O-Mopsi: Mobile Orienteering Game for Sightseeing, Exercising, and Education

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Location-based games have been around already since 2000 but only recently when PokemonGo came to markets it became clear that they can reach wide popularity. In this article, we perform a literature-based analytical study of what kind of issues location-based game design faces, and how they can be solved. We study how to use and verify the location, the role of the games as exergames, use in education, and study technical and safety issues. As a case study, we present O-Mopsi game that combines physical activity with problem solving. It includes three challenges: (1) navigating to the next target, (2) deciding the order of targets, (3) physical movement. All of them are unavoidable and relevant. For guiding the players, we use three types of multimedia: images (targets and maps), sound (user guidance), and GPS (for positioning). We discuss motivational aspects, analysis of the playing, and content creation. The quality of experiences is reported based on playing in SciFest Science festivals during 2011–2016.

CCS Concepts: • **Information systems** → **Location based services**; *Multimedia content creation*; • **Software and its engineering** → **Interactive games**; • **Human-centered computing** → *Empirical studies in ubiquitous and mobile computing*; • **Mathematics of computing** → Combinatorial optimization;

Additional Key Words and Phrases: GPS, location, orienteering, target finding, competition

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1 INTRODUCTION

O-Mopsi orienteering (O-Mopsi: http://cs.uef.fi/o-mopsi) is an orienteering game played in an outdoor environment. The goal is to find a number of real-world targets using a smartphone with GPS-guided navigation. To complete a game scenario (later referred to just as "a game"), the player needs to visit all targets. Player location and all unvisited targets are shown on a map in the device. The name and picture of each target are available to the player, as well as the distance to the nearest target.

Reaching a target is automatically detected using GPS. The target is successfully reached when the distance becomes less than 20 meters—a threshold found suitable for the accuracy of typical

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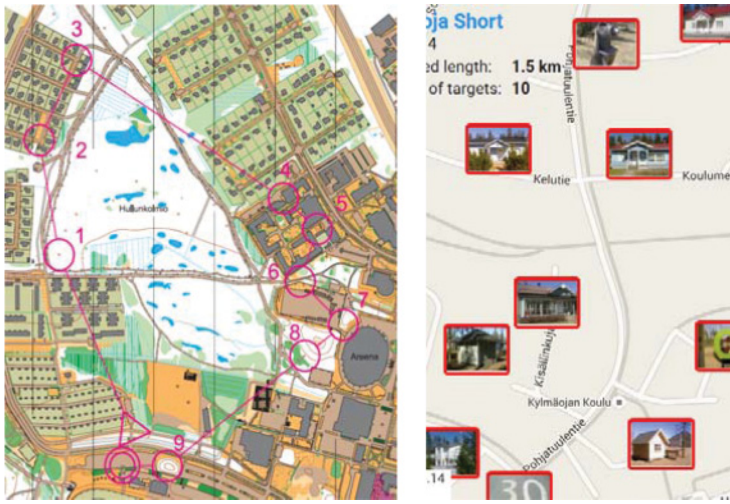

Fig. 1. Example of orienteering map (left) and O-Mopsi game (right).

devices. Additional sound guidance is given when approaching a target. Finding the targets is mentally rewarding and the main motivation for playing the game [57].

The positive sides of the game are that it encourages exercise and takes players outdoors, thus having health benefits as compared to other computer games [5]. To complete a game, the player needs to walk from 1km up to several kilometers depending on the game. Besides the physical movement, the main challenges of playing the game are the following:

— solving the order to visit the targets;
— finding the best route to the next target; and
— identifying the target.

The game is similar to classical orienteering with a few differences (see Figure 1). Orienteering is more challenging in that it takes place in nature (forest) where finding the way is more difficult. A player can know his location only by the use of a map and compass. In O-Mopsi, the location is known by the GPS, and the goal is just to navigate to the next target with the help of the device. The game scenarios are also located in cities and parks. These make it easier to play.

The extra challenge of playing comes from the fact that the order of targets is not fixed. The player has to choose the order in which he/she visits them, which makes the playing more challenging (Figure 2). Finding the optimal tour is a computationally hard problem even for computers; closely related to the traveling salesman problem (TSP) [29], and the vehicle routing problem (VRP) [51]. The game is also similar to another less-known variant of orienteering, known as Rogaining, where the goal is to find as many targets as possible in a given time limit. Computer-based solutions for this have been studied in [54].

Reaching the targets is automatically controlled by the device, so identifying the target does not raise any major challenges for the playing. Identifying the targets has mainly motivational purposes that increase the positive experience of playing. It is more motivating to search for something concrete like a statue, landmark, or any clearly recognizable object rather than just an anonymous location defined by its geo-coordinates (Figure 3).

The game is expected to have health benefits and unutilized potential in education. In this work, we study both its technological aspects of how to create good game scenarios (content creation), and also psychological aspects of how to motivate people playing.

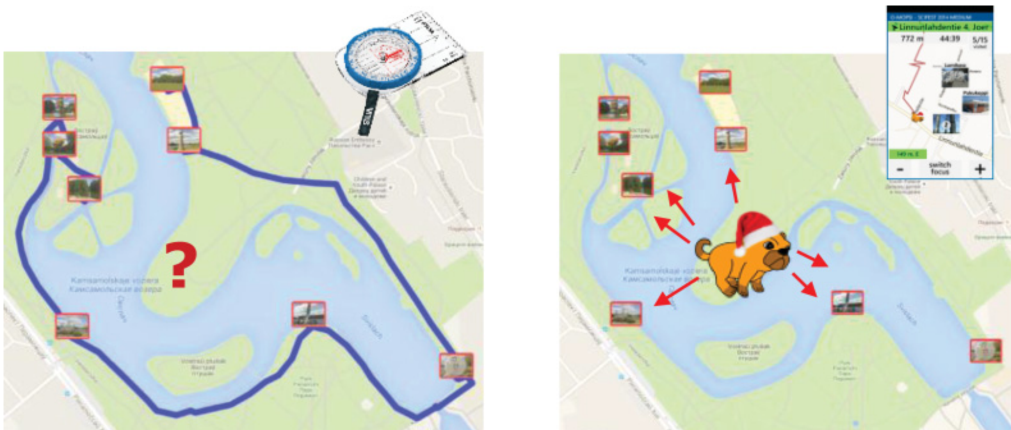

Fig. 2. Different challenges of classical orienteering (left) and O-Mopsi (right).

Fig. 3. Example of targets used in O-Mopsi.

The rest of the article is organized as follows. In Section 2, we review existing location-based games focusing on exergames and educational games. We study how the location has been used. Technical and safety issues are also discussed. O-Mopsi is introduced in Section 3. We describe how to play the game and discuss the motivational aspects of different playing modes. We study how to analyze the games and the problems in content creation. In Section 4, existing O-Mopsi games are reviewed, and playing experiences reported. Conclusions are drawn in Section 5.

2 LOCATION-BASED GAMES

Geo-caching is the longest-term location-based game that is still popular. Players seek a hidden treasure box, which is a small waterproof container containing a logbook, in which the players write the date they found it and sign it with their codename.

Since then, many ideas for location-based games have been introduced and implemented but very few survived and gained wider popularity. The early games suffered from technology deficiencies like unstable GPS signal, lacking internet connection, or low battery life. Now GPS positioning and smartphone technology have matured and became part of our everyday life, and they are no longer obstacles for creating successful games. We next review some of the previous games from the following viewpoints:

— main game playing modes,
— how to use and verify the location, and
— exergames and educational goals.

2.1 Game Playing Modes

We consider three types of game playing:

— organized events,
— playing at any time, and
— continuous playing.

Most of the early games required extensive setup and were played only as organized events. Nowadays the expectation is that the game can be played anytime and its management is completely automated. Even to the extent that the game server is expected to have some level of intelligence—acting as a social robot. The game in [48] was first organized to last entire day so that it could be played as background process but shorter game events were preferred.

Most people prefer games with short duration, or that the game is nonstop and can continue playing anytime. Another extreme was CityExplorer [30], which used complex rules inspired by the board game Carcassonne. Players compete for who can conquer the majority of the markers in a given area to earn points. Playing this strategic game may last from several days to months [30].

Many other location-aware games were also adaptations of traditional board games or computer games, such as Quake [37], Pacman [8], Tic-Tac-Toe [40], Monopoly [26], Chase and Catch [31], and Snake [10]. A Mafia game was also adapted to a location-based game called Invisible City: Rebels vs. Spies [46].

Another aspect is single-player vs. multiplayer games. Single-player games have one benefit: they can be played offline [21]. The player just opens the game and starts playing. Connection to the server might be required to download the game scenario, as well as uploading the results after playing. This is also the case in O-Mopsi, although some of our implementations do not yet work in the offline mode. If the game requires verification by the server, or the game is a real-time multiplayer game, then connection to the server is needed while playing. An important benefit of the multiplayer game is its social aspect [21].

2.2 How to Use Location

Lehmann [25] divides the games into four categories based on how the location is used:

— search-and-find,
— follow-the-path,
— chase-and-catch, and
— change-of-distance.

One of the oldest games, Can you see me now? [2], was introduced already in 2001. It uses mixed reality and belongs to the chase-and-catch category. One team (seekers) plays in the real world by searching for the members of the other team (hiders) who existed only virtually. The hiders set their location by computer and communicated via walkie-talkies. Playing the game required huge effort and the game could not be played ad hoc.

Most games belong to the search-and-find category. Game of Hidden Lion [7] promotes the sword lion culture in Anping, Taiwan, by combining geo-caching, cultural tourism, and arcade-style gameplay. Once discovering a lion, the player takes a photo of the lion, uploads it to the server, which then verifies using image recognition based on the target lion stored in the database.

A successful match then triggers a mini game designed for that area; for example, players need to clean bubbles for the Bath sword lion, or they need to run a star-figure route to release the Yu Jian Er sword lion.

See It [35] gives only a rough location with ambiguous visual clues. The player must search the target, which is a physically installed logbook similarly as in geo-caching. In Snap2Play [9], the player must first reach a given area based on given instructions like "Go to the lawn of business school." After reaching the area, players must take a photo of the scene (called physical card), which must resemble the given sample (called digital card) as closely as possible. The photo is then transmitted to a service that performs identification.

Games in the change-of-distance category make people wander around without any motive other than just to keep the player moving. Song of the North [24] happens in a virtual world where the player is given the role of a shaman, who can contact the spirit world of Nordic mythology using a drum as control of the game. A player's location is merely used as recording the moving which act as movements in the virtual world. Quests are given to the player to solve. The game supports both offline and multiplayer modes.

2.3 How is Location Verified?

Most games require players to reach a given location, which is identified by its GPS location or indirectly via clues or stories. Reaching the location must be verified in some way. At least the following options exist:

- GPS,
- RFID or QR code,
- taking photo,
- manual verification.

The games from the earlier years had to make compromises as GPS was not available or its quality was not good. Nowadays this is less an issue except maybe for indoor locations. The solution using GPS is simply to compare the distance of the user and the target location; if it is below a threshold, then the target is marked as found. Some more sophisticated methods, like detecting a stop, might be needed to prevent false alarms due to fluctuation of the signal. O-Mopsi uses a rather large threshold (20m). False alarms rarely happen but sometimes it gives the feeling that the targets are reached a little bit too easily. PokemonGo uses GPS only to reach the area but catching the Pokemon is performed by animated movement via phone camera screen.

Radio frequency identification (RFID) and quick response (QR) codes (2D bar codes) are also quite popular. Not all smartphones have the capability to read RFID tags but most devices support recognizing QR codes via the camera. This option is currently used in MOBO virtual orienteering in Finland (http://mobo.suunnistus.fi/), and in Stolpejakt (pole hunt) in Norway (https://www.stolpejakten.no/). Museum scrabble [45] is another example using QR codes. The drawback of both RFID and QR is that the targets must be physically installed. Printing visual bar codes is cheap and does not take much space to install but it still takes effort to prepare. More importantly, targets cannot be created automatically.

Pirates! [13] used physically installed radio frequency (RF) beacons to identify the locations of the islands that players need to reach. Meeting of other players at the open sea was also recognized by RF. The main benefit of this proximity-based approach is its suitability for indoor playing as such.

Some games use manual verification. The user either inputs the id of the target [42], or gives an answer to a question that can be concluded from information seen at the target. For example, "what year was the statue established?". Logbooks are used in geo-caching and also in See It [35].

A camera has also been used to verify the target. In [48], players take photos of other players so that the target does not notice this. This requires manual verification of the photos at the end of the game. In [30] both a photo and the GPS location are recorded at the location. A more ambitious approach is to use automatic image processing. In Snap2Play [9], players are given detailed instructions from which direction to take an image of the target. The image is then analyzed in the server to verify if it matches any target image in the game databases. In [7], the targets are the Lion sculptures and the photo must match one in the database. CityExplorer [30] uses more complex rules, which are inspired by the board game Carcassonne. The player who conquers the majority of markers in a given area earns points. Location is verified by taking a photo and recording GPS coordinates of the location, which are both uploaded to the server by the user.

2.4 Exergames

One very important aspect of location-based games or exergames in general, is their health benefits. Increase of physical activity levels were reported with 4th grade children who played the Dance Dance Revolution game three times a week, 30 minutes at a time [14]. However, no significant change in body fat was observed. Increased energy consumption of playing three exergames (tennis, bowling, boxing) was also reported in [16] when compared to games that are played sitting. Although positive effects, the exercise was not intense enough to reach the recommended amount of daily physical activity for children. Sitting time itself has a negative impact on metabolism and on the cardiovascular system of humans. According to [19], the impact is independent of whether the subject meets physical activity guidelines or not.

Location-based games have a higher potential to contribute to one'shealth than the other exergames because of their more excessive physical activity. In [5], three categories were listed: mobile location-based games, mobile location-aware fitness and sports applications with social and games features, and location-aware sports gadgets. We focus here mostly on the first category, although some games are quite close to fitness applications already.

SmartRabbit [28] is an example of a game that is quite similar to sport trackers. Players run a certain distance in the shortest time possible without the need to be in the same location. They share their achievements in social media or a tracker's website. Players are awarded with medals for reaching achievements like running 2km for the first time, or running 5km for 4 weeks in sequence. When reaching a certain level, players can challenge others to duels to earn more points. Thus, the game motivation comes from collecting merits.

It might appear challenging to get people outdoors to play games that require intense exercise, or even moving at all. Contrary to this, several studies have reported positive results and observed high motivation. The user feedback in [47] showed the game was perceived as being very exciting, easy-to-use, player's motivation being interested or very interested, and collaboration was reported to happen all the time. In [15], students became so involved in the tests concerning their spatial abilities that they wanted to perform similar tests later, and showed great interest in the spatial abilities in their curriculums.

2.5 Education and Computational Thinking

Savannah [12] aims at teaching animal behavior to children via role-playing. They carry out a series of lion missions such as hunting, marking territory, and hiding their cubs. The playing happens on a grass field the size of a football field. Movements are recorded using GPS.

Education is also the goal of Skattjakt (Treasure Hunt) [47], in which players solve a mystery surrounding a castle located on the university's campus. TidyCity [56] uses treasure hunting for educational purposes. Players solve location-based riddles during city exploration. The targets have two locations: one where the riddle is found, and another one where the players must go.

The target location is obtained by solving the clues given by the riddle. In the AnswerTree game [32], 8–12-year-olds learn about trees and wildlife within the University of Nottingham campus by collecting virtual cards and answering questions by combining the information of other players.

In [38], players take the role of a consultant who interviews virtual characters located all around the campus. The player must walk to the location of the character to interview and receive information. The goal is to take business education in a more natural context than the classroom. The location itself is not important.

Museums (especially in an open area) are quite suitable for educational games. Museum scrabble [45] in Zakynthos, Greece, is loosely based on the popular Scrabble word game. Targets are identified by scanning their QR codes. Players must then answer multiple-choice questions related to the targets. For example, "Elisabeth Moutzan-Martinegou is the first female writer in modern Greece." Lieksa Myst [42] is another example where answering multiple-choice questions is used. Answering then triggers a short story about the target and its history.

However, most games just make people wander around, possibly involving some story telling or question/answer sessions to educate about the targets. In Computer Science, games themselves have been designed even for learning programming [33] but very few integrate the actual physical movement in the problem solving. Animating a sorting algorithm can be performed during Algorithm course by instructing students to sort themselves from shortest to tallest (or by another criterion). But even then, the movement is still quite limited and does not really utilize the location element in the game.

O'Munaciedd is a game that aims at improving students' concentration, memorization, and problem-solving abilities, in addition to educating them on the artistic and cultural heritage of the city of Matera, Italy [17]. An important motivation is that the game playing must combine fun with learning to create a stimulating pedagogical learning path.

Orienteering is a sport that combines problem solving with physical exercise. It has also been shown to improve spatial abilities [15]. Visual-spatial abilities themselves are important in navigation and estimating distances but also in several fields in science. For example, solving kinematic problems in physics, and understanding abstract models of molecules and their spatial dynamics in chemistry require spatial skills. Spatial skills are especially important in computer graphics education [20] and engineering mechanics [18].

In O-Mopsi, we adopt a rarer variant of orienteering known as Rogaining, which emphasizes more computational thinking. In this variant, one of the main challenges is to find the shortest tour to visit all the targets. This is a variant of the well-known TSP, called Euclidean path-TSP, which is shown to be a NP-hard computational problem [36]. This means that large-scale problem instances cannot be solved by computer within a reasonable time. However, small-scale instances (about 10–20) can, and they make a good puzzle for humans to solve. Two other computationally hard problems, Sudoku [11] and Minesweeper [41], have been quite popular as a puzzle or as a game. We therefore expect the TSP problem involved in O-Mopsi can also be an inspiring computational problem to solve.

2.6 Technical Issues

There are some problems when implementing location-based games. Technical issues include unavailability of GPS signal, low processing capability of the device, small storage capacity, and small screen size [22]. Battery life, processing power, storage capacity, and graphics capabilities were also listed in [27].

However, most of these are minor issues nowadays. GPS technology has improved remarkably; screen size is not a significant issue for most (especially young) people using smartphones. Battery capacity still is an issue as it has evolved much slower than the other technical components. For this issue, one piece of advice is to keep it simple [27]. Most good games do not require massive computation or graphics. A camera and map on the device is often enough for enjoyable playing experiences as the enjoyment comes from other aspects like collecting, competition, and social aspects of the gaming.

GPS technology has also improved remarkably but still has restrictions: one is that it may not work indoors. Inaccuracies also happen aside tall buildings. Targets should therefore be put outdoors and preferably far from tall buildings. The inaccuracies do sometimes cause minor inconveniences when the player thinks he already reached the target but GPS forces him to make additional illogical movements. Having the 20m threshold used in the software keeps this kind of issues rare.

2.7 Safety Issues

Safety can also be an issue. Jacob and Coelho argued that racing against the clock or against other opponents could put players' health on the line [22]. This indeed became an instant worry in the press in Finland when PokemoGo came to markets. The risk of automatically generated targets is that the players can find themselves wandering in dangerous or prohibited areas. Targets might also be in locations that are inaccessible by foot [5]. In PokemonGo, additional risk comes from the fact that players are looking at the mobile screen to catch the Pokemon. This makes them aloof from the surrounding real world.

However, most games are played while walking and the risk of mobile game playing is related more to the general use of mobile phones like talking, text messaging, or listening to music. In [50], 29.8% of all pedestrians were found to perform a distracting activity while crossing the street. In [34], it was estimated that injuries due to mobile phones may double from 2010 to 2015. Thus, the use of mobile devices itself is already so popular that game playing adds no new danger to what is already there; except the more intensive focus might increase the risk.

Thompson et al. [50] did not offer anything new on how to deal with the threats of using mobile phones in traffic but speculated that the solutions are likely to include the "three E's" of injury prevention in general: education of the public about the risks, engineering modifications, and enforcement. Nasar and Troyer [34] also pointed out legislation: even if it was not enforced, it would make people better aware of the dangers. Locking mobile phones while detecting movement was also considered but this would not be applicable for game playing.

In O-Mopsi the targets are real locations such as landmarks and points of interest, and not virtual characters on the screen of the device as in PokemonGo. The areas are therefore expected to be accessible. Players must also observe the surrounding environment to find the targets. In addition, O-Mopsi uses a sound signal to indicate the proximity of the target, which reduces the need to look at the phone screen. In brief, more attention is paid to the environment than to the mobile device.

3 O-MOPSI ORIENTEERING GAME

The O-Mopsi game was first released in 2010 during the SciFest Annual Science festival [23] in 2010 in Joensuu, Finland. The first version of the game was available in Nokia Symbian phones and its brief document can be found in [49]. Since then the game has been improved and exported to all major mobile platforms: Android, iPhone, and Windows phones (Figure 4). We next review the game rules, and then discuss its status and future directions from the following point of views:

- motivations to play,
- game analysis, and
- creating content.

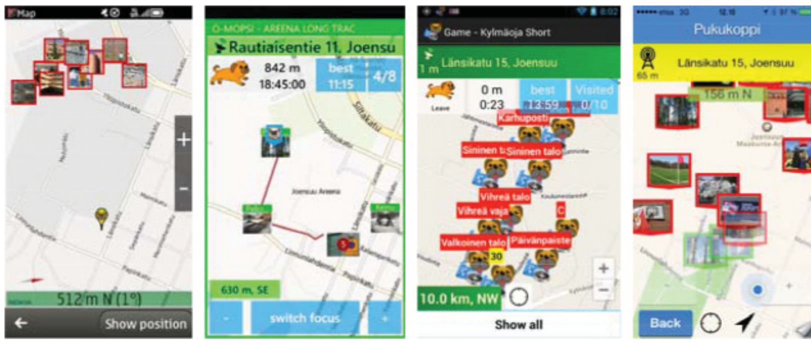

Fig. 4. Game view in four different platforms from left to right: Android, Windows Phone, Nokia Symbian, and iPhone.

Fig. 5. Target examples: landmark, construction, window, and statue.

3.1 Playing the Game

The goal of the game is to find all targets, which can be landmarks, buildings, recognizable structures, statues, or other points of interest. The targets should be outdoors and accessible by walking. Pictures of smaller objects can also be used as visual clues but the target should be recognizable from 20 meters away either from the picture or its textual description. Figure 5 shows a few examples.

Before the game starts, players can see only the area (bounding box) where the targets are but not their exact location. The number of targets and the estimated length of the tour are also shown (see Figure 6). This information helps players to decide whether to start playing this particular game.

The first decision the player must make is where to start playing. Obviously, it makes no sense to play a game located far away. Instead, it is better to go inside the game area to save time, or at least be aside of its border. Starting next to a target would be preferable but this would be merely guessing since their locations are unknown at this stage. The only information available is the game area that covers all the targets. But where exactly should one start playing: middle, corner, or just some random point along any side? This is what the player must decide first (see Figure 7).

Fig. 6. Game screen.

Fig. 7. Challenges of the game: where to start and what is the optimal tour?

The game starts by pressing the "play" button, after which the targets and their locations become visible. Time starts ticking. The challenge is now to decide in which order to visit the targets. In general, the shorter the better. Selecting the best order corresponds to an open-loop variant of TSP where each target corresponds to a city, and the player's start location is an additional city where the tour starts. The player does not need to return to the start point.

A major challenge is that TSP is computationally hard to solve (NP-hard), and the time spent for planning the tour is away from the actual traveling. This encourages players to develop different strategies for not only where to start playing, but also for solving the order of visiting the targets fast, and how much time to allocate for the planning. An experienced player can do the planning while moving.

The player then implements the plan by solving a sequence of routing problems between the individual targets (Figure 8). This corresponds to classical orienteering except that the location given by GPS is available, which makes the navigation easier than in orienteering. Nevertheless, there is still enough challenge for the player to navigate to the next target. From a computational point of view, it is like solving a series of shortest path problems in a road network.

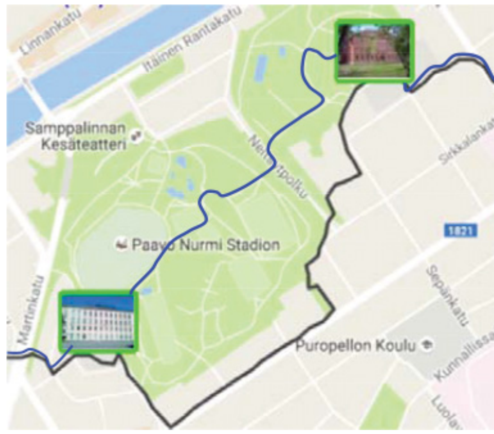

Fig. 8. Two alternative routes between Martin and Luostarivuori schools.

Distance	Sound interval	Freq-uency
>500 m	No sound	
400–500m	5s	640Hz
300–400m	4s	721Hz
200–300m	3s	807Hz
100–200m	2s	904Hz
60–100m	1s	1017Hz
20–60m	0.5s	1141Hz
< 20m	"found"	

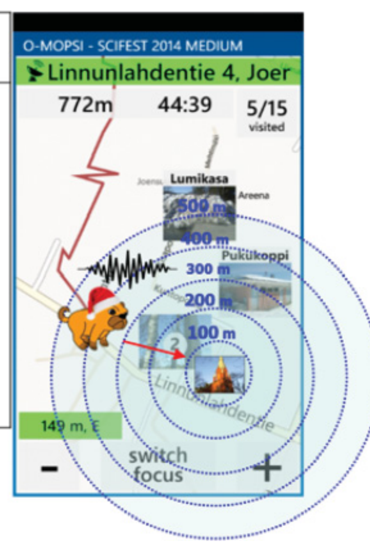

Fig. 9. Guiding sound when reaching a target.

Only unvisited targets are shown on the map. The player can zoom and pan the map using the functionalities of the device. Sometimes the targets may be clustered by showing only one picture with a number inside to indicate the cluster size. This is to prevent information overflow on the small screen. The player may also click on the target to see the image. To help in navigation, the distance and direction (taken from the devices compass sensor) to the nearest target are also shown.

Importance of audio feedback was found to be particularly effective to improve orientation of the player in [32]. Audio was triggered when a new target (tree in their game) came to the vicinity of the player, or when an action was successfully completed. In O-Mopsi, we play a beeping sound effect at fixed intervals when the player gets closer than 500m to the nearest target. The interval and frequency of the sound both increase when the player gets closer to the target (see Figure 9). Our motivation for the sound effect is to improve playing experience, and reduce the need for the

Fig. 10. Examples of sightseeing tours.

player to look at the phone screen to improve safety. An experienced player may not even need to look at the screen at all after reaching the 500m area.

A target is marked as visited when the player gets within 20 meters to it. "Tadaa" fanfare is played and the target is removed from the map. The game ends when all targets have been visited.

3.2 Motivational Aspects

We consider three different modes for playing:

— competing,
— sightseeing, and
— educational.

The main playing motive is competition: the player with the fastest time wins and his name appears at the top of the hall of fame. This motivates people with a competitive nature. It also encourages physical exercise which people might otherwise not be doing. To win, one must be faster than the others.

However, not all people are competitive. Another playing motive is to consider the game as a sightseeing tour (Figure 10). Targets can be attractions in a park, thematic tours in a city, or just favorite places in the game creator's hometown. Sightseeing tours could also be made easier than competitive games by suggesting a travel order. The game might also start and end in the same location, although scenery point-to-point trips are still possible.

The excellence of a tour can be measured by scoring the total popularity of the landmarks along the path relative to the distance. Personalized sightseeing tours were recommended in [6] by modeling it as a generalized maximum coverage problem: maximize how well the targets match the personal interest and divided by the time it takes to travel. The time was estimated by solving the TSP tour of the targets, with the difference being that the targets are smaller subtours with two terminal points instead of one fixed location. In [44], health-optimal tours are recommended to pedestrian navigation based on environmental factors (road segment complexity, segment length) and individual factors (body mass index (BMI), walking speed, time constraint, target calories to burn). In [43], air pollution exposure is used as the criterion.

Fig. 11. Possible targets for an educational game in biology.

A third motivation is to create educational games. Students have shown to make significant learning gains in game-based learning compared to classroom teaching in [53]. Educational orienteering games can be created quite naturally for geography, architecture, city history, and biology both in nature and in botanical gardens (Figure 11). Instead of just reaching the targets, students can be given a short story, ask questions, or complete some educational task at every target. Open area exhibitions and outdoor museums would be especially suitable applications.

Exercising itself can be useful for enhancing learning, especially when creative thinking is needed [4]. Cognitively engaging exercises have been reported to have a stronger effect than non-engaging exercise on children's executive function in [3]. Thus, there are clear potential benefits to combining physical exercise and learning. We sum up the motivations as follows:

— physical exercising and being outdoors,
— enhance learning and creative thinking, and
— just being fun.

The effect of having fun is also important [17]. In school, active teaching can bring the students outdoors but they would not necessarily be doing it on their own without strong self-motivation. In their free time, most people would just prefer to play computer games indoors with limited or no physical activity at all. Motivating people to get out and to move is an important goal, but it also one of the main challenges of creating good educational games. This is widely agreed but how to accomplish it has been much less studied as noted in [1].

In [39], motivational aspects include points, badges, and leaderboards. Achieving points creates immediate positive reinforcements. Badges fulfill the need for success but also work as virtual status symbols. Being at the top of leaderboards gives a feeling of competence. If associated with team scores, it can also enhance social relatedness. Other motivational mechanisms mentioned were progress bars and performance graphs, quests, meaningful stories, avatars, and profile development.

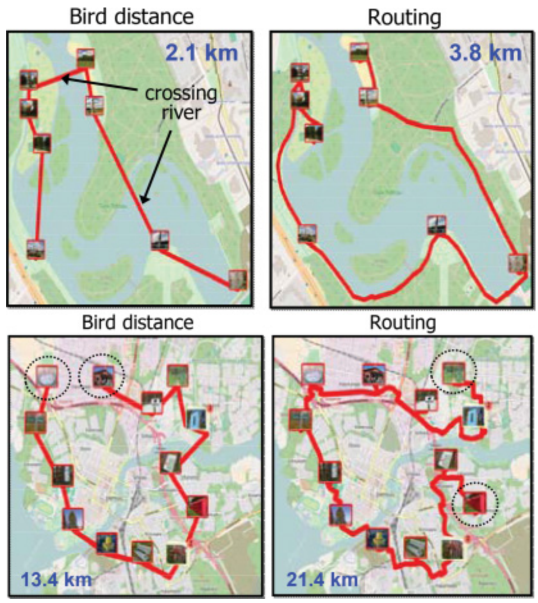

Fig. 12. Effect of the route network and start point for solving optimal tour in the case of Minsk 4 (above) and Autumn Moon (below).

3.3 Game Analysis

Game playing includes three challenges: (1) navigating to the next target, (2) deciding the order, and (3) physical movement. All of them are relevant and unavoidable in the game playing. Deciding the order of targets is a real problem that the players need to face. On one hand, they rarely find the optimal tour but, on the other hand, they do not need to. The question of how well they optimize it affects merely how long they need to walk.

To provide the post-game feedback to the players about the quality of their playing, we calculate the optimal tour. Another reason for calculating it is that not everyone wants to compete on speed. Measuring who has the shortest tour, or who has been the most active player in the area can be alternative goals. Improvement over past performance, or measuring how good the chosen route compared to the optimal route can also give satisfaction. Knowing the optimal tour would also allow user-to-user comparison, and estimating game complexity.

To calculate the optimal route, we need to solve TSP with the following three exceptions:

—player can freely choose the start place,
—player does not need to return back, and
—moving might be restricted by the road network.

For this, we need a distance matrix between all the targets. Bird's (Euclidean) distance is usually enough but near rivers a road network can be needed. However, not only the individual distances but also the order of the tour can be different when using bird's distance and when routing via the network (see the two examples in Figure 12). Two elements are needed to compute road-based distances between a pair of points: a road network and a path-finding method. For the former, we installed a copy of Open Street Map (OSM: https://www.openstreetmap.org) on the O-Mopsi server. It is a free to use, collaboratively generated map of the world, which includes information such as terrain, buildings, and roads. In addition to car roads, OSM also contains walking and cycling paths, which are essential for O-Mopsi players. The path finding is solved by installing the Open Source Routing Machine (OSRM: http://map.project-osrm.org) on the O-Mopsi server and configuring it to use the walking and bicycle paths. OSRM is then used to calculate the distance matrix.

The road-based distances are useful in large games, spanning many kilometers in cities with complicated street structures. Even so, unwanted artifacts exist. For instance, players may cross parks, fields, forest, parking lots, and even frozen lakes. This aspect can let the player achieve a shorter tour length than the optimum length provided by an algorithm. Other aspects such as traffic lights might also affect the routing but they have only minor significance because the games are mostly played in quiet areas without traffic lights. They affect only the speed but not the shortest path. Nevertheless, it is desirable to have an accurate reference route in all occasions.

TSP itself has been widely studied in literature for decades. The open-loop variant in O-Mopsi is known as Euclidean path-TSP, and it has been shown to be a NP-hard computational problem [36]. Optimization techniques such as tabu search, ant colony optimization, and genetic algorithms have been considered but they can either be too slow or provide sub-optimal results, which might confuse the player who had found a better tour. However, since the size of the games is relatively small, we use a branch-and-bound technique in the experiments of this article to guarantee that the optimal solution can be found.

When a player starts the game, the start point is fixed and the player location is considered as an additional start target. However, when we estimate the optimal tour for the game in general, the problem becomes open-loop TSP. The optimal solution for this cannot be concluded from the closed-loop TSP simply by removing its longest edge. The Autumn Moon game in Figure 12 demonstrates this: although the terminal points are close to each other when bird's distance is used, they are not when a road network is used. Thus, the start point of the tour is an additional parameter in the problem solving.

To calculate the optimal tour, we first create a N*(N-1) distance matrix by calculating pairwise distances between all N targets. We then solve the TSP using *branch-and-bound*. Euclidean distance is used, although our implementation also supports routing via OpenStreetMap.

3.4 Content Creation

The quality of the game depends on two aspects:

—quality of the individual targets (content) and
—overall layout of the targets (playability).

Creating good and motivating content can be surprisingly challenging and it requires both aesthetic and technical skills. Geo-coded pictures (GPS location embedded inside) are the best source for the game, especially when automated or semi-automated tools are used. However, the location defines the point where the picture is taken, which can be far from the actual target. It might also be confusing whether the player needs to visit the viewpoint or the point where the target is (Figure 13).

Using GPS also limits the playing outdoors as most positioning systems do not work inside the buildings. Tall buildings in city centers can also cause confusion when the player thinks he is within the 20m radius from the target but the GPS signal is not. These issues give challenges for the game creator.

The second challenge is how to measure playability of the game. Complexity of the game layout is one factor. A good game should not be too trivial but also not too difficult, especially for beginner users. Ideally, the complexity should match the player's experience level but we do not make any recommendations but simply let the player choose freely any game wanted. We estimate the

Fig. 13. Confusing targets due to mismatch between locations of target and viewing point.

complexity of the game as follows:

$$\text{Complexity} = d_{opt}/d_{rand},$$

where d_{opt} is the length of the optimal tour, and d_{rand} is the length of a greedy heuristic when started at the location of a randomly chosen target. The result is the average of 10 repeats. Values of the games in our database currently range from 0.5 (easiest) to 8.05 (toughest). This gives a rough estimation of how challenging is the problem of finding the optimal order. Note also that the effect to the overall result (time), depends both on the cognitive challenge (how easy it is to solve the optimal order) and the effect of the sub-optimal order on the total distance. This measure helps the game creator estimate the merit of the game in one point of view.

Besides the complexity, another important issue is the source of the material. Currently the biggest problem is that people who have downloaded O-Mopsi do not find any games to play in their area. To solve this problem, we should be able to automate the game creation. This has two major challenges:

— where to get content (potential targets) and
— how to select a suitable combination automatically.

So far, we have used pictures in the Mopsi database, and downloaded a small database from the material available from the View on the Cities web site. However, these cover only very few cities and a better (public) source of geo-tagged pictures would be needed. TripBuilder in [6] extracted categorized points of interest from Wikipedia and albums of geo-referenced photos from Flickr.

Engaging players to create content from their travel pictures would be one solution and make it a participatory cultural experience. In the same way, the riddles of TidyCity cannot be transported from one city to another, or be automatically generated, as all of them are closely related to the location. Instead, it relies on users to create new missions for others to play [56].

Once there is enough content, the question becomes how to select a suitable set of pictures to make an enjoyable game. Our rules of thumb for a good game are as follows:

— the number of targets should be from low to moderate (5–12) and
— avoid too simple a layout (line structure).

To motivate people to start playing, the number of targets cannot be too high. We hypothesize that this is the biggest factor for initial motivation and that the layout matters less. However, simple layouts might become boring and more complex layouts provide more challenge. Players also tend to underestimate the challenge of solving TSP; most players do not even know that it is

Table 1. Statistics of 10 Sample O-Mopsi Games. Heuristic Tour Refers to Greedy Nearest Neighbor Algorithm Starting from Random Target (Result is from 10 Repeats). Difference Shows How Much Longer It is than the Optimal

Game	Targets	Complexity	Optimal tour (km)	Heuristic tour (km)	Diff.
Otsola	9	0.9	0.86	1.23	44%
Ranta-Mutala mini	6	1.0	0.80	0.86	7%
Marjala	11	1.4	3.20	3.37	5%
SciFest 2014 short	10	2.0	0.98	1.01	4%
SciFest 2016	13	2.5	1.48	1.54	4%
Toulouse	8	3.0	3.20	4.09	28%
Symmetry	9	4.0	8.77	13.35	52%
Christmas Star	10	5.3	14.27	17.8	25%
Barcelona Grandtour	18	6.2	13.83	15.76	14%
Niinivaara 27/8km	27	7.7	8.26	9.56	16%

a computationally hard problem. Random distribution of targets looks simple but is probably the most difficult to solve.

Other considerations are that the individual targets should have sufficient spread (not too close to each other), and their average distance to each other should not have huge variations. For example, if one goal is far from the others, the player can easily become frustrated when finished with all other targets and the last one requires just lengthy walking but no other challenge.

Our current game creation tool on the Web is documented in [55]. A prototype for automatic game creation can be found in [52].

4 EXPERIENCES AND FUTURE CHALLENGES

Next, we summarize the existing games created for O-Mopsi and playing experiences in SciFest festival. On 6/6/2016, there were 139 games, of which 97 are in Finland (see Appendix). The number of targets varies from 4 to 27, being 12 on average. Their estimated length (optimal tour using Euclidean distance) varies from 0.5 to 17km, being 3.5km, on average.

Ten sample games are shown in Figure 14 and their details summarized in Table 1. The heuristic tour represents the corresponding result of a human player who starts from a random location and always goes to the nearest target. The difference (penalty) to the optimal tour demonstrates how much longer the player using this heuristic is expected to travel if not knowing the optimal tour.

In general, the more complex the game is, the higher is the difference but the correlation is not very strong. Even a low complex game can have high penalty (Otsola). The number of targets has a stronger effect both on the complexity and on the expected difference, but only when the number of targets is relatively high (18 or higher). The games with 13 or less targets have no clear correlation with the complexity or the penalty. To sum up the statistics, nearest target strategy is 24% longer than the optimal tour, on average. The corresponding minimum, median, and maximum differences are 0.06%, 20%, and 110%.

SciFest (www.scifest.fi) is an annual international festival organized in Joensuu, Finland. Thousands of children of schools and their teachers participate in several workshops to discover new experiences about science, technology, and the environment [23]. O-Mopsi has been organized in SciFest every year in 2011–2016. Because of the limited availability of devices with GPS and data connection, the players were organized into teams. However, nowadays, many children in schools have their own smartphones to which they can install the software.

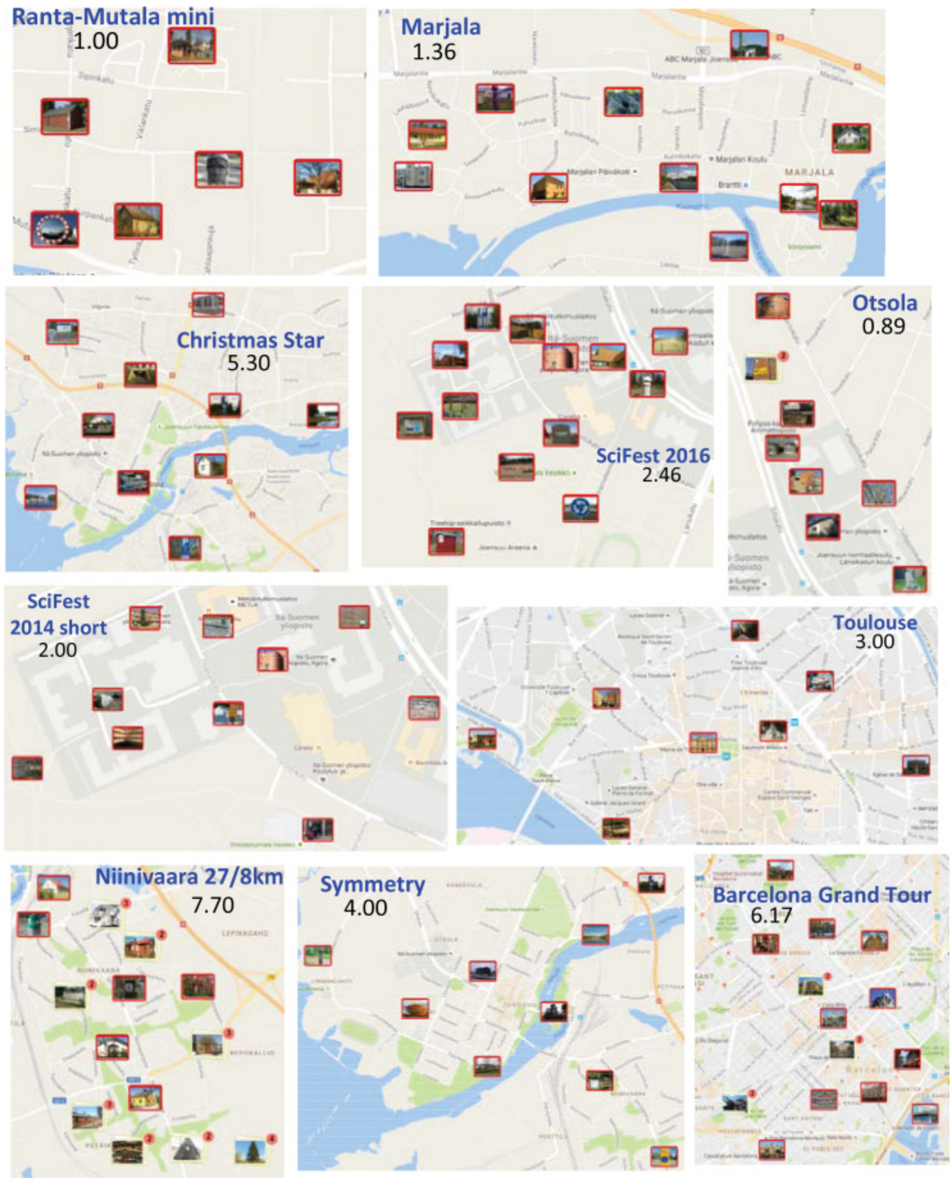

Fig. 14. Ten selected games and their complexity values.

Several games were created in each year for SciFest. Table 2 summarizes the statistics of the most popular game played each year. On average, 47 participants played the game, of which 38% completed. If there were more games available to play, a shorter one was usually preferred. The length or the number of targets, however, does not strongly correlate to how many completed the game. An exception is 2016, when the game was significantly longer. Among those who did not complete, half collected at least two targets and 25% collected more than half of the targets before giving up.

Table 2. Game and Player Statistics from SciFest Games during 2011–2016

	Game statistics			Player statistics				
Year	Complexity	Targets	Length (km)	Started	Completed	Solved	Winning time	Median time
2016	2.5	13	1.5	47	28%	0	15:37	30:12
2015	3.0	14	1.2	32	60%	0	14:41	26:24
2014	2.0	10	1.0	55	45%	3	6:22	32:00
2013	2.5	8	0.5	49	27%	1	7:06	17:50
2012	1.0	7	0.5	64	38%	7	8:15	16:33
2011	1.4	5	0.6	32	28%	4	11:26	13:53
Aver.	2.1	9.5	1.1	47	38%	2.5	10:26	22:32

Table 3. Overall Playing Experience during SciFest 2011–2016

Feedback	Very good	Good	Needs improvement	Bad
2016	7	16	2	0
2015	9	9	1	0
2014	8	19	3	0
2013	2	21	6	0
2012	1	7	0	2
2011	3	6	0	0
Total	30	78	12	2

Of those who completed the game, only a few managed to solve the optimal TSP tour. Best achievers were in the early years (2011 and 2012) when both the number of targets (five and seven) and game complexity (1.4 and 1.9) was lowest. In general, there is a clear correlation between game complexity and being able to find the optimal tour. The toughest games (complexity = 2.5-3.0) were in 2013, 2015 and 2016. In 2015 and 2016, none solved the optimal order (best had one difference) and in 2013, only one team solved it.

Median times spent for the games was about half an hour for the longer games (>1km) in 2014–2016, and 14–18 minutes for the shorter games in 2011–2013 (about 0.5km). In 2016, the total distance traveled among those whose GPS route was successfully recorded, varied from 2.1 to 3.6km when the optimal tour was 1.5km. Note that the estimation is done using bird's distance. This is mostly because the route network does not cover the campus area and open areas like plazas and parks.

4.1 Detailed Feedback

After playing, the teams filled out a short feedback survey as summarized in Tables 3 and 4. Feedback shows that most rated the game as being very good or good. According to users, game rules are easy to understand and playing the game is enjoyable. Overall, the results are rather similar as in [47], where the following were measured: excitement (very exciting), ease-of-use (easy), motivation (interested/very interested), and collaboration (all the time). In SciFest, some players got so involved about O-Mopsi that they return year after year trying to improve their performance. Negative feedback was caused by software problems, or inadequate GPS signal.

Table 4. SciFest Feedback in 2016

Question	Very easy	Easy	Difficult	Very difficult		
Easy to use?	7	12	6			
Enjoyed the game?	Very good	Good	Needs improvement	Bad		
	7	16	2			
Recommend to others?	Yes	No	N/A			
	22	1	2			
Which part liked most?	Automatic login	Interface	Game rules	Map	Find goal	Tracking
	3	1	8	14	13	6

In general, the feedback shows that players most liked finding the goals (20 + 13) and the map (10 + 14) than the game concept itself, i.e., rules (8 + 4) or the ability to track (6 + 8). In other words, the game playing itself is more enjoyable than completing the task. The fun aspect is strong. This attractiveness is the same in real (hobbyist) orienteering where people mostly enjoy finding the targets.

The detailed feedback also shows that usability is the most important factor for the quality of experience. Although 75% found the game easy to play, still 25% considered it difficult. Two potential further improvements were found. First, adding a brief tutorial in the game itself might be helpful. Now only the workshop tutors gave overall instructions after which the kids were playing on their own. Second, dependency on internet sometimes caused delays. It would be possible to play offline as well. The targets still need to be downloaded, but the connection to the server is not needed anymore during the playing (having GPS is enough).

Another issue was occasional GPS inaccuracies, which were shown in two ways. Sometimes the target was not detected even if the player was where he or she was supposed to be. Vice versa, sometimes the target was detected too far away, like 50 meters away. In PokemonGo, the inaccuracies are avoided by using artificial targets. Even if the places (PokeStops) are real, the Pokemon characters are not, and it is therefore less critical where they exactly appear; the players are catching these creatures and not the actual places.

4.2 Computational Thinking

Since the original motivation for playing O-Mopsi in SciFest was merely to promote science and technology, achievements in exergaming and educational goals were never measured in these events. However, we did a brief survey on our Computer Science students in September 2016 to find out if playing the O-Mopsi game increases their problem-solving capability with TSP.

We created 20 sample games of $n = 6 - 10$ points in two-dimensional space shown on a computer screen. Each student was asked to solve all the problems one by one while we measured the time it took in total. We then divided the students randomly into two groups: The O-Mopsi group was instructed to play O-Mopsi outdoors during the next week while the control group was idle. After this, we repeated the TSP solving task with all students.

The results are summarized in Table 5. As expected, both groups showed improved performance in the second week compared to the first week, mainly because of prior experience on the task and the tool. However, the O-Mopsi group performed 30% better, whereas the control group improved only 22%. The difference is not big but it is statistically significant. It indicates that playing O-Mopsi

Table 5. TSP Problem-Solving Skills of Students. The Numbers are the Total Time Spent to Solve 20 Problems of Size n = 6–10. The O-Mopsi Group Played One Game of O-Mopsi between the Experiments, whereas the Control Group Did Not

Group	Students	Week 1	Week 2	Impr.
O-Mopsi	9	79s	55s	30%
Control	22	81s	63s	22%
Total	31	80s	61s	24%

might enhance TSP problem-solving skills, although the reason might as well be that having more outdoor activity (or activity in general) caused the improvement. In either case, a positive effect of the game playing was measured no matter which was the reason.

5 CONCLUSIONS

A location-based orienteering game was introduced. It has the potential to become widely accepted for fun, sightseeing, and educational purposes. It promotes computational thinking by involving TSP and shortest path that the player needs to solve during the game play. In the following, we list research questions that have been discussed in this article, or should be studied in the future.

Being an exercise game, the concept of O-Mopsi is expected to have health benefits. However, competing about who is fastest may not motivate all. Competitive playing could be based on finding the shortest overall path, or solving the optimal order of the tour. This would put the emphasis more on problem solving and accuracy rather than speed. Formulating the game as a sightseeing tour or providing educational content for the targets is another direction worth pursuing. In general, a better rewarding mechanism would be needed to improve motivation for playing.

From a competitive point of view, it might be interesting to study the best winning strategies. Besides finding the targets, playing involves questions like where to start playing, and how to solve the optimal tour. A sub-optimal tour can add up to 50% to the tour length according to our results, but the effect on starting point was not studied. The effect of using bird's distance and routing via a road network also affects the result. For analysis purposes, better tools are needed.

Solving TSP is not an issue for small games but is worth some consideration. Local search solutions can be based on switching the edges (2 opt), swapping the location of a target, or permuting subsequent triples in the tour. But are these operations sufficient for solving the problem, and which search strategy will work best: local search, tabu search, simulated annealing, or swarm intelligence? Since finding the optimal tour closely relates to another problem, VRP, solving TSP might be worth studying as well.

The biggest open question is the content creation. The games need geo-tagged material: photos and their short descriptions. Automatic game creation needs to address two questions: how to evaluate the quality of individual targets and how to measure the quality of the overall game. The first depends on factors like visual quality of the photos, and attractiveness and approachability of the target. The latter can depend on factors like the number of targets and game complexity. User feedback should be utilized to evaluate these.

APPENDIX

O-Mopsi games distribution in Europe and Finland.

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