2437. Number of Valid Clock Times

Easy String Enumeration

Problem Description

You are given a string `time` representing the current time on a digital clock in the 24-hour format "hh:mm". The string `time` can include the character `?`, which stands for an unknown digit that you'll need to replace with a number from `0` to `9`. Your task is to determine how many unique valid times can be generated by replacing every `?` in the `time` string. A valid time is one that is between "00:00" and "23:59" inclusive.

The problem is essentially asking to calculate the count of all possible valid times that can be created from the given string by substituting the `?` with appropriate digits, while also respecting the restrictions of time format, where the hours range from `00` to `23` and the minutes range from `00` to `59`.

For example, if the input `time` is "?0:47", the first `?` can be replaced by any digit from `0` to `9` to still make a valid hour (since `00` to `09` are all valid hours), and the second `?` can be replaced by any digit from `0` to `9` to make valid minutes (since `40` to `49` are all valid minutes). You must count all such valid combinations.

Intuition

The key intuition behind the solution is to handle the hour and minute parts of the time independently since they have different valid ranges. The first two characters ("hh") of `time` can range from `00` to `23`, while the last two characters ("mm") can range from `00` to `59`.

The strategy is to count the number of possibilities for the hour and minute parts separately and then multiply those two counts to get the total number of valid times.

For each part, we need to consider two scenarios:

1. The character is a `?`, which means it can take any value within the allowed range.
2. The character is a digit, which imposes a constraint on the possible values.

This is achieved by a function `f` that takes a substring (either the hour or the minute) and the maximum value it can take (`24` for hours, `60` for minutes). It then iterates over all possible values within the range, checks if they are compatible with the given substring, and counts the number of valid possibilities.

Solution Approach

The solution approach leverages a simple, yet effective methodology for deciphering the number of valid times that can be created from a string with unknowns represented by `?`. The approach uses a nested helper function `f` inside the main function `countTime` to count the possibilities for each part of the time string (hour and minute).

The helper function `f(s: str, m: int) -> int` is designed to work with a substring `s` of the time and a maximum limit `m` (24 for hours, 60 for minutes), and returns the count of possible numbers that fit within the constraints, matching the given pattern `s`.

Here's the breakdown of the implementation:

1. **Nested Function Definition**: The function `f` takes a substring `s` representing either the hour (`time[:2]`) or the minute (`time[3:]`) part of the time and an integer `m` that is the maximum value (`24` for hours, `60` for minutes). The return value is the count of valid numbers for this part of the time.
2. **Loop Over Range**: A loop runs from `0` to `m` (exclusive), checking each potential valid integer value within the constraint range. The value `i` represents the current number being checked for validity against the substring pattern `s`.
3. **Variable Assignments**: Within the loop, two boolean variables `a` and `b` are assigned.
   - `a` checks if the first character of `s` is a `?` or if it matches the tenth digit of `i`.
   - `b` checks if the second character of `s` is a `?` or if it matches the unit digit of `i`.
4. **Counting Possibilities**: The count `cnt` increments only if both `a` and `b` are `True`, meaning the number `i` is valid according to the substring pattern `s`.
5. **Return Total Counts**: For the final result, `f` is applied to the hours and minutes separately and the respective counts are multiplied. This gives the total number of valid times, as the possibilities for hours and minutes are independent of each other.

This methodology is both efficient and sufficient, as it directly counts the valid possibilities without having to materialize them. It avoids unnecessary computation by ignoring invalid potential values.

Data structures used are minimal in this approach, with a primary focus on the algorithm and logical checks. There aren't any complex patterns - just straightforward comparison logic and a loop to tally up the valid combinations.

By applying this solution approach to the `countTime` function, the code effectively calculates the number of distinct valid times that can be made by replacing `?` with digits from `0` to `9`.

Example Walkthrough

Let's use the time "1?:2?" to illustrate the solution approach. We need to determine how many unique valid times can be generated by replacing each `?` with a number from `0` to `9`.

Analyzing the Hours

First, we look at the hour part `1?`. Since the first digit is `1`, the second digit (which is `?`) can be any number from `0` to `9`, because any such number paired with `1` at the start will form a valid hour (from `10` to `19`).

Using the helper function `f` for hours (`s = "1?"` and `m = 24`), the function will loop from `0` to `23`. It will increase the count `cnt` every time the value `i` satisfies the conditions:

- `a` will be `True` since the first digit of `s` is `1`, not `?`.
- `b` will be `True` for any value of `i` from `10` to `19` because `?` can be any digit.

Therefore, there are 10 possible hour combinations when the hour part of `time` is `1?`.

Analyzing the Minutes

Now we look at the minute part `2?`. Since the first digit is `2`, the second digit (which is `?`) can also be any number from `0` to `9`, forming a valid minute (from `20` to `29`).

Using the helper function `f` for minutes (`s = "2?"` and `m = 60`), the function will loop from `0` to `59`. It will increase the count `cnt` every time the value `i` satisfies the conditions:

- `a` will be `True` because the first minute digit in `2?` is `2`, not `?`.
- `b` will be `True` for any value of `i` from `20` to `29`.

As a result, there are 10 possible minute combinations when the minute part of `time` is `2?`.

Combining Hour and Minute Possibilities

We multiply the possibilities for the hours (10) by the possibilities for the minutes (10), which gives us a total of `10 * 10 = 100` unique valid times that can be generated from the time `1?:2?`.

In this walkthrough, we saw how to use the solution approach to find the total possible valid times. We separately calculated the possibilities for each segment of the time pattern and then combined them to find the overall number of valid combinations.

Solution Implementation

Python

```python
class Solution:
    def count_time(self, time: str) -> int:
        # Helper function to count the valid numbers for a part of the time (hour/minute)
        def count_valid_combinations(part: str, max_value: int) -> int:
            count = 0
            # Iterate through all possible values based on maximum for hour/minute
            for i in range(max_value):
                # Check if the first character is '?' or matches the tens place of 'i'
                matches_first_char = part[0] == '?' or int(part[0]) == i // 10
                # Check if the second character is '?' or matches the ones place of 'i'
                matches_second_char = part[1] == '?' or int(part[1]) == i % 10
                # Increment count if both characters match
                count += matches_first_char and matches_second_char
            return count

        # Separating the time string into hours and minutes parts
        hour_part = time[:2]
        minute_part = time[3:]

        # Return the product of the count of valid combinations for hours and minutes
        return count_valid_combinations(hour_part, 24) * count_valid_combinations(minute_part, 60)
```

Java

```java
class Solution {

    // This method calculates the number of valid times that can be represented by the given string
    public int countTime(String time) {
        // Split the time string into hours and minutes and pass to helper method
        int possibleHours = calculatePossibilities(time.substring(0, 2), 24);
        int possibleMinutes = calculatePossibilities(time.substring(3), 60);

        // Total combinations are the product of possibilities for hours and minutes
        return possibleHours * possibleMinutes;
    }

    // Helper method to calculate the number of valid possibilities for a given time component
    private int calculatePossibilities(String timeComponent, int maxValue) {
        int count = 0;
        // Loop through all possible values for the given time component
        for (int i = 0; i < maxValue; ++i) {
            // Check if the first character matches or is a wildcard '?'
            boolean firstCharMatches = timeComponent.charAt(0) == '?' || timeComponent.charAt(0) - '0' == i / 10;
            // Check if the second character matches or is a wildcard '?'
            boolean secondCharMatches = timeComponent.charAt(1) == '?' || timeComponent.charAt(1) - '0' == i % 10;
            // Increment the count if both characters match the current possibility
            count += (firstCharMatches && secondCharMatches) ? 1 : 0;
        }
        return count; // Return the total count of valid possibilities
    }
}
```

C++

```cpp
class Solution {
public:
    /**
     * Count the number of valid times that can be represented by the given time string.
     *
     * @param time A time string that includes wildcards '?'.
     * @return The number of valid times that the input can represent.
     */
    int countTime(string time) {
        // Define a lambda function that counts the possible valid numbers for the given pattern
        auto countMatches = [](string pattern, int maxValue) {
            int count = 0;
            for (int i = 0; i < maxValue; ++i) {
                // Check if the first character matches or is a wildcard
                bool isMatchFirstChar = pattern[0] == '?' || pattern[0] - '0' == i / 10;
                // Check if the second character matches or is a wildcard
                bool isMatchSecondChar = pattern[1] == '?' || pattern[1] - '0' == i % 10;
                // Increment count if both characters match or are wildcards
                count += isMatchFirstChar && isMatchSecondChar;
            }
            return count;
        };
        // Apply the lambda to the hour portion of the time
        int hourMatches = countMatches(time.substr(0, 2), 24);
        // Apply the lambda to the minute portion of the time
        int minuteMatches = countMatches(time.substr(3, 2), 60);

        // Return the product of the matches for hour and minute as the total count
        return hourMatches * minuteMatches;
    }
};
```

TypeScript

```typescript
function countTime(time: string): number {
    // Helper function to count the valid numbers that can replace the '?'
    // 'timeSegment' is the part of the time string ('HH' or 'MM')
    // 'maxValue' is the maximum value that the time segment can have (24 for hours, 60 for minutes)
    const countValidCombinations = (timeSegment: string, maxValue: number): number => {
        let validCount = 0; // To keep track of the count of valid combinations
        for (let i = 0; i < maxValue; ++i) {
            // Check if the first character matches or is a '?'
            const matchesFirstChar = timeSegment[0] === '?' || timeSegment[0] === Math.floor(i / 10).toString();
            // Check if the second character matches or is a '?'
            const matchesSecondChar = timeSegment[1] === '?' || timeSegment[1] === (i % 10).toString();

            // Increment the count if both characters match or are '?'
            if (matchesFirstChar && matchesSecondChar) {
                ++validCount;
            }
        }
        return validCount; // return the final count of valid combinations
    };

    // Extract the hour and minute segments from the input time string
    const hoursSegment = time.slice(0, 2); // "HH"
    const minutesSegment = time.slice(3); // "MM"

    // Count valid hour and minute combinations and multiply them to get total valid time combinations
    const hourCombinations = countValidCombinations(hoursSegment, 24);
    const minuteCombinations = countValidCombinations(minutesSegment, 60);

    // The total number of possible valid times is the product of the number of
    // valid hour combinations and the number of valid minute combinations.
    return hourCombinations * minuteCombinations;
}
```

```python

class Solution:
    def count_time(self, time: str) -> int:
        # Helper function to count the valid numbers for a part of the time (hour/minute)
        def count_valid_combinations(part: str, max_value: int) -> int:
            count = 0
            # Iterate through all possible values based on maximum for hour/minute
            for i in range(max_value):
                # Check if the first character is '?' or matches the tens place of 'i'
                matches_first_char = part[0] == '?' or int(part[0]) == i // 10
                # Check if the second character is '?' or matches the ones place of 'i'
                matches_second_char = part[1] == '?' or int(part[1]) == i % 10
                # Increment count if both characters match
                count += matches_first_char and matches_second_char
            return count

        # Separating the time string into hours and minutes parts
        hour_part = time[:2]
        minute_part = time[3:]

        # Return the product of the count of valid combinations for hours and minutes
        return count_valid_combinations(hour_part, 24) * count_valid_combinations(minute_part, 60)
```

Time and Space Complexity

Time Complexity

The given Python function `countTime` primarily consists of two nested calls to a helper function `f`. The helper function is responsible for counting the number of valid permutations for given position constraints in a digital clock format.

The function `f` is called twice:

1. To calculate the number of valid hours when the input is the first two characters of the string corresponding to hours.
2. To calculate the number of valid minutes when the input is the last two characters of the string corresponding to minutes.

The first call to `f` considers all possible hour values, which in a 24-hour format, are 00 to 23, totaling 24 possibilities. The second call to `f` considers all possible minute values, which are from 00 to 59, totaling 60 possibilities.

In both cases, `f` iterates over a fixed range:

- For hours: `range(24)`
- For minutes: `range(60)`

Within the function `f`, there are constant-time operations being performed, such as comparison and arithmetic operations. These constant-time operations do not depend on the size of the input and thus have a time complexity $O(1)$.

Therefore, the time complexity of `f` is $O(24)$ for hours and $O(60)$ for minutes, which are both considered constant, and we can simplify this to $O(1)$ complexity for each call of `f`.

Since we call `f` twice, once for hours and once for minutes, and each call has a $O(1)$ time complexity, our total time complexity for function `countTime` is also $O(1)$.

Space Complexity

The space complexity of the function `countTime` is determined by the space used by variables inside the function that are required to perform the computation.

The helper function `f` uses a few local variables (like `cnt`, `a`, and `b`) to store temporary calculation results. These variables require a constant amount of space that does not depend on the size of the input and thus have a space complexity of $O(1)$.

The outer function `countTime` similarly uses only a constant amount of space, calling `f` twice and storing the results in a return statement.

All variables are of primitive data types, and there are no data structures used that would grow with the size of the input. Therefore, the overall space complexity of the `countTime` function is $O(1)$ as well.