821. Shortest Distance to a Character

Easy Array Two Pointers String

Problem Description

In this problem, we are given a string `s` and a character `c`, with the requirement that `c` occurs at least once in `s`. We need to return an array of integers `answer` such that for every index `i` in the string `s`, `answer[i]` represents the shortest distance from the character at `s[i]` to the nearest occurrence of the character `c`. The distance between two indices is defined as the absolute difference between those indices.

Intuition

The intuition behind the solution is to iterate through the string `s` twice to find the distance to the nearest occurrence of character `c`. On the first pass, we move from left to right, keeping track of the most recent position of `c` (using a variable `pre` initialized with a value smaller than any valid index). For every character in `s`, we update `ans[i]` to be the distance from the current index `i` to the closest occurrence of `c` encountered so far.

The key point to notice is that this only accounts for the nearest occurrence of `c` that is either at the current index `i` or to its left since we have moved from left to right.

To find the overall nearest occurrence, we need to also check for the closest `c` to the right of our current position. Hence, we do a second pass from right to left. In this pass, we use a variable `suf` initialized with a value larger than any valid index to track the latest occurrence of `c` from the right. As we move leftward, we update `ans[i]` with the minimum of its current value and the distance to the nearest `c` from the *right*.

By comparing `ans[i]` obtained from the leftward and rightward passes for each index `i`, we ensure that the closest `c` in either direction is considered. This allows us to compute the shortest distance for each character in `s` to the nearest `c`.

By using two passes, we make the algorithm efficient with linear time complexity, since each pass processes every element exactly once.

Solution Approach

The solution approach involves a two-pass algorithm to compute the minimum distance to the closest occurrence of the character `c` for each index in the string `s`. Here is the step-by-step implementation explained:

1. **Initialize the data structures and variables**: We initialize an array `ans` with the same length as string `s`, filled with `n`, the length of `s`. This ensures that at the beginning, the minimum distances are set to the largest possible value. We also initialize two variables, `pre` and `suf`, to `-inf` and `inf` respectively. These will hold the indices of the most recent occurrence of character `c` from the left pass and the right pass, ensuring that they are initially set to invalid positions outside the range of valid indices.
2. **First pass (left to right)**: We loop through `s` from left to right using `i`. To track the current index. If we find an occurrence of `c`, we update `pre` to the current index `i`. For each index `i`, we compute the distance from `i` to `pre` and update `ans[i]` to be the minimum of its current value and `i - pre`.

   This leftward pass sets `ans[i]` to the correct value if the nearest `c` is to the left or at index `i`.
3. **Second pass (right to left)**: We perform a backward loop through `s` from the last index to the first, again tracking the current index with `i`. If `s[i]` is `c`, we update `suf` to `i`. Then for each index `i`, we calculate the distance to `suf`, and we update `ans[i]` to be the minimum of its current value and `suf - i`.

   This rightward pass corrects `ans[i]` if the nearest occurrence of `c` is to the right of `i`.

By combining the results of both passes, `ans[i]` ends up with the minimum distance to the closest `c` from either direction. Since we are moving in both directions once, our time complexity remains $O(n)$, where n is the length of `s`.

4. **Return the result**: Finally, after both passes are completed, we return the array `ans` which contains the minimum distance to the closest `c` for each index in the string `s`.

In terms of data structures, we only use a list to store the result. The algorithm heavily relies on the two-pointer technique, where the pointers (`pre` and `suf`) move through the string in opposite directions, updating the distances based on the latest seen occurrences of the target character `c`.

Example Walkthrough

Let's consider an example where the string `s` is `"leetcode"` and the character `c` is `'e'`.

Step 1: Initialize the data structures and variables

We start by creating the `ans` array of the same length as `s`, which is 8 in this case. The `ans` array is initially filled with the largest possible minimum distances, which would be 8 (the length of `s`).

```
ans = [8, 8, 8, 8, 8, 8, 8, 8]
```

We'll have two variables `pre = -inf` and `suf = inf` to track the most recent occurrence of `c` from both ends.

Step 2: First pass (left to right)

1. Start from index `i = 0`, since `s[0] != 'e'`, we skip updating `pre` and `ans[i] = max(8, i - (-inf))`, which remains `8`.
2. Move to index `i = 1`, `s[1] = 'e'`, we update `pre = 1`, and `ans[i] = min(8, 1 - 1) = 0`.
3. Continue to index `i = 2`, `s[2] != 'e'`, so `ans[2] = min(8, 2 - 1) = 1`.
4. Repeat until the end of `s`, creating the array after the left to right pass:

```
ans = [8, 0, 1, 2, 0, 1, 2, 3]
```

Step 3: Second pass (right to left)

1. Start from the last index `i = 7`, `if s[7] != 'e'`, and update `ans[7] = min(3, inf - 7) = 3`.
2. Move to index `i = 6`, `s[6] != 'e'`, and `ans[6] = min(2, 7 - 6) = 1`.
3. Proceed to index `i = 4`, `s[4] != 'o'`, we update `suf = 4`, and `ans[4] = min(0, 4 - 4) = 0`.
4. Continue moving left and updating `ans` until `i = 0`, resulting in:

```
ans = [2, 0, 1, 0, 0, 1, 1, 3]
```

Now, `ans[i]` represents the shortest distance to the nearest `e` for every character.

Step 4: Return the result

Finally, we return the updated `ans` array:

```
ans = [2, 0, 1, 0, 0, 1, 1, 3]
```

This `ans` array provides the shortest distance from each character in `s` to the nearest occurrence of `c`, as desired. Each element in `ans` is computed by considering the closest occurrence of `c` from both directions in the string. The solution is efficient with a linear time complexity due to the two-pass algorithm.

Solution Implementation

Python

```python
class Solution:
    def shortestToChar(self, s: str, c: str) -> list[int]:
        # Find the length of the input string
        string_length = len(s)

        # Initialize the answer list with a default high value
        answer = [string_length] * string_length

        # Initialize the previous occurrence index of character 'c' to minus infinity
        previous_occurrence = float('-inf')

        # Forward pass: Find the distance to the closest occurrence of 'c' to the left
        for index, character in enumerate(s):
            if character == c:
                # Update the previous occurrence when we find 'c'
                previous_occurrence = index
            # Update the answer list with the minimum distance so far
            answer[index] = min(answer[index], index - previous_occurrence)

        # Initialize the next occurrence index of character 'c' to infinity
        next_occurrence = float('inf')

        # Backward pass: Find the distance to the closest occurrence of 'c' to the right
        for index in range(string_length - 1, -1, -1):
            if s[index] == c:
                # Update the next occurrence index when we find 'c'
                next_occurrence = index
            # Update the answer list with the minimum distance from either direction
            answer[index] = min(answer[index], next_occurrence - index)

        # Return the populated list of minimum distances to 'c'
        return answer
```

Java

```java
class Solution {
    public int[] shortestToChar(String s, char targetChar) {
        // Get the length of the string to create and fill the output array
        int strLength = s.length();
        int[] shortestDistances = new int[strLength];

        // The variable 'inf' represents an effective infinity for our purposes
        final int inf = 1 << 30; // 2^30, which is greater than the maximum possible string length
        Arrays.fill(shortestDistances, inf); // Fill the array with 'infinite' distance initially

        // First pass: move from left to right,
        // updating the closest target character seen so far
        for (int i = 0, closestLeft = -inf; i < strLength; ++i) {
            // Update the position of the closest target character if found
            if (s.charAt(i) == targetChar) {
                closestLeft = i;
            }
            // Update the shortest distance for position i
            shortestDistances[i] = i - closestLeft;
        }

        // Second pass: move from right to left,
        // updating the closest target character seen so far
        for (int i = strLength - 1, closestRight = inf; i >= 0; --i) {
            // Update the position of the closest target character if found
            if (s.charAt(i) == targetChar) {
                closestRight = i;
            }
            // Update the shortest distance for position i only if it's smaller than the current value
            shortestDistances[i] = Math.min(shortestDistances[i], closestRight - i);
        }

        // Return the array of shortest distances to the target character
        return shortestDistances;
    }
}
```

C++

```cpp
#include <vector>
#include <string>
#include <algorithm> // Include necessary headers

class Solution {
public:
    std::vector<int> shortestToChar(std::string s, char c) {
        int n = s.size(); // Get the size of the string
        const int INF = 1 << 30; // Define an 'infinity' value for initial distances
        std::vector<int> distances(n, INF); // Create a vector to store distances initialized with 'infinity'

        // Forward pass: Find closest 'c' before the current position
        // Initialize previous position of character 'c' to a very negative number
        for (int i = 0, prevPosition = -INF; i < n; ++i) {
            if (s[i] == c) {
                prevPosition = i; // Update position when we find character 'c'
            }
            // Calculate distance to the closest 'c' so far from the left
            distances[i] = std::min(distances[i], i - prevPosition);
        }

        // Backward pass: Find closest 'c' after the current position
        // Set suffix position of character 'c' very high initially
        for (int i = n - 1, nextPosition = 2 * INF; i >= 0; --i) {
            if (s[i] == c) {
                nextPosition = i; // Update position when we find character 'c'
            }
            // Calculate distance to the closest 'c' so far from the right
            // We use the min() function again to ensure the closest 'c' in either direction
            distances[i] = std::min(distances[i], nextPosition - i);
        }

        return distances; // Return the computed vector of distances
    }
};
```

TypeScript

```typescript
function shortestToChar(s: string, c: string): number[] {
    // Get the length of the string for iteration purposes.
    const length = s.length;
    // Define an 'infinite' large number for initial distances.
    const infinity = 2 ** 30;
    // Initialize an array to store the shortest distances to character 'c'.
    const shortestDistances = number[] = new Array(length).fill(infinity);

    // Forward pass: find distances from left-side occurrences of 'c'.
    for (let i = 0, lastOccurrenceLeft = -infinity; i < length; ++i) {
        if (s[i] === c) {
            // Update last occurrence of 'c' when found.
            lastOccurrenceLeft = i;
        }
        // Calculate distance from the last occurrence found on the left.
        shortestDistances[i] = i - lastOccurrenceLeft;
    }

    // Backward pass: find and compare distances from right-side occurrences of 'c'.
    for (let i = length - 1, lastOccurrenceRight = infinity; i >= 0; --i) {
        if (s[i] === c) {
            // Update last occurrence of 'c' when found.
            lastOccurrenceRight = i;
        }
        // Store the minimum distance between the previous value and
        // the distance from the last occurrence found on the right.
        shortestDistances[i] = Math.min(shortestDistances[i], lastOccurrenceRight - i);
    }

    // Return the array containing shortest distances to character 'c'.
    return shortestDistances;
}
```

```python
class Solution:
    def shortestToChar(self, s: str, c: str) -> list[int]:
        # Find the length of the input string
        string_length = len(s)

        # Initialize the answer list with a default high value
        answer = [string_length] * string_length

        # Initialize the previous occurrence index of character 'c' to minus infinity
        previous_occurrence = float('-inf')

        # Forward pass: Find the distance to the closest occurrence of 'c' to the left
        for index, character in enumerate(s):
            if character == c:
                # Update the previous occurrence index when we find 'c'
                previous_occurrence = index
            # Update the answer list with the minimum distance so far
            answer[index] = min(answer[index], index - previous_occurrence)

        # Initialize the next occurrence index of character 'c' to infinity
        next_occurrence = float('inf')

        # Backward pass: Find the distance to the closest occurrence of 'c' to the right
        for index in range(string_length - 1, -1, -1):
            if s[index] == c:
                # Update the next occurrence index when we find 'c'
                next_occurrence = index
            # Update the answer list with the minimum distance from either direction
            answer[index] = min(answer[index], next_occurrence - index)

        # Return the populated list of minimum distances to 'c'
        return answer
```

Time and Space Complexity

The time complexity of the code is $O(n)$, where n is the length of the string `s`. This is because the code processes each character in the string twice: once in the forward direction and once in the backward direction.

As for the space complexity, the space used by the program is also $O(n)$. An additional array `ans` of size n is used to store the minimum distance to the character `c` for each position in the string.

In detail, the algorithm involves the following steps:

1. It initializes the `ans` array with n, where n is the size of the string `s`. This action itself has a space complexity of $O(n)$.
2. It iterates through the string once from left to right (forward traversal) to calculate and update the minimum distance from each character to the previous occurrence of `c`. This has a time complexity of $O(n)$ for the traversal.
3. It then iterates through the string again from right to left (backward traversal) to update the minimum distance based on the following occurrences of `c`. This backward traversal also takes $O(n)$ time.
4. No additional data structures are used that are dependent on the size of the input, so the space complexity remains $O(n)$.

Based on these operations, the total time complexity is $O(n)$ (forward $O(n)$ + backward $O(n)$ is still $O(n)$), and the total space complexity remains $O(n)$ given the above analysis.