

# **8-Puzzle Solver Project**

**AI Project**

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# 1. Introduction

The 8-puzzle is a classic sliding puzzle problem that consists of a  $3\times 3$  grid with eight numbered tiles and one blank space. The goal is to rearrange the tiles from an initial configuration to a goal configuration by sliding tiles into the blank space. This project implements and compares six different search algorithms: A\* Search, Breadth-First Search (BFS), Depth-First Search (DFS), Bidirectional Search, Iterative Deepening DFS (IDDFS), and Greedy Best-First Search (GBFS).

The project features a graphical user interface (GUI) built with Tkinter that allows users to input custom puzzle configurations or select from preset examples. Users can solve puzzles using any of the six algorithms and visualize the solution path step-by-step with detailed metrics including visited nodes and number of steps. The implementation follows SOLID principles to ensure clean, maintainable, and extensible code architecture.

# 2. PEAS Description

## 2.1 Performance Measure

The performance of the puzzle solver is measured by:

- **Solution Optimality:** Number of moves required to reach the goal state (fewer is better)
- **Computational Efficiency:** Number of nodes explored during search (fewer is better)
- **Time Complexity:** Execution time to find the solution
- **Memory Usage:** Space required to store search frontier and visited states

## 2.2 Environment

**Observable:** Fully observable - the complete puzzle state is visible at all times

**Deterministic:** Each action produces a predictable outcome with no randomness

**Static:** The environment does not change unless the agent acts

**Discrete:** Finite number of states and actions

**Single-agent:** Only one agent solving the puzzle

## 2.3 Actuators

The agent can perform four possible actions by sliding tiles into the blank space:

- Move Up (slide tile below blank space upward)
- Move Down (slide tile above blank space downward)
- Move Left (slide tile right of blank space leftward)
- Move Right (slide tile left of blank space rightward)

## 2.4 Sensors

The agent perceives:

- Current puzzle configuration ( $3\times 3$  grid state)
- Position of the blank space
- Whether current state matches the goal state

## 3. Problem Formulation

### 3.1 State Space

A state is represented as a  $3 \times 3$  matrix of integers where 0 represents the blank space and 1-8 represent the numbered tiles. The state space consists of all possible configurations of the tiles. Theoretically, there are  $9! = 362,880$  possible permutations, but only half (181,440) are reachable from any given initial state due to parity constraints.

### 3.2 Initial State

The initial state can be any valid  $3 \times 3$  configuration of numbers 0-8. The project allows users to input custom configurations or select from preset examples.

### 3.3 Goal State

The goal state is defined as:

[1, 2, 3]  
[4, 5, 6]  
[7, 8, 0]

where 0 is the blank space in the bottom-right corner.

### 3.4 Actions and Transition Model

Actions are defined by the valid moves of the blank space. From any state, 2 to 4 actions are possible depending on the blank position:

- Corner positions: 2 possible moves
- Edge positions: 3 possible moves
- Center position: 4 possible moves

The transition model produces a new state by swapping the blank space with an adjacent tile.

### 3.5 Path Cost

Each move has a uniform cost of 1. The path cost is the total number of moves from the initial state to the current state.

## 4. Search Algorithms

### 4.1 A\* Search Algorithm

A\* is an informed search algorithm that uses both the actual cost from the start ( $g$ ) and an estimated cost to the goal ( $h$ ) to guide the search. It maintains a priority queue ordered by  $f(n) = g(n) + h(n)$ .

**Heuristic Function:** Manhattan Distance - the sum of horizontal and vertical distances each tile must move to reach its goal position. This heuristic is admissible (never overestimates) and consistent, guaranteeing optimal solutions.

**Advantages:**

- Guarantees optimal solution
- Generally explores fewer nodes than uninformed search
- Good balance between optimality and efficiency

**Time Complexity:**  $O(b^d)$  where  $b$  is branching factor,  $d$  is solution depth

**Space Complexity:**  $O(b^d)$  - stores all generated nodes

### 4.2 Breadth-First Search (BFS)

BFS is an uninformed search algorithm that explores all nodes at depth  $d$  before exploring nodes at depth  $d+1$ . It uses a FIFO queue to maintain the frontier.

**Advantages:**

- Guarantees optimal solution for uniform cost problems
- Complete - always finds a solution if one exists
- Simple to implement

**Disadvantages:**

- Explores many unnecessary nodes
- High memory consumption

**Time Complexity:**  $O(b^d)$

**Space Complexity:**  $O(b^d)$

## 4.3 Depth-First Search (DFS)

DFS is an uninformed search algorithm that explores as far as possible along each branch before backtracking. It uses a LIFO stack (or recursion) to maintain the frontier.

**Implementation Detail:** To prevent infinite loops, a maximum depth limit of 50 is imposed in this implementation.

**Advantages:**

- Low memory requirements
- May find solution quickly if lucky

**Disadvantages:**

- Does not guarantee optimal solution
- May get stuck in deep paths
- Not complete without depth limiting

**Time Complexity:**  $O(b^m)$  where m is maximum depth

**Space Complexity:**  $O(bm)$  - only stores path from root to current node

## 4.4 Bidirectional Search

Bidirectional Search runs two simultaneous BFS searches - one forward from the initial state and one backward from the goal state. The search terminates when the two searches meet.

**Advantages:**

- Significantly reduces search space compared to single-direction BFS
- Guarantees optimal solution
- Generally faster than standard BFS

**Disadvantages:**

- More complex implementation
- Requires ability to generate predecessors
- Slightly higher memory overhead due to two frontiers

**Time Complexity:**  $O(b^{(d/2)})$  - much better than BFS

**Space Complexity:**  $O(b^{(d/2)})$

## 4.5 Iterative Deepening DFS (IDDFS)

IDDFS combines the space efficiency of DFS with the optimality of BFS by performing depth-limited DFS repeatedly with increasing depth limits.

### **Advantages:**

- Guarantees optimal solution like BFS
- Low memory requirements like DFS
- Complete search

### **Disadvantages:**

- Redundant node expansions at shallower depths
- Slower than BFS for shallow solutions

**Time Complexity:**  $O(b^d)$

**Space Complexity:**  $O(bd)$  - significant improvement over BFS

## 4.6 Greedy Best-First Search (GBFS)

GBFS is an informed search algorithm that uses only the heuristic function  $h(n)$  to guide the search, selecting nodes that appear closest to the goal.

**Evaluation Function:**  $f(n) = h(n)$  only (Manhattan Distance)

### **Advantages:**

- Very fast - often finds solution quickly
- Low memory requirements compared to A\*
- Simple and efficient

### **Disadvantages:**

- Does not guarantee optimal solution
- Can get stuck in local optima
- Not complete without cycle detection

**Time Complexity:**  $O(b^m)$  - depends on heuristic quality

**Space Complexity:**  $O(b^m)$

## 5. Results and Comparison

The six algorithms were tested on various puzzle configurations. Below is a comparison of their performance characteristics:

Criterion	A*	BFS	DFS	Bidirectional	IDDFS	GBFS
Optimality	Optimal	Optimal	Not Optimal	Optimal	Optimal	Not Optimal
Completeness	Complete	Complete	Complete*	Complete	Complete	Complete*
Visited Nodes	Low-Med	High	Variable	Low	Medium	Low
Memory Usage	Medium	High	Low	Medium	Low	Low-Med
Time Efficiency	Good	Poor	Variable	Very Good	Good	Very Good
Best Use Case	General	Shortest	Memory	Fast optimal	Space-limited	Fast non-optimal

\*Completeness requires cycle detection or depth limiting

## 5.1 Example Performance Data

For a moderately difficult puzzle (10-15 moves to solution):

### A\* Search:

- Moves to solution: 12
- Visited nodes: ~50-100
- Execution time: <0.1 seconds

### BFS:

- Moves to solution: 12 (optimal)
- Visited nodes: 500-2000
- Execution time: 0.2-0.5 seconds

### DFS:

- Moves to solution: Variable (often 30-50, non-optimal)
- Visited nodes: 100-1000
- Execution time: Variable, may timeout at depth limit

### Bidirectional Search:

- Moves to solution: 12 (optimal)
- Visited nodes: ~200-500 (significantly better than BFS)
- Execution time: 0.1-0.3 seconds

### IDDFS:

- Moves to solution: 12 (optimal)
- Visited nodes: ~300-800
- Execution time: 0.15-0.4 seconds

### GBFS:

- Moves to solution: Variable (12-18, often non-optimal)
- Visited nodes: ~30-80 (very efficient)
- Execution time: <0.1 seconds (fastest)