CSE 202 Project Proposal
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Pooja Sounder Rajan, Anusha Ravichandran, Nevasini Sasikumar, Akhila Yekalluri, Viroopaksh

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1 Introduction

Hearts is a classic card game that presents unique challenges for AI due to its imperfect information nature and complex strategic elements. While significant progress has been made in AI for perfect information games like chess and Go, imperfect information games like Hearts remain an active area of interest. The primary goal is to create an AI agent that can learn optimal strategies for Hearts through self-play and experience, without relying on hard-coded rules or human expertise. The novelty of this approach lies in addressing several specific challenges posed by Hearts:

- **Imperfect information:** Players do not know the cards held by other players, requiring the AI to reason about probabilities and make decisions under uncertainty.
- **Multi-agent environment:** Hearts involves four players, making it more complex than two-player games that have been the focus of much game AI research.
- **Non-zero-sum nature:** Unlike many classic game AI problems, Hearts is not strictly zero-sum, as multiple players can perform well simultaneously.
- **Long-term strategy:** Successful play in Hearts often requires planning across multiple rounds and considering the entire game, not just immediate moves.

By tackling these challenges, this algorithm aims to push the boundaries of what's possible in card game AI, potentially leading to breakthroughs that could be applied to other imperfect information games and real-world decision-making scenarios. The resulting AI agent could serve as a valuable tool for game developers, a challenging opponent for players, and a stepping stone towards more advanced AI systems capable of handling complex, uncertain environments.

2 What is Hearts?

Hearts is a strategic card game played by 4 players. The goal of the game is to minimize the number of points acquired by the end of the game. Players aim to avoid collecting certain cards that contribute points, with gameplay centered around strategy and adherence to specific rules.

2.1 Key Pre-Game Information

2.1.1 Point System:

- Each Heart card contributes 1 point, regardless of its face value.
- The Queen of Spades is worth 13 points, the highest single-point card in the game.

2.1.2 Winning Condition:

- The player(s) with the least total points at the end of the game is declared the winner.
- Multiple winners are possible if players tie for the lowest points.

2.2 Gameplay

2.2.1 Card Distribution:

- A standard 52-card deck is shuffled and distributed anticlockwise among the 4 players.

2.2.2 Starting the Game:

- The player holding the 2 of Clubs begins the game by playing this card.

2.2.3 Playing a Round:

- The player who won the previous round (except for the first round) starts the next round by playing any card of their choice.
- Once a card is played, all players must follow the base suit (the suit of the first card played).
- If a player does not have a card from the base suit, they can play a card from any other suit.

2.2.4 Winning a Round:

- The round is won by the player who plays the highest card of the base suit.
- The stack of cards from that round is placed beside the winner for point calculation later.

2.2.5 Game Progression:

- The game consists of 13 rounds, during which all cards are played.
- At the end of the game, players tally the points based on the cards they have collected.

2.3 Rules to Remember

2.3.1 Heart-Break Rule:

- Hearts cannot be played as the base suit in any round unless a card from the Hearts suit has been played in a previous round. This event is called a heart-break.

2.3.2 Compulsory Start with 2 of Clubs:

- The player holding the 2 of Clubs must start the first round with this card.

2.3.3 Order of Play:

- Cards are played in an anticlockwise direction throughout the game.

2.4 Possible Outcomes

Point Range per Player:

- **Minimum Points:** 0 (No Hearts or Queen of Spades collected).
- **Maximum Points:** 25 (12 Hearts and the Queen of Spades).
- **Special Case:** A player collecting all 13 Hearts and the Queen of Spades earns -26 points (referred to as "shooting the moon"), which is considered a better outcome than zero as it forces all opponents to receive 26 points each.

3 Scope

This project focuses on leveraging reinforcement learning (RL) to optimize decision-making in the card game Hearts, with an emphasis on minimizing penalty points and developing efficient card selection strategies. A key computational objective is to train an agent to minimize the number of penalty points collected, requiring the modeling of decisions under uncertainty and balancing short-term risks with long-term rewards. The main computational question addressed here is: *How can reinforcement learning identify and prioritize moves that reduce penalties while accounting for dynamic game states and opponent actions?*

Another critical focus is identifying the optimal set of cards to play during each turn. This involves evaluating cards in hand, analyzing the cards already played, and predicting opponent moves. The project addresses the computational question: *How can the agent use reinforcement learning to simulate possible game outcomes and determine the most favorable card to play in each scenario?*

To achieve these goals, the project utilizes game simulation and self-play, enabling the RL agent to learn strategies iteratively through gameplay. The computational challenge lies in designing an efficient environment where the agent balances exploration (trying new strategies) and exploitation (using known optimal moves) to converge on effective strategies. The associated question is: *What mechanisms can ensure the RL agent efficiently explores the strategy space and optimizes learning within a feasible training timeframe?*

Finally, the project evaluates the agent's performance through metrics such as average points scored per game and consistency in minimizing penalties. This raises a computational question: *What metrics are most effective for evaluating performance and strategy improvement in a multi-agent RL setting for Hearts?* These evaluations provide insights into the effectiveness of reinforcement learning for mastering strategic card selection and point minimization.

4 Increased problem complexity

4.1 Implementing "Shooting the Moon"

We can add complexity by incorporating the "Shooting the Moon" rule. This rule allows a player to attempt to collect all the Hearts and the Queen of Spades in a single round, effectively reversing the scoring dynamics. If successful, the player earns 0 points, and all opponents are penalized with 26 points each. This introduces a new layer of strategy, requiring players to not only focus on minimizing their points but also to anticipate and block an opponent's attempt to shoot the moon. This addition could significantly enhance the sophistication of player strategies.

4.2 Introducing Card Passing

Adding the rule where each player passes three cards to another player at the beginning of each round increases both strategic depth and complexity by allowing players to manipulate their hands before gameplay begins. With the passing direction alternating (left, right, or across), players can sabotage opponents by passing undesirable cards like the Queen of Spades or high-value hearts, while also strengthening their own hands by discarding weaker cards or consolidating suits to gain more control during play. Additionally, this mechanic introduces a layer of prediction and adaptation, as players must anticipate the cards they might receive from others, further enriching the game's strategic dynamics.

4.3 Multi-Agent AI Learning

Incorporating multi-agent AI learning adds significant complexity to the algorithm by introducing multiple AI agents that interact, learn, and adapt dynamically during gameplay. Each agent employs reinforcement learning techniques, optimizing strategies based on rewards and penalties, such as avoiding high-value cards or blocking an opponent's attempt to shoot the moon. This dynamic interaction among agents fosters an environment of continuous strategy development, enabling more sophisticated and adaptive gameplay.

5 Related Works

Culhane (2021) explores applying Deep Q-Learning to the four-player imperfect information card game Hearts, concluding that while the method shows promise, computational limitations prevented it from it from fully solving the game. Wagenaar (2021) investigates using reinforcement learning and a Multi-Layer Perceptron (MLP) to learn the card game Hearts, comparing the performance of Sigmoid and ReLU activation functions, and examining the impact of hidden layers on learning efficiency and strategy. Zha et al. (2019) introduce RLCard, an open-source toolkit designed for reinforcement learning in card games which aims to advance research in multi-agent reinforcement learning for games with large state and action spaces and sparse rewards.

References

[1] Culhane, T. (2021). Reinforcement Learning on Hearts. Department of Symbolic Systems, Stanford University.

[2] Wagenaar, M. (2021). Learning to Play the Game of Hearts Using Reinforcement Learning and a Multi-Layer Perceptron. Bachelor's Project Thesis, University of Groningen.

[3] Zha, D., Lai, K.-H., Cao, Y., Huang, S., Wei, R., Guo, J., & Hu, X. (2019). RLCard: A toolkit for reinforcement learning in card games. *arXiv preprint arXiv:1910.04376.*