Pervasive Games: Bringing Computer Entertainment Back to the Real World

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This article gives an introduction and overview of the field of pervasive gaming, an emerging genre in which traditional, real-world games are augmented with computing functionality, or, depending on the perspective, purely virtual computer entertainment is brought back to the real world.
The field of pervasive games is diverse in the approaches and technologies used to create new and exciting gaming experiences that profit by the blend of real and virtual game elements. We explicitly look at the pervasive gaming sub-genres of smart toys, affective games, tabletop games, location- aware games, and augmented reality games, and discuss them in terms of their benefits and critical issues, as well as the relevant technology base.
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1. INTRODUCTION

In the precomputer age, games were designed and played out in the physical world with the use of real-world properties, such as physical objects, our sense of space, and spatial relations. Interactions in precomputer games consisted of two elements: human to physical-world interaction and human-to-human interaction. Nowadays, computer games have become a dominating form of entertainment due to their higher level of attractiveness to game players.

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Computer games have some advantages that make them more popular than traditional games. First, they attract people by creating the illusion of being immersed in an imaginative virtual world with computer graphics and sound [Amory and Naicker 1999]. Second, the goals of computer games are typically more interactive than that of traditional games, which brings players a stronger desire to win the game. Third, computer games, usually designed with an optimal level of information complexity, can easily provoke players' curiosity. Consequently, computer games intrinsically motivate players by bringing them more fantasy, challenge, and curiosity, which are the three main elements contributing the fun in games [Malone 1981].

However, the development of computer games has often decreased the users' physical activities and social interactions. Computer games focus the users' attention mainly on the computer screen or 2D/3D virtual environments, and players are bound to using keyboards, mice, and gamepads while gaming, thereby constraining interaction. To address this problem, there is a growing trend in today's games to bring more physical movement and social interaction into games while still utilizing the benefits of computing and graphical systems. Thus, the real- world is coming back to computer entertainment with a new gaming genre, referred to as *pervasive games*, stressing the pervasive and ubiquitous nature of these games: Pervasive games are no longer confined to the virtual domain of the computer, but integrate the physical and social aspects of the real world.

2. PERVASIVE GAMING GENRES

Despite the nascency of the field, we can already identify several unique types of pervasive games, each setting the focus on different aspects of the gaming experience. In the following sections, we briefly discuss each of these genres and present some of their prominent representatives. We do not claim that either of the proposed game genres or the examples discussed are the ultimate realization of pervasive games, but they should give the uninitiated reader an idea of the scope and diversity of this exciting and emerging field.

2.1 Smart Toys

Augmenting traditional toys with pervasive computing technology is a first, and not necessarily complicated, step towards the realization of pervasive games.

*Due to their shapes or forms, toys might suggest in which ways they should be played with*but in contrast to games, they are not bound by any rules or limitations on their use. Thus, they are the perfect means by which to explore the effects that the integration of pervasive computing technologies have on the way the toys are used, and on the ensuing gaming experiences that might emerge.

Most current realizations include traditional physical toys equipped with simple sensing technology linked to computer logic. The logic reacts to changes in the toy's physical state by either playing sounds or displaying graphical information, if the toy is connected to a personal computer. A corresponding computer application might also be used for digital storytelling, encouraging children to use the toy in one way or another.

2.1.1 *Zowie Playsets*. Zowie playsets are a commercially successful foray into the field of smart toys [Shwe 1999]. Zowie playsets consist of a physical toy with movable pieces (see Figure 1) accompanied by a CD-ROM and a serial connection to a PC.

Fig. 1. A Zowie smart toy.

The toy has integrated sensors that transmit the state of the playing pieces to the computer application. The computer application was crafted after scientific studies with children and offers several modes of play (Discovery and Exploration Play, Hands-On Active Play, Problem-Solving Play), each fostering different aspects of the children's development.

The exact sensing technology used by Zowie toys is not publicly available; but in general, it consists of a portfolio of patented sensing and recognition technologies that track the 3D motion and rotation of pieces. Objects are tagged with a small piece of technology and are tracked by an antenna embedded in the toy.

2.1.2 *Story Toy*. A rather similar approach to the Zowie playsets was recently presented by Fontijn and Mendels [2005]. The StoryToy is a storytelling environment that uses an audio replay engine in conjunction with a tactile user interface based on a sensor network. The tactile interface consists of an animal farm with a multitude of animals as actors.

In contrast to the Zowie playsets, no computer display is necessary to enjoy the various stories and games that come with the animal farm. The authors conducted a study to test the toy on children between the ages of two to six. The study demonstrated that audio feedback alone already creates an enjoyable level of interactivity, in addition to the traditional free play that the toy provides. Given the reluctance of many parents to expose their young children to computer displays, it appears to be a promising approach to use unobtrusive audio signals as a primary interface instead of traditional interaction with graphical user interfaces.

2.1.3 *SenToy.* Höök et al. [2003] present an interesting affective control toy, named SenToy, used to control a synthetic character in the computer game, FantasyA. SenToy is a doll wirelessly connected to a PC. It allows players to influence the emotions of a synthetic character in FantasyA. Via SenToy, by using gestures associated with anger, fear, surprise, sadness, and joy, players influence the emotions of the characters they control in the game.

The toy's hardware is well designed; sensors include two magnetic switches that detect the motion of putting hands in front of eyes. To detect walking, force-sensing resistors are used in the legs, together with a plastic structure that allows the detection of bending leg movements. Accelerometers in the torso of the doll are used to detect all movements, and provide a measure of the acceleration in one or two axes.

Indeed, in a related study, the intuitive expression of emotions via a set of body gestures is shown to work. Hence SenToy is a welcome application of pervasive computing technology that abrogates the necessity of verbalizing emotional states.

2.2 Affective Gaming

One of the goals of pervasive computing is to create context-aware applications that will adapt their behavior to information collected from the environment [Abowd and Mynatt 2000]. The same is true for pervasive games. The *who* and *where* of a players' context has been harnessed in some location-based pervasive games (see Section 2.4), while the *what* and *when* are common elements of most traditional games. Capturing *how* a player is feeling at any given moment and integrating this very personal representation of context into a game is the goal of affective gaming.

Affective computing [Picard 1997] is described as "computing that relates to, arises from, or deliberately influences emotions," and affective gaming aims to integrate a player's emotional state into the game so that the game environment can adapt to create a magical game experience. Sensing an individual's emotional state is a complex and open research problem; but sensing certain aspects of a player's experience while engaged in entertainment technologies is more manageable [Mandryk and Inkpen 2004]. The most common approach to sensing an affective state is via sensors that measure the user's changing physiological activity. Skin surface sensors like those that measure galvanic skin response, or activity in the cardiovascular, respiratory, and muscular systems can accurately measure physiological activity. But many users could perceive them as invasive. Although they may be less accurate than surface sensors, they can also be built into the environment by, for instance, embedding them in a chair [Anttonen and Surakka 2005] or in a game controller [Sykes and Brown 2003], so that users can interact very naturally with their entertainment technologies. Other methods for measuring affective states include thermal cameras [Puri et al. 200], voice analysis, or facial expression analysis.

2.2.1 *Utilizing Affect in a Game Environment.* Once a player's affective state has been sensed, it can be used to inject "personality" into a gaming environment, resulting in an environment that meaningfully responds to a player's context rather than to preconceived gaming challenges [Mandryk and Stanley 2004].

A preliminary example of this approach is given in S.M.A.R.T Braingames [http://www.smartbraingames.com/]. Braingames uses real video games played on a Sony Playstation™ integrated with NASA technology. The system determines whether the user is in the desired brain state by using brain waves measured by an EEG, and adjusts accordingly. If the user maintains the desired brain state, he or she gains full control of the game controller. If not, the speed and steering control decrease. Basically, as the player maintains focus, the game responds, and when the player loses focus, ground is lost. This particular game was developed to train patients to achieve a desired

Fig. 2. Brainball: players' EEG signals control the movement of a physical ball on a table.

brain state, and not as a source of fun in itself. Researchers tested this game environment against a traditional biofeedback training environment and found no difference between the two systems in terms of performance, but found that both parents and children preferred using the video game system. The principle used in this game can also be used to develop games that dynamically respond to how the player is feeling in order to create a more engaging experience. Along these lines, Gilleade and Allanson [2003] created a software development kit (SDK) that, by means of monitoring the player's physiological condition and integrating this information into an appropriate game environment, allows the interactions between man and machine to become dynamic entities during play.

2.2.2 *Physiology as Direct Input*. Instead of using a player's context to manipulate the game environment, one could use it as a direct and natural input to a game. For example, Brainball [Hjelm 2003] is a game where brain waves (from EEG) are used to alter the direction in which a physical ball rolls on a physical table. Players sit across from each other and must relax to make the ball move towards the opponent.

AffQuake (http://affect.media.mit.edu/projects.php?id=180) alters game play in the popular Quake first-person shooter game via the player's galvanic skin response, sensed through metal contacts on the hands or feet. In AffQuake, when a player is startled, the player's avatar is also startled and jumps back. AffQuake also relates the size of the player's avatar to the player's arousal. In Relax To Win [Bersak et al. 2001], a player controls the speed of a racing dragon via galvanic skin response. As a player relaxes, the dragon moves faster. This was also the principle behind a commercially unsuccessful car racing game released by Human Engineered Software and promoted by Leonard Nimoy.

These are relatively simple instantiations of using a physiological signal as an explicit input to a game environment. Affective gaming is a very young research area, and there is a lot of fertile ground to explore. When affective game techniques are combined with traditional input techniques or other pervasive game elements, the possibilities for an engaging, contextually- aware game system are endless.

2.3 Augmented Tabletop Games

While affective games mainly focus on using physiological state parameters to exchange information with virtual game elements, augmented tabletop games also integrate the states of players as central to the gaming experience. Augmented tabletop games do not serve as an input to the virtual game logic alone, but also add the richness of the social situation to the virtual domain. Traditional tabletop games such as Chess or Go have been popular for thousands of years; they are still going strong today, despite the arrival of attractive computer entertainment technology. Their continuing success can clearly be attributed to the direct interaction and communication between the players, who sit together around the same table, facing each other at an intimate distance. A dense social situation is stimulated by close face-to-face interaction that integrates discussion, laughter, and all kinds of nonverbal communication hints that are integral elements of Poker-like tabletop games.

While the social aspects of traditional tabletop games render them interesting enough in their own right, the static nature of their traditional game media limits the scope of realizable games. The lack of computing technology necessary for multi-sensual stimulation with audio and visuals or smart and proactive behaviors hinders the realization of many believable and immersive game concepts.

Complementarily, many claim that the drawback to traditional computer games is the lack of social interaction in a face-to-face setting, which tabletop games provide. At the same time, computer games offer the attractions of computer technology, which tabletop games lack. Therefore, it is only a natural evolution to combine the benefits of computer and tabletop games into a novel type of augmented tabletop game that sets out to provide new and engaging gaming experiences.

2.3.1 *The STARS Platform*. One of the more elaborated platforms in the field of augmented tabletop games is called STARS [Magerkurth et al. 2004]. It consists of a dedicated hardware setup of devices such as public vertical displays and personal digital assistants (PDAs) centered on a smart interactive table. The STARS hardware is based on so-called Roomware components]Streitz et al. 2001], which are room elements unobtrusively augmented with information technology.

The actual gaming applications are built on top of a STARS software layer that frees the developer from anticipating the exact set of input devices during a game session and provides functionality for creating user interfaces, administering players, and so on.
The central component of each STARS game is an interactive game table (see Fig. 33), on which the respective game boards are displayed. Currently, the table is an InteracTable Roomware component [Streitz et al. 2001] with a touch-sensitive display set into its horizontal surface. Physical playing pieces provide a tangible interface that feels similar to the interface of traditional board games. The playing pieces are detected by an overhead camera that also determines the positions of the players by tracking their hands as they reach over the table's surface. Additionally, an integrated RF-ID antenna detects

Fig. 3. The STARS tabletop platform.

physical tokens placed on the table surface, which allows integration of arbitrary game artifacts such as wands, potions, or gems, and hence sensed by the game logic.

We avoid computer interfaces that involve mice, keyboards, or desktop monitors to ensure that the user experience remains human-centered and socially supportive. Playing pieces remain the primary interaction devices during game-play because they provide the most natural interface to a board game. The displayed game boards are superior to the static nature of traditional physical media. These visually impressive boards change dynamically as the game progresses. The problem of positions and viewing angles in traditional tabletop games (someone on the left side of the table sees a different image than someone at the opposite, right side) is tackled by a sophisticated auto-rotation board instead of an abstract, unoriented one. From any viewing angle, playing pieces look mostly the same. The system can rotate any object on the game board to the angle from which the current player can see the best.

So far, several games have been implemented on the STARS platform. For instance, the role-playing game KnightMage (see Figure 3) deals with the exploration of a dungeon filled with treasure, equipment, and, most important, monsters. In the game, players must cooperate to survive against the monsters in the dungeon, but at the same time compete for individual riches. The combination of competitive and cooperative play is also frequently found in traditional board games like Risk, which exploits the social richness of face-to-face gaming. Demonstrating its platform, with its dynamically changing large game boards, is KnightMage's primary focus.

2.3.2 *False Prophets*. False Prophets is a hybrid board-video game system designed to enhance player interaction [Mandryk et al. 2002]. Its development was motivated by the various properties of board and computer games: board games are mobile, highly interactive, provide a nonoriented interface, and allow for a dynamic number of players and house rules. They are also limited to a fairly static environment, don't allow players to save the game state, and have simple scoring rules. On the other hand, computer games provide complex simulations, impartial judging, evolving environments, suspension of disbelief, and the ability to save game state. But computer games often support interaction with the system, rather than with other players. Even in a colocated environment, players sit side-by-side and interact with each other through the interface. Consequently, the goal of developing the False Prophets hybrid game system was to leverage the advantages of both of these mediums, encouraging interaction between the players.

In False Prophets, players use tangible pieces to move around a digital game board projected onto a touch-sensitive table. The playing pieces are equipped with a button for simple game operations, while more complex interactions and private information are managed through a hand-held computer. Players move their tokens around a dynamic game board, gathering clues from the environment and observing the characteristics of the other players. The physical distance between the player tokens impacts the level of digital information "observed" by the player. For example, from a distance, a player might be able to tell that his opponent is tall, while up close the player can see fine-grained characteristics such as tattoos and freckles. By synthesizing all of this digital information, the players try to determine who are their friends and who their enemies. This unique game environment has the computational advantages of a computer game environment, while still supporting interpersonal interactions. In addition, it allows for the development of novel game elements that couldn't exist with either of the traditional game technologies.

2.3.3 *Smart Jigsaw Puzzle*. Another interesting research prototype was presented by Jürgen Bohn from ETH Zürich [2004]. The smart jigsaw puzzle is a hybrid tabletop game that augments the physical pieces of a jigsaw puzzle with RFID tags. The underlying RFID reader technology is linked to a PC application that demonstrates a virtual representation of the jigsaw puzzle's physical state. By using calm RFID technology, the smart jigsaw puzzle preserves the original qualities of the game, namely robustness and social compatibility. The augmented game is robust in the sense that even if the computer or RFID hardware should fail or be temporarily unavailable, the augmented puzzle can still be played in the traditional way.

2.4 Location-Aware Games

While augmented tabletop games utilize pervasive computing technology to enrich physical game boards, another popular approach in the pervasive gaming field is to regard the entire world, the architecture we live in, as a game board. Technically, it is quite feasible to identify and track the positions of passive physical playing pieces on a Handy game board. When an entire building, a block, or even a city becomes the game board and the human players themselves become the proactive and highly unpredictable playing pieces, a host of technical and conceptual challenges arise.

Technically, a player's position in a location-aware game is either determined by GPS satellite signals, WiFi, or GSM signal strength and/ or cell ID, or by using short range proximity-sensing technologies such as RFID, infrared beacons, or ultrasonic emitters. Some of the earliest location-aware games were implemented using short-range proximity sensors.

Björk et al. [2001] provided one of the earlier examples that describe the world as a game board. In Pirates! players move around in the physical domain and are presented with location-dependent games on mobile computers they carry with them. Even though actual game-play takes place on ordinary PDAs, the context of the players' location is nicely integrated in the overall concept of the game. Each PDA resembles a pirate ship, and several locations in the physical world are associated with islands the players can visit and experience via games on their PDAs. In contrast to recent pervasive games played outdoors, Pirates is an indoor game with a relatively small playing field, from which only a few key locations need to be identified. So positioning is simply via short-range radio frequency (RF) proximity sensors, which works appropriately given the affordances of the game.

Due to the necessity for a corresponding infrastructure, short-range proximity sensors are not ideal for implementing pervasive games; thus GPS and WiFi form the basis of most recent location-aware games. Given the massive market penetration of mobile phones, GSM cell-based games will probably become more prominent in the future. The Swedish company It's Alive is already offering two location-based pervasive games that perform positioning via GSM cell identifications at http://www.itsalive.com/.

GPS signal reception does not work indoors, and is only moderately accurate outdoors; but it allows us to cover a large playing field (the entire planet). Since GPS does not provide arbitrary means of communication, it is usually necessary to set up an additional communication channel using WiFi, peer-to-peer technologies such as IrDA or Bluetooth, or GPRS /UMTS-based data transfer.

WiFi can be used to exchange arbitrary data between players and to locate clients, both indoors and outdoors by using signal-strength measurement. While data exchange normally works fine for a radius of a few dozen meters, even through walls and other obstacles, positioning using triangulation requires an appropriate infrastructure and a careful layout of stationary WiFi access points. Many pragmatic (not only technical) problems encountered in setting up a pervasive game in a building, based on WiFi triangulation for locating players, are described in “The Drop” (Ian Smith et. al.) in this issue of ACM CiE.

Benford et al. [2005] also describe the significant issues relevant to large-scale pervasive games. Among them is the problem of dealing with uncertainty in sensing and wireless communications. Naturally, it can be very harmful to a pervasive game if communication between players or the virtual representation of the game fails. Positioning the players might work more or less reliably and accurately, up to the point where the inaccuracy becomes intolerable. One could either work to improve the technical robustness of the system to ensure an appropriate gaming experience, or, if this is not possible, tailor the game around the technical shortcomings and make them part of the actual gaming experience.

A nice example of a game that successfully manages to deal with a limited radius of 802.11b hotspots is called Treasure, developed by Chalmers et al. [2005].

2.4.1 *Treasure.* Treasure is a pervasive multiplayer game played on an outdoor area of several thousand square meters. The game revolves around collecting virtual coins that are hidden in the game area. Players are equipped with a combination of GPS and 802.11b hand-held computers and learn about the positions of the coins on their PDA displays. When they approach the corresponding physical locations of the coins, they can pick them up and later score for “uploading” them to a server. What makes the game special is the notion of *seamful* gaming (alluding to Mark Weiser, a pioneer in the pervasive computing area, and to his term, i.e., *seamless interaction*). A key aspect in pervasive computing is the seamless integration of technology into our everyday lives. However, since Wifi coverage in the Treasure game is not constantly available throughout the entire playing field, there are seams between the areas with and without WiFi coverage. Instead of trying to disguise the seams, they are made central components of the game-play. (Players hide in the shadows of the missing connectivity, and strike other connected players by sneaking up on them and “stealing” their coins when the thieves suddenly enter their WiFi connected area.)

It is also possible to combine gaming in the real world with traditional online computer game-play via screens and keyboards. The artists group, Blast Theory, and the Mixed Reality Lab at the University of Nottingham have been working successfully on several titles that mix street and online players into a unique blend of traditional and pervasive computer gaming.

2.4.2 *Can You See Me Now*? CYSMN combines pervasive gaming action in a real part of a city with online game-play in a virtual model of the game area. In real streets, runners equipped with GPS and 802.11b WiFi run around to catch the online players that move through the virtual representations of the streets. The real runners have their own positions and those of online players permanently displayed on hand-held computers, and additionally, use walkie-talkies to coordinate their movements to catch the online players. The online players, at their home computers, are connected to the game via the Internet, and listen in on the runners' walkie-talkies via streamed audio. Thereby the online players get to know the conditions and experiences on the real streets, and can react accordingly. Text messages can be exchanged to coordinate with other online players, in turn the messages can be delivered to the runners in the streets, so that an exciting atmosphere of mutual exchange of vital information emerges.

CYSMN is a great example of the creation of entirely new and engaging gaming experiences based on a tried and tested simple game idea (i.e., CYSMN is essentially a game of catch). Several user studies have been conducted to research the mutual effects of online and pervasive gaming in CYSMN [Flintham et al. 2003].

2.4.3 *Uncle Roy All Around You.* URAAY is a successor to CYSMN, created by the same team [Benford et al. 2004]. While CYSMN managed to mix online and physical gamers, URAAY picks up the concept of these two domains. But it also integrates more aspects of the real world into the game mechanics. In particular, physical players remain constantly uncertain about which parts of the real environment are actual parts of the game. For instance, through communication with online players or the game itself, players in the streets receive hints such as the gender or color of other important persons in their vicinity, effectively integrating passers-by into the action. The story is about finding, somewhere in a city, a mysterious character known as Uncle Roy, with the physical players searching the streets. They are supported by online players who track their progress and aid them with hints about the way to Uncle Roy (see Figure 4).

2.4.4 *Catch the Flag*. In an augmented twist on the popular traditional game [Xu et al. 2003], smart phones are used as the main interface, enabling physical role-play, as players are n ot confined to desktop computers. Players can move about freely in the real world over wide-area outdoor spaces, while maintaining seamless real-time networked contact with other players in both the real and virtual worlds. The movements of players in the real world are tracked and represented in the virtual world. CTF explores novel, tangibleaspects of human physical movement and perception, both on the player's environment and on the interaction with the digital world.

Fig. 4. An online player in Uncle Roy All Around You.

The conventional Capture-the-Flag is a popular outdoor game for children. In the mixed-reality version, each team has at least one knight and one guide, as well as other entities including bombs, traps, flags, magic potions and castles. Throughout the game, guides use a desktop application to assist allied knights by giving guidelines and setting magic potions, which for a short period can turn knights into warriors, as well as catch opponent knights by setting traps.

Knights navigate and receive guidelines through a smartphone, and can catch the opponent's flag by acquiring the Bluetooth object representing the flag in the real world. Any team that can safely bring the opponent's flag to its base wins the game.

2.5 Augmented Reality Games

Perhaps the most technically advanced pervasive games use augmented reality techniques as a basis. Augmented reality is a variation on virtual reality that draws virtual objects into a real-world environment. Users see their view augmented with 3D objects registered such that they appear to exist in real space. Though augmented reality can be created with a range of different technologies, there are three general approaches appropriate for gaming.

- *Using head-mounted displays*: In video see-through augmented reality, users see virtual objects along with video of the real world taken from a camera mounted on their headsets. Thus, their views of the real world are mediated. In optical see-through augmented reality, the computer-drawn imagery is combined optically, so users see the real world without mediation. However, problems with occlusion now become apparent.
- *Using images projected on real-world surfaces*: This approach is limited by its inability to display 3D content and individual perspectives. Further, interaction between projector and display surface obscures the image, and spoils the effect.
- *Using hand-held devices*: Users hold a lightweight display device with attached camera, while images from the camera are combined with virtual content and presented on the device, producing a "window into augmented space."

Augmented reality technologies are becoming mature; although such technical considerations are outside the scope of this article. Key areas of technical research in augmented reality are tracking and registration, error reduction and stability, display systems, and the development of effective interaction metaphors.

2.5.1 *The Characteristics of AR Games*. There are several characteristics that differentiate AR games from other types of pervasive games.

As in real world meetings, the social space through which users communicate is aligned with the task space where they interact. Further, the task space is enhanced by a visualization space where information may be presented. This allows users to communicate face to face, while working with objects and viewing content, all with reduced context-switching.

Augmented reality systems strive to track a user's full range of motion. This allows games to use a wide range of physical interactions, including location, gestures, and posture. Physical objects may also be tracked, allowing the use of props, sporting equipment, and more. A limitation of the current technology is that while physical objects may affect virtual objects, it is more difficult to affect physical objects with virtual ones.

In augmented reality, players are not immersed in virtual content, rather, virtual elements are added to the real world. Since players are mobile during play, the real-world environment can provide play areas and affect players in ways impossible for computer games

Augmented reality has the potential to hit the sweet-spot in Stapleton's Mixed Fantasy Triad. It posits that the ideal entertainment experience comes from the combination of physical experience, virtual content, storytelling, and the imagination of the user. Augmented reality offers both physical and virtual aspects, leaving creative designers to stimulate the imagination [Stapleton et al. 2002].

The development of augmented reality games is in its early stages. Many early systems are simple affairs that focus on the technology rather than on game design. However, they offer a foundation to build on. More recent games have focused on increased complexity, the application of ideas from real- world and digital games, and the interaction between physical and virtual objects. The field is now at a point where the technology is becoming stable, and novel game designs are beginning to appear.

2.5.2 *AR² Hockey* is an early attempt at a physical AR interface. It implemented a version of the classic arcade game, that is, air hockey with a difference. In it, players wield tracked physical paddles, but the puck is virtual. While the project's intent was to demonstrate technology, it can serve to illustrate the possibility of new game features. Suggestions include virtual targets for point scoring and game modification (similar to the classic "Arkanoid" games).

PingPongPlus [Ishii et al. 1999] is another game along similar lines. In it, the ball remains physical, but the system tracks its movement and presents visual effects on the game table using a projector.

Various game modifications similar to AR² Hockey, such as AquaGauntlet (www.mr-system.com/project/aquagauntlet/) were proposed. They demonstrated the use of player posture as input. The players wield a virtual weapon and shield to protect themselves against swarming virtual sea creatures. To aim, fire, and activate their shields, players change their postures. In addition they can move around the game environment (a large room) by moving physically. Players were augmented with a virtual helmet and weapon, conveniently hiding the head-mounted display and other hardware. Game design is comparatively simple but effective.

2.5.3 *ARQuake*. The ARQuake project demonstrates the use of an outdoor augmented reality system for gaming [Piekarski and Thomas 2002]. ARQuake replaces classic Quake levels with levels based on real outdoor environments in which players can move naturally. As in Quake, opponents move around the environment with the player and these opponents can be shot at with a plastic gun**.** Although the hardware is cumbersome, ARQuake clearly illustrates the potential of using the real-world environment in augmented reality games.

2.5.4 *Human Pacman*. Human Pacman [Cheok et al. 2004] is a novel interactive entertainment system that ventures to seamlessly combine a virtual playground with the real physical world. The name itself implies a human player, who takes the role of Pacman. Besides the Pacman, there are other players who physically assume the role of

Ghosts. The ultimate goal of the game closely resembles that of the original arcade Pacman. In the Human Pacman game, the Pacman character collects all virtual plain cookies in Pac-World while avoiding the Ghosts. On the other hand, the aim of the Ghosts is to capture Pacman in Pac-World.

Pacman and Ghost players can see, via head-mounted displays (HMD), virtual cookies scattered in a maze-like manner (for example on real footpaths) over the real physical game area. The cookies are shown from the first-person perspective of the player, dependent on her physical position and head motion. The Pacman player sees the cookies on the footpath, as though she were a real Pacman in a Pacman maze and could simply collect the virtual cookies by walking through them (see Figure 5).

To add to the excitement of the game-play, a real Bluetooth-embedded box is hidden somewhere inside the game area. If the Pacman player is able to find and physically hold the box, the player will gain Ghost-capturing capability for a limited period of time. The capture is another tangible interaction, which involves touching the capacitive sensor attached to the opposing players' backpack; see Figure 6. The Ghost player will win the game by capturing Pacman before Pacman reaches her goal.

While contact in terms of competition exists between both parties, collaborations is lacking. To extend the game beyond the physical domain and promote social interaction and collaboration, an additional role, the Helper, is introduced (which was not included in the original Pacman game). The new role enhances the game by contributing an alternate means for hybrid interaction between the real and virtual players.

The Helper can connect to the game server from almost anywhere in the world through the Internet and view the game, "live" in virtual reality form from any angle and distance. Every movement in the physical world will be reflected immediately in the virtual realm. Even when the Pacman becomes Super Pacman, the Helper will see a

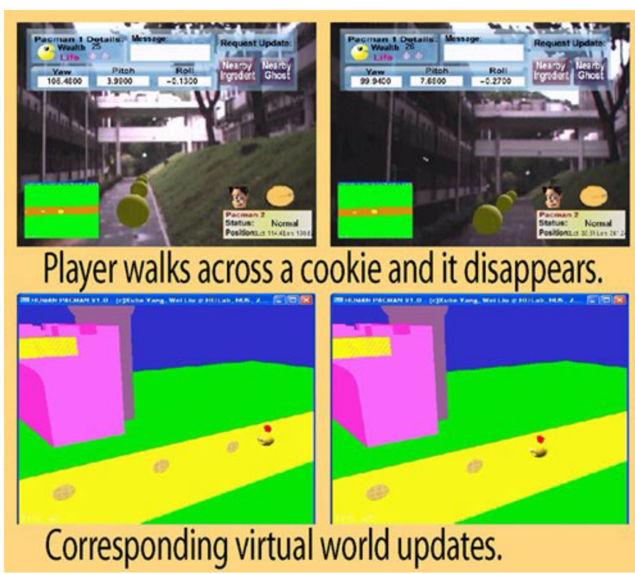

Fig. 5. Pacman collecting cookies.

Fig. 6. Capturing Pacman by touching the back.

corresponding change in the 3D graphic model. This mode of virtual viewing (watching a real live event in alternate graphical form) provides a new dimension, which is both efficient and entertaining, to participants watching an event.

The Helpers, however, are not restricted to watching the game passively. They can actually communicate with the Pacman or Ghost in real time via bidirectional text messaging. While Helpers use the computer keyboard for text-input, Pacman and Ghost communicate and respond to their Helpers in the chat room by using the Twiddler, a hand-held input device. The communication that takes place could either be casual chat or discussion on the winning strategy. Such interactions could promote social cooperation and establish relationships between humans who are operating across radically different contexts.

2.5.5 *Tilt-Pad Pacman*. Tilt-pad Pacman [Xu et al. 2003] enables tangible human interaction with a computer; it is an embedded system that focuses on new hardware devices that are small, lightweight, wireless, and fun. Similar to Human Pacman, Tilt-pad Pacman is based on the popular computer game that features a Pacman that runs around a maze to eat cookies and at the same time tries to avoid being devoured by the ghosts. The augmented reality version of the Tilt-pad Pacman game converts all the 2D screen characters into 3D objects attached to the board with pictures of these objects. The game is carried out in a virtual maze with a narrow pathway. The Pacman and two Ghosts are set to move along a path on which cookies are scattered. When Pacman meets the cookies on the path, it automatically eats them; when Pacman meets a Ghost instead of cookies, Pacman will be eaten. Pacman's death is shown by an animated model that gets smaller and smaller until it is invisible.

A user wearing a head-mounted display (HMD) holds a tilt-pad and manipulates the Pacman's movements by tilting it. If he wants the Pacman to go forward, he tilts the pad forward, and vice versa if he wants it to move backwards. This is a really tangible interaction: the user does not use the keyboard to control Pacman's movements; he uses physical hand-movements that very closely resemble the Pacman's physical movements. A camera is attached to the HMD, and based on mixed-reality tracking technology, the user, through the HMD, sees virtual 3D characters of the Pacman itself, the Ghosts, the cookies, and the maze.

2.5.6 *Magic Land*. Magic Land [Qui et al. 2005] is an augmented reality environment in which 3D avatars of live human beings and 3D computer-generated virtual animations play and interact. The environment has two main areas: the recording room and the interactive room. The recording room with 9 Dragonfly cameras is where users can have themselves captured and made into live 3D models that will interact in the mixed-reality scene. After being captured, the user can go to the interactive room to play with her own figure. The interactive room consists of three main components: a menu table, a main interactive table, and five playing cups. There are different marker patterns on top of these tables and cups. A four-camera system is put high above the main interactive table to track the relative positions of its markers via the cups' current markers. The users view the virtual scenes and/or virtual characters, which will be overlaid on these tables and cups, via the video see-through HMDs, with Unibrain cameras mounted in front, looking at the markers. The system obtains images from this camera, tracks the marker pattern on the images, calculates the position of the virtual viewpoint, generates a novel view of the captured subject from this viewpoint, superimposes the generated view to the image obtained from the Unibrain camera, and displays it on the HMD.

The main interactive table (see Figure 7) is first overlaid with a digitally created setting, an Asian garden for instance; whereas the cups serve as the containers for the virtual characters and tools for users to tangibly manipulate the virtual characters. There is also a screen on the wall that reflects the mixed-reality view of the first user when he or she uses the HMD, or if nobody uses the HMD for 15 seconds, shows the whole magic landscape seen from a far distant viewpoint in virtual reality mode.

Users can select the virtual characters they want to play with from the menu table There are two mechanical push buttons on the table corresponding to two types of characters: 3D avatars of live human beings on the right and VRML models on the left.

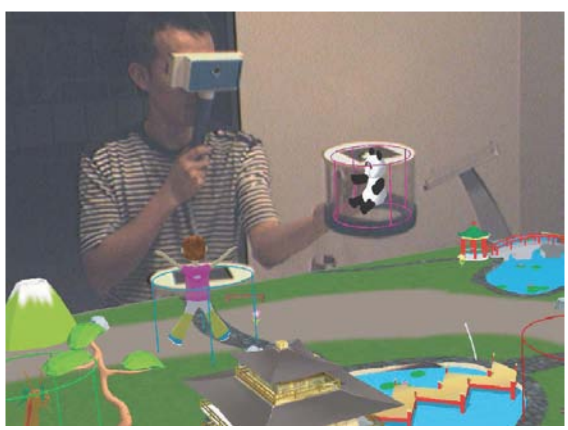

Fig. 7. Tangible interaction in MagicLand.

Users can press the button to change the objects shown on the menu table, and move the empty cup close to the object to pick it up. To empty a cup (trash), users can move the cup close to the virtual bin placed at the middle of the menu table.

After picking a character, users can bring the cup to the main interactive table and play with it. Consequently, there will be many 3D models that move and interact in a virtual scene on the table, to form a beautiful virtual world of small characters. If two characters are close together, they will interact with each other in a predefined way. For example, if a dragon comes close to the 3D avatar of a live human being, it will blow fire on the human. The tangible merging of real humans with the virtual world will engender feelings of excitement

2.5.7 *AR Worms*. The AR Worms project [Nilsen et al. 2004] was an attempt, using augmented reality, to port the popular PC game Worms to a tabletop setting.

In Worms, players control cartoon worms on a 3D map in an attempt to destroy each other using bazookas, sheep, and a variety of other silly weapons. To interact with the game, players use a combination of wireless game pad and gaze selection. The experience of players shows that the use of augmented reality for table-top games has great possibilities. However, it also demonstrates the difficulties with gaze-based selection and illustrates the difficulty of today's hardware.

2.5.8 *AR Tankwar*. AR Tankwar took the lessons learned from Worms and applied them to a more conventional strategy game. AR Tankwar attempts to blend elements from popular real-time strategy games and miniature table-top games. In it, players control armies of tanks, helicopters, and artillery attempt to capture objectives on a map on a table top (see Figure 8).

Multiple players may compete or collaborate against computer opponents. A wireless game-pad is again used for interaction, this time in conjunction with lens selection. A virtual lens is attached to the game-pad and used for targeting. Various aids were implemented to aid collaboration between players. The player's gaze targets were projected into the map as translucent view frustums, and players immersed in the game's virtual reality mode were presented on the map as small floating heads.

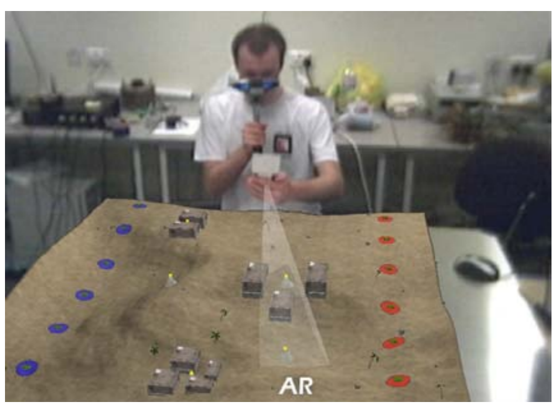

Fig. 8. Tankwar.

To allow spectators to participate, we implemented a projector that displays an overview of the game with various statistics. Spectators could also communicate with or offer advice to players via a tablet PC. Messages and diagrams drawn on the map screen are transmitted to players and appear as ghostly blue lines.

Tankwar also experimented with multimodal game interfaces by incorporating speech commands. This proved quite effective for some players, but has been under-utilized due to difficulties with training our speech-recognition software.

Tankwar will shortly become the subject of a more intensive evaluation of players in augmented reality games; but it has already been presented informally at open houses and games conventions. Player reactions were almost universally positive, even when the novelty of augmented reality wore off. The chief criticism was a lack of interaction with the physical world. Further enhancements to the game will address this problem in the next year.

2.5.9. *Open Issues In AR Games*. As well as offering a unique combination of characteristics for game design, augmented reality presents some unique problems.

For example, there is limited collaboration, particularly with the use of head-mounted displays. Interaction with head-mounted displays is known to be better than voice-only, but weaker than unencumbered face-to-face communication. However, the exact characteristics of interaction via head-mounted displays are not understood. And, while the role of physical artifacts in social situations is comparatively well understood, that of virtual artifacts is not

The development of interaction metaphors is still immature (paddle, pointer, and lens-based interactions are some examples). While *augmented reality* ***may allows players to use their whole bodies to interact with the game, research is needed to determine what metaphors are most effective in different gaming situations.***

Current augmented reality systems require especially configured hardware and controlled environments. Such systems are expensive to set up, and so commercial game development is not viable. In the near future, hand-held augmented reality games may become popular via use of PDAs and mobile phones; but head-mounted displays may require drastic changes in technology or the marketplace to become viable. Fixed installations and other business models may be another option.

Augmented reality offers many possibilities for game design. Games designed using it may draw on the characteristics of both real-world and computer games. However, there are significant challenges due to its expense, difficulties with hardware, and lack of design guidelines.

3. CONCLUSIONS

With this article we tried to give an introduction to the field of pervasive games. We discussed several subgenres that emerge within the pervasive gaming paradigm and presented state-of-the-art examples in each of the genres discussed. Naturally, other interesting works in the field had to be omitted, since this article was not intended as a comprehensive survey of all pervasive games. We thus want to conclude with pointing the reader to the PerGames workshops that feature many more research projects and academic papers that revolve pervasive gaming.

The International Workshops on Pervasive Gaming Applications (PerGames) are dedicated to discussing results, sharing experiences, and publishing research papers in the field of pervasive games. In 2004, the event was held at the PERVASIVE

International Conference in Vienna, Austria. In 2005, PerGames took place at the PERVASIVE conference in Munich, Germany.

PerGames events are supported by the *ACM Computers in Entertainmen*t. Four high-quality research papers presented at PerGames 2005 are published in this issue of *ACM CiE*. More papers can be found at the PerGames website at www.pergames.de. With almost 40 participants, 15 accepted full papers, several live demonstrations, and many highly stimulating discussions and exchanges of ideas, PerGames 2005 has grown significantly over previous events and has become a valuable starting point in exploring the field of pervasive gaming.

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REFERENCES

ABOWD, G. D. AND MYNATT, E. D. 2000. Charting past, present, and future research in ubiquitous computing. *ACM Trans. Computer-Human Interaction 7,* 1 (2000), 29-58.

AMORY, A. NAICKER, K., VINCENT, J., AND ADAMS, C. 1999. The use of computer games as an educational tool: Identification of appropriate game types and elements. *British J. of Educational Technology. 30,* 4 (1999), 311-321.

ANTTONEN, J. AND SURAKKA, V. 2005. Emotions and heart rate while sitting on a chair. In *Proceedings of Conference on Human Factors in Computing Systems* (Portland, OR, 2005.). ACM Press, New York, 491–499.

BENFORD, S., SEAGAR, W., FLINTHAM, M., ANASTASI, R., ROWLAND, D., HUMBLE, J., STANTON, D., BOWERS, J., TANDAVANITJ, N., ADAMS, M., ROW-FARR, J., OLDROYD, A., AND SUTTON, J. 2004The error of our ways: The experience of self-reported positioning in a l location-based game. In *Proceedings of Ubicomp 2004* (Nottingham, Sept.2004). Springer-Verlag, Berlin.

BENFORD, S., MAGERKURTH, C., AND LJUNGSTRAND, P. 2005. Bridging the physical and digital in pervasive gaming. *Commun. ACM 48*,3 (2005), 54-57.

BERSAK, D., MCDARBY, G., AUGENBLICK, N., MCDARBY, P., MCDONNELL, D., MCDONALD, B., AND KARKUN, R. 2001. Intelligent biofeedback using an immersive competitive environment. In *Proceedings of UBICOMP 2001 Workshop on Ubiquitous Gaming.*

BJÖRK, S., FALK, J., HANSSON, R., AND LJUNGSTRAND, P. 2001. Pirates! - Using the physical world as a game board. In *Proceedings of Interact 2001, IFIP TC.13 Conference On Human-Computer Interaction* (Tokyo, July 2001).

BOHN, J. 2004. The smart jigsaw puzzle assistant: Using RFID technology for building augmented real-world games, In *Workshop on Gaming Applications in Pervasive Computing Environments at Pervasive 2004* (Vienna). http://www.pergames.de.

CHALMERS, M., BARKHUUS. L., BELL, M., BROWN, B., HALL, M., SHERWOOD, S., TENNENT, P. 2005. Gaming on the edge: Using seams in perva sive games. In *The Second International Workshop on Gaming Applications in Pervasive Computing Environments at Pervasive 2005* (Munich). http://www.pergames.de.

CHEOK, A. D., GOH, K. H., LIU, W., FARBIZ, F., FONG, S. W, TEO, S. L., LI, Y., AND YANG, X. B. 2004. Human pacman: A mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal Ubiquitous Computing 8*, 2 (2004), 71-81.

FLINTHAM, M., ANASTASI, R., BENFORD, S., HEMMINGS, T., CRABTREE, A., GREENALGH, C., RODDEN, T., TANDAVANITJ, N., ADAMS, M., AND ROW-FARR, J. 2003. Where online meets on-the-streets: Experiences with mobile mixed reality games. In *Proceedings of the 2003 CHI Conference On Human Factors in Computing Systems* (April 2003). ACM Press, New York, 569-576.

FONTIJN, W. AND MENDELS, P. 2005. StoryToy the interactive storytelling toy. In *The Second International Workshop on Gaming Applications in Pervasive Computing Environments at Pervasive 2005* (Munich, 2005).

GILLEADE, K. AND ALLANSON, J. 2003. A toolkit for exploring affective interface adaptation in videogames. In *Proceedings of HCI International 2003*. Vol. 2. LEA, NJ. 370-374.

HJELM, S. I. 2003. The making of Brainball. *Interactions 10*, 1 (2003), 26-34.

HÖÖK, K., BULLOCK, A., PAIVA, A., VALA, M., CHAVES, R., AND PRADA, R. 2003. FantasyA and SenToy, In *Proceedings of CHI 2003* (Fort Lauderdale, FL, April 5-10, 2003). ACM, New York.

ISHII, H., WISNESKI, C., ORBANES, J., CHUN, B., PARADISO, J. 1999. Pingpongplus: Design of an athletic-tangible interface for computer-supported cooperative play. In *Proceedings of CHI'99*. ACM, New York.394–401.

MAGERKURTH, C., ENGELKE, T., AND MEMISOGLU, M. 2004. Augmenting the virtual domain with physical and social elements. In *Proceedings of the International Conference on Advancements in Computer Entertainment Technology* (Singapore, June 3-5, 2004). ACM, New York, 163-172.

MAGERKURTH, C., MEMISOGLU, M., AND ENGELKE, T. 2004. Towards the next generation of tabletop gaming experiences. In *Proceedings of the Conference on Graphics Interface 2004* (GI'04. London, Ont., Canada, May 17-19, 2004). AK Peters. 73-80.

MALONE, T. W. 1981. Toward a theory of intrinsically motivating instruction. *Cognitive Science 4*, 13 (1981),333-369.

MANDRYK, R. L. AND INKPEN, K. M. 2004. Physiological indicators for the evaluation of co-located collaborative play. In *Proceedings of the Conference onComputer Supported Cooperative Work* (Chicago, IL, 2004).

MANDRYK, R. L., MARANAN, D. S., AND INKPEN, K. M. 2002. False prophets: Exploring hybrid board/video games. In *Extended Abstracts of the Conference on Human Factors in Computing Systems*. 2002. 640-641.

MANDRYK, R. L. AND STANLEY, K. G. 2004. Gemini: Accumulating context for play applications. In *Proceedings of the Ubicomp 2004 Workshop on Playing With Sensors* (Nottingham, England, 2004).

NILSEN, T., LINTON, S., LOOSER, J. 2004. Motivations for AR gaming. In *Proceedings of the Fuse 04, New Zealand Game Developers Conference* (Dunedin, New Zealand, June 26-29, 2004). 86-93.

PICARD, R. W. 1997. *Affective Computing*. MIT Press, Cambridge, MA, 1997.

PIEKARSKI, W. AND THOMAS, B. 2002. ARQuake: The outdoor augmented reality gaming system. *Commun. ACM 45*, 1 (Jan. 2002), 36-38.

PURI, C., OLSON, L., PAVLIDIS, I., LEVINE, J., AND STARREN, J. 2005. StressCam: Non-contact measurement of users' emotional states through thermal imaging. In *Conference Supplement to Conference on Human Factors in Computing Systems*. ACM, New York, 2005. 1725–1728.

QUI, T. C. T., NGUYEN, T. H. D., MALLAWAARACHCHI, A., XU, K., LIU, W., LEE, S. P., ZHOU, Z., TEO, S. L., TEO, H. S., THANG, L. N., LI, Y., CHEOK, A. D., AND KATO, H. 2005. Magic land: Live 3d human capture mixed reality interactive system. In *Interactivity Venue, SIGCHI 2005*. ACM, New York.

SHWE, H. 1999. Smarter play for smart toys. Zowie Intertainment White Paper 3208.

STAPLETON, C. B., HUGHES, C. E., AND MOSHELL, J. M. 2002. Mixed reality and the interactive imagination. In *Proceedings of the First Swedish-American Workshop on Modeling and Simulation* (SAWMAS 02. Orlando, FL, Oct. 30-31, 2002).

STREITZ, N., TANDLER, P., MÜLLER-TOMFELDE, C. AND KONOMI, S. 2001. Roomware: Towards the next generation of human-computer interaction based on an integrated design of real and virtual worlds. In *Human-Computer Interaction in the New Millennium*, J. A. Carroll (ed.). 553–578.

SYKES, J. AND BROWN, S. 2003. Affective gaming: measuring emotion through the GamePad. In *Conference Supplement to the Conference on Human Factors in Computing Systems*. ACM, New York, 732-733.

XU, K., PRINCE, S. J. D., CHEOK, A. D., QIU, Y, AND KUMAR, K. G. 2003. Visual registration for unprepared augmented reality environments. *Personal and Ubiquitous Computing 7,* 5 (Oct. 2003), 287–298.

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