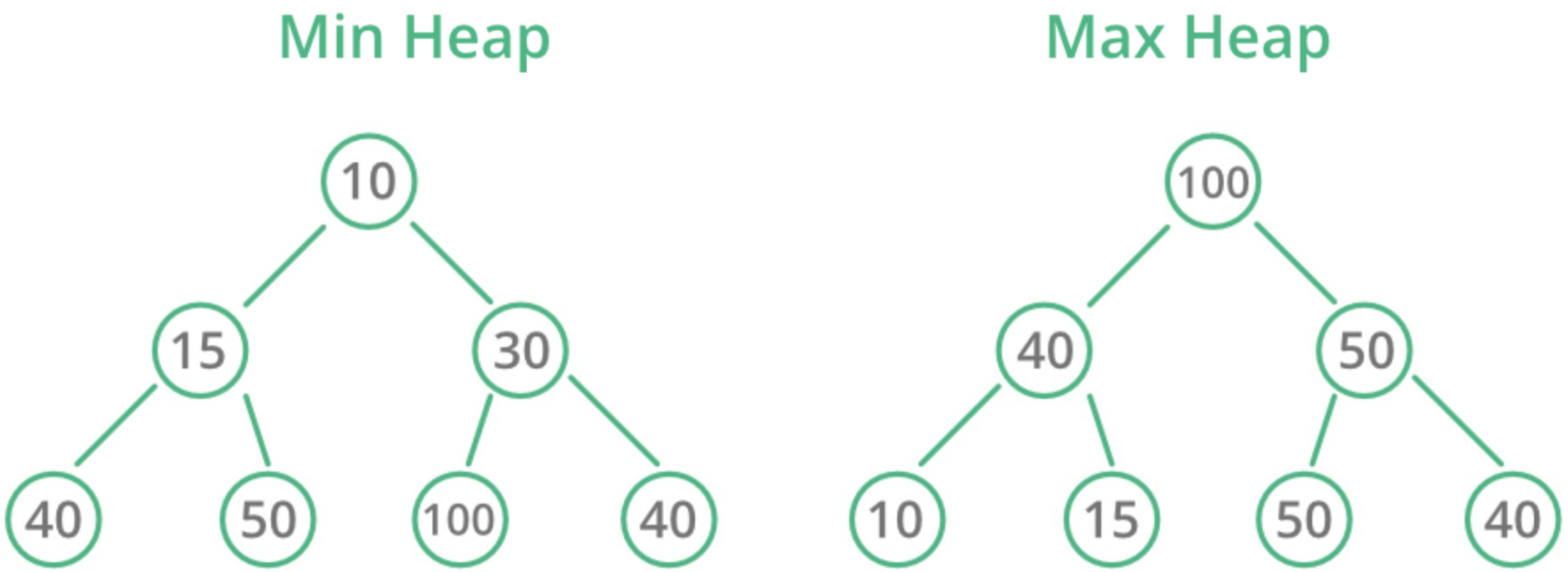
# HEAP / PRIORITY QUEUE

# 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



# 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

```cpp
// 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

```cpp
// 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:**

```
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)**

```cpp
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