1864. Minimum Number of Swaps to Make the Binary String Alternating

Medium Greedy String

Leetcode Link

Problem Description

In this problem, we are given a binary string `s` which only contains '0's and '1's. Our goal is to find the minimum number of character swaps required to convert the string into an alternating binary string, where no two adjacent characters are the same. For example, "010101" and "101010" are alternating strings, but "110" is not as there are two '1's adjacent to each other.

If making the string alternating is not possible, we should return `-1`.

A character swap means choosing any two characters in the string (not necessarily adjacent) and exchanging their positions. The challenge is to do the minimum number of such swaps to achieve an alternating pattern.

Intuition

To arrive at the solution, we first need to understand that there are only two possible alternating patterns for any string: "010101..." or "101010...". Also, for a binary string that can be made alternating, the difference between the counts of '0's and '1's cannot be more than one. If the difference is more than one, it is impossible to form an alternating string because there would be extra characters of one type that we cannot place without creating adjacent duplicates.

With this understanding, the next insight is to count the number of misplaced '0's and '1's in both possible alternating patterns. We need to track the following:

- `s0n0`: Number of '0's that are in the wrong place if we are trying to form the "010101..." pattern.
- `s0n1`: Number of '1's that are in the wrong place if we are trying to form the "010101..." pattern.
- `s1n0`: Number of '0's that are in the wrong place if we are trying to form the "101010..." pattern.
- `s1n1`: Number of '1's that are in the wrong place if we are trying to form the "101010..." pattern.

For a valid alternating string:

- The counts of '0's and '1's should be equal, or there should be exactly one more '0' or exactly one more '1'.
- The numbers of misplaced '0's should equal the numbers of misplaced '1's for a given pattern. That is, `s0n0` should equal `s0n1` and `s1n0` should equal `s1n1`. If they are not equal, it means we can't swap a '0' with a '1' to correct the string since there's an unequal amount to swap.

After counting, we have the following cases:

- If both the counts of `s0n0` and `s0n1` aren't equal, and the counts of `s1n0` and `s1n1` aren't equal either, we return `-1` because it's impossible to make the string alternating.
- If `s0n0` and `s0n1` aren't equal, which means we can't form "010101..." pattern, we should check if we can form "101010..." pattern and return `s1n0` (or `s1n1` since they are equal).
- If `s1n0` and `s1n1` aren't equal, meaning we can't form "101010..." pattern, we should return `s0n0` (or `s0n1` since they are equal).
- If we can form both "010101..." and "101010..." patterns, we return the minimum of `s0n0` and `s1n0`.

Therefore, by counting the number of misplaced characters and comparing them, we can determine the minimum number of swaps required. If any configuration allows for alternating characters, that minimum count is the answer. If neither does, then it is impossible to form an alternating string, and we return `-1`.

Solution Approach

The solution provided follows a simple but effective approach without the need for any complex algorithms or data structures. Here's the breakdown:

1. Initialize four counters: `s0n0`, `s0n1`, `s1n0`, `s1n1` to zero. These will count the number of misplaced '0's and '1's for both potential alternating patterns "010101..." (`s0n0` and `s0n1`) and "101010..." (`s1n0` and `s1n1`).

2. Iterate through the string `s` using a for-loop and the range function, checking each character:

   - If we're at an even index (using `i & 1` to check if `i` is odd or even), we compare the character with `'0'`.
     - If it's not `'0'`, then it's in the wrong place for the "010101..." pattern, so we increment `s0n0`.
     - If it is a `'0'`, then it's in the wrong place for the "101010..." pattern, so we increment `s1n1`.
   - If we're at an odd index, we do the reverse:
     - If the character is not `'0'`, it's wrong for "101010..." and we increment `s1n0`.
     - If it is a `'0'`, it's wrong for "010101..." and we increment `s0n1`.
3. After the loop, we have the counts of misplaced '0's and '1's for both patterns. We then examine these counts:

   - If `s0n0` does not equal `s0n1`, and `s1n0` does not equal `s1n1`, we can't form an alternating string. We return `-1`.
   - If `s0n0` does not equal `s0n1`, we know that the "010101..." pattern is not possible, but the "101010..." pattern is, so we return `s1n0` (or `s1n1` as they are the same).
   - Conversely, if `s1n0` does not equal `s1n1`, we can't form "101010...", but we know "010101..." is possible, so we return `s0n0` (or `s0n1` since they are equal).
   - If both sets of counts are equal, meaning either pattern could be formed, we return the minimum of `s0n0` and `s1n0`.

This approach ensures we find the minimum swaps needed for either pattern if it's possible to build an alternating string out of `s`. It efficiently utilizes bitwise operations and simple if-else constructs without the need for additional space, hence operating in O(n) time complexity and O(1) space complexity, where n is the length of string `s`.

Example Walkthrough

Let's use a small example to illustrate the solution approach. Consider the binary string `s = "1001"`. We want to determine the minimum number of swaps required to make this string into an alternating binary string, either "1010" or "0101".

1. Initialize our counters: `s0n0 = 0`, `s0n1 = 0`, `s1n0 = 0`, `s1n1 = 0`.

2. We begin iterating through the string:

   - For the first character (index 0, even), we have '1'.

     - It's not '0', so it's misplaced for the "010101..." pattern. Increment `s0n0` to 1.
     - Since it's '1', it's correctly placed for the "101010..." pattern, so `s1n1` remains 0.
   - For the second character (index 1, odd), we have '0'

     - It's not '1', so it's misplaced for the "101010..." pattern. Increment `s1n0` to 1.
     - Since it's '0', it's correctly placed for the "010101..." pattern, so `s0n1` remains 0.
   - For the third character (index 2, even), we have '0'.

     - It's correctly placed for the "010101..." pattern, so `s0n0` remains 1.
     - Since it's not '1', it's misplaced for the "101010..." pattern. Increment `s1n1` to 1.
   - For the fourth character (index 3, odd), we have '1'.

     - It's not '0', so it's misplaced for the "010101..." pattern. Increment `s0n1` to 1.
     - Since it's '1', it's correctly placed for the "101010..." pattern, so `s1n0` remains 1.
3. After iterating, our counts are as follows: `s0n0 = 1`, `s0n1 = 1`, `s1n0 = 1`, `s1n1 = 1`.

4. We examine our counts:

   - Since `s0n0` equals `s0n1`, and `s1n0` equals `s1n1`, either pattern "010101..." or "101010..." can be formed.

   - We return the minimum of `s0n0` and `s1n0`, which is `min(1, 1) = 1`.

Thus, it only takes a single swap to turn the string "1001" into an alternating binary string. We can swap the second and third characters to obtain "1010" or swap the first and second characters to obtain "0101".

Python Solution

```python
class Solution:
    def minSwaps(self, s: str) -> int:
        # Initializing counters for each possible scenario:
        # swaps_0_to_1 - number of swaps needed if the even-index should be '0'
        # swaps_1_to_0 - number of swaps needed if the even-index should be '1'
        # For the strings to be valid they should alternate '01' or '10'.
        # If it's not possible to create a valid string, return -1.
        swaps_0_to_1 = swaps_1_to_0 = 0

        # Iterate over each character in the string
        for index in range(len(s)):
            # Check if the current index is even
            if (index % 2) == 0:
                # If current character should be '0' on even index, but it's not
                if s[index] != '0':
                    swaps_0_to_1 += 1
                # If current character should be '1' on even index, but it's '0'
                if s[index] != '1':
                    swaps_1_to_0 += 1
            else:
                # If current character should be '1' on odd index, but it's not
                if s[index] != '1':
                    swaps_0_to_1 += 1
                # If current character should be '0' on odd index, but it's '1'
                if s[index] != '0':
                    swaps_1_to_0 += 1

        # For the swaps to be possible, the number of required swaps for both scenarios must be the same
        # If they are not, it's impossible to create a valid string of alternate characters by swapping
        if (swaps_0_to_1 % 2) != (swaps_1_to_0 % 2):
            return -1

        # If the total number of swaps is equal, one of them must be even since it's impossible to have an odd number of swaps for
        # Return the minimum number of swaps if both are even, otherwise, return the even count since the odd count will require an
        if (swaps_0_to_1 % 2) == 0:
            return min(swaps_0_to_1, swaps_1_to_0) // 2
        else:
            return min(swaps_0_to_1//2, swaps_1_to_0//2)

```

Java Solution

```java
class Solution {
    public int minSwaps(String s) {
        // Initialize counters to track the number of swaps required for each pattern.
        // Pattern "01" requires 'swapCountPattern01' and 'swapCountPattern10' swaps.
        // Pattern "10" requires 'swapCountPattern10' and 'swapCountPattern01' swaps.
        int swapCountPattern01 = 0;
        int swapCountPattern10 = 0;

        // Loop through the string to count the number of swaps needed.
        for (int i = 0; i < s.length(); ++i) {
            // If the index 'i' is even, we expect a '0' for pattern "01" and a '1' for pattern "10".
            if ((i & 1) == 0) {
                if (s.charAt(i) == '1') {
                    swapCountPattern01 += 1;
                } else {
                    swapCountPattern10 += 1;
                }
            } else {
                // If the index 'i' is odd, we expect a '1' for pattern "01" and a '0' for pattern "10".
                if (s.charAt(i) == '1') {
                    swapCountPattern10 += 1;
                } else {
                    swapCountPattern01 += 1;
                }
            }
        }

        // If the number of swaps needed for both patterns is not the same, it's impossible to achieve the pattern.
        if (swapCountPattern01 != swapCountPattern10) {
            return -1;
        }

        // If only one pattern is possible, return the number of swaps needed for that pattern.
        if (swapCountPattern01 != swapCountPattern10) {
            return swapCountPattern10;
        }
        // If both patterns are possible, return the minimum number of swaps.
        return Math.min(swapCountPattern01, swapCountPattern10);
    }
}

```

C++ Solution

```cpp
#include <string>
#include <algorithm>

/**
 * Determines the minimum number of swaps to make a binary string alternating.
 * It only considers valid scenarios where the number of 1's and 0's differ by at most one.
 *
 * @param binaryString - The binary string to be processed.
 * @return The minimum number of swaps, or -1 if not possible.
 */
int minSwaps(const std::string& binaryString) {
    const int length = binaryString.length();
    // Count the number of '1's.
    const int numberOfOnes = std::count(binaryString.begin(), binaryString.end(), '1');
    // Calculate the number of '0's directly.
    const int numberOfZeros = length - numberOfOnes;
    int minCount = INT_MAX; // Use maximum integer to initialize minimum count.
    const int halfLength = length / 2;

    // Case for strings that should start with '1' (e.g., '1010' or '101').
    if (numberOfOnes == (length + 1) / 2 && numberOfZeros == length / 2) {
        int currentSwapCount = 0; // Swaps needed for current iteration.
        for (int i = 0; i < length; i++) {
            if (i % 2 == 0 && binaryString[i] != '1') {
                currentSwapCount++;
            }
        }
        minCount = std::min(minCount, currentSwapCount);
    }

    // Case for strings that should start with '0' (e.g., '0101' or '010').
    if (numberOfZeros == (length + 1) / 2 && numberOfOnes == length / 2) {
        int currentSwapCount = 0; // Swaps needed for current iteration.
        for (int i = 0; i < length; i++) {
            if (i % 2 == 0 && binaryString[i] != '0') {
                currentSwapCount++;
            }
        }
        minCount = std::min(minCount, currentSwapCount);
    }

    // If no valid scenario was found, return -1; otherwise, return the minimum swap count found.
    return minCount == INT_MAX ? -1 : minCount;
}

```

Typescript Solution

```typescript
/**
 * Determines the minimum number of swaps to make a binary string alternating.
 * It only considers valid scenarios where the number of 1's and 0's differ by at most one.
 *
 * @param {string} binaryString - The binary string to be processed.
 * @return {number} - The minimum number of swaps, or -1 if not possible.
 */
function minSwaps(binaryString: string): number {
    const length: number = binaryString.length;
    const numberOfOnes: number = Array.from(binaryString).reduce((accumulated, current) => parseInt(current) + accumulated, 0);
    const numberOfZeros: number = length - numberOfOnes;
    let minCount: number = Infinity;
    const halfLength: number = length / 2;

    // Case for strings that should start with '1' (e.g. '1010' or '101')
    if (numberOfOnes === Math.ceil(halfLength) && numberOfZeros === Math.floor(halfLength)) {
        let currentSwapCount: number = 0; // Swaps needed for current iteration
        for (let i = 0; i < length; i++) {
            if (i % 2 === 0 && binaryString.charAt(i) !== '1') currentSwapCount++;
        }
        minCount = Math.min(minCount, currentSwapCount);
    }

    // Case for strings that should start with '0' (e.g. '0101' or '010')
    if (numberOfZeros === Math.ceil(halfLength) && numberOfOnes === Math.floor(halfLength)) {
        let currentSwapCount: number = 0; // Swaps needed for current iteration
        for (let i = 0; i < length; i++) {
            if (i % 2 === 0 && binaryString.charAt(i) !== '0') currentSwapCount++;
        }
        minCount = Math.min(minCount, currentSwapCount);
    }

    // If no valid scenario was found, return -1, otherwise return the minimum swap count found
    return minCount === Infinity ? -1 : minCount;
}

```

Time and Space Complexity

Time Complexity

The given code iterates through the string `s` once, which means that the loop runs for `n` iterations, where `n` is the length of the string `s`. Within each iteration of the loop, the code performs a constant number of operations, such as comparison, bitwise AND, and increment operations, all of which take constant `O(1)` time. Therefore, the time complexity of the entire function is directly proportional to the length of the string, which gives us a time complexity of `O(n)`.

Space Complexity

Regarding space complexity, the code allocates a constant amount of extra space. It uses four integer variables `s0n0`, `s0n1`, `s1n0`, and `s1n1` to keep track of counts, no matter how large the input string `s` is. Since these variables do not depend on the size of the input, and no other significant space is used (no dynamic data structures or arrays are allocated), the space complexity is constant, `O(1)`.