

ECM2423 - Artificial Intelligence and Applications

Continuous Assessment

How to run the code?

For this continuous assessment, I will be using Python as my programming language of choice.

Dependencies: *time*, *itertools*, *random*. All of these should be installed by default.

"dfs.py" and *"bfs.py"* are the solutions to questions 1.2 and 1.3. *"a-star.py"* and *"maze-generator.py"* are additional research and experimentation. *"dfs.py"*, *"bfs.py"* and *"maze-generator.py"* all come with an interface complete with prompts, instructions and help to navigate them. Please note that the functionality included within these programs extends beyond what is expected to answer the questions, which necessitates the requirement for a high level of interactivity with the programs. Simply running the programs by double clicking on them, through terminal or through IDE all work perfectly fine. Follow the instructions on-screen and you will be able to run the algorithms, conduct analysis and create mazes with these programs.

Question 1.1

A search problem is a problem with some start state, goal state and some state space (search space). These problems can be represented as graphs, with nodes and edges. Solving a search problem is then formulated as finding a path, from one node to another. A maze can be framed as a search problem quite intuitively – the cells (spaces) in a maze can be represented as nodes, and adjacent spaces can be connected with arcs. If an arc exists between two nodes (spaces), one can traverse between them. From here, we simply need to search for the goal (end of the maze) from the start.

Question 1.2:

1. Depth-first search (DFS) is an uninformed searching algorithm for graph (and tree) data structures. It makes use of a stack and a visited list. It involves starting at some root node, and travelling as far as it can down some branch, before backtracking. The stack is required to enable the backtracking. DFS does not guarantee the shortest path from the root node to the target node.

2. (See code: *dfs.py*)

Solution for maze-Easy.txt (with DFS):

```
[(0, 1), (1, 1), (1, 2), (1, 3), (1, 4), (1, 5), (1, 6), (1, 7), (1, 8), (1, 9), (1, 10), (1, 11), (1, 12), (1, 13), (1, 14), (1, 15), (2, 15), (3, 15), (4, 15), (5, 15), (6, 15), (6, 16), (6, 17), (7, 17), (8, 17), (8, 18), (9, 18)]
```

3. (See code: *dfs.py*)

Statistics for maze-Easy.txt (with DFS):

--- Number of nodes explored: 35 nodes ---

--- Execution time: 0.0009951591491699219 seconds ---

--- Number of nodes in path: 27 nodes ---

4. (See code: dfs.py)

Solution for maze-Medium.txt (with DFS):

[Not included here; too large. Please see “maze solutions” towards bottom of document.]

Statistics for maze-Medium.txt (with DFS):

--- Number of nodes explored: 549 nodes ---

--- Execution time: 0.0039904117584228516 seconds ---

--- Number of nodes in path: 321 nodes ---

Solution for maze-Large.txt (with DFS):

[Not included here; too large. Please see “maze solutions” towards bottom of document.]

Statistics for maze-Large.txt (with DFS):

--- Number of nodes explored: 10303 nodes ---

--- Execution time: 0.06483006477355957 seconds ---

--- Number of nodes in path: 1092 nodes ---

Solution for maze-VLarge.txt (with DFS):

[Not included here; too large. Please see “maze solutions” towards bottom of document.]

Statistics for maze-VLarge.txt (with DFS):

--- Number of nodes explored: 87795 nodes ---

--- Execution time: 0.6392557621002197 seconds ---

--- Number of nodes in path: 3691 nodes ---

Analysis: DFS is extremely fast and extremely efficient in nature. It rapidly solves even the largest maze, and does so with an extremely efficient solution, thanks to some optimisation steps I have taken (see “further experimentation”). It will be very difficult to produce an algorithm with faster performance than this, and I should look instead to optimise other characteristics.

Question 1.3:

1. I had managed to develop an extremely fast algorithm in DFS; 0.6 seconds for the largest maze is exceptional. There isn't much point in looking to build a faster algorithm; I looked to build one which finds the optimal solutions for mazes. I considered A* (see “further experimentation”) but settled on breadth-first search (BFS), because it guarantees optimality and completeness, which DFS doesn't. I chose BFS over A* because A* has a higher space complexity and becomes impractical for large mazes

2. (See code: bfs.py)

Solution for maze-Easy.txt (with BFS):

[(0, 1), (1, 1), (1, 2), (1, 3), (1, 4), (1, 5), (2, 5), (3, 5), (4, 5), (5, 5), (5, 6), (5, 7), (5, 8), (6, 8), (6, 9), (6, 10), (6, 11), (6, 12), (6, 13), (6, 14), (6, 15), (6, 16), (6, 17), (7, 17), (8, 17), (8, 18), (9, 18)]

Statistics for maze-Easy.txt (with BFS):

--- Number of nodes explored: 76 nodes ---

--- Execution time: 0.0009968280792236328 seconds ---

--- Number of nodes in path: 27 nodes ---

Analysis: Extremely fast, rivalling DFS in timing, while also guaranteeing optimal solution. Also, more space efficient, exploring 8 less nodes than DFS did. Overall, a complete success.

3.

Solution for maze-Medium.txt (with BFS):

[Not included here; too large. Please see "maze solutions" towards bottom of document.]

Statistics for maze-Medium.txt (with BFS):

--- Number of nodes explored: 8477 nodes ---

--- Execution time: 0.03950142860412598 seconds ---

--- Number of nodes in path: 321 nodes ---

Solution for maze-Large.txt (with BFS):

[Not included here; too large. Please see "maze solutions" towards bottom of document.]

Statistics for maze-Large.txt (with BFS):

--- Number of nodes explored: 81993 nodes ---

--- Execution time: 0.5421068668365479 seconds ---

--- Number of nodes in path: 974 nodes ---

Solution for maze-VLarge.txt (with BFS):

[Not included here; too large. Please see "maze solutions" towards bottom of document.]

Statistics for maze-VLarge.txt (with BFS):

--- Number of nodes explored: 796575 nodes ---

--- Execution time: 36.48565626144409 seconds ---

--- Number of nodes in path: 3691 nodes ---

Analysis: Not as space-efficient as DFS for these mazes, but still rivalling in terms of time (apart from for the largest maze), with sub-second timings for the medium and large mazes. Still providing the most optimal solution possible for all mazes. For the largest maze, the performance hit is expected, but still completed running within 1 minute. Overall, good performance.

4. BFS found the optimal solution to all the mazes, and within reasonable time (< 60 seconds). With the exception of the largest maze, it also performed at a speed comparable to that of DFS, with sub-second times for 3 out of the 4 mazes. The performance detriment on the largest maze is to be expected, but BFS still completed well within reasonable limits, showing the solution is amenable to large mazes. Curiously, DFS has found the most optimal path from the start to the goal on a few of the mazes. This is due to optimisation I have applied to make the algorithm more efficient for the four mazes (see “further experimentation”). Although DFS has found the optimal solution for these 3 mazes, it isn’t guaranteed to do so for other mazes, and this is where BFS is useful. Between the rapid DFS and optimal BFS, we have a powerful set of tools to solve mazes.

Further experimentation

A* algorithm

I conducted some extensive further experimentation, research, and analysis to supplement my work, improve efficiency, learn more about the mazes and for my own enjoyment.

While trying to decide which algorithm to use for question 1.3, I decided to experiment first with the A* algorithm. The code featured in the directory does **NOT BELONG TO ME**, and is only included for the purpose of completeness. You can find the source here:

<https://medium.com/@nicholas.w.swift/easy-a-star-pathfinding-7e6689c7f7b2>.

I adapted and added my own functions to this code for compatibility purposes. The main reason why I chose to adapt this code and experiment with it was to decide if A* was appropriate for the larger mazes. Ultimately, my suspicions and research were confirmed – A* does not perform well at all for larger mazes. A* is quite similar to Dijkstra’s algorithm, except with a heuristic and a specific goal, rather than having every node as a goal. Admittedly, space efficiency was not at the forefront of my concerns, but is definitely another downside of A*. Because of this, I opted to go for breadth-first search instead. It is simpler to understand, explain and implement, and can be optimised similarly to DFS. It is also complete and guarantees optimality.

Optimising DFS and BFS

In the early stages of implementing DFS, I found that it ran unacceptably slow, particularly for the larger mazes, with an estimated runtime of about 6 hours for the largest maze provided. I managed to cut this down to sub-second times simply by eliminating any linear searching over any maze-dependent data structures; my initial implementation had many of these, causing huge detriments to the performance. As well as eliminating linear searches, I made use of a set for the “visited” structure, largely due to the rapid speed of membership checking operations (due to hash tables).

With my function *“find_neighbours”*, I found that the order in which neighbours are discovered (and returned in the list to the main DFS method) has a major impact on the algorithm performance. Neighbours can be in four possible directions – up, down, left, or right. This means that there are 24 possible orders in which the neighbours can be discovered (calculated from permutations of four objects: 4!), all of which slightly impact the algorithm performance, for better or for worse. Because of this, I decided to write a new function, *“dfs_analysis”*, that tests and evaluates the performance of every single permutation of “up”, “down”, “left”, “right” for a maze, and gives statistics for each permutation. My program can also show the user which permutations performed best and worst in which categories. This analysis not only allows for optimisation of DFS for specific mazes, but also reveals insights into the mazes themselves, such as biases and characteristics, as well as reflecting on the algorithms that built them. For the four supplied mazes, I built their most optimal permutations into the “default” option of the program – these are the results displayed in this document as answers to questions 1.2 and 1.3. (This is why some of the DFS answers miraculously have also managed to obtain the shortest path, as well as being extremely fast and efficient – they have been optimised for their exact mazes, by selecting the best permutation.)

I carried over the same ideas to my BFS implementation, although it can be argued that the effects on BFS are rather strange and unexpected. All solutions generated by BFS are guaranteed to be optimal, which means that all paths produced will likely be identical. However, optimising BFS comes in the form of improving time taken and reducing nodes explored. I was quite surprised to discover that the configuration of neighbour discovery mattered quite a lot for the time efficiency of BFS – certain permutations would run over twice as slow as others. Again, I optimised each BFS configuration for each maze, but I also found that in general, BFS was significantly less consistent, even when applying the same configuration on the same maze, the time may vary quite a lot.

The main limitation of this idea is that the permutation cannot be changed during runtime; if it were possible, it could be used to even further improve performance, especially on larger mazes. However, I felt that second-order neighbour discovery configuration (and all subsequent) would be needlessly complicated and require a major refactoring of the rest of the algorithm and, given the already excellent performance of DFS and BFS, not worth it at all.

Maze generation

A few years ago, during my time in sixth form, I created a program to generate mazes as part of a larger project. The program is limited in the sense that it can only generate square mazes (where the width and height are the same), but nonetheless I decided to include it as part of my extra research, by adapting it to match the formatting outlined by the specification and allowing it to write mazes to files to be tested. I have included a few mazes in this submission that have been generated by this algorithm, as well as the algorithm itself (again, for completeness purposes). “bigMaze.txt” is a 1001 by 1001 maze; “mediumMaze.txt” is a 101 by 101 maze, and “smallMaze.txt” is a 11 by 11 maze. I also included elements of the DFS module for testing purposes, to ensure that all mazes generated are solvable. I used this maze generation algorithm to further test my algorithms too, as well as for analytics and insight into the generation algorithm (biases, patterns, etc.).

User interaction

"dfs.py", *"bfs.py"*, *"maze_generator.py"* all feature user prompts and interaction from shell in order to convey information to the user. I added this in to allow the user to easily and unambiguously experience the full range of tools I have provided – the algorithms, the configuration tools, the analysis tools and the maze generation algorithm. I have done my best to ensure that false inputs are appropriately handled and denied, but if any bugs are discovered, please do contact me.

The user can supply the algorithms any maze they wish, but mazes that are found to be unsolvable are rejected with a message. The user is also allowed to customise the configuration for looking for neighbours – this should be entered (at the relevant menu) with only the four directions, first letter capitalized, sitting within single quotes, and comma separated. Do not include brackets.

An option is also included to give extra information, in case the user is lost or confused by the options provided.

Maze solutions

Solution for maze-Medium.txt (with DFS):

```
[(0, 1), (1, 1), (1, 2), (1, 3), (1, 4), (1, 5), (1, 6), (1, 7), (1, 8), (1, 9), (2, 9), (3, 9), (3, 10), (3, 11), (4, 11), (5, 11), (5, 12), (5, 13), (5, 14), (6, 14), (7, 14), (8, 14), (9, 14), (10, 14), (11, 14), (12, 14), (13, 14), (14, 14), (14, 15), (14, 16), (14, 17), (15, 17), (16, 17), (17, 17), (18, 17), (19, 17), (20, 17), (21, 17), (21, 18), (21, 19), (21, 20), (21, 21), (21, 22), (22, 22), (23, 22), (24, 22), (25, 22), (25, 23), (25, 24), (25, 25), (26, 25), (26, 26), (27, 26), (28, 26), (29, 26), (30, 26), (31, 26), (32, 26), (32, 27), (32, 28), (33, 28), (33, 29), (33, 30), (34, 30), (34, 31), (34, 32), (34, 33), (34, 34), (35, 34), (35, 35), (35, 36), (35, 37), (34, 37), (34, 38), (34, 39), (34, 40), (34, 41), (35, 41), (35, 42), (35, 43), (35, 44), (35, 45), (35, 46), (36, 46), (36, 47), (37, 47), (38, 47), (39, 47), (39, 48), (39, 49), (38, 49), (38, 50), (38, 51), (38, 52), (38, 53), (38, 54), (38, 55), (38, 56), (38, 57), (39, 57), (39, 58), (40, 58), (41, 58), (42, 58), (42, 59), (42, 60), (43, 60), (43, 61), (44, 61), (45, 61), (46, 61), (47, 61), (47, 62), (48, 62), (49, 62), (49, 63), (49, 64), (49, 65), (50, 65), (51, 65), (51, 66), (52, 66), (52, 67), (52, 68), (52, 69), (53, 69), (53, 70), (54, 70), (55, 70), (56, 70), (57, 70), (58, 70), (58, 71), (58, 72), (58, 73), (58, 74), (58, 75), (58, 76), (58, 77), (59, 77), (60, 77), (61, 77), (61, 78), (61, 79), (61, 80), (61, 81), (61, 82), (62, 82), (63, 82), (63, 83), (64, 83), (65, 83), (65, 84), (65, 85), (65, 86), (65, 87), (65, 88), (65, 89), (66, 89), (67, 89), (67, 90), (68, 90), (68, 91), (69, 91), (69, 92), (70, 92), (71, 92), (71, 93), (72, 93), (73, 93), (73, 92), (74, 92), (75, 92), (75, 93), (76, 93), (76, 94), (76, 95), (76, 96), (76, 97), (77, 97), (77, 98), (78, 98), (78, 99), (79, 99), (80, 99), (80, 100), (80, 101), (80, 102), (81, 102), (81, 103), (81, 104), (81, 105), (81, 106), (81, 107), (82, 107), (82, 108), (82, 109), (82, 110), (83, 110), (84, 110), (84, 111), (85, 111), (86, 111), (86, 112), (86, 113), (85, 113), (85, 114), (85, 115), (85, 116), (85, 117), (85, 118), (85, 119), (85, 120), (85, 121), (86, 121), (87, 121), (87, 122), (87, 123), (87, 124), (88, 124), (89, 124), (90, 124), (90, 125), (91, 125), (91, 126), (91, 127), (91, 128), (91, 129), (91, 130), (91, 131), (92, 131), (92, 132), (92, 133), (92, 134), (92, 135), (93, 135), (93, 136), (93, 137), (92, 137), (91, 137), (91, 138), (91, 139), (90, 139), (90, 140), (90, 141), (90, 142), (90, 143), (91, 143), (91, 144), (91, 145), (92, 145), (93, 145), (94, 145), (94, 146), (94, 147), (95, 147), (95, 148), (95, 149), (95, 150), (94, 150), (94, 151), (94, 152), (93, 152), (93, 153), (93, 154), (93, 155), (93, 156), (92, 156), (92, 157), (92, 158), (92, 159), (92, 160), (92, 161), (92, 162), (92, 163), (92, 164), (92, 165), (92, 166), (92, 167), (92, 168), (92, 169), (92, 170), (92, 171), (92, 172), (92, 173), (92, 174), (92, 175), (92, 176), (92, 177), (92, 178), (92, 179), (92, 180), (92, 181), (92, 182), (93, 182), (94, 182), (95, 182), (96, 182), (96, 183), (96, 184), (96, 185), (96, 186), (95, 186), (95, 187), (95, 188), (95, 189), (95, 190), (96, 190), (96, 191), (96, 192), (95, 192), (95, 193), (95, 194), (95, 195), (95, 196), (95, 197), (95, 198), (96, 198), (97, 198), (98, 198), (99, 198)]
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Solution for maze-Large.txt (with DFS):

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Solution for maze-VLarge.txt (with DFS):

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Solution for maze-Medium.txt (with BFS):

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Solution for maze-Large.txt (with BFS):

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Solution for maze-VLarge.txt (with BFS):

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