

Algorithm and Problem Solving Quick Guide in C++

Data Structures, Algorithms and Coding Interview Problem Patterns in C++

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INTRODUCTION

Motivation

The tech industry hiring standard is based on algorithm and data structure.

There are plenty of free resources available around algorithms and data structures. The purpose of this project is to be a quick guide where you can learn and review algorithms and data structures.

Some of the intended **key features**:

- Non-verbose, short-structured, and easy to follow descriptions
- Slide-based, practical for reviewing
- Free and open-source

★ If you like, please add a star at github.com/rfdavid/cpp-algo-cheatsheet

How do I created and use this document?

Creating this document was a great exercise to learn and review data structures and algorithms. I encourage anyone to create its own notes

- Have sections based on the type of the problems (string, array, tree, dynamic programming)
- Start solving the problems randomly on Leetcode
- Create one slide for each question, including: problem, solution, code
- Write with your own words
- If you are not confident you have fully captured a problem, write the problem and leave the solution and code to another day when you redo it.

★ If you like, please add a star at ***github.com/rfdavid/cpp-algo-cheatsheet***

Some Useful Links

Tech Interview Handbook

<https://www.techinterviewhandbook.org>

A very well-structured resource for interview preparation

Blind 75 Leetcode Questions

<https://leetcode.com/discuss/general-discussion/460599/blind-75-leetcode-questions>

Common problems

- Blind 75 is a popular list of algorithm problems that intends to cover the main data structures and patterns.
- It is a curated list of 75 popular coding questions created by an ex-Meta Staff Engineer

Array

- ✓ [Two Sum](#)
- ✓ [Contains Duplicate](#)
- ✓ [Product of Array Except Self](#)
- ✓ [Best Time to Buy and Sell Stock](#)
- ✓ [Maximum Subarray](#)
- ✓ [Maximum Product Subarray](#)
- ✓ [Find Minimum in Rotated Sorted Array](#)
- ✓ [Search in Rotated Sorted Array](#)
- ✓ [3 Sum](#)
- ✓ [Container With Most Water](#)

Binary

- ✓ [Sum of Two Integers](#)
- ✓ [Number of 1 Bits](#)
- ✓ [Counting Bits](#)
- ✓ [Missing Number](#)
- ✓ [Reverse Bits](#)

Dynamic Programming

- ✓ [Climbing Stairs](#)
- [Coin Change](#)
- [Longest Increasing Subsequence](#)
- ✓ [Longest Common Subsequence](#)
- [Word Break](#)
- [Combination Sum](#)
- ✓ [House Robber](#)
- [House Robber II](#)
- [Decode Ways](#)
- ✓ [Unique Paths](#)
- [Jump Game](#)

Matrix

- ✓ [Set Matrix Zeroes](#)
- ✓ [Spiral Matrix](#)
- ✓ [Rotate Image](#)
- [Word Search](#)

Common Problems

Tree

- ✓ [Maximum Depth of Binary Tree](#)
- ✓ [Same Tree](#)
- ✓ [Invert/Flip Binary Tree](#)
- ✓ [Path Sum](#)
- ✓ [Binary Tree Level Order Traversal](#)
- ✓ [Serialize and Deserialize Binary Tree](#)
- ✓ [Subtree of Another Tree](#)
- ✓ [Construct Binary Tree from Preorder and Inorder Traversal](#)
- ✓ [Validate Binary Search Tree](#)
- ✓ [Kth Smallest Element in a Binary Search Tree](#)
- [Lowest Common Ancestor of Binary Search Tree](#)
- ✓ [Implement Trie \(Prefix Tree\)](#)
- [Add and Search Word](#)
- [Word Search II](#)
- [Balanced Binary Tree](#)

Heap

- ✓ [Top K Frequent Elements](#)
- [Find Median from Data Stream](#)

String

- ✓ [Longest Substring Without Repeating Characters](#)
- ✓ [Longest Repeating Character Replacement](#)
- ✓ [Minimum Window Substring](#)
- ✓ [Valid Anagram](#)
- ✓ [Group Anagrams](#)
- ✓ [Valid Parentheses](#)
- ✓ [Valid Palindrome](#)
- [Longest Palindromic Substring](#)
- [Palindromic Substrings](#)
- [Encode and Decode Strings](#) ★

Linked List

- ✓ [Reverse a Linked List](#)
- ✓ [Detect Cycle in a Linked List](#)
- ✓ [Merge Two Sorted Lists](#)
- ✓ [Merge K Sorted Lists](#)
- ✓ [Remove Nth Node From End Of List](#)
- ✓ [Reorder List](#)

Graph

- ✓ [Clone Graph](#)
- ✓ [Course Schedule](#)
- ✓ [Pacific Atlantic Water Flow](#)
- ✓ [Number of Islands](#)
- ✓ [Longest Consecutive Sequence](#)
- [Alien Dictionary](#) ★
- ✓ [Graph Valid Tree](#) ★
- ✓ [Number of Connected Components In an Undirected Graph](#) ★

Interval

- ✓ [Insert Interval](#)
- ✓ [Merge Intervals](#)
- ✓ [Non-overlapping Intervals](#)
- ✓ [Meeting Rooms](#) ★
- [Meeting Rooms II](#) ★

Other problems

- ✓ Maximum Level Sum of a Binary Tree
- ✓ Minimum Number of Increments on Subarrays to Form a Target Array
- ✓ Leaf-Similar Trees
- ✓ Count Good Nodes in Binary Tree
- Min Cost Climbing Stairs
- Longest Palindromic Subsequence
- ✓ Minimum Cost for Tickets
- ✓ Webcrawler
- ✓ Network Delay Time
- ✓ Rotated Digits
- ✓ Ransom Note
- ✓ String to Integer (atoi)
- ✓ Middle of the Linked List

Time Complexity

If the input gets bigger, how many steps does the algorithm take?

- Measure of how much the execution time of an algorithm grows relative to the size of its input (usually called n)
- Expressed in **Big-O notation** (e.g. $O(1)$, $O(n)$, $O(n^2)$, etc) to describe the **upper bound** of how fast the algorithm's runtime grows
- Asymptotic notations

Big-O (O) – Upper Bound (**Worst-case**): Describes the maximum amount of time/memory an algorithm could take.

Theta Θ – Tight Bound (**Exact**): describes both the **upper** and **lower bound** (the **exact** growth rate)

Omega (Ω) – Lower Bound (**Best-case**): describes the minimum time/space the algorithm needs.

Time Complexity

Examples

$O(1)$

Examples	Problems
Accessing an array element (<code>arr[i]</code>)	Hash table lookups
Swapping two variables	Checking if a number is even/odd
Stack/Queue <code>push</code> or <code>pop</code>	Returning first element of a list

$O(\log n)$

Binary Search	Search in sorted array
Balanced BST insert/find (AVL, Red-Black Tree)	Find k-th smallest in BST
Finding floor/ceil in sorted array	Finding square root with binary search

$O(n)$

Linear Search	Maximum subarray sum (Kadane's algo)
Finding min/max in an array	Counting frequencies with hash map
Traversing linked list or array	One-pass string processing problems

Time Complexity

$O(n \log n)$

Merge Sort / Heap Sort	Sorting an array
Efficient algorithms for Closest Pair	Finding inversion count in array
Heapify operations	Kth largest element with heap

$O(n^2)$

Bubble Sort / Insertion Sort	Two Sum (brute force)
Checking all pairs in array	Longest Palindromic Substring (DP)
Floyd-Warshall algorithm	Edit Distance (DP)

$O(n^3)$

Matrix multiplication (naive)	Boolean matrix multiplication
DP on subsequences of length 3	Some DP path-finding problems
Floyd-Warshall for dense graphs	Counting triangles in graph

$O(2^n)$

Recursive Fibonacci (no memo)	Subset sum (brute force)
Backtracking for combinations/permutations	N-Queens
Traveling Salesman (brute force)	All subsets of array (power set)

Time Complexity

$O(n!)$

Generating all permutations	Traveling Salesman (brute force)
Brute-force anagram check	Word ladder with all transformations
Solving puzzles with all arrangements	Hamiltonian Path

V = vertices (nodes)

E = edges

$O(V + E)$

DFS / BFS (adjacency list)	DFS / BFS (adjacency list)
----------------------------	----------------------------

$O(E \log V)$

Dijkstra with priority queue	Dijkstra with priority queue
------------------------------	------------------------------

$O(VE)$

Bellman-Ford

$O(V^3)$

Floyd-Warshall

$O(E \log E)$

Kruskal's MST algorithm

Space Complexity

As the input size n grows, how much extra memory does the algorithm need to run?

- Measure of how much memory an algorithm uses relative to **input size**
- Expressed in **Big-O notation** (e.g. $O(1)$, $O(n)$, $O(n^2)$, etc)
- It includes auxiliary space (extra memory used by the algorithm, not counting the input itself) and sometimes considers input space depending on the context
- Count only extra space needed (**exclude output**)
- The space complexity of a recursive tree traversal is **$O(h)$** , where h is the height of the tree. This is because each recursive call adds a frame to the call stack, and in the worst case, the maximum stack depth is proportional to the tree's height

Space Complexity

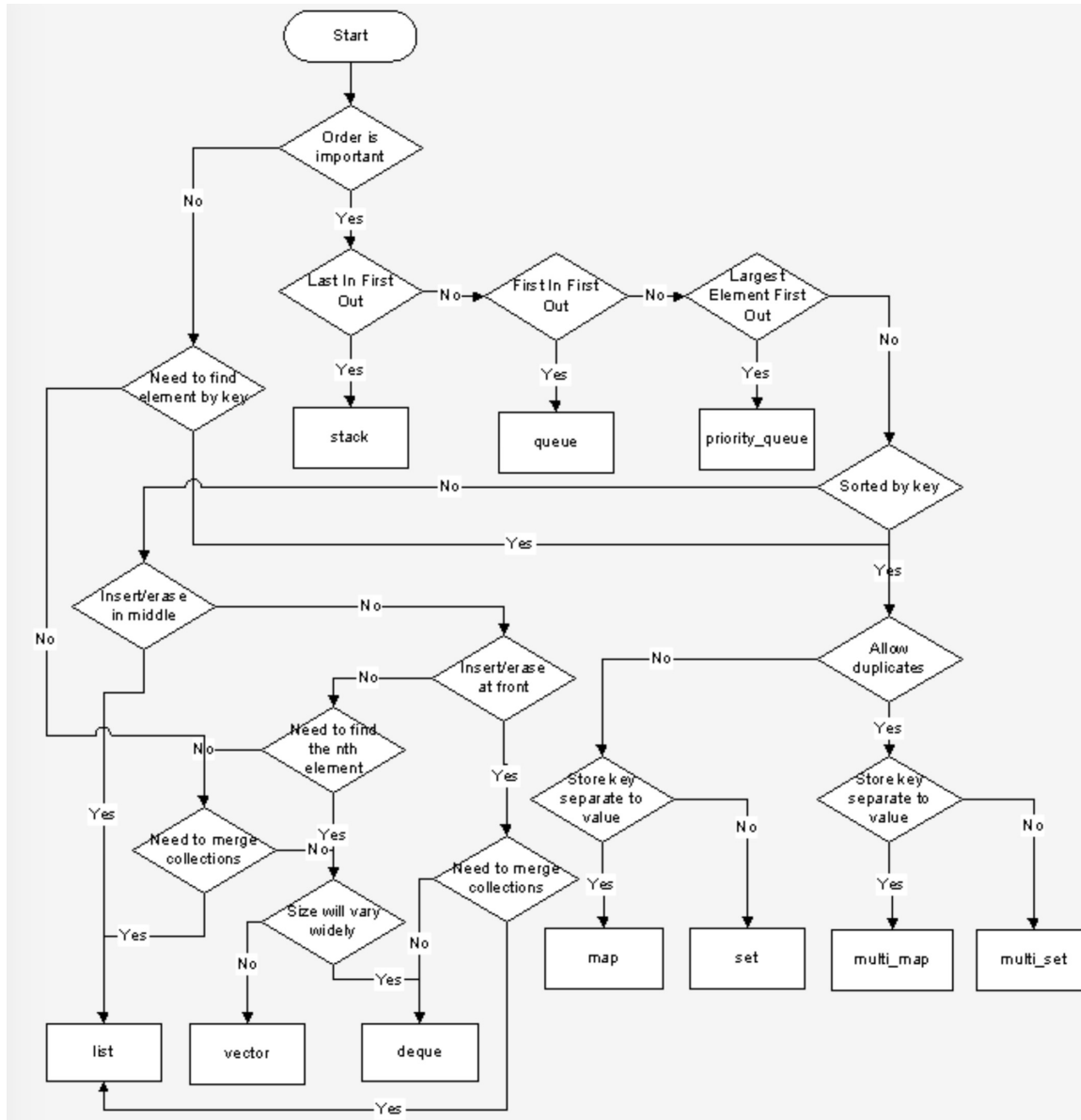
Examples

Algorithm / Operation	Space Complexity	Explanation
Swap two integers	$O(1)$	Only uses constant space
Iterate through array and sum values	$O(1)$	No extra memory used besides accumulator
Store array copy	$O(n)$	Needs space to store the copied array
Recursive factorial (factorial(n))	$O(n)$	n stack frames in the call stack
Binary search (recursive)	$O(\log n)$	Recursive depth is $\log(n)$ for sorted array
Binary search (iterative)	$O(1)$	No extra space beyond a few variables
Merge sort	$O(n)$	Needs temp arrays to merge subarrays
Quick sort (in-place)	$O(\log n)$	Call stack for recursive calls
Depth-first search (recursive) in tree	$O(h)$	h = height of the tree (stack frames)
Breadth-first search (using queue)	$O(n)$	Stores all nodes at current level in queue
DP with full 2D table (e.g., LCS)	$O(m*n)$	Stores results of all subproblems
Optimized Fibonacci with two variables	$O(1)$	Only tracks last two results
Memoized Fibonacci (top-down DP)	$O(n)$	Memoization table + recursion stack
Using a hash map to count frequencies	$O(n)$	Stores one count per element
Storing all substrings of a string	$O(n^2)$	Total number of substrings is $\sim n^2$
Adjacency list for graph with V nodes, E edges	$O(V + E)$	One list per node, total edges stored

DATA STRUCTURES IN C++

Data Structure Decision Diagram

- The following diagram gives you the direction to which data structure to use in C++ according to the problem you are trying to solve



Note: I don't have the source of this diagram. If you know it, please drop me a msg so I can add it here.

Arrays

- Fixed-size collection of elements of the same type
- Stored in **contiguous memory**
- Declared with syntax: **type arrayName[size]**

Example:

```
int numbers[5]
```

- Can also be initialized at declaration:

```
int arr[3] = {1 ,2, 3}
```

- Cannot resize after declaration
- Size can be calculated by **sizeof(arr) / sizeof(arr[0])**
- `stdlib` provides **std::array<type, size>**

▪ **Example:**

```
std::array<int, 3> a = {1, 2, 3};
```

Arrays (vectors)

- `std::vector` is a sequence container that encapsulates dynamic sized arrays*

Linked List

- desc

- desc

Queue

- desc

Heap

- desc

Hash Table

- desc

Tree

- desc

ARRAY

Arrays

- **Memory layout:** hold values in a **contiguous** block of memory.
- **Fixed Size:** the size of an array is defined when it is created and cannot be changed.
However, high-level languages have different implementations, making it dynamic.
- **Homogeneous elements:** all elements are of the same data type (int, float, char...)
- **Efficiency:** accessing elements by index is very efficient $O(1)$, since each index maps directly to a memory location. Also, range scans benefit from CPU cache lines since arrays are stored in contiguous blocks of memory.

Problem – 1. Two Sum

Easy



LeetCode

leetcode.com/problems/two-sum

Problem

- Given an **array** of numbers and a **target**, example: **array** [2,7,11,15] and **target** 9
- Return indices of two numbers where they add up to **target**
- **Output:** [0,1]

$\text{array}[0] + \text{array}[1] = 2 + 7 = 9$

Solution – 1. Two Sum

Easy



LeetCode

leetcode.com/problems/two-sum

Solution

- Iterative over each number in the array
- Calculate the difference between target and each number, example:
 $\text{array}[0] = 2, \text{ target } 9, \text{ then } 9 - 2 = 7$
- Now we know we need the number **7** to sum up to **9**
- Check in a *hashmap* if we have 7 in some part of the array
 $\text{hash}[7]$ exists?
- If yes, return the current index and the index of 7
- If not, store the index of the current number in the hashmap for future evaluation
 $\text{hash}[2] = 0$

Code – 1. Two Sum

Easy



LeetCode

leetcode.com/problems/two-sum

Code Time: $O(n)$ Space: $O(n)$

```
vector<int> twoSum(vector<int>& nums, int target) {
    std::unordered_map<int, int> numMap;
    // n being the size of nums
    for (int i = 0; i < nums.size(); i++) {
        // current number of the array
        int number = nums[i];
        int diff = target - number;

        // check if the difference is in some part of the array
        // by using a hashmap
        if (numMap.find(diff) != numMap.end()) {
            return { numMap[diff], i};
        }

        // register the current number index
        numMap[number] = i;
    }
    // no matches
    return {};
}
```

Problem – 217. Contains Duplicate

Easy



LeetCode

leetcode.com/problems/contains-duplicate

Problem

- You are given an array of numbers
- Return any value that appears at least twice

Solution

- Loop through the array
- Check if the value is in a hash table
- Return **true** if the value exist
- The problem requires at least twice, but one modification may be having a specific count

Code – 217. Contains Duplicate

Easy



LeetCode

leetcode.com/problems/contains-duplicate

Code Time: $O(n)$ Space: $O(n)$

```
bool containsDuplicate(vector<int>& nums) {
    unordered_map<int, int> seen;
    for (int i = 0; i < nums.size(); ++i) {
        if (seen[nums[i]] == 1) {
            return true;
        }
        seen[nums[i]]++;
    }
    return false;
}
```

Another solution (less flexible)

```
bool containsDuplicate(vector<int>& nums) {
    unordered_map<int, bool> seen;
    for (const auto& num : nums) {
        if (seen[num]) {
            return true;
        }
        seen[num] = true;
    }
    return false;
}
```

Problem – 238. Product of Array Except Self

Medium



LeetCode

leetcode.com/problems/product-of-array-except-self

Problem Statement

- You are given an integer array **nums**
- Return another array where each element is multiplied by all the elements except itself
- Example:

```
nums = [14,2,5,99]
```

```
nums[0] = 2 * 5 * 99 (all except 14)
```

```
nums[1] = 14 * 5 * 99 (all except 2)
```

```
nums[2] = 14 * 2 * 99
```

```
nums[3] = 14 * 2 * 5
```


Solution – 238. Product of Array Except Self

Medium



LeetCode

leetcode.com/problems/product-of-array-except-self

Solution

- Go over the array once and calculate the product of the left side. Example:

```
nums = [14,2,5]
```

```
left[0] = 1 (think of multiplying all elements before 14, so 1 because there is none)
```

```
left[1] = 14 (all elements from the left multiplied, except 2)
```

```
left[2] = 14 * 2 = 28 (all elements from the left multiplied, except 5)
```

```
left = [1, 14, 28]
```

- Using the same logic, do the same calculation but starting from the right

```
right[2] = 1 (no elements after 5)
```

```
right[1] = 5 (only 5 after 2)
```

```
right[0] = 2 * 5 = 10
```

```
right = [10, 5, 1]
```

- Multiply each element from left and right:

```
left ⊙ right = [1, 14, 28] ⊙ [10,5,1] = [10, 70, 28]
```

Code – 238. Product of Array Except Self

Medium



LeetCode

leetcode.com/problems/product-of-array-except-self

Code Time: $O(n)$ Space: $O(n)$

```
vector<int> productExceptSelf(vector<int>& nums) {
    int n = nums.size();
    vector<int> output(n, 1);
    vector<int> right(n, 1);

    // calculate left first
    for (int i = 1; i < n; ++i) {
        output[i] = nums[i - 1] * output[i - 1];
    }
    // calculate right
    for (int i = n - 1; i >= 0; --i) {
        right[i] = nums[i + 1] * right[i + 1];
        output[i] = output[i] * right[i];
    }

    /* or you can save some space using this logic,
       although I don't find it as intuitive as the previous one
    int right = 1;
    for (int i = n - 1; i >= 0; --i) {
        output[i] *= right;
        right *= nums[i];
    }
    */

    return output;
}
```

Problem – 53. Maximum Subarray

Medium



LeetCode

leetcode.com/problems/maximum-subarray

Problem

- You are given an array `nums`
- Find the subarray with the largest sum

- **Example:**

`nums = [-2,1,-3,4,-1,2,1,-5,4]`

`output = 6`

The subarray `[4,-1,2,1]` has the largest sum 6.

Problem – 53. Maximum Subarray

Medium



LeetCode

leetcode.com/problems/maximum-subarray

Solution

- Use Kadane's algorithm to find the maximum sum of a contiguous subarray in linear time
- Core idea:
at each index, either:
 1. start a new subarray at **nums[i]** or
 2. extend the current one by adding **nums[i]**

Arrays – Kadane's algorithm

- Kadane's algorithm is a dynamic programming algorithm to solve **maximum subarray sum**
- At every **index i**:
start a new subarray at **i**
extend the previous subarray to include **array[i]**

- **Algorithm**

1. Initialize:

```
int maxSoFar = array[0];  
int maxEndingHere = array[0];
```

2. Loop through the array

```
for (int i = 1; i < array.size(); ++i) {  
    maxEndingHere = max(array[i], maxEndingHere + array[i]);  
    maxSoFar = max(maxSoFar, maxEndingHere);  
}
```

3. Return maxSoFar;

Problem – 53. Maximum Subarray

Medium



LeetCode

leetcode.com/problems/maximum-subarray

Code Time: $O(n)$ Space: $O(1)$

```
int maxSubArray(vector<int>& nums) {  
    int maxSum = nums[0];  
    int currentSum = nums[0];  
    for (int i = 1; i < nums.size(); ++i) {  
        currentSum = max(nums[i], currentSum + nums[i]);  
        maxSum = max(maxSum, currentSum);  
    }  
    return maxSum;  
}
```

Problem – 152. Maximum Product Subarray

Medium



LeetCode

leetcode.com/problems/maximum-product-subarray

Problem

- You are given an array **nums**
- Find a subarray that has the largest product and return the product
- The array may contain negative numbers

- **Example:**

`nums = [2, 3, -2, 4]`

`output = 6`

`[2,3]` has the largest 6 ($2 * 3$)

Problem – 152. Maximum Product Subarray

Medium



LeetCode

leetcode.com/problems/maximum-product-subarray

Solution

- Use a modified version of Kadane's algorithm
- Keep track of the minimum and maximum product
- Once the current number is negative, swap minimum product with maximum product
- Check the largest product between maximum product and the final result

Problem – 152. Maximum Product Subarray

Medium



LeetCode

leetcode.com/problems/maximum-product-subarray

Code Time: $O(n)$ Space: $O(1)$

```
int maxProduct(vector<int>& nums) {
    int result = nums[0];
    int maxProd = nums[0];
    int minProd = nums[0];
    for (int i = 1; i < nums.size(); ++i) {
        if (nums[i] < 0) {
            swap(minProd, maxProd);
        }

        minProd = min(nums[i], nums[i] * minProd); // -2
        maxProd = max(nums[i], nums[i] * maxProd); // -30

        result = max(result, maxProd);
    }
    return result;
}
```

Problem – 153. Find Minimum in Rotated Sorted Array

Medium



LeetCode

leetcode.com/problems/find-minimum-in-rotated-sorted-array

Problem

- You are given a sorted array but “rotated”
- Rotated means the elements are displaced in order
- Return the **minimum element**

- **Example:**

nums = [3,4,5,1,2]

output = 1 (minimum element)

Solution – 153. Find Minimum in Rotated Sorted Array

Medium

 leetcode.com/problems/find-minimum-in-rotated-sorted-array

Solution

- Perform an adapted binary search
- Example:

[3,4,5,1,2]

left = 3, mid = 5, right = 2

You find mid (5), but have to go right, so adjust left:

```
if (mid > right)
```

```
    left = mid + 1
```

```
else
```

```
    right = mid
```

Code – 153. Find Minimum in Rotated Sorted Array

Medium



LeetCode

leetcode.com/problems/find-minimum-in-rotated-sorted-array

Code Time: **$O(\log n)$** Space: **$O(1)$**

```
int findMin(vector<int>& nums) {
    int left = 0;
    int right = nums.size() - 1;
    while (left < right) {
        int mid = left + (right - left) / 2;
        if (nums[mid] > nums[right]) {
            left = mid + 1;
        } else {
            right = mid;
        }
    }
    return nums[left];
}
```

Problem - Best Time to Buy and Sell Stock

Easy



LeetCode

leetcode.com/problems/best-time-to-buy-and-sell-stock

Problem Statement

- You are given an integer **array** of stock prices
- Choose a **price[i]** to buy and **price[i]** to sell where you achieve maximum profits

- **Example:**

`prices = [9, 1, 3, 4]`

- **Output:** [1,3]

`array[3] - array[1] = 4 - 1 = 3`

Solution - Best Time to Buy and Sell Stock

Easy



LeetCode

leetcode.com/problems/best-time-to-buy-and-sell-stock

Solution

- Initialize **profit = 0**
- Initialize **lowestBuyPrice = prices[0]**
- Loop through the prices
- Track the lowest buy price → **min(lowestBuyPrice, prices[i])**
- Check if selling “today” will make the maximum profit and update profit:
max(prices[i] - buy > profit, profit)
- Update profit
max(prices[i] - buy

Code - Best Time to Buy and Sell Stock

Easy



LeetCode

leetcode.com/problems/best-time-to-buy-and-sell-stock

Code (simplified) Time: $O(n)$ Space: $O(1)$

```
int maxProfit(vector<int>& prices) {  
    int profit = 0;  
    int buy = prices[0];  
    for (auto i = 1; i < prices.size(); i++) {  
        buy = min(buy, prices[i]);  
        profit = max(profit, prices[i] - buy)  
    }  
    return profit;  
}
```

Code - Best Time to Buy and Sell Stock

Easy



LeetCode

leetcode.com/problems/best-time-to-buy-and-sell-stock

Code (optimized) Time: $O(n)$ Space: $O(1)$

- Same logic, but with better branch prediction and less computation

```
int maxProfit(vector<int>& prices) {
    int profit = 0;
    int buy = prices[0];
    for (auto i = 1; i < prices.size(); i++) {
        if (prices[i] < buy) {
            buy = prices[i];
        } else if (prices[i] - buy > profit) {
            profit = prices[i] - buy;
        }
    }
    return profit;
}
```


Problem - Best Time to Buy and Sell Stock II

Medium



LeetCode

leetcode.com/problems/best-time-to-buy-and-sell-stock-ii

Problem

- You are given an integer **array** of stock prices
- Choose a **price[i]** to buy and **price[i]** to sell where you achieve maximum profits
- You can buy/sell **multiple times**, but only hold **at most one** transaction at a time
- Output is the **maximum profits**
- **Example:**

`prices = [9, 1, 3, 4]`

Output: $2 + 1 = 3$

`buy (price = 1), sell (price = 3), profit = 2`

`buy (price = 3), sell (price = 4), profit = 1`

Solution - Best Time to Buy and Sell Stock II

Medium

 LeetCode leetcode.com/problems/best-time-to-buy-and-sell-stock-ii

Solution

- Loop through the array starting from index 1
- If current **price[i]** is lower than previous **price[i - 1]**, buy and sell

- **Example:**

`prices = [1, 8, 4]` `prices[0] = 1, prices[1] = 8, prices[2] = 4`

`prices[0] < prices[1] → true, profit = 8 - 1 = 7`

`prices[2] < prices[1] → false, do nothing`

Code - Best Time to Buy and Sell Stock II

Medium



LeetCode

leetcode.com/problems/best-time-to-buy-and-sell-stock-ii

Code Time: $O(n)$ Space: $O(1)$

```
int maxProfit(vector<int>& prices) {  
    int profit = 0;  
    for (int i = 1; i < prices.size(); ++i) {  
        if (prices[i] > prices[i-1]) {  
            profit += prices[i] - prices[i - 1];  
        }  
    }  
    return profit;  
}
```

Problem - Best Time to Buy and Sell Stock IV

Hard

 leetcode.com/problems/best-time-to-buy-and-sell-stock-iv

Problem Statement

■ ...

Solution - Best Time to Buy and Sell Stock IV

Hard

 leetcode.com/problems/best-time-to-buy-and-sell-stock-iv

Solution

■ ...

Code - Best Time to Buy and Sell Stock IV

Hard

 leetcode.com/problems/best-time-to-buy-and-sell-stock-iv

Code (simplified) Time: $O(n)$ Space: $O(n)$

```
int maxProfit(vector<int>& prices) {  
    int profit = 0;  
    int buy = prices[0];  
    for (auto i = 1; i < prices.size(); i++) {  
        buy = min(buy, prices[i]);  
        profit = max(profit, prices[i] - buy)  
    }  
    return profit;  
}
```

Problem – 33. Search in Rotated Sorted Array

Medium



LeetCode

leetcode.com/problems/search-in-rotated-sorted-array

Problem

- Variation of *Find Minimum in Sorted Rotated Array* problem
- You are given a sorted **array** but “rotated” and a target number **n**
- Rotated means the elements are displaced in order
- Search the number **n** and return its index

- **Example**

`nums = [4,5,6,7,0,1,2], target = 0`

Output: 4

4 is the index where the target number **0** is located

Problem – 33. Search in Rotated Sorted Array

Medium



LeetCode

leetcode.com/problems/search-in-rotated-sorted-array

Solution

- Perform a binary search with some modification
- One side is always sorted, so find which side (left or right)
- Check if the target is in the range of the sorted side and adjust mid

Example:

[2,4,5,6,7,0,1] target = 0

1. Find mid (6)
2. Find the sorted side (left) = [2,4,5]
3. Check if your target is in this side. Is **target** between 2 and 5?
4. Adjust mid to search at the other side if not, otherwise continue searching at the same side

Problem – 33. Search in Rotated Sorted Array

Medium



LeetCode

leetcode.com/problems/search-in-rotated-sorted-array

Code Time: $O(\log n)$ Space: $O(1)$

```
int search(vector<int>& nums, int target) {
    int left = 0;
    int right = nums.size() - 1;

    while (left <= right) {
        int mid = left + (right - left) / 2;
        if (nums[mid] == target) return mid;

        // figure it out the sorted side
        if (nums[mid] >= nums[0]) {
            // left side is sorted
            // is target within this range?
            if (target >= nums[0] && target < nums[mid]) {
                right = mid - 1;
            } else {
                left = mid + 1;
            }
        } else {
            // right side is sorted
            // is target within this range?
            if (target <= nums[right] && target > nums[mid]) {
                left = mid + 1;
            } else {
                right = mid - 1;
            }
        }
    }
    return -1;
}
```

Problem – 15. 3Sum

Medium



LeetCode

leetcode.com/problems/3sum

Problem

- You are given an array of integer **nums**
- Find distinct triples that the final sum is equal to zero
- **Example:**

`nums = [-1,0,1,2,-1,-4]`

Output:

`[[-1,-1,2],[-1,0,1]]`

Explanation:

$\text{nums}[0] + \text{nums}[1] + \text{nums}[2] = (-1) + 0 + 1 = 0.$

$\text{nums}[1] + \text{nums}[2] + \text{nums}[4] = 0 + 1 + (-1) = 0.$

$\text{nums}[0] + \text{nums}[3] + \text{nums}[4] = (-1) + 2 + (-1) = 0.$

The distinct triplets are `[-1,0,1]` and `[-1,-1,2]`.

Problem – 15. 3Sum

Medium



LeetCode

leetcode.com/problems/3sum

Solution

- Use three pointers: **i**, **j** and **k**
- Sort the array. This is necessary to move the pointers **j** and **k**
- Pointer **i** starts at the beginning the array
- Pointer **j** starts at $i + 1$ (second position)
- Pointer **k** starts at the end of the array
- Pointer **i** always move forward until the end of the array
- For each value of **i**, **j** and **k** will move either forward or backward, depending on the results of the sum
- Once find a sum $== 0$, add to a set to guarantee no duplicates

Problem – 15. 3Sum

Medium



LeetCode

leetcode.com/problems/3sum

Code Time: $O(n^2 \log n)$ Space: $O(n^2)$

```
vector<vector<int>> threeSum(vector<int>& nums) {
    set<vector<int>> triplets;
    sort(nums.begin(), nums.end());
    for (int i = 0; i < nums.size() - 2; ++i) {
        int j = i + 1;
        int k = nums.size() - 1;
        // it is a solution
        while (j < k) {
            int sum = nums[i] + nums[j] + nums[k];
            if (sum == 0) {
                triplets.insert({nums[i], nums[j], nums[k]});
                j++;
                k--;
            }
            if (sum < 0) {
                j++;
            } else {
                k--;
            }
        }
    }
    vector<vector<int>> result;
    // convert the solutions to the expected return
    for (const auto& t : triplets) {
        result.push_back(t);
    }

    return result;
}
```

Problem – 11. Container With Most Water

Medium



LeetCode

leetcode.com/problems/container-with-most-water

Problem Statement

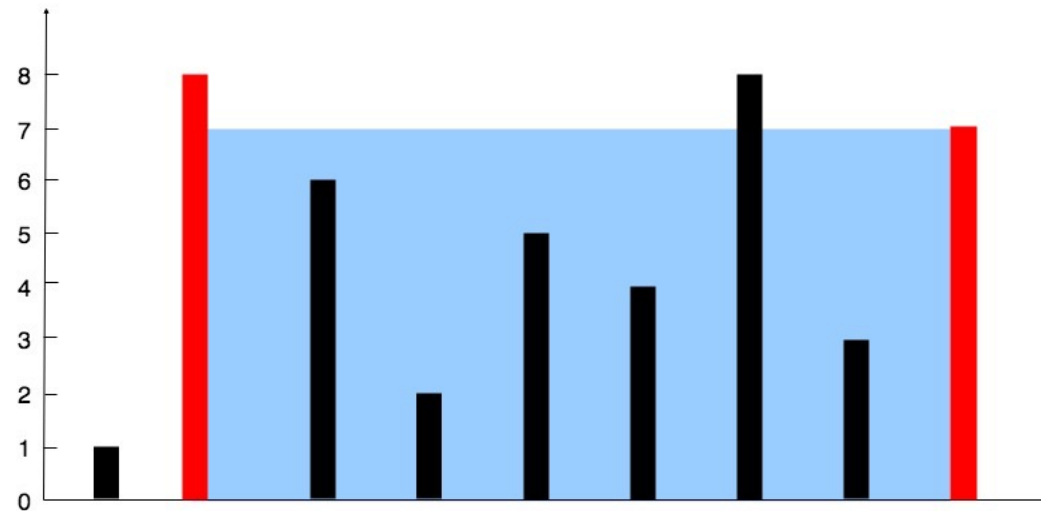
- You are given an integer array **height**
- Find two lines that together with x-axis form a container with most water
- Example:

Input:

height = [1,8,6,2,5,4,8,3,7]

Output:

49



Solution – Container With Most Water

Medium



LeetCode

leetcode.com/problems/container-with-most-water

Solution

- Initialize the maximum area **maxArea = 0**
- Initialize two pointers, **left = 0** and **right = height.size - 1**
- Loop while pointer **left < right**
- Calculate the area:
area = min(height[left], height[right]) * (right - left)
- Update the global maximum area:
maxArea = max(maxArea, area)
- Move the smallest pointer (increment **left** or decrement **right**)
- Return **maxArea**

Problem – 11. Container With Most Water

Medium



LeetCode

leetcode.com/problems/container-with-most-water

Code Time: **O(n)** Space: **O(1)**

```
int maxArea(vector<int>& height) {  
    // left and right = positions  
    int left = 0;  
    int right = height.size() - 1;  
    int maxArea = 0;  
    while (left < right) {  
        int area = min(height[left], height[right]) * (right - left);  
        maxArea = max(maxArea, area);  
        // adjust left and right based on 'greedy' algorithm  
        // move from the lowest height  
        if (height[left] < height[right]) {  
            left++;  
        } else {  
            right--;  
        }  
    }  
    return maxArea;  
}
```

STRING

Problem – 3. Longest Substring Without Repeating Characters

Medium



LeetCode

leetcode.com/problems/longest-substring-without-repeating-characters

Problem Statement

- You are given a string and the goal is to find the longest substring without repeating characters

- **Example**

Input: "abcbd"

Output: 4 (abcd since "b" is repeated)

Solution – 3. Longest Substring Without Repeating Characters

Medium



LeetCode

leetcode.com/problems/longest-substring-without-repeating-characters

Solution

- Use sliding window algorithm (left and right)
- Loop through the string
- Try to find if the current character is already added by using unordered set or bitmap
- If added, remove from the set alongside with others using left pointer
- If not, add to the unordered set or bitmap
- Maximum length will be $\text{right} - \text{left} + 1$

Example – 3. Longest Substring Without Repeating Characters

Medium



LeetCode

leetcode.com/problems/longest-substring-without-repeating-characters

Example

- String: abcbd. Our goal is to return 3 (**abc**bd)
- Initialize **maxLength = 0**
- Loop through the string

Iteration 1: left = 0, right = 0, string[left] = 'a',

bitmap = ['a'] ('a' is not in bitmap, add), **maxLength = max(maxLength, right - left + 1) = 1**

Iteration 2: left = 0, right = 1, string[right] = 'b'

bitmap = ['a','b'], **maxLength = 2**

Iteration 3: left = 0, right = 2, string[right] = 'c'

bitmap = ['a','b','c'], **maxLength = 3**

Iteration 4: left = 0, right = 3, string[right] = 'b'

bitmap = ['a','b','c','b']

'b' is already in the bitmap. start "clearing" the character using left:

Iteration 4a: left = 0, string[left] = 'a' is different from 'b', so remove 'a'

bitmap = ['b','c','b']

Iteration 4b: left = 1, string[left] = 'b' is the same as the repeated one, remove

bitmap = ['c','b']

Iteration 5: left = 1, right = 4, string[right] = 'd'

bitmap = ['c','b','d']

Code – 3. Longest Substring Without Repeating Characters

Medium

Code (unordered_set)

- Use unordered_set when question requires unicode chars

```
int lengthOfLongestSubstring(string s) {  
    int maxLength = 0;  
    int left = 0, right = 0;  
    // track the seen characters  
    unordered_set<char> seen;  
    for (right = 0; right < s.size(); ++right) {  
        char currentChar = s[right];  
        // if currentChar is in the set, clean  
        // the character and everything from left of it  
        // basically, reset the longest substring  
        while (seen.count(currentChar)) {  
            char c = s[left];  
            seen.erase(c);  
            left++;  
        }  
        // insert the current read character  
        seen.insert(currentChar);  
        // set max length  
        maxLength = max(maxLength, right - left + 1);  
    }  
    return maxLength;  
}
```

Code – 3. Longest Substring Without Repeating Characters

Medium

Code (bitmap)

- Using bitset: create a bitmask with 128 bits where each bit represent a character
- Optimal solution for ASCII since ASCII size is 127 characters
- Unicode / UTF-8 can represent over 1.1 million characters, so use **unordered_set** approach instead

```
int lengthOfLongestSubstring(string s) {
    std::bitset<128> bitmask;
    uint32_t left = 0;
    uint32_t maxLength = 0;

    for (uint32_t right = 0; right < s.length(); ++right) {
        uint32_t bitIndex = s[right];
        // if char is already in the bitmask, move left until we reset the bits
        while (bitmask.test(bitIndex)) {
            bitmask.reset(s[left]);
            ++left;
        }

        bitmask.set(bitIndex);
        maxLength = std::max(maxLength, right - left + 1);
    }
    return maxLength;
}
```

Problem – 424. Longest Repeating Character Replacement

Medium

 leetcode.com/problems/longest-repeating-character-replacement

Problem

- You are given a **string s** and an **integer k**
- You can replace one character by any other uppercase English character **k** times
- Return the longest substring with the same character

- **Example:**

Input:

`s = "ABAB", k = 2`

Output: 4

Replace the two 'A's with two 'B's or vice versa.

Problem – 424. Longest Repeating Character Replacement

Medium

 leetcode.com/problems/longest-repeating-character-replacement

Solution

- Start with two pointers: left and right
- Keep track of the frequencies of each letter in a **vector<int>** since we know there are 26 characters
- Initialize **maxFreq** to keep track of the letter with maximum frequency
- Initialize **maxLength** to keep track of the maximum substring
- Go over the string, and for each iteration:
 - calculate the windowSize
 - calculate the maximum frequency
 - check how many replacements is needed. That is, $\text{windowSize} - \text{maxFreq}$
 - if no replace can be done ($k < \text{replaces}$) then move left pointer to the right

Problem – 424. Longest Repeating Character Replacement

Medium

 leetcode.com/problems/longest-repeating-character-replacement

Code Time: $O(n)$ Space: $O(1)$

```
int characterReplacement(string s, int k) {
    int left = 0;
    int maxLength = 0;
    int maxFreq = 0;
    vector<int> freq(26, 0);
    for (int right = 0; right < s.size(); ++right) {
        int index = s[right] - 'A';
        int windowSize = right - left + 1;
        // keep track of the frequencies
        freq[index]++;
        maxFreq = max(maxFreq, freq[index]);

        // check if the subwindow need to change
        int needReplace = windowSize - maxFreq;
        if (k < needReplace) {
            // need to move sub window
            int leftIndex = s[left] - 'A';
            freq[leftIndex]--;
            left++;
            windowSize = right - left + 1;
        }
        maxLength = max(maxLength, windowSize);
    }
    return maxLength;
}
```


Problem – 76. Maximum Window Substring

Hard

 leetcode.com/problems/minimum-window-substring

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 242. Valid Anagram

Easy



LeetCode

leetcode.com/problems/valid-anagram

Problem

- You are given two strings **s** and **t**
- Return true if **t** is an anagram of **s**

- **Example:**

t = word

s = dwor

Output: true

both have the same number of same characters

Problem – 242. Valid Anagram

Easy



LeetCode

leetcode.com/problems/valid-anagram

Solution

- Initialize a vector of integers to keep track of the count of each letter
- Loop over **s** and increase the count of each character found
- Then, loop over **t** and decrease the count of each character found
- Finally, loop over the vector and if there is one count greater than 0, return false

Problem – 242. Valid Anagram

Easy



LeetCode

leetcode.com/problems/valid-anagram

Code Time: **$O(n)$** Space: **$O(1)$**

```
bool isAnagram(string s, string t) {  
    // count the number of characters in 's', store in a vector  
    // go over the vector and check if it's empty  
    vector<int> letters(26);  
    for (const auto& c : s) {  
        letters[c - 'a']++;  
    }  
    for (const auto& c : t) {  
        letters[c - 'a']--;  
    }  
    for (const auto& c : letters) {  
        if (c != 0) return false;  
    }  
    return true;  
}
```

Problem – 49. Group Anagrams

Medium



LeetCode

leetcode.com/problems/group-anagrams

Problem

- You are given an array of strings, Example:
`strs = ["eat", "tea", "tan", "ate", "nat", "bat"]`
- Group the anagrams together:
`[["bat"], ["nat", "tan"], ["ate", "eat", "tea"]]`
- No anagram of "bat", where "nat" and "tan" are anagram so they're grouped together

Solution – 49. Group Anagrams

Medium



LeetCode

leetcode.com/problems/group-anagrams

Solution

- Go over each word
- Sort the words

Example: ["eat", "tea", "tan", "ate", "nat", "bat"]

After sorting: ["aet", "aet", "ant", "aet", "ant", "abt"]

- Add the words in their respective buckets using a hashtable `unordered_map<string, vector<string>>`
hash["aet"] = "eat", "tea", "ate"
hash["ant"] = "tan", "nat"
hash["abt"] = "bat"
- Go over the bucket and add to the results

Code – 49. Group Anagrams

Medium



LeetCode

leetcode.com/problems/group-anagrams

Code Time: $O(n * k \log k)$ Space: $O(n * k)$ where n is the number of strings in `strs` and k is the maximum length of a string in `strs`

```
vector<vector<string>> groupAnagrams(vector<string>& strs) {
    // go over the strs
    // sort each of them, store it
    // ["eat","tea","tan","ate","nat","bat"]
    // ["aet","aet","ant","aet","ant","abt"]
    // hash["aet"] = ["eat","tea","ate"]
    unordered_map<string, vector<string>> hash;
    for (const auto& s : strs) {
        string key = s;
        sort(key.begin(), key.end());
        hash[key].push_back(s);
    }
    // go over this hash map and push to the final output
    vector<vector<string>> result;
    for (const auto& [k, v] : hash) {
        result.push_back(v);
    }
    return result;
}
```

Problem – Valid Parentheses

Easy



LeetCode

leetcode.com/problems/valid-parentheses

Problem Statement

- You are given a string containing only the characters '(', ')', '{', '}', '[' and ']'
- A valid input have closed brackets by its own type

- **Example**

`()[]{} → valid`

`[]{}(→ invalid`

`{()} → valid`

Solution – Valid Parentheses

Easy



LeetCode

leetcode.com/problems/valid-parentheses

Solution

- Loop through the string
- If **open** brackets (**{** push to a stack
- If **closed** brackets:
 - **pop** the last added bracket
 - **check** if the **closed** bracket corresponds to the **popped** bracket
 - if not, return false
- after the loop, **return true** if the **size** of the stack is empty (all brackets closed)

Code – Valid Parentheses

Easy



LeetCode

leetcode.com/problems/valid-parentheses

Code Time: $O(n)$ Space: $O(n)$

```
bool isValid(string s) {  
    // stack (LIFO)  
    std::stack<char> brackets;  
    // O(n)  
    for (int i = 0; i < s.size(); ++i) {  
        char bracket = s[i];  
        if (bracket == '(' || bracket == '[' || bracket == '{') {  
            brackets.push(bracket);  
        } else {  
            if (brackets.size() == 0) return false;  
            char lastBracket = brackets.top();  
            if (bracket == ')' && lastBracket != '(') return false;  
            if (bracket == '}' && lastBracket != '{') return false;  
            if (bracket == ']' && lastBracket != '[') return false;  
            brackets.pop();  
        }  
    }  
    // all brackets must be closed  
    return brackets.size() == 0;  
}
```

Problem – 125. Valid Palindrome

Easy

 leetcode.com/problems/valid-palindrome

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – Minimum Number of Increments on Subarrays

Hard



LeetCode

leetcode.com/problems/minimum-number-of-increments-on-subarrays-to-form-a-target-array

Problem Statement

- You are given an array of integers initialized with zeros (e.g. **[0,0,0,0]**)
- The goal is to reach some target (e.g. **[1, 2, 2, 3]**)
- The valid operations is to increment a subarray by one
- The output is the total number of operations

In this case:

[1,1,1,1] → increment the subarray starting from 0 to total size

[1,2,2,2] → increment the subarray starting from 1 to total size

[1,2,2,3] → increment the subarray starting and ending from the last element

Output: 3 (total number of operations)

Solution – Minimum Number of Increments on Subarrays

Hard



LeetCode

leetcode.com/problems/minimum-number-of-increments-on-subarrays-to-form-a-target-array

Solution

- Take this example:

`target = [1000, 1, 1000]`

- Initialize total number of operations `totalOp = target[0] = 1000`
- Loop through the array, compare the first element with the previous:
 - `target[1] > target[0] → 1 > 1000` → do nothing, `totalOp` is still 1000
- `target[2] > target[1] → 1000 > 1` → add the difference to `totalOp`:
 - `difference = 1000 - 1 = 999`
 - `totalOp = 1000 + 999 = 1999`
- This is the number of operations needed, equivalent to:
 - add 1 to each element: `[1,1,1]`
 - add 999 to the subarray `[0,0]`
 - add 999 to the subarray `[2,2]`

Code – Minimum Number of Increments on Subarrays

Hard



LeetCode

leetcode.com/problems/minimum-number-of-increments-on-subarrays-to-form-a-target-array

Code

```
int minNumberOperations(vector<int>& target) {  
    int totalOp = target[0];  
    for (int i = 1; i < target.size(); ++i) {  
        // can't reuse  
        if (target[i - 1] < target[i]) {  
            totalOp += target[i] - target[i - 1];  
        }  
    }  
    return totalOp;  
}
```

Code [2] – Minimum Number of Increments on Subarrays

Hard



LeetCode

leetcode.com/problems/minimum-number-of-increments-on-subarrays-to-form-a-target-array

Code (optimized)

```
int minNumberOperations(vector<int>& target) {  
    return target[0] +  
        inner_product(target.begin() + 1, target.end(),  
            target.begin(), 0,  
            plus<int>(),  
            [](int curr, int prev) { return max(curr - prev, 0); });  
}
```

Problem – 788. Rotated Digits

Medium



LeetCode

leetcode.com/problems/rotated-digits

Problem

- You are given a number **n**
- From the range between 1 to n, find “good” numbers
- A good number must meet **2 requirements**:
 - 1.** Be still valid after flipping: You physically “rotate” this number by 180 degrees, flip the number upside-down. The number can be either valid or invalid. For example, flipping **8** is still **8**, flipping **6** becomes **9**, but flipping **3**, becomes **ε** which is invalid.
 - 2.** Be a different digit after flipping. If you flip **1**, it is still a valid number but it is the same number (1), so it is not good. However, **16** is valid because it becomes a different number: **19**
- Return the number of good numbers between **1** and **n**

Problem – 788. Rotated Digits

Medium



LeetCode

leetcode.com/problems/rotated-digits

Solution

- The simplest and readable approach:
- Create a function to check if a number is good or not
- Go over the range (1,n) and check every number. If it is good, count as a valid
- Inside the function to check:
- Extract digit by digit from the number ($\text{digit} = \text{num} \% 10$)
- Check if the digit is valid (a.k.a “flippable”). In other words, return false if it is 3, 4 or 7.
- Now check the second condition (same number). So keep a bool “changed”, if you find a number that “changes”, mark changed as true. The numbers are 2, 5, 6 and 9, since when they flip they become different numbers
- Return “changed”

Problem – 788. Rotated Digits

Medium



LeetCode

leetcode.com/problems/rotated-digits

Code Time: $O(n \log n)$ Space: $O(1)$

For each number, we examine each of its digits:

- A number i has $\log_{10}(i)$ digits \rightarrow in worst case: $O(\log n)$ per number

```
int rotatedDigits(int n) {
    int count = 0;
    for (int i = 1; i <= n; ++i) {
        if (isGood(i)) count++;
    }
    return count;
}

bool isGood(int num) {
    bool changed = false;
    while (num > 0) {
        int digit = num % 10;
        if (digit == 3 || digit == 4 || digit == 7) return false;
        if (digit == 2 || digit == 5 || digit == 6 || digit == 9)
            changed = true;
        num /= 10;
    }
    return changed;
}
```

Problem – 383. Ransom Note

Easy



LeetCode

leetcode.com/problems/ransom-note

Problem

- You are given two strings: **magazine** and **ransomNote**
- Return true if **ransomNote** can be constructed by using letters from **magazine**
- A letter **cannot** be reused

- **Example:**

ransomNote = "aa", magazine = "ab"

Output: false (a letter from magazine cannot be used twice)

ransomNote = "aa", magazine = "aab"

Output: true

Solution – 383. Ransom Note

Easy



LeetCode

leetcode.com/problems/ransom-note

Solution

- Initialize an array with 26 characters (total letters in the English alphabet)
- Go over **magazine** string and count each character
- Go over **ransomNote** string and decrease each character
- If you get a negative number, return false

Code – 383. Ransom Note

Easy



LeetCode

leetcode.com/problems/ransom-note

Code

Time: $O(n + m)$ Space: $O(k)$ where n is the length of **magazine** and m the length of **ransomNote**, and k is the number of unique characters in magazine

```
bool canConstruct(string ransomNote, string magazine) {
    int count[26] = {0};
    for (const char& c : magazine) {
        count[c - 'a']++;
    }
    for (const char& c : ransomNote) {
        if (--count[c - 'a'] < 0) return false;
    }
    return true;
}
```

Problem – 8. String to Integer (atoi)

Medium



LeetCode

leetcode.com/problems/string-to-integer-atoi

Problem

- You are given a string **s**
- Implement **myAtoi(string s)** using the following rules:
- Skip leading whitespace
- Determine sign (+ or -)
- Convert digits until non-digit or end of string
- Clamp result to 32-bit signed integer range $[-2^{31}, 2^{31} - 1]$

Solution – 8. String to Integer (atoi)

Medium



LeetCode

leetcode.com/problems/string-to-integer-atoi

Solution

- Initialize an index i
- Position i to skip white spaces
- Check the sign and set a variable $sign = -1$ or 1
- Go over the remaining of the string and use the following:
 $digit = digit * 10 + s[i] - '0'$
- **Important:** use long long for the result and check overflows:
 $if (sign == 1 \ \&\& \ result > INT_MAX) \ return \ INT_MAX;$
 $if (sign == -1 \ \&\& \ -result < INT_MIN) \ return \ INT_MIN;$

Problem – 8. String to Integer (atoi)

Medium



LeetCode

leetcode.com/problems/string-to-integer-atoi

Code Time: **$O(n)$** Space: **$O(1)$**

```
int myAtoi(string s) {
    int i = 0;
    int n = s.size();
    // skip leading whitespace
    while (i < n && s[i] == ' ') i++;

    // some sanity check
    if (i == n) return 0;

    // check the sign
    int sign = 1;
    if (s[i] == '-') {
        sign = -1;
        i++;
    } else if (s[i] == '+') {
        // keep sign = 1
        i++;
    }

    // convert
    long long result = 0;
    while (i < n && isdigit(s[i])) {
        result = result * 10 + s[i] - '0';
        if (sign == 1 && result > INT_MAX) return INT_MAX;
        if (sign == -1 && -result < INT_MIN) return INT_MIN;
        ++i;
    }
    return result * sign;
}
```


BINARY

Bit Manipulation in C

- **Operators**

& AND **|** OR **^** XOR **~** NOT **<<** LEFT SHIFT **>>** RIGHT SHIFT

- **Common Operations**

set bit: `num |= (1 << pos)`

clear bit: `num &= ~(1 << pos)`

toggle bit: `num ^= (1 << pos)`

check bit: `(num & (1 << pos)) != 0`

extract bit: `(num >> pos) & 1`

extract a range of bits: `(num >> pos) & ((1 << length) - 1)`

- **Example**

```
void copyBit(int *dst, int src, int srcPos, int dstPos) {  
    int bit = (src >> srcPos) & 1; // extract bit  
    *dst &= ~(1 << dstPos); // clear destination bit  
    *dst |= (bit << dstPos); // set destination bit  
}
```

Binary

- In C++, **std::bitset** represents a fixed-size sequence of N bits

- Example:

```
std::bitset<8> bitmap;
```

```
bitmap.reset(1)
```

```
bitmap.set(1)
```

```
if (bitmap.test(1)) { // true
```

```
...
```

- **reset** : set bit to false
- **set** : set a specific bit
- **test** : check a specific bit
- **count** : return the number of bits set to true
- **flip** : toggle the value of the bits (if true, set to false and vice-versa)

Problem – 371. Sum of Two Integers

Medium



LeetCode

leetcode.com/problems/sum-of-two-integers

Problem

- Sum two integer numbers **a** and **b**
- You can't use **+** or **-**

Problem – 371. Sum of Two Integers

Medium



LeetCode

leetcode.com/problems/sum-of-two-integers

Solution

■ ...

Problem – 371. Sum of Two Integers

Medium



LeetCode

leetcode.com/problems/sum-of-two-integers

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 191. Number of 1 Bits

Easy



LeetCode

leetcode.com/problems/number-of-1-bits

Problem

■ ...

Problem – 191. Number of 1 Bits

Easy



LeetCode

leetcode.com/problems/number-of-1-bits

Solution

- ...

Problem – 191. Number of 1 Bits

Easy



LeetCode

leetcode.com/problems/number-of-1-bits

Code

- ...

Problem – 191. Number of 1 Bits

Easy

 leetcode.com/problems/number-of-1-bits

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 338. Counting Bits

Easy



LeetCode

leetcode.com/problems/counting-bits

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 338. Counting Bits

Easy



LeetCode

leetcode.com/problems/counting-bits

Problem

■ ...

Problem – 338. Counting Bits

Easy



LeetCode

leetcode.com/problems/counting-bits

Solution

- ...

Problem – 338. Counting Bits

Easy



LeetCode

leetcode.com/problems/counting-bits

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 268. Missing Number

Easy



LeetCode

<https://leetcode.com/problems/missing-number>

Problem

■ ...

Problem – 268. Missing Number

Easy



LeetCode

<https://leetcode.com/problems/missing-number>

Solution

- ...

Problem – 268. Missing Number

Easy



LeetCode

<https://leetcode.com/problems/missing-number>

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 190. Reverse Bits

Easy



LeetCode

leetcode.com/problems/reverse-bits

Problem

- ...

Problem – 190. Reverse Bits

Easy



LeetCode

leetcode.com/problems/reverse-bits

Solution

- ...

Problem – 190. Reverse Bits

Easy



LeetCode

leetcode.com/problems/reverse-bits

Code Time: $O(-)$ Space: $O(-)$

■ ...

Negabinary

- Non-standard positional numeral system that uses base of -2
- Allow representing negative numbers in binary
- Example:

1101_{-2}

$$(-2)^3 + (-2)^2 + 0 + (-2)^0 = -8 + 4 + 0 + 1 = -3$$

Summing Negabinary

- Add as a regular binary number, but with **negative carry**

$$0 + 0 = 0$$

$$1 + 0 = 1$$

$$1 + 1 = 0 \quad \text{with a negative carry 1}$$

$$\mathbf{1} + 1 = 0 \quad (\text{subtract})$$

$$\mathbf{1} + 0 = 1 \quad \text{with a positive carry 1}$$

Negabinary

Example 1

$$\begin{array}{r} 11\ 1 \\ 1011 \\ + 1110 \\ \hline = 110001 \end{array}$$

$$1 + 0 = 1$$

$$1 + 1 = 0 \text{ with negative carry } 1$$

$$1 + 1 = 0$$

$$1 + 1 = 0 \text{ with negative carry } 1$$

$$1 + 0 = 1 \text{ with positive carry } 1$$

$$1 + 0 = 1$$

red 1 = negative carry

green 1 = regular carry

Example 2

$$\begin{array}{r} 1111 \\ 101010 \\ + 101100 \\ \hline = 11110110 \end{array}$$

Reference

<https://math.stackexchange.com/questions/3251605/how-to-add-negabinary-numbers>

Problem 1073 – Adding Two Negabinary Numbers

Medium

<https://leetcode.com/problems/adding-two-negabinary-numbers>

Given two numbers `arr1` and `arr2` in base -2, return the result of adding them together.

Each number is given in *array format*: as an array of 0s and 1s, from most significant bit to least significant bit. For example, `arr = [1,1,0,1]` represents the number $(-2)^3 + (-2)^2 + (-2)^0 = -3$. A number `arr` in array, format is also guaranteed to have no leading zeros: either `arr == [0]` or `arr[0] == 1`.

Return the result of adding `arr1` and `arr2` in the same format: as an array of 0s and 1s with no leading zeros.

Example 1

Input: `arr1 = [1,1,1,1,1]`, `arr2 = [1,0,1]`

Output: `[1,0,0,0,0]`

Explanation: `arr1` represents 11, `arr2` represents 5, the output represents 16.

Example 2

Input: `arr1 = [0]`, `arr2 = [0]`

Output: `[0]`

Example 3

Input: `arr1 = [0]`, `arr2 = [1]`

Output: `[1]`

Solution 1073 – Adding Two Negabinary Numbers

Medium

<https://leetcode.com/problems/adding-two-negabinary-numbers>

GRAPH (BFS/DFS)

Tips

- When to build an **adjacency list** from the input data?
 - When the graph is **sparse**
 - When working with **non-grid graphs**
 - When you want to perform multiple or complex traversals and need fast neighbour lookups.

Problem - Keys and Rooms

Medium

<https://leetcode.com/problems/keys-and-rooms>

```
int maxProfit(vector<int>& prices) {  
    int profit = 0;  
    int buy = prices[0];  
    for (auto i = 1; i < prices.size(); i++) {  
        if (prices[i] < buy) {  
            buy = prices[i];  
        } else if (prices[i] - buy > profit) {  
            profit = prices[i] - buy;  
        }  
    }  
    return profit;  
}
```

Problem – Clone Graph

Medium



LeetCode

<https://leetcode.com/problems/clone-graph>

Problem Statement

- Given a node reference, create a deep copy of the graph
- The class node has two variables: val and neighbours

```
class Node {  
    public int val;  
    public List<Node> neighbors;  
}
```

- **Output** is the node reference of the copy

Solution – Clone Graph

Medium



LeetCode

<https://leetcode.com/problems/clone-graph>

Solution

- First check the edge cases (is the node null?)
- Create a hash map to store the nodes that is already created
`unordered<int, Node*> graph;`
- Check if the current node already exists in the graph
- If not, create a new Node object and store in the hashmap
- Visit all the neighbors and add the neighbors to this current node

Code – Clone Graph

Medium



LeetCode

<https://leetcode.com/problems/clone-graph>

```
std::unordered_map<int, Node*> graph;

Node* cloneGraph(Node* node) {
    if (node == NULL) {
        return NULL;
    }
    // does this node object exists?
    if (graph.find(node->val) == graph.end()) {
        // node wasn't visited yet, store in the hashmap
        graph[node->val] = new Node(node->val);
        // visit all neighbours
        for (const auto& n : node->neighbors) {
            graph[node->val]->neighbors.push_back(cloneGraph(n));
        }
    }
    return graph[node->val];
}
```

Problem – 207. Course Schedule

Medium



LeetCode

leetcode.com/problems/course-schedule

Problem

- You are given the number of courses and a course pre-requisite array
- Course pre-requisite indicates the dependency between courses

- **Example:**

`numCourses = 2, prerequisites = [[1,0],[0,1]]`

To take course 1, you must take course 0 first

to take course 0, you must take course 1 first

- In this example, this schedule is not possible since one course depends on the other
- Return if the schedule is valid or not



LeetCode

leetcode.com/problems/course-schedule

Solution

- Model as a graph problem
- Create a dependency graph between courses: **course A** depends on **course B**
- If there is a cycle, **A** to **B** and **B** to **A**, the schedule is invalid
- For the implementation: first convert the schedule to adjacency list
- Use DFS and track two status: **VISITING** and **VISITED**
- Go over each node in the adjacency list, and perform a DFS
- Once you find a node which status is **VISITING**, you've detected a cycle

Code – 207. Course Schedule

Medium



LeetCode

leetcode.com/problems/course-schedule

Code Time: $O(n + p)$ Space: $O(n + p)$ where n is the number of courses and p the number of edges in the graph

```
enum class VisitState {
    NOT_VISITED,
    VISITING,
    VISITED
};

bool hasCycle(int node, const unordered_map<int, vector<int>>& adjList,
              unordered_map<int, VisitState>& visited) {
    // if we are revisiting a node in the current path, there's a cycle
    if (visited[node] == VisitState::VISITING) return true;

    // if we've already completed visiting this node, no need to check again
    if (visited[node] == VisitState::VISITED) return false;

    // mark the node as being visited
    visited[node] = VisitState::VISITING;

    for (int neighbor : adjList.at(node)) {
        if (hasCycle(neighbor, adjList, visited)) return true;
    }

    // mark the node as fully visited
    visited[node] = VisitState::VISITED;
    return false;
}
```

```
bool canFinish(int numCourses, const vector<vector<int>>& prerequisites) {
    // build the adjacency list: course -> list of its prerequisites
    unordered_map<int, vector<int>> adjList;
    for (const auto& dependencyPair : prerequisites) {
        int course = dependencyPair[0];
        int prerequisite = dependencyPair[1];
        adjList[course].push_back(prerequisite);
    }

    unordered_map<int, VisitState> visited;

    // check each course for cycles
    for (int course = 0; course < numCourses; ++course) {
        if (adjList.count(course)) {
            if (hasCycle(course, adjList, visited)) return false;
        }
    }

    return true; // no cycles detected
}
```

Code – 207. Course Schedule

Medium



LeetCode

leetcode.com/problems/course-schedule

Code (simplified) Time: $O(n + p)$ Space: $O(n + p)$ where n is the number of courses and p the number of edges in the graph

```
bool canFinish(int numCourses, vector<vector<int>>& prerequisites) {
    // construct the graph
    vector<vector<int>> adjList(numCourses);
    // states:
    // unvisited = 0, visiting = -1, visited = 1
    vector<int> visited(numCourses, 0);
    for (const auto& pre : prerequisites) {
        adjList[pre[1]].push_back(pre[0]);
    }
    for (int n = 0; n < adjList.size(); ++n) {
        if (hasCycle(adjList, visited, n /* starting node */)) {
            return false;
        }
    }
    return true;
}

bool hasCycle(vector<vector<int>>& adjList, vector<int>& visited, int node) {
    if (visited[node] == -1) return true;
    if (visited[node] == 1) return false;

    // visiting
    visited[node] = -1;
    for (const auto& n: adjList[node]) {
        if (hasCycle(adjList, visited, n)) {
            return true;
        }
    }
    // already visited
    visited[node] = 1;
}
```

Problem – 417. Pacific Atlantic Water Flow

Medium



LeetCode

leetcode.com/problems/pacific-atlantic-water-flow

Problem

■ ...

Solution – 417. Pacific Atlantic Water Flow

Medium



LeetCode

leetcode.com/problems/pacific-atlantic-water-flow

Solution

- ...

Code – 417. Pacific Atlantic Water Flow

Medium



LeetCode

leetcode.com/problems/pacific-atlantic-water-flow

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 200. Number of Islands

Medium



LeetCode

leetcode.com/problems/number-of-islands

Problem

- ...

Solution – 200. Number of Islands

Medium



LeetCode

leetcode.com/problems/number-of-islands

Solution

- ...

Code – 200. Number of Islands

Medium



LeetCode

leetcode.com/problems/number-of-islands

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 128. Longest Consecutive Sequence

Medium



LeetCode

leetcode.com/problems/longest-consecutive-sequence

Problem

- ...

Solution – 128. Longest Consecutive Sequence

Medium



LeetCode

leetcode.com/problems/longest-consecutive-sequence

Solution

- ...

Code – 128. Longest Consecutive Sequence

Medium



LeetCode

leetcode.com/problems/longest-consecutive-sequence

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 261. Graph Valid Tree

Medium



LeetCode

leetcode.com/problems/graph-valid-tree

Problem

- ...

Solution – 261. Graph Valid Tree

Medium



LeetCode

leetcode.com/problems/graph-valid-tree

Solution

- ...

Code – 261. Graph Valid Tree

Medium



LeetCode

leetcode.com/problems/graph-valid-tree

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 323. Number of Connected Components

Medium

 leetcode.com/problems/number-of-connected-components-in-an-undirected-graph

Problem

- You are given a graph of **n** nodes, and an array of **edges (source, destination)**
- Edges indicates the edge between node **source** and **destination**
- Find the total number of isolated components (subgraphs)

- **Example:**

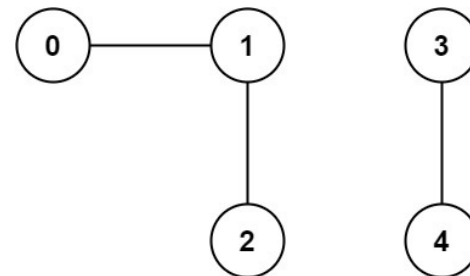
Input:

`n = 5, edges = [[0,1],[1,2],[3,4]]`

Output: 2

0 is connected to 1, 1 is connected to 2

3 is a new subgraph connected to 4



Solution – 323. Number of Connected Components

Medium

 leetcode.com/problems/number-of-connected-components-in-an-undirected-graph

Solution

- Build an adjacency list from edges
- From each node, check if its visited
- If it is not visited, mark as a new “component” or subgraph
- Perform a DFS from that node

Code – 323. Number of Connected Components

Medium

 leetcode.com/problems/number-of-connected-components-in-an-undirected-graph

Code Time: $O(n + E)$ Space: $O(n + E)$ where n is the number of nodes and E is edges size

```
int countComponents(int n, vector<vector<int>>& edges) {
    vector<bool> visited(n, false);
    vector<vector<int>> adjList(n);

    // build adjacency list
    for (const auto& edge: edges) {
        adjList[edge[0]].push_back(edge[1]);
        adjList[edge[1]].push_back(edge[0]);
    }
    int totalComponents = 0;
    for (int i = 0; i < n; ++i) {
        if (!visited[i]) {
            dfs(adjList, visited, i);
            totalComponents++;
        }
    }

    return totalComponents;
}

void dfs(vector<vector<int>>& adjList, vector<bool>& visited, int node) {
    if (visited[node]) return;
    visited[node] = true;
    for (const auto& neighbour : adjList[node]) {
        dfs(adjList, visited, neighbour);
    }
}
```

Problem – Maximum Level Sum of a Binary Tree

Medium

 LeetCode <https://leetcode.com/problems/maximum-level-sum-of-a-binary-tree>

Problem Statement

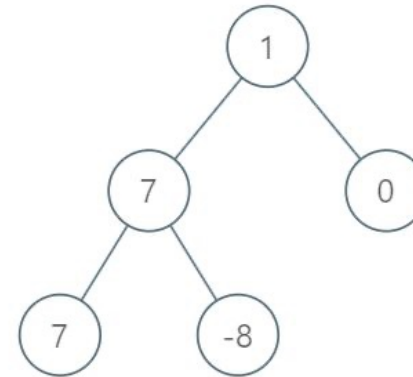
- Given the root of a binary tree, find the smallest level with the maximum sum
- For example, the tree below has the follow sums for each level:

level 1 (root) = 1

level 2 = 7 + 0 = 7

level 3 = 7 - 8 = -1

- Therefore, **level 2** has the maximum sum



Solution – Maximum Level Sum of a Binary Tree

Medium

 LeetCode <https://leetcode.com/problems/maximum-level-sum-of-a-binary-tree>

Solution

- Have a queue with the nodes for the current level
- Sum the values from that level by taking the nodes from the queue
- Example, we know that level 1 has one node. Hence, pop the first node from the queue
If level 2 has 2 nodes, pop two nodes, sum the values
- In addition, add left and right to the end of the queue to process the next level

Code – Maximum Level Sum of a Binary Tree

Medium

 [LeetCode https://leetcode.com/problems/maximum-level-sum-of-a-binary-tree](https://leetcode.com/problems/maximum-level-sum-of-a-binary-tree)

```
int maxLevelSum(TreeNode* root) {
    std::queue<TreeNode*> nodes;
    int currentLevel = 0;
    int maxLevel = 1;
    int maxSum = INT_MIN;

    nodes.push(root);

    // traverse the graph
    while(!nodes.empty()) {
        int levelSum = 0;
        int levelSize = nodes.size();
        currentLevel++;

        // sum the values in current level
        for (int i = 0; i < levelSize; ++i) {
            TreeNode* node = nodes.front();
            levelSum += node->val;
            nodes.pop();

            if (node->left) nodes.push(node->left);
            if (node->right) nodes.push(node->right);
        }

        if (levelSum > maxSum) {
            maxLevel = currentLevel;
            maxSum = levelSum;
        }
    }

    return maxLevel;
}
```

Problem – 1236. Web Crawler

Medium



LeetCode

<https://leetcode.com/problems/web-crawler>

Problem

- You are given a starting URL `startURL` and an interface `HtmlParser` with a method `getUrls(url)`
- `getUrls(url)` returns a vector of strings with the URLs found on the given page
- Start crawling from `startUrl` and recursively visit all reachable URLs
- Only visit URLs that share the same hostname as `startUrl`
- Return a list of all visited URLs (in any order)

Solution – 1236. Web Crawler

Medium



LeetCode

<https://leetcode.com/problems/web-crawler>

Solution

- This is a graph problem framed as an object
- Both BFS and DFS are valid options
- Each url represent a node, and `getUr1s` retrieve the neighbours
- Visit each node and add to the result if they have the same hostname



LeetCode

<https://leetcode.com/problems/web-crawler>

Code (BFS) Time: $O(n + m)$ Space: $O(n + w)$ where n is the number of unique URLs, m the number of links (edges), w is the explicit queue

```
vector<string> crawl(string startUrl, HtmlParser htmlParser) {
    string hostname = getHostname(startUrl);
    queue<string> urls;
    unordered_set<string> visited;
    vector<string> result;

    urls.push(startUrl);
    visited.insert(startUrl);
    result.push_back(startUrl);

    while(!urls.empty()) {
        string url = urls.front();
        urls.pop();
        for (const auto& u : htmlParser.getUrls(url)) {
            // is it the same hostname?
            // have I already visited this one?
            if (visited.count(u)) continue;
            if (getHostname(u) != hostname) continue;
            urls.push(u);
            result.push_back(u);
            visited.insert(u);
        }
    }
    return result;
}
```

```
string getHostname(const string& url) {
    int start = url.find("://") + 3;
    int end = url.find("/", start);
    return url.substr(start, end - start);
}
```

Problem – 1236. Web Crawler

Medium



LeetCode

<https://leetcode.com/problems/web-crawler>

Code (DFS) Time: $O(n + m)$ Space: $O(n + h)$ where n is the number of unique URLs, m the number of links (edges), h is the recursive stack

```
string getHostname(const string& url) {
    int start = url.find("://") + 3;
    int end = url.find("/", start);
    return url.substr(start, end - start);
}

void dfs(const string& hostname, const string& url, HtmlParser& htmlParser,
unordered_set<string>& visited, vector<string>& result) {
    if (visited.count(url)) return;
    result.push_back(url);
    visited.insert(url);

    for (const auto& u: htmlParser.getUrls(url)) {
        if (getHostname(u) == hostname) {
            dfs(hostname, u, htmlParser, visited, result);
        }
    }
}

vector<string> crawl(string startUrl, HtmlParser htmlParser) {
    string hostname = getHostname(startUrl);
    unordered_set<string> visited;
    vector<string> result;
    dfs(hostname, startUrl, htmlParser, visited, result);
    return result;
}
```


Problem – 994. Rotting Oranges

Medium



LeetCode

leetcode.com/problems/rotting-oranges

Problem / Solution / Code Time: $O(-)$ Space: $O(-)$

- 1
- 2

Solution – 994. Rotting Oranges

Medium



LeetCode

leetcode.com/problems/rotting-oranges

Solution

- 1
- 2

Code – 994. Rotting Oranges

Medium



LeetCode

leetcode.com/problems/rotting-oranges

Code Time: $O(-)$ Space: $O(-)$

- 1
- 2

SHORTEST PATH

Shortest Path Algorithms

Algorithm	Use Case	Graph Type	Time Complexity	Notes
BFS	When all edges have equal weight	Unweighted / same-weighted edges	$O(V + E)$	Simplest and fastest when all weights are equal.
Dijkstra	When edge weights are non-negative	Weighted, no negative weights	$O((V + E) \log V)$ with heap	Greedy, efficient for SSSP (Single Source Shortest Path).
Bellman-Ford	When edge weights can be negative	Weighted, allows negative weights	$O(V * E)$	Slower, but handles negative weights and detects negative cycles.
Floyd-Warshall	For all-pairs shortest paths	Dense graphs, small number of nodes	$O(V^3)$	Easy to implement; handles negative weights (but not negative cycles).
A* Search	For shortest path with a goal node and heuristic	Weighted, heuristic needed	Depends on heuristic quality	Often used in pathfinding (e.g. maps, games); faster than Dijkstra if heuristic is good.
Johnson's Algorithm	All-pairs shortest paths in sparse graphs with negative weights	Weighted, allows negative weights	$O(V^2 \log V + V * E)$	Reweights graph with Bellman-Ford, then runs Dijkstra from each node.
SPFA	Practical variant of Bellman-Ford, often faster	Weighted, allows negative weights	Avg: $O(E)$, Worst: $O(VE)$	Queue-based; faster in practice, not guaranteed. Handles negative weights.
Bidirectional Search	When you know start and target , speeds up search in undirected graphs	Unweighted or uniformly weighted	$O(b^{(d/2)})$ in best case	Runs two simultaneous searches (from start and end); fast when goal is known.

Problem – 743. Network Delay Time

Medium



LeetCode

leetcode.com/problems/network-delay-time

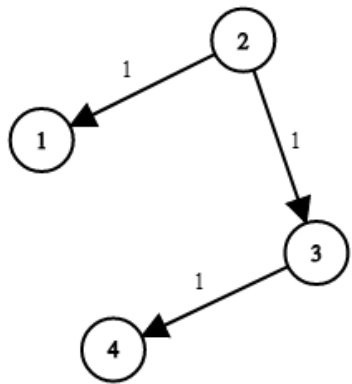
Problem

- You are given a network of nodes n with destination and time to reach that node
- You are given a starting node k and the number of nodes in the network n
- A signal is sent from node k to all nodes in the network
- Find the minimum time required for all nodes to receive the signal from k

- **Example:**

$k = 2$ $n = 4$

Output: 3



Solution – 743. Network Delay Time

Medium



LeetCode

leetcode.com/problems/network-delay-time

Solution

- This is solved using Dijkstra algorithm
- Build the graph by storing in the destination node and the time from a source node:
`graph[node] = [[node, distance]]`
`graph[2] = [[1,1], [2,3]]`
- Set up a min-heap for Dijkstra (priority_queue) with distance and node
- Perform Dijkstra algorithm and store the shortest paths
- Check if all nodes were reached
- Return the longest distance among shortest paths

Code – 743. Network Delay Time

Medium



LeetCode

leetcode.com/problems/network-delay-time

Code Time: $O((n + e) \log n)$ Space: $O(n + e)$ where n is the number of nodes and e the number of edges

```
int networkDelayTime(vector<vector<int>>& times, int n, int k) {
    // node => (destination, distance)
    unordered_map<int, vector<pair<int, int>>> graph;
    for (const auto& time : times) {
        // time[0] = source node, time[1] = dest node, time[2] = time
        graph[time[0]].emplace_back(time[1], time[2]);
    }

    // min heap: distance from the origin 'k' to 'node'
    priority_queue<pair<int, int>, vector<pair<int, int>>, greater<>> minHeap;
    minHeap.emplace(0, k); // distance, starting node

    // shortest path from each node to the origin 'k' (node, distance)
    unordered_map<int, int> dist;

    // we start exploring the nodes from the minimum
    // distance to the origin 'k'
    while (!minHeap.empty()) {
        auto [distance, node] = minHeap.top();
        minHeap.pop();
        // already visited, skip
        if (dist.count(node)) continue;
        // set the distance
        dist[node] = distance;
        // look at the connections
        for (const auto& [n, d] : graph[node]) {
            // n[node, distance]
            // quick optimization, not necessary
            if (dist.count(n)) continue;
            // add the distance since we want
            // the distance from the origin
            minHeap.emplace(distance + d, n);
        }
    }

    // check if all nodes were visited
    if (dist.size() != n) return -1;

    // all the minimum distances are calculated
    // find the max one since we want to reach
    // all nodes
    int minTime = 0;
    for (const auto& [n, d] : dist) {
        minTime = max(minTime, d);
    }

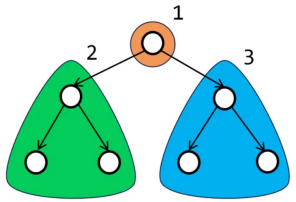
    return minTime;
}
```


TREE

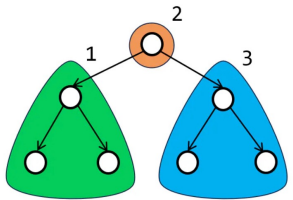
Tree Traversals

Depth-First Traversals

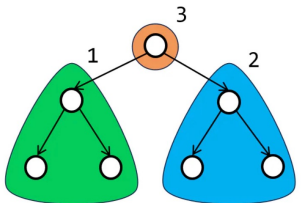
- **Pre-order:** Root - Left - Right



- **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.

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

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

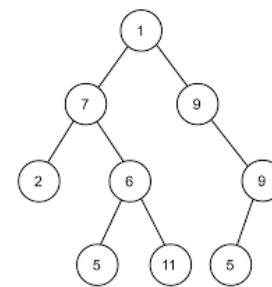
Problem Statement

- 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](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 max(maxLeft, maxRight) + 1;  
}
```

Problem – 100. Same Tree

Easy



LeetCode

leetcode.com/problems/same-tree

Problem

- You are given the root of two trees
- Write a function to check if they are the same

- **Example:**

$p = [1,2,3]$, $q = [1,2,3]$

Output: true

Solution – 100. Same Tree

Easy



LeetCode

leetcode.com/problems/same-tree

Solution

- Traverse both trees (**p** and **q**) recursively and check if the nodes are the same
- Start by the base case:
are **p** and **q** null? return true
- One of them are null? return false, because they should be the same
- Finally, check if **p->val** is equal to **q->val** and also for both and left, recursively

Code – 100. Same Tree

Easy



LeetCode

leetcode.com/problems/same-tree

Code Time: **$O(n)$** where n is the number of nodes Space: **$O(h)$** where h is the height of the tree. Best case is usually $O(\log n)$ for balanced trees, but skewed trees is usually $O(n)$

```
bool isSameTree(TreeNode* p, TreeNode* q) {  
    // base case: leaf is null. If both are null, then return true  
    if (!p && !q) return true;  
    // if both are not NULL, then they must have value.  
    // If one of them doesn't have value, then they're different, return false  
    if (!p || !q) return false;  
    // they must have the same value  
    // as any other nodes in the tree  
    return p->val == q->val &&  
           isSameTree(p->left, q->left) &&  
           isSameTree(p->right, q->right);  
}
```

Problem – 226. Invert Binary Tree

Easy

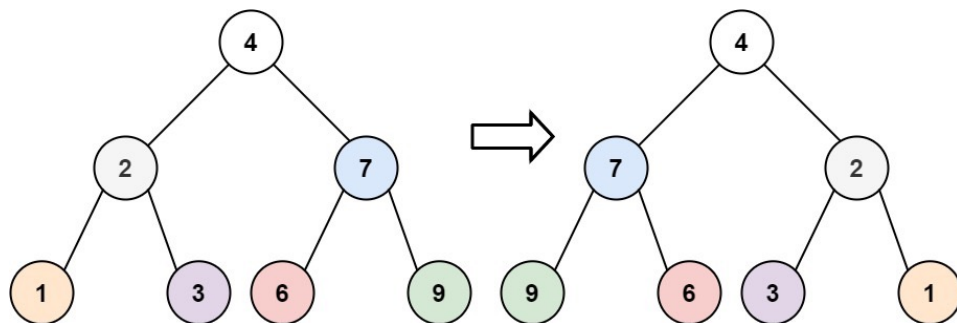


LeetCode

leetcode.com/problems/invert-binary-tree

Problem

- You are given the root of a binary tree
- Invert the tree and return the root
- **Example:**



Solution – 226. Invert Binary Tree

Easy



LeetCode

leetcode.com/problems/invert-binary-tree

Solution

- Recursively traverse the tree
- Create a new pointer **temp** that points to **left** node
- Set **left** node to **right**
- Set **right** node to **temp**
- Call the function recursively for **left** and **right**
- Return root

Code – 226. Invert Binary Tree

Easy



LeetCode

leetcode.com/problems/invert-binary-tree

Code Time: **$O(n)$** Space: **$O(h)$** where h is the height of the tree

```
TreeNode* invertTree(TreeNode* root) {  
    // base case  
    if (!root) return nullptr;  
  
    // create a new pointer to left  
    TreeNode* temp = root->left;  
    // invert  
    root->left = root->right;  
    root->right = temp;  
  
    // recursively invert left and right  
    invertTree(root->left);  
    invertTree(root->right);  
  
    return root;  
}
```

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:**

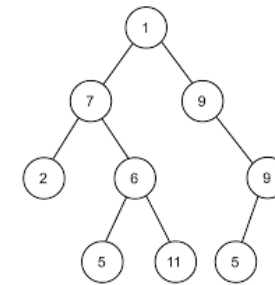
root = [1,7,9,2,6,null,9,null,null,5,11,5,null]

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

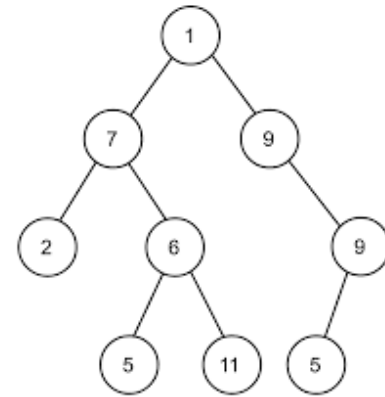


LeetCode

<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 – 102. Binary Tree Level Order Traversal

Medium



LeetCode

leetcode.com/problems/binary-tree-level-order-traversal

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 297. Serialize and Deserialize Binary Tree

Hard

 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.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.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.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 – 572. Subtree of Another Tree

Easy



LeetCode

leetcode.com/problems/subtree-of-another-tree

Problem

- You are given the root of a binary tree `root` and the root of another binary tree `subRoot`
- Determine whether `subRoot` is a **subtree** of `root`.
- A subtree of a binary tree is a node in the tree along with all of its descendants
- The tree itself is also considered a subtree.

Problem – 572. Subtree of Another Tree

Easy



LeetCode

leetcode.com/problems/subtree-of-another-tree

Solution

- Define a helper function `isSameTree(a, b)` that checks if two trees rooted at `a` and `b` are identical in both structure and node values.
- Traverse the root tree, and for each node:
- Use `isSameTree(node, subRoot)` to check if a matching subtree starts at that node.
- Return true if any such match is found; otherwise, return false.

Problem – 572. Subtree of Another Tree

Easy



LeetCode

leetcode.com/problems/subtree-of-another-tree

Code Time: $O(m * n)$ Space: $O(h)$ where n is the number of nodes of the tree and m the number of nodes of the subtree, and h the height of the tree.

```
bool isSame(TreeNode* q, TreeNode* r) {
    // both are null, so they're the same
    if (!q && !r) return true;
    // if they're not null, both must be not null
    if (!q || !r) return false;
    // now check the values
    if (q->val != r->val) return false;
    // check left and right
    return isSame(q->left, r->left) && isSame(q->right, r->right);
}

bool isSubtree(TreeNode* root, TreeNode* subRoot) {
    if (!root) return false;
    // Check starting from the root first
    if (isSame(root, subRoot)) {
        return true;
    }
    // they are not the same starting from the root,
    // but still subRoot may be in the middle of root. So check it recursively
    return isSubtree(root->left, subRoot) || isSubtree(root->right, subRoot);
}
```

Problem – 105. Construct Binary Tree from Preorder and Inorder Traversal

Medium

 leetcode.com/problems/construct-binary-tree-from-preorder-and-inorder-traversal

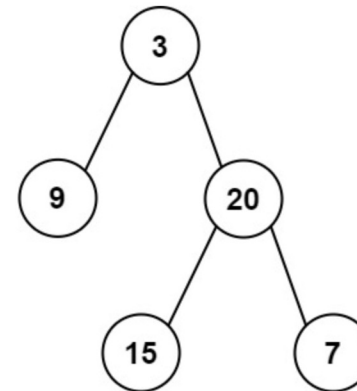
Problem

- You are given two **array of integers: preorder and inorder**
- **preorder** is the pre-order traversal of a binary tree
- **inorder** is the in-order traversal of a binary tree
- Based on those two arrays, construct the binary tree
- **Example**

Input: preorder = [3,9,20,15,7]

inorder = [9,3,15,20,7]

Output: the head pointer of the binary tree



Solution – 105. Construct Binary Tree from Preorder and Inorder Traversal

Medium

 leetcode.com/problems/construct-binary-tree-from-preorder-and-inorder-traversal

Solution

- 2

Code – 105. Construct Binary Tree from Preorder and Inorder Traversal

Medium

 leetcode.com/problems/construct-binary-tree-from-preorder-and-inorder-traversal

Code Time: $O(-)$ Space: $O(-)$

- 1
- 2

Problem – 98. Validate Binary Search Tree

Medium



LeetCode

leetcode.com/problems/validate-binary-search-tree

Problem

- You are given the root of a **binary tree**
- Determine if the tree is a valid **binary search tree** according to the following:
- The left subtree contains all elements less than the node's key
- The right subtree contains all elements greater than the node's key
- Both left and right must also be binary search trees

Solution – 98. Validate Binary Search Tree

Medium



LeetCode

leetcode.com/problems/validate-binary-search-tree

Solution

- For each node, there is a **maximum** and a **minimum** value where node lies
- The range of the root is $(-\infty, \infty)$
- Traverse from **top to bottom**
- If you are checking the right subtree, all the elements must be higher than a minimum value
- When traversing right, make sure to update the minimum value
- The same is true for the left subtree - all the elements must be less than the maximum value

Solution – 98. Validate Binary Search Tree

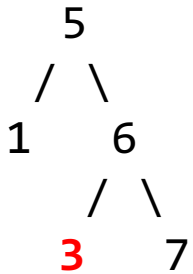
Medium



LeetCode

leetcode.com/problems/validate-binary-search-tree

Solution (example)



- The minimum of all elements at the right of "5" should be greater than 5
- So this tree is invalid
- For each node, the values must range between a min and a max:

node = (max, min)

node 5 = $(-\infty, +\infty)$ can be any value

node 1 = $(-\infty, 5)$ must be any value less than 5

node 6 = $(5, +\infty)$ this node can be any value greater than 5

node 3 = (5, 6) must be greater than the subtree the node belongs and less than the immediate parent

Code – 98. Validate Binary Search Tree

Medium



LeetCode

leetcode.com/problems/validate-binary-search-tree

Code Time: $O(n)$ Space: $O(n)$ where n is the number of the nodes in the tree

```
// Use long long for min/max due the constraints
bool isValid(TreeNode* root, long long min, long long max) {
    // base case: if we reach the bottom, that means we've
    // checked all nodes along the way and everything is fine
    if (!root) return true;

    // compare the min/max values
    if (root->val <= min || root->val >= max) return false;
    // go right and left. When going right, the minimum should be updated and
    // when going left, the maximum should be updated by its immediate parent
    return isValid(root->right, root->val, max) && isValid(root->left, min, root->val);
}

bool isValidBST(TreeNode* root) {
    return isValid(root, LONG_MIN, LONG_MAX);
}
```

Problem – 208. Implement Trie (Prefix Tree)

Medium



LeetCode

leetcode.com/problems/implement-trie-prefix-tree

Problem

- Implement Trie (prefix tree)
- Trie is a specialized search tree data structure used to store and retrieve strings from a dictionary set
- **Each node** represents a character of a string
- **Root node** is usually empty and does not store any character
- **Path from root to leaf node** represents the path that forms a word
- Insert/Search/Delete operations are done character by character
- Typically time complexity is **$O(L)$** where L is the length of the word
- The problem ask to implement a Trie class, including:

`Trie()` initialization

`void insert(string word)`

`bool search(string word)`

`bool startsWith(string prefix)`

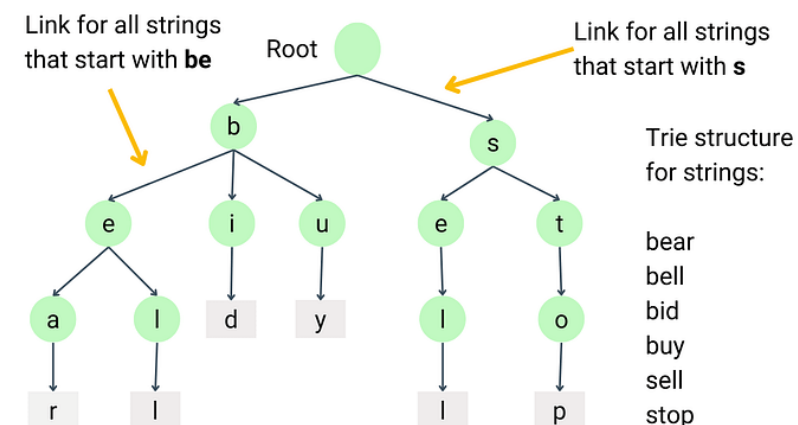


Image from <https://www.enjoyalgorithms.com/blog/introduction-to-trie-data-structure>

Problem – 208. Implement Trie (Prefix Tree)

Medium



LeetCode

leetcode.com/problems/implement-trie-prefix-tree

Solution

- Create a struct to represent the node. Each node is connected to 26 children (size of the English alphabet)

```
struct TrieNode {  
    TrieNode* children[26] = {};  
    bool isLeaf = false;  
};
```

- **Initialization**

Create a new TrieNode object root

- **Insert**

Iterate over each character 'c' in the word

if children[c - 'a'] is nullptr, create a new TrieNode

Move to the child node

After the last character, mark the node as leaf (isLeaf = true)

Problem – 208. Implement Trie (Prefix Tree)

Medium



LeetCode

leetcode.com/problems/implement-trie-prefix-tree

Solution

▪ Search

Traverse the trie character by character

If at any point the child node for a character doesn't exist, return false

After traversal, return true only if isLeaf == true

▪ StartsWith

Traverse the trie character by character

If any character node is missing, return false

Once reach the end of the string, return true

Problem – 208. Implement Trie (Prefix Tree)

Medium



LeetCode

leetcode.com/problems/implement-trie-prefix-tree

Code Time: $O(L)$ Space: $O(L)$ where L is the average length of each word

```
class Trie {
private:
    struct TrieNode {
        TrieNode* children[26] = {};
        bool endOfWord = false;
    };

    TrieNode* root;
public:
    explicit Trie() {
        root = new TrieNode();
    }

    void insert(string word) {
        TrieNode* node = root;
        for (const auto& c : word) {
            int i = c - 'a';
            if (!node->children[i]) {
                node->children[i] = new TrieNode();
            }
            node = node->children[i];
        }
        node->endOfWord = true;
    }

    TrieNode* findLastNode(const string& word) {
        TrieNode* node = root;
        for (const auto& c : word) {
            node = node->children[c - 'a'];
            if (!node) return nullptr;
        }
        return node;
    }

    bool search(string word) {
        TrieNode* node = findLastNode(word);
        return node && node->endOfWord;
    }

    bool startsWith(string prefix) {
        return findLastNode(prefix) != nullptr;
    }
};
```

Problem – Kth Smallest Element in a BST

Medium



LeetCode

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

Problem Statement / Solution

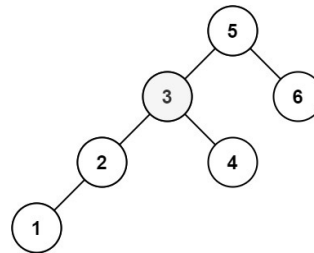
- You are given the **root** of a binary search tree and an **integer k**
- Find the k^{th} smallest value

- **Example**

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

k = 3 so find the 3th smallest value

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



Solution – Kth Smallest Element in a BST

Medium

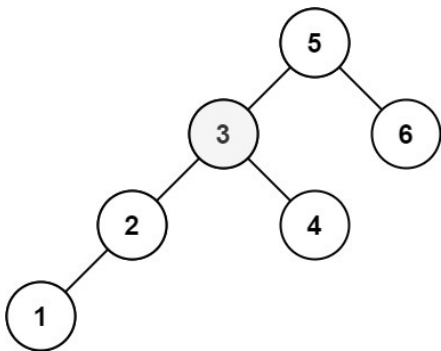


LeetCode

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 \rightarrow big values from left \rightarrow root \rightarrow 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;
}
```

Problem – 124. Binary Tree Maximum Path Sum

Hard

 leetcode.com/problems/binary-tree-maximum-path-sum

Problem

- You are given the root node of a binary tree
- Return the **max path sum** of any path
- A path can be linear (from the root all the way down to the leaf) or the three node: root, left and right)
- A path can start at any node

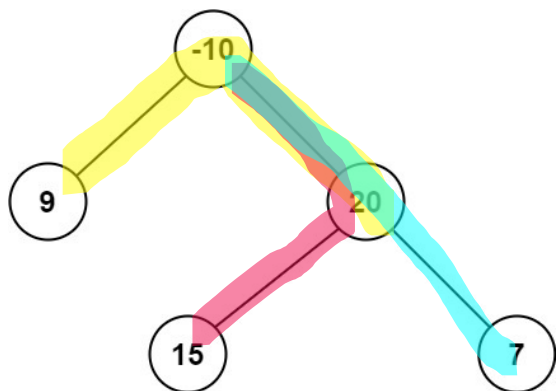
- **Example:**

$9 \rightarrow -10 \rightarrow 20$ is a valid path

$-10 \rightarrow 20 \rightarrow 15$ is a valid path

$9 \rightarrow -10 \rightarrow 20 \rightarrow 7$ is **NOT** a valid path

$20 \rightarrow 7$ is a valid path



Solution – 124. Binary Tree Maximum Path Sum

Hard

 leetcode.com/problems/binary-tree-maximum-path-sum

Solution

- Use **post-order** traversal (bottom-up recursion)
- At each node:
 - Recursively compute left and right max path gains
 - Consider all 3 possible paths:
 1. Turn path: left + root + right
 2. Linear path: root + left
 3. Linear path: root + right
 - Also consider just the root (if the children is negative)
- Track the maximum path seen so far
- Only return linear path (root + one child) upward to maintain the valid structure
- Also, prune negative gain before returning

Problem – 124. Binary Tree Maximum Path Sum

Hard

 leetcode.com/problems/binary-tree-maximum-path-sum

Code Time: $O(n)$ Space: $O(h)$ where n is the number of nodes and h is the height of the tree.

```
int findMaxSum(TreeNode* root, int& maxSum) {
    if (!root) return 0;
    int left = findMaxSum(root->left, maxSum);
    int right = findMaxSum(root->right, maxSum);
    // 1st possible path: exactly the only 3 nodes: root, right and left
    int threeNodes = left + right + root->val;
    // 2nd possible path, linear recursive path: root + left
    int secondPath = root->val + left;
    // 3rd possible path, linear recursive path: root + right
    int thirdPath = root->val + right;

    // check if we should consider left, right or only root itself
    int bestPath = max({root->val, secondPath, thirdPath});

    // maxSum can be the accumulated 2nd and 3rd (linear path)
    // or the threeNodes path
    maxSum = max({maxSum, bestPath, threeNodes});

    // Prune subtree: we start from the bottom, so we can set 0
    // to ignore left or right path
    return max(0, bestPath);
}

int maxPathSum(TreeNode* root) {
    int maxSum = INT_MIN;
    findMaxSum(root, maxSum);
    return maxSum;
}
```

Problem – 124. Binary Tree Maximum Path Sum

Hard

 leetcode.com/problems/binary-tree-maximum-path-sum

Code (compact) Time: $O(n)$ Space: $O(h)$ where n is the number of nodes and h is the height of the tree.

```
int find(TreeNode *node, int& totalMax) {
    if (!node) return 0;
    int leftGain = max(0, find(node->left, totalMax));
    int rightGain = max(0, find(node->right, totalMax));
    int currentMax = node->val + leftGain + rightGain;
    totalMax = max(totalMax, currentMax);
    return node->val + max(leftGain, rightGain);
}

int maxPathSum(TreeNode* root) {
    int totalMax = INT_MIN;
    find(root, totalMax);
    return totalMax;
}
```

Problem – 872. Leaf-Similar Trees

Easy



LeetCode

leetcode.com/problems/leaf-similar-trees

Problem Statement

- You are given two trees
- The goal is to compare if they have the same leaves
- The leaves should be in the same order
- Example:

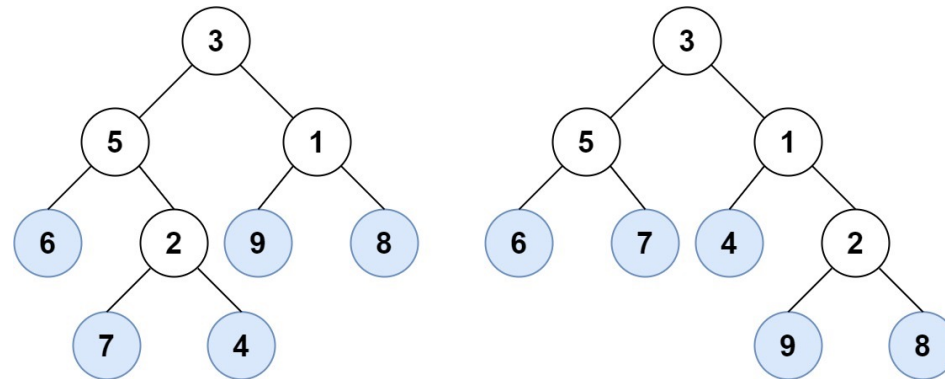
First tree:

leaves = 6,7,4,9,8 (blue nodes)

Second tree:

leaves = 6,7,4,9,8

- Return true if the leaves are the same



Solution – Leaf-Similar Trees

Easy



LeetCode

leetcode.com/problems/leaf-similar-trees

Solution

- Get the first leaf value from tree 1
- Get the first leaf value from tree 2
- Compare, if they are different, return false immediately
- Otherwise, continue finding the next leaf value for tree 1 and 2

Implementation

- Create two stacks **stack<TreeNode*> left** and **stack<TreeNode*> right**
- Add the

Code – Leaf-Similar Trees

Easy



LeetCode

leetcode.com/problems/leaf-similar-trees

Code Time: $O(n + m)$ where n and m are the numbers of nodes for trees 1 and 2 Space: $O(h_1 + h_2)$ where h_1 and h_2 represents the height of the tree

```
// returns the value of the leaf, or -1 if empty
int getLeaf(stack<TreeNode*>& tree) {
    // tree is a reference, we will always pop an element from it
    while(!tree.empty()) {
        // get the top element from the stack
        TreeNode* node = tree.top();
        // already visited, so remove from stack
        tree.pop();
        // is this a leaf?
        if (!node->left && !node->right) {
            // yes, return the value
            return node->val;
        }
        // push the right FIRST to the stack
        if (node->right) tree.push(node->right);
        // left should be on top of the stack
        if (node->left) tree.push(node->left);
    }
    return -1;
}
```

```
bool leafSimilar(TreeNode* root1, TreeNode* root2) {
    // initialize the stacks, add root1 and root2
    std::stack<TreeNode*> leftTree, rightTree;
    leftTree.push(root1);
    rightTree.push(root2);

    while(true) {
        // get the leaves to compare
        int leaf1 = getLeaf(leftTree);
        int leaf2 = getLeaf(rightTree);
        // exit immediately if one leaf is different
        if (leaf1 != leaf2) return false;
        // stop when there are no leaves left
        if (leaf1 == -1 || leaf2 == -1) break;
    }
    return true;
}
```


Code – Leaf-Similar Trees

Easy



LeetCode

leetcode.com/problems/leaf-similar-trees

Code (another approach) Time: $O(n + m)$ where n and m are the numbers of nodes for trees 1 and 2 Space: $O(h1 + h2)$ where $h1$ and $h2$ represents the height of the tree

```
void extractLeafs(TreeNode* node, vector<int>& leafValues) {
    // base case, return
    if (!node) return;
    // if it looks like a leaf, no left child
    // like a leaf, no right child like a leaf,
    // then it's probably a leaf
    // add to the vector
    if (!node->left && !node->right) {
        leafValues.push_back(node->val);
    }
    // continue looking at left and right
    extractLeafs(node->left, leafValues);
    extractLeafs(node->right, leafValues);
}
```

```
bool leafSimilar(TreeNode* root1, TreeNode* root2) {
    vector<int> tree1Values;
    vector<int> tree2Values;
    // extract all leafs from tree 1
    extractLeafs(root1, tree1Values);
    // extract all leafs from tree 2
    extractLeafs(root2, tree2Values);
    // compare
    return tree1Values == tree2Values;
}
```

Problem – 1448. Count Good Nodes in Binary Tree

Medium

 LeetCode leetcode.com/problems/count-good-nodes-in-binary-tree

Problem Statement

- You are given a binary tree and have to find “**good**” nodes
- A **good node** is a **node** where the values in the path are always less than or equal to the **node**
- The **root node** is always a **good node**
- Example:

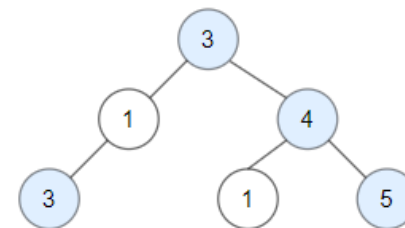
- root 3 is a good node

left side:

- left **leaf 1** is not a good node because $1 < 3$
- **leaf 3** is a good node because $3 > 1$ and $3 == 3$

right side:

- **leaf 4** is a good node because $4 > 3$
- **leaf 1** is not a good node because $1 < 4$
- **leaf 5** is a good node because $5 > 4 > 3$



Solution – 1448. Count Good Nodes in Binary Tree

Medium

 LeetCode leetcode.com/problems/count-good-nodes-in-binary-tree

Solution

- Use DFS traversal to explore the tree from the root to all leaf nodes
- As you traverse, **keep track of the maximum value** along the path from root to node
- Update max value once you find a node value greater than the max value
- **Recursive logic**

Base case: if the node is *nullptr*, return 0

At each node:

- Compare its value to max so far
- If it is a good node, increase a local count
- Recursively repeat this process for the left and right children, passing along the updated max value

Code – 1448. Count Good Nodes in Binary Tree

Medium

 leetcode.com/problems/count-good-nodes-in-binary-tree

Code Time: $O(n)$ Space: $O(h)$

```
int traverse(TreeNode* root, int maxValue) {
    if (!root) return 0;
    // is this a good node?
    int count = 0;
    if (root->val >= maxValue) {
        maxValue = root->val;
        count = 1;
    }
    count += traverse(root->left, maxValue);
    count += traverse(root->right, maxValue);
    return count;
}

int goodNodes(TreeNode* root) {
    if (!root) return 0;
    return traverse(root, root->val);
}
```

INTERVAL

Some Common Patterns

Merge Intervals

- Sort by **start time**
- Merge if `current.start <= previous.end`
- Classic use: *merging calendar events, range compression*

Interval Scheduling (Max Non-overlapping Intervals)

- Sort by **end time**
- Greedy: select interval only if `start >= last_selected.end`
- Optimal because ending earlier leaves more time for future

Minimum Number of Arrows to Burst Balloons

- Same as interval scheduling
- Sort by **end time**
- Count how many non-overlapping intervals = minimum arrows needed

Some Common Patterns II

Minimum Meeting Rooms

- Sort by start and end times separately
- Use a min-heap to track active meetings
- Greedy, but uses more advanced data structure

Can Attend All Meetings?

- Sort by start time
- Check if any overlap with previous: if `start < previous.end`, return false

Problem – 57. Insert Interval

Medium



LeetCode

leetcode.com/problems/insert-interval

Problem Statement

- You are given an array of **intervals**, where **intervals[i] = [start_i, end_i]** and **newInterval = [start, end]**
- **newInterval** must be inserted into **intervals**
- Overlapping intervals must be merged
- Example

intervals = [[1,2],[3,5],[6,7],[8,10],[12,16]] **newInterval** = [4,8]

Output: [[1,2],[3,10],[12,16]]

Solution – 57. Insert Interval

Medium



LeetCode

leetcode.com/problems/insert-interval

Solution

- Sort intervals by the first element (start)
- Initialize **result**
- Solve in three loops:
 1. While there is no overlap with **newInterval**, add to **intervals[i]** to **result**
 2. While it overlaps, merge **newInterval**
 3. While until the end intervals and add the remaining **intervals[i]**

Code – 57. Insert Interval

Medium



LeetCode

leetcode.com/problems/insert-interval

Code Time: $O(n)$ Space: $O(n)$ where n is the size of intervals

```
vector<vector<int>> insert(vector<vector<int>>& intervals, vector<int>& newInterval) {
    vector<vector<int>> result;
    int tupleIndex = 0;
    int totalTuples = intervals.size();
    // 1. check if it overlaps
    // 1 ----- 2
    //           4 ----- 8
    while (tupleIndex < totalTuples && intervals[tupleIndex][1] < newInterval[0]) {
        result.push_back(intervals[tupleIndex]);
        ++tupleIndex;
    }

    // 2. merge overlap. We already know there is an overlap here,
    // otherwise it should be sorted out in the previous step
    // 3 ---- 5
    //      4 ----- 8
    while (tupleIndex < totalTuples && intervals[tupleIndex][0] <= newInterval[1]) {
        newInterval[0] = min(newInterval[0], intervals[tupleIndex][0]);
        newInterval[1] = max(newInterval[1], intervals[tupleIndex][1]);
        ++tupleIndex;
    }
    result.push_back(newInterval);

    // 3. add remaining parts
    while (tupleIndex < totalTuples) {
        result.push_back(intervals[tupleIndex]);
        ++tupleIndex;
    }
    return result;
}
```

Problem – 56. Merge Intervals

Medium



LeetCode

leetcode.com/problems/merge-intervals

Problem Statement

- You are given an array of intervals, example:

```
intervals = [[1,3],[2,6],[8,10],[15,18]]
```

- Merge all overlapping intervals. So the output should be:

```
[[1,6],[8,10],[15,18]]
```

- Interval [1,3] was merged with [2,6]

Solution – 56. Merge Intervals

Medium



LeetCode

leetcode.com/problems/merge-intervals

Solution

- Sort the array based on the beginning of the interval
- In C++, when applying `sort(intervals.begin(), intervals.end())` the default comparator compares `vector<vector<int>>` lexicographically:
 - it first compares the first element [0] of each sub-vector
 - if those are equal, it compares the second element [1] and so on
- Go over each interval and compare
- `interval[i][begin] <= interval[i - 1][end]` ? then merge
- To merge, set the current `interval[i][begin]` to `interval[i - 1][begin]` and set the `interval[i][end]` to the maximum value between `interval[i][end]` and `interval[i - 1][end]`
- If no merge is necessary, push the previous interval to the result array
- Once the loop finishes, add the last element and return the result

Code – 56. Merge Intervals

Medium



LeetCode

leetcode.com/problems/merge-intervals

Code Time: $O(n \log n)$ Space: $O(n)$

```
vector<vector<int>> merge(vector<vector<int>>& intervals) {
    if (intervals.empty()) return {};
    sort(intervals.begin(), intervals.end());
    vector<vector<int>> result;

    result.push_back(intervals[0]);

    for (int i = 1; i < intervals.size(); ++i) {
        vector<int>& current = intervals[i];
        vector<int>& previous = result.back();

        // check if they overlap, if so merge...
        // they're sorted, we know that:
        // previous[0] >= current[0]
        // 1 --- 3 (previous)
        // 2 ----- 6 (current)
        if (current[0] <= previous[1]) {
            // merge
            previous[1] = max(previous[1], current[1]);
        } else {
            result.push_back(current);
        }
    }
    return result;
}
```

Problem – 435. Non-overlapping Intervals

Medium



LeetCode

leetcode.com/problems/non-overlapping-intervals

Problem Statement

- You are given an array of intervals `vector<vector<int>>` with start and end, Example:
`intervals = [[1,2],[2,3],[3,4],[1,3]]`
- The intervals **must not** overlap each other
- You have to remove the minimum number of pairs to make it non-overlapping

Solution – 435. Non-overlapping Intervals

Medium



LeetCode

leetcode.com/problems/non-overlapping-intervals

Solution

- Sort the array by the ending time:

$[[1,2],[2,3],[3,4],[1,3]] \rightarrow [[1,2],[2,3],[1,3],[3,4]]$

- In C++ a lambda function can be used with sort:

```
sort(intervals.begin(), intervals.end(), [](const vector<int>& a, const vector<int>&b) {  
    return a[1] < b[1];  
});
```

- Note that **std::sort** is not stable (opposite of **std::stable_sort**), so there is no guarantees that [2,3] comes before [1,3]. But for this algorithm, it doesn't matter
- Iterate over the array and check overlaps by comparing the end[i] with begin[i - 1]
- If they overlap, logically remove the current pair and count + 1
- Logically removing means just setting the end to compare to the previous element, so "skip" the current interval

Code – 435. Non-overlapping Intervals

Medium



LeetCode

leetcode.com/problems/non-overlapping-intervals

Code Time: $O(n \log n)$ Space: $O(1)$

```
int eraseOverlapIntervals(vector<vector<int>>& intervals) {
    // sort by the ending time O(log n)
    sort(intervals.begin(), intervals.end(), [](const auto& a, const auto& b) {
        return a[1] < b[1];
    });
    int result= 0;
    int end = intervals[0][1];

    // O(n)
    for (int i = 1; i < intervals.size(); ++i) {
        // does it overlaps?
        if (intervals[i][0] < end) {
            ++result;
        } else {
            // it doesn't overlap, just 'skip'
            // the current interval
            end = intervals[i][1];
        }
    }
    return result;
}
```


Problem – 110. Balanced Binary Tree

Easy



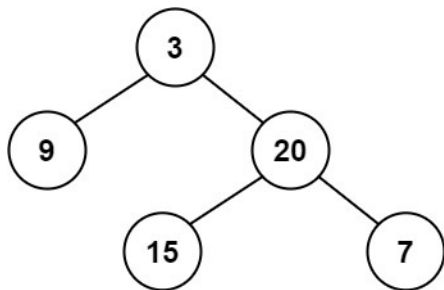
LeetCode

leetcode.com/problems/balanced-binary-tree

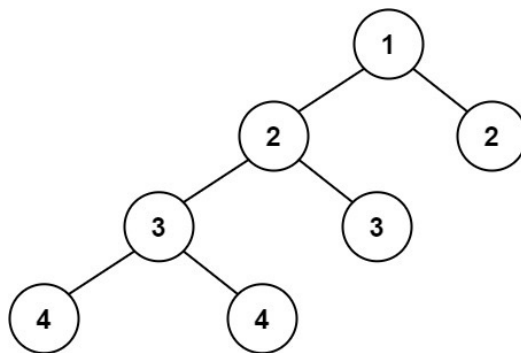
Problem

- You are given the root of a binary tree
- Return true if it is height-balanced
- A tree is height-balanced when the height of two subtrees does not differ by two

Height balanced



Not Height balanced



Problem – 110. Balanced Binary Tree

Easy



LeetCode

leetcode.com/problems/balanced-binary-tree

Solution

- Recursive approach: go all the way down
- Calculate the height of the left subtree
- Calculate the height of the right subtree
- Compare both to check if they differ by more than one
- Continue going up the tree to check all the nodes

Problem – 110. Balanced Binary Tree

Easy



LeetCode

leetcode.com/problems/balanced-binary-tree

Code Time: $O(n)$ Space: $O(h)$ where n is the number of the nodes and h is the height of the tree

```
int checkHeight(TreeNode* node) {
    if (!node) return 0;

    int left = checkHeight(node->left);
    // left tree is unbalanced
    if (left == -1) return -1;

    int right = checkHeight(node->right);
    // right tree is unbalanced
    if (right == -1) return -1;

    // check the different, -1 is unbalanced
    if (abs(left - right) > 1) return -1;

    return max(left, right) + 1;
}

bool isBalanced(TreeNode* root) {
    return checkHeight(root) != -1;
}
```

LINKED LIST

Problem – 206. Reverse Linked List

Easy

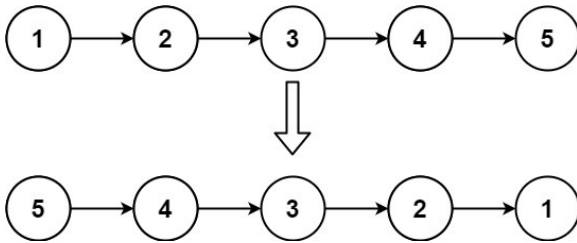


LeetCode

leetcode.com/problems/reverse-linked-list

Problem

- This is a classic problem
- Given a singly linked list, reverse its order



Solution – 206. Reverse Linked List

Easy



LeetCode

leetcode.com/problems/reverse-linked-list

Solution

- Use recursive approach
- Looking at the pseudo-code, this recursion will return the last node:

```
reverseList(head) {  
    if (!head->next) return head  
    node = reverseList(head->next);  
    return node  
}
```

- From end to beginning, each head will be a node in the list
- Therefore, you can change this node by setting a new head:

```
head->next->next = head;  
head->next = nullptr;
```

Code – 206. Reverse Linked List

Easy



LeetCode

leetcode.com/problems/reverse-linked-list

Code Time: **$O(n)$** Space: **$O(1)$**

```
ListNode* reverseList(ListNode* head) {  
    if (!head->next) return head;  
    ListNode* node = reverseList(head->next);  
    head->next->next = head;  
    head->next = nullptr;  
    return node;  
}
```

Problem – 141. Linked List Cycle

Easy



LeetCode

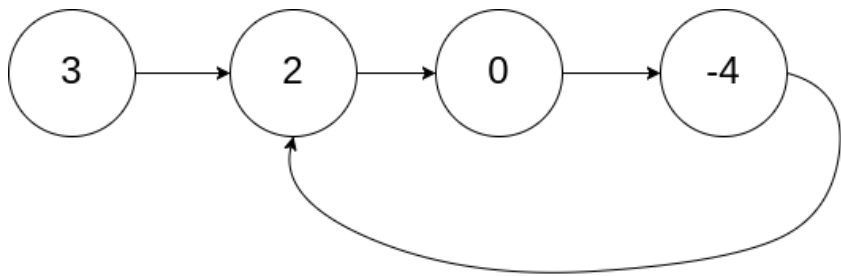
leetcode.com/problems/linked-list-cycle

Problem

- You are given the head of a linked list
- Return **true** if there is a cycle, false otherwise
- **Example:**

In the image below, there is a cycle (-4 to 2)

Output: true



Solution – 141. Linked List Cycle

Easy



LeetCode

leetcode.com/problems/linked-list-cycle

Solution

- Have two pointers: fast and slow
- Slow will go over each item in the linked list
- Fast will go twice as fast as slow (`fast = fast->next->next`)
- If fast reach at the end, there is no cycle
- If fast encounter slow, there is a cycle, return true

Code – 141. Linked List Cycle

Easy



LeetCode

leetcode.com/problems/linked-list-cycle

Code Time: **O(n)** Space: **O(1)**

```
bool hasCycle(ListNode *head) {
    if (!head || !head->next) return false;
    ListNode* slow = head;
    ListNode* fast = head;
    while (fast && fast->next) {
        slow = slow->next;
        fast = fast->next->next;
        if (slow == fast) return true;
    }
    return false;
}
```

Problem – 21. Merge Two Sorted Lists

Easy

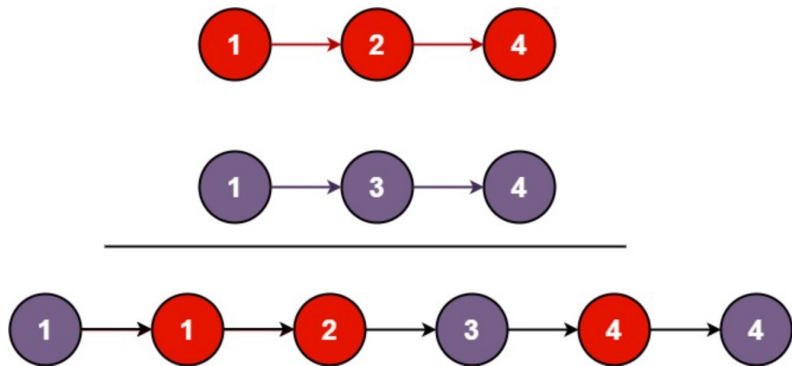


LeetCode

leetcode.com/problems/merge-two-sorted-lists

Problem

- You are given the head of two linked lists (list1 and list2)
- Merge the two lists into one **sorted** list



Solution – 21. Merge Two Sorted Lists

Easy



LeetCode

leetcode.com/problems/merge-two-sorted-lists

Solution

- Recursively explore the two lists. Base case:

```
if (!list1) return list2;
```

```
if (!list2) return list1;
```

- Compare the value of the current node of list 1 and list 2

```
if (list1->val > list2->val) { ...
```

- Set the next node of the node with the minimum value:

assume the previous condition is true, so

```
list2->next = mergeTwoLists(list1, list2->next);
```

```
return list2;
```

meaning, we want list2->next to come before list1. But we do this recursively since we need the next result

Code – 21. Merge Two Sorted Lists

Easy



LeetCode

leetcode.com/problems/merge-two-sorted-lists

Code Time: $O(n + m)$ Space: $O(n + m)$ where n is the length of list1 and m is the length of list2

```
ListNode* mergeTwoLists(ListNode* list1, ListNode* list2) {  
    if (!list1) return list2;  
    if (!list2) return list1;  
  
    if (list1->val < list2->val) {  
        list1->next = mergeTwoLists(list1->next, list2);  
        return list1;  
    } else {  
        list2->next = mergeTwoLists(list2->next, list1);  
        return list2;  
    }  
}
```

Problem – 23. Merge k Sorted Lists

Hard



LeetCode

leetcode.com/problems/merge-k-sorted-lists

Problem

- You are given an **array of k linked lists**
- Each linked list is **sorted** in ascending order
- Merge all linked lists into one **sorted** linked-lists

Solution – 23. Merge k Sorted Lists

Hard



LeetCode

leetcode.com/problems/merge-k-sorted-lists

Solution

- Create a function to merge two lists
- Go over the lists and merge with each over; **or**
- Use divide and conquer to merge (more optimal)
- Divide and conquer is more efficient because it avoids merging a big list with a small one multiple times

Code – 23. Merge k Sorted Lists

Hard



LeetCode

leetcode.com/problems/merge-k-sorted-lists

Code Time: $O(N \log k)$ Space: $O(\log k)$ where **N** is the total number of nodes across all lists and **k** is the number of lists

```
ListNode* mergeKLists(vector<ListNode*>& lists) {
    if (lists.empty()) return nullptr;
    return divideAndConquer(lists, 0 /* left */, lists.size() - 1 /* right */);
}

ListNode* mergeTwoLists(ListNode* l1, ListNode* l2) {
    if (!l1) return l2;
    if (!l2) return l1;

    if (l1->val < l2->val) {
        l1->next = mergeTwoLists(l1->next, l2);
        return l1;
    } else {
        l2->next = mergeTwoLists(l2->next, l1);
        return l2;
    }
}

ListNode* divideAndConquer(vector<ListNode*> lists, int left, int right) {
    if (left == right) return lists[right];

    int mid = left + (right - left) / 2;
    ListNode* l1 = divideAndConquer(lists, left, mid);
    ListNode* l2 = divideAndConquer(lists, mid + 1, right);
    return mergeTwoLists(l1, l2);
}
```


Problem – 19. Remove Nth Node From End of List

Medium

 leetcode.com/problems/remove-nth-node-from-end-of-list

Problem Statement / Solution / Code Time: $O()$ Space: $O()$

■ ...

Problem – 143. Reorder List

Medium



LeetCode

leetcode.com/problems/reorder-list

Problem Statement / Solution / Code Time: $O()$ Space: $O()$

■ ...

Problem – 24. Swap Nodes in Pair

Medium

<https://leetcode.com/problems/swap-nodes-in-pairs>

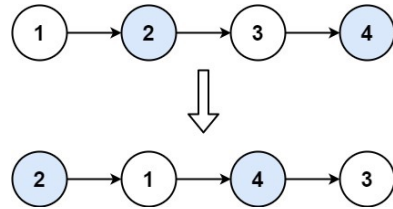
Problem

Given a linked list, swap every two adjacent nodes and return its head. You must solve the problem without modifying the values in the list's nodes (i.e., only nodes themselves may be changed.)

Example 1

Input: head = [1,2,3,4]

Output: [2,1,4,3]



Example 2

Input: head = []

Output: []

Example 3:

Example 3

Input: head = [1]

Output: [1]

Solution – Swap Nodes in Pair

Medium

<https://leetcode.com/problems/swap-nodes-in-pairs>

```
ListNode* swapPairs(ListNode* head) {
    if (head == NULL || head->next == NULL) {
        return head;
    }
    ListNode *node = head;
    ListNode *prev = NULL;
    head = head->next;

    while (node && node->next) {
        ListNode *second = node->next;
        ListNode *next_pair = second->next;
        second->next = node;
        node->next = next_pair;
        if (prev) {
            prev->next = second;
        }
        prev = node;
        node = next_pair;
    }
    return head;
}
```

Solution (recursive) – Swap Nodes in Pair

Medium

<https://leetcode.com/problems/swap-nodes-in-pairs>

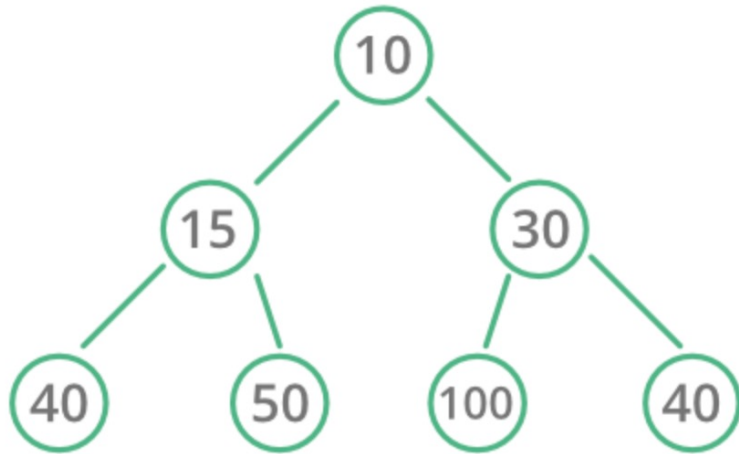
```
ListNode* swapPairs(ListNode* head) {  
    if(!head || !head->next)  
        return head;  
    ListNode* newHead = head->next;  
    head->next = swapPairs(head->next->next);  
    newHead->next = head;  
    return newHead;  
}
```

HEAP / PRIORITY QUEUE

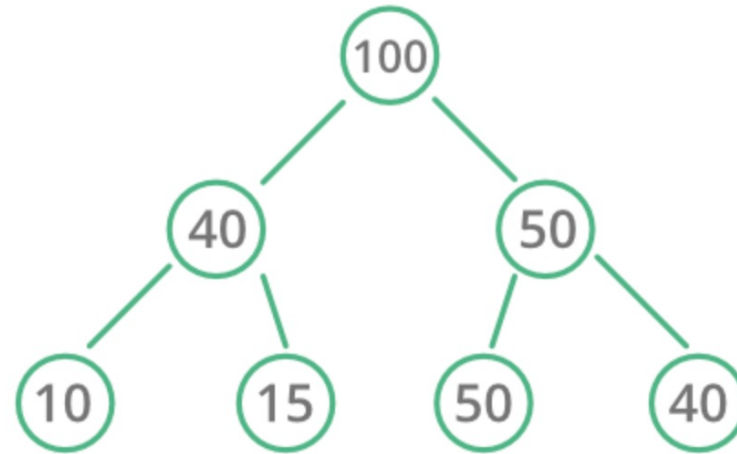
Heap

- **Heap** is a complete binary tree that satisfy the heap property (max or min)
- **Min heap**: root node contains the minimum value
- **Max heap**: root node contains the maximum value

Min Heap



Max Heap



Heap in C++

Two main ways to implement:

1. Using **std::make_heap** from **<algorithm>**

```
std::make_heap(RandomIt first, RandomIt last)
```

```
std::push_heap(RandomIt first, RandomIt last)
```

```
std::pop_heap(RandomIt first, RandomIt last)
```

```
std::sort_heap(RandomIt first, RandomIt last)
```

2. Using **std::priority_queue** from **<queue>** **(recommended)**

```
std::priority_queue<T, Container, Compare>
```


Heap in C++ – `std::priority_queue` example

Min heap

```
std::priority_queue<int, std::vector<int>, std::greater<int>>
```

Max heap

```
std::priority_queue<int> or
```

```
std::priority_queue<int, std::vector<int> std::less<int>>
```

```
// Min heap
std::priority_queue<int, std::vector<int>, std::greater<int>> minHeap;

minHeap.push(3);
minHeap.push(6);
minHeap.push(4);
// remove top element (3)
minHeap.pop();
// root node (top) is now 4
std::cout << minHeap.top();
```

Problem – Kth Largest Element in an Array

Medium

<https://leetcode.com/problems/kth-largest-element-in-an-array>

Problem

Given an integer array `nums` and an integer `k`, return the k^{th} largest element in the array. Note that it is the k^{th} largest element in the sorted order, not the k^{th} distinct element.

Example 1

Input: `nums = [3,2,1,5,6,4]`, `k = 2`

Output: 5

Example 2

Input: `nums = [3,2,3,1,2,4,5,5,6]`, `k = 4`

Output: 4

Although this problem is classified as “medium”, in my opinion it should be classified as “easy”

Solution 1 – Kth Largest Element in an Array

Medium

<https://leetcode.com/problems/kth-largest-element-in-an-array>

// SOLUTION 1

```
int findKthLargest(vector<int>& nums, int k) {
    std::priority_queue<int, std::vector<int>, std::greater<int>> minHeap;
    for (const auto& num : nums) {
        if (minHeap.size() < k) {
            minHeap.push(num);
        } else if (num > minHeap.top()) {
            minHeap.pop();
            minHeap.push(num);
        }
    }
    return minHeap.top();
}
```

Solution 2 – Kth Largest Element in an Array

Medium

<https://leetcode.com/problems/kth-largest-element-in-an-array>

```
// SOLUTION 2 - Simpler approach
```

```
int findKthLargest(vector<int>& nums, int k) {  
    // min heap: minimum values will be always at the top  
    std::priority_queue<int, std::vector<int>, std::greater<int>> minHeap;  
    for (const auto& num : nums) {  
        // push each num to the heap  
        minHeap.push(num);  
        // we need the kth largest element only, so once after pushing more than k  
        // elements, remove the smallest one (the top)  
        if (minHeap.size() > k) {  
            minHeap.pop();  
        }  
    }  
    return minHeap.top();  
}
```

Problem – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Problem

- You are given an **array** of numbers and an **integer** k
- Return an array with the **k** most frequent elements

Example

Input:

$\text{nums} = [1, 1, 1, 2, 2, 3], k = 2$

Output:

$[1, 2]$

Solution – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Solution (1) - hashmap + array sort

- Go over the array, count the numbers and store them in an *unordered_map*

Example:

`nums = [1,1,1,2,2,3], k = 2`

`freq[1] = 3`

`freq[2] = 2`

`...`

- Go over the *unordered_map*, add to an array and sort descending
- Create another array adding the **k** first elements and return

Code – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Code (1) Time: $O(n \log n)$ Space: $O(n)$

```
vector<int> topKFrequent(vector<int>& nums, int k) {  
    // 1. Create the number's frequency map  
    // O(n)  
    unordered_map<int, int> freq;  
    for (const auto& num : nums) {  
        freq[num] += 1;  
    }  
    // 2. Create an array with the frequencies  
    vector<pair<int, int>> freqVec(freq.begin(), freq.end());  
    // 3. Sort by the frequency  $O(n \log n)$   
    sort(freqVec.begin(), freqVec.end(), [](auto& a, auto& b) {  
        return a.second > b.second;  
    });  
    // 4. Create the result with the k first elements  
    // O(k)  
    vector<int> result;  
    for (int i = 0; i < k; ++i) {  
        result.push_back(freqVec[i].first);  
    }  
    return result;  
}
```

Solution – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Solution (2) - hashmap + min heap

- Go over the array, count the numbers and store them in an *unordered_map*

Example:

`nums = [1,1,1,2,2,3], k = 2`

`freq[1] = 3`

`freq[2] = 2`

`...`

- Go over the frequencies, add to a min heap. If the size of the heap exceeds **k**, remove the top one (the minimum value)
- Create another array result adding all elements from the heap and return it

Code – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Code (2) Time: $O(n \log k)$ Space: $O(n)$

```
vector<int> topKFrequent(vector<int>& nums, int k) {
    // 1. Create the number's frequency map
    // O(n)
    unordered_map<int, int> freq;
    for (const auto& num : nums) {
        freq[num] += 1;
    }
    // 2. Create the min heap with priority queue
    // O(n log k)
    priority_queue<pair<int, int>, vector<pair<int, int>>, greater<>> minHeap;
    for (const auto& [num, count] : freq) {
        minHeap.push({count, num});
        if (minHeap.size() > k) minHeap.pop();
    }
    // 3. build the result
    vector<int> result;
    while (!minHeap.empty()) {
        auto num = minHeap.top().second;
        minHeap.pop();
        result.push_back(num);
    }
    return result;
}
```

Solution – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Solution (3) - hashmap + bucket sort

- Go over the array, count the numbers and store them in an *unordered_map*

Example:

`nums = [1,1,1,2,2,3], k = 2`

`freq[1] = 3`

`freq[2] = 2`

...

- Create buckets for each frequency and add the corresponding numbers:

`bucket[1] = [3]` → 3 only appears once in *nums*

`bucket[2] = [2]` → 2 appears twice

`bucket[3] = [1]` → 1 appears three times

- Go over each bucket, add to the result and return it

Code – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Code (3) Time: $O(n)$ Space: $O(n)$

```
vector<int> topKFrequent(vector<int>& nums, int k) {  
    // Create the number's frequency map  
    unordered_map<int, int> freq;  
    for (const auto& num : nums) {  
        freq[num]++;  
    }  
    // create the buckets  
    // e.g. [[1,2,3],[4,5,6]] ...  
    vector<vector<int>> buckets(nums.size() + 1);  
    for (const auto& [num, count] : freq) {  
        buckets[count].push_back(num);  
    }  
    // go over each bucket to build the result  
    vector<int> result;  
    for (int i = buckets.size() - 1; i >= 0; --i) {  
        for (const auto& num : buckets[i]) {  
            result.push_back(num);  
            if (result.size() == k) return result;  
        }  
    }  
    return result;  
}
```

Problem – 347. Top K Frequent Elements

Medium



LeetCode

leetcode.com/problems/top-k-frequent-elements

Some considerations

- Theoretically, bucket sort should be the fastest solution $O(n) < O(n \log k)$
- In practice, min heap end up being faster:
 - fewer allocations: priority_queue stores flat pairs rather than inner vectors
 - better cache locality: heap is built over a single array (binary heap)
 - if **k** is small, heap touches fewer elements

MATRIX

Problem – 73. Set Matrix Zeroes

Medium



LeetCode

leetcode.com/problems/set-matrix-zeroes

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 54. Spiral Matrix

Medium



LeetCode

leetcode.com/problems/spiral-matrix

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

1 →	2 →	3
4 →	5	↓ 6
↑ 7	← 8 ←	↓ 9

Problem – 48. Rotate Image

Medium



LeetCode

leetcode.com/problems/rotate-image

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

DYNAMIC PROGRAMMING

Dynamic Programming

Dynamic Programming (DP) is an algorithm technique used to solve problems that can be broken down into **simpler, overlapping subproblems**.

Key Concepts of Dynamic Programming

- **Overlapping subproblems:** a problem has overlapping subproblems if it can be broken down into subproblems.
- **Memoization (Top-Down Approach):** store the results in a cache (typically a dictionary or array) to avoid recalculation – recursion and caching approach.
- **Tabulation (Bottom-Up Approach):** first solve all possible subproblems iteratively, and store them in a table.

Common Patterns in Dynamic Programming

- **Toy example (Fibonacci):** Climbing Stairs, N-th Tribonacci Number, Perfect Squares
- **Constant Transition:** Min Cost Climbing Stairs, House Robber, Decode Ways, Minimum Cost For Tickets, Solving Questions With Brainpower
- **Grid:** Unique Paths, Unique Paths II, Minimum Path Sum, Count Square Submatrices with All Ones, Maximal Square, Dungeon Game
- **Dual-Sequence:** Longest Common Subsequence, Uncrossed Lines, Minimum ASCII Delete Sum for Two Strings, Edit Distance, Distinct Subsequences, Shortest Common Supersequence
- **Interval:** Longest Palindromic Subsequence, Stone Game VII, Palindromic Substrings, Minimum Cost Tree From Leaf Values, Burst Balloons, Strange Printer
- **Longest Increasing Subsequence:** Count Number of Teams, Longest Increasing Subsequence, Partition Array for Maximum Sum, Largest Sum of Averages, Filling Bookcase Shelves
- **Knapsack:** Partition Equal Subset Sum, Number of Dice Rolls With Target Sum, Combination Sum IV, Ones and Zeroes, Coin Change, Coin Change II, Target Sum, Last Stone Weight II, Profitable Schemes
- **Topological Sort on Graphs:** Longest Increasing Path in a Matrix, Longest String Chain, Course Schedule III
- **DP on Trees:** House Robber III, Binary Tree Cameras
- **Other problems:** 2 Keys Keyboard, Word Break, Minimum Number of Removals to Make Mountain Array, Out of Boundary Paths

Credits

https://www.youtube.com/watch?v=9k31KcQmS_U

<https://algo.monster/problems/dp-list>

Dynamic Programming – Example – Fibonacci Sequence

Naive Recursive Approach

$O(2^n)$

```
int fib(int n) {  
    if (n <= 1) {  
        return n;  
    }  
    return fib(n - 1) + fib(n - 2);  
}
```

Memoization (Top-Down DP)

$O(n)$

```
std::unordered_map<int, int> memo;  
  
int fib(int n) {  
    if (n <= 1) {  
        return n;  
    }  
    if (memo.find(n) != memo.end()) {  
        return memo[n];  
    }  
    memo[n] = fib(n - 1) + fib(n - 2);  
    return memo[n];  
}
```

Tabulation (Bottom-up DP)

$O(n)$

```
int fib(int n) {  
    if (n <= 1) {  
        return n;  
    }  
    int dp[n + 1];  
    dp[0] = 0;  
    dp[1] = 1;  
    for (int i = 2; i <= n; i++) {  
        dp[i] = dp[i - 1] + dp[i - 2];  
    }  
    return dp[n];  
}
```

Problem – Climbing Stairs

Easy



LeetCode

leetcode.com/problems/climbing-stairs

Problem Statement

You need to climb a staircase with n steps to get to the top. Each time you can choose to climb either **1 step** or **2 steps** at a time. Find out how many different ways you can climb to the top of the staircase.

Example 1

Input: $n = 2$

Output: 2

Explanation: There are two ways to get to the top

1. Climb 1 step at a time, twice
2. Climb 2 steps in one go

Example 2:

Input: $n = 3$

Output: 3

Explanation: There are three ways to get to the top:

1. Climb 1 step at a time, three times
2. Climb 1 step, then 2 steps
3. Climb 2 steps, then 1 ste.

Solution – Climbing Stairs

Easy



LeetCode

leetcode.com/problems/climbing-stairs

```
std::unordered_map<int, int> memo;
```

```
int climbStairs(int n) {  
    // Identify the sequence, when:  
    // n = 0 (0 way), there is no way to get up  
    // n = 1 (1 way): only one way : 1-step  
    // n = 2 (2 ways): 1s + 1s | 2s  
    // n = 3 (3 ways): 1s + 1s + 1s | 1s + 2s | 2s + 1s  
    // n = 4 (5 ways): 1s + 1s + 1s + 1s | 1s + 1s + 2s | 1s + 2s + 1s | 2s + 1s + 1s | 2s + 2s |  
  
    if (n <= 2) {  
        return n;  
    }  
  
    if (memo.find(n) != memo.end()) {  
        return memo[n];  
    }  
  
    memo[n] = climbStairs(n - 1) + climbStairs(n - 2);  
    return memo[n];  
}
```

Problem – 1143. Longest Common Subsequence

Medium

 <https://leetcode.com/problems/longest-common-subsequence>

Problem Statement / Solution / Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Problem

- The robot is placed in a $m \times n$ grid
- It starts at the top-left cell $(0,0)$ and must reach the bottom-right $(m - 1, n - 1)$
- The robot can only move right or down at any point
- Return the number of unique paths the robot can take to reach the destination



Solution – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Solution 1 (recursive)

- Define a recursive function `countPaths(m, n)`

- **Base case**

If $m == 1$ or $n == 1$, there's only one way to reach that cell (either all downs or all rights).

- **Recursive case**

To reach cell (m, n) the robot must come from:

Cell $(m - 1, n) \rightarrow$ from above

Cell $(m, n - 1) \rightarrow$ from left

So the number of of paths to (m, n) is the **sum** of the paths to those two cells

- **Memoization**

Use a 2D vector `[m + 1][n + 1]`

Code – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Code Time: $O(m * n)$ Space: $O(m * n)$

```
int countPaths(int m, int n, vector<vector<int>>& memo) {
    if (m == 1 || n == 1) return 1;
    if (memo[m][n] != -1) return memo[m][n];
    memo[m][n] = countPaths(m, n - 1, memo) + countPaths(m - 1, n, memo);
    return memo[m][n];
}
int uniquePaths(int m, int n) {
    /*
        count(m, n) = count(m, n + 1) + count(m + 1, n)
        same as (imagine robot going from m,n to 0,0 up and left)
        count(m, n) = count(m, n - 1) + count(m - 1, n)
    */
    vector<vector<int>> memo(m + 1, vector<int>(n + 1, -1));
    return countPaths(m, n, memo);
}
```

Solution – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Solution 2 (iterative)

- Create a 2D vector `dp` of size $(m+1) \times (n+1)$ to store intermediate results
 - Set `dp[1][1] = 1` because there is exactly one way to stand on the starting cell
 - Iterate through each cell `(row, col)` from `(1, 1)` to `(m, n)`:
 - Skip `(1, 1)` since it's already initialized
 - For every other cell, the number of unique paths to it is the sum of:
 - Paths from the cell above: `dp[row-1][col]`
 - Paths from the cell to the left: `dp[row][col-1]`
- `dp[row][col] = dp[row - 1][col] + dp[row][col - 1]`**

Code – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Code Time: $O(m * n)$ Space: $O(m * n)$

```
int uniquePaths(int m, int n) {
    vector<vector<int>> dp(m + 1, vector<int>(n + 1));
    dp[1][1] = 1;
    for (int row = 1; row <= m; ++row) {
        for (int col = 1; col <= n; ++col) {
            if (row == 1 && col == 1) continue;
            dp[row][col] = dp[row-1][col] + dp[row][col-1];
        }
    }
    return dp[m][n];
}
```

```
// Optimized 1DP
int uniquePaths(int m, int n) {
    vector<int> dp(n, 1); // base case: first row is all 1s
    for (int row = 1; row < m; ++row) {
        for (int col = 1; col < n; ++col) {
            dp[col] = dp[col] + dp[col - 1];
        }
    }
    return dp[n - 1];
}
```

Solution – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Solution 3 (combinatorics)

- **Grid size:** $m \times n$
- **Start:** top-left cell $(0, 0)$
- **End:** bottom-right cell $(m - 1, n - 1)$
- To get from the top-left to the bottom-right:

You must move exactly $m - 1$ times down

And exactly $n - 1$ times right

These two types of moves must be made in some order, with a total of:

$$(m - 1) + (n - 1) = m + n - 2 \text{ moves}$$

- **Hence**, from a sequence of $m + n - 2$ moves, choose $m - 1$ of them to be down moves (the rest will be right), or vice versa

$$\text{Number of unique paths} = \binom{m + n - 2}{m - 1} = \frac{(m + n - 2)!}{(m - 1)! (n - 1)!}$$

Code – 62. Unique Paths

Medium



LeetCode

<https://leetcode.com/problems/unique-paths>

Code Time: $O(\min(m,n))$ Space: $O(1)$

```
int uniquePaths(int m, int n) {
    // we will compute the binomial coefficient:
    // (m + n - 2) choose (m - 1) => total moves choose down moves
    // = (m + n - 2)! / ((m - 1)! * (n - 1)!)

    long long res = 1;

    // we compute the result iteratively to avoid large factorials
    // res = (n) * (n+1) * ... * (m+n-2) / (1 * 2 * ... * (m - 1))

    for (int i = 1; i <= m - 1; ++i) {
        // multiply numerator: (n - 1 + i)
        // divide by denominator: i
        res = res * (n - 1 + i) / i;
    }

    return (int)res;
}
```

Problem – 983. Minimum Cost For Tickets

Medium



LeetCode

leetcode.com/problems/minimum-cost-for-tickets

Problem

- You are given two arrays of integers, days and costs
- Days represent

Problem – 983. Minimum Cost For Tickets

Medium



LeetCode

leetcode.com/problems/minimum-cost-for-tickets

Solution

- ...

Problem – 983. Minimum Cost For Tickets

Medium



LeetCode

leetcode.com/problems/minimum-cost-for-tickets

Code Time: $O(-)$ Space: $O(-)$

■ ...

Problem – 198. House Robber

Medium



LeetCode

leetcode.com/problems/house-robber

Problem

- You are robbing houses lined up in a row
- Each house has a cash value **nums[i]**
- You **cannot rob two adjacent houses**
- Goal: maximize total money robbed without triggering alarms



LeetCode

leetcode.com/problems/house-robber

Solution

- Solve as a DP problem
- `dp` represents the maximum value you can get once rob only `i` or the previous houses
- At each “house” `i`, you can either rob or skip

- **Example**

`nums = [1,2,3,1]`

at position `i = 0`, you can have two options:

rob: you end up with 1; or **skip**: you end up with 0

at position `i = 1`

rob: you get 2 + total of two houses before; or **skip**: total of robbed before

- Therefore:

rob = `nums[0] + dp[i - 2]`

skip = `dp[i - 1]`

Problem – 198. House Robber

Medium



LeetCode

leetcode.com/problems/house-robber

Code Time: $O(n)$ Space: $O(n)$

```
int rob(vector<int>& nums) {
    int n = nums.size() + 1;
    // base case: start dp[0] = 0 (no rob)
    // dp[1] = nums[0]
    vector<int> dp(n, 0);
    dp[1] = nums[0];
    for (int i = 2; i < n; ++i) {
        int numPos = i - 1;
        // if I rob
        int rob = nums[numPos] + dp[i - 2];
        // if I skip
        int skip = dp[i - 1];
        dp[i] = max(rob, skip);
    }
    return dp[n - 1];
}
```

Problem – 198. House Robber

Medium



LeetCode

leetcode.com/problems/house-robber

Code (space optimized) Time: $O(n)$ Space: $O(1)$

```
int rob(vector<int>& nums) {
    int prev = nums[0];
    int prev2 = 0;

    for (int i = 2; i <= nums.size(); ++i) {
        int numPos = i - 1;
        // if I rob
        int rob = nums[numPos] + prev2;
        // if I skip
        int skip = prev;
        prev2 = prev;
        prev = max(rob, skip);
    }
    return prev;
}
```

Problem – 213. House Robber II

Medium



LeetCode

leetcode.com/problems/house-robber-ii

Problem

- Similar to House Robber I but with a new constraint:
- You are robbing houses **lined up in a circle**
- Each house has a cash value **nums[i]**
- You **cannot rob two adjacent houses**
- You **cannot rob the last and first houses at the same time**
- Goal: maximize total money robbed without triggering alarms

Solution – 213. House Robber II

Medium



LeetCode

leetcode.com/problems/house-robber-ii

Solution

- 1
- 2

Code – 213. House Robber II

Medium



LeetCode

leetcode.com/problems/house-robber-ii

Code Time: $O(-)$ Space: $O(-)$

- 1
- 2

EOF

Problem Statement / Solution / Code Time: $O(n)$ Space: $O(n)$

- ...

Problem – number. name

Easy

Hard

Medium



LeetCode

leetcode.com/problems/...

Problem / Solution / Code Time: $O(-)$ Space: $O(-)$

- 1
- 2