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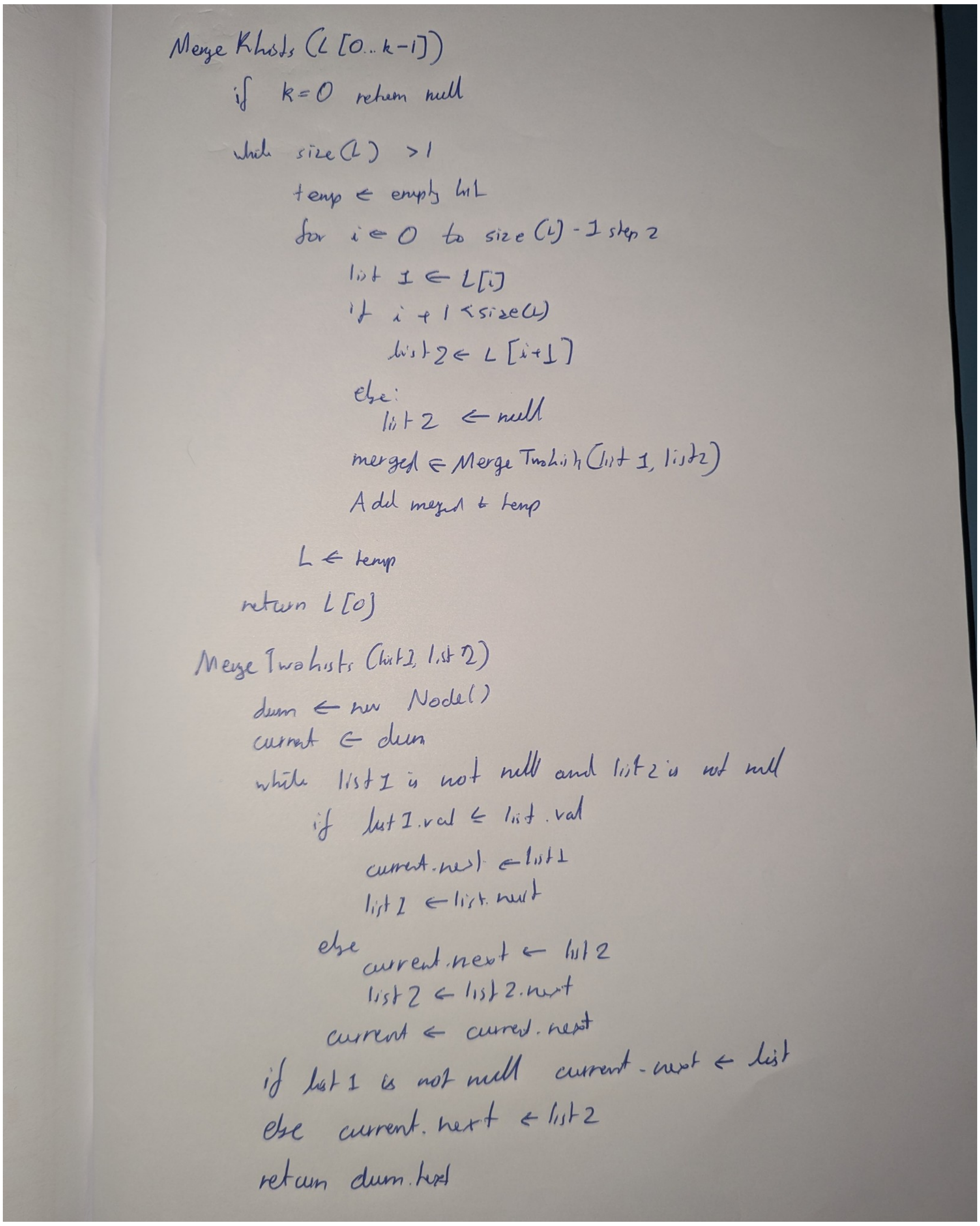
Assignment 4: Algorithms using Divide and Conquer

Competitive Programming

Question 1

Aim: You are given an array of k linked-lists lists, each linked-list is sorted in ascending order. Using divide and conquer, Merge all the linked-lists into one sorted linked-list and return it.

Algorithm



```
MergeKLists (L [0..k-1])
    if k = 0 return null
    while size(L) > 1
        temp ← empty list
        for i ← 0 to size(L) - 1 step 2
            list 1 ← L[i]
            if i + 1 < size(L)
                list2 ← L [i+1]
            else:
                list 2 ← null
            merged ← MergeTwoLists (list 1, list2)
            Add merged to temp
        L ← temp
    return L[0]

MergeTwoLists (list1, list 2)
    dum ← new Node()
    current ← dum
    while list1 is not null and list2 is not null
        if list1.val ≤ list.val
            current.next ← list1
            list1 ← list.next
        else
            current.next ← list2
            list2 ← list2.next
        current ← current.next
    if list1 is not null current.next ← list
    else current.next ← list2
    return dum.next
```

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Code

```
class Solution:
    def mergeKLists(self, lists: List[Optional[ListNode]]) -> Optional[ListNode]:
        if not lists or len(lists) == 0:
            return None

        while len(lists) > 1:
            tmp = []
            for i in range(0, len(lists), 2):
                list_1 = lists[i]
                list_2 = lists[i+1] if i + 1 < len(lists) else None
                tmp.append(self.merge_lists(list_1, list_2))
            lists = tmp

        return lists[0]

    def merge_lists(self, list_1, list_2):
        node = ListNode()
        ans = node

        while list_1 and list_2:
            if list_1.val > list_2.val:
                node.next = list_2
                list_2 = list_2.next
            else:
                node.next = list_1
                list_1 = list_1.next
            node = node.next

        if list_1:
            node.next = list_1
        else:
            node.next = list_2

        return ans.next
```

Time complexity

Recurrence relation:

$$T(k) = 2T(k/2) + f(k)$$

Applying Master's Theorem

A = 2, b = 2,

$f(k) = \Theta(n)$

Comparing a with b^d,

$$a = 2$$

$$b^d = 2^0 = 1$$

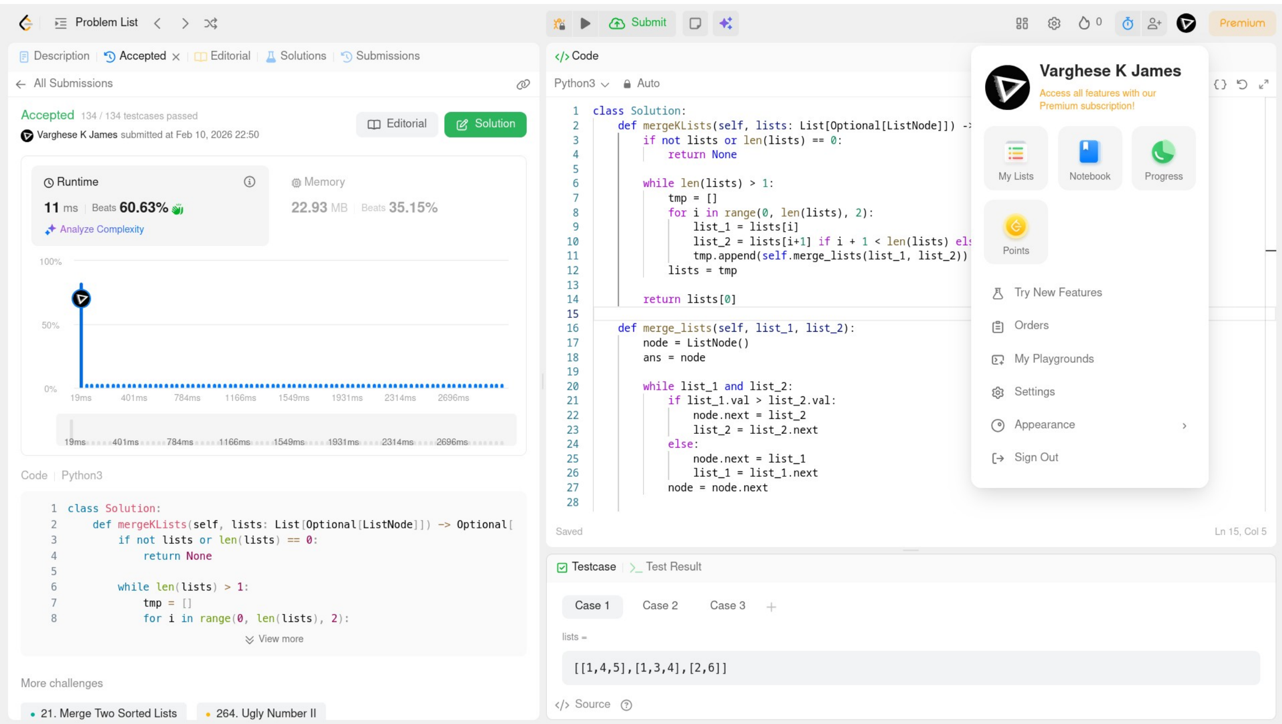
Since a > b^d, standard Master Theorem suggests

$$\Theta(k^{\log_b a}) = \Theta(k^1).$$

However, because the work at each level is actually n, there are log(k) levels.

$$T(n, k) = \Theta(n \log k)$$

Screenshot of Output



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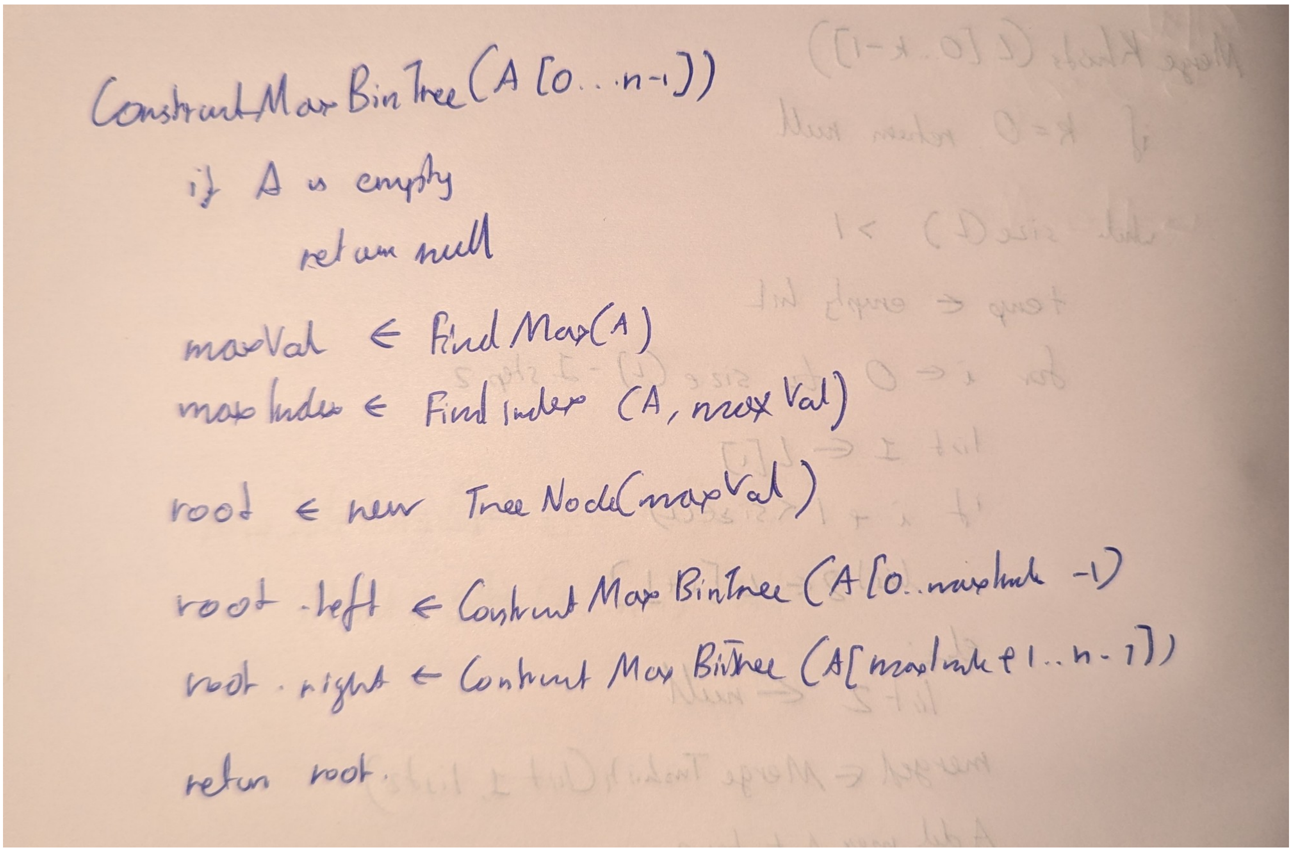
Question 2

Aim: You are given an integer array nums with no duplicates. A maximum binary tree can be built recursively from nums using the following algorithm:

- Create a root node whose value is the maximum value in nums.
- Recursively build the left subtree on the subarray prefix to the left of the maximum value.
- Recursively build the right subtree on the subarray suffix to the right of the maximum value.
- Return the maximum binary tree built from nums.

Algorithm


ConstructMaxBinTree(A[0..n-1])
if A is empty
return null
maxVal ← FindMax(A)
maxIndex ← FindIndex(A, maxVal)
root ← new TreeNode(maxVal)
root.left ← ConstructMaxBinTree(A[0..maxIndex-1])
root.right ← ConstructMaxBinTree(A[maxIndex+1..n-1])
return root.

Code

```
class Solution(object):
    def constructMaximumBinaryTree(self, nums):
        if not nums:
            return
```

```
        element = max(nums)
        index = nums.index(element)

        node = TreeNode(element)

        node.left = self.constructMaximumBinaryTree(nums[0:index])
        node.right = self.constructMaximumBinaryTree(nums[index + 1:])

        return node
```

Time complexity

Recurrence relation:

$$T(n) = T(i) + T(n - i - 1) + \Theta(n)$$

Applying Master's Theorem

A = 2, b = 2,

$$f(n) = n^1 \implies d = 1$$

Since $a = b^d$ ($2 = 2^1$), this is case 2 of Master's Theorem,

$$T(n) \in \Theta(n^d \log n) = \Theta(n \log n)$$

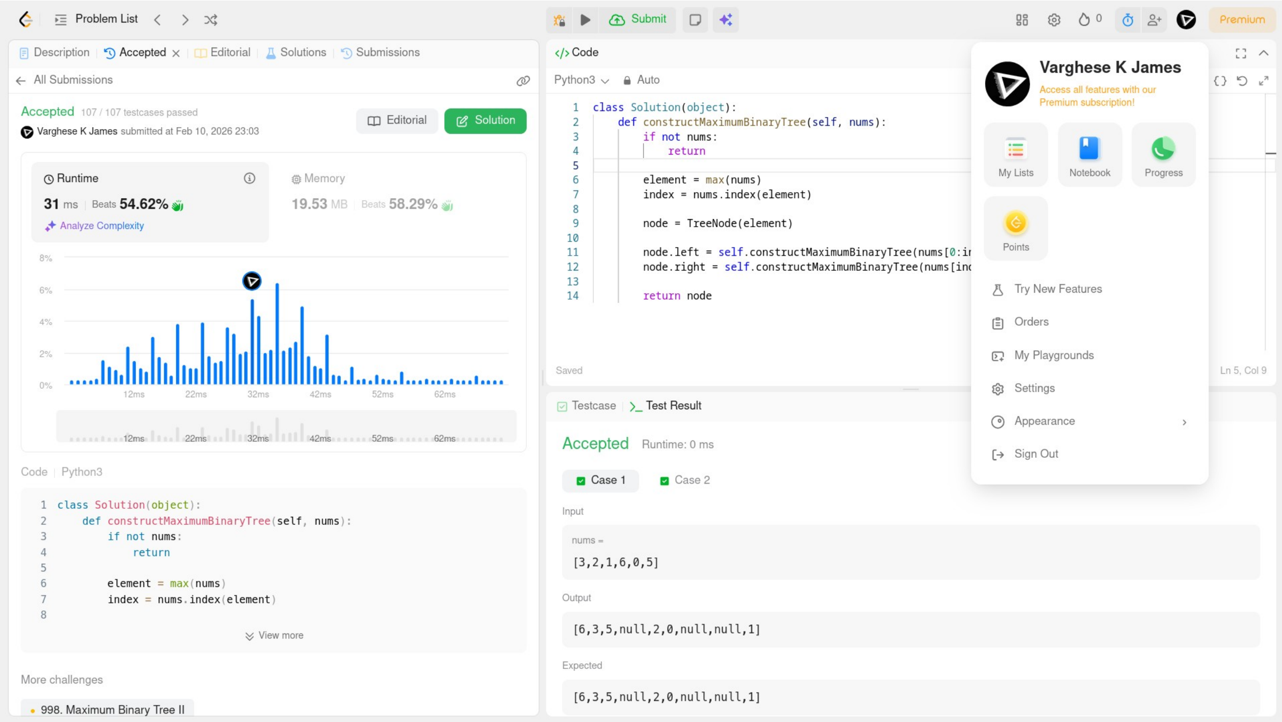
In the worst case,

$$T(n) = T(n - 1) + \Theta(n)$$

This is recursive summation and results in,

$$T(n) \in \Theta(n^2)$$

Screenshot of Output



Question 3

Aim: A city's skyline is the outer contour of the silhouette formed by all the buildings in that city when viewed from a distance. Given the locations and heights of all the buildings, return the skyline formed by these buildings collectively.

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Algorithm

```
Skyline (B[0...n-1])
    n ← length (B)
    if n=0 return []
    if n=1
        [L, R, H ← B[0]
        return [[L,H], [R,0]]
    mid ← ⌊n/2⌋
    leftSkyline ← skyline(B[0..mid-1]))
    rightskyline ← skyline(B[mid..n-1]))
    return MergeSkylines(leftSkyline, rightSkyline)

MergeSkyline(left, right)
  h1 ← 0, h2 ← 0, i ← 0, j ← 0
  result ← empty list
  while i < length(left) and j < length(right)
     if left[i].x < right[j].x
         x ← left[i].x
         h1 ← left[i].h
         i ← i+1
     else if left[i].x > right[j].x
         x ← right[j].x
         h2 ← right[j].x
         j ← j+1
     else:
         x ← left[i].x
         h1 ← left[i].h
         h2 ← right[j].h
         i ← i+1
         j ← j+1
  maxH ← max(h1, h2)
  if result is empty or result.last.h ≠ maxH
     Append [x, maxH] to result
```

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Code

```
class Solution:
    def getSkyline(self, buildings: List[List[int]]) -> List[List[int]]:
        n = len(buildings)
        if n == 0: return []
        if n == 1:
            L, R, H = buildings[0]
            return [[L, H], [R, 0]]

        mid = n // 2
        left = self.getSkyline(buildings[:mid])
        right = self.getSkyline(buildings[mid:])
        return self.merge(left, right)

    def merge(self, left: List[List[int]], right: List[List[int]]) -> List[List[int]]:
        h1, h2 = 0, 0
        i, j = 0, 0
        res = []
        n_l, n_r = len(left), len(right)

        while i < n_l and j < n_r:
            if left[i][0] < right[j][0]:
                x, h1 = left[i]
                i += 1
            elif left[i][0] > right[j][0]:
                x, h2 = right[j]
                j += 1
            else:
                x, h1 = left[i]
                h2 = right[j][1]
                i += 1
                j += 1

            h = max(h1, h2)
            if not res or res[-1][1] != h:
                res.append([x, h])

        res.extend(left[i:] or right[j:])
        return res
```

Time complexity

Recurrence relation:

$$T(n) = 2T(n/2) + \Theta(n)$$

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Applying Master's Theorem:

a = 2, b = 2,

$$f(n) = \Theta(n^1) \implies d = 1$$

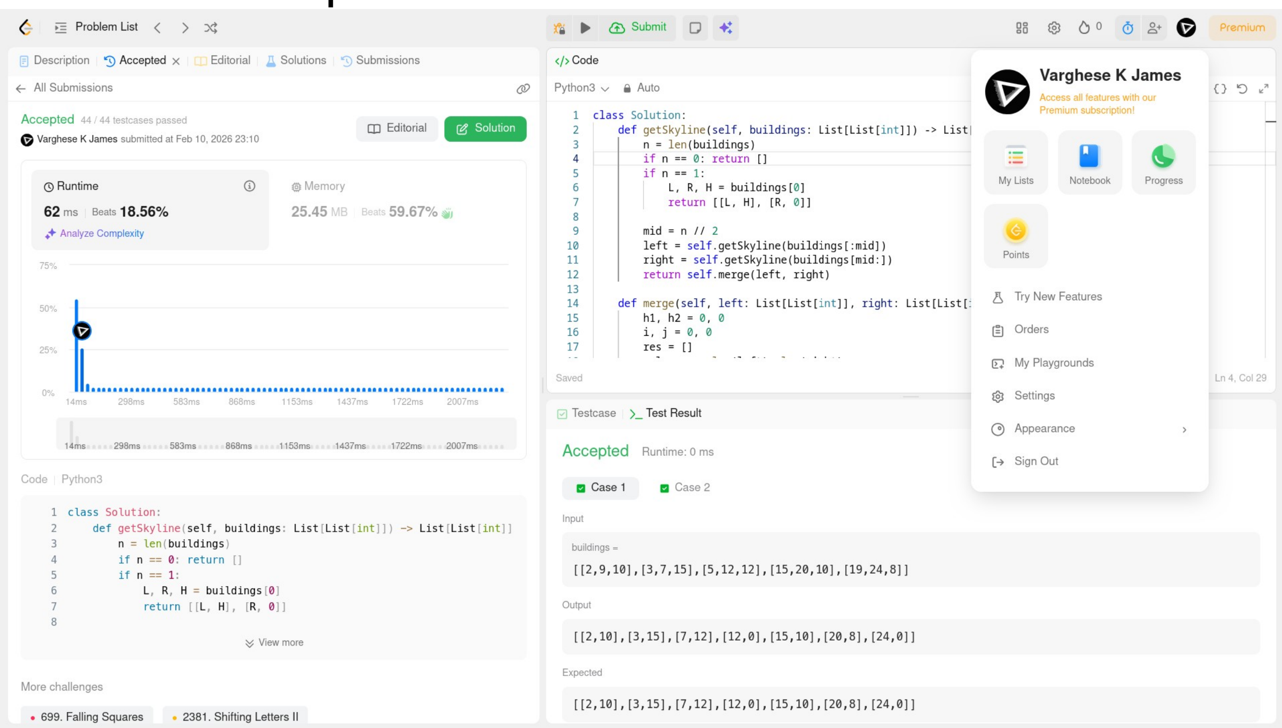
Since, a = b^d (2 = 2), it is case 2 of Master's Theorem

$$T(n) \in \Theta(n^d \log n)$$

Substituting d = 1,

$$T(n) \in \Theta(n \log n)$$

Screenshot of Output



Learning Outcomes

- Learned about using divide and conquer algorithms to solve questions.
- Learned about optimisations done to solve competitive programming questions.