Abstract. This article shows how the performance of a Monte-Carlo Tree Search (MCTS) player for Havannah can be improved by guiding the search in the playout and selection steps of MCTS. To improve the playout step of the MCTS algorithm, we used two techniques to direct the simulations, Last-Good-Reply (LGR) and N-grams. Experiments reveal that LGR gives a significant improvement, although it depends on which LGR variant is used. Using N-grams to guide the playouts also achieves a significant increase in the winning percentage. Combining N-grams with LGR leads to a small additional improvement. To enhance the selection step of the MCTS algorithm, we initialize the visit and win counts of the new nodes based on pattern knowledge. By biasing the selection towards joint/neighbor moves, local connections, and edge/corner connections, a significant improvement in the performance is obtained. Experiments show that the best overall performance is obtained when combining the visit-and-win-count initialization with LGR and N-grams. In the best case, a winning percentage of 77.5% can be achieved against the default MCTS program.

1 Introduction

Recently a new paradigm for game-tree search has emerged, the so-called Monte-Carlo Tree Search (MCTS) [6,13]. It is a best-first search algorithm that is guided by Monte-Carlo simulations. In the past few years MCTS has substantially advanced the state-of-the-art in several deterministic game domains where αβ-based search [12] has had difficulties, in particular computer Go [15], but other domains include General Game Playing [3], LOA [25] and Hex [1]. These are all examples of game domains where either a large branching factor or a complex static evaluation function do restrain αβ search in one way or another.

A game that has recently caught the attention of AI researchers is Havannah, regarded as one of the hardest connection games for computers [24]. Designing an effective evaluation function is quite hard and the branching factor is rather large, making MCTS the algorithm of choice. A substantial amount of research has been performed for applying MCTS in Havannah [10,19,23,24], but humans are still superior. In this article1 we therefore investigate how the performance

---

1 This article is based on the research performed by the first author for his M.Sc. thesis [21].
of our MCTS-based Havannah program\textsuperscript{8,11,21} can be improved by enhancing the playout and selection steps. For the playout step we propose to apply the Last-Good-Reply policy\textsuperscript{2,7} and N-grams\textsuperscript{[14,20]}. For the selection step, we bias the moves by using prior knowledge\textsuperscript{10} based on patterns.

The article is organized as follows. In Section 2 we explain the rules of Havannah. Next, Section 3 discusses the application of MCTS to Havannah and describes our enhancements for the playout and selection steps. Subsequently, the enhancements are empirically evaluated in Section 4. Finally, in Section 5 we conclude and give an outlook on future research.

2 The Rules of Havannah

Havannah is a turn-based two-player deterministic perfect-information connection game invented by Christian Freeling in 1976\textsuperscript{9}. It is played on a hexagonal board, often with a \textit{base} of 10, meaning that each side has a length of 10 cells. One player uses white stones; the other player uses black stones. The player who plays with white stones starts the game. Each turn, a player places one stone of his color on an empty cell. The goal is to form one of the following three possible winning connections (also shown in Fig. 1).

- \textbf{Bridge}: A connection that connects any two corner cells of the board.
- \textbf{Fork}: A connection that connects three sides. Corner cells do not count as side cells.
- \textbf{Ring}: A connection that surrounds at least one cell. The cell(s) surrounded by a ring may be empty or occupied by white or black stones.

![Fig. 1. The three possible connections to win the game. From left to right: a bridge, a ring and a fork.](image)

Because White has an advantage being the starting player, the game is often started using the swap rule. One of the players places a white stone on the board after which the other player may decide whether he\textsuperscript{2} will play as White or Black. It is possible for the game to end in a draw, although this is quite unlikely.

\textsuperscript{2} For brevity, we use 'he' and 'his' whenever 'he or she' and 'his or her' are meant.