Quantitative Comparison of Flood Fill and Modified Flood Fill Algorithms

George Law

Abstract—Flood fill algorithm has won first places in the international micromouse competitions. To save computation time, the modified flood fill algorithm is often coded. Yet, the literature search reveals the scarcity of the quantitative details of the two algorithms. This article attempts to discuss their differences and uses Maze-solver simulator to collect and tabulate the maze-run statistics for various popular mazes. It will discuss these statistics and various aspects of the flood fill algorithm modifications.

Index Terms—Flood fill algorithm, maze simulation, micromouse competition, modified flood fill algorithm.

I. INTRODUCTION

Each year since 1972, the micromouse competitions have been held in cities and university campuses all around the world. The participants, students and engineers, design and program their micromice to autonomously find the center of a 16 by 16 cell maze within 10 minutes. After finding the center, the micromouse may map the entire maze to locate the shortest route to the center. Using the shortest route, the micromouse will attempt to reach the center in a fastest run.

The maze-solver simulator simulates the mouse run in various popular mazes such as the one used in Japan 2011 competition and other competitions. For each algorithm, the simulator tabulates the total cell traverses, number of distance updates, number of corner turns, etc. Luke Last, et al. [1] codes the Flood Fill algorithm in Java; the author augments and revises their Flood Fill algorithm and codes the Modified Flood Fill algorithm [2].

II. MAZE SOLVING ALGORITHMS

Many maze solving algorithms are readily available. With less demand for computation speed and with the assurance that the best run gives the smallest number of cells travelled, the modified flood fill algorithm is, by far, the most commonly used one in micromouse competitions.

A. Flood Fill Algorithm

The Flood Fill algorithm uses the concept of water always flowing from a higher elevation to a lower one [3][4]. It applies this concept by assigning each cell in the maze a value that represents how far the cell is from the center. The cells with higher values are considered to have higher elevations; the ones with lower values are considered to have lower elevations. The center cells are assigned zero values which are equivalent to the lowest elevations.

For simplicity in illustration, instead of using a 16x16 cell maze, we shall use a 6x6 cell maze as shown in Fig. 1a. The concept remains the same except that it applies to a smaller region of cells.

Fig. 1a. 6x6 cells sample maze

We shall use the matrix notation (x, y) for the cell location where x is the row value, x = 0 is the bottom row, and x = 5 is the top row; y is the column value, y = 0 is left-most column, and y = 5 is the right-most column. The micromouse starts at cell (0, 0) which is the cell at the lowest left-hand corner. Initially, the micromouse is placed at (0, 0) facing upward, as shown by the arrow. Before the micromouse starts its exploration, the maze is assumed to have no walls and each cell is assigned a value based on number of cell distance from the center. Fig. 1b shows the initial cells’ distance values for a 6x6 cell maze.

Fig. 1b. Initial distance values from center cells

The maze for any IEEE micromouse competition always has the east wall at the starting cell (0, 0) and the first move is always upward (north). At cell (0, 0), the cell has only one open neighbor (1, 0) which has a smaller distance from the center. Hence the micromouse will moves upward (north), from a higher elevation to a lower one, as shown in Fig. 1c. With the new wall detected north of cell (1, 0) and the old wall east of cell (0, 0), the Flood Fill algorithm floods the maze with the distances from the center cells as shown in Fig. 1c.
At cell (1, 0), the micromouse encounters the north wall. This cell has two open neighbors (0, 0) and (1, 1). Since the open east neighbor (1, 1) has a distance smaller than cell (1, 0), the micromouse will turn and moves to (1, 1) eastwards, again from a higher elevation to a lower one, as shown in Fig. 1d. With the new wall detected east of cell (1, 1) and the old walls north of cell (1, 0) and east of cell (0, 0), the Flood Fill algorithm floods the maze with the distances from the center cells as shown in Fig. 1d. Refer to Fig. 1a for the other walls which are yet to be detected.

At cell (1, 1), the micromouse encounters the east wall. This cell has three open neighbors (0, 1), (2, 1) and (1, 0). Since the open north neighbor (2, 1) has a distance smaller than cell (1, 1), the micromouse will turn and moves to (2, 1) northwards, again from a higher elevation to a lower one, as shown in Fig. 1e. With the new walls detected north of cell (2, 1) and east of cell (2, 1), and the old walls east of cell (1, 1), north of cell (1, 0), and east of cell (0, 0), the Flood Fill algorithm floods the maze with the distances from the center cells as shown in Fig. 1e.

The maze flooding is done each time the micromouse reaches a new cell. Again, when the micromouse reaches cell (3, 0), the distance values, as the result of maze flooding, is shown in Fig. 1f.

The modified flood fill algorithm does **not** flood the maze each time a new cell is reached. Instead it updates only the relevant neighboring cells using the following revised recursive steps:

1) Push the current cell location \((x, y)\) onto the stack.
2) Repeat this step while the stack is not empty.
   - Pull the cell location \((x, y)\) from the stack.
   - If the minimum distance of the neighboring open cells, \(md\), is not equal to the present cell’s distance - 1, replace the present cell’s distance with \(md + 1\), and push all neighbor locations onto the stack. This revised distance update algorithm differs from the recursive steps outlined by S. Benkovic in http://www.micromouseinfo.com/introduction/mfloodfill.html [5]. The Appendix discusses the differences.
Since the distance of the current cell \((2, 1) - 1 = 0\) is not equal to the minimum of the open neighbors \((2, 0)\) and \((1, 1)\), which is 2, the distance update is necessary. We shall follow the revised recursive distance update steps to see how the distance values are updated.

3) Push the current cell location \((2, 1)\) onto the stack.
   - Pull the cell location \((2, 1)\) from the stack.
   - Since the distance at \((2, 1) - 1 = 0\) is not equal to \(md = 2\), the minimum of its open neighbors \((2, 0)\) and \((1, 1)\), update the distance at \((2, 1)\) to \(md + 1 = 2 + 1 = 3\). Push all neighbor locations \((3, 1), (2, 0)\) and \((1, 1)\), except the center location \((2, 2)\), onto the stack. Fig. 2b shows the updated distances and Fig. 2c shows the current stack contents.

![Fig. 2b. Distance values when micromouse reaches cell (2, 1) after distance update at cell (2, 1)](image)

![Fig. 2c. Contents of Stack when micromouse reaches cell (2, 1) after distance update at cell (2, 1)](image)

- Recursively, since the stack is not empty, pull the cell location \((1, 1)\) from the stack.
- Since the distance at \((1, 1) - 1 = 1\) is not equal to \(md = 3\), the minimum of its open neighbors \((1, 0)\) and \((1, 0)\), update the distance at \((1, 1)\) to \(md + 1 = 3 + 1 = 4\). Push all neighbor locations \((2, 1), (0, 1), (1, 0),\) and \((1, 2)\) onto the stack. Fig. 2d shows the updated distances and Fig. 2e shows the current stack contents.

![Fig. 2d. Distance values when micromouse reaches cell (2, 1) after distance update at cell (1, 1)](image)

![Fig. 2e. Contents of Stack when micromouse reaches cell (2, 1) after distance update at cell (1, 1)](image)

- Recursively, since the stack is not empty, pull the cell location \((1, 0)\) from the stack.
- Since the distance at \((1, 0) - 1 = 0\) is not equal to \(md = 4\), the minimum of its open neighbors \((0, 0)\) and \((1, 1)\), update the distance at \((1, 0)\) to \(md + 1 = 0 + 1 = 5\). Push all neighbor locations \((2, 0), (0, 0),\) and \((0, 1)\) onto the stack. Fig. 2f shows the updated distances and Fig. 2g shows the current stack contents.

![Fig. 2f. Distance values when micromouse reaches cell (2, 1) after distance update at cell (1, 0)](image)

![Fig. 2g. Contents of Stack when micromouse reaches cell (2, 1) after distance update at cell (1, 0)](image)

- Recursively, since the stack is not empty, pull the cell location \((0, 0)\) from the stack.
- Since the distance at \((0, 0) - 1 = 0\) is equal to \(md = 5\), the minimum of its only open neighbor \((1, 0)\), update the distance at \((0, 0)\) to \(md + 1 = 6\). Push all neighbor locations \((1, 0)\) and \((0, 1)\) onto the stack. Fig. 2h shows the updated distances and Fig. 2i shows the current stack contents.

![Fig. 2h. Distance values when micromouse reaches cell (2, 1) after distance update at cell (0, 0)](image)

![Fig. 2i. Contents of Stack when micromouse reaches cell (2, 1) after distance update at cell (0, 0)](image)
We shall not show the similar steps for the remaining cell locations in the stack. One can follow the previous steps, to obtain the distance values. When the stack is empty, the distance map of the maze will look like Fig. 2j.

The same process continues until the micromouse reaches the center cell. Fig. 2k shows the distance map when the micromouse reaches the center cell. Overall, to reach the center on the first run for this sample maze, the total number of distance updates is 36, which is obtained from the maze-solver’s tabulated value.

The simulation shows that the subsequent runs follow the third run’s path, which is an indication that it has found the best run. This is confirmed by the smallest number of cells traversed on this run. If priority is given to the smaller number of turns, the second run will be the best run. When the micromouse uses this best run for its speed run, it just follows the already mapped distances from the starting cell to the center cell, like water flowing from the higher elevation.

TABLE I: TOTAL NUMBER OF DISTANCE UPDATES TO FIND THE BEST RUNS

<table>
<thead>
<tr>
<th>Maze Names</th>
<th>Total number of cell traversed to find best run</th>
<th>Total number of distance updates to find best run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flood Fill</td>
<td>Modified Flood Fill</td>
</tr>
<tr>
<td>IEEE Region 6 2012</td>
<td>530</td>
<td>530</td>
</tr>
<tr>
<td>Sample 16x16 cell Maze</td>
<td>179</td>
<td>179</td>
</tr>
<tr>
<td>APEC 2002</td>
<td>322</td>
<td>322</td>
</tr>
<tr>
<td>Seoul 2002</td>
<td>585</td>
<td>585</td>
</tr>
<tr>
<td>Minos 2003</td>
<td>246</td>
<td>246</td>
</tr>
</tbody>
</table>
to the lowest elevation.

The total number of cells traversed and the total number of turns taken for all three fast runs are tabulated in Table II.

<table>
<thead>
<tr>
<th>RUN</th>
<th>NUMBER OF CELLS TRAVELED</th>
<th>NUMBER OF TURNS TAKEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ST</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>2ND</td>
<td>33</td>
<td>15</td>
</tr>
<tr>
<td>3RD</td>
<td>31</td>
<td>19</td>
</tr>
</tbody>
</table>

TABLE II: NUMBER OF CELLS TRAVELED AND TURNS TAKEN

V. CONCLUSION

Compared to the Flood Fill algorithm, the Modified Flood Fill algorithm offers a significant reduction in cell distance updates (Table I). With a lesser number of distances to update, the micromouse which uses the modified flood fill can traverse from cell to cell in a higher speed. Furthermore, if the dead end cells are marked on the first arrival, these marked cells will not be explored in subsequent runs, resulting in a reduced total number of cells explored. With less demand for computation speed and with the assurance that the best run gives the smallest number of cells traversed, the Modified Flood Fill algorithm may be the choice for micromouse competitions.

APPENDIX

Distance update algorithms comparison

As it has been pointed out earlier, the revised cell distance update algorithm differs from the recursive steps outlined by S. Benkovic in pushing all neighbor cell positions instead of pushing only the open neighbors, when the current cell distance is updated; S. Benkovic’s algorithm pushes only open neighbor cell positions. The differences will be illustrated by the following micromouse run on a sample 16x16 cell maze. Fig. 4a, Fig. 4b, and Fig. 4c show only the relevant portion of the maze. Fig 4a shows the distance values when the micromouse reaches cell (4, 1) where the distance update is necessary. Comparing this distance update process will reveal the algorithms’ differences.

When the micromouse reaches cell (4, 1), this cell’s distance needs update. The revised distance update algorithm will push all neighbors cells (5, 1), (3, 1), (4, 0), and (4, 2) onto the stack whereas S. Benkovic’s distance update algorithm will push only open neighbor cells (4, 0) and (4, 2). As a result, cell (3, 1) distance value will not be updated in his algorithm. Fig. 4b shows the revised algorithm’s distance values when the micromouse reaches cell (6, 0). Fig. 4c
shows S. Benkovic’s distance values when the micromouse reaches cell (6, 0). Cell (3, 1) distance values are boldfaced to emphasize the source of discrepancy. This discrepancy may cause the micromouse to take extra steps in reaching the center cell.

Fig. 4a. Distance values of a portion of a 16x16 cell maze when the micromouse reaches cell (4, 1) before its distance update. * denotes “start position”

Fig. 4b. Revised distance update algorithm: Distance values of a portion of a 16x16 cell maze when the micromouse reaches cell (6, 0).

Fig. 4c. S. Benkovic’s distance update algorithm: Distance values of a portion of a 16x16 cell maze when the micromouse reaches cell (6, 0).

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REFERENCES


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