Project Report: AI-Based 64-Puzzle Solver with Graph Traversal Visualization

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Course:

Artificial Intelligence

Instructor:

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1. Introduction

This project demonstrates the use of Artificial Intelligence techniques to solve a complex variant of the sliding puzzle game—the **64-Puzzle (8x8 grid)**. The traditional 15-puzzle was extended to increase complexity and further challenge our AI agent's efficiency. The core objective is to develop a solver using the *A Search Algorithm** with **Manhattan Distance** as a heuristic and to visualize the search space through a **graph traversal**.

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2. Objectives

- Design an AI agent capable of solving the 64-Puzzle optimally.
- Employ the A* algorithm for informed graph search.
- Utilize the Manhattan Distance heuristic for effective cost estimation.
- Visualize the traversal of the AI agent using NetworkX and Matplotlib.
- Develop a Tkinter-based GUI for interactive puzzle simulation and animation.

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3. AI Methodology

*3.1 A Search Algorithm**

The A* algorithm was chosen for its balance between completeness, optimality, and performance. Each node in the puzzle is evaluated based on:

- g(n): Actual cost from the initial state to current state
- h(n): Estimated cost (heuristic) to reach the goal from current state
- f(n) = g(n) + h(n)

3.2 Heuristic Function

The **Manhattan Distance** heuristic is used, where for each tile (excluding the blank), the sum of vertical and horizontal distances from its current position to its goal position is computed. This heuristic is:

- **Admissible**: Never overestimates
- **Consistent**: Ensures optimality of A*

3.3 Graph Visualization

A directed graph is dynamically constructed using **NetworkX** to represent state transitions during traversal. This provides intuitive insight into how the search progresses.

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4. Game Mechanics

4.1 Rules

- The 64 tiles (including a blank tile) are arranged on an 8x8 grid.
- Only adjacent tiles can slide into the blank space.
- The goal state is defined as an ordered arrangement from 1 to 63, with the blank tile at the last position.

4.2 GUI Interaction

- A GUI built with **Tkinter** allows users to:
    - Generate a randomized puzzle by specifying scramble steps.
    - Automatically solve the puzzle via the AI agent.
    - Visualize each move and the entire search space.

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5. Implementation Overview

5.1 Languages & Libraries

- **Python**: Core programming language
- **Tkinter**: GUI design
- **Heapq**: Priority queue management
- **NetworkX**: Directed graph construction
- **Matplotlib**: Graph visualization
- **Random, Time**: Puzzle generation and animations

5.2 Code Highlights

- `Environment` class handles grid logic and heuristics.
- `Node` class maintains A* attributes (`g`, `h`, `f`, and parent).
- `AIAgent` executes the A* search and builds the graph.
- `PuzzleGUI` provides user interface and visual feedback.

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6. Evaluation & Results

- The A* agent was tested with varying levels of scrambled puzzles (steps: 10–50).
- Real-time performance was acceptable for lower scramble depths (e.g., 10–20).
- For higher complexity (e.g., 50+), search space and memory demands increased significantly, highlighting A*'s limitations in large state spaces.
- Graph visualization provided excellent insights into path selection and node expansion patterns.

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7. Challenges

- The **state space for an 8x8 puzzle** is extremely large (factorial of 64), making some instances computationally intensive.
- Memory usage increased sharply with deeper searches.
- Ensuring a responsive GUI while solving complex puzzles required balancing sleep intervals and updates.

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8. Conclusion

This project demonstrated the feasibility and educational value of applying A* to solve high-complexity puzzles like the 64-tile variant. The integration of visualization tools and GUI significantly enhanced user understanding of AI traversal strategies. Though not practical for real-time solutions of all instances due to computational complexity, the project serves as a robust learning platform for AI concepts.

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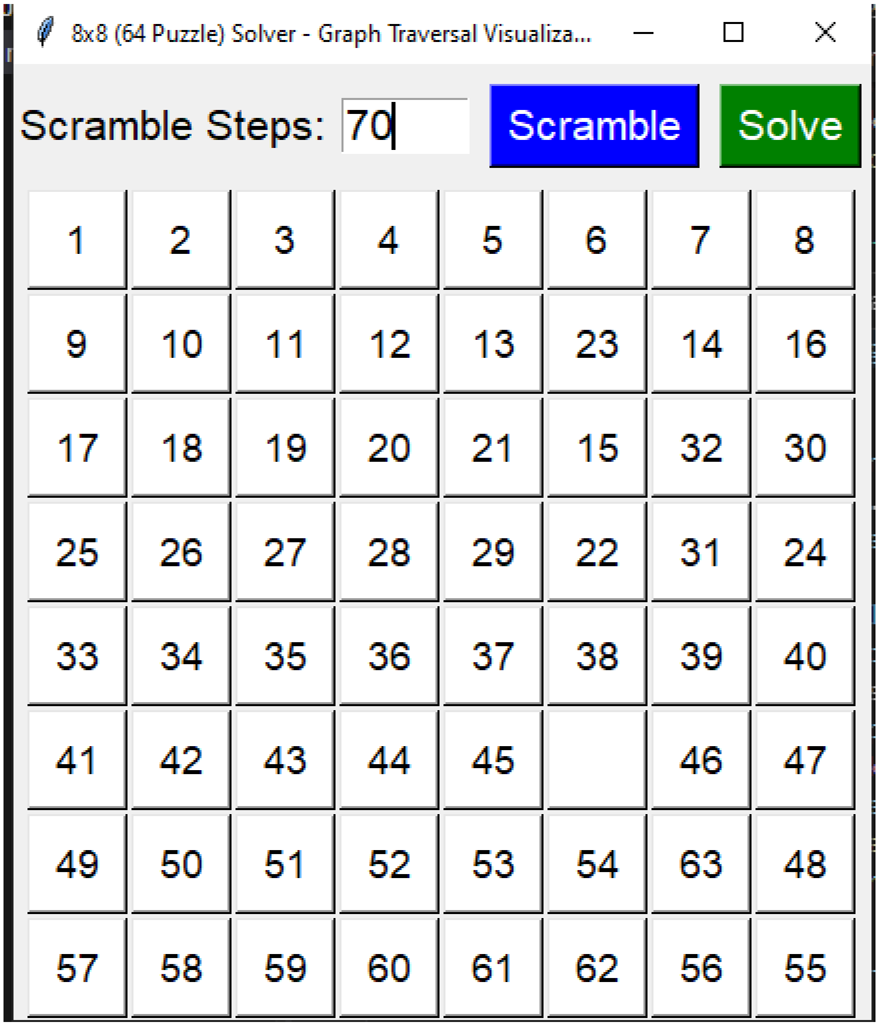
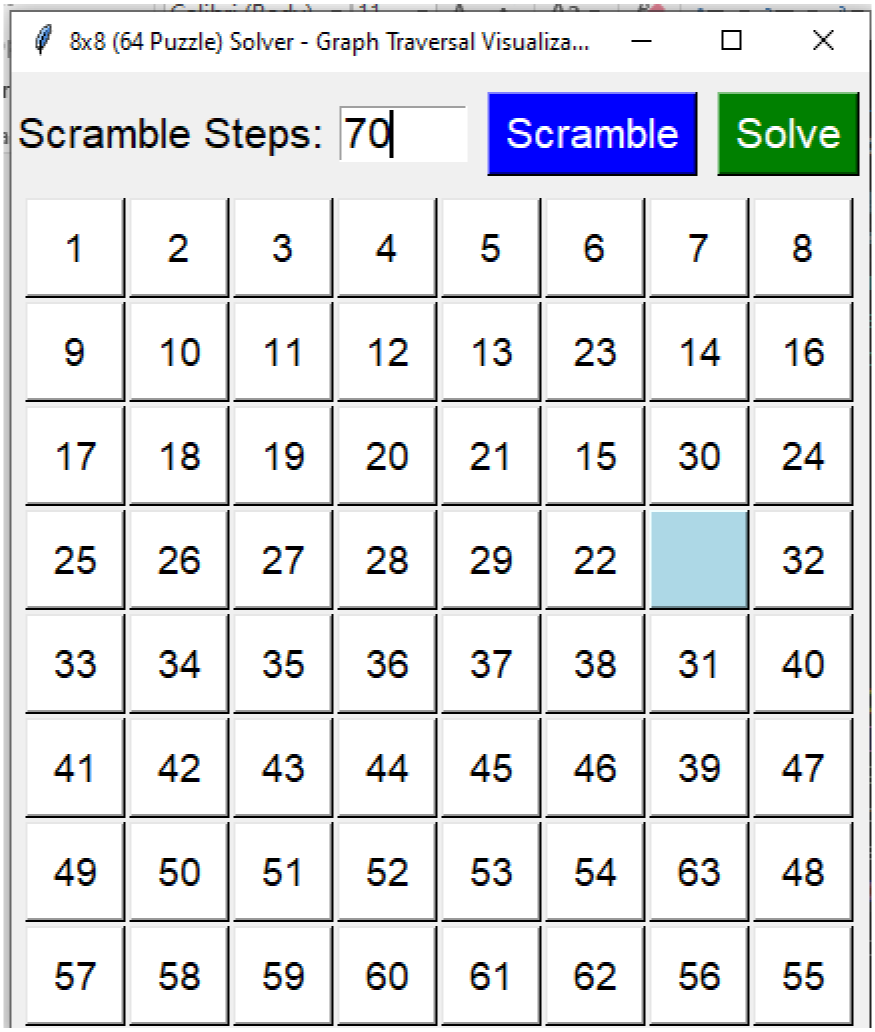
9. Future Work

- Implement **iterative deepening A*** (IDA*) for better memory management.
- Optimize search using **pattern databases** or other heuristic enhancements.
- Introduce **user-controlled manual moves** for educational comparison with AI decisions.
- Add metrics like time taken, number of nodes expanded, and solution length.

Output


8x8 (64 Puzzle) Solver - Graph Traversal Visualiza...
Scramble Steps: 70
Scramble
Solve
1 2 3 4 5 6 7 8
9 10 11 12 13 23 14 16
17 18 19 20 21 15 32 30
25 26 27 28 29 22 31 24
33 34 35 36 37 38 39 40
41 42 43 44 45 46 47
49 50 51 52 53 54 63 48
57 58 59 60 61 62 56 55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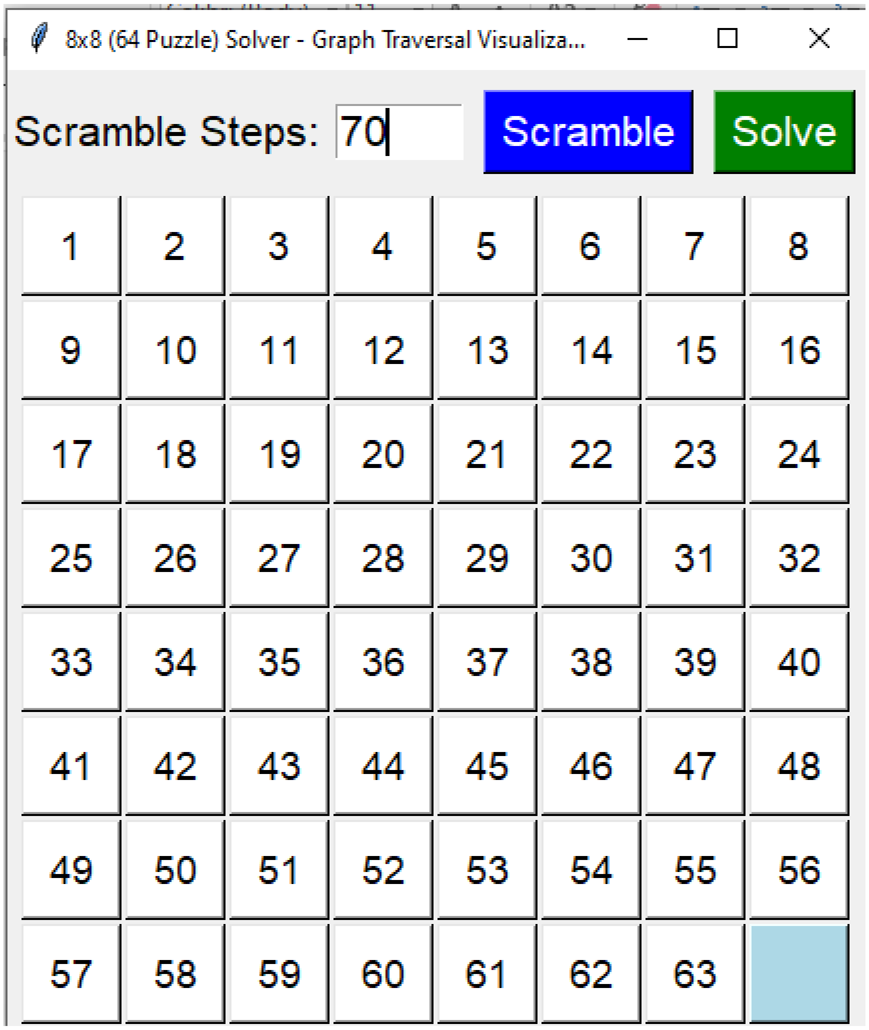
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57 58 59 60 61 62 63

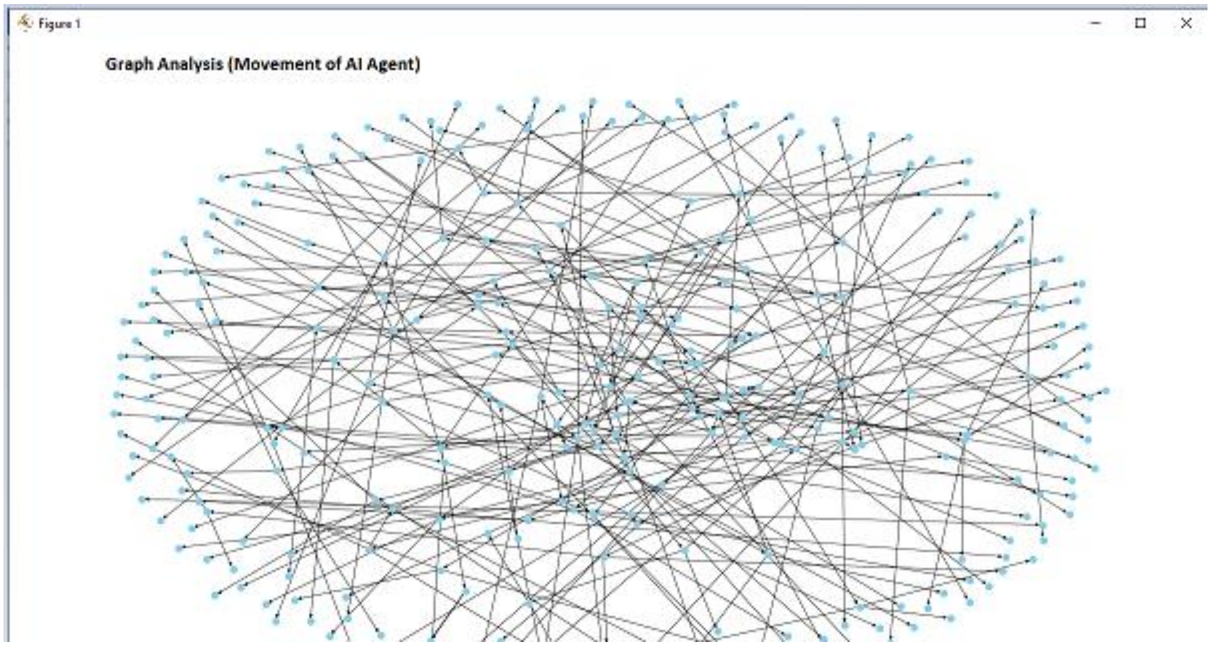
Figure 1
Graph Analysis (Movement of AI Agent)