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BBFS-STT: An efficient algorithm for number rotation puzzle ☆

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ABSTRACT

This paper introduces a quite novel intellectual game, number rotation puzzle (NRP), and deeply compares NRP with 8-puzzle. It comprehensively discusses some issues relevant to solving NRP, such as state representation, state duplicate detection, transition relation between states, solvability judging, and optimal solution. Upon these work, this paper proposes a solving algorithm based on bidirectional breadth-first search (BBFS) and states transition table, which is called BBFS-STT. It takes full advantage of transition relation between states, as well as advantages of BBFS. BBFS-STT achieves high time efficiency and well stability. In addition, this paper designs a game application of NRP, whose prominent feature is that users can seamlessly switch between automatically solving and manually solving modes. Finally, this article carries out experimental analysis on the proposed algorithm, as well as comparison with some search algorithms, i.e., depth-limited DFS, traditional BFS, and A*. Experimental results show that the proposed BBFS-STT outperforms these three search algorithms. The average time required for solving an instance of NRP is only 0.80592 ms when the test environment is configured as: Apple A6, 1.00 GHz; 1 GB memory. BBFS-STT meets the requirements of real-time solving and demonstration for NRP.

1. Introduction

Along with popularity of mobile products, a growing number of games run on these devices, such as feature phone, smart phone, PDA, tablet computer, portable media player. Picture puzzle (e.g., [1]), Beadz Puzzle (e.g., [2]), maze, 8-puzzle (e.g., [3–10]), knapsack (e.g., [11]), tower puzzle (e.g., [12,13]), Geocast Game (e.g., [14]), etc. are usually seen in mobile phones. These puzzles are also classic problems in such fields as theory of algorithms, artificial intelligence. Automatically solving these problems usually involves state representation, state duplicate detection, solvability judging, design of search algorithm, optimal solution, etc.

Number rotation puzzle (NRP) is a novel intellectual problem. In the early 2000s, NRP first appeared in some series mobile phones. In the literature, there are rare researches so far addressing NRP and its solution due to its novelty. This paper comparatively analyzes NRP and 8-puzzle, as well as proposes a novel and efficient algorithm for solving NRP based on the integration of bidirectional breadth-first search (BBFS) and states transition table, which is called BBFS-STT.

The main contributions of this paper are: (i) introducing a novel intellectual game, NRP, which is rarely addressed in the literature so far; (ii) presenting a novel and efficient solving algorithm, BBFS-STT, which provides a good reference for solving other intellectual games; and (iii) developing a game application of NRP, whose prominent feature is that users can seamlessly switch between automatically solving and manually solving modes.

The remainder of this paper is organized as follows. Section 2 introduces NRP and 8-puzzle, and comparatively analyzes these two puzzles. Section 3 summarizes research work. Section 4 discusses some issues relevant to solving NRP. Section 5 describes the construction of states transition table, presents the design and implementation of BBFS-STT in detail as well. Section 6 carries out experiments on BBFS-STT, and compares it with other search algorithms. Section 7 gives conclusions.

2. Number rotation puzzle and 8-puzzle

2.1. Number rotation puzzle

Number rotation puzzle, also known as *quick rotation*, is a novel intellectual problem. It is newly seen in mobile phones.

Fig. 1 describes an instance of NRP. An initial state of this problem is shown in Fig. 1(a), wherein numbers 1–9 are randomly arranged in a frame consisting of 3×3 square tiles. There are four 2×2 size sub-frames, which are upper-left, upper-right, lower-left, and lower-right corners. By clockwise rotating a 2×2 size sub-frame, the positions of four numbers in this sub-frame are

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1875-9521/

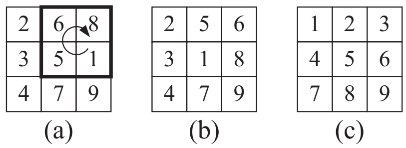

Fig. 1. An instance of NRP. (a) An initial state; (b) the obtained state after rotating the upper-right corner of the initial state; (c) the target state.

rotated 90° clockwise. For example, after rotating the upper-right corner of the initial state, the obtained state is shown in Fig. 1(b). The goal of NRP is to reach the target state shown in Fig. 1(c), through a series of rotating operations.

Note that, the rule of NRP is clockwise rotating sub-frames. However, introducing an anticlockwise rotating rule into this game does not reduce the difficulty of NRP. The reason is that anticlockwise rotating a sub-frame three times equals to clockwise rotating it once.

NRP can be solved by simple blind search algorithms (e.g., BFS, DFS), heuristic search algorithms (e.g., A* search algorithm), and other intelligent algorithms (e.g., genetic algorithms). But as a mobile game, a more efficient algorithm is needed. This paper proposes a theoretically most optimal algorithm, BBFS-STT.

2.2. 8-Puzzle

NRP is somewhat similar to another classic intellectual problem, sliding puzzle. Fig. 2 describes a 3×3 size sliding puzzle, which is also called 8-puzzle. An initial state of this problem is shown in Fig. 2(a), wherein numbers 1–8 are randomly arranged in a frame consisting of 3×3 square tiles. The remaining empty position is called the blank tile. The basic operations of 8-puzzle is moving the blank tile toward 4 directions, that is, up, down, left, and right. Actually, when the blank tile is moved, a corresponding numbered square tile is moved toward the opposite direction. Ultimately, the target state shown in Fig. 2(c) is reached through a series of basic operations.

8-Puzzle is a classic and ancient problem widely discussed in such fields as theory of algorithms, artificial intelligence. Therefore, 8-puzzle is fully studied in the literature (e.g., [3–10]).

2.3. Comparative analysis of NRP and 8-puzzle

NRP and 8-puzzle are similar in several aspects. For example, in both puzzles, there are only four kinds of basic operations, which are rotating four 2×2 size sub-frames or moving the blank tile toward four directions.

However, these two problems also have many different aspects as follows:

(1) There is a blank tile in 8-puzzle, while each position in NRP is occupied by a number.
(2) The basic four operations of 8-puzzle are moving the blank tile toward four directions, but not all of the four basic operations are available for all the states because of the presence of the borders. For NRP, the four basic operations are rotating four 2×2 size sub-frames. Moreover, all of the four basic operations are available for all the states.

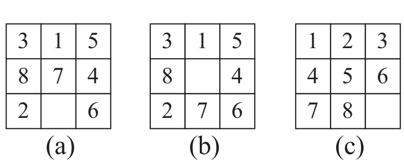

Fig. 2. An instance of 8-puzzle. (a) An initial state; (b) the obtained state after moving the blank tile upward; (c) the target state.

(3) Solving 8-puzzle manually is relatively easy. However, solving NRP manually is very hard. No effective manual solving strategy is reported so far. Therefore, automatically solving can provide useful cues for users.

In addition, these two puzzles are different in other aspects, such as solvability/insolvability of initial states, minimum steps of solutions. These aspects will be discussed in the following sections.

3. Related work

This section summarizes research work related to mobile games and search algorithms.

3.1. Mobile games and technologies

Along with development and popularity of consumer electronics products, pervasive gaming (PG) becomes a trend. Walther [16] describes and analyzes the formalisms of pervasive games and pervasive gaming. He proposes a general definition of pervasive gaming.

The field of pervasive gaming is diverse in the approaches and technologies used to create new and exciting gaming experiences that profit by the blend of real and virtual game elements [17]. Magerkurth et al. [17] survey the field of pervasive gaming. They discuss sub-genres of pervasive gaming in terms of their benefits and critical issues, as well as the relevant technology base.

In the literature, there are many researches addressing games in mobile phones. Mahamad et al. [1] present a Mobile Picture Puzzle with personalized capability which allows the player to use built-in camera to capture an image and use the newly captured image to create a picture puzzle.

Based on original Beadz puzzle games, Cho et al. [2] present a modified Beadz puzzle on mobile by adding layers of levels, a time limit, and life system.

Carvalho et al. [15] design the Multimodal Puzzle Game for the Android platform. This puzzle game allows users to solve puzzles across different modalities, including visual, audio and vibrating modalities. They also study puzzle solving strategies across different interaction modalities.

Except for the above games, some researches address other novel or classic games, such as 8-puzzle (e.g., [3–10]), knapsack (e.g., [11]), tower puzzles including tower of Hanoi (e.g., [12,13]) and Tower of London (e.g., [13]), Geocast Game (e.g., [14]). Introducing these games into mobiles enriches entertainments for users.

Most of the aforementioned mobile games (e.g., [1,2,15]) do not include automatic solving functions. While the mobile game application of NRP developed in this paper not only includes automatically solving and manually solving modes, but can seamlessly switches between these two solving modes.

Technologies relevant to mobile games include user interface, artificial intelligence, pattern recognition, simulation, multimedia, augmented virtual reality, social networking, electronics, sensors, storage, advanced software architectures, graphics tools.

Except for traditional means of user input, real time face detection combined with eye-gaze tracking provides a novel means of user input into a gaming environment. Corcoran et al. [18] present an advanced real-time eye & gaze-tracking algorithm, which has a wide range of potential applications in gaming systems and CE device applications.

Korhonen and Koivisto [19] introduce playability heuristics which are specifically designed for evaluating mobile games. These heuristics form a core model, which consists of three modules: