Guidelines for the Design of Augmented Reality Strategy Games

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Abstract

With augmented reality, we can create interfaces that merge virtual objects and data seamlessly with the real world, potentially improving collaboration and interaction. This technology offers opportunities for games, allowing new designs that merge the diverse social and physical interaction of real world games with rapid interactivity and computing power of digital games. To date, research has primarily focused on issues of technology, interaction design, and infrastructure; the design of compelling play has received little attention.

We play games because they are enjoyable; therefore, in order to create attractive games, we must understand enjoyment. In games, engagement, social interaction, and emotional involvement are among the most common causes. We can design for engagement in play using Csikszentmihalyi's model of 'flow'; for social play by making communication easy, natural, and useful; and emotional involvement by understanding the mechanisms by which games stimulate us.

Alongside an understanding of enjoyment, lessons must be drawn from design experience. AR Tankwar is an augmented reality strategy game developed over the course of this thesis, and has been evaluated in the field at a large games convention, and in a detailed comparative study with existing games on tabletop and desktop PC. Evaluations revealed predictable limitations with the technology, but also provided insight into how designers can make best use of the medium.

Based on these activities, and existing knowledge of interaction and collaboration in augmented reality, this thesis addresses compelling play in augmented reality by developing a set of design guidelines for augmented reality games, with particular focus on strategy games.

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Acknowledgments

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Chapter I

Introduction

> The plan adopted against the famine was to engage in games one day so entirely as not to feel any craving for food, and the next day to eat and abstain from games. In this way they passed eighteen years – Herodotus (Book I.94)

Games are an important part of human behaviour [19], and have played a major role in the development of civilization. They play an important role in culture and recreation, and they have become a significant economic activity. Their nature is subtle and ill-defined, yet we can all claim to understand them in some respect. As an unnecessary and usually unprofitable activity, they provide insight into human nature, particularly in the way we engage in play even in the face of pressing need. Johan Huizinga, in his landmark book 'Homo Ludens' [38], goes so far as to suggest that games are the foundations upon which most modern institutions evolved. Today's games industry has a cultural impact that rivals Hollywood, and is beginning to be acknowledged as a fertile new art form.

Time spent playing games can have a therapeutic effect, as they provide a form of release from day to day pressures and needs. An extreme example is described in the quote from Herodotus cited above. It is part of an account of a famine in Lydia in ancient times. To keep morale high, the Lydian king is said to have kept his population distracted through games for many years. Games produce an illusion of control by providing an environment with clearly defined goals, where our decisions have meaning, and where other distractions are irrelevant. Games provide a means for us to relax in a enthralling yet meaningful way.

With few exceptions, modern games can be clearly categorized as digital games, tabletop games, and sports. Each of these categories comprises its own distinct industry and market, and the environment in which they are played poses specific limitations on their design. The digital games industry now has annual sales of almost eight billion US dollars in the US alone [1], and modern computer games have become serious engineered systems with budgets in the tens of millions of dollars. However, this trend has unfortunately limited innovation as large price tags have forced publishers to become more conservative. Tabletop games are more free form, and thus allow for more and easier innovation. However, they lack mainstream appeal and are limited by the practicalities of the tabletop and the necessity of player involvement in all conflict resolution. New sports are freely developed by adults and children all the time as rules change and evolve. However, these are usually transient and informal, with limited cultural impact.

Augmented Reality is one of many new technologies that may offer benefits to game designers. It is of particular interest as it provides a means to merge traditional real world game environments with the strengths of digital games. Furthermore, it provides for new and diverse methods of interaction with a computer, alleviating a major limitation of modern digital games where interfaces have not seriously changed since the 1980s.

Research into the application of emerging technologies to game design has really only begun to scratch the surface. From the game player's perspective, researchers have had a disappointing tendency to use games only as a vehicle in which to try out new interaction techniques, demonstrate infrastructures, and explore human collaboration. This research is certainly interesting, but contributes very little to the understanding of how games can be designed to take advantage of these technologies.

To successfully apply emerging technologies to games, much research is needed. Firstly, the technologies must achieve maturity; they must be stable, their limitations must be well understood, and their infrastructures must be accessible to game designers as well as the specialists who created them. Secondly, their application to game design must be understood. Game design is a complex task, just as games are complex systems. As such, the best way to apply a technology to games is often not clear; there may be many good choices, and what might seem wise at first glance may fail for non-obvious reasons. Finally, means to bring them to market must be developed. Many new technologies rely on expensive and intimidating devices that make them commercially impractical. While the practicality of these technologies may improve, game designers must accommodate this fact and seek to design games that incorporate technologies in a way that makes it possible for the wider game playing population to experience them.

This research cannot be undertaken by a single researcher, nor a single research group. Furthermore, research in the second category may remain ongoing, as we can never truly say that we understand all of the ways in which a technology may be applied to game design.

I chose to examine the merits of augmented reality for the construction of strategy and war games. I chose this game type specifically because the limitations of traditional tabletop and computer strategy games are complementary to each other as discussed in section 5.1. Augmented reality in a tabletop setting offers an opportunity to draw the best from these platforms together and eliminate these limitations, preferably without introducing any new ones. To do this, I developed an augmented reality strategy game and evaluated it in several different ways with a wide range of players. In addition, I have compiled a set of theoretical models and recommendations based on my experience and the existing literature to produce a set of recommendations and guidelines for those seeking to design strategy games with augmented reality in the future.

1.1 Fundamentals

This thesis concerns two things; games and augmented reality. While we are all familiar with games, we often have a poor and inconsistent understanding of exactly what they are, how they are structured, and how best to think about them. On the other hand, augmented reality is a recent product of the modern technological process, so there exists a body of research that defines it, shows how it can be implemented, and investigates its effects on human perception. This section gives a short introduction to the fundamentals of these areas in order to provide clarity for the rest of the thesis.

1.1.1 *Augmented Reality*

The term 'augmented reality' (AR) typically describes interfaces that overlay images of virtual objects on images of the real world. Augmented reality is part of a general class of displays called 'mixed reality' that includes any display in which images of real and virtual objects are combined. Like many concepts, augmented reality is defined differently by different people; it may more broadly be used to refer to any system that augments natural feedback with simulated cues [27], including those that utilize auditory, haptic or vestibular feedback. In this thesis, I consider only visual augmented reality, as it is the most applicable to game design. In this thesis, I have used Ron Azuma's definition [9] of augmented reality that describes it as any interface that has these three characteristics:

1. Combines the real and the virtual
2. Is interactive in real time
3. Is registered in 3D

The relative prevalence of real and virtual imagery displayed by an augmented reality system is expressed as a point on the Reality / Virtuality continuum identified by Milgram and Kishino [48]. In particular, this continuum distinguishes between systems in which virtual objects are overlaid on the real (augmented reality), and systems in which real objects are overlaid on the virtual (augmented virtuality).

Figure 1.1 shows the R/V continuum with examples from games. Real world games such as sports and tabletop games occupy the reality end while computer games occupy the virtuality end. Recently, researchers have begun to explore the possibilities of games that use augmented reality. However, augmented virtuality displays have not yet been seriously investigated for use in game design. Chapter 2 presents a survey of technology driven game research that includes several augmented reality projects.

As well as games, augmented reality systems have been developed to solve problems in a wide range of application domains, including manufacturing

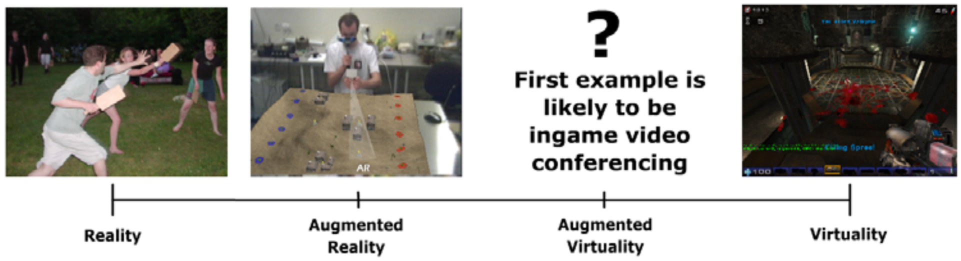


Figure 1.1: The Reality / Virtuality Continuum as applied to games

[26], medicine [66] [32], tourism [44], and defense [39]. For surveys of the field see [9] and [10].

Augmented reality displays may use a range of different devices, and require different amounts of tracking depending on the way images are to be displayed. Chapter 3 includes details on these different types of system, with particular note to the applicability of each for game design.

1.1.2 Games

While there are many definitions of the word 'game', in this thesis I am only interested in the one pertaining to card games, board games, sports, and similar activities. Games have traditionally been very hard to define in a way that is does not exclude activities commonly acknowledged as games without including activities that are generally excluded. A very good discussion of the varying definitions can be found in 'Rules of Play' [61], along with many other useful tools for thinking about game design. I have generally used their working definition:

> A game is a system in which players engage in an artificial conflict defined by rules, that results in a quantifiable outcome.

Since tabletop strategy games using augmented reality will draw from both traditional and digital strategy games, I will give a short introduction to each here.

Tabletop strategy games

Tabletop strategy games have existed for thousands of years. They come in several forms, ranging from abstract games such as Chess and Go to detailed simulations of warfare fought with armies of miniature lead soldiers. The modern miniatures war game has its roots in games played by the Prussian armed forces of the 19th century, where they were used to plan battles and train officers. When Prussia won the Franco-Prussian war in 1873, they were credited as a major cause of the victory. Following this, they were adopted as training tools by armed forces the world over, and played a major part in the wars of the 20th Century. Since the 1950s, war games have grown into a major hobby, with tournaments (for example, New Zealand has several annual tournaments), painting competitions, and conventions.

In a miniatures war game, two or more players assemble forces of figurines that represent an army, then pit them against each other in various battle scenarios. War games simulate conflict from the tactical to the operational level by using each figurine to represent different numbers of soldiers. Games are set in a range of milieus, from the ancient world (De Bellis Multitudinis), to a fictional galactic empire populated by various aliens and fantasy races (Warhammer 40k: shown in figure 1.2). Miniatures war games are mostly played by males from ages 15 up, though there are a small number of female players.

Digital strategy games

The term 'digital games' refers to games played on any computing device. My focus is on strategy games, which occur almost exclusively on personal computers. They evolved from tabletop strategy games during the 1980s, as war gamers realized they could simulate ever more complicated rules sets using computers. They remained a niche, but were sufficiently popular to displace much of the tabletop strategy games market.

During the 1990s, the real time strategy game was born. Some early examples were Dune 2, Warcraft, and Command & Conquer, others are shown in figure 1.3. In recent years, the real time strategy game has become one of the predominant genres. The turn-based digital strategy game still exists,

Figure 1.2: A typical large war game (Warhammer 40k)

but is much less popular. However, these are little more than complicated, solitary versions of the tabletop strategy. Our focus is on the real time strategy, which is arguably the more evolved type.

1.2 Thesis Structure

This work focuses on understanding the ways that augmented reality can be used to build and enhance strategy games. In particular, it focuses on game design, and the adaptations necessary for this new medium.

There are three ways to learn about game design. We can learn from theory, by understanding the experience of play and what creates it. We can also learn by designing; this forces us to examine a game from several perspectives—externally as a whole system, and internally as a series of interlocking parts. Finally, we can learn by playing ourselves and evaluating the play of others.

To lay the foundations for this work, chapter two presents a survey of

(a) Rise of Nations™ (b) Stronghold: Crusader™

Figure 1.3: Two digital strategy games

research in technology driven games. Following this, chapter three discusses the theory of game design, particularly focusing on the motivations for play and the nature of the experience. Chapter four discusses necessary precursors to the development of an augmented reality system, including an overview of the available technologies and pertinent research on interaction techniques and collaboration. Chapter five presents the design of AR Tankwar, an augmented reality strategy game developed over the course of this research, while chapter six discusses evaluations conducted with it. Finally, chapter seven draws this all together into sixteen guidelines for future designers of augmented reality strategy games.

1.3 Contributions

This work makes three major contributions:

- The assembly of a body of five conceptual and theoretical models for understanding the experience of playing a game. Of these, three are derived from the literature, one is extended from an existing model, and the last is wholly novel.

- The development of an augmented reality strategy game, and the results of two evaluation with it; one with over 200 participants at a large games convention, the other a formal laboratory study comparing it to similar tabletop and PC games.

- The proposal of sixteen guidelines for augmented reality game design, based on theory, design and evaluations.

Chapter II

A Review of Technology Driven Game Research

Technology can affect games in many ways. It can alleviate the limitations of game platforms, automate onerous tasks, allow play to be distributed across the internet and other networks, enable new modes of interaction with game devices, and provide means for smarter and deeper game designs. There are many different technologies that can be applied to games, and many different applications. This chapter provides an overview of research into technology driven games. This field includes augmented reality games, pervasive games, ubiquitous games, and other sub-fields of game research.

In order to make it easier to gain an understanding of the field, projects are categorized according the different problems that they attempt to address. Some projects address more than one problem—however, most have a single main contribution by which they can be classified.

Many technology driven game projects are focused on equipment, interface design, collaboration, or infrastructure rather than game design. This is not to suggest that they are less significant; all of these problems need addressing. However, it does show the need for work in this area. Furthermore, due to the difficulty of evaluation and the technology focus of most projects, there has been very little validation of technology in games.

2.1 Augmented game equipment

One of the most obvious uses of technology in games is to augment the equipment in some way. Appropriately applied, technology can help with scoring, provide new challenges, or allow equipment to be used in new ways. This approach also includes the development of 'smart' toys. While toys are not games, they are closely related. In normal play they are used as part of ad hoc games, and thus their consideration is relevant.

Many games and sports rely on referees and umpires to observe and identify events in a game. Their job can be made much easier by providing them with new tools. For example, referees in many sports can now refer to a video umpire to examine play in more detail in order to make decisions. In some cases, technology can be applied more directly. For example, in the sport of Tae Kwon Do, competitors score points by delivering blows to specific target areas on their opponent. Adjudicating whether blows are delivered to legal areas and whether they are of sufficient strength is particularly difficult by observation alone. However, by introducing force sensors into the protective padding worn by competitors, the Sensor Hogu [23] project greatly improves the speed and accuracy of scoring. This system has now become commercially available, and is being rapidly taken up for use in tournaments in the United States.

A common fantasy related to sports is the introduction of robotic opponents and sparring partners. This has been partly realized in the development of various robot combat leagues, where robot designers pit their creations against each other. However, robots are not yet sufficiently articulate for use in play against human players, though work proceeds in this area. Segway Soccer [7] uses a computer to remotely control Segway personal transportunits against other Segways piloted by humans. The Segways themselves are mounted with a shovel like implement for pushing a soccer ball, and the game is a simplified version of the same.

Another recent product is the FA1 Fighting Android (see figure 2.1) from Self Defense Technologies [4]. It is intended as a flexible robotic sparring partner for use in self defense training. This android is very new, and there has been no public evaluation of its effectiveness, but it is promising, at least in concept.

Both children and adults enjoy playing games using construction toys such as LEGO and Mechano. If blocks have embedded electronics, as well as a mechanism for power and communication, players can build toys with different behaviours, as well as different shapes. The LEGO MindStorms [43] is a commercially available system which provides special blocks that can power mechanical LEGO parts, as well as providing a computer interface so that players can specify behaviours. On the experimental side, the ActiveCube

Figure 2.1: Fighting Android 1 (Image courtesy Luther Trawick, Self Defense Technologies Inc)

[72] project is investigating more sophisticated blocks that include different types of sensors, allowing the construction of toys that have some awareness of their environment.

As well as being used as part of games, toys are often used to tell stories. By embedding sensors and speakers into a toy, a pre-written narrative can be told. The StoryToy [31] does just this. It consists of a set of toy animals, a toy farmhouse, and a computer interface. The toy detects the placement of the various animals, and the presence of a child. It tells a story involving the animals, and uses their movement as a form of input. For example, a child may alter the story by removing the cow from the barn, and so forth.

2.2 Input techniques

The largest area of technology driven game research is the development of novel input techniques. Traditional computer games are constrained to specialized game controllers such as joysticks, the keyboard and mouse, and in some cases devices such as computer driven steering wheels. Researchers are exploring input techniques based on new physical devices, tracking the user's motion via computer vision, tangible augmented reality, audio, and affective interfaces that use a player's emotional state to drive game play.

Physical Devices

The development of new physical devices is an important area of research into input techniques. While almost all interface research throughout HCI is relevant to games, it is far too wide to be covered here. However, there are some projects that are particularly relevant to play and gaming applications.

Virrig [36] is an input device with a cushioned seat with a hemispheric base, enabling players to lean from side to side. The angle of the seat is determined by ball switches and a gyroscope then transmitted to the game on a PC. This device enables the use of balance as an input modality; in a car racing game, players intuitively lean into a turn to steer their vehicle. Another important advantage of this interface is that it leaves the player's hands free to do other things.

In many computer games, players control in-game representation of a person using various indirect mechanisms. The SenToy [53] allows players to directly control a character by manipulating a replica in the form of a doll. The doll is instrumented using a series of force and flex sensors as well as an accelerometer to provide location tracking. Several doll types were made, though users generally preferred to use a soft, cuddly interface than a hard plastic one. This interface is of particular interest for games involving young children, and allows them to enjoy their toys in completely new ways.

Computer Vision

Using computer vision techniques, games can track the movement of players or objects in the real world and use this as input for games. The best known example of this is the EyeToy system for the Sony Playstation 2 [28], consisting of special software and a small camera mounted on top of the player's television. The image from the camera is used as a background image during games, and as players move around in front of their television, the software uses motion flow and background subtraction to determine which part of the screen they are gesturing at. Simple game designs include those where the player 'strikes' at virtual enemies or other targets, or moves around according to dance cues.

The CamBall [75] system uses slightly more sophisticated computer vision techniques to allow a player to play table tennis with their computer monitor. A web camera is mounted on top of their computer, and tracks a table tennis paddle which has been coloured green. The motion of the physical paddle is mapped onto the motion of a virtual paddle shown on the monitor which can be used to strike a virtual ball. Remote play against other humans is also possible over a network. The game is very easy to play, and surprisingly effective.

Tangible Augmented Reality

In augmented reality, physical objects are tracked so that virtual content can be displayed correctly. This positional information can then be used as an input modality. This is known as Tangible AR, and several games have explored the possibility of game interfaces using it.

AR^2 Hockey [52] was an implementation of the arcade game 'Air Hockey', and one of the first augmented reality games reported. In normal air hockey, players attempt to score points by getting a puck past the opposing player's defenses and into a goal mouth. They use paddles to strike the puck, which glides at high speeds across a frictionless air cushion. In AR^2 Hockey, the puck is virtual, while the paddles are tracked magnetically. When a paddle moves through the space occupied by the virtual puck, it is struck and moves accordingly. AR^2 Hockey is a very simple game, and like many early augmented reality games, it was developed primarily as an investigation into tangible interfaces with little interest in game design.

A similar game is the Phone Tennis project [34]. It uses augmented reality running on commodity cell phones with a small set of fiducial markers for tracking. By tracking the markers the phones can determine their own location, and can be used as 'tennis rackets' with a virtual ball. The game requires no specialized hardware and only a single A4 sheet with printed markers to play, making it very easy to set up and play (see figure 2.2).

In both AR^2 Hockey and Phone Tennis, the location of the device being tracked is used to directly interact with virtual objects. However, tangible AR interfaces can also be used to issue commands in a tabletop game, or even to randomize game events. Jumanji Singapore [77] is an AR board game that

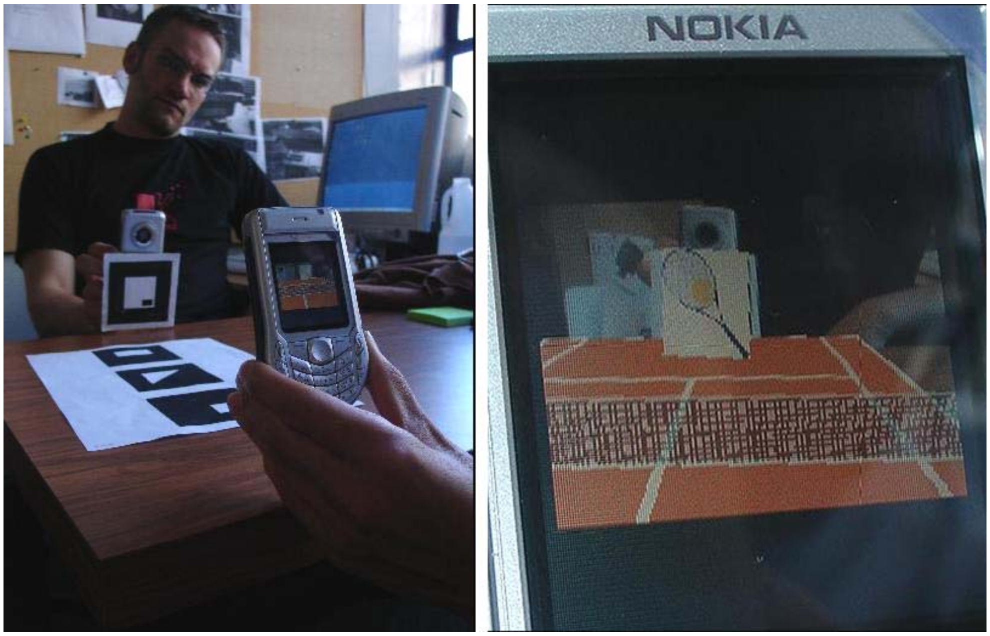


Figure 2.2: Phone Tennis: Real world view and view through phone (Images courtesy of Mark Billinghurst, HIT Lab NZ, University of Canterbury)

experiments with the use of AR marker cubes as the game's only interface (see figure 2.3). The game involves a trail of squares that leads around Singapore landmarks such as the Orchard Road shopping area, Sentosa Island and the Singapore Zoo. Players take turns moving along the trail by using the cubes as dice whose results are automatically recognized. At certain squares, events occur. At Orchard Road, players may purchase objects, manipulating the cubes in different configurations to browse and select. In other locations, players are shown short multimedia clips that can be paused, restarted or ended by placing the cubes on top of each other. Finally, players can choose to fly around inside the game world—in this case, the cubes are used to steer the player's viewpoint.

BattleBoard [6] is another augmented reality game project that uses an interesting tangible AR interface. The game is a grid based strategy game, similar to Chess or Stratego, that uses pieces made from Lego. These pieces can be fitted together, and when this is done, they form a unique fiducial pattern that triggers a combat animation between the characters on each piece.

Figure 2.3: Jumanji Singapore: Using an AR marker cube for a range of tangible interactions (Image courtesy of Adrian David Cheok, Mixed Reality Lab, National University of Singapore)

Victory is partially randomized, and determines who captures a given square. The game design is quite simple, and uses augmented reality primarily to help resolve conflict between two pieces as well as showing an animation. However, its use of LEGO game pieces that fit together and trigger computer events in this way is particularly novel.

Tangible augmented reality interfaces are particularly interesting when the physical objects being manipulated have meaning to the game world's physics engine. In a recent game 'Monkey Bridge' [11], players control the game with different shaped blocks that model pieces of land, bridges, and so forth. The game world is also populated by a group of monkeys, who will move around on the land area represented by the blocks (see figure 2.4). The player's goal is to lead them across the table to an exit without allowing them to fall off the edge of the land. This game is particularly effective as a player's use of the physical interface allows them to directly affect the world.

Posture tracking in AR

AR systems can also track a player's body and use this posture information as input. The RV Border Guards [69] project, also known as AquaGauntlet, uses the position of a player's arms as its interface. In this game, players stand scattered around a room facing the middle, where virtual creatures emerge

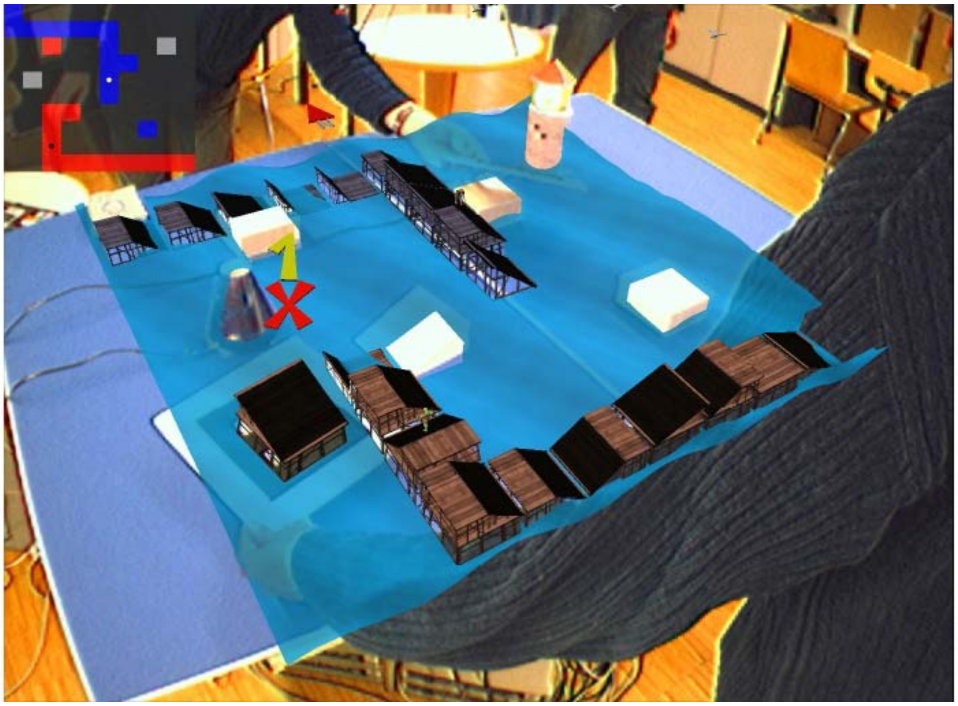


Figure 2.4: Monkey Bridge (Image courtesy of Istvan Barakonyi and Dieter Schmalstief, Technical University of Graz)

from a 'generator' to attack them. Players can shoot at these creatures by extending their arm forward and pointing, or they can shield themselves by holding their arm in front of their face. The augmented reality display is used to show the enemies, but also to augment the players; the systems shows them wearing a virtual helmet and gun, as well as wielding a glowing energy shield.

Another game that uses posture tracking is MIND Warping [65] from Georgia Tech. It uses a combination of posture, audio interface, and an augmented workbench as input. Player roles are asymmetric; one player, the 'summoner', creates virtual enemies to attack the 'warrior'. The summoner uses the workbench to place and move creatures in the game world. The warrior wears a head mounted display through which he can see the creatures. He can strike at them by assuming one of three poses (corresponding to high, mid and low attacks), then yelling 'hee-YAH' loudly to actuate the attack.

Audio Interfaces

Recently, however, Sony presented the game Singstar™ for the Playstation 2 [63]. In this, players sing along with music provided by the game in a manner similar to Karaoke. Their performance is captured using a microphone, and scored based on correct pitch, timing, and tonality. Players can play head to head with their performances scored independently and displayed on the screen. In addition to exploiting a novel input modality, Singstar™ is a digital game that incorporates a very strong social element, and may be played by groups during events such as parties.

Affective Interfaces

Affective computing uses biometric techniques to detect emotional state and use this as input. Correspondingly, affective games make use of a player's emotional state. The affective data can be used directly as the main input modality, or to affect the game indirectly, for example by altering atmosphere or difficulty.

The best known affective game is Brainball [35], in which two players seated opposite each other seek to roll a ball towards their opponent using only the power of their minds. It uses an electroencephalogram (EEG) to obtain a measure of how relaxed each player is. This is compared to the other player, and the ball rolls slowly towards the player who is least relaxed. Evaluation of this game showed that players found the concept extremely interesting, and surprisingly fulfilling to play. One particularly interesting application of games such as this may be to attempt to use them to teach concentration skills to children. However, EEGs are expensive pieces of hardware, and thus Brainball is not practical outside fixed exhibits or the laboratory.

Instead of using a player's affective state to directly control the game, it may be used to alter a game's difficulty or atmosphere. Sakurazawa et al. [60] developed a game that uses skin conductance response (SCR) to determine a player's stress level. This is then fed back into the game and used to increase difficulty as a player gets more stressed. SCR is sufficiently sensitive to pick up variations in stress due to surprising noise or camera flashes. The technology is also fairly lightweight, effectively involving a multimeter and two electrodes attach to the palm.

Using a player's stress level to increase game difficulty creates positive feedback, as increased difficulty leads to increased stress, and eventual defeat. Gilleade et al [33] argues that using affective input to modulate game difficulty will be an effective method of making games more accessible to players. Excessively difficult scenarios can be detected by the stress levels they induce, and toned down accordingly. Similarly, very easy scenarios can be made more difficult depending on a player's skills. This approach is already followed to an extent in some modern computer games. Unreal Tournament [70] attempts to determine a player's skill level by their performance in game, and can use this to automatically update the difficulty level of computer controlled opponents.

2.3 Facilitating collaboration

Games are an inherently social activity [19], but digital games are usually solitary or require players to focus most of their attention on a display device such as a television or monitor, leaving little left for social interaction. Many research projects focus on facilitating collaboration in digital games; some enable remote collaboration, some seek to eliminate the monitor with novel display techniques, and others attempt to re-introduce social interaction by embedding games into social activities with pervasive computing.

Games that involve physical exertion, such as sports, typically require players to play together in the same location. The Sports at a Distance project [50] created a game with sport like characteristics that can be played by two remote players. Each player has a soccer ball and a wall mounted with sensors, along with a camera and video projector. The video streams from each player's camera are projected on the other player's wall along with targets. This gives the illusion that they are facing each other through a virtual wall with virtual targets hanging between them. They can then collaboratively or competitively kick the ball at the targets, creating a 'Breakout' style game with both physical exertion and remote play.

The Shared Space [15] project explored the potential of augmented reality for face to face gaming. It consisted of a set of physical cards that, when seen through a head mounted display, appeared to have virtual characters attached to them (see figure 2.5). Players could put cards together, and in some combinations, the virtual characters would interact with each other. This game was very simple and intuitive, and was tried by thousands of people in the Emerging Technology exhibit at SIGGRAPH 1999.

Figure 2.5: Shared Space (Image courtesy of Mark Billinghurst, HIT Lab NZ, University of Canterbury)

A fruitful approach to increasing social interaction in games is to embed them in pre-existing social situations. The Schminky project [57] investigated this by developing a simple collaborative game to be played with PDAs and making it available as a fixture in a metropolitan café. The game required players to identify the presence or absence of different parts of a short audio piece. It could be played alone, but was far more popular when played as a group. Visitors to the café frequently played with complete strangers (surveys indicated that 35% of players played at least one game with a stranger). To provide a collective element to the game, player scores were collected and visualised as part of a piece of interactive art shown on a large wall monitor.

An important type of social game is the live role-playing game. In these, players act out the roles of characters in some social situation and pursue various goals, often political or social. The best known of these games is the ‘How to Host a Murder’ line of games [37]. However, these games have practical limitations that could be alleviated by careful application of pervasive computing devices. Pervasive Clue [62] is such a game. It replicates the classic murder mystery style of game, and introduces a PDA that can ‘detect’ hidden clues, as well as help organize a player’s information, and co-ordinate scoring and other support tasks.

The Pirates! game [29] follows a similar vein, but introduces location awareness, and elements drawn from digital games. Players move around a real world environment in which the wireless network provides location awareness. By visiting different parts of the environment, they are considered to have ‘sailed’ to ‘islands’, where they are able to do things such as hide or search for treasure, raid towns, and other piratical pursuits. They may engage in ship to ship combat by moving close to another player, and playing a short competitive game with their PDAs. In essence, the game provides a simple physical re-enactment of Sid Meier’s classic pirate simulations [55].

Games played around the tabletop are often particularly social. Technology introduced into this sort of situation can be used to enhance collaborative games. The game False Prophets [47] uses photo-sensitive tiles, pieces with infra-red LEDs mounted in their bases, a projector, and handheld computers. Players are divided into two teams by the game, but they are not informed who is on which team. Instead, identifying their team mates is the goal of the game. Players achieve this by moving their pieces around the map, gathering clues which are displayed on their handheld computer. The clues describe players specifically, so players are encouraged to pay attention to each other. There is also scope for collaboration and trading, provided players can negotiate agreement.

2.4 Infrastructure

An important research area is the exploration of feasibility and potential application of novel computing infrastructures for game design. These projects are often proofs of concept, focusing on issues of practicality and cost to determine whether games using these infrastructures are worthwhile, and eventually, whether they may be commercially viable.

One of the earliest investigations into Augmented Reality infrastructures for gaming was led by Zsolt Szalavári [68] of the Studierstube group. They worked in an instrumented indoor environment, and developed AR implementations of the game 'Mahjongg' for two or more players using the then new StudierStube framework. They used tracked wands and a pad device called the 'Personal Interaction Panel' as the game's interface, along with head mounted displays.

Our first work in augmented reality tabletop games was the AR Worms [51] project. It was conducted in late 2003 as part of a honours paper on augmented reality, then later extended. By this time, augmented reality was relatively well established as an infrastructure. However, there had been no work exploring interaction with large virtual maps. Worms used a 4m by 4m table covered in a large map, and it was a precursor to the work in this thesis.

Outdoor augmented reality is particularly difficult, since all hardware must be portable and there is little opportunity to instrument the environment beforehand. AR Quake [54] was the first outdoor augmented reality game. It is a limited replica of the classic first person shooter game 'Quake' using maps based on the real world (see figure 2.6). Unfortunately, game play is limited by constraints on mobility—real players do not move like characters in action games. Nonetheless, this project broke new ground, and when technology improves, outdoor augmented reality offers great potential for game design.

Another class of infrastructure that has received a great deal of interest is wide area wireless and cellular networks. The 'Can You See Me Now?' project [30] was conducted by researchers at the University of Nottingham in conjunction with a performance art group 'Blast Theory'. It used players moving around a city environment as well as players on the web using a Flash client. Players on the web could move around the same city using their keyboard, attempting to avoid the real players in the city, called 'runners', who used a PDA, GPS and wireless to capture them. Runners also had a constant voice connection with each other such that they could cooperate to trap web players. The game was run on several occasions in the city of Nottingham, with three runners, and up to twenty web players (at a time). One of the

Figure 2.6: ARQuake (Image courtesy of Wayne Piekarski, Wearable Computer Lab, University of South Australia)

key ideas from this work was the realization that players would develop ways to exploit limitations inherent in the technologies (such as inaccurate GPS), and so these limitations could be incorporated into game design. Research into this aspect of game design has continued under the term 'seamful games' [20].

Real Tournament [49] is another project relying on outdoor wireless networks. In it, players use toy guns to hunt and kill virtual ghosts. The guns are enhanced with various sensors and a PDA, and afford players a great deal of mobility, unlike outdoor augmented reality with head mounted displays. However, the PDA is not immersive, and so the game is very limited. This project focused on the relative advantages of different network and messaging architectures and their application to the specific requirements of games.

2.5 Design and Evaluation

The projects addressed thus far all focus primarily on technology—how we express our intentions through input devices, how technology can help us collaborate, and how we can use new infrastructures to create games. Research in game design is dependent on all of these areas, and game design cannot seriously be examined until the technical problems are dealt with.

The Mixed Reality Lab in Singapore under Adrian Cheok has completed several projects in mixed reality gaming that seek to move beyond the technology to the game play itself. Their Human Pacman [21] project is based on the classic 'Pacman' series of games, and is played in an outdoor environment at their university (see figure 2.7). Players act as either Ghost or Pacman; Pacman must collect 'cookies' scattered around the environment while avoiding capture by the ghost. To capture Pacman, the ghost must approach them in the real world and tap them firmly on the shoulder. However, Pacman can reverse the roles by collecting a set of 'super cookies' that enable him to capture the ghost instead. Each mobile player has a collaborator who uses a map on their computer to guide their partner.

Another project by this group is TouchSpace [22]. It uses a series of tangible and augmented reality interfaces, with varying levels of immersion. The game is played collaboratively by two or more players. The game was played by volunteers; on completion of play, they each answered five questions describing their experience. Player responses suggest that, compared to an unspecified multi-player computer game, the augmented reality game was more exciting, more entertaining, and slightly more collaborative. Unfortunately, no statistical evaluation of the results was performed, so these effects are not clear.

The STARS project at Fraunhofer IPSI [46] has focused on the nature of state representation in augmented game designs. In normal tabletop games, all game state is represented either physically in the game board, or socially as agreements between players. In technology driven games, game state can be represented in the virtual domain, which supplements the physical and virtual domains. The project has developed several games based on these principles and incorporating a range of novel game interfaces. Most notable of these

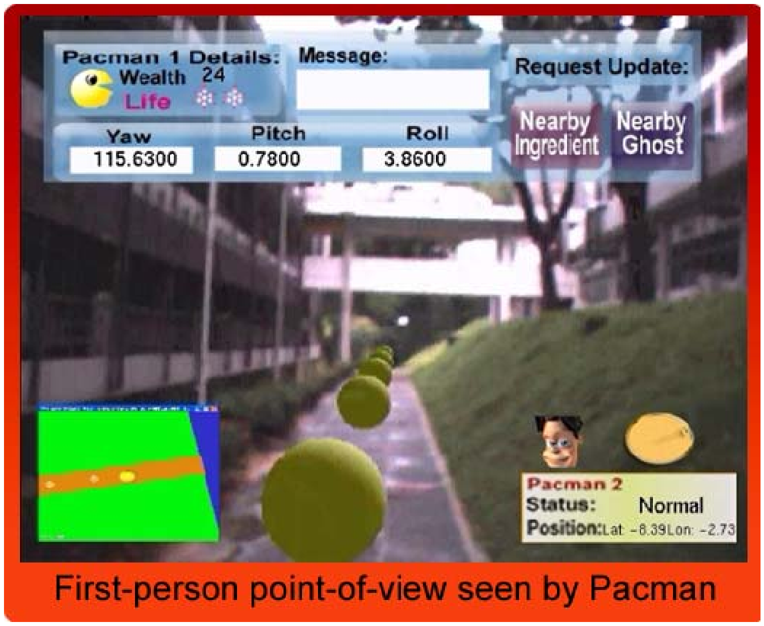


Figure 2.7: Human Pacman (Image courtesy of Adrian David Cheok, Mixed Reality Lab, National University of Singapore

games is KnightMage, a tabletop board game with elements of fantasy role playing games (see figure 2.8). Unfortunately, no formal evaluation of these games has been published. Nonetheless, the models of state representation and social play are interesting contributions.

2.6 Summary

In this chapter, I have summarized the state of research in the field of technology driven games. Rather than exhaustively list all of the games being developed, I have sought to characterize the field by presenting the most important projects in each research area. As a summary, Table 2.6 lists all of the projects mentioned, along with their citations and the technologies used.

From this survey, one can see that there are many projects that focus on technology—novel input techniques, attempts to better facilitate collaboration, and explorations of the practicality of games in different technology infrastructures. One can also see that there is little work that focuses on issues of good game design and evaluation. The work in this thesis aims to

Figure 2.8: KnightMage: Game board (Image courtesy of Carsten Magerkurth, Fraunhofer IPSI)

fit into this last category, for while it is interesting to use new technologies in games, good games will not be produced until there is good understanding of their design implications, validated by evaluation from game designers and players.

Table 2.1: Summary of technology driven games

Project	Technology	Cite
Smart Devices		
Sensor Hogu	Embedded piezoelectric sensors, wireless	[23]
Segway Soccer	Computer controlled 'robots'	[7]
MindStorms	Embedded electronics, tethered	[43]
ActiveCube	Embedded electronics, tethered	[72]
StoryToy	Embedded electronics, audio	[31]
Interfaces		
Virrig Cushion	Embedded electronics, wireless	[36]
SenToy	Embedded electronics, tethered	[53]
EyeToy	Computer vision, playstation	[28]
CamBall	Computer vision, PC & webcam	[75]
AR^2 Hockey	Augmented reality, head mounted	[52]
Phone Tennis	Augmented reality, mobile phone	[34]
Jumanji Singapore	Augmented reality, head mounted	[77]
BattleBoard	Augmented reality, tabletop, LEGO	[6]
RV Border Guards	Augmented reality, head mounted	[69]
MIND Warping	Augmented reality, audio, gestures	[65]
Singstar	Microphone, playstation	[63]
Brainball	Electroencephalogram	[35]
Sakurazawa et al.	Skin conductance, PC	[60]
Gilleade et al.	Theoretical	[33]
Faciliating collaboration		
Soccer at a Distance	Impact sensors, projector	[50]
Shared Space	Augmented reality, head mounted	[15]
Schminky	PDA, audio	[57]
Pervasive Clue	PDA, RF sensors	[62]
Pirates!	Handheld computer, proximity sensors	[29]
False Prophets	Photosensors, projection	[47]
Infrastructure		
Szalavari	Augmented reality, head mounted	[68]
AR Quake	Mobile augmented reality, GPS, HMD	[54]
Worms	Augmented reality, tabletop	[51]
Real Tournament	WLAN, PDA, GPS	[49]
CYSMN	Remote PCs, PDA, WLAN, GPS	[30]
Design & Evaluation		
Human Pacman	Mobile augmented reality, GPS, HMD	[21]
TouchSpace	Augmented reality, tangible AR	[22]
STARS	Plasma screen, RFID, PDA	[46]

Chapter III

Understanding the Experience of Play

Games are without reason. Strictly, they convey no reward yet we often play them to the detriment of other needs or responsibilities. Why? What qualities do they have that make them so attractive? To design augmented reality games that people will want to play, we must understand what motivates us to play them in general.

Almost universally, people say that they play games because they are enjoyable. In the late 1940s, Roger Caillois described enjoyment in games as the satisfaction of a set of primordial desires; these are presented in section 3.1. However, these are insufficient to guide design, and so enjoyment remains ill defined, a rough grouping of positive emotions.

When people describe an enjoyable experience, they often refer to it as engaging, as having absorbed their attention fully. This phenomenon is best understood through the concept of 'flow', and this is discussed in section 3.2. Another source of enjoyment is social interaction. This requires communication, which is sometimes promoted and sometimes inhibited by games. Section 3.3 proposes a model of communication during games. Games often stimulate us emotionally, by providing narrative, characters and atmosphere. Section 3.4 presents the Mixed Fantasy framework, which describes the ways in which this occurs. Finally, the ways that we enjoy games can be considered according to the modality through which they stimulate us, and this is discussed in Section 3.5.

3.1 Caillois' game taxonomy

Roger Caillois was a prominent early theorist of games and play. In his landmark work 'Les jeux et les hommes' [19], he studied the origins and nature of play from a sociological perspective. He sought to understand its origins in human nature and the ways in which it has contributed towards the development of modern culture. As part of this he sought to understand why we play them. To do so, he developed a model of game types based around the desires that play can fulfill. His four categories were agôn, alea, mimicry, and ilinx, roughly corresponding to competition, chance, personal simulation, and vertigo.

- *Agôn* includes all games that are motivated by the desire for competition, either against another player, or against oneself. Games of agôn are based around the assumption of equality, even when produced by handicaps or asymmetric rules. The attitude of agôn is perhaps the attitude of game play that we are most familiar with as it appears in almost all common games. It is the desire most close to the concept of flow, because it concerns the desire to pit ones skills against a challenge of an appropriate level.

- *Alea* encompasses the element of chance in games. Chance offers the thrill of uncertainty, of sitting on the edge of one's seat, not knowing what will come next. Caillois describes it as a surrender to the forces of fate and the gods; it is a form of suspending one's sense of control.

- *Mimicry* is the joy of pretending. Many games offer us a chance to pretend to be someone else, to behave in ways that we normally would not, and to absolve ourselves of onerous responsibility and duty, if only for a while. Mimicry lets us experience the world from different perspectives.

- *Ilinx* is the thrill of adrenaline, the thirst for danger. It encompasses games where we put ourselves at perceived risk so as to achieve a form of heightened awareness. Games of ilinx involve experiences of vertigo, danger, speed, extreme forces, and stimulation of the vestibular system.

Caillois' categorization is not exhaustive; it is limited by his understanding of games that were popular in his day. Since the advent of modern digital games, two new desires that games may fulfill have become obvious. The first is curiosity; in some games, players play in order to discover, they seek to explore new worlds, and see new things. The second is the joy of creation. This is particularly obvious in simulation games. Players play because they want to create something, be it a city, a farm, a nation or life, and then they want to see how it performs in different situations.

None of Caillois' definitions are intended to be exclusive. No game fits clearly into only one of these classifications; most involve a combination of several attitudes. The laxness of these categories also applies to Caillois' distinction between games and play. His definition calls for rules, and stresses the free, unconstrained, but unproductive nature of the activity, but does not distinguish between play in the pursuit of game goals, or play with no particular direction in mind. However, a rough distinction can be obtained by considering the element of agôn, as it enforces competition, which, regardless of whether against another or oneself, necessarily results in the completion of goals. Play without some element of agôn does not meet our definition of a game (see section 1.1.2).

Following this argument, alea, mimicry, and ilinx, as well as curiosity and the desire to create, are factors that may motivate game play, but are not limited to games, nor are they necessary. However, they may be considered as additive factors to the basic desire that causes us to play games. Successful game design should attempt to make use of these motivational factors to further our desire to play.

3.2 Flow

Up until the 1970s, research into sources of motivation focused on external sources of motivation such as money and prestige, and subconscious explanations such as those of Freud. At about this time, Mihaly Csikszentmihaly began research into the motivations behind activities such as painting, rock-climbing and games [24]. These activities were seen to take up a large amount of time and effort, and in some cases involved dangerous circumstances, all for little or no reward. Participants in these activities were examined through interviews and detailed questionnaires about the perceived source of enjoyment in their activities. From these initial studies, more participants were studied, and eventually the concept of ‘flow’ was articulated to explain the sense of intense engagement felt by those involved in all of these unrelated activities.

Flow is described as a feeling of complete engagement with the task at hand. One’s full attention is focused, and there is no remaining room for other concerns; even the need for food and sleep tends to be ignored until the experience has ended. In sports, the sense of flow is sometimes described as ‘being in the zone’, though this often refers to a particularly positive flow experience. A flow experience typically has the following characteristics [24]:

- Your attention is completely focused on the task, at the expense of other concerns. You find that distractions are easy to ignore, if you notice them at all. Other responsibilities and worries are pushed out of mind until the flow experience ends.

- You forgot about all feelings related to the self, even feelings of embarassment. You feel as if all there is is the task. On finishing, your self awareness is heightened, and you are more aware of your skills. This usually results in increased self esteem.

- Your sense of time is distorted. Time seems to speed up, and hours may pass by without you realizing it.

- You feel that completing the task is worthwhile, regardless of any external rewards. By completing it you are achieving goals you have set for yourself.

- Finally, you feel competent, as your skills are sufficient to make the task manageable, but not sufficient to make it feel trivial.

While flow can in principle occur during almost any activity, there are certain activities that are more conducive to it. Furthermore, the likelihood of a flow experience is altered by the environment, and the presence of other people. Scenarios that are more likely to result in flow are those in which [24]:

- The task has clear goals. You know what you must do, and you know how to do it.

- Immediate feedback is received for actions. You know which of your actions contribute to the task, and you generally know how they contribute.

- The task requires attention to maximum. If attention wanders elsewhere, due to interruption or lack of concentration, flow will not occur.

- There is a correspondence between the challenge and the level of skill required. If the task is too easy, attention will not be held, and boredom will ensue. If the task is too difficult, you will be come frustrated, and anxiety will occur. Flow experiences rely on tasks with a high level of challenge, where a high level of skill is available to meet this.

If flow occurs, it means that the experience was engaging. Furthermore, flow has distinct effects that can be looked for in questionnaires. Thus, flow is a strong candidate for measuring the level of engagement in games. Engagement is often described as a major contributor towards enjoyment of a game (and, in fact, in much of the literature on flow, flow experiences are taken as equivalent to enjoyment).

3.3 A communication model for games

Social interaction and collaboration is an important source of enjoyment in games, and one of the supposed advantages of augmented reality is that it provides an improved environment for it. However, from existing systems, it can be seen that it does not yet live up to this promise, due to immaturity and complication introduced by the devices needed to implement it. Therefore, it is important to have some understanding of how limitations on communication will affect play. This section discusses the types of communication that occur during play, and makes some predictions on how they will be affected by limitations.

During games, players communicate with each other extensively in different ways, and for different reasons. In [76], Zagal proposed a useful taxonomy for the different types of messages that are exchanged in games. An extended version is presented here:

- Stimulated communication is communication that is part of the game itself. Examples include calling ‘Snap’ when a pair of cards is seen, announcing an accusation in ‘Clue’, or requesting payment of rent in ‘Monopoly’.

- Strategic communication is discussion of game play and actions. It occurs during the game, and includes the discussion of tactics by allies, the dispersal of misleading information to enemies, the issuing of commands to subordinates, or even the bluffing behaviours of players of Poker.

- Meta-game communication is about the game, and is not limited to players. It may include discussion of the rules, commentary on the effect of decisions, and discussion of preferred strategies. It differs from strategic communication in being about the game in general, rather than about a game in progress.

- Natural communication is ‘out of game’. It is not stimulated by the game, nor does it it have any real relation to the game, except that it occurs at the same time, between people who may have been brought together only by the game.

- Audience communication is a special case, as it involves non-players. It can be further classified into strategic, meta-game and natural communication. Audience communication involves non-players, and is often only the background against which the game is played. Nevertheless, audience communication may have an important effect on players, as it may motivate, anger or distract the players.

When channels of communication become limited or more difficult to use, messages become less detailed and less frequent. Those of high importance will degrade least, as players are willing to put more effort into them, and specialized means may be developed to convey them. The classification above roughly orders messages according to their importance to the game. Based on these classifications, and the presumption that important messages degrade last and least, we predict the that the following will occur as communication is inhibited. First, messages become more terse, in an effort to convey meaning with less effort. Natural communication is of minimal importance to the game, and thus it will begin to disappear first. Following this, meta-game discussions begin to disappear, except in circumstances where resolution of meta-game issues prevents the game from continuing. Meta-game discussion is relevant and may contribute to the game in some way, but is not normally necessary. Strategic communication is driven by the desire of players to win, and is thus important to them. Nonetheless, if communication is sufficiently inhibited, it will disappear next. Stimulated communication disappears last, and as it is normally essential to play, this heralds the end of play. Audience communication is a special case, as it involves non-players, who may not be constrained in the same way that players are.

These predictions have not been tested, but are verifiable by informal observation of games in different environments. Regardless, the classifications are both interesting and useful as they help understand the different types of communication that go on during play.

3.4 Stapleton's mixed fantasy model

Chris Stapleton's Mixed Fantasy model (shown in figure 3.1) focuses on experiential content, classifying it according to whether it came from real, virtual or imaginative sources [64]. In this model, real experiences are those which are experienced directly by the audience; for example, playing in a sport, participating in a masquerade, or riding an amusement park ride. Virtual content is that conceived by another and channeled to the audience in some codified form such as film or text. Its defining characteristic is that it is experienced vicariously. Finally, imaginative content is provided by the audience themselves, as they expand their visualization of an experience by filling in the gaps; it describes the process whereby one suspends belief and a stage mockup becomes a real place, the Mixed Fantasy model is similar to the

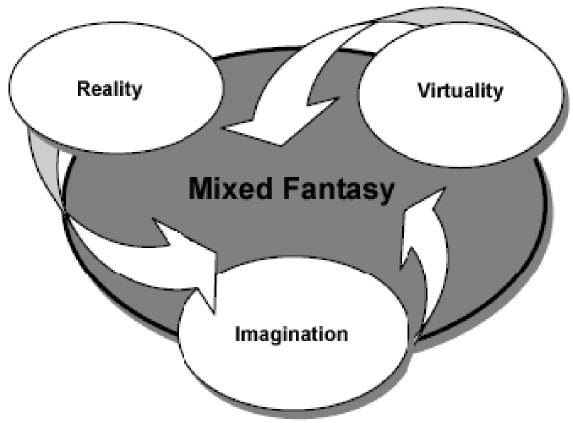


Figure 3.1: Stapleton's Mixed Fantasy Model (Image from [64])

Reality / Virtuality continuum (see Figure 1.1) except that it distinguishes between reality and virtuality as sources not of images, but as of ideas and content within an experience. This requires a subtle redefinition of real and virtual, as experiences in the real world may include content of a 'virtual' nature.

The main implication of this model has less to do with actual reality and virtuality than with the factors that make up a memorable and meaningful experience. Players want to feel that they are significant to the course of a game; that their actions are significant and meaningful. Content provided and generated by others, both designers and other players, remains important; it provides the context, atmosphere and motivation for meaningful decisions. Player decision without context is meaningless, context without player decision is not engaging. The ideal game experience involves the player's real experience, placed within a virtual context, then supplemented and given life by a player's imagination. Such experiences are termed 'mixed fantasy'. Mixed Reality is thought to be particularly conducive to such experiences, as it facilitates new methods of integrating virtual content into real experiences.

3.5 Faculty model

In [51], I introduced a model of engagement in games that focuses on the ways in which a game stimulates us. I divide stimulation into four general categories, and refer to these as 'faculties'. This term is no longer used by psychologists, but once referred to one's inherent capabilities and senses, and so seems suited to describe the capabilities and senses through which a game may stimulate us. I divide games into four faculties; games that stimulate the body, games that stimulate the brain, games that stimulate us socially, and games that stimulate us emotionally. Each faculty may be divided up further on the particulars of how they are stimulated.

The faculties represent different methods by which a game may stimulate a player, and by considering the relative strengths of different game platforms to stimulate each, we can understand the possible range of games that may be effective on each platform. In the following sections, I discuss the details of each faculty, including examples from real world and digital games, and the implications of game design in augmented reality for each of these faculties.

Physical

The physical faculty encompasses all of our physical senses. These are touch, proprioception and haptics, balance and the vestibular system, pain, and the sense of exertion. It also includes the sense of achievement that comes through successful use of skills involving manual dexterity, tool use, bodily agility, strength and reflexes. In short, it covers all aspects of the use of the body within a game, and thus may seem quite broad. The obvious example is of course sports, but other examples are puzzles that rely on interaction with a physical model and digital games that require physical skill to play.

Real world games often have a strong physical component. In them, players are free to use their whole bodies, and can affect each other physically. The game environment can be also affect players in some way; different race courses offer different challenges, and a game in the rain differs from a game in the sun. Furthermore, real world games may involve the use of physical artefacts as playing pieces, equipment and ad hoc props.

Traditional digital games have a very limited physical component, as all interaction with the computer is through a narrow set of interface devices, normally limited to keyboard, mouse, joystick and game pad. Nonetheless, there are genres of digital game that focus on physical skill—beat 'em ups, first person shooter and other action games are often referred to as 'twitch' games as they rely on mastery of a physical interface. In recent years, computer vision techniques have begun to offer new physical interfaces for digital games [28]. The key limitation is that digital games have no way to offer any form of physical feedback with today's technology.

Ideally, augmented reality games will eventually allow physical stimulation at the same level as real world games, with the added advantage that game content can be injected seamlessly into the real world. Unfortunately, today's augmented reality systems are cumbersome and subject to many constraints. Furthermore, augmented reality systems cannot directly affect players physically, though there may be partial solutions to this in haptic feedback and other emerging technologies.

Mental

The mental faculty includes the elements of traditional intellect. Games that stimulate it rely on problem solving, reason, memory, planning and management, strategy, wit, and cunning. It does not include empathy or emotion; these are sufficiently complex and different enough to have their own faculties. Example games include games such as chess and go, most modern board games, most card games, and digital strategy and resource gathering. When we are drawn to a game via the mental faculty, we are stimulated by the presence of a problem or situation that we can solve through thought and analysis.

Digital games are particularly strong at mental stimulation. Computers can support complex game models, the simulation of real world systems, and large amounts of data, allowing much more sophisticated game scenarios. Artificial intelligence allows for solitary play against interesting opponents, and the creation of agents that can assist a player in learning and dealing with complex systems. Finally, computers can aid players in visualizing complex and detailed data.

Real world mental games are based around simpler rules, as players must resolve all simulation themselves. This by no means limits the depth of a real world mental game, but does limit the scope of potential scenarios. The real world is also particularly strong for games that require spatial reasoning. Players can inspect objects from different perspectives, and use their natural perception of space to solve the puzzle.

Games written for augmented reality will have access to the same computing resources for simulation and AI. Furthermore, since augmented reality merges virtual objects with a real environment, they will be able to present game information in a spatial context, which may allow players to reason about it better.

Social

The social faculty has some cross-over with the mental and emotional faculties, and concerns the use of our social skills such as empathy, negotiation, building and managing relationships, politics, and social manipulation. Whereas the mental faculty focuses on analytical reasoning, the social faculty focuses on charisma and emotional intelligence. A classic social game is the role playing game, in particular the live role playing game. Other examples include theatre sports, games such as poker, and many massive multiplayer online games that rely on interaction with other players.

Computers are of mixed benefit to social games. Through networking, they allow players to interact remotely with each other, and allow for games involving far more players than could reasonably be organized in a real world game. They can also provide a persistent game world in which players can establish reputations and possessions, effectively creating surrogate lives. The politics and economics of such a world may provide a rich and immersive environment for social interaction.

Though mediated communication is normally considered a limitation, it does have some advantages. By restricting all users equally, those who are disabled or isolated from regular social interaction can communicate on an equal footing with other players. Furthermore, mediated communication hides much of a players real world self, providing greater scope for the creation of virtual characters, and anonymity that can protect players from harassment on grounds of race, gender or disability.

Real world social games have none of the advantages of networked games, but they allow for players to communicate face to face. In face to face communication players use a wide range of non-verbal cues that are impossible in mediated communications. In political or character oriented games, these subtle cues play important roles, and it may be very difficult, if not impossible, to play without them.

In an ideal augmented reality system, participants will be able to interact with each other in natural face to face communication. In principle, AR games should be able to involve remote players as in computer games, though the scope and nature of interaction will be different.

Emotional

The emotional faculty is perhaps the least defined. It encompasses the way in which we develop an emotional attachment with parts of a game. It includes feelings of nostalgia for games of our childhood, sympathy and other emotions felt for game characters, romanticism attached to a game's setting, paternal or maternal feeling towards one's creations, and the perception of game atmosphere such as fear, anticipation, and joy. When we are attracted to emotional games it is because we have developed some personal emotional reason for wanting to; we play because we care about the game itself. Examples include games such as the Sims, most games with compelling narratives, games from our childhood, games with compelling settings and atmosphere, and games in which we feel some emotional attachment to the act of playing or the environment of play.

Real world games seek to engage a player's emotions by the use of less convincing, but more immediate and diverse stimulation. A mental puzzle game (such as walking through a maze) can be turned into a far more imaginative experience by the introduction of differing lighting conditions, audio effects, and moving parts. A classic example of entertainment that attempts to engage the emotions by real world experience is the theme park roller coaster. More subtly, the real world may serve an important role in establishing atmosphere; no digital first person shooter can truly convey the feeling of lying in the mud, sneaking up on an opponent, as in a game of paintball.

However, digital games can provide rich graphical and audio environments that stimulate a player's emotions by drawing them into the game world through their eyes and ears. This is best illustrated by games in the horror genre that may cause some players to play only in a well lit room. It is also apparent in the extended interest that players often have in the story of characters outside the context of the game--once a player has developed sympathies for a game character, they may carry this on into their own lives or creative work. Fan fiction is an overt manifestation of this.

3.6 Summary

Games are complex entities; they cannot be well understood through a simple definition. However, understanding can be gained by examining them through from several perspectives using a range of different conceptual frameworks. In this chapter, I have presented early work at classifying games according to the nature of their experience by Roger Caillois, and more recent work exploring it through the Csikszentmihalyi's model of flow. Games are typically a social act involving multiple people, and I have presented a model by Zagal for understanding both the communication between individual players, and between players and a game's audience. Augmented reality games are, to some extent, a hybrid of computer and real world games, and Stapleton's Mixed Fantasy model addresses this combination with the addition of imaginative elements. Finally, I present my faculty model, which seeks to explain the different ways in which a game can affect players.

Chapter IV

Design Issues in Augmented Reality

Before we can discuss the design of games using new technologies, we must understand the technology in question. This chapter presents an overview of augmented reality systems, starting with the technology choices, and related design issues described in section 4.1. Following this, section 4.2 discusses interaction techniques appropriate for tabletop augmented reality, particularly strategy games. Finally, section 4.3 discusses the effect of augmented reality on collaboration, and presents some pertinent research. This chapter is intended only as an overview; references are provided for more detailed information.

4.1 Augmented Reality Technology

Augmented reality systems contain two main technology challenges; the display of the augmented world, and the tracking of the real world. Each problem has several solutions, each with different strengths and limitations.

4.1.1 Issues to consider

When choosing technology for augmented reality, we must consider both its practical limitations, and the limitations imposed on the user such as discomfort and reduced perception. Typically, the designer must choose technologies to meet a set of minimum practical requirements, while minimising the adverse effects on the user's experience.

Important practical considerations include:

- **Cost.** Consumers are only willing to spend about NZ$100 on a single game purchase. If a technology can be used for multiple games, the effective cost drops. Alternatively, cost can be spread across many players through installations at exhibitions or arcades. Cost is flexible however; as a technology become popular, it typically becomes cheaper to use due to economies of scale.

- **Mobility.** Some technologies require users to be seated, while others allow them to move within a certain region. Others allow free roaming, sometimes outside.

- **Accuracy.** Tracking error varies from millimetres to metres. For effective table top games, tracking must be accurate to within a few millimetres, with as little noise as possible. In outdoor and mobile games, tracking requirements are typically much lower, as the objects with which one must interact are typically much larger.

- **Robustness.** Tracking technologies may be sensitive to lighting, the composition of objects within the tracked area, noise, or other ambient effects. Similarly, some displays require certain environments; for example, projective displays are ineffective in brightly lit rooms.

- **Setup requirements.** Some technologies are impractical outside of a laboratory, as they require substantial effort to set up, require specialized knowledge, or extensive knowledge of the working environment.

User centered considerations include:

- **Lag.** Tracking and rendering takes time, and so virtual images are delayed slightly with respect to feedback from the real world. This is called lag, and is a temporal disconnect between two sources of feedback. It has been shown to adversely affect performance with delays as short as 50ms [74].

- **Stereoscopy and view displacement.** The display technology may prevent the transmission of some stereoscopic cues. Furthermore, in some systems the user's viewpoint is offset from the position of their eyes. Both of these effects interfere with 3D perception and the ability to grasp objects, among other effects [59]. In some situations, it may disorient, cause headaches and other symptoms of simulator sickness [41].

- **Display resolution.** When user views the real world through a camera, the images they see are limited by both the camera and display devices. This usually results in low resolution and reduced contrast, and can make small objects hard to resolve and reading difficult or impossible. It may also interfere with the perception of subtle non-verbal communication cues.

- **Field of view.** Some display technologies reduce the user's field of view. This eliminates peripheral vision, and forces users to move their head more often in order to see the environment.

- **Tracking noise.** Jittery tracking can make interaction very difficult. During one of the evaluations described in chapter 6, one of the participants remarked that jitter while attempting to perform precise movements was 'like writing with an eel'.

- **Comfort.** Heavy or cumbersome equipment will detract from the game, while complicated equipment may be intimidating and cause users to feel self conscious. Furthermore, equipment can easily become a safety hazard if players are expected to move around the environment. Finally, equipment may reduce a player's mobility and their willingness to interact socially.

There are often other issues; these lists suggest the most common ones that designers should be aware of and consider when designing augmented reality games.

4.1.2 Display technologies

There are many display technologies that can be used to construct augmented reality systems; for a thorough introduction see [16]. As shown in Figure 4.1, it is convenient to classify displays according to their location along the optical path between user and augmented object. Under this scheme, displays are either head mounted, hand held or spatial. As well as this classification, there are several other distinctions that may be useful. Firstly, augmented images may either be displayed on a screen or similar device, or they may

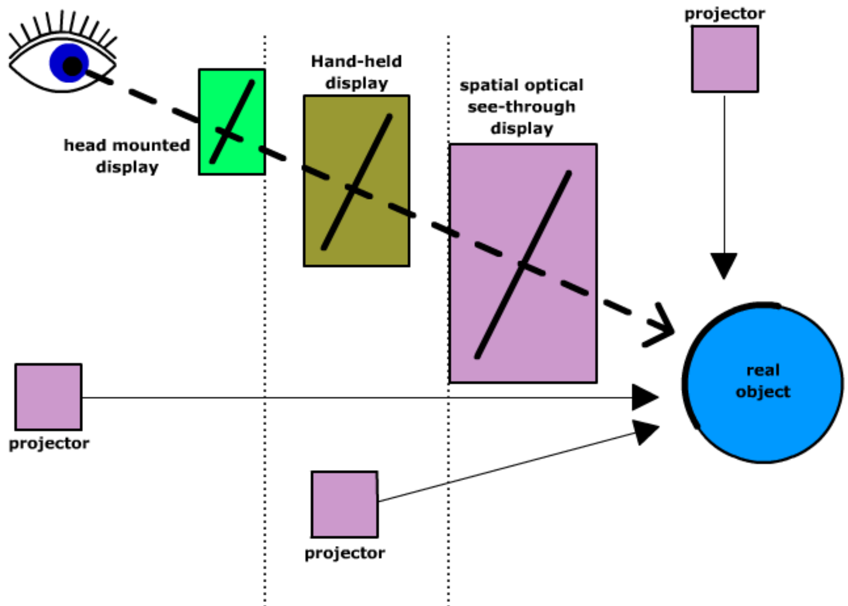


Figure 4.1: Types of AR display (Image based on [16])

be projected on to objects in the real world. Secondly, we can distinguish whether physical objects appear to be in the same location in the augmented image as they are in the real world; that is, the system can either provide the illusion of transparency, or provide a remote perspective. Finally, in see-through systems, the combination of real and virtual images may be achieved using optical or video methods.

Head mounted displays

Head mounted displays (HMDs) are the 'purest' form of augmented reality displays in that they provide the best illusion that virtual objects really exist in the real world. With HMDs, the user sees virtual objects directly around them, no matter what perspective. Unfortunately, current state of the art HMDs are still heavy and cumbersome to wear and tether the user to a computer. They substantially limit the user's field of view, and prevent proper face to face communication as collaborators cannot see each other's

Figure 4.2: Example head mounted display - eMagin z800 (Image courtesy of eMagin Corporation)

eyes or face. Figure 4.2 shows an example head mounted display. HMDs may be used for augmented reality in two ways; optical see-through, and video see-through.

Optical see-through HMDs use semi-silvered mirrors or other optical techniques to display the virtual objects over a user's direct view of the real world. This approach has the advantage that the view of real objects is un-mediated, and sometimes the user's field of view is completely unconstrained. However, correct alignment of virtual objects is often impossible, it is difficult to occlude real objects with virtual ones, and virtual objects are lagged compared to the real world.

Video see-through displays add virtual imagery to images of the real world taken from a camera, normally mounted on the user's head. This approach makes spatial alignment easier, lags real and virtual images equally, and allows occlusion. However, the user's view is limited to the resolution of the camera, and the user's point of view is displaced. Furthermore, the user's view is always lagged as the camera images are processed.

Hand-held displays

In recent years, augmented reality researchers have begun to use hand-held display devices such as tablet PCs, PDAs and cell phones. These incorporate a camera on the reverse side of the device, and give the illusion that users are looking through them into the augmented world. The advantage is simplicity—the whole system is embodied in one device, while the disadvantages are low computing power, and a lack of immersion as users can see only a limited portion of the augmented world at one time. These devices are sometimes characterized as providing a 'portal' into the augmented world.

Spatial displays

Spatial augmented reality encompasses a range of display technologies including volumetric displays, large screens and projection units (see figure 4.3). Spatial displays have the important advantage that they do not require users to wear or hold any special equipment. However, this is also a limitation; all imagery is shown to all viewers, leaving no scope for privacy.

Volumetric displays display 3D objects in an enclosed volume; this prevents direct interaction with the virtual objects, limiting their utility for games. Large screen displays are normally inappropriate for see-through applications, as they obstruct users from interacting with the space behind them. However, they may offer promise when used in a remote configuration, where the interaction space lies between the users and the screen. Projective displays use a video projector to directly display virtual images on real objects that users may interact with directly. However, these displays can only display 2D images. Furthermore, the projection may interfere with computer vision tracking, and images are occluded as users move their hands through the augmented region.

4.1.3 Tracking technologies

Tracking technologies provide the location of objects in the real world, allowing virtual images to be rendered with correct alignment alongside them. Depending on the type of stabilization required, different real world objects

Figure 4.3: Example spatial display—Virtual Showcase (Image courtesy of Oliver Bimber)

must be tracked, potentially including the user, their tools, and the environment itself.

- **Head or screen stabilized:** Virtual objects are fixed relative to the user's point of view. This sort of stabilization is particularly appropriate as a 'heads up display' that displays game status information or other information unrelated to the real world. It requires no tracking.

- **Body stabilized:** Virtual objects are fixed relative to the user's position, but change as they rotate their body and head. This type of stabilization is suitable for the display of objects related to the user but not the real world. This type of stabilization is comparatively rare in augmented reality and only requires tracking the orientation of the user's point of view.

- **Object stabilized:** Virtual objects are placed relative to particular physical objects in the real world, such that when a physical object is moved, its associated virtual objects move too. This type of tracking is useful for attaching information to particular real objects, and as part of a tangible interaction metaphor where a physical tool is augmented in some way. This type of stabilization requires tracking of the particular physical objects, but not the whole world.

- **World stabilized:** Virtual objects are placed relative to the real world environment. This technique is useful for placing virtual objects in fixed locations so that they may be interacted with, for example a virtual map, a virtual console, or a virtual display. This requires tracking of the environment itself. Since this is normally achieved by tracking particular real objects that are assumed to have fixed locations, the whole 'environment' is shifted if these objects are shifted.

A range of different tracking technologies are available with varying characteristics. The following list introduces the main tracking technologies that are available to AR game designers. For a more detailed examination of tracking technologies, see [73].

- **Magnetic** tracking is fast and accurate, but is vulnerable to distortions caused by the presence and motion of metal objects in the tracked area. Furthermore, magnetic tracking can interfere with some devices, particularly CRT monitors. Example systems include those by Polhemus^{TM} and Ascension^{TM}.

- **Inertial** trackers require no instrumentation of the environment, but suffer from drift in both position and orientation. To be effective, they must be re-calibrated frequently.

- **Computer vision** tracking encompasses a range of techniques including fiducial marker tracking, colour tracking, and horizon tracking. It uses commodity devices such as web cameras, and is thus usually the cheapest option. However, it may require significant computing power and is susceptible to occlusion and changes in lighting. A particularly popular example is the ARToolkit [40].

- **Mechanical** tracking can be very accurate, but is limited as users must be attached to the device. It is appropriate for certain limited manipulation tasks, and has the advantage that it may also provide haptic feedback, such as in the Phantom systems from SensAble™ .

- **Ultrasound** can be used for certain limited tracking scenarios, and can be quite cheap. However, it may suffer from interference from audio in the environment. Intersense™ provide a range of systems, including the IS-600 and IS-900.

- **GPS** is an attractive option in outdoor settings as it requires no pre-instrumentation of the environment. However, it is comparatively inaccurate requires line of sight to a reasonable portion of the sky, and is impractical in certain conditions.

Hybrid tracking systems may be used to combine any of the above techniques to obtain a tracking solution that meets a particular set of requirements. However, some constraints (particularly weight, cost and complexity) may compound. Typically hybrid systems trade these for increased accuracy and reduced noise.

4.2 Interaction techniques

Designing user interfaces for a 3D augmented reality environment is more than a matter of simply porting techniques and assumptions from traditional 2D interfaces. That said, the types of task that must be performed in an augmented reality environment do not differ significantly from those on a regular desktop PC. It is useful to decompose tasks in order to determine what type of interface is best. 3D environments are particularly suited to selection, manipulation, travel, and navigation tasks; system control and symbolic input are also possible, but are often best handled by recourse to two dimensional interfaces. For a detailed and thorough treatment of the field of 3D user interface design, see the book by Bowman et al [18].

Of particular interest are selection and manipulation techniques, as it can be seen from both digital and tabletop strategy games that these make up the bulk of a player's interactions. In these, most of a player's game choices involve moving units and engaging in combat, both of which are selection tasks. Other game tasks are platform specific (such as measuring distances or rolling dice), or are extraneous to the core game play of attempting to destroy an opponent's forces. Before proceeding, let us consider the role which these interactions play in each.

In a tabletop game, players move units by picking them up, determining the destination, and placing them. A measuring task must often be completed first to determine whether the move is valid or not. Combat consists of announcement of intent, resolution of the conflict by dice or some other mechanic, the marking of damaged units, and removal of defeated units.

In digital games, players move by selecting a unit with a cursor, then selecting the destination. The system provides direct feedback as to the legality of the move, removing the need for any measurement tasks. Combat actions are performed by selecting the shooter, then ordering it to fire by selecting the target. In real time games, the player may not have to order units to fire at all, as they may automatically shoot when a target presents itself. Similarly, the shooter will usually keep firing until its target is destroyed. In turn based games, players normally have to order all combat actions individually. Unlike tabletop games, players do not have to manually resolve the effects of combat, as the system does this for them. In addition to normal interaction with the game state, digital strategy games have additional features that the interface must provide for; players must navigate their view around the game map, and they must engage in system control to start, save and restore games, as well as configuring game options.

4.2.1 Selection Tasks

Interaction with physical objects in augmented reality is no different from normal; the user may grasp objects and move them in whatever way they desire. This affordance can be used to improve interactions with virtual objects by attaching them to physical objects or using physical objects to indicate them. In addition, most selection techniques from virtual reality are applicable. One important limitation concerns the mapping between physical motion and motion of a virtual hand or cursor. Since augmented reality includes the physical environment, any mapping should be isomorphic (one to one) so as to be the same for real and virtual objects.

Using the taxonomy of [17], selection tasks can be decomposed into three parts that may be considered separately; indication of object, actuation of selection, and feedback. A selection interface may mix different techniques for each sub-task.

There are several general approaches to indicating a virtual object:

- **Grasping a related physical object.** This is the most natural type of interaction. Limitations include inability to grasp objects outside a user's reach, occlusion of the task space by arms and hand, and the necessity for associations between virtual and physical objects (which may limit the number and size of objects).

- **Gesturing with a selection tool.** A tracked physical object can be used to indicate the region of space where a virtual object resides. Common tools include paddles (placed under or next to an object) and wands (positioned such that the tip points at an object).

- **Hand tracking.** The user's hands are tracked and may be used to select objects. The lack of haptic feedback can make this difficult, and clear feedback showing when an object is indicated or selected is necessary.

- **Ray casting.** The user's hands or a tool can be used to cast a ray into the scene, indicating the first object that it intersects. This technique can be used to select distant objects, but may prove difficult to use if objects have low angular width. By incorporating a zoom effect, this problem can be somewhat alleviated.

Actuating the selection involves issuing a command, and is thus similar to many system control tasks. Common choices include:

- **Voice recognition** is a natural method of actuation, but requires that the computer be trained to each user's voice. Furthermore, it may be susceptible to noise in the environment, and may distract other users. Its chief advantage is that it leaves the user's hands free for other tasks.

- **Gestures** are usually difficult to integrate with indication techniques as they require large hand motions. However, they may be effective for de-selecting or placing objects.

- **Time** is used as an actuator in some interfaces. Once a given object has been indicated for a set time, it is considered to have been selected. Unfortunately, this may be problematic if it is hard to maintain indication (due to a moving object or instability), and is slow.

- **Buttons and physical controls** are the most common device used for issuing commands. One problem is that pressing a button causes a device to move slightly, which can interfere if the device is also used to indicate virtual objects.

Finally, some sort of feedback is required to indicate that the selection has been successful. Three forms are common; audio, video and haptic. Audio feedback is difficult to tie to small or close together objects, may be distracting to other users, and may interfere with normal communication. On the other hand, it does not introduce any visual clutter, which may be a big advantage. Video feedback involves marking a selected object in some way, such as a coloured outline. In augmented reality, selection can also be indicated by moving the virtual object, for example attaching it to the selection tool. Haptic feedback delivers information via the senses of touch and proprioception, and commonly take the form of vibrating controllers. More sophisticated haptic feedback is possible, for example using the Phantom®series of devices from SensAble™ [3], however this has not yet been explored in a gaming context.

4.3 Collaboration in AR

It has been suggested that augmented reality has potential as an environment to enhance co-located collaborative tasks [13]. Two particular reasons are usually cited.

Figure 4.4: Collaboration around a computer, and face to face. AR seeks to emulate the second.

- Firstly, augmented reality, particularly when unified with tangible user interfaces, provides a seamless interaction space. Both physical and virtual objects exist in the same space and so, in tasks where interaction with both is required, no context switching is necessary. In traditional co-located environments utilizing computer data, users must view data on a separate monitor, and relationships between physical and virtual objects are not clear [14]. This is illustrated in figure 4.4.

- Secondly, in co-located collaborative augmented reality environments, the task and communication spaces are aligned, such that no context switch is required when moving between interaction with data and interaction with a collaborator. The alignment of task and collaboration spaces also means that non-verbal cues have a common frame of reference, as in regular face to face communications. In particular, gestures and spatial cues become meaningful.

Unfortunately, current augmented reality systems involve cumbersome equipment that interfere with these benefits, and until these problems are alleviated, its promise is limited. For this reason, it is difficult to convincingly evaluate collaborative augmented reality, and so we are left to surmise the effects from reasons argued.

To be worthwhile, collaborative AR applications must be at least as good as interaction in the real world. However, they must also go beyond this, as otherwise there is no reason to move from face to face interaction in the real world. By introducing virtual objects into the real world space that collaboration occurs in, augmented reality can achieve this. Furthermore, augmented reality may have potential for introducing remote participants who may be displayed as virtual avatars that move around the communication space.

Unfortunately, augmented reality technology does not yet offer an experience equal to face to face interaction, primarily due to the encumbrance and perceptual difficulties forced by tracking and display technologies. While full head mounted augmented reality may in theory promise a fully augmented, yet natural environment, this is not yet possible. Alternative, lightweight, augmented reality systems are possible that represent virtual objects projected onto a surface [58], or displayed on a flat panel display [67]. However, in these, virtual objects are only two dimensional, and require focus on the table surface between users. This has been shown to slightly inhibit collaboration as compared to HMD based augmented reality [42].

A particular problem with augmented reality is that head mounted displays block view of the face and eyes. In normal face to face interaction, both are important modes of non-verbal communication [8]. Eyes in particular play a major role in determining whether a collaborator is paying attention, as well as assisting us in determining honesty. Thus, augmented reality systems are likely to be a hindrance in tasks that involve negotiation and consensus building.

More research in this area is obviously needed before results can be relied on to guide game design. Until then, experimentation with collaboration in games during design is wise.

Chapter V

AR Tankwar: Design Theory in Practice

The act of designing is an important source of insight into good design. It requires intuitive understanding of the medium, the expectations of players, the ways in which game play can be made compelling, and how game balance can be achieved. One must consider the game both holistically and as a system of parts that must be understood independently. This includes considerations of how the game mechanics ensure fairness and realism, how the overall game structure supports game play that is both meaningful and enduring, how players express their game play decisions and the interfaces they use, and how the game data is presented. In short, game design requires an appreciation of the entire game system at both a general and specific level. As a result, design experience provides context into which lessons learned from players and theory can be placed.

This chapter focuses on the game 'AR Tankwar'. Section 5.1 lays foundations by discussing the sorts of strategy games that work on related platforms. Following this, section 5.2 presents the game itself, along with details of its implementation and discussion of the design decisions involved in creating it. Finally, section 5.3 discusses the design process with the benefit of hindsight.

5.1 A starting point: related platforms

Before beginning design, it is wise to play existing games, as they comprise a foundation to build upon. Unfortunately, for augmented reality there are not many, as it is such a new platform. There have been previous efforts (many of which are described in chapter 2), but few have taken a design centered approach, and the few that have are not strategy games. Therefore, it is appropriate to look at strategy games on two related platforms; the traditional tabletop war game and the computer war game. These have much in common, but there are also several important differences, and their limitations reveal areas where augmented reality may offer interesting improvements or innovation.

5.1.1 *Commonalities*

In both tabletop and computerized war games, players attempt to complete objectives by deploying and maneuvering armies on a map. Objectives are diverse, but common examples are the destruction of an opponent's forces, the capture of territory, or survival for a given time period. These objectives force the players into conflict, which takes place as a series of engagements between the units of each player's army.

War games take place on almost any scale, from tactical games involving independent control of each individual soldier, to operational and strategic games in which the player controls their army as units of hundreds or even thousands of men. Abstract scale is also very common—conflicts that would in reality involve thousands of troops are often representatively modeled by much smaller forces in order to make the game practical.

During play, the actions available to players normally center around moving units, and engaging in combat. Some war games add additional layers of resource management which make for more sophisticated games, but the classic war game centers around movement and combat.

5.1.2 *State representation*

The way in which game state is represented differs widely between tabletop and computer war games. Game state consists of unit locations, agreements between players, and logistic information such as unit health and ammunition.

In tabletop war games, unit locations are stored and represented by the location of figurines, card tokens, or model terrain on a map laid out on the table. This approach is simple, but has limitations. Firstly, it is not precise, as figurines and tokens move slightly every time they are touched or the table is nudged. When accurate measurement of range, line of sight, or unit location is needed, players may disagree, so some sort of dispute resolution and good sportsmanship is needed. Secondly, the table size limits the game area; tabletop war gamers often own particularly large tables for this reason. Thirdly, all units are revealed to all players. A limited solution is to allow players with hidden units to place them at a later time.

Alliances and such agreements are regulated easily by the players around the table, and may be quite complex, or contingent on time or game progress. Logistic information is stored on individual information sheets, which may be hidden from other players. However, they may be time-consuming to refer to, and players often prefer to memorize them. In some games, some logistic information is stored publicly by the placement of numbered tokens next to units on the table.

In computer war games, units are shown on a graphical map that shows a region of the game world in detail. This has many advantages over tabletop representations, and one important limitation. Because of the limited screen space on a monitor, the rest of the world is shown on a miniature map with the current viewpoint and some important information. Unless they move their viewpoint around, however, it is easy for players to lose track of what is going on, or miss important events on other parts of the map.

Logistic data is easy to handle, it is simply displayed privately to each player on demand. Agreements between players are limited somewhat as the computer must understand them if they are to be reflected in the automated behaviour of units. Thus, they are formalized, normally just into simple alliances that may change as the game progresses.

Augmented reality offers a compromise between these two approaches. By displaying units as virtual objects on a virtual tabletop map, players gain the advantages of graphical representation while still maintaining a face to face tabletop environment. The limitation of screen space disappears, as the whole table becomes available as display area. Limitations on the size of the table may be overcome by the use of zooming interfaces such as the AR Magic Lens (as described in section 5.2.1).

5.1.3 User interface

To perform in-game actions, players must express their intent to the game in some way. Players of tabletop games express themselves simply by picking up units, stating their intention, and moving them. In computer games, each player has their own display, and express their intent by moving a cursor to select and place units. These interfaces are quite different, but both achieve the same task.

Interaction with objects in augmented reality is different again. Thankfully, there has been much fruitful research on interface design for augmented reality, so we will not have to devise new interaction techniques from scratch. An introduction to some of the more common techniques can be found in section 4.2.

5.1.4 Time

As well as being an important resource to players in the real world, time is an important resource in games. As a result, rules determining how time is spent are fundamental to a game design. In tabletop games, play is necessarily turn based, as it is impractical for players to act simultaneously. Turns may consist of phases during which players act simultaneously, but overall, game time is structured. This can upset game balance, as moving first is often an important advantage, and games must have rules to compensate. Furthermore, turns force a level of granularity on the game design—it is convenient to have units fire some number of times per turn, and move a certain distance per turn. This means that events do not occur continuously, but at discrete intervals.

Computer games are freed from these restrictions, as simultaneous play is much more practical. However, if play is real time, players must focus their attention on the game at all times, lest events occur without being noticed. Another difference is the time taken to complete a game. Tabletop games typically take much longer to play than computer games, as players must do everything by hand. A tabletop war game usually takes several hours, while computer war games may be as short as 20 minutes. However, the additional time is by no means wasted, as tabletop games are social occasions that include more than just game play.

5.1.5 Conflict resolution

All conflict between game units is handled through conflict resolution rules. These rules determine the victor and effects of combat, as well as concerns of mobility and objective capture. On computers, all of these rules are resolved by the computer, allowing virtually unlimited complexity and contributing factors. However, these rules cannot be tinkered with, and are often not well understood by players. This is normally acceptable, but prevents players from employing house rules, and removes a certain level of appreciation of the game.

On the tabletop, however, all conflict must be resolved by the players themselves, often using dice or cards. To be able to do this, players must understand and know the rules, which takes time and effort, and is unattractive to many players. Furthermore, conflict resolution is slow. Finally, players are only willing to handle rules of limited complexity. Thus, rules may have a forced level of simplicity that may compromise game realism.

5.1.6 Social Play

War games are essentially multi-player; single player versions only exist due to the availability of computerized opponents. However, the nature of the social experience is quite different between tabletop and digital war games. In tabletop war games, all of the players get together at a single location and play together around the table. During play, they may pause to talk about almost anything, even topics completely unrelated to the game. They may eat while playing, and players may come and go throughout the course of the game. Tabletop war games exist within the context of a social gathering. Furthermore, communication is natural and unmediated. Players have access to the full gamut of communication cues, from eye movements to gesture to facial expressions to spatial cues. Finally, the game map and pieces may be used as part of the communication. Players may indicate particular units by pointing, or they may pick up units to use as part of gestures.

Computer games limit social play in several ways. If players are co-located, they may communicate freely, but they normally only employ speech, as they are reluctant to move away from their monitors. Computer games have one big advantage, however: they allow the involvement of remote players across the internet. However, in this case, communication is mediated and normally limited to text or speech. Furthermore, there is normally no way to indicate units or locations on the map during communication.

Augmented reality offers an opportunity to re-introduce free communication into games that include the other advantages of computer war games. In principle, players can interact with each other face to face around the game table, while enjoying the benefits of computerized conflict resolution, artificial intelligence and other factors. Furthermore, remote players may be able to be better integrated as virtual avatars with scope for more natural communication. Unfortunately, as discussed in section 4.3, the technological limitations of today's augmented reality systems interfere with this potential.

5.1.7 Engagement

As described in section 3.2, an important part of what makes a game fun is the sense of engagement that it establishes. One of the important elements of an activity that promotes engaging experiences is the notion of instant feedback; the player must see the effects of their actions instantaneously, and be able to judge these actions in the context of their goals. Computer games are particularly strong in this area, as they afford such instant interactivity. Furthermore, computer games are commonly played in real time, and require constant player attention and interaction.

Tabletop games, on the other hand, do not offer such instant interactivity. In these, when players have the opportunity to make actions, they typically see the results immediately. Between actions, there are often long periods of inactivity while other players take their turns, and this may reduces engagement. This is particularly prevalent in larger games. However, though players are not necessarily involved with game actions at all times, they are always present within its social context. So, while tabletop games offer less opportunity for direct engagement with the game proper, they offer much more opportunity for engagement with each other.

Augmented reality games offer both instant feedback and real time play, in an environment that, it is hoped, will be more conducive to social interaction. Therefore, it walks a balancing act of sorts; fast real time play may offer better engagement with the game proper, but excludes the opportunity for social engagement.

5.1.8 Simulation of game world

As well as handling conflict resolution and graphics, computing power can be harnessed to simulate complex game systems. In war games, environmental effects such as weather are particularly interesting, as are political and economic simulations that govern the forces a player has available. Another useful application is to invest player units with a level of autonomy, such that they can respond to changing conditions without player input. For example, units may open fire automatically on approaching enemy units, or they may flee when they reach a certain level of damage. This reduces the level of micro management that a player must perform, and correspondingly increases the amount of units that they can effectively control at once. However, automated behaviour must make certain assumptions about a player intentions, and thus units may behave in unintended ways. Therefore, it is important that players have some ability to control or configure it.

One of the most important applications of computing power is the artificial intelligence that allows games to include computer controlled opponents. These allow single player games against computer opponents, but may also supplement multi-player games by allowing collaborative rather than competitive play. The main problem artificial opponents is that they are not as adaptable as human players, and become boring as their weaknesses are discovered.

Once again, augmented reality games inherit these advantages, and thus offer the potential for games that combine them with the advantages of a tabletop setting.

5.1.9 Game setting & Content

Most games have a setting, such as "World War II", "Orion's Arm", or "Middle Earth". Setting does not affect a game's formal structure, but it stimulates our emotions and imagination. In tabletop games, setting is conveyed through flavour text as well as colourful maps and game pieces; for example, war games are played with armies of finely painted lead figurines. In computer games, content is conveyed by game art and cut scenes. Augmented reality can conceivably support the methods of both mediums.

5.1.10 Practical issues

If there are practical problems in setting up or organizing a game, players are much less likely to play. Tabletop games usually require at least half an hour of setup time, as armies must be composed, the tabletop map must be laid out, and space must be cleared to accommodate the game. Players must be able to set aside several hours to play, and it is often difficult to organize a time that is convenient for all. Therefore, games are often organized well in advance, but are comparatively infrequent. There is an unexpected benefit, however; if a game is well organized, other players and spectators are more likely to hear about the game and attend.

Computer games require little setup, meaning play can be impulsive. Furthermore, the availability of the internet and other fixed networks for remote play means that computer war games can almost always be played with little to no organization or setup. However, if players wish to play with a particular group of players, more effort is required. Finally, computers have an important advantage in state management; games can be saved and resumed at a later date, making play of them even more convenient.

Augmented reality games, at least for now, are encumbered with complicated equipment that requires significant time and effort to set up. Until this problem is alleviated, they will be of limited appeal outside novelty installations.

5.2 AR Tankwar

AR Tankwar[1] combines elements from both modern miniatures war gaming and the modern PC real time strategy game. In it, players command virtual tanks, artillery and helicopters on a virtual terrain mounted on a tabletop. Their goal is to defeat their opposition (either the computer or another player), and capture objectives. In essence, it is a tabletop war game with virtual miniatures.

AR Tankwar uses video see-through augmented reality to display a virtual terrain and game units spread out across a tabletop. To interact with the game, players use an AR magic lens along with a handheld mouse to select and issue orders to units. A single player can play alone against the computer, or multiple players can play together competitively or collaboratively. Play is real time, though the game speed is comparatively slow to allow time for social interaction.

The greatest limitation of augmented reality game designs to date is that they have mostly been developed with technical considerations foremost in mind. Game elements are present to provide a coherent application, but their main contribution is to overcome some technical challenge or demonstrate some new innovation. In designing AR Tankwar, I focused on game design, with particular attention to making it worth playing for its own sake, beyond the initial attraction of augmented reality. The game needed depth of play to make it worth playing multiple times, and it needed to accommodate both collaborative and competitive play for multiple players. Finally, I wanted to explore ways to involve spectators without also immersing them in augmented reality.

5.2.1 AR Tankwar: Architecture

Most of the details of the game's implementation do not need discussion; the algorithms used are based on existing systems and other available examples. Nonetheless, I will provide a general overview of the game's overall architec-

[1] AR Tankwar was built with the help of another student, PhD candidate Julian Looser, who provided advice on the game's interface design, and assisted with the implementation of the initial prototype

ture as this will provide context, and may serve as a useful guide to someone seeking to replicate or improve on this game design. I will also discuss the specific technology choices, as they have a large impact on the overall game design.

Software framework

AR Tankwar is built as a client / server application, as illustrated in figure 5.1. The game server handles all game logic and synchronizes the display clients which handle all animation and input from players. Each display client holds a copy of the game state which is updated periodically by the server. In turn, they send user input back to the server as move or attack orders for particular units. Each display client runs on its own machine, and supports a single player.

We developed AR Tankwar with both C++ and Java. The game server was implemented in Java, as Java makes for easy debugging and rapid prototyping of game logic. The game clients required real time graphics performance, and were developed in C++ using the Open Scene Graph framework [2]. Communication between the different game processes is facilitated by the ICE framework, a lightweight middleware component available as open source [5].

Each game scenario is specified using XML along with a height field stored as a grayscale image. The scenario designer can specify starting locations, behaviours, and victory conditions for all units, objectives and obstacles.

Hardware setup

AR Tankwar requires requires a web camera, head mounted display, and a single PC for each player, as well as a PC for the game server. The group requires a set of fiducial markers consisting of black squares with unique symbols. Though head mounted displays are currently specialty items, the rest of the hardware is cheap and readily available and the system is relatively easy to construct.

AR Tankwar uses video see-through augmented reality, as described in section 4.1.2, and the ARToolkit tracking library [40], a computer vision

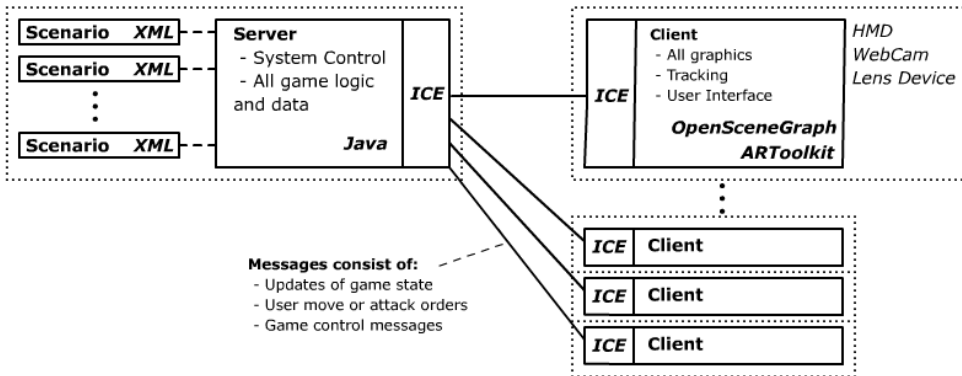


Figure 5.1: AR Tankwar: Software architecture

system based on fiducial markers. AR Tankwar uses a set of 16 markers for the game map, and one for each player's lens tool. Tracking using the ARToolkit is very cheap and easy to setup, though there are still limitations; these were discussed in section 4.1.3.

User Interface

The user interface uses a technique based on MagicLenses [12], called AR MagicLenses [45]. With this technique, each player holds a marker attached to a handle or device (such as a game pad or handheld mouse). This marker is tracked, but instead of representing a virtual object in the scene, it represents a lens tool through which the underlying scene can be shown. This view may modified in some way; for example, the scene may be magnified or drawn differently. Alternatively, the lens can be used as a selection tool; a ray between the player's viewpoint and the lens can be cast into the scene and used to select game objects. An example of the Magic lens in use can be seen in figure 5.2. In AR Tankwar, the magic lens is used in conjunction with a handheld mouse as both a selection and zooming tool.

5.2.2 AR Tankwar: Version 1

AR Tankwar was developed over several months in early 2004. The first implementation focused on proof of concept and exploration of the medium.

(a) Simple lens tool (b) Lens using PDA

Figure 5.2: AR Magic Lens

Thus, depth of game play was limited; only one unit type was available, there were no computer controlled opponents, terrain was simplistic, and only scenario was available. However, it included several experimental interfaces:

- In AR Tankwar, the player's viewpoint is exocentric; they look in at the game area from above. As part of his work on lens based interfaces, Julian implemented a transitional interface that allows players to shift from their exocentric viewpoint in augmented reality to an egocentric viewpoint in virtual reality. In this mode, the player's viewpoint shifts to that of an observer standing on the map surface. They are then free to move around the map with a game pad. While this interface was interesting, it was not used at all during play, and was not re-implemented.

- AR Tankwar includes three interfaces intended to support spectators. The first was a game summary screen showing the game map along with some game statistics, and was to be projected on a wall. The second allowed spectators to use a tablet PC to communicate with players spatially by drawing on a game map, and having their drawings appear on the map as seen by players. The third supported remote spectators by showing game information via a web interface. All three interfaces are interesting and useful in certain situations, but for Tankwar, they were unnecessary.

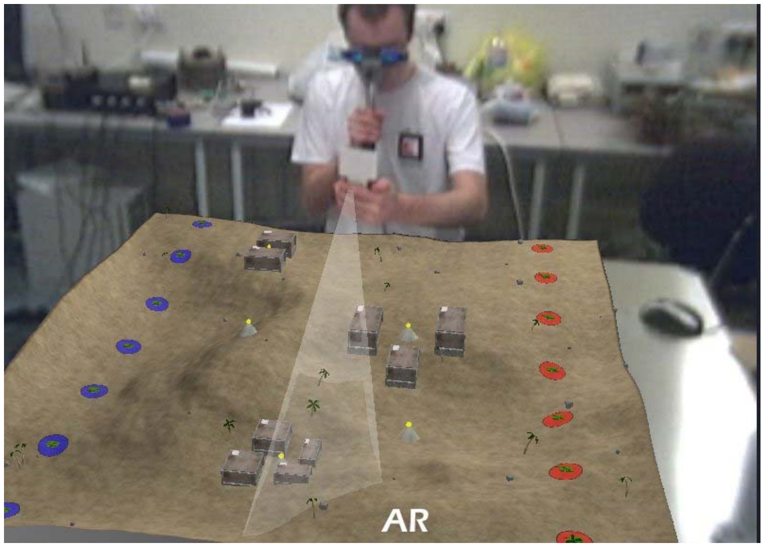


Figure 5.3: AR Tankwar: Version 1

- As an alternative to using a handheld mouse or game pad, AR Tankwar was initially implemented with a speech recognition interface that allowed players to issue commands verbally. This left players' hands free, and was simple and intuitive to use. However, speech recognition requires the computer to be trained to a player's voice in advance, which was clearly impractical. Furthermore, with multiple players, there would be problems of crosstalk.

- Finally, AR Tankwar included a interface intended to assist in collaboration. This consisted of a semi-transparent view frustum extended from each player's lens tool into the terrain. It enabled players to see more easily what their partner was working on. Though we felt this interface was valuable, players sometimes found it confusing, and so it was not implemented in version 2. However, further exploration of its potential is warranted.

Version 1 was not tested in any formal environment. However, it was demonstrated on several occasions to different audiences, including several groups of attendees at the Advances in Computer Entertainment conference in 2004, a group from Singapore's Defence, Science & Technology Agency (who helped fund the development of the game), and at the New Zealand Game Developers Conference 2004 in Dunedin, as well as at various open days within the HITLab NZ.

Though there was no formal evaluation, players during these demonstrations indicated that they found the game quite playable, even if they had no previous exposure to augmented reality. However, feedback also confirmed that more units and scenarios were needed, and that while interesting, most of the experimental interfaces were unnecessary and occasionally confusing. Most importantly, version 1 demonstrated that the design was sufficiently interesting and practical to play, and worthy of further investigation.

5.2.3 AR Tankwar: Version 2

Version 1 was developed rapidly and insufficient time was spent on architectural concerns. For version 2, it was necessary to re-implement most elements of the game to solve concurrency issues and to add new features. Version 2 took advantage of the Open Scene Graph library to simplify the graphics engine, and was rewritten from scratch. The server was enhanced with scripting capability for the definition of new scenarios, as well as a command interface with debugging information and details of games in progress. Finally, better unit behaviour and simple artificial intelligence were added to make computer opponents more interesting. With these architectural changes, it became easy to add new units and scenarios to the game.

Another area of change was the animations and graphics. Projectile and explosion effects were added, and new 3D models were acquired for all game units. In order to make it easier to tell units apart, the models were produced with bright and contrasting coloration.

Version 2 was finished in July 2005, and was intended to be playable by members of the general public as part of a fixed installation. In August, it was demonstrated at GenCon Indy 2005, a large tabletop games trade show and convention. Over 300 players played the game, none of whom had any previous experience with augmented reality. As part of the demonstration, we collected questionnaires from players; the results of this evaluation is discussed in section 6.4.

In November 2005, AR Tankwar was evaluated in an in-depth, comparative user study. During it, players played the AR version of the game, a PC real time strategy game using the same game rules and server, and a tabletop game with cardboard pieces and rules designed to be equivalent to the AR and PC versions. Players completed five experimental scenarios of the game, completed several questionnaires, and participated in informal interviews. Furthermore, their play was videoed for later analysis. This study is discussed in detail in section 6.5.

5.2.4 Design issues

Some of the design decisions in AR Tankwar were quite difficult, and if chosen differently, it would have probably still produced interesting results. In this section, I shall discuss these decisions and outline their reasons and consequences.

5.2.5 Technology Choice

Augmented reality can be implemented using several different technologies. video see-through AR was used as our display technology, and the ARToolkit for tracking. These choices were largely made for us, as the HITLab NZ specializes in these technologies. Consequences of these technology decisions have been discussed in detail in sections 4.1.3 and 4.1.2.

5.2.6 Real time vs Turn-based

The manner in which game time passes can affect game play significantly. While AR Tankwar is real time, there is much potential for compelling games with sequential or simultaneous turns. In digital games, real time is usually the preferred style, as it involves less abstraction, provides for continuous action, and is generally simpler to understand. However, real time games often demand a player's full attention, and this tends to reduce the amount of time spent on social interaction. To alleviate this somewhat, the game speed was set quite slow such that players would have time between issuing commands. This was also useful, as it meant that players had much more time to interact with the unfamiliar user interface.

5.2.7 Removal of extra interfaces

As described in section 5.2.2, AR Tankwar initially included a range of extra interfaces for experimental purposes. However, none of them were essential to the core game play, and so in later versions, they were stripped away. Though they had merit, the study of a simple, polished game was felt to be more likely to provide interesting results than one attempting to examine the utility of so many interfaces at once.

5.2.8 Interaction metaphor

Lens based interaction is a fairly intuitive interaction metaphor, and feels quite similar to using a mouse cursor to point in 3D, as is popular in most PC real time strategy games. However, it relies on the relationship of two tracked objects; the lens device itself, and the tabletop map. The tracking of both objects is somewhat noisy, and when compounded, this can make the interface quite jittery. To some extent, the decision to use lens based interaction was due to my collaboration with Julian Looser, a PhD candidate studying the utility of lens interaction in augmented reality.

Alternatively, the game could have employed a tangible user interface in which players select units by physically picking up and placing associated physical tokens (AR markers) on the map. Unfortunately, this approach was impractical for several reasons. Firstly, each unit would require its own marker as the ARToolkit begins to suffer from performance issues if more than 40 markers are tracked simultaneously, limiting the size of scenarios. Secondly, the quality of the available cameras was such that markers had to be reasonably large, limiting the scale of the game world. Thirdly, the displacement and lag problems of the display technology make it difficult to accurately pick up and place small objects on the table. Finally, markers representing units would have to be placed on top of the markers representing the map, leading to occlusion problems. However, tangible user interfaces are a very promising area for augmented reality, and of great potential for tabletop games.

5.3 Overview of design process

Game design often follows the iterative design process, which dictates a cycle of design and testing through play. AR Tankwar went through two major and several minor iterations, with play testing by ourselves and guests in the laboratory as described in section 6.3. However, since funding was dependent on external sources, the process was constrained by the demands of these projects. Version 1 was developed for demonstration to the Defense, Science & Technology Agency of Singapore, as part of a research project in conjunction with the Mixed Reality Lab of Singapore, while version 2 was partly funded as an exhibition for GenCon LLC.

Tankwar was designed from a theoretical approach. The initial game designs were inspired by traditional tabletop and digital strategy games. Following the construction of initial prototypes, the iterative process refined the game concept and its implementation, but it was never changed significantly.

Alternatively, more time could have been spent experimenting with interaction and collaboration in a series of simple games, leaving final game design until later. However, this approach would have left less time for reflection and analysis of play.

Chapter VI

Evaluations of an Augmented Reality Game

Evaluations of a game inform the iterative design process, help determine whether design goals have been met, and can provide insight into whether a given technology is suitable for game design. Games are difficult to evaluate, and those using new technologies more so.

This chapter discusses the reasons for game evaluation and the potential problems, followed by presentation of three phases of evaluation performed with AR Tankwar.

6.1 Goals

There are several reasons to evaluate games, and different types of evaluation are suitable for each. AR Tankwar was evaluated in three phases, each with a different goal.

1. **To inform the design process:** A series of informal evaluations were conducted to identify problems and limitations with the design, and to determine whether the general approach to augmented reality strategy games was viable.

2. **To see whether design goals were met:** A wide evaluation was conducted at a large games convention to determine whether design goals of playability and collaboration were met for players in general.

3. **To evaluate the medium:** An in-depth comparative study was conducted to compare AR Tankwar against two similar games on other platforms to examine the suitability of augmented reality for strategy games.

6.2 Evaluation difficulties

Augmented reality games inherit difficulties with evaluation from two sources: games and augmented reality. Games are ephemeral and subjective; augmented reality is not yet mature and may induce disproportionate enthusiasm known as the 'WOW!' effect [71].

6.2.1 Evaluating games

We play games because they create an enjoyable experience. Though we all have an intuitive understanding of enjoyment, it is difficult to make comparative and objective statements about it. Engagement is part of enjoyment, and can be measured using the framework of flow, but enjoyment is also affected by comfort, effectiveness, and sociability. Variations in our mood, the environment, other players, and the course of the game all affect our enjoyment, and so ratings from a given play session are rarely definitive. Large or obvious effects can be discerned, but more detailed variations in the experience are very difficult to examine.

Individual players vary widely in their reaction to games—every player has their own preferences. A group of players may all agree that they enjoy a game, but their reasons may all be different. Gender is often a controversial variable, but factors such as age, intelligence and coordination all have an effect. Some of these variables can be controlled in an evaluation, but others cannot, making it hard to generalize results.

Another difficulty is that games are complex systems with emergent properties. Simple designs can lead to complex play as in, for example, chess. Furthermore, slight changes to rules or the course of play may cause significant effects; imagine how different chess would be if the king could move two spaces instead of one. This means that exceptional circumstances may occur unpredictably and be impossible to reproduce. An evaluation shows how a particular group of players performed and felt during play, but gives little insight into how the game structure performs in general.

Finally, games take time to play. This means that evaluations cannot rapidly cycle through variations, and the designer must carefully choose the modifications they make to a game before evaluating it.

6.2.2 Evaluating new technologies

When evaluating applications that use a new technology, it is important that evaluations examine the application rather than the current state of technology. In the evaluations of AR Tankwar, we had particular problems with tracking and cumbersome equipment. It is important not to pre-judge later versions of a system based on findings that were affected by the problems of a particular implementation.

People often react differently to new technologies; they may be disproportionately enthusiastic, creating a 'WOW!' effect, or they may be intimidated. It is important to evaluate users after this effect has passed, otherwise the results of evaluation are biased.

Finally, if a new technology requires completely novel skills, it can be difficult to conduct comparative evaluations against systems that participants already know well. Normally, participants are trained during the experiment, but this is not always satisfactory, as participants can take more time than is practical to become proficient in physical skills.

6.3 Evaluation 1: Formative Play Testing

This phase of evaluation was conducted in parallel with game development, starting shortly after the first working version was completed. It acted as feedback into the design process, and consisted of a series of informal evaluations during various conferences and open day events at which player comments were collected and observations made.

6.3.1 Method

In June 2004, AR Tankwar was demonstrated at the Advances in Computer Entertainment conference in Singapore. In July 2004, it was demonstrated to attendees of Fuse 2004, the New Zealand Game Developer's Conference. Following these events, it was demonstrated on several occasions at open days and the HIT Lab NZ's consortium meeting. In total, over 50 players tried the game.

Each demonstration was conducted in a different environment, and hardware varied slightly, using different HMDs and cameras depending on what was available. Version one of AR Tankwar was used; in later demonstrations, more features were added as described in section 5.2.2.

No fixed procedure was followed during evaluations. Typically, players received a short series of instructions on how to manipulate the interface, a few minutes of practice, followed by a game against another player. However, this varied; some players were thoroughly tutored, while others worked it out themselves by watching. No formal data collection procedure was followed; players were observed and sometimes questioned, but this varied case by case.

6.3.2 Results

Most players found the game playable. Approximately half of them reported that they found it enjoyable and interesting. A small number found it sufficiently so that they later returned in order to play more. However, it did not appeal to everyone; some players were made uncomfortable by the heavy equipment, and so were uninterested in playing.

The biggest problems were hardware related. The head mounted displays were heavy and cumbersome, and cameras became loose as players frequently attempted to adjust them. Children and players with smaller heads were difficult to accommodate as straps on the HMDs were insufficient to distribute the weight, leading the display to press down on the nose, or slip off the head entirely. Finally, the system involved many cables, and it was necessary to keep these bound together and slung over the player's shoulder.

Early versions of AR Tankwar included experimental interfaces (see section 5.2.2). However, players generally did not use them as they were not directly necessary for play. Only one game scenario was available, and though players found it interesting, lack of variety meant that they lost interest after two or more games (approximately 20 minutes of play).

6.3.3 Weaknesses

Since the evaluations were conducted in a demonstration environment, most players only played for five to ten minutes each. This was insufficient for them to become proficient, and meant that their experience was shallow. To some extent this is useful because it emphasizes problems of usability and learnability, but it conceals any deeper implications of the game design.

6.4 Evaluation 2: GenCon Indy

The second evaluation was run as part of a demonstration during GenCon Indy 2005, a large tabletop games convention that attracts upwards of 25,000 attendees. The game was demonstrated for the entire duration of the convention, and over 300 players participated, each for 10 to 15 minutes. Feedback was collected from discussions with players and spectators, as well as a questionnaire.

6.4.1 Method

The evaluation was run with the help of volunteers provided by the convention. They were given specific instructions for player treatment, and before working on their own, spent at least 20 minutes playing the game and half an hour helping another demonstrator.

Procedure

Upon arrival at the exhibit, players were given an information sheet with an introduction to augmented reality and instructions on how to control the game. Generally, the game would be in use; this gave players a chance to watch before trying themselves. Players were also provided with information on data collection procedures and its potential usage.

When the time came, each player was led to a set of equipment by a demonstrator who helped them put it on and instructed them on how to issue orders to their units. Players were given several minutes to practice the game, and once ready, they were given a fresh scenario to play. Players played in pairs, and in most cases both players had not played before. In a few cases, no opponent was available, in which case a demonstrator played the second side. Once the scenario was over, players were asked to fill out the questionnaire. Each player spent about 15 minutes at the demonstration, about 10 of which were spent playing the game.

Apparatus

A single set of hardware was used throughout the evaluation: the two display units consisted of iO Display Systems i-glasses SVGA HMDs and Logitech 4000 web cameras, while the lens device was constructed with Logitech wireless game pads. The cameras were attached to the HMDs by means of a pivot joint, meaning that players could easily adjust the camera to suit their preference. Both the camera and HMD required cables to connect them to a PC; these were at least 5 metres long and neatly bundled together with cable ties. For mobility and safety, we instructed players to keep cables slung over their shoulder. Since the system was to be used by hundreds of players during the demonstration, we required that each player clean their forehead before playing. Furthermore, we thoroughly washed the forehead pads on the HMDs every two hours.

The evaluation was run using version two of AR Tankwar, with two limitations. Firstly, users could not interact with more than one unit a time. Secondly, the zoom feature was disabled due to an intermittent crash bug that was not acceptable in the context of a public display. The evaluation used several different scenarios; most players played a simple competitive match, while players requesting a challenge also played collaborative scenarios with more complicated objectives and opponents.

The evaluation was conducted in a booth, approximately 10m by 5m in size, in the convention's exhibit hall (see figure 6.1). The bulk of the area was cordoned off from spectators, and included the game table, space for the necessary equipment, as well as several chairs and a table for questionnaires. One end of the space was taken up by a large projection screen showing the view point from one of the headsets, so that spectators could see what was happening. The game table was quite low, approximately 50cm off the ground, and larger than necessary for the fiducial markers. It was set in the middle of the space; the computer table was up against one side, while the other three sides had at least one metre of clear space for players to move around in. Finally, a space at one end of the enclosure was set aside for prospective players to sit while reading through instructions and asking questions.

Figure 6.1: AR Tankwar booth at GenCon Indy 2005

Data collection

In the questionnaire, players were asked five questions about the game interface, collaboration, comfort, and disorientation. They were also asked to rate their willingness to play augmented reality games in the future, and to rate their interest in the use of augmented reality to enhance four common types of tabletop game. The complete questionnaire is included in appendix A.

6.4.2 Results

About 300 people played AR Tankwar, and 228 of them filled out and returned questionnaires. Details of their responses are shown in table 6.1. Demographic data was not formally collected, but players were observed to range from approximately 10 to 70 years in age, with most were in their 20s, 30s and 40s. About 90% of them were male. These demographics reflected those of convention attendees overall.

Ease of Use

Players varied very widely in their ability to control the game, rating it with *mean* = 3.34 and *sd* = 1.63 where 1 was '*Hard*' and 5 was '*Easily*'. Jitter was a major problem; players who were able to remain relaxed and keep their hand steady had a much easier time coping with it, which made them more likely to use the interface effectively.

Visualization

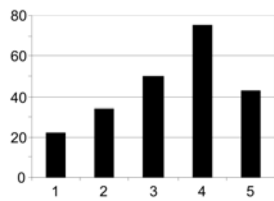
Players were less varied in rating their ability to see what was going on during the game, and responded to the question "*Could you easily tell what was going on?*" with *mean* = 3.35 and *sd* = 1.15 where 1 was '*Hard*' and 5 was '*Easily*'. Some players found that the units were too small to see, and several suggested that some method of zooming into the game map was necessary. Players also had trouble distinguishing different unit types due to the low quality of their displays. Finally, players had trouble with the game map, which would sometimes disappear momentarily due to tracking errors. Observation suggested that players who took the time to understand the relationship between camera, markers, and virtual imagery found the interface easier to use.

Social Play

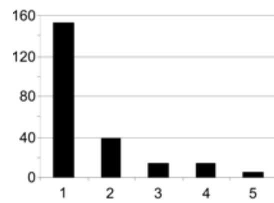
Most players had good awareness of the actions of the other player, responding with 4 or 5 to the question "*Were you aware of the other player's actions?*" where 1 was '*Unaware*' and 5 was '*Aware*'. However, a few players had a great deal of trouble; see figure 6.2(b). Most pairs communicated frequently during play; though this was normally limited to the exchange of challenges and boasts.

Discomfort

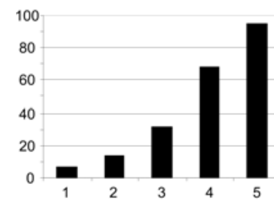
Most participants reported some discomfort caused by the head mounted displays. The most common complaints were neck strain and pressure on the nose and ears. Children and those with smaller heads reported it most frequently, as the HMDs did not fit them well. In some cases, a demonstrator helped by standing behind a player and taking the weight. Most players described comfort as the greatest limitation on their enjoyment and responded to the question "*How comfortable were you while playing?*" with with *mean* = 2.93 and *sd* = 1.09 where 1 was '*Uncomfortable*' and 5 was '*Comfortable*'. A few players reported that discomfort was only apparent after play was finished, as they were too engaged during it to notice.



(a) Awareness



(b) Disorientation



(c) Overall potential

Figure 6.2: Selected questionnaire responses from Evaluation 2

Disorientation

Approximately 25% of players reported disorientation caused by the camera viewpoint and the low resolution of the display. A very small number also reported slight dizziness and nausea after play. When asked "*Did you feel disoriented at all after playing?*", players responded with *mean* = 1.39 and *sd* = 1.02 where 1 was '*Not at all*' and 5 was '*Definitely*'.

Potential of augmented reality

Most players felt that the medium had potential. When asked "*Cost notwithstanding, how willing would you be to play multi-player tabletop games augmented using headsets?*" where 1 was 'Unwilling' and 5 was 'Willing' , players responded with *mean* = 4.08, *sd* = 1.07. Players were generally sympathetic towards the game, and problems were frequently downplayed with acknowledgements that the game was a prototype. The 'WOW!' effect was quite visible in the reactions of some players, and contradictory positions such as "hard to see what's happening, uncomfortable headset, map keeps flipping out, I love it!" were expressed quite frequently.

Table 6.1: Evaluation 2: Results of questionnaire

Question	Median	Mean	S.D.
How easily could you control the game?	3	3.34	1.63
Could you easily tell what was going on?	3	3.35	1.15
Were you aware of the other players actions?	4	3.39	1.23
How comfortable were you while playing?	3	2.93	1.09
Did you feel disoriented at all after playing?	1	1.59	1.02
Cost notwithstanding, how willing would you be to play multi-player tabletop with AR?	4	4.08	1.07
Do you think this technology would be suitable to supplement or enhance (rated 1 to 3):			
Miniatures games?	3	2.65	0.54
Card games?	2	1.73	0.70
Board games?	2	2.28	0.66
Role playing games?	3	2.47	0.63

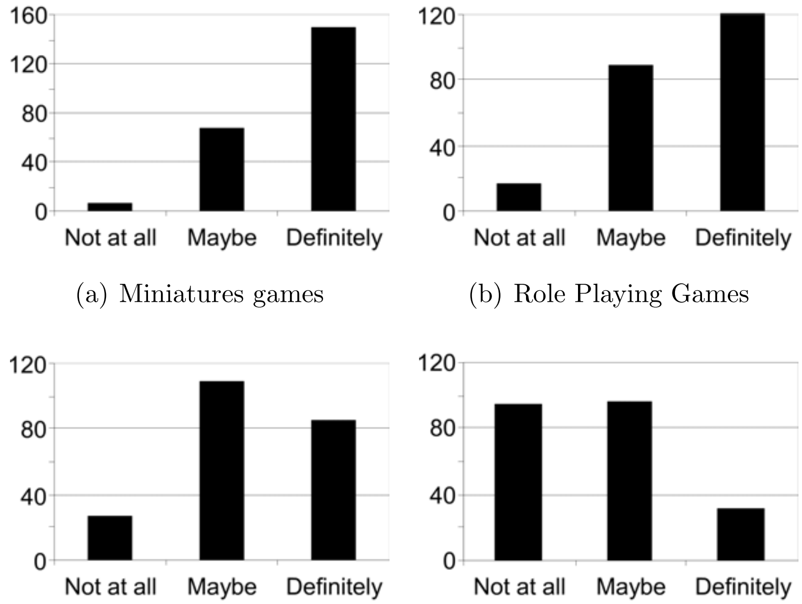
Most players felt that augmented reality was very appropriate for miniatures games and role playing games. Some felt that it was appropriate for board games, while most felt it that it was not suitable for card games. Their responses are graphed in figure 6.3.

Practical issues

There were very few practical problems with the game hardware during the evaluation, and both the pivot mounted cameras and low table proved useful. In particular, the low table allowed players to kneel over the game map or sit while playing. Several players also suggested that the system could be made more practical by attaching the display to a hat or helmet.

Experienced players

Demonstrators played the game a lot more than visitors; after about an hour of play, most became proficient and began to exhibit new behaviours. While other players usually remained static during play, moving only their hand and arms in order to target, more experienced players were inclined to



(a) Miniatures games (b) Role Playing Games

(c) Board games (d) Card games

Figure 6.3: Suitability of AR for different game types

walk around the table, crouch, even stand on the table in order to change their viewing perspective. They also separated the lens marker and game pad, claiming that it made it easier to hold the lens steady while selecting units. Finally, some of them began to build scenarios and discuss their own augmented reality game design ideas.

6.5 Evaluation 3: Laboratory Evaluation

The third evaluation was a detailed examination of game play that compared AR Tankwar to similar games on tabletop and PC. It consisted of a formal laboratory study with pairs of participants playing a series of collaborative scenarios with each of the three games. Data was collected from questionnaires, game logs, observation, and player comments.

6.5.1 Method

The evaluation was organized as a single factor within subjects design with three levels: AR, PC and tabletop. In each session, participants played five experimental scenarios; two each on AR and PC, and one on tabletop. This imbalance was necessary as tabletop games are very time consuming. Each evaluation session took from three to four hours to complete.

Participants

Participants were recruited from a local games club, and all were experienced in tabletop and computer games. In most cases, the participants already knew each other, and had played games together before. Four of them had experience with augmented reality, and one had experience with virtual reality but not augmented reality. All participants were male, and between the ages of 21 and 32. Participants were not paid.

Procedure

Upon arrival, participants were given an information sheet describing the rules common to all three games. Once they were satisfied that they understood the game rules, they completed a training scenario with each game until the experimenter was satisfied that they understood the interface thoroughly. This normally about took ten minutes for each of the AR and PC games, and about thirty minutes for the tabletop game.

Following training, participants completed the five experiment scenarios in a random order. The AR and PC games were balanced among four of the scenarios, while the tabletop game was always played with the same scenario. Once players had finished playing each game, they were asked to fill out a detailed questionnaire describing their experience. After completing all five experiment scenarios, players were asked to fill out a final questionnaire. Before leaving, most players made several comments on the game and their experience.

Measures

Three questionnaires were employed. The first asked players about their previous experience with games and augmented reality, while the third asked players to rank the three games. The second was the most detailed, and was filled out once for each game. It consisted of five parts: the first part characterized the experience of play, the second gauged the flow experience using questions derived from [25], the third covered the user interface, the fourth covered collaboration, and the fifth rated the games overall. For reference, all three questionnaires are presented in appendix B.

Four dependent variables for performance were derived from game logs: whether each scenario was completed successfully, the percentage of units lost, the percentage of enemies killed, and the time taken. The tabletop game used a special scenario and performance in it could not be compared to that in the AR or PC games.

Players were observed during play, and their behaviour was recorded on video for later review. Comments made during play and following the evaluation were also recorded.

Hardware & Software setup

This evaluation used the final version of AR Tankwar. Hardware consisted of two eMagin z800 head mounted displays and Logitech 4000 cameras. These displays are lighter than those used in previous evaluations, and are of a higher quality.

Both the PC and tabletop games were designed to be typical of their platform, while using rules as similar as possible to those of the AR game. The tabletop game differed from typical games of its type by using card tokens instead of lead figurines. It also differed from the AR and PC games by being turn based rather than real time.

Game scenarios were designed to be impossible to complete by a single player, and difficult for players working together. The scenarios for the AR and PC games used both mobile and fixed opponents, while the tabletop scenario used only fixed opponents. To resolve enemy behaviour in the tabletop game, players were instructed to roll the attack dice themselves, always choosing the weakest unit of theirs in range as a target. This was congruent with the artificial intelligence employed in the AR and PC games. For reference, all five experimental scenarios are reproduced in appendix C.

The evaluation used a two metre square table of normal height for both the AR and tabletop games. A table for the PCs was placed against one side of the game table, and the other three sides had at least one metre of clear space for players to move around in.

Game play was recorded with a pair of digital video cameras placed in obvious locations in the room. These cameras were moved between each game in order to have the best possible view of the players and their displays. However, since players moved around during play, in some cases, the cameras were obscured.

6.5.2 Results

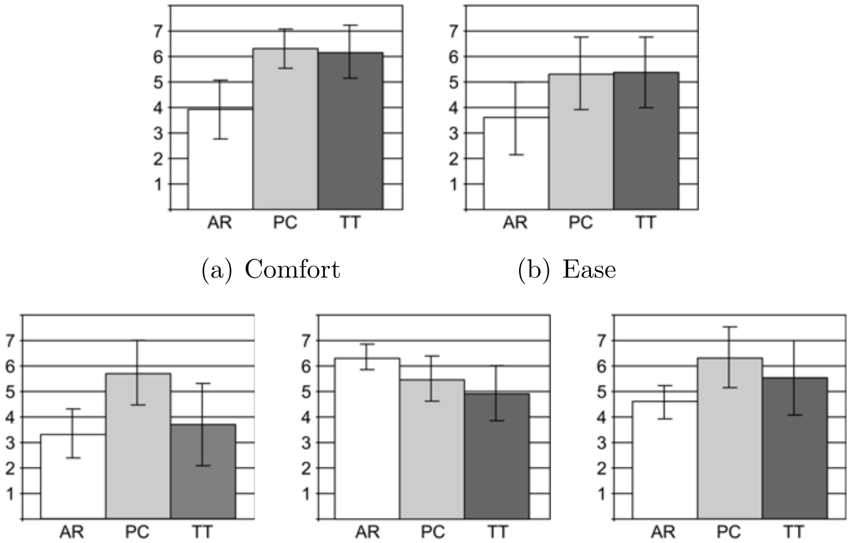
Fourteen participants (seven pairs) of players participated in the experiment. The results from one pair were discarded, as technical problems caused interruptions during the AR game. Performance measures were considered jointly for each pair (that is, $df = 5$).

Player Experience

Data about the experience was collected from two questionnaires, and comments made by players both during and after the evaluation were re-corded.

The first questionnaire was completed once for each interface and the results were analysed using the Friedman χ_2^r test with $df = 11$. Full details are shown in tables 6.2 and 6.3. In the first section of this questionnaire, players were asked to describe their experience by rating it from 'None' to 'Very' on seven point scales for each of twenty one different feelings. Of these, only five showed significant differences between games at the 95% confidence level (see table 6.2).

Players found the AR game significantly less comfortable than either the PC or tabletop games (table 6.2, row 1). A lack of comfort was attributed to the head mounted displays and the need to stand during play, and was the most frequent complaint about the AR game.



(a) Comfort (b) Ease

(c) Precision (d) Interest (e) Relaxation

Figure 6.4: Ratings of play experience significant at $p < 0.05$

Players found the tabletop and PC games significantly easier than the augmented reality game (table 6.2, row 3). They also found the PC game significantly more precise than either the AR or tabletop games (table 6.2, row 5). In player comments, the AR game's low rating was attributed to tracking noise and difficulty keeping the lens steady. For the tabletop game, the low precision rating was attributed to the ease with which they could disturb the card game pieces.

Players rated the AR game as significantly more interesting than either the tabletop or PC games (table 6.2, row 7). However, it is likely that this difference was partly caused by the 'WOW!' effect. Players also found it less relaxing than the tabletop game, which in turn was less relaxing than the PC game (table 6.2, row 21). In their comments, players attributed the lack of relaxation in AR to stress caused by tracking noise, and the need to stand. No indication was given as to why they found the PC game more relaxing than tabletop. The other 16 measures showed no significant differences.

Table 6.2: Evaluation 3: Results of interface questionnaire - Player experience

		Means				
	Measure	AR	PC	TT	χ_r^2	P
1	**Comfortable**	**3.92**	**6.33**	**6.17**	**15.17**	**p<0.001**
2	Frustrating	4.17	2.50	3.50	5.04	0.080
3	**Easy**	**3.58**	**5.33**	**5.42**	**7.04**	**p<0.05**
4	Boring	2.33	2.42	3.17	3.12	0.209
5	**Precise**	**3.33**	**5.73**	**3.67**	**8.77**	**p<0.05**
6	Obvious	5.17	5.75	5.08	3.04	0.219
7	**Interesting**	**6.33**	**5.50**	**4.92**	**11.62**	**p<0.005**
8	Vague	3.75	2.25	3.08	4.87	0.087
9	Collaborative	5.83	5.67	6.33	2.54	0.280
10	Efficient	4.50	5.73	4.67	2.59	0.273
11	Intuitive	4.50	6.00	5.25	3.17	0.205
12	Solitary	2.92	2.73	2.17	4.41	0.110
13	Fun	6.00	5.92	5.42	3.79	0.150
14	Empowering	4.08	5.40	4.83	2.15	0.341
15	Effective	4.67	5.58	4.50	4.50	0.105
16	Engaging	5.67	5.50	4.83	4.54	0.103
17	Sociable	5.08	5.42	6.00	3.50	0.174
18	Focused	5.18	5.25	5.17	0.04	0.978
19	Satisfying	5.27	5.50	5.08	2.36	0.306
20	Skilled	5.09	4.67	4.67	0.41	0.815
21	**Relaxing**	**3.45**	**4.75**	**4.17**	**6.05**	**p<0.05**

Flow

Part two of the questionnaire examined the experience of flow with questions taken from standard ESM (Experience Sampling Method) questionnaires provided in [25]. None of the results showed any significance when analysed.

User Interface

In part three, players were asked questions about the user interface. Three of these showed significant differences between games. Players felt more in control during the PC and tabletop games than they did during the AR game (table 6.3, row 10), and they found their interfaces significantly easier to use than that of the AR game (table 6.3, row 11). Finally, players found the PC interface more precise than either the tabletop or augmented reality interfaces (table 6.3, row 12).

Collaborative experience

Part four examined the collaborative experience. Of the seven questions, six were found significant at the 95% level of confidence. In all, the tabletop game was rated most collaborative, followed by the PC game, with the AR game clearly last. Players remarked that while they felt they could effectively communicate verbally in AR, they often felt isolated from the other player. This was attributed to difficulty moving and looking at their partner, and a feeling of mediation caused by the head mounted display.

Overall enjoyment

The final question asked players to rate their overall enjoyment. No statistically significant difference was detected.

Rankings

Players completed the second questionnaire once all five scenarios had been played. In it, they ranked the three interfaces six times; five according to specific criteria and once according to their overall preference. The results

Table 6.3: Evaluation 3: Results of interface questionnaire - Flow, interface and collaboration

	Measure	Means AR	PC	TT	χ_r^2	P
Flow						
1	Felt anxious	2.92	2.25	1.90	5.04	0.080
2	Felt involved	5.58	5.67	5.55	0.41	0.815
3	Clear goals	5.75	6.00	6.55	3.45	0.178
4	Visible progress	5.75	6.00	6.27	1.95	0.376
5	Could handle task	5.75	6.33	6.36	1.68	0.431
6	Difficult to focus	3.08	3.33	4.27	1.95	0.376
7	Would play voluntarily	5.75	5.92	4.91	2.91	0.233
8	Easily distracted	2.25	2.25	3.36	5.77	0.056
9	Time passed quickly	5.92	6.00	4.81	3.59	0.166
User Interface						
10	**Felt in control**	**3.75**	**5.92**	**5.64**	**8.77**	**$p<0.05$**
11	**UI easy to use**	**3.33**	**6.17**	**5.55**	**14.05**	**$p<0.001$**
12	**Control was precise**	**3.00**	**5.58**	**5.09**	**8.77**	**$p<0.05$**
13	Felt powerful	3.58	4.92	4.09	0.73	0.695
Collaboration						
14	**Efficient collab**	**5.33**	**5.83**	**6.45**	**7.09**	**$p<0.05$**
15	**Referring to objects**	**3.33**	**2.08**	**1.73**	**8.59**	**$p<0.05$**
16	**Understand partner**	**4.67**	**5.92**	**6.36**	**9.86**	**$p<0.01$**
17	**Partner's work area**	**4.00**	**5.25**	**6.45**	**11.64**	**$p<0.005$**
18	**Partner's activity**	**4.00**	**4.83**	**6.18**	**11.77**	**$p<0.005$**
19	**Work together easily**	**4.83**	**5.67**	**6.36**	**12.40**	**$p<0.005$**
20	Communicate clearly	5.33	6.00	6.36	2.90	0.234
21	Overall	5.50	5.83	4.91	2.59	0.273

were analysed with the Friedman χ_r^2 test, and are shown in figure 6.4. Statistically significant differences were found between games for the five specific criteria, but not for the overall ranking.

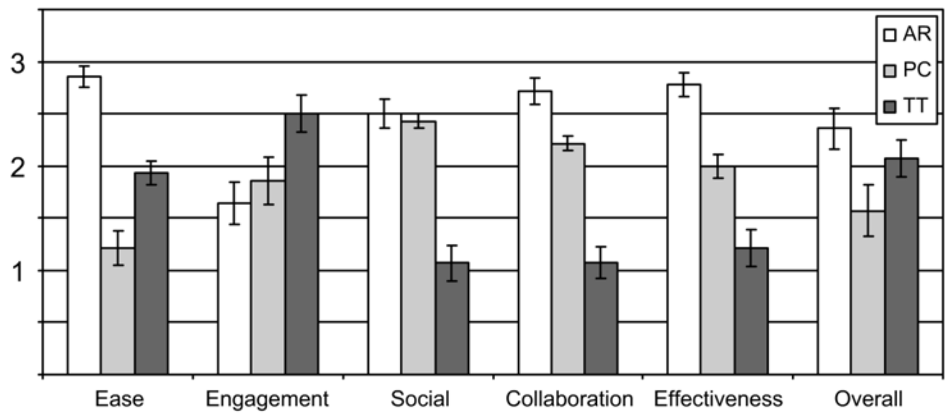


Figure 6.5: Average ranking of games (low is best)

Players found the PC game easier to play than the tabletop, followed by the AR game (table 6.4, row 1). However, they felt that the tabletop game was more effective for solving problems (table 6.4, row 5). The AR interface was ranked first for only one criteria, that of engagement (table 6.4, row 2).

The social and collaborative criteria were expected to show similar rankings. Players clearly found the tabletop game best for both, and the PC game was better than AR for collaboration (table 6.4, row 4), but the two were closely ranked for social play (table 6.4, row 3).

Performance measures

Performance data was derived from logs of the AR and PC games. The tabletop game used a special scenario; therefore, it cannot be compared to the AR or PC games for performance. Four dependent variables were measured; completion of objectives, percentage of friendly units lost, percentage of enemy units killed, and the time taken.

The scenarios were designed to be difficult for a pair and impossible for a single player. However, they were not of perfectly equal difficulty. Of the

Table 6.4: Evaluation 3: Results of final ranking questionnaire

	Measure	Means AR	PC	TT	χ_r^2	P
1	**Easiest to Play**	**2.86**	**1.21**	**1.93**	**16.67**	**p<0.0005**
2	**Most Engaging**	**1.64**	**1.86**	**2.50**	**7.17**	**p<0.05**
3	**Most Social**	**2.50**	**2.43**	**1.07**	**15.17**	**p<0.001**
4	**Ease of collaboration**	**2.71**	**2.21**	**1.07**	**19.50**	**p<0.0001**
5	**Problem solving**	**2.79**	**2.00**	**1.21**	**15.17**	**p<0.001**
6	Overall	2.36	1.57	2.07	3.17	0.205

four scenarios played using the PC and AR games, scenarios one and two were completed by all players, scenario three was only completed by players in the PC game, and the only pair that completed scenario four did so with the PC game. These results suggest that the PC game made players more effective.

This trend also showed in some of the loss and kill ratios. This data was analyzed with t-tests, and showed a significant difference at 95% confidence for losses in scenario three, and kills in scenarios three and four. In all of these cases, players with the PC game lost less units, and killed more enemies, making their performance superior.

Game times are only meaningful for completed scenarios. Since only scenarios one and two were completed by players with both games, only these two can be compared. Times were analysed by t-tests, and significant differences at 95% confidence were found for both, favouring the PC game as fastest.

All six pairs completed the tabletop scenario, and it was ranked in the interface questionnaire as most effective. Players took much longer to complete it; approximately five times longer than scenarios in the AR or PC game.

Observations

Most players did not move around during the AR game. However, two players did so, moving around and leaning over the table in the same manner as experienced players during the second evaluation. Generally, players did not try to look at each other; they remained focused on the game map.

Players communicated frequently during all three games. During the tabletop game, they tended to speak continually, whereas communication in the AR and PC games did begin until one of the players began to encounter difficulties. A common first phrase was "Well, I'm almost dead... How about you?". Following the first comment, they communicated frequently through the remaining scenarios. One player noted that he would probably not have communicated with his partner during the AR or PC games had they not been forced to by the difficulty of the scenarios. Communication was not measured, but pairs appeared to communicate in different amounts; the pairs who communicated most tended to perform best.

While playing the AR and PC games, players usually discussed their intentions and decisions at a general level; they acted as independent collaborative partners. In the tabletop game, however, players discussed their actions in detail, even including the specific probabilities of each move. They tended to act as a single unit; actions usually occurred only after consensus was reached, and individual initiative was rare.

Player comments

Several players stated that they felt isolated during the AR game; one remarked "I knew [my partner] was there, but it felt detached; like watching him on TV". This was attributed to the HMD and camera; players commented that the quality of the images was too low and the camera displacement was confusing. They also complained that the weight of the HMD made it difficult to look at their partner. Several players stated that the HMD was the most significant detraction from the experience.

During the evaluation, each player used the AR interface for approximately half an hour. Afterwards, several stated that they still did not feel proficient. One remarked "I was still learning how to move the [lens] properly when we had to stop". Several players had used augmented reality systems before, and they were more effective. However, none of the players achieved the same level of proficiency and enthusiasm displayed by the demonstrators at GenCon.

Players had different reactions to the lens interface. Some became effective with it quickly, while others were still troubled by it at the end of the evaluation. Generally, players felt that it was elegant and intuitive but severely inhibited by tracking noise. Players also reacted favourably to the zoom feature. However, they complained that they could not zoom past a certain depth as the lens marker caused the map to disappear. One player was particularly enthusiastic about the interface, and described it as "a RTS with handheld camera control".

Summary

In all significant measures other than level of interest and level of engagement, the AR game was rated worst or equal. It was less precise, less easy, and less relaxing. Furthermore, play with it resulted in less victories, the loss of more units, less enemy kills, and took longer to play.

However, players were enthusiastic about the technology, and often ascribed their problems to specific technical or practical issues that could be addressed in commercial systems. The prevailing attitude during the final informal discussion was one of optimism and excitement about the technology's potential. Further development and polish is clearly needed before tabletop augmented reality games are viable outside the laboratory, and almost all of the players expressed an interest in participating in future developments.

6.5.3 Weaknesses

As described in section 6.2, games are difficult to evaluate. This study in particular had several weaknesses. Firstly, there is no guarantee that the tabletop and PC games were representative of those platforms, and so these results may reflect problems with my particular implementations.

Secondly, there were technical problems during the evaluation. Most of these occurred during the second session, and were sufficiently disruptive that the results from that session were removed.

Another weakness arises from player motivation and the laboratory environment. Players played the games because they were asked to as part of the evaluation, not simply to have fun. Thus, they remained focused on completing the scenarios, and did not interrupt play with unrelated talk. When played in the home, games are often informal and may involve spectators, interruptions, or other concurrent activities that may affect the experience. A laboratory study can never encompass these factors. Ethnographic study may be a remedy, though possibly uneconomical for lightweight studies during design.

Finally, this evaluation was very time consuming; each session took upwards of three hours. Thus, it was difficult to acquire participants, and only seven session were run. This led to low statistical power, and may have resulted in type 2 errors for some of the measures.

6.6 Summary

This chapter presented the results of three phases of evaluation of AR Tankwar. The first was a series of informal play tests. The second tested the game with a wide range of players at a games convention, and the third compared it to traditional tabletop and computer strategy games.

The key benefit of these studies comes not from measuring player experience, but from understanding its causes and gathering player reactions to specific elements of the game design. Chapter seven discusses the implications of these evaluations in the context of the theoretical discussion in chapter three, and the design experience discussed in chapter five.

Chapter VII

Guidelines for Tabletop AR game design

The previous chapters have covered conceptual and theoretical models, and the presentation and evaluation of a sample augmented reality strategy game. Aloe, this information is not sufficient to provide any meaningful guide for game designers. This chapter draws all of this material together into sixteen guidelines concerning the design process, good game design, and evaluation.

7.1 Guidelines for the design process

7.1.1 Understanding the game experience

Designers of tabletop and computer games have a wealth of previous work to draw from; design goals can be articulated by comparison to previous games with a list of key differences. With new technologies such as augmented reality, we do not have this background. It is useful to consider examples from other platforms and understand how different elements of experience are created, but to be able to pursue them, the design goals must be thoroughly understood. The designer should carefully consider the intended play experience before beginning design. This advice is also appropriate to designers of traditional games, but the price of not heeding it is less there, as games can be based around previous designs.

7.1.2 Frequent evaluation, fluid design

In augmented reality, we do not yet fully understand which techniques are optimal for interaction, collaboration, and visualization. Consequently, it is important to evaluate a game frequently in order to validate design decisions. On traditional platforms, designers can afford to rely on their previous experience, as assumptions about how players will react to particular interfaces are likely to be correct. Designers should evaluate early and often.

For similar reasons, it is wise not to commit to most aspects of the game design until late in the process. A lack of knowledge means that our early assumptions may be proved wrong, and so the designer should be willing to radically change the design even late in the process.

7.2 Guidelines for game design

7.2.1 Technology balance

Head mounted displays can cause discomfort, interfere with social interaction, and reduce mobility. A little effort spent to improve practicality can have a large effect on usability. Effective strategies include mounting the camera with a pivot, using long cables neatly bound together, and integrating the HMD into a hat or helmet to spread its weight.

Of the available display technologies, HMDs require the most from the user. They may be inappropriate if the design does not call for immersion or 3D virtual objects, and handheld or spatial displays should be considered. Typically, the game designer must choose technology to meet minimum requirements, while minimizing the load on the player. AR Tankwar used head mounted displays, but a similar game could have been built using projected augmented reality, and this may have been more compelling.

7.2.2 Models of time

Game designs handle time in two ways; it is either continuous and mapped to real time, or packaged into discrete blocks such as turns. If game time is discrete, slow, or can be paused, the rate of play is flexible and can better accommodate social interaction producing a more relaxed game experience. Alternatively, games that are fast and real time produce temporal pressure, and engage players more by forcing them to focus. However, temporal pressure may exacerbate difficulties with the user interface, causing frustration.

It is important to understand this trade off, and structure game time so that the desired experience is created. In AR Tankwar, we used a slow real time approach; this gave players time to collaborate, but also created temporal pressure when engaging the enemy.

7.2.3 *Collaborative interface design*

Collaborative augmented reality is sometimes described as 'shared space' [56]. Sharing an augmented space helps users share and work with virtual objects. However, it also forces them into a shared workspace in order to preserve spatial references. This can be problematic when users need their own views. In strategy games involving maps; the map area must either be static, or any scrolling must affect the views of all players. Personal interface devices such as magic lenses or interaction panels may help, but they may also make it harder to collaborate. More research is needed to determine the best use of these interfaces. To build games effectively, designers need to be aware of developments in the field of interface design, and be prepared to experiment themselves.

7.2.4 *Encouraging collaboration*

A game can be designed to promote or inhibit collaboration. Difficult scenarios tend to increase it as it can be necessary for success. On the other hand, temporal pressure reduces it, as players have less attention available. Collaboration between players wearing HMDs is inhibited to at least the same extent as co-located players of desktop computer games; in both cases, players must withdraw focus from the game to look at the other player. Furthermore, it is difficult for players to look at each other, their face and eyes are concealed, and spatial gestures may be occluded by virtual imagery. Fortunately, some of these problems will diminish with advancing technology.

Social interaction is an important part of play, though games can still be enjoyable without it. Game designers need to determine how much collaboration they want, and tailor the design to encourage it.

7.2.5 *Balancing reality and virtuality*

Augmented reality systems allow interaction with both real and virtual objects. To make full use of the medium, game designs should allow this. Virtual objects allow the visualization of complicated data and automated behaviours. However, it is easy to treat augmented reality as simply a glorified display medium. By occluding most of the table space with a large map, AR Tankwar veered close to this extreme. Real objects can be used for intuitive tangible interfaces. However, to interact with physical objects, the user must be able to see them; if they are behind virtual objects, their location must be revealed by virtual tags or transparency.

If a game design uses mostly virtual objects, a desktop computer may be more appropriate; if it uses mostly physical objects, a tabletop game may be more appropriate. The ability to mix the real and virtual is augmented reality's strength; game designs should take advantage of this.

7.2.6 Coping with tracking noise

Augmented reality often suffers from tracking noise. This is particularly problematic for interfaces that require fast and precise movements, and those that require the tracking of multiple physical objects. For example, an AR magic lens interface tracks the table and the lens marker to derive the relationship between the user's lens cursor and the game map.

There are several design strategies for coping with noise. Firstly, if movements are slow and deliberate, tracking errors can be smoothed out. Secondly, the interface may 'snap' selections or placements into a subset of valid locations. Finally, noise may be adapted as a source of randomness or a test of skill. For example, shooting games move the targeting reticle randomly to make the task more realistic, and war games may use it to make precise targeting of artillery bombardments hard.

Tracking noise is not likely to be eliminated in the foreseeable future, particularly in cheap systems, and so successful game designs need to accommodate it.

7.2.7 Abstract representations

Modern computer games often use detailed and realistic graphics, and there is a temptation for augmented reality games to follow suit. However, the display devices used in augmented reality, particularly HMDs, are of much lower quality than most monitors. When display quality is low, priority should be given to making graphics easy to recognize. Colourful, abstract or schematic representations may be much better for this purpose than high detail, realistic graphics. Tabletop games often rely on abstract representations, and are good a source of ideas for how this may be done well.

7.2.8 Game state visualization

By drawing objects in the real world, augmented reality is suited to visualizing spatial and structural data, particularly in 3D. However, the low spatial resolution of most augmented reality displays makes viewing large amounts of textual or numeric data difficult. This should be taken into account in design; given current augmented reality systems, games that involve high information density are suited more to desktop computers. However, games that rely on spatial relationships are particularly suited to augmented reality.

7.2.9 Emergence in design

Game designs do not need to be complicated to be fun, interesting or meaningful. In a new technology such as augmented reality, complicated systems are more likely to introduce problems that will detract from the play experience, as our understanding of best practices are limited. Instead, game designers should seek to design simple games with strong properties of emergence. Player choices may be limited in order to accommodate problems with interface design, but their effects should vary widely depending on context. Augmented reality technology will improve, but until then, compelling game play is more likely to come from simple, strongly emergent game designs.

7.3 Guidelines for evaluation

7.3.1 Know your target audience

Players vary widely in their reaction to a particular game. Gender and age are obvious variables, but subtle differences in taste also have an effect. To understand how a game will be received, it is important to evaluate it with many players from different backgrounds. In certain situations, it may be acceptable to limit evaluation to a particular set of players, but it is important to understand that results are unlikely to be generalizable. Inevitably, some people will not appreciate the game, but wide evaluations will allow the design to be tailored to make it attractive to as many players possible.

7.3.2 Evaluate collaboration and interface

Most game evaluations examine the way in which play unfolds, and the sort of experience it creates. With augmented reality, there are unanswered questions about interface design and the way in which the technology affects behaviour. These factors affect game design, and should be evaluated, though a high level of rigor is not required. When building games with any new technology, a designer should expect to have to evaluate some elements of the technology itself, as well as their game.

7.3.3 Use rankings rather than ratings

Subjective experience is difficult to quantify, making comparison problematic. When ranking games, this problem is lessened, as players compare their experience internally without having to express it in numbers. This is likely to produce clearer results, particularly if players are asked to justify their rankings. This was held up by results from the evalation of AR Tankwar, where rankings showed effects much more clearly than ratings.

7.3.4 Technology effects

When evaluating games that use new technology, it is important to account for both the 'WOW!' effect and the extra time taken for players to become proficient with the game interface. Both effects are best dealt with by allowing players as much time as possible to get used to the game before asking them to rate their experience. The designer must ensure that they are evaluating the game rather than the technology.

7.3.5 Environment matters

The environment in which a game is played can affect play. Games should be evaluated in an environment similar to that in which they will eventually be played; if a game is to be played in a friendly, social environment, it

Table 7.1: Summary of guidelines

Process	
1	Understand desired game experience in advance
2	Evaluate frequently, keep design fluid
Game Design	
1	Balance use of technology against player comfort
2	Model time according to desired pace
3	Keep up to date with interface research
4	Encourage collaboration through challenges
5	Balance reality and virtuality
6	Employ coping strategies for tracking noise
7	Use abstract representations over realism
8	Rely on spatial and referential game states
9	Utilize emergence and simple designs
Evaluation	
1	Conduct wide evaluations
2	Evaluate collaboration and interface
3	Consider subjective evaluations carefully
4	Beware technology effects
5	Conduct evaluation in appropriate environment

should be evaluated in the same. If a game uses new technologies, this is particularly important, as it may expose problems of practicality that would not be present in the laboratory.

7.4 Summary

These guidelines were derived from the implications of the background presented in chapter three, the experience of designing AR Tankwar as described in chapter five, and the results of evaluations described in chapter six. If followed, they should help create a smoother design process, a more playable and enjoyable game, and more meaningful evaluations.

Chapter VIII

Conclusion

New technologies, such as augmented reality, offer new opportunities for game design, and there have been many projects that seek to exploit them to build new games. However, many of these projects have focused on the technical issues rather than game design. Chapter two presented a survey of technology driven games that illustrates this.

In this thesis, I have sought to redress this by focusing on the impact of augmented reality technology on game design, in particular of strategy games. With augmented reality, designers can build games that draw elements from traditional real world games and modern computer games. This is particularly clear in strategy games, where the strengths and limitations of both platforms are complementary. These were presented in depth in section 5.1.

We play games for the sake of enjoyment, and an understanding of it will help us build better games. Enjoyment can occur for many reasons; in games, it usually occurs when activity is engaging, social, and emotionally stimulating. To help understand engagement, section 3.2 described flow, a psychological framework for understanding feelings of intense experience created by engaging activities such as games. Social play relies on inter-player communication, which is inhibited or promoted by different game mediums. Section 3.3 presented a taxonomy of different types of communication in games, and suggested that as communication becomes harder, different types of messages disappear in a predictable fashion. Games can stimulate us in many ways; sections 3.4 and 3.5 presented two models describing the different ways in which this may occur. Finally, we are motivated to play games by several attitudes; these are described by a well known taxonomy presented in section 3.1.

When creating games in augmented reality, the designer must choose between several technologies for display and tracking. Section 4.1 contained an overview of the options and discusses important considerations. There are many ways to construct augmented reality user interfaces. Section 4.2 discussed interface design, with particular focus on interfaces suitable for use in strategy games. Finally, augmented reality is a promising medium for constructing collaborative applications, but it is not yet clear how it affects our behaviour. Section 4.3 discussed current knowledge about collaboration in augmented reality, and presented pertinent research results.

Game design cannot be understood from purely theoretical cogitation; it is important to actually design games, too. Chapter five presented AR Tankwar, a multi-player tabletop strategy game using augmented reality. Sections 5.2.2 and 5.2.3 presented the two versions of the game, while section 5.2.4 discussed its design. Finally, section 5.3 discussed the design process, in particular the approach of iterative design.

Evaluation of a game is necessary for several reasons; it informs the design process, and can determine whether design goals have been met. Within this thesis, the medium itself must also be examined, in order to understand how it affects the design of strategy games. Chapter six was dedicated to evaluation, and presented three evaluations with AR Tankwar in sections 6.3, 6.4, and 6.5.

Finally, chapter seven drew ideas from the preceding chapters together to present sixteen guidelines for augmented reality game design. These were organized into guidelines for the design process (section 7.1), guidelines for design (section 7.2), and guidelines for evaluation (section 7.3).

8.1 Future Work

AR Tankwar was only one of many possible strategy game designs. Appreciation of augmented reality's potential can only be obtained through more game designs. Research must continue not only into new interface devices, new infrastructures, and new ways to stimulate social play in games, but also into design, in order to learn how we can enhance play and enjoyment.

Before augmented reality games can become widely available, the expense of the hardware required for them must diminish. For head mounted displays, this will not occur without some sort of 'killer' application that is compelling enough to increase demand such that economies of scale can come into play. Alternatively, augmented reality systems that distribute their cost among many users are possible, for example in arcades and museums. For any of this to occur, entrepreneurs are needed.

8.2 Conclusion

Augmented reality offers a bright future for game design. Though today's systems are limited by expense, impracticality and perceptual difficulties, these problems will become insignificant in the face of advancing technology. When this finally occurs, we can look forward to a multitude of new game designs.

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Appendix A

Evaluation 2: Questionnaires

There was a single questionnaire for evaluation 2.

Questionnaire:

Thank you for trying AR Tankwar! Please answer a few questions about your experience. See below for how your answers will be used.

Please circle your response below.

Playing the game:

How easily could you control the game?

Hard	**1**	**2**	**3**	**4**	**5**	**Easy**

Could you easily tell what was going on?

Hard	**1**	**2**	**3**	**4**	**5**	**Easy**

Were you aware of the other player's actions?

Unaware	**1**	**2**	**3**	**4**	**5**	**Aware**

How comfortable were you while playing?

Uncomfortable	**1**	**2**	**3**	**4**	**5**	**Comfortable**

Did you feel disoriented at all after playing?

Not at all	**1**	**2**	**3**	**4**	**5**	**Definitely**

Opinions

Cost notwithstanding, how willing would you be to play multi-player tabletop games augmented using headsets?

Unwilling	**1**	**2**	**3**	**4**	**5**	**Willing**

Do you think this technology would be suitable to supplement or enhance

Miniatures games?	**Not at all**	**Maybe**	**Definitely**
Card games?	**Not at all**	**Maybe**	**Definitely**
Board games?	**Not at all**	**Maybe**	**Definitely**
RPGs?	**Not at all**	**Maybe**	**Definitely**

General Comments

Did you have any particular problems? Got any cool ideas or suggestions? Think it ruled? Think it sucked? Write on the back..

Thanks for your time. I hope you enjoyed playing. If you're interested in more information, write your email address on the list next to these questionnaires.

Appendix B

Evaluation 3: Questionnaires

There were three questionnaires for evaluation 3.

B.1 Demographics

Questionnaire - Demographics

Participant	

Please complete this questionnaire about your background and experience.

Age: ______________________________

Gender: Male Female

How much experience do you have with Augmented Reality?

None 1 2 3 4 5 Expert

How much experience do you have with table top war games and board games?

None 1 2 3 4 5 Expert

How much experience do you have with computer strategy games?

None 1 2 3 4 5 Expert

B.2 Game specific

We asked players to fill out this questionnaire once for each interface.

Questionnaire – Interface

Interface	
Participant	

User Experience

Please rate your experience playing this version of the game.

Not comfortable	1	2	3	4	5	6	7	Very comfortable
Not frustrating	1	2	3	4	5	6	7	Very frustrating
Not easy	1	2	3	4	5	6	7	Very easy
Not boring	1	2	3	4	5	6	7	Very boring
Not precise	1	2	3	4	5	6	7	Very precise
Not obvious	1	2	3	4	5	6	7	Very obvious
Not interesting	1	2	3	4	5	6	7	Very interesting
Not vague	1	2	3	4	5	6	7	Very vague
Not collaborative	1	2	3	4	5	6	7	Very collaborative
Not efficient	1	2	3	4	5	6	7	Very efficient
Not intuitive	1	2	3	4	5	6	7	Very intuitive
Not solitary	1	2	3	4	5	6	7	Very solitary
Not fun	1	2	3	4	5	6	7	Very fun
Not empowering	1	2	3	4	5	6	7	Very empowering
Not effective	1	2	3	4	5	6	7	Very effective
Not engaging	1	2	3	4	5	6	7	Very engaging
Not sociable	1	2	3	4	5	6	7	Very sociable
Not focused	1	2	3	4	5	6	7	Very focused
Not satisfying	1	2	3	4	5	6	7	Very satisfying
Not skilled	1	2	3	4	5	6	7	Very skilled
Not relaxing	1	2	3	4	5	6	7	Very relaxing

Please rate your agreement with the following statements about your experience playing this version of the game.

I felt anxious

Disagree 1 2 3 4 5 6 7 Agree

I felt involved with what was going on

Disagree 1 2 3 4 5 6 7 Agree

I understood clearly what I was supposed to do

Disagree 1 2 3 4 5 6 7 Agree

I could clearly understand my progress as I performed each task

Disagree 1 2 3 4 5 6 7 Agree

I felt that I could handle the demands of the tasks

Disagree 1 2 3 4 5 6 7 Agree

I had to make an effort to keep my mind on what was happening

Disagree 1 2 3 4 5 6 7 Agree

I would play, even if I didn't have to

Disagree 1 2 3 4 5 6 7 Agree

I was easily distracted

Disagree 1 2 3 4 5 6 7 Agree

I felt that time passed quickly

Disagree 1 2 3 4 5 6 7 Agree

User Interface

Please answer these questions about the user interface.

The user interface made me feel in control

Disagree 1 2 3 4 5 6 7 Agree

The interface was easy to use

Disagree 1 2 3 4 5 6 7 Agree

I could precisely control my units

Disagree 1 2 3 4 5 6 7 Agree

The user interface made me feel powerful

Disagree 1 2 3 4 5 6 7 Agree

Social play

During the game, you played with another person, both competitively and collaboratively. Please rate your agreement with the following statements about playing this version of the game socially.

We were able to collaborate efficiently

Disagree 1 2 3 4 5 6 7 Agree

It was difficult to talk about particular objects in the task

Disagree 1 2 3 4 5 6 7 Agree

I always knew what my partner was talking about

Disagree 1 2 3 4 5 6 7 Agree

I was always aware of where my partner was working

Disagree 1 2 3 4 5 6 7 Agree

I was always aware of what my partner was doing

Disagree 1 2 3 4 5 6 7 Agree

We could easily work together on tasks in the game

Disagree 1 2 3 4 5 6 7 Agree

We could communicate clearly

Disagree 1 2 3 4 5 6 7 Agree

Overall

How much did you enjoy playing this version of the game?

Not at all 1 2 3 4 5 6 7 Very much

B.3 Final

Final Questionnaire

Participant	

Please rank the three game versions by writing 1, 2 or 3 next to each. Please do not them as equal.

In order of which game was easiest to play

Tabletop		Augmented Reality		Desktop PC	

In order of which game was most engaging

Tabletop		Augmented Reality		Desktop PC	

In order of which game was most social

Tabletop		Augmented Reality		Desktop PC	

In order of which game was easiest to collaborate in

Tabletop		Augmented Reality		Desktop PC	

In order of which game was easiest to solve in-game problems

Tabletop		Augmented Reality		Desktop PC	

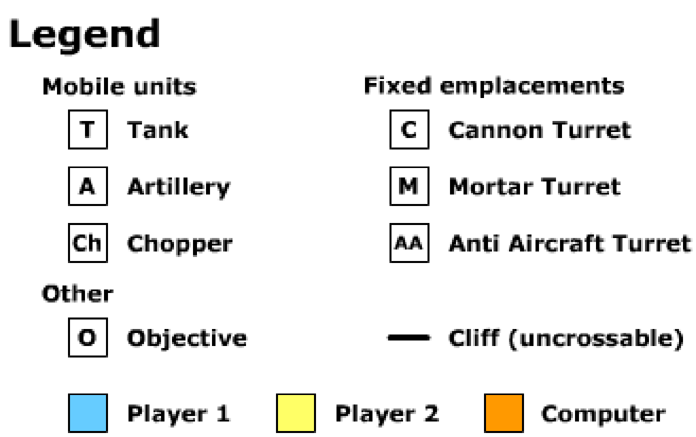
Overall

Tabletop		Augmented Reality		Desktop PC	

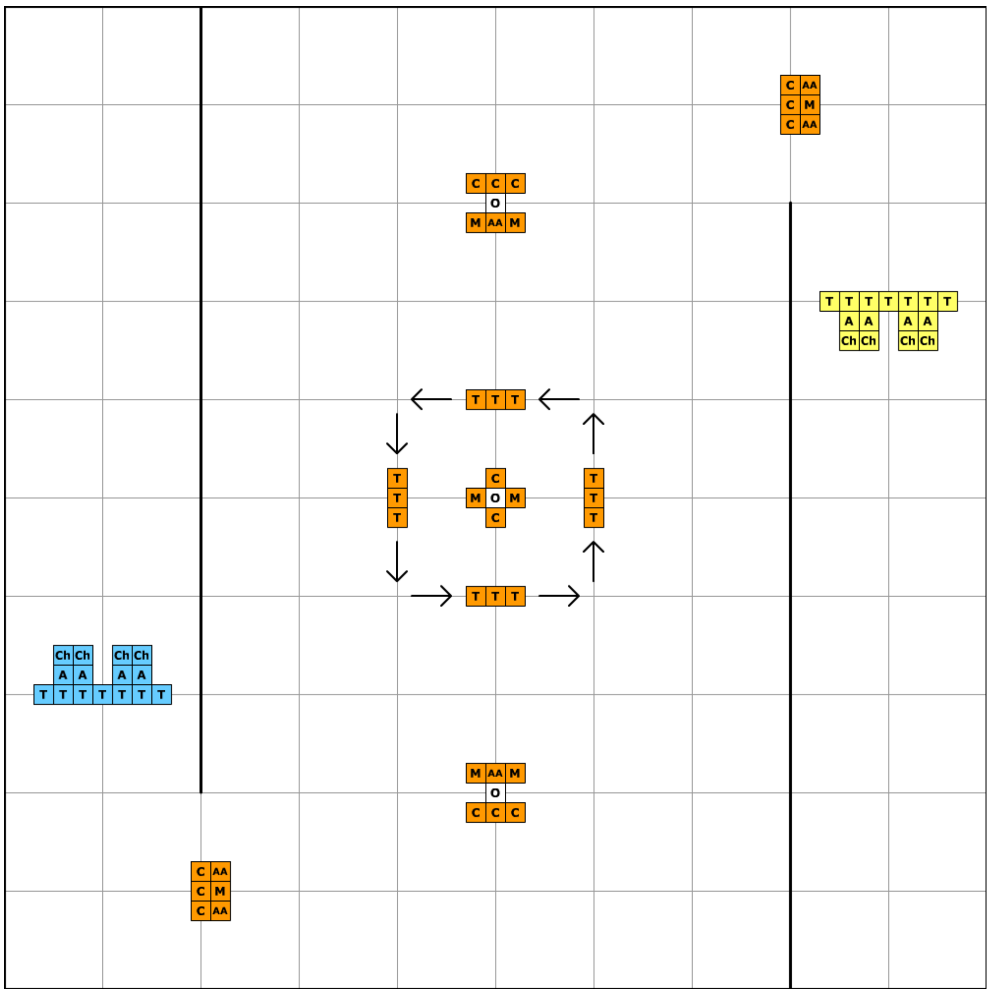
Appendix C

Evaluation 3: Scenarios

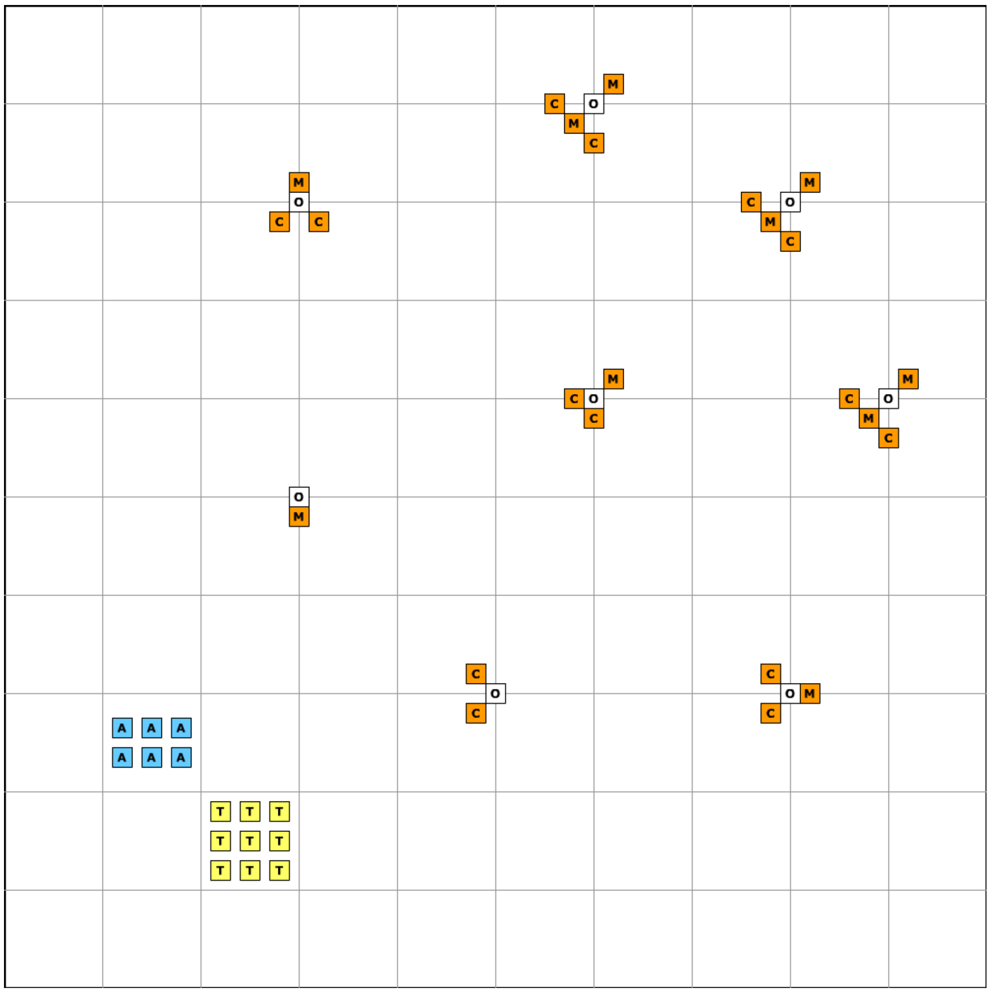
There were five experimental scenarios. Scenarios 1 through 4 were played alternately with the PC and augmented reality games. Scenario 5 was always played as a tabletop game. None of the five scenarios could be completed by a player on their own, but two players working together could do so successfully.



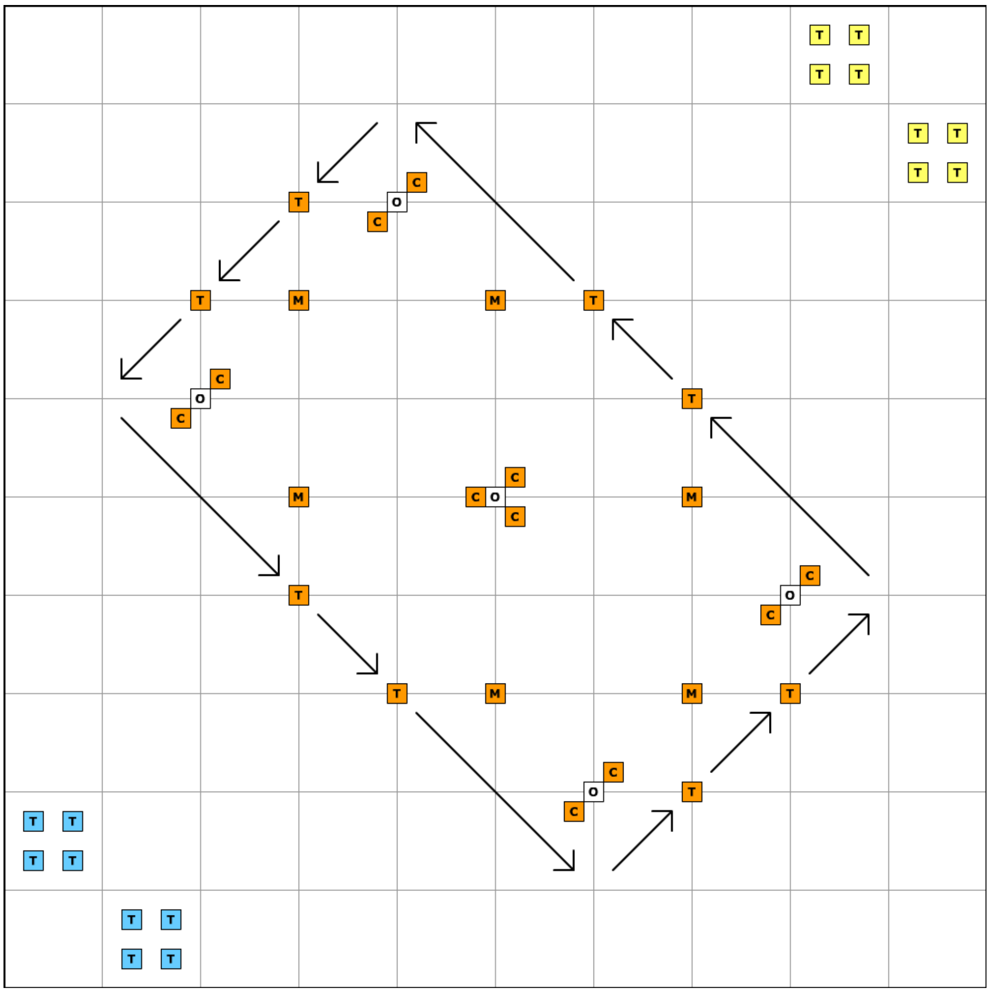
C.1 Scenario 1 (AR or PC)



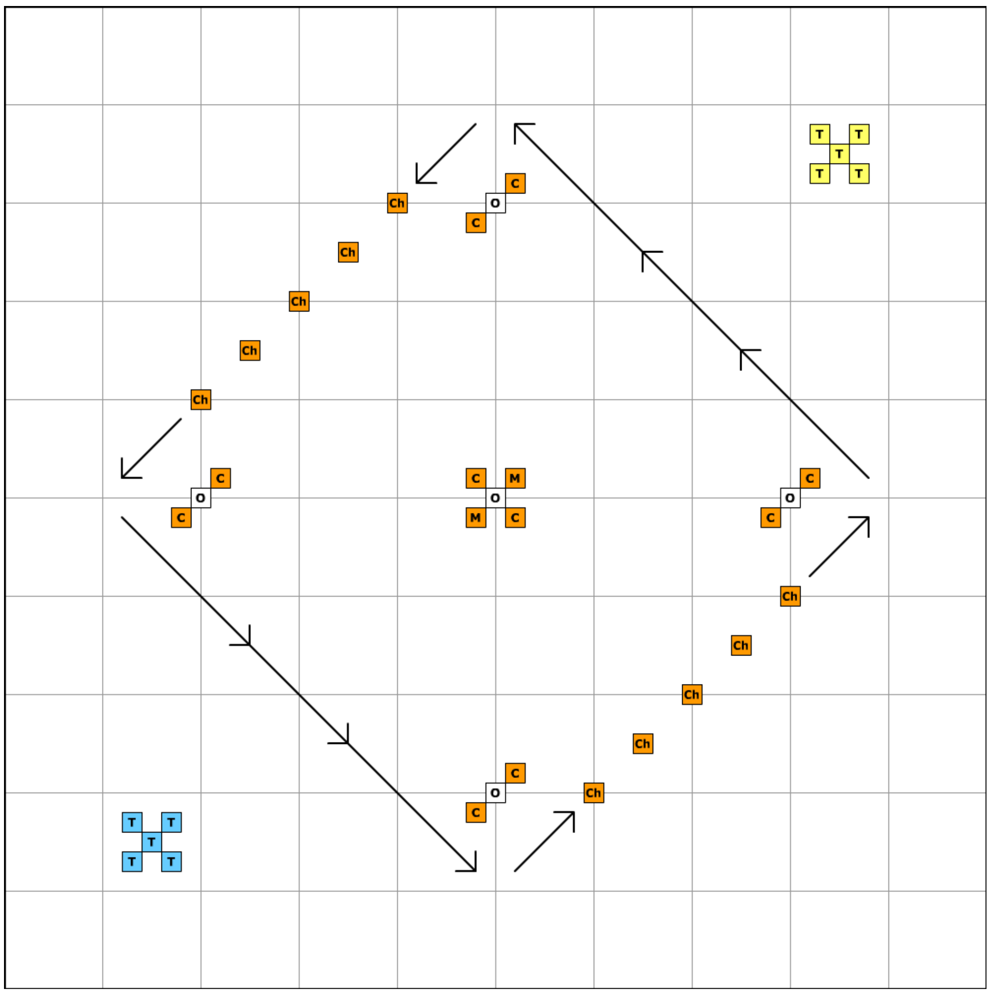
C.2 Scenario 2 (AR or PC)



C.3 Scenario 3 (AR or PC)



C.4 Scenario 4 (AR or PC)



C.5 Scenario 5 (Tabletop)