Connect Six: A Modified Game with AI-Powered Hints

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1 Executive Summary

1.1 Project Overview

This project developed a modified version of the classic Connect Four game, reimagined as Connect Six, with an 8x9 grid and row-based disc placement. The primary objectives were to implement new gameplay mechanics and integrate a Minimax algorithm with Alpha-Beta pruning across three game modes: Human-to-Human with an AI-powered hint system (limited to three hints per player), Human-to-AI, and AI-to-AI demonstration. The Human-to-Human mode enhances strategic decision-making with optional AI hints, while the Human-to-AI mode allows players to compete against the AI, and the AI-to-AI mode showcases the AI's strategic capabilities. Implemented in Python using the NumPy library, the project demonstrates the application of AI techniques in a modified game environment.

2 Introduction

2.1 Background

Connect Four is a two-player connection game where players alternate dropping discs into a vertically suspended 6x7 grid, aiming to connect four discs in a row, column, or diagonal. This project selected Connect Four for its simplicity and potential for AI integration. We modified it into Connect Six, increasing the grid to 8x9, requiring six discs to win, and changing disc placement to rows (leftmost empty slot) instead of columns. These changes increase strategic complexity and provide a fresh challenge for AI development.

2.2 Objectives of the Project

The project aimed to:

- Develop a modified Connect Six game with an 8x9 grid and row-based mechanics.
- Implement three game modes:
    1. Human-to-Human mode with an optional AI hint system, limited to three hints per player.
    2. Human to AI mode for competitive play against an AI opponent
    3. AI to AI mode to demonstrate the AI's strategic capabilities
- Utilize the Minimax algorithm with Alpha-Beta pruning to provide intelligent move suggestions.
- Evaluate the AI's effectiveness in providing strategic hints and ensure robust gameplay mechanics.
- Deliver a console-based implementation in Python, leveraging NumPy for efficient board management.

3 Game Description

3.1 Original Game Rules

Connect Four is played on a 6x7 grid where two players take turns dropping colored discs into columns. The discs fall to the lowest empty position in the chosen column. The objective is to be the first to form a horizontal, vertical, or diagonal line of four discs. The game ends when a player achieves this or the grid is full, resulting in a draw.

3.2 Innovations and Modifications

The modified game, Connect Six, introduces the following changes:

- **Increased Grid Size:** The grid is expanded to 8 rows and 9 columns, increasing the strategic depth.
- **Connect Six Requirement:** Players must connect six discs (instead of four) in a row, column, or diagonal to win.
- **Row-BasedPlacement:** Players place discs in rows, filling the leftmost empty slot, unlike the column-based gravity mechanic of Connect Four.
- **Human-to-Human Mode with AI Hints:** A new mode allows two human players to compete, with an optional AI hint system (limited to three hints per player) powered by Minimax with Alpha-Beta pruning.
- **Human-to-AI Mode:** A mode where a human player competes against an AI opponent, with the option to choose who goes first, leveraging Minimax with Alpha-Beta pruning for AI moves.
- **AI to AI Mode:** A demonstration mode where two AI instances compete against each other, showcasing strategic gameplay using Minimax with Alpha-Beta pruning.

4 AI Approach and Methodology

4.1 AI Techniques Used

The project employed the Minimax algorithm with Alpha-Beta pruning to provide AI-powered hints in the Human-to-Human mode. Minimax evaluates possible game states to determine the optimal move, while Alpha-Beta pruning reduces computational complexity by eliminating branches that cannot affect the final decision. This approach ensures efficient and strategic move suggestions for players requesting hints.

4.2 Algorithm and Heuristic Design

The Minimax algorithm operates with a maximum depth of 3 to balance performance and strategic accuracy. The heuristic evaluation function assesses board states based on:

- **WinningPositions:** Assigns a high score(1000) for six connected discs.

- **Near-WinningPositions:** Scores 100 for five discs with one empty slot, and 10 for four discs with two empty slots.
- **Threats:** Penalizes opponent near-winning positions(-200 for five discs, -20 for four discs).
- **Control:** Awards bonus points for discs in the center column to prioritize strategic positions.

The algorithm evaluates all valid moves (rows with empty slots) and selects the move maximizing the score for the current player.

4.3 AI Performance Evaluation

The AI's hint system was evaluated through gameplay testing. The hints provided were consistently strategic, often suggesting moves that blocked opponent threats or advanced the player's winning chances. The average decision time for hints was approximately 0.5–1 second, suitable for a console-based game. The three-hint limit ensured players relied on their own strategies while benefiting from occasional AI assistance. Formal win-rate analysis was not conducted, as the AI served as an advisor rather than a competitor.

5 Game Mechanics and Rules

5.1 Modified Game Rules

The Connect Six game includes the following rule changes:

- The game is played on an 8x9 grid.
- Players must connect six discs horizontally, vertically, or diagonally to win.
- Discs are placed in the leftmost empty slot of a chosen row, not dropped into columns.
- In Human-to-Human mode, each player can request up to three AI hints per game.

5.2 Turn-based Mechanics

In Human-to-Human mode, players alternate turns. Each turn involves:

- Selecting a row (1–8) or requesting a hint by entering 'h'.
- If a hint is requested and available (within the three-hint limit), the AI suggests a move using Minimax.
- The player's disc is placed in the leftmost empty slot of the chosen row. The game validates moves, ensuring the chosen row has at least one empty slot.

5.3 Winning Conditions

A player wins by connecting six discs in a horizontal, vertical, or diagonal line. The game ends in a draw if the grid is full without a winner. The console displays the outcome (e.g., "Player 1 (Red) wins!" or "It's a draw!").

6 Implementation and Development

6.1 Development Process

The game was developed iteratively using Python. The process involved:

- Designing the 8x9 grid and row-based mechanics using NumPy arrays for efficient board management.
- Implementing core game logic, including move validation, win detection, and board display.
- Integrating the Minimax algorithm with Alpha-Beta pruning for the AI hint system.
- Adding Human-to-Human mode with a three-hint limit per player.
- Testing gameplay, hint accuracy, and user input handling.

6.2 Programming Languages and Tools

- **Programming Language**: Python
- **Libraries**: NumPy (for board representation and calculations)
- **Tools**: GitHub for version control, Colab for development and testing

6.3 Challenges Encountered

Key challenges included:

- **Minimax Performance**: The 8x9 grid and six-disc requirement increased the state space, slowing down Minimax. This was addressed by limiting the search depth to 3 and using Alpha-Beta pruning.
- **Hint System Integration**: Ensuring the hint system was optional and limited to three uses per player required careful state management, resolved by tracking hint counts in the game class.
- **Console Interface**: Designing a clear console-based interface for row based input and hint requests was challenging but achieved through robust input validation and clear prompts.

7 Team Contributions

7.1 Team Members and Responsibilities

Warda Masood:

- Implemented the basic code of Connect 4, including the 8x9 grid, row-based placement, and core game mechanics (e.g., turn-based moves and win detection).

Aymen Shakil:

- Made modifications according to the proposed proposal, including implementing the Minimax algorithm with Alpha-Beta pruning and the heuristic evaluation function to enhance the AI gameplay and added the Connect 6 rule.

Aina Bibi:

- Made further modifications, such as designing the Human-to-Human mode and integrating the AI hint system with a three-hint limit.
- Handled console interface development, input validation, and gameplay testing.

8 Results and Discussion

8.1 AI Performance

The AI hint system performed effectively, providing strategic move suggestions that enhanced player decision-making. The Minimax algorithm with Alpha-Beta pruning ensured hints were computed within 0.5–1 second, maintaining a smooth gameplay experience. The three-hint limit encouraged players to rely on their own strategies while benefiting from AI assistance. Informal testing showed the AI consistently suggested moves that blocked opponent threats or advanced winning opportunities. The game's mechanics were robust, with no observed bugs in move validation, win detection, or hint functionality.

9 References

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– NumPyDocumentation. https://numpy.org/doc/stable/(Forarraybased board implementation)

– Python Official Documentation. https://docs.python.org/3/ (For Python programming reference)