    // generate a string with comma separator,
    // example: 1,2,N,N,3 ...
    string result;
    traverse(root, result);
    return result;
}

TreeNode* deserialize(string data) {
    // split the input data
    vector<string> tokens = split(data);
    // index to be used to access the elements from tokens recursively.
    // Hence, we need to create it here to pass by reference.
    // Note that index is bounded by the number of tokens, so it won't overflow
    int index = 0;
    TreeNode* root = buildTree(tokens, index);
    return root;
}
```

continue...

Code – 297. Serialize and Deserialize Binary Tree

Hard

LeetCode leetcode.com/problems/serialize-and-deserialize-binary-tree

```
TreeNode* buildTree(vector<string>& tokens, int& index) {
        // read the current token based on the index
        const string& token = tokens[index];
        // increment index before checking for null
        ++index;
        // base case: null node
        if (token == "N") {
            return nullptr;
        }
        // build root
        TreeNode* node = new TreeNode(stoi(token));
        // build left
        node->left = buildTree(tokens, index);
        // build right
        node->right = buildTree(tokens, index);
        return node;
    }
```

```
// traverse in pre-order (root, left, right)
// and append the values to the string 's'
// append 'N' if it is NULL
void traverse(TreeNode* root, string& s) {
    if (!s.empty()) s += ",";
    // base case, we need to append null
    if (!root) {
        s += "N";
        return;
    }
    // visit root
    s += to_string(root->val);
    // visit left
    traverse(root->left, s);
    // visit right
    traverse(root->right, s);
}

// helper function in C++ to split string
vector<string> split(const string& s) {
    vector<string> result;
    stringstream ss(s);
    string token;
    while(getline(ss, token, ',')) {
        result.push_back(token);
    }
    return result;
}
```

Code – 297. Serialize and Deserialize Binary Tree

Hard

LeetCode leetcode.com/problems/serialize-and-deserialize-binary-tree

Some interesting alternative to split

- C++ 23 have an interesting way to split using std::views::split

```
vector<string> split(string s) {
    auto result = s |
        views::split(',') |
        views::transform([](auto&& subRange) {
                return string(subRange.start(), subRange.end());
                });
}
```

- To understand, this follow a structure similar to unix pipes:

  echo "123,N,556" | split | transform

- std::views::split returns ranges, something like:

  [range("123"), range("N"), range("556")]

- std::views::transform converts each subrange into an actual string

Problem – Kth Smallest Element in a BST

Medium

LeetCode leetcode.com/problems/kth-smallest-element-in-a-bst

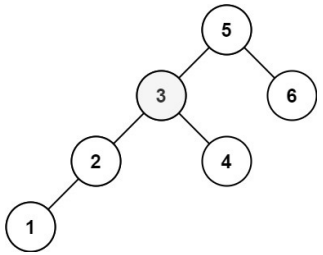
Problem Statement / Solution

- You are given the **root** of a binary search tree and an **integer k**
- Find the k^{th} smallest value
- **Example**

  From all values in the tree: 1,2,3,4,5,6

  k = 3 so find the 3^{th} smallest value

  Output is 3: 1,2,**3**,4,5,6 (3th)



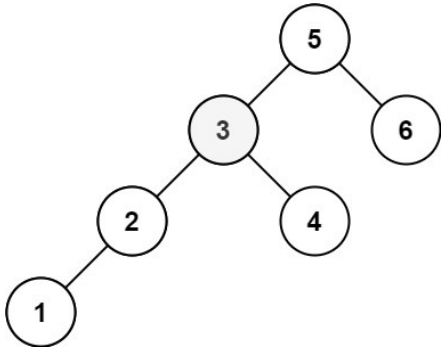
Solution – Kth Smallest Element in a BST

Medium

LeetCode leetcode.com/problems/kth-smallest-element-in-a-bst

Solution

- Note that the smallest element is in the left leaf
- Therefore, there is an order from small → big values from left → root → right
- Perform in-order traversal **k** times and stop in the desired node



Code – Kth Smallest Element in a BST

Medium

LeetCode leetcode.com/problems/kth-smallest-element-in-a-bst

Code

Time: **O(k)** Space: **O(h)** where **h** is the height of the tree

```
// in-order traversal: left, node: right
void traverse(TreeNode* node, int& k, int& result) {
    // base case
    if (!node) return;
    // visit left first
    traverse(node->left, k, result);
    // visit node
    k--;
    if (k == 0) {
        result = node->val;
        return;
    }
    // visit right
    traverse(node->right, k, result);
}

int kthSmallest(TreeNode* root, int k) {
    // perform pre-order traversal
    int result;
    traverse(root, k, result);
    return result;
}
```