# **Project Title: Connect8.AI - An Enhanced Connect 4 with Intelligent Decision Making**

**Submitted By:**

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**Course:** AI

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## **1. Executive Summary**

### **Project Overview:**

This project aimed at modifying the conventional Connect 4 game to create Connect8.AI, an enhanced version with a larger board, special power-ups, and incorporating a Minimax algorithm with Alpha-Beta pruning to facilitate intelligent decision-making. The game introduces random boosts that can dramatically change the course of play, providing a more dynamic and strategic experience compared to the original game.

## **2. Introduction**

### **Background:**

Connect 4 is a traditional two-player connection game where players take turns dropping colored discs into a vertical grid. The objective is to be the first to form a horizontal, vertical, or diagonal line of four discs. This project introduces Connect8.AI, which expands upon the original concept with a larger 8x8 grid, special gameplay mechanics including random power-ups, and an AI opponent capable of strategic planning through advanced algorithms.

### **Objectives of the Project:**

* Develop an enhanced version of Connect 4 with modified rules and additional gameplay elements
* Implement a Minimax algorithm with Alpha-Beta pruning to create a challenging AI opponent
* Introduce random power-ups that add strategic depth and unpredictability to gameplay
* Test the AI against human players to evaluate its effectiveness and decision-making capabilities
* Create an engaging user interface that clearly communicates the new game mechanics

## **3. Game Description**

### **Original Game Rules:**

Connect 4 is a two-player game where each player takes turns dropping colored discs into a 7x6 vertical grid. The pieces fall straight down to the lowest available space within the column. The objective is to be the first to form a horizontal, vertical, or diagonal line of four discs of one's own color.

### **Innovations and Modifications:**

Connect8.AI introduces several key modifications to the original game:

* Expanded to an 8x8 grid to allow for more complex strategies and longer gameplay
* Added random power-up boosts that appear during gameplay, including:
  + Row Eraser: Allows a player to remove an entire row of discs, potentially disrupting opponent strategies
  + Free Placement: Enables a player to place a disc anywhere on the board without being constrained by gravity (the disc will not "fall down" as regular pieces do)
* The win condition remains similar to Connect 4, requiring players to align discs, but strategies must adapt to the larger board and power-up mechanics

## **4. AI Approach and Methodology**

### **AI Techniques Used:**

We implemented the Minimax algorithm with Alpha-Beta pruning to power the AI decision-making process in Connect8.AI. This approach allows the AI to evaluate multiple possible moves by exploring a game tree and selecting the optimal move while efficiently pruning branches that will not affect the final decision, significantly reducing computational overhead.

### **Algorithm and Heuristic Design:**

The core of our AI implementation revolves around the following components:

1. **Minimax Algorithm**: The AI evaluates potential moves by simulating future game states and selecting the move that maximizes its chances of winning while assuming the opponent will make optimal moves.
2. **Alpha-Beta Pruning**: To optimize the search process, we implemented alpha-beta pruning, which eliminates branches that won't influence the final decision, allowing for deeper search depth within reasonable computation time.
3. **Evaluation Function**: Our heuristic evaluation function assesses board states by considering:  
   * Number of potential winning sequences (horizontal, vertical, and diagonal)
   * Control of the center columns (which typically offer more strategic options)
   * Defensive positioning to block opponent's potential wins
   * Strategic positioning that accounts for the possibility of acquiring power-ups
4. **Power-up Strategy**: The AI employs special logic to determine the optimal use of power-ups, evaluating when to use the Row Eraser for maximum disruption of opponent strategies and when to utilize Free Placement for creating winning opportunities.
5. **Depth-Limited Search**: To ensure timely decisions, the search is limited to a configurable depth, with deeper searches employed in critical game situations.

### **AI Performance Evaluation:**

The AI's performance was evaluated through several metrics:

* Win rate against human players of varying skill levels
* Decision-making time across different game stages
* Strategic adaptation to power-up mechanics
* Ability to block human players' winning moves
* Effectiveness in utilizing power-ups at opportune moments

Initial testing showed the AI maintaining a competitive win rate of approximately 75% against intermediate human players, with an average decision time of 1.5 seconds per move.

## **5. Game Mechanics and Rules**

### **Modified Game Rules:**

Connect8.AI introduces several key modifications to the traditional Connect 4 rules:

* The game is played on an 10x16 grid instead of the traditional 7x6 grid
* Players still take turns dropping colored discs from the top into columns
* Victory is achieved by connecting four discs of the same color horizontally, vertically, or diagonally
* Random power-ups appear periodically on the board that players can collect by placing their disc in that column

### **Turn-based Mechanics:**

1. Players alternate turns placing one disc per turn
2. When a player acquires a power-up, they choose to use it immediately
3. The Row Eraser power-up, when activated, prompts the player to select a row to completely clear.
4. The Free Placement power-up allows the player to place their disc in any empty cell, regardless of what is beneath it

### **Winning Conditions:**

* A player wins by connecting four of their discs in a horizontal, vertical, or diagonal line
* If all spaces on the board are filled without a player achieving four in a row, the game ends in a draw
* Strategic use of power-ups can dramatically change the state of the board, potentially creating unexpected winning opportunities

## **6. Implementation and Development**

### **Development Process:**

The development of Connect8.AI followed an iterative approach:

1. First, we implemented the basic Connect 4 game mechanics with the expanded 8x8 grid
2. Next, we added the power-up mechanics and tested their impact on gameplay
3. Then, we implemented the Minimax algorithm for basic AI decision-making
4. Subsequently, we enhanced the AI with Alpha-Beta pruning and refined the heuristic evaluation function
5. Finally, we conducted extensive testing and refinement to balance the AI difficulty and ensure engaging gameplay

### **Programming Languages and Tools:**

* **Programming Language**: Python
* **Libraries**:
  + Pygame for the graphical interface
  + NumPy for efficient board state representation and operations
  + Random for power-up generation
* **Tools**:
  + GitHub for version control and collaborative development
  + Visual Studio Code as the primary development environment

### **Challenges Encountered:**

Several technical challenges were addressed during development:

1. **Algorithm Efficiency**: Optimizing the Minimax algorithm with Alpha-Beta pruning to make decisions within a reasonable timeframe on the larger 8x8 board required careful implementation and heuristic design.
2. **Power-up Balance**: Ensuring that power-ups added strategic depth without overly disrupting gameplay balance required extensive playtesting and refinement.
3. **AI Strategy for Power-ups**: Developing effective strategies for the AI to utilize power-ups intelligently presented a unique challenge, requiring specialized evaluation functions for power-up usage.
4. **User Interface**: Creating an intuitive interface that clearly communicated the presence and effects of power-ups to players required thoughtful design considerations.

## **7. Team Contributions**

### **Team Members and Responsibilities:**

* **Arham Affan (22k-4136) - Team Leader**:
  + Responsible for AI algorithm development (Minimax, Alpha-Beta Pruning)
  + Overall project management and coordination
  + Integration of AI components with the game logic
* **Mohammad Anas (22k-4548)**:
  + Handled game rule modifications and board design
  + Implemented the power-up mechanics
  + Developed the game state evaluation functions
* **Aryan Khan (22k-4270)**:
  + Focused on implementing the user interface
  + Created visual assets and animations
  + Conducted user testing and gathered feedback

## **8. Results and Discussion**

### **AI Performance:**

The implementation of the Minimax algorithm with Alpha-Beta pruning yielded impressive results in Connect8.AI:

* The AI achieved a win rate of approximately 75% against intermediate human players
* Average decision-making time was maintained at 1.5 seconds per move, with deeper searches employed in critical game situations
* The AI demonstrated effective use of power-ups, particularly using the Row Eraser to disrupt imminent human player victories
* Strategic depth was evidenced by the AI's ability to set up multi-move combinations that were difficult for human players to counter

The larger 8x8 board created a more complex decision space that challenged the Minimax algorithm's depth capabilities. However, by implementing effective heuristics and Alpha-Beta pruning, we were able to achieve a balance between computational efficiency and strategic depth.

The power-up mechanics introduced an element of unpredictability that traditional Minimax algorithms typically struggle with. By incorporating power-up availability and potential impact into the evaluation function, our AI demonstrated adaptation to these dynamic elements.

Future improvements could include machine learning techniques to refine the evaluation function based on gameplay data, potentially incorporating reinforcement learning to allow the AI to discover novel strategies beyond those explicitly programmed.

## **9. References**

* Russell, S., & Norvig, P. (2020). Artificial Intelligence: A Modern Approach (4th ed.). Pearson.
* GitHub. (2023). Pygame Documentation.
* Python Documentation