Smash the Maze with Search Algorithms Comparison BFS VS A*

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Abstract— This project compares the performance of two classical search algorithms—Breadth-First Search (BFS) and A* Search—in maze pathfinding. BFS represents the uninformed search family, while A* utilizes Manhattan Distance as its heuristic within an informed search framework. Mazes were generated using Randomized Depth-First Search and evaluated in two scenarios: (1) a standard single-path maze, and (2) an altered open-zone maze created by breaking additional walls. Across five randomized trials, A* consistently explored fewer nodes than BFS in both scenarios, with dramatic improvements in open-zone conditions (up to 84%). However, in narrow mazes with constrained movement, the heuristic advantage of A* diminishes, resulting in performance close to BFS. These findings highlight the significant impact of maze topology on the effectiveness of heuristic-guided search.

Keywords— Pathfinding, BFS, A* Search, Informed Search, Maze Generation, Heuristic Search

I. Introduction

Pathfinding algorithms are fundamental in robotics, navigation, games, and AI systems. Two commonly compared algorithms are Breadth-First Search (BFS), which explores the search space evenly without additional guidance, and A*, which uses heuristic functions to direct the search more efficiently.

This project aims to compare the performance of these two algorithms in maze environments with different structural characteristics. Specifically, it examines how maze openness, branching, and path flexibility influence the effectiveness of heuristic-guided search compared to uninformed search.

II. Related Work

BFS is one of the earliest uninformed search methods and is optimal when all actions have equal cost. A*, introduced by Hart et al. (1968), is widely adopted in heuristic-based pathfinding due to its balance of exploration and exploitation.

Previous research shows that heuristics such as Manhattan Distance significantly reduce exploration when the environment allows movement in the general direction of the goal. However, fewer studies directly address how maze structure—particularly open vs. constrained spaces—affects the relative advantage of A*. This work builds on that gap by evaluating both algorithms using controlled maze variations.

III. Experimental Methodology

A. Breadth-First Search (BFS)

- *Uninformed search*
- *Explores nodes level by level*
- *Guarantees shortest path*
- *Typically explores many nodes in large or open spaces*

B. A* Search

- Informed search utilizing the evaluation function
  $$f(n) = g(n) + h(n)$$
- Heuristic used: Manhattan Distance (admissible)
- Implemented with heapq for priority queue efficiency
- Performance depends heavily on geometry and available movement paths

C. Maze Generation

- All mazes are 60×60 (3,600 cells)
- Generated using Randomized Depth-First Search (DFS)
- Produces a single-solution, corridor-based maze
- Open-zone scenario created by randomly breaking additional walls

D. Experimental Scenarios

- Scenario 1 — Standard Maze (Single-Solution)
  Narrow paths, limited freedom of movement.
- Scenario 2 — Open Zone (Modified Maze)
  Additional openings allow multiple routes, widening decision space.

E. Experimental Procedure

- Generate a maze using Randomized DFS
- Duplicate the maze and apply random wall removal to create the open-zone version
- Execute BFS and A* using the same start and goal positions
- Visualize the shortest path using backtracking, highlighted with a red path

- Measure performance based on the number of explored nodes
- Repeat the experiment five times, generating a new maze for each trial

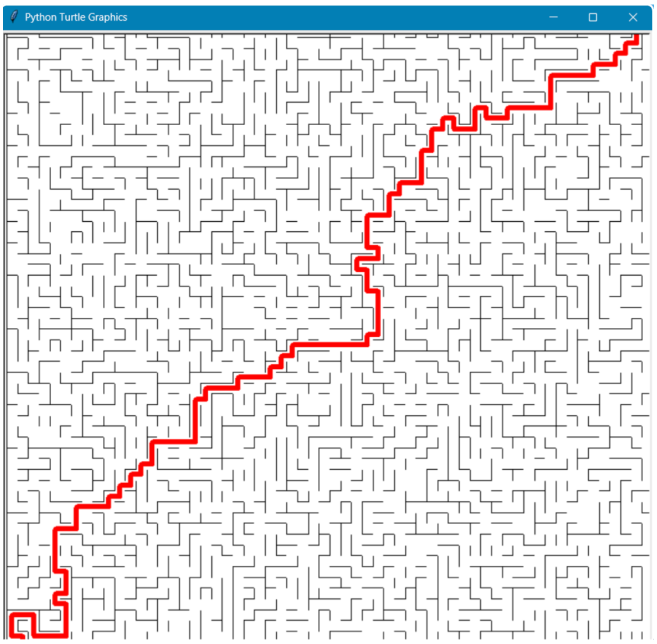

Figure 1. Example of a 60×60 maze with the shortest path highlighted in red.

IV. Results

The experimental results obtained from five trials are summarized below.

A. *Experimental Data Summary*

Trial 1

- Scenario 1: BFS = 734 nodes, A* = 597 nodes (A* −18.66%)
- Scenario 2: BFS = 3595 nodes, A* = 1080 nodes (A* −69.96%)

Trial 2

- Scenario 1: BFS = 1997, A* = 1878 (−5.96%)
- Scenario 2: BFS = 3594, A* = 569 (−84.17%)

Trial 3

- Scenario 1: BFS = 3596, A* = 3587 (−0.25%)
- Scenario 2: BFS = 3599, A* = 1813 (−49.62%)

Trial 4

- Scenario 1: BFS = 3596, A* = 3395 (−5.59%)
- Scenario 2: BFS = 3598, A* = 2068 (−42.52%)

Trial 5

- Scenario 1: BFS = 1046, A* = 1017 (−2.77%)
- Scenario 2: BFS = 3600, A* = 1266 (−64.83%)

ครั้งที่	สถานการณ์ 1 (Nodes)	A* ดีกว่า	สถานการณ์ 2 (Nodes)	A* ดีกว่า
1	BFS 734 →A* 597	18.66%	BFS 3595 → A* 1080	69.96%
2	1997 → 1878	5.96%	3594 → 569	84.17%
3	3596 → 3587	0.25%	3599 → 1813	49.62%
4	3596 → 3395	5.59%	3598 → 2068	42.52%
5	1046 → 1017	2.77%	3600 → 1266	64.83%

Figure 2. Comparison of Node Exploration Between BFS and A* Search

B. *Observations*

Across all trials and scenarios, A* Search consistently explores fewer nodes than BFS. The difference is more pronounced in open-zone mazes where heuristic guidance can effectively reduce search space. In tightly constrained mazes, A* and BFS perform similarly due to limited heuristic leverage.

V. Discussion

A. Heuristic Effectiveness

In Scenario 1, the maze's constrained structure limits heuristic benefit, yielding comparable exploration between algorithms. A heuristic that estimates proximity to the goal offers minimal advantage when forced to navigate maze walls.

B. Open-Zone Advantage

In Scenario 2, breaking walls creates open regions where the Manhattan heuristic can direct the search towards the goal more effectively, minimizing unnecessary exploration and substantially reducing node counts relative to BFS.

C. Algorithm Suitability

BFS remains a robust choice for guaranteed shortest paths in uniform cost spaces, but A* offers superior performance where heuristic estimation is reliable. The choice of algorithm should consider maze complexity and available heuristic information.

These results suggest that the effectiveness of heuristic-based search is highly dependent on the structural properties of the environment.

VI. Conclusion

This study empirically demonstrates that A* Search outperforms BFS in exploring fewer nodes while still finding correct paths, particularly in open or less restricted environments. In highly constrained mazes, the performance gap narrows due to limited heuristic influence. Future work may explore alternative heuristics or dynamic maze structures.

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