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## Gaming with augmented reality interface and quantum dot technology

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### Abstract

In Augmented Reality (AR), interfaces consist of a blend of both real and virtual content. In this paper we examine existing gaming styles played in the real world or on computers. We discuss the strengths and weaknesses of these mediums within an informal model of gaming experience split into four aspects; physical, mental, social and emotional. We find that their strengths are mostly complementary, and argue that games built in AR can blend them to enhance existing game styles and open up new ones. To illustrate these ideas, we present our work on Quantum AR Worms, a re-implementation of the classic Quantum Dot model with the computer game Worms using Augmented Reality. We discuss how AR has enabled us to start exploring interfaces for gaming, and present informal observations of players at several demonstrations. Finally, we present some ideas for AR games in the area of strategy and role playing games.

Augmented reality interfaces have proven valuable in many application areas. For example, using this technology doctors can see medical imagery superimposed over a patient's body, giving them a form of X-ray vision [2], archaeologists can see virtual reconstructions on historic sites [3], and engineers can see virtual overlays showing how to assemble machinery [4]. In these settings a user typically wears a head mounted display (HMD) with a camera attached so that they can see virtual imagery overlaid on live video of the real world.

**Keywords:** Quantum computation, quantum dots, nano-technology, augmented reality, mixed fantasy, games, collaboration, interaction

### 1. Introduction

Mixed Reality computer interfaces are those that combine content from the real world with virtual imagery [1]. Augmented Reality is a subset of this where virtual content is overlaid into a user's perspective of the world. The concept of AR extends to include virtual content from graphical, audio, and haptic sources, though our work focuses on graphical content.

Almost a decade ago, Milgram characterized Mixed Reality interfaces on his Reality – Virtuality Continuum (Figure 1) [1], where interfaces at one end provide completely real content, while those at the other use only virtual content. In between lie Augmented Reality (where virtual content is added to a real environment), and Augmented Virtuality (where real content is added to a virtual environment).

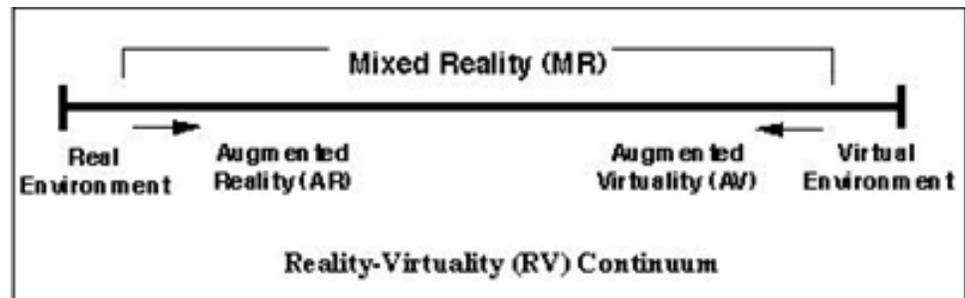


Fig 1: Milgram's Reality-Vitality Continuum [1]

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### 1.1 Mixed Fantasy

The Reality – Virtuality Continuum can be applied to entertainment applications as a means of describing a user's experience by showing the proportion of real and virtual content. Stapleton *et al.* [5] extend it by adding the participant's imagination as a third source of content. In games like role-playing, interactive drama, and children's games of make-believe, imaginative content plays a large role. In games where a player's experience comes from the establishment of an atmosphere, a large part of the perception of this atmosphere emerges from the player's imagination in response to other stimuli. For example, some first person shooter games attempt to establish a game atmosphere that affects a player's emotional state by the use of oppressive level design, foreboding music and game events designed to surprise the user.

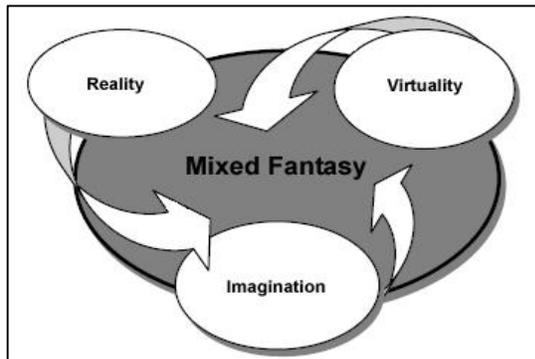


Fig 2: The Mixed Fantasy Triad [5]

Using the Mixed Fantasy Triad (Figure 2), we can characterize most real world games as using varying amounts of real and imaginative content (with limited virtual content in the form of illustrative text in some games) while most computer games are primarily a combination of virtual and imaginative content. Stapleton *et al.* [5] suggest that the best path to creating an interactive and immersive experience is to create games that use both real and virtual world content to stimulate the player such that their imagination fills in the gaps and they become truly immersed.

### 1.2 AR gaming

Immersion is only one way for players to enjoy a game. For the purposes of examining the possibilities of AR in gaming we characterize the experience of playing games as four aspects; physical, emotional, social, and mental. In this paper we examine real world and computer games using these criteria, and discuss the contribution that Augmented Reality can make. We find that while real world and computer games have different strengths in these areas, AR techniques can be used to produce games that utilize these strengths together. We demonstrate this with our game Hybrid AR Worms, our augmented reality version of the classic game Worms. Finally, we discuss our future research directions in terms of expanding Worms, building other games, and looking for ways to use the specific strengths of AR to build new and unique gaming styles.

## 2. Related Work

As mentioned in the introduction, the bulk of AR applications that have been developed in the industrial

space. However there have also been a number of examples of AR gaming interfaces. In this section we introduce a few of the more interesting systems that cover a range of ways AR can enhance gaming. In general these can be divided into single-user experience and collaborative systems.

### 2.1 Single User Experiences

One of the key characteristics of AR interfaces is the ability to overlay virtual information on an outdoor environment. The potential for this in gaming is shown by ARQuake [6], a well known adaptation of the popular first person shooter Quake. Using the Tinmith [7] outdoor AR system, players can navigate a Quake level by walking around in the real environment and shoot their enemies using a handheld plastic gun. The player's enemies appear as virtual characters superimposed over the real world. While the game requires the use of a bulky wearable computer, it demonstrates the ability of AR to merge normal outdoor games with computer games.

Geist [8] also explores outdoor gaming, but from a different direction. It focuses on narrative and an immersive atmosphere in a historical adventure game set in 17<sup>th</sup> century Germany. To do this, it uses the actual castle of Heidelberg as a play area. In the game, the castle becomes haunted by ghosts presented as disembodied voices and AR characters. Players explore the castle and interact with the characters to solve various adventure puzzles associated with them. Geist is a compelling example of creating an immersive environment using an interesting physical environment augmented with appropriate virtual content.

### 2.2 Collaborative Games

One of the first collaborative AR games, AR<sup>2</sup> Hockey [9], replicates the classic game of Air Hockey. Players at either end of a table use real paddles to hit a virtual puck back and forth. Despite the fact that it was missing haptic feedback players were able to play it as naturally as in the physical game.

The Shared Space interface [10] further explored collaborative gaming in a face to face setting. In this case 3-4 users stood around a table on which there were a number of cards. When players turned the cards over they saw virtual content popping out of the cards, and when they put matching pairs of cards together the content became animated. The virtual images are attached to real cards and so can be manipulated as easily as a real object. Thousands of people tried the system and found it very easy to interact with and a natural way to support collaborative gameplay.

Collaboration can also be between face to face and remote users. Human Pacman [11] is a more recent effort at outdoor gaming, and incorporates tangible interfaces and collaborative gaming between local and remote participants. Participants play as Pacmen or Ghosts navigating an outdoor gaming area. Ghosts hunt the Pacmen and devour them by touching them on the shoulder, while Pacmen collect points and ingredients for special cookies that allow them immunity or the opportunity to devour Ghosts. Players are supplemented by helpers at regular PC terminals who see an overview of the game and can pass on advice and other information to players in the field. Human Pacman is particularly successful in that it merges several interaction techniques into a single coherent game demonstrating the attractive features of AR and ubiquitous computing in games.

Collaboration is particularly important in small group settings. The STARS project <sup>[12]</sup> explores collaborative gaming in such groups. It consists of a software platform for augmenting board games with a hybrid user interface consisting of PDAs, a table imaging device, a touch sensitive wall display and headphones. STARS does not use HMD oriented augmented reality, however hybrid user interfaces offer great promise in collaborative gaming. By offering multiple interfaces with different affordances, they can accommodate diverse modes of face to face communication.

### 3. Motivations

Real world and computer games have their own distinct strengths. By allowing us to combine these strengths, we can use AR to improve existing game styles and produce new ones. For discussion, we consider a player's gaming experience as consisting of four parts; physical, social, mental and emotional.

Research into AR gaming serves another purpose beyond the improvement of gaming styles and the development of new ones, as gaming environments are well suited for exploratory research.

In this section we examine the strengths of real world and computer games, the role of AR in combining and extending them, and the value of gaming as an exploratory research area.

#### 3.1 Physical

A game's physical aspect includes the physical feeling of playing the game, the physical skills a player must use, and the game's use of physical artefacts. Examples of strongly physical games would be paintball, most sports, and skill based computer games.

Computer games are limited in their physical aspect to the player's use of interface hardware to play the game. While this does not prevent games focusing on physical skill, the range of physical interactions possible is limited. Further, computer games normally have no real way of affecting the player's environment so as to give physical feedback.

Real world games are often strongly physical. Players are free to use their whole bodies in games, and can affect each other physically. The game environment can be chosen to affect players, and may be used as a source of game content. This may include the use of a darkened physical maze to support a game of laser tag, or a playground to support children's games of fantasy. One limitation is that game designers and players have limited control over the physical environment, though this may be alleviated by the introduction of virtual content in AR.

Players are free to use physical artefacts both as playing pieces and as ad hoc props in play, and the physical skills used in playing games may include a player's ability to manipulate them. Finally, real world games allow direct physical competition.

Ideally, AR games could be physical to the same extent as real world games, with the added advantage that game content can be injected seamlessly into the real world. Current AR equipment is usually awkward and cabled – as technology is improved and becomes more of a consumer commodity, this will most likely cease to be a problem. Today's AR hardware cannot affect players physically, but there may be solutions in haptic feedback and other emerging technologies.

#### 3.2 Mental

The mental aspect of a game concerns problem solving, deductive thought and reason. Examples of strongly mental games are puzzles, resource management games, and strategic games.

Computers support complex game models, the simulation of real world systems, and large amounts of data, allowing much more sophisticated game scenarios. AI allows for solitary play against interesting opponents, and the creation of agents that can assist a player in learning and dealing with complex simulations. Finally, computers can aid players in visualising complex and detailed data. Essentially, computers improve mental games by allowing more complex games and by providing AI agents and opponents.

Real world mental games use more simple 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 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. A good example is the classic jigsaw puzzle, particularly 3D puzzles.

Games written for AR will naturally have access to the same resources for simulation and AI. Further, they will be able to present game information in a spatial context, which may allow players to reason about it better.

#### 3.3 Social

The social aspect of a game is the way in which players play with each other. It contains elements of collaboration, negotiation and relationship building. The classic example of a social game is the table top role playing game, but many massive multiplayer online games also have a strong social aspect.

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 beyond their own real world. The politics and economics of such a world provide a rich and immersive environment for social interaction. There are some advantages to the mediated nature of communication in computer games. By restricting all users equally, those who are disabled or isolated from regular social interaction can communicate on an equal footing with other players. Further, mediated communication hides much of a player's real world self, providing greater scope for the creation of virtual characters, and anonymity that can protect them 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 can use a wide range of cues to communicate, including vocal, gesture and gaze. 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.

Previous research <sup>[13]</sup> has shown that users of a collaborative AR interface exhibit the same behaviour as in normal face to

face conversation. Thus, participants in AR games should 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. One particular challenge is creating applications in which remote participants can collaborate to similar (or at least approaching) levels to those who are face to face.

**Table 1:** Summary of real world and computer game aspects.

	Physical	Mental	Social	Emotional		
<b>Real World</b>	- Can use player's whole body	- Players unwilling to resolve complex rules	- Supports natural face to face communication	- Can stimulate across senses	players	full range of
	- Real world can provide game environment	- Supports spatial reasoning, particularly 3D		- Limited ability to control environment	by	practical
	- Physical artefacts can have game significance					
<b>Computer</b>	- Physical interaction limited by input devices	- Supports complex game models and rules	- Mediation limits communication, but can provide other facilities	- Potential virtual environments and scenarios	for	diverse
		- Can provide AI opponents and agents	- Allows remote and massively multiplayer games	- Limited to audio and visual stimulation		

**3.4 Emotional Backgrounds**

The emotional aspect of games is perhaps the most difficult to understand. It concerns the way a game affects a player emotionally, by the sympathies they develop with game characters or players and the emotions brought forth by immersion in the game world.

Computer 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 can leave a player feeling jittery after playing. 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.

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. The classic example of entertainment that attempts to engage the emotions by real world experience is the theme park ride.

In the Mixed Fantasy Triad, Stapleton suggests that the best route to engaging a player's imagination lies through the provision of both physical and virtual content.

**3.5 Merging strengths with AR**

No game fits cleanly into any of these categories; most games are a combination of all four. While computers are a good medium for some areas and real world games for others, neither is ideally suited for many gaming genres. Augmented Reality's great strength is that it allows us to build games that take the best from both mediums.

To illustrate how AR may merge these strengths to solve the limitations of some current games, we present two short case studies, followed by our development 'Hybrid AR Worms'.

**3.5.1 Quantum Strategy gaming**

In table top war games, players pit armies of miniature models against each other in games of turn based strategy. Game conflict is resolved through a set of rules that usually calls for dice to randomize results, and decisions by consensus to resolve ambiguous situations. The resolution of these ambiguities can sometimes be contentious, particularly among younger players, and often leads to ill feelings and reduced enjoyment of the game. Thus it is desirable to eliminate these ambiguities where possible.

Sources of ambiguities may include issues of precise measurement, interpretation of game rules, and the exact location of miniatures on the table. Well-designed game rules can reduce the frequency of these situations, and ad hoc solutions (such as flipping a coin if neither side is willing to compromise) can help resolve them.

Another limitation of table top war games is the complexity of game rules. One of several motivations for war gamers is the desire to replicate historical scenarios with realistic looking units and terrain with realistically simulated rules of combat. As players must resolve all rules by hand, the rules must be simple, and thus they are quite abstract from the actual behaviour of units and weaponry on the battlefield. Incidentally, aside from the unsatisfying lack of realism, such rules simplification can lead to plainly ridiculous situations that contribute to player dissatisfaction.

In computerised war games, most of these problems do not exist; the game is precisely modelled so as to eliminate ambiguities, and the rules complexity is only limited by the dedication of the game developer. However, there are a different set of problems. War gaming has two essential elements that are missing in computer war games. Firstly, computer war gaming lacks support for the social aspect of traditional table top war gaming. Secondly, war gaming is both a hobby of gaming, and a hobby of modelling. Some players gain a great deal of satisfaction out of painstakingly assembling and painting an army. There is also a secondary social aspect to the hobby in that players compete in the authenticity or look of their army. War gaming competitions

frequently go hand in hand with model painting competitions.

In an AR enhanced war game, both sets of problems could be solved, though some compromise may be necessary. A suggested table top war game may use the player's miniatures as a tangible layer on top of a simulated game layer, or it may supplant them all together. The social aspect of game play is preserved through AR's superior support for face to face communication, ambiguities are eliminated (or reduced) by game simulation and additional visual and audio effects could be added. The game could be further enhanced by the use of AI players, and the addition of meta-game functionality (for example, loading, saving, recording, and analysing the game) could be added.

### 3.5.2 Role playing games (RPGs)

Role playing is a game of shared narrative in which players take on the roles of characters in a fictional world or scenario. It is different from improvised drama and 'live' role playing in that players do not act out the role of their characters; instead, they describe their character's actions within the context of the game scenario. One player is the game's referee or games master (GM), who manages all non-player characters, the game world, and the game's mechanics. Normally, the overall game plot is fabricated by the referee, but players have the opportunity to affect the course of the game to various degrees, depending on the style of play.

The best-known role-playing game is Dungeons & Dragons, in which the players play a team of adventurers in a world of heroic medieval fantasy. However, role playing games cover almost all conceivable fictional settings, including science fiction, horror, and modern political intrigue. In terms of the aspects of gaming described above, role playing games could be described as containing a mix of mental, social and emotional element. More complete introductions to role playing can be found on the web <sup>[14]</sup>.

Computer role playing games (CRPGs) have similar content to table top role playing, but the style of play is quite different. CRPGs usually focus on tactical combat, plot and character puzzles, and occasionally simple games of skill. Where table top role playing is a very personal and social game, the limitations of social interaction through the computer mean that CRPGs are usually solitary or played across a network with limited channels of communication. The strength of computers in role-playing games is in their use of graphics and audio for visualization, and their ability to handle complex game simulation and AI.

Real world RPGs can have several inadequacies. In a small group setting, players communicate face to face. While this is the most natural method of communication, it can impose two limitations. Firstly, players have no privacy in their communication – they cannot send secret messages without raising suspicion. Secondly, it is difficult to maintain a consistent understanding of the game world across all players. Situations arise where a player contends that they have performed an action, while other players contend that they have not. Such ambiguities are usually resolved fairly by the GM, but such occurrences interrupt the game, and can cause ill feelings.

Game consistency is also affected by the ability of the GM to describe the game world to players. Some GMs are master storytellers who can evoke convincing scenarios using language alone. However, such skills are rare, and

may still be insufficient to describe complex spatial scenarios. To solve this, some GMs use props such as miniatures and maps to describe situations. These may be sufficient for simple spatial layouts, but can introduce ambiguities as in strategy games.

Normally, the GM is involved in every game transaction, as well as managing the game's mechanics. Thus, their time and attention becomes a bottleneck. This can be alleviated by allowing players to resolve non contentious actions alone, and handling game mechanics in software.

Some of these inadequacies can be alleviated with support software. An early support package 'Dungeon Master's Assistant' included random encounter and treasure generators, along with dice rolling and data access tools <sup>[15]</sup>. Since then, support tools have grown to include random generators for worlds, maps, names, and even whole populations. However, since computers interfere with natural face to face communication, they are usually only used to assist an individual player, or behind the scenes during game planning.

Since AR allows the integration of virtual content with the real world at minimal cost to natural face to face communication, it is ideally placed to extend the use of support software to further alleviate these problems. In a hybrid AR RPG, each player might each have an interface device to manage their data (a PDA or tablet PC, for example). The game scenario could be laid out across the table between them in AR, allowing consistent visualisation, and much of the game's mechanics and simple action could be handled directly and immediately by software. The mechanical tasks taken care of, the players and GM can focus more on character interaction and game plot.

### 3.6 Gaming as research

As a side note, while we believe that gaming is a valid research area unto itself, it is also an attractive application domain for exploration of general interaction and collaborative behaviour. Players can be motivated to try out new methods of interaction with game content, and once cast in a gaming context, such exploration is often motivation enough. The creative and relaxed environment of gaming may also provide justification for researchers to explore beyond the directly applicable into areas they would not otherwise have considered. Finally, game applications have fewer constraints than industrial applications, and can thus be tailored around the limitations of a prototype or to focus on a particular point of study.

### 4. Worms

As an initial exploration of some of these ideas, we have developed an augmented reality adaptation of the classic computer game Worms. Worms was released in 1994 by Team 17 <sup>[16]</sup>, and has been re-released with incremental improvements every few years since. In it, players control a team of worms spread across a simple 2D landscape (expanded to 3D in a later version). Players take turns at using one of their worms to fire one of a variety of weapons at their opponent's worms. A player is eliminated when all their worms are dead.

The game supports multiple players, originally by taking turns at the keyboard, and later by network. Players can harm their own worms as well as their opponents, and the nature of the game's weapons is such that this is a common occurrence. At each turn, a player may execute one move

with a particular worm. With turns this short, players are encouraged to attempt spectacular moves with a high return. Unlike some adversarial games, players focus on eliminating each other in amusing ways rather than overall victory.

Worms requires a blend of strategy and physical skill to play successfully. It also encourages social interaction between players, as they try to persuade and distract the active player. Worms is a competitive game that is humorous, unpredictable, and can involve impressive displays of skill. It often attracts a supportive audience, whose members will often shout encouragement, suggestions, and otherwise verbally interact with participants. Despite its age, it remains popular.

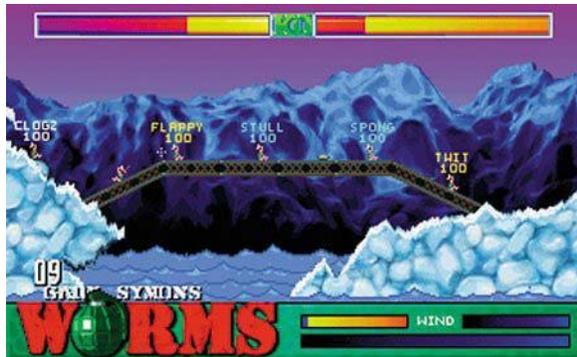


Fig 3: Original Worms (Team 17)

The combination of mental, physical and social entertainment makes Worms a good candidate for augmentation, and a good platform to explore our ideas. The general frivolous nature of the game and range of weaponry gives us justification to explore novel interaction ideas with few limits. Finally, Worms' attractiveness to spectators makes it a good game for exploring hybrid game interfaces that support spectators and participants in different roles.

#### 4.1 AR Worms

Our first version 'AR Worms' was developed by Steven Linton, Allister Cournane, Nilufar Baghaei and Kieran Molloy as a project for the Augmented Reality course taught at the University of Canterbury in 2003. AR Worms is implemented with the ARToolkit<sup>[17]</sup>, OpenGL, and OpenAL.

In AR Worms, the game area is a large table set up between players. Each player wears a head mounted display with an attached web camera. Video from the camera is merged with virtual content and displayed back to the user on their HMD.

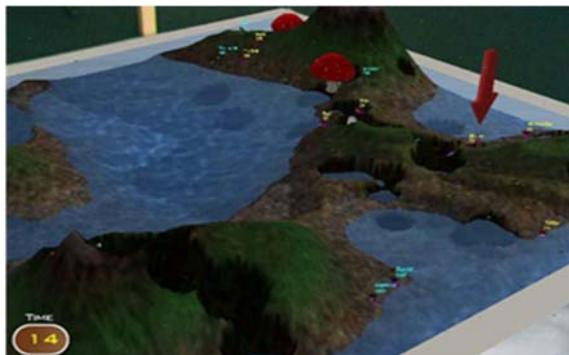


Fig 4: AR Worms

The game area is augmented with a deformable 3D terrain, with worms laid out randomly across it. Each worm has their name and health floating above them and a large red arrow is used to indicate the active worm. To control their worms, players use a wireless gamepad. We have implemented gaze selection; to select a worm or weapon a player looks directly at them on the table, and after a short time the selection is made.

In Worms, all projectile weapons are affected by the wind, which varies from turn to turn. To indicate this in AR Worms, we use leaf particles that float through the air between players in the appropriate speed and direction.

As well as AR, players can control their worms from a first person perspective by using a virtual reality mode. Players shift between these modes using a simple transition in which the real world fades and the camera descends to the level of the worm. If a player wishes to, they can also play the game from in front of the computer, though in this case they are restricted to VR mode or moving a camera in their hand (for a very limited AR mode).

Sound is provided by speakers set up around the game room, and includes a set of amusing voices provided by staff and students at the University of Canterbury.

#### 4.1.1 Observations

AR Worms was demonstrated at the HIT Lab's open day in October 2003 to a range of visitors including children, students, and various academics. It was demonstrated again at the end of year barbecue for the University of Canterbury's Department of Computer Science. No formal or informal user studies were done at either of these demonstrations, but observation of participants gave us various insights into its use, and future directions for research and development.

As we had expected, there were some limitations from the AR hardware in use. In particular, short cables prevented players from moving around the board, and the HMDs were not suitable for some younger players. However, these factors did not limit participant's enthusiasm – players were excited by the prospect of playing the game in AR, and were thus forgiving of these shortcomings. In particular, children seemed to have little trouble in picking up the rules and interface of the game, and were perhaps the most thorough and forgiving players.

We had some trouble with our marker tracking – players reported problems with disappearing or shifting content. This was expected, and was something that we had not had the time to eliminate. That said, some players were able to learn to hold their heads such that content remained mostly stationary. For the most part however this made it difficult for players to focus on game content. It also made gaze selection impossible to use, such that it was not demonstrated.

Players generally had trouble seeing small game pieces, such as worms and indicators for weapon direction and power. Coupled with the difficulties in focus, most players were unable to play the game effectively, and were limited to exploring the AR medium. Those few players with previous experience in AR were generally able to avoid some of these problems, and play the game quite effectively.



Fig 6: Hybrid AR Worms (AR mode)

## 4.2 Hybrid AR Worms

Most of the problems we observed in AR Worms seemed to be fixable. Thus, during January and February 2004, we redeveloped AR Worms, adding new features and fixes to alleviate some of the problems we'd observed. We also implemented two new interfaces; a PDA and a large screen game overview. This latest version was named called 'Hybrid AR Worms'.

We increased the size of the worm characters to make them easier to see, and implemented a zooming mechanism as a 'sniper scope' that appears in the centre of the player's view. We revisited gaze selection and improved the stability of our tracking, making it more practical to use.

Hybrid AR Worms has been extended to start exploring ideas of hybrid user interfaces to improve collaboration. We have implemented an alternate game interface using a PDA to control worms and view other game information (such as available weapons). We have also implemented a configurable overview screen made up from several panels including one that incorporates game statistics, as well as views of the game from different perspectives. This is displayed using a wall projector and lets spectators watch the game in progress. Different perspectives include views from each of the worms, a camera circling in the sky, and a camera that follows projectiles in flight.

Finally, we implemented various additional game effects – randomised terrain using several algorithms, 'crates' containing health and other bonuses, 'lego bridges', and various particle effects.

### 4.2.1 Observations

We demonstrated Hybrid AR Worms at the HIT Lab's Virtual Worlds Consortium meeting in February 2004. Once again, we observed various players with the game, and made some observations.

Spectators appreciated the overview projection. While we only had sufficient hardware for two players, the game area usually had at least 5 people around it, most of who were gathered around the projection screen. Both players and spectators particularly appreciated the projectile camera. We observed some interaction between spectators and players such as suggestions and encouragement.

The PDA interface proved a mixed success. It allowed players to more precisely control their worms, particularly in calibrating and aiming their shots. However, it was of very limited use to AR players, as the resolution of the cameras used was insufficient to read details on the PDA screen. Players also found it disconcerting to work with their hands, due to a displacement between their view with the

camera and their normal view with their eyes. As such, most users favoured the gamepad interface over the PDA.

We made some observations specific to playing Hybrid AR Worms in a demonstration context. Players were unwilling to wait between turns, and requesting a real time game in which players could both shoot at once. We also found that many players were more interested in the novel technology and game effects, rather than actually playing the game. This made it difficult to make good observations about player behaviour, and encourages us to try to evaluate users in a play situation.

Generally, the experience of playing Hybrid AR Worms was an improvement over AR Worms. Most marker tracking problems were resolved – players occasionally found that the game content swayed slightly, but it remained generally intact. The zoom interface was found to be useful in moving and shooting, and made the gaze selection reasonably usable.

Players continued to be enthusiastic about the game, and seemed on the whole to be better able to play it effectively. Problems remain to be addressed, and we hope to continue to address these in the future.

## 5. Future Work

In the future, we hope to further explore the merging of strengths through AR, initially through enhancements of our existing Hybrid AR Worms, and later through the development of other systems, perhaps following the lines of the case studies presented. We hope to integrate ongoing research in other areas of interaction within the HIT Lab into these projects, in particular work into Magic AR Lenses [18] and Hybrid AR interfaces.

In addition to enhancing existing game styles, we intend to explore the nature of interactions within AR to develop games that are uniquely suited to AR. Initially, we hope to explore tangible interactions within Worms. This will include novel weapons, such as air strikes where players drop a series of small markers onto the map representing bombs, weapons whose power is determined by audio input, and gesture based weapons (magic spells and the like; where more complex gestures create more impressive effects).

In re-developing Worms, we have moved towards more modular components with XML configurations. As part of our future work with AR worms, we hope to further develop it as an engine for creating AR games and applications.

## 6. Conclusion

We have presented the strengths and weaknesses of games in the real world and on computers using a simple scheme of interactive aspects; physical, social, mental and emotional. With the observation that most games combine factors from different aspects, we have described how the strengths of either medium are usually insufficient to fully support them, leading to problems of practicality, ambiguity and immersion.

To illustrate this, we have presented two case studies. Each discusses an existing game style that can be played with both mediums, the deficiencies of each medium, and the ways that AR could be used to solve these.

Our initial development was Hybrid AR Worms. We have presented its features, discussed some of the shortcomings that we are facing, and outlined some of our ambitions. Hybrid AR Worms has become an effective platform for the exploration of interaction and collaboration.

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