Connect Four AI Project Report

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This report details the evaluation criteria and implementation aspects of our AI project, a web-based Connect Four game featuring both human-vs-human and human-vs-AI modes with adjustable difficulty.

1. Evaluation Criteria

The AI's performance is evaluated based on the criteria outlined in [1], focusing on heuristic scoring, search depth, and winning move prioritization:

- **Heuristic Function:** Adapted from [1], the evaluateBoard() assigns scores to potential 4-cell windows:
    - +100 for AI's 4-in-a-row, -100 for human's 4-in-a-row.
    - +50 for AI's 3-in-a-row with an empty spot, -80 for human's 3-in-a-row.
    - Lower scores for less threatening configurations.
- **Minimax with Alpha-Beta Pruning:** Balances depth and performance. Higher difficulty levels increase search depth (Easy: 1–3, Medium: 4–5, Hard: 6–7).
- **Early Stopping mechanism:**
    - **Time-Based Termination:** Limits the minimax search duration to prevent delays in AI decision-making.
    - **Adaptive Depth:** Dynamically halts the search if a predefined time threshold (maxDuration) is exceeded, ensuring real-time responsiveness without sacrificing critical evaluations.
    - **Fallback to Heuristic:** Returns the current heuristic score if interrupted, maintaining a balance between accuracy and performance.
- **Immediate Win Detection:** The AI checks for instant wins before initiating minimax, reducing unnecessary computation.

2. Implementation Details

- **Game Modes**
    - Human vs. Human: Turn-based gameplay with visual/sound feedback.
    - Human vs. AI: Features difficulty levels (Easy, Medium, Hard) via a dynamic pop-up menu.
- **AI Architecture**
    - **Minimax Algorithm:** Recursively simulates moves up to the chosen depth.
    - **Alpha-Beta Pruning:** Reduces the search space by pruning non-optimal branches.
    - **Randomized Depth:** At "Easy" difficulty, depth varies randomly (1–3) to mimic suboptimal play.
- **User Interface**
    - **Visual Board:** Rendered using a 6x7 grid of elements with CSS animations.
    - **Turn Indicators:** Dynamic labels ("Your Turn" vs. "AI's Turn").
    - **Interactive Buttons:** Different buttons for different game modes.
    - **Difficulty Pop-Up:** Prompt player with Easy, Medium, Hard difficulty in "vs AI"

mode.
    - **Game Over Pop-Up:** Displays winner/draw and offers a replay option.

- **Technical Features**
    - **Sound Effects:** Disc drop and game-over sounds enhance interactivity.
    - **Responsive Design:** Gradient buttons and overlays for modern aesthetics.
    - **Randomized First Turn:** In AI mode, the first player is randomized for fairness.

3. Challenges & Solutions

- **Performance:** Infinite game tree made the searching challenging. We have used alpha-beta pruning and depth limiting to ensure real-time responsiveness.
- **State Management:** The board array and DOM elements are synchronized to avoid visual/data mismatches.

4. Results

The AI consistently wins at "Hard" difficulty (depth 6–7) and provides balanced gameplay at lower levels.
The heuristic function effectively prioritizes blocking opponent wins while seeking opportunities.
UI elements (e.g., turn indicators, sounds) improve user engagement.

Reference:

[1] Evaluation of the Use of Minimax Search in Connect-4—How Does the Minimax Search Algorithm Perform in Connect-4 with Increasing Grid Sizes?

GitHub Repository: https://github.com/FarhanTausif/ConnectFour