Trapping Rainwater Problem

Session No.: 07
Course Name: Advanced Algorithmic Problem Solving
Course Code: R1UC601B
Instructor Name: Dr. Jitendra
Duration: 50 mins
Date of Conduction of Class: 20 Feb 2026

Recap of Previous Topic

[1-mins]

Bit Manipulation

Concept and Definition for (LO-1)
Optimized Approach
Brian Kernighan's Algorithm

```
vector<int> countBitsOptimized(int n)
{
    vector<int> result;
     for (int i = 0; i <= n; i++) {
       int count = 0, num = i;
       while (num > 0)
       {
         // Removes the last set bit
         num = num & (num - 1);
         count++;
       }
       result.push_back(count);
    }
    return result;
}
```

```
int main()
{
    int n = 5;
    vector<int> res = countBitsOptimized(n);

    for (int i = 0; i <= n; i++) {
        cout << res[i] << " ";
    }
    return 0;
}
```

Time Complexity: O(nlogn)
Each number takes O(number of set bits), which is at most O(logn). Its **Faster**

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Concept and Definition for (LO-2)
Optimized Approach

A number n is a power of two **if and only if** it has exactly **one set bit** in its binary representation.

Using **bitwise AND**: $n\&(n-1)==0$

- This expression removes the lowest set bit.
- If the result is 0, then n had only **one** set bit, meaning it was a power of two.

Time Complexity: O(1)
Uses a single **bitwise AND** operation, which is extremely fast.

```
bool isPowerOfTwoOptimized(int n)
{
    return (n > 0) && ((n & (n - 1)) == 0);
}

int main()
{
    int num = 16;
    if (isPowerOfTwoOptimized(num))
        cout << num << " is a power of two." << endl;
    else
        cout << num << " is NOT a power of two." << endl;

    return 0;
}
```

Pre-Class Assessment

[2-mins]

1. Go to wooclap.com
2. Enter the event code in the top banner

Event code
ULCZPY

[1-mins]

Imagine a row of uneven bars forming a histogram, just like buildings in a city skyline. Now, picture a heavy rainfall—some areas between the bars collect water, while others let it flow away.

Your goal is to calculate how much water is trapped between these bars.

Learning Outcomes

[2-mins]

By the end of this session, You will be able to:

Explain the Trapping Rainwater problem statement and its constraints.

Implement different approaches to solve this problem.

Session Outline

- Introduce the Trapping Rainwater problem.
- Explain different approaches.
- Demonstrate optimal strategies to calculate the maximum trapped water efficiently.
- Provide hands-on coding practice to implement the optimized solution.
- Reinforce learning with an interactive quiz and discussion.

Activity-1 (Think – Pair – Share)

[1-mins]

Given an array height[ ], where each element represents the height of a bar, determine how much water can be trapped after the rain.

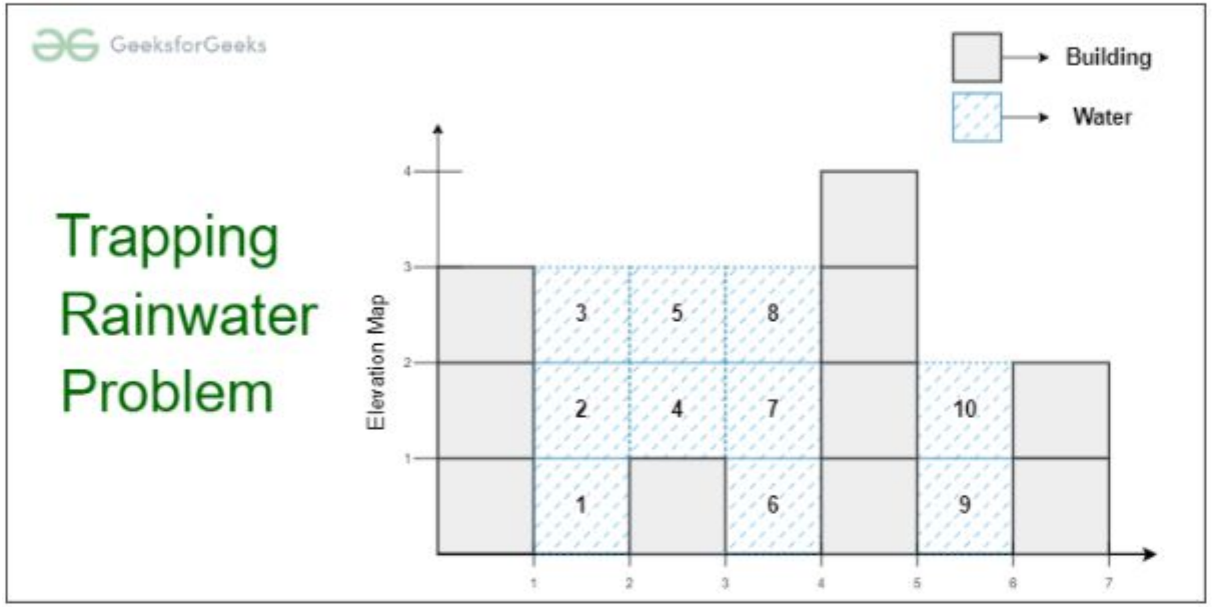
Input:
height [ ]= [4, 2, 0, 3, 2, 5]

Output: 9

Concept and Definition for (LO-1) Trapping Rainwater:

Trapping Rainwater Problem states that given an array of **n** non-negative integers **arr[ ]** representing an elevation map where the width of each bar is **1**, compute **how much water it can trap after rain**.

Examples:
Input: arr[] = [3, 0, 1, 0, 4, 0, 2]
Output: 10
Explanation: The expected rainwater to be trapped is shown in the above image.
Input: arr[] = [3, 0, 2, 0, 4]
Output: 7
Explanation: We trap 0 + 3 + 1 + 3 + 0 = 7 units.
Input: arr[] = [1, 2, 3, 4]
Output: 0
Explanation: We cannot trap water as there is no height bound on both sides
Input: arr[] = [2, 1, 5, 3, 1, 0, 4]
Output: 9
Explanation : We trap 0 + 1 + 0 + 1 + 3 + 4 + 0 = 9 units of water.



Trapping Rainwater Problem

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Concept and Definition for (LO-1) Trapping Rainwater:

The basic intuition of the problem is as follows:

- An element of the array can store water if there are higher bars on the left and the right.
- The amount of water to be stored in every position can be found by finding the heights of the higher bars on the left and right sides.
- The total amount of water stored is the summation of the water stored in each index.
- No water can be filled if there is no boundary on both sides.

[Naive Approach / Brute Force Approach]

Trapping Water Problem (LO-1)

Find left and right max for each index

- Traverse every array element and find the highest bars on the left and right sides.
- Take the smaller of two heights.
- The difference between the smaller height and the height of the current element is the amount of water that can be stored in this array element.

```
// Function to return the maximum water that can be stored
int maxWater(vector<int>& arr)
{
     int res = 0;
    for (int i = 1; i < arr.size() - 1; i++)
    {
       int left = arr[i];
       for (int j = 0; j < i; j++)
              left = max(left, arr[j]);

       int right = arr[i];
       for (int j = i + 1; j < arr.size(); j++)
              right = max(right, arr[j]);

       res += (min(left, right) - arr[i]);
        }
     return res;
}
```

```
int main()
{
    vector<int> arr = { 4, 3, 1, 0, 6 };
    cout << maxWater(arr);
    return 0;
}
```

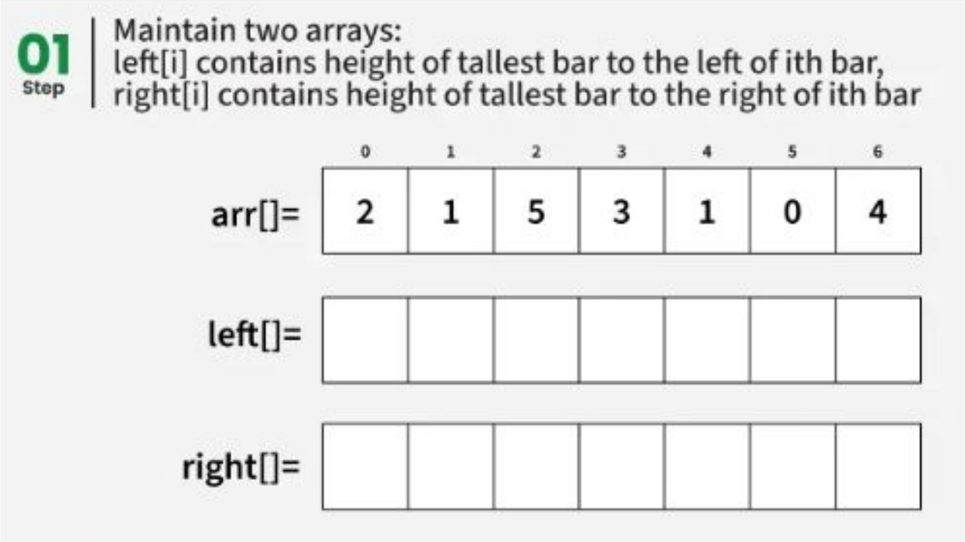
Time Complexity: O(n^2)

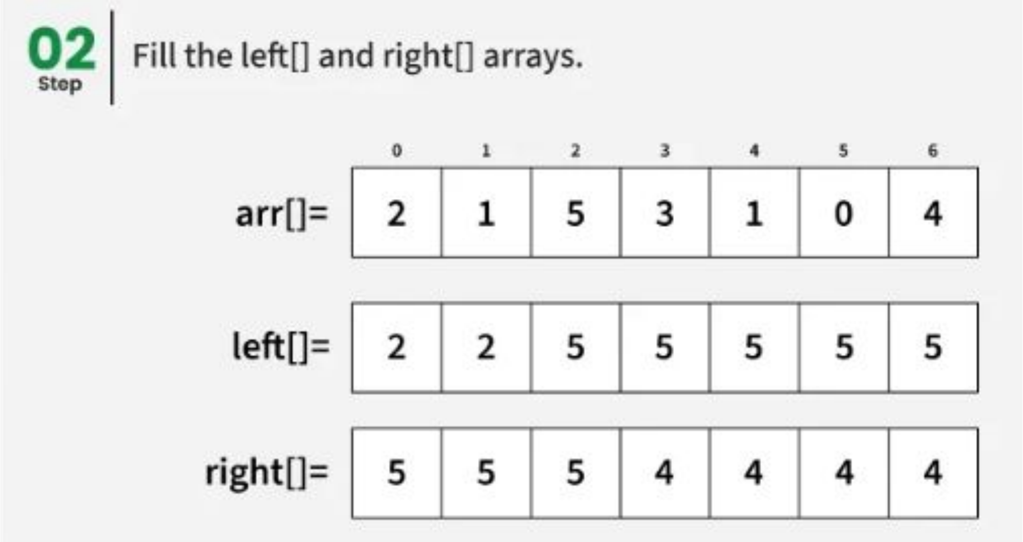
Auxiliary Space: O(1)

Concept and Definition for (LO-2) Better Approach

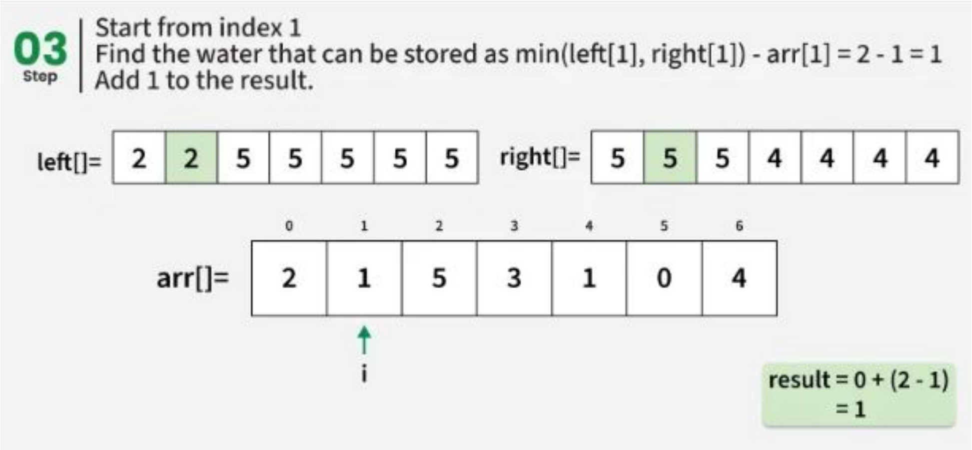
In the previous approach, for every element we needed to calculate the highest element on the left and on the right. So, to reduce the time complexity:

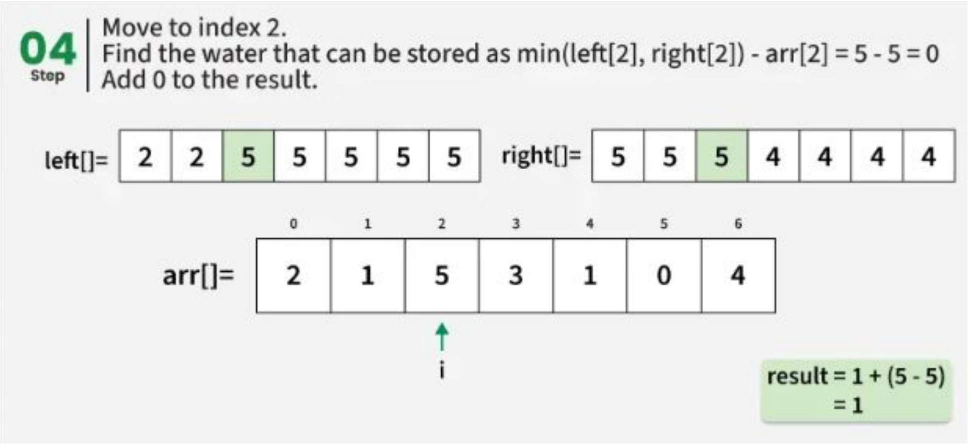
- For every element we first calculate and store the highest bar on the left and on the right (say stored in arrays **left[]** and **right[]**).
- Then iterate the array and use the calculated values to find the amount of water stored in this index, which is the same as (**min(left[i], right[i]) – arr[i]**)

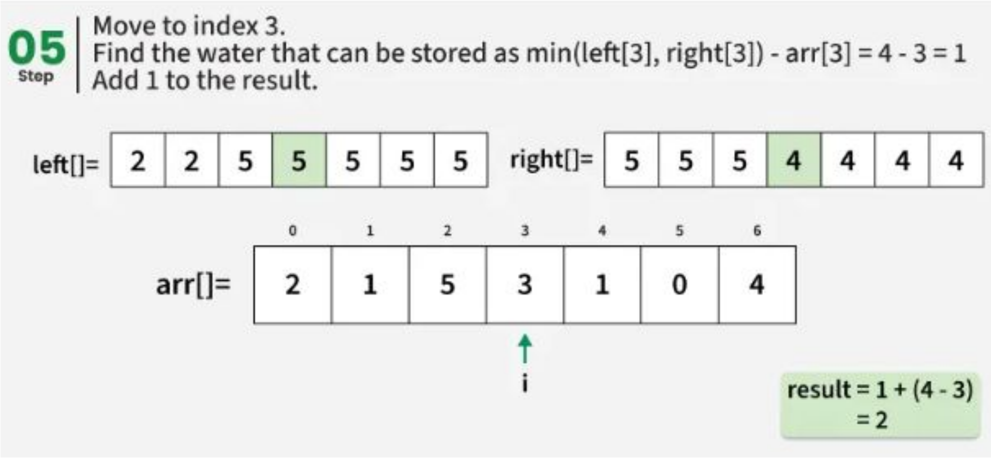


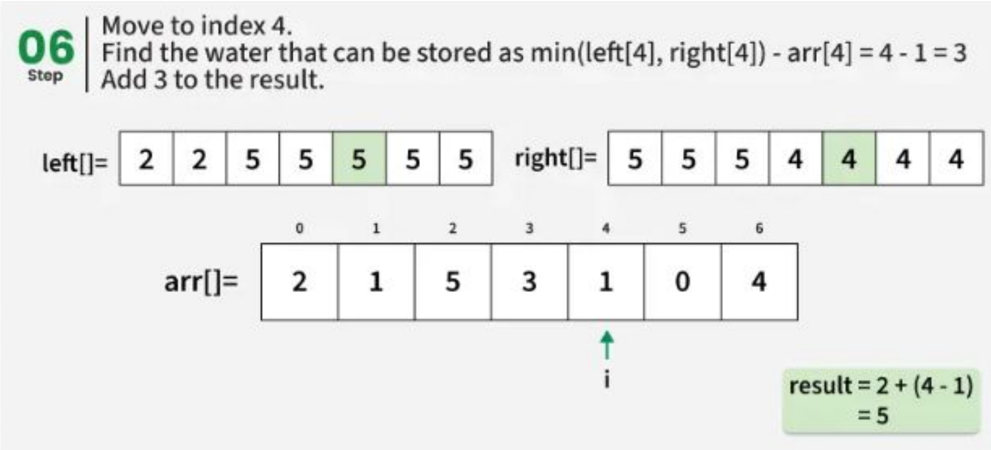


Concept and Definition for (LO-2) Better Approach







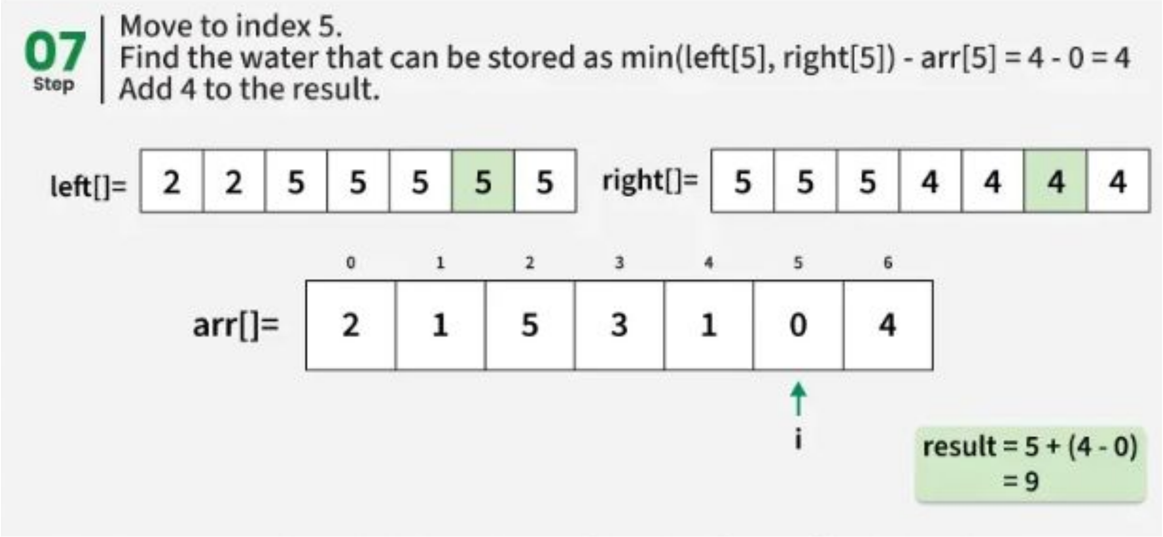


Concept and Definition for (LO-2) Better Approach

```
int maxWater(vector<int>& arr) {
    int n = arr.size();
        vector<int> left(n);
        vector<int> right(n);
    int res = 0;
    left[0] = arr[0];
        for (int i = 1; i < n; i++)
            left[i] = max(left[i - 1], arr[i]);

    right[n - 1] = arr[n - 1];
        for (int i = n - 2; i >= 0; i--)
            right[i] = max(right[i + 1], arr[i]);

    for (int i = 1; i < n - 1; i++) {
            int minOf2 = min(left[i - 1], right[i + 1]);
            if (minOf2 > arr[i]) {
                res += minOf2 - arr[i];
            }
        }
    return res;
}
```



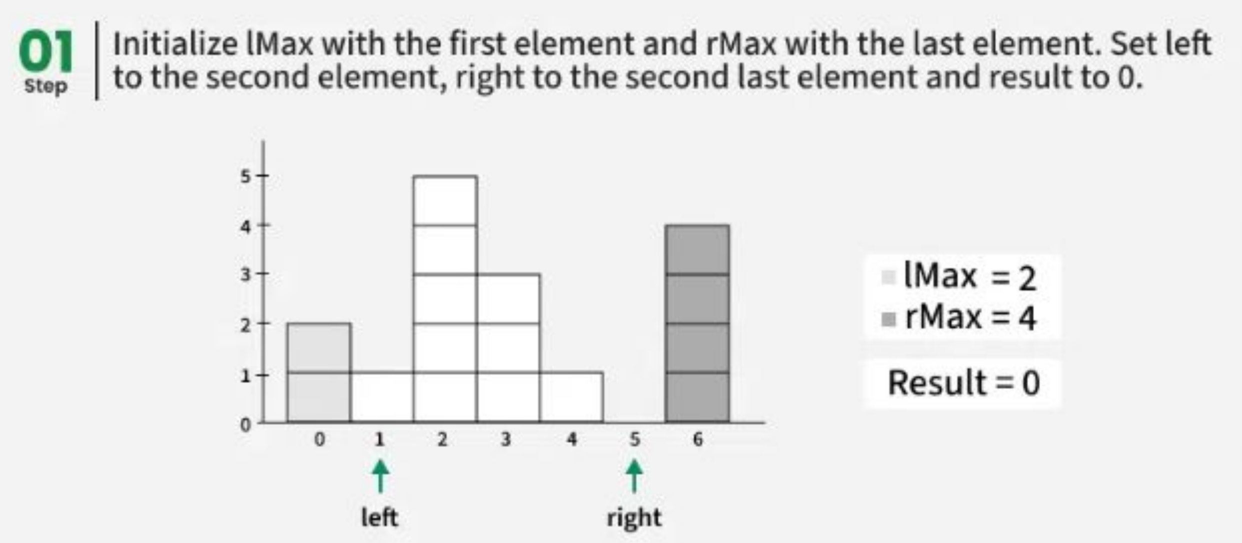
Time Complexity: O(n)

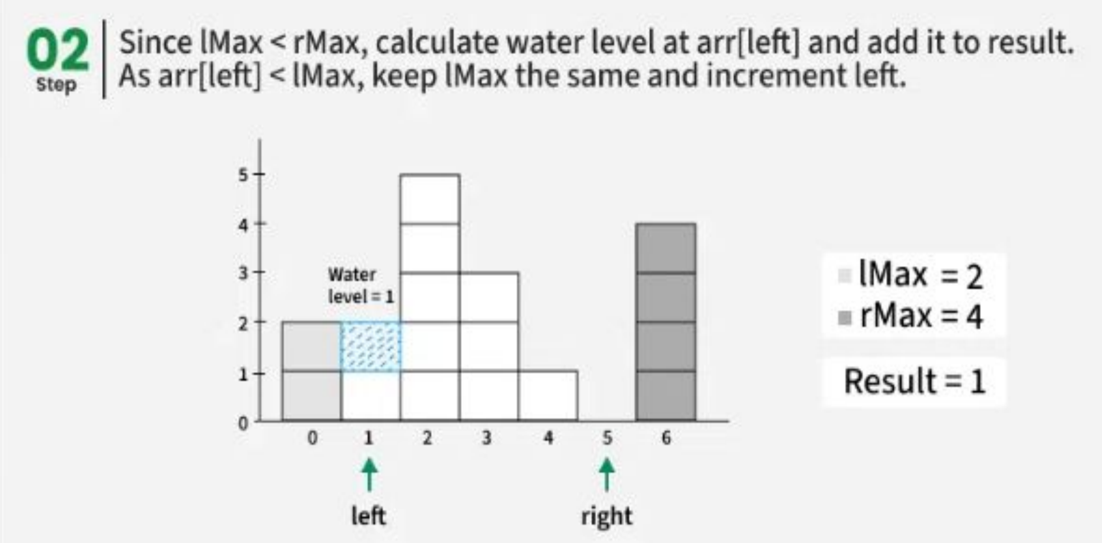
Auxiliary Space: O(n)

Concept and Definition for (LO-2) Optimized Approach

Two Pointer approach is mainly based on the following facts:

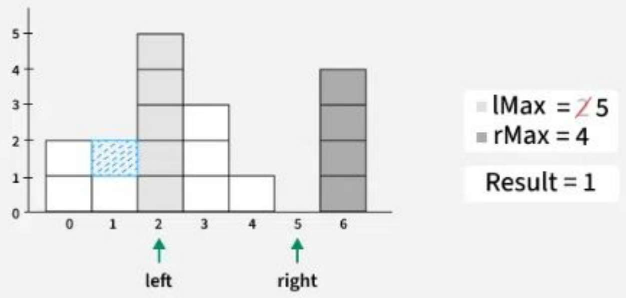
- If we consider a subarray arr[left…right], we can decide the amount of water either for arr[left] or arr[right] if we know the left max (max element in arr[0…left-1]) and right max (max element in arr[right+1…n-1].
- If left max is less than the right max, then we can decide for arr[left]. Else we can decide for arr[right]
- If we decide for arr[left], then the amount of water would be left max – arr[left] and if we decide for arr[right], then the amount of water would be right max – arr[right].



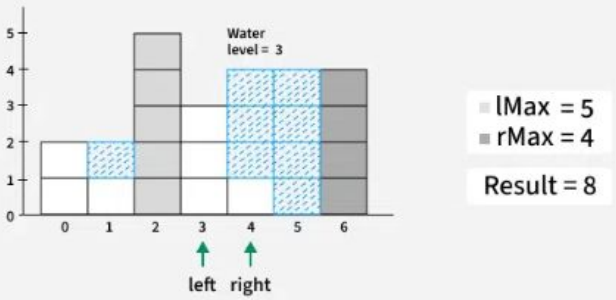


Concept and Definition for (LO-2) Optimized Approach

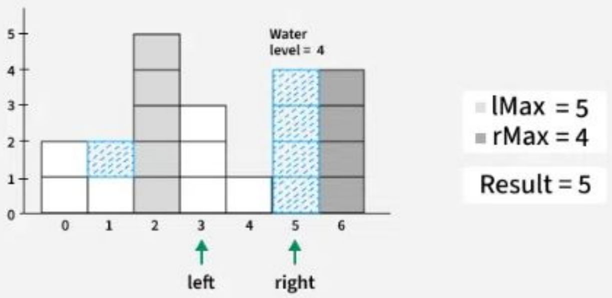
03 Step Again, lMax < rMax, so calculate water level at arr[left] and add it to result.
Now arr[left] > lMax, so update lMax to arr[left] and increment left.



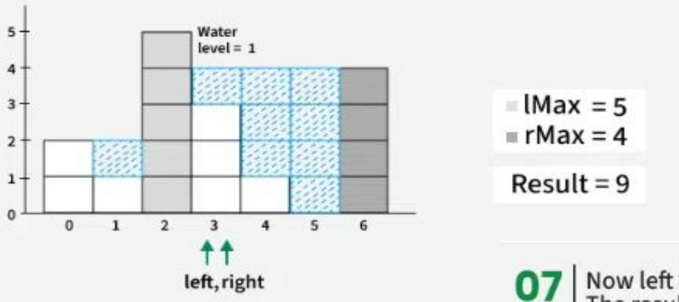
05 Step Again, lMax > rMax, so calculate water level at arr[right] and add it to result.
Since arr[right] < rMax, keep rMax the same and decrement right.



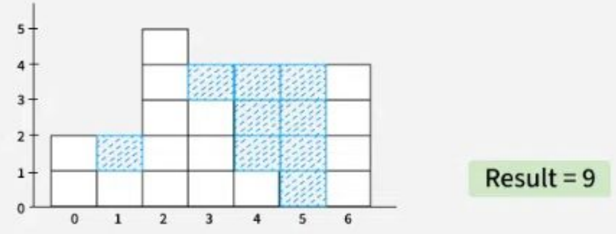
04 Step Since lMax > rMax, calculate water level at arr[right] and add it to result.
As arr[right] < rMax, keep rMax the same and decrement right.



06 Step As lMax > rMax, calculate water level at arr[right] and add it to result.
Since arr[right] < rMax, keep rMax the same and decrement right.



07 Step Now left > right, so the iteration completes.
The result holds the maximum water trapped.



Activity 2 (Pen Paper): Coding Problem

Problem Statement:

- Given an array, find trapping water units with Time Complexity O(n).
- ***Input:*** *arr[] = [3, 0, 2, 0, 4]*
  Output: *7*
  Explanation: *We trap 0 + 3 + 1 + 3 + 0 = 7 units.*

Concept and Definition for (LO-2) Optimized Approach

```
int maxWater(vector<int> &arr) {
    int left = 1;
    int right = arr.size() - 2;

    int lMax = arr[left - 1];
    int rMax = arr[right + 1];

    int res = 0;
    while (left <= right) {
        if (rMax <= lMax) {
            res += max(0, rMax - arr[right]);
            rMax = max(rMax, arr[right]);
            right -= 1;
        }
        else {
            res += max(0, lMax - arr[left]);
            lMax = max(lMax, arr[left]);
            left += 1;
        }
    }
    return res;
}
```

```
int main()
{
    vector<int> arr = {2, 1, 5, 3, 1, 0, 4};    cout
<< maxWater(arr) << endl;
    return 0;
}
```

Time Complexity: O(n), where n is the size of the given array.
Auxiliary Space: O(1)

Assessment: WooFlash Quiz

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https://app.wooflash.com/moodle/1XHK4J...

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1XHK4JQC

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Summary

[1-mins]

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[Naive Approach / Brute Force Approach]

Trapping Water Problem (LO-1)

Find left and right max for each index

- Traverse every array element and find the highest bars on the left and right sides.
- Take the smaller of two heights.
- The difference between the smaller height and the height of the current element is the amount of water that can be stored in this array element.

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Concept and Definition for (LO-2) Optimized Approach

```
int maxWater(vector<int> &arr) {
    int left = 1;
    int right = arr.size() - 2;

    int lMax = arr[left - 1];
    int rMax = arr[right + 1];

    int res = 0;
    while (left <= right) {
       if (rMax <= lMax) {
          res += max(0, rMax - arr[right]);
          rMax = max(rMax, arr[right]);
          right -= 1;
       }
       else {
          res += max(0, lMax - arr[left]);
          lMax = max(lMax, arr[left]);
          left += 1;
       }
    }
    return res;
}
```

```
int main()
{
        vector<int> arr = {2, 1, 5, 3, 1, 0, 4};
        cout << maxWater(arr) << endl;
        return 0;
}
```

Time Complexity: O(n), where n is the size of the given array.
Auxiliary Space: O(1)

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Learning Outcomes

[2-mins]

Ensure attainment of LO’s in alignment to the learning activities:

Explain the Trapping Rainwater problem statement and its constraints.

Implement different approaches to solve this problem.

Discussion on the post session activities

Key points:

- Understanding the Trapping Rainwater Problem: How to calculate the amount of water trapped between histogram bars.

Different Approaches:

- Brute Force ($O(n^2)$) – Time and O(1) – Space : Check water above each bar by scanning left and right heights.
- Dynamic Programming (O(n)) – Time and O(n) – Space : Pre-compute left max and right max for each index.
- Two-Pointer (O(n)) – Time and O(1) – Space : Efficiently track left and right boundaries to calculate trapped water.

Next Session:

Counting Bits: Count the number of 1s in the binary representation of numbers from 0 to n.

Power of Two: Check if a number is a power of two using bit manipulation.

Review and Reflection from students

Lec -11 Pre Class Lecture Notes DOCX

Lec-11 Pre Class Assessment [SCG] Completion

Lec-11 Activity-2 Upload code here [SCG]
Opened: Sunday, 16 March 2025, 12:00 AM **Due:** Sunday, 23 March 2025, 12:00 AM

Lec-11 Post Class Assessment [SCG] Completion