1020. Number of Enclaves

Medium Depth-First Search Breadth-First Search Union Find Array Matrix

Problem Description

You have a matrix where each cell can either be land (`1`) or sea (`0`). A move is defined as walking from one land cell to an adjacent land cell. Adjacent means above, below, to the left, or to the right (but not diagonally). The edge of the matrix is considered as a boundary that one can walk off from. The problem asks you to find out how many land cells are there in the matrix such that it's not possible to walk off the edge of the matrix starting from any of these cells; in other words, these land cells are enclosed by other land cells or by the matrix boundaries. This can be visualized as counting the number of land cells from which you cannot reach the sea by moving only horizontally or vertically on the land cells.

Intuition

To solve this problem, we can make use of a Depth-First Search (DFS) approach. The key intuition is to identify and eliminate the land cells that can lead to the boundary (and hence, to the sea), so that what remains will be our "enclosed" cells.

We start by iterating over the boundary rows and columns of the grid. If there's a land cell on the boundary, it means that this land cell can directly lead to the sea. But we also need to consider the land cells connected to it. Thus, we use DFS starting from this land cell on the boundary to traverse and "sink" all connected land cells, marking them as sea cells (by setting them to `0`). "Sinking" in this context means we are marking the cell as visited and ensuring we won't count it later as an enclosed land cell.

DFS is continued until all cells that can reach the boundary are marked as sea cells. After marking these cells, the remaining land cells in the grid are guaranteed to be enclosed as they cannot reach the boundary.

Lastly, we count and return the number of cells left with a `1`, which represents the number of enclosed land cells. For this, we simply iterate through the entire grid and sum up the values.

Solution Approach

The solution utilizes a Depth-First Search (DFS) algorithm to explore and manipulate the grid. Here's a step-by-step explanation of how it works:

1. Define the `dfs` function, which will be used to mark the land cells that can lead to the boundary as sea cells. This function takes the current coordinates `(i, j)` of a land cell as arguments.
2. Inside the `dfs` function, the current land cell is first "sunk" by setting `grid[i][j]` to `0`.
3. The function then iterates over the adjacent cells in the 4 cardinal directions using a tuple `dirs` that contains the relative coordinates to move up, down, left, and right. The `pairwise` pattern (a common programming idiom) is used to retrieve directions in pairs. However, in this particular solution code, it seems they have made an error by referring to `pairwise(dirs)`, which should have been a traversal through the directions one by one; instead, this should be replaced with code that iterates over each pair of directions in `dirs`, something akin to `(dirs[i], dirs[i + 1])` for `i` in `range(len(dirs) - 1)`.
4. It checks if the new coordinates `(x, y)` are within the grid and if the cell is a land cell. If these conditions are met, DFS is recursively called on that cell.
5. Before starting the DFS, the main part of the function initializes the dimensions of the grid `m` and `n`.
6. The function then iterates over the cells on the boundaries of the grid - this is done by iterating through the rows and columns at the edges.
7. For each boundary cell that is land (has value `1`), the DFS is called to "sink" the cell and any connected land cells.
8. After DFS traversal, all the cells that could walk off the boundary will be marked as `0`.
9. Finally, the function counts and returns the number of cells with a value of `1`, which now represent only the enclosed cells, by summing up all the values in the grid.

The data structure used here is the grid itself, which is a 2D list (a list of lists in Python), which is modified in place. The solution doesn't use any additional complex data structures. The DFS pattern is crucial for this solution, as it enables systematically visiting and modifying cells related to the boundary cells.

Please note that the actual code given has a mistake in the usage of `pairwise`, which isn't actually defined in the standard Python library's context and is not suitable for the way directions are used. It would need to be corrected for the code to function as intended.

Example Walkthrough

Let's consider a 5×5 matrix as a small example to illustrate the solution approach:

```
1 0 0 0 1
1 1 1 0 1
1 0 1 0 0
1 1 1 0 1
1 0 0 1 1
```

In this matrix, `1` indicates land, and `0` represents sea. We want to find out the number of land cells that are completely surrounded by other land cells or the borders of the matrix and thus cannot reach the edge.

Following the solution approach:

1. We enumerate the boundary cells. These would be cells in the first and last rows and columns.
2. As we check these cells, we find `1`s at `(0,0)`, `(0,4)`, `(4,3)`, and `(4,4)` on the corners and some other on the edges. We know these cannot be enclosed as they are on the matrix edge.
3. We begin our DFS with each of these boundary `1`s to mark the connected land cells as `0` (sea). Starting with `(0,0)`, we find it's already on the edge and mark it as `0`. We do the same with other boundary `1`s.

The matrix after sinking the boundary land cells is:

```
0 0 0 0 0
1 1 1 0 0
1 0 1 0 0
1 1 1 0 0
1 0 0 0 0
```

4. All reachable cells have been "sunk". The land cells at `(1,0)`, `(1,1)`, `(1,2)`, `(2,0)`, `(2,2)`, `(3,0)`, `(3,1)`, and `(3,2)` remain as `1`s. Now, we only count the `1`s not on the boundary.
5. We iterate over the remaining cells to count the number of land cells that are enclosed. From our matrix above, the count is `8`.

Through this DFS approach, we have effectively identified and eliminated any land cell connected to the boundary. The remaining land cells are the enclosed cells that we are interested in counting.

Solution Implementation

Python

```python
class Solution:
    def numEnclaves(self, grid: List[List[int]]) -> int:
        # A Helper function to perform depth-first search and mark visited land cells as water
        def dfs(row, col):
            grid[row][col] = 0  # Mark the current cell as visited by setting it to 0 (water)

            # Loop through the four directions (up, right, down, left)
            for direction in range(4):
                new_row = row + dirs[direction]
                new_col = col + dirs[direction + 1]
                # Check if the new cell is within the bounds of the grid and is land
                if 0 <= new_row < num_rows and 0 <= new_col < num_cols and grid[new_row][new_col]:
                    dfs(new_row, new_col)  # Recursively apply DFS to the new cell

        num_rows, num_cols = len(grid), len(grid[0])  # Get the dimension of the grid

        # Directions for upward, rightward, downward, and leftward movement
        # dirs = [-1, 0, 1, 0]
        d_col = [0, 1, 0, -1]

        # Start DFS for the boundary cells that are land (i.e., have a value of 1)
        for row in range(num_rows):
            for col in range(num_cols):
                if grid[row][col] and (row == 0 or row == num_rows - 1 or col == 0 or col == num_cols - 1):
                    dfs(row, col)  # Remove enclaves touching the boundary by DFS

        # Count the remaining land cells that are enclaves (not touching the boundaries)
        return sum(value for row in grid for value in row)
```

Java

```java
class Solution {
    private int rows; // Total number of rows in the grid
    private int columns; // Total number of columns in the grid
    private int[][] grid; // The grid representing the land and water

    // This method calculates the number of enclaves.
    public int numEnclaves(int[][] grid) {
        this.grid = grid; // Assigns the input grid to the instance variable grid
        rows = grid.length; // Sets the number of rows
        columns = grid[0].length; // Sets the number of columns

        // Iterate over the boundary cells of the grid
        for (int i = 0; i < rows; ++i) {
            for (int j = 0; j < columns; ++j) {
                // On finding a land cell on the boundary, initiate DFS
                if (grid[i][j] == 1 && (i == 0 || i == rows - 1 || j == 0 || j == columns - 1)) {
                    dfs(i, j); // Call DFS to mark the connected land as water (0)
                }
            }
        }

        // Count the land cells (value 1) that are not connected to the boundary
        int enclaveCount = 0;
        for (int[] row : grid) {
            for (int value : row) {
                enclaveCount += value;
            }
        }
        return enclaveCount; // Return the number of cells in enclaves
    }

    // DFS method to convert connected land cells to water cells
    private void dfs(int i, int j) {
        grid[i][j] = 0; // Mark the current cell as water
        int[] directions = {-1, 0, 1, 0, -1}; // Array representing the 4 directions (up, right, down, left)

        // Explore all 4 possible directions
        for (int k = 0; k < 4; ++k) {
            int x = i + directions[k], y = j + directions[k + 1];
            // Check if the next cell is within the grid and is a land cell
            if (x >= 0 && x < rows && y >= 0 && y < columns && grid[x][y] == 1) {
                dfs(x, y); // Continue DFS from the next cell
            }
        }
    }
}
```

C++

```cpp
#include <vector>
#include <functional> // Needed for std::function

class Solution {
public:
    int numEnclaves(std::vector<std::vector<int>>& grid) {
        int numRows = grid.size();    // Number of rows in grid
        int numCols = grid[0].size(); // Number of columns in grid

        // Direction vectors for exploring adjacent cells.
        int directions[5] = {-1, 0, 1, 0, -1};

        // DFS function to explore and flip land cells (1's) into water cells (0's)
        std::function<void(int, int)> depthFirstSearch = [&](int i, int j) {
            grid[i][j] = 0; // Flip the current cell to water
            for (int k = 0; k < 4; ++k) { // Explore all four adjacent cells
                int x = i + directions[k], y = j + directions[k + 1];
                // Check for bounds of grid and if the cell is land
                if (x >= 0 && x < numRows && y >= 0 && y < numCols && grid[x][y]) {
                    depthFirstSearch(x, y); // Continue DFS if adjacent cell is land
                }
            }
        };

        // First pass to remove all land regions touching the grid boundaries
        for (int i = 0; i < numRows; ++i) {
            for (int j = 0; j < numCols; ++j) {
                // Check if the cell is land and at the border, then start DFS
                if (grid[i][j] && (i == 0 || i == numRows - 1 || j == 0 || j == numCols - 1)) {
                    depthFirstSearch(i, j);
                }
            }
        }

        // After removing enclaves touching the border, count remaining enclaved lands
        int enclaveCount = 0;
        for (auto& row : grid) {
            for (auto& cell : row) {
                enclaveCount += cell; // Cell will be 1 if it's land not touching the border
            }
        }

        return enclaveCount; // Return the final count of enclaved lands
    }
};
```

TypeScript

```typescript
function numEnclaves(grid: number[][]): number {
    // Get the number of rows and columns in the grid.
    const rows = grid.length;
    const cols = grid[0].length;

    // Directions array represents the four possible movements (up, right, down, left).
    const directions = [-1, 0, 1, 0, -1];

    // Depth-first search function to mark land (1's) connected to the borders as water (0's).
    const dfs = (row: number, col: number) => {
        // Mark the current land piece as visited by setting it to 0.
        grid[row][col] = 0;

        // Explore all four directions.
        for (let k = 0; k < 4; ++k) {
            const nextRow = row + directions[k];
            const nextCol = col + directions[k + 1];

            // Check if the new coordinates are in bounds and if there is land to visit.
            if (nextRow >= 0 && nextRow < rows && nextCol >= 0 && nextCol < cols && grid[nextRow][nextCol] === 1) {
                dfs(nextRow, nextCol);
            }
        }
    };

    // Run the DFS for lands connected to the borders to eliminate those.
    for (let row = 0; row < rows; ++row) {
        for (let col = 0; col < cols; ++col) {
            // If the cell is land and it's on the border, start the DFS.
            if (grid[row][col] === 1 && (row === 0 || row === rows - 1 || col === 0 || col === cols - 1)) {
                dfs(row, col);
            }
        }
    }

    // Count the number of enclaved land pieces remaining in the grid.
    let enclaveCount = 0;
    for (const row of grid) {
        for (const cell of row) {
            enclaveCount += cell;
        }
    }

    // Return the count of enclaves, which are land pieces not connected to the border.
    return enclaveCount;
}
```

```python
class Solution:
    def numEnclaves(self, grid: List[List[int]]) -> int:
        # A Helper function to perform depth-first search and mark visited land cells as water
        def dfs(row, col):
            grid[row][col] = 0  # Mark the current cell as visited by setting it to 0 (water)

            # Loop through the four directions (up, right, down, left)
            for direction in range(4):
                new_row = row + dirs[direction]
                new_col = col + dirs[direction + 1]
                # Check if the new cell is within the bounds of the grid and is land
                if 0 <= new_row < num_rows and 0 <= new_col < num_cols and grid[new_row][new_col]:
                    dfs(new_row, new_col)  # Recursively apply DFS to the new cell

        num_rows, num_cols = len(grid), len(grid[0])  # Get the dimension of the grid

        # Directions for upward, rightward, downward, and leftward movement
        # dirs = [-1, 0, 1, 0]
        d_col = [0, 1, 0, -1]

        # Start DFS for the boundary cells that are land (i.e., have a value of 1)
        for row in range(num_rows):
            for col in range(num_cols):
                if grid[row][col] and (row == 0 or row == num_rows - 1 or col == 0 or col == num_cols - 1):
                    dfs(row, col)  # Remove enclaves touching the boundary by DFS

        # Count the remaining land cells that are enclaves (not touching the boundaries)
        return sum(value for row in grid for value in row)
```

Time and Space Complexity

The given code performs a Depth-First Search (DFS) on a two-dimensional grid to find the number of enclaves, which are regions of 1's *not* connected to the grid's border.

Time Complexity:

The time complexity of the code is $O(m * n)$ where m is the number of rows and n is the number of columns in the grid. Each cell in the grid is processed at most once. The DFS is started from each border cell that contains a '1' and marks all reachable '1's as '0's (meaning they're visited). Since each cell can be part of only one DFS call (once it has been visited, it's turned to '0' and won't be visited again), each cell contributes only a constant amount of time. Therefore, the time complexity is proportional to the total number of cells in the grid.

Space Complexity:

The space complexity of the DFS is $O(m * n)$ in the worst case, which happens when the grid is filled with 1's, and hence the call stack can grow to the size of the entire grid in a worst-case scenario of having a single large enclave. However, the function modifies the grid in-place and does not use any additional space proportional to the grid size, except for the recursion call stack. Thus the space complexity is determined by the depth of the recursion, which is $O(m * n)$ in this worst case.