Distributed Pervasive Worlds: The Case of Exergames

Teemu H. Laine1* and Carolina Islas Sedano2

1Department of Information and Computer Engineering, Ajou University, Woncheon-dong, Yeongtong-gu, 443-749 Suwon, South Korea // 2School of Computing, University of Eastern Finland, P.O. Box 111, 80101 Joensuu, Finland

tlaine@ajou.ac.kr // carolina.islas@uef.fi

*Corresponding author

ABSTRACT

Pervasive worlds are computing environments where a virtual world converges with the physical world through context-aware technologies such as sensors. In pervasive worlds, technology is distributed among entities that may be distributed geographically. We explore the concept, possibilities, and challenges of distributed pervasive worlds in a case study—an exergame entitled Running Othello. Combining a board game with sensor-enhanced physical activity, Running Othello aims at motivating young players to be physically active. Based on the analyzed literature and mixed-method evaluations of Running Othello, the following contributions emerged: (i) a total of 13 design principles for distributed pervasive exergames, (ii) the players’ perceptions with distributed gameplay, (iii) an analysis of development challenges, and (iv) four dimensions of distribution in Running Othello. Player evaluations were conducted on university students and on children and young adults participating at a science festival. These results are useful scholars and developers interested in the concept of pervasive worlds. With this exploratory paper, we have taken the first steps toward comprehending the conceptualization, design, implementation, and evaluation of distributed pervasive worlds.

Keywords

Pervasive world, Game, Exercise, Distribution, Context-awareness

Introduction

Virtual worlds, such as Second Life, typically run on desktop computers. Although mobile applications are available for virtual worlds (e.g., Mobile Grid Client, Lumiya, Pocket Metaverse), they often ignore the smartphone’s capacity to adapt to the user’s experience by detecting the context. One of the current challenges in the field of education is to enable context-sensitive learning experiences (JISC, 2006). To support educators using alternative approaches to learning—such as behaviorism, cognitivism, and constructivism—computer scientists should explore, develop, and understand technical systems that aim to facilitate the achievement of objectives set by educators and students (JISC, 2006). Therefore, to overcome the technological hurdles facing virtual worlds in education, we set out to explore the possibilities that exist beyond the computer-simulated virtual worlds by considering the converging space between the physical and the digital world. Pervasive world is a system that enables the interplay between physical and digital worlds by detecting the user’s context. Technologies that implement a pervasive world, or any other pervasive system, include smartphones, sensors, wireless communication devices, and algorithms that enable context-awareness (Chalmers, 2011). This technology can link resources from the physical world to the virtual world, allowing novel interactions, such as using the body itself as a controller (Kiili & Merilampi, 2012).

Milgram and Kishino (1994) proposed a reality-virtuality continuum that encompasses the real environment, augmented reality, augmented virtuality, and the virtual environment. We expanded the reality-virtuality continuum to include world types that utilize these environments (Figure 1). Virtual worlds are based on virtual environments, while pervasive worlds may utilize augmented reality to enhance the visualization of, and interaction with, the virtual content. In augmented reality, real-world images (e.g., from a camera feed) are augmented with virtual elements. By contrast, augmented virtuality enhances the virtual-world by embedding real-world resources (e.g., from a webcam feed). We see pervasive worlds as the next generation of virtual worlds—releasing users from their keyboards to explore the physical world with context-sensitive digital content.

In virtual and pervasive worlds, technical components and users are distributed over a network. The notion of distribution is important, from both a technical and conceptual perspective, for understanding the challenges and possibilities for virtual and pervasive worlds. This paper is among the first to explore the concept of distributed pervasive worlds, with a focus on their design, implementation, and deployment. Educators and scholars interested in pervasive worlds will benefit from our study.

As a case study for distributed pervasive worlds, we present Running Othello—a distributed pervasive exergame (DPE) combining a board game with physical exercise. An exergame was chosen as the target of our exploration in part because obesity...
is a global challenge (World Health Organization, 2014), and games are intrinsically motivating and immersive (Garris, Ahlers, & Driskell, 2002; Islas Sedano, Leendertz, Vinni, Sutinen, & Ellis, 2013; Malone & Lepper, 1987; Sweetser & Wyeth, 2005).

Figure 1. Connections between world types and Milgram and Kishino’s environments (1994)

By reviewing the literature and analyzing the development and evaluation processes in Running Othello, we aim to address the following questions: What aspects are important in the design process of DPEs? How do the players perceive the concept and distributed gameplay in Running Othello? What challenges does developing a DPE? What are the dimensions of distribution for Running Othello? Before investigating Running Othello, we survey the literature to understand DPEs generally and to determine their design principles.

Literature survey

Exergames

Exergames combine physical exercise with digital gaming to deliver cognitive and physical challenges in an attractive package—with physical, psychological, cognitive, and academic benefits (Staiano & Calvert, 2011). Modern exergames utilize context-aware technology, which is also used in pervasive games (Magerkurth, Cheok, Mandryk, & Nilsen, 2005).

Researchers have coupled exergames and networking to enable distributed gameplay. Table tennis for three (Mueller & Gibbs, 2007) combines a table tennis board with video conferencing to allow three players to play against each other on distributed installations. The players are able to communicate through video and audio channels. Virtual Network Marathon (VNM) players participate in a marathon over a network connection (Zhang et al., 2012). The players run on sensor-enhanced treadmills as they observe their avatars in a virtual 3D environment while learning about Chinese culture and the Beijing Olympics. In Virtual Tug-of-War (Harfield, Jormanainen, & Shujau, 2009) players of two distributed teams pull a physical rope connected to a device measuring the force of pull. This measuring device relays the force data to software that visualizes the data and exchanges it with software running on the opposing team.

Smartphones eliminate the need for specialized controllers and enable outdoor gameplay in exergames. In Zombies. Run! (Six to Start, 2012), a player is chased by virtual zombies, and the smartphone’s sensors track the player's location, motion, and speed. GeoBoids (Lindeman et al., 2012) uses augmented reality, GPS, and audio to allow the player to interact with and capture GeoBoid creatures by running after them. Health Defender (Wylie & Coulton, 2008) is a Space Invaders clone where the player shoots down viruses. A heart-rate monitor is used in bonus tasks. Kiili and Merilampi (2012) use the smartphone’s accelerometer for simple exergames, monitoring physical activities such as squats and jumps.

The design for most exergames focuses on physical activity, such as running (VNM, Zombies. Run!), or pulling (Virtual Tug-of-War). What if we could focus on strategy in games, with physical activity as a consequence of gameplay? To explore this possibility, we transformed the strategic board game, Othello, into an exergame.

Design principles for distributed pervasive exergames

In ideal circumstances, design principles guide the application development process. In the case of novel systems, such design principles are often derived after analyzing empirical interventions. In developing Running Othello, we
did not have any design principles for DPEs to guide us. However, we derived design principles from exergame literature to aid in the analysis and discussion of our study, and these can later serve as guidance for developers.

The VNM was built using the ISCAL (Immersion, Scientificalness, Competitiveness, Adaptability, Learning) design model (Zhang et al., 2012). An exergame should support immersion such that the players feel that they are participating in a realistic sporting experience. Scientificalness implies that the game’s exercises are scientifically valid. Competitiveness calls for competitors to be included to increase the feeling of a competitive sport. An exergame should also be adaptable to the players’ respective fitness levels. Finally, the game should include learning content.

The Dual-Flow model (Sinclair, Hingston, & Masek, 2007) was developed for optimizing the effectiveness of exergames. The model (Figure 2) explains how a player can enter the flow in two dimensions: attractiveness and effectiveness. For an exergame to be attractive, a balance should be reached between skill and challenge. To be effective, it must have an optimal intensity-to-fitness ratio. Because all these properties are subjective, the exergame should be adaptive to player profiles.

Gao and Mandryk (2011) proposed the concept of casual exergames for motivating people to exercise in small chunks of time. They demonstrated the concept with a PC-based exergame, using the Microsoft Kinect motion detector, and discovered nine design principles for casual interaction and efficacious exercise (Figure 3). Gao and Mandryk derived the design principles from casual-games research and based efficacious exercise principles on the recommendation that effective exercise must continue for a period of 30 min per day where the heart rate and caloric expenditure reaches a certain level.

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**Figure 2.** Dual-Flow model (Sinclair et al., 2007)

**Figure 3.** Casual exergame design principles (based on Gao and Mandryk, 2011)
Social exergames comprise social interaction via online gameplay. The ExerLink platform (Park et al., 2012) supports the construction of social exergames that can be played with heterogeneous exercise devices such as jumping ropes, treadmills, and stationary bicycles. The ExerLink platform design was based on (1) the adaptation to exercise- and player-specific differences, (2) adaptability to network latency, (3) the provision of rich interaction modalities, and (4) the provision for exercise history information.

We identified 13 design principles for DPEs from the reviewed literature (Figure 4), grouping them into five topics organized into three layers. The Technical layer contains essential principles for any reusable pervasive system development (Baldauf, Dustdar, & Rosenberg, 2007; Laine, Islas Sedano, Sutinen, & Joy, 2010). The Socio-cognitive layer focuses on the user’s mind and interactions. It comprises principles that aim at making the system appealing and useful through social and cognitive dimensions. Finally, the Exergame layer contains principles related to exergames.

![Figure 4. Design principles for DPEs](image)

These principles are a starting point for the design and analysis of DPEs. Although they are described exclusively from the DPE perspective, the technical and socio-cognitive principles are generic and thus applicable to any distributed pervasive world. For example, Adaptability might refer a system’s ability to adapt its behavior to learner profiles and learning contexts. Furthermore, the Gaming principles are pertinent to any game-like pervasive world.

Running Othello

“It was fun and different. You can see that a mobile phone doesn't always have to have a negative effect on health.” (F16)
The game concept

Othello is a strategic turn-based board game where two players compete on an 8×8 board using black and white pawns. All pawns have the same properties and available moves depending on their position on the board. The players capture the opponent's pawns by moving their own pawn over it in a straight line (Figure 5). The game ends when the board is full, when there is only one color left, or when no further moves are possible.

![Figure 5. Tag reading and game-board](image)

Running Othello is an Android-based exergame version of Othello, developed for the SciFest 2013 science festival in Finland. Players in Korea and Finland played together in a virtual world using their respective physical environments. The Running Othello board size can be customized to any physical dimensions and grid size to encourage running. For example, a 10×10 board might be deployed in a large area in a park where local matches can take place on a single board. However, Running Othello encourages distributed gameplay over a network connection on boards.

![Figure 6. Running Othello missions](image)
distributed worldwide. Near-Field Communication (NFC) tags are used as game-board cells for quick interaction. Numbers on the NFC tags and on the virtual board are identical, so the player must visually match the boards. To make a move (i.e. to conquer a cell), the player touches a tag with a smartphone initiating a random mission. If the mission is successful, the smartphone displays an updated virtual game-board. There are three mission types: physical, awareness, and reaction (Figure 6). An awareness mission is a quiz on the importance of water, in accordance with SciFest’s theme.

As a design decision, we removed turn-taking from the game to encourage running and thinking quickly, resulting in two consequences. Firstly, sporty and clever players can make consecutive moves. We used additional pawns in the initial setup to prevent a skilled player from finishing the game too quickly. Secondly, two players can read the same tag simultaneously. In such cases, the first player to successfully finish the mission conquers the cell.

**Distributed implementation**

Distributed gameplay is enabled with a server running on J2EE Servlets to which game clients connect via HTTP. The system architecture is presented in Figure 7. The server manages user profiles, channels, the board/rules, and the database. After first configuring the server address in client’s preferences, the player must register a new profile. Then, the player can login and create a game channel or join an existing channel. A single channel supports two players, but the server can handle multiple channels. Once a channel is full, the match begins. Two players can share the same physical board or play on distributed boards. One board can host multiple simultaneous matches. In every case, the board must be constructed from the NFC tags before playing. Tags must be programmed with numbers indicating their location on the board. The game client requires Android 2.3 or higher. Apart from tags and smartphones connected to the server, no other equipment is needed for gameplay.

![Figure 7. Architecture for Running Othello](image)

The content of a read tag is sent to the board/rule manager for validation. If the move is invalid, an error is returned. Otherwise, the server returns a randomly chosen mission, or—if the player is lucky—the cell is conquered directly.
The player must complete a given mission before the cell is conquered. Clients receive game-board updates from the server after conquering the cell or by polling.

Extensibility is important in any learning system for facilitating reusability. Running Othello’s extensibility is twofold. Firstly, new quizzes can be added to the database without updating the software. Secondly, missions are implemented as Android Activities that are linked to the game-board Activity. New missions (e.g., educational tasks) can be added to the system with simple source-code modification. When the player makes a move (i.e., reads a tag), any mission attached to the game can be launched. This way, Running Othello can be used as a platform for any type of game activity.

**Evaluation**

To identify the technological hurdles facing distributed pervasive worlds we evaluated Running Othello from two perspectives:

- Players’ perceptions of gameplay, answering the research question: *How do the players perceive the concept and distributed gameplay in Running Othello?*
- Developers’ perceptions on the game-development process, answering the research question: *What challenges does developing a DPE entail?*

The gameplay was evaluated in three sessions with a total of 28 players. After local evaluations in Korea during two sessions, we evaluated the game between players in Korea and Finland at SciFest 2013 where players communicated over Skype. Figure 8 illustrates the evaluation settings with distributed gameplay.

![Figure 8. Evaluation settings](image)

<table>
<thead>
<tr>
<th>Time and location</th>
<th>Purpose</th>
<th>Participants</th>
<th>Gender; average age</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 2013, Korea and Finland</td>
<td>Evaluate distributed gameplay during SciFest 2013 festival.</td>
<td>2 university students from Korea; 7 SciFest participants.</td>
<td>Koreans: 2 males; 27 Finnish: 4 males; 28</td>
</tr>
</tbody>
</table>

Figure 9 indicates the process for a mixed-method evaluation to answer the research questions above. The gameplay data were collected with a questionnaire and through observations. The questionnaire was based on a previous exergame evaluation (Kim et al., 2014). The questionnaire included demographics, qualitative and quantitative (Likert scale) instruments on previous gaming and exercise experiences, positive and negative experiences with Running Othello, motivation, game features, usability, suitability, and a comparison with computer games and sports. The questionnaire was available in Korean, Finnish, and English. The development evaluation utilized the data from developers’ essays written after the project.

For the evaluations, we first installed the game on Samsung Galaxy S2 and S3 smartphones that connected to the server in Korea. The players were first presented with the game concept and research objectives. The players then played against opponents for approximately 2-10 min during which they only used Running Othello and no other features of the phone. During the gameplay, researchers and developers noted observations, and prompted the players for verbal feedback after playing. Finally, the players answered the questionnaire and were permitted to ask for clarifications.
Gameplay evaluation

The following presents the evaluation results on features, ease of use, and suitability of Running Othello with mean ($\mu$) and standard deviation ($\sigma$) values, followed by a correlation analysis. Statements that were exclusive to the SciFest questionnaire are marked “SF.”

Features

Statements 1-5 in Figure 10 refer to the question “Which of the following features were interesting?” Among the features, using NFC tags was rated the highest (93%) whereas Othello game rules received the lowest rating (68%), possibly because 25% had no opinion and 29% reported that they did not know Othello beforehand. These results followed these open question answers regarding what they liked or enjoyed about the game:

“Touching the tag is amazing and fun. It is a fun game.” (M13).
“It is fun to think to get more points than my partner to win.” (F21).
“A real opponent. A feeling of doing something vs. sitting on a computer.” (M33).
The aforementioned comments reveal some motivators (curiosity about technology, competition, social gameplay, and hands-on experience) complemented by the developers’ perceptions (curiosity, novelty, and exercise):

“The game fascinated the kids somehow since they can play with Korean players, use smartphones, and explore surprising tasks. For example, one kid tried to spin as fast as possible. Consequently, he fell down, but he still laughed loudly. In aspects of curiosity and technology, the game succeeded.” (M24).

“Two of the teachers showed great interest in the game. They believed it is a new type of game and will make kids do more exercise when playing.” (F29).

Statements 6 and 7 answer the question “What was the reason for you to continue playing (what motivated you)?,” thus measuring how running and phone usage influenced the players’ motivation. Running connects to aforementioned hands-on experience and exercise motivators, whereas phone usage relates to curiosity about technology, and particularly to interactions through NFC and sensors, which bore novelty in the target contexts at the time of evaluation. The phone usage motivated most players (71%) while many had no opinion regarding running (39%), thus leaving positive answers for 36%. This can be partly explained by the test locations where limited board sizes did not require much running.

**Ease of use**

Statement 1 measures a phone’s easiness as an interaction tool for DPEs (Figure 11). In contrast to traditional user-phone-interaction, interaction in Running Othello occurs via embedded motion sensors and NFC tags on the floor. The result of statement 1 (79%) shows that the novel way of using the phone was considered as easy, yet it could be improved (see comments below). Understanding the challenges (89%) and reading tags (78%) were also regarded as easy. The ease of game’s controls received 68% positive and 25% negative answers. Poor sensitivity in the sensors might explain some of the negative answers. Players reported this and other problems, when asked what they disliked or found difficult in the game:

“Some tasks didn't work properly. For example, in turning I had to spin 10 times to count.” (M25).

“Finding point [the NFC tag] is difficult.” (M13).

“I didn’t know the game rules the first time.” (F21).

![Figure 11. Ease of use](image)

A developer suggested that Othello’s unfamiliarity could be mitigated were the rules better explained:

“Many kids do not know this game before; they felt it is hard to get the rules. However, after we presented [the game] they were getting excited.” (F29).
Suitability

The game’s suitability to the players’ skill levels, available time, and money is reported in Figure 12. It was considered easy for beginners (79%), and most thought it matched their skill levels (86%). Statements 3 and 4 were both rejected by 46% of the players, while 36% gave no opinion. Statement 5 was answered by 19 players, most of whom were willing to pay up to $4.99. This shows that Running Othello could go beyond prototyping.

Figure 12. Suitability (1 = This is easy game for beginners, 2 = This game is suitable for my skill level, 3 = Game was too long, 4 = Game was too short, 5 = How much would you pay for the game)

The game can feel long due to repetitive missions. One player suggested that the game should include more variety when we asked how it might be improved:

“Don’t make the same mission appear. Add more variety of missions.” (M25)

Correlations

Table 1 presents statements having significant correlations (<= -0.5, >= 0.5). Age (1 = 13-17, 2 = 18-22, 3 = 23-26, 4 = 27-30, 5=>30) correlates negatively with running as a game motivator (-0.57) and with the game being easy for beginners (-0.5). This suggests that young players enjoyed the running more than older players and that they felt the game was more approachable.

Table 1. Correlations

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-</td>
<td>-0.49</td>
<td>-0.19</td>
<td><strong>-0.57</strong></td>
<td>-0.4</td>
<td><strong>-0.5</strong></td>
<td>-0.42</td>
</tr>
<tr>
<td>2. Interesting feature: Othello game rules</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td><strong>0.53</strong></td>
<td>0.05</td>
<td><strong>0.65</strong></td>
<td><strong>0.76</strong></td>
</tr>
<tr>
<td>3. Motivation: using mobile phone</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.31</td>
<td><strong>0.5</strong></td>
<td>0.23</td>
<td>0.22</td>
</tr>
<tr>
<td>4. Motivation: running</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.16</td>
<td>0.35</td>
<td>0.34</td>
</tr>
<tr>
<td>5. Willingness to pay for the game</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.07</td>
<td>-0.3</td>
<td></td>
</tr>
<tr>
<td>6. Easy game for beginners</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td><strong>0.72</strong></td>
</tr>
<tr>
<td>7. Suitable for my skill level</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

The simplicity of Othello’s rules made it easy for beginners (0.65) and at a suitable skill level (0.76), two qualities that also correlated (0.72). Furthermore, those who liked Othello’s rules were also often motivated by running (0.53).
The players who were motivated to play with a mobile phone were more willing to pay for the game (0.5). The culture of purchasing mobile applications among children and young adults may have an effect on these results, and this should be explored in future research.

Development evaluation

In 2012 fall two Korean undergraduate computer science students created the first prototype for Running Othello. In January 2013, one Vietnamese and two Chinese students from a Finnish university joined the project. Korean students spent three weeks in Finland to initiate the distributed work. When the project was completed, the developers wrote essays on their experiences. The analysis of the data, including our observations, resulted in 11 challenges and solution proposals (Table 2) which can help distributed pervasive world developers.

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Explanation</th>
<th>Solution proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Network connectivity</td>
<td>In a distributed environment, the network is often a bottleneck. During SciFest, the game server was located in Korea, causing a noticeable delay in client-server communication. The game was playable, but location transparency failed.</td>
<td>Slow connection speeds can be mitigated by providing adequate network resources between clients and servers, by minimizing the number of server calls, and by applying data compression.</td>
</tr>
<tr>
<td>2. Activity detection</td>
<td>In exergames, detecting the player’s activity and physical status is essential. Some players reported that the game did not react properly to physical activity. There are two possible reasons for this: (1) The sensor data was poorly processed, and (2) the players were performing the missions incorrectly. For example, the activity detection algorithm can fail if the phone is held incorrectly.</td>
<td>Some physical missions used the deprecated orientation sensor. To improve the results, missions compute orientation from the accelerometer and magnetic field sensors. Low-pass filtering could be used to remove noise from the sensor data. Players should also be instructed to perform the missions correctly.</td>
</tr>
<tr>
<td>3. Distributed development</td>
<td>Distributed game development between two countries was challenging in terms of time and cultural differences. Because Korean students started the project earlier, it was difficult for the students in Finland to join, thus limiting their work input. The most productive time for collaboration was when two Korean students travelled to Finland.</td>
<td>With any global software development, special care must be taken to foster multicultural collaboration. All members should join the project as early as possible. Furthermore, student-researcher exchanges should be encouraged and cultural differences mitigated by the project leader.</td>
</tr>
<tr>
<td>4. Contextualization</td>
<td>Running Othello was designed to be portable across contexts. The game rules are easy, and the content was translated into target languages. Despite this, one of the challenges was to integrate the game with SciFest’s water theme.</td>
<td>A successful pervasive exergame should serve the target context’s needs. The user interface and content should be customizable so that the game can be adapted to different contexts. In Running Othello, we used customizable quiz missions to match SciFest’s theme.</td>
</tr>
<tr>
<td>5. Multiplayer management</td>
<td>To run multiple concurrent matches, a multi-channel mechanism was developed. This was not part of the original prototype server design.</td>
<td>Server design should focus on multiplayer aspects. Furthermore, support for multiple concurrent game sessions should be planned from the</td>
</tr>
</tbody>
</table>
Modifying the server code produced errors in the code. Channel joining, parting, and synchronization were particularly tedious to implement reliably. Channel joining, parting, and synchronization were particularly tedious to implement reliably. Multiplayer management should be tested in different environments.

### 6. Game-board updates and synchronization

To update game-boards, the clients request updates from the server at regular intervals. This generates several network requests, which may slow down the connection. Game-board synchronization is challenging when two players try to conquer the same tag simultaneously. In Running Othello, the client who transmits a successful mission message first will conquer the tag.

In the case of game-board updates, the client should know which one is the latest. This can be solved with a timestamp. To decrease the number of client-server requests, a push mechanism (e.g., Google Cloud Messaging) could be used.

### 7. Game-board visualization

Some players found it difficult to match the NFC tags with the virtual game-board. This requires visual coordination skills that vary from person to person. We used the tag ID numbers to make matching easier, but it was challenging nevertheless.

To improve the game-board visualization, the game should use visual cues, such as background colors, to indicate rows and columns. LED lights could also be connected to the NFC tags with the cost of increased price and decreased portability.

### 8. Multimedia

Running Othello does not use any sound effects other than background music. Moreover, there are no videos or animations. Whereas the lack of multimedia does not render the game unplayable, including them could boost the user experience.

Sound effects, vibration, and other interaction methods should be used to indicate the opponent’s actions. By including tutorial videos and animations, we can decrease the learning curve.

### 9. User interface

Both players and developers mentioned Running Othello’s unpolished user interface, which was due to lack of time and skills.

All mobile apps should have a simple and intuitive user interface. Because the programmers may be unskilled with interaction and graphic design, it is important to work with specialized designers.

### 10. Player communication

Player communication is important in a distributed environment. During SciFest, we opened a Skype video connection between Korea and Finland, but the players did not use it during gameplay.

Player communication through multimedia can enhance the social aspects of gameplay. Communication should also be available when selecting the channel/room.

### 11. Player motivation

Original technology and ideas motivated the players at first, but the game was evaluated over a short period of time. The long-term motivational effects are unknown. Some players noted that repetitive missions could be de-motivating.

Exergames should contain features that are known to facilitate the players’ intrinsic motivation (e.g., challenge, fantasy, competition, control, cooperation, recognition and feedback). They should avoid repetition and encourage variation.

### Discussion

The players evaluated Running Othello’s features, ease of use, and suitability. The game’s technology played a central role in the players’ perceptions. Positive ratings given for the NFC tags usage may have been the result of
their novelty because NFC tags were uncommon technology at the time of evaluations. From the perspective of ease of use, one interesting point is that despite the difficulty that some players experienced in locating tags, reading them was considered easy (78%). These results suggest that the NFCs are suitable for pervasive exergames, but mappings between virtual and physical worlds must be clearly defined.

Because of the fact that gameplay is short, it is not possible to comprehensively analyze the game’s immersive aspects. However, there is evidence that most players were stimulated by the challenge in terms of mastering the technology, competing and solving the puzzles (Figure 10). One developer cited curiosity as a motivator. It is possible that the novelty of the technology, or the game system itself, raised the curiosity of the players.

Some players complained that mission instructions were unclear and activity detection was poor. We used graphical illustrations to show players how to perform the physical missions, but these may not have been sufficiently clear. A tutorial could be used to rectify this, and the quality of the sensor data could be improved with filtering. These could increase the success rate of missions and player satisfaction.

Although suitability statements showed positive results, it is difficult to say whether the game would remain suitable given long-term deployment. Strong correlations between Othello’s rules, its ease for beginners, and its suitability to varying skill levels suggest that basing the game on Othello without turn-taking was a successful design.

Many players answered quantitative statements with “No opinion”—e.g., regarding the “Othello game rules” (25%), and whether the “Game was too long/short” (36%). Perhaps these statements were poorly understood by some players. The questionnaire should be improved in order to increase its clarity and encourage respondents to have an opinion.

To facilitate an understanding of the meaning and implications of the evaluation results, we identify four dimensions of distribution in the following section. Additionally, we analyze the applicability of our 13 DPE design principles for Running Othello. Finally, we discuss the educational potential for Running Othello and the limitations of this research.

Dimensions of distribution

Through the analysis of the game’s concept, development, and evaluation, four dimensions of distribution emerged: focus, gameplay, technology, and development.

**Distributed focus** refers to a situation where the user’s attention is shared between multiple activities. In Running Othello, the player’s focus is distributed between activities that occur simultaneously in the virtual world (the virtual game-board, awareness and reaction missions, and the virtual opponent) and the physical world (the physical game-board, physical missions, and a real opponent). The player must sustain cognitive thinking and strategic reasoning under time pressure and physical exertion. Supported by Gameplay Evaluation: Features; Development Challenge 7: Game-board visualization.

**Distributed gameplay** has been studied from several perspectives. Massively Multiplayer Online Role-Playing Game (MMORPG) researchers have investigated how virtual worlds can be handled technically by dividing them into regions across servers (Assiotis & Tzanov, 2006). The rise of pervasive technology has called for explorations beyond technical challenges into game mechanics that combine distributed gameplay and enjoyment together (Mueller & Gibbs, 2007). In Running Othello, distributed gameplay manifests itself as a real-time battle between players in different locations. By providing player-to-player competition and communication, the feeling of togetherness can be enhanced. Unlike MMORPGs, it is not necessary to divide computing across multiple servers because there are few concurrent players. Supported by Gameplay Evaluation: Features, and Development Challenge 10: Player communication.

**Distributed technology** enables distributed gameplay over the internet. Conceptually, Running Othello’s client-server architecture enables players from anywhere in the world to play against each other. Practically, some players are affected by limitations such as communication latency and cost. Designing distributed technology requires special attention to the implementation of efficient communication and to graceful error handling. Supported by
Development Challenge 1: Network connectivity; Challenge 5: Multiplayer management; Challenge 6: Game-board updates & synchronization.

The distributed development for Running Othello was conducted by students in South Korea and Finland. The developers gained unique experience from this international collaboration, allowing them to work remotely and also face-to-face. The distributed development provided a natural environment for distributed evaluation. Supported by Development Challenge 3: Distributed development.

Running Othello and design principles

We used the 13 proposed design principles for DPEs (see Figure 4) as a tool for analysis. Table 3 exemplifies the applicability of each design principle for Running Othello with supporting data gathered in this study.

<table>
<thead>
<tr>
<th>Principle</th>
<th>Applicability in Running Othello</th>
<th>Supported by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All ages and fitness levels</td>
<td>Game rules and content suit everyone. Physical missions should be scientifically valid for all age groups and fitness levels.</td>
<td>・Gameplay Evaluation: Suitability ・Challenge 11: Player motivation</td>
</tr>
<tr>
<td>Physical challenges</td>
<td>Running Othello has physical missions, but they should be scientifically valid. Moreover, physical challenges that are more effective should be created.</td>
<td>・Gameplay Evaluation: Features, Suitability ・Challenge 2: Activity detection</td>
</tr>
<tr>
<td>Gaming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear rules and controls</td>
<td>Othello’s rules are well-known and simple. Controls for the game are easy, but additional instructions are needed for physical missions.</td>
<td>・Gameplay Evaluation: Usability, Suitability ・Challenge 7: Game-board visualization ・Challenge 9: User interface ・Gameplay Evaluation: Features ・Challenge 8: Multimedia ・Challenge 11: Player motivation</td>
</tr>
<tr>
<td>Immersion</td>
<td>Challenge is a motivator in strategic games. Running Othello is motivating in the regard, as well as with regard to curiosity. Other motivators (e.g., fantasy) could be included in future research.</td>
<td></td>
</tr>
<tr>
<td>Sociality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competition, collaboration</td>
<td>In Running Othello, two players compete against each other. Currently there are no collaborative tasks.</td>
<td>・Gameplay Evaluation: Features ・Challenge 5: Multiplayer management ・Challenge 10: Player communication ・Gameplay Evaluation: Features ・Challenge 8: Multiplayer management ・Challenge 10: Player communication</td>
</tr>
<tr>
<td>Social interaction</td>
<td>Playing against a human rather than a computer was a key design decision. The interaction with a remote opponent could be improved by text, voice, and video chat features.</td>
<td></td>
</tr>
<tr>
<td>Cognition and learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive challenges</td>
<td>The player’s cognition is stimulated with Othello’s strategic challenges and the demand for visual coordination. The quiz presents additional cognitive problems to solve.</td>
<td>・Gameplay Evaluation: Features ・Challenge 7: Game-board visualization</td>
</tr>
<tr>
<td>Raising awareness</td>
<td>Running Othello included a quiz to raise awareness on the importance of water. In the future, the game could also raise awareness about exercising and the player’s body.</td>
<td>・Challenge 4: Contextualization</td>
</tr>
<tr>
<td>Distributed pervasive architecture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptability</td>
<td>Running Othello is not adaptable to different user profiles or surrounding contexts.</td>
<td>・Challenge 4: Contextualization</td>
</tr>
</tbody>
</table>
Context-awareness

Context-awareness is achieved with the NFCs and smartphone sensors. This can be improved by enhancing data processing and using body sensors (e.g., a heart-rate monitor).

Extensibility

It is easy to launch any Android Activities (i.e., missions) from Running Othello. Quiz missions can be extended with customized questions.

Portability

Transferring Running Othello between contexts is easy because it does not depend on the physical location. The game is deployable anywhere with the basic technology (smartphones, networking, and tags).

Distributed operation

The architecture of Running Othello was designed to support distributed gameplay. Communication delays should be minimized.

Gameplay Evaluation: Features

- Challenge 2: Activity detection
- Challenge 4: Contextualization
- Challenge 6: Game-board updates and synchronization

Gameplay Evaluation: Features, Suitability

- Evaluations locally in Korea, and globally between Korea and Finland
- Challenge 1: Network connectivity
- Challenge 5: Multiplayer management

- Challenge 1: Network connectivity
- Challenge 5: Multiplayer management
- Challenge 6: Game-board updates and synchronization
- Challenge 10: Player communication

The proposed design principles applied here as a tool for analysis constitute the first means for guidance in comprehending the complexity of DPEs. These principles are not intended to replace existing design principles for games, human-computer interaction, or pervasive software development. Rather, they are intended to complement previous knowledge, and to offer guidelines for critical areas typical to DPEs.

Educational potential of Running Othello

It is noteworthy that Running Othello is more than a DPE. It functions as a distributed pervasive world platform that can be extended with missions (i.e., with Android Activities). When a player makes a move, any mission (e.g., an educational task) can be launched. Running Othello has potential to support the following:

- The learning objectives of the educator to use the platform as a tool for gamification or to support game-based learning and facilitate the immersion and motivation of students.
- The learning activities of students to achieve the educator’s vision: Cognitive challenges related to a specific theme (e.g., illustrate sport injuries, ask mathematical questions, or show language flash-cards). A suitable pedagogical model for this is so-called microlearning, where a large topic is divided into micro-learning units to be studied in brief sessions (Hug, 2007) Physical challenges that entice the player to learn about their physical capabilities (e.g., in physical education classes).
- A contextualized impact on the learner by involving contextual resources with collaboration and competition. Developers can utilize context data (e.g., sensors and the weather) to make missions relevant to the student’s particular context.
- Novel interactions enabled by the distribution dimensions of the system that are not otherwise possible (e.g., in real-time global play with local objects).

Limitations

The study is limited as follows: (1) The sample size (28) was too small to make generalizations or claim a high degree of reliability, (2) the play time was too short to identify the long-term impacts, (3) the physical missions were not validated with scientific guidelines, and (4) the educational potential of Running Othello was not verified. These limitations will be addressed in future research.
Conclusions

The concept of pervasive worlds is an evolutionary shift away from virtual worlds toward the border area straddling the physical and virtual world. This process is facilitated by the ubiquity of smartphones and their capacity to deliver context-sensitive experiences to the user. To answer four research questions, we presented the development and evaluation of the Running Othello exergame as a case of distributed pervasive worlds.

The research question “What aspects are important in the design process of DPEs?” was answered with a literature review. As the result, 13 design principles for DPEs emerged. The gameplay evaluation answered the question “How do the players perceive the concept and distributed gameplay of Running Othello?,” suggesting that the concept of Running Othello has the potential to motivate and support players to explore and discover various subjects beyond their physical locations through play. However, the results also indicated that the merging of physical and virtual worlds introduces diverse challenges. To answer the question “What challenges does developing a DPE entail?,” we analyzed developers’ reflections and our own experiences with the development challenges. Finally, based on multiple analyses of the evaluation results and the development process, four dimensions of distribution (viz., focus, gameplay, technology, and development) emerged to answer the question “What are the dimensions of distribution for Running Othello?”

The dimensions of distribution we identified introduce many technical and conceptual challenges that need to be addressed in the development process. Some technical challenges were presented in this paper, but a complete taxonomy remains to be created. The proposed design principles can alleviate some of the challenges, but we have just now taken the first steps toward a thorough comprehension of the conceptualization, design, implementation, and evaluation of distributed pervasive worlds.

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References


