Abstract

Artificial intelligence technology (AI technology, AI) has made remarkable progress, and various types of AI have been used in various aspects of our lives. An example is the game field, which has often been used as a good target for AI research because of its clear rules, relatively easy evaluation, and deep involvement with human intellectual curiosity and abilities. For decades, the major goal of game research has been to create AI players that are stronger than humans. With the advent of AlphaZero and the Deep Q-Network, this goal has been achieved in many games.

With such achievements, there has been an increasing need for AI that entertains or teaches human players in recent years. For example, AI players that behave naturally may cause less discomfort to human players and can increase the immersion of the games. Also, AI teachers can help human players improve by providing instructions at a level appropriate to the player. In addition to AI players or teachers, automatic content generation is also needed to create game levels or puzzles that are fun to play and provide practice. Such automatic content generation, like AI players/teachers, will allow human players to enjoy the games and improve their skills.

Furthermore, some content has an aspect that can be considered a kind of art. For example, tsume-shogi (shogi mating problem) is a kind of puzzle using the rules of shogi for one player to play, which enables players to improve their skills while enjoying the game. Many of the puzzles are loved as *works of art* because of various aspects, such as the "beauty of the arrangement on the board," the "beauty of the checkmate state," or the "unique trajectory of the pieces."

In this study, we target *Puyo puzzles*, a single-player version of a famous two-player falling object puzzle game called Puyo Puyo, aiming to create artistic Puyo puzzles. For a Puyo puzzle, the player is given a board and a sequence of *next Puyos* (i.e., the coming Puyos that will fall down) and is asked to find a way to place the next Puyos to satisfy a clear condition such as "completing 3-chain in 2 moves" or "erasing all Puyos in 3 moves." Elements of real-time and randomness in the original Puyo Puyo are removed in Puyo puzzles. Therefore, players can solve these puzzles slowly and thoughtfully, which not only makes the players enjoy but is also expected to help the players improve their chain-making skills.

Takahashi et al. and Makita et al. conducted research on automatic generation of Puyo puzzles. They also attempted to filter the generated puzzles using estimation models of interestingness and difficulty trained by supervised learning. Such a mechanism enables the extraction of interesting and difficult puzzles.

In this study, we aimed to proceed further in this direction and create artistic Puyo puzzles.

First, we solved 30 Puyo puzzles at levels that can be said to be art in order to investigate the factors of artistic puzzles. As a result, we extracted the following five factors: "the connections are difficult to understand," "simultaneous erasing is likely to happen," "the order of the chains is different from what can be imagined on the initial board," "the Puyos are connected in a way different from that on the initial board," and "chains with the same color happen in a row." We also confirmed that, in many cases, it is necessary to utilize *Ojama Puyos* (also called Garbage Puyos, Nuisance Puyos, and Hindrance Puyos) to satisfy the factors of artistic puzzles.

Next, we proposed methods for generating artistic Puyo puzzles. The methods involved generating Ojama Puyos, changing Puyo colors, and filtering for extracting Puyo puzzles of particular factors. Changing Puyo colors is necessary for two of the five factors: "the Puyos are connected in a way different from that on the initial board," and "chains with the same color happen in a row." This is because these two factors of artistic puzzles require chains of the same color to happen twice, but existing methods could not generate such puzzles since those methods only generated puzzles whose chains are all of different colors. In addition, we implemented the filters for the two factors. For puzzles that "the Puyos are connected in a way different from that on the initial board," we stored for each Puyo on the board the order of its chain taking place and then checked whether connected Puyos on the board were erased in separate chains. Similarly, for puzzles that "chains with the same color happen in a row," we stored for each Puyo on the board the order of its chain taking place and then checked whether chains with the same color happen in the solutions.

Finally, we conducted subjective evaluations on the Puyo puzzles generated using the proposed methods. As a result, we confirmed that the proposed methods were able to generate artistic Puyo puzzles with high frequency. However, the process of generating puzzles took too much time because many puzzles were rejected through the filters. The methods of generating puzzles need to be improved in terms of how to insert Ojama Puyos and normal-colored Puyos.