2048. Next Greater Numerically Balanced Number

Medium Math Backtracking Enumeration

Leetcode Link

Problem Description

An integer is considered *numerically balanced* if for each digit `d` that appears in the number, there are exactly `d` occurrences of that digit within the number itself. For example, the number `122` is numerically balanced because there is exactly one `1` and two `2`s.

The problem at hand involves finding the smallest numerically balanced number that is strictly greater than a given integer `n`. That means if `n` is `1`, then the next numerically balanced number is `22` because it's the smallest number greater than `1` that satisfies the numerically balanced condition (two instances of the digit `2`).

Intuition

The intuition behind the solution is to start from the number immediately greater than `n` and check each successive number to see if it meets the criteria of being numerically balanced. This is essentially a brute-force approach since it examines each number one by one until it finds the solution.

The function `check(num)` assesses whether a number `num` is numerically balanced. It creates a list `counter` that keeps track of the occurrences of each digit. The number is converted into a string to iterate over its digits, updating `counter` accordingly. Following that, the function verifies whether the occurrence of each digit in `counter` matches its value, thus confirming the number is numerically balanced or not.

This method is not the most efficient solution, particularly for large `n`, because it potentially evaluates many numbers until it finds the next numerically balanced number. However, it's a straightforward and easy-to-understand approach.

Solution Approach

The solution uses a straightforward brute-force approach. Here's a step-by-step guide to how the algorithm is implemented:

1. **Validation Function (`check`)**: A key part of the solution is the `check` function, which takes an integer `num` as input and determines if `num` is numerically balanced. The function does the following:
    - Initialize a `counter` list of 10 zeros, with each index representing digits `0` to `9`.
    - Convert `num` to a string to iterate over its digits.
    - Increment the `counter` at the index corresponding to each digit `d` by 1 for each occurrence of `d` in `num`.
    - Iterate over the digits of `num` again, and for each digit `d`, check if `counter[d]` is equal to the digit `d` itself. This step confirms that the number of occurrences of each digit `d` is equal to its value.
    - If any digit `d` does not meet the balance condition, return `False`.
    - If all digits satisfy the condition, return `True` indicating the number is numerically balanced.
2. **Main Function (`nextBeautifulNumber`)**: This function looks for the smallest numerically balanced number strictly greater than `n`.
    - Start iterating from `n+1`, since we are looking for a number strictly greater than `n`.
    - Call the `check` function for each number `i` in the iteration.
    - Stop the iteration and return the current number `i` as soon as a numerically balanced number is found.
    - The upper limit of `10**7` is an arbitrary large number to ensure that the next numerically balanced number is found within practical computational time.
3. **Efficiency**: While the provided approach is correct, it's important to note that the efficiency isn't optimal for large numbers because it may require checking a large number of candidates. Advanced techniques or optimizations such as precomputing possible balanced numbers or using combinatorics to generate candidates more intelligently could potentially improve efficiency.

The algorithm uses iteration and simple counting, making it easily understandable. The `check` function uses a list as a counting mechanism, which is an instance of the array data structure, and the iterations over the sequence of numbers and their digits are basic patterns used in brute-force algorithm implementations.

Example Walkthrough

Let's take an integer `n = 300`. According to the problem description, we need to find the smallest numerically balanced number greater than `n`.

Starting from `301` (the next integer after `n`), we apply `check(num)` to each subsequent integer:

1. Check `301`: Is there one `3`, zero `0`'s, and one `1`? No, because there has to be zero `0`'s (which is correct) but also three `3`'s and one `1`, so `301` is not numerically balanced.
2. Check `302`, `303`, ..., up until `312`: None of these numbers will be numerically balanced because there will never be three `3`s, or two `2`s until at least `322` (the instance where the digit matches its count).
3. Check `312`: It is not numerically balanced either because there's only one `1` and one `3`, but there should be three `3`s and one `1`.
4. Skip forward to `322`: This is the first number where the digit `2` appears twice, satisfying its requirement. But we need three occurrences of `3` and none of the numbers `313` to `322` meet this criteria.

Proceeding with this method, the first number to satisfy the checking criteria after `300` is `333`. In `333`, there are exactly three `3`s, which meets the requirement of being numerically balanced.

This example shows that the `check` function will iterate over the numbers `301`, `302`, `303`, ..., `332`, `333`, and when it reaches `333`, it will return `True`, indicating that this is the smallest numerically balanced number greater than `300`. The number `333` will then be returned by the `nextBeautifulNumber` function.

Thus, applying the brute-force approach outlined in the solution, we conclude that the next numerically balanced number greater than `300` is `333`. While this method is straightforward, it is also clear that for a large number the number of iterations can become significant, which highlights the inefficiency for larger inputs.

Python Solution

```python
class Solution:
    def nextBeautifulNumber(self, n: int) -> int:
        # Define a function to check if a number is 'beautiful'.
        # A number is beautiful if the frequency of each digit is equal to the digit itself.
        def is_beautiful(num):
            # Initialize a counter for each digit from 0 to 9.
            frequency_counter = [0] * 10

            # Increment the counter for each digit found in the number.
            for digit_char in str(num):
                digit = int(digit_char)
                frequency_counter[digit] += 1

            # Check if the frequency of each digit is equal to the digit itself.
            for digit_char in str(num):
                digit = int(digit_char)
                if frequency_counter[digit] != digit:
                    return False
            return True

        # Iterate through numbers greater than n to find the next beautiful number.
        for i in range(n + 1, 10**7):
            if is_beautiful(i):
                # If the number is beautiful, return it.
                return i

        # If no beautiful number is found (which is highly improbable), return -1.
        # This is a safeguard, and in practice, this return statement should not be reached.
        return -1
```

Java Solution

```java
class Solution {

    // Finds the next beautiful number that is greater than a given number `n`
    public int nextBeautifulNumber(int n) {
        // Start from the next integer value and check up to an upper limit
        for (int i = n + 1; i < 1000000; ++i) {
            // Utilize the check method to determine if the number is beautiful
            if (isBeautiful(i)) {
                // Return the first beautiful number found
                return i;
            }
        }
        // Return -1 if no beautiful number is found (should not occur with the given constraints)
        return -1;
    }

    // Helper method to check if a number is beautiful
    private boolean isBeautiful(int num) {
        // Initialize a counter to store the frequency of each digit
        int[] digitCounter = new int[10];

        // Convert the number to a character array
        char[] chars = String.valueOf(num).toCharArray();

        // Increment the count for each digit found
        for (char c : chars) {
            digitCounter[c - '0']++;
        }

        // Check if each digit appears exactly as many times as the digit itself
        for (char c : chars) {
            if (digitCounter[c - '0'] != c - '0') {
                // If not, the number is not beautiful
                return false;
            }
        }

        // If all digits match the criteria, the number is beautiful
        return true;
    }
}
```

C++ Solution

```cpp
#include <vector>
#include <string>
using namespace std;

class Solution {
public:
    // Function to find the next beautiful number greater than a given number n.
    int nextBeautifulNumber(int n) {
        // Loop starts from the next number after n and stops when it finds a beautiful number.
        for (int i = n + 1; i < 1000000; ++i) {
            // If i is a beautiful number, return it.
            if (isBeautiful(i)) {
                return i;
            }
        }
        // Return -1 if no beautiful number is found (this won't happen given the problem constraints).
        return -1;
    }

private:
    // Helper function to check if a number is beautiful.
    // A beautiful number has each digit appearing exactly d times where d is the actual digit.
    bool isBeautiful(int num) {
        // Convert the number to a string.
        string numStr = to_string(num);

        // Initialize a counter for each digit (0-9).
        vector<int> digitCounter(10, 0);

        // Increment the counter for each digit found in the number.
        for (char digit : numStr) {
            ++digitCounter[digit - '0'];
        }

        // Check if the count of each digit matches its value.
        for (char digit : numStr) {
            if (digitCounter[digit - '0'] != digit - '0') {
                // If any digit count doesn't match its value, the number isn't beautiful.
                return false;
            }
        }

        // All digit counts match their values, so the number is beautiful.
        return true;
    }
};
```

Typescript Solution

```typescript
function nextBeautifulNumber(n: number): number {
    // Start checking numbers greater than the given number
    for (let answer = n + 1; ; answer++) {
        // Check if the current number is "beautiful"
        if (isValidAnswer(i)) {
            // If it's a beautiful number, then return it as the answer
            return answer;
        }
    }
}

function isValid(n: number): boolean {
    // Initialize digit occurrence record with zeros
    let digitFrequency = new Array(10).fill(0);

    // While there are still digits to process
    while (n > 0) {
        // Get the rightmost digit of the number
        const currentDigit = n % 10;
        // Increment the frequency of the currentDigit
        digitFrequency[currentDigit]++;
        // Remove the rightmost digit from the number
        n = Math.floor(n / 10);
    }

    // Check all digits from 0 to 9
    for (let i = 0; i < 10; i++) {
        // If a digit occurs and its frequency is not equal to the digit itself, it's not valid
        if (digitFrequency[i] && digitFrequency[i] != i) return false;
    }

    // If all conditions are met, return true
    return true;
}
```

Time and Space Complexity

Time Complexity

The function `nextBeautifulNumber` increments a number, starting from `n + 1`, and checks each number to see if it is a "beautiful" number as defined by the function `check`. The `check` function verifies if the number of times each digit appears is equal to the digit itself.

The time complexity of the check function is as follows:

1. Converting a number to its string representation is $O(\log(num))$, because the length of the string is proportional to the number of digits in the number.
2. Counting the digits by using an array of size 10 (for each possible digit) is done in $O(\log(num))$, where $\log(num)$ is the number of digits in `num`.
3. Again, it iterates over each digit to verify if the number is beautiful, which is also $O(\log(num))$.

Combining these steps, the function `check` alone is $O(\log(num))$. However, we need to consider that it is called for each number starting from `n + 1`.

The loop can be considered to go on until the next beautiful number is found, which is the worst-case scenario since we do not know the distribution of beautiful numbers. If we say finding the next beautiful number from `n` has a maximum range of `r`, the total time complexity is $O(r * \log(r))$.

The exact value of `r` is not straightforward to determine as it depends on the pattern distribution of beautiful numbers, but given the constraint that the for loop can go up to 10^7, in the worst case scenario `r` would be close to 10^7, making it $O(7 * 10^7)$, which simplifies to $O(10^7)$.

Space Complexity

The space complexity is primarily impacted by:

1. The counter array which holds 10 integers, representing each digit, so it remains constant $O(1)$.
2. The string representation of the number being checked inside the loop, which has a space complexity of $O(\log(num))$ for each number `num`.

Since the counter array is static and doesn't grow with the input, and the string representation of the current number is only stored temporarily for each check, the space complexity can be simplified to $O(1)$ because the logarithmic space required for the string representation does not affect the overall space complexity which is dominated by the fixed size of the counter array.