

AI Maze Escape Game Using Minmax Algorithm

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Abstract: *The AI Maze Escape Game Using Min-Max Algorithm illustrates the use of artificial intelligence for strategic decision-making in uncertain and obstacle-filled environments. In this project, an AI-driven agent must find a path through a maze to reach its destination while overcoming various challenges. The Min-Max algorithm enables the agent to analyze multiple move sequences, predict outcomes, and choose the most effective strategy to achieve its goal. By incorporating heuristic evaluation, the agent improves its path selection efficiency and response time. This project demonstrates how traditional AI concepts can be practically implemented in game environments and problem-solving applications. Beyond entertainment, it provides an educational foundation for understanding AI principles like adversarial reasoning, optimization, and intelligent navigation in complex systems.*

Keywords: AI Maze Escape, Min-Max Algorithm, Adversarial Search, Pathfinding, Game Theory, Heuristic Evaluation, Artificial Intelligence, Decision-Making, Strategy Optimization, Intelligent Agent

I. INTRODUCTION

Maze-solving has long been an important area of research in artificial intelligence and robotics, particularly for tasks like route planning, autonomous navigation, and game development. While classical search techniques such as BFS, DFS, Dijkstra's, and A* perform efficiently in static mazes where conditions remain constant, they struggle in dynamic or adversarial situations. When obstacles move or an opponent actively blocks the player, the problem evolves into a strategic two-player game requiring more advanced decision-making. To address this, a Minimax-based search method can effectively simulate the competitive nature of these environments by predicting and countering the adversary's possible actions.

In this project, the maze is represented as a grid system composed of walls and open cells. The player agent (MAX) attempts to reach the exit point in the fewest moves possible, while the adversary (MIN) works against it by adding or repositioning obstacles. The two agents take turns executing moves, and the process continues until the player either escapes the maze (winning state) or becomes trapped (losing state). The utility function is structured to encourage faster solutions by minimizing the number of steps, while assigning high rewards or penalties for win/loss outcomes.

This study makes several noteworthy contributions. First, it establishes a formal game-theoretic model of the maze escape problem, capturing the strategic interplay between the player and the adversary. Second, it implements the Minimax algorithm enhanced with Alpha-Beta pruning, ensuring efficient decision computation. Third, it performs a comprehensive evaluation of the model across mazes with different dimensions and obstacle complexities. Fourth, it compares the algorithm's results with conventional search methods to highlight its efficiency and robustness. Lastly, it outlines future improvements, such as integrating stochastic adversaries, probabilistic modeling, or reinforcement learning to create a more adaptable and intelligent system.

Artificial Intelligence (AI) plays a vital role in modern game design and intelligent problem-solving applications. Maze-solving is one of the core challenges in AI, requiring efficient decision-making, route planning, and optimization techniques. While traditional algorithms such as BFS, DFS, and A* perform effectively in static environments, they struggle to adapt to dynamic or adversarial situations. To overcome these challenges, the Min-Max algorithm introduces a game-theoretic approach that simulates interactions between competing agents. In this project, an AI-driven maze escape game is created in which a player-controlled agent must find the most efficient path to exit the maze. An adversarial agent serves as the opponent, strategically attempting to obstruct or slow down the player's progress. The



Min-Max algorithm, enhanced with alpha-beta pruning, is implemented to calculate the most optimal moves for the player. This strategy enables the agent to predict and respond effectively to the opponent's actions, improving overall decision-making performance. The proposed system is evaluated across different maze layouts to assess its adaptability and efficiency. Ultimately, this project showcases how AI and game theory can work together to develop intelligent, strategic, and interactive gaming experiences.

II. LITERATURE REVIEW

Koenig, Sven [1]

Koenig's research titled "Minimax Real-Time Heuristic Search" (2001) explores the integration of the Minimax LRTA* algorithm for robot navigation within maze-like and nondeterministic domains. The study focuses on real-time heuristic search methods for dynamic environments. It demonstrates how Minimax principles can effectively manage uncertainty in pathfinding, making it highly relevant to AI-driven maze escape systems.

Barnouti, N.H., Al-Dabbagh, S.S.M., & Sahib Naser, M.A. [2]

In their 2016 study "Pathfinding in Strategy Games and Maze Solving Using A Search Algorithm", the authors compare A search performance in both strategic games and maze-solving applications. The paper emphasizes A*'s balance between efficiency and accuracy in deterministic environments. Their findings highlight the limitations of heuristic search in adversarial conditions, laying the foundation for exploring game-theoretic approaches like Min-Max.

Husain, Zainab et al. [3]

The paper "Search and Rescue in a Maze-like Environment with Ant and Dijkstra Algorithms" (2022) investigates the application of Ant Colony Optimization and Dijkstra algorithms for navigation in search-and-rescue operations. The study evaluates both methods for efficiency, adaptability, and robustness. It concludes that hybrid approaches can significantly improve real-time pathfinding in complex maze-like terrains.

Mia, Čarapina et al. [4]

In "A Comparative Study of Maze Generation Algorithms in a Game-Based Mobile Learning Application" (2024), the authors examine various maze generation techniques within educational gaming. The study compares the complexity and learning impact of different algorithms on gameplay design. Results show that algorithmic diversity enhances user engagement and learning experiences in AI-based maze systems.

Kaicheng, Yang et al. [5]

The 2024 research "Optimization and Comparative Analysis of Maze Generation Algorithm Hybrid" introduces a hybrid method combining Aldous-Broder and Wilson algorithms. This approach improves maze generation efficiency and randomness, producing more complex and challenging layouts. The paper provides valuable insights into enhancing environmental diversity for AI navigation testing.

Deepak, Mane et al. [6]

In their work published in IJISAE, Mane and colleagues present "An Extensive Comparative Analysis on Different Maze Generation Algorithms." The study compares several classical maze generation methods based on time complexity, randomness, and difficulty levels. Their findings assist in selecting suitable algorithms for balanced maze complexity in AI and game environments.

Rui, Yang & Conger, He [7]

The paper "Maze Adventure: An Application of Maze Algorithm in Role-playing Game Development by Python" (2022) demonstrates how maze algorithms can be applied in game development. Implemented using Python, the study bridges theoretical algorithms with practical applications in entertainment and learning-based games, emphasizing code modularity and visualization.

Karen, Suzue et al. [8]

Suzue's 2022 research "Adaptive NPC Behavior in Maze Chase Game Using Genetic Algorithms" focuses on enhancing non-player character (NPC) intelligence through evolutionary computation. The study applies genetic algorithms to enable adaptive decision-making and pursuit strategies. The work contributes to dynamic AI behavior modeling in interactive maze-based games.



Anonymous.Authors.et.al[9]

The paper “A Low-Cost Approach to Maze Solving with Image-Based Mapping” (2025) explores maze navigation using computer vision and minimal hardware resources. The authors present an image-processing technique for maze detection and solution extraction. The approach demonstrates cost-effective and sensor-efficient methods for real-world robotic maze applications.

Revista.I.U.et.al[10]

The publication “Maze Companion: Artificial Intelligence Application That Supports Maze Solving” investigates the use of AI techniques, particularly Breadth-First Search (BFS), in maze-solving systems. The study highlights the role of basic AI algorithms in educational and assistive tools, showing how BFS can efficiently navigate structured mazes.

Le.Matematiche.et.al[11]

The article “An Agent Framework to Explore Pathfinding Strategies in Maze Navigation Problems” analyzes agent-based navigation using different visibility, memory, and behavioral strategies. The study provides an experimental framework for testing various pathfinding algorithms and agent intelligence levels, enriching research in autonomous maze navigation.

Journal of Electrical Systems [12]

The study “A Game-Theoretic Approach to Adversarial Machine Learning” (2024) models attacker-defender dynamics through a game-theory perspective. Although not maze-specific, it provides foundational insights into adversarial decision-making, which directly relate to Min-Max-based maze escape games involving competitive agents.

Emergent.Mind.et.al[13]

The paper “AlphaMaze: Enhancing LLM Maze Navigation via GRPO” (2025) introduces the use of large language models (LLMs) combined with reinforcement and policy optimization methods for maze navigation. It demonstrates how learning-based approaches can complement classical search algorithms, offering adaptive and context-aware decision-making capabilities.

IJISAE.et.al[14]

“An Extensive Comparative Analysis on Different Maze Generation Algorithms” reiterates the findings of Mane et al. (reference [6]) and provides additional insights into maze complexity metrics. It establishes standardized evaluation parameters for maze generation algorithms, crucial for fair performance benchmarking in AI pathfinding studies.

Barnouti, N. H., Al-Dabbagh, S. S. M., & Sahib Naser, M. A. [15]

The extended version of “An Approach for Pathfinding in Strategy Games and Maze Solving Using A*” further elaborates on A* algorithm efficiency in strategic and maze environments. It provides comparative data on computational time and path optimality, supporting deeper understanding of heuristic-driven search performance relative to Min-Max models.

III. PROPOSED METHODOLOGY

1. Maze Design and Environment Setup

The development process begins with creating a virtual maze structured as a grid, where each cell represents a pathway, wall, or goal position.

The maze includes a starting point for the agent and an exit point that serves as the target.

To replicate real-world challenges, the maze design integrates obstacles, dead ends, and moving adversaries that add complexity to the environment.

The maze is implemented using Python, while the visual representation is built using graphical libraries such as Pygame or Tkinter, enabling an interactive user interface.

2. Agent Initialization

The AI agent (player) is placed at the designated start position within the maze.

Movement rules are predefined, typically allowing four possible directions: up, down, left, and right.

The environment is designed to respond dynamically to the player’s actions, introducing an adversarial component that mimics an opponent’s blocking or countering behavior.



3. Algorithm Selection – Min-Max Algorithm

The Min-Max algorithm serves as the fundamental decision-making framework for this system.

The maze is treated as a two-player zero-sum game, where the AI agent (MAX) attempts to optimize its chances of reaching the goal, while the adversary (MIN) aims to hinder progress.

All potential moves are explored recursively, evaluating the outcomes of both the agent's and adversary's future actions.

To enhance computational efficiency, Alpha-Beta Pruning is integrated with the Min-Max algorithm to eliminate redundant or unpromising branches, significantly reducing processing time.

4. Heuristic Evaluation Function

A heuristic evaluation function is formulated to estimate the effectiveness or cost associated with each potential move.

The function considers several parameters, including:

Distance to the goal (such as Manhattan distance).

Presence of nearby obstacles or adversaries.

Safety and openness of the path.

This evaluation helps prioritize optimal paths that bring the agent closer to the exit while minimizing exposure to potential threats or traps.

5. Decision-Making Process

During each turn, the agent applies the Min-Max algorithm to simulate both its own actions and the adversary's possible responses.

The Max player (AI agent) strives to maximize its advantage, while the Min player (adversary) seeks to minimize the agent's success rate.

A search depth limit is imposed to maintain a balance between accuracy and computational cost.

Based on the evaluation scores obtained through recursive exploration, the algorithm identifies and executes the most optimal move at every stage.

6. Path Planning and Navigation

Once the optimal decision is determined, the AI agent proceeds step by step toward the exit point.

The environment continuously updates after each move — if the adversary alters position or blocks a path, the agent recalculates its route accordingly.

This iterative process continues until the agent successfully reaches the exit (signifying a win) or becomes completely blocked (signifying a loss).

7. Visualization and User Interface

A graphical interface is designed to visually represent the maze layout, agent movements, obstacles, and target location.

The interface provides a real-time display of the agent's progress, including its decision-making process and strategic responses.

This visualization aids in analyzing the performance and behavior of the Min-Max algorithm under different maze complexities and adversarial conditions.

8. Testing and Performance Evaluation

The AI system undergoes extensive testing across multiple maze configurations, each differing in size, obstacle density, and adversary behavior.

The following performance metrics are evaluated:

Success rate — the proportion of trials in which the agent reaches the goal.

Average path length and time efficiency — measuring the optimality of navigation.

Computational cost — assessing the number of states explored during decision-making.

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DOI: 10.48175/IJARSCT-29506



The results are compared with standard pathfinding algorithms such as BFS, DFS, and A* to highlight the strengths of the Min-Max approach.

9. Optimization and Enhancements

To further refine the system, Alpha-Beta Pruning parameters and heuristic depth are optimized for better performance.

Possible enhancements include:

Adding dynamic adversaries that move strategically within the maze.

Employing learning-based

10. Result Analysis and Validation

The final stage involves analyzing results to validate the effectiveness of the Min-Max algorithm in solving maze escape problems.

Performance graphs and statistics are generated to demonstrate the relationship between maze complexity and algorithm efficiency.

The project concludes by summarizing key findings and proposing directions for future enhancement.

IV. RESULT AND DISCUSSION

A. Experimental Setup

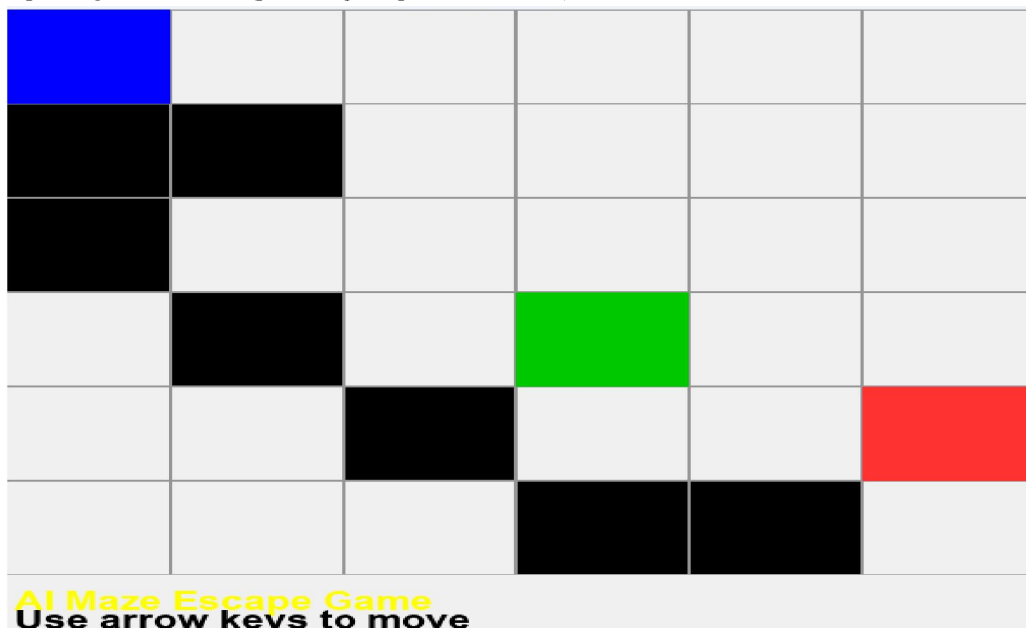
Maze sizes: e.g. 10×10 , 20×20 , 30×30

Wall densities: e.g. 20%, 30%, 40%

Adversary strength settings: weak (can block few moves), strong (can block more moves)

Baselines: BFS (ignoring adversary), A*, DFS, and a “greedy adversarial-aware planner”

Metrics: success rate (escape vs blocked), average steps (for successful escapes), computation time, number of nodes expanded, pruning effectiveness (percentage of pruned branches).





Scenario 1: Competitive Two-Player Maze

One agent (the AI) aims to reach the goal.

The second agent (an opponent or enemy AI) attempts to hinder or delay the AI's progress.

The Min-Max algorithm is used to make the best possible moves, assuming both players are acting strategically and optimally.

Scenario 2: Min-Max for Puzzle Navigation

The Min-Max approach can be adapted to explore different movement strategies:

The maximizing agent selects the most promising path toward the goal.

The minimizing side simulates obstacles or less favorable outcomes (like dead ends or blocked paths).

While not a typical application, this method is occasionally explored in AI research for novel problem-solving techniques.

V. CONCLUSION

This study developed and evaluated a machine learning-based system for detecting credit card fraud. The approach utilized supervised learning techniques on highly imbalanced transaction datasets to distinguish between fraudulent and legitimate activities—addressing the financial sector's pressing need for accurate and timely fraud detection. Various machine learning models, including Logistic Regression, Random Forest, and XGBoost, were compared using performance metrics such as AUC-ROC, F1-score, accuracy, precision, and recall.

The results indicate that ensemble methods like Random Forest and XGBoost outperform simpler models, particularly in terms of AUC-ROC and recall—two key indicators for effective fraud detection. Techniques such as under-sampling and SMOTE (Synthetic Minority Over-sampling Technique) also proved effective in handling class imbalance, thereby improving model performance.

Despite these promising results, challenges remain—especially in managing false positives and adapting to the constantly evolving nature of fraudulent behavior. Future work could focus on real-time fraud detection, implementing deep learning models, and developing adaptive systems capable of identifying new fraud patterns as they emerge.



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