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Proposal of Endgame Puzzles and Generation of Interesting Ones for the Imperfect Information Game "Geister"

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With the development of hardware and algorithms in past decades, artificial intelligence (AI) in games has shown impressive results. One possible way to make AIs involved more deeply in humans' daily lives is game content generation, which can be used to entertain human players and has become one of the popular fields among research in games. On the one hand, much research in content generation for perfect information games, such as tsume-shogi (shogi mating problems), has been well conducted. On the other hand, for imperfect information games, topics on how to entertain human players or content generation were less explored. However, for decision-making in real-world problems, people are not always provided with perfect information. Thus, it is expected that the research in imperfect information games can bring useful insights into solving real-world problems.

Geister is a two-player zero-sum deterministic imperfect information board game. At the beginning of a game, both players own the same sets of eight pieces, which contain four pieces of two types. Different types are labeled by different colors. One notable feature of the game is that players cannot observe the opponents' piece colors. Thus, players need to infer piece colors from past actions. For beginners of the game, inferring opponents' piece colors and misleading opponents about their piece colors are difficult skills to learn. Besides, it also happens that beginners miss the chances to win games where they could. From these aspects, we considered that it is necessary to provide players with environments that can assist them in improving playing skills. As tsume-shogi is to shogi, we thought that it is also possible to generate puzzles for Geister, which gives consideration to both entertainment and real plays. Considering that missing chances to win is one of the most important problems to overcome, we focused on endgame puzzles. Still, some other types of puzzles may also benefit beginners, such as "inferring the opponents' piece colors" and "indicating the best actions."

This research aimed to "propose Geister endgame puzzles" and "investigate how to generate interesting Geister endgame puzzles of proper difficulty quickly." First, we need to survey research in game content generation, particularly that related to endgame puzzles, and then define Geister endgame puzzles. Also, the difficulty and interestingness of the generated puzzles should vary. To train players, interesting puzzles or those whose difficulty is proper to the target players should be provided. Thus, we also need to investigate features that can represent the interestingness and the difficulty of puzzles.

In this research, we proposed Geister endgame puzzles and generated interesting puzzles. First of all, we defined two kinds of Geister endgame puzzles. “Normal version” followed the same rule as the original Geister about the observation of opponents’ piece colors, i.e., players cannot observe opponents’ piece colors. “Partially-informed version” differed in that the players are informed of part of the opponents’ piece colors. We expected the strategies for playing the two versions to be different. Since players can usually infer some of the opponents’ piece colors near endgames, we considered the partially-informed version to be closer to real plays.

With regard to generating various puzzles efficiently, we tried two algorithms, random method and reverse method. The former randomly placed given numbers of both players’ pieces on the board, while the later backtracked legal actions from existing puzzles. We analyzed each generated puzzle by the time cost and the length of the longest winning path. For simplicity of discussions, “game length” refers to the length of the longest winning path of a puzzle in the rest of this Abstract. Experiments on the random method showed that the numbers of generated puzzles decreased drastically as the game lengths increased. In more detail, we collected puzzles whose game lengths were between 9 and 19. The number of puzzles with game lengths of 19 was less than 0.1% of all collected puzzles. Besides, the experiments demonstrated that the generation time for one puzzle increased considerably as the numbers of pieces increased. For example, when both players had one piece of each color (i.e., each player had two pieces), generating one puzzle cost 2.7 seconds on average. The time became 1,299 seconds per puzzle when both players had three pieces of each color.

By applying the reverse method, we generated new puzzles from existing ones. The results showed that the probability of generating a new puzzle from an existing one was higher than 50%. Especially, we succeeded in generating puzzles with game lengths of 21 from those of 19, while the random method failed to generate any. Moreover, the generation time was about 60 times faster than that of the random method. We concluded that the reverse method could generate Geister endgame puzzles more efficiently than the random method, especially puzzles whose game lengths are long.

As the next step, we conducted a subject experiment to investigate how human players feel about difficulty and interestingness for Geister endgame puzzles. We prepared a variety of puzzles and asked human subjects to solve these puzzles and then rate the interestingness and the difficulty in five-grade evaluation (-2, -1, 0, 1, and 2). From the results, the correlation coefficient between the average values of the interestingness and the difficulty was 0.63, which showed a moderately positive correlation. We also found that puzzles too difficult made players feel less interesting. Based on the evaluations from humans, we applied supervised learning to predict the interestingness and the difficulty of Geister endgame puzzles. The root-mean-square errors of interestingness and difficulty were 0.52 and 0.64, respectively, which showed that rough predictions could be made. We also analyzed crucial factors in predicting interestingness and difficulty, respectively. More specifically, interestingness was strongly influenced by the numbers of opponent's pieces to capture during the solving process and the numbers of pieces that the player should move. We suspected because puzzles involving capturing opponents' pieces were more attractive to players than those just to win by moving their pieces to "exits."As for difficulty, the maximum proof numbers at root nodes of depth-first proof-number (df-pn) search greatly influenced. Df-pn was used to prove whether a player can win from a given board, and the proof number of a node represents the number of leaf nodes to be examined. We considered that it was natural that players felt difficult for puzzles with high proof numbers at the root nodes.

To sum up, this research proposed endgame puzzles for Geister, an imperfect information game. We then applied the random method and the reverse method to generate puzzles, where the later was much more efficient. Furthermore, predictions on human players' ratings on difficulty and interestingness of Geister endgame puzzles were reasonably accurate. Based on the results, we thought that it would be able to generate puzzles of some designate difficulty or interestingness easily. Unlimited to Geister, we expected this research to contribute to the whole game society since Geister shares some general properties with other games.