Designing tangibles for children: Games to think with

Alissa Antle
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Tangible Play

Research and Design for Tangible and Tabletop Games

Workshop at the 2007 Intelligent User Interfaces Conference

January 28, 2007
Honolulu, Hawaii, USA

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Workshop Proceedings

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Abstract

Many people of all ages play games, such as board games, PC games or console games. They like game play for a variety of reasons: as a pastime, as a personal challenge, to build skills, to interact with others, or simply for fun.

Some gamers prefer board games over newer genres, because it allows them to socialize with other players face-to-face, or because the game play can be very improvisational as players rework the rules or weave stories around an unfolding game. Conversely, other gamers prefer the benefits of digital games on PCs or consoles. These include high quality 3D graphics, the adaptive nature of game engines (e.g. increasing levels of difficulty based on player experience) and an abundance of digital game content to explore and experience.

With the increasing digitization of our everyday lives, the benefits of these separate worlds can be combined in the form of tangible games. For example, tangible games can be played on digital tabletops that provide both an embedded display and a computer to drive player interactions. Several people can thus sit around the table and play digital games together.

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INTRODUCTION

Many people of all ages play games, such as board games, PC games or console games. They like game play for a variety of reasons: as a pastime, as a personal challenge, to build skills, to interact with others, or simply for fun.

Some gamers prefer board games over newer genres, because it allows them to socialize with other players face-to-face, or because the game play can be very improvisational as players rework the rules or weave stories around an unfolding game. Conversely, other gamers prefer the benefits of digital games on PCs or consoles. These include high quality 3D graphics, the adaptive nature of game engines (e.g. increasing levels of difficulty based on player experience) and an abundance of digital game content to explore and experience. With the increasing digitization of our everyday lives, the benefits of these separate worlds can now be combined, e.g. in the form of digital tabletop games. This emerging game type is played on a table that provides both an embedded display and a computer to drive player interactions with the game. Several people can thus sit around the table and play digital games together.

In tangible games, everyday physical objects, such as pawns or dice, can be detected and tracked, e.g. on the surface of the tabletop display. The tracking can be done with diverse technologies, such as optical cameras, RFID tags or sound (see Mazalek 2006, for an overview). The information from the tracking technology is then used as input for the game, which in turn provides visual output. For example, when a pawn has been moved across a display, the game can respond by ending the pawn owner's turn and showing the appropriate visual feedback. The next pawn can then be moved by one of the other players.

BACKGROUND AND EXAMPLE WORKS

Player interactions with existing PC or console games often happen via keyboards or specialized game controllers. In many cases, the mappings from keystrokes or button presses to game actions are obscure and can be difficult for players to learn. By making use of emerging technologies for user input devices, it is now possible for users to interact with digital applications by means of physical objects, through graspable or tangible user interfaces (Fitzmaurice 1996, Ullmer 2000). Known as tangible interaction, this area of interface research leverages the skills humans have in negotiating their physical world to enable natural and intuitive digital interactions.

A benefit of tangible user interface technologies is that they can enable collaborative interactions with digital applications for co-located users (Rogers 2006), for example around tabletop displays or in e-learning situations. This makes tangibles suitable for multi-user digital game play. Some examples of tangible games research include the hybrid board/video game *False Prophets* (Mandryk 2002), interactive storytelling applications and games developed on the TViews table (Mazalek 2005), role-playing games developed on the STARS platform (Magerkurth 2004), tangible games created to stimulate learning in children, such as Hunting the Snark (Rogers 2002), Read-it (Weevers 2004), PITABoard (Eden 2002) and CarettaKids (Sugimoto 2004), and digital board games with tangible interaction, *Weathergods* and *Ballz* (Dujia 2005) on Philips Entertaible (Hollemans 2006). In all these systems, tangible playing pieces, such as pawns or pucks, serve as the primary means of navigation within the virtual game spaces. Other digital tabletop games have been created on multi-user touch-based surfaces, such as the DiamondTouch table (Esenther 2005). Additionally, there has also been research work on table-based Augmented Reality systems for digital gameplay (Ulbricht 2003, Lee 2005, Nilsen 2005).

MOTIVATION

In order to design successful tangible and tabletop games, we need to bring together designers and researchers from a number of different fields, ranging from tangible interaction and game design, edutainment and learning technologies, to interface and sensor technology development. One of our motivations for studying tangible games is thus to understand how we can best combine new interface technologies and game features in ways that engage players, allowing them to focus both on the challenge of the game and on their interactions with one another.

Another motivating factor are the recent results from the User-Centered Engineering Group at Eindhoven University of Technology in collaboration with the Philips Entertaible team, which have shown that tangible objects designed to fit the game theme are appreciated by game players over more general tangibles (based on a TUI-taxonomy by Hoven&Eggen 2004). Currently, the reasons for this are not completely understood, and we hope to learn how the design (of the table, game, objects and interaction), personal preferences and gaming experience influence this preference. By studying these questions, we hope to come up with design guidelines or a taxonomy for designing tabletop games with tangible interaction.

WORKSHOP AIMS

The workshop aims to bring together people who have experience in any of the related areas to tangible and tabletop games in order to discuss ongoing work, identify opportunities for the field, and demonstrate implemented tabletop technology, games or objects. In particular, we hope to address questions related primarily to the areas of tangible interaction, game design and emerging technologies for tangible and tabletop games. In addition to these three areas, we are also interested in the evaluation and potential marketability of these games, and in the ways in which researchers from different fields can collaborate to move this field forward. We want to address some of the following questions during the workshop:

Tangible Interaction: Why is tangible important and how can we assess this? What kinds of tangible objects are suitable for different kinds of games, i.e. how does tangible object design relate to game design? What are the different ways in which users can interact with the tangible objects and how does this relate to game design? Are current tangible interaction taxonomies suitable for game object design and what are possible alternatives?

Game Design: What types of games are suitable for tangible or tabletop platforms, for both entertainment and educational purposes? What are the benefits of face-to-face social interaction for gaming and how can we assess this within specific contexts? How does the type of game influence visual and physical interaction design? How do different games handle multi-user interactions on one or more platforms at once?

Sensing Technologies: Which sensing technologies are most appropriate, e.g. for digital tabletops? Which point to commercially viable solutions? Are different technologies suited to different tables and/or games? What are the advantages and disadvantages of each technology?

Evaluation: How do we evaluate games from the perspective of tangible interface design, tracking technologies and game design? What have game designers done in terms of evaluation thus far? What have their results indicated?

Marketability: Is there a market for tangible games? What needs to happen for these games to make it in the market in terms of tangible/visual interface design, game design and sensing technologies? How do we turn research initiatives in this area into potential products?

Collaboration: How do we build a community of people working in this area and what are the relevant communities of research? What are the key future research directions? How do we bring together researchers from different areas who are interested in this topic? How do we share knowledge and expertise across different areas and work together to push forward this area of research? (Note: many of these are general questions faced by any interdisciplinary research topic and are not really specific to tangible and tabletop games, but are still worthwhile to discuss in terms of identifying a collaborative approach that works for our area.)

PARTICIPANTS

We hope to involve a mix of researchers and practitioners working on (including but not limited to) digital tabletops, sensing technologies, tangible interaction, collaborative play, edutainment and game design. These participants will ideally come from diverse fields, including HCI, computer science, education, interaction design and game design.

WORKSHOP PROCEDURE

A call for participation will be posted online and sent out to relevant lists. Potential participants will be asked to submit a 4-page position paper on any of the above-mentioned or related topics using the ACM-template, which can be found on the workshop website: http://synlab.gatech.edu/workshops/tableplay2007/. Papers will be selected based on quality, relevance and also diversity, since we aim to discuss work that comes from different research areas and environments, such as HCI, computer science and design, across both academia and industry.

We will have to limit the number of position paper presentations to no more than 15, due to time limitations. The total number of participants will be limited to 20-25 in order to keep the session interactive.

The workshop will consist of a morning program including an introduction and position paper presentations (of approximately 10 minutes each). Since we would like to have an interactive and informal session, participants will be able to pose questions during and after each presentation. We have also invited a relevant guest researcher to give a special presentation in the morning session (to be confirmed). In the afternoon, participants will be divided into 5-6 smaller groups based on some of the topics of interest mentioned in the previous section. These topics and related questions raised in the morning session will be used to drive discussion and brainstorming in the break-out groups. In the last part of the afternoon, the break-out groups will present their results to all of the workshop participants. We plan to end the workshop with a group discussion on future directions for this area of research. Below is a rough first schedule:

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FUTURE PLANS

We plan to discuss the follow-up of the workshop during the workshop itself. There might be a need for a forum, a wiki, or a mailing list to keep the discussion going. If sufficiently mature work is presented and discussed, we hope the workshop will lead to a special journal issue or a book for publication of results. We are confident that this workshop will facilitate future collaboration and continuing discussions.

WORKSHOP ORGANIZERS

Elise van den Hoven, an assistant professor at the User-Centered Engineering group at the Industrial Design department of the Eindhoven University of Technology in The Netherlands, has an MTD and PhD in User-System Interaction. Her PhD work on tangible interaction (Hoven, 2004) was funded by Philips Research. Elise is interested in designing, building and evaluating tangible interaction in different application areas, including games. Her approach is user-centered and inspired by Dourish's Embodied Interaction (2001).

Ali Mazalek is an assistant professor in digital media at the Georgia Institute of Technology, where she directs the Synaesthetic Media Lab at the GVU Center. Her research interests include emerging physical sensing and tangible interaction technologies for media arts and entertainment. Mazalek has an MS and PhD from the MIT Media Laboratory's Tangible Media and Media Fabrics groups, where she was a Samsung and MediaLabEurope Fellow.

PROGRAM COMMITTEE

A program committee will be assembled from leading researchers in the areas discussed above in order to review submitted position papers.

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Biography

Evert van Loenen is Principal Scientist in the Media Interaction Group of the Philips Research Laboratories in Eindhoven, The Netherlands.

He studied physics in the Netherlands and received his MSc degree from the University of Groningen in 1981. He specialized in Surface Science, and received his PhD degree from the University of Utrecht in 1985. He subsequently joined IBM in Yorktown Heights as visiting scientist, where he worked on one of the first Scanning Tunneling Microscopes (STM's) capable of imaging the surface states of Si and Ag/Si interfaces.

He joined Philips Research in 1986, where he set up micro-technology and nano-imaging activities, and later became Department Head of a research group on professional imaging systems. He is author of twelve patents and more than sixty scientific papers.

In 1999, as Principal Scientist he expanded his research interests into the emerging field of Ambient Intelligence. He managed one of the largest European projects in this field, the ITEA - AMBIENCE project, which was awarded the 2003 ITEA Achievement Award. In 2003 he initiated the Entertaible research project with several colleagues. He is currently responsible for a number of projects which explore future user needs, invent Ambient Intelligent solutions to address these, and realize these solutions in Philips' new Experience Labs in Eindhoven.

Entertaible: A Solution for Social Gaming Experiences

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ABSTRACT
Interactive tables are attractive systems that allow novel gaming experiences which combine the social setting of boardgames with the dynamic qualities of video games. They can furthermore be used for a range of other applications. Most of these applications include co-located collaboration with other people. Based on the guidelines of Scott et al. [1] the need for a new input solution is indicated. The input technology of Entertaible is presented, which allows detection of multiple concurrent inputs from fingers and objects. Finally, an example of a gaming application is discussed.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Input devices and strategies.

General terms: Design**,** Human Factors

Keywords: interactive table, tangible objects, input technology, user interaction, collaboration.

1. INTRODUCTION
In recent years interactive tables have started to receive considerable attention. A valuable characteristic of interactive tables is the support they can provide for collaboration in interaction with information. A need for this is found in digital board games [2], [3] but also in domains stretching from office use [4], [5] and education [6], [7] to museums [8].

2. ELECTRONIC BOARD GAMES
Advances in electronics and networks have enabled rapid and enticing developments in gaming, proponents of which are the console and PC video games. The Internet has involved large communities of gamers in online role-playing [9] and generally electronic games enable gamers to connect through a network and play together. In spite of these possibilities to play together, the natural need for direct human and social interaction is underserved and the gamers meetings that are often organized to meet 'in real life' are testimony to this.

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The social and direct human interaction is well supported in the traditional board games such as *Monopoly*, *Risk* [10], and *Settlers of Catan* [11]. However, apart from a few exceptions, such as *King Arthur* [12] and *Cluedo Live* [13], there is a gap between the world of electronic games and the world of board games. Evidently, there appears to be a space for the electronic board game, a concept that combines the attractiveness of the two worlds. The interactivity and dynamics of the electronic games together with the direct social interaction and the physical objects of board games enables a whole new class of games. So the aim of the Entertaible project was to develop the concept of electronic board games and explore its potential.

Figure 1. Entertaible allowing multi-user interaction

3. CONCEPT REALIZATION
To realize Entertaible, as the concept is called, an LCD panel is mounted in the top surface of a table and used for the board; see Figure 1. The large viewing angle of the chosen panel suffices to provide all players, who can sit around the table, a good viewing experience. For natural game play, it is desirable that the players can use physical playing pieces (e.g. pawns), just as they are used to. This means that a touch detection technology is needed that can register the positions of objects on the display as well as the inputs that the players make with their hands and fingers. Moreover, all these inputs need to be handled simultaneously.

4. INPUT TECHNOLOGIES
4.1 User Requirements
In their overview, Scott et al. [1] list eight guidelines for co-located collaborative tabletop interactive displays. Five of these guidelines have implications for the input technology that is used.

Two guidelines put restrictions to the impact that the interaction technology may have on the ergonomics of the table. Users should be able to sit comfortably around the table (Guideline 1: 'Support interpersonal interaction'), which means that bulky components under the table are to be avoided. Additionally, users should be able to sit anywhere around the table (Guideline 7: 'Consideration for the appropriate arrangements of users'), implying that input solutions should not occupy or favor one side of the table. A third guideline related to the input technology (Guideline 2: 'Support fluid transitions between activities') prefers universal input devices so that few switches between input devices are required to accomplish tasks. Back projection solutions typically do not meet de first requirement, but several other interactive table solutions comply with these three guidelines. The two other input technology-related guidelines considerably reduce the number of compliant interactive table solutions however: 'Support the use of physical objects' (Guideline 5) and 'Support simultaneous user actions' (Guideline 8).

There are several multi-user concurrent input solutions:

I. Using multiple mice, styli, or similar devices in combination with software that enables multiple concurrent inputs. However, such solutions counteract the natural interpersonal interaction (Guideline 1) since the use of deictic (pointing) references and gestures are not well supported [14].

II. Use special object and sensing combinations (e.g., electromagnetic objects Sensetable [6]). However, such solutions typically require a projection display, which does not lend itself to (bright) day light conditions.

III. Enhancing touch-sensing technologies to detect multiple concurrent inputs as shown by, e.g., DiamondTouch [15] and SmartSkin [16].

IV. Use computer vision-based solutions like the VIP system [17] or DViT [18].

Computer vision-based solutions (IV) and special object and sensing combinations (II) also support the interaction with physical objects well (Guideline 5). This is different for the touch-sensing solutions (III). For example, conductive and capacitive touch sensing solutions require that (a) the objects are made of conductive materials and that (b) the user touches the object to enable the system to 'see' it, which means that a location history needs to be maintained for all (no longer touched) objects.

In spite of the fact that standard computer vision-based solutions (with a view from above the table) as well as the DViT system (with a side view) comply with all guidelines, these too have drawbacks. Computer vision-based solutions require controlled light conditions [6] and the cameras of the DViT system can be easily occluded because they are mounted in the corners of a frame that surrounds the display/input area.

4.2 Entertaible Multi-touch Solution

A new touch detection technology was invented and used for Entertaible. This technology uses infrared LEDs and photodiodes, which are discretely mounted around the perimeter of the LCD. By intelligently processing the data that are generated by this setup, the location of up to 40 objects or fingers can be determined simultaneously [18].

Infrared-based touch sensing is a technology that can detect conductive and non-conductive objects as well as fingers. The principle of an infrared touch screen is the combination of an infrared (IR) LED and an IR-sensitive photodiode. As soon as there is an object or finger between the LED and the photodiode, the latter no longer detects the IR light from the LED. This information is the basis for the input detection. By using a series of LEDs and photodiodes along the edges of the display multiple objects and fingers can be seen concurrently (see Figure 2).

Figure 2. Detection of multiple concurrent inputs

Novel concurrent input detection algorithms have been developed. Using these, Entertaible is capable of localising multiple objects (including fingers) simultaneously, thereby complying with all the guidelines that Scott at al. have described, without the drawbacks of some of the other solutions:

- There is no need for controlled light conditions as no computer vision or projection display is used.
- Objects do not need to be conductive or otherwise prepared for detection. Of course, IR light needs to be blocked by the objects, but almost all objects do so.
- The direct interaction of pointing support interpersonal interaction with deictic references and gestures.

4.3 Tangible Object Interaction

The combination of display and position detection for multiple objects simultaneously enabled the creation of a new type of tangible object: Adaptive Pawns. Transparent pawns transport the light from the display underneath the pawn to the top of the pawn using the principle of total internal reflection. When the color of the display changes, the color of the pawn changes (see Figure 3). The state of the pawn can now be controlled by the display. For example, the playing piece of the active player can blink.

5. GAMES

The games that can be played on Entertaible run on a computer that is connected to it. In principle any gaming platform can be used to drive Entertaible and the computation needed to run and render the game can also be embedded in Entertaible itself. To illustrate some of the new possibilities for board games that are enabled by Entertaible, a new game was developed, called *YellowCab*.

When playing a game of Yellow Cab, each player is a taxi driver in Manhattan, and has to pick up passengers from the sidewalks and bring them to their destination in order to earn points. A map representing Manhattan is displayed on the screen. The taxis are represented by pawns and matching sounds accompany the actions in the game, e.g. driving or slamming the car doors. Other cars that drive on the streets, road wear, traffic lights, and police chasings upon ignoring a red light are digital and showcase some of the newly enabled dynamics and interactivity. These represent the daily life challenges of a taxi driver: gridlocks, roadblocks, slow traffic, and (potentially) fines. The winner of the game is the player who picked up and delivered most passengers when the game time is over.

Figure 3. Adaptive pawn on the Entertaible

6. CONFRONTATION WITH THE WORLD

Before presenting Entertaible to the outside world, it was informally tested with a large group of children in the context of an internal event. Given the choice between watching a movie, playing a game on a video game setup with 3D graphics, and playing YellowCab on Entertaible, most children preferred the Entertaible, and played for hours, explaining to newcomers how the game worked. No explanation of the concept or how to interact with the table was necessary. Even though technical glitches sometimes required the game to be restarted for optimal playing, the children were reluctant to let the researchers do this, as they wanted to continue playing.

Entertaible was shown publicly on the Philips booth at the CES show in Las Vegas in January 2006. Hundreds of people tried the table and reacted very enthusiastically. Also the international press showed a profound interest. TV, online and printed press covered the story and the number of hits in Google peaked at 800.000 a couple of days after the show. This was even surpassed after the presentation of the second generation Entertaible at the IFA in Berlin in August 2006, with over 900.000 hits.

After the CES event Philips decided to launch a business start-up activity aimed at bringing the Entertaible to the market.

7. CONCLUSION AND FUTURE WORK

In this paper the Entertaible has been presented: an interactive table solution that allows multiple users to interact simultaneously with games or other applications using touch and/or tangible objects. The need for a new interaction solution for this concept has been described and an infrared-based solution has been presented.

Several interactive games have been implemented successfully on the Entertaible, receiving very positive feedback from users.

The use of this technology for other applications is promising, but requires further investigation.

8. ACKNOWLEDGEMENTS

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Position Papers

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Designing Tangibles for Children: Games to Think With

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ABSTRACT
New forms of tangible and spatial child computer interaction and supporting technologies can be designed to leverage the way children develop intelligence in the world. In order to design playful learning games designers must understand how children interact with and understand the representations embedded in tangible objects. In this short position paper the author summarizes relevant theory from cognitive developmental psychology which should be considered in the design of tangibles to support playful and game-based learning. A series of design considerations related to children's cognitive development provide food for thought for the design of tangible game systems.

Author Keywords
Tangibles, spatial interaction, embodied cognition, cognitive development, dynamic systems, children.

ACM Classification Keywords
H.5.1 [Multimedia Information Systems]: Artificial, augmented and virtual realities, H.5.2. [Information Interfaces and Presentation]: User interfaces.

INTRODUCTION
Tangible systems, such as tabletop games, have a powerful ability to engage school age children in active learning. These new models of interaction should provide children with unique forms of learning. Healy provides support for tangible, physically-based forms of child computer interaction when she states that body movements, the ability to touch, feel, manipulate and build sensory awareness of the relationships in the world is crucial to children's cognitive development [9]. Conceptual understandings of these new forms of tangible interaction for children are needed. Developing a conceptual framework for the design of tangible technologies based on an understanding of how and why augmentation supports certain cognitive processes in children is the focus of the author's ongoing research. This short position paper summarizes several theoretically grounded design considerations, presented as questions, which may inform and inspire the design of tangible games for children.

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

The short page length of this paper prohibits a detailed discussion of the four theoretical perspectives proposed as foundations for the design of tangible learning games for children. However the reference section provides further guidance to the theoretical literature. This review focuses on cognitive aspects of child players and as such does not explicitly cover literature on game design, game mechanics or game-based tangible tabletop applications. It is hoped that the design challenge of designing tabletop games to support play-based knowledge acquisition in children will be collaboratively discussed in the IUI workshop. This paper contributes design knowledge about users of such systems.

DESIGN CONCEPTS FOR TANGIBLE INTERACTION
Much research on tangible user interaction focuses on the design of new systems [11]. A special issue: 'Tangible Interfaces in Perspective' marks a shift towards research based on theoretical and conceptual understandings of tangible interaction [10]. Hornecker [11] provides a good overview of recent perspectives on tangible interaction.

Zuckerman presents child-specific work on tangibles which focuses on the classification of tangible manipulatives as "Froebel-inspired" or "Montessori-inspired" [24]. Rogers *et al.* present a conceptual framework for mixed reality for children. It focuses on the notion of transforms between virtual and physical dimensions [18]. Marshall *et al.* highlight the possibility of using the distinction between "readiness-to-hand" and "presence-at-hand" in tangible user interface design to promote reflection in children [14].

The design considerations presented in this paper are a continuation of the author's previous work which mines the rich domain of developmental psychology for theoretical descriptions and explanations which can inspire and inform the design of interactive technologies for children (e.g., [1]).

CHILDREN'S DEVELOPMENT THROUGH PLAY
Cognitive development proceeds as children actively explore the physical and spatial aspects of their environment. Piaget, Gibson, Vygotsky, Dewey and Newell share an emphasis on children as active learners embedded in a physical and social environment [15]. Cognitive development involves the acquisition of organized knowledge structures called *schemata*. Cognitive

development also involves the gradual acquisition of strategies for remembering, understanding and solving problems [15]. DeLoache *et al.* have shown that even young children develop metacognitive strategies (i.e., learning about learning) [4]. These include the ability to self-regulate learning and reflect on the appropriateness of strategies. Gardner's theory of multiple intelligences helps explain why development varies across individual children [7].

One of the primary ways children learn is through play, both informal play and game play. Tangibles games can provide what Resnick calls "conceptual leverage" which enables children to learn concepts and develop schemata which might otherwise be difficult to acquire [17]. Designing these kinds of tangibles assumes child users who learn through play and game play and engage in learning which is active, social and involves self-motivated knowledge acquisition. These assumptions mirror how children learn "in the wild" of the playground or the playroom as they engage in group games. The challenge is to design tangible games that support playful learning and also provide age-appropriate conceptual leverage.

COGNITIVE DEVELOPMENT THROUGH TANGIBLE SYSTEM PLAY?

What kinds of play-based cognitive development can tangibles be designed to support in school age children? The author proposes that understanding the following three areas of cognitive development is important for the design of tangibles: embodied cognition; spatial cognition; and symbolic reasoning [2]. In addition, the perspective on children's cognitive development which views development as a non-linear dynamic system is also relevant. Key concepts from each of these four areas are briefly introduced in this paper. Preliminary design considerations based on these theoretical concepts are presented as bulleted points.

Based on this theoretical grounding, research may then proceed by exploring the utility of these design considerations through small empirical studies of prototypes. For example, the authors are currently conducting user studies to explore ways of supporting children to understand the relationship between 3D forms and 2D shapes. Observations of children cutting clay primitives to reveal sections and using flashlights to reveal silhouettes provide insight into the kinds of embodied, physical interactions and mappings between multiple representations required to build a tangible system. These user studies combined with theoretical ideas have lead to the proposal for a tangible tabletop game similar to Tetris. In the tangible version, 3D geometric blocks are placed on a table and act as system input. Blocks can be manipulated by players to align them with a dynamically changing displayed 2D puzzle.

THEORETICALLY GROUNDED DESIGN

The concepts outlined below are presented with the goal of providing information which may inform and inspire the design of tangible games for children. They are meant to stimulate discussion, highlight design considerations and provide fodder for inspiration. A more detailed design framework for tangibles can be found in [2] or by contacting the author for work in progress.

Embodied Cognition

An embodied perspective on cognition views cognition as grounded in bodily experience [16, 22, 23]. This perspective is particularly salient for children who develop new schemata through a combination of sensation, perception, action and reflection. For example, children often learn to count using their fingers and to measure using their body as a reference (e.g., "an arm's length"). The following are related design considerations:

- How can we leverage the way children solve problems using their bodies and performative knowledge?
- How can we use multi-sensory exploration of an object or space and/or multimodal representations to support individual learning strategies and intelligences?

The perspective of embodiment also provides an understanding of how children's ideas are organized in growing conceptual systems grounded in physical, lived reality. For example, the abstract concept of balance has several meanings: balancing colors in a picture; balancing a chequing account; and balancing a system of simultaneous equations. Each is a conceptual extension of the bodily experience of 'balance' [12]. Children develop abstract understandings by basing them on concrete bodily experiences.

- How can we leverage children's understandings of bodily-based concepts to help them understand abstract concepts?

The interplay of action and cognition is made salient by an example from research by Funk *et al.*. They present empirical evidence which shows that children as young as five can successfully solve kinetic mental rotation tasks without moving their bodies. Although they do not move, they solve these tasks using both motor and cognitive processes. That is, they imagine their hands moving the object in order to solve the task [6].

- How can we support parallel (not competing) use of motor, perceptual and cognitive processes?
- Does a direct mapping between the physical actions and digital reactions reduce the load on children's limited cognitive capacities or, inversely, does it inhibit accommodation which requires conceptual conflict?

The Development of Spatial Cognition

Spatial schemata are developed prior to abstract schemata. Gattis argues that spatial schemata provide a foundation for more abstract reasoning [8]. Spatial schemata aid cognition because their familiar organizational structures can be used to facilitate memory, communication and reasoning. While the mechanisms are debated, it is clear that children use rich spatial schemata as a foundation for the development of other concrete and abstract schemata. For example, children are often taught counting using the metaphor of counting as adding to a pile of objects. Later they are introduced to the abstract concept of time using the analogy that time is like the linear distance from self to some place or event.

- How can we base abstract concepts on children's understandings of concrete spatial relationships?

Maps are one form of symbolic representation of space. Tangible interfaces provide both a model and a control for physical space which is then mapped either directly or indirectly to virtual space. Liben provides empirical evidence that the relation between cartographic map use (i.e., use of a spatial representation) and the development of spatial cognition in children is reciprocal [13]. Children's developing conceptions of space and mental abilities to visualize, transform and change perspective in space improves their understandings of maps. In turn, their developing conception of maps improves their ability to conceive of space and understand spatial information [20]. For example, some children will solve simple jigsaw puzzles physically at first, and then later mentally. Physically, they will rotate a jigsaw puzzle piece to fit to the either the "picture" or the "form." They soon learn to perform these operations mentally.

- How can we support externalization of children's mental activities to connect cognition to their spatial physical environment?
- How can the physical and digital aspects of tangibles be used to support reciprocal mappings between spatial and mental representations?

The Development of Symbolic Reasoning

Manipulatives are objects (e.g., rods, blocks) designed to promote development of children's understanding of the world. Uttal summarizes that children under the age of seven may have difficulty relating physical manipulatives to other forms of representation (e.g., written) across contexts [21]. This stems from the difficultly young children have appreciating that a single object can represent two different things or be seen in two different ways. Uttal also cites research that describes how allowing children to play with an object may detract from their ability to see that object as representing something other than itself. A small model of a room cannot easily be viewed or used as a map of a real room if children have played with the model. That is, when they see the small room model as an object to be played with it is difficult for them to see it also as a model of something else. This research pertains to preschool age children. However, it exemplifies how the development of symbolic reasoning proceeds slowly and individually rather than all at once.

- How can we support children to build up meaning actively through explorations of the relationships between representations and actual entities which are being represented?
- How can we make mappings between representations explicit or easily revealed?

Dourish's case for variable coupling between intentional action and effect in order to allow elements of an interactive system to take on meaning is deeply relevant for how children develop new schemata [5].

- How can we design representations to communicate how they are coupled to the world in ways that allow children to manipulate and understand multiple levels of meaning?

Development as a Non-Linear Dynamic System

Recent infant studies (e.g., [19]) suggest that development (e.g., motor and cognitive) may be understood in terms of interactions of multiple local factors, each with relatively equal importance. Factors include: bodily growth, environmental factors, brain maturation and learning. Clarke calls this approach to systems design "soft assembly" and contrasts this to systems with centralized control [3]. Development of schemata can be viewed as complex adaptive behavior which emerges from physical experience in biologically-constrained systems. Schemata development requires the ability to perturb a system, explore misconceptions and revise thinking.

- How can we promote interaction-driven actions rather than prescribed interactions? (i.e., How can we promote dynamic generation of meaning through interactions between user and environment?)
- When and how should we provide fast, direct, real time feedback?
- How can we create a system that allows flexible interactions and intelligent adaptive responses which allow children to adapt thinking over time?

Another feature of soft assembly systems are external scaffoldings. These are external aids that can include interactions with other children, adults, or aspects of the environment. For example, children (and adults) often organize tangible objects as a memory aid.

- How can tangible qualities of objects and spaces be utilized as adaptable, external aids which support the development of new understandings of schemata over time?

CONCLUSION

The long term goal of this work is to design tangible play-based systems based on an understanding of why and how tangible systems can support cognitive development in children. The paper introduces four areas of cognitive development which may be relevant for the design of tangibles systems. Specifically, this work focuses on design to support action-based knowledge acquisition through active play and game play.

Concepts from embodied cognition and dynamic systems suggest that successful tangible systems will incorporate an adaptive, body-based style of interaction which leverages children's developing and existing repertoire of physically-based actions. Acquisition will be achieved through exploration with real time feedback of how things work.

Children often develop understandings of abstract concepts based on existing understandings of body-based and spatial concepts. Thus, tangible systems might be well suited to help children develop abstract schemata. Abstract schemata related to causality, time and spatial relations may be good candidates. Each new schema can be acquired through metaphor or analogy which utilizes existing spatial schemata and physical aspects of the tangible system. Understandings can be built up through game play levels.

Tangible systems inherently contain multiple representations. However, children slowly develop an understanding of object and referent. Thus, the mappings between physical and digital representations must be carefully designed and communicated in ways which are explicit, flexible and can be explored by children in game play.

These are only some of the important theoretically grounded design considerations. There will be others. Empirical user studies of children using experimental prototypes will reveal the importance and interplay of these factors as children play tangible games which help them develop new understandings of the world.

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Patcher: A Tangible Game for Making Ecological Simulations in Museum Settings

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ABSTRACT
We present a tangible game for collaborative construction of ecological simulations. The system has been designed for and evaluated in the context of school classes visiting the Nature in Sweden exhibition at the Museum of Natural History in Stockholm. Based on card-based interaction using RFID-technology, the system affords discussion and collaborative play, leading to animated simulations displayed on a large screen. We discuss how technologies like this afford playful learning experience, especially in collaborative activities such as field trips to a museum.

Author Keywords
Tangibles user interfaces, children's programming, physical interaction.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Patcher is a physical interaction space where children can create their own computer games and dynamic simulations. The system builds on and expands work in children's programming as it has been developed in the constructionist tradition by e.g. [9, 13]. A primary feature of the system is that it affords co-located collaborative activity, meaning that it can be integrated into settings that require group work, which are otherwise difficult to combine with computer use [see e.g. 2, 4]. The system has been designed and used in school environments as well as in an art gallery and a museum setting [5-7], and won much popularity both by children and grownups. The educators at the museum have expressed the values of Patcher primarily in terms of the possibility for groups of children to work together on a shared project. This means that it fits well both with how children normally move about in the exhibition space, as well as with educational theories that emphasise aspects of discussion and collaboration [e.g. 2]. The system also connects to a general trend in schools and at museums to make more extensive use of explorative learning with new technologies. Apart from pedagogical values, many children enjoy being able to create interactive play worlds, and to do that together with their friends.

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

Patcher consists of an interactive physical play surface connected to a computer application, which can be programmed using physical artefacts in the form of cards and blocks. By placing the blocks on the play surface a position, or 'patch', on the screen gets highlighted, where pictures may be added and programmed. There are different kinds of play cards, used to add behaviours and interactive properties to the pictures on the screen. There are also cards that let the user perform global actions to the system, such as playing, stopping and saving what has been created.

The open design of the system means that it is easy to create different applications for specific themes and domains. The example application that we present here is a system for making dynamic simulations of ecological systems, developed in collaboration with the Museum of Natural History in Stockholm. This application has been designed specifically for the Nature in Sweden exhibit, in which it has been tested with twelve different groups of visiting school classes. We present the technical setup of the system and describe a typical use situation, as well as some reflections provided by the educators in charge of the activities at the museum.

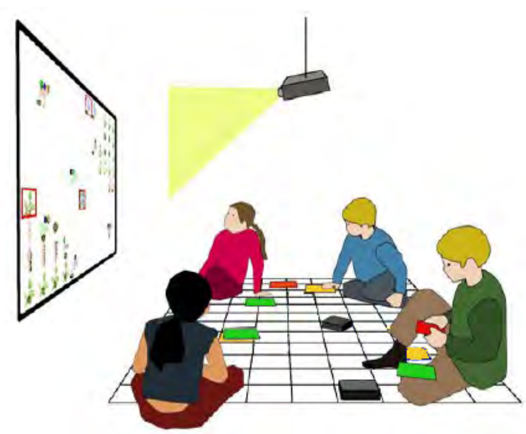

Figure 1. Overview sketch of the system in use.

BACKGROUND

The technical platform of Patcher has been designed within the context of several research projects on the theme of children's programming for different settings and activities. A goal of one of these projects was to explore new forms of computer modelling and simulation tools for children in the area of ecological systems. This work thereby extends research on groups of children creating and exploring computer simulations in PC settings [8, 17], participatory simulations [14] as well as research related to physical programming [e.g. 11, 12, 16, 18].

The system that we present here was initially aimed for programming in the general domain of making dynamic and interactive games. This means that focus has been on explorations into the specific aspects of making tangible artefacts that can represent objects and behaviours that somehow get visually represented on a screen. An important challenge has been to make the physical resources reusable, i.e., what is created for the screen should not get restricted by what can happen in the physical space (things on the screen should be able to get copied, grow and shrink, change colours, move, etc).

Since the resulting design takes the form of a physical space the system is closely related to research on the theme of spaces for collaborative storytelling activities (such as StoryMat [15], KidStory [1], and Pogo [3]), as well as interactive tabletop surfaces [see e.g. 10]. It also has some resemblance to a range of commercial systems targeted at children, such as interactive dance mats and robotic construction kits.

The design process has been accounted for in [5, 6] in which aspects of social performance and tangibility have been especially discussed. User studies have further emphasizing aspects of offline interaction, and how the tangibles afford collaborative construction of play rules, as well as in negotiating what is being created together [7].

Figure 2. A play card is placed on one of the readers. Note the relationship between objects on the screen and on the physical play surface.

SYSTEM DESIGN

The technical platform is based on a PC-based software system in combination with RFID and Bluetooth technology. Figure 1 shows the technical setup of the system, consisting of an interactive play surface with a grid of identifiable position tags underneath, a set of plastic play cards, wireless RFID-readers, and a visual display showing the system that is being built.

When users interact with the system, they add objects to the on-the screen representation by placing cards on top of the readers. A rectangle moves on the screen in correspondence to how the reader is moved on the play surface. There are several different kinds of play cards: pictures, behaviours, and control cards. Picture cards are used to place pictures at specific locations on the screen, while the behaviours are used to specify the functionality of pictures that have already been added. Behaviours are added to existing pictures by first placing the reader at a position where there is an object and then placing a behaviour card on top of it.

There are especially two aspects that distinguish Patcher from most other digitally enhanced play surfaces. The first is that the interaction space is physically separated from the display surface, i.e., a digital projection of the game is displayed on a vertical screen rather than on the actual interaction surface. This reduces the problem of directionality of differing user viewpoints when interacting around a tabletop display, as discussed e.g., in [10]. This also allows users to use interaction space in very flexible manner, such as spreading physical objects, and even sitting on top of the interaction surface, without obstructing the shared display (see Figure 2). Furthermore, using a vertical screen means that the system can make use of affordable and commonly available displays in homes and in schools.

The second aspect that distinguishes Patcher from most other tangible play systems is that the readers add an extra interaction layer between the physical game elements and their digital representations. This allows the same physical object to be used at several positions on the screen simultaneously. Users may for instance like to add many copies of a specific picture, something that would not be possible with a more direct mapping between each physical object and the pictures on the screen. A central function of the readers is also that they work as 'sights', allowing users to locate a position on the screen before adding something there (see Figure 2), as well as working as an aid in accounting for ones actions in the larger social setting. Moreover, this setup means that the readers could be used for actions beyond adding and modifying pictures and behaviours at specific positions on the screen, e.g., to perform global actions, such as playing, stopping, and saving a simulation or game that has been built.

The behaviours designed for the ecology game consist of a set of functions for movement, collisions, and for changing properties of objects. The pictures consist of plants and animals present in the exhibition at the museum, which can be assigned *colours*, and behaviours for *eating* objects with specific colours, as well as *moving* in certain ways. The activity thereby gets a character of a 'puzzle game', where each object must be given a colour that fits into the system as a whole. Figure 3 shows how objects have been added to a simulation created by a group of children. When the simulation is switched to run-mode, all the signs on top of the pictures disappear and the pictures start to animate and act according to their behaviours.

USER STUDIES

During the spring 2006, the system was taken into more systematic use by educators at the museum. 12 groups of 4-10 children in the age span of 8-15 participated in these activities, in the context of school trips to the museum.

The activity normally starts with the group gathering in the room where the system is located, next to the Nature in Sweden exhibition. An educator at the museum introduces the activity by giving a quick introduction to how the system works, and that the goal is for the group to design a working computer simulation based on a Swedish forest. Thereafter cards are handed out to the children, each with a picture of an animal, and the task is now for the children locate their animal in the exhibition space and find out what that animal eats. As the children get back there is a quick check that everyone has found the information that they needed, and the simulation building activity begins. The children gather around the play surface and generally start by adding a few pictures and then stop for a short discussion on which colour should go with which animal and which colours that each of the animals should eat. They keep on discussing and playing until they agree to test run the simulation to see what happens, and iterate until they have a simulation that they are happy with.

We have let the educators at the museum reflect on their experiences of using the system. These reflections have been grouped into three themes: explorative process, the subject content, and collaboration.

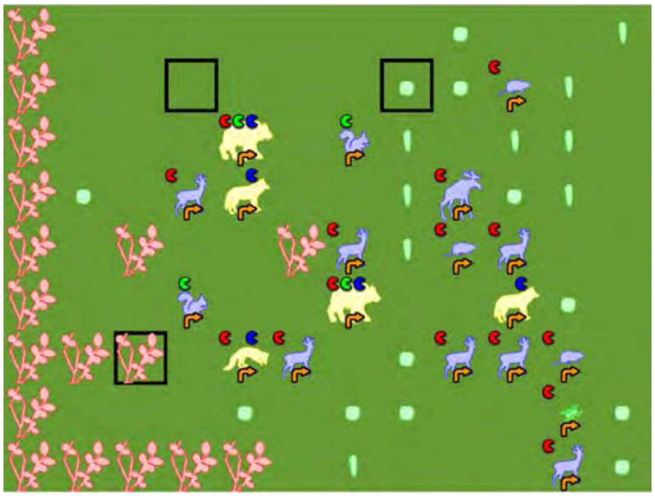

Figure 3. Screen shot of a simulation created by a group of children, while in construction mode. The black squares indicate the positions of readers.

The first theme that was emphasised by the educators was that combining playful activities with Patcher with explorations in the museum exhibitions supported a highly creative and explorative activity. A goal for the museum is not so much that the content is exactly right, but that it leads to meaningful discussions. Simulations built with Patcher provide one viewpoint, while going out in the exhibition and comparing how the same phenomenon is presented there provides another. Moreover, in playing with the system the children naturally set up, test, and evaluate 'hypotheses', which provides new perspectives of the subject content. This allows for unique experiences for each group of students, giving the children a feeling of personal ownership of the knowledge they have reached rather than having to rely on how things are presented in textbooks or by their teachers.

Second, the educators emphasised that working with Patcher supported children in reasoning about relationships in ecological systems. At the first test run the simulation usually runs out surprisingly quickly, all the animals starve too fast since there is not enough food for them to eat. The children can then discuss if they need to add more plants, or more of the small animals, and maybe a few less of the bigger animals like wolves and bears. The group might come up with a fairly elaborated ecosystem simulation, or sometimes something more imaginary. However, the importance of the activity is that it fosters discussions that capture some important aspects of ecological systems. Common topics brought up in the discussions are for instance that the animals that eat everything survive longer, that there are many more plants needed in a forest than there can be predators, and that everything is connected and interdependent. Thereby, the children get a sense of the interplay in natural systems in relation to more abstract concepts such as food-chains, food-webs, and food-pyramids. Conceptions such as these are often described as less engaging in school but in this setting they are experienced as engaging and fun. Furthermore, the educators emphasised that the experiences of working with Patcher can be used as 'anchors' from which interesting threads of discussion can be started, e.g. to discuss notions such as balance between consumers and producers, the concepts of herbivores, carnivores, and omnivores.

The third aspect that the educators emphasized was how Patcher supported collaborative activity in a fashion that allows for several students to be active concurrently. By being situated around a shared physical play surface, the actions of each participant become visually accessible to the others. This creates conditions for engaging in a rich collaborative activity. In playing with the system, the students have to discuss issues such as what objects to include, how they should be related, how many to include of each, etc. When they subsequently play and observe the outcomes of their initial decisions new seeds for discussion and explorations are provided.

DISCUSSION

The specific physical setup of Patcher is designed for creation of digital artefacts through a shared collaborative activity. Moreover, the application that we present here is aimed at for a specific use context, and would probably have a quite different design if intended solely for playing.

However, the tangible properties of the system, the cards, the readers and the interactive surface upon which all the interface action take place, allows for a highly open-ended construction activity that children can take ownership of themselves. The large screen allows users to collaboratively observe the outcome of what has been created, so that it becomes an integrated part of the discussions as well as for social play. While traditional computer games often lack the possibility to participate more than two people at the time, this system allows for a shared and social activity while still providing users to engage in a computer game like experience.

The design differs from the common approach to tangible interfaces, which usually aims to integrate the physical and digital domains as far as possible. We have instead attempted to preserve the specific qualities of both tangible and digital artefacts in combination by making a stricter separation between them. Based on this approach we hope to be able to further explore interactive artefacts and systems that let users blend properties of social, physical and digital activity.

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Dynamic Rules: Towards interactive games intelligence

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ABSTRACT
In respect to a state-of-the-art on intelligent tabletop games, this paper introduces a novel challenge that is the creation of a flexible and interactive tabletop framework in which game rules are re-definable by players at any instant of the game. This article discusses the importance of this aspect in the acceptance and personalization of the game, which is a key feature for the players' social interaction. The article first compares classical physical games with purely digital ones to highlight the key features of each world. Based on those features, the article classifies the current intelligent tabletop frameworks and highlights the unexplored dimensions. Finally, the article proposes a research agenda to build a framework for developing tabletop games supporting the dynamic redefinition of rules.

Categories and Subject Descriptors
H.5.2 [User Interfaces and Presentation]: User Interfaces
H.1.2 [Models and principles]: User/Machine systems
D.2.2 [Software Engineering]: Design tool and techniques

General Terms
Algorithms, Design, Human Factors, Theory.

Keywords
Tangible User Interaction, Tabletop gaming, Interactive Intelligence, Mixed-reality, Games rules flexibility.

1. INTRODUCTION
Tangible User Interfaces (TUIs) have recently shown a high potential for enhancing gaming experience, playful learning and for supporting social interaction and collaboration. TUIs are however only one way to build more general mixed reality games. Mixed reality games, as illustrated in the state-of-the-art of this article, tries to take the best of purely physical games and the best of purely digital games to create an augmented gaming experience. Our intuition is that mixed reality games should go further and aim to create novel paradigms of interaction that are superior to just the sum of the advantages of each world, targeting the synergy of both.

This article reviews existing tabletop games and compares classical tabletop games with digital board games in order to elicit the functionalities that are best in each world: physical versus digital. The aim of this state-of-the-art is to discover what are the challenges of mixed reality intelligent tabletop games, and how to go from augmented reality to a real mixed reality where the natural intelligence of human players and the artificial intelligence of computational assistant can create a synergy and lead to novel interaction paradigms that do not exist neither in the classical physical tabletop games nor in digital board games. The article further focus on rules dynamic reprogramming a feature that exist intrinsically in physical games and the related social interactions, that have disappeared from current mixed reality tabletop games. The article finally proposes a brief research agenda to tackle this research issue.

2. STATE OF THE ART
This state of the art first compares gaming in the physical world to gaming in the digital world exclusively with the goal to elicit the most important features and advantages of both worlds for gaming. The section then reviews the related works, i.e. the existing tabletop intelligent games, and classifies them according to the major functionalities elicited in the first subsection in order to highlight the major challenges to tackle in future developments.

Physical versus Digital games
One of the most important characteristic of classical board games is the face-to-face communication. Players sit around a table and communicate via speech, gesture, mimic and by the manipulation of tangible objects on the game board. The communication around the table is mainly public, and if two players want to share private information, they have to leave the table, informing other players that something is going on, or to correspond via codes hidden in standard communication modalities (facial expressions, speech, etc.). Moreover, in standard classical game, the game rules can be treated as fully flexible objects, house rules can be defined before a game session, properties of object can be re-defined, on the fly winning conditions can be dynamical added during the game by means of the social agreement between players. On the other hand, it is difficult to create new objects, or to redefine the game world. Finally, a drawback of the physical world is the huge amount of pieces and cards to manage, leading to a big amount of mundane tasks (sort of similar pieces, shuffling cards, etc.) and increasing the probability that a piece can be lost, what in certain cases can lead to the impossibility of playing.

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

In digital games the interaction between players is always mediated by the system and thus the communication can be either public or fully private (secret). Further, the degree of game rules flexibility is fixed by the developer of the game. Most of the time, parameters can be tuned at the beginning of the game session, after what they remain fixed until the end. Complementary to this lack of flexibility on the game rules side, the game board and objects are more flexible in the digital world; the game board can be more detailed and can dynamically change according to the game evolution.

Further, digital games offer some computational supports. For instance, the state of the game can be saved and restored in a future session; the machine can provide tutorials, visual cues and helps to support users in games with complex rules. Finally, mundane tasks are always performed by the system. Another aspect that provides the digital world is the ubiquitous dimension; players can be geographically distributed and communicate via network connections.

Table 1 summarizes the observations made above and groups the discovered key features in four major classes: communication, flexibility, support and game interactions. The set of chosen features is far from being exhaustive but should, in our opinion, embrace the most representative features for each provenance i.e. physical or digital as stressed in the table 1. When the feature is "mixed", its provenance is considered to emerge only from the synergy of both worlds.

Table 1. State-of-the-art tabletop systems: key features and novel challenges.

Features	**Physical**	**Digital**	**Mixed**	**Short definitions**	***STARS***	***Entertaible***	***TViews***	***TARBoard***	***MERL***
Communication									
Face-to-face				Human face-to-face interaction through natural communication channels (e.g. speech, gestures, physical contact, gaze, mimic, tangible interaction, etc.)	+	+	+	+	+
Mediated secret				Sharing private information between two or more players where either the content or the communication remains secret (e.g. private chat in on-line games)	+	-	-	-	-
Augmented private face-to-face				Two or more players sharing private information or virtual game objects in a fully secret manner (either the content or the communication act is private) without breaking the face-to-face configuration.	+	-	-	-	-
Flexibility									
Predefined rules				The set of rules that can be modified is fixed by the game developer and cannot be changed during a game session	+	+	+	+	+
Game rules				Rules of the game can be freely and dynamically redefined before and during each game session by the players	-	-	-	-	-
Game board				The game board can change dynamically	+	+	+	+	+
Game rules & board				The rules of the game can be freely redefined before and during the game. Similarly, the game board can change dynamically, as well as the relationship between rules and game objects (e.g. modifying, adding a object and redefining the related rules).	-	-	-	-	-
Support									
Computational support				State save, save/resume of game sessions, support for complex rules (e.g. evaluate complex winning conditions), help, etc.	+	+	+	+/-	+
Mundane tasks				Sort of similar pieces, shuffling cards, setting the board, etc.	-	-	-	+	-
Game Interactions									
Ubiquitous, distributed				Players could be distributed in space over a network.	-	-	+	-	-
Multimodal				The interaction with the game is possible via various modalities (speech command, gesture, gaze, touch, keyboard, mouse, etc.)	+/-	-	-	-	+
Tangible				The interaction with the game is done through objects' manipulation.	+	+	+	+	-
Tangible + multimodal				Tangible and multimodal interactions are combined and integrated.	-	-	-	-	-

Mixed reality tabletop game-platforms

In recent years, many hybrid board games platform have been proposed (STARS [2,3,4,5,6], Entertaible [9,10], Tviews [7], TARBoard [1], MERL & University of Calgary [8]) aiming at improving the player experience by augmenting the physical world of standard board games with computer capabilities. Table 1 compares these systems, and stresses which functionalities of standard board games have been preserved, which new ones have been brought from the digital world and how, by the mixing of these two worlds, some functionalities are lost or new ones emerge only in the mixed world. In the following list, the major observations are commented, where P, D and M, i.e. respectively Physical, Digital and Mixed, indicates the provenance of the feature:

- *Face-to-face communication (P):* It appears clear that a tabletop configuration is sufficient to preserve the face-to-face communication of classical board games;

- *Mediated secret communication (D):* All the platforms preserve the public and private communication forms in all their variants (implicit or explicit). Only STARS allows the use of other ubiquitous devices (such as PDA's, cellular phones, etc.). This kind of devices allows the exchange of private information or game elements without being suspected by other players (i.e. secret communication);

- *Augmented face-to-face secret communication (M):* In STARS a new form of secret communication between players emerged, that is an augmented secret face-to-face communication. Two or more players can exchange private information or even virtual game object in a fully secret manner, trying at the same time to dissimulate their relationships with mimics and speech;

- *Game rules flexibility (P) vs. predefined rules flexibility (D):* None of the examined platforms achieves the rule flexibility of standard board games. The game rules are fully implemented in the digital world and similarly to standard digital games, only a set of predefined rules can be chosen by the players;

- *Game board flexibility (D):* The game board is digital, either projected or on a LCD screen, thus all the platforms support the game board flexibility, i.e. the board can dynamically evolve;

- *Computational support (D):* All the presented platforms could offer some computational supports, since they embed a virtual representation of the game world and rules;

- *Mundane tasks (P):* The amount of mundane task that have to be performed by the players is directly proportional to the number of physical object used for the games. In most of the platforms (STARS, Tview, Entertaible), the number of object can be chosen as a parameter of the game, for example one can chose to use only pawns representing the players figures, which leads to a minimal amount of mundane tasks. In TARBoard, the player can only interact with the tangible object (tagged cards, etc.), and thus it is impossible to avoid for the players mundane tasks such as for example card shuffling;

- *Ubiquitous, distributed (D):* One of the interesting aspects that emerge in hybrid board games is the opportunity to mix face-to-face interaction between players sitting around a table with the potentials offered by on-line games. Potentially all the platforms can support this modality but only the TViews project implements it;

- *Multimodal game interaction (D, P):* The platform proposed by MERL and University of Calgary support multi-modal interaction. Commands to the game can be given through combined modalities, e.g. pointing (touch screen) and speech. STARS lets the player interact with the game through touch or using some external devices such as PDA. Further, feedbacks can be either visual (public on the table or private on the PDA) or audio (public on loudspeaker or private on headphones);

- *Tangible game interaction (P):* All platforms except MERL support interaction with tangible objects, which are tracked using different techniques (RFID, overhead camera detection, marker-based camera detection, electromagnetic or acoustic signal measurement, etc.);

- *Tangible + multimodal game interaction (M):* For the moment, none of the examined platforms offer the combination of tangible and multimodal interaction techniques. However, in all of them such functionality seems easy to integrate.

3. RESEARCH GOALS & AGENDA

Game rules flexibility

In [6], it is stated that in simple games, such as Backgammon, it might be better not to implement the complete game rules into the digital world. If no computer logic forbids rules' variation, it would be easier for players to modify them in the context of a particular situation, and to develop novel house rules. On the other hand, when the game rules are complex, e.g. the winning condition takes into account many parameters, computational supports would be helpful, which can not be achieved without letting the system be aware of the game rules. These two aspects motivate us to explore the possibility of redefining dynamically the game rules at a high abstraction level.

Dynamic rules redefinition is particularly suited for games that exist in many different variants e.g. the Mancala games (Awele, Awale, Ayo, Ourin, Wari, etc.). Players should be allowed to experiment one variant by simply redefining the corresponding rule before a game session, or even invent a new variant defining a new rule without prior knowledge of the underlying programming language but using a high level user interface.

In our opinion, letting the human natural intelligence and imagination interact in a natural and direct way with the artificial intelligence embedded in the virtual world could create a new synergy and lead to a novel interaction paradigm for games. The player will be able either to play a game in the standard way defined by the game creator either to free her/his imagination and experiment variants or fully novel ideas without being limited by the constraints of the physical world (materials, definition of new elements, etc.) and avoiding the lack of flexibility of the digital board by letting the system be aware of the new rules and of the role of the new objects (virtual and tangible) in a natural way.

An interesting use case could be an interactive test environment for game developers where novel ideas and game mechanics could be dynamically and easily evaluated.

Research Agenda

According to the previously presented state of the art, it becomes apparent that one of the most important features of standard board games, i.e. the high degree of flexibility of the game logic, has to be supported by intelligent tabletop games. Our major objective is to define a general framework in which users can easily and dynamically redefine game rules in a natural way. To achieve this goal we have planned to achieve the following tasks:

1. **Modeling**: Define a model suitable for the description of game logic. The logic can be decomposed in three layers: Game world laws, social laws, game rules. The game world laws take into account the topology and the entities affected by the “physical” laws of the world, which are global laws. The social laws affect the behavior of the players and of the abstract entities of the game; those are dynamic local rules that depends on the history of the game. Game rules control the score, and the winning condition of the game.
2. **Framework**: Design and implement a general game development formalism and framework. Further, our work in this task will target a general design framework helping a game designer in its design process by generating a on the fly test environment.
3. **Toolkit for rapid creation of multimodal and tangible interfaces**: A Toolkit for rapid prototyping of multimodal and tangible interfaces will be created to ease the redefinition of rules and game interactions through natural commands.
4. **Integration and applications**: A simple game (e.g. Awele) where the rules can be easily changed before each game instance will be first implemented. The design of the game will exploit the dynamic changing rules paradigm and the multimodal interaction possible. The challenge of this task is to fusion the framework with the multimodal interaction capabilities.
5. **Assessment and evaluation**: The goal of this task is to experiment our novel framework and interaction paradigms. Assessment will be performed through user evaluations both quantitative and qualitative.

4. CONCLUSION

This article compares classical tabletop games with digital board games in order to elicit the functionalities that are best in each world: physical versus digital. The aim of this state-of-the-art is to discover what are the challenges of mixed reality intelligent tabletop games, and how to go from augmented reality to a real mixed reality where the natural intelligence of human players and the artificial intelligence of computational assistant can create a synergy and lead to novel interaction paradigms that do not exist neither in the classical physical tabletop games nor in digital board games. The article further focus on dynamic redefinition of rules, a feature that exist intrinsically in physical games and the related social interactions, that have disappeared from current mixed reality tabletop games. The article finally proposes a brief research agenda to tackle this research issue.

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Collaborative Play Through Digital and Physical Interaction.

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ABSTRACT
This paper summarizes key points and findings of an interaction design research and development project coordinated between Carnegie Mellon University (USA) and Technishe Universitat Eindhoven (Netherlands). The interactive system concept introduced in this paper reflects focused research on collaborative play and presents opportunities for children of various ages to cooperatively explore shape grammar, cause and effect, and story telling through digital and physical interaction. This concept named "Lila," defined in Hinduism as "purposeless play," promotes the ideas of inquiry, spontaneity and causality as children explore the relationships of physical components and their subsequent digital visualizations. We explore the notion of "play" enabling children to experiment and subsequently learn by encouraging the ideas of shape grammar, exploration, visualization, and collaboration. "Lila" is a continuing research project that was tested with numerous children in Eindhoven, and continues to be refined and tested.

1. INTRODUCTION
An increasing portion of contemporary children's toys and products are "modernized" with electro-mechanical noise making apparatus (visual and auditory). This excessive overload of "bells and whistles" contributes to turning a normal household into what we call a "kid house," where toys and child-centric products visually, physically, and acoustically dominate the space. Furthermore, the amount of time children spend pressing buttons and playing with purely screen-based games may have an impact on their socialization and attention spans, and may raise their expectations for complexity. As a reaction to this, our research aims to capture the rich interactions of mechanical/physical toys while promoting embedded computing and digital technology. The opportunity here is to explore products that fuse physical and digital interaction to create new and rich interactions that engage the mind and body.

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

Over the past few years, there have been numerous projects that blend digital and physical interaction. Of note, 'POGO' (Rizzo et al 2003) used physical and virtual media to allow children to invent stories on an interactive table, and 'Playware ' (Lund & Jessen 1995) explored ambient intelligence in the physical play of children through a set of tangible tiles.

The opportunity in this space is not completely new, as these works are great examples of tangible interaction in play, however the blending of digital and physical components, and the structuring of interaction within a given context presents opportunities to explore how product form language can enable a synthesis of entertainment, engagement, and learning.

Figure 1. A "bells and whistles" and traditional toy, by comparison. Images from www.imagecave.com and www.reviewcorner.com

2. A NEW OPPORTUNITY
There have been many attempts to create products that can entertain a child like a television does, educate in an unconscious way, and engage a child's imagination. The unfortunate scenario is that many of these products are cheaply built, have exaggerated and poor quality acoustics, and are flooded with flashy and unnecessary features. The average lifespan is less than a year, as children grow tired and bored of the flash, and in some cases long for more direct response physical interaction.

Current products, such as those seen in Figure 1, cover a wide range in this spectrum. The LeapStart® Learning Table, shown in Figure 1, is an example of this imbalance in input and output. The exaggerated noises it sends in response to simple physical actions are not proportional. However, wooden blocks (also shown in Fig. 1), as primitive as they may be, balance action and reaction.

Building up blocks, and then knocking them down, is a clear way to show cause and effect to children in scenarios where distance, weight, form factors, and material have significant affect on the interaction.

3. DIGITAL+PHYSICAL+SPATIAL = FUN

3.1 The Search for Rich Interaction

In order to successfully engage children in our defined world of play, we needed to understand what sort of tangible interactions would be meaningful to kids of varying ages. The focus of our project centered on interactions between young siblings within an age range of 1 to 9 years.

With digital cameras and camcorders in hand, we went into homes to inquire and observe the everyday lives of families such as these (See Figure 2). In particular, the interactions between siblings during play, structured activities, and mealtimes were crucial to our inquiry process, in order to discover opportunities where the children could benefit from more collaborative interactions while their caretakers might be relieved momentarily from constant supervising.

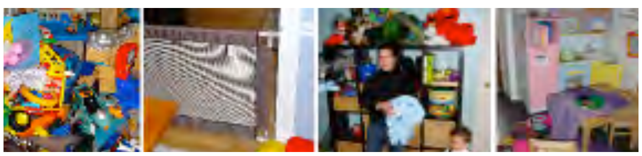

Figure 2. Data collected from contextual inquiry shows everyday lives of parents with small children. Photos by Julia Frederking

One of our key findings throughout this process was the apparent stress parents endured to avoid their older children feeling resentment toward the younger sibling. Considering the varying abilities of children, we explored different kinds of interactions within one product/space – viewing the behavior of the children and the parent(s) as choreography. One of the challenges of supervising more than one child is keeping them in one space simultaneously, which is why we saw an opportunity for our product to create a larger sense of space. This idea also afforded the concept of physical play, incorporating whole body movement around the product space in addition to minor movements within the product space. Essentially, an approach to "containing" the children in a defined space without physical barriers, such as gates, and concentrating activity around focused interactions was stated as being most desirable for parents.

Within our contextual inquiry, user studies, product reviews, and anecdotes, an opportunity emerged for a standalone smart product that enables children to invent, explore, and create relationships between physical and digital elements. Such a product must have the ability to provide a seemingly infinite array of pathways for interaction, a sensitive use of materials, and exhibit a metamorphosis between its active and inactive states. With careful structuring of physical and digital input, and digital output, the system would provide an antithesis to the current array of over-stimulating and desensitizing products commercially available.

With these goals in mind, a set of design criteria guided concept development. This criteria included the following: enabling children of varying ages to play simultaneously; integrating natural materials and clear visual language to create a "quieter" visual presence; and, defining a virtual and physical play space through the combination of physical elements, digital interaction and environment.

3.2 Establishing a Virtual Play Space

Ryan and Sarah are anxiously awaiting their names to be called at their family pediatrician. To make the time pass, they decided to play with "Lila" while they wait. Sarah, age 3, is attracted to the soft looking wooden pegs, while her brother, age 6, goes right for the touch screen. Sarah shuffles through the peg collection, and begins to plug them into the board on the table, while Ryan starts drawing a picture on the screen with his fingers. After a brief moment, they both smile in amazement at the screen as Sarah's shapes begin to form into a visualization of a tulip growing from a small seed. Ryan is intrigued and decides to make the garden grow even bigger by adding grass and more flowers alongside Sarah's tulip. They are both proud of their creation, and call their mother over with excitement. Ryan tells "Lila" to replay their story, and the family watches as it is projected on the wall.

The "Lila" concept therefore integrates three key components: a smart pegboard, touch screen for input, and a mini digital projector to display the visual outcomes. The pegboard creates digital animations from combinations of physical wooden pegs placed on the board, the digital touch screen provides a child with a quasi-authentic painting experience to create drawings and backgrounds for the animations being created, and the projector brings the imagery into the real world to define the virtual and physical play space (Shown below in Figure 3).

Figure 3. "Lila" defines a sense of space by concentrating activity around its form.

4. TANGIBLE PLAY / DIGITAL WORLD

4.1 No Instructions Needed

The act of playing, involves activities that bring amusement or enjoyment, especially enhanced through spontaneous activities and serendipity. Playing is an innate ability that is unscripted and often includes discovery.

Our approach to play and learning, in this context, is based on making things tangible and intuitive, providing children with the opportunity to solve problems through experimentation and learning through trial and error.

"Lila" emphasizes experimentation through cause and effect scenarios involving parings of objects and actions that can lead to layered images, complex sequences, and stories.

4.2 Tangible Graphics: Story Telling through Exploration and Visualization

Within "Lila," the concept of tangible interaction is a bridge between the advantages of current technology (touch screen, sensors, and projector), and traditional "hands-on" play (wooden pegs) as means for a child to communicate with the software. Our aim was to make the digital components almost disappear by blurring the lines between the virtual and physical worlds.

Figure 4. Projection, touch screen "notepad" feature, and unit in its closed position. Photos by Wouter Walmink and Michael Cruz.

Animations are generated by experimenting with combinations of physical wooden pegs placed onto the "smart" pegboard. When a peg is first placed into the pegboard, a static graphical representation shows up on the touch screen. As subsequent pegs are placed onto the board, the program recognizes combinations, and a specific animation is then created.

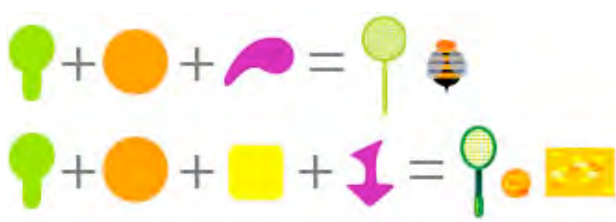

Figure 5. The outcome of the animation is dependent upon the combination of pegs put onto the pegboard.

By design, this system is simple in appearance. In reality, there is a methodology to creating the animations that children will discover quickly. "Lila" has two different types of pegs. The light colored pegs are the object pegs, and the dark colored ones, represent actions. In order to create an animation, the child must first plug in 2 or more object pegs, followed by an action (Shown in Figure 6). Each combination is recognized by the system, and an appropriate animation is generated. The action peg is how a "sentence" is ended, and thus defines what the object pegs will represent. Through this object/action pairing, "Lila" abstractly introduces the idea of nouns and verbs with a beginning, middle, and end to each action and sequence.

The object pegs consist of simple nondescript shapes, but when translated to a digital graphic, each specific object is determined by the combination of objects and action placed onto the board (See Figure 5). Here, a circle can represent many things, including a sun, ball, ring, and cup. With so many possibilities we found that children repeatedly tried shapes to discover how the action pairing affected the object visualization.

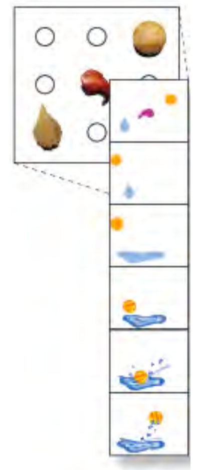

Figure 6. A Sample animation created by the combination of three wooden pegs.

Since the graphic representation would appear in real-time on the screen with peg placement on the board, simplicity was a necessity to being able to identify objects quickly. In keeping with the same style, the interface on the touch screen (Shown in Figure 7) is also simplified to be more intuitive. The framing of the screen emphasizes the child's work, locating iconographic hot keys and buttons on the periphery. The digital note pad/art board behaves similarly to real tools and paper where drawing instruments are represented to scale, move and respond like authentic tools, and behave in response to physical movement of the child's hand - to turn to a clean page, the child drags the bottom corner up towards the spiral.

Figure 7. The digital notepad for drawing.

4.3 Making Connections

The concept of turning a three dimensional shape into a two dimensional pixel-based object on screen presents the opportunity to pair shapes and color to reinforce this specific shape language for young children and novice users. The pegs (as mentioned previously), along with the graphics, have been assigned specific attributes in order to create common threads that the children will use to make the translation from object to graphic. For instance, every time the square shaped peg is used, it is represented on screen as being a yellow object, and every time a circle peg is used, its objects are orange (As Shown in Figure 8). Every peg is assigned a different on-screen color. Digitally, the action pegs never change shape, and are always purple in color. The action pegs are the only instance in which purple is used in the graphics, thus guiding the children to see this connection.

Figure 8. Sampling of possible object translations from basic shapes.

4.4 Collaboration

While children can play independently at the touch screen and the pegboard, initial testing revealed that the geometry of "Lila" encouraged children to play cooperatively as they explored object/action combinations together.

By design, the child at the pegboard creates the specific scenarios, setting the primary cast members and actions. The child at the screen provides the context and embellishes the setting through drawing. Through initial testing we saw that a benefit of a tangible user interface like the pegboard and touch screen combination of "Lila" enables collaborative interactions where each child had different input and responsibilities, and both shared ownership of the final product.

5. MARKETABILITY

5.1 Growth

The form of "Lila" was designed to be fairly neutral and timeless in appearance. In addition, the computer system/module can be upgraded or replaced, supported with periodic software enhancements and packages. Historically, toys and technology products have extremely short life spans before planned obsolescence makes them worthless; however, we hope that products like "Lila" provide a platform for products that can be customized, enhanced and adapted to the varying abilities of players and potentially grow in complexity and capabilities as a child ages.

5.2 Possible Applications

Public places such as hospitals, waiting rooms, museums retail spaces, doctors' offices, airports, schools, or anywhere children wait, are potential venues that would benefit from having a product like "Lila". Additional possibilities for "Lila" include components that could assist in teaching language to Autistic children, visually demonstrate health scenarios to critically ill children, or enable a classroom of children to write a story together.

6. CONCLUSION

While more thorough user testing of "Lila" is still being conducted, initial rounds of testing did yield positive feedback from parents, interaction design professionals, and most importantly, children. The children demonstrated an understanding of the cooperative nature of "Lila," with older children generally gravitating to the touch screen, and younger ones to the wooden pegs. In a couple cases, an interesting relationship also occurred, which we had not anticipated. The parents became engaged in the storytelling, as opposed to standing back. "Lila," in form and function, was just as intriguing and attractive to the adults as it was to the children. This extra level of cooperation could play a key role in expanding "Lila's" capabilities to be even more inclusive and encourage adult participation. "Lila" is intended to exemplify intelligent and simple interaction in a unique product form and to show how synthesizing tangible and digital interaction with open-ended storytelling can create a cooperative activity for a broad range of ages.

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Tangible and Collectible Entertainment System with Capsule Vending Machine

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ABSTRACT

We developed a tangible entertainment system that enables to play video game with physical collectibles as game components. It consists of a capsule toy vending machine with LCD panel, capsule toys with embedded RFID tags, an RFID sensor board and a computer.

Nowadays a huge amount of collectibles is sold: baseball cards, dollhouse miniatures, character figures, candy tins, and so on. Usually, collectibles are finely formed so that they satisfy owner's desire of possessions. On the other hand, collectibles in video game become popular. Those collectibles often have some special features such as magic power, but lack neither tangibility nor attractive form.

Our system is designed to combine these two advantages of virtual and real game components.

1. INTRODUCTION

In recent years, there has been a significant effort to develop tangible game components, that externalizes game components of video games from inside to outside of video display. Tangible game system provides intuitive interface that emulates traditional board games that are familiar to us, and enables to combine both advantages of board games (tangibility, intuitive interface) and video games (flexible input and output, computer aided game play).

Currently most of effort is aimed at externalizing game components such as player's pieces or scoring markers. Basically these components are used during a game play. Players do not own those components before a game, and they return the components after the game although they temporarily own some components during the game.

On the other hand, collectable game component is becoming popular. For example, many kinds of trading card games,

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

Figure 1: System overview of Narrative vending machine

e.g. "Magic: the gathering", are developed and played all over the world. Not only in table games, collectibles can be seen in video games too. For example, in "Animal Crossing: Wild World"[1], players can collect various collectibles such as cloths, insects or fossils. Especially in multiplayer network games, such as "Ultima online"[4] or "Second Life"[3], collectible is very popular and important game feature.

Usually, collectibles in real world such as miniatures or trading cards are finely formed or printed so that they satisfy owner's desire of possession. On the other hand, collectibles in video games often provide special features. Typical instances are magic items that provide special power to a player. Moreover, some video games give special bonus to the player who completed all of collectibles in the game world. In other words, those collectibles give some practical merits in the game world to players who won them.

We developed a tangible entertainment system that exter-

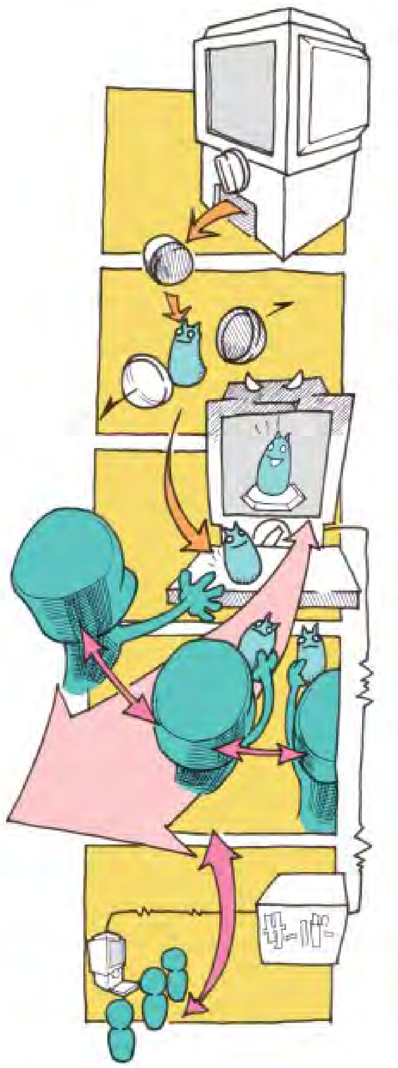

Figure 2: Application scenario of the system: the player purchases a collectible (randomly selected), then put it on the sensor board to play the game. The player can put more collectibles simultaneously, and cooperate with the other players. The system can be connected to the other system via the net, that allows competitive online game.

nalizes collectibles in computer world and enables to play with them as tangible game components. We hypothesize that our system not only satisfies players' desire of possession, but also improves the game experience by allowing to play the game with the tangible collectibles.

2. SYSTEM ARCHITECTURE

Our entertainment system consists of a collectible vending machine, a sensor-embedded game board, and collectibles. The vending machine has a LCD on its front surface and it is connected to a computer. Collectibles are played on the game board. The sensor in it recognizes collectibles and transmits their IDs to the computer. Figure 1 shows an overview of the system.

Figure 3: Two types of RFID tags.

At the beginning, a player insert a coin to the vending machine to buy a collectible, then a capsuled collectible is dispensed. Typically a collectible is selected randomly. The player opens the capsule and put the toy on the game board to play the game. The player can put any collectibles of his own collection. Cooperation or trading with the other players is allowed.

2.1 RFID Tag

RFID tag/sensor system is used to recognize collectibles on the sensor board. We employed Nippon Signal's IC tag reader that enable to scan at most 40 RFID tags on a sensor board simultaneously. Its scan range is 5 cm above the sensor, and it took around 1 second to scan 40 tags. RFID tags are shown in Figure 3. We embedded these RFID tags into collectibles. The current system recognizes the type and numbers of collectibles on the game board, but does not track the positions of them. However, it would be able to support positional input by using multiple sensor boards or some other sensing device.

2.2 Capsule Toy

Capsule toy and capsule toy vending machine are very popular culture in Japan. We employed a traditional capsule toy vending machine that is operated without power. The diameter of capsules is 48 mm, therefore the RFID sensor can recognize tags in collectibles on the board certainly.

3. APPLICATIONS

We developed two applications on this entertainment system.

3.1 Narrative Capsule Toy

The first application consists of six characters and the system shows their stories by animation. Figure 4 shows four of them and a capsule. Each of them has their own background story and players can see the animation movies when they purchased a collectible. When a capsule is dispensed from the vending machine, the capsule is caught on the sensor board and it is recognized, then the corresponding movie is shown on the display.

Then when an additional collectible is put on the board, the

Figure 4: Figures and capsule

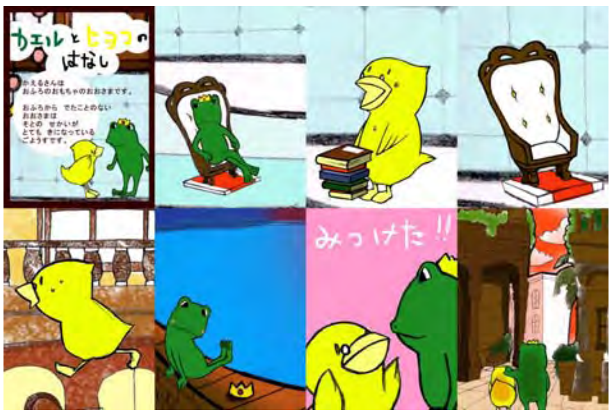

Figure 5: Screenshots of animation movie of Frog and Chick

sensor recognizes two characters, and the system shows a movie corresponding to the pair of the characters. Figure 5 shows some screenshots of the movie of “Frog” and “Chick”. By introducing multiple RFID tags sensing, it enables to provide variations of story telling and the players have fun of discovering the stories.

Because all tags are different to each other, the system can recognize not only the type of collectibles, but also the number of them. Therefore, it is able to provide varied result according to the number of the collectibles. For example, when a “Duck” and a “Chick” are put on the board, the duck teaches how to fly to the chick, but it will not succeed (Figure 6, left). However, when more than three ducks are put with the chick simultaneously, the result will be changed (Figure 6, right).

3.2 Battle Game

Our second application implements a semi-realtime battle game (Figure 7). The basic architecture is same to the previous application, but this system allows the player to put or remove collectibles at anytime during a game. This application provides five characters (Figure **??**, 9) and each

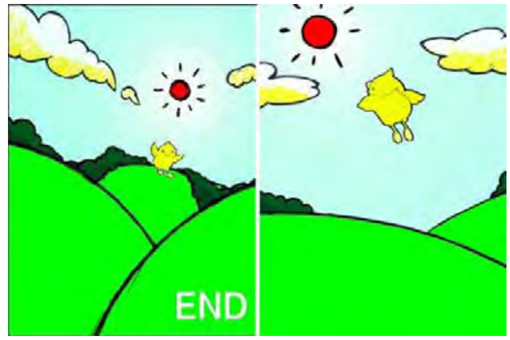

Figure 6: Variations of the result

character has different properties.

At the beginning of a game, an opponent character is displayed. The task of the game is to bring down the opponent character, but each character has different weakness and the player should to put appropriate characters in appropriate sequence. Currently the game rule of this application is quite simple, like “paper-rock-scissors”. If the appropriate character is not put within seconds, the player lose the game.

The game rule would be able to complicated by allowing positional input, or parametric input that is introduced in the previous application. In addition, we plan to introduce multiplayer competitive game over the network. [1]

4. FUTURE WORK

Currently each collectible has a unique ID in a tag, but the data is static. But the RFID tag system we employed allows to rewrite the data from the sensor board, so that status of the character can be stored in the tag. This will expand the design possibility of the game, for example the character can grow after the games, like role playing games.

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[1]This kind of game application is already released as computer-aided collectable card game, “Sangokushi-taisen”[2]. Each game cabinet has a flat sensor board and each player manipulates multiple cards on it. The type and positions of the cards are recognized. Two players battle against to each other over the network.

Figure 7: System overview of Battle game prototype

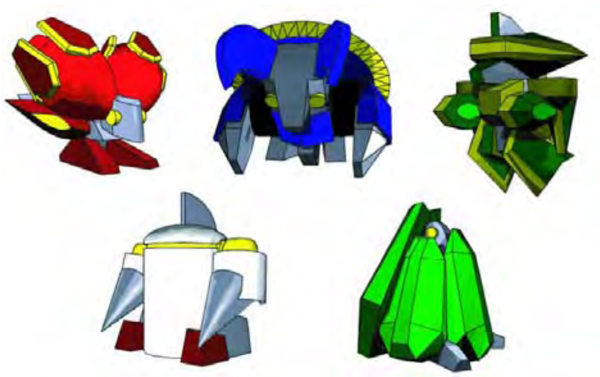

Figure 8: Characters of Battle game prototype

Figure 9: Figures (mock-up)

Going through digital versus physical augmented gaming

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ABSTRACT

This paper presents three systems that explore the use of tangible user interfaces to enhance gaming experience and physical interaction with digital information. TJass is an augmented reality game that extends regular card playing, without modifying players' habits, with computational supports, in particular with a learning by trial assistant. Elcano is an augmented virtuality system, augmenting digital multimedia information management with physical access and allowing the creation of multimedia albums that can be associated to tagged personal objects. Finally, Phong is a mixed reality game, which uses localization of objects as a solution to augment the players' physical implication in the digital board. The paper presents the three systems and briefly presents the lessons learned from their implementation and user evaluations.

Author Keywords

Tangible Interfaces, Augmented Reality, Mixed Reality, Tabletop Games

ACM Classification Keywords

H5.2. User Interfaces.

INTRODUCTION

Mixed reality games, as illustrated in this article, can augment various aspects of games purely digital (collaboration, socialization, communication, cognitive load) and also games purely physical (flexibility, assistance, modalities of interaction). The challenge of mixed reality games is first to take the best of each world to create an augmented gaming experience and further to create novel paradigms of interaction that are superior to just their sum.

This paper presents three systems we developed that explore three paradigms of interaction: the systems *TJass* [5], an *augmented reality* game that extends regular card playing; *Elcano* [1], an *augmented virtuality* system that allows tangible browsing of personal information; and finally, *Phong* [6], a *mixed reality* pong game, combining augmented reality and augmented virtuality to augment gaming experience.

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

AUGMENTED REALITY: TJASS, A SMART BOARD FOR AUGMENTING CARD GAME PLAYING AND LEARNING

The goal of Tjass [5] is to extend card gaming with computational aids in a non intrusive and transparent way to support both beginner and expert players and to enrich their gaming experience. In comparison to another similar system mentioned in [7], which uses TFT display, the output devices in Tjass are designed for a maximum transparency and a minimum intrusiveness. Furthermore, while help is provided by a relative external PDA in the Smart Playing Cards project [7], Tjass beginner's assistance is directly available on the game board. In the traditional jass card game the players have to count and notate manually the scores. As well they need to observe continuously the status of the score to determine the winner team. In addition the rules of jass are complex and require keeping in mind the overview of all played and remaining cards. Therefore beginners often have difficulties to learn the game. Tjass will disburden the players of these tasks by (1) counting and displaying the score automatically in real time and (2) putting at beginner's disposal a decision assistance to teach them the game.

TJass avoids the use of mouse, keyboard and monitor, in order to preserve card players' habits and guarantee non-intrusiveness. Instead an augmented game board and real cards have been preferred. Tjass design has been guided by this motto, augmenting gaming experience without modifying players' traditions. Each card is marked by an RFID tag that identifies it uniquely (Fig. 2d). An RFID reader is then used for card identification and game observation. The Tagsys Medio L200 RFID Reader [8] middle range reader that we used is designed for 3D and volume detection applications. The reader is able to read a high number of tags simultaneously. At the distribution phase, the timesharing between the four antennas is done by tickets which correspond to missing cards. The more tickets an antenna owns, the longer time it is active. At the playing phase, the active player's antenna has a higher reading priority than the others, which optimizes tag reading performance. Physical devices built using Phidgets [2] are used for additional interaction during the game. Fig. 2a illustrates the setup of Tjass. On each side of the table resides a player. Each of the 4 players is supported by one antenna which is attached under the table right in front of him (Fig. 2c). The card detection zones for the players are marked in Fig. 2a. The playing zone is the square in the middle of the table. To get into that zone each card passes through the sensor field of an antenna. This feature guarantees habitual playing comportment like in the traditional jass. To help the players know who shall play, the yellow led in front of the active player will blink. If a played card is valid according to the rules of jass, the green led lights up and a discrete sound is played. If the card is not valid, the red light will blink and the player should play another card. This prevents mistakes and denounces cheating attempts. Other sonorous outputs acknowledge for several events like announces, end of game or trump selection. Another RFID reader, a single tag short distance reader, allows users to define the trump color in a tangible way by putting trump tokens on the antenna. When a round is finished, the points are calculated and added to the score. The round points and the global score are then shown on each player's LCD (Figure 2a). In addition, to provide a constant score overview, the score needle (Figure 2e) of each team, animated by motors, increases in real time to give a tangible visual output. Decision support can be obtained pressing the help button (Fig. 2a). The button is useful to check if a card is optimal, good, miserable or denied to play, which is indicated by a multicolor led. For this, the button has to be pressed while the card to be tested is passed over the sensor field. Thus the game can be learned by playing the game itself, following a "trial and error" concept. Finally, the system is modular and thus allows rapid prototyping of card games (poker, Bridge, etc.) since it is based upon a framework that manages input and output interfaces, e.g. phidgets, RFID readers, sounds, etc.

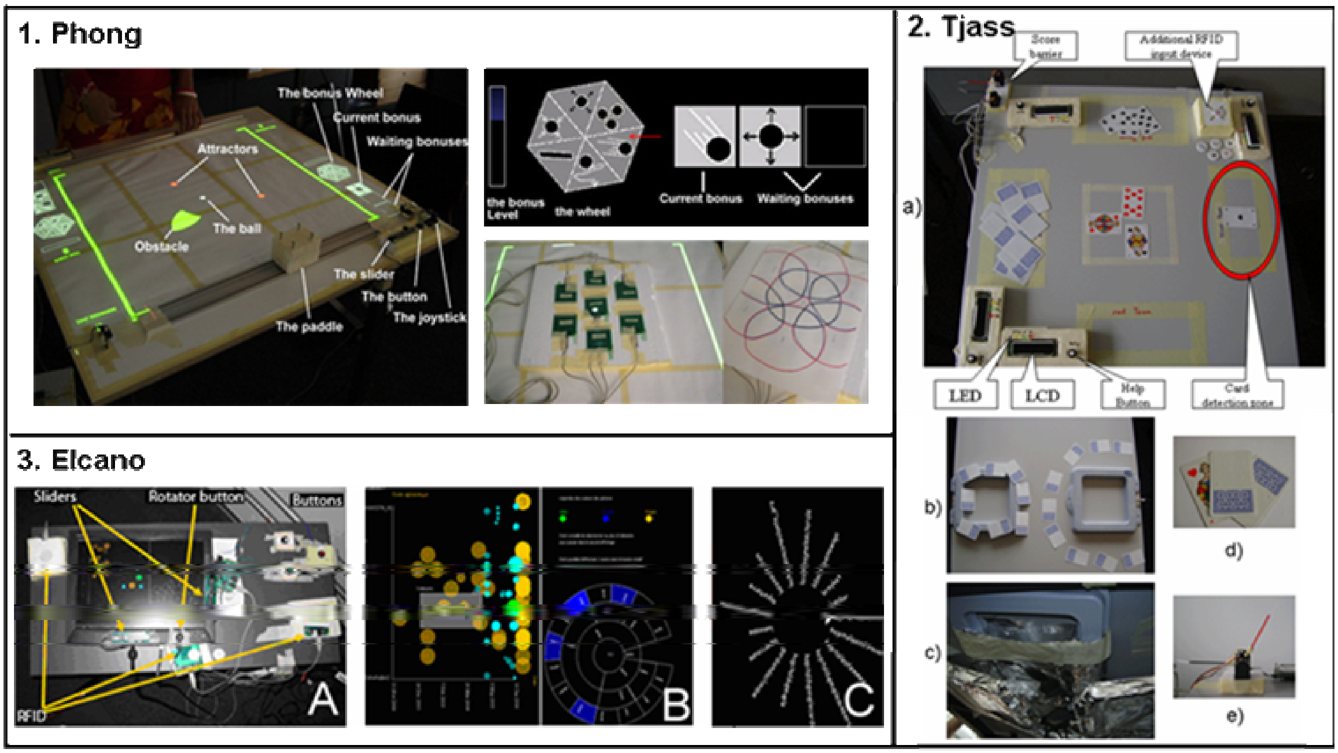

Figure 1: Phong, Tjass and Elcano, exploring augmented and mixed reality gaming and tangible multimedia browsing.

Transparent and pleasant for learners

Tjass is a good example of augmented reality system that supports real card playing with computational assistants such as score counting, winner determination, and decision support. A recent user satisfaction test has shown that Tjass satisfies players because of its usability, its preservation of the game physical playability and the augmented computational supports. Furthermore, it has appeared to be a suitable solution for beginners to learn card games in real context and to take decisions by their own, without disturbing the other players and the normal game process.

AUGMENTED VIRTUALITY: ELCANO, A TANGIBLE MULTIMEDIA BROWSER AND ORGANIZER

Nowadays, it is possible to store a great quantity of documents on a storage medium and it won't stop increasing. A natural drawback is that browsing becomes increasingly difficult. The goal of the Elcano project [1], similarly than in [3], was to develop a simple tangible browser providing original views of the multimedia content of a storage medium, facilitating navigation using tangible sorting and filtering mechanisms and interactive visualizations. In this case, a memory stick is used as storage medium to provide mobility to the user.

Elcano provides interactive visualizations to ease navigation through a great quantity of documents. The main visualization (see Figure 3b) is divided into two parts. On the left part, documents are plotted according to two axes and are represented by circles in the resulting scatter plot, different circle colors being mapped onto different types of files (jpg, mp3, avi), and a circle's size representing the actual size of the document it stands for. To navigate in this plot, i.e. to select a subset of documents, two physical sliders, each one being connected to one axis, are used to move a rectangular selection box. A special "rotator" button may also be turned to resize the selection area, or pushed in order to zoom in and out in a cyclic way. In the case of zooming in, the scatter plot is rescaled to contain the selected elements only. Hence the navigation space is narrowed down through physical filtering. On the right part of the visualization, a "sunburst" represents a sample of the tree structure of the memory stick. Directories to which belong the selected documents in the scatter plot are highlighted in the sunburst. This gives a compact preview of the selected documents' locations in the tree structure, rather than the exact directories containing the documents, which would take up more room.

When the satisfying subset of documents has been selected in the scatter plot, the user may switch to the documents wheel visualization (see Figure 3C) by clicking on the appropriate button. In the documents wheel, documents names are displayed around the perimeter. The rotator button triggers the rotation of the circle in order to select a particular document. Pushing the rotator button runs the selected document. Three additional buttons map onto other tasks: (1) create an album, i.e. a link between a personal object and a document, (2) read an album and (3) switch back to the scatter plot view. The technology used to attach a document to a personal object is explained in the next section.

Sorting and filtering algorithms as well as binding to personal objects are activated using physical tokens augmented with RFID tags. Two RFID antennas are used to control the visualization sorting algorithms. In the scatter plot visualization, filtering and sorting mechanisms are available. Filtering reduces the amount of documents displayed, while sorting algorithms applied on the axes of the scatter plot re-organize the layout of the documents accordingly. Three types of sorting algorithms are useful for any type of files: alphabetical order, modification date of file, frequency of use. The remaining sorting algorithms are suited to music files: album's date, author's name, real name of song, style of song, album's date. A third RFID reader allows users to associate documents to personal objects, in order create a direct link between one's digital memories and an object of the real world.

Rematerializing multimedia information for home

Although Elcano is not a game, it is a good example of augmented virtuality; the virtual world is augmented with physical access to information. Further, Elcano shows how tangible user interfaces can be used not only to manipulate multimedia digital data but also to allow end-users program their own links between digital information and tangible personal objects. A heuristic evaluation of Elcano has been performed by three usability experts to detect usability problems. Experts followed a list containing ten themes, which guided them in discovering 30 major usability problems, mainly falling in the category "Match between system and the real world". For example, the position of the phidgets was not found adequate. Most usability holes have been fixed and a satisfaction evaluation, on 8 users, conducted afterwards, showed encouraging results: users found the visualizations useful and most of them were in favor of using it for a home usage, although they experienced some difficulties to interact with the tangible devices.

MIXED REALITY: PHONG, AUGMENTING VIRTUAL AND REAL GAMING EXPERIENCE

The goal of the Phong project [6], contraction for Physical Pong, is to implicate players physically in digital games. Tangible user interfaces have proved to be an intuitive and natural mean of interaction [3], particularly useful to reduce the gap between digital and physical worlds, since objects can co-exist in both dimensions. A recent project, PingPongPlus [4], also dealt with an augmentation of a real ping pong game by projecting animations on the table. The purpose of Phong is to go further adding both physical elements to the virtual world and virtual elements to the real world, making it a good example of mixed reality system.

Phong's basic gameplay is inherited from pong, the most classic arcade game; each player moves his racket and tries to return the ball. Missing the ball makes the opponent scores. The main difference with pong is that the racket is no longer a virtual object, but becomes a real one. Besides, to extend the original pong gameplay, special actions can be triggered by bonuses collected by each player during the game. The first category of bonuses involves manipulating other physical controllers: a joystick, a push-button and a slider. These affect the virtual ball properties in an indirect way. A second category of bonuses allows players to place additional physical elements in a direct way on the game board, which affect the behavior of the ball.

Thanks to a beamer, fixed on the ceiling, and to a loud speaker, virtual items such as balls, scores, bonuses, are animated on the board and enriched with sounds. On the other hand, the principal interactor, i.e. each player's paddle, is physical. It can be moved can move horizontally to interact physically with the virtual ball (see Figure 1). Its position is detected by two IR distance sensors, one on each side. Three phidgets, placed on the right side of each player, are dedicated to bonuses manipulation and are activated when the player has reached a certain number of balls successfully returned. A slider controls the ball speed, the button launches an extra ball or blasters, and the joystick controls the direction of the ball. Certain bonuses, such as obstacles or attractors, modify the trajectory of the ball. We call them localization bonuses. They must be put on the game board, within one of the 25 areas that can be seen on the bottom-right side of Figure 1. The player uses a stamp to place a modifier directly onto the game board. No mouse or keyboard is needed to set the location of the bonus; instead it is directly placed on the board. The localization works with seven RFID readers which create 25 distinct zones, drawn by their intersections. The bonus location corresponds to the intersecting zone of radius of the readers that detect it. Since the readers do not work when they are too close to one another, they are switched on and off sequentially, rapidly enough not to disturb the game play.

When the bonus wheel (top-right of figure 1) rotates, a bonus can be caught. To stop the wheel, the player must push the button. The selected bonus is then put in the bonus boxes under the wheel. A maximum of three bonuses can be accumulated in the stack of boxes, which follows a “last in, first out” rule. A bonus is activated if it is on top of the stack, in the “current bonus” box. All bonuses last for a limited time, except extra ball that is not limited. The first category of bonuses, extra ball, speed and direction, do not need localization. To use these bonuses, the player has to push the button that is located on his right side to load them during the game. After that the player may manipulate, if necessary, the appropriate physical device to apply the bonus. If extra ball is activated, another ball will be sent simply by pushing the button. If the speed bonus is selected, the slider will be activated, allowing changing the speed of the ball, etc. To use the second category of bonuses, called the localization bonuses, namely attractors, expulsors and obstacles, the player has to load the current bonus in the stamp. This action is simple, he only needs to put the stamp on the virtual bonus box and wait for the sound that validates the transfer. Then he can stamp the game board where he wants the localization bonus to appear. If it is an attractor or an expulsor, the ball will be deviated from it. If it is an obstacle, the ball will behave like on a wall.

Good playability and augmented fun

Phong combines augmented reality with augmented virtuality to form a “real” mixed reality system, emerging from both physical and digital worlds. Phong is an augmented pong game with tangible interactors, allowing players to physically interact with digital elements. This interaction style puts players in between real and virtual worlds. A preliminary user evaluation of Phong, in the form of a satisfaction questionnaire, has shown encouraging results, i.e. high playability and good system reactivity, and in general players were enthusiastic because they could directly manipulate and control the digital world.

CONCLUSION

This paper presents three systems that explore the use of tangible user interfaces to enhance gaming experience and physical interaction with digital information. TJass is an augmented reality game that extends regular card playing with computational supports. Elcano is an augmented virtuality system, augmenting digital multimedia information management with physical access and allowing the creation physical multimedia albums. Finally, Phong is a mixed reality game, which uses localization of objects as a solution to augment the players’ physical implication in the digital board. Each system and interaction style provides advantages: Tjass has been appreciated for being not intrusive and very adapted for learners to play in real conditions with computational guides. Elcano has been valued for rematerializing information and creating tangible shortcuts to multimedia data. And finally Phong has been recognized fun to play for its novelty, since the interactions it proposes can not be mimicked in pure digital versus pure physical games. In the future, we plan to concentrate our efforts in building mixed reality systems that combine the best of the physical and digital worlds, in a complementary way, and hopefully bringing to light novel interaction paradigms.

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Wearable RFID for Play

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ABSTRACT
Radio Frequency IDentification (RFID) technology has recently been moving into everyday use contexts. Previous work has shown wearable RFID systems to be a viable mechanism for collecting data about a user’s interactions with her environment. In this paper, we present wearable RFID systems as a promising new direction in tangible game interfaces. We provide an overview of the affordances of RFID for game-play, and present some existing and future wearable RFID-based games. We also describe the construction of a cheap, easy-to-build wearable RFID system and present a how-to resource for other researchers interested in building off our work.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *input devices and strategies, interaction styles*;
H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces – *collaborative computing, synchronous interaction*.

Keywords
Wearable computing, RFID, tangible interfaces, game interfaces.

1. INTRODUCTION
Radio Frequency IDentification (RFID) is a popular technology that allows for easy proximity sensing of specially-tagged objects. Objects tagged with a small passive (unpowered) RFID tag, can be reliably sensed at ranges from a few centimeters to half a meter or more. All RFID tags contain unique identification numbers (sometimes along with other data) that easily allow for exact identification of objects from a very large set. Passive RFID tags are inexpensive (currently as little as $0.10 USD per tag), which makes it possible to tag large collections of objects.

Because of their low cost, RFID systems are becoming common for inventory tracking and other industrial uses. Government and commercial uses are quickly emerging, too: RFID tags can also be found in instant payment devices such as ATM/credit cards (e.g. Speedpass and Go Pass), passes for public transportation systems (e.g. BreezeTickets for Atlanta’s MARTA, or the CharlieCard for Boston’s T), and, most recently, inside passports. Even with these new uses, however, RFID technology is not yet likely to be found in most homes or offices.

In this paper, we explore wearable RFID systems. These are designed to be worn by the user for the purposes of recognizing her interactions with objects in her physical surroundings. Wearable RFID systems usually take the form of an RFID reader built into a glove or a bracelet. Recent research has made use of wearable RFID systems in the context of eldercare and activity recognition [[1], [2], [3], [5], [6], [7]]. Gaming is also becoming a popular theme in the development of wearable RFID systems [[4], [9]]. We wish to further explore the properties and affordances of these systems, with respect to gaming applications.

2. PREVIOUS WORK
Some of the earliest research in Wearable RFID technology was done by Schmidt, Gellersen, and Merz, who embedded a RFID tag reader’s antenna into a work glove [8]. The reader’s electronics, power, and a radio transponder were housed in a casing worn on the user’s belt. The authors presented two applications: “real world bookmarks” in which RFID IDs are mapped to simple web pages, and integration with mySAP.com, which allowed for tasks such as inventory management and logistics execution to be performed using the wearable RFID glove.

Much of the current work on wearable RFID systems focuses on activity recognition and detection of user interaction with objects. One major application of this research is in assisting with elderly care – specifically with recognizing Activities of Daily Living (ADLs). As part of this, their studies of wearable RFID focus on it as a sensing platform for activity recognition.

Philipose and colleagues at Intel Research Seattle and the University of Washington have developed the Proactive Activity Toolkit (PROACT) [[6], [7]], a probabilistic system for recognizing and recording ADLs. PROACT uses RFID tags placed on household objects, a wearable SkyeTek RFID reader embedded in a glove, and a probabilistic activity-inferencing engine. The wearable reader has a range of approximately three inches around the user’s palm. The PROACT system proved to be durable and had encouraging precision/recall for many simple activities. A more recent project, Guide [[2], [5]], also addresses the problem of activity recognition, but with the intent of improving the variety of activities that can be recognized.

The two wearable RFID systems developed by Intel Research Seattle scientists for the projects just described, and others, are the iGlove (Figure 1) and iBracelet (Figure2) [3]. The iGlove uses the SkyeTek M1 13.56 MHz reader for its RFID reader, and a Mica2Dot mote radio to send tag data to a nearby computer. The

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI’07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

Figure 1 The iGlove from Intel Research Seattle.

RFID-sensing antenna consists of a single coil of wire sewn into the palm of the glove. The read range of the iGlove is tuned to a few centimeters, so as only to detect tags within the user's grasp. Due to the miniature size of the iGlove's components, they are easily encased in a small box that sits on top of the user's hand.

The iBracelet is a re-configuration of the iGlove's components that fits in a bracelet to be worn by the user. The antenna of the iBracelet loops around the user's wrist. The read-range of the device is increased to 10cm, allowing fairly accurate detection of objects that are grasped near their RFID tag. Though the iBracelet is more prone to detect false positives (because of its increased read-range), its aesthetic and non-intrusive form make it quite suitable for everyday use.

ReachMedia [1] is a system developed by Feldman and colleagues to detect users' interactions with everyday objects. Similarly to the iBracelet, the system takes the shape of a bracelet worn around the users' wrist. The RFID reader used is a SkyeTek M1-mini, which has a diameter of less than twenty five millimeters and a thickness of less than two millimeters. Information about the tagged objects that the user is holding is transmitted to a host computer. In addition to object detection, the ReachMedia bracelet uses accelerometers in order to allow for gesture-based input.

The authors are aware of only two wearable RFID games that have been implemented. Tagaboo [4] is a multi-player children's game loosely based on the game of tag, and the Real-Life Sims (RLSims) project [9], which one of the co-authors was involved with, is a game inspired by the computer game The Sims[1]. Both of these will be discussed in more depth in section 4.

3. OFF-THE-SHELF WEARABLE RFID

While previous research into the design and applications of wearable RFID systems is extensive, all of the systems that have been described are expensive and challenging to construct. The SkyeTek RFID readers are expensive devices, with current prices from the manufacturer being around $1000 USD for a development kit. The amount of electrical engineering knowledge that goes into building the systems is also non-trivial. Thus, the goal of our research is two-fold. First, we wish to further explore the design space of wearable RFID-augmented games. At the same time, we wish to provide a resource for other researchers (as well as amateurs) looking to construct their own wearable RFID systems, especially when faced with limited funds, time, or hardware knowledge. In this section of the paper, we describe our current wireless RFID reader prototype and our further plans for its development. We are in the process of building a how-to website for interested parties, which will be available at http://www.gvu.gatech.edu/ccg/resources/wearableRFID.html

3.1 Building a Wireless RFID Reader

We have built a prototype of a wireless, wearable RFID system from a SonMicro SM3005 RFID Development Kit[2] and a Socket Cordless Serial Adapter[3]. The SonMicro SM3005 Kit comes with an RFID reader and with two detachable, quasi-flexible antennas which may be inserted or sewn into a glove. The Socket adapter allows a computer to communicate with the RFID reader's serial port over Bluetooth, giving an approximately 10 meter range of operation. The two devices can be powered for a number of hours off a regular 9V battery. The SonMicro RFID reader is pre-built with a 9V battery connector, and the Socket can be powered by running a lead from the battery's positive terminal to pin 9 of the SonMicro reader's serial port. Figure 3 shows our current prototype.

The reader from the SonMicro SM3005 kit works in the 125 kHz range. Though 125 kHz tags are slightly more expensive than 13.56 MHz tags, they are not affected by water or metals. We use 30mm Global Tags from Phidgets[4] (many different tag styles are available). With these tags, the smaller of the two antennas gives us perfect detection within 4-5 cm of its center, which is sufficient for detecting tagged objects which are touched or grasped.

Our current prototype consists of approximately $200 USD worth of hardware and requires a minimal amount of basic soldering. We are exploring the use of an alternative serial-over-Bluetooth adapter[5] that might further decrease the cost and amount of soldering. Additional, up-to-date information can be found on our project website: http://www.gvu.gatech.edu/ccg/resources/wearableRFID.html.

We have also explored using a waysmall gumstix[6] connex computer and STUART expansion board to drive the SonMicro RFID reader and communicate with a remote computer. The gumstix is a fully functional Linux computer in a very small form factor. These characteristics not only make developing for them easy for persons with UNIX development experience, but also allow the wearable itself to perform complex computations without relying on a remote computer. Using these configurations

Figure 2 The iBracelet from Intel Research Seattle.

[1] http://thesims.ea.com/

[2] http://www.sonmicro.com/125/sm3005.php

[3] http://www.socketcom.com/product/CS0400-479.asp

[4] http://www.phidgetsusa.com/cat/viewsubcategory.asp?category=3000&subcategory=3200

[5] http://www.aircable.net/serial.html

[6] http://www.gumstix.com/

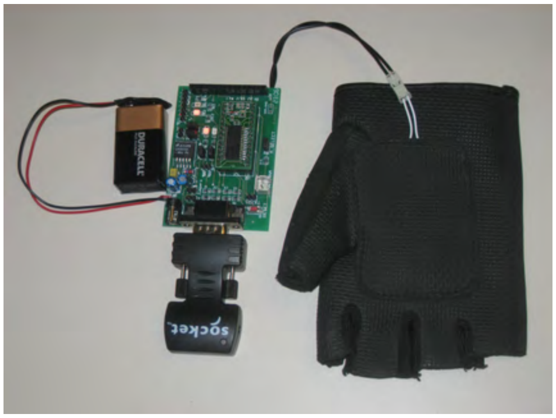

Figure 3 SonMicro and Socket Adapter prototype.

might make it possible to create tangible gaming experiences independent of any infrastructure other than the wearable(s) themselves – the gumstix could keep track of game state, drive a wearable video or audio display, etc. Such gaming interfaces could be used over wide territories (e.g. a large mall, or a city's downtown district) and other environments where an always-on Bluetooth connection to a host computer is not possible.

However, our current focus is on simplicity and low cost. While we have documented our experience with the gumstix on our website, we have not built a fully functioning wearable prototype with it.

3.2 Future Work

We are currently constructing a casing for our prototype. Due to the fairly bulky size of our prototype, we are considering a forearm mounted enclosure (possibly in two pieces – one for the electronics and one for the battery). We are unsure as to whether this setup will be more or less comfortable than an enclosure mounted on top of the hand. Since we are designing for gaming interactions, both comfort and durability are important considerations – and a forearm mounted encasing might be less likely to be hit against things than one mounted on the hand. Finally, miniaturization might also not be desirable if a bigger, more "techie"-looking encasing is actually more engaging for players.

4. WEARABLE RFID GAMES

In this section, we explore the interesting affordances a wearable RFID system brings to gaming interactions. We then describe Tagaboo and RLSims, two games that use wearable RFID systems as part of their interfaces. We finish by presenting two other multi-player game ideas that we are exploring, which make use of the unique interactional properties afforded by wearable RFID.

4.1 Affordances of Wearable RFID

The most obvious property of a wearable RFID system is that it localizes a proximity sensor on the user's body (namely, in her palm). Therefore, it is not necessary to have other in-world sensors to detect interactions with objects. Since RFID tags can be very small, they can be incorporated without difficulty into existing game pieces (such as chess pieces) or everyday objects (such as furniture) [9]. Non-traditional "game objects," such as locations on players' bodies, can also be easily tagged [4]. All of these different types of objects may then be used as game objects. See [10] for an alternative implementation of such functionality.

Another property of wearable RFID systems, which is especially convenient for multi-player games, is the ability to easily distinguish between the actions of different players. Since each player's wearable system uses its own separate Bluetooth connection to the host computer, the system can easily keep track of which players are interacting with which in-game objects. Thus, for any reasonable number of players, it is possible to know which player is interacting with which object, for how long, and their history of interactions.

Furthermore, it is possible to increase the complexity of this input modality by giving players wearable RFID readers on both hands. Especially if combined with a small, wearable Bluetooth accelerometer[7], this type of system could allow for the detection of a large and varied number of player gestures and activities – shaking, throwing, multi-handed interactions, etc [1].

4.2 Tagaboo

Tagaboo [4] is a tag-like game played by two or more children. Though its designers describe several variations on the theme, the game's interface consists of a vest with a number of RFID tags in different pockets, and a wearable RFID glove with an onboard microcontroller. Each child wears a vest and a glove. The object of the game is to touch different points on other players' vests with the glove. Different RFID tags may correspond to different game actions, and players are encouraged to run around during the course of the game.

Tagaboo's design is interesting for a number of reasons. First, it highlights wearable RFID's potential to easily turn non-traditional objects – in this case, sites on the players' bodies – into game objects. Also, because the RFID sensors and the score-keeping logic are located on the players' hands, players are free to run around and play in a large area, unconstrained by the strength or availability of wireless connections (scores are tallied only after a round is over). Finally, the game's designers creatively give the gloves an overstuffed, Mickey Mouse®-like look, which provides space for the electronics and padding, as well as being fun for the game's participants.

4.3 Real-Life Sims

Mazalek and von Hessling have built Real-Life Sims (RLSims), a wearable RFID a game inspired by The Sims [9]. In the game, a player performs common, everyday activities that implicitly control an avatar living in a virtual home. Objects around the player's home or office are tagged with RFID tags, and the player wears a wireless RFID reader. As she proceeds through her day, the game interprets her activities and her avatar mirrors her actions. An interesting aspect of this type of interaction is that distributed players – such as couples in long-distance relationships – can interact naturally in the same virtual space while going about their daily lives separately.

To experiment with this game design, Hessling and Mazalek tagged furniture and various objects around a constructed lab space and created an application that tracks and infers a user's activities from the objects she interacts with. The application then updates a visualization showing the various activities that players are engaging in, as if they were performing them in the same physical environment.

[7] http://www.gvu.gatech.edu/ccg/resources/btacc/

Figure 4 Children interacting with the DiamonTouch Simon game.

Real-Life Sims highlights the ability of a wearable RFID gaming interface to easily turn interactions with everyday objects into game actions.

4.4 Proposed Games

4.4.1 Multi-Player Simon

Researchers at the Georgia Institute of Technology have built a variation of the popular Simon sequence-memorization game to help therapists teach autistic children turn-taking. The game is deployed on a DiamondTouch[8] table, an expensive touch-screen device which is able to recognize which user is touching it at a given moment. The game flashes a sequence of colors across a virtual Simon interface, and the children must take turns re-inputting the order of the sequence. Figure 4 shows children interacting with the game under the supervision of a therapist.

Such a game would be easy to re-create using a real Simon game fitted with RFID tags under each of the four color buttons. Since the host computer would know which player's wearable RFID system touched which tag, it would know whether players acted out of turn and could provide appropriate feedback. For maximum simplicity, the sequence of colors presented by the Simon game could be inputted into the computer in real-time by the therapist in charge of the session.

We do not make any claims as to the effectiveness of such a game in treating autistic children (and, indeed, the original game turned out to have a number of flaws). Rather, we wish to highlight the ease in which it may be possible to appropriate and augment existing, familiar interfaces for use in games with wearable RFID input devices.

4.4.2 Multi-Player Whac-a-Mole™

A multi-player modification of the popular Whac-a-Mole™ game can be played with a wearable RFID interface. The game board can be constructed out of a large piece of cardboard, with many colored areas, each tagged by one or more RFID tags. The computer can instruct players to hit one color or another, keeping track of which players hit the areas the quickest, or which succeed in hitting the most areas of the same color. It is not difficult to think of other variants and modifications of this simple concept.

The design of this game highlights the ease of prototyping some forms of tangible games with wearable RFID systems. With RFID tags, it is possible to make nearly any surface or object into a game board or game piece.

[8] http://www.merl.com/projects/DiamondTouch/

5. CONCLUSION

In this position paper, we hope to have motivated our interest in wearable RFID systems as a promising interface for tangible games. We have described our wearable RFID system prototype, with its focus on low-cost and simple reproducibility. We have also presented some games, both developed and which are currently being designed, which make use of the unique interactional properties that a wearable RFID system offers.

A how-to and updated information on this project are available at http://www.gvu.gatech.edu/ccg/resources/wearableRFID.html

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ApartGame: a Multi-User Tabletop Game Platform for Intensive Public Use

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ABSTRACT

ApartGame is a tabletop platform that supports multiple games for social environments and intensive public use. This paper summarizes the design of ApartGame and the results from preliminary user evaluation. The integration of physical control and digital objects was a crucial design decision and it made the games on the platform tangible.

Categories and Subject Descriptors

J.5 [**Computers Applications**]: Computers in other systems - consumer products; H.5.2 [**User Interfaces**]: Input Devices and Strategies

Keywords

Tangible User Interfaces, Tabletop, Game Platform

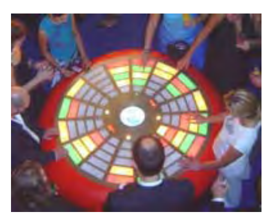
1. INTRODUCTION

Digital games become more diverse and widespread in its form and content, designed for and played by people from different groups of age, culture and gender. Playing games is not necessarily at home or alone. It often serves as a social activity and provides as a good opportunity for leisure. There is a growing trend that digital games are augmented with physical and tangible objects (and vice versa), and provided with more social context. Digital games are no longer just audiovisual. In this trend, tabletop and tangible computer games steadily gain more popularity for improving the user experience in playing digital games. Yet most of these improvements stay in laboratory research settings [6, 8–10, 12, 13, 16].

In Europe, bars, cafés and discos are equipped with game machines, providing a wider range of entertainment. In the past they were mainly mechanical machines for example pool billiard, table football, darts, pinball and air hockey. Later they replaced by screen-based gaming terminals with video games [11]. Photoplay [15] is one of the examples. These machines were there not only serving for the gaming purposes, but also as places that bring people together in these social occasions. Another example is is FishPong [20] where Yoon et al. designed an informal computer-supported cooperative play (CSCP) that act as an icebreaker for social interaction in coffeehouses. The way these environments are changed by these machines also changes the way people behave in these spaces [14]. People notice the changing technology and possibilities, and they are eager to play with technologically improved entertainment.

Moreover, in festivals and events (conventions, conferences) there is a need for public games to enhance the overall experience for the visitors. It demands different designs and implementations in comparison to the traditional machines used in public spaces such as bars and cafés [9]. It is more important to stimulate the social interaction between visitors. People in different mind sets, moods and physical capabilities encounter each other in these public events [3] and more social interaction would enhance the social atmosphere hence the effects of these public events. Ensuring durability and robustness of the product without compromising the quality of physical and tangible interaction with traditional games is a challenge not many have achieved for a market-ready product. Other aspects such as social and face-to-face collaboration between multiple users add more to the list of the requirements. One of the products that aim at these requirements and are available in the market is a game installation called PainStation [7], however it supports no more than two players playing together. Jam-O-Drum [2] and Jam-O-World [1] are table-top designs for group interaction and public use, but they are designed for musical play other than a generic game platform.

(a) CHI 2004



(b) A movie festival

Figure 1: ApartGame Exhibitions

The ApartGame [4] platform described in this paper takes all these aspects into account in an aesthetic and easy installation. The first prototype was shown in CHI

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

2004 (Figure 1(a)), after which both the hardware platform and the software system were redesigned and improved for market-ready production. The later version (Figure 1(b)) was evaluated by observing and interviewing the users.

2. DESIGN

2.1 Platform

The ApartGame prototype (Figure 2) is 85cm high and has a diameter of 175cm. The active play field has an effective diameter of 130cm in the center and consists of grid cells divided in 16 sectors and 5 rings. The inner ring of cells (7cm wide) is subsequently smaller then each other ring to the outside (up to 24cm wide). Each cell is built with firm wooden construction (MDF [1] laser cutting for absolute symmetry), with a depth of 9cm. Herein a reflector with three lamp-holders and three color (red, yellow, green) lights are fixated. On both longitudinal sides are two cutouts for two micro switches that are connected in parallel, so that the entire cell acts as a big push button. At every top corner of each cell, four holes contain springs supporting a layer of acrylic glass. A stainless steel raster covers the entire grid and closes the whole. The colorful outer rim rounds at the top and overlaps the base. Inside the rim, four speakers spread equally and a bass-box positioned inside the base. The base also contains a computer and custom-made electronics for input and output signals at high refresh rates, interfaced via the parallel port. During a game, all cells are used as interactive objects for both output and input

In the center a circular screen is mounted for additional graphical and textual output. There are four round buttons between the screen and the inner ring of the cells. These buttons are designed for interacting with the information displayed on this screen. They are often used for selecting games at the beginning.

Figure 2: ApartGame prototype

2.2 Games

When ApartGame is idle, an animation randomly changes the grid color patterns. After any button action, the lights direct the user to the screen in the center. The screen shows the possible games and four round buttons light up for the selections: *Collapse*, *HitAndDo*, *Snake* and *Oball*. These games are corresponding to existing game concepts and slightly adapted for ApartGame platform. When no cells are pushed for a period of time during a game, the platform returns to its idle state.

2.2.1 Collapse

Collapse is a multi-user game where everyone cooperates to get a score together. From the center colored blocks "drop down" and pile up. When three or more of the same color are connected by the sides of each cell, this forms a valid combination. Pushing one of the cells in this combination, game points are collected according to the number of cells, and the combination is cleared. Color of a dropping block can be changed by push the cell it is in. By actively push a cell of a block, the block disappears hence a new pattern forms. The dropping speed of the blocks are subject to the current score. The higher the score is, the faster the blocks drop. When participants work together in creating large combinations by using the entire grid, the score is likely to be higher. In addition, mistakes in pushing the cells result in a penalty from the score. When participants are not able to clear the cells and all cells in any of sectors are entirely stacked with colors, the game is over, resulting in overall red. The final score and rank are displayed on the center screen and the participants have the opportunity to save their names if the score creates a new record.

2.2.2 Hitando

Hitando is a competition game for at least two and at most three teams, challenging the participants on their movement speed and accuracy. The team first need to select its color.

At the first level, teams have to hit their color appearing randomly on the grid, as fast as possible. A number is displayed on the screen for each team, counting down from 15 if there is a hit. Participants need to move around the table, struggle over each other to hit the color. The team that reaches zero first wins the game. A score is calculated for each team by counting the hits and the time used. The game announces the winner and counts down to level two.

The second level is slightly different from the first level. When a color is hit, the colors of the opposite teams are relocated to surrounding cells. The third level uses the same game principle as the second level, but now the colored cells are not relocated nearby but randomly over the entire grid. This creates a setting where participants become more and more challenged to hit their own color faster but not to be hindered by the other teams.

2.2.3 Other games

Oball is a table tennis variant where the ball must be hit back before it "drops off" the table. The faster it is hit, the faster it is returned. *Snake* is like the famous Snake game, now with two snakes in one grid. Other game implementations on this platform are *Sequencer, Memory and Reversi* [4].

2.3 Design decisions

The goal is to design a platform for games that allows participants play together in public events. Since these events are often temporary, installation of games as such should not aim at long-term involvement of the participants. Rather, they should be easy to understand with no need of reading manuals, yet brings a lot of fun to play together with others. The platform aims at the general public that

[1] Medium-density fibreboard

visits the events. They can be people from all ages with different physical conditions. So the design does not focus on a particular user group.

The games are to be played by multiple users to stimulate the social contact. This requirement results in the dimension and the round shape of ApartGame. This makes it to be able to support up to about 10 people gathering around and playing against or with each other, and still being able to have face-to-face communication among them.

The form and color design tries to attract attentions from visitors by using bright colors and the colorful grid cells, and to arouse curiosity with the shape that may imply several metaphors (mushroom, UFO, donut). Leaving space for the rim around the grid and rounding it off invites the participants to lean forward for interactions.

The structure and the dimensions of ApartGame are designed for easy assembly and transportation, aside from the ergonomic considerations. The platform consists of two parts: the top and the base. The top makes up the interactive tabletop and the base tidily and steadily conceals the supporting computer. For transportation, a carrier case holds both the top and the base, fitting a door width.

For public events the platform needs to be robust for intensive use and to be able to withstand vandalism. Thus, it employs a sturdy construction equipped with durable components and mechanics. Although it seems consisting of separated parts, these parts are not loose or detachable. There is no wide openings or fragile components. The interactive cells use a modular construction, from fine details on the surface to larger parts downwards, creating a firm structure to divert the force exerted on the surface.

To distinguish the selection buttons from the interactive cells, these buttons are designed with a different shape (round) and a much smaller size. These buttons light up only when interaction with the screen is needed, otherwise they dim off and require no attention during a game.

3. USER EVALUATION

To see how the users would react on ApartGame and to collect their feedback for future improvements towards a market ready product, a user evaluation was conducted together with a research company Taapken [17].

The users had the following profile: 1. Age range from 16 to 30 years; 2. Go a night out regularly; 3. Play games (e.g. pool, darts) regularly. In total 53 teenagers and young adults (average age of 23) from various educational backgrounds (2 high school, 17 community college, 21 college, 9 academic) were invited to the evaluation. They were paid 25 euros each for their time and effort. The evaluation was held in four evenings in a café.

The evaluation contains of three sections: Observations on the users playing ApartGame, a questionnaire with 33 questions [5] and at the end two sessions of group discussions. The whole process took about 2.5 hours.

The first part of the questionnaire was designed to collect general information from the users, such as 1. nightlife patterns of the users; 2. types of entertainment in their night lives; 3. types of games often played. The rest of the questionnaire was designed to collect data and feedback about ApartGame, such as spontaneous responses, willingness to play, caused curiosity, usability, comparable games etc. They were also asked for their comments and suggestions with open questions.

The ApartGame table was considered striking at the first sight and appeals to their curiosity due to its form and styling. They also liked bright color lights, big robust size and attractive round shape. Other Spontaneous reactions were: “looks trendy”, “cool”, “stylish”, “easy and without too much complexity”, “tempting”, “attractive”.

Many participants commented on the easiness of playing ApartGame. “Playing a game is relaxation, during leisure you don’t want to think too much”. Playing ApartGame is relatively easy: one does not need much instruction in order to play the games; the ApartGame active cells were easily understandable and accessible for them; The round table design was easy for team play.

The following aspects received positive reactions (range from 6 to 8 in 10 point scale): 1. unique concept; 2. attractive irradiance; 3. ease of use; 4. team play; 5. being active; 6. creating good atmosphere; 7. providing competitive games; 8. covering a big group of end users.

Some of the participants mentioned that the size of the table size of the table could a limiting factor for storage space. Other suggestions for improvements were: 1. the display was not nicely readable from all sides; 2. sound was irritating and monotone. It could be hard to hear in busy nights with loud music; 3. there was no space to place a drink; 4. it could be attractive for children but then the size and height of the table should be adapted accordingly.

Based on the evaluation results, the design was continued. Market exploration pointed to an international leading gaming company with strong emphasis on gambling and leisure products. Their interests leaded to the ApartGame applications in the catering industry, where these applications could appeal to teenagers and young adults in particular. A process started to fine-tune towards a second prototype and finally a market ready product.

4. DISCUSSION

The ApartGame table is designed with deliberate decisions on forms and colors. However the game table has to fit in the social environment, with the available space and its interior taken into account. Variations in forms and colors should be available for different environments and events, when more detailed requirements are available.

The technologies used in this platform are simple and straightforward. Nevertheless, the enthusiastic user feedback shows that how these simple and straightforward technologies can create interesting products through the delicate designs of the form and the interaction.

The user evaluation did provided a lot of valuable feedback on the design, and many suggestions for improvements as well. But it was not intended to be a formal user study on certain aspects of the design, for example the effects of the active cells on the users’ gaming experience in comparison to touch screens or game consoles, and the effects of ApartGame on the visitors’ experience in a public event etc. These topics are highly interesting for future research though.

Is ApartGame tangible? According to the framework of TUI (Tangible User Interfaces) from Ullmer and Ishii [18], the answer is yes. The active cells of ApartGame appear in the games as both input and output devices, and they are representing digital objects in the games (e.g. the falling blocks in Collapse, the table tennis ball in Oball, and the snakes in Snake). The integration of the physical control and the digital objects falls nicely into their TUI framework.

One may argue that the integration of the physical control and digital objects is not fixed in ApartGame, which may raise questions on its tangibility. For example the falling blocks and the table tennis ball move from cell to cell, and the representation of a snake needs to combine multiple cells. The integration is not one-to-one tightened. But then the question is, is it necessary to bind a digital object to a physical one to make an interface tangible? We leave this question open for discussion.

The coupling of the user input and the game output happens in both space and time. In space, the user needs to interact with the digital objects at the places where these objects appear. In time, the reaction of the digital objects to the user input is immediate. However, in tangible interaction, more can be achieved by coupling the input and output in other dimensions, such as modality, direction, dynamics and expression [19]. The digital objects are represented using colored lights – in modality the tactile input (touch) are not coupled with the visual output. In Oball, the users need to push the active cells down to hit the ball back – in direction the input and output are not coupled. Also in Oball, the force the user applied to the active cells are not taken as a input for the speed of the ball hit back – in dynamics the input and output are not coupled either. The ApartGame platform does have certain expressions through its design of shape, color and symmetry, however these expressions are fixed and do not react on the users. Improvements in any of these directions would make the tangible interaction with ApartGame richer.

5. CONCLUSIONS

We presented a tabletop platform supporting multiple games for social environments and intensive public use. The responses from the user evaluation were in general positive, yet there was still space for improvements.

The integration of physical control and digital objects was a crucial design decision and it made the games on the platform tangible, although it is arguable whether the integration is tight enough for richer user interaction.

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PlayTogether: Playing Games across Multiple Interactive Tabletops

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ABSTRACT
Playing games together can be surprisingly difficult – people have limited free time and are tending to live live farther away from friends and family. We introduce PlayTogether, a system that lets people play typical (and as-yet-unimagined) board games together even when they are far away from each other. We have adapted the PlayAnywhere tabletop system so that multiple remotely located people can engage in game-play. PlayTogether enhances the play experience by exchanging carefully composited video of remote players' hands and real game pieces. The video that is transmitted mimics a player's viewpoint via careful camera location. Because PlayTogether's camera senses in the infrared, it is easy to distinguish between objects in the camera's view and projected imagery. These capabilities create an interesting and engaging way to blend the virtual and real in multi-player gaming.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces—*Input devices and strategies*
H.5.3 Groups and organizational interfaces*: Computer supported cooperative work.*

General Terms: Algorithms, Design, Human Factors, Mixed presence groupware

1. INTRODUCTION
People who want to play games together can't always be in the same place. We are developing an interactive tabletop system to allow multiple people to play typical (and not-so-typical) board games from multiple remote locations. Our system, PlayTogether, uses off-the-shelf projectors and cameras and turns nearly any flat surface into an augmented play area.

There is an emerging field of real-world surface based applications that are enabled by novel sensing and projection techniques. This includes systems that use cameras and video projectors, flat-panel displays with embedded sensors, and tangible objects with active or passive tags. Typically these systems have focused on multiple co-located users on single device. In this paper we describe PlayTogether, a system that allows multiple non-co-located players to interact via multiple interactive tabletop systems. Using our system we have explored different degrees of sensing and sharing. This can best be understood in the context of a board-game, such as checkers or chess.

Figure 1. Playing checkers and chess with a remote player using PlayTogether. The remote player's game pieces and hands are projected, superimposed on the local player's real board and pieces. In both cases, hands and pieces on the far side of the table are projected. Hands and pieces on the near side, and game board, are real.

PlayTogether focuses on enabling game playing between people at a distance through manipulation of real game pieces on real game boards. Camera-based sensing is used to enable synchronized sharing with appropriate compositing. Because of our use of video, the representation of players and game pieces is much more realistic than if we used synthetic virtual objects. This helps the player by providing rich non-verbal cues, unique player identification, and seamless gestures.

When an environment effectively supports play or pleasurable work (―flow" [4]) participants engage in graceful choreography

Tangible Play: Research and Design for Tangible and Tabletop Games, workshop at IUI'07 (Intelligent User Interfaces conference 2007), January 28, 2007, Honolulu, Hawaii, USA.

[15]. Players stop thinking about how they are moving their own hands and instead concentrate on the game and other players. Our main goal with PlayTogether is to give players an unconscious sense of immediacy so that they can focus on the game and not on the mechanics of distant collaboration. To do this we are developing a tightly-coupled real-time system that does not tether players to input devices such as mice or other hand-mounted sensors. In essence there is no user interface: players pick up and move their own physical games pieces, gesture to the other players' pieces, and immerse themselves in the game. Players don't have to identify themselves, pick a cursor color, or select “rules of interaction.” They just sit down and play.

2. RELATED WORK

PlayTogether is inspired by the large body of work on multi-user interaction both in shared physical spaces and at a distance [3] [9][10]. We are especially interested in systems that give a high-fidelity impression of remote users.

ClearBoard [8] maintained remote awareness by compositing video of a remote participant behind a shared virtual workspace. Related systems use various video techniques to subtract out extraneous portions of the video feeds [13] [1]. Each focuses on collaboration with purely virtual content such as virtual whiteboards or PowerPoint slides.

There is much recent work on the use of interactive surfaces to support real-time collaboration [2] [8] [11] [14]. This work has generally focused on: 1) merging real with the virtual, 2) facilitating interaction between people who are collocated and sharing one active work-space, and 3) enabling people at a distance to collaborate in shared virtual environments.

For example, in VideoArms [15], video representations of remote users' arms are shown alongside virtual content within the context of *Mixed Presence Groupware* (MPG). We resonate with and take advantage of the concepts of virtual embodiments as discussed in this work. VideoArms' authors propose four principles for virtual remote embodiments. These principles are meant to give a sense of presence, encourage decorum, and enable rich interaction between remote participants. PlayTogether differs from VideoArms in the manner which local and remote scenes are sensed, processed, and combined.

3. PLAYTOGETHER

PlayTogether builds upon the infrastructure and technological innovations of the PlayAnywhere interactive tabletop system [16]. PlayAnywhere combines a commercial front-projector with a co-located camera and infrared (IR) emitter that works on most any flat surface. PlayAnywhere focuses on the technology behind compact and reliable table-top sensing, and includes techniques for “green-screen” keying, real-time tracking of rectangular objects, rectification, visual tag recognition, optical-flow based motion tracking, finger tracking, and shadow analysis based touch recognition.

As with PlayAnywhere, we illuminate the scene with an IR source and block all but IR light to the camera with an IR pass filter. The projected image is thus easily removed from the scene, thus avoiding the dynamic range constraints acknowledged in the VideoArms system. We currently use a short-throw (NEC WT600 DLP) projector.

The current PlayTogether configuration employs two PlayAnywhere devices, each exchanging grayscale video over a

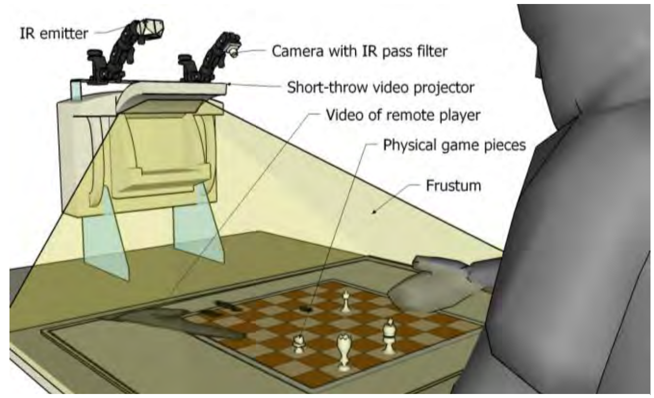

Figure 2. The main elements of the PlayTogether system are a camera, IR emitter, and projector.

local gigabit network. This video is projected onto the local desktop: the remote user's hands and game pieces are visible, superimposed on the local user's tabletop. In the case of two-player board games, it is desirable to rotate the projected video 180 degrees so that the remote user's hands and pieces appear on the opposite side of the table, as if the remote user were sitting across the local user.

Rotating the incoming video has other consequences for viewing. In the PlayAnywhere configuration the camera is mounted onto the projector such that it mimics the general eye position of a player seated at the table. It was only when we networked multiple PlayAnywere systems together that we noticed that objects in the remote video are automatically shown with the correct perspective foreshortening for the local user seated at the table. See Figure 1 for an example of this effect, and Figure 3 for an illustration.

While PlayTogether's projection can include a graphical depiction of the game board, we have explored superimposing video onto real game boards on the tabletop. A real game board may be moved on the table, causing the remote (projected) game pieces to no longer appear at the correct location on the local game board. We address this by tracking the position and orientation of the local game board, and transmitting this information with the video. This information is then used to precisely warp the video onto the remote user's tabletop, such that the remote and local game boards precisely overlap. Aside from shifting shadows and perspective, players are not even aware of remote players adjusting their game boards. PlayAnywhere's board tracking algorithm requires some contrast between the board and the tabletop.

One drawback of the current configuration is the introduction of

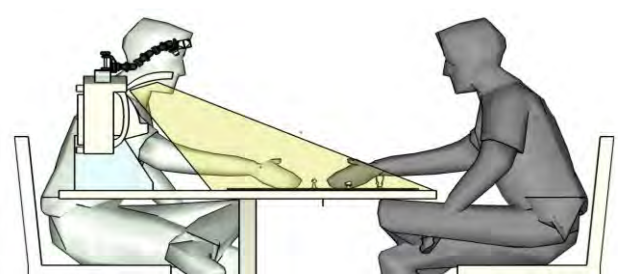

Figure 3. Local camera is at approximately the same point as (imaged) position of remote player (on left).

shadows cast by tall objects (with the projector as the main light source). This can obscure the projected video. Shorter and/or translucent game pieces may help. Contrast is also important in terms of perceiving top-bottom relationships. Physical objects, including hands and game-pieces, almost always appear to be on top of objects in the remote video. Most of the time this is acceptable but it can create unusual situations such as when one user attempts to put their hand "on top of" a remote user's hand. Each user will see their own hand on top!

4. NEW EXPERIENCES

4.1 Game Experiences

PlayTogether supports different levels of intervention on the part of the application. PlayTogether does not necessitate application controlled mechanisms for enforcing etiquette. Many existing CSCW systems impose turn-taking. "Out-of-turn" participants' cursors are disabled or preventing from acting on certain elements in the shared space or the cursor color may indicate state. In shared space systems such as DiamondTouch [5], the actual physical presence of other participants' hands discourages conflicting interactions. A game designer could also borrow from work in the area of *proxemics* to design sharing cues [6] [7]. In our distributed system we capitalize, as much as possible, on this kind of real-world presence based turn-taking. Our hope is that the more realistic the transmitted representation of remote participants is, the higher the inclination for participants will be to use real-world etiquette.

Very quickly, questions of how to synchronize two physical worlds arise. For example, in the case of checkers and chess, each player is responsible for removing their own pieces from the board (which is opposite from usual play). There are a class of very complicated research systems that use actuators to enforce bi-directional synchronization between the real (phicons) and the virtual [12]. Since our goal is to make a self contained system that works on nearly any tabletop, we have not explored actuators.

One way to partially address synchronization in a future version of PlayTogether is to offer visual cues ("halos") around game pieces. These cues would indicate needed updates on the part of the player. If a player places a piece in a position that violates game rules, a visual cue would then pop-up around the offending piece. The system could also intervene and remove undesired elements by video processing. In practice this might work like this: Player 1 moves their piece. Player 2 then "jumps" player 1's piece. If each piece is tracked as distinct objects, Player 2 can then press their finger down on the jumped piece and drag the image of the piece off the board. Consequently, Player 1 would see a red X projected over their physical piece. At that point it would be up to Player 1 to physically remove the jumped piece to maintain synchronization. If they did not do this, Player 2 might never know because of its having been removed from the presentation.

Because this is a networked system we can also enable new twists on familiar games. We can imagine a democratic game of group chess where multiple players on each side implicitly vote the next move by simultaneously placing pieces. As players move their pieces, real-time feedback gives a notion of what all other teammates are doing – modulated to reduce visual noise. If the game designer so chooses, opposing teams may only see a blur during voting but then get a clear image when voting is complete. In the real world, whoever "goes first" has an unconscious and undue influence over other players. The simultaneity enabled by

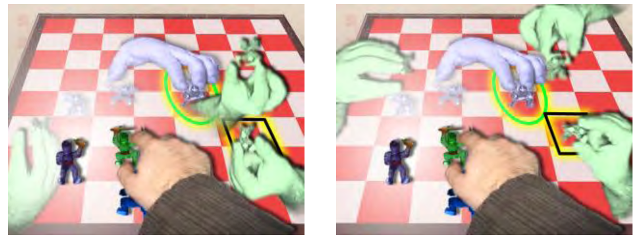

Figure 4. Simulated view of a multi-player team scenario where teammates are shown tinted differently than the opposing side. At left teammates' hands are shown on the same side as the local player. At right, teammates' hands are distributed around the game board.

PlayTogether's virtual space may have the benefit of freeing each player this order based influence. A team-member could also indicate disagreement with another team member's move by placing a "delete" phicon on top of the image of the other teammate's piece. This message would then be sent to the appropriate teammates.

Using a vision system gives us a great deal of choice in how to display each stream. To accommodate multiple players we choose a metaphor of people sitting around a table and we radially distribute each stream (see Figure 4b). We can thus fit more people around the board then could actually fit in a single shared physical space. Players who have finished their move, but whose hands are still in the camera field of view, can also have their video stream dimmed or even removed to help de-clutter the view. To be fair, there are several tricky visual issues that come up when implementing team style games. Because our camera is looking from a ¾ view rather than top-down, there is an implicit orientation in each exchanged video stream.

4.2 Collaborative Drawing

We have implemented a basic artistic collaboration application in which each participant draws on a real piece of paper placed on the desktop. All participants can see each person drawing with real writing instruments on their own pieces of paper. Because of the automatic paper registration, each participant can continuously adjust the angle of their paper to suit their own comfort, and the projected video is precisely aligned (see Figure 5).

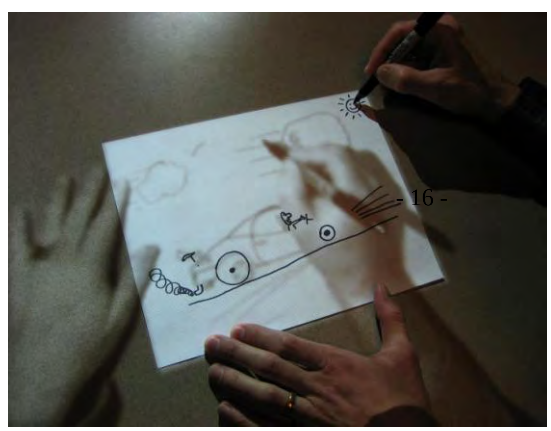

Figure 5. Example drawing application superimposes remote participants' drawing, and hands entering from the local participants' side of the table.

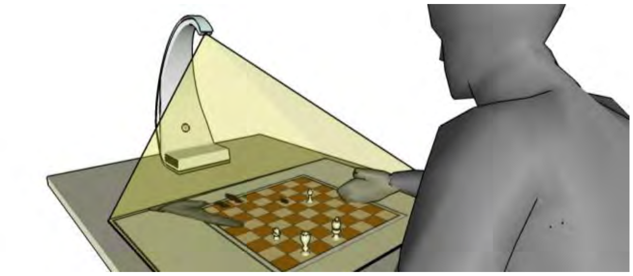

Figure 6. Future configuration using laser projector with collocated camera and IR source

5. FUTURE WORK

Our current implementation of PlayTogether is limited to exchanging grey-scale video. It may be possible to enable the exchange of color video by adding a color camera to the configuration: the IR camera feed would be used to calculate a ―mask" indicating the real objects on the table (hands, game pieces, and game board). This mask would then be combined with the color image input to determine the natural color of the real component of the input, as well as determine where it is safe to project color graphics so as to not conflict with the color video. With more processing each player could also use different size game boards and the systems would adjust appropriately, sending scaled video to the other player. With object tracking capabilities, the system could add dynamic annotations and synchronization cues. More than two players could also be supported with more networked PlayTogether systems and/or multiple players in the same shared physical space.

The current video projector is quite expensive and fairly large. We are investigating an emerging crop of lower-cost LED and laser-based projectors that can easily be mounted on light-weight booms. These advances in projection technology might allow a much smaller device, such as that depicted in Figure 6.

6. CONCLUSION

We have introduced PlayTogether, an interactive tabletop system that enables multiple remotely and co-located people engage in games with real games pieces. A combination of sensing capabilities and real-time video give players a strong sense of remote players and an immediacy of interaction. This technology suggests new experiences in the domains of game-play, artistic expression, and computer mediated collaboration.

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