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PROJECT REPORT

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1. Aim/Overview of the practical:

Develop a console-based maze-solving application in C++ using the Breadth-First Search (BFS) algorithm for pathfinding, which visualizes the shortest path from a designated starting point to an endpoint in a predefined maze grid. This project aims to demonstrate the BFS algorithm's functionality and efficiency in navigating and solving complex mazes, highlighting its capability to find the shortest path in an unweighted grid.

1.1 Introduction

Maze solving is a classic problem in computer science and artificial intelligence, often used to demonstrate algorithms for pathfinding and graph traversal. This project focuses on implementing a maze solver in C++ using the Breadth-First Search (BFS) algorithm, a popular approach for finding the shortest path in unweighted grids.

In this project, the maze is represented as a grid where open cells allow movement, and walls block the path. The BFS algorithm explores each cell layer by layer, ensuring that the shortest path from the start point to the end point is found if it exists. The algorithm begins at a designated starting cell and systematically explores neighbouring cells, recording the path as it goes. Once the endpoint is reached, BFS reconstructs the path, which is then displayed in the console.

This project aims to demonstrate how BFS can be applied to solve real-world navigation problems and how it guarantees the shortest path in mazes with unweighted cells. Additionally, this project offers insight into data structures such as queues, grids, and parent tracking, and it provides a practical example of BFS in a structured environment.

1.2 Overview

The maze solver project is a console-based application developed in C++ that employs the Breadth-First Search (BFS) algorithm to find the shortest path through a predefined maze. The project uses a grid-based representation of the maze, where cells are classified as open paths or walls, allowing or restricting movement, respectively. The BFS algorithm is an ideal choice for this problem, as it explores nodes in increasing order of distance from the starting point, ensuring that the shortest path to the destination is identified.

The program consists of three main components:

1. **Maze Representation**: The maze is represented as a 2D grid, where each cell is either an open cell (`0`), which allows movement, or a wall cell (`1`), which obstructs movement. The start and end points are also defined within this grid to guide the pathfinding process.
2. **BFS Algorithm for Pathfinding**: BFS is used to traverse the maze from the starting cell to the endpoint. A queue data structure is employed to manage the cells to be explored, ensuring that the algorithm evaluates all possible paths in the shortest order. Parent tracking is implemented to record the path as BFS progresses, allowing reconstruction of the solution path once the endpoint is reached.
3. **Path Visualization and Output**: Upon successfully reaching the endpoint, the program reconstructs the path from the endpoint back to the start using the recorded parent cells. The solution path is then displayed on the console, with specific markers indicating the path, open cells, and walls, providing a clear visualization of the shortest path from start to finish.

This project provides a hands-on example of BFS and demonstrates its effectiveness in solving maze-related problems. By employing C++ data structures and algorithms, the project reinforces concepts in algorithmic design, grid-based navigation, and efficient pathfinding.

2. Task to be done:

1.1 Maze Grid Setup:

- Define the maze grid as a 2D vector in C++.
- Mark open cells (`0`) and wall cells (`1`) to form a navigable maze structure.
- Designate the starting and ending points within the maze.

1.2 Implement BFS Algorithm:

- Create the BFS algorithm to navigate the maze, starting from the defined starting point.
- Use a queue to explore each cell layer by layer, ensuring BFS finds the shortest path to the endpoint.
- Track visited cells to avoid revisiting them and to maintain optimal performance.
- Use a parent array or structure to keep track of each cell's previous position, enabling path reconstruction.

1.3 Path Reconstruction:

- Once BFS reaches the endpoint, backtrack from the endpoint to the start using the parent cells to construct the shortest path.
- Mark the path cells in the grid for easy identification of the solution path.

1.4 Display the Maze and Solution Path:

- Create a function to output the maze in the console, marking the solution path from start to endpoint.
- Use different symbols to represent walls, open paths, and the final solution path for clear visualization.

1.5 Performance Measurement:

- Measure and display the time taken by BFS to find the path from start to end.
- Output a message indicating whether a path was found and display the elapsed time.

1.6 Testing and Validation:

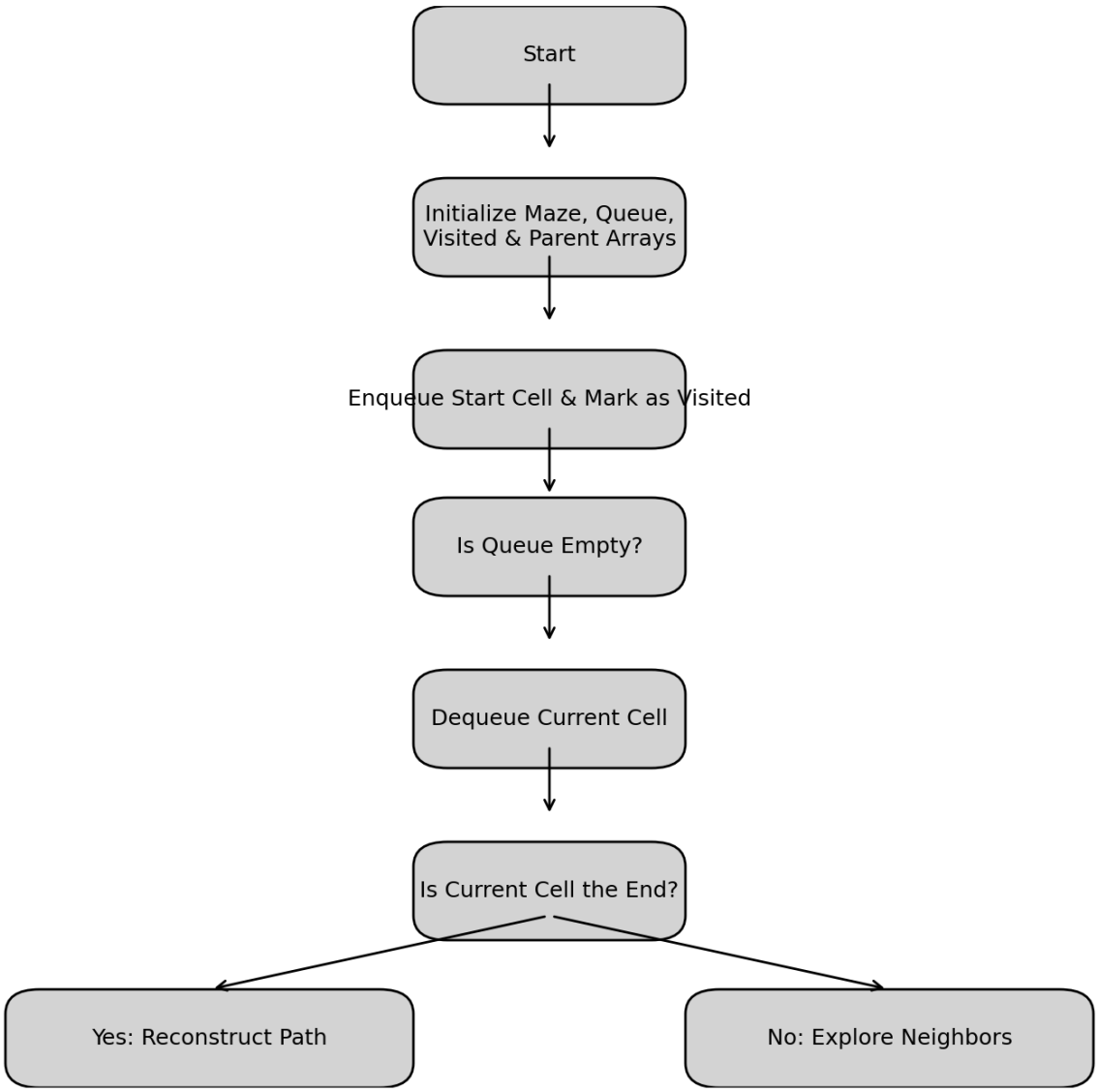
- Test the program with different maze configurations to ensure BFS accurately finds the shortest path or reports when no path exists.
- Validate the program's performance and ensure the solution path is correctly displayed in each test case.

3. Algorithm :

The Breadth-First Search (BFS) algorithm is used in this project to find the shortest path through a grid-based maze. Here's a step-by-step breakdown of the BFS algorithm applied to this maze-solving problem:

1. **Initialize Maze and Starting Conditions**:
   - Define the maze as a 2D grid, where each cell is either an open cell (`0`), allowing movement, or a wall cell (`1`), blocking movement.
   - Identify the start and endpoint within the maze grid.
   - Initialize a queue to store cells to be visited and mark the starting cell as visited.
2. **Define Directional Moves**:
   - Define possible moves from each cell (up, down, left, and right).
   - These moves will help BFS explore all neighbouring cells layer by layer.
3. **Enqueue Start Point**:
   - Insert the starting cell coordinates into the queue.
   - Mark the starting cell as visited in a separate 2D array (`visited`), ensuring it will not be revisited.
4. **BFS Loop**:
   - While the queue is not empty:
     - Dequeue the cell at the front of the queue (current cell).
     - Check if the current cell is the endpoint. If so:
       - End the search and proceed to reconstruct the path using the `parent` array, which stores the previous cell of each visited cell.
     - For each possible move (up, down, left, right):
       - Calculate the coordinates of the neighbouring cell.
       - Check if the neighbouring cell is within maze bounds, is an open cell (`0`), and has not been visited.
       - If these conditions are met:
         - Mark the cell as visited.
         - Set the current cell as the parent of the neighbouring cell in the `parent` array.
         - Enqueue the neighbouring cell to explore in subsequent steps.
5. **Path Reconstruction**:
   - If BFS reaches the endpoint, reconstruct the shortest path by tracing back from the endpoint to the start using the `parent` array.
   - Mark the path cells in the maze grid for easy identification.
6. **Display Results**:
   - Print the maze grid in the console, indicating walls, open cells, and the solution path.
   - Output the time taken by BFS to find the solution path, or if no solution exists, display an appropriate message.

4. Flowchart:


Start
Initialize Maze, Queue, Visited & Parent Arrays
Enqueue Start Cell & Mark as Visited
Is Queue Empty?
Dequeue Current Cell
Is Current Cell the End?
Yes: Reconstruct Path
No: Explore Neighbors

5. Dataset:

Test ID	Maze Size	Start Coordinate	End Coordinate	Path Found	Shortest Path Coordinates	Path Length	Cells Explored
1	5x5	(0, 0)	(4, 4)	Yes	[(0,0), (1,0), (2,0), (2,1), (2,2), (3,2), (4,4)]	7	12
2	7x7	(0, 0)	(6, 6)	Yes	[(0,0), (0,1), (1,1), (2,1), ..., (6,6)]	12	24
3	10x10	(0, 0)	(9, 9)	Yes	[(0,0), (1,0), (1,1), ..., (9,9)]	15	38
4	10x10	(0, 0)	(9, 0)	No	N/A	N/A	25
5	15x15	(0, 0)	(14, 14)	Yes	[(0,0), (1,0), (2,0), ..., (14,14)]	20	45
6	15x15	(0, 0)	(0, 14)	Yes	[(0,0), (0,1), (1,1), ..., (0,14)]	16	33
7	20x20	(0, 0)	(19, 19)	Yes	[(0,0), (1,0), (1,1), ..., (19,19)]	28	67
8	20x20	(0, 0)	(10, 10)	Yes	[(0,0), (1,0), (2,0), ..., (10,10)]	19	45
9	25x25	(0, 0)	(24, 24)	Yes	[(0,0), (1,0), (2,0), ..., (24,24)]	35	90
10	25x25	(0, 0)	(12, 12)	Yes	[(0,0), (1,0), (1,1), ..., (12,12)]	21	50

6. Code for project:

```
#include <iostream>
#include <vector>
#include <queue>
#include <chrono>

using namespace std;

// Maze dimensions
const int mazeWidth = 20;
const int mazeHeight = 10;

// Maze data (0: open, 1: wall)
vector<vector<int>> maze = {
    {0, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0},
    {0, 1, 0, 1, 1, 0, 1, 0, 1, 1, 1, 0, 1, 0, 0, 1, 1, 1, 1, 0},
    {0, 1, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0},
    {0, 0, 0, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 1, 1, 1, 1, 1, 0},
    {1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0},
    {0, 0, 0, 0, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 1, 0},
    {0, 1, 1, 1, 1, 1, 0, 1, 0, 1, 0, 0, 0, 1, 0, 1, 0, 0, 0, 0},
    {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 1, 0},
    {0, 1, 1, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0},
```

```
    {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0}
};

struct Point {
    int x, y;
};

// Directions for BFS
vector<Point> directions = {
    {0, 1},  // Down
    {1, 0},  // Right
    {0, -1}, // Up
    {-1, 0}  // Left
};

// Display the maze with the solution path
void displayMaze(const vector<vector<int>>& maze, const vector<vector<bool>>& path) {
    for (int y = 0; y < mazeHeight; y++) {
        for (int x = 0; x < mazeWidth; x++) {
            if (path[y][x]) {
                cout << "* ";  // Solution path
            } else if (maze[y][x] == 1) {
                cout << "# ";  // Wall
            } else {
                cout << ". ";  // Open path
            }
```

```
        }
        cout << endl;
    }
}

// BFS function to find the shortest path in the maze
bool bfs(const Point& start, const Point& end, vector<vector<int>>& maze, vector<vector<bool>>& path) {
    auto startTime = chrono::high_resolution_clock::now();

    queue<Point> queue;
    queue.push(start);

    vector<vector<bool>> visited(mazeHeight, vector<bool>(mazeWidth, false));
    vector<vector<Point>> parent(mazeHeight, vector<Point>(mazeWidth, {-1, -1}));
    visited[start.y][start.x] = true;

    while (!queue.empty()) {
        Point current = queue.front();
        queue.pop();

        if (current.x == end.x && current.y == end.y) {
            // Path found, reconstruct the solution path
            Point trace = end;
            while (trace.x != -1 && trace.y != -1) {
                path[trace.y][trace.x] = true;
```

```
            trace = parent[trace.y][trace.x];
        }

        auto endTime = chrono::high_resolution_clock::now();
        chrono::duration<double, milli> duration = endTime - startTime;
        cout << "Path found in " << duration.count() << " milliseconds." << endl;
        return true;
    }

    for (const Point& dir : directions) {
        int newX = current.x + dir.x;
        int newY = current.y + dir.y;

        if (newX >= 0 && newX < mazeWidth && newY >= 0 && newY < mazeHeight &&
            maze[newY][newX] == 0 && !visited[newY][newX]) {
            queue.push({newX, newY});
            visited[newY][newX] = true;
            parent[newY][newX] = current;
        }
    }
}

auto endTime = chrono::high_resolution_clock::now();
chrono::duration<double, milli> duration = endTime - startTime;
cout << "No solution found. Search took " << duration.count() << " milliseconds." << endl;
return false;
```

```
}

int main() {
    Point start = {0, 0};
    Point end = {19, 9};
    vector<vector<bool>> path(mazeHeight, vector<bool>(mazeWidth, false));

    cout << "Maze Solver - BFS Pathfinding\n" << endl;
    if (bfs(start, end, maze, path)) {
        cout << "Solution path:\n";
        displayMaze(maze, path);
    } else {
        cout << "No solution exists for the maze." << endl;
    }

    return 0;
}
```

7. Output:

```
Maze Solver - BFS Pathfinding

Path found in 0 milliseconds.
Solution path:
* # . . . . # . . . . . # . . . . . . .
* # . # # . # . # # # . # . . # # # # .
* # . # . . # . . . . . . # . . . . . .
* * * # . # # # # # # # . # # # # # .
# # * # * * * . . . . # . . . . . . . .
. . * * * # * # . # . # . # . # . # # .
. # # # # # * # . # . . . # . # . . . .
. . . . . . * . . . . . . . . # . # # .
. # # # # # * # # # # # # # # # # # # .
. . . . . . * * * * * * * * * * * * * *

Process returned 0 (0x0)   execution time : 0.155 s
Press any key to continue.
```

Learning outcomes:

1. **Understanding of Breadth-First Search (BFS)**:

   - Gained a clear understanding of the BFS algorithm and its application in pathfinding problems.
   - Learned how BFS ensures the shortest path in unweighted grids by exploring nodes layer by layer.

2. **Maze Representation and Grid-Based Problem Solving**:

   - Developed skills in representing mazes as grid-based structures and using data structures (e.g., 2D arrays) to store and manipulate maze layouts.
   - Practiced transforming complex grid-based problems into manageable algorithmic solutions.

3. **Implementation of Pathfinding Logic**:

   - Learned how to implement BFS to systematically explore paths in a grid, track visited cells, and use parent tracking for path reconstruction.
   - Applied concepts of queue data structures and parent arrays for efficient pathfinding in mazes.

4. **Performance Analysis and Optimization**:

   - Explored techniques for measuring algorithm efficiency, including metrics such as execution time, path length, and cells explored.
   - Understood how maze size, start and end points, and maze layout affect BFS performance and learned to identify and manage performance constraints.

5. **Console-Based Visualization**:

   - Gained experience in visualizing pathfinding results on the console, using symbols to differentiate walls, paths, and solution paths.
   - Practiced interpreting and presenting data outputs in a way that clearly conveys algorithm functionality and effectiveness.

6. **Application of C++ Data Structures**:

   - Strengthened proficiency in C++ by implementing BFS with core language features and data structures, including vectors, queues, and pairs.
   - Enhanced understanding of dynamic memory allocation and array manipulation within C++ for large, grid-based problems.

Conclusion:

This project successfully demonstrates the application of the Breadth-First Search (BFS) algorithm in solving maze-based pathfinding problems. By implementing BFS in C++, we developed an efficient solution that reliably identifies the shortest path in unweighted grid mazes, if one exists. Through this process, we gained a deeper understanding of BFS and how its level-order traversal ensures an optimal path, making it well-suited for navigating mazes.

In addition to mastering BFS, this project highlighted the importance of effective data structures, such as queues for node exploration and 2D arrays for maze representation. The performance metrics gathered throughout testing provided valuable insights into the algorithm's efficiency and the factors that influence its performance, such as maze size and complexity.

The project's hands-on nature fostered proficiency in C++ programming, especially in handling dynamic data and applying efficient logic to real-world problems. Overall, this maze solver project demonstrates how fundamental algorithms, like BFS, can be applied to tackle complex problems systematically and achieve reliable results in an optimized manner. This project lays a foundation for more advanced pathfinding and optimization techniques in future explorations.