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Research article

Puzzle-Mopsi: A location-puzzle game

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Abstract: This paper presents a new class of games: location puzzle games. It combines puzzle games with the use of the geographical location. The game class is closely related to location-based games except that no physical movement in the real world is needed as in most mobile location-based games. For example, we present a game called Puzzle-Mopsi, which asks users to match a given set of images with the locations shown on the map. In addition to local knowledge, the game requires logical skills as the number of possible matches grows exponentially with the number of images. Small-scale experiments show that the players found the game interesting and that the difficulty increases with the number of targets and decreases with the player's familiarity with the area.

Keywords: games; LBG; location-based games; location puzzle games; Mopsi

1. Introduction

Location-based games (LBG) combine the player's physical movement with the gaming. Examples include *Pokémon Go* [1], *Geocaching* [2] and *Ingress* [3]. These games allow people to interact with the real world in an engaging way [4]. Location-based games have been used for campus exploration in the *Gilmorehill mystery* [5] and for educational purposes in *Skattjakt* [6], where players solve a mystery surrounding a castle on the campus. *TidyCity* [7] is a treasure hunting game where players solve location-based riddles during city exploration.

Another popular class of games are *puzzle* games. Examples include *Sudoku* [8], *Minesweeper* [9], and *Mastermind* [10]. The commonality of these games is that there is an exponential number of possible combinations to find the solution. These puzzles are usually NP-hard problems that cannot be solved by a computer within a reasonable time on a large scale. However, small-scale problem instances are good puzzles for humans to solve [11].

O-Mopsi [11] is a location-based treasure hunt game where the goal is to find a set of locations (called targets) in the real world. The players can freely choose the order of visiting the targets. This freedom makes the game seemingly an easy orienteering task. However, finding the shortest tour is an NP-hard problem known as the *travelling salesperson problem* [12]. If the players must solve the best order of visiting the targets, then O-Mopsi would also be a puzzle game.

This paper introduces a new class called *location-puzzle games* (LPG). It is closely related to location-based games via the use of location as the central component of the game. However, we do not require the user to physically move in the real world since the puzzles can be solved anywhere. These games may lack the health aspect that location-based games have by forcing players to exercise. Instead, the games focus on other qualities, such as education, local knowledge, and puzzle solving.

There definition for location-based games varies. The most general definition is that a game is location-based if it involves location aspect in one way or another regardless of whether the player's current location is utilized or not. *Mobile location-based games* have a stricter requirement and explicitly state that player's location is used in the game play. However, it is common implicit assumption that LBGs also utilize player's location. For this reason, we call the new class location-puzzle games, instead of location-based puzzle games as the player's location is not utilized.

The paper's second contribution is a new game called *Puzzle-Mopsi*, an example of a location-puzzle game. The player receives a set of images and an equal number of locations on a map. The task is to move all these images into their correct locations. The game is solved when they are all in their correct places. When all images are positioned at the available locations, the game provides feedback to either congratulate the user for solving the puzzle or to show how many images are incorrectly placed, see Figure 1.

The game includes the treasure hunt motivation of O-Mopsi but replaces the navigational problem by a matching problem. This change emphasizes more the local knowledge of the places instead of route planning and navigational skills. In the rest of the paper, we describe the game rules, show a few example game scenarios, and discuss their playability and technical aspects of the implementation. We administered a small-scale survey to provide feedback about the idea and how the players perceived different game scenarios. We also discuss practical limitations.

Figure 1. Puzzle-Mopsi is a location-puzzle game where the task is to move all images into their correct locations on the map.

2. Puzzle games

It is not obvious what is the difference between a game and a puzzle [13]. One typical characteristic is that single players solve puzzles, whereas games emphasize these interactions between the players [14]. However, puzzles can also be multi-player, where players team up to solve the same puzzle, or their puzzles can interact with others. Players can also collaborate or compete against each other, as in the case of *Tetris Link* [15].

A puzzle characteristically has a solution to be found. It can be a specific configuration of the pieces or a goal reached by a sequence of moves. In general, a good puzzle requires that the players be motivated to find the solution, and it has some challenges to keep up their interest.

Some of the oldest puzzles ever existed are *puzzle locks* in ancient China [16]. They had a trick mechanism to open (with or without a key), and then they developed into a puzzle toy called *Luban lock*. A much newer invention is *Rubik's Cube* [17], which has fascinated people since its invention in 1974. Rubik's Cube has over 43×10^{18} combinations of arrangements, but only one is correct. Interestingly, this solution can always be found by at most 20 moves, but the best solvers in the world can do it in about three seconds [18].

The jigsaw puzzle game is one of the most popular puzzle games out there. Many people see the concept *puzzle game* and automatically associate it with a jigsaw puzzle game [19]. While the task is to find the correct order of the pieces, jigsaws typically have pictures on them, which make the task more about visually matching the neighboring pieces rather than finding the correct combination. Number jigsaws also exist for math education purposes [20].

Sudoku is currently the most famous number puzzle game [20]. The game is played on a 9×9 square where each row, column, and nine independent nine-square grids must be filled with the numbers from 1 to 9 so that every number appears only once. The puzzle is a partially pre-filled matrix, so the given numbers serve as hints for the players to fill in the rest of the matrix. Sudoku is also an NP-hard problem, so it is suitable for a puzzle game [21].

A marble puzzle is solved by finding a move sequence that removes all the marbles except the last one. *Escape Room* is a puzzle game that involves several independent puzzles to be solved. Some puzzles may be solved in a sequence, and some require the cooperation of the players. There is also a storyline in the game. The first Escape room, *Crimson Room*, was created by Toshimitsu Takagi in 2004 [22]. Figure 2 shows examples of well-known puzzle games.

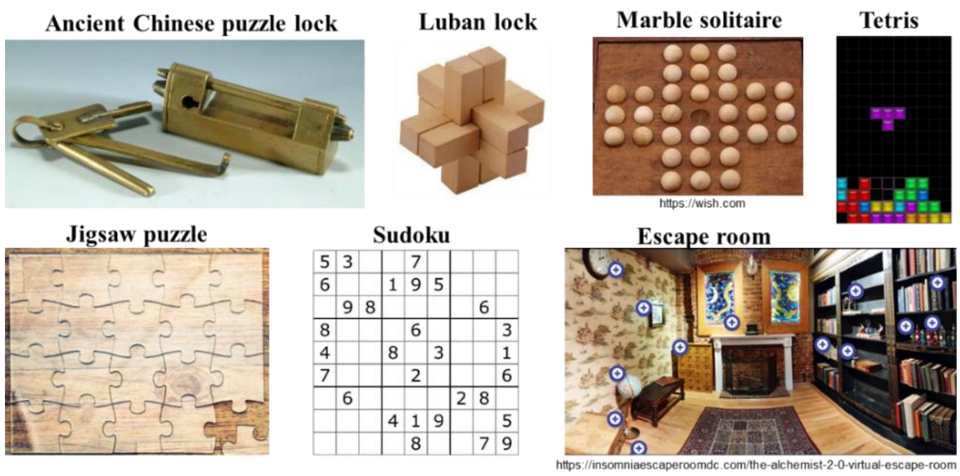

Figure 2. Examples of puzzle games.

3. Location-based games

Location-based games (LBGs) introduce physical location into the gameplay, usually via real-time positioning techniques [23]. These games use digital maps such as Google Maps and Open Street Maps and guide players through these maps to experience various activities [4]. *Geocaching* [2] is the oldest and still popular location-based game. The cache owner hides the geocache and records its location with GPS. The goal is then to find the cache and add a written entry into the log found inside it. Some caches may involve additional tasks or trading of the items.

Since then, many LBGs have been published, but only very few remained popular after Geocaching was invented more than 20 years ago. Early games faced technical issues, such as the accuracy and stability of the GPS signal, internet connection, and short battery life [11]. With the advancement of smartphones and positioning technology, many limitations have disappeared, and intriguing games such as *Pokémon GO* and *Ingress* have emerged. Current concerns are privacy [24], safety [25], and the contribution to distracted driving [26].

Most of the earliest location-based games lacked creativity since the players only wandered around, possibly involving story-telling or questions/answers sessions to educate about the targets [11]. Augmented reality is added in games like Pokémon GO to enhance the playing experience [27], while traditional treasure hunt games like Geocaching merely focus on visiting locations and completing tasks. According to Söbke [28], the three main benefits of Ingress gameplay are socializing, outdoor activities, and exploring the environment. Laato et al. [29] reported that games like Pokémon GO support navigation (cartography exercise), social interaction, and exercise.

A treasure hunt game must somehow verify that the player has visited the targets. O-Mopsi performs this verification automatically by determining a visit whenever the player appears within 20m distance from a target. QR codes are used in virtual orienteering games like *MOBO*[1] in Finland and *Stolpejakt*[2] (pole hunt) in Norway, as well as *Museum scrabble* in Greece [30]. However, it requires physical installations on the game sites, which takes more effort. Capturing a photo of the target is a common technique, but it requires either manual verification [28,29] or the development of automatic image matching, as in *Snap2Play* [33].

Location-based games can also have educational benefits. Learning gain can be achieved by moving the teaching outdoors [34], but being out of the classroom is not enough, and good content is still required [35]. Many topic-specific location-based games have also invented. O'Munaciedd [36] educates the history of the city of Matera in Italy. The Heraklion Fortification Gates [37] studies the history of the Venetian walls in Heraklion, Greece. The authors emphasized that both the content and the game concept must be interesting to motivate players and that content creation requires a specialist.

O-Mopsi is a mobile orienteering game where the targets are real locations, such as landmarks and other points of interest. It was introduced in 2010 during the SciFest Annual Science festival [38], where school kids played the game using Nokia Symbian phones [39]. Its main advantage is that the game scenarios with virtual targets are easy to establish as long as geotagged photos are available from the playing area. The enjoyment comes from the exploration and navigational challenges but

[1] http://mobo.suunnistus.fi/

[2] https://www.stolpejakten.no/

solving the order of the targets are visited poses an additional challenge. While most players just rushed to the nearest unvisited target, careful planning can save time, see Figure 3. Even the start point of the game playing matters [40]. Can you solve the order in Figure 4?

Figure 3. O-Mopsi requires the player to visit all targets. The best tour involves solving the open-loop traveling salesperson problem, in which the choice of the start point also matters.

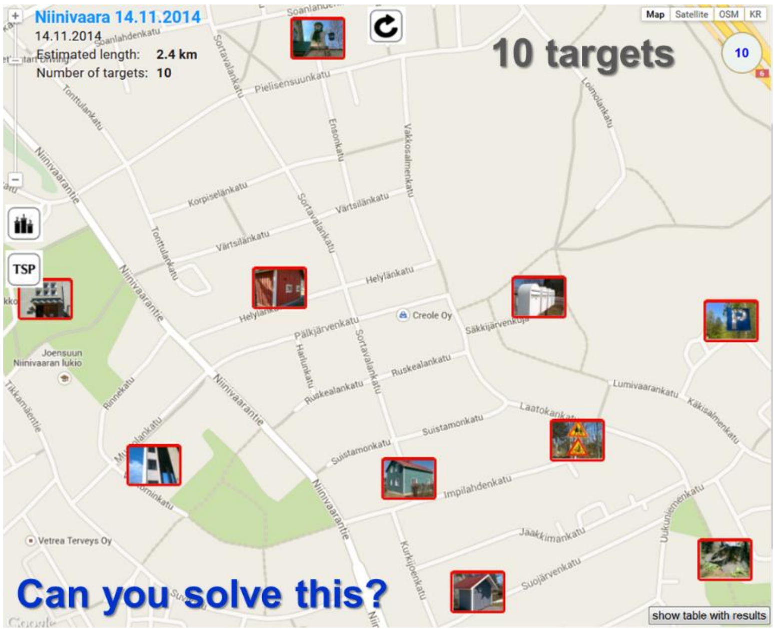

Figure 4. Simple O-Mopsi game of only ten targets. There are 10! = 3.6 million possible orderings. Can you find the shortest tour using Bird (Euclidean) distance?

4. Puzzle-Mopsi: a location-puzzle game

The game consists of a set of images taken in selected locations. It provides these images and their locations separately, and the player's task is to determine which image is from which place. The player can use any strategy to solve the puzzle. The gameplay happens on a computer screen consisting of two parts: the list of images and a map with equally many open slots where they may be moved by drag-and-drop. A game called *GeoGuesser* is similar to Puzzle-Mopsi in that the player must match a given picture to its location. The difference is that in GeoGuesser the player must pinpoint the exact location of a single picture, and then process the set of pictures one-by-one. Puzzle-Mopsi shows candidate locations and asks to solve all the target locations at the same time.

Once the player has filled all the locations, the game will provide feedback to the player how many images were in wrong place. However, it does not inform which images are the wrong ones. The game is solved when all pictures are in their correct locations. A demonstration of the progress of the gameplay appears in Figure 5.

In computer science, the problem seemingly relates to bipartite matching problem which is an optimization problem that tries to maximize the weights between the paired items. However, Puzzle-Mopsi is more like a classification problem where the image provides visual hints but only Oracle knows the correct solution (ground truth).

In Puzzle-Mopsi, there is an exponential number of combinations to be tested and no shortcuts in finding the correct one other than trying them all. The feedback provided to the player can significantly reduce the search space. For example, the player can systematically swap images and see the effect on the number of incorrect images. If the number increases by +2, both swapped images were in correct place, and if by +1, one was in correct place. Despite of this, the game is still likely to be an NP-hard problem; similarly as *Mastermind* was shown in [41].

The player must use his local knowledge and less guessing. Some players might use the satellite view of Google Maps to provide hints such as, "are there buildings at the location?" and then try images taken of a building. Nothing prevents the player from making it a real location-based game and going to the actual places himself, while lazier players might use Google Map Street View (if available). When all images are in the available locations, the game provides feedback either to congratulate the user for solving the puzzle or tell him how many images are incorrectly placed, see Figure 1. The details of the game implementation appear in [42].

Puzzle-Mopsi has the same exploration motive as O-Mopsi and other treasure hunt games but replaces the navigational problem by a matching problem. This makes it a puzzle game. It also relies more on the knowledge of the places instead of the route planning and navigational skills. The game is a combination of the matching (requires location knowledge) and puzzle solving (requires logical thinking). Both aspects are included. The more the player knows about the location, the less puzzle solving is required. If it was just one of them, the game would become just a standard location-based game (in its wider definition), or a puzzle game (without any need of location knowledge).

One known limitation of the game is the need for data to create new location puzzles. We have used the O-Mopsi database, which has plenty of geotagged photos in Joensuu. But to make the game playable anywhere, we need to have much more material, which is an existing challenge. Using open sources such as open street maps (OSM) and Flickr was studied in [43], but the results were discouraging. Figure 6 shows two areas in Joensuu where the O-Mopsi database has enough content, but OSM and Flickr do not. In O-Mopsi, one prefers to have landmarks and other interesting objects, but in Puzzle-Mopsi, random views from Google Maps Street View might be enough. This difference is because the game tests the player's geographical knowledge without the need to visit the places.

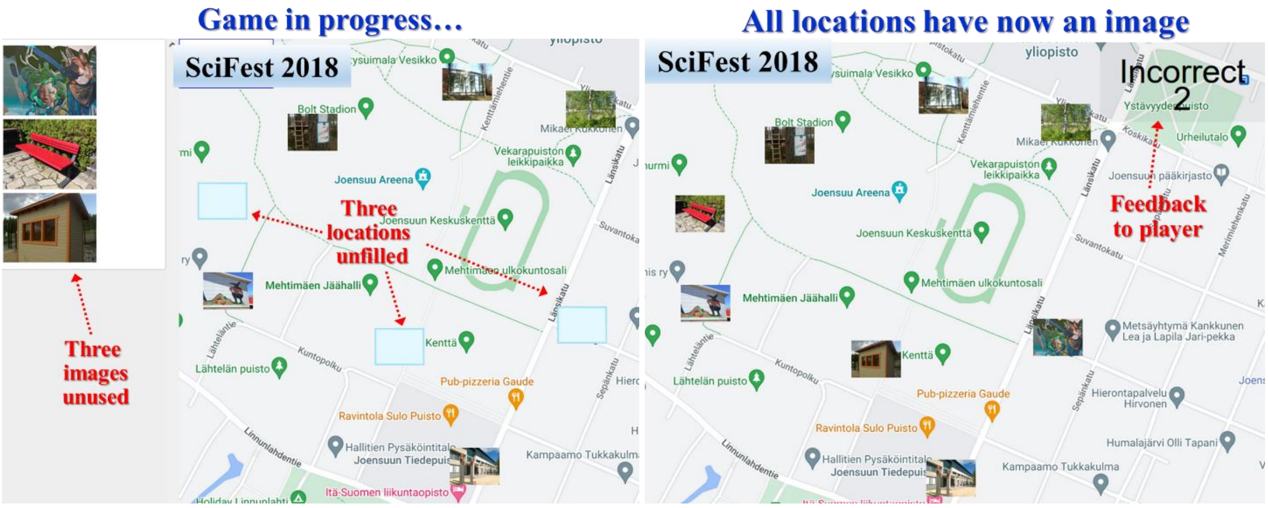

Figure 5. Example of the process of the game. The images can be dragged from the list on the left to the location slots (light blue box) and back and from one location to another. Once all slots contain an image, the game will provide feedback by congratulating the player for solving the puzzle or informing him about how many pictures are in the wrong place.

Figure 6. Material for the Puzzle-Mopsi can be limited. Two locations in Joensuu (Penttilä and Marjala) have enough data in the Mopsi database, but sources such as OSM and Flickr, are lacking.

4. Experiments

We made a brief experimental study of the selected game scenarios. We invited current and previous group members to play five selected games and report how they perceived them. We also recorded their playing time and the number of moves needed to solve a game. We also asked the players to grade the difficulty of each game on a scale from 1 (very easy) to 5 (very difficult) and express their general feelings about the gameplay. Eight members participated the experiments.

We selected five games from the O-Mopsi database[3] in Figure 7. Four are in Joensuu (three used in SciFest, one used downtown), and one in Helsinki. The local knowledge of the participants was rather similar and many of them (but not all) were familiar with location-based games via O-Mopsi. The participants had most knowledge of the SciFest games as they all near the campus and our department. The one with the least knowledge is the game in Helsinki. The other parameters used to describe the difficulty of the games are the number of targets, which vary from 5 to 14, and the difficulty as a TSP instance [44].

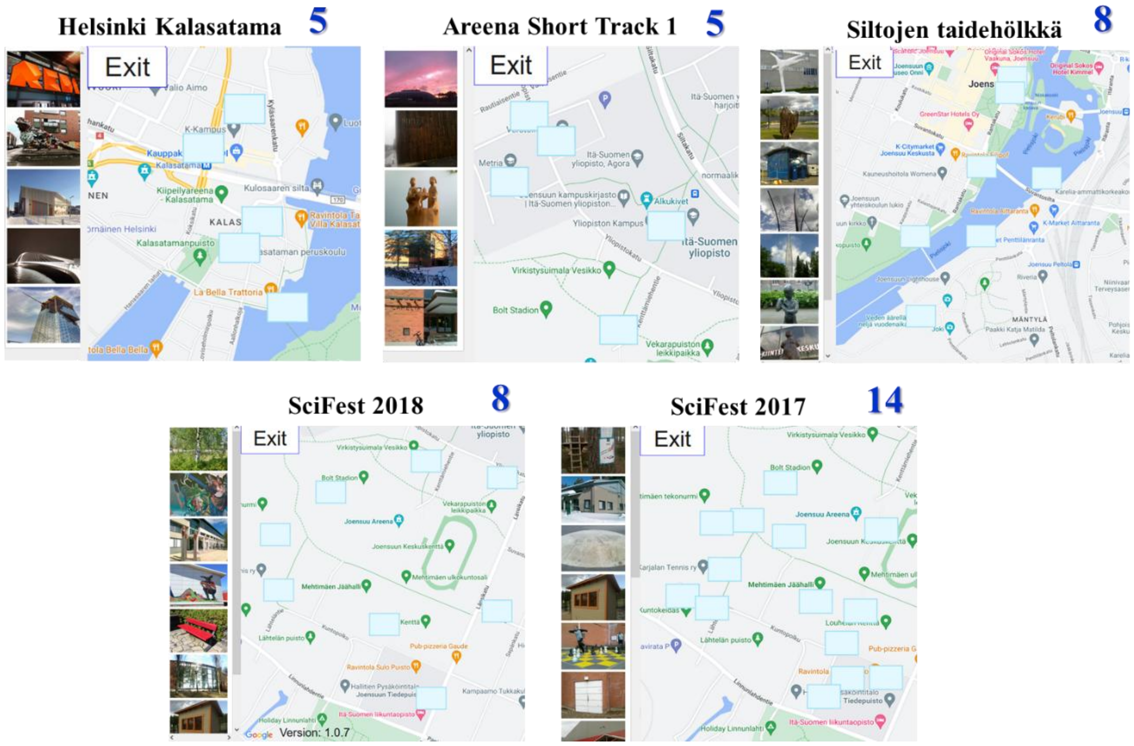

Figure 7. Selected five games for the experiments. Three games were located around the Joensuu Areena (the venue of the annual SciFest event), neighboring our campus. *Siltojen taidehölkkä* (Art job of the bridges) was further downtown, and *Helsinki Kalasatama* was in a different city and, therefore, less familiar to the participants.

Table 1 summarizes the game's statistics and results. First, we observe a clear correlation between the game properties and the playing time (Pearson = 0.62). The more targets the game has, the longer it takes to solve, on average. *Helsinki Kalasatama* was the only exception due to the players' lack of local knowledge of the game area. Even if the game had only five targets, the players

[3] Puzzle-Mopsi can use the same content created for O-Mopsi.

considered it more difficult (score 2.75) than the games in Joensuu with eight targets (scores 2.50 and 2.38). Figure 8 shows all the game results (time taken) regarding the difficulty level, as reported by the players.

Local knowledge depends on how far the game is from the School of Computing in Joensuu Science Park). MST branches refer to the difficulty of the problem as a TSP instance, according to [44]. The term “difficulty” refers to players’ opinions (on average) using the scale 1 = very easy, 2 = easy, 3 = normal, 4 = difficult, 5 = very difficult. Time and moves are the average time and moves required by the player to find the solution.

Most players liked the games the most at places they were familiar with and the least at areas they had never visited. They preferred games with fewer targets. There was one exception, though, a player who liked games with more targets and in unknown areas. The player employed some detective work, such as looking at satellite images and using multiple map service providers. Most reported issues related to deficiencies in the game interface, but the quality and accuracy of two targets were also minor issues.

Table 1. Summary of the games and their properties.
Local knowledge of the player is coded as: neighborhood (***), same city (**), and different city (*)

Game			Properties		Results		
Name	Year	Local knowledge	Targets	MST branches	Difficulty	Time (min)	Moves
Helsinki Kalasatama	2019	*	5	0	2.75	3:04	13.00
Areena Short Track 1	2011	***	5	1	1.50	1:13	7.25
Siltojen taidehölkkä	2015	**	8	1	2.50	4:51	24.50
SciFest 2018	2018	***	8	0	2.38	2:20	17.75
SciFest 2017	2017	***	14	3	3.25	6:50	67.75

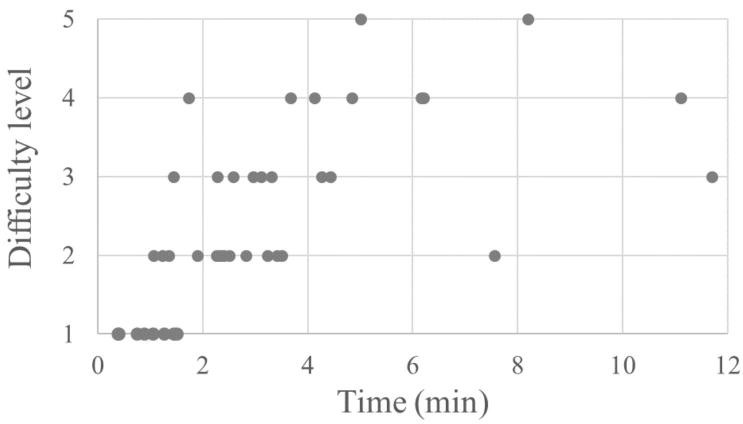

Figure 8. The difficulty of the games (as reported by the players) versus the time to solve the game. Difficulty was evaluated on the scale 1 = very easy, 2 = easy, 3 = normal, 4 = hard, 5 = very hard. There is a clear correlation (0.64) between the two variables.

5. Conclusions

We have introduced a new class of games called location puzzles. Puzzle-Mopsi was one such game. It is inspired by a treasure hunt game called O-Mopsi but does not require physical movement. Instead, the game tests the player's logical skills in addition to his local knowledge of the game areas. The more player has the knowledge, the less it requires puzzle solving skills, and vice versa. Experiments showed that the two features that most affected the difficulty of the game instance were the number of targets and how familiar player were with the location.

Conflict of interest

All authors declare that there is no conflict of interests in this paper.

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