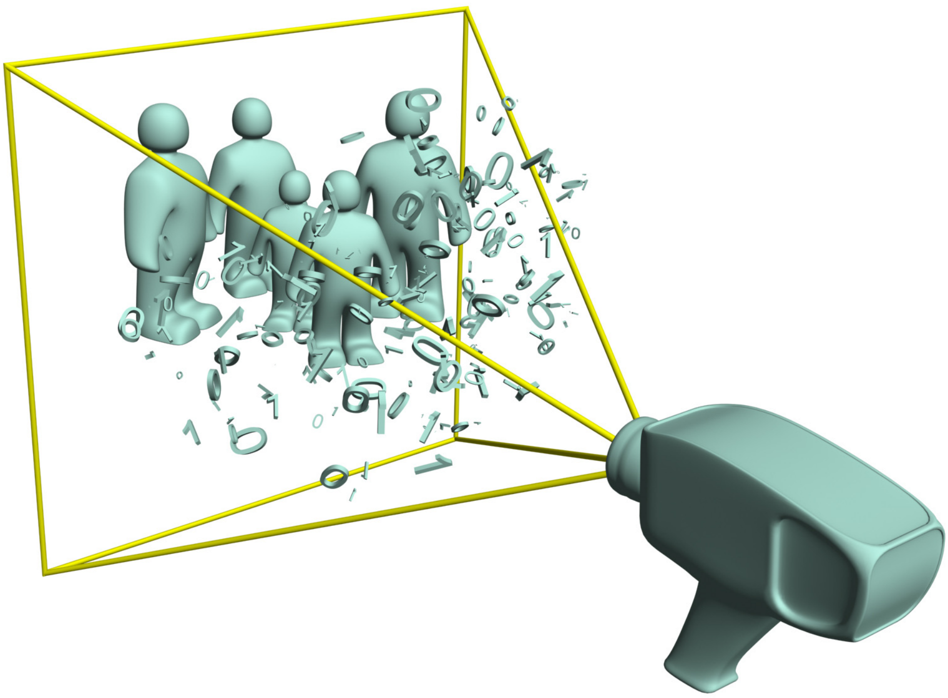
SPACE AS INTERFACE

- BRIDGING THE GAP WITH CAMERAS



Ph.D. Dissertation

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"Imagination is more important than knowledge" A. Einstein

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As time is running out…

Thank you iSpacers for your great help and collaboration

Thank you Researchers for approaching interaction design from other perspectives

Thank you Kaj and Uffe for getting me on track

Thank you Community for letting me travel all over the world

Thank you Christian for playing table tennis

Thank you Tobias, Rune and Thomas for endless fun and curiosity in kollision

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Thank you Friends for reminding me of the world outside

Thank you Kasper for running with me in the forest

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Thank you Family for being my family

Thank you Eva for being my fantastic girlfriend

…now crash and burn!

ABSTRACT

English Abstract

This Ph.D. dissertation takes its offset in the migration of technology and computing power into our physical environment. The consequence of this movement, termed ubiquitous computing (Wieser, 1991), is a new relationship between humans, technology and spaces. In this new context, I seek to conceptualize space as more than the physical container for human activity. I do this by investigating space as interface.

Based on a theory of space and place set forth by Tuan (Tuan, 1977), and informed by an explorative research approach, I make the distinction between space and place as a Euclidian space and a Phenomenological experienced place. In this perspective, place is created by humans as they appropriate space in investing it with emotions and memories and hereby making it meaningful. Space consists of formable physical and digital space, whereas place is made up by four dimensions relating to personal, physical, social and cultural aspects towards space. As these dimensions are tied to the humans who experience the space, the designer can not directly influence and form the creation of place.

This division puts attention to two gaps necessary to bridge. The first is the gap between physical and digital space, that in order to make the two domains communicate has to be perceived as a measurable Euclidian space. The other gap is between space and place, in which the design of space has to serve as a carrier of intentions towards place-making. This hermeneutical gap confronts the use as a definition by design with actual use (Hallnäs et al. 2006). The challenge thus becomes understanding space as the interface, and further how intentions can be induced into the design of space in ways that point towards the dimensions of place, when interpreted in actual use situations.

By designing and exploring a range of interactive systems through the Ph.D. project, I have identified different significant aspects in the relation between space and interface. Based on empirical work, I distill a fragment of work concerned with cameras as the interface for bridging the gap between physical and digital space. By looking across multiple projects spanning over fields such as tangible user interfaces, augmented reality, and mobile computing, a conceptual framework characterizing camera-based mixed interaction spaces is developed.

To show the applicability of the framework, it is deployed on one of the presented cases and discussed how aspects in the framework can address the intentions towards the user's creation of place. On the basis of these discussions, a number of guidelines for the design of mixed interaction spaces is presented.

Dansk Resume

Denne Ph.D.-afhandling tager sit afsæt I den tiltagende migration af teknologi ud i vores fysiske omgivelser. Konsekvensen af denne udvikling, som betegnes *ubiquitous computing* eller *it i alting*, er nye relationer imellem mennesker, teknologi og rum. I denne nye kontekst forsøger projektet at konceptualisere rum som mere end en fysisk ramme for menneskelige aktiviteter og handlinger. Dette gøres ved at undersøge rummet som grænseflade.

Projektet bygger på en teori omkring rum og steder fremsat af Tuan (Tuan, 1977). Denne er yderligere informeret af en eksperimentel forskningstilgang. Her laves en distinktion imellem rum og sted, som et euklidisk rum overfor et fænomenologisk oplevet sted. Herved bliver sted skabt ved at mennesker tager rum i besiddelse idet de fylder det med følelser og minder og herved gør rummet til et meningsfyldt sted. Rum i denne forbindelse består af det formbare fysiske og digitale rum, mens sted skabes af fire dimensioner der relaterer til menneskers fysiske, personlige, sociale og kulturelle værdier i forhold til det pågældende rum. Da disse dimensioner er knyttet til denne menneskelige oplevelse har designeren ikke direkte indflydelse på skabelsen af sted.

Denne opdeling af rum og sted sætter fokus på to tomrum der er nødvendige at bygge bro over. Det første tomrum eksisterer imellem det fysiske og det digitale rum, der som en forudsætning for at disse kan kommunikere med hinanden må opfattes som et målbart euklidisk rum. Det andet tomrum eksisterer imellem rum og sted, hvorimellem rum må fungere som formidler af designerens intentioner i forhold til skabelsen af sted. Hallnäs et al. kalder dette tomrum et *hermaneutical gap*, hvilket konfronterer brug som en definition af design med den virkelige brugssituation (Hallnäs et al. 2006). Udfordringen ligger derfor i at forstå rummet som grænseflade, og videre hvordan intentioner kan indlejres i designet af rum på en måde så det adresserer stedets dimensioner når det tolkes af brugeren.

Ved at designe og udforske en række forskellige interaktive systemer igennem dette Ph.D.-projekt har jeg identificeret en række aspekter som knytter sig til rum som grænseflade. Ud af denne omfattende mængde empiri er et fragment der anvender et kamera til at bygge bro imellem fysiske og digitale rum blevet undersøgt nærmere. Ved at kigge på tværs af projekter der spænder over forskningsfelter som tangible user interfaces, augmented reality og mobile computing udvikler projektet en konceptuel ramme der kan karakterisere og analysere kamerabaseret interaktion i blandede rumligheder (camera-based mixed interaction spaces).

For at vise anvendeligheden af den udviklede ramme diskuteres en af projektets cases ind i det. Ved at forholde aspekter i rammen til observationer fra projektets anvendelse i virkelige brugssituationer belyses dets evne til at inducere intentioner i forhold til skabelsen af meningsfulde steder hos brugeren. På baggrund af disse diskussioner præsenteres en række guidelines til design af kamerabaseret interaktion i blandede rumligheder.

1 INTRODUCTION

Since I graduated from the Department of Communication Design at the Aarhus School Architecture in 2000 space to me has undergone a huge change. It has moved from a pure physical understanding of space towards a mix between physical and digital realities. This shift was founded in the last year of study and during my first years as an architect working with technologies that in different ways inspired, influenced and ultimately matured my view on space and technology. I realized that space was much more than the physical structure that makes up our build environment. And that the coupling with technology had much potential to offer physical space and vice versa, in the sense that technology could offer interactivity and responsiveness to physical spaces; and physical spaces could offer a new territory for computing that initially would open up for new perspectives on technology.

My curiosity led me into a more focused approach towards the role of space, when coupled with technology through this Ph.D.-study. In the following introduction I will try to clarify my point of departure for this dissertation, as well as present the challenges as I see them for working with interactive spaces or when considering *Space as Interface*. I find it important to include and shortly introduce some previous work to give an impression of some aspects that has shaped me and established the filters I carry with me, and through which I see the world. These filters have been even more obscured through the last years of work, but hopefully I will be able to show that the work also has evolved a few clear spots, through which you can get a better understanding of space when designing for interactive environments.

1.1 CHALLENGES

This Ph.D. dissertation sets out to investigate *space as interface*. The background for focusing on space and interfaces is the increasing migration of technology (interfaces) into our physical environment (space). This development is by many referred to as pervasive computing, ambient intelligence and ubiquitous computing, which I will be using in this dissertation. When technology and computing power moves from the desktop into new physical constellations we are forced to approach the interaction with and conception of technology in new perspectives. This is true for a number of reasons.

- The interaction paradigm known and well-studied from interacting with computers on the desktop does not comply when traditional input devices such as the mouse and keyboard are not around anymore and the computing power is distributed into the physical environment;

- With technology constantly around us we are not just using technology but living with it; gadgets such as mobile phones extend our body offering constant access to available networks opposed to the old paradigm where interacting with technology happened in well defined situations as when seated in front of the PC;

- An expanded physical environment suggests a use perspective that is turning towards multiple users and social interaction, related to activities of everyday living opposed to a single user paradigm of conducting specific tasks e.g. in excel. Aspects as fun and reflection become players in the design of technology outside the work domain.

Much research and investigation has been put into this area of ubiquitous computing, however, not from disciplines of architecture and design. Thus answers to many of the challenges of bringing interaction and computation into the environment has been answered by people from the fields of engineering, computer science, cognitive psychology, and ethnography. Malcolm McCullough calls for architects and designers to approach this field of interaction design to help ground the technical, social, and cultural aspects to the places and spaces of our build environment (McCullough, 2004).

As an architect migrated into the field of interaction design my question is:

> *How can space engage in the shift of interaction paradigm to serve as more than the physical container inscribing the interactions between humans and technologies?*

Questioning space in this way implicitly requires a focus on the social implications of the design of novel interaction paradigms. Thus to investigate these implications an explorative approach intervening in the real world is necessary. Further, my question is not concerned with space as architecture but rather at defining a conception of space suitable for adding a new perspective on designing the interactions between humans and technology off the desktop.

Through the sub-question:

> *Which technologies can bridge the gap between physical and digital domains?*

I explore numerous interfaces and their ability to couple interaction between humans and technology in spatial contexts. This dissertation ends up by going into depth with the interface of cameras and investigates the space of potentiality expanded by such an interface.

To address the challenges in exploring the concept of space other disciplines are needed to engage in understanding and intervening in complex social contexts of everyday life. Thus this dissertation is not a slim confined piece of work within a narrow research field; rather is it based on what Buchanan describes as the new learning, seeking to exploit isolated knowledge from multiple fields and apply these in the real world (Buchanan, 2001). To be able to conduct this work I have expanded my own competencies as an architect towards computer science as well as engaged in collaborations with numerous talented colleagues from other disciplines whose different perspectives on the ingredients of interactive spaces has challenged the conceptualization of space.

Before proceeding to describing the three parts of this dissertation I will introduce to a number of spatial encounters I have undertaken before starting out on this Ph.D. project. They can be skipped but nevertheless, I think they give an impression of my faceted relations to space and technology.

1.2 BACKGROUND ENCOUNTERS WITH SPACE

I initially come from an architectural tradition that focuses on the build environment, but in the latter part of my studies I touched upon aspects of technology migrating into architecture both regarding process and product. At first this led to a great fascination of huge computers and advanced 3D software for generating and visualizing possible futures for architecture. The technology provided new possibilities for designing in scale-less environments in 3D and from that extract the necessary drawings. This approach was exploiting the ability of PC's to create a simulated digital space that not directly related to real physical space but only represented it through the computer screen. I however, touched upon a range of projects and employments that expanded this view on space further. In the following I will give a short introduction to incidents before I started on this Ph.D.-project to present the various ways I had been working with and understood the concept of space beforehand.

The following spatial encounters are done through three different channels – firstly as a student at the Aarhus School of Architecture; secondly as a research assistant within the *University of Aarhus* and at the *Aarhus School of Architecture;* and thirdly as an architect and partner in the small architectural studio *kollision*[1]. These three channels represent my initial view on space through study/education, research/teaching and business/development and should therefore be seen as a broad spectrum that has and still is influencing my view on space and thus also the way I think and work.

Odessy – Designing the Constraints of Space

During my last years of studying at the Department of Communication Design at the Aarhus School of Architecture my advisor Uffe Lentz introduced my study partner and later colleague Tobias Løssing and me for a group of engineers researching in parametric design at AUC within CID (Center for Integrated Design). They were developing ODesSy – Optimum Design System - a piece of software for optimizing constructions from a given set of parameters. The interesting thing about this computer program was that it was capable of optimizing both topology and form using FEM - Finite Element Method algorithms (FEM, 2006).

The principle is that the shape of the design artifact is only addressed indirectly. Instead of directly drawing an object the parameters in relation to its intended functionality are configured and through the software these are shaping the optimal form of the artifact. We met a lot of resistance and interesting discussions from and with other designers as they claimed that there is no such thing as a computer that can generate an optimal design. In other words you can not automate the design process (I will get back to this discussion in the chapter 3). The point here is that the outcome is only optimal to the parameters defined by the designer opening a hole new discussion on the relevance and importance of criteria for the specific design case and not only focusing on the aesthetics of appearance.

To me this led to a new understanding of the design space moving from the design of the actual form towards defining the criteria and parameters that should form and mould the design. The form would of course be evaluated and parameters would be altered and the design recalculated if the outcome was unacceptable but the form of the design was not solely a work of the artist's hand but done in close collaboration with other disciplines helping to define the parameters and technology calculating the optimal output.

[mapping: 58, 59]

brandTilst – Identifying Overlapping Spaces

The brandTilst builds on the parametric design approach from the above *ODesSy* example but brought into an urban planning context. The *brandTilst* project is a *kollision* competition entry for the planning of a new suburb outside Aarhus, Denmark. Inspired by the parameters used to frame and define the physical design space in *ODesSy,* we developed a history machine or 3D matrix that should accumulate wishes, activities, conditions and conflicts from different scales and sectors, and relating these over time to open up for new views into the complex task of planning an entire suburb. Similar to *ODesSy* the important design job was to collect and balance the right data and set up the right parameters to establish a design proposal not based on hardcore algorithms but on negotiations and potential win-win situations across scale and sectors. One of the benefits from this approach was that social parameters were equal to form-focused parameters establishing a planning process that was not about drawing the vision of the architect but to a higher degree plan for the social spaces that either collocated or distributed, physically or digitally would improve living in the new suburb and relate it to its local, regional and global context. The project builds on the importance of understanding the social and cultural spaces and that mere physical space only to a limited extent can define the activities of an

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[1] Kollision is a small architecture studio that was founded by Tobias Løssing, Rune Nielsen, and Andreas Lykke-Olesen in 2000. The objective was to continue the research oriented approach regarding architecture and technology that we had followed in the last years of studying at the department of communication design. Later Thomas Delman joined and is contributing with valuable insights from literature and information studies. Kollision is serious fun between methodological oppressed work and playful reflective investigations.

environment unless they are designed in line with the future users, which the history machine tries to incorporate.

[mapping: 51]

Panorama – Immersed in Virtuality

Through an employment at CAVI – Center for Advanced Visualization and Interaction (CAVI, 2006), I got introduced to the concept of *virtual reality* through the *panorama* that affords possibilities for creating immersive real-time rendered worlds and interfaces. In *virtual reality* the user immerge into a fully computer generated 3D world and can interact with spatial interfaces through various input devices. The 3D experience is achieved by the use of projectors that respectively renders an image for the left and the right eye, which is synchronized with a pair of special glasses – shutter glasses – worn by the user that opens and occludes the left and the right glass creating an illusion of being in a three dimensional digital world.
One of my experiences coming from a tradition of designing for and relating to the real physical world was that the technology is focused on the digital domain even though it is situated in physical space. This lack of connection to the real world results in an "out of this world" experience that is not taking part in real life, but works as a digital intermezzo from this. Being disconnected from the physical world makes it hard to get a sense of scale as small objects or entire worlds can be moved and scaled instantly in front of your eyes. Despite the impressive worlds that one can immerse into it is very much an experience for the head and eyes while the body is disconnected and left in the physical world.

[mapping: 30, 36]

Virtual Studio – Acting in Mixed Reality

While working at *CAVI* I got involved in a research project that was to explore the aesthetic potentials of the newly build *virtual studio*. The *virtual studio* is a chroma-key blue TV-studio that affords the existence of a real-time collocated digital and physical set or environment. The technology is build on the classic blue-screening method that in simple terms extracts a certain color from an image stream and replaces that by another image. In addition to the technology used in the weather forecast the cameras are tracked by ceiling-mounted infrared cameras within the studio in three dimensions and mechanical tracking is measuring the zoom factor of the lens. What this means is that position, orientation and zoom factor is known for the camera in every frame – basically how the camera sees the world. This information is sent to a 3D-software that generates a virtual camera based on the parameters of the physical camera. Now the two cameras look at two different worlds with the same optic. A computer renders the digital scene in real-time and the image is merged with the frame from the physical camera creating a mix between actors and physical props within the studio. Unlike the *panorama* scale plays a whole different role in the *virtual studio* as the final result or experience is not that of being in the studio but the composited output of the virtual and physical cameras.

The real-time mix between physical and digital space can be seen as a kind of a mixed reality environment. In this setup one suddenly has the potential of exploiting spatial and time-based properties from both the physical and digital domain such as mixing two parallel realities that runs in two different speeds of time or suspend gravity to create the illusion of levitating props and actors. A challenges for this technology is to improve interactions between the physical and digital environments, which in most cases are solved through some kind of "wizard of oz" (Kelley, 1983), however, the technology has shown its worth for creating virtual video prototypes for future or even unrealizable environments (Bardram et al., 2002).

[mapping: 8, 30, 33, 34]

Artoolkit – Augmenting the Real World

During my work at the above described research project in the *virtual studio* our research group went to *Siggraph2002* in *Los Angeles* where I got introduced to the concepts of augmented reality and mixed reality (Milgram et al., 1994) through the *ARtoolkit* package (Kato et al., 1999). *Artoolkit* is an open source toolkit for developing vision based augmented reality applications. By using cheap off-the-shelf cameras to recognize printed graphical markers the software can calculate position and orientation of the camera in relation to the recognized marker. As with the *virtual studio* this gives an understanding of how the physical camera looks at the real world. These data are sent to a 3D application that in real-time renders an image based on the parameters from the physical camera. The live footage image and the rendered image are then merged by superimposing the rendered image onto the live footage using the alpha channel of the rendered image. A display or a head mounted display show the merged image stream that creates an illusion of the virtual and physical domains matching and meeting up in real time. The technology is very like the *virtual studio* in the sense that you obtain a strict geometrical match between a digital model and a physical environment, however, the studio works primarily by placing real physical actors and props into a virtual environment whereas the *Artoolkit* works the other way around placing virtual objects into a real environment.

The encounter with this technology opened up for new ways of thinking the digital into the physical and creating mixed reality environments. The 3D scenes we had been working with in *Maya* and *3DstudioMax* suddenly broke out of the screen and became a part of physical space. At *kollision* we made a range of projects exploiting the possibility of designing spatial digital overlays on the real world.

First we focused on a direct and literal way of matching physical geometrical space with digital geometrical space. In our later work we used multiple markers as augmented and digitally enhanced game pieces that represented and carried information that related to and visualized other information than correct 3D geometry. We made a collection of urban planning board games that used augmented markers as game pieces connecting parameters to the context on the board putting focus on activity spaces rather than merely physical spaces by using the digital overlay to visualize social, cultural, economic etc. data. The games draw on the work done with *odessy* and *brandTilst* where accumulating and defining the parameters for a design problem are in focus, however, the technology enabled us to bring the activity from the computer screen to a space where multiple actors could engage in the planning process.

[mapping: 10, 29, 44, 45, 46, 47, 49, 50]

Summary

As can be seen from my above description on selected works with space prior to this dissertation it is very broad and characterized by a wish to work with and explore the material in practice and use findings in one project to develop the next. However, this shall not be seen as a structured development of project *'understanding space'* but rather as a selection of works that has borrowed ideas and concepts from each other and slowly matured and revealed a complex set of approaches towards space.

In *odessy* and *brandTilst* using technology to help design space shifts the focus from designing the actual plan, structure or form to define criteria and alter parameters for the given design space. This approach acknowledges that there can be an optimal form or answer to a problem but likewise accepts that it can be an optimal answer to a set of stupid or incompetent defined parameters. One can say that these spaces are made up of a range of other spaces that go beyond the strict physical domain like social, cultural and economic aspects.

Being an architect I think it was natural that my starting point for engaging in the mix between physical and virtual was understood as the matching of geometric spaces. A dream of creating buildings or cities that are made up by physical and digital intertwined structures lies straight forward and is mostly interested in the fact that digital structures can mime and transgress reality in form and appearance without obeying the laws of physics or the laws of planning legislation. However, the dream does not pose the question on how to live inside a digital building nor does it focus on the fact that a part of such a new reality is an optical illusion.

In the move from a pure visual mix of spaces towards a more critical view on the various properties of physical and digital spaces came the focus of exploiting the domains instead of decreasing their potential in the search for having them seamlessly blend together. This led to physical environments that exploited the digital domain by augmenting physical objects to make them carriers of dynamic digital information that related to its physical context. Just like *brandTilst* could pin-point the emergence of social communities within a physical area the *harbourGame* worked as a large physical space containing distributed digital spaces linked to physical objects that would change content according to context (Nielsen et al., 2005) (Løssing, 2005).

In summary my initial view on space can be defined as made up by a range of internal and external properties that go beyond the physical realm and that adapts to changes in these properties. What my work within this Ph.D. has helped to unfold is how interactions within spaces influence the creation and perception of these overlaying physical, personal, social, and cultural spaces.

2 THE DISSERTATION PARTS

Compiling this Ph.D.-project has challenged me in finding the right form and focusing on the right content. This is due to a number of reasons e.g. that I have been working in the borderlands between The Department of Design, Aarhus School of Architecture and The Department of Computer Science, University of Aarhus. These institutions have different norms (not laws!) for how research is carried out and also what the product of the research can be. At computer science the usual form is a number of reviewed papers and a report that summarizes these and maybe establishes an overall discussion. The most Ph.D.-projects I have come across at the architecture school are dissertations in book form.
The second reason is that a great part of my work has been conducted through a reflective practice, which is something that I would like the form of the dissertation to reflect and express. A third reason lies in realizing that three years of work for me does not result in a linear path of subsequent eye opening findings but rather of multiple intertwining paths that through certain perspectives might reveal some more generalizable guidelines.

In the light of these reasons I have made a dissertation that consists of three different parts that all together should make a balance between form and content that provides a range of potential perspectives into the work I have conducted as well as a more in depth discussion and reflection on a smaller part of the work. The parts are *the thesis*, *the papers*, and *the project diagram.* What this all together should give is a broad but important overview over the work conducted in a visual interactive form; a selected number of reviewed papers that describe and discuss clusters within the project overview; and finally a summarizing discussion and reflection on what can be seen as the largest coherent fragment in the *project diagram*. Each part can be looked upon individually, however, the idea is that they should support and link into each other.

By going for this balance between form and content my project hopefully might be of interest to a broader range of disciplines, which I find very important as the field of interaction design inscribes so many different areas of research and practice.

2.1 PART I: THESIS

The thesis part consists of a number of chapters leading to the main contribution of this dissertation – a framework for camera-based mixed interaction spaces. The main chapters are:

Chapter 3: Method and Research Approach
Describes the way I as an architect and designer has approached the field of interaction design. It discusses different conceptions of design and ends with an approach based on research-through-design. This approach is focusing on the design of computational artifacts but is especially concerned with the change of social and cultural behavior as a result of inducing the design into a context of interest. The approach takes its offset in the lived world and is thus practical and explorative.

Chapter 4: Interfaces Beyond the PC
Presents an overview of related work based on and derived from the concept of ubiquitous computing. The objective of this chapter is to bring an overview to the field but also to identify different objectives for bringing technology into space.

Chapter 5: Moving into Space
Presents a concept of space and place within interactive systems adopted from Tuan's phenomenological notion of place as made up by four dimensions (Tuan, 1977). An approach towards space and place is distilled, in which space as a material reality can be designed for users' appropriation into place. Space is in this sense conceptualized as the formable space inscribing physical and digital domains.

Chapter 6: Cases
This chapter describes the three cases iFloor, storySurfer, and Mixis and presents a number of aspects that are useful for understanding *interfaces beyond the PC* as well as aspects of *moving into space*. More important they are chosen as they utilize the same interface for bridging the physical and digital domains, namely a camera.

Chapter 7: Interacting in Camera Spaces
This chapter presents the main contribution of this dissertation – the framework for camera-based mixed interaction spaces. It is based on numerous projects presented in the case chapter, in the *project diagram*, as well on related work. The framework approaches the use of camera interfaces as a spatial construction and describes the aspects related to this space.

Chapter 8: Passing Intentions through the Design of Space
This chapter confronts the conception of space and place described in chapter 5 and the framework described in chapter 7. It discusses how intentions based on the concept of place can be induced into the design of space. In other words it is confronting use as a definition by design with actual use. From this discussion a number of guidelines for the design of mixed interaction spaces are distilled and presented, and examples of using the framework to identify areas for future work within mixed interaction spaces are described.

Chapter 9: Conclusion
The final chapter in the thesis part summarizes the arguments for taking a spatial approach and presents the contributions of the dissertation.

2.2 PART II: PROJECT DIAGRAM

The project diagram is a software program I have designed to dynamically visualize and explore work I have undertaken during the last couple of years and that has helped me inform, unfold and frame the conceptualization of space as interface. To explore the diagram you thus need to insert the DVD attached in the dissertation in your computer or view the diagram online:
http://www.daimi.au.dk/~alo/diagram/diagram.swf
I however, recommend that you run the application on your local computer as some of the content might take up a lot of bandwidth.

The *project diagram* is a visio-spatial entry into the diverse types of work conducted in this Ph.D.-project. Where the *thesis part* is concerned with going into depth with the fragment of mixed interaction spaces the *project diagram* seeks to unfold and relate the different types of projects and the different aspects they address to visualize connections and influences between prototypes, concepts, methods, and papers.

After discussions with my advisors it is not mandatory to explore the *project diagram* but I highly suggest that you put a little time into it as it serves as an alternative into grasping and visualizing my design process and the diverse work undertaken.

Clearly you can explore the diagram after reading the thesis but my idea has been to link from the thesis into the *project diagram* to provide continuous entries to the ways my work is connected and interlinked. Thus it is important to notice the *Mapping ID's* that I use to link from the thesis to the project diagram. Mapping ID's appear in the right side of the page as shown here and can contain multiple ID's to projects related to the content in focus in the text.

[mapping: 6]

This ID can be used in the input text field in the Mapping ID tab in the tab menu in the bottom of the *project diagram*. Read in *Part III: Papers* about how to use the ID's and the *project diagram* in general.

2.3 PART III: PAPERS

The work conducted in this Ph.D.-dissertation is based on practical work and reflections on these. As the entire research field of human computer interaction (HCI) and interaction design are fast developing research fields, in which results usually are small steps building on, derived from, or developments of related work the primary way of presenting results is through papers in peer reviewed conferences and journals. This means that results and findings often become *old news* if they are not published continuously why I have adopted this form of publishing my results. The paper part contains a number of selected papers that I have taken part in writing during my Ph.D.-project. Publishing results together with other colleagues reflects the research practice within a multi-disciplinary field as interaction design. I have not included all papers as I find it more relevant to focus on those that inform the content in the *thesis part* and that have something in common or link different areas of my work in a meaningful way. To read the papers that are not explicitly included in the *paper part* I refer to the *project diagram* that provides the full overview and relation between all papers as well as links to the actual papers in pdf.

Included Papers:

Paper 1: Help Me Pull That Cursor - a Collaborative Interactive Floor Enhancing Community Interaction
Full paper accepted at OZCHI2004. Received Best Paper Award and is also published in the Australian Journal of Information Systems (AJIS) 2004.

Krogh, P.G., Ludvigsen, M., Lykke-Olesen, A. (2004) Help me pull that cursor - A Collaborative Interactive Floor Enhancing Community Interaction. In proceedings of OZCHI 2004, 22-24 November, 2004, Wollongong, Australia. CD-ROM. ISBN:1 74128 079.

Paper 2: Floor Interaction - HCI reaching New Ground
Short paper accepted at CHI2005.

Petersen, M. G., Krogh, P. G., Ludvigsen, M., and Lykke-Olesen, A. 2005. Floor Interaction HCI reaching new ground. In CHI '05 Extended Abstracts on Human Factors in Computing Systems (Portland, OR, USA, April 02 - 07, 2005). CHI '05. ACM Press, New York, NY, 1717-1720. ISBN:1-59593-002-7.

Paper 3: Mixed Interaction Spaces – Expanding the Interaction Space with Mobile Devices
Short paper accepted at HCI2005.

Hansen, T. R., Eriksson, E., Lykke-Olesen, A. (2005) Mixed Interaction Spaces – Expanding the Interaction Space with Mobile Devices. In proceedings of HCI2005 on The Bigger Picture (Edinburgh, UK, September 05 - 09, 2005). Springer-Verlag London, 365-380. ISBN 1-84628-192-X.

Paper 4: Movement-Based Interaction in Camera Spaces – a Conceptual Framework
Journal paper accepted in Personal Ubiquitous Computing 2005.

Eriksson, E., Hansen, T. R. and Lykke-Olesen, A. (2006) Movement-based Interaction in Camera Spaces: a conceptual framework. In the Journal of Personal and Ubiquitous Computing, special issue on movement based interaction. Publisher Springer London, November 15, 2006, ISSN 1617-4909 (Print) 1617-4917 (Online). DOI 10.1007/s00779-006-0134-z

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Paper 5: Reclaiming Public Space - Designing for Public Interaction with Private Devices
Full paper accepted at TEI2007.

Eriksson, E., Hansen, T. R., Lykke-Olesen, A. (2007) Reclaiming Public Space - Designing for Public Interaction with Private Devices. To appear in proceedings of Tangible and Embedded Interaction '07, February 15-17, Baton Rouge, Louisiana.

Additional Papers not Included:

Paper 6: Evaluation of Visualization Methods
Consultancy report prepared by The Alexandra Institute for NCC (in Danish).

Delman, T., Lentz, U., Lykke-Olesen, A. (2003) Evaluation of Vizualisation Methods. Consultancy report prepared by The Alexandra Institute for NCC, 87 pages, December, 2003, Aarhus, Denmark.

Paper 7: Software and Design Process
Short paper published in Arkitekten (not reviewed, in Danish).

Lykke-Olesen, A. (2004) Software and Design Process. Arkitekten, 2004, 106, 3, 10-13, Denmark.

Paper 8: Quality Control in Visualization Processes
Full paper accepted at ECAADE2004.

Lentz, U., Lykke-Olesen, A. (2004) Quality Control in Visualization Processes. Proceedings of ECAADE2004, September, 2004, Copenhagen, Denmark.

Paper 9: Movement and Space – Exploring the Space in Movement Based Interaction
Workshop paper accepted at CC2005.

Hansen, T.R., Eriksson E., Lykke-Olesen, A. (2005) Movement and Space – Exploring the Space in Movement based Interaction. In Workshop Proceedings of "Approaches to Movement-based Interaction", under The Fourth Decennial Aarhus Conference Critical Computing (Aarhus, Denmark, August 20 - 24, 2005). CC'05. Aarhus, Denmark, ISBN 0-9757948-0-9.

Paper 10: Mission from Mars: a Method for Exploring User Requirements for Children in a Narrative Space
Full paper accepted at IDC2005.

Dindler, C., Eriksson, E., Iversen, O. S., Lykke-Olesen, A., and Ludvigsen, M. (2005) Mission from Mars: a method for exploring user requirements for children in a narrative space. In Proceeding of the 2005 Conference on interaction Design and Children (Boulder, Colorado, June 08 - 10, 2005). IDC '05. ACM Press, New York, NY, 40-47. ISBN:1-59593-096-5.

Paper 11: Mixed Interaction Space: Designing for Camera Based Interaction with Mobile Devices
Short paper accepted at CHI2005.

Hansen, T. R., Eriksson, E., and Lykke-Olesen, A. (2005) Mixed interaction space: designing for camera based interaction with mobile devices. In CHI '05 Extended Abstracts on Human Factors in Computing Systems (Portland, OR, USA, April 02 - 07, 2005). CHI '05. ACM Press, New York, NY, 1933-1936. ISBN:1-59593-002-7.

Paper 12: Mixed Interaction Spaces - a New Interaction Technique for Mobile Devices
Demo paper accepted at Ubicomp2005.

Hansen, T. R., Eriksson, E., Lykke-Olesen, A. (2005) Mixed Interaction Spaces - a new Interaction Technique for Mobile Devices. In Proceedings of UbiComp2005, September, 2005, Tokyo, Japan.

Paper 13: Use Your Head: Exploring Face Tracking for Mobile Interaction
Short paper accepted at CHI2006.

Hansen, T. R., Eriksson, E., and Lykke-Olesen, A. (2006) Use Your Head: Exploring FaceTracking for Mobile Interaction. In CHI '06 Extended Abstracts on Human Factors in Computing Systems (Montréal, Québec, Canada, April 22 - 27, 2006). CHI '06. ACM Press, New York, NY, 845-850. ISBN:1-59593-372-7.

Paper 14: Bthere or be Square: a Method for Extreme Contextualization of Design
Full paper accepted at Wonderground2006.

Eriksson, E, Ludvigsen, M, Lykke-Olesen, A, Nielsen, R. (2006) Bthere or be Square: a Method for Extreme Contextualization of Design. In Proceedings of Wonderground 2006 Design Conference, Lisbon, Portugal, Nov 1-4, 2006.

Paper 15: Taking the Physical Aspects Serious - A Design Approach to Children's Interactive Library
Full paper rejected at Nordichi2006, revised and under review.

Eriksson, E., Krogh, P. G., Lykke-Olesen, A. (2006) Taking the Physical Aspects Serious - A Design Approach to Children's Interactive Library. Under review.

SPACE AS INTERFACE

- BRIDGING THE GAP WITH CAMERAS

PART I: THESIS

3 METHOD AND RESEARCH APPROACH

In this chapter I will describe the research center that I am a part of, my research approach and position myself within the field of interaction design. I will do this firstly by introducing the research center to point at the ways my work has been influenced by the overall objective of the center as well as through the collaboration with colleagues from multiple disciplines both within and outside the research center. Then I will unfold different views on design and research in a historical perspective and use that to point at different design understandings within HCI and interaction design. This will finally lead to my definition of the kind of practice-based exploratory design research that I have conducted through this Ph.D. project. This definition will lead to explaining the kinds of results that my research approach has produced.

I will unfold the different design methods used in my research, both the use of existing design methods and touch upon the design use of novel methods to gain new insights.

3.1 THE CENTER FOR INTERACTIVESPACES

The Ph.D. project is conducted within the Interactive Spaces Research Center. InteractiveSpaces is an interdisciplinary research center bringing together architecture, engineering, and computer science with the research mission to create new concepts for future interactive spaces. It includes competences within a number of IT research areas such as augmented reality, virtual reality, hypermedia, human-computer interaction, context-awareness, tracking, mobile computing and physical computing.

InteractiveSpaces are obligated to bring together companies and public researchers in R&D activities leading to new products and services for specific domains. This creates a map of interests consisting of *public researchers* from the different research institutions that make up the center, *company partners* that in different ways have knowledge and expertise within the domain at focus, *representatives from institutions* within the domain we work with and finally and most important the *users* within the domain. Clearly these different partners have different goals and objectives for participating in such projects. To avoid that projects become pure product developments InteractiveSpaces are focusing their research activities on seven themes, which may be applicable to one or more of the application domain projects undertaken in the center. The application domains that have been studied during the last three-four years include schools, libraries, museums, homes and specific workplaces, in which I have been involved in projects related to schools and libraries. Different researchers are responsible for or subscribe to one or more of the research themes providing each project with multiple parallel perspectives to inform and influence the process in the broadest possible way and to be able to harvest results from the projects that can fit into the research of the individual research participant.

The research themes are:

- Space as Interface
- Tangibility and Palpability
- Context-awareness
- Augmenting Reality
- Aesthetic Interaction
- Playfulness
- Social Computing

I will touch upon these themes in the following chapter, however, mention that through the projects my theme has been Space as Interface, whereas the other themes has been adduced by others and hereby influenced and enriched my one perspective during the work in the common projects.

In the research center we have applied a variety of Participatory Design (Ehn and Kyng 1992) methods in order to involve prospective users and partners in the designs of new interactive environments. I will return to discuss the method of participatory design in the later section on design methods, however, for the research center participatory design has helped to create more relevant solutions for users and it reduces the number of early design mistakes through working with concretized design visions such as video-prototypes, mock-ups, prototypes and scenarios.

As the center consists of many disciplines the concept of design is considered differently, thus in the following sections I will present my understanding of design and the way I have conducted research-through-design.

3.2 DESIGN AND SCIENCE

In "Design Research and the New Learning" Buchanan describes the role of design within research from the early seventeenth century till the future challenges for design research. The objective of Buchanan is to show that design from these early days played an important role within the natural sciences exemplified through Galileo's *Dialogues Concerning Two New Sciences* that shows how conversations with and work by skilled craftsmen led to an investigation of a new mathematical science of mechanics. In this case practice is a part of research and theories are build in conversation with the materials and the experiences from the real world.
In the later emergence of "The new learning" design and science is divided.

> *"The new learning was theoretical and oriented towards subject matters, marked off from each other by principals and causes that were, in a sense, in the nature of Being". (Buchanan)*

This division between universities producing knowledge trough theories within narrow fields and art schools fostering natural talents teaching individuals how to *create* has been, and many places still is, the dominant trend. Buchanan describes what he sees as the new Battle of Books[2] being the struggle between the theoretical learning based in the Renaissance and the new *new learning* that in many ways like the Galileo example merges design and science into a new learning. We can see this tendency in the way that human ability to create and construct enters the universities e.g. in the form of engineering and computer science.

> *"The reason for this new battle is evident. While we do not deny the value and the ongoing benefit of theoretical investigations of subject matters in the sciences and arts, we also recognize that the powerful development of this learning has left us in a deeply troubling situation. We possess great knowledge, but the knowledge is fragmented into so great an array of specializations that we cannot find connections and integrations that serve human beings either in their desire to know and understand the world or in their ability to act knowledgeably and responsibly in practical life. While many problems remain to be solved in the fields that currently characterize the old learning - and we must continue to seek better understanding through research in these areas - there are also new problems that are not well addressed by the old structure of learning and the old models of research". (Buchanan)*

[2] The Battle of Books refers an English characterization of the long struggle between old and new learning in our culture in which design was part of the old learning.

The new learning is bridging specialized chunks of knowledge from distinct research fields and operationalizing them and applying them to real life. Buchanan suggests that one of the areas where the new learning is needed is within interaction design. By referring to the development of design as orders Buchanan identifies four orders – *symbols*, *things*, *action*, and *thought*. These orders relate to graphic design, industrial or product design, interaction design and environmental design. The first two orders are concerned with form, function, materials, manner of production and use of products. The order of interaction design on the other hand is concerned with understanding *"products from the inside – not physically inside, but inside the experience of human beings that make and use them in situated social and cultural environments"*. Of course this order emerge from and build upon the first two orders but propose that without understanding how symbols and things take part in the living experiences of human beings these will have no value or significant meaning.

> *"We call this domain "interaction design" because we are focusing on how human beings relate to other human beings through the mediating influence of products. And the products are more than physical objects. They are experiences or activities or services, all of which are integrated into a new understanding of what a product is or could be". (Buchanan)*

The old theoretically based learning can not deal with this complex field alone as it goes across traditional domains of science and theory. I see my self, together with numerous other experts, in this new learning that is trying to bridge between multiple disciplines as it puts new things in the world to understand the complex challenges of interactive products and systems whether physical or digital in its nature. As the field of interaction design inscribes a number of disciplines I will use the following section to unfold my definition of interaction design.

3.3 CHARACTERIZING INTERACTION DESIGN

Is interaction design part of HCI? Is HCI within interaction design? Or are they two separate fields? Frankly I am not sure, and I do not find it important in this context, however, I find it necessary to describe what I see as their differences. If we look to the early days of HCI or rather Man-Machine-Interaction (MMI) the development of technology was difficult and expensive due to the state of production methods. There was no product customization or mass customization for that matter e.g. exemplified by Henry Ford's famous quote "you can have your Ford T in any color as long as it is black". In WW1 fighter plane pilots had to match and fit into the constraints of the plane and its functionality as it would be too costly to adapt the plane to different pilots (see figure 1 a).

As technology developed the thoughts on the relationship between man and technology developed as well. The WW2 fighter planes were developed to meet some of the different requirements and constraints defined by the fighter pilots, or machine operators if you will, both as a consequence of improved production methods but also and perhaps more importantly as a consequence of a shift in focus where technology should adapt to man and not the other way around (see figure 1 b). As the development of computers emerges engineers, computer scientists, cognitive psychologists, and social scientist work to understand how cognitive tasks are carried out by man interacting with increasingly interactive technology. Input devices and advanced graphical interfaces are designed to minimize cognitive load and to increase efficiency and task completion. As the technological penetration increases it becomes clear that the adaptation of technology in relation to man is only one side of the story. As man interacts with technology, technology is influencing the way we work with and appropriate the technology. This leads to a "dance" between user and technology where the two are constantly influencing each other, meeting up and breaking apart (see figure 1 c). This is today a common understanding that man and technology exist in an influential relationship that is constantly under change. The focus in all three examples is task completion and the goal of minimizing the gap between technology and user to make the lines meet and make the ultimate "fighter plane"…

I consider the above examples as the core of HCI. They are concerned with efficiently accomplishing a task and are dominated by a work-oriented focus, even though much research within HCI has gone beyond the work domain. The argument will be that *this* is better than *that* as it is faster or more productive rather than *this* is better than *that* as it is more fun, more challenging, or more aesthetically appealing. In the shift from the work-oriented desktop personal computer (PC) to the PC being a part of everyday life new approaches emerge. New disciplines take part in the development of technologies e.g. industrial designers as appearance becomes more important as the PC has to match the sofa; or graphical designers as user interfaces has to be compelling and suit an entire family rather than just the hard working spreadsheet cowboy. The computer is still a tool concealed in a grey box, however, a more playful tool. Weiser introduces a vision of Ubiquitous Computing where computers migrate from the desktop and become an integral part of our physical environment (Weiser, 1991). HCI research takes up this challenge and goes into space, which I will describe more thoroughly in chapter 4. Disciplines like architecture and design in general enters the scene to discuss and design new forms of spaces and computers as technology breaks out of its shell. The domain of HCI is now populated by a broad range of disciplines that have their different views on technology, interaction, psychology, sociality, space, emotions, design, users, and ultimately how and what is important for the way we live our lives.

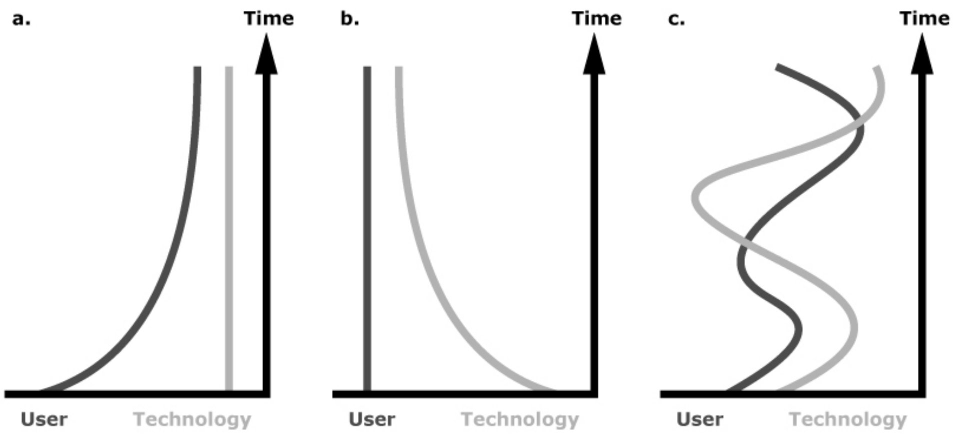

Figure 1: The relationship between technology and man.

This is where I see a split between HCI and interaction design. Both fields are dealing with interaction between technology and users. However, HCI is influenced by its history of focusing on *tasks* by improving and optimizing the interaction between humans and computers from an analytic approach that seeks to evaluate and gain results primarily through quantitative methods. Interaction design on the other hand is focusing on the interaction or the act itself with less focus on a specific task. As the name *interaction design* implies it is a constructive practice that often uses qualitative methods to understand and evaluate systems in use. These two approaches have consequences for how design is defined, how it is applied and further, how to evaluate interactive systems - I will go into the role of design later in this chapter. As well as there a differences between HCI and interaction design there are also many similarities. Interaction design is derived from multiple fields where HCI is one among others such as industrial design, architecture, and engineering. Terry Winograd describes to some extend the relationship in the following:

> *Human-computer interaction is by necessity a field with interdisciplinary concerns, since its essence is interaction that includes people and machines, virtual worlds and computer networks, and a diverse array of objects and behaviors. In the midst of this interdisciplinary collision, we can see the beginning of a new profession, which might be called "interaction design". While drawing from many of the older disciplines, it has a distinct set of concerns and methods. It draws on elements of graphic design, information design, and concepts of human-computer interaction as a basis for designing interaction with (and habitation within) computer-based systems. Although computers are at the center of interaction design, it is not a subfield of computer science." (Winograd 1997)*

In "Interaction Design - foundations, experiments" Hallnäs and Redström take the definition further, by adding more focus to the *interaction*.

> *"Interaction design is design of the acts that define intended use of things." (Hallnäs and Redström, 2006)*

And further:

> *"Interaction design is product- and systems design where computational technology is a basic design material." (Hallnäs and Redström, 2006)*

The first definition is similar to the one of Buchanan in the previous section who states that from a design perspective we see a shift from a focus on the things themselves to the acts that define them in use. Buchanan argues that interaction design does not have to include computational things but is concerned with any kind of interaction between users, products, and systems. In many ways he might be right, however, I will adopt the second definition of Hallnäs and Redström as I am interested in the interaction potentials made possible by the merge between users, space, and computation.

To summarize the main difference between HCI and interaction design lies in the shift in focus from the thing or task itself to the acts that define the intended use of things. This difference has consequences for how the user and design is perceived. In the next two sections I will discuss some of these differences regarding the concept of the user.

3.4 THE FUZZY USER

A user is a user is a user, why all this fuzz? Well, it is not quite that simple, there are loads of perspectives on the concept of the user e.g. how to understand him (is it a man?!) in relation to a system, how to gather design requirements from a user in relation to a system that has not yet been designed, which role the user should play within the design process, and how to design a system in situations where the designer can hardly define the user.

In the following I will introduce a number of these perspectives and discuss them to present what I see as the concept of a fuzzy user. I will be drawing on perspectives developed within HCI and interaction design as they represent different approaches to understanding the relationship between designer, system, and user.

In "From Human Factors to Human Actors" Bannon suggests a shift from a user approach through human factors to a user approach through human actors within systems design (Bannon, 1991). As described in the above section the development of HCI has from its early days been highly influenced by engineering and cognitive psychology applying the concept of human factors or what we could call cognitive and physical ergonomics to systems development. Bannon criticizes this approach by stating:

> *"Within the human factors approach, the human is often reduced to being another system component, with certain characteristics, such as limited attention span, faulty memory, etc. that need to be factored into the design equation for the overall human – machine system." (Bannon, 1991)*

In this case the user is a system component and in fact the worsted and most *stupid* part of the system. The strength, if one can call it that, in this approach is that the system designer can create a cognitive model of the user that will answer all questions for what suits the user when designing the system. In this way designers can rely on a model and expect the user to adopt the system in exactly the same manor as the model predicts. Instead of considering the user as a predictable component Bannon suggests considering the user as an actor:

> *"By using the term "human actors" emphasis is placed on the person as an autonomous agent that has the capacity to regulate and coordinate his or her behavior, rather than simply being a passive element in a human – machine system." (Bannon, 1991)*

Bannon is painting a picture of a user that is behaving as an autonomous agent meaning that predicting his actions is almost impossible. To coup with the problem of predicting how a future user of a system will appropriate it Bannon is drawing on the Scandinavian tradition of Participatory Design (Ehn and Kyng 1992), in which the user is acknowledged as an expert in his own work-practice and therefore holds valuable information for the design of future systems. The design process is democratized by *inviting* the user into the actual design process. The argument is that direct collaboration between designers and future users will improve the design of new systems as it creates a shared understanding of the design problem as well as the solution to this. Well aware that the two roughly described approaches are very different and basically represent two extremes in their way of understanding the user they have one thing in common. As they are both concerned with work practice and task completion they strive to unify the designers' and users' interpretation of the problem and its presumed solution. Sengers and Gaver put it like this:

> *"While different areas disagree on whose interpretation (e.g., the users' or the designers') should be privileged, there is general agreement that there should be a single, correct way to interpret a computer system…" (Senger and Gaver, 2006)*

Sengers and Gaver argue that openness to interpretation in the design of interactive systems is a way of taking the user serious in the sense that the user herself can investigate and create meaning trough use. To some degree I will agree to this, however, this is very dependant on the criticality of the designed system and also on the domain the system is designed for – are we designing for games and play spaces, are we designing for work environments, or are we designing for increased reflection in our everyday life with no specific use in mind. To me the role of interpretation or system ambiguity represents another distinction between HCI and interaction design in their different ways of striving towards a single or multiple interpretations of use. As described in the above section Hallnäs and Redström define interaction design as *"design of the acts that define intended use of things"*.

I am not claiming that the HCI community does not have the same overall objective, however, in the definition of Hallnäs and Redström lie an openness through the recognition that predicting actual use is impossible and is always building on the designer's interpretation and definition of the user. This understanding is deeply rooted in their definition of design that differs from the traditional design understanding within HCI, which I will unfold in the following section. Their argument regarding the "user" is, however, that we can talk about three kinds of users – namely the *empirical user*, the *user as a definition by design*, and the *actual user*. None of these are the same, not even if we made a definition of a user based on empirical studies of a user that we knew would also be the future actual user of our designed system. This is due to the hermeneutical gap that exists within the design circle (see figure 2). The consequence is what Hallnäs and Redström describes as the *disappearing user* because he constantly changes between these three user states as we as designers resolve the design circle going from the abstract to the concrete. Can we forget about the user then? No because as we design interactive systems between people and computational things some kind of user and use will always be a part of the design. To understand if the user we define by design, who we derive from the empirical user, and the actual user match, we have to design, construct and intervene – this is the nature of interaction design. Inherently in interaction design lie the activity of designing, because only through design can we understand the relation between intended use and actual use and hereby understand if the result is what we could call a successful design. Parts of HCI are also constructive and design related but as mentioned earlier they work with a different concept of design, which I in the following section will show makes the most significant difference between HCI and interaction design. In the following section I will clarify the concept of design as I see it within HCI and interaction design.

3.5 DESIGN IN HCI AND INTERACTION DESIGN

Triangulating Across Disciplines

Design plays a role in most of the disciplines engaged in HCI and interaction design. There are different approaches and understandings to design – is it the styling that is applied after "the core project" is finished?, is it a scientific rational activity that can bring us valid measurable results in our research?, is it a process of interpretation that might give us answers?, or is it a mix of all of these? I am not able to come about with all answers to these questions but I will in the following point out how design is carried out depending on the involved disciplines and from that distill the concept of design that I subscribe to. But first I will look at ways these different perspectives on design can work together.

As described above interaction design and HCI are both multidisciplinary fields that borrow techniques and approaches from their component disciplines. According to Mackay (Mackay et al. 1997) instead of looking at competing approaches it is more important to understand enough about each approach and the corresponding assumptions to be able to choose, which is most appropriate for addressing a particular design problem.

As disciplines involved in HCI and interaction design range from natural and social sciences to engineering, design, and fine arts a single thorough research method does not exist and would be impossible to distill. Further, as most interactive systems and artifacts are highly complex a single research approach will fail to uncover most important aspects as different research strategies contain different forces and threats to validity.

To overcome this problem Mackay proposes a solution of triangulation across scientific and design disciplines; meaning that as HCI questions go beyond a single well defined discipline multiple research approaches should be applied to address the same question and hereby produce more robust and useful results. To accomplish Mackay's framework of triangulation can roughly be done in two ways. Either one needs to have expert insights into all component disciplines both regarding "interesting research questions" as well as techniques and methods to avoid that these are adopted without understanding the proper background; otherwise the triangulation can happen in multidisciplinary teams that more often is the reality of HCI research projects. In this case each participant needs to have an acceptance of parallel, however, different research approaches that through theory, observation or design will produce new insights to the question studied. Mackay et al. exemplifies their framework through their study on and redesign of French air traffic control systems and concludes that their triangulation approach improved the final interface.

Design Accounts

In many ways the approach of triangulation is appropriate for the field of interaction design as it just like HCI is dealing with technology, behavior, social interaction, design of physical artifacts and environments etc. However, I tend to see that the different parallel approaches that Mackay et al. argue for are not valued equally within the community of HCI, it seems that some approaches are considered more valid than others. Wolf et al. addressed this problem in a, to some provocative, paper at CHI2006. They investigate the use of *design* within the community and argue that the traditional *design* exists as a part of cognitive science, which they find at best limiting and at worsted flawed. This design approach is oriented towards the quantitative and hereby allows designers to conduct *formal iterations* making it an acceptable practice within the CHI community.

By drawing on Löwgren's distinction between *engineering design* and *creative design* (Löwgren, 1995) they argue that most design within CHI falls in the category of *engineering design*, an approach to problem solving that assumes that a problem can be comprehensively described and specified leading to a solution, which is the core mission. The design evolves as a linear chain of transformations from the abstract to the concrete.

Opposed to this approach *creative design* is about understanding the problem as much as the solution. The design space consisting of the interplay between the problem setting and the problem solving is explored through the creation of parallel ideas and concepts. The *creative design* practice is highly unpredictable as the designer plays a personal role in the process.

An important argument for the need to accept the approach of *creative design* into the solving of HCI problems is the notion of wicked problems. A few aspects of wicked problems from Rittel et al. include (Rittel et al., 1973):

- You don't understand the problem until you have developed a solution.
- Solutions to wicked problems are not right or wrong.
- Wicked problems have no stopping rule.
- Every wicked problem is essentially unique and novel.

From these aspects it is obvious that if one acknowledges a design problem to be *wicked* one will have a hard time dealing with it only through an *engineering design* practice. However, Wolf et al. argues that *creative design* is considered a "black art" within the CHI community leaving little space for approaching wicked problems through creative design. Fällman unfolds three accounts for what design "is". Much like Löwgren's *engineering design* the *conservative account* is aiming to convert an undesired situation into a desirable one. Here, design is thought of as a scientific or engineering endeavor, borrowing methodology and terminology from the natural sciences, mathematics, and systems theory, drawing on a philosophical base in rationalism. A good designer in this tradition is someone who is able to follow a set of prescribed actions.

> *"Design takes on the character of being a problem-solving activity; something that begins when a problem has occurred." (Fällman, 2003)*

In Fällman's *romantic account* designers are seen as imaginative masterminds equipped with almost magical abilities of creation. The designer of the *romantic account* is an *individual*; who puts imagination over abstract reasoning and creativity over rational problem solving. Further, this type of designer is someone who is able to generate creative designs but not able to, or at least not interested in, explaining how they came about.

> *"…like golfers, designers might come to loose their swing if they think too much about what it is they actually do when they design. This account of design can be thought of as 'black boxed'." (Fällman, 2003)*

When the CHI community refers to design as a "black art" it is this type of design account it is pointing towards. Clearly this account creates a difficult basis for triangulating different research approaches as Mackay suggests because the process is not open or described in any explicit way. However, what Wolf et al. argues for is that *creative design* and the *romantic account* of Fällman is not the same; it is rather coupled to the third account of Fällman namely the *pragmatic account*. Rather than science or art, under the *pragmatic account* design takes the form of a hermeneutic process of interpretation and creation of meaning, where designers iteratively interpret the effects of their designs on the situation at hand. The pragmatic account focuses on the situatedness of the designer in the life-world and brings to light the interweaving of roles, practices, and technologies involved in design.

> *"The designer in the pragmatic account can be thought of as a 'self-organizing system' with constructive as well as reflective skills." (Fällman, 2003)*

To unfold the pragmatic approach further, I turn to Hallnäs and Redström and their concept of *the design circle* that is inspired by Jones:

> *"The fundamental problem is that designers are obliged to use current information to predict a future state that will not come about unless their predictions are correct. The final outcome of designing has to be assumed before the means of achieving it can be explored: the designers have to work backwards in time from an assumed effect upon the world to the beginning of a chain of events that will bring the effect about". (Jones, 1992)*

This builds on the assumption that *design is always the design of something given*. The given is the designer's understanding of *something* in present time – to design a chair you have to have some notion of "chair" in order to be able to design a new instance of "chair". In going from the abstract to the concrete the *something* is in the process of design interpreted into *something* as a definition of design. This introduces what Hallnäs and Redström terms *the hermeneutical gap* – a gap between what is actually given and what we actually design. In the case of users as discussed above it is the gap between the empirical user and the user as a definition by design and further, as described in their definition of interaction design the gap between intended use and actual use.

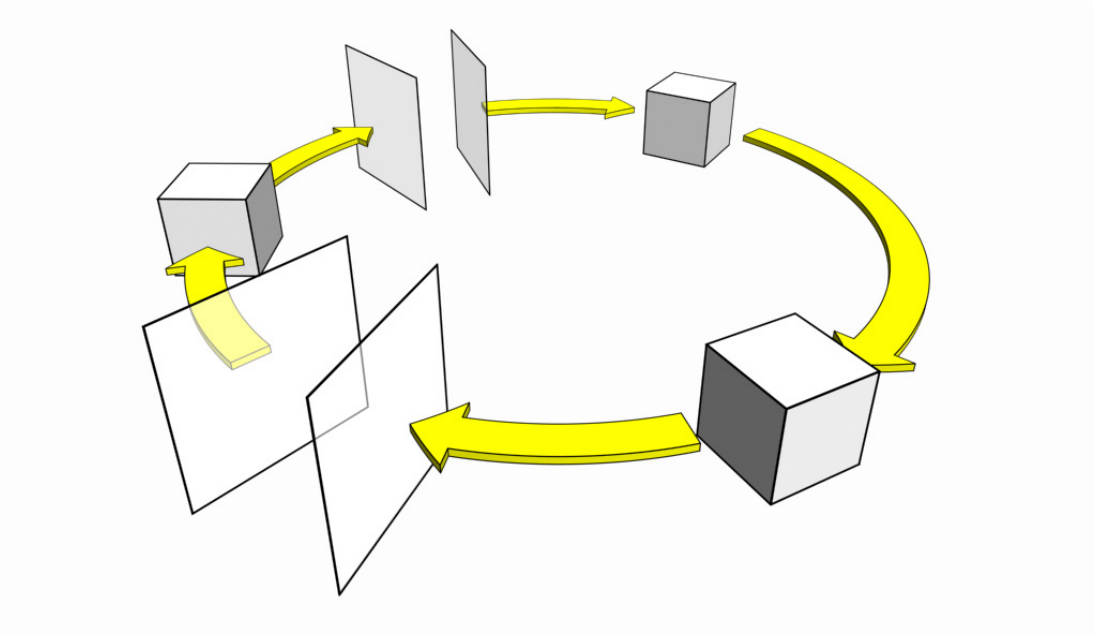

Figure 2: The design circle.

Figure 2 describes the gaps in the design circle and also points to the fact that the actual design will return to us and change our understanding of what is given – our notion of "chair" is enriched. The important learning from this understanding of the design circle is not that new *things* change our perception of those *things* in use, which is basically what I described above as the dance between technology and man, rather is it that hermeneutical gaps are an integral part of design practice. This means that *engineering design* falls for the *empirical fallacy* as it builds on pure rational reasoning and the assumption that a problem can be analyzed and understood fully and from that we can derive a valid design solution. This means that no matter how many different design methods and disciplines you use to solve a design problem you will only be making predictions based on current understandings. This does not mean that methods and some sort of design rigor, as proposed by Wolf et al., does not count but that we will never end at a perfect rational concluded design circle.

3.6 RESEARCH THROUGH DESIGN

From the above unfolding of design within HCI and interaction design I will describe how design practice can serve as a means for design research within the field of interaction design. My approach is a practice-based explorative approach that is best described as *research-trough-design* (Frayling, 1993). Research-through-design can be seen in relation to two other types of design research namely research-on-design and research-in-design. The distinction between these three kinds of design research can crudely be seen here[3]:

Research-on-design has an art-historian focus on designed *things* and the effects of these *things* in use. This approach is not a constructive practice in the sense of creating new *things* but rather an analytic descriptive practice that might serve to grasp what is *given* in the design circle or the implications of actual use.

Research-in-design is concerned with the process of design. It is focusing on the methods and processes that bring forth new *things* and seeks to understand the influence of these different steps in relation to the final result. The aim of the research is to understand the design process by breaking it into formalized reproducible parts to gain a scientific insight in design.

Research-through-design is carried out as a design practice but not with the primary focus on the designed *things* themselves but rather these *things* used as a means to get insights into a context of interest and the lived life within that context. The designer is not an observer but an interventionist who creates space for investigation through bringing the proposed design into context.

Research-through-design has many similarities with *action research,* in which the basic assumption is that complex social systems can not be reduced for meaningful studies. Trying to analytically separate different parts of a social system does not make sense, as the meaning arises in the complexity of the whole system (Baskerville, 1999). Thus action researchers investigate social systems by applying changes to these and observe the effects. That is also the objective of research-through-design, however, this approach also put a great focus on the design of the intervening prototype itself. Fällman calls this *design-oriented research,* which is opposed to his *research-oriented design* that has production of new artifacts as its main motivation (Fällman, 2003).

> *"In design-oriented research, the knowledge that comes from studying the designed artifact in use or from the process of bringing the product into being is the contribution, while the resulting artifact is considered more a means than an end". (Fällman, 2003)*

This research approach is both resembling the above described research-in-design and research-trough-design. It is inspired by Schön's notion of a *reflective practice* (Schön, 1983); reflective conversations with the material as well as with the situation, which is happening in the *talk back* between material, situation, and designer. As will be clear in the following section on design methods research-in-design has also been a part of my work, however, my main contributions are conducted by a research-trough-design approach.

Buchanan describes design research as being *clinical*, *applied*, or *basic*.

Clinical research:

> *"Clinical research focuses on the problem for action that the designer faces. To solve a particular, individual design problem, it is essential to gather whatever information or understanding may be relevant in its solution".*

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3 For a thorough discussion on these three types of design research I refer to the Ph.D.-dissertation of Martin Ludvigsen (Ludvigsen, 2006).

Applied research:

> *"The common trait of applied research in design is the attempt to gather from many cases a hypothesis or several hypotheses that may explain how the design of a class of products takes place, the kind of reasoning that is effective in design for that class, and so forth".*

Basic research:

> *"In general this type of research is associated with design theory, which provides a foundation for all other activities in design. Furthermore, the development of basic research often suggests bridges to other disciplines, as the problems unfold and become focused".*

Clearly clinical research is a research that includes design activities, in which the design of *something* requires some understanding of what is *given*. That has of course also been a part of my work both as individual researcher and designer, and in the project teams I have been part of. But in this Ph.D.-project I present a number of findings done through an applied research approach. This is hopefully made clear through the *project diagram* that I have used to identify, understand, and present connections between the individual cases, that each might have different aspects that they seek to unfold, but from which common findings can be extracted to give more general insights. These findings are presented later through the framework for camera-based mixed interaction spaces.

3.7 DESIGN METHODS

In the following I will describe my use of design methods as well as a discussion on the use of methods related to my design and research approach as described above.

Design methods help us understand how we shall conduct certain activities within the design process to get *something* in return. It is more or less formalized and structured recipes for controlling the design process in ways that makes others understand what we have done and how we have done it[4]. We use methods depending on where we are in the process; we choose methods depending on the people involved and who we are designing for; and we choose methods depending on our objective, who we are, and how we understand what it is that we do. Despite all different reasons for choosing certain design methods they all work within the design circle, which implies hermeneutical gaps that we can not bridge no matter how many methods we apply to the design problem. This is, however, not a *carte blanche* for turning to *black-box-design* but rather an argument for obtaining a healthy scepticism towards the methods used. In (Harrison et al., 2006) the use of multiple and contrasting methods are discussed and presented as a way of providing a rich and productive notion of design.

> *"We address this downside by teaching many contrasting methods. Each is a set of rules or behaviors that produce artifacts for reflection and development". (Harrison et al., 2006)*

Further, they argue that methods in their nature of to some extent being formalized can help different disciplines collaborating in the design process.

> *"A plurality of methods is one means to understand that designing is composed of different activities and that these activities have names, and using the names of the activities enables collaboration. Contrast and reflection are key components to method use". (Harrison et al., 2006)*

[4] In the following I will leave out the methods that exist within *black-box-design* or what is described above as the *romantic design account* as it has no relevance in a research context that rely on some degree of rigor and transparency.

Being conscious of the methods used by a design team within the design process can be a good step for bridging and triangulating (Mackay et al., 1998) across the different involved disciplines. The outcome of the method might only be of particular interest for parts of the design team but given that the method is somewhat formalized clarifies the objective of the method for the rest of the design team. Like Fällman (Fällman, 2003) I will on the other hand argue for a use of methods that in some cases are used more unstructured, meaning that the methods are molded to fit a certain design situation. The method is still an external communicative tool, however, internally for the designer the method becomes transparent – the method is not important, it is what the method can do for us that is important.

My research-through-design approach implies that I am engaged in a constructive design practice in, which the designed *something* is introduced into a context of interest to investigate the effects of possible relations between the context and this new *something*.
As described earlier parts of this Ph.D.-project has been conducted:

- In multi-disciplinary teams within the domains of schools and libraries. The work has including collaboration with industry partners as well as domain specific institutions. The projects have had a tight user focus.

[mapping: 1, 2, 5]

- As work done around the MIXIS concept with Thomas Riisgaard Hansen, Ph.D.-student at Pervasive Healthcare, Department of Computer Science, University of Aarhus and Eva Eriksson, Ph.D.-student at Interaction Design, Chalmers Technical University of Gothenburg. The project has had no specific user focus either any specific application domain.

[mapping: 6, 24]

- As work done within *kollision,* that consists of Thomas Delman, Literature and Information Science; Rune Nielsen, Tobias Løssing and, I all architects. Most work includes to some extent a real client. We are, however, mostly conducting work that implies some sort of R&D and that includes collaborators from other disciplines. A lot of the work has informed the Ph.D.-projects of both Rune Nielsen and Tobias Løssing and to some extent this present project.

[mapping: 0, 47]

- As work done by my self as extensions to ongoing projects or as smaller branches of work that I had interest in exploring to inform my overall research perspective on space as interface.

[mapping: 28, 48]

These broad work conditions imply the need for multiple and diverse design methods. Well aware that it is almost impossible, I have had and still have the eager to obtain thorough insights into all disciplines involved in interaction design, both regarding methods and techniques. I would like to master all disciplines, not to avoid collaborating but instead to be even better to engage in discussions that are constrained by the involved fields.

My background as an architect has provided me with multiple methods and techniques for sketching, modeling, animating, and representing design proposals. Löwgren and Stolterman (Löwgren et al., 2006) describe sketching as something more than drawing on a piece of paper to visualize an idea. It is a conversation between eye and hand; it is a way to communicate. Design ideas are made available for others' inspection, appropriation, criticism and development. It is a way to persuade. Other stakeholders in the design process may be convinced of the value of a design idea through sketches. Sketching is both a technique for internal and external dialogue and conversation carried out through numerous techniques. As interaction design is concerned with both spatial and temporal aspects sketching techniques need to be able to handle these. An example of a sketching technique, in which temporal and spatial aspects are addressed in real-time can be seen in the *project diagram*.

[mapping: 8]

One thing is sketching out ideas but to be able to actually understand *IT as a design material* as proposed by Redström (Redström, 2001) I have obtained skills in programming as well as basic knowledge on sensor systems to understand the interface between physical and digital domains. This has not only made me capable of actually building working prototypes, as opposed to *just* visualize them as scenarios and concepts, but also to understand the nature of interactive technology in use. Moreover than *just* learning how to program it has introduced me to object-orientation and a concept of problem-solving, which implies breaking everything down to small pieces – separation of concerns. In some ways this approach differs from what I was taught as an architect where a strong grasp of the overall design would give *answers* to all the details. Clearly I was taught that a good architect and planner were able to jump between different scales to investigate how consequences on one level of scale would influence another but the approach was very seldom *bottom-up* but rather *top-down*. I am trying to do both and go *middle-out*.

The skills and knowledge I have accumulated in these different fields has helped constrain the design process, which of course touches on the relationship between blue-sky-ideas and down-to-earth proposals that is often influenced by the knowledge you have within the involved fields e.g. farming, space travel, or interaction design. Nevertheless, I believe in the importance of having hands-on experiences through working with the material and hereby create a base for a more abstract understanding of the material at hand. This returns to design as design of something *given*, and one way of getting a notion of this *given* is through experiments with the material. Stolterman talks about understanding the potentiality of materials through a *close* and a *distant* approach (Stolterman, 2005).

> *"These two ways to approach a material, a technology, are extremely important, i.e., to have a distant "theoretical" or abstract understanding of the technology, and to have a close and hands-on sensitivity". (Stolterman, 2005)*

Stolterman suspects that almost no one within academic work master both perspectives, but more likely subscribe to one of the two. I will not argue that I posses and master both these perspectives but I strive to get an increased abstract understanding through my practical and empirical work with the material. It is also worth noting that the *distant* perspective has been carried out through the overall research theme - Space as Interface whereas the *close* perspective lies in the actual exploration of the materials.

Sketching, Scenario-making and Prototyping

In this section I will be a bit more concrete on the design methods used to undertake the different empirical projects within this Ph.D.-project. I will not go into depth with each and every method but rather give a broad view on methods used, which is in line with my practice-based explorative research approach.

As parts of the projects have been directed towards specific domains we have had a good basis for observing the context, access to potential future users, as well as testing designed prototypes in real world settings. The description below is mixing methods and projects, and serves only to present the different methods used. In chapter 6 described later methods will be explained in relation to each case.

As ways of approaching the domains and gathering design requirements we have conducted *context* as well as *user observations* in schools and libraries (Beyer et al., 1998). During these we have engaged in both *formal* and *informal interviews* with teachers, school kids, librarians, and users of the public library in different ages (Jones, 1992). The interviews have mainly concerned practice of use as ways into understanding how the present school and library affect the different users. But we also engaged in more playful and constructive methods as *drawing sessions* with kids on libraries trying to imagine the library in a hundred years and how libraries would look like on mars. These sessions were derived from a method we designed for gathering user requirements for the design of the eBag (Brodersen et al., 2005) by creating a *shared narrative space* (Dindler et al., 2005). In two cases we left kids alone with video cameras asking them to *make films* on *how they go to school* or *how they use the library*. The objective here was to see the physical space from the *kids' perspective* as well as have them frame what they see as important instances or places in their environment.

Figure 3: Examples of design methods; bodystorming, narratives, constructive workshops, and lab evaluations.

As a supplement to the external activities we have had teachers, librarians and industry partners working on the side with the design teams. These partners have been engaged through multiple sessions throughout the different design processes. These sessions include seminars for *creating a common ground*, *brainstorms* (Jones, 1992) for generating initial ideas, *bodystorms* (Oulasvirta et al., 2003) for acting them out, *storyboarding* to add the notion of time and space, *video prototypes* (Bardram et al., 2002), and sessions for *evaluating and killing darlings*. Further, we have made *mock-ups* and *hardware tests* to improve communication with partners outside the core design team.

Figure 4: Examples of design methods; informal interviews, drawing sessions, user tests, and alternative ways for gathering user requirements.

I have used sketches of all types to develop, communicate, understand, and evaluate the design proposals we were working on. These sketches go from static representational techniques such as simple pencil sketches, and diagrammatic CAD sketches; over dynamic representations like advanced 3D animation mixing real world footage and digital layers, and virtual video prototyping using real-time blue screening; to interactive software sketches such as flash and vrml mock-ups.

[mapping: 25, 11, 33, 3]

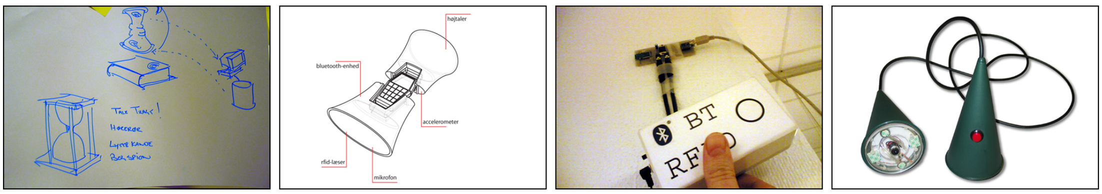

Figure 5: From sketch to prototype; raw sketch, conceptual sketch, hardware test, and final working prototype.

As design prototypes matured in the lab these have been used as intervention artifacts in the contexts of the domains in focus. The activity of bringing the prototypes into real context is, as described earlier, a condition for confronting intended use with actual use. The prototypes have been evaluated in a number of ways according to the questions raised by the project itself e.g. "how can the iFloor stimulate communication between library users?", as well as by the overall research themes. We have used weeks *observing* the use of prototypes in schools and libraries; we have made *formal interviews* with users, held *user test* sessions, and changed the prototypes in the fly to meet some of the findings.

3.8 CONTRIBUTIONS OF AN EXPLORATIVE APPROACH

The contributions of my research fall into different categories.

- Interactive artifacts exploring space as interface.
- A number of methods designed to gain new insights into the design process
- A conception of space and place based on empirical work and theories of place and space.
- A framework based on empirical work applicable for analyzing, comparing, and designing camera-based mixed interaction spaces.

Working in project teams with both industry partners and other institutions forces a common goal for a project that is not necessarily related to my overall theme. Thus these projects can produce two kinds of results. The ones related to the overall goal or question and the ones informing my own spatial theme. Both of these are carried out through a research-through-design approach and most of the designed artifacts are confronted with actual use as they are tested in a specific context of interest. In the discussion between rigor and relevance taking a large perspective on the projects and insisting on placing computational artifacts into real social contexts has placed the contributions towards the latter. Each project has not been tested rigorously why some of the findings and guidelines might be weak but still holds much relevance for others engaging in such contexts. Nevertheless, the artifacts themselves are contributions to the research as they inform and change the conception of what is *given*. They are novel interfaces that approach the design of technology from a spatial perspective. Some of these findings are presented in chapter 6 (*cases*), whereas others are published as papers available in the *Part II: Project Diagram* and the *Part III: Papers.*

In several of the projects I have been involved in we have conducted research-in-design by designing methods suitable for certain activities in the design process. I am not focusing on these aspects in this dissertation but nevertheless, find it important to mention as it is part of defining my explorative approach, and further because they are valuable contributions published as papers into the HCI and interaction design community. *Paper 10* and *paper 14* are examples of such and available in the *Part II: Project Diagram*.

The conception of space is based on my empirical work and not by being speculative and theorizing on it. This is in line with both the definition of interaction design that I subscribe to and my research approach inspired by action research. They are based on taking action and putting things into the world for reflections afterwards. I have developed these reflections further by adopting a useful theory on place and space and add certain focus to the spatial and formable aspects.

The framework contribution falls within Buchanan’s applied research and by looking across different projects it distills aspects and guidelines that are generalizable for these types of projects. This framework that I present in chapter 7 is based on my own empirical work as well as related work projects from different domains. Because of their differences they serve to inform an understanding of the projects on a higher level than the individual projects. The framework presents a new approach to space in camera based interactive systems and proves its applicability for both analyzing and designing such systems.

3.9 SUMMARY

In this chapter I have clarified my research approach for conducting this Ph.D.-project. I am positioning my work within the interaction design community and subscribe to a research-through–design approach that is derived from action research. This approach is engaged with deploying interactive artifacts into social context to investigate changed behaviors as a consequence of the intervention. At the same time the interactive artifact itself produces new knowledge as it informs and changes our perception of the *given*.

The approach is in line with my conception of design as being an activity doomed to deal with hermeneutical gaps that first of all rejects the design process as straight forward and further acknowledges that there might very well be differences in the use as a definition by design and actual use. Therefore the interventions of designed computational artifacts in real social contexts are necessary to confront these two definitions of use.

In the following I will give an overview of the developments within HCI and interaction design as technology is migrating off the desktop. This is to present inspirational and related work as well as to set the scene for my later presented and discussed work.

4 INTERFACES BEYOND THE PC

As I have stated in my introduction space as interface is seeking to investigate how space can play a part in the design of interactive systems. Space as Interface basically introduces a concept of perceiving space as a potential interface. It is a technological concept that goes beyond the traditional way we as users interact with technology and explores interfaces as an integral part of space.
By using the term *space as interface* I am not trying to create a new concept or approach towards computing that goes alongside such concepts as *ubiquitous computing*, *pervasive computing*, *ambient intelligence*, *embodied interaction*, *tangible computing*, *physical computing*, *augmented reality*, *mixed reality*, *context-aware computing*, *computer supported collaborative work*, *mobile computing*, and so on rather I want to put the attention towards space, computing and interaction knowing that such an approach will borrow from and exploit perspectives, theories and examples from all these fields.

In *space as interface* lies a range of questions such as what is an interface? What sort of space is included? What does interacting in space imply?

To understand this more in depth I will describe some of the technological developments from around the time when the term *ubiquitous computing* was coined by *Mark Weiser* at *Xerox Parc* and up till today. By doing so I hope to give a brief overview of the development of different approaches that I am inspired by. Further, by making this broad outline I am hoping to create a basis for understanding the various stands within the development of HCI and interaction design. This is to clarify my work for people within my initial field of architecture and design that are not usually engaged in the development of technology.

The overview will in the later chapter serve as a basis for discussing how different conceptions of space is taking part in the interaction or how interaction is taking part in space, which will lead to a conception of space useful for understanding and conducting interaction design.

4.1 UBIQUITOUS COMPUTING

In his influential paper “The Computer for the 21st Century” *Weiser* describes his vision for the “third age” of computing namely *ubiquitous computing* (Weiser, 1991).

The first computing age around the 60’s and 70’s was the era of the mainframe computer where hundreds of people shared a single computer for multiple different tasks. This was an elitist era where computing was only available for the chosen ones and was exclusively work oriented.

The second computing age around the 80’s and 90’s was the one of the personal desktop computer providing a PC to every desktop. The environment for the second age was “simple” – one user one computer and a limited set of input/output devices e.g. keyboard, mouse, display. At first the human computer interaction (HCI) research focus was work oriented and influenced by cognitive psychology but as PC’s migrated to domestic environments studying game and leisure activities started to play a more significant role.

By introducing the concept of ubiquitous computing *Weiser* suggests that each user will be served by hundreds of computational devices that are spread out in the environment.

"Hundreds of computers in a room could seem intimidating at first, just as hundreds of volts coursing through wires in the walls once did. But like the wires in the walls, these hundreds of computers will come to be invisible to common awareness. People will simply use them unconsciously to accomplish everyday tasks". (Weiser, 1991)

So what does this vision imply and what are the initial consequences? First of all it means a shift from the desktop computer to a kind of computer or technology that is all around us and might be perceived as invisible or transparent in the sense that we take its functionality and appearance for granted just like we do with electricity. The context in which the computer or computing takes place is expanded from the space inscribing PC and user to basically any environment – meaning that space in a broader sense should be considered when designing ubiquitous computing systems.

Apart from reacting to the use of computers as one mainframe or as one user one PC *Weiser* is also opposing to the concept of *virtual reality* as it *"...focuses on enormous apparatus on simulating the world rather than on invisibly enhancing the world that already exists". (Weiser, 1991)*
Instead of *virtual reality* he is suggesting the term *"embodied virtuality"* that refers to drawing computers out of their electronic shells and into the physical world. In the concept of embodiment lies a first steps towards a social perspective on computing, which I will get back to later in this chapter.

"By pushing computers into the background, embodied virtuality will make individuals more aware of the people on the other ends of their computer links. This development may reverse the unhealthy centripetal forces that conventional personal computers have introduced into life and workplace". (Weiser, 1991)

Most of the technologies e.g. *tabs*, *pads* and *boards*, as well as scenarios that *Weiser* envision are largely based on the traditional *Graphical User Interface* (GUI) style interaction metaphor, however, here each device represents one window on the traditional PC desktop. *Weiser* compares the physical desktop full of spatially organized piles of material and the PC desktop interface, in which everything is crammed together on a small screen resulting in a cluttered view of ones materials and concludes that this analogy will only work on multiple spatially distributed devices in many different scales.

4.2 CONTEXT-AWARE COMPUTING

Inspired by Weiser Fitzmaurice introduces a somewhat different approach to the multiple distributed displays. By talking about *"situated information spaces"* he stresses the need for anchoring digital information to physical locations (Fitzmaurice, 1993).

"…we will browse, interact, and manipulate electronic information within the context and situation in which the information originated and where it holds strong meaning." (Fitzmaurice, 1993)

These situated information spaces are accessible through a personal wearable computer that serves as a peephole into the digital content. This introduces technology that is aware of its context as well as information that is related to a certain space or context. The interaction with the digital content is obtained by gesturing the handheld device introducing very spatially aware concepts for interacting with digital material – tilting, rotating, raising the device to provide input to the system.

Similar concepts emerge within the development of *Context-Aware Computing* that has its focus on understanding the context, in which actions take place. The critical issue here is the one of *context* and how (if possible at all) a sensor system is able to sense the context and provide meaningful feedback to users according to its gathered inputs. One of the first definitions of context is by Schilit et al.:

> *"Context encompasses more than just the user's location, because other things of interest are also mobile and changing. Context includes lighting, noise level, network connectivity, communication costs, communication bandwidth and even the social situation, e.g. whether you are with your manager or with a co-worker". (Schilit et al. 1994)*

An example of such a system could be the sliding doors in the supermarket that "intelligently" opens when you approach them during opening hours. This is a very simple case but it still shows the potential complexity of grasping the context. In a later definition Dey defines context as:

> *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." (Dey, 2001)*

Further, Dey defines context-aware as:

> *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task." (Dey, 2001)*

According to Dey, and others in the computer science field, context within context-aware computing is more than getting a hold on the physical conditions. Consider the above sliding door example if the system should be able to exclude certain suspects from entering the store or if we wanted the doors to sense if users were actually facing the doors or just walking a bit too close to the sensors as they walked along the doors. These small changes certainly change and increase the complexity of context and solving these fairly simple issues might require a heavy setup of sensor and monitoring systems and still what happens if a suspect tries to enter at the same time as a cleared costumer? How will the system provide meaningful feedback to the users?

Dourish takes an approach towards context from the field of ethnography where he explores the relationship between technical and social aspects of context and, what for Dourish follows to be, the mismatch between those two in most current research within ubiquitous computing.

> *"…, the notion of context in ubiquitous computing has a dual origin. On the one hand, it is a technical notion, one that offers system developers new ways to conceptualize human action and the relationship between that action and computational systems to support it. On the other hand, it is also a notion drawn from social science, drawing analytic attention to certain aspects of social settings". (Dourish, 2004)*

He points at two social theories for understanding context within ubiquitous computing systems namely *positivist* and *phenomenological* theories.
The positivist theory is derived from the rational, empirical, scientific tradition and usually ends up in quantitative results:

> *"…, positivist theories seek objective, independent descriptions of social phenomena, abstracting from the detail of particular occasions or settings, often in favour of broad statistical trends and idealized models". (Dourish, 2004)*

The phenomenological theory is subjective and qualitative:

> *"…; in this view, social facts are emergent properties of interactions, not pre-given or absolute but negotiated, contested and subject to continual processes of interpretation and reinterpretation." (Dourish, 2004)*

The two approaches afford very different understandings of context, which has great influence on the systems designed from these views, which can be described as follows:

Systems based on the positivist approach result in context as a representational problem – *context is a form of information*, *context is delineable*, *context is stable*, and *context and activity are separable* – and pose the question: *"what is context and how can it be encoded?"*

Systems based on the phenomenological approach result in context as an interactional problem – *contextuality is a relational property*, *the scope of contextual features is defined dynamically*, *context is an occasioned property*, and *context arise from the activity* – and pose the question: *"how and why, in the course of their interactions, do people achieve and maintain a mutual understanding of context and their interactions?"*

Dourish questions the dominant positivist approach as it does not acknowledge meaningful practice as a dynamic process, in which context is created. Grasping context through the two presented social theories show the range of challenges for the design of ubiquitous computing systems and also presents the variety of disciplines engaged in and contributing to the fields of HCI and interaction design. It is clear that a computer scientist through his practice is used to create abstractions, models and representations; this view will influence and filter the way he "chooses" to look at the world. From a representational point of view the positivist theory makes sense to him – these kinds of contexts can be modeled consistently whereas the phenomenological theory includes a subjective richness and dynamic that is hard to grasp and formalize for a computer scientist, but which makes sense for the more "soft" disciplines engaged in defining the context such as some designers, ethnographers, and anthropologists. The distinction becomes very clear when you consider how Schilit et al. defines the social situation regarding context as to whether you are with your manager or a co-worker. All other content in this definition can just like the reduced view of social aspects be turned into measurable parameters that fit perfectly into a computational model of "context".

I will return to the concept of context-awareness later in the space-section, however, regardless of understanding context from a positivist or phenomenological perspective this thinking is a consequence of the migration of technology from a well defined desktop situation into a complex environment of humans and spaces.

4.3 TANGIBLE COMPUTING

When introducing "Tangible Bits" Ishii and Ullmer acknowledged the approach of Weiser and Fitzmaurice but were seeking to take the physical aspects further into account when designing ubiquitous computing systems. Through developments such as Graspable User Interfaces evolved the concept of Tangible User Interfaces (TUI) (Fitzmaurice et al., 1995).

> *"To make computing truly ubiquitous and invisible we seek to establish a new type of HCI that we call "Tangible User Interfaces" (TUIs). TUIs will augment the real physical world by coupling digital information to everyday physical objects and environments." (Ishii and Ullmer, 1999)*

A significant development from Weiser's vision to the one of Ishii and Ullmer is the focus on alternative and diverse input devices for sensing a wider range of inputs from the physical environment. By developing new input devices they are seeking to rejoin the richness of interacting in and with the physical world and HCI. The goal of Tangible Bits is to bridge the gap between cyberspace and the physical world by making digital information (bits) tangible.

The tangible interaction approach opens up for any object being a potential input and output device putting much more focus on the physical objects – their form, shape, and texture - and how we handle them, than on considering them as part of a computer system. In this way the computer becomes transparent as interactions are mediated through digitally enhanced everyday objects. At first the research on TUIs focused on developing new systems and interfaces but as a certain critical mass of empery has evolved, several researchers have tried to develop frameworks and taxonomies for designing, discussing and analyzing these tangible interfaces. Sharlin et al. argue that TUIs increase productivity as they make tools easier to use:

> *"TUIs achieve this by exploiting human spatiality, our innate ability to act in physical space and interact with physical objects". (Sharlin et al., 2004)*

They suggest three spatial heuristics as important when designing and evaluating physical/digital mappings in what they identify as "spatial TUIs". These are:

Successful spatial mapping is building on Norman's notion of *"natural mapping"* (Norman, 1999) and Beaudouin-Lafon's *"degree of integration"* (Beaudouin-Lafon, 2000). It is the relationship between the characteristics of the TUI's objects and their use that for good spatial mapping to occur must be spatially congruent and/or well known.

Unify input and output space is concerned with the coupling of *"action space"* and *"perception space"*. When we in the physical world interact with physical objects e.g. with our hands the action space is seen as the way we handle the object with our hands whereas the perception space is the way we perceive e.g. weight and texture of the object. In this case there exist a tight coupling of the two spaces, however, Sharlin et al. argue that this is often not the case in traditional GUIs where action space might be your hand moving the mouse on the desktop and perception space being the screen. They suggest that a unification of inputs and outputs avoids putting attention to multiple distributed spaces at the same time.

Enable trial-and-error activity is concerned with the ability to do both pragmatic and trail-and-error (epistemic) activities. There are different ways of utilizing a hammer but often computer systems must be used in very specific way. This spatial heuristic addresses a similar potentiality within system design.

The three spatial heuristics of Sharlin et al. provides ways of analyzing, comparing, as well as guiding design for different TUIs, however, this is primarily done from a perspective of efficiency and productivity:

> *"Like any sort of human-computer interface, TUIs strive to improve human productivity by making the full power of automation accessible to users". (Sharlin et al., 2004)*

To me the focus on the efficient task limits its possibility of appreciating interfaces for investigation, negotiation and play. The framework is introducing several "spaces" that are not really elaborated, however, mostly concerned with the physically spatial distribution of input and output and translations between physical and digital domains.

Another attempt to create a framework or taxonomy for tangible user interfaces is the one of Fishkin that seeks to unify an even broader range of TUIs than Ishii and Ullmer originally did. By setting up a space inscribed by *metaphor* and *embodiment* Fishkin is able to analyze and compare a range of even very different TUIs (Fishkin, 2005).

The axis of embodiment (Fishkin's *embodiment* is a small subset of Dourish's *embodied interaction*) is divided into – *full*, *nearby*, *environmental* and *distant,* which in many ways can be seen as a further elaboration of Sharlin et al.'s notion of "*unify input and output space"*.

The axis of metaphor is divided into – *none*, *noun or verb*, *noun and verb*, and *full*. These segments represent different ways that the physical/digital mapping in a TUI is/is not supported by a metaphor. Fishkin cites Mithen:

> *"…the most powerful [metaphors] are those which cross domain boundaries, such as by associating a living entity with something that is inert or an idea with something that is tangible". (Mithen, 1996)*

On the basis of this TUIs should work ideally with metaphors as they are themselves cross-domain between the physical and the digital realm. It is my opinion that Fishkin's taxonomy offers a very consistent frame for designing, analyzing, and comparing different TUIs. The terms *metaphor* and *embodiment* serve as good takeoffs for understanding the core interactions as well as the form and appearance of these interfaces. However, where I think the taxonomy lacks is in its use of space, which to me is very weakly defined - basically through the concept of embodiment as a container for interaction.

4.4 AUGMENTED AND MIXED REALITY

Yet another approach to computing that grew from ubiquitous computing towards bridging physical and digital space came with the concept of Augmented Reality (AR) that as its starting point were seeking to augment the physical world with digital information through visual overlays.

In (MacKay, 1998) MacKay describes three basic strategies for augmenting the physical world – *augmenting the user*, *augmenting the object*, and *augmenting the environment*. This segmentation is concerned with the paradigm of ubiquitous computing and further to identify what should be augmented to design meaningful applications. Augmenting the user provides specific and individual views for one user (might be multiple), however, the entire environment can exist in its usual manor. Augmenting the environment would require other types of hardware but also a more intrusive technology even though it is argued that it might become invisible. According to Mackay:

> *"The most innovative aspect of augmented reality is not the technology: it is the objective. Instead of replacing physical objects with a computer, we create systems that allow people to interact with the real world in natural ways and at the same time, benefit from enhanced capabilities from the computer. The future we envision is not a strange world in which we are immersed in "virtual reality". Instead, we see our familiar world, enhanced in numerous, often invisible ways". (Mackay, 1998)*

In parts of AR geometrical space is an important player in matching the perspective of the real world with digital overlays (Kato et al., 1999). Like with TUIs the PC slips in the background but in most AR applications traditional output devices are exchanged by head-mounted or hand-held displays potentially enabling the entire environment to be part of the interface.

Milgram and Kishino introduces the idea of mixed-reality based on a classification of different augmented reality technologies focusing on overlaying two "collocated" Cartesian spaces at different levels of detail (Milgram et al., 1994). Opposed to this very strict geometrical approach towards mixing physical and digital spaces Benford et al. (Benford et al., 1998) introduces a perspective on mixed-reality within Computer Supported Collaborative Work (CSCW) in "Understanding and Constructing Shared Spaces with Mixed-Reality Boundaries" that includes a range of spaces, Cartesian as well as non-Cartesian, at distributed locations. This perspective opens up for slightly different ways of mixing spaces across digital and physical domains as well as over distance. However, as this work is mainly directed towards CSCW space is very "simple" defined in the sense that it is about physical location, orientation, and shared perspectives rather than social and cultural filters influencing and broadening the understanding of space.

4.5 REFLECTIONS ON UBIQUITOUS COMPUTING

In 2000 Abowd et al. (Abowd et al., 2000) conducted a survey on ubiquitous computing systems to characterize the past years of research and on the basis of that put forward new guidelines for research within the field. They propose that the past decade has been an application-driven research in ubiquitous computing. From analyzing a range of these applications they distill three interaction themes: *natural interfaces*, *context-aware applications*, and *automated capture and access*. Across these themes Abowd et al. note that research in ubiquitous computing implicitly requires addressing some notion of scale, whether in the number and type of devices, the physical space of distributed computing, or the number of people using a system. For future research within the field they expand this notion of scale to encompass scaling with respect to time. They do this to posit a new area of application research named *everyday computing*. The argument is this:

> *"Just as pushing the availability of computing away from the traditional desktop fundamentally changes the relationship between humans and computers, providing continuous interaction moves computing from a localized tool to a constant companion". (Abowd et al., 2000)*

As the vision of Weiser slowly becomes a reality an important consequence is that computing is available at anytime as it is all around us and not necessarily as the work-oriented tool we used to have on our desktops that required our total attention. Rather they suggest:

> *"Our motivations for everyday computing stem from wanting to support the informal and unstructured activities typical of much of our everyday lives. These activities are continuous in time, a constant ebb and flow of action that has no clear starting or ending point". (Abowd et al., 2000)*

Everyday life and activities are as stated above often informal and unstructured and therefore hard to formalize and represent, so to understand and support them through some ubiquitous information system Abowd et al. point towards a further development within context-aware systems through a better understanding of context. As discussed earlier regarding positivist and phenomenological social theory there are many ways of approaching and defining context. I find it notable that while suggesting moving into an even more complex and unstructured setting than might be the case for a work environment there is still a strong belief that context can be represented through technological means

> *"Without good representations for context, applications developers are left to develop ad hoc and limited schemes for storing and manipulating this key information". (Abowd et al., 2000)*

Personally I am puzzled that giving new directions for ubiquitous computing research does not in anyway touch on the fields that contain the technology or the users using the technology. Even though they suggest that "a user-centric perspective is always possible and necessary" the social richness of everyday life does not break through this engineering approach.

4.6 APPEARANCE AND INTERACTION

Looking at everyday computing this perspective introduces an additional approach to interaction design and tangible interfaces, coming from the field of industrial design. There are many ways of looking at industrial design, however, the proliferation of computing power in our environment be it dish washers, toys, cars, and so on has added complexity to the field both in the actual design and in use.

Djajadiningrat et al. distinguish between two approaches towards TUIs called *data-centered* and *perceptual-motor centered* (Djajadiningrat et al., 2004). What they claim is that the most common ones are *data-centered* TUIs that resemble the traditional GUI in the sense that they rely on metaphor and semantics. They are, however, 2.5D as they are taken to the physical world as phicons (Ishii and Ullmer, 1997), but their appearance and ways of interacting does often not differentiate from other phicons or tokens even though they carry out different actions in the information system.

Instead Djajadiningrat et al. argue for a *perceptual-motor centered* approach that they do not see as a substitute but as another entry to tangible interaction. Through a longer period the group has approached the field of TUIs from a more physical perspective related to what they name as formgiving. By this term they stress the importance of the appearance of physical artifacts to form an understanding of its functionality for the user. Through numerous design cases they refine this view to include the potential actions that a user can perform with the artifact, leading to their idea of aesthetics of interaction.

> *"In this view it is the rich opportunities for differentiation in appearance and action possibilities that make physical objects open up new avenues to meaning and aesthetics in interaction design". (Djajadiningrat et al., 2004)*

They point out three factors, which they think play a role in aesthetics of interaction:

- *The first is the interaction pattern that spins out between user and product.*
- *The second is the richness of motor actions.*
- *The third factor in aesthetics of interaction is freedom of interaction.*

These aspects highlight the *perceptual-motor centered* approach as being about the interaction between user and product with respect to the appearance of the product; through a rich interaction that exploits all human skills; and does that in a way opening up for differentiated entries towards interacting with the product and finally the system.

What is worth noticing here is that Djajadiningrat et al. shift focus from technology and system to appearance and interaction. They open up for dealing with technology in a way, in which the user engage with differentiated beautifully designed objects that guide them into meaningful actions through exploiting the potential of the interactive artifacts. In this way the user can complete a task or alter a control of a system in a more playful way as it stimulates explorative aspects of interaction.

> *"The differentiation provides the 'hooks' for our perceptual-motor system to get a grip on a system's functionality and to guide the user in his actions." (Djajadiningrat et al., 2004)*

Investigating technology, interaction, and design from an industrial design starting point clearly focuses on a range of physical aspects that has not been addressed in the more technology driven approaches described above. Further, Djajadiningrat et al. introduces the notion of aesthetics that is not only coupled to the physical appearance of interactive artifacts but also to the interaction itself. I will not go into deep discussions on aesthetics, however, mention that there is an emerging movement within this field especially as technology migrates from work-oriented environments to more domestic environments and leisure activities.

People such as (Redström, 2001), (Hallnäs et al., 2001), (Overbeeke et al., 2002) ,(Djajadiningrat et al., 2000), and (Petersen et al., 2004) explore an aesthetic approach towards interaction through concepts of *slow technology*, *informative arts*, *interaction relabelling* and *pragmatist aesthetics* to explore how we as designers can understand and design for aesthetic experiences that goes beyond the physical boundaries.

Despite the ambiguity in defining "aesthetics" within interaction design, generally these concepts go from considering interactive systems and artifacts as tools to focus on how technology becomes a part of the everyday environment. By avoiding the tool approach that is characteristic for a more traditional work-oriented HCI approach ideals such as *efficiency*, *usability*, *seamlessness*, *transparency*, and *affordances* are exchanged by themes as *reflective "use"*, *beauty in interaction*, *enjoyment of the experience*, *temptation*, and *poetic elements exciting imagination*.

The design space is widened into a more explorative space, in which users live and interact with technology over time and in ways that stimulate reflection in action. The concept of time here is not the one of Abowd et al. (Abowd et al., 2000) when they consider everyday computing, in which they are concerned with time in respect to interruptions, resumption, and continuity to be able to seamlessly and transparently support everyday living. Instead Hallnäs and Redström refer to "technology that stretches time and slow things down" (Hallnäs et al., 2001).

(Overbeeke et al., 2002) (Djajadiningrat et al., 2000) and (Petersen et al., 2004) argue for stimulating and involving multiple senses and let the entire body take part in the interaction. Where (Overbeeke et al., 2002) and (Djajadiningrat et al., 2000) are very focused on products and the experience of interacting with these, (Petersen et al., 2004) are also concerned with a larger spatial context to challenge our kinaesthetic skills as well as social aspects of the interaction.

4.7 EMBODIED INTERACTION

Like the field of aesthetic interaction, embodied interaction is also looking towards the ways we as humans relate to digital systems and artifacts especially in an everyday context. Dourish defines embodied interaction as a mix between tangible interaction and social computing (Dourish, 2001). Embodiment is not the mere physical reality, but the way physical and social phenomena unfold in real time and real space as a part of the world in which we are situated. The concept of embodiment is based on a phenomenological perspective. Where several of the above approaches to computing are concerned with carrying out well defined cognitive tasks based on an identified problem, embodied interaction is concerned with the unreflective practice of the everyday.

> *"…phenomenology explores our experiences as embodied actors interacting in the world, participating in it and acting through it, in the absorbed and unreflective manner of normal experience" (Dourish, 2001).*

Rather than embedding fixed notions of meaning within technologies, embodied interaction is based on the understanding that users create and communicate meaning through their interaction with the system (and with each other, through the system).

In their thorough framework for tangible interaction Hornecker et al. adds aspects of spatiality and embodiment for understanding how these systems are experienced.

> *"We cannot escape spatiality - we dwell, act and meet each other in space; it is our habitat (Merleau-Ponty). Being spatial beings, our body is the central reference point for perception. Movement and perception are tightly coupled and we interpret spatial qualities, such as the positioning of objects, in relation to our body" (Hornecker et al., 2006).*

Klemmer et al. argue that as *"physical bodies play a central role in shaping human experience in the world, understanding of the world, and interactions in the world"* it is necessary to take aspects that relate to our embodiment in the world into account within interaction design (Klemmer et al., 2006). They propose five themes that they find salient for interaction design. These are *thinking through doing*, *performance*, *visibility*, *risk*, and *thick practice*. Klemmer et al. react against the way that the desktop computing paradigm has homogenized our physical performance. No matter if you are composing music, writing an article, or playing a "shoot'm up" game the situation is exactly the same, you are stuck with display, mouse and keyboard. By proposing their five themes they are seeking to put attention to aspects of embodiment to acknowledge users as humans situated in social constellations in the real world, learning through their actions.

As the themes *thinking through doing* and *risk* indicates it is an approach that builds on an understanding of the user as hard to grasp, however, demanding in the sense that interactions might exploit his skills as a physical situated human but in the sense that the interactions with technology has to challenge or afford the construction of meaningful engagement.

4.8 SUMMARY

In this chapter I have described a number of approaches towards computing derived from or related to the concept of ubiquitous computing. They all take their departure in technology moving off the desktop and into space, however, with different objectives for doing so.

Inherent in all examples space is considered a consequence of ubiquitous computing but apart from that no one is directly approaching the paradigm shift from a spatial perspective. While building on the above approaches I have found it interesting to investigate the concept of space further.

In the following chapter I will discuss how space can play a role in the migration of technology into our physical environment.

5 MOVING INTO SPACE

The slippery concept of space has at all times led to discussions within fields such as philosophy, physics, mathematics, geography, psychology, and architecture; why it constantly has been and still is approached and conceptualized in countless ways. This chapter is concerned with describing a concept of place and space informed by my empirical work in the real world and on theories of place and space from a phenomenological perspective. This entire dissertation could have been theorizing on and unfolding the distinction between Euclidian space and phenomenological space within ubiquitous computing, but that has not been my initial aim. Rather, my aim is to conceptualize space in a way that is applicable in practice. I will not include the founding fathers such as Edmund Husserl and Maurice Merleau-Ponty within philosophy, and Christian Nordberg-Schulz within architectural theory; but ground my concept on others who have already inscribed this perspective into interaction design (Ciolfi, 2004) and ubiquitous computing (Dourish, 2001).

Coming from a background in architecture, my initial conception of space has been as our built physical environment, however, as described in the introduction of this dissertation, I have been influenced by factors and aspects that has led to conceptualizing space as more than mere physical structure. When focusing on interfaces and interaction through my explorative approach, I have made my way closer to humans and their activities than has often been the case when designing architectural spaces for the same humans. This experience has not suppressed the importance of physical space as a stage for the activities of lived life, but rather emphasized that it is one of multiple aspects that influence humans in their everyday life. Thus the space I am concerned with is a space related to and experienced by humans.

The previous chapter's broad sweep of approaches to computing derived from the concept of ubiquitous computing, displays multiple objectives for handling technology once it has gone spatial. Tangible interfaces are striving to bridge the physical and digital domain by exploiting metaphors coupling the handling of physical objects to actions in the digital realm; context-aware computing evolves as a consequence of technology slipping into our everyday environments transparently seeking to analyze our activities and take meaningful actions; augmented and mixed reality has its main focus on exploiting the physical world as it exists, however, expanding its properties by augmenting digital information layers to support user activities; part of the aesthetic interaction field is seeking to exploit human perceptual-motor skills to enrich the experience of a product by challenging the interaction; CSCW recognizes that many work situations are carried out in social constellations and often spatially distributed why it seeks to support these dynamic creations of physical and social spaces across physical and digital boundaries; and finally the concept of embodied interaction is merging social computing and tangible interaction by acknowledging humans as beings situated and acting in a spatial physical world creating meaning through its interactions in and with the world.

In the following, I will discuss how these approaches along with a notion of space and place adopted from Tuan (Tuan, 1977) establish a basis for approaching space within interactive systems as made up by a geometrical space and an experienced place.

In "e-topia: Urban life, Jim - but not as we know it", William J. Mitchell writes:

> *"Architecture is no longer simply the play of masses in light. It now embraces the play of digital information in space" (Mitchell, 1999).*

Mitchell is addressing the emergence of technology within our built environment. What is architecture and space when invaded by information and technology? How can space serve as an interface for this emerging technology? What are the consequences for users of these digitally enhanced spaces? These broad and difficult questions are hard to answer, thus I will use them as guiding and inspirational questions for framing a conception of space.

Architecture has always had an interest in new technologies, and used these to develop and expand the language of space and form. We have seen new technology literally forming architecture, with reinforced concrete in the modernism, and more indirectly in advanced blob architecture only made possible to draw, design, and produce by means of computer technology (Lynn, 1999). Today, we see lots of modern architecture plastered with displays, pushing all sorts of commercial and informative imagery, and "intelligent" gadgets controlling spaces in different ways: opening windows, shutting doors, switching the light, and so on. In my understanding, this resembles the way many architects understand what it means to merge technology and architecture – it is basically a job for the interior designer. First we design "the architecture", and then we accommodate the spaces with technology[5]. The way this technology functions is most often similar to the respond I get when explaining to my friends that I am investigating interactive spaces: "ah, like when the music and the light condition adjust as you enter a room". No, that is not it!! That is what slick architects and computer scientists from the positivist tradition (as described above) think; that pure physical form and context-aware systems is the way to create spaces and systems for automated living.

Opposed to the idea of embedding technology into the built environment to improve easy living, I see the potential of technology within space and embedded in architecture as interaction between people and computers, as well as interaction between humans mediated by ubiquitous technology. The range of automated technologies in our built environment has a dangerous tendency to neglect the power of old school physical and social interactions, e.g. in which I open the fridge to see what is needed from the supermarket instead of the fridge ordering milk when I want ice-tea; talk to my girl friend about the music that we would like to listen to instead of letting a computer system suggesting that we feel like "reggae"; and deciding ourselves whether we want the lights on or not when we do our thing. Bonanni et al. makes a brilliant example in their augmented kitchen project (Bonanni et al., 2005). The kitchen prototype is crammed with displays and sensor technology, which is argued to help the user in his activity of cocking. What is tragic here is that the designers of this project are implying that they have probable never cocked up food in anything else than a microwave oven. They are degrading the activity of cocking to a question of completing a task, and building on a model of the user as stupid. To avoid these degrading approaches towards human activity, it is important to consider the fuzzy user as I have described in the earlier in chapter 3, as an autonomous actor that creates meaning through actions.

5.1 INFRASTRUCTURES MEDIATING SOCIAL AND CULTURAL CHANGE

Technologies that are migrating into space are appropriated by users differently. We are not just *users* of technology, as we perhaps were during the first eras of computing, we are *living with technology* (McCarthy et al., 2005). We are shaping technology and it is shaping us, likewise we are shaping architectural space and it is shaping us in our actions, e.g. the way sacred spaces affect our vocal pitch. For some, the often radical changes technology performs to use practice happen so slowly or invisibly that we do not even notice it. A good example is the penetration and development of mobile phones, and the changes this has brought about. I will give a few examples of this below, and discuss how this migration of technology into architectural space is forming a hybrid of space, technology, and interaction.

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[5] The "wisdom wells" designed within interactivespaces are being implemented into a new school building designed by a local architecture studio. The design of physical space and the design of technology have however happened in two separate groups basically not interested in what the other part is doing. This lack in acknowledging the involved domains has caused quite some problems.

The loss of the cord disconnected the phone from a static physical context. Before, calling "you" would imply connecting to a specific location, I would know where you were located as I would call you at *home* or at *work*. Now, you might be in another country when answering the phone, thus a typical question in the mobile phone paradigm is: "where are you?"

The phone as a personal device formed a tighter relation between a specific user and the mobile phone. By calling a certain number you would not reach the Jones family, instead you expect a certain person answering, regardless of physical location.

Being online while mobile has resulted in appointments constantly changing or being made on the fly. Usually we would meet at a café at two o'clock, whereas we now almost expect and accept that an appointment can change anytime.

The SMS has provided a less intrusive but nevertheless powerful communication channel. This is suitable for staying in touch, as an escape way for delivering unpleasant information, to participate in TV shows, or for buying stuff online. These use practices have developed despite of that the SMS was never intended for these purposes, no one could foresee the potential power of a simple text message.

The mobile phone mediates the creation of social spaces spanning across almost any physical boundary. Earlier, when being on the move, you would enter a physical space, a phone box, designed for the activity of talking on the phone and connect yourself to another static physical location associated with the phone number you called. Now basically any space is appropriate for establishing a phone call.

The mobile phone has become a small scale office and living room. On top of the changes in user behavior as a consequence of the telephone gone mobile, the mobile phone has been added with cameras, calendars, email clients, game consoles, and music players. These functionalities afford working, communicating, and playing in any physical setting, and hereby challenge or compromise an initial intended use of the physical environment.

Services are reconnecting the mobile phone to physical space- Interesting developments are seeking to visualize the physical distribution of your social network. and the mobile device is hereby slowly reconnecting to the physical context. This happens as network service providers exploit the networked nature of these devices, and offer location based information services and opportunities for peers to see your physical location at any time (Rashid et al., 2006) (Hansen et al., 2004).

If we look at the spaces involved in this merge between mobility, i.e. bringing technology and computing into physical architectural space, and the functionalities brought by the technology, it becomes obvious that many different types of spaces are evolving, overlapping, interweaving, and disappearing. The changes brought about by this, are huge and basically induced by one change in the infrastructure – disconnecting the phone from a specific physical location.

Through the example, I would like to point to how these apparently meaningful actions of users are indirectly determined or influenced by architectural space; but what is more important are social and cultural relations and habits, in this case, mediated by mobile technology. In other words, architecture serves as the physical container in which social life unfolds. Whether the architecture is beautiful, old, or ugly is a matter of taste, style, and frosting and does not necessarily influence how life evolves; people are still connected and able to exploit physical spaces in new ways through their mobile technology. What matters is how the spatial container supports the everyday life of humans, not by its looks, but by its relationship and connectedness with the present technology. In the mobile phone example, physical space has an indirect influence through its relationship with hertzian spaces as investigated by Dunne (Dunne, 1999). Technology on the other hand has a tremendous direct influence on everyday interactions by creating social spaces supporting the activates listed above; these of course vary due to culturally differences, but it is the potentiality within the connected infrastructure of mobile devices that is the real driving force for the social and cultural change mobile technology has brought about. Dourish (Dourish et al., 2005) and McCullough (McCullough, 2003) see the concept of space as infrastructure, including cultural, social, structural, technological aspects.

> *With a particular focus here on space as an interactional and cultural construct, we are concerned not just with electricity, water, and sewage, but with other infrastructures that define elements of the experience of space. (Dourish et al., 2005)*

The argument here is that space is made up by layers of infrastructures supporting relations between interacting entities. Apart from focusing on the elements that make up architectural space, social interactions and cultural aspects are important, because both designing and understanding ubiquitous computing environments requires acknowledging behaviors beyond physical elements.

5.2 PLACE AND SPACE

So far, I have briefly discussed how technology, through the example of mobile phones, influence and change social and cultural conventions, both within private and public living. It suggests a way of looking at the complex phenomena of the merge between technology and space, as spaces or infrastructures on multiple levels and across physical, cultural, and social domains. How can we further characterize such a complex space?

In my opinion, we can not generalize the perception of space; it is highly subjective and dependant on the senses that absorb and interpret space. I might not notice the same aspects of the historical buildings around us as you do; and I have no clue that we just passed the place where you kissed your beloved one the first time. Returning to the mobile phone example, the behavior in and perception of space becomes even more dependant on the experiences provided by the present infrastructures. Thus mixing physical and digital worlds increase the potential differences in perceiving a space. Only I know that just around the corner is a hertzian shadow, and I will not be able to send the SMS I just wrote from there; or I just received a great SMS-offer as we passed a trendy shop, because I subscribe to the "elite-spam". We are acting in the same physical space and nevertheless, will our perception be biased by issues that go way beyond the physical space. In Steve Harrison and Paul Dourish' Re-Place-ing Space: The Roles of Place and Space in Collaborative Systems (Harrison et al., 1996), they elaborate on a distinction between place and space set forward by Yi-Fu Tuan in Space and Place (Tuan, 1977), and apply this to the field of collaborative interactive systems. In the paper, Harrison and Dourish make the distinction:

> *"Space is the opportunity; place is the understood reality" (Harrison et al., 1996)*

A space, in the sense of pure physical structure, becomes a place when it is filled and invested with meaning, e.g. a house becomes a home for a family through lived experience or your grandma's backyard is special to you because you once as a kid buried two smurfs in the soil. They are long gone, but the space is still invested with emotions that make it a special place to you. What is important here is that place-ness is based on the lived experiences in that specific space, which will often differ from others perception of that specific space.

In (Ciolfi, 2004) Ciolfi is proposing to extend existing approaches to the design and development of interactive environments through a novel conceptualization of spaces as places, based on the concepts developed within Humanistic Geography. Like Harrison and Dourish, she builds on Tuan's notion of space and place in which space is the physical setting where human behavior is possible, and place as the lived reality; the experienced space we interact with every day and invest with meaning and memories. This tradition is grounded in the phenomenological theory on human perception, which also lies as the basis for the concept of embodied interaction.

Tuan divides the notion of place into four dimensions: physical, personal, social, and cultural.

- *The physical dimension* grounds place in the material reality;
- *The personal dimension* is tied to subjective feelings and emotions associated with or invoked by a place;
- *The social dimension* is related to social interaction and communication within the place;
- *The cultural dimension* regards rules and conventions of a place and its inhabitants.

When designing interactive systems, the four dimensions all play a part in the creation of the user's experience of the system. The four dimensions, however, differ in the way that only one of them is fully controlled by the designer, namely the physical dimension. As a designer, I can not design a user's subjective feelings towards a system, explicit social interactions, or specific cultural conventions. I can, however, design the physical, interactive, and spatial aspects of the system with my intentions to support different issues of the four dimensions. The challenge thus lies in turning space into place by means of interaction design.

Returning to the approaches to computing I described in the previous chapter, we see various ways of addressing the four dimensions. Tangible interfaces are concerned with efficiency through exploiting humans' skilled knowledge of the physical world; aesthetic interfaces are seeking to invoke feelings and emotions in the user to stimulate a strong and meaningful relationship between user and product; Computer Supported Corporative Work (CSCW) is addressing social and cultural aspects of collaborating people in an effort to make the work activity more meaningful and efficient; and embodied interaction resembles tangible interfaces and CSCW is ,however, also concerned with activities not dedicated to solving specific tasks.

My point of departure is in space as a construct in the physical world, both inscribing physical and digital aspects. This space is *formable* and can thus be designed and induced with the intentions of the designer. Returning to the design circle and coupling it with the above described dimensions of place, the intended use is informed by the *given* understanding of the users' physical, personal, social, and cultural dimensions, these are in the design interpreted, transformed, and expressed through the design of the physical space, which results in an intended use as a definition by design. By deploying the design in the context of interest, actual use will determine how the system, and in the end the designed structural space, is appropriated as users are reinterpreting the expressed physical system into place and experienced reality.

This leads to a central aspect in the interplay of digital and physical realms for the construction of space as presented to the user. In the following section I will discuss such interfaces.

5.3 BRIDGES OF PHYSICAL AND DIGITAL DOMAINS

In designing potentially meaningful systems through a focus on space a very important aspect is the interpretation and translation of the dimensions of place across domains. As the construction of place is based on a phenomenological perspective it is not possible to design the personal, social, and cultural aspects. Thus all design has to be transformed into a computational artifact that seeks to handle and express these aspects as users engage in interaction with the system. These interactions happen in an input/output relation between the physical and digital domain. Most often analogue interactions in the physical domain are translated into digital parameters to bridge the physical and digital domain.

Many ways of bridging or interfacing between these domains exist; the mouse and keyboard are mapping 2D movements and press into cursor coordinates as mouse movements and ASCII values as characters. But sensor interfaces such as accelerometers (Tomlinson et al., 2005), cameras (Hansen et al., 2005), touch sensors (Hinckley et al., 1999), weights (Boucher et al., 2006), and microphones (Rosenfeld et al., 2001) are also examples of ways of interfacing the digital and the analogue.

My point is that when designing an interactive system even with regards to the four dimensions of Tuan, the intentions of the designer no matter whether physical, personal, social, or cultural has to be transformed and expressed through this bridge. The language or taxonomy of this bridge or interface is of course constrained, which increases the challenge of expressing the intended use of a system through the physical dimension. The two first images of figure 6 show the gap within space.

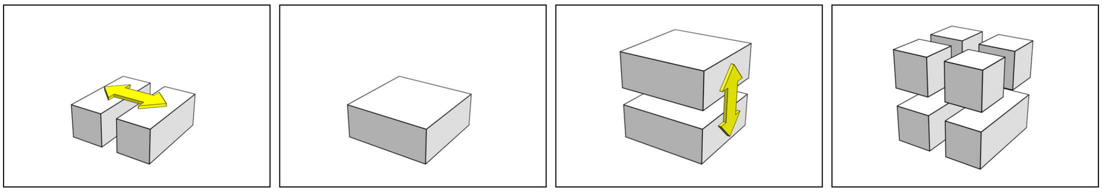

Figure 6: The gaps of space and place; the formable space is made up by physical and digital space bridged by the interface, the potentiality of place is made up by intentions regarding the four dimensions of place induced into space. These are the two gaps that we have to design for bridging.

The consequence as I see it is that even though I am building my conception of space and place on a phenomenological tradition the intended experience and use has to be induced through the design of a mathematical Euclidian space. Space is in the design approached as measurable parameters necessary for interfacing the digital and physical domains. Thus no matter the choice of interface intended use has to be informed from two sides; the objectives of the system and *given* preconceptions of the dimensions of place; and the *close* understanding of the potentiality of the interface as I have touched upon in chapter 3. The two last images in figure 6 show the gap between space and place.

This conception is not rejecting all the approaches towards computing migrating into space as explained in chapter 4 *(interfaces beyond the PC)*. I am, nevertheless, trying to put focus to space of course as an element of humans being embodied in the world but also and perhaps more importantly in a direct physical manner. To think social interaction in interactive systems beyond the desktop we have to think it through the concrete space that interfaces the formable physical and digital domains.

In practice it is hard to keep a distinction between aspects of space and place because understanding space implicitly gives you the tools to influence place. You do not connect the sleeping room and the garage without having a certain purpose and therefore an intention towards users' appropriation of space. On the other hand if you do not understand the concept of connecting spaces you would not see the potential of driving directly to bed.

In the following section I will exemplify the understanding of interfaces as Euclidian spaces without going into their potential consequences for place-making. In this way I will stick to the lower part of figure 6 above.

5.4 THINKING SPACE AND TECHNOLOGY

Thinking space and technology requires abilities to combine physical and digital properties. In order to do this, one must work with the actual material, which is why my research contains multiple practical experiments. In the following, I will illustrate how interfaces can be approached from a spatial perspective, and further that the diversities of such spaces requires them to be considered differently for a deep understanding of them. By doing so, I will try to present space as an interface, without relating it to intended use. This means that I will leave out the intentions towards the dimensions of place-making and only look at the formable space merging physical and digital domains. As mentioned earlier, it is often not the case that you can separate space and place, my argument is though, that the better you know space, the better you will be able to address aspects related to place-making.

The following two examples serve as a transition for moving from my overall concept of space and place to the chapter 6 (*cases*) that informs the understanding of space in relation to cameras. On the base of these cases, I will distill the mixed interaction space framework, and in relation to this space discuss how intentions can be passed through the design of a camera space.

Relative Spaces

In one of our library projects; the interactive childrens library, we developed a bibPhone. The bibPhone prototype enables children to annotate physical material with digital recordings. Children are able to add oral comments to books by talking into the bibPhone when placed over an RFID tagged book. The comments recorded by others can be listened to by placing the bibPhone over a book.

[mapping: I]

If we forget about the actual use context of the bibPhone prototype, but instead look into utilizing a large physical space, unique distributed objects, and wireless near range interaction technologies, we can discuss it as a more general space. This space consists of objects unique in content, appearance, physical location, and in their digital metadata counterpart. By exploiting near range interaction, such as RIFD readers and mobility provided by wireless connectivity, the physical space becomes the materialized representation of the database containing the metadata of the objects. The near range interface forces a close physical proximity between the object of interest, and the user mediated by the technology. This constraint, set by the technology, creates a temporal, physically well defined information space evolving in use, as objects are investigated through the technology. The information spaces are not tied to the physical location within the space, but can be seen as invisible spheres inscribing each physical object. Thus space becomes reconfigurable both regarding physical and digital content. Each object adds physical form to its metadata, as well as the metadata adds background information about the physical object, which is accessible only in that limited space. Apart from that the technology communicates information from the digital domain, through the physical object, to the user, it also provides an infrastructure for the user, which changes the content of space. A user can exploit the technology, and leave information in the temporal space created around a physical object. While the physical space is providing an invisible infrastructure for accessing and inducing digital information, it is still affording the same graspable potentials of interacting with the objects (see figure 7).

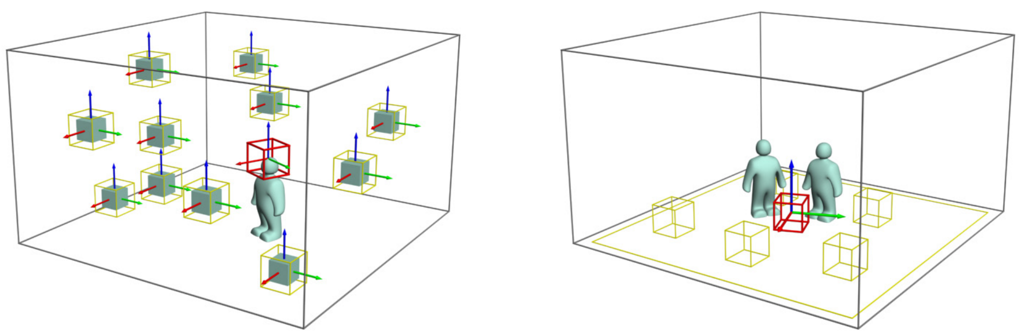

Figure 7: The spatiality of interfaces; the bibPhone and byensStemmer as examples. The yellow spaces are digital, the arrows indicate moveable entities and the red cubes are the actual interaction objects.

Absolute Spaces

The byensStemmer[6] project is seeking to involve potential future users by gathering their dreams, stories, and user requirements for a not-yet-built multi-media house (Nielsen, 2006). In a library space, a mobile cordless table displays a digital map on a horizontal screen. By moving the table around in the space, the map will update accordingly to the movements. Sounds are played when bumping into icons on the map. Further, users can add their own comments at any location on the digital map.

[mapping: 0]

Again, trying to look at the project without thinking about the actual use context, but rather look into the different elements, reveals a more general view of the evolved space. The space is made up of a large physical space, inscribing a mobile display operating on a floor surface. By exploiting the 2D tracking capabilities of a mouse, and the orientation data of a digital compass, an invisible digital space is expanded and overlaid the physical space. The display of the table becomes a visual frame into a digital world, and on the other hand the digital map visualizes the invisible data laid out in physical space. To explore the digital content the way physical and digital space corresponds in a one-to-one absolute mapping, forces the visual frame to be moved in physical space. Only through this visual frame are the physical and digital domains exploiting each others properties to create a physical space that stores sound and image data distributed onto specific locations within that space. Further, as the technology provides possibilities for users adding sound content, physical space becomes configurable and changing through the space of the interface. To others, the space is unchanged (see figure 7).

The two examples above are describing and illustrating the different kinds of spaces involved, without looking at a specific application, and thus not focusing on the intentions in use – at least not directly. Aspects of size, scale, configuration, proximity, location, temporality, and movement are describing how the physical and digital domains are merging up in different ways, and thus creating very different spaces. Even though both examples can be considered as Euclidian spaces clearly they are different and need to be considered individually when looking into their most significant aspects. This is also why I will not go into the discussion of the meaning of these aspects in relation to investing intentions into space. I will do this later in relation to my framework based on an in-depth characterization of camera spaces as interface.

5.5 SUMMARY

In this chapter, I have presented a concept of space and place based on Tuan (Tuan, 1977). It is not a deep theoretical concept, but rather a conception of space applicable in practice. The concept makes a distinction between space and place, and acknowledges place as a phenomenological construct in the mind of humans, and space as the potential and not yet appropriated place. Place is made up by four dimensions related to a humans physical, personal, social, and cultural values and preconceptions related to that place. Space on the other hand is Euclidian and formable; it consists of both physical and digital domains. The consequence of this conception is that only by understanding and designing space can we address the dimensions of place-making. This concept of space and place when looking at the design of interactive ubiquitous systems is faced with two gaps; the gap between physical and digital domains making up formable space, and the gap between formable space and its potentiality of being place as it is appropriated by users.

These two gaps differ in how we as designers address them. In relation to space, the gap calls for a deep understanding of the interface bridging the physical and digital, and hereby being able to exploit

[6] This project is thoroughly described and discussed in the Ph.D.-dissertation of Rune Nielsen. Unfortunately the thesis is in Danish and thus hard to grasp in an international context. We are however working on a research article that will be finished some time after handing in this dissertation.

the potentiality of this space to bridge the gap between space and place. By this, I mean understanding space in such a way that it becomes possible to induce intentions towards the dimensions of place, and hereby seeking to make the interactive artifact meaningful as the actual user appropriates it.

In the following chapter I will move into my three cases that serve as an entry to understanding the space expanded by cameras as an interface.

6 CASES

In the following, I will describe three projects that serve as cases for my discussion on mixed interaction spaces. These cases have been chosen as they, in different ways, explore and help explaining the aspects of mixed interaction spaces that have led to the framework, which will be presented in chapter 7 (*interacting in camera spaces*). As can be seen in the *project diagram,* by looking through a "camera space"-relation, I have been involved in several other projects that explore mixed interaction spaces, e.g. mapping 10. Some of these will be included and mentioned when developing the framework later, even though the specific application is not the focus. The same goes for the beneath presented cases; the findings within each study is of course part of this dissertation, and presented in the included papers, but they serve as underlying findings that help to inform and discuss the generalizable aspects of mixed interaction spaces.

The iFloor case is further discussed and described in *paper 1*, *paper 2*, and *paper 4*; storySurfer is discussed in *paper 4*; and finally the Mixis project is further described in *paper 3*, *paper 4*, and *paper 5*.

6.1 CASE 1: IFLOOR

The iFloor project is a prototype developed under the *Future Hybrid Library* project. The background for the project is that the traditional library is facing a number of future challenges, which are interconnected with society's increasing use of IT-technology. In Denmark, the library holds a position as a strong democratic and cultural institution in our society. However, as a consequence of the increased digitalization of materials in our everyday, the role of the library needs to be reconsidered and ultimately redesigned.

In this process, focus move from the library being a place for borrowing and reading printed material to being a place where a wide range of media – especially digital media – will be available to the users, and also play an ever increasing role in the activities on site. Through this process, the future libraries will be suited to support users in learning and processing different media – hereby reaching a state of multimedia literacy. Thus the challenge lies in understanding how the library as an open institution in society can hold its position as a physical place in the battle with the network-based services of the internet. How can the library provide new activities and materials that differ from what you can achieve through your mobile phone or your internet connection at home?

Process and Concept

In collaboration between librarians from a number of libraries, industry partners, and designers and researchers from InteractiveSpaces we worked on a number of concepts that should put attention to the library as a physical place. We did this through multiple workshops and gatherings where design proposals, primarily developed at the research center, were discussed and evaluated, see figure 8 + 9.

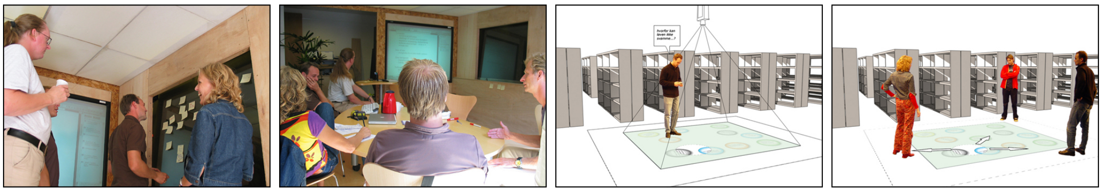

Figure 8: Brainstorms, workshops, and conceptual sketches.

Inspired by the *playful interaction* video prototype, we got the idea to work with the architectural element of the floor as a starting point.

[mapping: 34]

As the library in Denmark has a very democratic status we found it interesting to exploit what we saw as the most shared surface to be the ground for the project (*paper 2*). Another characteristic that was derived from the physical aspects of the library was collocated people. However, through user studies and knowledge from the librarians we discovered that most users of the library come to the library to retrieve information and not to engage in any communication activity with other peers and users. This inspired the project team to design an interactive installation that could serve as an ice-breaker and a communication tool between different users of the library. The initial result was basically a "questions and answers" (QA) forum embedded in the floor, see figure 11.

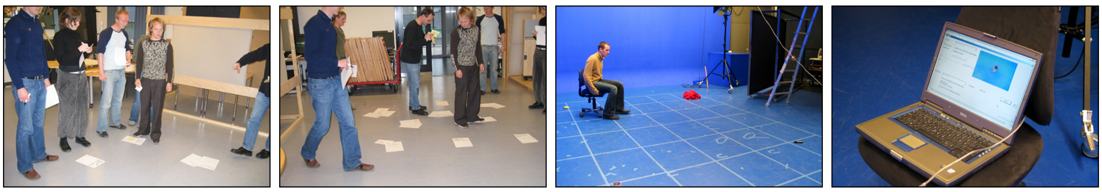

Figure 9: Bodystorms and camera tracking tests.

Through several design iterations and visits to the actual library space where the prototype was supposed to be tested we developed the concept further. We decided on two ways of interacting with the prototype: with a mobile phone trough SMS, and through bodily movements around the floor projection tracked by a ceiling-mounted camera. We tested different ways of tracking people but came down to a small software program called Retina written by Allesandro Valli (Valli, 2006). We discussed the tradeoffs on deciding on a technology like SMS that is not familiar to all users of the library and that further charges users small amounts for interacting with the system. We concluded however, that SMS is a well tested technology that held interesting perspectives in the mix between a shared floor projection and a number of small connected personal displays and keyboards. Further, we thought that even if one could not interact through a mobile phone it would still be possible to interact on the floor using ones body. We tested software and different cameras to find a constellation of hardware that would fit in the arrival space of the main municipality library of Aarhus. The final setup proved to be suitable for implementation in a public space as all technology is out of reach of users, which is shown in figure 10 where a light intense projector is mounted on the ceiling together with a camera that overlooks an area slightly larger than the projected image on the floor.

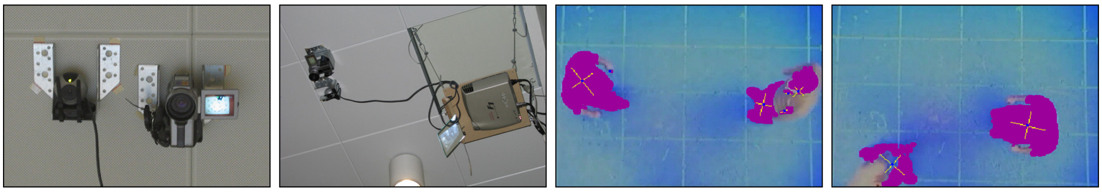

Figure 10: Final hardware setup and user representations as blobs.

The Prototype Setup

The iFloor prototype was installed in the library space. In summary, the intention was to design an interactive system that would require users' physical presence and that could create a space for communication exchange rather than information retrieval.

By creating an open space for questions and answers, the project seeks to stimulate communication between users of the library. Further, by putting the information system into a physical setup that requires physical collaboration, the prototype was bound to the library space and not yet another service that could be distributed over the internet.

The setup consisted of two white pvc-boards providing a light background for the camera tracking; a regular USB webcam for tracking users on the rim of the projection; a projector that projected the application interface onto the white pvc-boards; a pc running the iFloor application written in flash and the database of questions and answers; and a SMS-box that could receive the questions and answers and input them to the database.

Figure 11: Use of iFloor and the QA interface.

Interaction

Interacting with the system happens in two ways: as a constructive user producing questions and answers through a mobile phone; and as a tracked body that influence the shared cursor in the application.

Posing a question on the floor happens by sending a SMS to the phone number of the iFloor. When the SMS is received the question will appear on the graphical interface. The user will receive a SMS saying "thank you for your question; you will receive a SMS when your question is answered".

Answering a question happens by sending the answer as a SMS to the iFloor phone number starting with the ID of the specific question. When the SMS is received by the system, the interface update and attach the answer to the question as one, of up to five, graphical leafs beneath the question. When an answer is received by the system, the user who posed the question will receive a SMS containing the proposed answer. In this way, the installation expand the interaction space, both regarding time and physical space, as a user can receive answers in another location than the library, and days after she posed the question on the floor, but the library is still serving as a physical mediator for this interaction.

Interacting with the content on the floor happens as users move around the floor projection. By tracking the position of the users, a resultant vector is calculated that moves a shared cursor around the floor. The cursor expands questions and answers as it rolls over them, which also reveals the ID of the question. To keep the cursor in a fixed position, users have to collaborate and pull the cursor towards them with the same amount of force, but in different directions.

To avoid users stepping onto the floor and hereby casting shadows on the projection, all detected users within the projection are not influencing the movement of the shared cursor. This is visualized as all tracked users around the floor are connected to the shared cursor by a graphical string indicating that they pull in the cursor. If you however, enter the projection area you will loose the string, and hereby loose the relation between user and the camera that tracks the floor area.

Interface

In the design of iFloor's graphical interface, we have tried to adapt it to its new context off the desktop and embedded in space. As the entry space at the library serves as a transit and connection space between the different areas of the library and the outside, the floor is approached from all directions. Thus we experimented with a circular interface that would "democratize" the system, avoiding a single perfect perspective and instead stimulating movement around the floor to be able to read questions and answers that otherwise would turn upside down. Additionally we were interested in exploring if users would start communicating and help each other to read questions and answers aloud.

The questions and answers are inscribed in small color-coded graphical boxes that are scaled down when the question is not in focus, meaning that the shared cursor is within the question. The answers are hidden under the questions, and are only visible as a question is in focus. This is to avoid cluttering of the interface, but also to stimulate a collaborative interaction. If all information were accessible in the interface, users could walk around on their own and retrieve the content. Collaboration is induced by contracting, and thereby hiding, a lot of the information that is not in focus.

Observations and Field Studies

iFloor was installed at the library in four weeks. We evaluated the system according to our intentions on investigating its ability to create a space for communication, as well as an anchoring to the physical library.

We conducted a number of different qualitative evaluations, to inform how users appropriated the system. During the entire test period, we were in a close dialogue with the librarians among who some had participated in the initial concept development. One aspect that very quickly became clear to us, was that the iFloor compromised the function of the librarian as a provider of knowledge and correct answers. In the initial version, the librarian was "degraded" to administer the database of questions and answers through a web-interface. This was a filtering functionality that could censor and delete content on the floor, however, not before questions and answers had arrived at the floor. The problem consisted in iFloor building on an idea that there could be several answers, right or wrong, to a question, why each question could be accompanied by up to five answers. Because of this uncertainty of validity of answers, we opened up for a special kind of answer that only the librarians could pose through the web-interface, which would be marked as a librarian-answer, emphasizing validity and supporting the librarians in their function as knowledge providers.

During our daily observations in the test period, a number of issues arouse. Moving technology off the desktop, as discussed earlier regarding the concept of ubiquitous computing, implies several problems.

The interaction paradigm known from WIMP-interfaces[7] was by many users transferred to the iFloor interface. Users expected the floor surface to contain advanced technology that could sense footsteps as "double clicks", and further that the interface would resemble traditional concepts of direct manipulation (Schneiderman, 1987) as known from the desktop.

Even users who understood that only their position around the floor would influence the movement of the cursor started stepping on the floor, to speed up the process or to "battle" with other users who tried to move the shared cursor in another direction. A helping factor to these contrasts between the expectations of users and the interaction concept of iFloor, was to have expert users interacting to act out to newcomers how the system worked.

Another evaluation method we conducted was video taped interviews of users demonstrating how they thought the system worked, and what it was intended for. Some said that their first impression was that the system was intended for disabled and physically impaired people. Only few users in these interviews had realized that the interaction was mediated through the ceiling-mounted camera, and others did not figure out that their mobile phone could be used to input questions and answers. We tried to improve this by designing a yellow tool-tip that appeared as questions were expanded to inform on how to reply to the specific question. However, limited text size made it hard for some users to read the content of these tool-tips.

Finally we made a user test with school kids from 7th grade (see figure 12). First of all we wanted to see how skilled SMS-users would appropriate the floor and also how large groups of users would interact around the floor. Apart from this session the maximum amount of simultaneous users during the day was around 6. Further, we wanted to see if iFloor could serve as a mediator between users and the physical material of the library. So far most of the content submitted to the floor related to everyday questions like "where can I unlock my mobile phone?". Thus we made a formalized assignment where the kids in groups should answer pre-made questions on the floor by using the physical library to find the proper information. When answering a question a timestamp was attached to the graphical leaf adding a competitive aspect to the assignment. The kids worked hard to find answers in the library, but the collaborative interaction proved to be somewhat problematic with that many users as the groups fought hard to expand certain question to get the related answering ID. Apart from these dead-lock situations that had to be negotiated and solved by their teacher the kids expressed positive reactions to the form of learning.

Figure 12: User tests with 7th grade kids and video interviews with library users.

We also discovered that the kids used the floor as a platform for expression. Rather than sending a SMS to one or multiple mobile phones, they used the floor as a surface for posing statements to the public, which others could answer to or post a new statement.

[7] WIMP is an acronym for Windows, Icons, Menus and Pointing Devices / Pull-down menus denoting a style of interaction using these elements. It is used as an approximate synonym for graphical user interfaces.

6.2 CASE 2: STORYSURFER

The storySurfer prototype is developed within *the future Interactive Children's Library* project, which includes interests from within design, research, industry, and libraries. The objective of the future Interactive Children's Library is to give room for and encourage the physical activities of children, while pursuing to connect this with the basic services of the library e.g. storytelling, information, and access to a rich variety of media.

Process and Concept

The process leading to the storySurfer prototype is thoroughly described in (*paper 15*) and is one prototype out of a number of concepts developed within the research project. However, as the storySurfer project has not yet been published I will go through the overall conceptual process as well as the design process and implementation of storySurfer.

As the project team consisted of many different partners we spent a lot of time to create a common ground and understanding for working with the children's library. One way of getting insight into the children's library was done through field studies (see figure 13). Apart from observing the physical space and organization of different books and materials we had informal talks and interviews with children either coming to borrow books or just hanging out by the computers.

Figure 13: Interviews, observations, and drawing sessions with children at the library.

We engaged the children in drawing sessions, where we discussed and visualized how the library would look like in one hundred years and further how a library could look like on Mars (Dindler et al., 2005). This method for approaching the children's understanding of the library through a common activity, gave both fun and valuable inspiration to the project. Another way into the children's perspective on the library was explored by having children make small documentaries on using their library (see figure 14). How they would make the film was all up to them and they were left alone while shooting the film. These small snippets into the children's library were useful not just as they focused on certain aspects, but also because things that would seem important for a grown up for defining the library were left out. Further, the fact that the films were shot from the eye point of a child changed the spatial perception of the physical space, e.g. as shelves constrained the space into corridors because the children could not look over these.

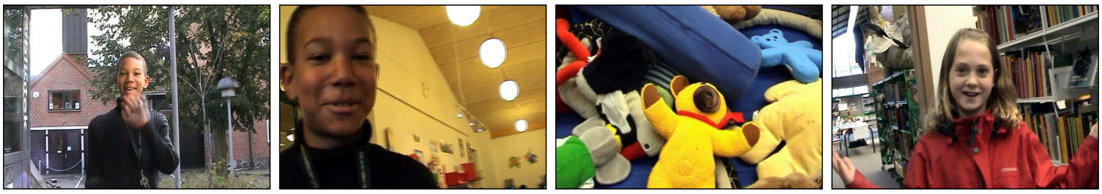

Figure 14: Children making videos of their library.

Regarding searching for books, we discovered that children are visually oriented towards finding books at the library and that they only very seldom search for books by typing a string into a search engine. Further, they are often inspired by what their friends read or even what the elder children find interesting. The findings from the field studies, the focus on the library as a physical space that should make a bridge between users and digital material, as well as valuable information from the librarians within the project team, served as a basis for developing the first concepts in a couple of workshop sessions with all project partners.

[mapping: 1, 2, 4, 16, 54, 55, 60]

The initial concept of storySurfer was called cubeSearch (mapping 4), and consisted of a range of cubes that on each of their six sides contained a keyword that could be used to search for books within the library e.g. "love", "horror", or "horses" (see figure 15).

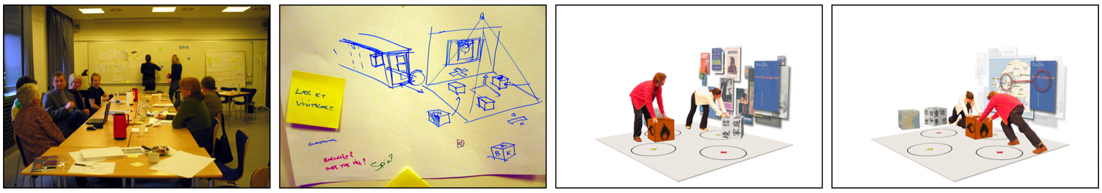

Figure 15: Workshop session, the first sketch of cubeSearch, and sketches from the developed concept.

The idea was that the cubes together with a floor and a large wall projection made up an alternative physical search machine. By sliding the cubes on the floor, more or less like a certain keyword would be influencing the book results presented on the wall display. Using multiple cubes would function as a Boolean search, presenting books relating to *this* and *that* keyword.

Before developing the entire system, a group within the project team made a "wizard of oz" workshop (Kelley, 1983) to test the feasibility regarding kids browsing books with cubes representing keywords. This showed that the children had difficulties coupling the cube activities on the floor with the books presented on the wall display. Thus the concept was iterated, redesigned, and later developed into storySurfer.

StorySurfer evolved trough numerous iterations by sketching ideas out and discussing these with the core group involved in storySurfer. To put focus on the physical aspects of the library, and inspired by technologies supporting a potential social or collaborative interaction, we focused on the floor and the table as two surfaces that relate to the body in different ways. The floor was supposed to relate to the entire body, as in iFloor, whereas the table should relate to hands and gestures. By making this distinction we divided the search of books into two activates: roughly browsing pools of books with your body on the floor; and investigating interesting books from the floor more deeply on the shared table. The interaction on the floor resembled iFloor, but adjusting it to support multiple simultaneous users interacting trough their own cursor. Finding a suitable multi-user interaction technique for the table proved to be rather challenging as it was a new domain for the entire group. Several multi-user interaction techniques for tables exist like e.g. Sensetable (Patten et al., 2001), AudioPad (Patten et al., 2002), Reactable (Jordà et al., 2005) and DiamondTouch (Dietz et al., 2001). Most of these are, however, costly and heavy in regards to hardware setup. Thus we looked at an emerging concept that had been developed at the research center in collaboration between Jesper Nielsen, Kaj Grønbæk and I called MultiLightTracker (MLT).

[mapping: 9]

The concept of MLT is to track multiple different colored LED's on a back-projected surface by the use of a camera (Nielsen et al., 2006). Jesper built the LED's into pens that would switch on and off as they were pressed against the interaction surface (see figure 16). By help from several computer scientists at the center, the system got optimized to run smoothly calibrated with 4 pens.

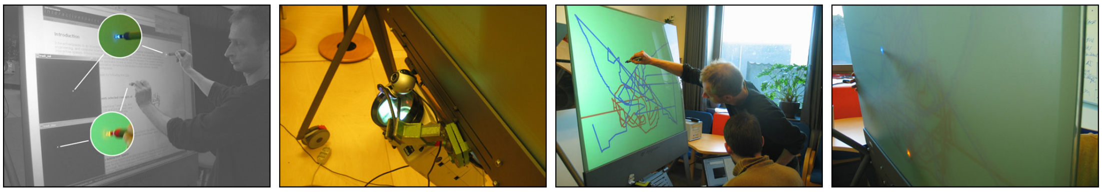

Figure 16: Initial tests with MultiLightTracker.

The physical design of storySurfer evolved into a waveform, mediating the connection between floor and table. The complexity and rather large physical size required people working on all aspects of the prototype. The physical waveform had to match specifications of the two ceiling-mounted projectors creating the pools of books on the floor, the projector hidden beneath the table, as well as the buttons around the rim of the floor used to change keywords while browsing books on the floor. Likewise the software applications running on the floor surface and the table surface had to be developed and connected to a database that could facilitate the exchange of books between the two surfaces. Behind the graphical user interface applications, all tracking software had to be fixed, tracking people on the floor and colored light dots on the table. Most of this work was done by people at the research center as a mix between architects, designers, computer scientists, and electrical engineers. Part of the floor application was programmed by one of the industry partners, which caused quite some problem because of problems committing to the project[8].

The Prototype Setup

The storySurfer prototype was installed in the main municipality library space. In summary, the intention was to design an interactive system that in a new way could bridge the physical and digital library. To support children's visual approach towards searching books, storySurfer presents pools of book covers related to specific keywords on the floor. Boolean search queries are presented where pools overlap. The keywords can be changed by stepping on the buttons around the floor, which will blow up a new pool of books related to the chosen keyword. By tracking multiple users and providing each of them with a personal cursor working as a magnifying glass, storySurfer is trying to support social browsing by serendipitously being inspired by other children browsing the floor. When entering the floor, the cursor will be projected in front of the user. When the cursor rolls over a book it will expand in size to ease the investigation of the cover. By keeping the cursor over a book cover, a timer

8 I will not go further into this discussion however mention that huge problems exist within research projects of this type. This is because they are only fully funded if they are conducted between industry and research institutions often leading to constellations that are not based on common interests but on getting the funding.

will start to count down, which eventually will invoke a "double click" and the book will slide up the waveform of storySurfer towards the table.

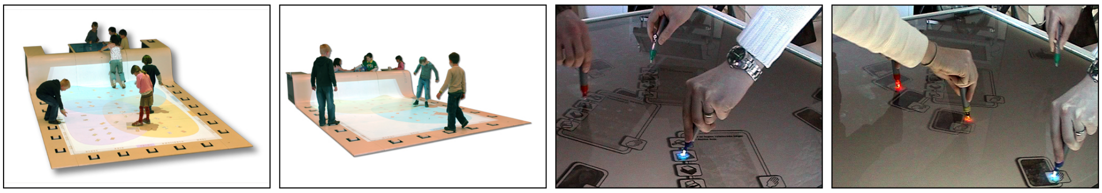

Figure 17: StorySurfer in action and MultiLightTracker functioning with four pens in the table application.

The table supported by the MLT-system enables multi-user interaction on the table surface, where books “kicked” from the floor can be inspected about content, author, related books and the possibility to print the cover and directions to where to find the physical book on the library. Again, the intention with the table is to design a platform for potential social interaction. Users can play with the books they have found on the floor on their own, or they can be inspired by other books located on the table and engage in a dialogue with other children around the table.

Interaction

Interacting with storySurfer happens on two levels; the rough book cover search on the floor and the more in depth inspection of the book objects on the table. To add content to the floor, users must first adjust their search query by stepping on the large buttons along the rim of the floor. Projected over each button is a keyword that serves as an input into the database of books. The buttons are made from a torn apart keyboard where each button triggers a key press mapped to a certain keyword in the floor application. When stepping on a button, e.g. “love”, a pool of book covers related to “love” expands from the button and out on the floor. Up to three keywords can be activated at the same time, why the central set on the floor is consisting of three overlapping pools of books, which presents books that contain all three keywords.

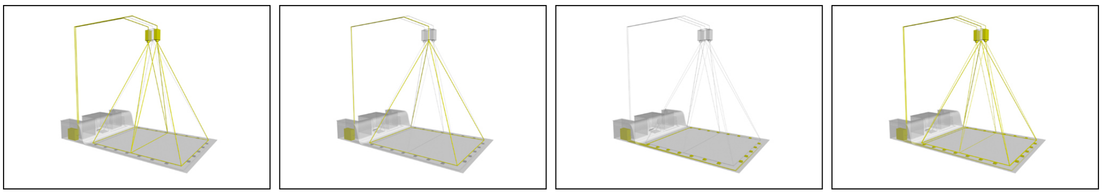

Figure 18: The projection space, the camera space, the keyword input buttons, and all inputs and outputs related to the floor interaction.

The image on the floor is made up by two projectors mounted in the ceiling in the center of the floor. The projection and the single camera overlooking the floor tracking users are aligned. Unlike the iFloor setup, the camera is tracking users within the projection and not outside. On the floor, each user is tracked individually and provided with a cursor functioning as a magnifying glass, projected in front of the user and always turning towards the center of the floor. As the projectors are mounted in the center of the floor, user shadows are cast from the center and outwards and hereby avoiding shadows occluding the cursor turning towards the center. The cursor will follow the user as he walks around the floor. When rolling over small book covers, they expand as seen on figure 19. When keeping the cursor over the expanded book cover for a short time, a graphical timer will indicate a selection count-down. On time out, the book is sent from the floor to the table via the wave. The book is literally sliding up the wave and appearing on the table surface.

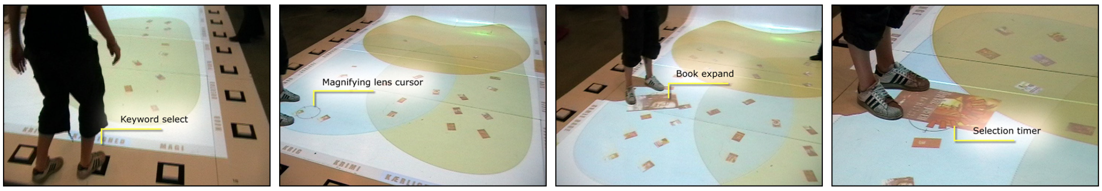

Figure 19: Selecting a keyword, cursor as magnifying lens, expanding book on rollover, selecting book via timer.

The interaction on the table is exploiting the MLT pen-based interaction technique. The pens can be used to manipulate book objects "kicked" from the floor. When book objects arrive on the table they reveal new properties that are not visible on the floor, as the rough bodily interaction technique does not support browsing content within each book object. By pressing the pen on the "hand" icon on the table, and hereby activating the LED, book objects can be dragged around on the surface. When releasing the pen, and hereby deactivating the LED, the book object expands to double size and uncovers ways of investigating the book object. Apart from the cover image, book objects now contain buttons to information on author, summary, related books, and access to a printer.
The configuration of book objects on the table is governed by the users, however, a few constraints has been applied to avoid extreme cluttering of the interface. Each pen can only have one book object expanded at a time. When choosing a new book object, the book object in focus by the according pen color will contract. Further, the table can contain a maximum of 15 book objects at a time. When new books arrive from the floor, the book objects that have been on the table for the longest period of time, without being inspected by users, are exchanged.

If a user find a book interesting and want to locate the physical book in the library, the user can print a slip of paper that contains directions to the shelf, the related meta-information, as well as the cover image (see figure 20).

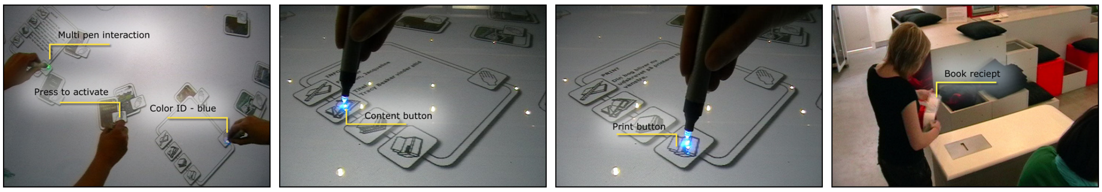

Figure 20: Selecting a keyword, cursor as magnifying lens, expanding book on rollover, selecting book via timer, printing info on interesting book object.

Interface

The two graphical interfaces that users are interacting with in storySurfer are both implemented in flash. These both connect to a server and a database containing only the books of the library with pictures of scanned book covers[9]. The floor application connects the keyword buttons and the actual search results. On the rim of the projection, keywords, that can be changed from session to session, are displayed in relation to the physical keyword buttons. Active keywords are colored in the same color as the pool containing books relating to that specific keyword. The pools of books are outlined by a stroke, and are slightly transparent to emphasize sets emerging from the overlap between two or more pools of books.

The books presented on the floor are arranged in a circular array, much like iFloor, ordered in a way so that expanded book covers do not cover up for other books. As mentioned earlier, a book cover expands as the magnifying lens of a user rolls over the cover. The magnifying lens is smoothly following the user's movements and is projected so it turns towards the center of the floor in relation

[9] There exist some copyright issues regarding scanned book covers why we only used a limited selection of the books at the children's library, approximately 3000 book titles.

to the user. Tracking of users is done in Retina (Valli, 2006), which provides the position of multiple simultaneous users on the floor. Selections of books are solved by using timers that count down before executing a selection action, see figure 19. In summary, this means that interaction on the floor requires choosing keywords of interest by stepping on the buttons in the rim of the floor, moving your body around the floor to expand book covers within the pools of books relating to selected keyword, and selecting books be keeping still over a book while a graphical timer counts down selecting the book.

The table interface displays book objects selected from the floor. The graphical representation of a book has two states; contracted and expanded. When contracted, the book object consists of the cover image inscribed in a graphical container with a hand icon serving as an anchor point for dragging and rotating the object. When expanded, the book object scales up and buttons leading to further information scales up in a quick animation. Like on the floor, double-clicking is not possible[10], however, in this case selection is made on the "mouse up" event when the LED is switched off after been pressed on one of the buttons. The feedback is similar to the counter used on the floor to make a graphical coherence between the floor and table application.

The book objects are initially arranged to afford interaction from the three sides of the table by having all objects rotated in relation to a rotation icon located in the upper center of the table. By dragging the rotation icon with one of the pens, the books can be rearranged and e.g. resemble iFloor by placing the icon in the center of the table.

Observations and Field Studies

Through two periods of approximately 3 weeks storySurfer was exhibited and tested in the main municipality library of Aarhus.

storySurfer was installed in the library at two different occasions, where we were able to study it in actual use. Due to the multiple birth problems related to the very large setup, it was decided that trying it out once was not sufficient. So when installing it for the second time in a library, storySurfer had undergone a number of design iterations to correct the problems from the first test. storySurfer did not function properly as intended in either of the two test session, even though it was much better the second time. There have though been many valid observations during the tests, and some of them will be presented here.

storySurfer appeared to be a place where people do something together. Both individual children, children in groups and children and parents explore the prototype. As it is an unknown setup to all, it is a meeting place for doing investigations together. No parent can be the instructor, why the child and the parent rather meet in a common unfamiliar ground. The smaller children use the installation too, through play they investigate books they will read later. Most new visitors, no matter age, are hesitating at start and are very careful. But after a while, when nothing dangerous seems to happen, they start running and jumping on buttons and floor. There appears to be a fear of breaking something in the start, but when they see that nothing strange happens, they become more relaxed and confident.

There is a lot of social talking going on around the installation, comments on the covers and exclamations when someone recognises a book they have read. There is not a particular high level of noise around the installation though. At start there is a lot of communication about how to use the installation, and then visitors pass that knowledge further to others. There is also cooperation between parent and child, where the child surf the floor for interesting books that the parent reads about on the table, and when they have decided upon some books, the parent goes out to find the books.

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[10] We have been working on a MLT listener that detects double-clicks however this is not implemented in the storySurfer version.

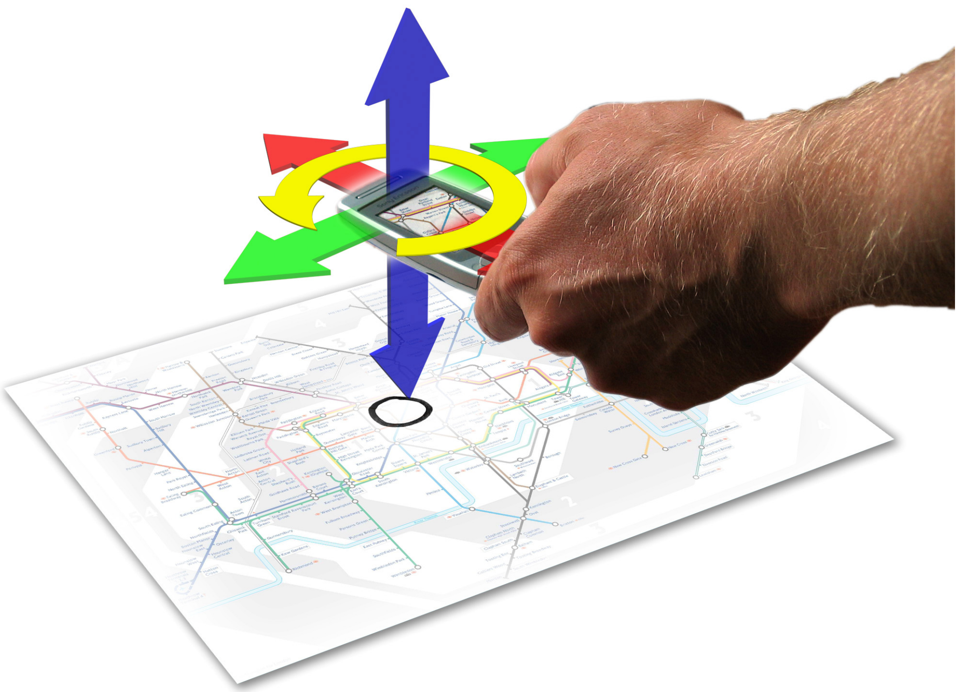
Though the social interaction is high, there is not much physical contact. As the cursors on the floor are individual, users tend to avoid going to close to each other to interfere with the other users' search and cursor.

Most children get a hence quite quickly of how to use the system, even though technical restrictions did not make everything work out the way it was meant. At the floor, the interaction is based on pushing buttons and dragging a cursor. Some misunderstanding came across the fact that you can not step on a book to choose it, and there is no double-click. The hand icon on the table was misguiding, as you were supposed to use the pen and not the hand. Some starts out by the table, as they believe it to be the "keyboard" controoling what is on the "screen" on the floor.

An interesting observation is that an understanding for how the installation function come quicker if the children tried all the functions of the installation first, instead of asking for help before trying it out. So the understanding for how it works turned out to be more dependant on carefulness versus the lust to explore, and less on the actual level of difficulty for understanding.

The overall reactions are mostly joy and laughter, and verbal expressions of how cool and fun it is. There are a few unfortunate disappointments too, mostly because of that the technology was not optimal at that time. There are some differences in the use of StorySurfer when they have tried it for a while. Some just find it fun and amusing, while others see the use of it and returns several times to search for books.

6.3 CASE 3: MIXIS



The Mixis concept, and the prototypes developed on top of this interaction technique, is work done in collaboration between Thomas Riisgaard Hansen, Eva Eriksson, and I. We have all used the work as part of our Ph.D.-projects, however, with different angles as our backgrounds are computer science, interaction design, and architecture respectively. The concept came about as Thomas implemented a visual tracking algorithm used by the camera of a mobile phone. I was interested in the space that was produced by the camera sensor in the physical world, and Eva had great interest in the potential interactions that such a concept could afford.

We have worked with this project on the side of other projects that we have been involved in at our different research centers. The work has not been driven by a specific goal or a certain application domain, but has evolved as an explorative journey inspired by the technology and its new possibilities for interaction, the emerging research field within mobile technologies, as well as work we have carried out in our other parallel projects. The project is thoroughly described in *paper 3*, *paper 4*, *and paper 5*.

Process and Concept

Basically, the project has evolved from questioning if there are other ways of interacting with mobile devices than through buttons, thumbwheels or pens. This question was triggered from the, at that time, very poor cameras build into mobile phones; could such a camera serve other purposes?

By using the camera, Mixis expands the interaction with mobile devices into the physical world. MIXIS uses the camera in mobile devices to track a fixed-point and thereby establishes a 3 dimensional interaction space wherein the position and rotation of the phone can be tracked (see figure 21). As much research has, and still is, going into making very reliable and precise tracking e.g. (Kato et al. 1999) by using predefined features, we saw potentialities in exploiting a tracking technology that could run on the fairly limited processor of the mobile phone, and use parts of the environment as a fix-point between the physical and digital domain.

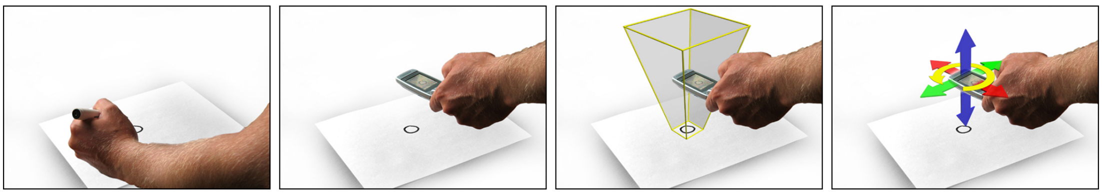


Figure 21: The basics of mixis.

The first proof of concept was basically to detect a specific fixed point. We used the Randomized Hough Circle Detection Algorithm as described by (Xu et al., 1990), and optimized it for detecting a single circle in a picture. The simple test application could place a red graphical crosshair in the center of the circle on the mobile phone display while tracking the circle. As simple and banal as it might seem, this led to some, for us, very interesting discoveries regarding the relation between mobile device and feature (circle). We saw the setup as a kind of joystick, in which changes in the relation between circle and camera could serve as inputs to an application.

We started by investigating and exploring the kind of space that emerged from the camera, concepts of drawable interfaces, as well as the mobile device in relation to other remote information appliances. Through discussions and design sessions, this led to applications such as ImageZoomViewer, DRoZo, and LayeredPieMenu (Hansen et al., 2005) that address some of these issues.

Later we developed the discussions to include multi-user aspects and possibilities of using the near context as a reference point for establishing the mixed interaction space. Thomas implemented a new tracking algorithm based on a color histogram analysis, opening up for basically defining anything that stands out from its background as a reference point. We worked with multiple interacting users mediated through shared displays, e.g. in MixisPong (*paper 12*) and in PhotoSwapper (*paper 5*) where the personal properties of mobile devices proved valuable in public settings as suggested by (Ballagas et al., 2004) in "Bring your own device".

By using mobile phones equipped with two cameras, we have explored using the user's face as the tracked feature. Such a setup creates a system, in which both feature and camera space are mobile, why interactions can happen by moving your head or by moving the mobile device in relation to your head. Further, using the user's face as feature has the advantage that the feature is constantly with you, opposed to having to locate something in your near environment that is suitable for tracking (Hansen et al., 2006).

The development process of Mixis has been long and rather slow, because we all have been obligated in other projects, why Mixis often ended up in the background. This slowness might, however, have forced a sensible space for reflecting on our work and guiding new possible ways of progressing. A result of this is that the collaboration with Thomas and Eva that has led to the framework that looks across camera-based projects, which I will distill in the following chapter.

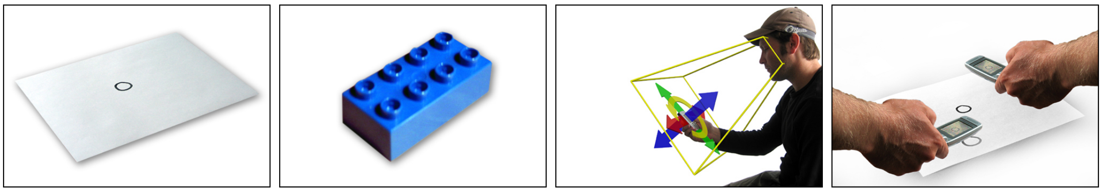


Figure 22: Features; hand drawn circle, color object, face and multiple features.

The Prototype Setup

Despite the use of tracking algorithm and type of feature - circle, colored object, or face - the Mixis concept is exploiting a visual relation between a camera and a feature (see figure 22). The several developed prototypes explore aspects such as ways of mapping interactions within the camera space to both local and remote applications; limited screen space on the local device opposed to interacting through Mixis on large remote displays; ways of merging or dividing feedback from the application and feedback regarding the state of tracking; mobile potentials both regarding feature and camera space; multi-user aspects that exploit the mobile device as a personal information container; ways of bridging and utilizing the physical environment with the digital domain.

The following four application examples are all based on the Mixis interaction technique. They are chosen as they summarize the most important aspects that we have investigated while developing the Mixis project. Videos of the applications in action can be seen in the *project diagram*.

[mapping: 6, 24]

ImageZoomViewer

The ImageZoomViewer uses movement-based interaction to navigate in a map or a large image on the small local display. By using any of the above mentioned Mixis tracking techniques, changes in the relation between camera and feature are mapped to navigation actions on the map. If the mobile device is close to the feature the application zooms in on the map, if the device is far away from the feature the application zooms out, if the device is to the left, right, up, or down in relation to the tracked feature the application pans accordingly. The display of the mobile device becomes a looking glass or peephole into a virtual world. The concept is similar to the byensStemmer project, as described in the previous chapter, where a large mobile horizontal display is used as the peephole into a large map expanded virtually on the floor. However, the two projects differ in ImageZoomViewer being a relative navigation whereas Byens Stemmer is an absolute navigation (this is discussed in depth in chapter 7 (*interacting in camera spaces*).

[mapping: 0]

The application is addressing aspects regarding browsing large images on small displays, natural mapping, and system feedback overlaid on the application (feedback is discussed thoroughly in chapter 7 - *interacting in camera spaces*).

DrawMe

The DrawME application is using the Mixis circle tracking technique. Apart from just recognizing a clean circle, the application is also able to distinguish between a set of hand drawn symbols within the circle. Like in (Landay et al., 2001), DrawME opens up for the idea of drawable interfaces, where the user is able to draw shortcuts in the physical domain that trigger specific actions in applications in the digital domain. These shortcuts can be drawn on paper, whiteboards and walls, and hereby the user adds another layer or functionality to disposable doodling. When the user draws a circle containing a specific symbol, the camera recognizes the input and performs the function mapped to the specific symbol. The algorithm stores a set of masks of known symbols and finds the best match between the symbol in the centre of the circle and the known masks. In DrawME, we mapped different symbols to the single function of calling a certain contact from the address book, as illustrated in figure 23. To either confirm or reject calling the contact appearing on the display, the user pan towards the yes and no icons displayed on the phone interface.

The application is addressing aspects regarding semantic mapping, drawable interfaces, and identity of features.

DRoZo

The DRoZo application (Drag, Rotate and Zoom) focus on how the mobile device can be used to interact with pervasive devices equipped with an interactive circle in the surroundings. Commands are sent through a generic protocol to the remote device. By attaching a circle underneath digital materials, like e.g. pictures on a large wall display, the user can drag these materials around on the screen using the mobile device. The user can zoom in and out on the picture, like the ImageZoomViewer application, by moving the device closer to or away from the circle. Rotation of digital materials is also supported by rotating the phone. However, to be able to rotate materials, the circle must contain a small mark for the tracking algorithm to detect the rotation as illustrated in figure 23. The prototype uses Bluetooth or GPRS to communicate between the remote display and the mobile device.

The application is addressing aspects regarding direct manipulation, natural mapping, and the coupling between local and remote displays.

PhotoSwapper

Photo-Swapper is an application wupporting the mobile camera device to operate a cursor on a shared display. The shared surface can be used to expose and exchange digital material stored on the connected local devices. Hereby, the shared surface becomes a public display open for any user who carry his own combined interaction device and memory stick (mobile phone). Several users can connect to the shared display with their own personal device, resulting in several simultaneous cursors. The cursor can be moved on the shared display by moving the mobile device in relation to the tracked feature, regardless of tracking technique. Moving the cursor in the xy-plane of the remote display happens similarly to ImageZoomViewer, however, moving the device closer to the feature results in picking-up an image on the display; and moving the device away from the feature is mapped to a drop action. It is possible for up to seven users to connect to the same shared display, thus operating seven independent camera spaces simultaneously and using them as input in the same application.

The application is addressing aspects regarding multiple users, providing all feedback on the remote shared display, and interaction in public settings.

Figure 23: Four mixis application examples, ImageZoomViewer, DrawMe, DRoZo and PhotoSwapper.

Observations and Field Studies

The Mixis interaction technique has, as I have mentioned earlier, not been developed for a specific purpose or application domain. We have worked on the project with a playful approach towards interaction. Thus our main objective has not been proving its speed and ease-of-use. We have, nevertheless, conducted a small formal usability study to compare browsing large images on the mobile device, using the ImageZoomViewer application versus the traditional way of pushing buttons to pan and zoom. The Study showed that after a bit of practice, the participants were slightly faster using Mixis than the traditional interaction method. The study is further described in *paper 3*.

Where much of the core HCI community would evaluate this technique much further, we have been interested in exploring the space of possibilities for using a mobile phone equipped with a camera to interact in the real world. Thus this work has led to a range of applications that hardly proves the feasibility of the technique in a specific context, but on the other hand expands the space for what you can do with mobile camera devices, and hereby expanding and informing what is *given* in the design circle.

Some of the observations were directed towards feedback related to surfaces of attention. We found that providing feedback about the state of tracking in the same display as the application was running, caused less confusion in swapping attention from e.g. a remote display and the local mobile display.

The technique itself influenced our design of applications, because of its potential as a 3D input device. Both ImageZoomViewer, DRoZo, and PhotoSwapper exploit the 3D space between camera and feature, and translates these into the applications to add manipulations related to 3D interaction such as translate, rotate, and scale (zoom). An aspect that has not been tested, but which should definitely be explored, is using Mixis for interaction with real 3D graphics as we tested with the eMote and my 3Dsitemap.

[mapping: 32]

6.4 SUMMARY

In this chapter I have described three selected cases developed and explored through my Ph.D.-project, namely iFloor, storySurfer, and Mixis. These cases are different in their approach and application domain but have similarities towards using a spatial interaction technique expanded by cameras. In the following chapter I will go into depth with the space expanded by cameras as a means for bridging the gap between physical and digital space. I will use this in depth understanding of this space as interface to discuss how intentions can be induced into the design of space to afford the potentiality of place-making in actual use, as I have discussed in chapter 5 (*moving into space*).

7 INTERACTING IN CAMERA SPACES

In this chapter I will go deeper into describing a specific type of space as an interface. I will describe and discuss the type of spaces that exist in the mix between physical space and digital space augmented through cameras. The chapter is based on the three cases, examples from the *project diagram*, and related work within the area. As explained in *part II: Project Diagram* there are many possible perspectives into the work I have carried out during my Ph.D.-project. However, this chapter is concerned with a view through a *camera-based* perspective. This perspective inscribes a number of projects and examples that resemble and exploit these types of spaces. From looking across the different cases and projects I will distill a conceptual framework that provides explanatory power for analyzing, comparing, and designing mixed interaction spaces based on camera tracking. The initial framework is developed together with Thomas Riisgaard Hansen and Eva Eriksson and is presented in *paper 4*. I will develop this framework further, which will lead to a characterization of mixed interaction spaces. The framework will later be discussed in relation to my conceptualization of space and place, as described and discussed in chapter 5 - *moving into space*.

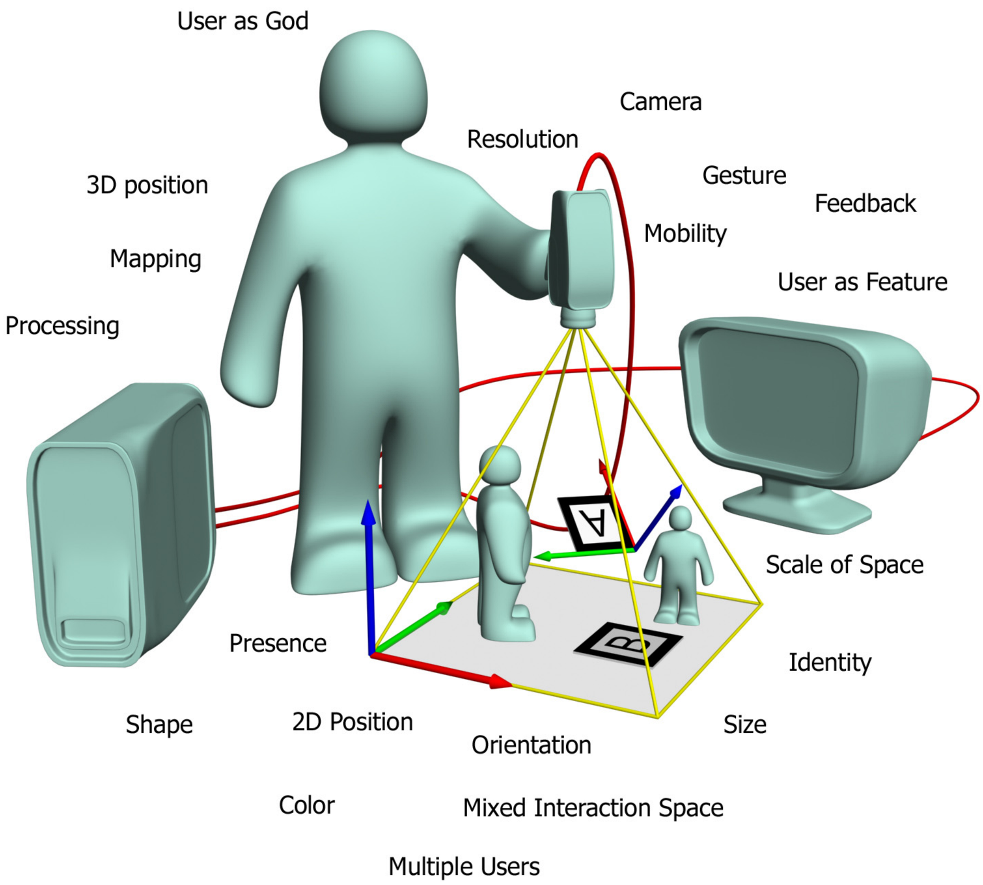
Many frameworks and taxonomies have already been developed for grasping different ubiquitous computing systems. Some of these seek to frame interactions within an entire field such as Fishkin's taxonomy for tangible interaction (Fishkin, 2004); others go across fields and approach the interaction in an even more general perspective such as Benford et al. (2005) in their framework for understanding movements as expected, sensed, and desired; and Belotti et al. in their discussion on new challenges for user interfaces as they move off the desktop (2002). Interesting and useful as they are on a general level, none of these do, however, address the use of cameras in particular. Milgram et al., however, developed a taxonomy for augmented and mixed reality setups (Milgram et al., 1994); and Mackay describes a number of approaches towards using cameras for augmenting different elements of the environment (Mackay, 1998). None of the two do, however, consider the camera interface as a space but mainly as a technical interface that can help to establish overlaid physical and digital 3D worlds in real-time.

While we have been inspired by the above frameworks and taxonomies they are all too general in their approach to cameras or they address them simply as a technical interface, which is not in line with my spatial approach towards the interface.

7.1 CHARACTERISTICS OF CAMERA SPACES

When looking at the three cases, described in chapter 6 above, they might at first glance seem very different as iFloor is engaged with communication mediated through SMS and an interactive floor; storySurfer affords a bodily and a pen-based approach to visual book searching; and mixis is a way of interacting with remote and local information through the camera of mobile devices. Despite these apparent differences the three prototypes exploit the same kinds of spaces established between physical and digital space through a camera. All three cases use a camera space to create a zone for potential input as either a 2D surface or a 3D space.

The basic concept is that a camera is used to monitor the physical world; software is analyzing the image stream and detects certain changes within the camera's field of view; and these changes are mapped to actions in the system.



7.2 INTRODUCING THE ELEMENTS OF THE FRAMEWORK

The Mix of Spaces

As described and discussed in chapter 5 there are many ways of mixing physical space and digital space. The choice of interface technology constraints and molds the way the mixed space takes form within the context, thus influencing how intentions regarding the dimensions of place-making can be translated and expressed in the actual use situation. Hence working with cameras for bridging the two domains introduces some aspects that are specific to cameras, and which need to be considered when designing and analyzing such systems. These aspects will be described in detail later but include e.g. *field of view*, *frame rate*, and *resolution*. The field of view defines how the camera looks at the physical world, which eventually is the defining factor for the shape of the mixed interaction space: the space where *physical space* and the *camera space* are overlapping (see figure 24). This interaction space usually[11] has the shape of an inverse pyramid as seen on figure 21 image 3. The camera-based setup results in a number of co-present spaces with different properties. The entire system is regardless of

11 Depending on the camera and lens this shape can differ, however the cameras used in this dissertation have rectangular output creating a space of a pyramid.

scale inscribed in some *physical space* that contains the camera; the camera expands and represents the potential *interaction space*; and in the merge between physical container space and interaction space, creates what we have termed a *mixed interaction space* (Hansen et al., 2005). In the following I will describe and discuss a number of aspects that relate to these spaces that will make up the conceptual framework for interaction in camera spaces. Later I will deploy the framework on one of my cases and discuss how the configurations of aspects in the framework influence the four dimensions of place-making – basically confronting the intended use with actual use. The framework consists of five aspects: camera, space, relation, feedback, and user. I will start with basic technical aspects related to understanding and designing these interactive systems and slowly make my way to the interaction within this type of space.

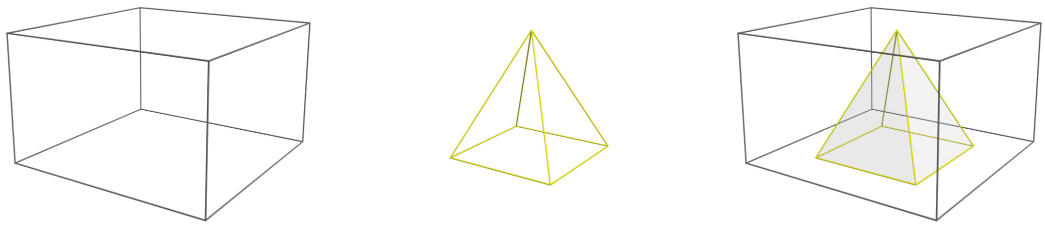


Figure 24: The basic components – physical space, camera space and mixed interaction space.

Sensing with a Camera

As mentioned while describing my research approach the use of a *distant* and *close* perspective is necessary for understanding the potentiality of interactive technologies (Stolterman, 2005). The following aspects regarding the use of cameras as sensors are empirical experiences obtained through working with the technology in multiple projects over the past five years. It is aspects that might seem trivial and obvious but nevertheless, important to unfold for discussing and understanding the materiality of the camera as a sensor.

When using a camera to sense events or changes in the physical world data is transformed from the 3D physical space that the camera overlooks to a 2D digital plane. This is equivalent to taking a photograph with a camera; the real world is projected through the lens to the image plane of the camera; and a 2D photo can be developed and printed. But when using the camera as a sensor for interaction in real-time the image is analyzed to find features that match a certain pattern. Here I will not go into the deeper technical details regarding digital image processing and analysis but rather describe what is at stake when trying to get something meaningful from understanding the world through a camera.

The following aspects relate to Camera:

Camera	**Aspects that relate to the camera as a sensor.**
Field of View	*The defining factor for the interaction space. Has an influence on the distortion of the captured image.*
Resolution	*Defines the amount of pixels in the captured image. Relates to the scale of the space and the size of features. Confronts issues of privacy.*
Frame rate	*The switch of the mixed interaction space. Turns potentiality of interaction on and off.*

Field of view

The field of view is defining the shape of the mixed interaction space. As mentioned above the space usually has the shape of an inverse pyramid. We can strive for cameras that can overlook enormous spaces using very wide angled lenses or we can go for narrow lenses that keep track of very specific areas within a space. Apart from changing the shape of the interaction space, the changed optic influences how the image is projected through the lens to the image plane of the camera (Delman et al., 2003). We see this phenomenon, perhaps unconsciously, when going through the zoom range of a camera. Going from wide to narrow will make objects appear closer to each other along the depth axis. To relate this to architectural drawing and 3D modeling software zooming is going from a wide perspective view towards, however, never reaching an orthogonal view.

Obviously one can choose a wide lens and later trim the image to "narrow" the interaction space but this will influence the resolution of the image and thus limit the information that can be retrieved from the image stream.

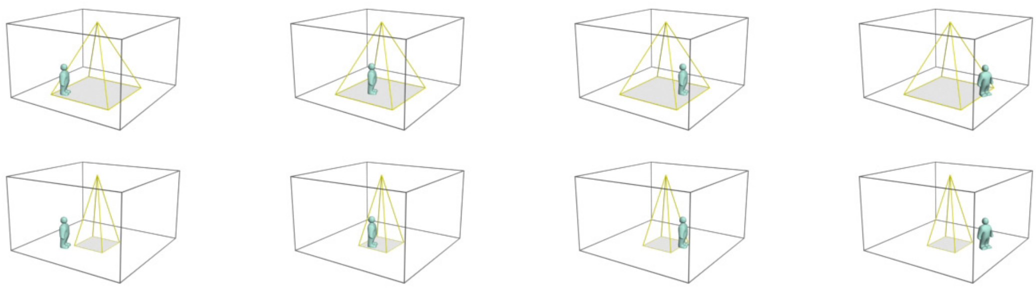


Figure 25: Field of view as a design issue.

Frame Rate

A camera monitoring a space is functioning by capturing multiple snapshots and combining the separate images into an image stream. The speed in which this happens is referred to as frame rate, indicating how many snapshots or frames the camera captures every second. Some scientific cameras capture up to 168000 frames per second (Memrecam, 2006), cameras for live motion film[12] captures between 24 and 30 frames per second, and other types of cameras for making for instance time lapse films might have a frame rate of one frame per minute or hour. Figure 26 shows how a person's movement through a camera space depending on the frame rate changes the information we can retrieve from the situation. In the upper film strip the person is captured four times within the camera space whereas the lower film strip has two frames containing the person. Technology driven design that seeks try to maximize the frame rate to capture as much information as possible is not the point for addressing the aspect of frame rate. Rather is it to put focus on frame rate depending on the system and the intended use. Most often the frame rate can be considered as a seamful property as the image stream will always consist of discreet image entities that leave out the activity in the time span between two frames. In many ways this is equivalent to the design of seamful interaction by (Bell et al. 2006) who exploits the seams between wireless networks as a constraint in their Yoshi game. Regarding frame rate the same seamful potential should be considered as a design parameter in mixed interaction spaces.

[12] Motion Picture films run 24 fps, PAL run 25 fps, and NTSC run 29,7 fps.

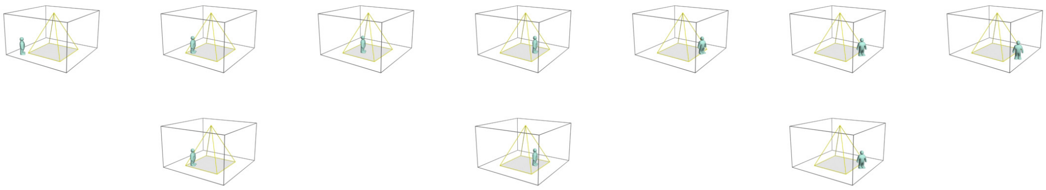


Figure 26: Frame rate as a design issue.

Resolution

Another aspect that plays a role when a camera captures images is the resolution. For digital images the resolution describes the number of pixels (dots) describing the entire image. Whenever the camera captures a frame of some space or situation that it overlooks, this frame is processed into an image made up by dots. Clearly with a low resolution camera it will be hard to capture Taj Mahal and make up the fine details afterwards. But on the other hand high resolution cameras require a much faster processor to analyze captured images in real-time. Figure 27 shows how the resolution influences the quality of captured images as a person passes through a camera space. It is worth noting that in both cases we can detect an object standing out from the background; in the upper film strip we might be able to recognize that it is a person and even who that person is; in the lower film strip the object can basically be anything. Again as with the frame rate the resolution has to be negotiated against processing power but also against what we need to know and what we would like to know. Regarding aspects like privacy there might be a point going for a low resolution solution as the system only to some extent can serve as a surveillance system (I will discuss privacy and identity more in depth later on).

Regardless of the resolution the image and what can be extracted from it is influenced by the field of view. Imagine a wide lens and a narrow lens with the same resolution; the wide lens has to describe a wider angle of the context with the same amount of pixels as the narrow lens camera, which results in less detail and more context in the wide lens image, and more detail and less context in the narrow lens image.

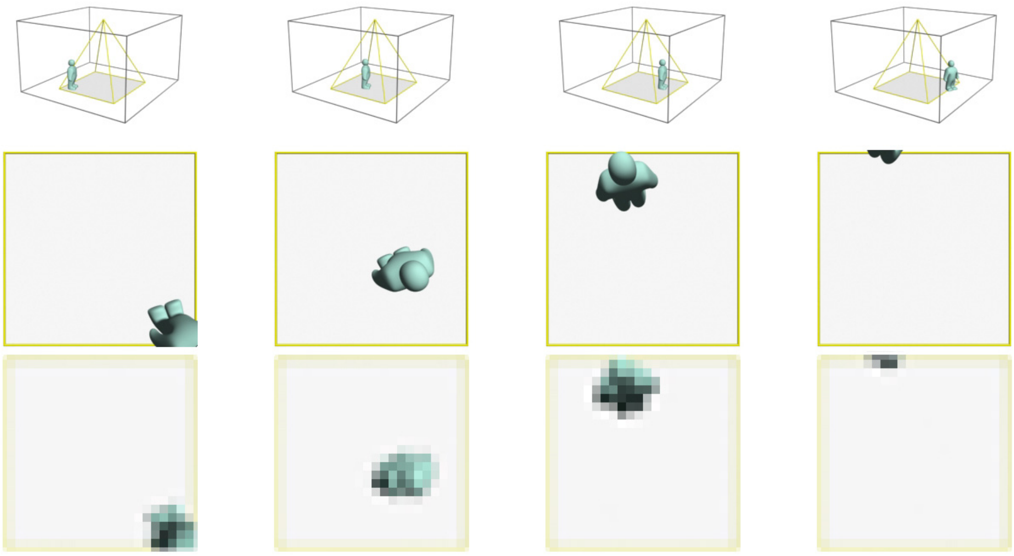


Figure 27: Resolution as a design issue.

Analyzing Data

The framing and quality of the images captured by the camera are basically defined by the above described field of view, frame rate, and resolution. There are of course aspects regarding the quality of the light sensor, adjustment of the camera driver, the problem of changing light conditions that influence as well but I will not go further into these aspects.

Regardless of different camera specifications what the computer "sees" as the images arrive at a certain frame rate is pixels in varying color in a matrix defined by the resolution and the image aspect ratio. There exist thousands of algorithms and methods to analyze the captured frames but it is not the focus of this thesis to discuss all these. Rather is it to put forth a broad range of approaches to making sense of the pixels based on my empirical projects as well as related work.

One way of approaching the image stream is to look for changes in subsequent frames. An example of this can be a camera that detects movement by matching image frames in a *time interval* to see if these frames lie within a certain threshold. In case of differences the software can point to areas in the images that differ more than the accepted threshold. Figure 28 shows how images, the left and right, are matched against each other and areas of difference are detected. In this case the camera is used to sense that someone in the context has moved.

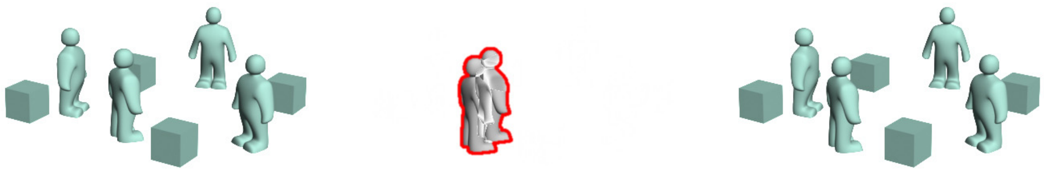


Figure 28: Movement detection by comparing differences in image frames.

Another way of approaching the image stream is to analyze each frame for certain features that match predefined patterns. In iFloor tracking of multiple users is done by converting the image stream into grayscale images and analyze them for areas over a certain size, to discriminate noise, and over a certain grayscale threshold to subtract the background. As the physical floor is white most users will appear as darker blobs in the grayscale image. The system does, however, not know if someone left a bag on the floor or if the blob detected really is a user; or if two users suddenly stand so close that the system will detect them as one blob instead of two.

The storySurfer prototype uses two kinds of tracking. On the interactive floor users are detected in the same way as on the iFloor. The two floors are using the camera to determine positions of features or users on a 2D floor surface. This adds some problems as the camera expands a 3D space for input and not a 2D input surface. The problem becomes clearer when looking at users with different heights that depending on their position within the camera space will be calculated differently. Figure 29 shows how a camera will see two users as being located at different positions due to their different height and the fact that the camera sees the world in perspective and not as an orthogonal view.

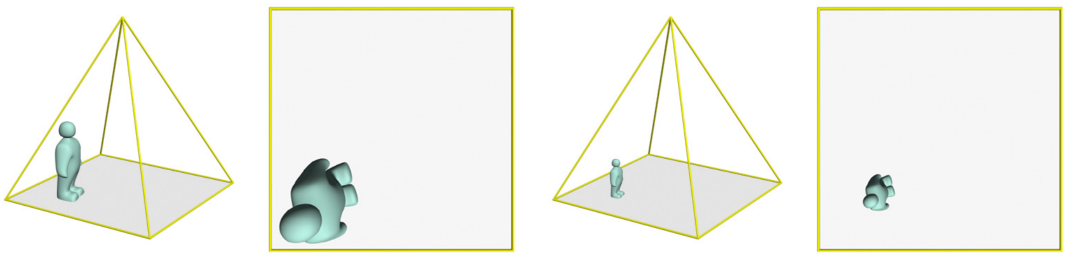


Figure 29: Uncertainty of tracking.

We have addressed the above problem in the storySurfer's second tracking setup used in the MultiLightTracker table (MLT) by tracking a translucent surface from beneath. By detecting multiple colored lights that are only visible while touching the surface the uncertainty of tracking as seen in iFloor and storySurfer is largely reduced. Figure 30 shows how light blobs are only visible to the camera when they are in contact with the table surface. Like the two floors multiple features can be tracked, however, using different colored lights opens up for discriminating different light colors and hereby different users. In the MLT the camera is mounted beneath the translucent surface together with a projector. As the projection has a high luminous intensity and consisting of all sorts of colors it can produce a lot of noise when the captured image is analyzed for colored points sent through the translucent surface by the light pens. We have solved this by adjusting the camera driver and changing the shutter time to a minimum so only the extremely intense LED's from the pens make their way into the camera as colored blobs (Nielsen et al. 2006).

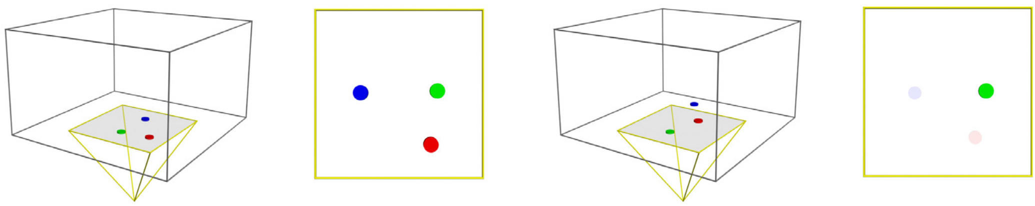


Figure 30: Surface tracking – only features touching the surface are visible to the camera sensor.

In contrast to iFloor, storySurfer, and MLT that basically uses the camera space for 2D surface tracking the Mixis concept is exploiting the entire mixed interaction space. Tracking is done in two ways. In the circle tracking applications tracking happens by analyzing the image stream for a circular fragment with a color value over a defined threshold (Hansen et al., 2005). The other Mixis tracking concept (color tracking) is similar but is basically a match between a predefined mask and a similar pattern in the image stream. In this case the user chooses a feature in the context and creates a mask by taking an image with the camera that is stored and used as the predefined pattern. Anything that differs from the background can be used as feature. As described in chapter 6 hand drawn signs, colored objects, and faces have been used as features. Opposed to the above described tracking setups the Mixis algorithms are only capable of recognizing a single predefined pattern or a circle. As seen in figure 31, when a feature is recognized its xy-position within the camera space can be determined in the same way as iFloor, storySurfer, and MLT.

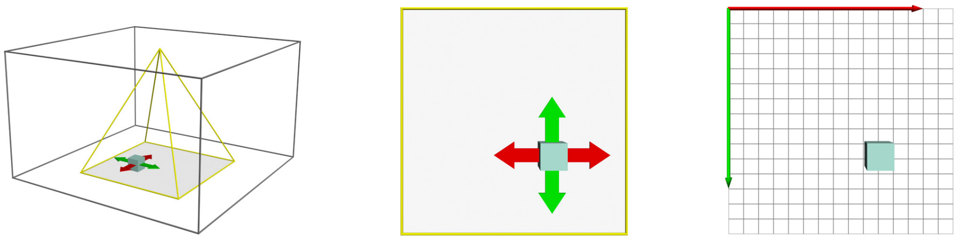


Figure 31: The basics of determining a position in 2D.

The third dimension is determined in another way. The feature does not have a predefined size, which makes it impossible to calculate how far the feature is positioned from the camera. A huge feature that is positioned far from the camera and a tiny feature close to the camera will appear the same to the camera. Thus the z-value is determined as the size of the feature in relation to the entire image frame. This gives a relative position of the feature in relation to the camera, meaning that it exploits the entire interaction space as a mix between absolute and relative positions. As seen in figure 32 when moving the feature towards the camera it will occupy a larger amount of the entire image width and height, which derives the relative z-value.

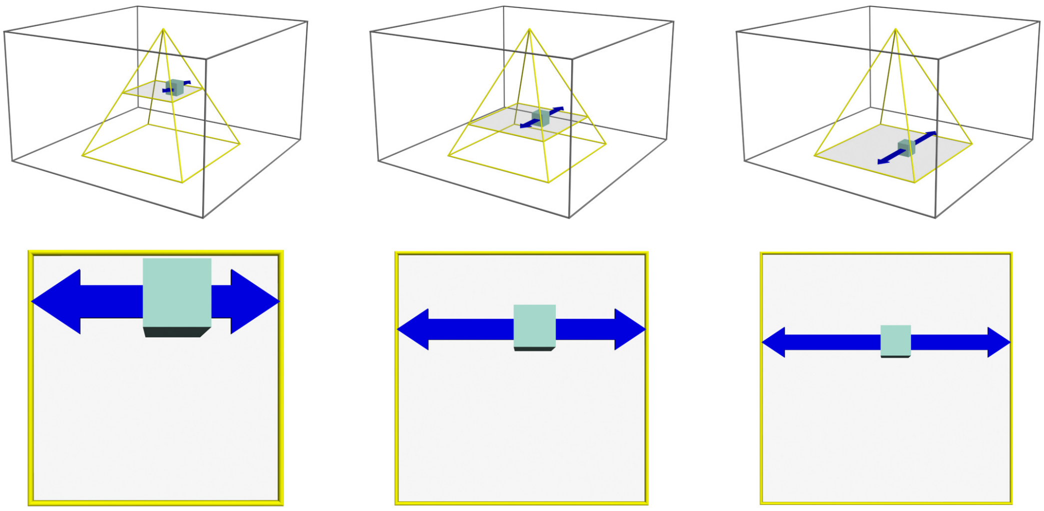


Figure 32: The relative z-value is calculated as the relation between the feature size and the entire image.

So far I have described ways of analyzing images for general changes in context, position of features in 2D, as well as relative 3D positions. I have described systems that can track a single feature and systems that can track multiple features within a single camera space. I have briefly touched the aspect of *identity* through the multiple color pens tracked in the MLT setup. I see identity as a property of the *feature,* which I will discuss later in relation to the types of interaction and applications this affords. I will end this section on analyzing data by looking at a way of establishing a more accurate tracking within the interaction space. This is done by encoding more technical specifications about the camera and the features into the system than just e.g. that it is a circle or that it has this specific color. Hereby the system can increase the information that can be extracted from the camera's view of the context. One way of doing this is by using printed 2D patterns similar to barcodes; figure 33 shows different examples of such patterns. Multiple researchers have worked with such a tracking technique and a number of applications as well as toolkits have been developed (shotCode, 2006) (semaCode, 2006) (Artoolkit, 2006) (cyberCode, 2006) (reactable, 2006) (QR codes, 2006). Personally I have been working with the Artoolkit in a number of projects within kollision.

[mapping: 10, 29, 44, 45, 46, 47, 49, 50]

Figure 33: 2D barcodes examples: barcode, cyberCode, semaCode, spotCode, qrCode, reactable, and Artoolkit.

The basic concept is that the captured image is analyzed against a single or multiple different patterns. It is similar to the barcode scanner in the supermarket, however, this infrared scanner will only detect if there is a feature present and if so the identity of that feature. This type of recognition is similar to e.g. semaCode that uses the camera to take a photo of a 2D black and white data-matrix pattern to retrieve a URL. Apart from detecting a certain pattern applications like Artoolkit, cyberCode and spotCode are able to calculate how the feature is oriented in relation to the camera. Figure 34 shows the basic differences from tracking blobs without identity to fully predefined unique patterns. The images are converted into black and white, scanned for black fragments that can make up a square, these fragments are matched against the camera specifications, positions and orientations are calculated in relation to the camera, and finally is the identity determined from the center of the pattern. Using visual barcodes opens up for tracking multiple identified features and retrieve information about their position and orientation in relation to the camera.

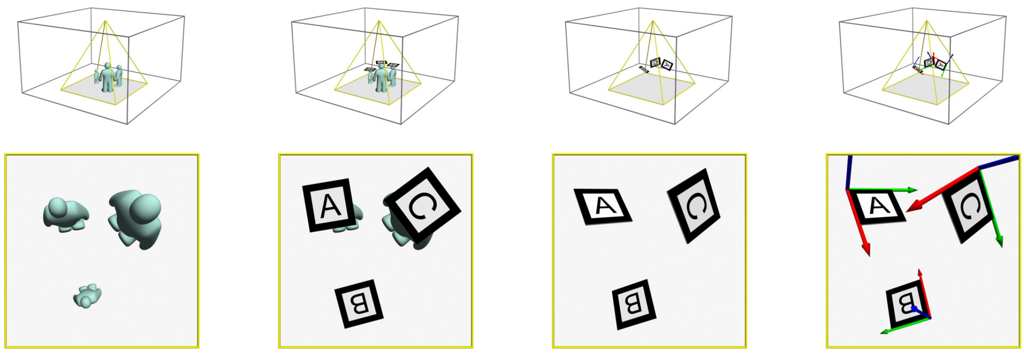


Figure 34: Using predefined barcodes as features can exploit identity and orientation.

The presented techniques for analyzing captured images show how simple and how complicated the process of tracking can be, which influence the amount of information that can be retrieved. Of course there exist thousands of methods for analyzing images, which I have not been around here. However, my point is that regardless of method what the camera provides is a bunch of pixels that the system designer has to make sense of. At first one would think that the best way to go would be full 3D tracking with identity but it is not! It depends on what your purpose is, what you see as intended use, and how you expect users to experience the mixed interaction space. I will return to this discussion on identity in a later section.

So far I have described how captured images are turned into positions; how these are used to make the actual system interactive will be discussed in the sections on relation and feedback. First I will look into the properties of the mixed interaction space that is partly created by the camera and the aspects of this as a sensor.

The Properties of Space

The following section describes aspects that relate to the actual mixed interaction space. This space is expanded in the physical space but has no real graspable properties.

The following aspects relate to Space:

Space	**Aspects that relate to the space expanded by the camera in physical space.**
Type	*Relates to the space as a single entity or as a part of a network of spaces.*
State	*Defines whether the space is static or dynamic.*
Orientation	*Defines how the space is oriented in relation to physical space, e.g. horizontal, vertical or dynamic.*
Scale	*Relates to the scale of tracked features. The scale can be dynamic depending on the mobility on the interaction space.*

Scale of Space

When talking about scale within spatial environments it is usually in relation to *something*: atoms, our body, a room, or a city. The scale of *something* can change depending on the relation we view this *something* in. To a New Yorker Copenhagen might seem small scale, however, large scale to someone living on the countryside. But the city of Copenhagen is not changing its actual size only the different perceptions are influencing the scale of the city. Scale regarding mixed interaction spaces is somehow different. The same camera can expand a space that inscribes an entire parking lot or five ants running around on a piece of candy paper on the sidewalk. Figure 35 shows the multi-scaled nature of camera-spaces. The same camera space can change its size and hereby also its scale. Obviously the scale of the space is dependant on a number of factors. To get meaningful information out of the captured images the scale of features (the patterns that the camera is seeking to detect) must to some extent follow the increase or decrease in scale. Likewise is the resolution influencing how far from the camera a feature is recognizable. And finally will physical space ultimately set the limits and constraints for the scale of a mixed interaction space. So when talking about scale regarding interaction spaces it relies on the relation that they exist in. Depending on the system the scale can be static like the iFloor and storySurfer floors that relate to the entire body; and the MLT table that relates to gestures with arm and hand mediated through the light color pens. On the contrary the scale of mixed interaction spaces established through Mixis can potentially take on any scale as the space itself is mobile and hereby dynamically can relate to different parts of the context. The aspects of orientation and mobility will be discussed in the following sections.

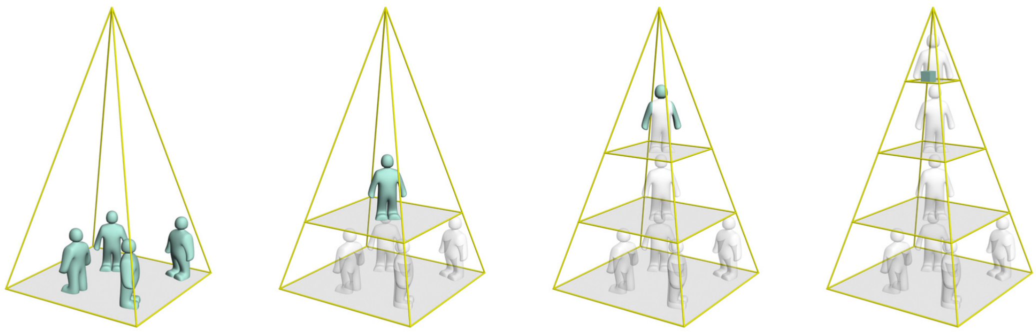


Figure 35: Camera spaces are potentially multi-scaled.

Orientation of Space

A property that we have identified but not investigated into depth is the one of orientation. In this section orientation is mostly related to interaction spaces with a static scale and character like the iFloor, storySurfer and MLT table. Most of the static space experiments we have conducted have had a ceiling- or bottom-mounted camera for over- or under-looking an approximated 2D surface. What this setup tries to do is to turn the surface into a xy coordinate system, on which features can be recognized and their positions determined. This is quite easily obtained as the gravity will make sure that features stay put on the surface. This changes when we for instance rotate the space in a setup like the eyeToy (eyeToy, 2006) where the feature is the user gesturing in front of the camera. The interaction whether the feature is a person or an object is confronted with the same problem relating to gravity. Just like in the horizontal plane examples this vertical plane setup expands a 2D coordinate system but the feature is not forced onto a "surface" but instead acts in space. This changes the interaction pattern in the sense that the feature is literally confronted with the camera face-to-face and positioning features hanging in space is concerned with certain gravitational challenges. I will claim that the awareness regarding the camera space is highly influenced by the orientation of the camera. The horizontal plane setup adds focus to the surface and movement on this due to gravity whereas the vertical plane setup adds focus to the space and gesturing and acting in this. Striking a pose seems more natural when monitored vertically opposed to being monitored from above by a camera that is out of sight. Clearly the aspects of orientation are closely related to where system feedback is provided, which I will discuss in a later section.

Unlike the horizontal plane setup the vertical plane setup opens up for changing the scale of the space by moving towards or away from the camera. The orientation might be static but the scale becomes dynamic in ways that resemble the mobility e.g. seen in the Mixis case.

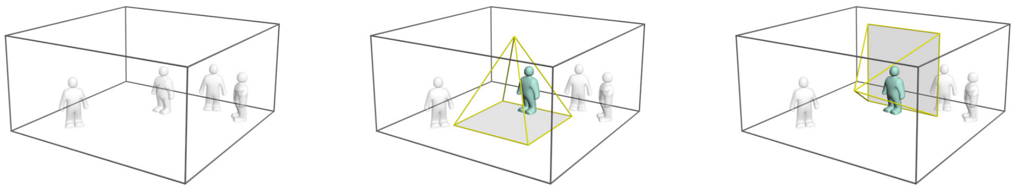


Figure 36: Orientation of space influence the potentiality of interaction.

Mobility of Space

Some spaces have a mobile nature. Think of the bus as a mobile waiting room making its way through the city, or a person walking the city talking in her mobile phone moving an invisible personal bubble through the streets. We can look at mobility regarding camera spaces in a similar way. By the use of handheld devices such as mobile phones, cameras become independent of the physical environment. This changes a number of things regarding the space and the potential interaction within the space. Figure 37 show the principal difference between moving a feature into a mixed interaction space versus moving the entire space in relation to a feature. Furthermore, given the mobility of the camera the space can take on any orientation and basically scan the physical space that inscribes the camera space.

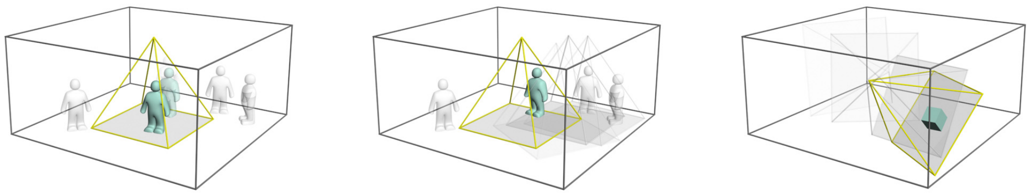


Figure 37: Mobility of space influence the potentiality of interaction as both space and feature might invoke changes

As described above one way of using camera tracking is recognizing features and determining their relative positions within the camera space. This can be aligned with the geometrical understanding of the physical space to give information regarding the overall orientation of the feature; from where did it enter the space, where did it leave and so on. Figure 38 shows the changes occurring when the interaction space goes from static and aligned to mobile. The otherwise potential corresponding coordinate systems are disconnected and only by very advanced tracking will it be possible to understand how physical space and camera space relate to each other. Mobile spaces become closer related to the camera than to the physical space, which differs from the static space setup where both camera and a specific physical space in conjunction establish the mixed interaction space.

If we look at the mixed interaction space as a space with potential functionality that differs from the surrounding physical space and we call this the potentiality of space, then the mobile property results in a potentiality of space that is not tied to a strict physical location but rather exist in a dynamic relationship between suitable physical space and the camera space.

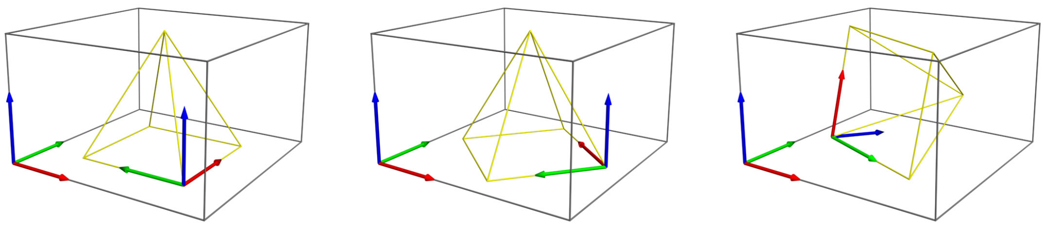


Figure 38: Multiple coordinate systems exist as spaces are mixed.

Temporality of Space

I have discussed how we can talk about mixed interaction spaces as expandable/contractible regarding scale, and as spaces with a direction related to their orientation or mobile nature. An aspect that serves as the underlying factor for the spaces to exist at all is time. This is in some ways related to the aspect of frame rate as described above. The frame rate functions like a light switch that constantly turns the light on and off. In this case, however, it is space that is turned on and off. This property adds a certain volatile nature to mixed interaction spaces, not just based on frame rate, but in its capability of controlling the potentiality of space. Spaces can instantly change its potential functionality as the camera space is switched off. We can compare this to a public space, in which the consumption of alcoholic beverages becomes illegal. This might change the behavior of people in that particular space but the potentiality still exists. With mixed interaction spaces the potentiality disappears as the space itself disappears.

Network of Spaces

A necessity for users to interact with systems through mixed interaction spaces is situatedness either as a feature as in iFloor, by manipulating features as in MLT, or by controlling the space as in Mixis. But multiple mixed interaction spaces can serve as an input zone for the same system either as collocated or distributed spaces. In this way spaces can make up a network of connected interaction spaces regardless of their different properties. In the PhotoSwapper application (*paper 5*) multiple mobile spaces are interacting on a shared surface in public space. In the Wisdom Well (Grønbæk et al., 2006), which is an extension of the iFloor into learning environments, three static spaces are thought to be connected as distributed but collaborative interactive environments in the school (Buxton, 2005). As these spaces are static users on the distributed floors can interact in the "same" coordinate system; figure 39 shows the principle of these connected spaces.

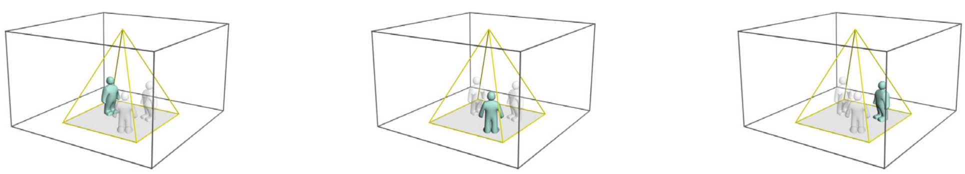


Figure 39: Network of spaces interacting in the same application.

Relations

A valuable way of understanding the different entities of mixed interaction spaces is through a *relation* approach. The relation is the smallest part of the system as entities with no relations to the rest of the system are meaningless. In this section I will describe and discuss aspects of *relations* and how changes in a relation serve as an input that can be mapped to actions in the system.

The following aspects relate to Relation:

Relation	**Aspects that relate to the relation between the camera and the tracked feature within the interaction space.**
Feature	*Describes the type of feature, e.g. human, hand, object, tag.*
Number	*Defines whether the space can contain multiple relations between camera and features.*
Presence	*Defines if the system can detect if a feature is present or not.*
Position	*Defines which position parameters of a feature are determined within the interaction space, e.g. 2D or 3D.*
Orientation	*Defines if changes in the orientation between feature and camera within the interaction space can be identified, e.g. rotation or tilt.*
Identity	*Defines whether a feature has a unique identity.*
Other	*These could be size, shape, or gestures.*

Camera-Feature Relation

Relations exist within the mixed interaction space between the camera and a feature. The relation describes how input is provided to the system. As described above a *single* or *multiple* features can be recognized by a camera depending on the tracking algorithm. The mixed interaction space of iFloor and storySurfer contains multiple relations as the camera can detect multiple features. In Mixis only a single relation can exist between camera and feature within the interaction space. This relation property remains unchanged even if multiple circles are present within the camera space; only one of the circles will be recognized and provide input. Another situation is when multiple camera spaces establish a relations to the same feature as e.g. in ARtennis (Henrysson et al., 2005) where the same features establish a common reference point for the tennis court. Figure 40 shows the four different cases of relations between camera and features within one or multiple mixed interaction spaces.

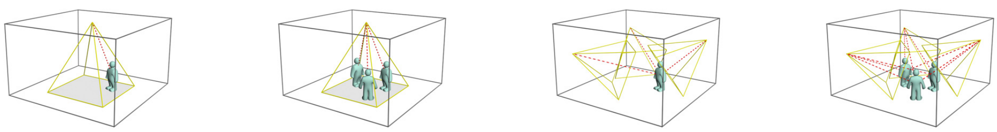


Figure 40: Relation types: one-to-one, one-to-many, many-to-one and many-to-many.

Presence of Features

For the system to create a relation a feature must exist within the interaction space. As I have described earlier the properties of the camera as well as the interaction space influence which and how features are detected by the camera. Thus features need to relate to the scale of the interaction space to be able to provide input. In the *Harbor Game* a huge ARtoolkit marker of 144 square meters was produced and hanged on the side of a large storage building. To the camera the marker was visible from at least a hundred meters and was used as a reference point for placing virtual building in the physical harbor context (Nielsen et al., 2005).

[mapping: 47]

In iFloor we rejected detected blobs under a certain *size* to reduce noise in the system. This means that features can be within the interaction space without being able to interact with the system. The aspect of *size* is an interesting design parameter that can induce collaborative aspects as we explored in iFloor where larger blobs would pull harder in the shared cursor than smaller ones. Users who noticed this feature merged their blobs by standing close together. It is, however, important to provide sufficient feedback regarding the state of the relation. I will discuss ways of providing *system feedback* and *application feedback* to users later on.

Presence of features can also be thought in relation to changes in the feature. If the system is detecting a certain *shape* a feature can be within the interaction space but not establishing a *relation* before it takes on that specific shape e.g. that a person tracked from above stretches his arms to each side and forms a blob that is eight times as long as it is wide. Or it could be systems detecting a certain color and features capable of changing their color and hereby suddenly be present to the camera as they change into the predefined color.

Apart from the system detecting whether features are *present* or not relations can have other properties that extend the possible inputs.

Position and Orientation

As explained in the *analyzing data* section above, some of the information that can be retrieved from the captured images is different degrees of *position* and *orientation*. These properties range from more or less accurate 2D positions as in iFloor, storySurfer, and MLT; approximated 3D positions in Mixis; and 3D positions as well as orientation in the Artoolkit examples. Through a relation's position property a broad range of inputs can be mapped to the system. One aspect is the use of position itself; e.g. that the camera in iFloor detects a blob of a certain size, calculates its position, gives *system feedback* through the rendered string between blob and cursor, and provides *application feedback* as it updates the interface according to the cursor position. The user does not need to move to interact with the system, *presence* and a single *position* is sufficient. Another aspect is to use changes in the relation as input by looking at multiple positions over time to form a movement either by the feature, camera, or both. As seen in figure 37 the potential mobility of both interaction space and feature affords multiple ways for changing the position property of a relation. We can understand these movements in two ways, as an isolated *gesture* where changes in the property are monitored over time and then matched against a pattern; or as a sequence of subsequent positions that provide *direct inputs* to the application. Examples of the use of gestures can be seen in the *project diagram* both sensed by cameras and accelerometers, and further as an increasing field within computer science due to enhanced processing power of mobile devices providing the ability to recognize gestures and use these as inputs (Hinckley et al., 2005) (Kela et al., 2006).

[mapping: 8, 13, 14]

By using *direct input* as e.g. in storySurfer where relation changes in the position property between a user and the camera updates the personal looking glass cursor, the user does not require any special knowledge about the system like remembering a set of special gestures to produce inputs to the system. But in storySurfer when multiple users enter the floor the users will look the same to the system. Hence the system assumes that a detected blob in the present frame is the "same" blob that was recognized in the previous frame if it lies within a certain distance of that previous blob. However, if two users stand so close that they for the system merge into one blob, the system will detach and remove one of the two cursors. When the users split up again one of them will get a new cursor and the other user will keep the one they shared while being one blob. Thus the position property alone will only be able to provide input to applications where linking of digital material to features is not essential. This issue of differentiating features will be discussed in the following section.

Identity

As seen in the iFloor case each feature looks the same to the camera. By adding an *identity* property to the relations in the camera space, it becomes possible to differentiate the various features in the camera space. Exploiting *identity* affords the design of applications where relations can have different functions in relation to the system. This is equivalent to my present activity of writing this; I exploit that the keys of my keyboard have different identities to my word processor. Luckily these keys have a static position property even though such a property could open up for new spatially dynamic keyboards[13].

Nevertheless, by adding identity to relations the system will know who is where. In the iFloor case we can talk about two types of users: the users/features browsing the floor with their bodies, and the users posting questions and answers to the floor through their mobile phones. The camera system can only recognize the number of users and their position on the floor. It will not know if a detected blob is a returning user, which questions and answers the user has already read, or if the user recognized as a blob has also posted a question.

In the MLT table user interactions are mediated through the colored light pens. The colors provide some identity to the system. The system makes sure that each pen has only one book object open at the same time to avoid cluttering the interactive surface. When e.g. the green pen opens a new book object the green pen's former open book object will automatically contract. But as a pen is not linked to a specific user the system will not know if it is the same user creating input through the green pen as it was two minutes ago, hence the system can not rely on its knowledge about which book objects green pen has already opened. In storySurfer the two mixed interaction spaces differ in their use of identity. As users in the two use situations, represented as blobs on the floor and colored light dots on the table, are not coupled users and the digital material they select can travel between the two *networked spaces* but no links exist between them. The system and users in general will not be able to know who "kicked" a certain book from the floor to the table.

Another way of adding identity to relations in an interactive system is by dividing the space into various areas. If a feature is present within one area it is associated with one identity, and another when present in other areas of the interaction space. Such an example is the floorQuest game where four players are positioned on a floor resembling the tracking of iFloor. When positioned in one of four squares on the floor detected blobs are associated with player 1, player 2 and so forth. This setup does, however, not deal with players swapping position but as long as players stick to their area they have a certain identity to the system.

[mapping: 7]

Examples of relations that exploit both identity and full 3D positioning are applications such as Book, inspired by *magic book* (Billinghurst et al., 2001), and Block presented in the *project diagram* as well as other applications that rely on tracking predefined visual markers as exemplified above in the *analyzing data section*.

[mapping: 10, 29]

In Book a single relation exist in the interaction space, one feature per book page, but each relation has its own *identity* that provides links to the sound and 3D model relating to the present book page. The 3D position property is used to calculate the distance between camera and feature, which controls the sound volume of the narrator or triggers animations through invisible proximity sensors placed in space around the 3D models. Block on the other hand functions with multiple simultaneous identity relations. Some of the markers/features are fixed in the physical world to establish an absolute link between real world coordinates and virtual world coordinates. Other features are placed on tangible spatulas that serve as interaction tools for constructing and destructing simple 3D models. The prototype exploits that the systems knows *who* are *where*. The *who* represents the functionality of the

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13 This is actually how the buttons around the storySurfer floor are made; each button represents a key from a torn apart keyboard.

tool e.g. a constructor or a destructor spatula; and the *where* represents how a feature is positioned in relation to the application and other features.

An aspect worth noting here is how the identity property constraints use in different ways. As we have seen in the iFloor and storySurfer floors relations have no identity as features are roughly tracked as blobs. Users can behave exactly as they want within the interaction space and most likely they will still be recognized as a blob; however, in the visual marker applications a focus on orientation is much more needed as the marker will not be detected as present if it is not fully visible to the camera. Of course depending on *system feedback* the user will know if a marker is not detected as present. But as the markers are 2D surfaces that can exploit both a 3D position property as well as an orientation property it invites to tilt and rotate the relation either through a mobile interaction space or by manipulating the feature, which might result in "turning" the feature away from the camera causing the relation to vanish. This occlusion aspect can be used as an intentional design decision or partly be solved e.g. by linking multiple markers together in a spatial configuration that allows the feature to "turn away" from the camera. In *parc* four markers are placed on the sides of a large cube. The markers have themselves a unique identity, however, their internal static spatial configuration makes it possible to see them as one feature where detection of at least one marker will reveal how the entire cube is positioned and oriented in relation to the camera.

[mapping: 49]

The Mixis applications afford another kind of identity that is closer tied to the user. As the interaction space can only establish a single relation, *one-to-one*, it seems needless to talk about identity. This is in many aspects true for the single user applications that run on the local device like e.g. ImageZoomViewer and DrawMe (see the Mixis case in chapter 6). In contrast, applications like the PhotoSwapper afford that multiple users can interact through a network of mixed interaction spaces mediated by a remote shared display, see figure 41. By connecting the personal device and hereby also connecting a local interaction space to the shared display, changes in the relation within the interaction space is producing input to the shared PhotoSwapper application. Inputs from different users arriving to the application have the identity of the users' personal device meaning that different users are unique to the system. This kind of identity is closer related to the interaction space than to the actual relation between camera and feature, however, it differentiates the multiple simultaneous users. In addition, the personal device follows the user enabling the system to recognize returning users opposed to e.g. the MLT setup where the pens are tools belonging to the setup and therefore are used by multiple but anonymous users.

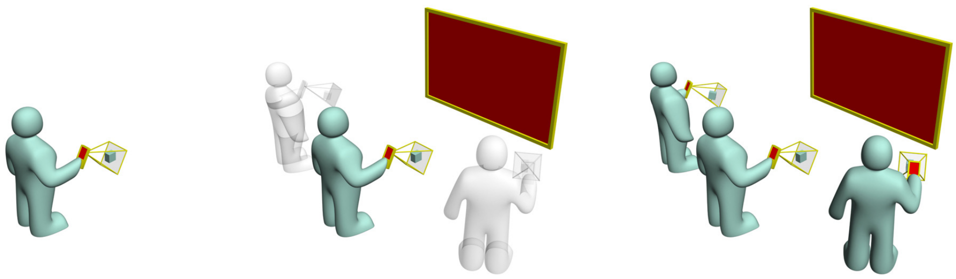

Figure 41: Identities in the Mixis applications are relevant in the multi-user applications.

Mapping

Relations can be described by properties such as presence, position, orientation, and identity. These properties or changes in these can provide input to the system. How inputs are used in the system is dependent on how they are *mapped* to actions in the application. Regarding mixed interaction spaces I have been working with two kinds of mapping namely natural mapping and semantic mapping. Mapping is a huge issue within HCI and technology design in general, thus many other ways of mapping inputs to actions exist, I will however, stick to the experiences gained within the before mentioned mapping types.

Natural mapping introduced by Norman (Norman, 1999) indicate that the relationship of input on the one hand and output on the other hand shall be made considering physical analogies. An example of this is the ImageZoomViewer application, where moving the device to the left, right, up or down makes the application pan the image accordingly to the movements. Moving the phone closer to or further away from the feature make the application zoom in and out. We can however, divide natural mapping into two types: *absolute* and *relative mapping*. In *absolute mapping* (Yee, 2003) there exists a one-to-one mapping between a feature's specific position in the mixed interaction space and the application. Such a mapping is used in storySurfer where moving around on the floor will create inputs dependant on changes in the position property, which will be mapped to the corresponding cursor that will move and update accordingly to the feature movements. One of the problems with absolute mapping is that the mixed Interaction space has the form of an inverse pyramid (see figure 21 image 3), meaning that, if the camera is close to the feature, the x, y plane is smaller than when the device is far from the feature. This aspect makes mixed interaction spaces unsuitable for absolute mapping in situations where the relation in z-axis between camera and feature is not static. Naturally it is possible to use absolute mapping in one axis and relative mapping on others.

Relative mapping (Fällman et al., 2004) is implemented e.g. in the PhotoSwapper application where a specific feature position in the space is mapped to a movement vector instead of a position in the application. Keeping the device in the centre of the interaction space resembles the movement vector null, which we call the stable zone (*paper 3*). If the device is moved outside the stable zone the change in the relation's position property is mapped to a movement vector in the application. E.g. moving the device to the left of the stable zone will be mapped to moving the cursor to the left until the device is moved back into the stable zone. Similar mapping is used in 2D in the iFloor where the movement of the shared cursor is calculated as a resultant vector of all present blobs around the floor.

The second type of mapping we have been working with is what we call *semantic mapping*. With semantic mapping moving the interaction space or a feature in a specific direction does not necessarily map to the application moving in the same direction. With semantic mapping a metaphor is used to bridge between the physical movement and the action on the device. For instance moving the phone to the left might correspond to the action "play media file" and not to move left. This kind of mapping resembles the mapping used in gesture based applications where performing a gesture is mapped to a specific function and not the same movement in the interface. A characteristic of semantic mapping is that it is discrete; the space is divided into different zones that can be mapped to activate different functions. E.g. in the LayeredPieMenu (*paper 3*) moving the phone down towards the feature and back into the stable zone is mapped to the function "go to the next menu". Likewise a gesture can be executed by "not changing the position property", in other words by keeping the relation between camera and feature static. This is used in storySurfer where keeping the cursor positioned over an expanded book after a few seconds will start a selection timer, which substitutes the *double click*.

Semantic mapping between gestures in the interaction space and the application can be arbitrary, which might result in problems with purely gesture based interfaces. These potential problems depend on how gestures recognized by the system are mapped to the application and how they are visualized as *system feedback* and *application feedback*. I will discuss this aspect of feedback in the following section.

Feedback

In the above sections I have described how a camera can be used to expand a space, in which inputs can be made depending on the properties of the space as well as the properties of the relations existing between camera and feature. The inputs can be mapped in different ways to actions in the application: Some systems are exploiting that users or features unconsciously or implicitly provide input, others rely on consciously or explicitly made inputs. Clearly both input types can be described as a relation between camera and feature within a camera space, however, in case of implicit inputs it will give no meaning to talk about feedback because this aspect is concerned with closing the loop between input and output. A project like NORA serves as a good example of this (Jensen et al., 2006). NORA is a pavilion exhibited in Venice 2006. Both inside and out in the surroundings of the pavilion visual tracking (both regular cameras and IR) detects movements of people and maps these to light and sound changes within and around the pavilion. Inputs happen unconsciously and some sort of feedback or changes in the system is provided in a not clarified pattern and thus de-coupling the causality between input and output. I will not discuss such projects in this framework as they to me are not interactive; they are at most interesting as they live a life of their own. In the following I will distill and discuss a number of issues related to feedback in systems using mixed interaction spaces.

The following aspects relate to Feedback:

Feedback	**Aspects that are concerned with feedback from the system to the user regarding the state of relations as well as feedback of the actual application.**
System	*Relates to feedback providing information on the state of a relation, e.g. through sound, visually, or through tactile means.*
Application	*Relates to the way the application communicates changes, e.g. through sound, visually, or through tactile means.*
Configuration	*Describes how system feedback and application feedback are located and organized in relation to user and interaction space, e.g. overlaid visually within the interaction space, on distributed displays, or through sound and vibration.*

System feedback and Application feedback

In our work with several projects utilizing camera spaces for input we have identified two types of feedback suitable for describing the relation between input and output – *system feedback* and *application feedback*. System feedback refers to the kind of feedback that informs the user on the state of a relation – in a desktop metaphor that would be where the mouse cursor is located and whether its shape is a pointer, a hand, or a magnifying glass. Application feedback is feedback about the actual application – in a desktop metaphor that would be how a page is presented in word. The two sorts of feedback can manifest themselves in different ways and have different importance depending on the system setup, spatial configuration, and application.

Output Destination Remote vs. Local

As mixed interaction spaces can have mobile properties, exist in a network of spaces, and support multiple input relations, the aspect of feedback is not tied to a single display or output source as we know it from the desktop computer. Thus the issue of local and remote output destinations becomes a way for analyzing and understanding the system. In iFloor system feedback and application feedback are provided within the interaction space, see figure 42a. The application feedback consists of animations of expanding questions and answers as the shared cursor rolls over, as well as animations of contracting questions as the cursor rolls out. The system feedback is directly coupled to the shared cursor and is provided as a visual string connecting the position of the user and the cursor. As soon as the user/feature is not present the string will disappear informing the user of a lost relation.

Similarly in ImageZoomViewer the two feedbacks are overlaid but interaction space and feedback space are separated and feedback is limited to the small screen of the mobile phone, see figure 42e. The tracked feature is not visible in the display but represented by a small graphical object visualizing the input vector mapped from the relation between camera and feature. Before developing the PhotoSwapper application we experimented with other multi-user applications that exploited both the local mobile phones and a remote shared display. An example is a *pong game* that can be played by two players connecting to a remote display. System feedback was provided for each player on the local display basically as the live video stream from the camera overlaid with a small crosshair indicating if the feature was found and the location of it within the camera space. Application feedback was provided on the remote display by updating each player's pad position according to changes in the relation properties, see figure 42d. Even though the game worked it revealed problems regarding focus. Each player had to put focus on both the local display and the remote display to be able to play the game. To deal with this constant shift in focus we tried to move the system feedback to the remote display to let users focus on a single feedback area, see figure 42f. This was achieved in PhotoSwapper by designing a cursor that could provide the necessary system feedback on top of the application feedback. The cursor can graphically display the xy-position of the feature within the camera space, the relative z value, and the mean color of the tracked feature to provide a low level identification of users. In this way the local display was discarded and only used for operations related to uploading and downloading images to and from the shared display. Figure 42b represents systems like the eyeToy where the user is tracked in a vertical interaction space and feedback is provided graphically on a screen outside the camera space. Lastly figure 42c describes systems like the MLT setup, in which system feedback and application feedback are provided on the "flipside" of the camera space.

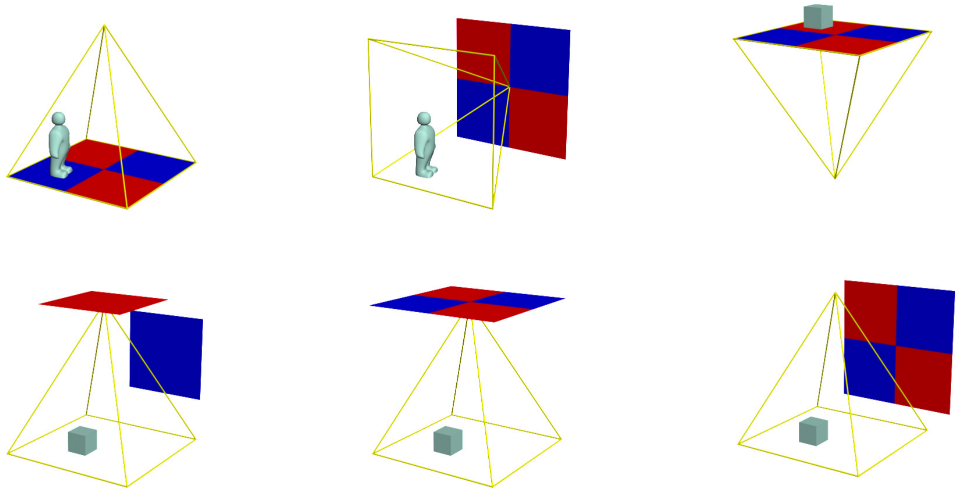

Figure 42: Configurations of system feedback (red), application feedback (blue) and interaction space.

Feedback Types

So far I have described systems where feedback is given visually. Naturally feedback can be provided in other ways. As e.g. seen in the Mouthesizer (Lyons et al., 2001) a small camera in front of the mouth of a guitarist is used to track mouth shapes and modify the music according to the camera mouth relation. System feedback can be seen on a small monitor while rehearsing, but the important feedback lies in the sounds played. Here application feedback and system feedback melts together as a piece of music played on the guitar modified in real-time by mouth interactions in a camera space.
Other methods for providing feedback that I have not been working with are through tactile means. It could for instance be trough the vibrator of a mobile phone that could indicate when the feature is at the boundary of the camera space or more sophisticated hapticons as suggested by Luk et al. (Luk et al., 2006).

These feedback types and others should be explored further, nevertheless, they are dependant on the actual application and likewise function as valuable design parameters when designing and using the interactive system, think of the potential in exploiting the local loudspeaker in a mobile phone opposed to broadcasting feedback trough a shared loudspeaker.

The User in Mixed Interaction Space

The last aspect in the framework is addressing the user. To relate this *user* to the one discussed as the fuzzy user in chapter 3 would be the user as a definition by design; the user as we imagine her interacting with the system.

The user is potentially inscribed in a number of the aspects of the framework e.g. as a feature in iFloor, as god of the interaction space in Mixis, or mediated through an object as the light pen in MLT or architectural building blocks in URP (Underkoffler et al., 1999). Further, spaces can support one or multiple users.

The following aspects relate to User:

User	**Aspects relating to the user/users of the mixed interaction space; concerned with where and how users interact.**
Where	*Relates to the location of the user in relation to the mixed interaction space – user as feature or user as god.*
How	*Relates to the way the user interacts with the system and other potential users – single user, multiple single users, user as collaborator, and users as contestant.*

The User as Feature or the User as God

Looking at users in relation to actual mixed interaction spaces they can roughly be divided into to categories, which I have termed *the user as feature* and *the user as god*. The user as feature is significant for static interaction spaces and relates to setups in which users are interacting within the interaction space, and hereby functioning as both feature and user. Depending on the scale of the interaction space this can range from multiple users as in iFloor, over body movements and gesture inputs as in eyeToy (EyeToy, 2006), to MLT and Block where features mediate and extend user actions, however, the user is still the active part within the interaction space.

The other category is significant for dynamic interaction spaces where the user is literally carrying and controlling the entire space. Regardless of the scale or how many relations the space can contain the user can alter the properties of the space and he hereby becomes a kind of god of the world inside the interaction space. The term god is not referring to a spatial religion but to the relation between user and space in which the user is outside the actual interaction space and in absolute control of its orientation, movement and so forth.

A setup that falls within both of the user categories is e.g. the Mixis face tracking applications where the user is both feature and god at the same time. But as this type of interaction space can only contain a single relation inputs can occur by moving the feature (the user) within the interaction space, or by moving the camera in relation to the feature (Hansen et al., 2006).

Regardless of category a common aspect is that users of these systems have to take part either within or around the interaction space. The user's situatedness is a condition for interacting with mixed interaction spaces, but whether they act as gods or features are primarily defined by the scale of the interaction space as well as whether the space is static or dynamic.

The User as Collaborator

From interacting with desktop computers we are used to being in control of the entire system ourselves as it is designed for a single user. However, in systems that can contain several simultaneous relations multiple users can interact together. In iFloor the user becomes part of a collaborative system. Only if he is unaccompanied he has the full control of the system. Otherwise he will have to negotiate with other users, which content to browse on the floor. Further, the collaboration might be with users that he probably does not know as the floor is situated in a public place and anyone can participate. By forcing collaboration, interaction relations move from just user-system relations to also include user-user interactions.

There could, however, be many other ways of designing for collaborative users in such systems, e.g. by mapping certain functionalities to different users. Such a setup would require either an identity property or dedicated areas in the interaction space, in which inputs would be mapped to a specific functionality in the application.

The Multiple Single Users

Another user aspect in a one-to-many system is the possibility of moving the single user metaphor to a shared computer. This is what happens on the storySurfer floor where each user is provided with a personal cursor. A user can browse the floor without putting any attention to what other users are browsing. Similar on the MLT table where multiple users can investigate book objects further. The objective is to open up for a platform for sharing knowledge – "look what I found here, I think that could be interesting to you" as well as exploit serendipity in the sense that users have a peripheral awareness of what other users look at and might get inspired in that way.

The User as Contestant

Multiple relations can also serve to turn users into contestants as in e.g. ARtennis (Henrysson et al., 2005) and in the floorQuest.

[mapping: 49]

The two games exploit different aspects of the framework; ARtennis uses two networked mobile interaction spaces, multiple predefined makers and two small feedback displays attached to each interaction space; floorQuest is established in a static horizontal interaction space, tracking multiple people without identity, and providing all visual feedback on the floor within the interaction space. In ARtennis each user is experiencing the game through their personal display of the mobile phone, as a looking glass into a mixed reality world. On the other hand floorQuest users experience the same application feedback on the shared display surface and can constantly follow the progress of other users in the "Q and A" game.

The above aspects regarding the user characterize two ways of thinking about the user when designing mixed interaction spaces; *where* he acts and *how* he acts.

7.3 ASSEMBLING THE FRAMEWORK

In the previous pages I have addressed and described issues and properties regarding the five aspects significant for using a mixed interaction space as an interface. These are informed by my cases, projects presented in the *project diagram*, and related work projects that are all utilizing the camera as input device.

I will in the following assemble and present the framework in a general form. What this framework does is to put focus on the spatial properties in the interaction technique. In line with my conceptualization of space, as discussed in chapter 5 (*moving into space*), I am arguing that to truly understand the potentiality of using cameras as input sensors the entire system must be considered as a space. In this case a space that exists as a local extension of physical space. Only by understanding this space one is able to design and configure it in ways that address intentions relating to the dimensions of place-making and thus potentially making the interaction meaningful for the actual users.

As described in *paper 4* the framework holds explanatory power for comparing and analyzing even very different interactive systems build on camera tracking. It is capable of comparing HCI and interaction design projects within such fields as augmented reality, tangible interfaces, and mobile computing. The framework of *paper 4* is, however, not directly addressing the discussion of intentions induced into the system and how these are confronted with actual use. Thus in the following chapter I will deploy the framework to my cases, discuss how the framework can bridge and express the designers' intentions, and finally distill a number of guidelines for designing interactive systems in mixed interaction spaces.

Below is the conceptual framework in its assembled and general form:

Camera	**Aspects that relate to the camera as a sensor.**
Field of View	*The defining factor for the interaction space. Has an influence on the distortion of the captured image.*
Resolution	*Defines the amount of pixels in the captured image. Relates to the scale of the space and the size of features. Confronts issues of privacy.*
Frame rate	*The switch of the mixed interaction space. Turns potentiality of interaction on and off.*
Space	**Aspects that relate to the space expanded by the camera in physical space.**
Type	*Relates to the space as a single entity or as a part of a network of spaces.*
State	*Defines whether the space is static or dynamic.*
Orientation	*Defines how the space is oriented in relation to physical space, e.g. horizontal, vertical or dynamic.*
Scale	*Relates to the scale of tracked features. The scale can be dynamic depending on the mobility on the interaction space.*
Relation	**Aspects that relate to the relation between the camera and the tracked feature within the interaction space.**
Feature	*Describes the type of feature, e.g. human, hand, object, tag.*
Number	*Defines whether the space can contain multiple relations between camera and features.*
Presence	*Defines if the system can detect if a feature is present or not.*
Position	*Defines which position parameters of a feature are determined within the interaction space, e.g. 2D or 3D.*
Orientation	*Defines if changes in the orientation between feature and camera within the interaction space can be identified, e.g. rotation or tilt.*
Identity	*Defines whether a feature has a unique identity.*
Other	*These could be size, shape, or gestures.*
Feedback	**Aspects that are concerned with feedback from the system to the user regarding the state of relations as well as feedback of the actual application.**
System	*Relates to feedback providing information on the state of a relation, e.g. through sound, visually, or through tactile means.*
Application	*Relates to the way the application communicates changes, e.g. through sound, visually, or through tactile means.*
Configuration	*Describes how system feedback and application feedback are located and organized in relation to user and interaction space, e.g. overlaid visually within the interaction space, on distributed displays, or through sound and vibration.*
User	**Aspects relating to the user/users of the mixed interaction space; concerned with where and how users interact.**
Where	*Relates to the location of the user in relation to the mixed interaction space – user as feature or user as god.*
How	*Relates to the way the user interacts with the system and other potential users – single user, multiple single users, user as collaborator, and users as contestant.*

Project table. Six example projects in the framework for camera-based mixed interaction spaces.

	iFloor	MLT	PhotoSwapper	floorQuest	Block	Book
Camera	**Aspects that relate to the camera as a sensor.**					
Field of View	*45*	*45*	*35*	*45*	*45*	*45*
Resolution	*320*240*	*640*480*	*160*120*	*320*240*	*320*240*	*320*240*
Frame rate	*15fps*	*25fps*	*10fps*	*15fps*	*20fps*	*20fps*
Space	**Aspects that relate to the space expanded by the camera in physical space.**					
Type	*Single space*	*Single space*	*Multiple space*	*Single space*	*Single Space*	*Single space*
State	*Static space*	*Static space*	*Dynamic space*	*Static space*	*Static space*	*Dynamic space*
Orientation	*Horizontal space, top*	*Horizontal space, bottom*	*Dynamic space*	*Horizontal space, top*	*Dynamic space*	*Dynamic space*
Scale	*Human scale*	*Object scale*	*Dynamic scale*	*Human scale*	*Object scale*	*Object scale*
Relation	**Aspects that relate to the relation between the camera and the tracked feature within the interaction space.**					
Feature	*Human*	*Color dot*	*Cirle, color, object, face*	*Human*	*2D marker*	*2D marker*
Number	*Multiple features*	*Multiple features*	*Single feature*	*Multiple features (up to four)*	*Multiple features*	*Single feature*
Presence	*Detects presence*	*Detects presence*	*Detects presence*	*Detects presence*	*Detects presence*	*Detects presence*
Position	*Approximated 2D position*	*2D position*	*Approximated 3D position*	*Approximated 2D position*	*3D*	*3D*
Orientation	*None*	*None*	*Height and width property*	*None*	*Yes*	*Yes*
Identity	*None*	*Color*	*Coupled to the space*	*Position within space*	*Unique patterns*	*Unique pattern*
Other	*Size*	*None*	*None*	*None*	*None*	*None*
Feedback	**Aspects that are concerned with feedback from the system to the user regarding the state of relations as well as feedback of the actual application.**					
System	*Visual, overlaid feedback*	*Visual, direct manipulation*	*Visual, overlaid feedback*	*Visual, overlaid feedback*	*Visual, overlaid feedback*	*Visual, overlaid feedback*
Application	*Visual feedback*	*Visual feedback*	*Visual feedback*	*Visual feedback*	*Visual feedback*	*Visual feedback*
Configuration	*System feedback is overlaid application feedback and provided within the interaction space*	*Application feedback is provided within the interaction space*	*System feedback is overlaid application feedback and provided on remote display*	*System feedback is overlaid application feedback and provided within the interaction space*	*System feedback is overlaid application feedback and provided on remote display*	*System feedback is overlaid application feedback and provided on remote display*
User	**Aspects relating to the user/users of the mixed interaction space; concerned with where and how users interact.**					
Where	*User as feature*	*User as feature mediated by object*	*User as god*	*User as feature*	*User as feature mediated by object*	*User as god*
How	*User as collaborator*	*Multiple single users*	*Multiple single users*	*User as contestant*	*Single User*	*Single User*

8 PASSING INTENTIONS THROUGH THE DESIGN OF SPACE

In this chapter I will deploy the above assembled conceptual framework. It is important to understand that this is not a design manual for designing camera-based mixed interaction spaces. Like understanding the basic properties of wood does not tell you exactly how to do a certain task but rather provides you with an understanding of the potentiality of wood as a material, this framework points to the aspects that all together make up mixed interaction spaces.

8.1 DEPLOYING THE FRAMEWORK

I will confront the framework for mixed interaction spaces with my conception of space and place as described and discussed in chapter 5. The framework is putting attention to the aspects of mixed interaction spaces as an interface, and to how these can be configured to hold and pass the designer's intentions regarding the dimensions that make up meaningful places to users in their interaction with space. Figure 43 shows how the designer can have ideas, wishes, and intentions regarding the physical, personal, social, and cultural dimensions of place-making. These are interpreted and induced into the system by the designing of a mathematical Euclidian space; this conversion into measurable space is necessary to bridge the physical and digital domains. The interactive system is received, interpreted, and experienced by the user biased by his values towards the four dimensions of place. In the following, I will discuss how aspects of the framework can serve as carriers of specific issues related to the dimensions of place-making. Obviously both the dimensions of place and the aspects of the framework are hard to look upon in an isolated view; they might merge or be dependant on other aspects or not even be addressed in the design.

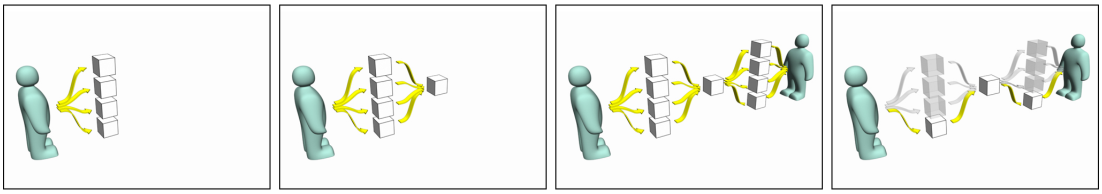

Figure 43: Inducing the dimensions of place (physical, personal, social, and cultural) into the design of space as physical/digital construct being interpreted and experienced in the actual use situation.

I will start the discussion be looking at iFloor as an example and discuss the framework in relation to actual use. After this specific look at one case I will look at the other projects I have placed into the framework *project table* above. By placing iFloor, MLT, floorQuest, PhotoSwapper, Book, and Block into the same table the scale or span of the different aspects of the framework are presented. This lead to some guidelines for understanding and designing mixed interaction spaces in different contexts and application domains.

iFloor as Example

The iFloor project, described in chapter 6 and in *paper 1,* had the overall intention of stimulating social interaction in the public library. In the following I will describe the iFloor setup using the terms from the framework; hereafter proceeding to discuss the induced intentions of the designer addressing the dimensions of place and how they corresponded with our observations of actual use.

iFloor Described through the Framework

iFloor consists of a *single static horizontal* camera space that has a *human scale* capable of tracking *multiple features*. The tracked features are the users themselves resulting in a *user as feature* setup. The system supports the *user as collaborator* in providing a single shared cursor that responds to the *approximated 2D position* of all participating users. *Application feedback* is provided as a graphical projection within the interaction space so that users can stand in the rim of the projection without obscuring the content and still being tracked by the camera. Thus the *field of view* of the camera is slightly larger than the projection angle of the ceiling mounted projector. The *system feedback* is visualized as a graphical overlay in the *application feedback*; it consists of a string connecting the position of each user to the shared cursor on the floor. Along with the *2D position* property each *relation* has a *size property* that influence the force the user is affecting the cursor with, changes in this property is, however, not visualized in the *system feedback*. As the *relations* do not have a specific *identity* any user within the interaction space and over a certain size capable of being recognized by the *320 by 240 resolution* camera are automatically establishing an interaction relation.

On Physical Aspects

Our intentions towards the *physical dimension* of place were that the interaction artifact should be physically visible and inviting without being obtrusive. Therefore as the mixed interaction space in itself has an immaterial character the system is embodied by the white PVC-boards and the large projection on the floor. As discussed in *paper 1* and *paper 2* the floor as an architectural element is the most shared surface and thus interesting to exploit for a social purpose that still respects movement across the surface. By placing the prototype in a public space we intended to express not necessarily a collaborative social system but a public system. This complies with another of our intentions not to attribute to interaction but rather to invite interested visitors to participate.

So how were these intentions met? We observed that mixing the physical floor surface and a computer projection attracted a good deal of people as they entered the library. There might be multiple reasons for this but it is reasonable to think:

- That the mere size of the projection was more interesting than a usual information booth PC screen.
- That the attention towards the floor was amplified by the bright projection on the white PVC-boards in contrast to the surrounding gray floor material.
- That other visitors' bodily interactions around and visual focus on the floor increased the attraction towards the bright surface.

This indicates that the *scale of the interaction space* influence the *physical dimension* in the sense that users are attracted and putting attention to it. Not all visitors were interested in the prototype why the attention fell into four groups:

- Visitors who did not notice the prototype at all. These people might be in a hurry; think public interventions are horrible, intrusive and intimidating; or just not interested in engaging in any social activity, which the system tried to express full respect for.
- Visitors in the library who did not notice the system as anything else than a projection and walked straight across the PVC-boards. This indicates that users considered the system a public

artifact that was not restricted and thus could be entered and crossed; and also that the system was not attributing to interaction.

- Visitors who noticed the *system feedback* when crossing the floor and engaged in interaction on their own. This indicates that the feedback was intriguing and at best surprising why a further investigation was necessary.
- Visitors who engaged in interaction after seeing others around the floor moving, reading and SMS'ing. This indicates that other users of the system are taking part in creating the physicality of the setup.
- Visitors standing around the floor watching others interact. This indicates an interest towards the system but might also imply that the system might be socially intrusive to some.

The many different users and non-users and their apparent perceptions of the system indicate that the system in its novel way of utilizing the floor as a display and further in containing responsive properties related to the near visitors influenced a great deal of users. Nevertheless, it did not reach many of the users which is line with the gap between space and place.

On Personal Aspects

Our intentions towards personal aspects of place were primarily the importance of individuals being able to communicate with and through the system. Apart from browsing the content on the floor together with other users we wanted to support individual activities in composing content input to the system. By considering the mobile device as a potential keyboard connected to the system users could post questions that gave meaning to them and that would also enable them to help others by answering questions displayed on the floor. In this way visitors could leave questions or answers behind and hereby taken part in constructing and configuring the space. As the floor was located in the library our initial intention was to use the iFloor for communicating about the materials and activities in the library. However, by looking at the composed questions and answers it became clear that users appropriated the systems in unintended ways:

- Visitors asking questions regarding unlocking their mobile phones and where to buy cheap print cartridges, which indicates a personal appropriation of the system towards content that might be more meaningful to that visitor than asking questions on literature topics.
- Visitors who posted a question received answers via SMS; we however, observed users who were interested in answers to a specific question and thus returned to the library just to check if someone had answered it. This indicates a relation to place mediated by the content of the floor.
- Visitors, especially kids (approximately 12 – 15 years), who used the floor not to ask questions but to expose themselves on a public display. Instead of writing questions they would promote themselves or comment on their friends. This again shows unintended but nevertheless for those kids meaningful ways of interacting and exploiting the system.

These observations indicate that designing a certain openness into the system might result in a personal engagement from some of the users (openness is discussed further in *paper 5*). And also that each visitor feels he is been taken serious in the sense that the system is not moralizing towards a specific use.

On Social Aspects

The aspects of sociality that we wanted to investigate by placing the prototype into the context of the library was induced and addressed through multiple aspects of the framework. By establishing a *scale* of the interaction space that could establish *multiple relations* between camera and *users as features* we laid out the basis for a system supporting several simultaneous users. Further, by designing the interaction to support *users as collaborators* we basically forced the users into collaborating on moving the cursor to preferred locations in the interface.

- We interviewed users who expressed that it made sense to interact around a collaborative interface in a public space.

- We interviewed users who found it barrier-breaking because they were not just supposed to interact one-on-one with a system in public but also together with strangers.
- We observed that if multiple users interacted on the floor it was mostly groups who knew each other on beforehand.

These aspects might indicate a respect for users already using the system. That would be similar to not obstructing someone riding the roundabout on the playground even though there is space for one more. On the other hand it might also imply that the system might be perceived socially intrusive by some.

A further aspect that we induced into the system to express our social intentions was the low threshold level for participation that proved to engage many of the different user groups of the library – kids, youngsters, adults, elderly, even a guy in a wheelchair. This we achieved by rejecting the *identity* of users that we in the first design phase found interesting as it could be coupled to their library tickets. Together with an interaction that basically required physical *presence* and exploited users' mobility, and spatial awareness and understanding all users were equal in the interaction – this limited functionality of the system made it hard to become an iFloor-shark and hereby take control over the floor due to extreme expertise.

On Interaction Aspects

Even though some visitors walked across the floor surface we intentionally wanted users to stay out of the actual projection to avoid obscuring the content of the projection. This was induced by rejecting blobs detected within the *application feedback* in the calculation of resultant vector moving the shared cursor. When entering the projection the user would loose his *system feedback* consisting of a graphical string connecting the user and the shared cursor. In this way we were seeking to notify the individual user that he was not interacting with the system (at least not in our intended way). As I have explained above some users did not notice this feedback at all.

Looking at the users who explicitly used the system we observed that many users' initial interaction approach was entering the floor and stepping on the graphical questions and answers. This proved a discrepancy between our induced *culture of use* and the one of most users highly influenced by WIMP interfaces. This might have been addressed by a more radical *system feedback* e.g. overlaying the floor with a warning text when entering the projection or by using sound. However, after a very short while engaged users of all ages got an idea of the interaction technique and positioned themselves around the projection as shown in the four examples in figure 44. This issue raises questions on whether to meet the users in providing their normal use culture or try to influence their view on technology when met in new contexts. To relate this to the dimensions of place we might have guessed that most users would stick to the desktop interaction paradigm and try to support this in the prototype. But through our intervening interactive artifact we were interested in investigating novel techniques for interaction and therefore not meeting the general expectations of users. This does not mean that the system fails in regards to the dimensions of place but rather that we in this case tried to challenge users, which also proved to be engaging to many users; meeting a whole new perspective on technology and social interaction in public space.

Figure 44: The physical layout along with the system feedback organized users in the rim of the projection.

On the Disappearing Space

An additional aspect worth noting is how the actual mixed interaction space was perceived by the users. Due to the configuration of the *horizontal oriented* space established by the ceiling mounted camera and the merged *system feedback* and *application feedback* putting focus towards the floor and away from the camera somewhat made the awareness of the space disappear. Clearly there are two kinds of users; the ones who wants to understand the system and *figure it out*, and the ones who engage in the system without questioning how the technology behind it functions. Looking at the latter the way physical and digital space is bridged seemed fairly natural to most users. They did not question the use of natural mapping effecting that when a user moves to the left his *system feedback* string moves accordingly the same way. Our intention was exactly to exploit the camera space to make a 2D tracking surface (approximated), as I have discussed regarding the *analyzing data section* above, and only use the camera space as a means for bridging the physical and digital domains. Due to this way of configuring the orientation and scale of space along with the provided feedback we observed users interacting on a 2D surface and not in a 3D space. I return to the aspect of orientation and feedback in the next section.

It is clear that not all of our intentions were met in the way we expected. There are many reasons for that. Returning to the design circle as well as the distinction between space and place confronts us as designers with gaps whose size only can be visualized and understood in the actual use situation. Further, believing that it is possible to induce aspects of place-making that will frame and relate to all users in a public library might be naïve, however, designing for the entire public requires such a focus. But nevertheless, we discovered changes in some visitors' social behavior and also new ways of appropriating the prototype. These were mainly kids and youngsters, which might indicate that they were actually the ones that our expressed intentions targeted.

In the following I will, based on the rest of the projects placed in the *project table* above, distill a number of guideline useful to consider when analyzing and designing mixed interaction spaces with the four dimensions of place-making in mind.

Guidelines Extracted from the Framework

In the table below iFloor, MLT, PhotoSwapper, floorQuest, Book, and Block are presented. By looking across these projects I will discuss aspects that differ and try to present guidelines regarding this in the framework.

In the examples the *resolution* differs between 160*120 pixels and 640*480 pixels. In iFloor interacting with the system is not focused on precision for the individual user. As the user is the feature and the entire body interacts, shaky as it might be, users are not focused on pixel precision. Further, as multiple relations influence the movements of the shared cursor there is some uncertainty within the system. Opposed to this the MLT is based on *multiple single users* interacting through direct manipulation on the tracked surface. In the setup *system* and *application feedback* are provided as a projection aligned with the tracked surface. In this case the resolution of the camera, meaning the ability to detect where the feature is placed within the surface and the resolution of the *application feedback* plays an important role. In the actual case the projection runs 1400*1050 pixels why there is not a one-to-one mapping between the interaction space and the application feedback. The consequence is that a pen can not hit a specific pixel in the interface but rather hit within an area of 5*5 pixels. To get a higher precision in the system one way is to increase the resolution of the camera and hereby increase the processor load; another way is to design applications that take the inaccuracy into account. This could be by designing physically larger elements in the interface or by exploiting other ways of mapping than direct manipulation.

Another aspect of resolution is coupled with the size of the feature. Regardless of identity a feature will only be visible to the camera if the resolution and distance between camera and feature are within a certain range. In iFloor dirt on the PVC boards that appear very visible to the human eye are not detected as they are not visible to the camera due to the rather limited resolution.

- *Higher resolution can increase the precision of tracking in the interaction space; however, this should be considered against how fine or coarse interaction is intended.*
- *Lower resolution can serve to confine the interaction space to a certain physical scale; the size of features has to be considered in relation to this.*

The aspect of *identity* is also treated differently in the six examples. In iFloor there is no *identity* of features corresponding with the *user as collaborator*. Any user can exploit the come-and-go possibilities that this low threshold-of-participation interaction setup affords. In floorQuest the interaction is slightly more formalized as the activity is a game and the *users are contestants*. However, the identity is like in iFloor and not tied to a specific user, but in this case to the user positioned within a certain area of the game board. This way of identifying the user makes good sense in public settings where users play for a while and leave in the middle of a game; however, the identity does not support if users return to the game and want to resume from where they left. MLT is partly dealing with this as the identity of each pen through the different colors provides possibilities to log the actions of a specific pen and thus provide possibilities to resume sessions. The light color pen is, however, not personal and thus not tied to a specific user. The PhotoSwapper exploits an identity that is connected to the interaction space and not to the feature; nevertheless, this creates a tight coupling between the user and the relation that he can influence within the interaction space.

- *Relations with no identity are suitable for less formal interactions with low threshold-of-participation.*
- *Some level of identity is needed to handle aspects of interruptions and resumption of sessions.*
- *A unique identity is necessary to make tight connections between users and content within the information system.*

The *type of space*, static or dynamic, has consequences for the number of potential relations supported by the interaction space. As seen with iFloor, MLT, and floorQuest multiple features are tracked in a static space. On the other hand PhotoSwapper supports multiple spaces, however, only a single feature within each space. A dynamic space will change the position property of all relations within the space when moving. Parc and ARtennis, as I have discussed earlier, are such examples, however, the features are used to increase the precision of tracking to get one set of coordinates, which basically makes it a single relation space, as the internal configuration of features does not change.

- *Use static interaction spaces when tracking multiple users as features.*
- *Consider the type of mapping between features and application when using multiple moveable features in dynamic interaction spaces.*

The *user* aspect in the examples present different degrees of engagement in the interaction, both through the level of *identity* and through the physical aspects concerned with the actual interaction. There seems to be a different focus on the camera space depending on systems based on *user as god* and *user as feature*. In iFloor, floorQuest, and MLT users have apparently no direct focus on being in a camera space, they are focused on the *system* and *application feedback* and taking actions according to these. In the PhotoSwapper application the interaction is physically much more constrained even though the interaction space supports tracking in 3D and system and application feedback are merged and provided on a remote display. Despite the merged feedback and thus putting most attention on the display the *user as god* is not "within" the interaction and application.

- *Interacting inside the camera space either as feature or mediated through an object seems to put less attention to the interaction space.*

These guidelines extracted from the framework can serve to guide future designs of interactive systems exploiting mixed interaction spaces. Apart from these the framework also holds a potential for identifying new areas for mixed interaction spaces. In the following section I will look a bit forward by the help of the framework.

8.2 USING THE FRAMEWORK - LOOKING FORWARD

In the previous section, I have shown how the framework can be used and induced with intentions of the designer, and discussed how these intensions have and have not been met in actual use situations, relating to the distinction between space and place. Further, I have presented a number of guidelines worth taking into account when designing camera-based interaction systems. As I have claimed earlier, apart from analyzing, comparing, and designing mixed interaction space systems, the presented framework is also applicable for identifying areas within mixed interaction spaces not yet explored, and that might hold interesting research aspects. By looking at the aspects of the framework and relating them to the cases and related work projects exploiting camera spaces for interaction, I will give a few examples that might point towards future work.

Differentiating Users as Collaborators

Two of the projects presented in the framework table can be seen as dealing with the user as collaborator – Block and iFloor.

[mapping: 5, 10]

Block is not designed as a multi-user system, but the mixed interaction space supports multiple relations with identity. Each of these features has different functionality within the system – some work as constructors others are destructors and so on. In iFloor, users are the features and have no identity, further all relations map to the same functionality in the system.

I see a challenge in developing systems that in new ways exploit the potential of differentiating the different relations. This does not necessarily require that each relation has a unique identity, but rather that the space and feedback is constructed in a way that it becomes clear to the individual user, which functionality his relation is mapped to, and thus expressing how he is taking part in the collaborating interaction. As I have explained, the floorQuest identity is based on position within the interaction space, and likewise could such a collaborative system exploit this setup.

The applications I envision are not for efficient work but more likely for the domain of physical gaming and learning; occupying specific areas of space at the same time to accomplish a task, or proceed to the next level in a game. The space could also be used for learning about trigonometry in a physical way. This could be accomplished by using tracked objects such as Artoolkit boxes or colored pillows, to create three dimensional configurations. When the configuration is matching the assignment, a new geometry has to be constructed or the different relations can serve to manipulate the common constructed object – scaling, rotating, translating, sectioning, and so on.

Such an approach could address social aspects regarding multi-user interaction, both when implemented in public and private spaces. Aspects of scale could also be investigated; a small scale space utilizing mediating objects on sticks and using the entire body in a human scale space.

Networked Static Spaces in Mobile Settings

In ARtennis, two mobile camera spaces are establishing relations to the same features (many-to-many). Both system and application feedback is provided for each player in the local display of the mobile phone. A setup derived from this can use the mobile phones as static camera spaces overlooking the same physical space from different perspectives. Instead of designing for the user as god as in the ARtennis, users could interact within the same static space and exploit the two overlapping mixed interaction spaces for tracking features. This would potentially expand an interaction space that could track game pieces or other features in new ways and exploit the mobile phones for providing feedback through sound or vibration.

Such an approach could address aspects of coupling personal devices to form social activities in mobile settings.

Physically Separated Networked Static Spaces

Much work has been done within CSCW regarding tele-presence in collaborative settings (Benford et al., 1998). Deriving such work towards interaction design and mixed interaction spaces can lay the basis for an interesting investigation in connecting multiple large scale static camera spaces.
Aspects of merging two physically separated Euclidian spaces and exploiting this to design applications for both users as collaborators and users as contestants seems interesting in regards to feedback, identity stamped by each camera space, as in PhotoSwapper, and distributed functionality.

Clearly numerous other applications exploiting mixed interaction spaces exist, however, by presenting the above examples, I have shown the ability of the framework to help identify new areas for mixed interaction spaces.

9 CONCLUDING REMARKS

In this Ph.D.-dissertation I have set out to approach the design of interactive systems in ubiquitous computing environments from a spatial perspective. The contributions of this dissertation are:

- A number of novel concepts and prototypes exploiting space as interface in general.
- A number of novel concepts and prototypes particularly exploiting space as interface in camera-based mixed interaction spaces.
- A conceptualization of space as interface, grounded in a concept of place and space set forth by Tuan (Tuan 1977), and informed by an experimental practice-based approach.
- A conceptual framework for analyzing and designing interactive systems based on mixed interaction spaces.
- A number of design guidelines for mixed interaction spaces based on the framework.

The contributions are presented as a number of peer reviewed papers presented in *Part III: Papers*; an overview of all methods, concepts, prototypes, and papers presented in a dynamic diagram in *Part II: Project Diagram*; and the conceptualization of *space as interface* and the conceptual framework for mixed interaction spaces are discussed and presented in the *Part I: Thesis*.

As described in chapter 4 (*interfaces beyond the pc*), much research and development within ubiquitous and pervasive computing is only implicitly dealing with the concept of space through a technical or a socio-cultural perspective. Building on a phenomenological perspective on place and space derived from (Tuan, 1977) (Harrison et. al., 1996) (Ciolfi, 2004), place is space appropriated and created by humans in investing it with meaning and emotions. Places can be seen as made up by four dimensions addressing physical, personal, social, and cultural aspects related to that specific place.

As I discuss in chapter 5 (*moving into space*), meaningful activities related to turning spaces into places are dependant on and connected to the values and experience of the actual user, designing interactive systems can only address physical, personal, social, and cultural aspects through the design of space. Further, as the design circle (Hallnäs et al. 2006) includes several hermeneutical gaps, we can only design for the potentiality of expressing our intentions towards the dimensions of place. This means that to be able to design for creating meaningful places, the formable space, which I see as a construct of physical space and digital space, has to serve as a carrier of the intentions addressing the non-formable aspects of place-making.

Bridging the physical and digital domain requires that space is considered as a formable Euclidean space serving as an interface between those two. The challenge thus becomes understanding this space as the interface, and further how the intentions can be induced into the system in ways that point towards the dimensions of place when interpreted in actual use situations.

By designing and exploring a range of interactive systems through my Ph.D. work, I have identified different significant aspects in the relation between space and interface. Through the collaboration with Eva Eriksson and Thomas Riisgaard Hansen, I have distilled a fragment of work concerned with cameras as the interface for bridging physical and digital realms. By looking across our own and related projects spanning over fields such as tangible user interfaces, augmented reality, and mobile computing we have developed a conceptual framework for this specific kind of interaction space. In chapter 7 (*interacting in camera spaces*), I develop this framework further by including aspects of the camera as a sensor and of the users within these systems.

To show the applicability of the framework, I have deployed it on the iFloor case and discussed how a deeper understanding of the specific interaction space, through the framework, can be used to induce the intentions addressing different dimensions included in the user's creation of place.

In this discussion I have shown that the framework is capable of analyzing, comparing, and designing interactive systems exploiting mixed interaction spaces. Further, I have shown how the framework can serve to identify new areas for research and exploration within camera-based interactive systems.

Finally I will return to my initial research question:

> *How can space engage in the shift of interaction paradigm to serve as more than the physical container inscribing the interactions between humans and technologies?*

and the sub-question:

> *Which technologies can bridge the gap between physical and digital domains?*

and add a few concluding remarks related to these questions. I have through my work developed a conception of space that is not just a physical container but an active and necessary element in designing interactive systems. Firstly, in considering and understanding interfaces for bridging physical and digital domains as formable Euclidian spaces. And secondly, in claming that only by inducing intentions into the design of formable space can we potentially address and bridge the gap between space and place. Hereby, space is introduced as an unavoidable aspect that needs to be designed and not just as a natural consequence of being situated and embodied in the physical world. In my experiments, I have briefly touched upon numerous interface technologies and shown how they can bridge the physical and digital domains, and further looked deeply into the (design?) space of camera interfaces.

Through my work within this Ph.D. project, I find it reasonable conclude that considering the space as interface is highly relevant for interaction design in ubiquitous environments. I am not hereby rejecting other technical or socio-cultural approaches, as they are of course also dealing with important aspects of everyday life, however, many of these aspects can only be addressed through the design of space…

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SPACE AS INTERFACE

- BRIDGING THE GAP WITH CAMERAS

PART II: PROJECT DIAGRAM

11 PROJECT DIAGRAM

The idea with this *project diagram* is to turn fragments into meaning. There are hundreds of ways of approaching the presented material, I am aware of that, but I tend to see this as a strength. When working, I constantly relate to, get inspired by, or build on already existing projects, ideas, and theories. By designing this *project diagram* I want to visualize this web of connections and relations that has emerged during the last couple of years. Both for my self and for You I find it important to see how different pieces of work are influencing each other over time and across types such as prototypes, concepts, methods, and papers.

Describing all different paths through my work would require an entire Ph.D.-project (or two) in itself and that is not the subject of this dissertation. However, by making this diagram I have been able to identify important relations between pieces of work that I had not thought of as related. Steve Jobs has in relation to his own career explained the following regarding making sense of his choices:

> *"Again, you can't connect the dots looking forward; you can only connect them looking backwards. So you have to trust that the dots will somehow connect in your future. You have to trust in something — your gut, destiny, life, karma, whatever. This approach has never let me down, and it has made all the difference in my life". (Steve Jobs)*

This is not to say that I have been working blindly but rather that in looking back the pieces start making sense whereas they might be hard to grasp while being in the middle of it all.

Further, the project diagram basically describes the way I work – in different teams on simultaneous projects and reflects my opinion that to get into a complex field as interaction design it is hard to go through a narrow approach. I have chosen to approach the field through multiple impacts that in the beginning might only slightly relate. Over time my understanding of different concepts within interaction design and HCI has matured and I have been able to couple some of the impacts whether these are methods, concepts, prototypes or papers to get a broader understanding of the field and finally of the concept of space.
The diagram is also an alternative way of opening up and visualizing my design process. Not in detail but on a broad level showing that I am aware of the different "links" and inspirations between the works. It is not an attempt to claim that the work is not inspired by and related to other research projects. It would certainly have been valuable if even deeper layers of inspiration could be included, however, my main focus was to gain overview and understanding of my own work at first.

I find it necessary to mention that this is a piece of software that has not been tested thoroughly by others than myself, thus there might be small bugs and issues not addressed in the current version. I have had discussions with my advisors on the position of this diagram in relation to the classic written parts and its influence in the entire dissertation. Currently it is somewhat in the back and working as an "if you want to know more"-part. Nevertheless, through this diagram I hope to be addressing the form of Ph.D.-dissertations especially in new interdisciplinary research fields working with time-based and human centered interventions. I personally praise the openness for reflection and the visio-spatial presentation that in many respects is inspired by Gardner theories on multiple intelligences. Hopefully this will help to reach others than egg-heads!!

Finally before jumping to the manual I will encourage you to play with the diagram both regarding arranging projects in type and time but also by stepping through the substantial amount of content, and remember that it inscribes quite complex work over several years and is thus not quick and easy to grasp – so give a chance!

In the following sections I will describe how the project diagram is used in a step by step manual. I will also show how the fragment of camera spaces is distilled which should give an understanding for how other relations and perspectives could be extracted and elaborated further on.

11.1 MANUAL

In the following section I will describe how to use the *project diagram* application. It is basically a manual that will be helpful both to configure the content but also to understand the different terms used.

First of all it is worth noting that the application is best run in a resolution of 1600 by 1200 pixels. I know that it is not every computer display that that is capable of running such a resolution but to present this kind of graphical content I really need the pixels. It is of course possible to run the application in a lower resolution but texts might render so small that they are not readable. I have implemented a number of scaling features to deal with these problems but I can not guarantee full readability in the entire application if not running 1600 by 1200 pixels.

The Application

The *project diagram* is divided into a content layer and a representational layer. The content is organized in an xml file representing each project entry and its attributes. The application parsing and representing the xml content is written in flash and can run in a stand alone player or any browser if the flash plug-in is installed.

The Tab Menu

In the bottom of the application the menu is located. It is designed as a tab menu that animates upwards as the cursor rolls over the different tabs. Each tab is labeled and present how the tab is configured e.g. the ID tab displays "ID# 6: Mixis", which indicates the name of the tab "ID" and the mapping id number and name of the current project in focus "#6: Mixis".

The menus are hidden on mouse rollout to maximize screen estate for the displayed project entries.

Figure 45: The interface tabs

The Mapping ID Tab

The mapping ID tab is used to establish links between the *Part I: Thesis* and the *project diagram*. A mapping ID is to be considered as a type of reference in line with footnotes and references to literature. When coming across a mapping ID in the *project diagram* this ID can be typed into the input text field of the mapping ID tab. Mapping ID's appear in the right side of the page as shown here and can contain multiple ID's to projects related to the content in focus in the text.

[mapping: 6]

When pressing the "GO!" button the project related to the specific mapping ID is put in focus and displayed in the center of the screen with related projects around it.

Figure 46: The mapping ID input tab

The Appearance Tab

The appearance tab can be used to configure multiple aspects of how the projects appear. The first slider is a time crop tool useable for narrowing in the timeline to focus on certain periods. By pressing the mouse on one of the slider buttons and dragging projects will instantly disappear from the display. Depending whether any lock types (see the lock tab section below) are activated the projects will arrange on a timeline, in a grid, or in a circle. It is not possible to slide either of the two slider buttons across the project in focus.

The scale slider can be used to globally scale the displayed projects. By pressing the slider button and dragging along the slider all projects will instantly update their size. Depending whether any lock types (see the lock tab section below) are activated the projects will rearrange in a grid, in a circle, or just scale in their current position.

The alpha slider has influence on all projects that are not in focus, meaning either the actual project in focus or projects linking to that project in the specific relation perspective (see the relation tab section below). Thus sliding the alpha button can be used to hide or fade down projects that are not in focus. As there are quite a lot of projects in the *project diagram* it can remove a too cluttered interface by keeping the alpha values low. On the other hand sliding to 100% can give a total overview of projects. If the alpha is set to 0% and the user has activates the sortCenter lock the projects in focus will exploit the entire display area.

The last two buttons in the appearance tab are also related to projects not in focus. When "grayscale" is activated projects not in focus are rendered as grayscale and when pressing the "color" button the projects are rendered in color. This can again help to differentiate projects currently in and out of focus.

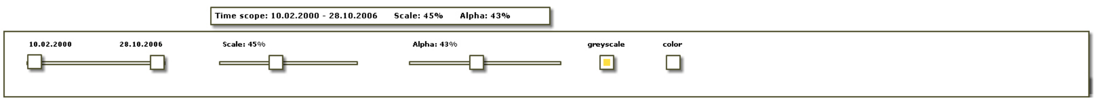

Figure 47: The appearance tab

The Relation Tab

The relation tab handles how the different projects relate to each other. The objective with this tab is to provide multiple entries into understanding how the different projects relate depending on type and topic in focus.

The default relation is "links". This is my relational and inspirational way of sorting the different projects across time, type, and perspective. This means that the connections between projects can represent similarities even though the projects work with different technologies, application areas, or theory. If we look at figure 55 below, among others Mixis links to eMote and colorSpace. Mixis is not designed as a direct inspiration of these projects but all three projects resemble some of the same aspects of functioning within a three dimensional space and hence these connections exist. In the same figure 55 links between Mixis categorized as a prototype links to several papers because Mixis is discussed in the papers. The "links" relation is the only perspective where all projects are connected in some way.

The following eight relation buttons relate to certain aspects that the projects can be characterized as containing or addressing. In figure 48 below "links" is activated indicated both by the tab label and in the full yellow button beneath the "links" label. However, the "movement based" and "camera space" buttons appear as half yellow. This means that the project in focus (Mixis) addresses these aspects but they are not currently influencing the connections to other projects. By pressing and hereby activating the "movement based" relation the project in focus connects to a new set of projects as seen in figure 55. By choosing one of the other projects in focus will result in that all connection strings are drawn from the new project in focus to all the other projects categorized by "movement based".

With Mixis in focus choosing a button that is not either full yellow or half yellow will result in the project not relating to anything. In other words this means looking through a specific project with a perspective that is not related to the project and thus no other projects will relate and connect.

The last section in the relation tab is concerned with the type of project. All entries are categorized by a certain type; method, prototype, concept, and paper. This is of course a rough categorization but it is still useful to e.g. look at all papers without looking at other projects by sliding the alpha value to 0%; or to see how methods has influenced a concept which has led to a paper and so on. Several of the presented projects could be characterized as multiple types; I have, however, only chosen one type per entry to avoid too much chaos. An example of this is the HarborGame that is indexed as a prototype but in using the prototype presents a new method for involving users in a planning process.

[mapping: 47]

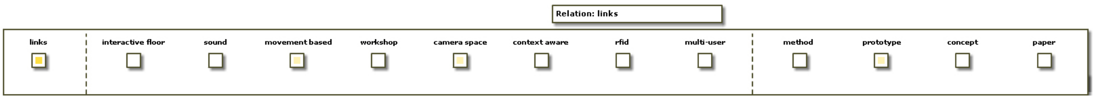

Figure 48: The relation tab

The Content Tab

The content tab can globally change the displayed content of the projects. When changing content by pressing one of the five buttons all projects will instantly present the chosen content type. Depending on whether any lock types (see the lock tab section below) are activated the projects will rearrange in a grid, in a circle, or change content in their current position.

The image button loads a bitmap image related to the project into the project container.

The video button loads a video clip into the project container. Not all projects are associated with a video clip why they will display the text "no video available". As pressing this button will load a severe amount of videos it is recommended to have some patience, especially if your system is slow or if you are running the application over the internet. Alternatively I will recommend toggling to video content on the local project as described later as this will only load the videos you are interested in watching.

The appearance of the video will also be affected by the grayscale/color buttons in the appearance tab meaning that you can run videos in black and white if you wish. By rolling the mouse over a project a video panel for operating the local video appears. The loaded videos will not start automatically but must be started individually. Depending on the system that the application is running on (and connection speed if running via internet) multiple videos can run simultaneously. I see this as an important feature because it adds the possibility of comparing different projects beside each other.

The description button displays a descriptive text about the project in the project container. This text might depending on the scale set in the appearance tab be hard to read. To solve this scale the project containers. If the description requires more space than the initial text area two scrolling arrows will appear to navigate in the text.

The info button displays background information about the entry. Here you can see the ID number that refers to the specific project and that can be used as input number in the mapping ID tab. If the project contains other types of textual material that is not suitable for being displayed in the description text, e.g. an entire paper, a link to a pdf-file is available. Furthermore, all keywords that characterize the project are displayed. These keywords are the same as the perspectives defined in the relation tab, e.g. "movement based". It is also possible to see which projects the entry links to if the relation is set to "links". Lastly I have mentioned people that have been more or less involved in the project. Of course it is not clear who has done what; the important thing here is to credit all involved.

The last content type is contract that displays all projects as small textual containers presenting name, timestamp, and type. This can be a less cluttered way of over viewing the material.

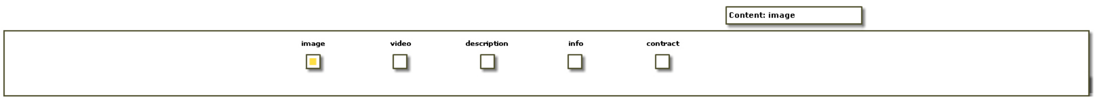

Figure 49: The content tab

The Sorting Tab

This tab relates to sorting and arranging the displayed projects.

By pressing the shuffle button all projects will animate to a new random position within the screen estate. The functionality of this shuffling might be more fun than actual usefulness, however, in situation where a selection of projects are all cluttered up shuffling might help.

Sort in grid displays all projects in a grid view starting in the top left corner with the project in focus and its connected entries followed by the rest of the projects. The grid view avoids projects overlapping, however, depending on the scale set in the appearance tab many projects might be displayed outside the screen estate. The grid view is, however, a good way to look at a specific set of relations e.g. a listing of all method projects can be done by selecting "method" in the relation tab and then sorting in grid.

Sort by type sorts all projects along four segments on the y-axis depending on the type of project – method, concept, prototype, and paper. The four areas will be visualized by a fading text indicating which types are placed where.

Sort by time sorts all projects within the time scope set in the appearance tab along the x-axis. This enables the user to see how projects have developed and how they have influenced other entries over time. Coupled with sort by type both type and time of entries can be sorted in the same view.

The sort in center button animates the project in focus to the center of the screen with connected projects arranged in a circle around it. Outside this circle projects that do not relate to the focus project in the specific relation perspective are arranged in yet another circle. This view puts focus to the connections of the current project in focus regardless of type and time.

If the sortCenter or sortGrid lock (see next section) is activated while one of the sort buttons are pressed this will deactivate the locking.

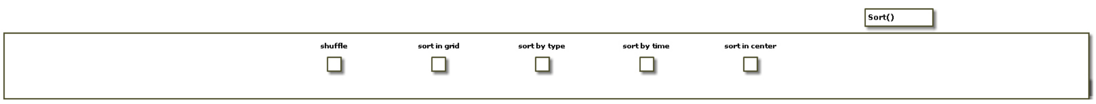

Figure 50: The sorting tab

The Lock Tab

The buttons in the lock tab offers three ways of locking the display of projects. This can be useful if you want to keep a certain order of projects without constantly having to use the buttons in the sorting tab. The buttons function as radio buttons meaning that activating one will automatically deactivate other active buttons. Pressing an active button will deactivate that current button. The default is that the lock type is "none".

If the "grid off" is activated the lock type will be set to sortGrid. This will invoke the sortGrid method described under the sorting tab section. Every time a new project is selected the interface will update by calling the sortGrid method. If the lock type is sortGrid changing the time scope, scale, or content type will also update the interface accordingly.

If the "center off" is activated the lock type will be set to sortCenter. This will invoke the sortCenter method described under the sorting tab section. Every time a new project is selected the interface will update by calling the sortCenter method. If the lock type is sortCenter changing the time scope, scale, or content type will also update the interface accordingly.

If the "unlocked" is activated the current project will be locked. This means that you can drag any project and toggle content both globally and locally but the project in focus will remain.

Figure 51: The lock tab

The Credit Tab

The credit tab presents all people who have participated in one or more of the displayed projects. People are ordered alphabetically after first name. Apart from the importance of giving credit to the involved people the list shows that the projects have been carried out within a quite extensive network of people, and I tank them all!!

If you are running the application in a stand alone player and not through a browser you can quit the *project diagram* by pressing the "quit" in the lower right corner.

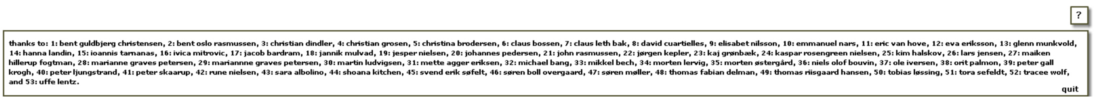

Figure 52: The credits menu

The Container

Each project entry whether a method, concept, prototype, or paper is represented in the same graphical container. The container can present images, video, and text; and has basically two states, an expanded and a contracted. The five content types are described above under the content tab section, and are in summary image, video, description, info, and contract. Figure 53 shows iFloor used as an example presenting the five content types of the container.

Figure 53: The five different content types of a container; image, video, description, info, and contract

One way of interacting with the displayed projects is as described above through the tab menu interface. Changes in this part of the application will invoke global changes to displayed content which might not always be preferable. Thus there are different ways of interacting with the local containers.

Each container is draggable meaning that you can place it anywhere in the interface by pressing the mouse in a certain area of the container and drag it around. This area is shown in figure 54 a) and d) as the drag/selection rim. When pressing the mouse on this area the container can be freely moved and this will further select the container making it the project in focus. This will invoke changes in the displayed connections between projects according to the new project in focus, the time scope, and relation perspective (for more info on this see the menu sections above). Note that while the lock type is "locked" you can drag all containers around but you can not change the project in focus. When a project is in focus the circle in the upper center will be full colored opposed to no color.

The arrow button next to the circle in the upper center of the container can be used to toggle between content types in the local container. Pressing the arrow will take you through the five content types image, video, description, info, contract, and then loop back to image. By using this toggling button you can customize the interface and have some projects shown as an image while others are presented as text or running video. To return to a single content type use the content tab.

When video is displayed it will not start automatically. By rolling the mouse over the container a small video control panel will appear as in figure 54 b). Use the buttons to control play, pause, and volume of the video. When rolling out of the container with the mouse the panel will fade out.

The last active area of the container is shown in figure 54 d). If the text amount exceeds the text area two scroll buttons will appear to navigate the text.

Figure 54: Active areas on the container; drag/selection rim, video buttons, toggle local content, scroll text, and drag/selection rim.

The Connections

When selecting a project by pressing the circle or rim of a project container the graphical string connections change according to the new project in focus. The application is always visualizing these connections in relation to the single project in focus, however, these vary depending on the relation perspective as described above in the relation tab section. In figure 55 the Mixis project is set in focus. The four images show how the project relate and connect differently depending on the relation perspective. The time scope is set to maximum meaning that all projects are present, and the projects are locked and sorted in the center. The first image shows "links" relations and the seven projects that relate to Mixis are rendered in the inner circle, and all other projects are arranged in the outer circle rendered with a lower alpha value. The second image shows how Mixis relate to projects through the "movement based" perspective. These include projects like iFloor, eMote, and storySurfer that in the first place would seem like very different projects, however, addressing some of the same issues regarding movement based interaction. The third image displays the "camera space" relation which is the part that I go into depth with in the *Part I: Thesis*. Projects here include concept, papers, and prototypes and different as they might be they all exploit the use of camera spaces. The fourth image displays Mixis connected to all other working prototypes, why all methods, concepts, and papers are displayed in the outer circle.

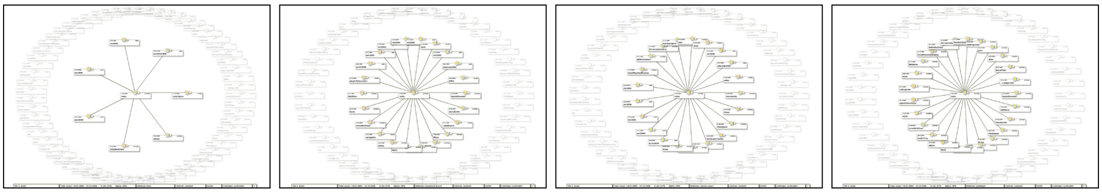

Figure 55: Four examples of connections with Mixis ID# 6 as projects in focus and content type "contract"; relation "links", relation "movement based", relation "camera space", and relation "prototype".

Arranging Projects

Still looking at Mixis as the project in focus the content type is changed to "image" and the relation perspective is set to "links"; see figure 56. This displays the same view as the first image in figure 55 only with another content type. The second image shows the same selection arranged in a grid view. This gives another overview where projects are not overlapping, however, depending of scale they might go beyond the screen area. In the third image the grid view from image two is sorted by type. As can be seen the screen is divided into four areas labeled methods, prototypes, concepts, and papers. From this view we can see that Mixis links to two other prototypes, one concept, and four papers. In image four the view of image three is sorted by time. In this view it is possible to see when and which type of project is relating to Mixis.

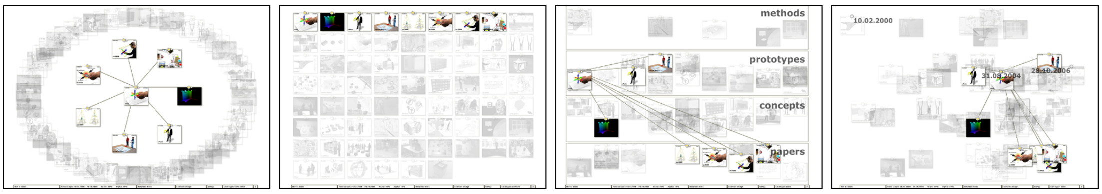

Figure 56: Mixis ID# 6 in focus; sorted in center, sorted in grid, sorted by type, and sorted by time.

To zoom into the projects in focus the time scope in the appearance tab can be used. Image 1 in figure 57 has Mixis in focus and all projects are sorted by type and by time. In image two the right time scope slider is dragged till the newest project in focus is the project most to the right on the screen. In image three the same is done with the left slider cutting all projects older than the oldest project in focus. By setting the alpha value to 0% all projects not in focus are hidden leaving only eight projects, Mixis and its seven related projects, arranged by type and by time exploiting the entire screen.

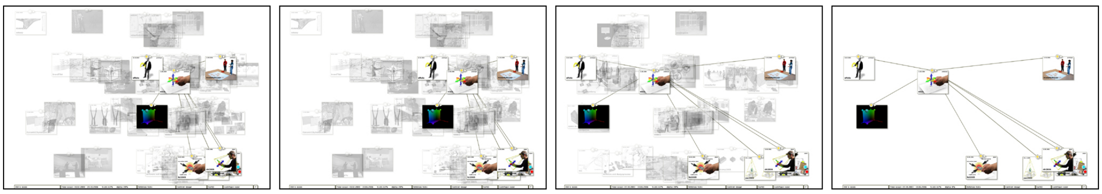

Figure 57: Using time scope; projects sorted by time and type in full time scope, time scope cuts all projects newer than the newest project in focus; time scope cuts all projects older than the oldest project in focus; alpha slider set to 0% shows the projects in focus within the set time scope.

11.2 DISTILLING THE CAMERA-SPACE FRAGMENT

I see the *project diagram* as useful in a couple of ways. First of all I have used it to get an overview of my work myself. Secondly it has helped me see relations between projects that I had not thought of beforehand. And thirdly it serves as an alternative way into my work than trough this textual linear presentation you are reading just now.

Generally it acknowledges the multi-faceted nature of my work and does not try to "cover" it up and pretend to have followed a clear goal all the way. I will argue that the projects within the diagram all address aspects of space in the borderlands between physical and digital domains. As described above regarding the different relation perspectives there are many points of departure into the work, and clearly it would be possible to find numerous other perspectives that could guide other discussions across the material. I am, however, "just" using the *project diagram* to unfold the *broadness* of my work and from that distill a fragment on which I will go into *depth*. Thus it is not the objective to present all possible entries but to show its general ability to present work by the examples provided in the relation tab menu.

During my collaboration with Thomas Riisgaard and Eva Eriksson we have developed a conceptual framework for interactive projects using cameras. This framework is described in *paper 4* and is the main contribution of this dissertation. Applying this notion or perspective of "camera-space" to the content of the *project diagram* filters, inscribes, and visualizes a coherent fragment that go across the different work and project contexts that I have been part of, and across projects that are not initially connected. Figure 58 identifies the camera space fragment within the *project diagram*. Image 1 displays the entire project space sorted by time and type. The iFloor project is in focus and the relation perspective is set to "camera space". What becomes clear from this view is that the work I have conducted regarding camera spaces falls within working prototypes and papers. Of course there lie concepts as a basis for the work but it has all ended up in a working system. Further, many of these systems have served as empirical test beds for several papers.

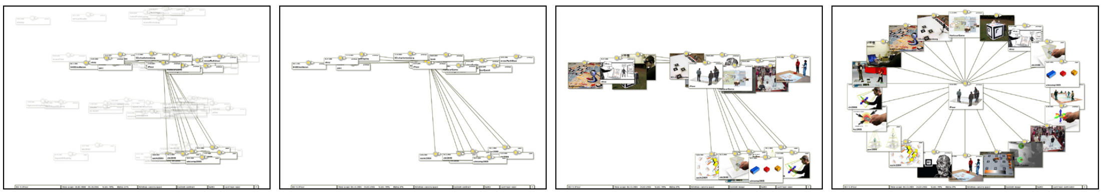

Figure 58: Camera space

Figure 59 presents all projects addressing the concept of camera spaces displayed in a grid view. As described while going through the tab menu interface different content types exist for each container. Use the tab interface or toggle the content on the local container to get an idea of the different prototypes and papers. Remember, however, that the entries in the *project diagram* serve to add further detail to camera spaces in conjunction with the three cases described in chapter 6 (*cases*) in *Part I: Thesis*. They are not described into depth but the videos, short descriptions, and for some entries links to pdf's will hopefully help to visualize and understand some of the potentials and limitations about interacting through camera spaces.

Figure 59: Camera space

By using the "camera space" relation perspective as well as all others except "links" the filtering of projects in focus is as mentioned in the relation menu tab section static. This means that camera projects relate to camera projects which might be a limiting way of looking at the content, thus I suggest applying multiple perspectives to investigate the complex relations that exist within my work. As an example to this I have in figure 60 kept iFloor as the project in focus and changed the relation to "links". The time scope is framing the projects connected to iFloor and all projects are sorted by time and type. What this view reveals is that iFloor came about highly inspired by the virtual video prototype (Bardram et al., 2002) playful interaction.

[mapping: 64]

Not because camera spaces are introduced there but because we imagined the floor as a social surface for interaction. Further, the view in figure 60 shows a relation between iFloor and two concepts.

[mapping: 8, 61]

The skub school project applies a concept similar to iFloor to a scenario of a future school environment (see the pdf under the info content type); and the floorConcept is mainly inspired by the idea of the floor as interaction surface, the video, however, shows possibilities of extending the gestures and features recognized for interacting in camera spaces (features and gestures are discussed in chapter 7 (*interacting in camera spaces*).
Also storySurfer and floorQuest has been directly influenced by iFloor mainly because of the reuse of tracking technique and of course as a consequence of the potentials we found in floor interaction while developing and deploying iFloor.

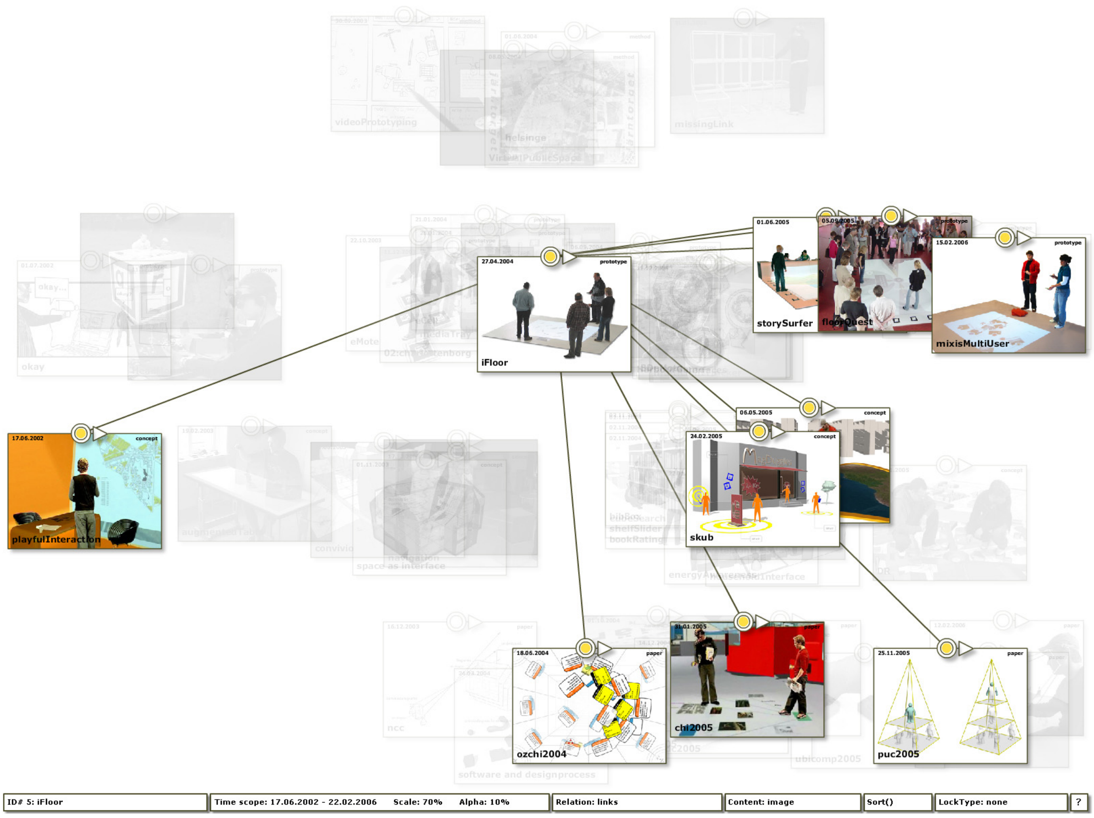

Figure 60: Inspirational links to iFloor

Hopefully the *project diagram* will function along with the *Part III: Papers* and the *Part I: Thesis* to create a consistent Ph.D.-dissertation. But I also see the *project diagram* as an instrument to invite others than the usual suspects into my work – namely the ones who are primarily directed towards the visual, spatial and non-linear; and who would not even bother to open the *Part III: Papers* and *Part I: Thesis* because of the weighting between text and images.

In the following *Part III: Papers* the five papers included in the dissertation are presented. For the additional papers I refer to the *project diagram* looking through the "paper" relation perspective.

SPACE AS INTERFACE

- BRIDGING THE GAP WITH CAMERAS

PART III: PAPERS

12 PAPERS

In this part of my dissertation I present five selected papers. They are selected as they all relate to the discussion on space as interface and help to inform the framework presented in the *Part I: Thesis*. The papers has been submitted to and accepted at different international conferences and journals within the HCI and interaction design community.

The papers not included in this dissertation are listed in the introduction of the dissertation and also available as pdf-documents through the *project diagram*.

Paper 1: Help Me Pull That Cursor - a collaborative interactive floor enhancing community interaction

Krogh, P.G., Ludvigsen, M., Lykke-Olesen, A. (2004) Help me pull that cursor - A Collaborative Interactive Floor Enhancing Community Interaction. In proceedings of OZCHI 2004, 22-24 November, 2004, Wollongong, Australia. CD-ROM. ISBN:1 74128 079.

Paper 2: Floor Interaction - HCI reaching new ground

Petersen, M. G., Krogh, P. G., Ludvigsen, M., and Lykke-Olesen, A. 2005. Floor interaction HCI reaching new ground. In CHI '05 Extended Abstracts on Human Factors in Computing Systems (Portland, OR, USA, April 02 - 07, 2005). CHI '05. ACM Press, New York, NY, 1717-1720. ISBN:1-59593-002-7.

Paper 3: Mixed Interaction Spaces – Expanding the Interaction Space with Mobile Devices

Hansen, T. R., Eriksson, E., Lykke-Olesen, A. (2005) Mixed Interaction Spaces – Expanding the Interaction Space with Mobile Devices. In proceedings of HCI2005 on The Bigger Picture (Edinburgh, UK, September 05 - 09, 2005). Springer-Verlag London, 365-380. ISBN 1-84628-192-X.

Paper 4: Movement-Based Interaction in Camera Spaces – a Conceptual Framework

Eriksson, E., Hansen, T. R. and Lykke-Olesen, A. (2006) Movement-based Interaction in Camera Spaces: a conceptual framework. In the Journal of Personal and Ubiquitous Computing, special issue on movement based interaction. Publisher Springer London, November 15, 2006, ISSN 1617-4909 (Print) 1617-4917 (Online). DOI 10.1007/s00779-006-0134-z

Paper 5: Reclaiming Public Space - Designing for Public Interaction with Private Devices

Eriksson, E., Hansen, T. R., Lykke-Olesen, A. (2007) Reclaiming Public Space - Designing for Public Interaction with Private Devices. To appear in proceedings of Tangible and Embedded Interaction '07, February 15-17, Baton Rouge, Louisiana.

12.1 "HELP ME PULL THAT CURSOR" - A COLLABORATIVE INTERACTIVE FLOOR ENHANCING COMMUNITY INTERACTION

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Abstract

In this paper we describe the development, experiments and evaluation of the iFloor, an interactive floor prototype installed at the local central municipality library. The primary purpose of the iFloor prototype is to support and stimulate community interaction between collocated people. The context of the library demands that any user can walk up and use the prototype without any devices or prior introduction. To achieve this, the iFloor proposes innovative interaction (modes/paradigms/patterns) for floor surfaces through the means of video tracking. Browsing and selecting content is done in a collaborative process and mobile phones are used for posting messages onto the floor. The iFloor highlights topics on social issues of ubiquitous computing environments in public spaces, and provides an example of how to exploit human spatial movements, positions and arrangements in interaction with computers.

Keywords

Interactive floor, library, ubiquitous computing environments, spaces as interface, social computing, interaction design, designing for community interaction, video tracking.

Introduction / Motivation

Much design and research effort within HCI have been put into supporting distributed communities e.g. family members being away or living apart from one another (Hutchinson 2003), geographically distributed fellow, or systems supporting the establishment of contact and formation of groups and communities between people not knowing one another on beforehand (Nielsen 2002). There is a growing interest in how to support and encourage social interaction between collocated people and how the physical surroundings e.g. (Wilde 2003) can be exploited in this regard. However, little work addresses how ubiquitous computing environments will go beyond spatially arranged devices as in e.g. (Streitz 1999) and take into account and exploit spatial qualities of physical rooms, spaces and places. The work and the prototype presented here are a step towards realising the concept of interactive spaces.

The user population addressed in the work presented here are the visitors of a central public library; people that do not necessarily know one another on beforehand, but might be interested in informal conversations and contact with other citizens. As one of the most profound institutions of a democratic society the public library primarily serves as a place giving every citizen unrestricted access to catalogued information and providing facilities for self-initiated life-long learning. But in doing so it also indirectly serves as a social space enabling awareness of fellow citizens and the pluralism that is equally important in maintaining a vivid democratic society.

In the research project denoted "The Future Hybrid Library", which is an initiative in the multidisciplinary research centre for "Interactive Spaces" mixing competences within architecture, engineering and computer science, we've been exploring how ubiquitous computing environments that take into account specific spatial qualities could support and enhance the social aspects of the library. As we would like to have as many potential users as possible to be exposed to the developed system the entrance hall of the local central public library was picked as framework for the design of the system as well as location for a later three week period of evaluation. On the basis of the spatial qualities and functions of the room we chose to explore this by means of an interactive display on the floor.

Background (and Challenges)

In his book, e-topia (Mitchell 2000), William J Mitchell starts out with a tale of the well and its importance in cities in the early days of civilisation. Beyond being water reserve the well also had a strong social attraction, as people would go there just to meet up, exchange goods, arrange marriages etc. To enable the cities to physically expand and to minimize the risk of diseases, water was put into pipes suffusing the whole city. Having direct access to water in each household made the practical role of the well obsolete, whereas the social needs remained the same. In response to these new social places e.g. cafes emerged. By means of the tale Mitchell asks the polemic question: "What will happen when information by means of broadband access to the Internet is "piped" into our households?" Will this be the death of e.g. the library? Which services and installations in the physical library will support the institution in maintaining its attractiveness and social role?

In recent years libraries throughout the world have focused on delivering web-based services for its users. Along with the web-based services there has been a growing focus in the physical library on meeting the needs of the individual user, and her ability to find relevant material. Activities and approaches as these have resulted in a starvation of the attractions of the physical library beyond erecting evermore-impressive buildings and architectural statements of the importance of the physical library.

Through user studies, interviews with librarians and statistics on numbers of visitors (Magistratens 4. Afdeling, 2004, only in Danish) at the local municipality library, we've learned that the by-product of these activities among others has been a decreasing number of visitors at the physical library. Many needs of the user in regard of finding relevant material can be met through advanced search and reservation facilities on libraries web sites. In addition to this the general facilities on the Internet: search engines, user groups, etc. also seemingly meet the users' needs for finding information. Furthermore, the social space in the physical library has taken a swing towards being more focused on the individual. Independently, some users and librarians in our user studies even talked about the local library as having developed a supermarket-like atmosphere where people are indifferent to the whereabouts of others. Probably this can be traced back to the increased focus of the library on serving the individual user supporting individual learning rather than providing a space for social gathering, activities and public awareness.

To summarize, the experienced social value of the public library shows tendencies to decrease. Visitors and librarians are becoming more and more focused on serving individual needs, efforts and tasks that obscure the view and attention to support and develop the social role of the library. To regain and strengthen the democratic role of the library it is necessary to devote more effort into the social aspects and activities of the library. New architectural monuments of the library and enhanced ways of efficiently organising the collection of materials are not enough to ensure the continued community-integrating role of the library. The design of computer systems also has to address the social challenges that the library is expected to meet.

Related Work

In order to address the challenges mentioned above the work presented here draws upon work in three areas: architectural design, ubiquitous computing and designing for community interaction. Furthermore, the interrelations of the three areas are explored in order to pursue the realisation of interactive spaces.

From a perspective of architectural design, the design of physical spaces, most of the work within ubiquitous computing has either worked on furniture-sized installations (Grønbæk 2001) following the concept of roomware (Streitz 1999) or generally applying the scheme of "tabs, pads and boards" initially described in (Weiser 1999). The only architectural element in these prototype environments that aims to transgress the affordances of furniture to become actual room-sized elements and interfaces are walls embedded with display facilities e.g. (Johanson 2002). The vertical orientation of large displays positioned to be touch by hand, makes it fairly easy to adopt many of the well-established ideals within HCI e.g. direct manipulation (Schniederman 1987) whereas interfaces that are hard to touch directly by hand e.g. ceilings and floors are less explored as interactive surfaces.
Interactive floor surfaces are typically experimented on in dance and performances like set-ups e.g. the prototype Magic Carpet (Paradiso 1997) and Litefoot (Fernstrom 1998). The prototypes are sensor intensive environments for the tracking of people's movements of feet and in the case of the Magic Carpet the sensor floor has been supplemented with sensor technologies for tracking the movements of the upper body and arms. To serve different shaping and sizes of an interactive floor the Z-tiles concept (McElliot, et al. 2002) was developed. As the above-mentioned systems the Z-tiles interactive floor is based on sensor technologies. Input from the interaction technologies is used to control and manipulate sound providing the idea of playing an instrument with your body movements. Another system exploring multi-user spatial interaction by means of an interactive sensor-based floor is the Virtual Space project (Leikas et al. 2001). The sensor technologies are in this case used to enable spatial interaction and control of a computer game projected on a vertical positioned display. Another approach to enable spatial interaction is the use of video tracking e.g. the commercially available eyetoy game. http://au.playstation.com/ps2/hardware/eyetoy.jhtml.

Most of the work with designing for community interaction uses computer interfaces to mediate distributed activities enabling awareness of distributed people's interests and whereabouts e.g. (Büscher et al.). Increasing effort has been directed towards enabling community interaction among collocated users (Churchil 2004). As computers and computer interfaces for community interaction become an increasingly influential part of our everyday lives (Grinter 2002) we see a need for addressing issues related to the experience of the social qualities related to the experience of collocated users. These concerns are intensified as computer interfaces transgress traditional interfaces and become embedded in the physical surroundings and spaces enabling groups of collocated people (Huang 2004) to simultaneously interact with the systems accessible or as experienced in awareness facilities in office spaces. From our point of view this body of work lacks to take the spatial qualities of the physical environment sufficiently into account in regard to of how systems might be operated and appropriated in use.

The new Seattle Central Library (Koolhaas 2004) is, a part from being an impressive architectural statement of the library as institution, also a refreshing example of how the need for social spaces and their nature can have just as strong impact on the design of the building as ensuring efficient organisation of the collection of media typically has when designing libraries. Though the use of computer systems and their physical materialisation in the new Seattle Central Library is fairly traditional with huge amounts of personal computers, floor spaces as "the living room" on 3rd floor and "the mixing chamber" on 5th floor, indicate an increased awareness of the social role of the library. But how would these floor spaces have materialised architecturally if they from the early design stages were thought of as ubiquitous computing environments, encouraging social interaction.

We see a need for including spatial concerns in the design of systems and interfaces for community interaction that goes beyond the mediation of distributed activities to include the experience of the collocated user. Furthermore, there is an unexplored potential in including more playful aesthetic ways for interacting with these systems. From our point of view experiments taking on this challenge could be informed by approaches to aesthetic interaction as promoted by (Petersen et al. 2004).

Design Rationale and Aims

In the following we will present our rationales and aims of the prototype design. The development of this prototype has two basic aims. The first is to facilitate a space for communication and collaboration, based on the exploitation of user knowledge and curiosity. The system should not announce itself as a community supporting system. It should merely be a trigger for collocated people to start talking and engaging with one another. The second aim is experimenting with collaboration on interactive floor surfaces with no need of special input devices apart from being present in the physical library. This is done in order to design an interactive system that can be appropriated by most of the broad range of people visiting the public library every day. These users include all ages, genders, races and professions e.g. children, disabled, students, mothers with bags full of books etc. For more advanced interactions we will experiment with mobile phones as 90% of all Danish families have minimum one mobile phone (Statistics Denmark 2004)

The prototype is to be located in the entry area of the local central library, a transit space that is approached by the users from all directions. To keep the spatial qualities of this transit area it is important to ensure visual overview of the adjacent spaces. In addition to this public spaces are characterized by people with many different doings and different attitudes towards disruptions in the public realm (Gehl 1987). To comply with this we will experiment with floor interaction that in many aspects will not alter the physical space.

Designing for public space requires certain considerations regarding the robustness of the system, which should result in an interactive system without any direct contact with the hardware.
By introducing the prototype we want to inspire to the change of the communication style of the library. Today most library users have interpersonal interactions with only the librarians, asking them for advice or references to books. The local central library is fairly visionary with respect to introducing technologies to make the daily handling of books and other materials more efficient. Thus they have introduced self-service check in- and out of materials, and recently also self-service check-out of reserved items. This means that the interactions between users and librarians have been minimized, and the library is decreasing its need for interpersonal interaction. In the design process library staff and mangers expressed the need to counter this trend by creating facilities and a space for informal exchange of knowledge among users, and encourage the transformation of the library into a more vivid social space. Addressing this became one of the key design issues of the developed prototype.

The Prototype

On the basis of the above identified challenges and needs a prototype was developed: an interactive floor for communication between users of the library named iFloor. We will describe the iFloor by looking at separate elements of the design: the general setup, the technology, the graphic user interface, bodily interaction and interaction by adding content. Basically the iFloor is an interactive floor that affords users individually or in collaboration to browse and discuss projected questions and answers produced by the users themselves, through the movement and position of their body. By the use of a mobile phone or an email client questions and answers can be posted on the floor.

Figure 1: the iFloor in use. Several users discussing and interacting with the floor and the man on the opposite side of the floor is writing a message to the iFloor using a mobile phone

Technical Setup

The system consists of a remote server for receiving and handling SMS' and emails and administering questions and answers. Furthermore, a projector mounted on the ceiling is connected to a local computer for the display on the floor. Due to the requirement for system robustness, tracking technologies like e.g. interactive tiles (e.g. Richardson) were rejected because this would require the installation of a technology-intensive floor that would be vulnerable in the public space. Instead the floor interaction works on the basis of a video tracking system software (Valli 2004) analysing the rim of the interface based on a video feed from a web-cam mounted on the ceiling. The tracking of people's position and movement are sent from Retina to Macromedia Flash and translated into magnetic forces attracting the cursor. This solution has the advantage that all fragile parts are mounted on the ceiling and thereby removed from direct access. Using projections in bright daylight caused problems regarding the visibility of the display and the tracking. This was solved by using a powerful projector to project the graphic interface onto thin white PVC boards on the floor creating a clear projection image and giving a good sufficient contrast in the video feed for the blob analysis and threshold tracking done in Retina.

Bodily Interaction and the Interface

Due to the novel interaction explored in the prototype and the unprecedented facilities offered by the prototype the graphic user interface had to be very simple and clear. Technical tests showed that the precision in tracking we got from a simple web cam was enough to keep track of at least 15 people at one time in a 5 meters by 4 meters rectangle. Diminishing the possibility of users entering the projection and thereby casting shadows on the content we only used data from the tracked persons in a one meter band surrounding the display. By using a visual feedback in form of a projected string connecting the cursor and the user while being in the tracked area, people could see that they were taking part in the interaction. As soon as they entered the projection on the floor the string would disappear and they would have no influence on the system. We used the coordinates from the tracked persons to calculate the movement of a graphical element representing a shared cursor. The cursor had its initial position in the centre of the floor but as soon as the camera detected a person in the tracked area, the string would connect user and cursor and the cursor would start moving towards the user. Stepping out of the tracked area would instantly make the cursor move towards the centre. In this way the system got very responsive supporting various playful ways of interacting with the cursor both as an individual and in collaboration e. g. by spreading out hands and feet one can obtain up to five strings giving five times the power of a user standing straight.

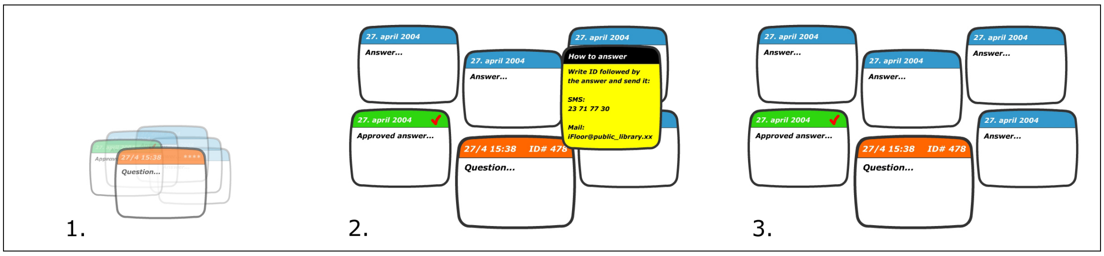

Figure 2: The unfolding of a question. A tool-tip provides the relevant instructions for replying. The green answer-box is an approved answer from a librarian.

The maximum number of questions on the floor was set to 15 due to screen space and text readability. Each question carried a time stamp that was used to exchange new questions with the oldest time stamp on the floor. We designed colour coded graphic elements as containers for the questions and answers. The fact that the floor was approached from all directions challenged the common layout of interfaces traditionally approached from one direction. To comply to that the questions were arranged in a circular array around the centre of the floor to provide equal access and readability of the display from all directions along the rim. Intentionally, this encouraged users to walk around the floor in order to read all questions or ask others about questions on the other side of the floor. In experimenting with an alternative to double click on the floor we used the event where the cursor entered a question to trigger an animation unfolding the question and revealing its specific ID number. If the question had been responded to earlier, these would fold out from behind the question enabling the user to read up to five different suggestions. The questions could be read at all times but users had to move and negotiate the cursor around to read the answers related to the questions. This was deliberately chosen to encourage users to communicate and negotiate on the movement of the cursor.

By designing the cursor to slow down when entering a question we gave users time to read the question and related answers and get the ID number. When leaving the unfolded question the cursor speed raised and an animation contracting the question and answers was triggered.

During the evaluation period in the library we made ongoing improvements and changes to respond to interviews and user observations. The changes were made both to respond to expressed user needs as well as to try out new features. Two changes are mentioned in particular here. In order to make the prototype more self-explanatory tool tips-like would evolve from the questions when the cursor would enter a question. The tool tips described exactly in three bullets how to answer the specific question either by mobile text messaging (SMS) or e-mail. Another change was made to encourage the librarians to take ownership of the prototype and to give their answers more integrity by developing an approved answer – colour coded in green - that could be posted through the same web interface that was used to clean up the floor for offensive questions and answers.

To experiment with different ways of having users interact with the system we tried making the cursor respond to movement instead of position. This resulted in a dance-like performance to get the attention of the cursor but making precise interaction very difficult.

Finally, we tested the implementation of cursor-speed adjusting facilities mediated by icons. By adding small symbols in the corners of the display representing two speed up and two speed down facilities, users could move the cursor to an icon and through feedback from a counter see the change in cursor speed. This was tried out to add a higher degree of interaction but the feature also had a tendency to create chaos on the floor by unfolding all questions in seconds because of the speed.

Adding Content

To compose new questions users were requested to use either an email client or their mobile phone as input device. By using mobile phones and SMS we could enable people to interact with the system without any specially designed gadgets supported by the library or the prototype itself. Questions could be posed by sending a SMS containing a question on max 120 characters to the iFloor phone number. About ten seconds after sending the question the user would get feedback in form of a SMS saying "thank you for your question, you will receive answers as soon as they arrive, regards iFloor". After that the oldest question and related answers disappear from the graphic interface making room for the new question to emerge on the floor during an animation clearly showing that new content has entered. Responding to a question is done by entering the ID number revealed from an unfolded question in a SMS or e-mail followed by the answer. This creates a new answer that is nested to the question. In order to give visual feedback to users around the floor on changes in content and to promote curiosity in exploring the floor animations were implemented.

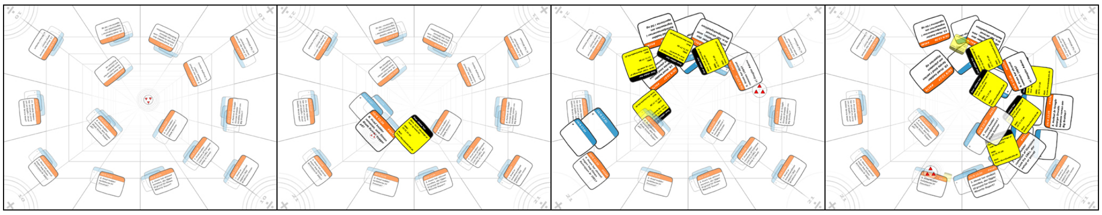

Figure 3: As the cursor enters the questions they unfold and reveal the ID-number and related answers. Too high cursor speed will activate neighbouring questions and responses creating a confusing overlapping pool of messages.

Evaluation

The evaluation with users in the library context was conducted with emphasis on qualitative interviews and observations of users. In our observations we focused on relevance of the prototype and on learning what users experienced when interacting with the system, on the expense of statistics. During the three weeks of evaluating the prototype, we had several users experimenting with the installation. Sometimes we stayed in the background to leave the users to figure out the interaction by themselves, and at other occasions we introduced the prototype to the users in order to engage in dialogue about how the installation was perceived. This way we had both informal talks with users and formal interviews conducted after users had worked or played with the prototype. In the course of the three weeks we also made observational videos of the space where the prototype was installed in order to see how people reacted to it, and how it affected people moving through the space.

Another source in the evaluation was the feedback from the library staff on how they experienced the support of users interacting with the floor and their reflections on how it contributed to the traditional library context. Along with the feedback from the user interviews, the librarians' feedback was the starting point of redesigning and altering aspects of the floor during the three weeks and in order to enhance a walk-up-and-use experience and make the prototype more self-explanatory, as explained in the prototype section.

As a part of the qualitative evaluation we also invited a 7th grade school class for a one hour quiz game. We posed the questions and they were supposed to find the answers by using the traditional search facilities provided by the library. With 25 pupils in the class it was a good way of seeing how the system would react to a maximum load of input. The experiences from this test emphasized the fact that even though the technology in theory could support an unlimited number of participants, the social and physical space set a certain limits to that number. The negotiation part of interacting with the prototype and trying to figure out how the tracking worked could not surpass the competitive element of the quiz game, so the prototype was often blocked by too many inputs. If the video tracking software can see users diagonally across from each other or, as in this case, all the way around the periphery of the floor, the cursor simply stops in a dead zone of equally balanced pull.

The kids in the class were especially fast at adopting the system, and quickly used the floor beyond its intended use, as they started to post teasing remarks and other messages to the school mates. This way the floor expanded into a different kind of communication surface of graffiti-like tagging and personal exhibition.

Reflection

The iFloor challenges several interaction paradigms (Svanæs 2000) as they are difficult to translate these into interacting with a floor. In the three week period of evaluation and redesign of the prototype at the local central library we learned that the questions posed typically would be in the category of seeking advice or tips and tricks on every day things as, how to un-lock ones mobile phone, or where to find the best and cheapest printer. It came to work at bit like the notice board found in local supermarkets; however, in this case the communication was not about runaway cats and baby carriages for sale but knowledge exchange between users at the library. Furthermore, as the floor was residing in the entrance and exit part of the library it came to work like a "sleeping policeman", causing people to stop and to start chatting about the questions and answers on display, and taking the opportunity to participate in the process by posing new questions and responding to the ones in the display. Furthermore, the playful way of navigating the interface was found very intriguing by the visitors and definitely also facilitated the process of making people talk to one another.

Figure 4: The iFloor in the library.

After having discovered the interaction mode and the idea of the system, most people are enthusiastic about the technology and idea of use. When asked, most users were capable of thinking of many other places where a physical/digital bulletin board-like functionality could be helpful or interesting. E.g. a group of student teachers had an idea for using it as a means of teaching because of its synergetic effect between play and serious content.

Spatial Interaction

Proximity

Using the body as the means for interaction is to many people a very provocative and challenging idea. It seems the single-user-in-front-of-a-desktop paradigm has been thoroughly accepted by the general public. Through the iFloor prototype we are experimenting with new principles for interacting with augmented floor surfaces. Walls and all kinds of furniture (e.g. Dunne 2001) have been used as interactive artefacts or displays, but using the floor surface as a collaborative multi-user surface sets design challenges as to how to point click and select content on the floor. Being out of reach in most situations, the floor is not a surface for direct manipulation (Schneiderman 1987). On the other hand, a potential input that is always available is if a user is able to view the floor he will be in the physical vicinity of it, so by using video tracking we can relate the floor to the user and afford interaction.

This physical proximity is translated and used to orient the interface to the user. The question boxes are rotated in relation to the centre of the floor to ensure readability no matter from where the user will approach the display. At the same time this rotation encourages the user to walk around the floor to read the other questions, thereby discovering that the cursor is attached to her by a string and responding in real-time to movements. This sets of an exploration of the interaction and in several cases we saw users in the library trying out different ways of enhancing their ability to attract the cursor by e.g. joining other users or spreading out arms and legs.

From Private to Public Displays

Sending questions and answers to the iFloor are done by SMS or via emails. This causes an interesting flow from using a public display in collaboration to using your private mobile phone or walking away to a computer, sometimes while still discussing the answer with a friend around the floor. The mobile phone becomes a remote control or a wireless keyboard for the shared display on the floor, causing a mix of private and public space.

Utilizing the mobile phone in the iFloor concept also means that the library extends its sphere of influence into the city, as you can pose questions or receive answers anywhere. The knowledge sharing that we try to establish in the library goes beyond the physical constraints of the library. However, the core of the community is still the collocated people at the library, since it is only the people present round the floor that can read and get access to the ID-numbers and thereby answer the question.

Social Issues

Social Navigation

During the first days of setting up in the library, we walked around the floor to ensure it was running properly. This attracted many users who interestedly started using the system. But when we stepped away from the floor the interest decreased. Not for the individual users currently engaged in interaction but as a general trend for people arriving at the library. The floor, we decided, did not convey its potential use strongly enough. It looked attractive and interesting at first glance but potential users rapidly lost interest as they were unable to figure out how to use it and what the point of the interaction was. We changed the set-up by placing A3 sized posters on the three sides of the floor where people would approach it. Thereby we allowed an opportunity to observe and learn what the system was about before stepping onto the floor and interacting. Even with this stepping stone approach, users were still hesitative to jump onto the floor and we sometimes had to jumpstart interaction simply by being present on the floor conveying a use pattern and the fact that the system was safe (and even fun) to use. When on its own, it seemed to us, the prototype was too unfamiliar for most people and the rate of how many walked up and experimented with the floor more than halved.

As described in (Höök et al. 2003) it is very important for a physical place as well as for a digital to convey it use context through the social interaction taking place. When designing a place that is both physical and digital and unfamiliar to the potential users, it is important somehow to provide the users with a possibility to gradually approach the system in a socially safe way. From observing how many people are using the floor and especially what they are doing, one can decide whether or not to participate. As a general rule when people are having fun or are deeply engaged in interacting it seems far more interesting for outsiders to try for themselves.

Negotiation and Collaboration

When users were experimenting with the prototype, we often saw problems with sharing the cursor. In most cases when the users did not know each other, the negotiation that had to take place in order to move the cursor to the desired location was limited. If a user finds a question interesting he will have to ask the other users around the floor to work with him to move the cursor to the question or tell them to get off the floor, which happened almost as often as the first approach. Contrary to this, users were quite helpful explaining how to interact with the system to other users approaching the floor. In one case an elderly man had experimented with the floor and read the poster beside it, and was able to introduce the conceptual idea and use of the floor to a family of three. After this introduction they explored both what could be done with the video tracking and when using the SMS-service. The single-user perspective is so deeply imbedded into users when it comes to using digital technology, that it seems surprising that a display and a cursor is addressing several users in 360 degrees. When approaching the iFloor a user discovers her influence on the system as a string is "attached" to her and follows her around as she walks round the floor to read the questions. When entering the floor, users will inadvertently disturb anyone else who might be doing something purposeful with the cursor. In this way the interaction with iFloor invites or even demands users to collaborate in order to control the interface. By setting up such "forced" collaboration, we wanted to create a hidden opportunity for library users to establish contact with each other, however transitory these contact might be.

Finally, we observed several users, who did not know each other beforehand, discussing possible answers to questions. As with a dinner table, it is seemed socially acceptable to be talking with the people you are sharing a point of attention with, and collaboratively solve the problem.

Play

As users become more familiar with the interaction and figure out how the system is controlled, they can use the iFloor in a more playful manner. The iFloor can be manipulated to give more pull to a single user if he or she discovers that spreading out arms and legs will give more pull, as the video tracker sees more blobs and therefore "attracts" more strings to the cursor. This can give two or three users an opportunity to play with the floor and compete on who has the power to control the cursor. This game was often initiated when users were walking around the floor and noticed e.g. that they had strings "attached" to both their feet. The game became almost sport-like as it is your agility and stamina that will decide who can attract the most strings and win the cursor over. Often these games appeared almost like dance performances as users really got captivated and expressive in their effort to attract the cursor. Making teams could also be a way of competing. Sometimes users would also insist on the efficiency of something that did not have any effect on the system, like stomping or dragging the feet backwards as if the strings were physically attached to them. This, of course, makes sense in a direct translating of a physical string's affordances, and this was often how users experimentally appropriated the prototype.

Future Work

In continuation of the "Future Hybrid Library" project a related project has been launched called "The Children's Interactive Library". In this work we will advance the exploration of spatial interaction paradigms in relation to the social spheres in the children's library. In further development in the library context we will address the following issues for improving the iFloor prototype:

- Visual aging of questions to create a fast overview of new and old questions.
- The relation to the physical surroundings e.g. using the floor for directing users to bookshelves related to their questions.
- Explore the use of the third dimension down in floor.
- Using gestures to improve the bodily interaction.

As the technical solution proved to be fairly robust we believe that similar installations could be applied in other domains of the public space with a projectable floor material and the proper light conditions to do the video tracking e.g. as an interactive informative city map in transportation transit spaces supporting newcomers to get the latest information on events and happenings.

Conclusion

The iFloor prototype, as we have presented in this paper, experiments with new interaction modes for using floors as collaborative display and interaction surfaces. Novel interaction was achieved through the use of video tracking to extract the positions of the users around the iFloor, and thereby placing a shared cursor to navigate the posted messages. Questions and responses were posted onto the floor by using a mobile phone as remote keyboards. In order to support community and informal interpersonal interactions in the library the iFloor encourages users to collaborate and negotiate when interacting with the cursor and browsing questions. The installation of the iFloor contributed to the library's desire to change the library into a more social and communicative space. Through user studies we evaluated and improved the prototype and found that in addition to fulfilling the design aims from the library, the iFloor also supported users' curiosity through playful and spatial interaction.

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12.2 FLOOR INTERACTION - HCI REACHING NEW GROUND

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Abstract

Within architecture, there is a long tradition of careful design of floors. The design has been concerned with both decorating floors and designing floors to carry information. Ubiquitous computing technology offers new opportunities for designing interactive floors. This paper presents three different interactive floor concepts. Through an urban perspective it draws upon the experiences of floors in architecture, and provides a set of design issues for designing interactive floors.

Author Keywords

Interactive floor, architecture, pervasive computing

ACM Classification Keywords

H5.2. User Interfaces, H5.3 Group and organization interfaces

HCI Reaching New Ground

What are the challenges and design issues of designing interactive floors, i.e. interactive surfaces embedded in the physical environment, which are controlled by several co-located people?

Rodden and Benford [8] draw upon research in architecture when they point to new directions for ubiquitous computing, and indeed, this tradition has a lot to offer when we seek to understand the role of floors and potentially interactive floors. Rodden and Benford [ibid] further the criticism that much research in ubiquitous computing has focused on 'stuff' and has not yet explored how ubiquitous computing can be realized on higher levels of 'space plan'. Interactive floors are an example of a focus on a higher level of space plan.

In this paper we discuss how architectural knowledge, as it has been used in three concrete prototypes of interactive floors, can provide a basis for design. Furthermore we discuss how new interaction paradigms are challenged and informed by an architectural approach to interactive floors.

Interacting with Floors

Understanding human computer interaction, when computation is embedded in interactive floors is yet an unexplored topic. However, a few design concepts have emerged, which point to the potential of this area. For instance in the area of game design, interactive floors have been used as means of controlling games [4]. Also a couple of interactive dance floors have emerged [2]. Thus current applications fall primarily in the area of gaming. There are also a couple of examples of the exploration of the technical side of interactive floors. E.g. camera tracking facilities have been developed allowing for tracking of peoples' movement of floors [5]. Furthermore, Georgia Tech has developed the smart floor concept allowing for seamless identification of users based on the pressure profile of their footsteps [6]. These technological possibilities are yet to be fully explored in design concepts and applications.

In the following, we wish to point out that interactive floors have a much richer potential than what current applications suggests. A way to pursue this is to understand some of the general qualities of interactive floors. Here the tradition of architecture is a good resource.

Floors in Architecture

Floors seen in a broad architectural frame can be understood as either streets or plazas [9]. To unfold the meaning of this we look to the classic European city where streets lead pedestrians in a direction whereas plazas exist as junctions between intersecting streets. The distinction between street and plaza lays in the controlled framing of the space. Street understood as floor is a surface that holds a certain direction which supports the understanding and perception of the space from a certain point of view, whereas the plaza is the floor where there is no perfect viewpoint and where the perception evolves as the pedestrian explores the space. This framing of floors can be transferred to interiors as well pointing at corridors and junctions of these e.g. a living room. The social impact of these two understandings of floors are not related to private/public but rather to the individual or shared perspective of the surrounding space that street and plaza enables. In the street the pedestrians stroll in a certain direction whereas the plaza supports multiple walk patterns. Over the centuries changes in artistic and stylistic paradigms has experimented with directing peoples' attention and traffic movements in both subtle and more outspoken ways. Throughout history floors either as streets or plazas has been an important architectural element both in terms of decoration, conveying information, regulating use and creating aesthetic and architectural coherence between collocated elements and buildings. To illustrate this two works of classic architecture is used.

In medieval churches and cathedrals the floor functioned as a decorative symbolic guidance as well as an information surface. In the Chartres Cathedral near Paris, France an eleven-circuit labyrinth divided into four quadrants is depicted on the floor. See figure 1, left. A part from being a decorative element, the floor serves symbolic acts of repentance as well as pilgrimage. At other sites such as Piazza del Campo Siena changes in the pavement is used to symbolize Siena's then ruling body, the Council of Nine, their power and the nine folds of the Madonna's cloak. See figure 1, right. Furthermore, del

Campo is not owned by any of the 17 "contrada" of Siena which is why the plaza is the preferred place for any public events, ranging from the famous Palio to everyday marketplace activities.

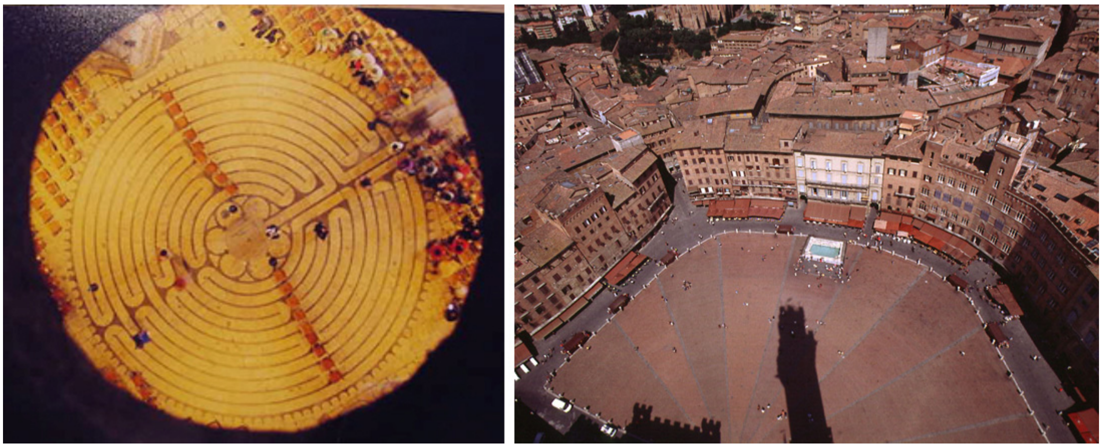

Figure 1 Labyrinth in Chartres Cathedral on the left, and Plazza del Campo on the right

From a design perspective one can take advantage of many subtle signs in defining areas and accessibilities on floors e.g. changes in colour, material and light. However, the main characteristic of a floor is the fact that it is equally shared by all of us.

From an architectural point of view interactive floors address a range of problems such as a high degree of flexibility, which is currently not supported in building components etc. With an interactive floor, surface styles, applications, and interface, can be changed based on who currently visit or rent the facility. In terms of designing applications for interactive floors, this implies that such installations in public space are especially suited for drop-by interaction and that interactive floors support several users cooperating and having a shared experience of a space. Interactive floors however, demands means for interacting with the material displayed on the floor.

Three Interactive Floor Concepts

In the following, we present three different interactive floors, which are results of our work in the research center of InteractiveSpaces. The three design concepts have different forms ranging from a vision prototype, a running prototype, to a full implementation, which has been tried out in a library setting over a period of two weeks. Thus although these design concepts have very different status, in the following, we discuss them on an equal basis, as they represent very different solutions to floor interaction, and thus provide a good basis for reflecting on challenges and possibilities around this.

Playful interaction

Playful interaction (See Figure 2, left) is a vision prototype developed as part of the Workspace project [1]. The motive behind the vision was to explore how more playful relations to materials can be established in a work environment. Among other ideas, this video depicts a vision where digital materials can be placed on- and picked up from a floor through bouncing a ball on the floor. Thus the ball is used as a means for placing and picking up documents on physical surfaces like floors and walls. Documents are organised in dynamic tree structures, oriented primarily one way. People stand on the surface when interacting with it.

Figure 2 Playful interaction on the left, and iFloor on the right

While other aspects of the video prototype have been implemented, the ball itself is not yet implemented due to technical challenges.

iFloor

iFloor (See Figure 2, right) is a concept for multi-user interaction around a digital floor in a library context [3]. The motive behind the concept is to create an attraction of the physical place of the library, in a time where more and more materials can be distributed from the library remotely. The concept is implemented in the form of a running prototype, and this experimental prototype has been set up at a municipal library for a period of three weeks.

The floor allows visitors in the library to post questions and send answers to each other. The Q/A's are displayed around on the floor, in a circular array such that they are equally well accessed from all directions. There is no dominant direction. Visitors browse them by means of a cursor. There is one shared cursor on the floor, which visitors through their body movements drag around on the floor. It is easier to control the cursor, when more than one person interacts with the floor, and the playful challenge consists in coordinating and negotiating movements to pull the cursor to the intended spot on the floor.

MediaSurfaces

MediaSurfaces is a concept allowing people to distribute their digital materials on a range of connected interactive surfaces in the home [7]. These surfaces range from being table projection, wall displays as well as projections on floors. Floor projections are oriented in one direction, e.g. such that the materials are displayed at the entrance and viewed as people come home.

Figure 3 From left to right: close-up of table. Emote, and mediafloor.

The concept draws upon various studies of how people handle physical materials in their homes, which also points to examples where placing e.g. paper mail on the floor at a specific spot in the home is a way of attaching status to the mail. The means of interacting with the digital floor display is through a gesture-based remote control. The remote allows users to control the materials displayed on the floor, e.g. flicking through pictures displayed on the floor. This concept is developed in the form of a prototype, which will be put out in a home for a two week period of testing.

Design Issues for Interactive Floors

The three different cases point to the range of different application areas of interactive floors, beyond the prevailing focus on games. The concepts presented in this paper address such diverse domains as the workplace (Playful interaction), public space in libraries (iFloor), as well as private homes (MediaSurfaces) and thus suggests that the full potential of interactive floors are yet to be explored. Using the distinction of street and plaza derived from urban planning research in understanding and characterizing the use situation of an interactive floor allow us to bring forward a set of design issues for such installations. The perspective points to a richer use of such floors than we have seen up till now. The architectural approach implies the notion of scale and orientation and alternative positions, which in the three cases goes beyond the common screen display requiring new interaction paradigms. The urban perspective on interactive floors also involves regarding technology as an integral part of the public environment implying that it should cope with filth and rough use as any other public design. In the case of the iFloor this is done by using technologies that slip into ceilings leaving only tracked projected footprint on the floor - street or plaza. Such setup introduces the notion of dirty computing where the interface is not treated as something precious and fragile but rather blurs into the environment through muddy footprints and spots from soft-ice, and is thus adapted into the fabric of everyday life (See Figure 4).

Figure 4 The iFloor – mud and technology go together

Apart from the three cases' ability to cope with dirty computing they relate, as mentioned earlier, differently to the architectural arc types of street and plaza. Viewing the three design concepts through these perspectives help describe and understand the different nature of the concepts, e.g. their social impacts and interaction styles. The three cases will now be discussed in relation to these issues.

Interactive Floors as Plaza

Interactive floors as plaza hold the following characteristics. It supports drop-by interaction and provides multidirectional access to materials. Playful interaction and iFloor resembles the plaza more than the street, in that they support people in meeting casually, on the fly, and provide multidirectional access and interaction as well as equal points of view.

As a shared surface between users, interactive floors as plaza hold opportunities for creating truly shared interfaces. Especially the concepts of iFloor and Playful interaction utilize this opportunity. iFloor being placed in the central space of the library, a public place with a public task of being open to any citizen, it needs to be egalitarian and accessible. This is supported through the walk-up and use interface providing equal and collective access for all library visitors.

Interactive floor as plaza is a shared interface supporting shared focus of attention – right up to the point in time when other people around the floor becomes more interesting. Then the interactive surface moves into the background and the interaction between people will step into foreground. This happens in Playful Interaction where a playful approach to knowledge sharing in the office environment is proposed in terms of picking up documents and transferring them to colleagues through bouncing a ball in the floor and throwing it to a colleague. This is in opposition to a more rigid notion of a productive and functional office environment.

Interactive Floors as Street

The nature of interactive floors as streets is characterized by designing to support individual strolling through providing directed routes, prepared for unidirectional access, and more efficient interaction as compared to what the Plaza represents. The concept of MediaSurfaces holds more the characteristics of the street than the plaza in that it assumes certain directionality in the access to materials. It supports the unidirectional access to materials as they are experienced as people stroll by a floor display. But MediaSurfaces, with the gesture-based remote control, explores more playful ways of interacting with the materials displayed on the floor than the Street arch type suggests.

Design issues for Interactive floors	Plaza	Street
Nature of interaction	*Drop-by interaction*	*Directed route*
Directions of access	*Multidirectional access*	*Unidirectional access*
Interaction ideals	*Playful interaction*	*Efficient interaction*
Social/individual	*Social interaction*	*Individual strolling*

Table 1 Design issues for interactive floors as Plazas and as Streets

While street and plaza are useful for analyzing concepts, they may also be used more generatively, as design parameters, or as a way to broaden up the design space. As summarized in table 1, they raise rather different design issues.

Conclusion

We have unfolded the challenges and design issues of designing interactive floors through pointing to the distinction between plaza and street. We have suggested that they are useful categories to consider when designing interactive floors. As characterized here, they can be seen as endpoints of a spectrum. Many concepts will be blends of these. However, the arch types illustrate the challenge of giving these different characteristics a concrete form in interactive floor concepts. A challenge, which we have just started to take up with the interactive floor concepts presented in this paper.

Acknowledgements

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12.3 MIXED INTERACTION SPACE – EXPANDING THE INTERACTION SPACE WITH MOBILE DEVICES

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Abstract

Mobile phones are mainly interacted with through buttons, thumbwheels or pens. However, mobile devices are not just terminals into a virtual world; they are objects in a physical world. The concept of Mixed Interaction Space (MIXIS) expands the interaction with mobile phone into the physical world [Hansen et al. 2005]. MIXIS uses the camera in mobile devices to track a fixed-point and thereby establishes a 3 dimensional interaction space wherein the position and rotation of the phone can be tracked. In this paper we demonstrate that MIXIS opens up for new flexible ways of interacting with mobile devices. We present a set of novel, flexible applications build with MIXIS and we show that MIXIS is a feasible way of interacting with mobile devices by evaluating a MIXIS application against a traditional mobile interface. Finally, we discuss some design issues with MIXIS.

Keywords

Mixed interaction space, Mixed reality, Mobile HCI, Zoomable interfaces, Mobile computing, Spatial aware displays, Drawable interfaces, Gesture interaction.

Introduction

Mobile devices such as mobile phones and PDA's have been adopted into our daily life. Researchers at Nokia have observed that an important factor contributing to this is the personalization of the device, not just the communication possibilities [Vänänen-Vaino-Mattila et al. 2000]. In constant use the mobile device becomes a personal object to such extent that it intensifies the user's feeling of being inseparable from this unique thing. Still, the mobile devices are more and more becoming a personal computer in both functionality and interaction. The most common interaction is through buttons, thumbwheel or pen, and through something that can be characterized as a downscaling of the classic

WIMP interface. The mapping of navigation and functionality to buttons, wheels and icons is not flexible and with low degrees of customization. The standard technique to view a large picture or map is scrolling by repeatedly press a button, roll a thumbwheel or drag a pen, and it is impossible to combine the manoeuvre with zoom, since the user has to divert the attention switching button to change function.

Designing for small mobile devices involves the classical problems of limited screen space, mapping functionality to small multifunctional buttons and traditionally a 2D interface. These problems can be reduced by expanding the interaction space outside the limits of the screen and the physical frames, and by using natural body gestures, the interface combine the digital and the physical world in a new 3D interaction space. By transforming the interface of the device into a 3D object it becomes a space belonging to the real world instead of the digital, and therefore reduces the cognitive load on the user

The Concept of Mixed Interaction Space

In this paper we present a set of applications that expand the classical interface and interaction of the mobile device, to create a more natural interaction with a mixed reality interface. The applications are build on mixed interaction space [Hansen et al 2005], and demonstrate a new way to interact with digital information by using the existing camera of a mobile device to extract location and rotation of the device. Independent of the applications, the concept is to expand the interface of the mobile device outside the display by using the space between the front of the camera and a fixed-point, as illustrated in Figure 1a. The space becomes the interaction space for gesture recognition. Moving the phone in the interaction space can be mapped to actions in the graphical user interface shown in the display or an action on a nearby device or display.

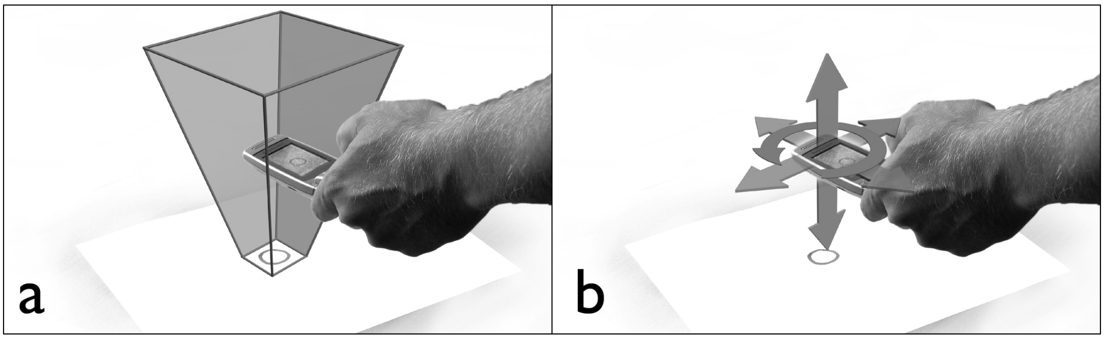

Figure 1: (a) Diagram of the Mixed Interaction Space. (b) Diagram of gestures for interaction.

To interact with the system the user only need one hand for the mobile device, and then use the natural gestures of the body to address the system. Depending on the application the device can be seen as having one to four degrees of freedom [Beaudouin-Lafon 2000]. Figure 1b displays how a four degree of freedom device can be generated by tracking the position and rotation of the device.
The size of the interaction space sets the borders both for the gesture recognition input and for the augmented interface, and is dependent on the size of the circle symbol representing the fixed-point and its distance from the viewpoint of the camera. A larger symbol spans a larger interaction space and therefore the gestures can be coarser. The fact that there is no fixed size opens up for the possibility to have small mixed interaction spaces, where the user have to use fine motor coordination or large spaces that requires the user to use larger movement.

The symbol can be anything as long as the camera can detect it. In the implemented concept a circle is used, it can be drawn or be a part of a decoration of some type and it can consist of different colours. Choosing simple symbols and using tolerant detection algorithms opens up for the possibility of drawable interfaces. The symbol can also be associated with a unique id, and combined with some type of generic protocol to send information, the concept can be used for controlling pervasive devices in the environment.

Even though the interaction is based upon natural body gestures, the concept does not require external sensor technology or specialized hardware. The concept can be implemented on standard mobile phones or PDA's equipped with a camera. The applications presented in this paper are build upon the principles of direct manipulation [Norman 1999], the actions are rapid, incremental and reversible and whose effect on the object is visible immediately. The users are able to act through gesturing and the display feedback or device functionality occurs immediately which convey the sense of causality.

In this paper we will demonstrate that MIXIS is a new and flexible concept for interacting with mobile devices that combines some of the properties of tangible interfaces with traditional mobile device interaction. We will argue for the novelty and flexibility of the concept by presenting four applications build with the concept. We have discussed several of the applications at small workshops, and we have made a formal evaluation of one of the applications to investigate and demonstrate that MIXIS is also a feasible way of interacting with mobile devices. Finally, we will discuss mapping and identity; two central aspects of MIXIS.

Related Work

Beaudouin-Lafon [2004] claims that it is becoming more important to focus on designing interaction rather than interfaces. Inspired by that, we argue that our applications are new compared to related work because: 1) support a high degree of mobility in the sense that it is not depending on any external tracking hardware, 2) are highly flexible because a wide set of different applications can be build by using the mixed interaction space in different ways and 3) provide a natural mapping between gestures and the interface since we are able to get quite precise information about the position of the mobile device in 4 dimensions.

New Interaction Techniques for Mobile Devices

Several projects have explored different new interaction techniques for mobile devices [Fitzmaurice et al. 1993, Yee 2003, Patridge et al. 2002, Fällman et al. 2004, Masui et al. 2004]. Fitzmaurice et al. [1993] uses a 6D input device to navigate in a virtual world, Yee [2003] uses special hardware from Sony to track a PDA and interact with different applications using 3 dimensions and Patridge et al. [2002] have equipped a small portable device with tilt sensors for text entries. These systems use specialized tracking hardware that limits the mobility [Fitzmaurice et al. 1993, Yee 2003, Masui et al 2004] or tracks the device in just two dimensions [Fällman et al 2004, Yee et al. 2003, Masui et al. 2004], constraining the flexibility of the systems.

Accelerometers, can interact with an application by using tilting, rotation and movement of the device as input. The clear advantage of this interaction technique is its independence of the surroundings why it supports mobility very well. It supports new ways of interacting with applications e.g. scrolling in applications by tilting the device [Harrison et al. 1998].

Using Cameras with Mobile Systems

Other projects have experimented with using the camera on mobile devices for tracking and augmenting reality [Rekimoto et al. 2000, Rohs 2004, SemaCode, SpotCode]. Several of these projects aim at augmenting reality by using bar codes in the environment to impose a 3D digital image on reality [Rekimoto et al. 2000] and do not focus on the interaction. SemaCode [SemaCode] is focusing on how to bridge the gap between digital and physical material. SpotCode [SpotCode] and Rohs [Rohs 2004] focus on the interaction, but both systems relies on tracking two dimensional barcode and e.g. not on drawable symbols.

Interaction techniques that use integrated cameras strongly resemble interactions that can be designed with accelerometers. The movement, rotation and tilting of the device, can partly be extracted from running optical flow algorithms on the camera images. However, the camera images can provide more information than the movement, tilting or rotation vector. It can be used to identify a fixed point, and it can calculate its relative rotation, tilting and position according to this point.

Physical Interfaces

MIXIS is related to tangible user interfaces (TUI) in the sense that both interaction techniques try to bridge the physical with the digital [Ishii et al. 1997]. TUIs focus on hiding the computer and having the interaction mainly in the physical world. This opens up for highly intuitive interfaces, but TUIs are not that suitable for more advanced interfaces with much functionality, because each object or function in the program would have to be associated with a physical representation. MIXIS uses a combination of the physical and digital world. Most of the interaction possibilities are presented in the digital world, but to guide the interaction and to build shortcuts in the navigation a fixed-point is used in the real world.

Applications

Implementation

Based on the conceptual discussion we designed and implemented a component to track the position and rotation of a mobile device within the mixed interaction space and identify a symbol drawn in the centre of the circle. Thereafter four applications based on the concept were implemented.

One of our main design goal was to build a system that everyone could use anywhere without having to acquire any new kind of hardware. Using the camera of mobile devices to track a fixed point fulfilled our requirements.

A circle is chosen as fixed-point in our prototype implementation of MIXIS, and it is appropriated for several reasons: 1) It is a symbol most people recognize and are able to draw. 2) There exists a lightweight algorithm for finding a circle in a picture. 3) The radius of the circle provides information about the distance between the camera and the circle. 4) The circle is suitable as a frame for different icons.

To detect the circle, we implemented the Randomized Hough Circle Detection Algorithm as described by Xu [Xu et al. 1990] on the phone. The main reason for choosing the randomized version is that it is lightweight and much faster than the Non-Randomized Hough Algorithm [Kälviäinen 1995]. We optimized the algorithm for the specific use by e.g. looking for only one circle in the picture.

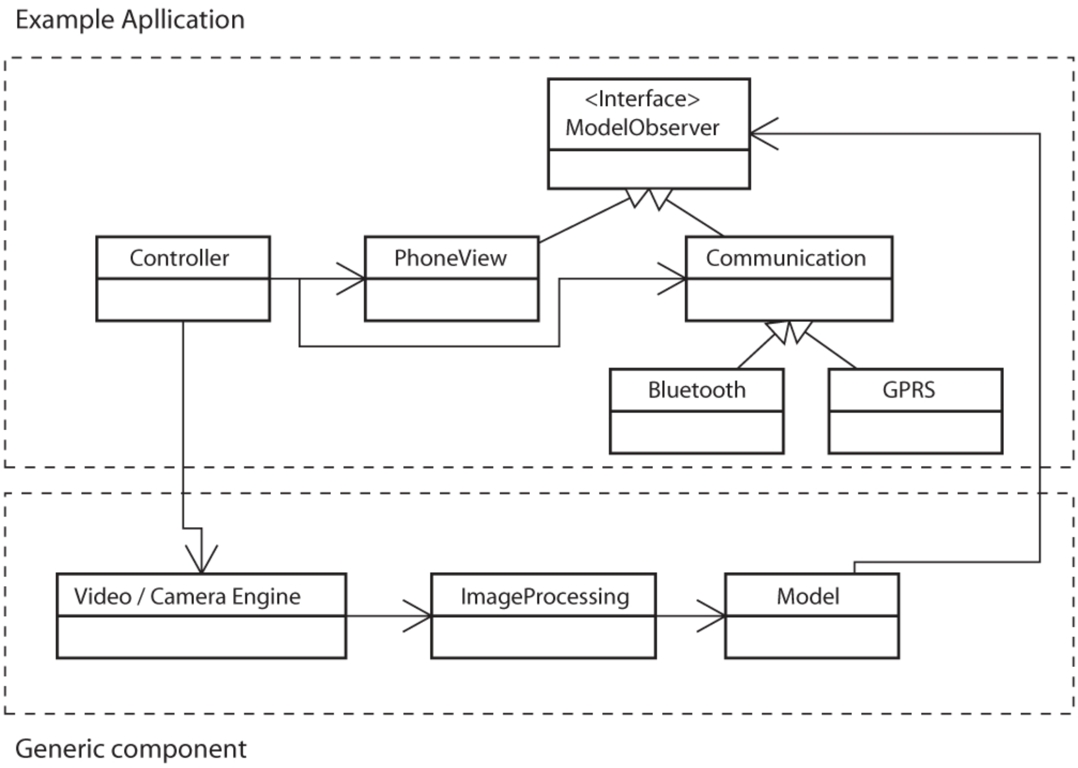

Figure 2: Diagram of the system and how the applications use the generic component. Depending on what application, the communication model is used to communicate with external devices.

The system is implemented in C++ for Symbian OS 7.0s on a Nokia 7610 mobile phone. To keep the interaction fluent and to reduce the memory used, we capture video in a resolution of 160x120 pixels in most of the prototype applications. In some of the applications where an instant response from the program was not required we used 320x240 pixels. In the current implementation a black circle on a mainly non-black surface is tracked. The circle does not have to be perfect, the algorithm easily recognizes a hand drawn circle and the algorithm is also able to find the circle in different light conditions, which makes it more robust for use in different environments. Figure 2 demonstrates how the applications use the generic component.

Applications

We have implemented four applications that use the mixed interaction space concept. To test the feasibility of the concept we carried out a formal evaluation of one of the applications and a set of workshops discussing some of the other applications. The conclusions from the evaluation are presented in the next section.

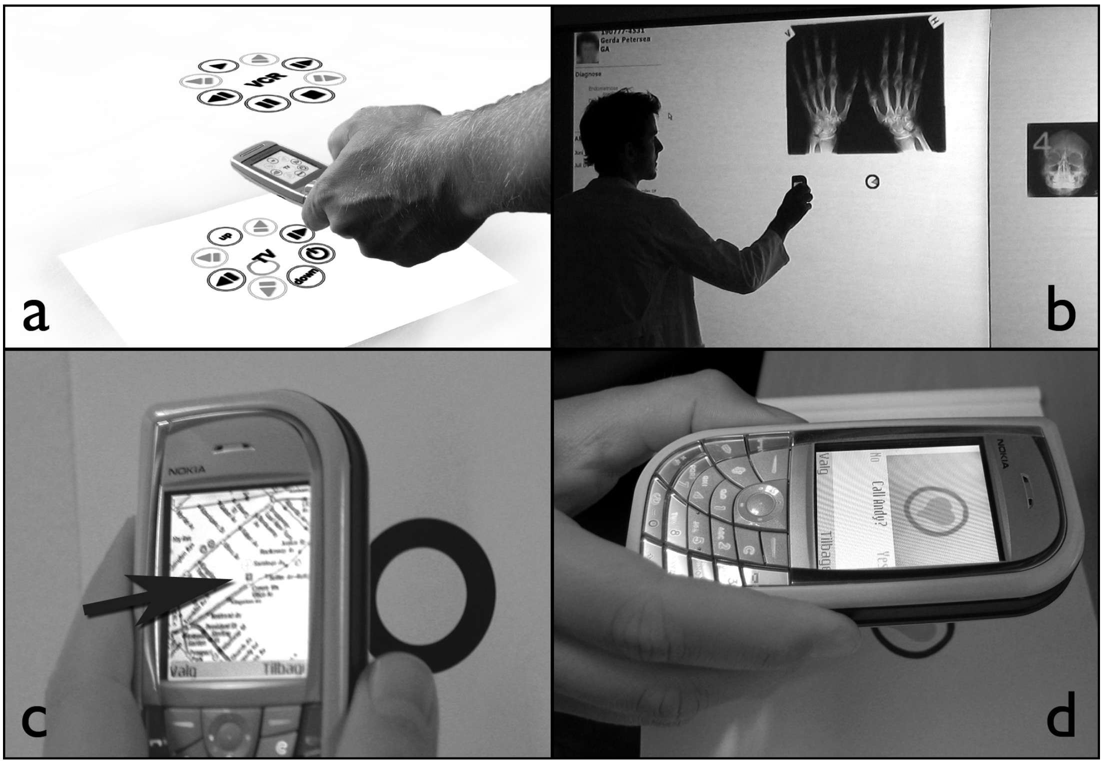

Figure 3: MIXIS applications (a) Diagram of the LayeredPieMenu application. (b) DROZO in use on a wall display. (c) ImageZoomViewer in use. (d) DrawME, "Call Andy?" "no" – left, "yes" – right.

ImageZoomViewer

The first application allows the user to pan and zoom simultaneously on a picture by moving the phone in the mixed interaction space, see Figure 1c. When moving the phone closer to or further away from the circle the application zoom in and out on the image. Moving the phone to the left - right or up - down makes the application pan the image in the direction the phone moved. We have worked with a basic scenario; navigation on a map. Maps are normally too large to fit on the screen of a mobile device and users need both an overview of the entire map and details like street names. In Figure 3c we demonstrate the use of the ImageZoomViewer for browsing a subway map, here using a printed circle placed on a wall. The arrow points at the visual cue displayed on top of the map that indicated what kind of interaction the user was performing. In the picture the visual cue on the display shows that the user has placed the physical circle slightly to the right of the centre of the camera view why the visible area of the map is panning slowly to the left. The applications resembles the application implemented by [Yee 2003, Fällman et al. 2004], but in our application no specialized tracking equipment is used and we were able to both pan and zoom at the same time.

LayeredPieMenu

In the application called LayeredPieMenus MIXIS is investigated and used to navigate a menu structure. The interaction space can contain numerous menus organized as pie menus [Callahen et al. 1998] on top of each other. When the camera recognizes the circle a pie menu appears and augments the circle on the display. The pie menu consists of up to eight function segments that surround an info text explaining which menu is at hand. The functions in each menu can be selected by panning the phone towards the specific segments and back to the centre. By making a simple gesture towards the circle and back again the next menu is selected and moving the phone away from the circle and back again selects the previous menu. The diagram in Figure 3a demonstrates the principle of the LayeredPieMenu application where virtual pie menus are stacked on top of each other.

DrawME

In the DrawME application the device is, besides from recognizing the clean circle, also able to distinguish between a set of hand drawn symbols within the circle. Like in [Landay et al. 2001] DrawME opens up for the idea of drawable interfaces where the user is able to draw shortcuts, to applications in the real world e.g. on paper, whiteboards and walls. In a sense the user add another layer or functionality to disposable doodling. When the user draws a circle containing a specific symbol the camera recognizes the input and performs the function mapped to the specific symbol. The algorithm stores a set of masks of known symbols and finds the best match between the symbol in the centre of the circle and the known masks. At the moment the mask is hard-coded to the different symbols, but we are working on a user interface for creating and mapping new symbols. In DrawME we mapped different symbols to the single function of calling a certain contact from the address book illustrated in Figure 3d. To either confirm or reject calling the contact appearing on the display the user pan towards the yes and no icons displayed on the phone interface.

DROZO

The application Drag, Rotate and Zoom (DROZO) focus on how the mobile device can be used to interact with pervasive devices in the surroundings equipped with an interactive circle. The commands are sent through a generic protocol, see Figure 2. We enhanced the application by putting a circle underneath an x-ray picture on a large wall display, allowing the user to drag the picture around on the screen using the mobile device. The user is able to zoom in and out on the picture by moving the device closer to or away from the display, and to rotate the picture by rotating the phone. In our first prototype we used GPRS to communicate between the wall and the phone, but in the new version we use Bluetooth to communicate between the device and the screen. To be able to rotate the picture we added a small mark to the circle that allowed us to detect rotation as illustrated in figure 3b.

Evaluation

Our main purpose of introducing the MIXIS concept is not to argue that this is necessary a faster way to interact with mobile devices: Our main purpose is to show an alternative and more flexible interaction concept. With the ImageZoomViwer we performed a usability test with fifteen persons to see if it is feasible to use MIXIS as an interaction technique. We have had some preliminary experiences with some of the other applications at a workshop where we invited a group of users and their children to test some of the applications. However, in this paper we will focus mainly on the usability test of ImageZoomViewer.

Usability Test of ImageZoomViewer

We wanted to investigate if users were able to use our interface as efficient as the traditional interface offered by mobile devices, to use the result as guidelines for further development. Therefore a usability study was conducted, comparing the ImageZoomViewer application to a standard application for picture viewing from Nokia. An even more important aspect was to test if MIXIS was perceived as a fun complement to traditional interaction techniques. The participants were 15 in total, and they had various degrees of experience from mobile devices, spanning from not owning one to software developers for mobile phones. None of them had ever before seen or used gesture interaction for mobile devices.

The test was performed in a quiet conference room, a Nokia 7610 mobile phone was used, and there was a drawn circle on a white paper on the table. The two tasks were designed to test map viewing, a typical use case for mobile devices, including shifting degrees of zoom for overview and detail. For each of the two tasks, a conventional Nokia interface for image viewing using buttons was compared to the ImageZoomViewer application. Each participant did both tasks using both interfaces, where half of the participants started out with the conventional interface and half with the new interface and then switched for the second task. Before starting instructions were given in both techniques and both interfaces were practiced on a dummy data set for a few minutes before proceeding with timing tasks. For each task a new data set was used, to reduce learning effects. The order in which the different data sets were used changed for half of the test group.

Task 1

First application: Given a subway map, locate the blue line and follow it from the most southern end station to the most northern end station of that line. Read the names of the end stations out loud.
Second application: Locate the green line and follow it from the most southern to the most northern station. Read the names of the end stations out loud.

Task 2

Second application: Given a second subway map, locate a station in the centre of the map and tell out loud the colour of all the lines that stop there. Follow one of those lines to the two end stations and tell the name of those.
First application: Go to a different centre station and tell what lines stop there. Follow one of those lines to its both end stations, and tell the names of the end stations out loud.

Result of Usability Test with ImageZoomViewer

Independent of what data set or interface, the user error rates were not significant, and there was no difference between the two data sets for each task. After the test was over, the participants were asked which application they preferred. The majority of the test persons, 80%, strongly preferred ImageZoomViewer for map viewing. Table 1 and 2 presents a summary of the experimental data. The conventional interface was 6% faster then ImageZoomViewer in the first test, but in the second test the ImageZoomViewer was 9% faster, as illustrated in Table 1. These results show that gesture interaction with ImageZoomViewer is a quicker method the second time, concluding that with some practice the concept is actually a more effective navigational technique.

During the user tests, it became obvious that the distance between the camera on the mobile device and the circle on the object was very relevant. The female test persons were a bit shorter in height, and the positioning of a circle on the table made the phone end up closer to the face leading to that the interaction was not natural to the same extent as for the men. It was a lack in our test that the test persons were not asked to test different positions of both the circle and of themselves, to find the most comfortable and effective distance.

The most positive comments were about the direct connection between the physical movement and the interface, and also the possibility to pan and zoom simultaneously. The overall experience was that it was intuitive, fun and effective. The most frequent complaint concerned the refresh rate and the sensitiveness of the system. This problem was due to the size of the circle: we should have chosen a larger circle, since enlarging the circle also enlarges the span of the interaction space and therefore the gestures. The ImageZoomViewer was due to the sensitiveness considered a bit less precise than the conventional interface. In some cases there were comments about the small size of the letters, which was a problem due to the quality of the picture we had chosen.

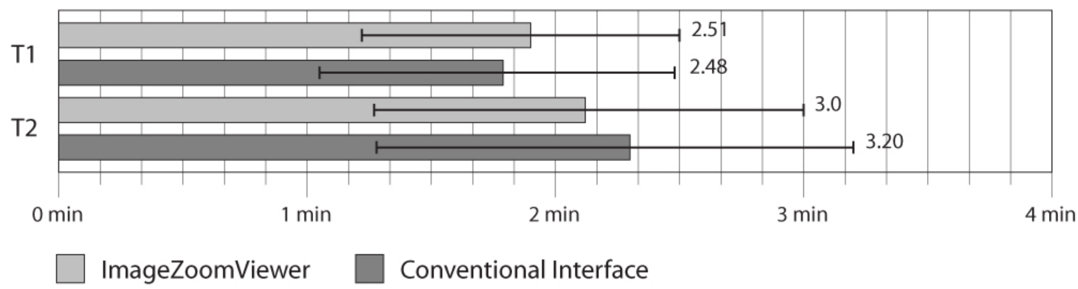

Table 1: Experimental data from the usability test where ImageZoomViewer was tested against a conventional Nokia interface for viewing pictures. The bars represent the time to complete two tasks (T1 and T2) for each interface.

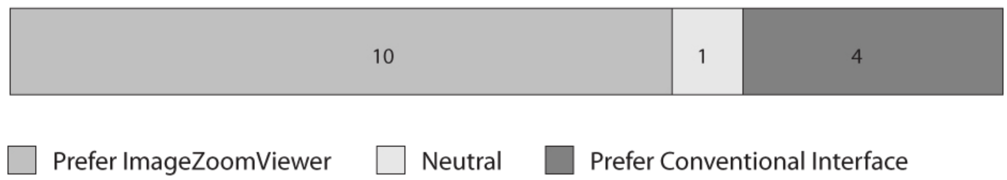

Table 2: Subjective preferences from the usability test.

Discussion

The main outputs from the tracking component are the location and rotation of the device in relation to the fixed-point and in some cases information about the symbol inside the circle. Applications can use this information in a number of ways to interact with the device. This flexibility open up for the creation of a wide variety of different types of applications as shown above. We found two aspects relevant in describing the characteristics of the different application. The first was how the movement of the phone in the mixed interaction space was mapped to the application and the second was if the tracked fixed-point was associated with an identity or ID. Below we will thoroughly discuss these two aspects.

Mapping Applications to the Mixed Interaction Space

Basically two different types of mapping were found present in the applications we explored, natural and semantic mapping.

Natural Mapping

In the first type of applications we tried to make a tight coupling between the physical movement and the application, trying to accomplish natural mapping introduced by Norman [Norman 1999]. One example of this is in the ImageZoomViewer application, where moving the device to the left, right, up or down makes the application pan the image. Moving the phone closer or further away from the circle the application zoom in and out. Another example is the DROZO application that uses the rotation of the phone to rotate the current picture.

To further discuss mapping we need to introduce a distinction between absolute and relative mapping. In absolute mapping there exists a one to one mapping between a specific position in the mixed interaction space and the application. E.g. each time the phone is in a specific position in the space the application will scroll and zoom to the same position. The project suggested by Yee uses what we call absolute mapping [Yee 2003].

Relative mapping maps a specific position in the space to a movement vector instead of a position. Keeping the device in the centre of the mixed interaction space resembles the movement vector null, which we call the stable zone illustrated in Figure 4. If the device is moved outside the stable zone the position of the device is mapped to a movement vector in the application. E.g. moving the device to the left of the stable zone would be mapped to keep scrolling to the left until the device is moved back into the stable zone. The further away the device is moved from the stable zone the faster the application scrolls. The project suggested by Fällman uses relative mapping [Fällman et al. 2004].

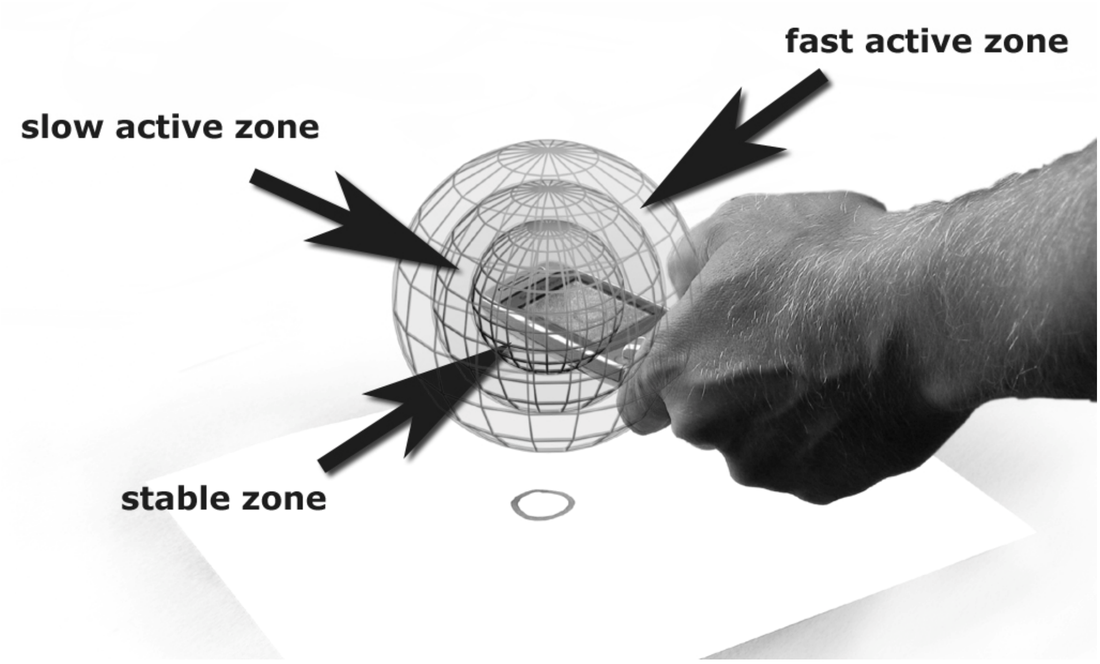

Figure 4: Diagram of the stable zone in relation to the drawn circle.

We explored both relative and absolute mapping in e.g. the ImageZoomViewer application. With absolute mapping moving the phone towards the circle results in a zoomed in picture, moving the phone to the left edge of the space moves the focus to the left edge of the picture and so on. One of the problems with absolute mapping is that the Mixed Interaction space has the form of an inversed pyramid (see Figure 1a), meaning that, if the device is close to the fixed-point, the x, y plane is smaller than when the device is far from the fixed-point. This property makes mixed interaction space unsuitable for absolute mapping or at least absolute mapping on all three axes. It is still possible to use absolute mapping for instance for zooming and then use relative mapping for panning. We found two other problems with absolute mapping. The image captured by the camera has to have similar size as the picture being watched; otherwise a small movement with the device will make the picture jump several pixels. Secondly, because the mechanism for determining the exact position and radius of the circle is not always exact, the picture becomes more vivid than with relative mapping.

Relative mapping is best suited in our applications. As an example, using a circle with a diameter about 2,5cm made a stable zone approximately 10 cm above the circle as illustrated in Figure 4. When the device is within this zone the picture is fixed and when moving the phone forward towards the circle or away from the circle the picture is zoomed in or out with a speed relative to the distance from the stable zone. The same applies for panning. The disadvantage with relative mapping is that it does not provide the same spatial awareness as absolute mapping about the position on the picture. Relative mapping is used in the evaluated applications.

Semantic Mapping

The second type of mapping we use is what we call semantic mapping. With semantic mapping moving the phone in a specific direction does not necessarily map to the application moving in the same direction. With semantic mapping a metaphor is used to bridge between the physical movement and the action on the device. For instance moving the phone to the left might correspond to the action play media file and not to move left. This kind of mapping resembles the mapping used in gesture based application where performing a gesture is mapped to a specific function and not the same movement in the interface. A characteristic of semantic mapping is that it is discrete; the space is divided into different zones that can be mapped to activate different functions. E.g. in the LayeredPieMenu moving the phone down towards the fixed-point and into the stable zone is mapped to the function "go to the next menu". The semantic mapping between the gesture in the interaction space and the application can be arbitrary which also results in problems with purely gesture based interfaces. How are the gestures the system recognizes visualized and how are these gestures mapped to the different applications? With LayeredPieMenu we use the display of the mobile device to guide the user. By graphically visualize the different menu items in the display the user was helped figuring out e.g. that making a gesture to the left would activate the function displayed to the left on the screen.

Mixed Interaction Space with or without Identity

One of the main strengths we found of Mixed Interaction Space in comparison to other systems [Rohs 2004, Semacode, Spotcode] is that the system also works with simple symbols e.g. a circle drawn by hand. We found, that a set of very different applications could be designed by giving the circle different types of identity. We made a distinction between interfaces needing solely a simple circle to function (simple fixed-point interfaces), interfaces that uses a simple fixed-point with an associated icon drawn by hand (drawable interfaces) and interfaces that need to associate a unique ID with the fixed-point (identity interfaces).

Simple Fixed-Point Interfaces

The simple circle interface proved to be the most flexible. A simple interface just needs to have the software to recognize a circle to work. The circle could be drawn with a pen, but we also explored how to use different things as a marker like special finger rings or a black watch. The ImageZoomViewer and the LayeredPieMenu are examples of simple interfaces.

5.2.2 Drawable Interfaces

The main characteristic of drawable interfaces is that the system is can recognize different symbols drawn by hand within the circle and provide a set of different mixed interaction spaces on top of each circle, as illustrated in DrawME. Landay et al. [2001] present an application recognizing the widget in a hand drawn interface. We wish to pursue the possibility with drawable interfaces, but in contrast to Landay in our system the drawing is the actual interface.

Instead of squeezing a lot of functionality into a single device, drawable interfaces are able to customize the interface with only the functions required in the given situation. The drawn symbols can be seen as physical shortcuts into the digital world and resemble TUIs that also try to distribute the controls to the real world. One of the problems with TUIs as pointed out by Greenberg [2002] is that you have to carry a lot of special tangible objects with you if you want to use these interfaces in a mobile setting. Greenberg [2002] propose to use easily customizable tangible objects, but still you have to use a set of tangible objects. With drawable interfaces all you need is a drawable surface and a pen, and after use the interface can be wiped out or thrown away.

Another advantage with drawable interfaces is that each circle can be associated with a 4D mixed interaction space with the interaction possibilities demonstrated in e.g. ImageZoomViewer.

Furthermore this application can be combined with the LayeredPieMenu concept as a fast physical shortcut to certain predefined functions in the phone e.g. the four most called persons, send/receive mail and so on.

The number of symbols the system recognizes and tracks is dependent on the software, the hardware and the context. Sometimes it is difficult for the application to recognize a colour because the colour seen by the camera depends on the quality of the camera, the lightning, the pen used to draw the colour, and the surface. Therefore a small set of different colours are best suited for drawing the symbols. The same restriction applies for symbols. Because the symbols are hand drawn and not computer generated to symbols never looks exactly the same. Choosing a set of symbols that does not resemble each other works best with drawable applications.
Drawable interfaces opens up for a whole new area of customization and personalization of the interface of the mobile device, which is one important factor contributing to the success of mobile devices. The user is able to adjust the device to recognize new and personal symbols, to make it even more "intelligent" and unique, since the user becomes the interface designer. In the workshop with DrawME, the participants strongly welcomed this possibility to customization, both because it is fun and that it provides the ability to personalize their device. The workshop also taught us the importance of having the user in total control of the mapping, and not have automatic mapping of any kind. We consider that it should be fun to interact with technology, and especially with the mobile and personal devices. Schneiderman [2004] highlights this aspect with a recent question: "Did anyone notice that fun is part of *fun*ctionality?".

Identity Interfaces

In the final type of interfaces the fixed-point is associated with a specific identity or unique ID. The identity can be read by printing a barcode in the circle [Semacode], providing the identity by using short range Bluetooth [Blipnodes] or by RFID tags [Want 1999]. The corresponding mixed interaction space can then be stored in the device, transmitted through for instance Bluetooth or downloaded from the internet. We used identity interfaces in the DROZO application.

Identity interfaces are especially suitable for interacting with external devices or as shortcuts to specific places on the internet. Using MIXIS to interact through identity interfaces can be seen as a possible method to interact with the "invisible computer". When computers get smaller, embedded or even invisible it is becoming more difficult for the user to know how to interact with them. A circle on a wall can be used as a visual cue, signalizing the existence of a hidden MIXIS interface and can at the same time be used as fixed point for the interaction space. In this way, the context can be used to reduce interface complexity.

Conclusion

The main contribution of this paper has been to introduce Mixed Interaction Space, a concept that investigate and demonstrate that the interaction with mobile devices is not something that has to be limited to the screen and buttons on the phone. By using the camera of a mobile device we are able to combine the phones abilities with the physical environment and introduce a new interaction concept.
In this paper the main focus has been to introduce MIXIS and demonstrate some novel applications with the concept. The applications use the camera in the mobile device to track a fixed point and thereby establish a 3 dimensional interaction space wherein the position and rotation of the device is calculated. The first application, ImageZoomViewer, allows the user to pan and zoom simultaneously on a picture by moving the phone in the mixed interaction space. In the application called LayeredPieMenu the mixed interaction space is used to navigate a layered menu structure. In the DrawME application the device is able to distinguish between a set of hand drawn symbols within the circle. The application Drag, Rotate and Zoom (DROZO) focus on how the mobile device can be used to interact with pervasive devices in the surroundings equipped with an interactive circle.

Mapping and identity, two central issues with MIXIS have been discussed and some relevant distinctions and design challenges have been pointed out. However, mapping and identity are just two aspects of MIXIS and we can see several other possibilities in combining tangible interfaces and mobile phones. Because the mobile phone is a highly personal device most people have we are e.g. currently looking into how to use the concept to design multi-user applications and so far MIXIS seems to have some interesting properties in this domain.

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12.4 MOVEMENT-BASED INTERACTION IN CAMERA SPACES – A CONCEPTUAL FRAMEWORK

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Abstract

In this paper we present three concepts that address movement-based interaction using camera tracking. Based on our work with several movement-based projects we present four selected applications, and use these applications to leverage our discussion, and to describe our three main concepts *space*, *relations,* and *feedback.* We see these as central for describing and analysing movement-based systems using camera tracking and we show how these three concepts can be used to analyse other camera tracking applications.

Keywords

Movement-based Interaction, Camera Spaces, Mixed Interaction Spaces, Camera Interaction, Mobile Phone Interaction

Introduction

Every interaction is in some sense movement-based: pressing a key, moving the mouse, or uttering a sound. By emphasizing the word *movement* in movement-based interaction though, movement is no longer just the source of interaction; it becomes the central element in the interaction. Movement-based interaction seems to be especially suited for interaction that takes place in a public or social context, and it provides interesting alternatives to traditional interaction techniques within social settings, games, public places, for encouraging exercise, and in mobile settings. Using movement-based interfaces, however, can be strenuous and is thus less suited for continuous e.g. desktop work. Location-aware games [1], fitness games [2], and interfaces based on accelerometer input [3, 4] are examples of already available systems based on movement-based interaction.

Cameras are a common ubiquitous sensor in movement-based interfaces and the wide-spread use of camera phones and webcams makes camera-based computer vision a feasible platform for novel interfaces. Hence applications that use real-time camera input are already common within the research areas of tangible user interfaces, virtual reality, sensor-based computing, ubiquitous computing, pervasive computing, and augmented reality. Within the computer vision community there is thus a great interest in analysing and extracting information from the video stream and use this information to provide new ways of interaction [5, 6]. However, little research has focused on how to actually use vision to design applications and on how to describe, compare, and characterise different approaches towards camera-based interfaces.

In this paper we focus on movement-based interaction that uses cameras to detect movement. Cameras have a limited field of view and the area within the camera's view can be seen as a bounded space. We call this space a *camera space.* It is only within this space movements can be detected and registered. By mapping the movement within a camera space to a virtual space in an application a combined space is obtained. We refer to this type of space as a *mixed interaction space* [7] pointing to the space being both physical and virtual. The mixed interaction space is a subset of the mixed reality concept with a major focus on space.

Based on our work with these types of spaces we present a conceptual framework for movement-based interaction based on camera spaces. The framework is grounded in four projects briefly described and discussed. Due to the spatial nature of camera spaces we have drawn on an architectural understanding of space which will be unfolded later on in this paper. The framework is build around the three central concepts of *space*, *relations,* and *feedback*. The concept of *space* describes properties of the mixed interaction space. The mapping between the captured physical movements and the virtual domain is captured by the concept of *relations.* The concept of *feedback* finally describes how the digital events are visualized to the users. The framework is finally used to present and discuss a number of movement-based interfaces, and hereby we demonstrate how the presented framework provides explanatory power beyond the scope of our own projects.

Related Work

Within several different research fields there are frameworks and taxonomies briefly touching upon the capabilities and aspects of camera sensor technologies. Together these frameworks form an important base, but being too general in their nature none of these go into depth with the specifics and potentials of camera-based interaction technologies and the use of them. As the main contribution of this paper is to present a conceptual framework for movement-based interfaces using camera tracking, we here present a short overview over some of the extensive related work, and use this as a springboard to a more in depth analysis.

In [8] Mackay presents the concept of augmented reality as opposite to the, then, increasing focus on virtual reality. Three basic strategies to augmented reality are presented, where video cameras as tracking sensors are used as examples to augmenting the environment surrounding the user and the object, but not discussed further. In [9] Benford et al analyse sensor-based interfaces in general, including a discussion of camera-tracking. They point out several problems with camera-tracking, such as the number of cameras needed, the frame rate, the field of view limits the extent of traceable surfaces, and that camera-tracking systems are usually unable to cope with different objects, multiple objects, occlusion, and changes in lightning. The two papers do not further discuss the possibilities with this technology. We take the opposite approach and explore how camera-tracking systems' strengths and weaknesses can be used in the process of developing movement-based interfaces.

In [10], Abowd et al state that research in ubiquitous computing implicitly requires addressing some notion of scale, whether in the number and type of devices, the physical space of distributed computing, or the number of people using a system. They posit a new area of applications research, everyday computing, focussed on scaling interaction with respect to time. Scale is further discussed by Ullmer and Ishii in the conceptual framework [11], which focuses on the characteristics of tangible user interfaces (TUI). Tangible interfaces are here divided into groups labelled spatial, constructive, relational, and associative. Camera-tracking systems can be found in all of the presented groups. The paper states that several concepts need to be explored further, e.g. physical scale and distance. Our aim is to continue some of these discussions by focusing on e.g. the aspects of space and scale in camera-tracking systems.

In [12] Holmquist et al strive to create a common vocabulary to systems where a physical object is used to access digital information stored outside the object. In Fishkin's taxonomy for tangible user interfaces [13], categorizations and definitions from previous frameworks are unified, such as the vocabulary of [12] and the classification system from [14]. Fishkin further suggests that tangible user interfaces are leaving the traditional computer-human interfaces into the realm of human interfaces in general, and draws more towards the communities of industrial design, kinesthesiology, architecture, and anthropology. We agree in this change in departure for TUIs in general, and especially for systems based on camera-tracking. In our work we have a base in the conventional computer virtual world, but we use inspiration and relations from the physical world, especially from the fields of architecture and kinesthesiology.

Surely, a lot have been left out, but the frameworks presented here are examples that cover a wide spectrum and involve different general perspectives on camera-tracking systems. These frameworks create a framing to the context of camera-based systems, and they provide tools of how to analyse, define, and re-design different types of systems in this wide context. Still, we stress the need for a more specific tool developed for camera-tracking, since these related frameworks present a too general picture and do not pay enough respect to the specific characteristics of camera spaces.

Movement-Based Applications in Camera Spaces

To frame and inspire the discussion of the movement-based framework we start out with a brief presentation of four selected movement-based projects. The first two applications are developed around an interactive floor with a ceiling mounted camera-tracking the people within the camera space. The last two applications use the mobile phone's camera to track different features, e.g. circles, coloured objects, or a person's face. The movement passed to the application is either the movement of the camera (the mobile device) or the movement of the tracked objects.

Application One: iFloor

iFloor is an interactive floor facilitating the exchange of information between users of a public library, as well as bringing some of the services that the library offers on the internet into the physical library. A video tracking system tracks the movements and size of the people present along the edges of the display. A single person or a group of people will attract a circular cursor that expands and highlights the different questions and answers displayed on the floor. As soon as a person is recognized by the camera within the legitimate space a string is drawn from the shared cursor to the person indicating a successful established relation and ongoing interaction. The cursor distributes a string to each person around the floor and calculates the resulting vector which determines the overall movement direction. The cursor is shared between all participants, why a collaborative effort and physical movement is necessary in order to navigate the cursor on the floor [15]. The iFloor prototype and the tracked movements are illustrated in Figure 1.

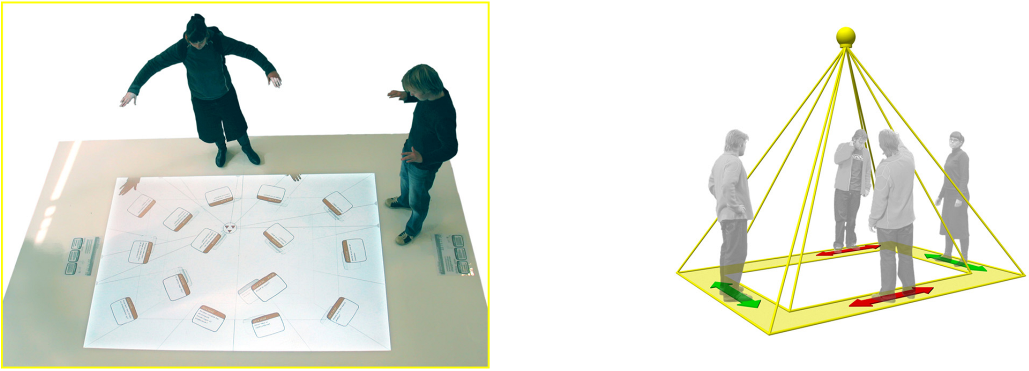

Figure 1: The iFloor prototype and a diagram of the tracked movements

Application Two: StorySurfer

StorySurfer is an interactive floor application displaying book covers which provide an alternative way for children to browse the library's collection of books. The book covers are evoked by stepping on buttons on the edge of the floor. Each button is associated with a keyword. Hitting a keyword button will evoke a cloud-like shape on the floor containing book covers associated to the selected keyword; overlapping clouds contain book covers associated with several keywords. A cover can be further examined by moving into the floor. Each person entering the floor and the camera space is provided with a cursor in the shape of a "magnifying lens" oriented and positioned in front of the user turning towards the centre of the floor. Thus the "lens" is controlled by the children's body movements. Keeping the lens icon still over a projected book cover causes it to enlarge for better inspection and maintaining the position even a bit longer will cause the image to move across the floor to an interactive table [16]. Figure 2 shows the StorySurfer prototype and the tracked movements.

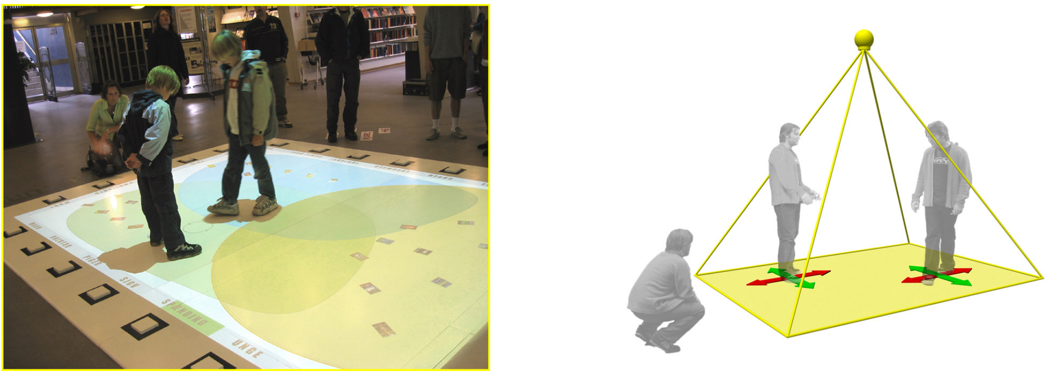

Figure 2: The StorySurfer prototype and a diagram of the tracked movements

Application Three: ImageZoomViewer

The ImageZoomViewer that is build on the Mixis tracking technique [17] is an application for mobile devices. It uses movement-based interaction to navigate in a map or a large image. The mobile device tracks either a hand-drawn circle, any coloured object, or the user's own face if the device is equipped with a second camera pointing towards the user. If the mobile device is close to the feature the application zooms in on the map, if the device is far away from the feature the application zooms out, if the device is to the left, right, up, or down in relation to the tracked feature the application pans accordingly. Figure 3 shows the ImageZoomViewer application running on a mobile phone and a diagram of the tracked movements. [17]

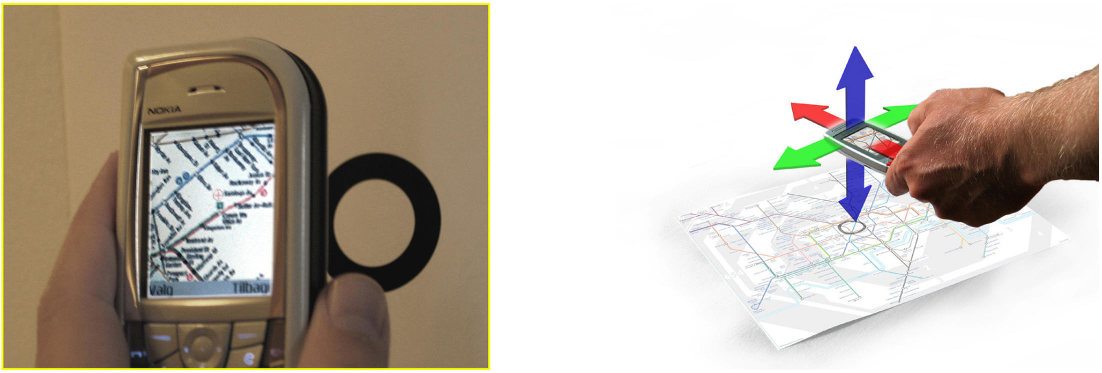

Figure 3: The ImageZoomViewer prototype navigating in a map with gestures and a diagram of the tracked movements

Application Four: PhotoSwapper

The PhotoSwapper is build on the Mixis tracking technique [17]. PhotoSwapper is an application that allows the mobile phone to operate a cursor on a shared display. Several users can connect to the shared display with their own personal device resulting in several simultaneous cursors. The cursor can be moved on the shared display by moving the mobile device in relation to the tracked feature: moving the device closer to the feature results in a pick-up action, while moving the device away from the feature is mapped to a drop action. It is possible for up to seven users to connect to the same shared display, thus operating seven independent camera spaces simultaneously and using them as input in the same application. Figure 4 shows the PhotoSwapper application and a diagram of three camera spaces connected to the shared display. [18]

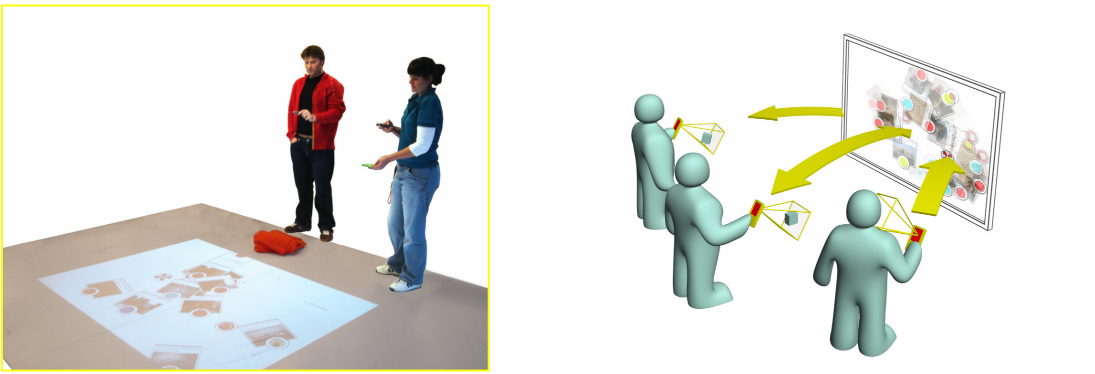

Figure 4: The PhotoSwapper prototype and a diagram of the camera spaces and feedback areas

Application Summary

Despite the projects different foci, setups, and use situations we present some recurrent themes binding these projects together. The main findings from the individual projects are presented elsewhere [15, 16, 17, 18].

First, *movement and space* play a central role in the four presented applications, but are used in different ways. In the first two applications the tracked features are human bodies moving around in a large static camera space, whereas in the last two applications it is the entire camera space that moves in relation to a set of tracked features and not the tracked features that move within the camera space.

Second, a special relationship exists between the camera and the features being tracked and used for interacting with the system. In application one and two several features (human shapes) are tracked and all user movements affect the system. In applications three and four a single feature (a symbol, a coloured object, or the user's face) is tracked, where changes in the location of the feature as well as changes in the camera position will affect the interaction. We call the relationship between the camera and a tracked feature a *relation*, because it is the changes in this relationship that trigger the interaction.

Third, these interfaces are not traditional desktop interfaces, why there is a clear need as well as many possibilities for providing user *feedback*. We distinguish between feedback mainly focused on the input system (*input feedback*), and feedback from the application about its state (*application feedback).*

In application one and two the input feedback is provided visually on the floor on top of the application feedback. In application three input feedback is visually overlaid the application feedback but in a very limited screen area. Finally, in application four all feedback is moved from the mobile device onto the shared display, combining input feedback and application feedback on the same display for multiple users. The feedback used in these applications is purely visual but other types of feedback will also be discussed.

Based on our work with the above described applications we hence find *space*, *relation,* and *feedback* to be central concepts useful for describing, explaining, and comparing movement-based interfaces based on camera spaces. *Relations* describe how users manipulate the system and provide input. *Feedback* describes how the computer system informs the user about its state and provides output, and *space* provides a context for the interaction by constraining and influencing the way in which interaction can take place.

Describing Movement-Based Interaction in Camera Spaces – Three Central Concepts

Space

A camera space has the shape of a pyramid. Close to a tracked feature the space is small, but expands the further away from the feature the camera is, until it finally blurs out (when a feature is too far away from the camera to be registered). Combined with a digital application the space becomes what we call a mixed interaction space. The mixed interaction space is the combination of a physical camera space and a digital application space, existing within the same setting. The setting can be seen as a physical space containing the mixed interaction space, e.g. a library, a hallway, a street corner, or an office.

Interaction, which results in a division of space between what is interaction sensitive and what is not, can only occur within the camera space. Before the Bauhaus period [19] space was understood and defined as a container that could contain other containers (spaces). During the Bauhaus period space was seen as a continuum where spaces dynamically would intertwine and flow among each other. This continuous space was changed by the observer moving in space. In our work we expand this understanding of space further through ubiquitous computing and virtual augmentations. With the dynamic nature of digital systems and interfaces the perception of space is not only changed by the observers moving point of view, but the space itself is dynamic, both regarding appearance and functionality. We hence see space as being highly defined by the potential functionalities afforded by areas or spaces within a continuous space, and not only as a container defined by a three-dimensional set of physical and virtual boundaries.

We see space and the physical environment as a design resource open to virtual and interactive augmentation. Using camera-based interaction we can design spaces that correspond perfectly with traditional physical spaces, where different connected but distributed spaces afford different functions and norms for social and working behaviours. An example of this is the kitchen where you cook, compared with the living room where you can crash on the couch and watch TV. As camera spaces are physically constrained they mime the pure physical spaces loaded with a certain functionality, however the augmented digital properties make the nature of these spaces different from traditional spaces for a number of reasons. Camera spaces can afford numerous functionalities depending on the specific user/users, time of day, kind of activity, and so on. This opens up for temporary ownerships of space or situations where different users of the camera space perceive it the space differently in a use perspective, or don't see it at all. Furthermore, functions are usually associated with specific parts of our build environment as e.g. the kitchen or bathroom, but camera spaces can adapt to any space because of its multi-scaled nature, understood in the sense that the kitchen has a scale that is adjusted to the human body, whereas camera spaces can take on any scale. As the camera space is not a physical container but just an area with extra or advanced properties, it can be established, moved, or wiped out instantly, changing the way user and space can engage and interact with the environment. Figure 5 shows how a camera space can be scaled to cover from small objects to several users depending on the distance from the camera to the tracked objects.

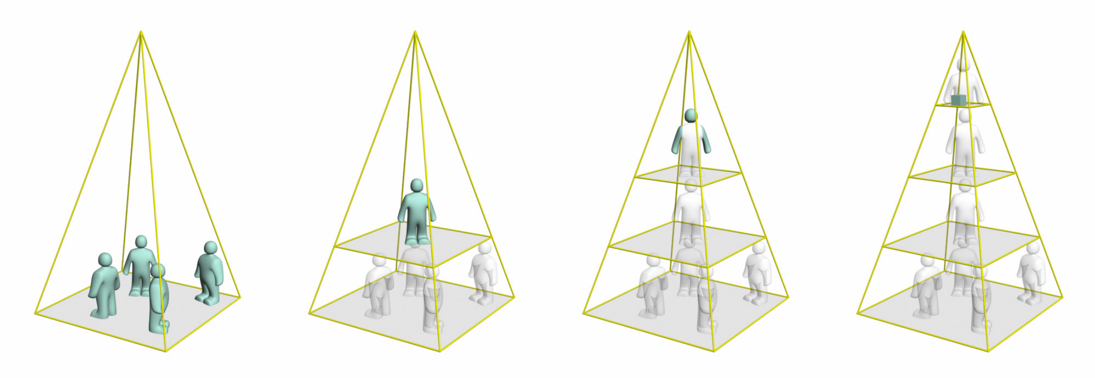

Figure 5: Scales of camera spaces; diagram showing how the same camera space can adapt to different scales of space and feature

As computer systems migrate into our physical environments space becomes an important player in the design of future interactive environments. Therefore we have to accept and play with the properties of physical space and their influences on the types of interactions. We characterize the camera space by a number of properties – type, scale, and orientation. The four above described applications show how the camera space can either be *static* or *dynamic.* In static camera spaces movement occurs when tracked features move in the camera space. In dynamic camera spaces it is the camera space itself that moves in relation to the tracked feature, see Figure 6.

In the large scale applications iFloor and StorySurfer the camera space is static and the ceiling-mounted camera tracks the people who, at the same time, are the users of the system. In the small scale applications (ImageZoomViewer and PhotoSwapper) the camera space is dynamic and used to track primarily small static features. The user is in charge of moving and orienting the camera space.

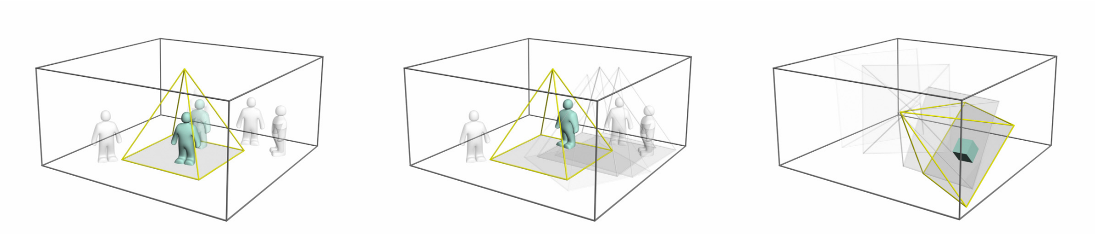

Figure 6: Static and dynamic camera spaces; a static camera space and dynamic features, b 2D dynamic camera space and static feature, c 3D dynamic camera space and static feature

Another property we have identified regarding *space* is the orientation of the camera space. As described earlier the camera space exists within a larger but continuous space. The importance of *orientation* is highly related to *scale,* and the relation between the user and the *space*. If we look at basic architectural elements such as walls, floors, and ceilings taking part in the definition and framing of physical space, we see that the orientation of the camera space influences the way in which a feature, being static or dynamic, can interact with the system. The floor is due to gravity our most shared architectural surface [20], why we as humans are used to act on the horizontal plane, see Figure 7. As gravity forces objects to the ground, tracked features in a horizontal camera-space will most often exist on the two dimensional ground plan. Trackingwise the horizontal ground plan serves as a two-dimensional coordinate system for measuring positions and movements of tracked features. Orienting the space in the vertical direction, e.g. towards a wall, affords a new set of potential interactions where the feature has to overcome gravity. Most features will not continue to hang in free space, thus this type of space is similar to many situations where gestures and acting are used. Further acting within a vertical camera space the notion of a solid plane is replaced by a more free space in which the z-axis roughly seen as the distance between feature and camera can play a more dominant role in the feature moving away or towards the camera. This difference is most prominent with the larger scale camera spaces, where the users are the features themselves. With dynamic camera spaces orientation becomes less important because of the user's changed role from being a tracked acting feature to controlling the entire camera space. In these setups the focus on physical space diminishes because gravity in some sense has less influence – we are able to move the world.

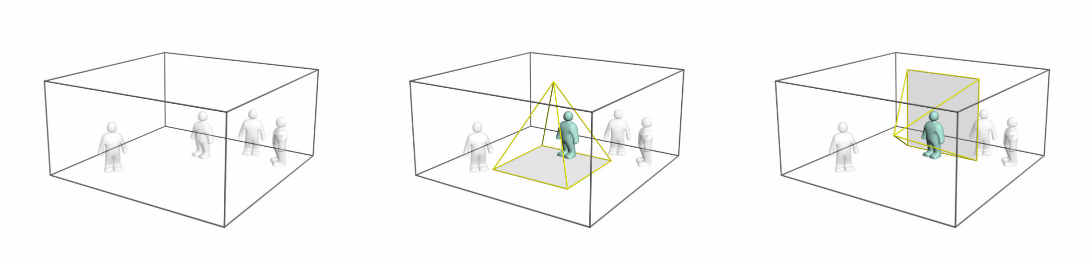

Figure 7: Orientation of camera spaces; a none, b horizontal, c vertical

Relations

Where space defines the context for movement-based interaction, relations describe the connection between a camera and the tracked features within the camera space.

Entities and Properties

A relation is an edge between a camera node and a tracked feature node. The edge can have a number of properties, and since vision algorithms are able to track multiple features a single camera can have multiple attached edges connected to the different features. However, a feature can also be tracked by different cameras, implying that also a feature can have multiple edges attached. Figure 8 shows how an interaction relation is created as a feature enters a camera space and how several relations can exist simultaneously.

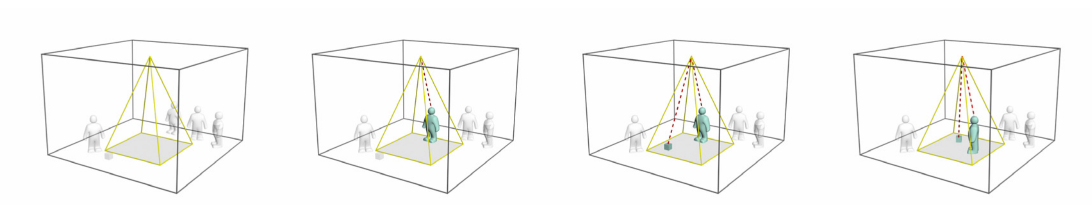

Figure 8: Relations between feature and camera; a none, b one relation, c two relations, d movement

The Mixis ImageZoomViewer application only utilizes a single relation between the mobile device's camera and a tracked feature (circle, object or user's face). In the iFloor application multiple features in form of human shapes are tracked within one camera space. Every time a new person enters the camera space a new relation is created, but the relation is not associated with a specific identity and no distinction is made between the different users. The PhotoSwapper application is the opposite case, where multiple camera spaces are facilitated, still with only a single relation associated to each space. The different relations are combined by the shared application where each user is able to manipulate the interface and receive feedback, see Figure 4.

A relation can be described by a set of properties that defines the potential interaction inputs. The number of properties depends on the algorithm used to analyse the input from the camera. The presence of a feature (on/off), the position of the feature in 1D, 2D or 3D space, rotation of the feature, the feature's size, its state, identity, or information about uncertainty, are examples of properties associated with a relation. Interaction is triggered by mapping a different action to changes in a relation's property.

The number of relations and the number of properties associated with each relation greatly determine the complexity of the interaction. With a complex setup there is a great need to visualize the way in which the user is actually able to influence the application through feedback. The iFloor application directly visualizes the relations present by drawing a line between the cursor and each user (tracked feature). Furthermore, each relation contains a 2D location and a size property based on the volume of the tracked object. Changes in the size property control the force associated with each user's pull in the cursor.

The Mixis applications use only a single relation, but this relation has a 3D location property, and can have a 1D rotation property as well. This design space opens up for a 3D spatial interface, and is hence richer compared to both StorySurfer and iFloor. The ImageZoomViewer application maps the movement in the physical space directly to pan and zoom in the application and it is therefore possible to pan and zoom simultaneously.

We found *direct input* and *gesture input* to be two different approaches on how to map changes in a relation's property to actions within an application. Direct input describes a mapping strategy where changes in a relation's properties directly influence the application. E.g. when a feature is positioned to the left in a camera space an application starts scrolling left. Gesture input describes a strategy where changes in a relation's property is monitored over time and matched to predefined patterns.

Multi-user Interaction

With multi-user systems the relation concept opens up for a discussion about how to map the different relations to the multiple users. In the StorySurfer application each user is given a separate relation associated with an independent cursor. While one user browses the floor content by moving on the floor and hereby invoking a change in the position property, other users can use the magnifying lens to examine a book by standing still, hereby starting a selection timer. The PhotoSwapper also gives each user a separate relation, but in this application each relation is associated with its own camera. In the PhotoSwapper the relations have an extra property where the colour of the tracked feature is transferred to the corresponding cursor on the shared display as a sort of an identity.

Feedback

Movement-based interaction in camera spaces is problematic in the sense that the interaction tool is invisible to the user. The user cannot see what the camera registers or what the algorithms applied calculate. Feedback is hence important in order to visualize the relations that govern the interaction. Feedback from movement-based systems can be divided into *input feedback* and *application feedback*.

Input feedback focuses on telling the user that the input system is actually working; that a relation exists, and that the user is able to control its properties. Bellotti et al. call it attention and use it to describe the problem of knowing when the system is ready and attending to actions [20].

Application feedback provides feedback about the application and its state. Bellotti et al. call this type of feedback alignment and address how to tell the users that the system does the right thing [21].

In the iFloor application input feedback about the relations is provided by a special cursor with a number of strings to each user. The application feedback is simultaneously provided on the floor in form of pictures, questions, and videos, which are highlighted and expanded as the cursor moves over them.

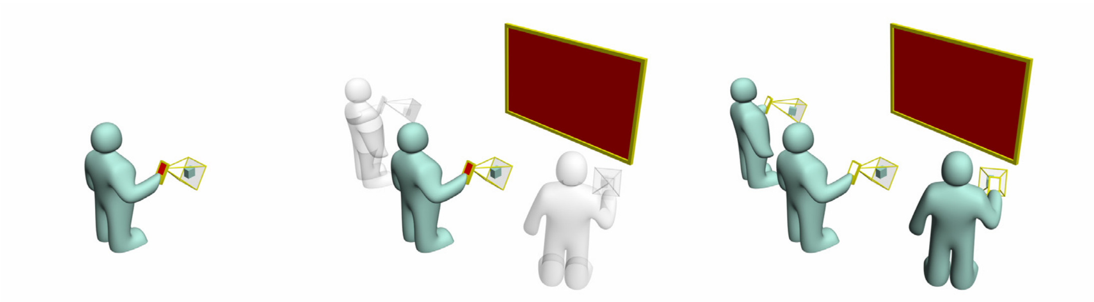

Figure 9: Options of inputfeedback and applicationfeedback; a local feedback, b local and remote feedback, c remote feedback

The four presented applications mainly use visual feedback and during our research it became evident that visual feedback needed to be provided close to the user's focus area. To further analyse feedback we found it useful to study focus shifts inspired by Bødker's work [23]. Bødker differentiates between focus shifts that are deliberate and focus shifts resulting from breakdowns and unsuccessful interaction design.

In the first iteration of PhotoSwapper we had two sources of feedback. The shared display showed information about the cursor and provided application feedback, whereas the display on the mobile device showed information about the position of the feature in the camera space (input feedback). This resulted in a below-average performance and user experience because of constant focus shifts between the mobile device's display and the shared display. We addressed this issue by designing a special cursor on the shared display with information about the input feedback previously provided on the phone. By eliminating a large number of focus shifts we were able to greatly improve the performance of the system. Figure 9 shows the different options for visual feedback in the PhotoSwapper setup.

Analysis of Movement-Based Interaction Systems

In this section we use the presented conceptual framework to analyse other movement-based interaction systems in order to demonstrate the framework's explanatory abilities. Furthermore, we use these systems to clarify our conceptual framework and fill in the gaps of the design space not covered by our own work, for instance non-visual feedback. The systems are selected as prototypes representing a number of different approaches to movement-based camera space interaction.

A Number of Movement-Based Systems

Sony Eyetoy is a motion recognition camera that plugs into a Playstation2 game console. The camera detects movements in the vertical plane from a user, and delimited areas of the screen are able to register input motion during a limited time period. In Beat Freak players are required to move their hands over a speaker in one of the four corners of the screen simultaneously as a CD flies across the speaker [24].

Urp is a tangible interface for urban planning, based on a workbench for simulating the interactions among buildings in an urban environment. The interface combines series of physical building models and interactive tools with an integrated projector/camera/computer node, the "I/O Bulb." [14].

Mouthesizer consists of a miniature head-mounted camera which acquires video input from the region of the mouth. It extracts the shape of the mouth with a computer vision algorithm, and converts shape parameters to MIDI commands, so that the users' facial gestures control a synthesizer or musical effects device. [25]

Kick Ass Kung Fu is a large display martial arts game installation where the player fights virtual enemies with kicks, punches, and acrobatic moves such as cartwheels. With the use of real-time image processing and computer vision the user's video image is embedded inside 3D graphics. By shouting the player can go into a special power mode for a limited time. [26]

The AR Tennis is a face-to-face collaborative application for mobile phones that use a set of three ARToolkit markers arranged in a line. When the players point the connected camera phones at the markers they can see and play on a virtual tennis court model superimposed over the real world. [27]

The above described projects are analysed based on the framework and presented in table 1.

Discussion

By using the above described framework to analyse different movement-based interaction applications a picture is starting to form of how these applications relate and differ. By looking at the space property in table 1 we see that the applications generally fall into two groups; they either use static spaces or dynamic spaces. The applications that use dynamic spaces are generally used to support mobile interaction, while the static spaces are augmentations of specific physical spaces. The Mouthesizer application provides an interesting combination: while the space is static the whole setup is mobile. In the selected projects only applications based on dynamic spaces use multiple spaces, e.g. ARtoolkit tennis and PhotoSwapper; however, applications that combine e.g. two static spaces appear as an uninhabited space open for exploration by new applications.

Table 1. The nine applications arranged after the concept of space, relation and feedback

	StorySurfer	iFloor	Kick Ass Kung Fu	EyeToy beat freak	Mouthesizer	URP	ImageZoom-Viewer	ARTennis	Photo-Swapper
Space									
Type	*Static single*	*Static single*	*Static single*	*Static single*	*Static single*	*Static single*	*Dynamic single*	*Dynamic two*	*Dynamic multiple*
Orientation	*Static horizontal*	*Static horizontal*	*Static vertical*	*Static vertical*	*Static vertical*	*Static horizontal*	*Dynamic*	*Dynamic*	*Dynamic*
Scale	*Humans*	*Humans*	*Human*	*Human/limbs*	*Limbs*	*Object*	*Object*	*Object*	*Object*
Relation									
Feature	*Human shape*	*Human shape*	*Human shape*	*Movement Shape*	*Movement Shape*	*Color dots*	*Color/circle object*	*Tags*	*Color/circle object*
Number	*Multiple*	*Multiple*	*Single*	*Multiple*	*Single*	*Multiple*	*Single*	*Multiple*	*Single*
Presence	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Position	*2D*	*2D*	*2D*	*2D*	*2D*	*2D*	*3D*	*3D*	*3D*
Id	*No*	*No*	*No*	*No*	*No*	*Yes*	*No*	*Yes*	*No*
Other		*Size*			*Shape*	*Rotation*		*Tilt*	*Rotation*
Feedback									
Type	*Visual*	*Visual*	*Visual*	*Visual*	*Audio*	*Visual*	*Visual*	*Visual*	*Visual*
Input	*Looking glass (floor projection)*	*Strings (floor projection)*	*Player representation (wall projection) & Sound*	*Player representation (TV)*	*Changes in sound*	*Overlay e.g. shadows (table projection)*	*Dynamic cursor (phone display)*	*Court/racket (phone display)*	*Dynamic cursor (phone & wall display)*
Application	*Visual (floor projection)*	*Visual (floor projection)*	*Visual and sound (wall projection)*	*Visual and sound (TV)*	*Audio (speakers)*	*Visual (table projection)*	*Visual (phone display)*	*Visual, sound and vibration (phone)*	*Visual (wall display)*

Looking at the orientation we have three different types represented: horizontal surface, vertical surface, or a dynamic space. Looking at Table 1 scale and orientation seem to be related. To use a horizontal orientation setup tracking human movements requires a large surface to move on, e.g. a floor, whereas if the setup scale is smaller and the tracking objects are e.g. limbs or objects a table top is more suitable (Urp). The applications that use dynamic spaces can potentially be used with large scale spaces, however, most of the applications we have looked at use relatively small spaces (ARTennis, PhotoSwapper and ImageZoomViewer). The applications we have chosen cover the scale from multiple human shapes to small objects, thus since camera spaces can be resized freely (only depending on the optics in the camera) this conceptual framework will also be able to describe and analyse smaller or larger camera spaces, e.g. spaces under a microscope or tracking cars in a parking lot.

With relations, the tracked feature is often closely connected to the scale of the space in use. Many projects use several relations, and in most of the projects a single user is given control of only one relation, and the relation controls a single cursor or object. However, two applications are interesting to point out. In KickAssKungFu one user controls several relations as each limb of the body is used to control a relation. In iFloor the approach is exactly the opposite since several users are given their own relation, and these relations are coupled to a single cursor.

Concerning feedback, the chosen applications mainly rely on visual feedback, only the Mouthesizer rely purely on auditory feedback. Even though several applications using more ambient feedback can be found and designed, the use of visual feedback seems to be the most common feedback mechanism for movement-based camera-space systems. To minimize focus shifts almost all the discussed applications use overlays or special cursors to present input feedback close to the application feedback.

Since some of these applications rely on complex interaction with multiple relations with many properties a standard cursor provides too little input feedback, hence specially designed cursors or overlays that visualize the properties of the relations need to be considered and designed. In the ImageZoomViewer application the cursor uses colours and changes in its size to visualize the distance to the feature and the presence/non-presence of a feature. In the KickAssKungFu input feedback is addressed by letting the user be the cursor, and all movements are thus mirrored in real time. However, in EyeToy Beat Freak the application feedback is weaker. Tracking the limbs being or not being in the right position of the camera space to intersect with an object in space-time only confirm the user in being right or wrong, the application do not provide the user with any type of information in orientation, for instance if leaning too much to the left. In Larssen et al. [22] an evaluation of Sony EyeToy was performed on how movement as input would hold as communication in the interaction. The evaluation highlights how challenging it would be to facilitate the interaction, without the use of a conventional GUI for feedback, even though the interaction is not based on detailed knowledge of orientation.

A further issue to discuss in relation to designing camera spaces is frame rate. All the projects described here are exploiting the maximum possible frame rate for the camera to give instant feedback. The frame rate can be seen as a property that connects the relation between space and feature dealing with the match or mismatch between physical space time and interaction space time, which could inspire to new ways of designing camera space interfaces.

Conclusion

Building camera tracking systems is not only about developing technically sound algorithms. Being able to describe and understand the design possibilities and limitations is an equally important factor in the development of a successful system.

With this conceptual framework we have covered some basic concepts relating to movement-based interaction using camera tracking, but there are other important concepts we have left for future work.

Mapping, privacy, tracking inaccuracy, ambient feedback, and affordance seem equally relevant, but to focus our discussion we have chosen the space, relation and feedback concepts.

With the space concept, properties of the setting that the system is deployed in are taken into account. Relation describes different approaches for mapping tracked features to interaction, and feedback address how the users are informed about the events taking place within the digital application. These concepts have proven not only to be useful for analysing our own four applications, but also to point out interesting aspects of a number of other very different movement-based camera tracking applications.

We believe the framework and table presented in this article can be used to describe and analyse a wide variety of movement-based applications in camera spaces. The aim has been to present both a general conceptual framework for comparison as well as provide concrete suggestions for the analysis of individual applications. We also hope that this framework will be useful for exploring novel variants and approaches to the design of movement-based applications with camera spaces.

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12.5 RECLAIMING PUBLIC SPACE - DESIGNING FOR PUBLIC INTERACTION WITH PRIVATE DEVICES

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Abstract

Public spaces are changing from being ungoverned places for interaction to be more formalized, controlled, less interactive, and designed places aimed at fulfilling a purpose. Simultaneously, new personal mobile technology aims at providing private individual spaces in the public domain. In this paper we explore the implications of interacting in public space and how technology can be re-thought to not only act as personal devices, but be the tool to reclaim the right and possibility to interact in public spaces. We introduce *information exchange*, *social support* and *regulation* as three central aspects for reclaiming public space. The PhotoSwapper application is presented as an example of a system designed to integrate pervasive technology in a public setting. The system is strongly inspired by the activities at a traditional market place. Based on the design of the application we discuss four design challenges when designing for public interaction.

Author Keywords

Interaction design, public space, mobile technology.

ACM Classification Keywords

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

Introduction

The information technology present in public spaces is increasing drastically. Billboards are replaced with digital displays, the number of portable devices has increased, wireless networks allow internet connection throughout the urban landscape, laptops are a common device in cafes and coffee bars and surveillance cameras monitor and analyze the life taking place in public spaces. All this technology affects how life develops in the public space. Mobile phones and mp3-players are designed to be single-user devices that most often create small enclosed personal spheres within the public space. Information displays are mainly designed to distribute advertisement or notification and are, with only a few exceptions, a setup for pushing information, where people's role is to consume messages. As a large part of the public space is occupied by commercial interests new rules, regarding acceptable social behavior as well as use of technology, become regulated.

The use of technology in public space today; for either pushing information or for creating personal islands, are to some extent the opposite of the notion of public spaces as being interactive, social, democratic and self-organizing. A number of initiatives have hence worked with using technology to reclaim these aspects of the public space [1, 5, 17, 22, 26, 32]. In this paper we follow this line of work and investigate how mobile, pervasive and tangible technology can be used to design more interactive, social and self-regulated systems for use in public space.

The outset for the discussion is our work with technology in public spaces, both indoors and outdoors. To leverage the discussion we present the PhotoSwapper application. The application evolves around a shared interactive surface where pictures from mobile phones can be viewed, shared, explored and interacted with by multiple simultaneous users. Based on this work, we present a number of design concepts that address design issues relating to balancing *information push* with *information dialog*, *personal spheres* in public spaces with *social interaction* and *control* versus *self-regulated behavior* in public.

Reclaiming Public Space

Public space can in general terms be described as a place open to all, free of charge. In democratic countries public space is considered a space where people can express themselves politically, e.g. through demonstrations, and live out their lives within the law. The use of public space is carried out in different ways. In some cities, urban planning forces people to use cars or other means of transportation to access public places, and some cities are designed to segregate people from other social classes, to minimize the "risk" of being confronted with strangers in the public. In cities not initially planned for cars, public spaces often function as an extension of the living-room, e.g. in Italy where most public life occurs in public places. As stated by [14] space is turned into place by the meaning, content and use added by people. Still, people's views on public spaces are very different depending on e.g. social status, age, and political observance. Public space is an amazing physical and social interface between different people and a set of urban interests, both regarding consumers, suppliers, dwellers and jurisdiction. The ways these interests interrelate have been and are under continuous development and depend on spatial layout, political agendas, climate and culture of use.

However, there seems to be a development in the use of public spaces towards increased centralization and control of the use of these settings. Being engaged in private activities in public is often looked down on and offends a range of other sub-cultures, as this behavior ruins their image of the division or gradient between public and private activities. In e.g. [14] it is exemplified through the development of the bedroom since medieval times till today turning from an open social activity to a private concealed activity. A similar tendency can be seen in the development of the public space: consuming alcoholic drinks in many public places is becoming illegal, but is still legitimate on sidewalk cafes. Nevertheless, it is the same social activity, though more uncontrolled in the public setting. A similar change is happening through the arising malls, privatizing the public space, mimicking the spatial structures and the rules of public space, but in reality creating controlled semi-public spaces filtering people, opinions and activities.

The design of technology in public spaces is a highly political act that can enforce the governance as well as the centralization of public spaces, or allow more unstructured social behavior. To discuss these issues we introduce three aspects of technology design in public spaces: *Information Exchange*, *Social Support* and *Regulation*. Figure 1 presents the three design issues. The dotted circles show what technologies for public spaces are mainly designed to support today, and the full circles describe a more balanced use of technology in the public. These aspects are further presented in the following sections.

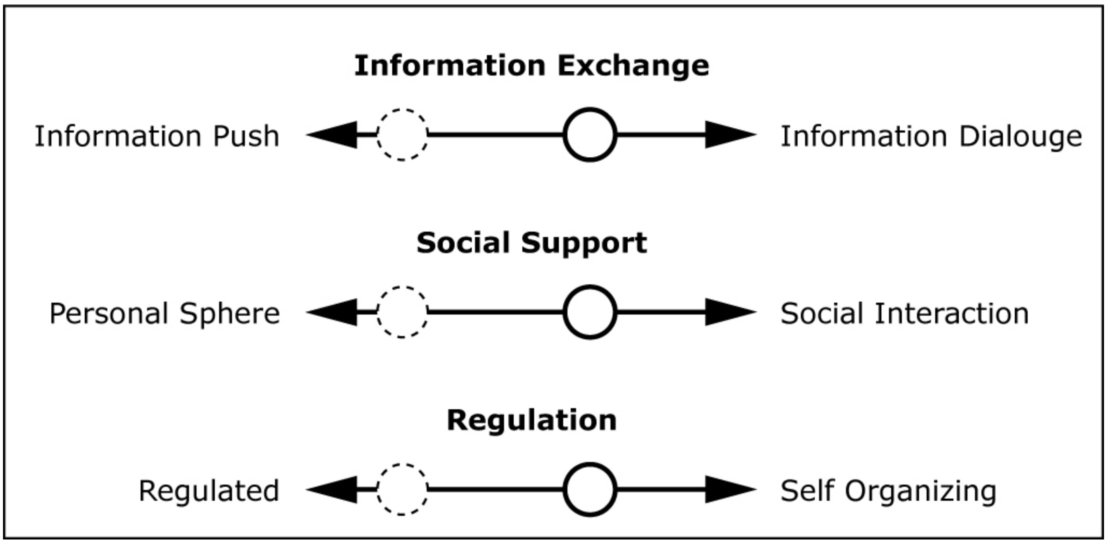

Figure 1: Design aspects for technology in public place.

The Push of Information in Public Spaces

As seen with the rise in large malls there is a huge commercial interest in controlling or being present in public space due to the number of people passing through. We see many examples on how these interests compete for the attention of people present in public for maximum exposure, e.g. on Time Square where the battle between the different billboards creates a massive push of information towards the public. This strong commercial interest in pushing information to the public leaves the average person in a public place as a consumer of advertisements. This is not necessarily negative, but in line with [26] it raises the questions: Is this the only type of information exchange possible in public places? What happens to the interaction between the physical space and the people present or between the people? Is it possible to design technology in public places that is more symmetric and democratic?

Public users should be able to change this information push tendency, towards a situation where the public can expose, comment and edit elements of the public space. Thereby, the space is formed and shaped by people passing by and not only by mimicking commercial interests. This leads to the design aspect we define *Information exchange*, meaning turning the tendency from information push towards information dialogue (see Figure 1).

Public Interaction with Pervasive Technology

To understand the activities taking place Gehl [10] defines the use of public space into three categories - necessary activities, optional activities and social activities. These categories are suitable to understand the different activities and to use the public space, both concerning work and leisure activities. In this paper we mainly look at the social activities in public space, however, as Gehl's categories are defined before the emerging pervasive and ubiquitous technologies we look at how new technology can enhance and facilitate these types of activities in public spaces.

Inspired by [14] and [6] we see place as a part of space extended with social, personal and cultural meaning. As the rules guiding public activity limit the interaction we see novel technology as a design material for reclaiming public interaction. The goal is to produce designs that encourage and support social interaction in public places without dictating any terms of use. To establish this design we take departure in the fact that a large part of physical public space is experienced visually, and therefore there is a need to move the bits in mobile devices out in public. An example is the "Blinkenlights" project [32], where people control the lights in an office building by SMS-technology.

Counting the number of digital installations and adding the number of personal devices present at any time in a public space in a modern western city the technology present is overwhelming. Wireless networks cover many city centers and people are becoming increasingly online anywhere through personal mobile devices. Though all these places and devices are connected they are not communicating with each other. A mobile device is personal and the user has the possibility to perform private activities in public settings, e.g. sending love mails, talking on the phone or buying stocks. So far, most of these activities are not exploiting the fact that they are performed in public space, one could say that the mobile device is just extending the office space into the public without engaging in public life, and even decreases the chance of people interacting [22].

If we imagine using a mobile device for engaging in public activities this changes the device from being an introvert gadget to a gateway to a digital interaction and presence in the public space. Mobile devices are so common that almost everyone carries at least one device. By letting the mobile device be the entry point to an interactive version of the public space the interaction is not limited to the person in control of the joystick, mouse, or control box, but lets everyone interact through their mobile device. The mobile device is always present and is also a highly personal device where personal information e.g. phone numbers, messages, pictures, music, videos, games, themes, and emails are stored. It is hence an interesting gateway between the personal and public domain.

This leads to the design aspect we identify as *social support*, meaning going from the personal sphere created by personal technologies towards social interaction in public places (see Figure 1).

The Control and Governance of Public Spaces

The rules governing the behavior in public spaces need to strike a balance between the fears of exploitation versus the joy of expression. Too much control results in doll predictable public spaces whereas no restrictions can end up in pure anarchy. In [20] the virtual city of Karlskrona2 is managed by a group of people through their virtual avatar citizens. What is interesting about this experiment is that from the beginning no laws and rules exist – Karlskrona2 is a totally open virtual city platform for discussion and experiments with governance and self-organizing planning. During the experiment lots of rules evolved creating a common understanding of the life in Karlskrona2. A similar approach to public spaces is needed to make a stronger potential connection between the public space and its inhabitants, and hereby establishing the ground for place-making [14]. Beliefs that systems to a certain extent will self-organize and find a level that is not offensive to the majority of the public are crucial.

The trend is however the opposite; more and more rules are applied (no alcohol, no loud sounds, no skateboarding) as well as more surveillance through video cameras to ensure highly safe and controlled environments. Again safe environments are definitely preferable, but the point is again to strike a balance between freedom of expression and control. Here it is important to remember that any part of a public space can be misused, and introducing a new channel of expression through technology will not make it better or worse, but maybe different.

Public space has to be able to provoke, inspire and push opinions – think about singing football supporters cheering, carnivals with music and dance, or political demonstrations. All these happenings and activities might provoke and offend, but they point exactly at the important part of a public space - it is alive and partly out of control.

This leads to the design aspect we identify as *regulation*, meaning going from regulated into more self-organizing behaviour (see Figure 1). In the following section we describe an application aiming to move the design towards the full circle rather than the dotted circle in Figure 1.

The Design of PhotoSwapper

Moving on to design, we wanted to create a design that aimed at balancing the three identified aspects in the public space discussion. We searched for an urban activity which could guide our design. We found the notion of a market place to be a strong metaphor for public space design.

An Interaction Metaphor: Market place

A market place is a highly interactive place where goods are traded and prices negotiated. Smalltalk with acquaintances and sales persons is the rule, not the exception. In many market places you can bring your own stuff and either sell it or trade it for new items. And if you have a special talent – being able to perform, draw, play chess, or pretend to be a statue - these types of activities are also highly appreciated in a market place. It is accepted to just *be there* to see what is going on, enjoy the atmosphere and hear other people's opinions.

Overall, a market place is full of atmosphere created not only by the physical space, but more by the people present. It is a place for negotiation and expression, but as a market place is relatively self-governed there is a risk of being cheated, tricked, offended or pick-pocked. The market place reflects the people there, both the good and the bad sides of life. As described earlier, place is created from public space in the user's appropriation of space adding content and meaning, in this case through the exchange of goods and the social activities this brings along [14].

In the design of an interactive tangible system for public space the market place seemed to be a good metaphor, in line with Oldenburg's 'third place'[33]. Users of the system should be able to come to the market with their goods, trade, look around, play games, talk to each other, pick up stuff and leave again.

In this paper we present the PhotoSwapper application as a prototype example, an application for viewing, talking about, playing with and sharing photos. The users can bring their mobile phones full of personal photos to the market place and use a shared public surface to upload, discuss, view and acquire photos.

The PhotoSwapper Application

The PhotoSwapper application is designed around one or several large public surfaces (see Figure 2). We call the setup with different projections or displays in public places a marketplace. The marketplace is alone relatively uninteresting, however, the surfaces become much more interesting when someone brings a mobile device to the market place. By connecting the mobile device to the market place a new mixed system consisting of both the public system and the personal device is created. The system is not limited to one single device - everyone can connect personal devices to the system and change the topology of the system. The constellation mixes personal and public devices as well as physical and digital spaces.

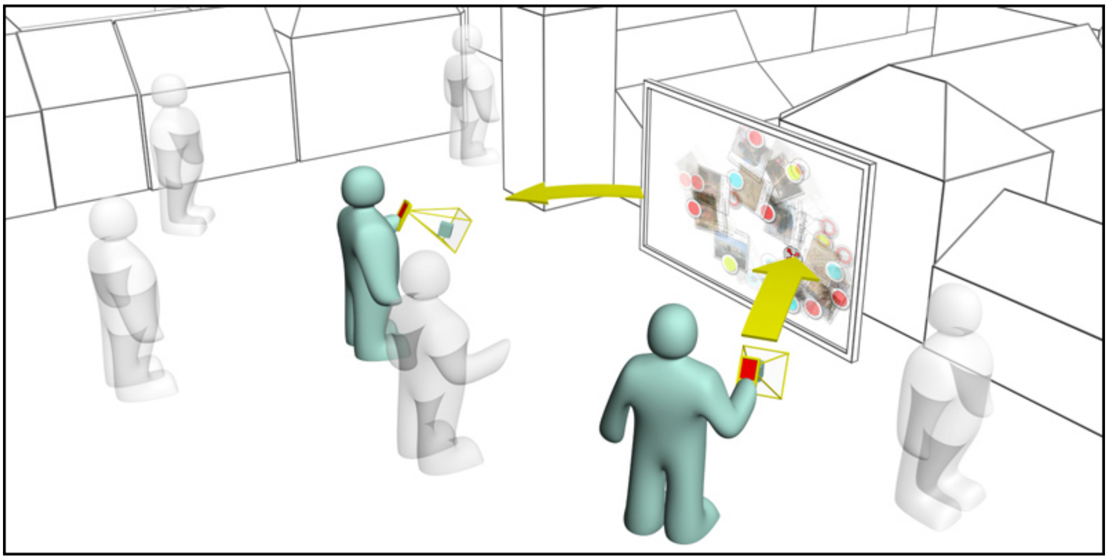

Figure 2: A market place shared display

In the PhotoSwapper application we use Bluetooth to connect the mobile devices to the public surfaces which requires people to interact with the system to be physically present. A small program on the mobile phone automatically connects to nearby surfaces when it is started. As soon as a user is connected to the surface the user is given a personal cursor which can be controlled from the mobile phone, e.g. by using the Mixis interaction technique (described in the next section). An important point is that each user is given an individual cursor which allows several users to interact with the display simultaneously, and the interaction is not limited to the person controlling the mouse.

By pressing a key on the phone a dialog box is opened where a picture from the mobile phone can be selected and uploaded to the public surface. A thumbnail of the picture is presented on the public surface together with a colored grapping point that links to the user that uploaded the picture (see Figure 3). The picture can be dragged, viewed in full resolution on another display, completely deleted or downloaded as a copy. Viewing photos in full resolution is achieved by dragging the picture to a porthole icon that moves the picture to a separate screen and shows it in full resolution. By pressing a key on the phone the picture can be deleted from the public screen or downloaded as a copy.

The described application is implemented and the shared display application runs on standard PCs with Bluetooth Dongles. A small C++ program handles the Bluetooth communication, whereas the main interface is written in Macromedia Flash. The application for the mobile devices is implemented in Symbian and runs on most high-end Nokia phones e.g. Nokia 7610, 6630, 6680.

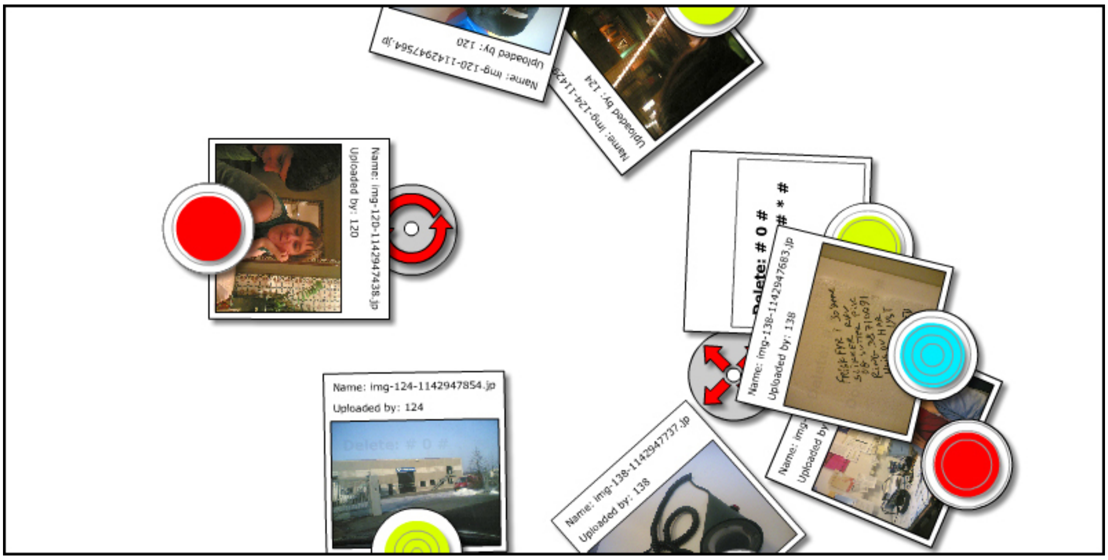

Figure 3: Detail of the PhotoSwapper application demonstrating the individual cursors, photos and porthole.

Using Vision to Interact Through Mobile Devices

For the navigation of the individual cursor we chose to explore an alternative interaction technique called Mixis [11, 12, 13], which supports interaction in 3-dimensions, and thereby uses the mobility of the handheld private device.

In Mixis an object is selected as a reference point by taking a picture of it with the mobile device. The reference object can be anything that stands out from the surroundings by having a specific color or pattern, e.g. a jewelry, some cloth, or a handwritten symbol. If no suitable object is found, the user's face can be used as a reference point (if the mobile device is equipped with a camera pointing towards the user) [12]. Video from the camera is analyzed on the mobile device, and the vector from the mobile device to the selected feature is calculated.

This vector is then used to control the cursor on the shared display. E.g. moving the mobile device closer or further away from the tracked object can grab and release photos or interactive icons. Moving the phone left, right, forward and backward can be used to move the cursor on the shared surface. See [11, 12, 13] for more information.

This technique has previously been used in several single user applications, but it turned out to also be highly useful in multi-user applications for one or more shared displays [12]. The advantage of using Mixis is that it allows interaction in three dimensions as well as more precise control than simply pressing the key up/down/left/right.

Identifying multiple cursors

Another issue with multi-user applications is how to identify which cursor belongs to whom.
In the PhotoSwapper application the color of the chosen reference object for the Mixis interaction technique is transferred to the interface, and this color identifies the user on the public display. The personal cursor is given this color and all uploaded pictures are tagged with this color. In that way the pictures on the shared surfaces are all marked with colors taken from an object that is present or has been present in the context surrounding the interface. Relating to the public space discussion this is analogue to referring to someone in the public as "the girl with the green hat" without knowing her phone number or name.

Test Set-up and Challenges with PhotoSwapper

In a test setup displayed in Figure 4 we used two large surfaces: a floor projection and a large wall back projected screen, but other setups could be used as well, e.g. PCs, or interactive tables. The floor projection acts as the market place and provides an overview of uploaded pictures from the co-located mobile phones. The pictures can be viewed and dragged around on the floor, and a portal icon allows the pictures on the floor to be viewed on the wall display.

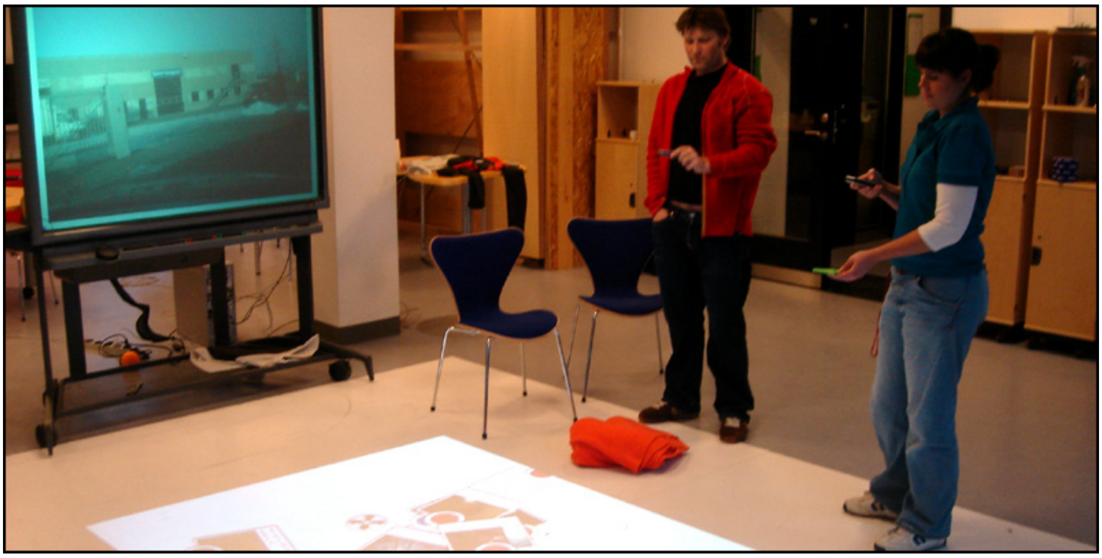

Figure 4: PhotoSwapper using floor and wall.

While testing the application, we were able to make a small unstructured test. People involved as test persons were familiar with the floor projection as well as the back projected screen, but not with this specific application. The setup was placed at the entrance of a research institution. The results were satisfying in system performance, functionality, scaling to number of phones present, and user satisfaction. But due to the test subjects' high technical skills and general interest in technology as well as the semi-public setting these results might far from reflect the lessons learnt from deployment in real public spaces. We are currently working on staging the setup out in the real world, but are faced with a number of technical challenges, among others to get the program responsible for connecting to the market place distributed to a large number of phones. See [13] for further evaluation on Mixis.

The Potentials of PhotoSwapper

While a substantial amount of work is needed to move this application to a real public place, the prototype directly addresses the aspects introduced in the discussion on public space. This is e.g. realized by supporting social interaction where multiple users simultaneously can engage in an information dialogue through the shared market place. The governance and regulation of the content is up to the users.

Being able to upload, download copies, delete and discuss photos in public places open up for new ways of influencing the public space. PhotoSwapper builds on the mechanisms of public rules and governance. Everyone can interact through a mobile device and expose statements, happiness or anger by adding content to the shared surface. People can show their holiday pictures to the public or McDonalds can post images of their menu. The only rule is that rules are made up by the users. This openness has the potential for the users of public space to appropriate it and turn space into a meaningful place that constantly reflects ongoing discussions, new opinions, joy, and sorrow. We imagine small games, riddles, comic strips, photo competitions, statements and more to evolve in different sub-cultures expressing the diversity of public life.

Discussion

Based on our work with design in public places we suggest four design challenges that need to be considered when designing tangible, interactive, social and self-organizing systems for public spaces:

- How to move from single-user designs to multi-user designs?
- How to move from individual to social design?
- How to move from closed systems to open and extendable systems?
- How to move from regulated to self-organizing and evolving designs?

From Single-User to Multi-User Systems

There is a constant struggle to develop new applications and technologies capable of multi-user interaction on shared surfaces. In the beginning the focus was on sharing existing single-user applications across a network, such as for instance the MMM project [2]. Later the notion of Single Display Groupware (SDG) was introduced [25], and findings such as significant learning improvements [8], more motivation [15], higher levels of activity and less time off [16] are arguments supporting the development of technologies where several people can interact simultaneously on a shared surface.
Still, far too many multi-user applications are actually single user interfaces with a public display and only one or two mice or keyboards can be active at the same time [18]. As we are designing for interaction in public space we argue that the application has to support and exploit the behaviors of people in public space, e.g. multiple simultaneous activities in the same place, why we argue for a democratization of the interaction where all users are potentially able to manipulate the interface simultaneously.

PDAs and mobile phones can be used to implement simultaneous inputs. The Web Wall [9] and Digital Graffiti [5], allow users to post comments and to annotate a shared display by constructing the annotation on a PDA or mobile phone and then apply it to the system through a web-based interface. This supports democracy, but it is networked-based and not completely simultaneous. An important aspect of the market place metaphor is the possibility of exchange - these systems do not support taking information with you through your interaction device.

Other multi-user systems include capacitive surfaces or devices like the SMART DViT [31] and the MERL DiamondTouch [7] that cope with simultaneous inputs, or active ultrasonic pens such as Mimio Virtual Ink [30]. Even more interesting is the capability of tracking and distinguishing between users actions, such as the Multi-Light Tracking system that allows four users to interact simultaneously on a back-projected display [21]. These techniques are based on direct interaction with the display, but this one-to-one mapping is not a realistic interaction paradigm to use in public spaces, where e.g. scalability, sanitation and physical security are problems [1].

In the PhotoSwapper application multi-user interaction is supported through the Mixis interaction technique. This technique uses people's mobile phones as interaction devices, and scales to the number of users as long as they carry a mobile device.

To increase the portability of the interaction device and the physical security and sanitation of the system, we find it straight forward to use the personal devices in peoples pockets as interaction tools, for instance mobile phones and PDAs. When using the private device for public interaction with a shared display, it is important to make the user in control of what data is transferred and displayed where, so sensitive data such as name and phone number is kept private. In Photo Swapper the users' privacy is secured by using Bluetooth as communication protocol, as it only transfers the ID of the Bluetooth unit, and not phone number or name.

From Individual Design to Social Design

Nevertheless, only focusing on multi-user design is not enough to build truly public, engaging, tangible, and pervasive systems. They also need to be designed for social interaction.
In today's public spaces, technology has to some extent been incorporated into our everyday life in line with Weiser's vision of ubiquitous computing [28]. Examples of this are our use of mobile phones, and other wearable computing gadgets. The notion of ubiquitous computing also acknowledges the fact that people interact socially and behave differently in different types of situations or contexts, which are so far not really supported in today's technology.

In a number of augmented reality systems wearable computers, head-worn displays and similar technologies have moved the focus away from the interaction between users. Another approach is to put the support for social interaction first. In e.g. [4] it is not mandated to interact with co-players for the game to proceed, but it encourages social interaction to occur during the play. Since the social interaction is primarily spontaneous the game explores what Zagal et al. [29] define as stimulated social interaction. We believe that when designing for public spaces, the applications and technology need to support spontaneous social interaction, meaning interaction that occurs naturally between the participants [29]. In the notion of market places, the social interaction can take place spontaneously among the visitors of the shared market/screen, but also be mediated and stimulated by objects within it. Inspired by [19], we wish to view social interaction as an entity in itself and not focus on the single user experience of participation.

In the PhotoSwapper application, the users' foci are not on the individual small screens on the private device, but on the shared display. Here, private material can be turned into public material, and it is possible to share information with several other users.

From Closed Systems to Extendable and Open Systems

Most digital systems in public spaces are closed controlled systems. Either they are not interactive at all, or there are some well-defined interaction sequences that are supported. To design systems for public information dialog, we argue for making systems that are more social and less restrictive.
In [27] photos taken with a mobile phone are sent as emails and then analyzed by a server to be displayed in one form or another on the public display. In this way the content on the public display will mirror the context, but the interaction is not simultaneous.

In [1, 23] visual codes are used for interacting with camera-enabled mobile phones on a large public display. The strength here is that a unique ID can be encoded in the tags; but the limitation is that the interaction technique can only be used in front of a 2D barcode, and the interaction situation is then limited in mobility and scale.

Technology and applications making use of contextual information are generally referred to as context-aware computing [24]. An example of this is location-based multi-user games, such as [3]. The game supports multi-user simultaneous gaming, but everybody is occupied with their personal device, here a modified PDA, and the interaction and action all take place individually on the screen, even though the entire city is the game board. In [4] the physical co-location of the players and objects in the world are adopted as important elements of the game mechanics. The game experience in [4] is inspired by traditional board games, and takes place in a social setting, where simultaneous participants play together in a limited physical area, a stage where players and the game meet. Still, focusing on an individual private screen is a limit in public places, and the common denominator is missing.
In PhotoSwapper we have tried to accomplish this openness by the shared display, the simultaneous interaction, and the possibility to connect and disconnect easily through your personal device.

From Regulated to Evolving Designs

A related issue is how to support open applications that are evolving through people's use.
One design principle is to support serendipitous or "come and go" interaction. The content of an application and the ongoing activities should not be affected by people joining and leaving the application and the system should support short-term interaction [1]. However as browsing a market place is an intentional activity, joining the interaction in the place requires the user to take action. Still serendipity should be supported in the sense that the user spontaneously can join, meaning without too much effort.

In Dynamo [17], anyone can use the interface. Users attach multiple USB mice, keyboards, PDAs or laptops, and Dynamo allows users to claim areas of the surface, place and take information, display information and leave items for others. Here, public interactive surfaces are defined as inside buildings, and it is possible to rely on different external hardware gadgets physically hooked up on the computer. This is not possible to support in outdoor public spaces. The Dynamo system introduces the concept of carving out parts of the public screen estate for private use. We find this analogue to the tendency discussed earlier regarding physical public space, namely an increased privatization expanding private activities to public spaces. However, it does not comply with what we understand as acknowledging the rules and interactions of public space.

Enforcing rules is one way of controlling the use of an application, but for self-organizing systems the rules are made up as the system evolves. Within a social group a range of local tacit urban rules exist, e.g. an unwritten rule for graffiti painters stating that you are not allowed to paint over a piece that you cannot do better yourself. These rules do not necessarily comply with the law and are primarily followed by the members of the sub-community who have defined the rule implicitly or explicitly. Those kinds of rules are inspiring to the discussion of regulation, since the graffiti world actually is self-regulated in a way, even though it is invisible to people outside that community.

We do not claim that it is purely a good idea to open up for more uncontrolled interaction in public places. A controlled environment is much safer since people passing through are ensured that they do not get bothered by homeless people, racists or provoking statements, or people simply behaving in a strange manner. The control aims at making the environment pleasant, nice and secure. Interestingly, sometimes the most innovative and thought-provoking ideas appear when something offends you, or something unexpected happens. By shielding off public places from uncensored, spontaneous events (while keeping a sense of accountability) the possibilities for being provoked in a positive sense also disappear.

In PhotoSwapper, everybody is offered equal chances of displaying and controlling information. Of course, information offending other people will certainly be uploaded, just like graffiti, but as the system is self-regulated, people who get offended can easily remove the offending material.

Conclusion

In this paper we claim that many public places, though still publicly available, are restricted in their use by a number of rules, stating how different groups of people are allowed to behave, and that these spaces are designed as being places for information or advertisement and not for personal expression. We further point to that personal technology, especially represented by the mobile phone, is being used extensively as a private anti-social device in public places. In this paper we ask the question if pervasive and mobile technology can be used the other way around - to enhance interaction in public places while still being a personal device - to be a facilitator for bringing interaction back into public spaces.

We have introduced the metaphor of the market place to guide the discussion of social interaction in public spaces and we have identified a number of central design issues relating to balancing information push with information dialog, personal spheres in public spaces with social interaction and control versus self-regulated behavior in the public. All of the issues relate to how digital technologies can play a role in a more democratized, sporadic, and social experience with digital technology in public spaces.

The PhotoSwapper application represents a project aiming to address some of the issues while not being able to embrace all of them. Using interaction technologies such as Mixis we demonstrate how it is possible to overcome hinders for social interaction. The PhotoSwapper application shows how multiple users can participate on "equal terms". The interaction is not controlled by the user with the mouse, but by everyone with a mobile phone acknowledging basic rules of public living.

In the paper we have focused on identifying current problems with public spaces, surveyed and discussed how mobile and pervasive technology can be used to facilitate interaction in public spaces, as well as presented a photo-sharing system based on the market place metaphor. We hope that the presented discussions can be used to move the focus from designing private mobile devices to designing new interesting places where mobile devices are integrated to support social interaction.

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