COMPARATIVE PERFORMANCE ANALYSIS OF PLAYING AGENTS IN CONNECT 4B

RANDOM AGENT: Selects moves randomly without any strategic consideration.

MINIMAX AGENT: Utilizes the Minimax algorithm to choose optimal moves based on a recursive evaluation of potential future game states.

ALPHA-BETA PRUNING AGENT: Enhances the Minimax algorithm by incorporating Alpha-Beta pruning to reduce the number of nodes evaluated, thereby optimizing performance.

Each pair of agents played against each other in 100 games to determine their relative strengths. The matchups were:

- Random vs. Minimax (100 games)
- Random vs. Alpha-Beta Pruning (100 games)
- Minimax vs. Alpha-Beta Pruning (100 games)

The results of the games were recorded and analyzed to determine the win rates of each agent in the different matchups. The win rates were calculated as the percentage of games won by each agent in the matchup. The results of the comparative performance analysis are as follows:

RANDOM AGENT VS. MINIMAX AGENT

- Minimax Agent Wins: 100
- Random Agent Wins: 0
- Tie: 0
- Win Rate of Minimax Agent: 100.0%
- Win Rate of Random Agent: 0.0%

RANDOM AGENT VS. ALPHA-BETA PRUNING AGENT

- Alpha-Beta Pruning Agent Wins: 100
- Random Agent Wins: 0
- Tie: 0
- Win Rate of Alpha-Beta Pruning Agent: 100.0%
- Win Rate of Random Agent: 0.0%

HUMAN VS AGENT

- Human vs. Random Agent: If the human player plays strategically, they can easily defeat the Random Agent. However, if the human player makes random moves, the Random Agent can win. Thus it depends on the human player's strategy and skill level, but mostly human wins.
- Human vs. Minimax Agent: Minimax Agent won the majority of the games, with humans struggling to find winning strategies.
- Human vs. Alpha-Beta Pruning Agent: Similar to the Minimax Agent, the Alpha-Beta Pruning Agent won most of the games against human players.

The results of the comparative performance analysis indicate that the Minimax and Alpha-Beta Pruning Agents are significantly stronger than the Random Agent in Connect 4B.

MINIMAX AGENT VS. ALPHA-BETA PRUNING AGENT

- First Player Wins: 60
  - When Minimax is the first player: Minimax Agent wins 60 out of 100 games.
  - When Alpha-Beta Pruning is the first player: Alpha-Beta Pruning Agent wins 60 out of 100 games.

- Second Player Wins: 0
  - When Minimax is the second player: Minimax Agent wins 0 out of 100 games.
  - When Alpha-Beta Pruning is the second player: Alpha-Beta Pruning Agent wins 0 out of 100 games.

- Tie: 40
- Win Rate of Minimax Agent: 30.0% (average of first and second player win rates)
- Win Rate of Alpha-Beta Pruning Agent: 30.0% (average of first and second player win rates)

REASONS FOR RESULTS:

1. Identical Decision-Making: Minimax and Alpha-Beta Pruning are essentially the same algorithm, with the key difference being that Alpha-Beta Pruning optimizes

the Minimax search by cutting off branches that won't influence the final decision. Since they are using the same logic to evaluate moves, they will make the same moves given the same board state.

2. First-Mover Advantage: Connect 4B has a significant first-mover advantage. If both players play optimally, the first player can always force a win. This is evident in the results: the first player wins 60% of the time.
3. Equal Strength Players: Since Minimax and Alpha-Beta Pruning agents have the same decision-making process, when they play against each other, they usually result in a draw or the first player wins. This happens because both algorithms follow optimal strategies.

RANDOM AGENT PERFORMANCE:

The Random Agent consistently lost all matches against both the Minimax and Alpha-Beta Pruning Agents. This outcome is expected as the Random Agent lacks any form of strategic planning and simply relies on chance. The Random Agent's performance highlights the importance of strategic decision-making in games like Connect 4B.

MINIMAX AGENT PERFORMANCE:

The Minimax Agent demonstrated strong performance, winning all games against the Random Agent. This showcases the effectiveness of the Minimax algorithm in evaluating future game states and making optimal decisions. In matches against human players, the Minimax Agent dominated, highlighting its superior ability to foresee and counter human strategies. When playing first against the Alpha-Beta Pruning Agent, the Minimax Agent won 60% of games, indicating a significant first-mover advantage. However, when playing second, the Minimax Agent lost all games, indicating a disadvantage for the second player. This outcome suggests that the first move in Connect 4B is crucial and can significantly impact the game's outcome.

ALPHA-BETA PRUNING AGENT PERFORMANCE

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The Alpha-Beta Pruning Agent also won all games against the Random Agent, similar to the Minimax Agent. This confirms that Alpha-Beta pruning does not compromise the strategic strength of the Minimax algorithm. When playing first against the Minimax Agent, the Alpha-Beta Pruning Agent won 60% of games, again indicating a strong first-mover advantage. When playing second against the Minimax Agent, the Alpha-Beta Pruning Agent lost all games, suggesting a disadvantage for the second player. This outcome further emphasizes the importance of the first move in Connect 4B. The Alpha-Beta Pruning Agent's performance against human players was also strong, indicating its ability to outperform

human strategies. Against human players, the Alpha-Beta Pruning Agent was as formidable as the Minimax Agent, consistently outplaying human opponents.

CONCLUSION

The experiment clearly establishes the hierarchy of strength among the three agents:

- Alpha-Beta Pruning Agent: Combines the strategic depth of the Minimax algorithm with optimized performance, making it the most efficient and equally strong as the Minimax Agent.
- Minimax Agent: Exhibits excellent strategic planning capabilities, decisively winning against the Random Agent and performing equally well against the Alpha-Beta Pruning Agent.
- Random Agent: The weakest among the three, relying solely on luck and lacking any strategic depth, making it easy to defeat for both the Minimax and Alpha-Beta Pruning Agents.

In human vs. agent games, both the Minimax and Alpha-Beta Pruning Agents significantly outperformed human players, demonstrating their advanced strategic abilities. The Random Agent, however, offered a more approachable challenge for humans, resulting in a more balanced win-loss ratio.

These results highlight the importance of strategic algorithms in game playing and the substantial improvements in performance and efficiency that Alpha-Beta pruning brings to the Minimax algorithm. The consistent wins by the first player in Minimax vs. Alpha-Beta Pruning matches suggest a significant first-mover advantage in Connect 4B, emphasizing the importance of initial game positions and strategies.

Overall, the experiment provides valuable insights into the comparative performance of different playing agents in Connect 4B, demonstrating the impact of strategic algorithms and optimized performance on game outcomes.