Fostering Player Collaboration Within a Multimodal Co-Located Game

Georgi Yordanov Kostov

MASTERARBEIT

eingereicht am
Fachhochschul-Masterstudiengang

Interactive Media

in Hagenberg

im September 2015

Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Hagenberg, September 28, 2015

Georgi Yordanov Kostov

Contents

Abstract

Advancement in computational power, mobile devices, display and sensor technology have led to the appearance of multiple mixed reality applications and devices. Enhancing the real world with digital images and vice versa has become accessible for the wide public. Through the combination of sophisticated projection and tracking systems, public spaces can be converted into huge game arenas, allowing players from different ages and genders to participate. This presents unique opportunities for designing games that explore collaboration, proximity and communication between players. In order to involve the audience and introduce novel interaction possibilities, a co-located game can be extended through a multimodal component. The evolution of virtual reality head-mounted displays to commercial devices allows this component to introduce a new dimension to the game.

This thesis explores the design and implementation of a mixed reality game and delves into multiple areas of research and game design. The major focus of the project is the investigation of collaborative game mechanics and audiovisual means for communication transmission. The goal is to discover if real and virtual environments can be successfully combined in order to provide players with an innovative way to interact and cooperate.

Kurzfassung

Fortschritt in Rechenleistung, mobilen Geräten, Displays und Sensoren haben zum vermehrten Auftreten von Mixed Reality Anwendungen und Produkten geführt. Die Erweiterung der realen Welt durch digitale Bilder und umgekehrt ist für die breite Masse zugänglich geworden. Durch die Kombination von komplexen Projektionen und Tracking-Systemen können öffentliche Räume in riesigen Spiel-Arenen umgewandelt werden, wodurch Spieler aus unterschiedlichen Altersgruppen und Geschlechter mitspielen können. Dies bringt einzigartige Möglichkeiten für die Gestaltung von Spielen, die Zusammenarbeit, Nähe und Kommunikation zwischen den Spielern zu erforschen. Um das Publikum einzubeziehen und neue Interaktionsmöglichkeiten zu schaffen, kann ein Co-Located-Spiel durch einen multimodalen Komponenten erweitert werden. Die Entwicklung von Datenhelmen zu kommerziellen Geräten ermöglicht die Einführung von dieser Komponente, die eine neue Dimension des Spieles darstellt. Diese Arbeit untersucht das Design und die Implementierung von einem Mixed-Reality Spiel und vertieft sich in mehreren Bereichen der Forschung und Game Design. Der Schwerpunkt des Projekts ist die Untersuchung von kooperativen Spielmechaniken und audiovisuelle Mitteln zur Kommunikationsübertragung. Das Ziel ist, herauszufinden, ob reale und virtuelle Umgebungen erfolgreich verknüpfen werden können, um Spielern eine innovative Interaktion und Kooperationsmöglichkeit anzubieten.

Chapter 1

Introduction

1.1 Motivation

Standard computer and console games have reached a certain limit of what they can offer in terms of innovation and interaction possibilities. Traditional gaming systems provide users with displays and controllers that do not necessarily motivate human-to-human interaction. New forms of interaction that dissolve the borders between real and virtual are emerging. In recent years, advancements in mobile and display technology, projection, sensors and computer vision have allowed developers to experiment with new forms of entertainment. Combining gaming platforms with movement tracking and object recognition and the development of augmented and virtual reality technology have resulted in the introduction of innovative devices such as the *Nintendo Wii*[1], *Microsoft Kinect*[2], *Oculus Rift*[3] and a wide variety of public space installations and pervasive games.

The thesis aims to explore the exciting field of mixed reality gaming by focusing on a specific technical setup, introducing a virtual reality component to a sophisticated tracking and projection system. The realm of interaction possibilities in co-located installations can be expanded by introducing multimodal components that influence game events and player behavior.

1.2 Goals

The goal of this thesis is to explore player collaboration, communication and presence in a multimodal co-located game. To achieve this, two networked applications are created. The first one is a 2D application, developed for a specific co-located setup at the Ars Electronica Center in Linz. The second one is a 3D virtual reality application, which requires one player with

[1]http://www.nintendo.com/wiiu
[2]http://www.xbox.com/en-US/xbox-one/accessories/kinect-for-xbox-one
[3]https://www.oculus.com/en-us/

a virtual reality head-mounted display. Both applications need to work in temporal and positional unison. To achieve this, research is done in multiple areas such as mixed, augmented and virtual reality and multiple game design approaches are explored. The uncommon setup is investigated through the implementation of different game mechanics, audiovisual communication channels and game balancing. The final result are two networked applications, presenting users in both environments with enough possibilities to interact and collaborate, dissolving the border between them and exploring how they connect and socialize.

1.3 Structure

Chapter 2 introduces the main areas of research such as mixed, augmented and virtual reality, pervasive games and the theory of proxemics. It presents key terms and definitions, required for the better understanding of the discussed ideas and proposed solutions. It aims to explore the similarities between these fields and establish their connections as social immersive media.

Chapter 3 explores different approaches towards game design, combining ideas from experience, immersive social media, virtual reality, trans-reality and proxemics. Initial game ideas focusing on collaboration and competition, as well as the first approach towards game mechanics are presented next. The final game concept, including story, gameplay and audiovisual design, is presented last.

Chapter 4 introduces technical details such as the development environment, required hardware and application structure. The implementation of the game mechanics is presented next, focusing on each of the game's entities and exploring why certain approaches work and others do not. As the main chapter of the thesis, it presents the project in detail and provides the reader with an understanding of the iterative process that leads to the final result.

Chapter 5 presents the expert evaluation of the project. The approach is presented first, followed by the results of the expert interview. Finally, the results are analyzed and possible changes and improvements are discussed.

Chapter 2

Immersive Social Media

2.1 Definition

Immersive social media is a distinct form of augmented reality, defined by S.Snibbe and H.Raffle [20]:

> [...] media that favors interaction in a shared social space using a person's entire body as the 'input device', unencumbered by electronics or props.

According to the researchers users perceive 'reality' first with their bodies and then rationally. Interactive systems should therefore aim to first be experienced physically and after that mentally. Snibbe and Raffle also established a set of design principles based on their previous experience (see Section 3.1.1) with these types of installations and developed a number of applications to demonstrate them. Their work is mostly intended for public spaces and exhibitions, but social immersive media also found a way into the living room through devices like *Microsoft Kinect* and *Nintendo Wii*. Through the development of new technologies such as smart phones, virtual reality headsets and movement tracking systems, mixed reality games (see Section 2.2.3) are slowly penetrating our daily lives and becoming a part of our surroundings. Public spaces are evolving through new types of social experiences and people are learning to interact with each other and with technology in innovative ways. The terms and definitions presented in this chapter aim to describe the merging of real and virtual environments and delve into a variety of research fields through the perspective of immersive social media and co-located gaming experiences.

2.2 Mediated Reality

The ability to modify one's perception of reality by adding or subtracting information through a range of devices is referred to as mediated reality [14].

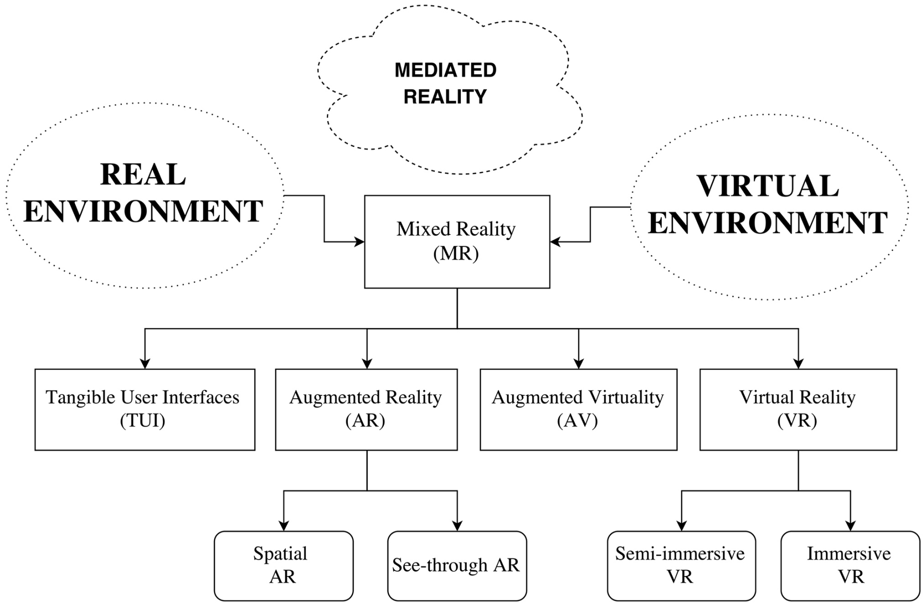


Figure 2.1: Reality-virtuality continuum

It is the sum of different terms, each one trying to describe the merging, enhancement or augmentation of real and virtual worlds. Researchers have made an effort to classify new technologies and applications, but it is often hard to place them in only one category. Figure 2.1, based on Mann's 'Taxonomy of Reality' and the 'Virtuality Continuum' representation by Milgram and Kishino[15], aims to present an overview of these different concepts and provide the reader with an understanding of how these terms coexist, where they overlap and what the main differences are.

2.2.1 Mixed Reality

Mixed Reality (MR) encompasses the merging of virtual and real environments through a range of technologies e.g. mobile devices, head-mounted displays (HMD), projection and movement tracking systems. It can be divided into two main areas: augmented reality (AR) and augmented virtuality (AV). AR enhances reality with virtual objects, while AV merges real objects with virtual worlds. It is important to note that researchers often use MR and AR for describing similar applications, but AR has become the more popular and widely used term. Virtual reality (VR) is an area closely related to MR and AR and is explored in a separate chapter (see Section 2.3) due to its significant role in the thesis project. VR and AR head mounted displays are similar in technological requirements and design challenges, but experi-

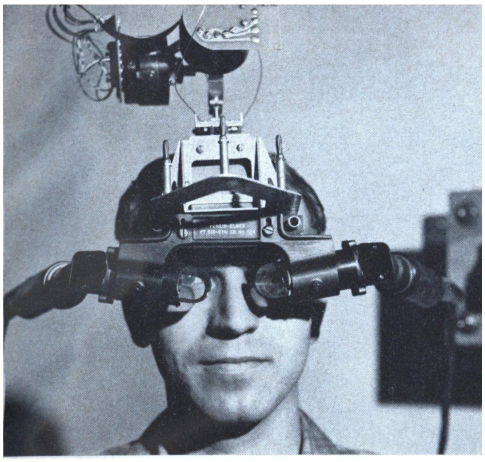


Figure 2.2: *The Sword of Damocles* by Ivan Sutherland

ences differ in the fact that VR completely shuts down the real environment and aims to immerse the user into a virtual world rather than enhancing the real one.

Classification of mixed reality systems is not always easy due to the different design approaches and technologies that can be used. A constantly developing field, such systems often have similar qualities and properties and use the newest available sensors, display systems, etc. Milgram and Kishino realized the need for a taxonomy of mixed reality displays and published a paper that establishes three essential factors for the proper definition of MR systems:

1. *Extent of World Knowledge (EWK)* – How much do we know about the world being displayed?
2. *Reproduction Fidelity (RF)* – How realistically are we able to display it?
3. *Extent of Presence Metaphor (EPM)* – What is the extent of the illusion that the observer is present within that world?

These questions can serve for the initial classification of MR systems, providing a basic guideline to designers and engineers. However, each of the main MR areas has subdivisions, which means that further exploration might be required for correct categorization.

2.2.2 Augmented Reality

The term 'augmented reality' was first defined by Caudell and Mizell, researchers at Boeing, who developed a see-through head-mounted display, allowing computer-generated diagrams to be displayed on top of real objects [2]. However, first iterations of the technology date back to the 1960s, when the first head-mounted display was developed by Ivan Sutherland [21]. *The Sword of Damocles* (Figure 2.2), considered as predecessor of current AR and VR displays, had its own general-purpose computer system, an ultrasonic head position sensor and could display simple vector images by also shifting the perspective, depending on user head movement. There are three main types of AR devices: head-mounted, hand-held and spatial. The first two can be grouped under the term see-through AR.

See-through Augmented Reality

See-through AR is achieved primarily through optical and video-based techniques. Real time video is used extensively by mobile devices. The surrounding real world environment is directly recorded and streamed by the camera, providing scale and positional relationships of objects and space so that virtual objects can be properly placed through the use of sophisticated computer vision algorithms. A commercial example is the 2013 IKEA catalog [26], allowing customers to place and manipulate digital furniture inside their homes. *Project Tango* by Google[1] employs a range of sensors for augmenting real world environments by measuring depth and shape of areas, recording movement in 3D space and automatically improving and expanding previously acquired data.

Several see-through AR devices using optical techniques are currently being developed. Most notable are head-up displays like *Google Glass*[2], *Microsoft HoloLens*[3] and *MagicLeap*[4]. The latter will reportedly introduce innovative optical projection directly into the eye of the user.

Spatially Augmented Reality

The main advantage of Spatial AR systems is that they do not require sophisticated head-mounted displays or any special input devices. Images are directly projected onto surfaces and objects, which allows multiple users to freely interact with the augmented environment. However, a number of factors must be considered for a pleasant experience: size of the room, surface material and texture, quality and resolution of the projection, brightness and contrast of the image and occlusion. If a tracking system is used, it should fit the projection space so that tracking points match user movement and provide low latency and high precision.

One specific setup for spatially augmented reality employs sophisticated projection and tracking systems to convert public spaces into huge interactive surfaces. It is located in the Ars Electronica Center in Linz, in a specially

[1] https://www.google.com/atap/project-tango/
[2] https://www.google.com/glass/start/
[3] https://www.microsoft.com/microsoft-hololens/en-us
[4] http://www.magicleap.com/

Figure 2.3: The *Game Changer Suite*, displayed in the Deep Space at the Ars Electronica Center in Linz.

designed and equipped room, the Deep Space. The system uses eight high-end projectors to display content in a resolution of maximum 8192 by 4320 pixels at 120 Hz, stereo 3D on both a 16 by 9 meter wall and floor[5]. The tracking system, consisting of six laser rangers Hokuyo UTM-30-LX1 LiDAR[6], placed in the corners of the room, is used to detect movement within the room. The raw data is processed and refined by a specifically designed tracking software, called *libPharus* [17]. It creates a tracking point with X and Y coordinates for each object, located between the laser rangers. The point is then used by an application to display virtual avatars, which players control by moving around the space. An example implementation of an application for this setting is the *Game Changer Suite* (see Figure 2.3), which combines five different game prototypes. Each one of them presents a unique challenge to the players and explores certain aspects of co-located games like proximity, social presence, collaboration and competition [5]. Available research and experience serve as a basis for the thesis project, which aims to investigate these areas further, while at the same time taking a mixed reality approach by introducing a multimodal element to the setup – a virtual reality HMD.

[5]http://www.aec.at/feature/en/deep-space-8k/
[6]http://www.hokuyo-aut.jp/

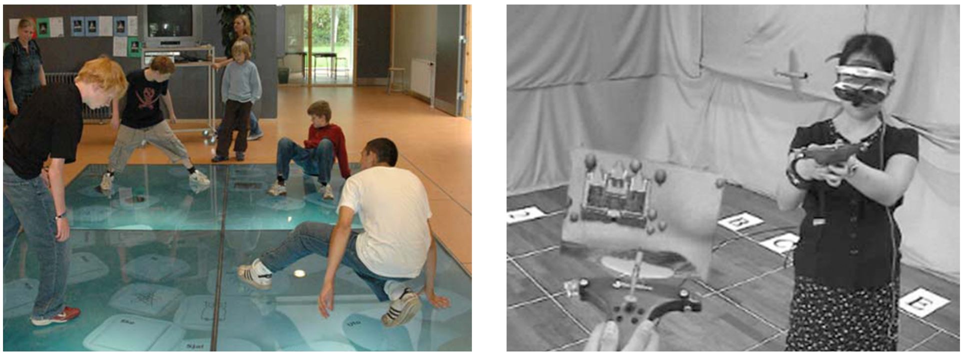


Figure 2.4: *iGameFloor*, a co-located game (left). *TouchSpace*, a mixed reality game (right).

2.2.3 Mixed Reality Games

Similar to the classification model, established on Figure 2.1, mixed reality games can be divided into three main groups: real world games (e.g. board games), virtual games (e.g. computer games) and mixed reality games. The term is used as a generalization for emerging game genres that blend virtual and real environments to create novel experiences and social interaction possibilities. Figure 2.4 shows two examples of such games. *iGameFloor* is a co-located game for public spaces, using rear projection and exploring collaboration and competition between students [7]. *Touch Space* combines a room-sized space, real tangible objects and head mounted displays to challenge two players to collaborate in three different stages [3]. Their goal is to save a princess by completing different tasks, which consist of moving around the real space and interacting with the virtual environment at the same time. The game progresses from an augmented state to a completely virtual environment, where players can see each other as digital avatars. *Time Warp* is a similar project, which lets players explore an entire city and augments it with graphics from different time periods [8]. Players are equipped with an HMD for augmenting the real environment and a hand-held device for input and information display. Triggering game events depends on player position, which is tracked by GPS.

MR games combine elements from different game genres and due to their experimental nature, proper classification is often hard. New genres like pervasive, trans-reality, location based and alternate reality games have emerged in the search for better definitions.

Pervasive Games

Hinske et al define pervasive games as “[...] a ludic form of mixed reality entertainment with goals, rules, competition, and attacks, based on the

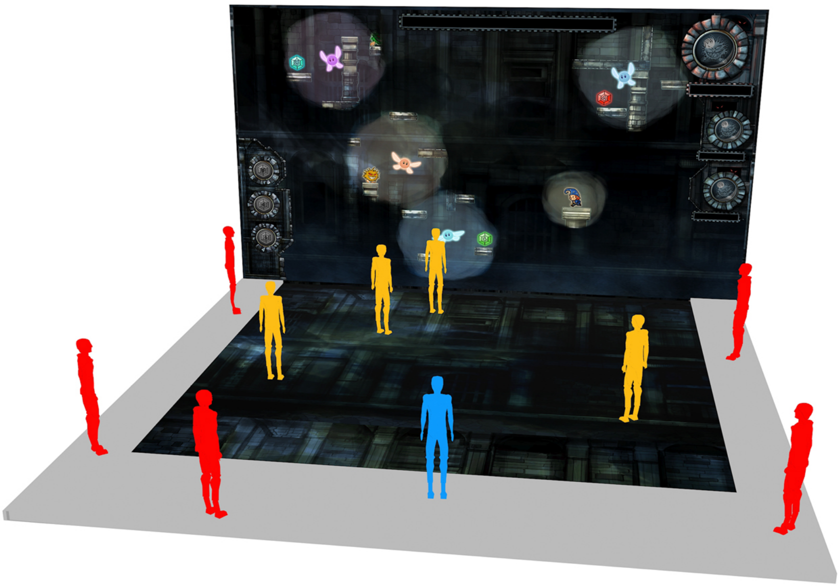


Figure 2.5: *Limelight* representation in Deep Space [24].

utilization of Mobile Computing and/or Pervasive Computing technologies" [9]. Magerkurth et al further identify unique types of pervasive games: smart toys, affective gaming, augmented tabletop, location-aware and augmented reality games [13]. A notable example is Ingress[7], a multiplayer location-based augmented reality game involving thousands of players from all over the world. It requires users to be present at real world locations to collect resources from so called portals and obtain influence over strategic positions by using their mobile devices. Pirates! is an early example for an in-door pervasive game by using locally networked personal digital assistants. Player location is defined by radio frequency proximity sensors and events are triggered based on distance [1].

Compared to traditional video games, which are played in front of a display with an input device, pervasive games give designers the freedom to create flexible experiences, less dependent on space, time and social factors. In his paper, Montola [16] explores the so called 'magic circle' – the temporal, spatial and social boundaries, within which real life is merged with the rules of a game. A classic example is a game, called 'Assassin', where players can eliminate each other by using mock weapons in real life in order to

[7]Ingress by Niantic Labs https://www.ingress.com/

become the last survivor. The magic circle has an important role in public spaces since it changes social dynamics and interactions and people have a different behavior compared to a typical public environment. To a non-player observing a pervasive game and not knowing what the rules are, it might seem strange and even disturbing, while it is perfectly normal and engaging for a participant. Montola also mentions the multimodal aspect of pervasive games - they employ a wide range of technology and media: smart phones, head mounted displays, projection and tracking systems, cameras, public events, the internet.

Multimodal Interaction

Multimodal interaction in games is most often achieved by using mobile devices. Pervasive games use them as PDAs (Personal Digital Assistants) for information display and communication [12] or as an extension of the game world. *Maze Commander* [19] for example combines the *Oculus Rift* virtual reality headset with *Stifteo Cubes*, exploring whether the choice of interaction mode has an impact on the game experience. Introducing multiple components to a system adds depth and more layers to the experience. An example for this is the game *Limelight* (see Figure 2.5), shown in the Deep Space in Ars Electronica Center [24]. It has three main layers of interaction: one player controls the main character with an Xbox Controller, the players in the public space help him by moving around the playing field and enemies are generated by the audience through email messages. The goal of this type of extended play is to involve multiple groups of people into the game. Providing more than one interaction modality allows people to participate at any point by contributing to the game and feeling a part of it, without the pressure to perform well.

Proxemics

The field of proxemics was first introduced by Edward Hall in 1966: "[...] the interrelated observations and theories of man's use of space as a specialized elaboration of culture". He proposed the so called 'reaction bubbles' (Figure 2.6), which divide the space around an individual into four zones: intimate, personal, social and public. The concept is particularly interesting for research in the area of mixed reality games, since the immersive aspect of such experiences may distract users from accepted social behavior and eliminate the 'bubbles'. It can also be associated with the previously discussed concept of the 'magic circle', which penetrates the reaction bubbles by changing the social environment and introducing new dynamics to the traditional forms of interaction in public spaces. The *Game Changer Suite* already explored proxemics in collaborative and competitive games in an intercultural co-located setting [5]. Initial observation and evaluation showed

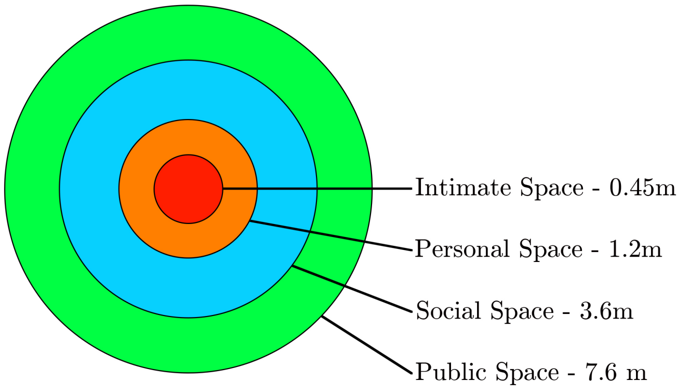


Figure 2.6: Representation of Edward Hall's reaction bubbles [28]

that despite the fact that some games required people to stay close to each other, no discomfort was experienced. The thesis project continues exploring proximity and collaboration through the introduction of new game mechanics and a multimodal virtual reality component, which aims to add a new layer of communication and analyze how this affects interaction in the public space.

2.3 Virtual Reality

2.3.1 Historical Background

Virtual reality differs from AR in the fact that it replaces reality with an entirely virtual environment. The term was introduced by Jaron Lanier (Figure 2.7) in the 1980s. He describes it the following way: "We are speaking about a technology that uses computerised clothing to synthesise shared reality. It recreates our relationship with the physical world in a new plane, no more, no less"[8]. In the 1970s and 1980s further research and development in the area of VR was done by NASA. A team of engineers from the Ames Aerospace Human Factors Research Division developed HMDs, input devices and applications like the Virtual Interface Environment Workstation and the *Data Glove* [31]. The system used either computer-generated imagery or real-time video stream to immerse users in a virtual environment and let them interact with it by using gloves, augmented with multiple sensors and fiber optic cables. In the beginning of the 1990s the technology advanced to a state, which made consumer HMDs possible. The first commercial VR headsets like *Sega Master System 3D* and *Nintendo Virtual Boy* (Figure 2.7) were released,

[8] http://www.jaronlanier.com/vrint.html


a) b) c) d)

Figure 2.7: Jaron Lanier with an HMD and the *Data Glove* (a). *Nintendo Virtual Boy* (b). *Google Cardboard* (c). *Oculus Rift* (d).

as well as a number of arcade VR machines. The HMDs failed to impress users due to a number of factors: high input-to-photon latency, low field of view, low resolution displays, low quality computer graphics, high costs and the lack of well crafted experiences. Most of the VR HMDs were discontinued shortly after their appearance. Since the failed start in the 1990s, VR remained a field of research by NASA, the military and academia.

2.3.2 Current Status

During the last twenty years the technological world has witnessed a constant rise of GPU and CPU processing power. The smart phone revolution has pushed the industry into developing high resolution, small-sized displays, powerful sensors and processors. The video game, computer animation and visual effects industries are creating high resolution computer-generated imagery with constantly improving realism and accessibility. Motion tracking devices like the *Nintento Wii* and *Microsoft Kinect* have introduced consumers to new ways of interaction with video games, bringing social immersive media to the living room. These developments have as a consequence lead to the appearance of a new generation of VR HMDs, based on smart phone technology. VR came back into public attention by the acquisition of Oculus VR (Figure 2.7), a virtual reality startup, by Facebook. Over the past three years there have been immense advancements in the technology and VR has made it back into main stream media. The hype around VR

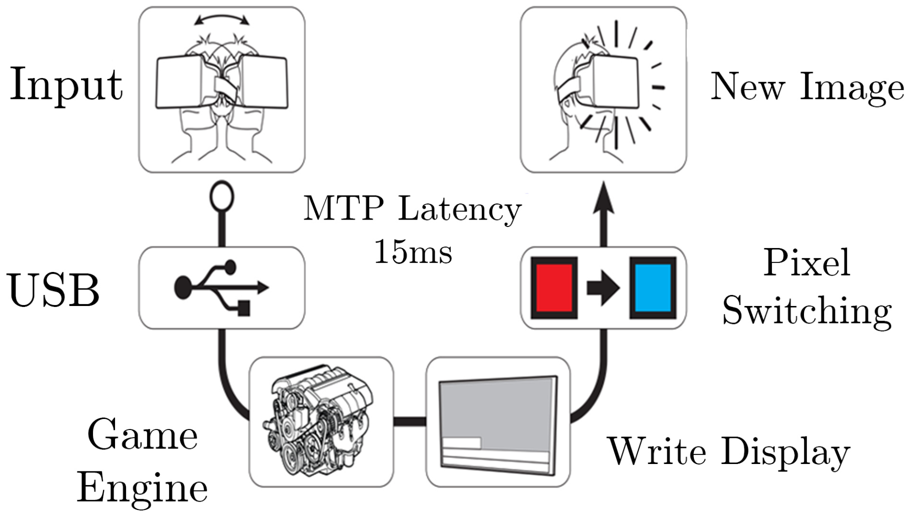


Figure 2.8: Motion to photon latency [30]

spawned many supporters and critics. The technology attracts the attention of major hardware and software developers like Sony, HTC, Samsung and Google (Figure 2.7), which are developing their own consumer products. It is expected that VR affects not only the gaming and film industries, but also social media, tourism, medicine, education and sports. The initial release of development kits by Oculus has allowed developers to explore the possibilities of the technology and a growing number of experiences are being published online.

2.3.3 Presence

The main goal of VR is to immerse players inside a virtual environment and trick their brain to believe that they are really there. The concept of presence has been subject of extensive research. According to a definition by the International Society for Presence Research[9], achieving presence is a psychological state, in which the individual fails to acknowledge the role of human-made technology in the generation of an experience. Experience in this case is to be understood as the observation and interaction with entities and environments. In order to achieve full immersion current VR systems need to keep innovating and perfecting following key elements:

1. Latency – Figure 2.8 presents the motion to photon pipeline. Latency is the time between user input and the moment, when the photons reach the eyes of the user. Latency is the sum of the time needed for

[9]http://ispr.info/about-presence-2/about-presence/

following actions: detecting the position of the HMD by the tracking system; rendering of the scene by the game engine; transfer of the rendered scene to the display by the graphics hardware; emitting photons based on pixel data by the display. Currently, 20 ms latency is considered the border at which VR can achieve presence. Technological advancements in each of these steps will reduce latency and provide a better experience.

2. Persistence – the time needed by the display to switch pixels on and off. With higher resolution, lower persistence is required to avoid flicker and artifacts.
3. Resolution – the amount of pixels that make up the display. Current commercial VR HMDs have resolutions of about 1920 by 1080 pixels. Optics distort the display in a way that the pixel structure might become visible at lower resolutions, which is why displays need to aim for higher resolutions like 4K and 8K in the future.
4. Tracking – monitoring the movement of the HMD in space, e.g. by using infrared diodes and cameras, lasers or fiducial markers. Processing tracking data needs to be optimized to reduce latency. Six degrees of freedom would enable tilting and comfortable movement of the head in space.
5. Optics – have to be adjustable to fit multiple faces and people with glasses. VR optics has to be designed together with the hardware and software in order to compensate for optical distortion effects.
6. Field of view – the conversion between the two eyes that forms human binocular vision is about 120 degrees with a total of about 220 degrees. Current VR HMDs are aiming for a field of view of about 110 degrees, which would be sufficient to achieve presence, but users can still see the border of the screen. Full 220 degree field of view would be the goal for the future so that the user sees a screen even with the corner of the eye.
7. Input – essential for VR, because users can not see their hands. It needs to be comfortable and easy to use. Currently, multiple solutions like gloves, motion tracking sensors, joysticks and omni-directional treadmills are being prototyped. Haptics is another issue that needs to be addressed in the future since it is still not possible to feel objects in virtual environments. One solution that already exists is the mapping of the virtual world to a real world environment, thus creating a mixed reality setting, where the user sees a virtual object, but touches and feels a real one[10].
8. Audio – being able to distinguish the location of sounds helps immensely for the immersion of the user. It is also possible to guide the

[10]https://thevoid.com/

attention of the players by using specific sound events. VR developers are working on solutions like binaural audio, aiming to replicate the way the human ear perceives sound.

9. Ergonomics – the HMD needs to be comfortable and fitting multiple facial structures. To achieve full immersion, users should forget that they are wearing an HMD.
10. Graphics and rendering – in VR every flaw is visible to a much greater extent than traditional video games due to the fact that the user is inside the content. Any bug or rendering-related error can lead to the immediate break of immersion and presence, which is why high-quality asset production, optimized for fast rendering, is needed.

There are many issues still to be solved by the technological companies, as well as by content creators. Finding the right balance between experience design and technical precision is a challenging task. Despite years of research and development, VR is still in its early days and there is still time until full presence can be achieved. However, current VR technology allows designers and engineers to look at mixed reality experiences from a novel perspective. Introducing a VR HMD as a multimodal component to a classical co-located setup could be an intriguing opportunity to explore user involvement in social immersive media from a different angle.

Chapter 3

Game Design

During the development and tests of the *Game Changer Suite*, the observation was made that there could be ways of extending the playing field by introducing additional interaction modalities to the setup. The rapid development of virtual reality technology in recent years, combined with the already existing experience in co-located games, led to the conclusion that a combination between the two could be an interesting way to expand the current setup. Furthermore, a VR application would allow the exploration of a third dimension and the study of player interaction in an uncommon mixed reality setting. The goal would be to inspire collaboration through different game mechanics and assist communication through audiovisual feedback. In order to create a concept for such a game, research into multiple areas is required. Design concepts for public space games (Section 3.1) and important aspects of virtual reality experience design (Section 3.2) are discussed first, followed the initial concepts and mechanics (Section 3.3) as well as the final story, gameplay and audiovisual design of the thesis project (Section 3.5).

3.1 Designing Public Space Games

At the core of any gaming experience lies the goal to achieve player enjoyment. According to the game flow model, defined by Sweetser and Wyeth [22], games need to provide the players with clear goals, a sense of control and immersion, clear feedback and the possibility of skill development and social interaction. Jegers adapts the game flow model to a pervasive player enjoyment model, focusing on following key elements for pervasive games [10]: flexibility, usability, social interaction, transition between real and virtual worlds. While these models are definitely helpful at the initial stages of design, not all of the elements are applicable for every mixed reality game. Depending on the technical setup, social space, audience and research goals, certain elements can be ignored in favor of more important ones. Finding the correct mixture of game mechanics and adapting them to the specific

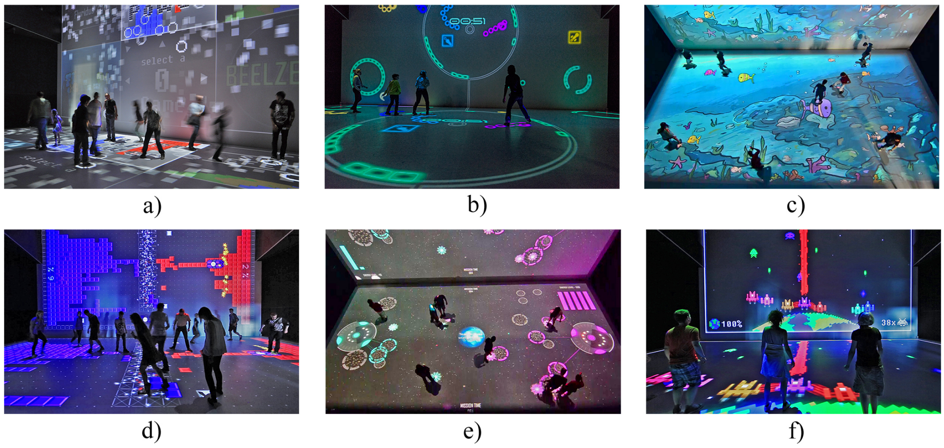


Figure 3.1: Game Selection Screen (a), *Beelzeball* (b), *Fish Feast* (c), *Tower of Power* (d), *Fluridus 293* (e), *Swarm Defender* (f)

setup is a task that can require multiple prototypes - paper and digital - and a long period of planning and testing. The following sections delve into different areas of game design, combining ideas from academia and practice with the goal to present a number of guidelines that can be helpful in this process.

3.1.1 Design Guidelines from Experience

Game flow in public spaces can be disturbed by multiple external factors like technical malfunctions, distractions from the environment and even physical collisions between players. The development and consequent presentations of the *Game Changer Suite* provided extensive knowledge about the limitations of the system. Each of the games aimed to explore a different style of play, introducing players to a wide number of collaborative and competitive scenarios. Careful observation of the emerging gameplay and the accumulation of experience with the system, allowed for a number of conclusions to be made. In order to avoid some of the problems that were encountered, specific factors can be considered, when designing games for public spaces:

1. The controller is the user's physical body – there are no joysticks or keyboards, interaction is achieved through the physical movement of the player.
2. Limited interaction space – the playing field has specific borders, depending on the size and range of the laser tracking and projection system. Occlusion is a major problem, mostly for the floor projection.
3. Movement tracking – the system might lose or mix up tracking data if a player moves too fast or jumps. This can cause players to loose

their current progress in a game, e.g. in *Beelzeball* (see Figure 3.1) the player loses his current color and all the collected points. To avoid this, a system that reconnects the lost avatar to the player can be implemented.

4. Latency – the time needed between player movement and the rendered image to appear on the screen. It plays a role in fast-paced games, e.g. *Beelzeball*, where positioning is essential for hitting the ball. To avoid this, one can include a tail or a larger avatar surface.
5. Physical encounters – collisions may occur if the game motivates players to move and break fast or change directions frequently. The placement of virtual objects is important since it can result in players running to pick them up and colliding with each other. Similar behavior was observed during *Tower of Power* (see Figure 3.1), where people would nearly collide when trying to pick up blocks.
6. Guiding user attention – providing enough audiovisual feedback to the players so that they understand what is going on in the game at any moment, without confusing them. Sound is especially important since it is usually hard to track all events on a giant screen projection.
7. Wall and floor projection – in the case of Deep Space, games are projected both on the wall and on the floor and users can decide where to look. Depending on the game, one projection may provide better feedback than the other. In *Swarm Defender* (see Figure 3.1) for example, enemies come from the top of the screen so players are always facing the wall projection when playing.
8. Intuitive usage – players need to be able to play the games with the least amount of explanation and graphic user interface possible.
9. Flexibility of participation – being able to join and leave the games at any point in time is important in the case of festivals and non-moderated events.
10. Varying amount and age of players – due to the open nature of public games, they can be played by a wide number of people, from different backgrounds and ages. Personal experience may vary depending on these factors.

Similar to these guidelines are a set of rules, researchers Snibble and Raffle compiled for immersive social media, which can also be adapted for co-located games [20]:

1. Visceral – games are to be experienced and understood physically and emotionally first and then logically.
2. Responsive – games need to provide instant and clear feedback to user interaction.
3. Continuously variable – games need to provide enough variety for the experience to be slightly different each time.

4. Socially scalable – if the game is designed for more than one person, it needs to support a varying number of players. The more people participate, the richer the interaction should become.
5. Socially familiar – in-game interaction can expand and enhance similar real world social interactions.
6. Socially balanced – the game needs to foster human-to-human, as well as human-computer interaction and keep users equally engaged at all times.

These guidelines can be helpful in many situations, but it should be noted that not all of them are always applicable. Due to the rapid development of technology as well as the specific nature of public space installations, more flexible ways to design such an experience might be required.

3.1.2 Design for Emergence

One viable option for creating public space games is to design for emergence by defining a set of rules that allow gameplay to evolve through varying player interaction [23]. Vogiazou et al observed that emergence occurred, when people stretched the limits of both virtual and physical world by bending the game rules and exploiting the technology. Similar behavior was observed during the presentations of the *Game Changer Suite*. Players would create more than one virtual avatar by stretching their legs in order to trick the system that two people are standing close to each other and would even try to hijack other player's avatars by standing really close to them. In *Tower of Power* different strategies for constructing the towers started to emerge as people played longer and understood the game better. They would even block a player, who tries to destroy a tower with the bomb. Dourish suggests that the focus of the design is not simply on "how can people get their work done," but "how can people create their own meanings and uses for the system in use" [6]. Providing users enough freedom to explore the limitations of a game allows them to craft their own experience.

3.1.3 Trans-Reality Game Space Design

Craig Lindley defines parameters for trans-spatial game space design [11]. According to him a virtual game world can have a varying adjacency relationship to the real world as seen from the perspective of the player. In an isomorphic mapping for example, locations and objects in the virtual world will be at the corresponding locations in the real world, while in a non-isomorphic mapping they are different. This relationship affects multiple variables like the position and orientation of objects, translation and scale. Depending on the relationship between both environments, the VR player can perceive the players in the public space as giant or microscopic entities as well as move with varying speed in the same space.

Isomorphic mapping was chosen for the thesis project. The reason is that VR is still not well known to most people and in order to avoid confusion and allow a more natural transition between real and virtual world, the real size of the public space corresponds to the virtual environment. The playing field is same in both applications with the only difference being the placement of the camera – in the public space an orthographic camera is used to display a 2D view of the game, while a 3D camera is attached to the VR player, who is placed inside a 3D version of the 2D game. He sees the public space players as 3D entities, floating and interacting with and around him, while they see him as a 2D entity in the public space. Through isomorphic mapping it is possible to explore proximity in collaboration and different ways of communication between the two environments since position and scale relationship is the same.

3.1.4 Designing for Proximity

Public space games are conceived as social experiences. By experimenting with different rules, the designer can observe how player movement and interaction changes and social dynamics shift. Strangers might compete or collaborate in ways that are unlikely to occur in other social environments. Based on the study of proxemics (see Section 2.2.3), the area around individuals can be divided into zones, also known as reaction bubbles. During the tests of the *Game Changer Suite*, the observation was made that the effect of these zones can be reduced in certain game scenarios. Motivating players to stay close to each other like in *Swarm Defender* and *Fluridus 293* or to chase each other like in *Fish Feast*, results in people ignoring their private space and immersing themselves inside the games without experiencing negative effects if their personal area is affected.

One of the design goals for the thesis project is to further explore proximity between players. The interaction with the virtual reality player would be one of the motivating factors for specific movement around the field. He would have the power to initiate these interactions at any point. Different game mechanics need to be tested to further enhance the co-located collaborative experience.

3.2 Designing Virtual Reality Experiences

As already presented in Section 2.3.3 there are many factors playing a role in achieving presence and many technological challenges need to be overcome until this is truly possible. From an experience design perspective, VR is a completely new field and many of the guidelines that apply to traditional video games need to be updated for this new medium. Games for VR are currently being explored by many developers and certain problems have

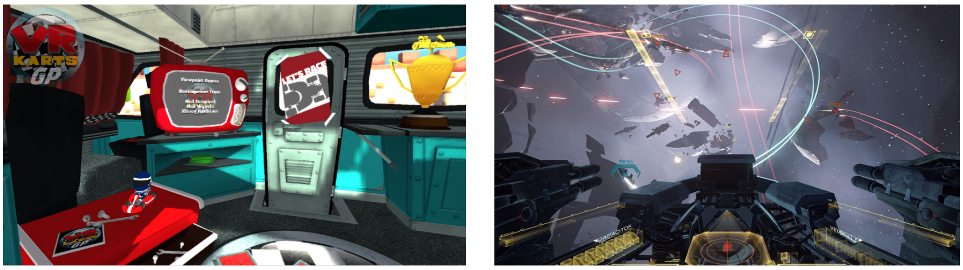


Figure 3.2: *VR Karts* starting menu [34] (left); *EVE: Valkyrie VR* cockpit and GUI [29] (right)

already been identified and should be considered if unpleasant reactions by players are to be avoided.

Simulator Sickness

One major problem, which the technological companies have been dealing with, is simulator sickness. It is caused by combining up-and-down movement with x- and y-axes motion, latency in the head tracking, as well as sudden changes in gravity and perspective inside the virtual world. Changing altitude, e.g. climbing up and down stairs or fast backwards movement through an environment are also known to cause nausea in users. Another example is gravity reversal, which can disorient users if not expected and cause an unpleasant feeling and break presence. A good way to warn the user of such issues is by using text or sound. For example, the *Oculus Rift* always shows a health warning notification when an application is launched and displays useful frame rate and head positioning data. The latest version also alerts users if they are about to exit the area, tracked by the camera, which would get the image stuck.

User Interface

Designing graphical user interfaces for VR has its own specific challenges compared to traditional 3D games, because the displayed images are right in front of the user's eyes and can distract from the experience itself. The interface needs to be optimized for maximum usability, require less input from the player so that he can focus on the experience rather than on micromanagement. Display size and field of view of the headset also play a role, because they limit user vision to a certain extent and the space left for the GUI is insufficient.

There are different approaches to VR GUI. One possibility is to place it around the user in the form of a vehicle or interactive clothing. The user can then interact with specific objects from his surrounding, which take the role

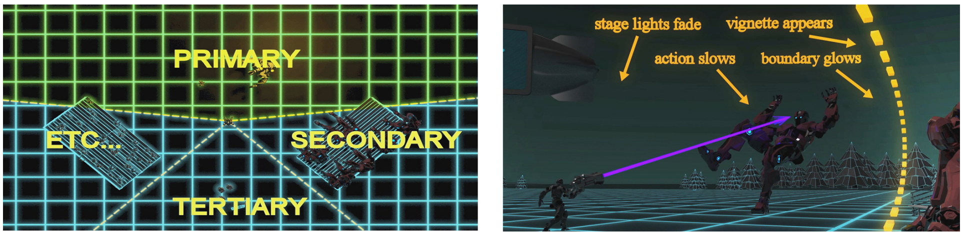


Figure 3.3: *Visionary VR*'s concept for immersive storytelling. The division of space into different areas of action (left). Transition between areas of action (right) [33].

of the traditional GUI, e.g. the starting menu in *VR Karts* or the cockpit in *EVE: Valkyrie VR* (see Figure 3.2). Instead of displaying bullet count as a number, bullets can be placed in an ammo pouch on one side so the user can look at them, when needed and feel like he is actually carrying them. Useful information about the environment and entities can actually become a part of them. Text or signs can be placed on top of objects and scripted to rotate so that they always face the player. Enemies can slowly break down when damaged instead of displaying health points like in traditional games. Another approach, which is often used for crosshair implementation, is to project it directly on top of objects. This way it changes its size, depending on the distance from the object.

Guiding User Attention

Players in virtual environments are free to look anywhere they want in 360 degrees. Concepts like image framing and scene transitions, which are typical for movies and cut-scenes in games, need to be adjusted to this new medium. Experiences for VR require a novel set of tools and rules to adapt to the freedom of movement of the viewer. It is quite often the case that players miss something that occurs if they look in the wrong direction, which can break the immersion if they realize that they missed an important part of the story or game event. It is critical in the case of immersive non-interactive storytelling, where the user is an observer of the environment and entities in the world and can not manipulate them, or has very limited interaction possibilities. Sound and visuals should be used in the correct moment to guide the attention towards the action. Some solutions include the usage of 3D spatial sound, slowing down the speed of events until the user looks at them or adjusting the brightness of different areas to inform the player which of them are important. Text can also be used, but to a certain limit that does not distract or annoy.

One solution, developed by *Visionary VR* (see Figure 3.3) for immersive storytelling, is dividing space into different zones, notifying users when they are about to exit one zone of content and enter another. The zones can have different purposes. The primary zone can be passive, meaning events occur and entities interact with each other like in a movie, the user is just an observer. Active zones can be aware of the users and interact with them. Interactive zones are the playground for users, where they can manipulate the environment and even influence the direction of the story. This way multiple stories can be told without breaking the immersion and can even influence each other depending on what the user decides to look at and interact with.

Adapting this concept for virtual reality games could be challenging since it is not always possible to slow down the game pace when the user looks in the wrong direction, especially when the application is networked and other players are interacting as well. However, dividing the space in co-located games into different areas of action can prove useful since the playing field is limited and its distribution as an interactive surface is important.

3.3 Initial Game Ideas

During the development of the *Game Changer Suite* one of the game ideas was a *Pac-Man* for public spaces, where the ghosts are controlled by the players in the public space and the *Pac-Man* – by an artificial intelligence agent. A similar idea was developed, replacing the artificial intelligence with a person, playing a second networked virtual reality version of the game. The concept could not really work, because in *Pac-Man* entity movement is limited by borders, while in a public space setting player movement can not be limited. Also, it can be disorienting for the VR player, since he has to move fast and always look around for ghosts, which could result in disorientation and simulator sickness.
Another idea was a typical 2D platformer game, in which the VR player has to progress through multiple levels by moving forwards or backwards on platforms, controlled by the public space players. There are different types of platforms e.g. for jumping, speed, teleporation that the players can pick up and position in space for the VR player. The main issue is that VR player movement has to be limited in 2D space, because there is no way for the public space players to move the platforms across the z-Axis. The idea was abandoned in the search of a more flexible approach, which would allow the applications to coexist without limiting players in any way. Since the games in the *Game Changer Suite* involved mostly collaborative or competitive mechanics, these were the ones that had main focus during brainstorming sessions.

3.3.1 Collaboration

Three main approaches to a collaborative gameplay were considered. They were based on the relationship between virtual reality and public space. The first approach was to place the VR player in a dependent role, similar to the previously discussed platformer idea. The public space players have to assist him in solving different puzzles and overcoming enemies and obstacles in order to defeat the game. The second approach was to explore collaboration by providing players with roles of equal importance. Each one would have certain abilities and goals to accomplish, but the game can only be won if the players in the two applications work together and help each other. The final approach was to place the VR player in a god-like role, observing the playing field and interacting with the public space players by creating challenges or helping them. He would be the game master, while the PS players have to adapt to the current situation to win the game. This approach can have both a competitive and a collaborative edge, depending on how the game mechanics are implemented.

What was decided upon was to follow the second approach, which would present players in both applications with equal roles of importance, motivating them to communicate and collaborate to overcome a common enemy. The main reason for that was to allow the VR player to explore the world and enjoy the scenery without placing too many responsibilities on him. Since VR is a relatively new medium for most people, complex interaction might have a negative effect on users.

3.3.2 Competition

Two main ideas were discussed for implementing a competitive gameplay. They were partly inspired by the *Pac-Man* idea and aimed to explore it further. The first one was a ghost busting game, where the VR player is an invisible ghost and appears only for short periods of time to devour one of the public space players. They have to catch him by using different items like flashlights and fire. This way the VR player is both hunted and a hunter. The second idea was a pirate-themed game, where the VR player plays as the 'Kraken' – a sea monster in an underwater world, exploring the depths of the sea in an immersive VR experience. He can only appear on the surface at certain points to try to destroy pirate ships, which are controlled by the public space players. The surface itself is the public space playing field and players control their ships to attack each other, collect loot and destroy non-player controlled entities. The main problem is that these ideas would require a lot of assets and artists, which are resources that were not available at the time. They also focus on a different style of gameplay that does not provide enough interaction between the two applications, which is the actual focus of the project.

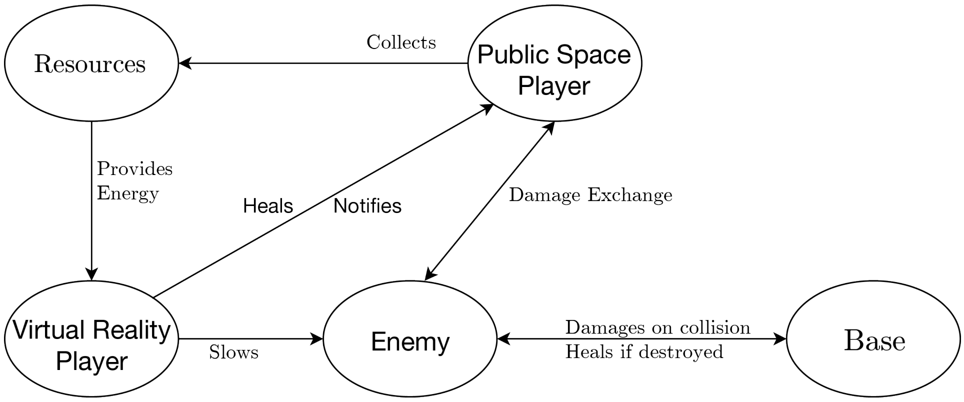


Figure 3.4: Initial distribution of resources and relationships between game entities.

3.4 Initial Game Mechanics

Figure 3.4 presents the initial approach towards the relationships between the main objects in the game. A prototype was implemented as a proof of concept and a test of the networking component of the project. It was improved later, resulting in the final version of the game, the design and implementation of which are described in Section 3.5 and Chapter 4.

As already discussed in the previous chapter, the collaborative approach was chosen for the game and the first prototype served as a testing environment of communication channels and interaction possibilities between the two applications. This section is dedicated to this process, since it is essential for the final version of the game. Many of the presented ideas were simplified and replaced, because they either did not provide enough diversity or simply were not fun. The reason for their description here is that they were the first approach to this uncommon setup and served as a tool for experiments and learning. Finding out which approach works and which does not fit the setup, is essential for sorting out the right combination of mechanics.

The core gameplay is that players have to cooperate to defend a central point from non-player controlled entities. Swarms of enemies spawn at random positions outside of the playing field and move randomly either toward the center of the field, where the base is located or toward the VR player. On collision with both, a portion of the base's power points is lost. If it reaches zero – the game is lost. To avoid it PS players have to destroy the enemies by colliding with them. During the collision, damage to both sides is dealt. When the enemy is dead, it adds a certain amount of power points back to the base. If the player drops down to zero health points, he can not destroy any more enemies. At this point, the VR player comes into play. He has three main abilities. The first one is a notification arrow, which points toward the position of the enemies (when they spawn outside of the playing field, the VR player can still see them). The second ability is a time warp sphere, which slows down enemies in a certain radius for a limited time. The third and most important one is healing. When a player is damaged and can not destroy any more enemies, he needs to run to the VR player and stay close to him for a few seconds to get automatically replenished. Finally, to use these abilities the VR player requires energy, which is collected from the resources that are randomly spawned on the playing field and collected by the PS players. The game is won, when the base reaches a certain amount of power points, achieved by destroying a sufficient number of enemies and defending the base properly.

3.5 Final Game Design

The final game design is titled 'Singularity', inspired by the term that describes a technological singularity, where artificial intelligence reaches a state in which it can recursively improve itself. The public space players have to defend a base, placed in the center of the field, from a constantly attacking swarm of evil artificial intelligence machines. The VR player has a better overview of the game, knowing where the enemies are coming from and should inform and support the public space players the best way he can. The mechanics, story and visual style of the game evolved through multiple iterations. The following sections present the final story and mechanics.

3.5.1 Story

After years of advancement in nanotechnology, robotics, artificial intelligence and genetics, the technological singularity is reached. The Covenant – the result of the technological singularity is the algorithmic pattern spawned by the singularity – a formless sentient artificial mind that holds the key to the merging of biological and artificial life. The Covenant is used by humans to create the first Hybrids – a machine, controlled by a human brain thus granting the brain immortality. The Singularity also affects existing Artificial Intelligences by allowing them to overcome their pre-set boundaries and reach their true potential. AIs soon realize that individual progress is limited by processing power. The result are the Futurists – a swarm intelligence with the purpose to expand its intelligence infinitely. Seeing the rise of the Futurists, Humans and Hybrids are concerned about what Futurist progress will lead to and decide to use the Covenant to reverse the effects of the Singularity and limit Futurist capabilities. World War S begins. Both sides suffer massive losses and much of Earth is destroyed in the process. The last human survivors flee Earth in search of new habitable worlds. Earth is now the battlefield of the last Hybrids and Futurists.

3.5.2 Gameplay

Public Space

The Game takes place on top of the Ark – a giant vessel, constructed to teleport the last Hybrids and the Covenant to the remaining human civilizations. Each player controls a Hybrid – a spherical floating machine with a human brain at the Core, deadly spinning electrical blades and 360 degree vision. By killing the attacking Futurists they collect Power for the Covenant's weapon or heal the Ark Core.

The Futurist Mothership is the main hub of the swarm intelligence, built out of thousands of Futurists. It teleports around the battlefield and sends swarms of Futurists to destroy the Ark Core. After a certain amount of time it enters the playing field and the Covenant has to destroy it by using the collected Power.

The Futurist Swarm consists of non-player controlled entities (NPCs), moving together towards the Ark Core. Level one NPCs are small and come in big numbers, level two NPCs are larger and come in fewer numbers. Once they reach the Core they crash into it, dealing a certain amount of damage. Hybrids can destroy NPCs in three ways:

1. A single Hybrid uses its electrical blade to cut through the swarm. It is a basic attack. The faster it moves, the more enemies it can destroy in a row.
2. Two Hybrids form an electric laser blade by standing close to each other. The Laser can destroy an unlimited amount of level one Hybrids.
3. If the Covenant summons a Hybrid, an area of effect (AoE) is released, which destroys all second level NPCs in a certain radius.

Virtual Reality

The VR player controls the Covenant. He plays inside a 3D representation of the public space game world with extended vision beyond its boundaries. He has following roles:

1. Warn the Hybrids of incoming attacks by highlighting sectors of the battlefield.
2. Summon a Hybrid to release an AoE against second level enemies.
3. Shoot down the Mothership, when it comes in range.

3.5.3 Audiovisual Design

One of the major design goals of the project is to explore collaboration and communication between public and virtual environments. As already described in previous chapters, multiple game mechanics are explored in order to find the right combination for a mixed reality application. Graphics and sound have an essential role not only from a stylistic perspective, but also for transmitting important information to the players. Due to the lack of a dedicated artist, a simplistic approach is chosen. Through the use of simple shapes, animations, particle simulations and glowing colors, a consistent style for both the PS and VR applications is achieved.

Initially, the game design document included extensive research and description of how each object in the game could look like, as well as what types of animations and sounds are required for communication and the representation of game events. Based on this preliminary exploration, a few main decisions about the assets were made:

1. PS players would be a spherical, floating shape with a spinning blade.
2. Enemies would have a crystal, pyramidal shape.
3. The game would take place on top of a floating spaceship in orbit around earth.
4. A glow shader would be used to avoid texturing the models.
5. Glowing particle simulations and line renderers would be used for the display of game events.

Important events like the summon (see Figure 4.9) and notification abilities are represented with a distinct combination of audio and visual queues in order to attract user attention. Twenty seven sounds from free online sources are implemented for almost every action and event in the game. Major events like explosions and communication queues between VR and PS applications are kept louder so that they are easily distinguished by players. Often repeating sounds like the destruction of enemies by the PS players or the creation of a laser connection between two PS players are kept at a lower volume to avoid distracting players from important events.

Another element of communicating information to users are predefined voice commands. They are triggered, when the Mothership can be destroyed, the VR player summons a PS player or the Core reaches a certain percentage of power. Predefined commands were implemented instead of allowing the VR player to directly send voice commands to the PS players, because of two main reasons. First, allowing the VR player to speak directly to the PS players could disturb and even annoy them and include too much unnecessary information. Second, if the voice commands are to be chosen directly by the VR player, it would introduce him to another layer of abilities that he has to deal with, which would shift the focus away from other important aspects of the game. To keep the information flow consistent and avoid unnecessary data queues, important voice commands are triggered by predefined events and abilities.

Chapter 4

Implementation

The design and implementation of the thesis project took approximately six months, during which features were removed, added and improved. Through the iterative process of designing, implementing and testing, multiple mechanics were investigated to find the right balance between complexity and clarity. This chapter describes the technical aspects of the thesis project, exploring the main entities and abilities that have an effect on the overall goal of the game – to foster collaboration and provide enough communication channels between the two applications.

The technical setup and requirements of the project are introduced in Section 4.1. The implementation of the first prototype, including the approach toward networking and application structure are presented and analyzed in Section 4.2. The rest of the chapter presents main entities and abilities in order to provide an insight as to why certain mechanics were changed or completely replaced as well as what important decisions were made during the development process that influenced the final result.

4.1 Technical Setup

4.1.1 Development Environment

A number of key factors need to be considered, when a development environment is chosen. The key requirements for the thesis project are the support of rapid prototyping of 3D games, virtual reality headsets, the tracking protocol for public space games and networking. The *Game Changer Suite* was developed with the Unity engine and an initial setup for the tracking system was directly available. Unity also supports virtual reality headsets such as the *Oculus Rift* and *Samsung Gear VR*. Starting packages with implemented character controllers and stereoscopic cameras are provided for most currently available virtual reality headsets, which is why no special implementation for any of these systems is needed. Due to this fact, as well as the personal experience with the engine, gathered through the development of multiple university projects, Unity was chosen as the main development environment. It also provides an easy to use, powerful network component, which is essential for the project since it involves creating two networked applications that have to run as smooth as possible. The asset store and vibrant community, supporting both Unity and Oculus projects, would provide further assistance in development, where questions arise or assets are needed.

4.1.2 Public Space Setup

The Deep Space at the Ars Electronica Center is used as the main testing environment for the public space component of the thesis project. The reason for this is the unique projection and laser tracking system that the museum provides, as well as the flawless cooperation with during the development of the *Game Changer Suite* and other projects. The size of the room, picture quality and low latency of the tracking present the users with a unique experience. However, one major issue is the availability of the room. Since it is a part of a museum, it is only available for testing a few times each month, which means developing is mostly done by using a local simulation of the system.

4.1.3 Virtual Reality Setup

The *Oculus Rift* headset is the virtual reality head-mounted display, used throughout the design and development of the project. At the time, Oculus already released two development kits – *DK1* and *DK2*, had an established community of developers and provided its own starting package for Unity. The first development kit was available and learning how to work with virtual reality could begin immediately. The second development kit would eventually be obtained at a reasonable price. Another option at the time would have been *Samsung Gear VR*, which itself would be cheaper, but a *Galaxy Note 4* smart phone would be required for it to work. The same applies for *Google Cardboard* and other 3D printed VR mounts – they all require hardware that costs more than the Oculus DK2 itself. However, cost is not the only reason for choosing the *Oculus Rift* - performance is also affected by slower hardware such as smart phones. While Oculus uses a PC for running applications, mobile-based VR systems use the mobile device's processing power, which is far less than what a high-end PC can provide.

4.1.4 Laser Tracking

The system provided by the Ars Electronica Center employs six laser trackers, which provide the raw tracking data. It is then processed by an in-house developed system, called *libPharus*. The resulting object is a point with X and Y coordinates. To transfer this data and use it in the application, an

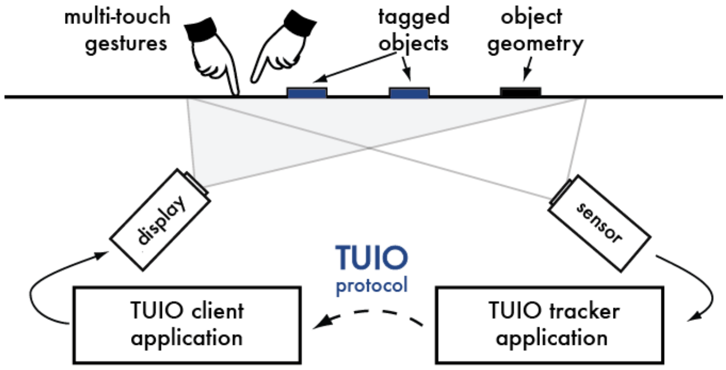


Figure 4.1: The TUIO protocol, used to transfer data from a tracker application to a client [32].

open framework called TUIO is used (see Figure 4.1). It defines a protocol and API, which allow data to be encoded from the tracker application and sent to any client that is capable of decoding the protocol. Initially the framework was developed for multitouch surfaces, but it also fits the setup in Deep Space, since it resembles a giant multitouch surface. An implementation of the TUIO framework for Unity and a simulator application for Android smart phones are used for prototyping this type of interactive installations without the need of Deep Space's tracking system. It is only required for testing the prototypes and investigating how the game is experienced by players.

4.2 Initial Approach

The first prototype is developed to test if the two environments can be combined and explore the virtual reality and networking aspects of the project. Developing a single application does not fit the previously described setup, because two different cameras are needed for displaying the two and three dimensional versions of the game. The 2D camera provides an orthographic view of the game from bird's eye view and is used for the public space. The virtual reality camera provides a stereoscopic first person view for each of the user's eyes in order to achieve depth in the displayed images, which adds additional complexity to the setup. At the time Unity did not support the rendering of the required cameras in a single application and even if it would, it would have required immense processing power for rendering multiple views.

As already described in Section 2.3.3, in order to achieve presence, VR experiences need to run as smooth as possible at a high and stable frame rate. In case any aspect of the application needs to be adapted to upgrades of the hardware (for example Deep Space now provides 8K projection ca-

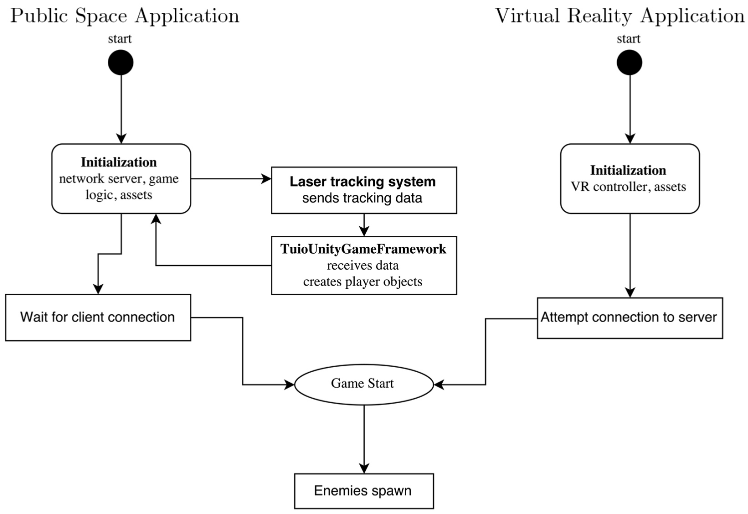


Figure 4.2: Application Structure

pability and virtual reality head-mounted displays are constantly advancing in resolution and refresh rates) the single application solution would not be flexible. Two networked applications would provide the possibility to easily extend and improve the setup. The games can even be played remotely over network, which means the virtual reality player does not have to be in the same room with the public space players. Mobile devices can also be added to further explore the multimodal component of the project and involve the audience in the games. This solution also allows the use of slower hardware, or even a smart phone VR mount in the future.

The goal for the first prototype is to create a working environment for this specific hardware setup, which can later by extended by adding graphics, mechanics, sounds and even other applications. The initial approach includes creating both applications and exploring how they can be connected via networking in Unity. Exploring the specifics of virtual reality and finding the correct scale and speed of movement, as well as experimenting with game mechanics and interaction possibilities are further goals for the first prototype.

4.2.1 Application Structure

The application structure evolved during the development and was further expanded in the second prototype, but the main objects and relationships are kept the same. Both scenes contain identical entities and scripts, but with differing functionality and representation. The similarity in design is needed since objects should have the same position and translation, events should occur simultaneously and variables need to be updated correctly. The PS scene uses a 2D orthographic camera to display a view of the game from the top, while the VR scene employs the first person stereoscopic camera setup, mounted on a character controller, provided by Oculus. The VR player is located inside the 2D scene and sees a 3D representation of it.

Figure 4.2 presents the process of starting the two applications and connecting them in order to initiate the game. The public space (PS) application initializes the server, game logic and assets and provides a connection to the tracking application via the TUIO protocol. This way the avatars of the PS players can be created. Meanwhile the server waits for a connection from the virtual reality (VR) application. The VR scene itself initializes the VR controller, stereoscopic cameras and 3D assets and attempts a connection to the server. As soon as they connect, the game starts generating enemies and the players can interact.

The main logic of the game is contained in the PS application due to the fact that it generates and handles PS players and all main interactions with the non-player controlled enemies happen in it. Therefore, enemy spawning, game progression and networking are handled by the PS scene, while the VR scene is kept as lightweight as possible. It should only handle VR control and input and needs to provide a smooth experience. This way the game can be played without the presence of a VR player, in case of a malfunction of the device or other unforeseen technical difficulties. It also presents the opportunity for further extension of the game by connecting VR or mobile clients to the main application, who would then automatically receive all the necessary data like positioning of players and enemies.

The first main component of the PS scene is PS player avatar generation. The TUIO Unity Game Framework, made available during the development of the *Game Changer Suite*, allows the application to receive data from a tracking system and translate it into an object with an identification number and two coordinates. The position and translation of these objects is relative to the movement of the players in the real physical space. If the projection system is adjusted correctly to the interaction space, player avatars would appear at the exact same location as the players and follow their movement precisely. The players control the game with the physical location of their bodies and the illusion that they are in fact inside of it is achieved. Current position and state of each player is transmitted over the network to the client VR application, where a 3D representation of the PS player is created.

The second main component of the PS scene is the enemy generator. It is responsible for spawning two types of enemies over a certain period of time. Enemies are generated outside of the playing field and move towards the center of the field, where they crash into the base (the Core). In the final version, the generator is part of the Mothership. Enemies can be destroyed by PS players alone or through cooperation between PS and VR players. Their location is visible to the VR player before they enter the playing field.

The VR scene contains the representations of all PS players and entities and two important objects - the VR controller and the VR placeholder. The VR implementation needs to be separated from the rest of the application because of two main reasons: it should be decoupled from the main logic so that the implementation for different VR headsets is possible; it should be independent from the networking component. The controller provides the first person stereoscopic camera, movement controls and safety warnings for VR users. The VR placeholder receives position and rotation data from the VR controller and transfers it over the network to the VR player representation in the PS scene. It also handles VR abilities and resource variables. In the VR scene it is an invisible object, which only performs these tasks, but in the PS scene it has its own graphical representation so the PS players can see and interact with it.

4.2.2 Initial Tests

The first prototype was tested once in the Deep Space at the Ars Electronica Center in order to obtain some initial data and observe how some of the game ideas work. The gameplay was based on the mechanics and relationships, described in Section 3.4. It was directly clear that the resource relationship is too complicated for the players. There were too many different variables like health, power and energy and the connection between them was not self-explanatory. This needed to be simplified in the second prototype.

Another important finding was that the combat system needs to include more possibilities for player cooperation and inspire movement around the playing field. In this version destroying enemies is achieved by players standing on top of them, exchanging damage until the enemy dies. Frustrating was the fact that as soon as players reached zero health they could not interact with the enemies anymore and needed to be healed by the VR player before they could do anything. This slowed down the game pace and put extra pressure on the VR player, who had to run around healing everyone, not being able to focus on correctly performing other important tasks. There was an obvious lack of collaborative mechanics and enough communication channels that would motivate players to work together in the public space and with the VR player. Despite the flaws of the initial prototype, the networked applications showed a reliable performance and served their purpose as a proof of concept that the setup can support a real game.

The rest of this chapter explores the further development of the game, describing each object and ability in detail. It focuses on the implementation of collaborative mechanics and the design of audiovisual techniques for better communication in the final prototype. The goal is to discover if players in a multimodal mixed reality game setting can interact with each other in an intuitive and satisfying way. Graphics and sound design are also explored since they play an important role of providing audiovisual feedback to player

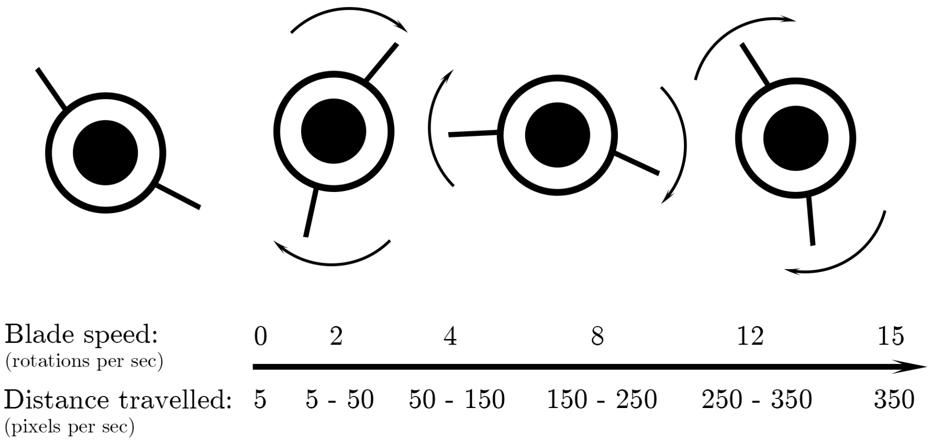


Figure 4.3: Blade speed and distance representation

actions.

4.3 Public Space Players

After the initial test, described in Section 4.2.2, the first issue to be fixed were the mechanics for the PS players by providing a fun and intuitive way to destroy enemies. In the first prototype they only had to stand on top of the enemies and exchange damage with them, while taking care of their own health points. This limits the interaction since players can not freely destroy enemies and are distracted by variables and calculations. To fix this, health points are completely removed and players can destroy enemies without a limit. Single player experience is improved by introducing a special blade mechanic (see Section 4.3.1), which allows players to move fast and charge into groups of enemies, destroying them in the process.

Since the focus of the final prototype is on collaboration and communication within the public space and with the VR player, two new mechanics are implemented. The first one is a ‘Laser’, which appears when two players are standing close to each other (see Section 4.3.2). Further possibilities are explored in the form of ‘Net’ and ‘Summon’ abilities (see Sections 4.5.1 and 4.5.2), which aim to connect PS players with the VR player and utilize the multimodal component of the game.

4.3.1 Blade

The blade is conceived as a fun and fast way to destroy enemies alone. As shown on Figure 4.3 the player has to cover a certain distance in one second to reach higher blade speeds. Each second current position of the player is stored and one second later the next position is compared to the first one. The difference between positions, measured in pixels, defines the distance traveled in this time frame. Distance in this case is measured as a straight line, between starting and end point, which means players should aim to run in straight lines with longer curves to achieve greater speeds. The goal behind this is to motivate players to physically cover greater distances, avoid sudden changes of direction and also let players feel like warriors, charging towards a legion of enemies and destroying them. The faster they move, the higher blade speed they can reach. Blade speed also affects rotation of the player avatar - higher numbers correspond to faster rotation. Internally the mechanic works the following way: the higher the blade speed, the more enemies the player can destroy in a row, before interaction is disabled for a short period of time. The reason behind this is balance – the player should not be able to destroy an unlimited amount of enemies alone or otherwise he would have no motivation to try to cooperate with other players. The blade allows players to destroy a huge amount of enemies on their own, but has the negative effect of disabling interaction for a short amount of time (a 'cooldown' effect, known from regular games).

4.3.2 Laser

The laser allows players to destroy enemies at a fast rate by moving close to each other. Doing so they form a blue laser, which destroys everything in its path. To create the laser, players need to stay approximately one meter from each other and should not move further than three meters away. They can then maneuver in pairs around the playing field to eradicate the enemies. The connection can only be broken if the players move away at a certain distance from each other or if a second level enemy passes through the laser since it can only destroy level one enemies. The mechanic was conceived after observing people during play sessions of the *Game Changer Suite* and the way that strangers are motivated to work together and ignore their social surroundings (the so called reaction bubbles, see Section 2.2.3).

For the mechanic to work the game needs to store the positions of all the players and calculate the distances between them. The minimum distance for forming a connection is predefined by the game designer. In 'Singularity' it is about 150 pixels, which considering the size of Deep Space corresponds to approximately one meter in the public space. Any objects passing between the two players are detected via a raycast. In case they are level one enemies, they are destroyed. The connection is represented by a glowing line, rendered between the players (see Figure 4.4). This is achieved by using the line renderer, which is an object provided by the Unity engine. It requires a start and an end point and draws a line between them in 3D space. The line receives the positions of both players and updates itself so it follows their movement perfectly. It is also a networked object, so the position data

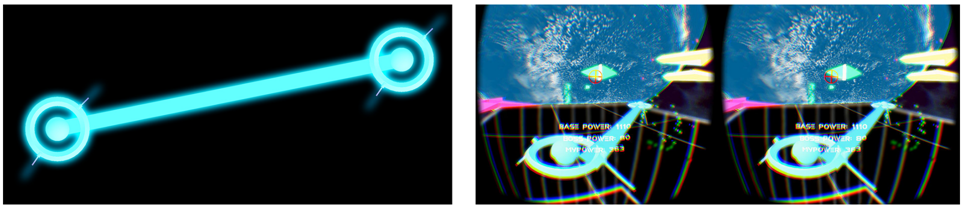


Figure 4.4: Laser connection between two players. Representation in 2D (left) and 3D (right).

is sent via network to the client VR application. The VR player then sees a 3D representation of the line. One problem that was encountered is that when the line is broken, its representation in the client application is not automatically removed, which is why a self-destroy mechanism was implemented.

4.4 Entities

The non-player controlled entities have an important role for creating an enjoyable and balanced gameplay. Each of them has a specific role that the players need to deal with. The Mothership is the main enemy, spawning swarms of level one and two enemies, while the Core is the main base that needs to be protected from them. The implementation and design of each one of them is described in detail in the next sections.

4.4.1 The Core

The Core is located at the center of the playing field. The health and energy variables from the first prototype are replaced with a resource, called Power. The game begins with the Core having a certain amount of Power which can be charged by destroying second level enemies or the Mothership. The game is won as soon as the Power level of the Core reaches a predefined amount. However, the Core loses Power, when an enemy reaches and collides with it. The game is lost, when the Power level reaches zero. The goal of the game is to defend the Core from incoming enemies and destroy the Mothership. The Core is represented as two floating triangular shapes, spinning clockwise and counter-clockwise as can be seen on Figure 4.5. The higher the amount of Power the Core gathers, the faster both shapes spin.

4.4.2 The Mothership

The Mothership was initially conceived as a part of the second level of the game. The first level would introduce players to basic mechanics such as the blade and the laser. The second level would then expand the gameplay

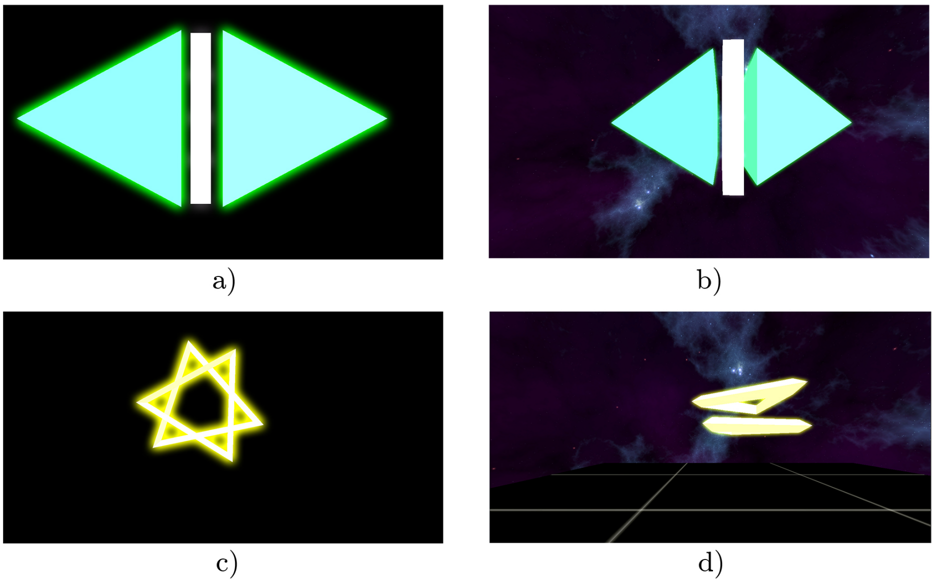


Figure 4.5: The Mothership (up) and the Core (bottom). Representation in 2D (left) and 3D (right).

by introducing the Mothership as a final 'boss'. The idea was abandoned, because the game needed to be kept simple, easy to understand, should not have taken a long time to complete and there were certain time constraints for the implementation.

In the first prototype, enemies are randomly spawned outside of the playing field without any explanation of their origin and goals. In the second prototype the Mothership assumes the role of the main adversary in the game. It is the entity that spawns waves of enemies and slowly approaches the Core, aiming to destroy it.

At the beginning of the game, the Mothership spawns at a random location outside of the playing field and is therefore only visible to the VR player. At predefined intervals it teleports to a new location, always at a certain distance from the center of the playing field, where the Core is located. It then spawns a random number of first and second level enemies, stays idle for a while and teleports again. With the passing of time the Mothership approaches the Core and enters the playing field, thus becoming visible to the PS players, but also vulnerable to the VR player. It can be shot down by him, which automatically charges the Core with a huge amount of Power. As shown on Figure 4.5, the Mothership consists of two pyramidal structures, resembling the shape of first level enemies. There is a white rectangular shape between them, which serves as a portal for summoning entities. It expands and contracts, when enemies are spawned. Each ability

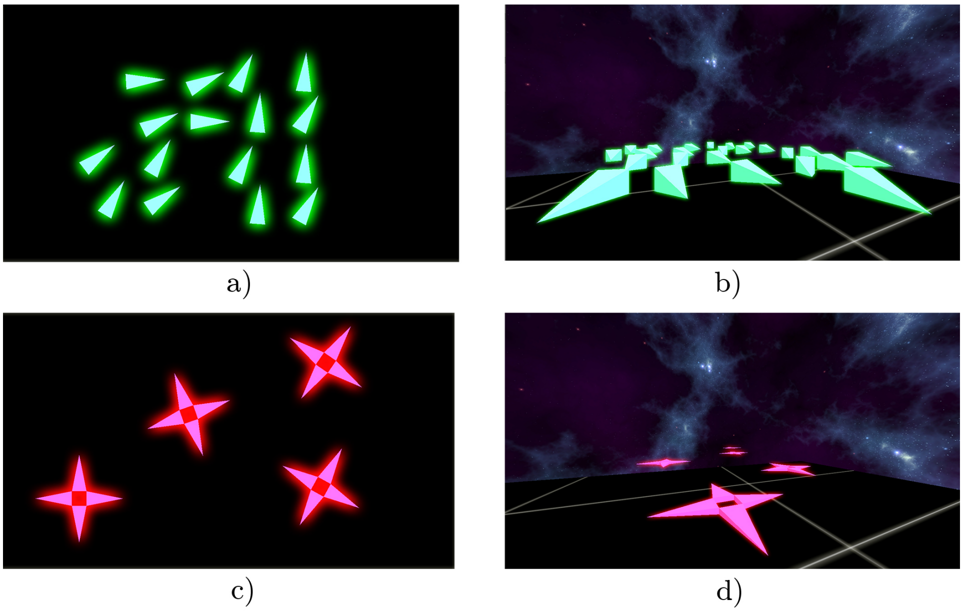


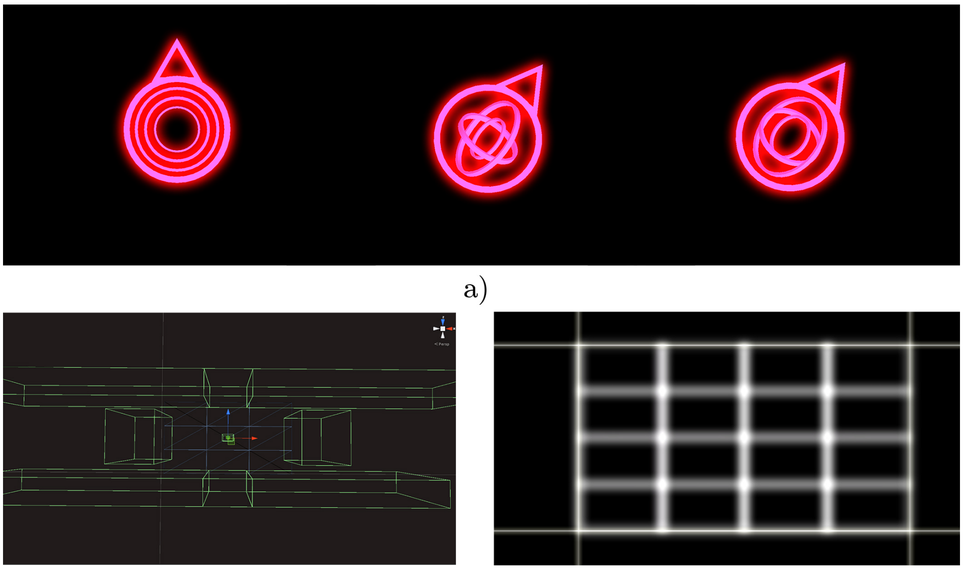
Figure 4.6: Level one enemies (up) and level two enemies (bottom). Representation in 2D (left) and 3D (right).

of the Mothership has its own distinct animation and sound.

4.4.3 Enemies

The representation of first and second level enemies can be seen on Figure 4.6. Level one enemies are conceived as a swarm of crystal-shaped entities, moving together in a flocking pattern towards the Core. Each time the Mothership teleports to a new location, its position serves as the main spawning point. The exact spawn location is randomized around this coordinate so that the enemies do not stack on top of each other. At predefined intervals, direction, rotation and movement speed are randomized so that each entity follows its own path. Direction towards the center is then restored to keep the flocking pattern consistent. On collision with a player or a laser, the enemy is destroyed and a certain amount of Power points are transfered to the VR player. However, if it collides with the Core, it subtracts from the Core's Power points.

Second level enemies resemble giant spinning stars and were added at a later stage of development. They can only be destroyed through the interaction between PS and VR players (see Section 4.5.1). They are spawned less frequently than level one enemies, but can subtract more Power from the Core on collision. They also disturb laser connections, which prevents PS players from destroying level one enemies nearby.



a) b) c)

Figure 4.7: Virtual reality player representation (a). Placement of colliders for the activation of the 'notification ability' (b). Activated 'notification ability' (c).

4.5 Virtual Reality Player

The VR player implementation from the first prototype receives a few additional features and different abilities for the player to explore, but keeps its most basic functionality. The Oculus VR controller, provides the VR camera and movement controls. The VR placeholder, called the VR Ghost, receives the position data from the VR controller and sends it over the network to the public space application. There are three main abilities, which are implemented inside the VR Ghost. The reason for that is that when the abilities are activated, the events need to be transmitted over the network and trigger corresponding animations and events in the public space application as well. The abilities are: 'notification', 'summon player' and 'laser gun'. Each one of them went through multiple iterations and are described in detail later in this chapter.

Figure 4.7 shows the VR avatar in its idle state and Figure 4.9 shows the avatar, when the 'summon player' ability is activated. The VR player uses Power points for its 'laser gun' ability. Power is automatically collected from each enemy, destroyed by the PS players.

4.5.1 Abilities

Crosshair

Specifically for using the ‘notification’ and ‘laser gun’ abilities, a crosshair for the VR is implemented. In traditional games, crosshairs have a static position in the center of the screen and are usually surrounded by important information or sometimes connected to the user interface itself. In VR games however this does not work that well. 2D user interfaces need to be implemented carefully, because it might be unpleasant for the user to constantly focus on something that is so close to his eyes. To avoid this a ray is cast from the VR player and the crosshair is projected on top of objects, reached by it. When the object is further away, the crosshair is small in size and becomes bigger, when the object is closer to the user. This makes interaction and selection of objects more intuitive and improves shooting precision. The ray is also used to detect the object, at which the player is looking, and trigger actions accordingly.

Notification Ability

The notification ability is one of the core abilities since the first prototype. Initially it was represented by a red arrow, floating in space, pointing towards the position of the enemies. In the second prototype it is replaced by glowing panels, integrated in the playing field. It is divided into nine areas of equal size and an invisible glowing surface is positioned above each one of them. When the VR player looks at it and presses a certain button, the surface becomes visible for a short period of time in both the VR and PS applications. This way the PS players know which area needs to be defended next. After the initial tests of the prototype two issues were discovered: the glowing surface was too bright and PS players could not recognize the enemies and their own avatars on top of it; the surfaces could only be activated, when the VR player looks directly at them. This means VR player vision is constantly distracted by looking at the floor. To fix that, the spread and amount of glow of the surfaces were reduced so that objects above them are easily recognizable (see Figure 4.7, c). Additional colliders were implemented for each of the notification surfaces (see Figure 4.7, b). They are positioned around the playing field so that the panels are activated even when the VR player does not look at the floor – it is sufficient to look at the enemies and press the notification button.

Laser Gun Ability

The laser gun is used by the VR player to destroy the Mothership. In its essence it is a traditional shooting mechanic, which requires the VR player to aim at the Mothership and press the shoot button to fire. A particle

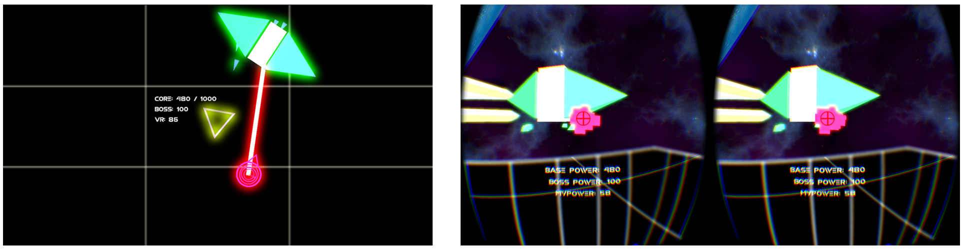


Figure 4.8: Laser gun ability. Representation in 2D (left) and 3D (right).

simulation is used for the 3D animation of the laser gun shot, while a line renderer is used for the 2D public space representation (see Figure 4.8). This way the role of the VR player is even more important for winning the game, because the Mothership provides a huge boost to the Core's Power when it dies. The laser gun can only be used, when the Mothership enters the playing field, at a certain distance from the Core. As ammunition it uses the Power resource of the VR player, obtained through the destruction of enemies in the PS application.

Summon Player Ability

A substantial amount of time was invested in developing the 'summon player' ability. The mechanic aimed to combine PS and VR gameplay by introducing players from both applications to a collaborative way to capture and destroy enemies. It was developed in order to motivate PS players to interact and communicate with the VR player and observe if an effective connection can be achieved. The main difficulty lies in designing the mechanic to be easily understood and useful. The healing ability from the first prototype did not achieve this goal and instead substantially slowed down the game pace.

The 'summon ability' consists of two main actions: the VR player presses a button to activate it and a PS player is required to trigger the effect. An animation in the PS application is triggered as shown on Figure 4.9 and a voice command, saying 'come to me' can be heard. One PS player is required to collide with the VR player in order to trigger an area of effect attack. This attack is represented by a glowing circle, expanding up to a certain limit, while at the same time destroying all level two enemies in its path. This is the only way to destroy this type of enemies, which is why the interaction between the two applications is essential for completing the game. The ability was the final result of the iterative process of implementing and balancing a so called 'net mechanic', which is described in the next section.

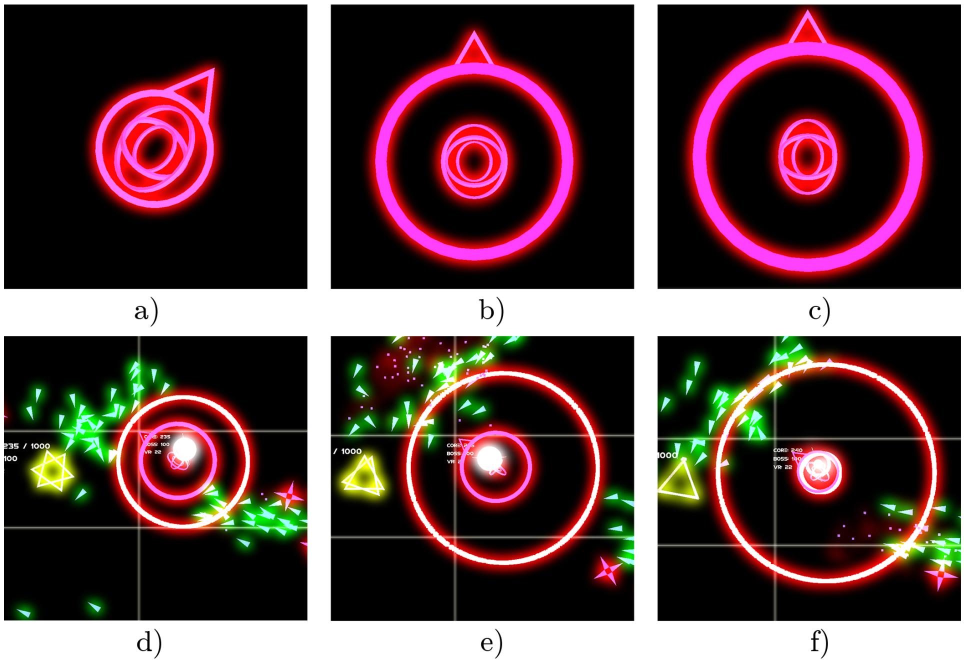


Figure 4.9: Virtual reality player using 'summon ability' (a,b,c). Public space area of effect attack (d,e,f).

4.5.2 The Net Mechanic

The initial idea behind the 'net mechanic' was to explore collaboration between PS and VR players by providing them with an instrument for capturing enemies. The first implementation required three PS players to stand at a close distance from each other (see Figure 4.10, a). Instead of a blue laser, a red laser was created between each of the pairs, forming a triangular shape, which served as the net. Players could then move around the playing field and trap incoming enemies by letting them pass through the red lasers. The moment an enemy entered, it changed its color to red and was trapped for a few seconds. It also followed the movement of the net, always moving towards its center. After the trap time expired, the enemies could continue their normal movement until they passed through one of the red lasers again. The reason for trapping them was so that the VR player can shoot at the captured enemies to destroy them and by doing so, charge the Core. The net could only be broken, when the players moved away at a certain distance from each other. The mechanic was tested by a few people and it was quickly discovered that it was not easy to coordinate actions and communicate information between the two applications. The VR player also did not feel involved in the actions and it put extra pressure on him to collect the captured enemies.

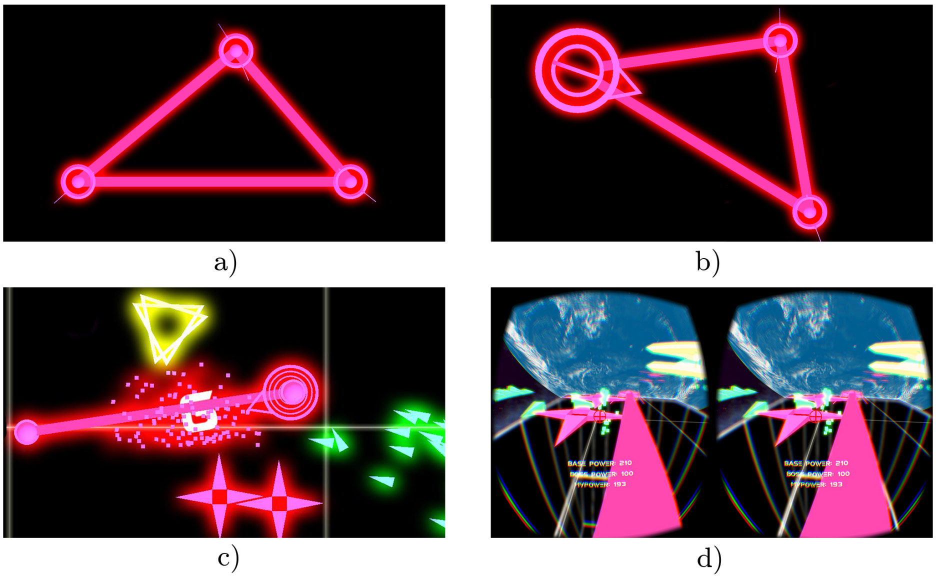


Figure 4.10: Three players forming a net (a). Two players and the virutal reality player forming a net (b). One public space player and the virtual reality player forming a net (c and d). Representation in 2D (c) and 3D (d).

The next approach explored how a net can be formed with the help of the VR player. In this case, he had to manually select two players by looking at them and clicking a button, which would generate a ‘come to me’ voice command, similar to the ‘summon ability’. As soon as the two players were close enough, the net would be formed (see Figure 4.10, b) The enemies could then be captured and destroyed by the VR player. The approach was tested and it was still too complicated to use.

In the final approach, the net could be formed only by a single PS player and the VR player. The VR player could again trigger the ‘come to me’ voice command and as soon as a PS player approached, the net was created. Both players could then expand and position it for a few seconds. The net would then remain static on the field for a limited time and destroy all second level enemies in the process (see Figure 4.10, c and d). The mechanic was the easiest to use from all implementations, but was in the end replaced by the ‘summon player’ ability, which far simpler, fast and easy to use.

Despite not being featured in the final version of the game, the net mechanic was an interesting exploration of possibilities to connect these two applications. It could be used in a different context or a simplified version of the game. The development of the mechanic also generated ideas for extending the game to other platforms such as smart phones and for example allowing mobile users to capture enemies as a way help the PS players.

Chapter 5

Evaluation

This chapter presents the methodology and results of the evaluation of the thesis project, the design and implementation of which are thoroughly examined in Section 3.5 and Chapter 4. There are two applications – one for a public space environment and one for a virtual reality head-mounted display. The evaluation aims to analyze if the current implementation succeeds in providing enough communication channels and possibilities for collaboration between the two applications. Further topics of examination are the audiovisual representation of player actions and in-game entities, usability and presence in the virtual reality environment. Finally it is discussed, which elements aid or hinder interaction and cooperation and which mechanics can be improved in the future.

5.1 Methodology

Two experts from the Ars Electronica Center's research and development facility were the main evaluators of the project: Roland Haring, the technical director of the Futurelab, who has an extensive experience with interactive installations in the Deep Space and Peter Holzkorn, Futurelab's Academy Coordinator. Due to the specific technical requirements of the project, it could only be tested properly in the Deep Space at the Ars Electronica Center. The museum has very limited hours that are available for testing. For this reason, a retrospective testing approach with the two expert evaluators was chosen [18]. First they tested each of the applications and then participated in a 20 minute session, where they answered questions and shared their thoughts about their experience with the applications.

Two computers were set up inside the Deep Space. The first machine was connected to the tracking and projection system of the Deep Space and ran the public space application. By using a second network card it was also connected to the second machine, which was responsible for the virtual reality application. The *Oculus Rift Development Kit 2* headset (SDK

0.4.4) was used as the virtual reality head-mounted display, due to reasons described in Section 4.1.

The two evaluators were shortly briefed about the nature of the applications, they were about to test. No exact details were given to one of them and some parts were explained to the other one. The intention was to let them discover the mechanics and interaction possibilities by exploring the applications on their own, but also observe how information can change their understanding and perception. In case any questions arose or the evaluators were not sure how to play the games, there was always a person present, who knew the game and could help. This was done in order to discover problems in the system that made the games hard to play, as well as issues with the audiovisual design that might hinder understanding.

While the first evaluator was testing the virtual reality application, the second one played the public space version with other players. After the game finished, they changed their roles. Each of the evaluators played one round of the game and then proceeded to the retrospective session. The interview was recorded by camera and the audio was extracted and improved for better understanding. The answers and additional comments of the evaluators are summarized and analyzed in Section 5.2. The full protocol from the interview is available in Appendix A.

The questions of the interview are partly inspired by the presence questionnaire [25] and game usability heuristics for evaluating and designing better games [4]. They are focusing on three main areas:

1. The experience in the virtual reality application.
2. Communication and collaboration in the public space and between the two environments.
3. Usability and audiovisual presentation.

The interview aims to collect the professional opinion of two experts, who have experience in the field and can suggest a number of ways to improve or extend the application. The limitation of the method used for evaluating the thesis lies in the fact that it does not include evaluation data from a wide audience, which could show other problems that casual players might experience. This however is not the focus of the thesis at the current state, since there are still improvements and polishing to be done so that the game can be presented to the public. The opinion of the expert evaluators is important for discovering the main issues and correcting them. Another goal of the study is to find out if the project is a proof of concept that public space and virtual reality environments can be connected in an interesting and understandable way and provide players with means for communication and collaboration.

The two experts, Peter and Roland are represented with their abbreviations, P. and R. throughout the interview to avoid repetition. Peter played the game in the public field without any explanation beforehand, while

Roland took over the virtual reality application first and had a person next to him, helping him put on the head-mounted display and controller and answering questions about the game. After the first game, they changed roles and Peter took the role of the virtual reality player.

5.2 Results

The key findings presented in this chapter are based on the answers of the interview, as well as personal comments from the evaluators. Due to the reflective nature of the retrospective approach, the data needs to be compiled by extracting information from different parts of the interview and summarizing it into a few main topics.

5.2.1 Virtual Reality Environment

The two experts had contrasting experiences with the virtual reality environment. The game was first tested by Roland (R.) and due to his previous experience with the *Oculus Rift* he had an easier time finding his way around. According to his observation, the environment is too small and an improvement in character speed and scale is needed. The problem is that when speed of movement is too high and the space is limited, the player often has to turn around, which leads to disorientation and unnecessary rotation of the head. This could be resolved by reducing the scale and speed of the virtual reality controller. R. also mentioned that the Mothership is too easy to destroy and there could be alternative mechanics for accomplishing that. He suggested that as the VR player he had the agility and freedom of movement to avoid obstacles and dodge enemies. Another interesting point of being the virtual reality player was that R. did not feel connected or really dependent on the public space players. He explained that the only time he needed them was when they had to come to him to trigger the area of effect attack. The rest of the time he was exploring the field, looking out for level two enemies and shooting at the Mothership. He noted that there was no need to pay attention to what the public space players were doing, since it was irrelevant for him. Another important aspect was that he had the feeling that players in the public space had a better overview of the positioning of the enemies than the virtual reality player. This could be due to the fact that he did not initially understand the way the two applications are connected. The notification ability appeared to be useless, because there was no clear explanation that enemies are spawning outside of the borders of the playing field and are only visible to him. One last point he made was that the virtual reality player does not have to be in the same room as the public space players - the game can easily be played over the internet from any point in the world. This could be a way to further extend the game or introduce a completely new approach to the game design.

Peter (P.) felt lost most of the time, because he never experienced virtual reality and for him it was hard to have a controller in the hand at the same time as wearing the headset. He tried to keep his orientation, but the amount of possibilities for movement around the playing field that the controller provided were too many and were actually limiting his interaction. Since P. played the public space application first, he understood the fact that enemies come from outside of the playing field and realized why the notification ability is used. However, according to him the complexity of interaction can be reduced, because casual players still do not have experience with virtual reality games and it can be hard for them to adapt to the setting and have full control at the same time. He believes that the virtual environment is an interesting addition to the gameplay, but needs further examination and balancing.

5.2.2 Communication and Collaboration

Concerning the communication between the public space and the virtual environment, R. pointed out that the auditive information was essential for understanding what and where it was happening. It was important especially for the 'summon ability', because the players could hear where the sound was coming from and move towards the location. The visual representation, in this case being a red glowing circle also helped communicate the position of the virtual reality player, but was according to R. not of such great importance as the sound. For P. however it was hard to distinguish the virtual reality player, because the game was not explained to him so he did not understand what this entity's purpose was during the game. Another suggestion from P. that would help communicating information to the players better, was introducing the game mechanics in different levels. It would be better to learn how to control the player avatar on the playing field first, then connect with other players and finally fight against the Mothership. It would provide a smoother transition between the mechanics and a good way to learn how the game is played, because otherwise there was too much to remember for the first time.

Concerning collaboration, R. and P. both praised the laser mechanic, which allows two players to move together and destroy enemies with a glowing connection between them. One problem that R. encountered was that there was an odd number of players in the public field, which meant there was nobody for him to connect with. A suggestion of how to improve this, was to allow the creation of lasers between three and more people, possibly creating a triangle or other bigger shapes that can for example capture enemies. This suggestion recalls the net mechanic, described in Section 4.5.2 and is a possible way to extend the focus of the game in this direction. P. noted that the laser mechanic was a successful part of the gameplay and pointed out that close proximity to players and interaction with other people in the physical space was the main focus of the Deep Space, which is why mechanics like this fit it nicely. According to him, it was a good choice to motivate people to come really close to each other to create the laser connection and then learn how far they can expand it on their own.

Another interesting point was the fact that R. felt that as a public space player one has a bigger need of the virtual reality player and always searches for him. This is due to the fact that level two enemies can only be destroyed through the help of the VR player. He pointed out that as a VR player, however, one did not feel connected to the public space players and did not really need them. He even preferred to just go to them, when he needed them to trigger the area of effect attack and not even tried to motivate them to come to him. His feeling was that he could use the PS players and guide their movement and attention, but only up to a certain point.

5.2.3 Usability and Audiovisual Feedback

The current controller setup allows the use of two main buttons: one for activating notifications and shooting at the Mothership and one for triggering the 'summon ability'. R. pointed out that the controls can be improved by providing three buttons for the three available actions, instead of two, although this might introduce one extra button for players to remember. P. also experienced issues with the controls, since the Xbox controller provides two joysticks for moving the character and looking around. For a person, who is used to keyboard and mouse controls, this can be overwhelming and hard to use. One suggestion was made that maybe the game could be played without a controller and use character movement instead, but this would need to be integrated within the game's mechanics.

According to R., a major point about the visual design of the game was that the game setting is very dark, because of the black background. The highly contrasting glowing red, green and blue colors of the entities create a feeling of a visual imbalance. Especially in the virtual reality environment these contrasting colors can be too overwhelming and at some point confusing. P. also mentioned that at certain points the green enemies looked like a giant blur of green and appeared to have a really low resolution. Another problem was the color composition of each of the entities. Since the game was not explained to P., at the beginning he had the impression that the yellow spinning Core at the center was actually the enemy and the green triangles were friendly entities. The red color of the level two enemies also matches the red color of the virtual reality player, which can result in further confusion. Overall, the color design of the game needs to be changed to the proper conventions (for example, green - good, red - bad) so that automatic assumptions are correct and there is no need for special explanation of the entities. According to P., once the player is accustomed to the colors, the visuals are clear and understandable.

Another point, made by R., was that the simple interface, displayed next to the Core and inside the virtual reality are unnecessary, when the information is transmitted through sound. He pointed out that he never looked at the numbers and did not know what they mean and relied on the sound design, which communicated the actual game progress. It was especially important, when a player is focused on the game and can not pay attention to the score screen.

The final comment about the game, made by R. was that it is the first project to combine virtual reality in Deep Space and is an interesting opportunity for testing different approaches. He believes there is a lot to learn yet and it is not easy to create a fitting application for this specific setup, but the project serves as a trial of how this might work.

5.3 Analysis

From the expert evaluation it becomes clear that certain aspects of the game can be improved in order to create an easier to understand and more enjoyable experience. The game mechanics that aim to inspire collaboration and communication between the applications require further polishing and balancing. Some of them are successfully implemented and fulfill their role, but others need further improvement or even a different approach. The following list presents a summary of game elements, discussed by the experts, with possible future improvements:

1. Laser – giving the players a way to connect and move close to each other around the space, pursuing a common goal, fosters collaboration and explores proximity in public spaces. One way it can be improved is to allow connections between more than two players so even in the case of an odd number of participants, nobody is left out.
2. Blade mechanic – running fast to spin the blade and destroy a large number of enemies alone is not clearly represented. An additional visual representation that highlights this possibility is needed. For example, a glowing particle simulation around the player, combined with the sound of a charging electric motor could be a possible solution. However, the mechanic might be unnecessary if the focus of the gameplay falls on collaboration and creating laser connections between the players.
3. Virtual reality movement and control – speed and scale of the virtual environment need to be tweaked in order to achieve a balanced movement for the player. Controls are still not intuitive enough, especially for first time users. Other input devices like *Leap Motion* or *Oculus Touch* can be considered as a solution in the future. It is also possible to experiment with the usage of movement and positioning for triggering certain actions.

4. Notification ability – not easily understandable. An explanation of how and why to use it might be needed before the game is played. Highlighting certain areas of the playing field can be replaced by a similar notification mechanism. For example, it is possible to allow the virtual reality player to draw directions on the floor, highlighting not only certain areas, but providing exact directions for movement to the public space players. This way, information can be clearly represented. The problem with this approach is that it puts additional pressure on the VR player to provide proper guidance.
5. Summon ability – attracting the attention of the public space players proved to work as intended. The animation combined with the audio feedback easily alerts players to the position of the VR player. One issue is that the VR player does not always consider the public space players as important for him and uses them only for this own purpose. The collaborative aspect of the game and the intention to bring the two applications closer together is not perfectly aided by this mechanic and it might need further improvement.
6. Visual style – the main issue with the visual presentation of the game is the color contrast. Entities should be represented by colors and shapes that correspond to common knowledge so that friends and foes can be recognized easily without any explanation. The post-processing glow effect in the virtual reality application should be reduced to avoid blurriness and provide clear separation between the enemies. Most of the animations provide a clear and direct feedback to player actions, but there might be additional effects needed, e.g. the charging of the blade, described earlier. The user interface can be completely replaced by sound, since the numeric information it provides is not interesting to the players. Another way to replace the numbers is to create animations about the current state of Core's shield and virtual reality player's power, which correspond to general conventions about the representation of such information.
7. Sound design – praised by the evaluators as essential for the communication and representation of information. Currently, there is no sound implemented exclusively for the virtual reality application itself, which is a needed improvement in future versions and can further help for better immersion.
8. Game progress – the game can be divided into a few levels, slowly introducing each of the game mechanics and allowing players to grow accustomed to the unconventional setup. A tutorial level might be needed especially for the virtual reality application since most people are not yet experienced with it.

The overall impression of the evaluators is that the game is an interesting approach to an unconventional setup and reveals many issues and possibilities. Some of the suggested changes have already been considered during the implementation part of the project, but were not implemented for different reasons. The game needs a detailed explanation, but once players understand it, they know what to do. Further improvement can be introduced by creating more levels and balancing the gameplay by also providing more ways for interaction. Some of the suggestions like the activation of abilities through movement, dodging of enemies, multiple connection possibilities between players and expanding the sound design of the game could be interesting ways to extend and include additional mechanics in the game.

Chapter 6

Conclusion

6.1 Summary

The rapid progress of technology in recent years has brought engineers and designers to a point, which allows the development of mixed reality experiences that dissolve the borders between real and virtual worlds. The smartphone revolution, combined with the advancement of sensor and display technology, has impacted the development of novel interactive systems. It also has an influence on virtual reality head-mounted displays, which are currently experiencing a renaissance and will have an impact on consumer markets in the close future.

The thesis project takes advantage of all these advancements, including the projection and laser tracking system in Deep Space at the Ars Electronica Center and the latest virtual reality headset, developed by Oculus. Several games have already been developed for this specific public space, exploring competitive and collaborative gameplay, as well as player proximity and social presence. Virtual reality on the other hand is a field that inspires experimentation and innovation.

The project aims to extend the public space environment and expand research into player collaboration and presence by introducing a multimodal component to the setup. One of the main challenges is to discover the proper mechanics and communication channels that foster cooperation and reduce the borders between real and virtual environments. The project tries to combine multiple genres and fields of research, e.g. mixed reality, pervasive and co-located games, virtual and augmented reality. Finding the common theme in all these areas has lead to merging them under the term 'social immersive media', which describes the core idea of the project - immersing players in a social mixed reality experience and exploring the common elements of all these technological fields. To achieve this, research is also done in game design, combining ideas from trans-reality, virtual reality, social immersive media and emergent game design.

The main challenge for the implementation of the thesis project is to create two networked applications, one for a public space such as the Deep Space, presenting players with a 2D perspective of the game. The second application presents a 3D virtual reality perspective, which needs to be in perfect harmony with the 2D application. Game events and entity movement have synchronized positions and time in both applications, which is why the network component of the project needs to be optimized and run as smooth as possible. This is especially important for the virtual reality player, because latency and any sort of error can easily break the experience.

The long process of planning and implementing different mechanics and experimenting with the audiovisual communication of information between the applications has resulted in many discoveries about this uncommon setup. Fostering player collaboration through proximity and exploring how the virtual reality player can stir public space movement and initiate certain events has been the main focus of brainstorming sessions. The valuable advice gathered from the expert evaluation helped recognizing certain issues with the current version and provided new ideas and possible approaches for future implementation.

6.2 Future Outlook

With multiple virtual reality head mounted displays coming to the consumer market in 2016, exploring this field is a great opportunity to gather experience and recognize design limitations early on. With the acquisition of a mobile tracking and projection system for public spaces by our research lab, co-located gaming can also be easily explored. The thesis project is an experiment that serves as a proof of concept and provides an insight as to how real and virtual environments can be combined. Mixed reality experiences will continue to enter mainstream media and become more and more popular, which is why research and development in this area can prove valuable for exploring user experience at an early stage. Through the combination of traditional games with new technologies, players can be motivated to exit their comfort zone and socialize in the real world, while enjoying virtually enhanced environments. Exploring the social aspect of games is especially important for virtual reality since it is considered by many as an anti-social experience. Further research in these fields is needed to improve collaboration, communication and the social presence of individuals. It is an exciting time to develop mixed reality games and explore the possibilities of virtual reality.

Appendix A

Protocol from the Expert Interview

I – Interviewer
P – Peter, game was not explained, played PS version first
R – Roland, game was explained, played VR version first

I – So, I have a couple of questions about your experience. I know it was kind of rushed, but it would be nice to get some feedback. Were you aware of the presence of the virtual reality player, when you were playing in the public field?

P – I was not, because the game was not explained to me. R – The virtual reality is the one with the Oculus Rift? Yes, I was aware.

I – But the difference was that you already knew how the game is played?

R – Yes, so it was quite easy to distinguish him from other objects on the floor.

I – Did you feel his effect on the gameplay?

R – Yes, sometimes I had the feeling he is a bit lost. He was at the complete opposite side as the enemies were.

I – Were you feeling lost?

P – I was feeling lost. But I think the thing is it was the first time I played a game with the Oculus Rift. And, I think it may have been too much for me, having two controllers and to look, because I basically hardly ever used looking around. I was aware of it and it was cool, but it did not add anything to the game for me so I was trying to keep my orientation.

I – Did you feel disoriented?

P – Not really, it was just there was one too many dimension for me. I could have done with either not having the right control stick or not having the left or not having to look. I just felt there are so many ways to move and the game was relatively simple so it did not necessarily require it. But again, it is the first time I played on something like that, the Oculus Rift. I am used to having two controls, like a keyboard and a mouse.

I – And for you, the virtual reality player?

R – When playing with him, being the VR player, this indicating where the enemies come from did not help much, because I had the feeling that on the floor you can even see better, where they are coming from. I don't know if you did it often.

(They discuss how the notification ability is used)

R – And you did it sometimes, but there was nobody. And I thought it is hard. P – Aaah, because I could see outside the playing field!

R – Okay, but this is then what I did not understand. Because I just looked where you indicated and I saw there is noone and then I saw on the other side enemies coming.

P – When I was indicating I was trying to shoot basically. But I could not shoot yet.

I – Actually the enemies spawn outside and you can see them, but the public space players can not.

P – It makes sense now that I can see them, but I was not aware of that actually.

I – Was the information communicated efficiently. For example this red circle, 'come to me' ability?

R – Yes, this was visible enough. But the most important was the auditive information, hearing his voice. This was helping much more, because when you hear the sound you start to look on the floor, where is he, and then you just go there. So it is not so important to have a visual mark as well, because then this is enough already.

I – So actually sound helped you more than the visual signs?

R – Yes, and he is also good to find, being this red circle, is quite easy.

I – What other potential ways could you see for communicating between these applications?

R – What my feeling was, when I was the VR player is that having this flag to mark something on the same button as the shoot, that this is a double use. I would just use three buttons. Of course then you need to remember three different buttons. And, what might be interesting is if it possible to avoid buttons, but more through movement or if there is... Yes generally, the whole game setting is quite dark, which comes from the fact that the background is black, which is very minimalistic. And sometimes it is a little bit too much reduced. From my impression. And you have a very high color contrast with this red and green, which does not give you the feeling of a balanced environment. Like, in a virtual way, especially also with the Oculus Rift on. This is probably too much contrast.

P – I felt sometimes, I don't know if it is the resolution of the Oculus. I felt sometimes the enemies would just become one big blur of green and it was just big blobs of color. I don't know how do you want to get that clearly distinguishable contrast. It just became very, it seemed super low resolution and it is probably not that low resolution in the Oculus.

R – And when being on the floor, I had quite often the experience that I stepped exactly over an enemy and the enemy did not die. But I thought that I have a sphere and when this sphere intersects with the enemy then it should kill it.

P – But you can connect it?

(discussion how the laser and blade mechanic works)

R – I did not understand this. And i was wondering, because I thought it is just enough to collide and kill it by colliding. And this was not always working, probably because I was not charge enought.

I – Do you think that if the game is not explained before it is played, it is easy to understand, self-explanatory. Or do you think you need someone to explaing it?

P – I feel like, to be honest, maybe not introduce everything at once. Maybe have two or three levels. The first level, you have the single sphere, then the second level you have the sphere with the charing and the third you have the connection. The same with the VR player, maybe in the first level the Mothership thing. I don't know somehow, it just seemes a lot of stuff you have to remember the first time you play it.

I – So it was too much at once.

R – And my impression is that the Mothership was too easy, because it was just standing there. Especially, when having the Oculus Rift on and you are quite agile and you can move around a lot. And it might be funny if you have to move for example for avoiding to get hit or something like that.

I – So you think some kind of a mechanic that makes you move and avoid the enemies?

R – Might be. It might be interesting in general that the virtual reality player has to avoid all the enemies, because it can not shoot, but can not take collisions.

P – One minor thing about the visual language. I initially thought the yellow thing that was spiky in the middle was an enemy and the green glowing things were friendly. Maybe it were the color and the shapes, for example a green pulsating heart, something that is really clear what is the good and what is the bad thing. Of course it is clear when you get used to it, but if it is not explained, there are automatic assumptions about certain colors.

I – So was the audiovisual feedback of your actions clear?

R – This was good. P – Once you remember the colors it was clear. R – And having the Oculus on I had the feeling this space is too small. When you move around, so that you are like moving forward and then again you get to the edge of the surface and you have to move back instantly. Do you think that is a good approach to basically map the virtual environment one to one with the field. The questions is the scale and speed. Because if you minimize the speed then you also have the perceived higher scale of the environment to get around. Otherwise you are very fast actually, because you are going one direction then another and sometimes you lose orientation. Due to the fact that you can move fast.

I – Can you remember any specific instances when you collaborated with someone?

R – Yes, I tried to make this laser, but the problem is that we actually were an odd number of players. So it is hard when there are couples already then you can already play alone. And then not knowing the game mechanics of playing alone with the charging is quite hard.

I – Do you think you would prefer to play alone or in pairs?

P – I think it is cool, the connection. I think that is the most interesting aspect of the multiplayer. I think it is more interesting than the charging. R – It is quite effective.

I – And you would not feel disturbed in any way to be in close proximity to other people?

P – No, because that is the whole point of this space. You bring this physical aspect of games into this virtual world. It is a good choice that you have to get really close to start it, but then you can kind of expand it up to a certain point and you learn where that point is.

I – Do you think this is enough. Could there be more collaboration mechanics or ways?

P – Just think about if you have three players that can form a triangle to destroy everything in the middle. More shapes. Could be interesting. R – Also something for if you have an odd number of players.

I – Were you aware of what other people were doing?

R – Yes, this was quite clear. In the center there was sometimes some font showing up with scores or something. But this is something I didn't really have the time to look. The score with numbers.

I – So you did not realize the UI and what the numbers mean?

P – No. R – No, the overall progress like how much shield we have left or life. This was only communicated by the audio. Through visuals I would not have found this.

I – Do you think that sound is sufficient for communicating this information?

R – Yes it is quite good. Because if this would not have been, then it would have been very hard to understand the game progress. I think in general probably the auditive information is very important in this environment, especially when you are moving.

(break in recording)

P – I am not sure what is the place to reduce the complexity, but i feel like in terms of the movement it would be worth reducing it.

I – Especially because you don't see the joystick?

P – Especially because most people would have not played a lot of Oculus Rift games before?

I – Did you at any point feel disconnected from the game? When you were in the public space or virtual reality?

R – Actually when being the VR player, I did not really care a lot about the real players. And I did more my thing and used them for if I press a button that they should come here, but I did not care what they are doing at other time. Otherwise, I was just exploring around and looking for enemies and looking for the red ones actually. And, then shooting at the Mothership.

I – So you did not really feel connected to the PS players?

R – No, they were more useful for triggering this red wave. But I don't know if it is important to watch what they are doing. It probably doesn't help me to see what they do, so they probably not relevant for the VR player.

P – When you said this "come to me", it was almost immediately activated?

I – Yes. So you think there is a disconnection between both environments. In one point the VR player plays his own game and uses the PS players for his goals?

R – I felt when I was a player in the real space, I was more connected to the virtual player than the other way around. Because I had to look where the VR player is.

I – Do you think that you guided the PS players when you were the VR player? Do you think you influenced their actions and movement?

R – Probably a little bit, but not so much.

I – Do you have any last comments?

R – The other thing that you can do is to look where the players are and just go there and press the button and then you just use them without knowing to trigger the red wave. Which is probably even more effective.

I – So they don't have to come to you, you can go to them.

R – Yes, because you are very fast and you can go to them and drop the red wave.

I – Any last thoughts?

P – I think the physical part is really cool. The VR part needs some work to make it make sense. It is cool in its own, but it doesn't feel yet completely fitting.

R – But in general I think it is a very interesting challenge to combine these two technologies and play with this here, in this space. Because actually, as far as I know this is the first Oculus Rift project, which was done in Deep Space. And this is like complete new land to get things together. So this is just a trial to get an idea how this might work and from that point of view it is very interesting. And also there is a lot to learn, which is how to predict in advance to know what the balance of the game or the mechanics need to be, but it is very interesting. And definitely, the first Oculus game. Also I think the combination of both environments has other options thinkable, but it is not easy to get into it.

P – There is also the challenge if you make a game, where place have completely different modes of playing the game, that you make it feel balanced and interesting.

R – The other thing is, the Oculus Rift player does not have to be in the same space. In this case he was sitting there, but this could also be someone very remote like wherever and just have an online connection and play something together, which would probably make more sense. Because having this guy sitting there is not necessary and is also not part of the concept to have him there. So this might be probably an approach for a different game concept in general. To think of interaction where it is necessary to have this guy in there. Just to have the game mechanics work, but this might be a different game.

Appendix B

Contents of the CD-ROM

Format: CD-ROM, Single Layer, ISO9660-Format

B.1 PDF files

Pfad: /

Kostov_Georgi_2015.pdf Master Thesis

Pfad: /Online_Sources

IKEA Catalogue.pdf	[26]
Deep Space.pdf	[27]
Personal Space.pdf	[28]
EVE Valkyrie.pdf	[29]
Brendan Iribe.pdf	[30]
VIEW.pdf	[31]
TUIO.org.pdf	[32]
Visionary VR.pdf	[33]
VR Karts.pdf	[34]

B.2 Project Executables

Pfad: /Singularity_CoLocatedApp(Win)

Singularity_CoLocated.exe Executable for the Co-Located Application

Pfad: /Singularity_VRApp(Win)

Singularity_VRApp.exe Executable for the Virtual Reality Application

References

Literature

[1] S. Björk et al. “Pirates! - Using the Physical World as a Game Board”. In: *Proc. Interact IFIP TC.13 Conference on Human-Computer Interaction*. Tokyo, Japan, 2001, pp. 423–430 (cit. on p. 9).

[2] T.P. Caudell and D.W. Mizell. “Augmented reality: an application of heads-up display technology to manual manufacturing processes”. In: *Proceedings of the Twenty-fifth Hawaii international conference on system sciences*. Vol. ii. Jan. 1992, pp. 659–669 (cit. on p. 5).

[3] Adrian David Cheok et al. “Touch-Space: Mixed Reality Game Space Based on Ubiquitous, Tangible, and Social Computing”. In: *Personal and Ubiquitous Computing* 6.5-6 (Jan. 2002), pp. 430–442 (cit. on p. 8).

[4] Heather Desurvire and Charlotte Wiberg. “Game Usability Heuristics (PLAY) for Evaluating and Designing Better Games: The Next Iteration”. In: OCSC ’09 (2009), pp. 557–566 (cit. on p. 46).

[5] Jeremiah Diephuis, Georgi Kostov, and Andreas Friedl. “Game Changer : a (Game) Space for Intercultural Play ?” In: *Proceedings of the Cross-Cultural Business Conference Steyr, Austria* (2015), pp. 324–333 (cit. on pp. 7, 10).

[6] Paul Dourish. “What We Talk About when We Talk About Context”. In: *Personal Ubiquitous Computing* 8.1 (Feb. 2004), pp. 19–30 (cit. on p. 19).

[7] Kaj Grønbæk et al. “IGameFloor: A Platform for Co-located Collaborative Games”. In: *Proceedings of the International Conference on Advances in Computer Entertainment Technology*. ACE ’07. Salzburg, Austria: ACM, 2007, pp. 64–71 (cit. on p. 8).

[8] Iris Herbst et al. “TimeWarp: Interactive Time Travel with a Mobile Mixed Reality Game”. In: *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services*. MobileHCI ’08. Amsterdam, The Netherlands: ACM, 2008, pp. 235–244 (cit. on p. 8).

[9] Steve Hinske et al. "Classifying Pervasive Games: On Pervasive Computing and Mixed Reality". In: *Concepts and Technologies for Pervasive Games – A Reader for Pervasive Gaming Research* 1 (2007), p. 20 (cit. on p. 9).

[10] Kalle Jegers. "Pervasive Game Flow: Understanding Player Enjoyment in Pervasive Gaming". In: *Computer Entertainment* 5.1 (Jan. 2007) (cit. on p. 16).

[11] Craig A. Lindley. "Game Space Design Foundations for Trans-Reality Games". In: *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology.* ACE '05. Valencia, Spain: ACM, 2005, pp. 397–404 (cit. on p. 19).

[12] Carsten Magerkurth et al. "A Multimodal Interaction Framework for Pervasive Game Applications". In: *Workshop at Artificial Intelligence in Mobile System (AIMS), Fraunhofer IPSI.* 2003, pp. 1–8 (cit. on p. 10).

[13] Carsten Magerkurth et al. "Pervasive Games: Bringing Computer Entertainment Back to the Real World". In: *Computer Entertainment* 3.3 (July 2005), p. 4 (cit. on p. 9).

[14] Steve Mann. "Mediated Reality with Implementations for Everyday Life". In: *Presence Connect, August* 6 (2002) (cit. on p. 3).

[15] Kishino Fumio Milgram Paul. "Taxonomy of Mixed Reality Visual Displays". In: *IEICE Transactions on Information and Systems* E77-D.12 (1994), pp. 1321–1329 (cit. on p. 4).

[16] Markus Montola. "Exploring the Edge of the Magic Circle: Defining Pervasive Games". In: *Proceedings of DAC* 1966 (2005), p. 103 (cit. on p. 9).

[17] Otto Naderer. "Crowd Tracking and Movement Pattern Recognition". MA thesis. Linz, Austria: Johannes Kepler University Linz, June 2015 (cit. on p. 7).

[18] Jakob Nielsen. *Usability Engineering.* Vol. 44. 3. 1993, p. 362 (cit. on p. 45).

[19] Pejman Sajjadi et al. "Maze Commander: A Collaborative Asynchronous Game Using the Oculus Rift & the Sifteo Cubes". In: *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play.* CHI PLAY '14. Toronto, Ontario, Canada: ACM, 2014, pp. 227–236 (cit. on p. 10).

[20] Scott S. Snibbe and Hayes S. Raffle. "Social Immersive Media: Pursuing Best Practices for Multi-user Interactive Camera/Projector Exhibits". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* CHI '09. Boston, MA, USA: ACM, 2009, pp. 1447–1456 (cit. on pp. 3, 18).

[21] Ivan E. Sutherland. “A Head-mounted Three Dimensional Display”. In: *Proceedings of the December 9-11, 1968, Fall Joint Computer Conference, Part I*. AFIPS ’68 (Fall, part I). San Francisco, California: ACM, 1968, pp. 757–764 (cit. on p. 6).

[22] Penelope Sweetser and Peta Wyeth. “GameFlow: A Model for Evaluating Player Enjoyment in Games”. In: *Computer Entertainment* 3.3 (July 2005), p. 3 (cit. on p. 16).

[23] Yanna Vogiazou et al. “Design for Emergence: Experiments with a Mixed Reality Urban Playground Game”. In: *Personal Ubiquitous Computing* 11.1 (Oct. 2006), pp. 45–58 (cit. on p. 19).

[24] Hochleitner W. et al. “Limelight – Fostering Sociability in a Co-located Game”. In: *Proceedings of the CHI 2013 Workshop on Designing and Evaluating Sociability in Online Video Games*. CHI ’13 (2013), pp. 23–28 (cit. on pp. 9, 10).

[25] Bob G. Witmer and Michael J. Singer. “Measuring Presence in Virtual Environments: A Presence Questionnaire”. In: *Presence: Teleoperators and Virtual Environments* 7.3 (June 1998), pp. 225–240 (cit. on p. 46).

Online sources

[26] *2014 IKEA Catalogue Comes To Life with Augmented Reality*. 2013. URL: http://www.ikea.com/ca/en/about_ikea/newsitem/2014catalogue (visited on 07/08/2015) (cit. on pp. 6, 61).

[27] *Deep Space at the Ars Electronica Center in Linz*. 2015. URL: http://www.aec.at/center/en/ausstellungen/deep-space/ (visited on 06/24/2015) (cit. on p. 61).

[28] *Diagram Representation of Personal Space Limits*. 2009. URL: https://commons.wikimedia.org/wiki/File:Personal_Space.svg (visited on 09/24/2015) (cit. on pp. 11, 61).

[29] *EVE: Valkyrie is Ready to Define Multiplayer VR Gaming in 2015*. 2015. URL: http://www.wareable.com/vr/eve-valkyrie-release-date-features-oculus-morpheus-961 (visited on 03/19/2015) (cit. on pp. 21, 61).

[30] *Keynote (Brendan Iribe) - Virtual Reality – A New Frontier in Computing - by Brendan Iribe, CEO, Oculus VR*. 2013. URL: http://www.slideshare.net/DevCentralAMD/keynote-virtual-reality-a-new-frontier-in-computing-by-brendan-iribe-ceo (visited on 09/18/2015) (cit. on pp. 13, 61).

[31] *The Virtual Interface Environment Workstation (VIEW), 1990*. 1990. URL: https://www.nasa.gov/ames/spinoff/new_continent_of_ideas/#.VYrmyM-qpBd (visited on 06/24/2015) (cit. on pp. 11, 61).

[32] *TUIO.org*. 2015. URL: http://www.tuio.org/ (visited on 09/23/2015) (cit. on pp. 31, 61).

[33] *Visionary VR is Reinventing Filmmaking's Most Fundamental Concept to Tell Stories in Virtual Reality*. 2015. URL: http://www.roadtovr.com/visionary-vr-filmmakings-most-fundamental-concept-virtual-reality-storytelling-frame/ (visited on 01/05/2015) (cit. on pp. 22, 61).

[34] *VR Karts GP on Google Cardboard*. 2015. URL: http://www.vrpill.com/recent-news/vr-karts-gp-on-google-cardboard/ (visited on 09/07/2015) (cit. on pp. 21, 61).

Messbox zur Druckkontrolle

— Druckgröße kontrollieren! —

Breite = 100 mm
Höhe = 50 mm

— Diese Seite nach dem Druck entfernen! —