Team Members

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Introduction

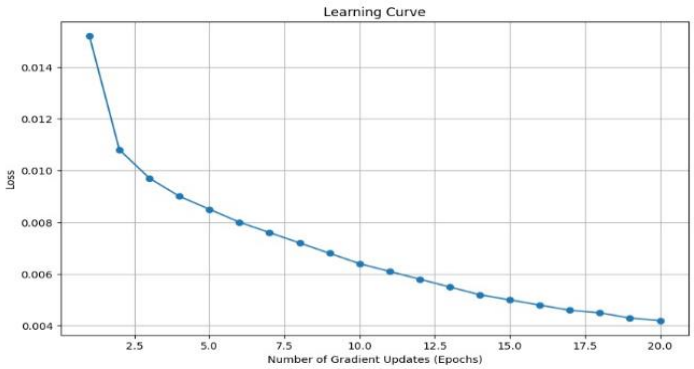
For our CIS667 (Introduction to Artificial Intelligence) Final Project (Fall 2023), we developed an advanced AI agent to play Gomoku on a 15x15 board. Our approach combines a custom Convolutional Neural Network (CNN) with a minimax algorithm enhanced by a tailored heuristic evaluation function. The neural network learns from real game states and adapts its strategy, while the minimax algorithm ensures optimal play when the neural network is uncertain or suggests an invalid move. This hybrid design results in an AI that is both strategically sound and adaptable to various playing styles, representing a state-of-the-art application of AI and game theory.

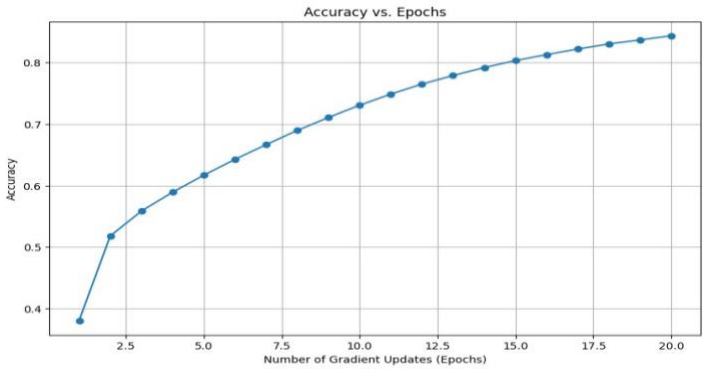
Key Features of the Custom Minimax

- **Dynamic Heuristic Evaluation:**
  The minimax algorithm uses a custom evaluation function that dynamically allocates scores and weighs the board state. It scans the board in all directions (horizontal, vertical, diagonal, and anti-diagonal) and aggregates scores based on consecutive player actions. The function also blocks the opponent up to two moves before a potential win, giving more weight to scores as the game nears completion.
- **Player Strategies:**
  - The **MIN player** adopts an aggressive approach, earning higher scores for potential winning sequences. This promotes proactive and offensive gameplay.
  - The **MAX player** typically plays defensively, focusing on blocking threats rather than creating them.
  - This dynamic often results in early victories for the MIN player, but sometimes leads to missed offensive opportunities for the MAX player.
- **Outcome:**
  The chosen strategies mean the MIN player often wins quickly but can also lose early. Occasionally, the MIN player outperforms the MAX player, especially when the MAX player is close to finishing the game.

Key Features of the Custom Neural Network

- **Input Data:**
  We used 2,880 input-output game states from the Gomo-cup competition (2022) to train our model.
- **Network Architecture:**
  - The model is a sequential CNN with six convolutional layers.
  - The architecture increases and then decreases in depth: 64 → 128 → 256 → 128 → 64.
  - All layers use ReLU activation, except the final layer, which is a 1x1 convolution followed by a reshape and sigmoid activation for binary classification.
  - The Adam optimizer was used, as it performed better than SGD for our data.
  - A batch size of 20 and 20 epochs were found to be optimal.
- **Training Performance:**
  - The best model achieved an accuracy of around **84%** and a loss of **0.042** after 20 epochs.
  - The training and validation curves are shown below:





- **Win Rate:**
  On average, our AI won **75%** of games played, with a **standard deviation of ±5%**.

Discussion

During development, we experimented with reducing the number of layers and increasing the number of training epochs. This led to slower improvements in accuracy and a risk of overfitting, as the model learned the training data too well but failed to generalize. Additionally, combining the CNN with the minimax heuristic at critical decision points improved the AI's performance, though it increased computational requirements.

Conclusion

Our hybrid approach, integrating a custom CNN with a minimax heuristic, resulted in a robust and adaptable Gomoku AI. The system demonstrates strong performance against baseline agents and showcases the effectiveness of combining deep learning with traditional search-based AI methods in strategic board games.

For any questions or further information, please contact Pavan Pandya or Jill Gosrani at the emails listed above.

Bibliography:

[1] Allis, Louis Victor, Hendrik Jacob Herik, and Matty PH Huntjens. Go-moku and threat-space search. Maastricht, The Netherlands: University of Limburg, Department of Computer Science, 1993.

[2] Fu, Xiang. "GomokuPro: An Implementation of Enhanced Machine Learning Algorithm Utilizing Convolutional Neural Network in Gomoku Strategy and Predictions Model." *2022 7th International Conference on Intelligent Computing and Signal Processing (ICSP)*. IEEE, 2022.