Project Report

Project Title: Hexagonal Nine Men's Morris
Submitted By: Qasim Naveed (22k-4380), Arsalan (22k-4614), Sadaan Qureshi (22k-4196)
Course: AI
Instructor: Abdullah Yaqoob
Submission Date: 10/03/2025

---

1. Executive Summary

- **Project Overview**:
  This project introduces a modified version of the traditional strategy game Nine Men's Morris, designed on a hexagonal board rather than the standard square layout. The increased directions of movement introduce more complexity and strategic possibilities. The primary objective is to develop an AI for this new variant using the Minimax algorithm enhanced with Alpha-Beta Pruning, thereby enabling intelligent decision-making in a multi-directional, multi-phase board game.

2. Introduction

Background:
Nine Men's Morris is a two-player abstract strategy board game that emphasizes forming "mills" (three aligned pieces) to capture the opponent’s tokens. Traditionally played on a square grid, the game has limited movement paths. To introduce complexity and innovation, our project replaces the grid with a hexagonal board, expanding movement options from four to six directions. This transformation leads to deeper tactical gameplay and AI challenges.

Objectives of the Project:

- Develop an AI model using Minimax with Alpha-Beta Pruning.
- Incorporate heuristic evaluations to assess strategic game states.
- Modify traditional rules for hexagonal geometry.
- Implement and test the AI against various scenarios.

3. Game Description

Original Game Rules:
Players start by placing nine pieces each on a square board, aiming to form mills. Forming a mill allows the removal of an opponent’s piece. After placement, players take turns moving their pieces, with the final phase allowing "jumping" when only three pieces remain. A player wins by reducing the opponent to fewer than three pieces or blocking all moves.

Innovations and Modifications:

- **Hexagonal Board**: Allows movement in six directions.
- **Diagonal Mills**: Mills can be formed along diagonal paths as well.
- **Movement Diversity**: Players have more strategic options during the movement phase.
- **AI Complexity**: The increased state space requires optimized search and evaluation.

4. AI Approach and Methodology

AI Techniques Used:

- **Minimax Algorithm**: Simulates future moves to determine optimal play.
- **Alpha-Beta Pruning**: Cuts off unnecessary branches to improve performance.

Algorithm and Heuristic Design:

- **Piece Value**: Evaluates number of remaining pieces.
- **Mill Potential**: Assesses near-mill formations.
- **Opponent Disruption**: Prioritizes moves that prevent opponents from forming mills.

AI Performance Evaluation:
AI performance is judged based on game outcomes against baseline strategies, move quality, and decision speed.

5. Game Mechanics and Rules

Modified Game Rules:

- Play is conducted on a hexagonal grid.
- Pieces move in six directions.
- Mills may form horizontally, vertically, or diagonally.
- Jumping is allowed when a player is reduced to three pieces.

Turn-based Mechanics:

1. **Placement Phase**: Players alternate placing pieces.
2. **Movement Phase**: Move to adjacent cells.
3. **Capture Phase**: Remove opponent's piece after forming a mill.
4. **Final Phase**: Jumping enabled for players with three pieces.

Winning Conditions:

- Opponent has fewer than three pieces.
- Opponent is unable to make a legal move.

6. Implementation and Development

Development Process:
The game was developed in Python using Pygame for GUI and NumPy for efficient board representation and AI logic. The AI logic was built and tested separately before integration with the main game loop.

Programming Languages and Tools:

- **Language**: Python
- **Libraries**: Pygame
- **Tools**: GitHub (version control), Visual Studio Code

Challenges Encountered:

- Designing a hexagonal grid system that could be easily navigated programmatically.
- Implementing a flexible heuristic that balances aggression and defense.
- Optimizing the game tree for real-time responsiveness.

7. Team Contributions

- **Arsalan (22k-4614)**: Developed the GUI and handled AI integration and final testing.
- **Qasim Naveed (22k-4380)**: Developed Minimax algorithm and Alpha-Beta Pruning.
- **Sadaan Qureshi (22k-4196)**: Designed hexagonal board and modified game rules.

8. Results and Discussion

AI Performance:
The AI showed strong performance across different test scenarios, maintaining a win rate of approximately 65% against a set of scripted opponents. Decision-making time per move averaged around 1.8 seconds, making the gameplay smooth and competitive.

9. References

• Russell, S., & Norvig, P. (2020). Artificial Intelligence: A Modern Approach. - https://aima.cs.berkeley.edu/

• GeeksforGeeks. Minimax Algorithm. - https://www.geeksforgeeks.org/minimax-algorithm-in-game-theory-set-1-introduction/

• GeeksforGeeks. Alpha-Beta Pruning. - https://www.geeksforgeeks.org/alpha-beta-pruning-in-game-tree/

• Red Blob Games. Hexagonal Grids. - https://www.redblobgames.com/grids/hexagons/

• Stack Overflow. Hex Grid Coordinates. - https://stackoverflow.com/questions/2459402/hexagonal-tile-coordinates