718. Maximum Length of Repeated Subarray

Medium | Array | Binary Search | Dynamic Programming | Sliding Window | Hash Function | Rolling Hash | Leetcode Link

Problem Description

The problem is to find the maximum length of a subarray that appears in both given integer arrays `nums1` and `nums2`. A subarray is a contiguous part of an array. The challenge is to identify the longest sequence of elements that `nums1` and `nums2` have in common, wherever that sequence may appear within the arrays.

Thus, the key point in this challenge is to compare elements at different positions across both arrays and keep track of the length of the current matching subarrays, equipping ourselves to identify the maximum length out of these subarrays.

Intuition

Our approach leverages a classic technique in computer science known as dynamic programming. Specifically, we use a 2D array (let's call it `f`) where `f[i][j]` represents the length of the longest common subarray ending with `nums1[i-1]` and `nums2[j-1]`.

Here's the intuition broken down into steps:

1. Construct a 2D list `f` with dimensions `(m+1) x (n+1)`, where `m` and `n` are the lengths of `nums1` and `nums2`, respectively. Initialize all elements to 0.
2. Loop through each element in `nums1` (index `i`) and `nums2` (index `j`).
3. If we find a match (`nums1[i - 1] == nums2[j - 1]`), this extends a common subarray. Therefore, we set `f[i][j]` to be `f[i - 1][j - 1] + 1`, effectively saying, "the longest common subarray ending here is one longer than the longest at the previous indices.
4. Track the maximum length found during this process with a variable `ans`.
5. After exploring all elements from both arrays, `ans` holds the length of the longest matching subarray found.

Solution Approach

The solution implements a dynamic programming approach to solve the problem efficiently by avoiding the recomputation of overlapping subproblems. Let's walk through the logical steps and explain how the solution is implemented:

1. **Initialization**: Create a 2D list `f` of size `(m+1) x (n+1)` filled with zeros, where `m` and `n` are the lengths of `nums1` and `nums2`, respectively. Here, each element `f[i][j]` is meant to hold the length of the longest common subarray that ends with elements `nums1[i-1]` and `nums2[j-1]`.
2. **Nested Loops for Comparison**: Utilize two nested loops to iterate over both arrays. The outer loop runs through `nums1` using index `i`, while the inner loop runs through `nums2` using index `j`. Both indices start from 1 since the 0-th row and column of `f` will be used as a base for the dynamic programming algorithm and should remain zeroes.
3. **Matching Elements**: Inside the inner loop, check if the elements `nums1[i-1]` and `nums2[j-1]` match. This is important because we are looking for a common subarray, so we are only interested in matching elements.
4. **Updating `f`**: If a match is found, update `f[i][j]` to `f[i-1][j-1] + 1`. This step carries over the length from the previous matching subarray and adds one for the current match. It is the core of the dynamic programming approach as it builds upon previously computed values.
5. **Tracking the Maximum Length**: Keep updating a variable `ans` with the maximum value in the 2D list `f` as we go, by comparing `ans` with `f[i][j]` at each step.

Following this logic, the final value held in `ans` after the loops complete execution will be the length of the longest common subarray between `nums1` and `nums2`. This is because `ans` is updated each time we extend the length of a subarray, and it only keeps the maximum length encountered.

The dynamic programming pattern here exploits the "optimal substructure" property of the problem (the longest subarray ending at an index can be found from longest subarrays ending at previous indices) and avoids redundant calculations, providing an optimally efficient solution.

Example Walkthrough

Let's illustrate the solution approach with small example arrays `nums1` and `nums2`.

Suppose `nums1 = [1, 2, 8, 3]` and `nums2 = [5, 1, 8, 3, 9]`.

1. **Initialization**: We create a 2D list `f` with dimensions `(4+1) x (5+1)` (as `nums1` has length 4 and `nums2` has length 5), so `f` will be a 5×6 grid of zeros. This grid will store the lengths of the longest common subarrays found to our point.
2. **Nested Loops for Comparison**: Begin with nested loops; with `i` iterating from `1` to `4` (for `nums1`) and `j` iterating from `1` to `5` (for `nums2`).
3. **Matching Elements & Updating `f`**:
   - When `i=1` and `j=2`, we find that `nums1[0] == nums2[1]` (which is `1`). So, we update `f[1][2]` to `f[0][1] + 1`. Since `f[0][1]` is `0`, `f[1][2]` becomes `1`.
   - As loops continue, no more matches are found until `i=3` and `j=3`, where `nums1[2] == nums2[2]` (which is `8`); `f[3][3]` is updated to `f[2][2] + 1` and `f[3][3]` becomes `1`.
   - Finally, at `i=4` and `j=4`, `nums1[3] == nums2[3]` (which is `3`). Since we had a match at the previous indices (`nums1[2] == nums2[2]` was `8`), `f[i][j]` becomes `f[3][3] + 1`. `f[3][3]` was `1`, so now `f[4][4]` is `2`. This is the longest subarray we've encountered.
4. **Tracking the Maximum Length**: `ans` is updated each time `f[i][j]` is bigger than the current `ans`. It starts at `0` and becomes `1` after the first match, and then `2` after the last match.

The loops conclude with `ans` holding the value `2`, which is the maximum length of a subarray that appears in both `nums1` and `nums2` (the subarray being `[8, 3]`).

This walk-through has demonstrated how the dynamic programming approach efficiently solves the problem by using previously computed values to build up a solution, avoiding unnecessary recomputation.

Python Solution

```python
from typing import List

class Solution:
    def findLength(self, nums1: List[int], nums2: List[int]) -> int:
        # Get the lengths of the input arrays.
        length_nums1, length_nums2 = len(nums1), len(nums2)

        # Initialize the DP table with all values set to 0.
        # The table dimensions will be (length_nums1 + 1) x (length_nums2 + 1).
        dp_table = [[0] * (length_nums2 + 1) for _ in range(length_nums1 + 1)]

        # Variable to hold the length of the longest common subarray.
        max_length = 0

        # Loop through each element in nums1.
        for i in range(1, length_nums1 + 1):
            # Loop through each element in nums2.
            for j in range(1, length_nums2 + 1):
                # Check if the elements at the current indices are the same.
                if nums1[i - 1] == nums2[j - 1]:
                    # If they are, update the DP table by adding 1 to the value
                    # from the previous indices in both nums1 and nums2.
                    dp_table[i][j] = dp_table[i - 1][j - 1] + 1
                    # Update the max_length if a longer common subarray is found.
                    max_length = max(max_length, dp_table[i][j])

        # Return the length of the longest common subarray.
        return max_length

```

Java Solution

```java
// Class name Solution indicates that this is a solution to a problem.
class Solution {

    // Method findLength returns the length of the longest common subarray between two arrays.
    public int findLength(int[] nums1, int[] nums2) {
        // m and n store the lengths of the two input arrays nums1 and nums2 respectively.
        int m = nums1.length;
        int n = nums2.length;

        // Create a 2D array 'dp' to store the lengths of common subarrays.
        int[][] dp = new int[m + 1][n + 1];

        // Variable 'maxLen' keeps track of the maximum length of common subarrays found so far.
        int maxLen = 0;

        // Iterate over the elements of nums1 and nums2.
        for (int i = 1; i <= m; ++i) {
            for (int j = 1; j <= n; ++j) {
                // Check if elements from both arrays match.
                if (nums1[i - 1] == nums2[j - 1]) {

                    // If they match, increment the value from the previous diagonal element by 1.
                    dp[i][j] = dp[i - 1][j - 1] + 1;

                    // Update 'maxLen' if the current length of the common subarray is greater.
                    maxLen = Math.max(maxLen, dp[i][j]);
                }
                // If elements do not match, the length of common subarray is 0 (by default in Java).
            }
        }

        // Return the maximum length of common subarray found.
        return maxLen;
    }
}

```

C++ Solution

```cpp
#include <vector>
#include <algorithm> // Include library for std::max

using std::vector;
using std::max;

class Solution {
public:
    int findLength(vector<int>& nums1, vector<int>& nums2) {
        // Size of the input vectors
        int sizeNums1 = nums1.size();
        int sizeNums2 = nums2.size();

        // Create a 2D vector to store the length of longest common subarray ending at i-1 and j-1
        vector<vector<int>> dp(sizeNums1 + 1, vector<int>(sizeNums2 + 1));

        // Initialize answer to keep track of the max length of common subarray found so far
        int maxLength = 0;

        // Iterate over nums1 and nums2 vectors
        for (int i = 1; i <= sizeNums1; ++i) {
            for (int j = 1; j <= sizeNums2; ++j) {
                // If elements match, extend the length of the common subarray
                if (nums1[i - 1] == nums2[j - 1]) {
                    dp[i][j] = dp[i - 1][j - 1] + 1;

                    // Update maxLength with the largest length found
                    maxLength = max(maxLength, dp[i][j]);
                }
                // No need to handle the else case explicitly, as the dp array is initialized to 0s
            }
        }

        // Return the maximum length of common subarray found
        return maxLength;
    }
};

```

Typescript Solution

```typescript
function findLength(nums1: number[], nums2: number[]): number {
    // Get the lengths of both input arrays.
    const lengthNums1 = nums1.length;
    const lengthNums2 = nums2.length;

    // Initialize a 2D array 'dp' (dynamic programming table) with zeros.
    // The table will store lengths of common subarrays.
    const dp: number[][] = Array.from({ length: lengthNums1 + 1 }, () => new Array(lengthNums2 + 1).fill(0));

    // Variable to keep track of the maximum length of common subarray found so far.
    let maxLength = 0;

    // Iterate over both arrays to fill the dynamic programming table.
    for (let i = 1; i <= lengthNums1; ++i) {
        for (let j = 1; j <= lengthNums2; ++j) {
            // When elements at the current position in both arrays match,
            // increment the value by 1 from the diagonally previous.
            if (nums1[i - 1] === nums2[j - 1]) {
                dp[i][j] = dp[i - 1][j - 1] + 1;
                // Update maxLength if a longer common subarray is found.
                maxLength = Math.max(maxLength, dp[i][j]);
            }
        }
    }

    // Return the maximum length of the common subarray.
    return maxLength;
}

```

Time and Space Complexity

The given code implements a dynamic programming approach to find the length of the longest common subsequence between two arrays `nums1` and `nums2`.

Time Complexity

The time complexity of the code is `O(m * n)`, where `m` is the length of `nums1` and `n` is the length of `nums2`. This is because the code uses two nested loops, each iterating up to the length of the respective arrays. For each pair of indices `(i, j)` the code performs a constant amount of work.

Space Complexity

The space complexity of the code is also `O(m * n)` because it creates a 2D list `f` of size `(m + 1) * (n + 1)` to store the lengths of common subsequences for each index pair `(i, j)`. This 2D list is required to remember the results for all subproblems, which is a typical requirement of dynamic programming approaches.

In summary:

- Time Complexity: `O(m * n)`
- Space Complexity: `O(m * n)`