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DEPtH
Designing for Physicality

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PREFACE

Second steps in Physicality

http://www.physicality.org/physicality2007/

This is the Second International Workshop on Physicality, a research area launched last year in response to the proliferation of hybrid physical/digital products and correspondingly pressing need for a more fundamental understanding of physicality. Although we live in an increasingly digital world, our bodies and minds are designed to interact with the physical. When designing purely physical artefacts we do not need to understand how their physicality makes them work – they simply have it. However, as we design hybrid physical/digital products, we must now understand what we lose or confuse by the added digitality.

Physicality 2006 proved very successful with contributions from disciplines including design, computing, sociology and music, and attracting both academic and commercial attendees. This year's range of papers and participants is equally diverse and also includes participants from philosophy, architecture and human geography. These workshops represent a still nascent, but growing, community of interest.

The 2006 workshop also gave us an excellent starting point for *DEPtH: Designing for Physicality*, a 2-year project funded by AHRC/EPSRC as part of their Designing for the 21st Century Initiative (www.physicality.org/DEPtH). DEPtH is a joint project between Lancaster University and the University of Wales Institute, Cardiff drawing on expertise including product design practice, mathematical modelling, human interface design, ubiquitous computing, lab-based user experiments and social-science methodology. As well as sponsoring the workshop, DEPtH will be creating a web portal and resource centre and we hope to draw on the collected wisdom of the attendees at the workshop.

CONTENT

As befits such cross-disciplinary area, the invited keynotes by Julie Jenson Bennett from PDD and Michael Wheeler from Stirling University will take us from the sharp end of product design where concepts become reality to philosophical reflection on the fundamental nature of embodiment.

The authors' contributions also cover a broad spectrum and, for inclusion here and presentation at the workshop, we have categorized them under the following themes:

Art Crossing Boundaries. These papers address the way digital and physical form and representations interact with the creative process. Treadaway looks at the how the memory of physical experience informs creative cognition in digital visual art and design practice, while Eales and Perera explore the creative processes at the physical-digital border through the artistic practices of a painter. In addition, the workshop will host a live performance that uses physical and virtual means to challenge the physicality of the workshop itself (Tan et al.).

Touchy Feely Interaction. The physical nature of controls and devices is central to the design of computational products and systems. Papers in this section look at the conflict between the 'affordances' of the physical and the digital within the realm of augmented reality (Hornecker) and at the importance of actions and associated 'natural inverse actions in physical and tangible interaction (Ghazali and Dix). However, people are not all the same, so Hengeveld et al. investigate the adaptability and adaptivity in product design to aid cognitive and physical therapy in children with developmental difficulties.

The Body as Instrument. This group of papers considers different aspects of the human body and its senses and how they influence interaction and design. Three of the papers are focused on the movements of the body in space exploring embodied collaboration around physical artifacts (Morrison and Blackwell), embodied interaction for creating tools to help young people, particularly women, understand programming concepts (Romero et al.), and the possibilities of psychomotor abilities in kinesthetic interaction design (Fogtmann). We each use our sense and abilities in different ways and so Koštomaj looks at how learning theories can be applied to the incorporation of media in an intelligent storybook.

Place and Space. Moving out from the body, we are also constrained and influenced by the nature of the spaces in which we live and interact. Papers discuss the physicality issues to be addressed when designing a domestic-aware space (Martinez and Greenhalgh) and presents a theoretical framework for incorporating technology into the design of public spaces drawing on computer science, architecture, design and philosophy (Malard and Cesar).

Virtuality: Moving between Worlds. Another group of papers address issues that arise when we move from physical to virtual environments. Sharp addresses the challenges involved in translating physical artefacts used by co-located software development teams to facilitate in-situ communication practices into a virtual arrangement for supporting distributed teams. Whitham explores the augmented interaction capabilities when switching from a purely physical work environment to partly virtual environments and the ensuing difficulties with facilitating predictability. McKnight looks at the design opportunities when making the transition from the physical world to virtual reality and its impact on creativity.

Representations. Representations and models are critical in design activity. Relatively formal models are used to capture the physical aspects of interaction in Mixed Interactive Systems (Dubois et al.) and to draw together existing theoretical work on physical interaction (Israel) in order to reflect and reason about systems including physical and digital components. In contrast, Hornecker considers different representational practices used within the design process itself, focusing on issues of materiality and physical interaction.

Virtuality: The Real and Unreal. The final theme explores the boundaries of physicality. Gjerlufsen and Olsen present a deep philosophical exploration of the qualities of physicality and digitality, whilst Last raises philosophical questions on the physicality of nano-technologies and explores the possibilities of understanding physical processes that are outside our perceptual range.

Any categorization is a simplification and during the workshop we will create alternative threads and themes using a physical variant of tagging, which has been so powerful in web-based social networking; borrowing ideas from the virtual and applying them in a physical form.

COVER IMAGE

The cover image shows three ‘pebbles’. These forms were produced as part of a design-exercise in the DEPtH project and represent a series of transformation across the physical digital threshold.

(i) the first pebble was sculpted out of clay to fit into the palm of the hand.

(ii) the second pebble is a digitally rendered image of a 3D ‘scan’ of the first pebble.

(iii) the third pebble was produced using a 3D printer based on the scanned 3D model.

So the pebbles are (i) a physical form, (ii) a digital representation of the physical form, and (iii) a physical representation of the digital representation of the physical form.

Finally the physical pebbles (i) and (iii) were digitally photographed, mixed with the digitally produced cover design and then printed onto physical paper.

So, in a way the cover is a metaphor of the flow between physicality and virtuality that lies within its pages. The pebbles represent the product of a design process that moves between these worlds and the cover encloses text, which from the time of Plato has teased the greatest minds in its own virtuality. The design itself embodies an aesthetic, philosophical and teasing message and, we hope, invites opening and reading, just as we hope the workshop will invite discussion, collaboration and fun.

Devina Ramduny-Ellis, Alan Dix, Joanna Hare, Steve Gill

August 2007

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Julie Jenson Bennett	Head of Research and Human Sciences, PDD, UK
Michael Wheeler	Department of Philosophy, University of Stirling, UK

KEYNOTE

Julie Jenson Bennett
Head of Research and Human Sciences
PDD

At PDD we design products, packaging and services for clients all over the world in industry sectors ranging from confectionary to industrial equipment, kitchen appliances to IV pumps. In my talk, I shall show examples of how PDD has explored and addressed physicality in our projects and process, particularly in the context of inclusive design for medical and pharmaceutical devices and highlight some of the challenges we perceive moving forward. In particular, there are large gaps in the types of dynamic anthropometric data designers and ergonomists need to create design for niche populations outside the traditional mass market and "average consumer."

KEYNOTE

Michael Wheeler
Department of Philosophy
University of Stirling

MINDS, THINGS AND MATERIALITY

In recent years attention has increasingly been focussed on the subtle ways in which human intelligence and human experience are determined at a fundamental level by the details of our physical bodies and by the enabling material web of natural, social, cultural, and technological scaffolding in which we are evolutionarily, historically, developmentally, and here-and-now situated. In some circles this attention has been aimed at helping us to design innovative technological products. As a result of all this intellectual activity, movements with names such as situated cognition, embodied-embedded cognitive science, distributed cognition, enactive cognitive science, the interactive mind, and the extended mind now loom large on the contemporary research scene. Nevertheless the precise shape of this new understanding of human-world relations remains frustratingly unclear. In this talk I shall attempt to disentangle some of the issues.

My springboard will be a rich and thought-provoking paper by the archaeologist Lambros Malafouris, entitled *The Cognitive Basis of Material Engagement* (Malafouris 2004). In this paper Malafouris argues that taking material culture seriously means to be 'systematically concerned with figuring out the causal efficacy of materiality in the enactment and constitution of a cognitive system or operation' (Malafouris 2004, 55). On Malafouris's view, then, taking material culture seriously involves accepting the claim that items of material culture (the physical objects and artefacts in which cultural networks and systems of human social relations are realized) are often partly constitutive of some cognitive system or operation. The bounds of cognition are thus recast so as to include things located beyond the skin. Malafouris (2004, 58) writes that 'what we have traditionally construed as an active or passive but always clearly separated external stimulus for setting a cognitive mechanism into motion, may be after all a continuous part of the machinery itself; at least *ex hypothesi*'. This is the position that, in philosophical circles, is known as the *extended mind hypothesis* (Clark & Chalmers 1998), henceforth EM.

I shall spell out what I take to be the only plausible reading of EM, and argue that, on this reading, the distinctive EM conclusion, that things-beyond-the-skin may sometimes count as proper parts of a cognitive system, is purchased using a currency of what I shall call *implementational materiality*. I shall then submit evidence that Malafouris would judge such implementational materiality to be an inadequate basis for capturing the distinctive causal efficacy of the materiality of material culture. This puts pressure on the link that Malafouris finds between his vision of what it is to take material culture seriously and EM. This pressure becomes decisive once we realize that the enactive aspect of Malafouris' approach – recall that we are concerned with the causal efficacy of materiality in the *enactment and* constitution of a cognitive system or operation – is plausibly in tension with EM. If this is right, then taking material culture seriously in the way that Malafouris urges us to will actually require us to reject EM.

Crucially, this critical response to Malafouris's paper has some important wider lessons. There is an increasing tendency in current discussions to run together certain rather different contemporary styles of thinking about thinking. Indeed, while the fans of the various movements mentioned earlier are wont to march together against the common enemy of a residual Cartesianism in our understanding of cognition, this unity against the shared foe serves to obscure certain critical differences between the fundamental commitments that define those movements. It is time to recognise and to debate those differences. My discussion of Malafouris's paper suggests that some of these differences turn on how the causal contribution of the physical/material is to be understood.

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Translating experience

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ABSTRACT
This paper describes research investigating the significance of physical experience and materiality in creative digital visual art and design practice. Findings are presented from a recent phenomenological study, which indicates the ways in which memory of lived experience informs creative cognition and feeds the imagination.

The importance of physical engagement with the world through the senses enables emotional expression to be made in artworks that can be perceived by both artist and audience. Digital creativity support tools have been found, in this research, to lack interfaces that facilitate the translation of these visual aesthetic qualities in the virtual representation.

Hand use and the sense of touch stimulate novel ideas and enable practitioners to break from fixated thinking when working with digital design tools. Examples of artworks are presented that illustrate ways in which artists, working with digital technology, make use of physical experience to inform visual ideas and innovate design solutions.

The concepts of *somatic principles*, *performative materiality* and *instrumentness* are introduced in order to illuminate the current discourse surrounding the importance of physical bodily experience when working creatively with digital technology.

Categories and Subject Descriptors
H5 [**Information Systems]:** Information Interfaces and Presentation: *user interfaces; evaluation/methodology; input devices and strategies*

J. Computer Applications: J5 [Arts and Humanities]: Fine arts

General Terms
Design, Human Factors

Keywords
Physicality, hand use, creativity, art, craft, design

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1. INTRODUCTION
Memory of physical experience informs creative cognition and inspires the imagination [1]. Most artists and designers are keenly aware of the significance of stimulating their imagination through experiencing new places, images and ideas; the artist's sketchbook is frequently the repository for visual memory prompts using photography, sketches, collaged ephemera and descriptive words. Memory of lived experience contains a wealth of visceral information that excites the emotions and affects the remembering and decision making processes that occur within creative cognition [15, 11]. Information supplied to the brain through the senses about daily experience is so complex that it must be clustered and blended [5] and only novel or emotionally laden experience is retained though a process of perceptual redundancy [6].

Recent research into digital creative practice has shown that the rekindling of lived memory informs visual representations and is essential in providing the practitioner with procedural knowledge with which to craft. Tacitly knowing how to use tools and which tools to select is fundamental in all making; digital technology is no exception [10]. Artists and designers find that input devices frequently lack the haptic and force feedback they would expect from conventional crafting tools [17]. This often leads to dissatisfaction and frustration that inhibits the creative process and disrupts *flow*: the fully engaged hyper-state of immersion in creative thought [3]. Practitioners often rely heavily on digital tools that lack fine sensitivity to pressure and gesture and note that the complex neuromuscular potential of fingers and thumbs is rarely exploited using current technology [22]. Understanding how physical hand use influences creative thinking will inform the development of better creativity support tools [18]. Physical making processes involve the working of a material and it is the physical characteristics and affordances of that material that inform the creative process. Expressions of materiality in the virtual world are often unconvincing in their visual representation and when output as digitally manufactured artifacts, are considered deficient in emotional and aesthetic qualities [22]. Research in the visual arts described in this paper is providing new knowledge that illuminates the role of physicality and materiality in creative cognition and digital practice.

2. MEMORY
2.1 Art practice informed by experience
Ward in Smith [19] describes how every new idea is the product of remembered experience. Wilson [25] asserts the connection between hand and brain in developing imaginative thought. In recent practice based research, investigations involving the generation of digital images based on specific

thematic memories, revealed the ways in which metaphors that combine physical experiences are used to generate novel ideas and drive the creative process [22] (Figure 1).

Figure 1

Panel – digitally printed silk

Cathy Treadaway

The artwork 'Panel' was developed as part of 'Five Elements' a series of five digital prints exhibited in 'Digital Perceptions'[1]. The image blends a selection of remembered experiences of a location in China and explores memory through metonymy and metaphor. The title of the work 'Panel' suggests both cloth and wood and is able to express a memory capturing visual qualities of the carved and painted wooden doors, markets selling textiles, visits to a museum and the artist's emotional connection to the location, as well as the broader philosophical theme of the five pieces of work that comprise 'Five Elements'.

Sensory stimulation derived from visual, aural and haptic responses to the lived environment were shown to stimulate the imagination and enable new visual representations to be formed using digital technology. These responses were frequently poetic; directed by an intuitive reaction to remembered experience that was enhanced with emotion.

Collaborative investigations involving empathic art making were used to interrogate this process [23]. A series of art works were developed in which memory of specific time and locations were used to fuel the creative process. The practitioners involved in the investigations found that the mutual experience of physical engagement with the environment enabled a shared visual response to be made. It became possible to communicate a common visual language and to establish shared end goals and criteria for idea selection.

[1] 'Digital Perceptions': an international touring exhibition of digital textile artwork and conference June 2005 – 2007 supported by the Surface Design Association, Wales Arts International, Scottish Arts Council and the Missouri Arts Council, USA.

Figure 2

Kilmory – digitally printed silk

Alison F. Bell and Cathy Treadaway

The initial stage of the creative process involves *preparation* in which the senses are stimulated and ideas recorded [20]. Digital cameras, sketchbooks and journals were used to gather visual information and digital tools including computers running Adobe Photoshop® software, scanners and printers were used to develop imagery iteratively shared between the collaborating artists. The imagery was exchanged between practitioners in layers via websites and on hard storage media enabling a series of artworks to be produced for exhibition[2] (Figure 2). Analysis of the qualitative research data indicates the importance of physical experience in the development and refining of visual representations. The shared experience enabled an empathic response to be made to the physical situation, informing both the critical selection of ideas within the creative process and providing direction to the development of the work.

2.2 Crafting and memory of physicality

The investigations described above incorporated both analogue and digital crafting processes. The sketchbook was fundamental to the collection and collation of initial visual ideas. Sketches produced on-site while the practitioners were physically immersed in the environment, were later perceived to be richer in conveying memory of the experience than the digital photographs taken at the same time and in the same location. The photographic images were unable to convey the emotional response of the practitioner; how it felt at that time and in that place. The sketches incorporated the muscular and gestured

[2] The artworks produced during the research comprised a series of digitally printed silk panels which were exhibited in *'Recursions: material expressions of zeros and* ones' Museum of Design, Atlanta, USA 2005, *'Digital Perceptions'* Leedy-Voulkos Gallery, Kansas City USA and Collins Gallery, Glasgow 2006

response of the body within the environment; the wet paper trapped the gritty sand, blown onto the sketch, resulting in textured marks that spontaneously captured the memory of physical sensation of sand on skin, wind on face and temperature of the location. The incongruity of the photographic representation compared to the physical sketch became the stimulus for the artwork 'Kilmory' (Figure 2).

The research findings indicate that practitioners find physical sketchbooks continue to be vital in digital art and design practice. The physical property of the book and the ability to flick through quickly, at a glance, in a non-sequential manner, assists the recollection and assimilation of visual ideas. The physical action of cutting out images, sticking, manipulating and assembling photographs, sketches and ephemera within a physical book also provide a sense of bodily and mental satisfaction as well as time for reflection.

Physical crafting takes time and the slowness of making frees the mind to reflect on the creative process and to develop new ideas [7] Creativity takes time [20] and hand making processes that are slow to perform, facilitate thinking space in which ideas can be associated and refined. Research has found that art and design practitioners, who work with digital imaging technology, crave hand crafting processes and they frequently engage in such activities in order to stimulate new ideas and break out of fixed patterns of thinking [22]. The physical manipulation of materials and tools also stimulate new ideas through the sensory information they convey. Objects can act as carriers of memory through a variety of sensory properties: sight, smell, sound as well as touch. Each sensory prompt becomes capable of stimulating memory and building imagination through physical proximity or bodily contact.

Craft can be described as skillful making using tacit knowledge or know how; practical ability, acquired by physical experience [4]. When working digitally, practitioners draw inspiration from making in the physical world to attempt *'to reclaim the bodily or human aspect to the digital process'* [2].

2.3 Conveying emotion

A handcrafted artifact is able to convey properties beyond its material constituents; it is a unique response to a material by the craftsman, often by hand. It may reference cultural tradition and process in its workmanship [24]. The way in which its audience perceives the crafted artifact may be impossible to prescribe, however the maker frequently strives to communicate values, intentions and emotional content through the making process. The emotive qualities of an artwork or 'aura' are derived from the *workmanship of risk*[3] [14] and are a unique acumination of creative responses to physical human interaction with the world [21]. Practitioners note the flatness of the digitally crafted product; CAD work is often described as looking the same, homogenous and without character[4] [12]. The lack of adequate physical bodily interaction with digital creativity support tools is felt by art and design practitioners, interviewed in the research, to be responsible for the perceived deficit in emotional content of digitally produced artwork.

[3] Pye [14] contrasts the safe machine made *workmanship of certainty* with the *workmanship of risk* in hand making when at any moment a mistake can be made and the work ruined.

[4] Matt Duckett founder of NICE states: *'I find if you stay on the computer too long, everything ends up looking the same'* [12].

3.0 PHYSICAL EXPERIENCE

Figure 3

Ceramic hug: Bonnie Kemske

3.1 Touch

Research at Edinburgh University is exploring the development of haptic interfaces to enhance the users' ability to craft more intuitively with digital technology [17]. Appreciation of exactly how touch, manual dexterity and gesture inform creative thinking is limited. Recent studies in neurophysiology and psychology are illuminating the ways in which perception is modified by touch [26]. This research has identified that separate streams of sensory information are fed to the brain from visual stimulation [26]. These have been shown to enable both physical manipulative action and also the perception of objects. Prytherch [13] links the sense of touch with sight and perception and asserts that both provide information to the brain in different ways. Haptic senses result from successive experiences in which substance is encoded; vision provides information concerning shape and location. Research by Goodale and Milner cited in Wing [26] identifies how visual control of prehension informs perception and cognition in order to mediate physical action. These connections between *vision*, *touch* and *cognition* inevitably impact on perception of physical experience and influence imaginative thought [25]. Harris [7] contends that those practitioners that have learnt haptic skills, such as textile handcrafting, have a more acute sense of touch and are more likely to feel constrained by the lack of sensory stimuli inherent in digital crafting. This appears to be confirmed by recent research involving human touch and ceramic surface at the Royal College of Art, London, which suggests that craft practitioners have a greater sensitivity to haptic stimulation [9] (Figure 3). This research has found that tactile surface qualities are perceived differently across the body and a range of stimuli such as temperature, pain, pressure, vibration, light touch and texture activate a variety of different nerve cells in the brain. The propensity of the body to acquire tactile sensory information through the whole body, not just the hands, indicates the rich information flow concerning experience in the physical world that informs cognition. This tactile information is mediated by visual perception, providing both information into the body and expressive output from the body, back into the physical world.

3.2 Bodily experience and digital interaction

As technology becomes physically smaller, ubiquitous and embedded, it is becoming less 'object based' and can be perceived as a set of invisible distributed processes. Schiphorst contends that *'technology is becoming an inseparable aspect of experience, palpable yet invisible'* [16]. Her research uses somatic principles to explore the lived experience of the moving body. In performance-based research at Simon Fraser University Canada, the Whisper project involved interactive digital artworks that investigate user experience from within the living body. Working with embedded sensors and wearable computing technology, the study sought to explore how the participants became aware of their own body state and they were encouraged to share this knowledge with others in a public art space space.

Figure 4

Wearable from Jacare Jungle: Tara Carrigy

Like Schiphorst, research by Tara Carrigy at NCAD Dublin is investigating physical computing using body sensors and wearable technology to create interactive artworks. Carrigy contends that:

'Computing is getting physical and interfaces are getting more tangible. The digital process is merging with the material world, connecting to it through sensors and interfaces that convert analogue to digital and back again' [2]

Her artworks involve the embedded integration of sensors into garments enabling the wearer interactivity with video images within performance (Figure 4). The 'Adaptive Craft' project comprised two artworks: 'Jacare Jungle' an interactive performance work for children that involved the dance performers in dynamic interaction with '*an interface that visually represented sensor data collected by their Wearables, using it to trigger responses in the theatrical backdrop of projected light and pattern'* [4, pp.301].

The second project 'Smart Yoga Wear' sought to present biofeedback in an intuitive and non-invasive manner through dynamic video representations in order to enhance the user's yoga practice. Both projects investigated the ways in which physical crafting could be combined with digital technologies, not to create a static craft object but towards *'a more integral union where the object is in transition, mediating between digital and physical world.'* [2, pp.302]

4.0 TRANSLATION

4.1 Materiality

Crafting processes involve direct engagement with a material. The physical properties and affordances of that substance require the practitioner to develop specific knowledge of how to work with it, based on empirical experience. This tacit knowledge of both material and tool use becomes combined in the act of crafting. Memory of the experience of crafting a physical material informs digital visual representations and provides the practitioner with an intuitive understanding of the creative potential and limitations of the digital craft. For example, in virtual draping for fashion, an understanding of the ways in which cloth handles and falls provides the digital designer greater awareness of the subtleties required in the virtual representation.

Physical materials can also act in a performative role within art and design making [8]. Research has shown that in collaborative art making the use of physical materials to explore concepts and construct prototypes, prior to and during digital design processes, is beneficial to creative thinking. Jacucci and Wagner [8] contend that *'materiality supports intuitive and simultaneous manipulation, mobilizing our tacit knowledge and enabling participation.'* In their research, physical objects have been shown to stimulate creative thinking through their multi-sensory dimensions, encouraging seeing, touching, smelling, gesturing, lifting and moving. They contend that important design decisions occur in the transitions and translations between representational formats and scales, and that material form provides opportunities for richer dialogues, particularly when working collaboratively. They contend that the multi sensory stimulation, derived from material objects, provides deeper understanding than it is possible to communicate verbally.

4.2 Instumentness

Recent research into creativity in digital musical collaboration has explored the notion of instrumentness, which *'points to the way musical instruments are controlled and conceptualized through values such as virtuosity and playability'* [1]. By exploring the metaphor of the musical instrument and its physical qualities they have proposed a new paradigm for developing software and interfaces that consider the aesthetics of use *'pointing to alternative values that differ from traditional usability'* [1]. Comparisons are made between making music on a physical instrument, which requires skilled competency (craft) and using a computer. Bertelsen and Breinbjerg, et al. contend that software can be considered a *material* comparable with music notation; by manipulating the notation, or computer code, it is possible to compose new work. McCullough [10] has made a similar claim for crafting with software when developing digital visual representations. The concept of *instrumentness* also implies the investment of time to practice with the software in order to become highly skilled. It negates the requirement for usability and transparency of software in favor of complexity of code that provides an expansive range of possibilities to enhance creative performance.

5.0 DISCUSSION

This position paper has identified some of the ways in which memory of physical experience informs creative cognition within digital visual art practice. The potential of physical material and crafting processes to stimulate creative digital practice has been illuminated through practical art making activities that have resulted in the production of artifacts for exhibition. The research has shown how multi-sensory information, acquired through physical experience, informs the development of visual concepts and impacts upon the making process through the development of tacit knowledge in both tool use and understanding of material properties. There is evidence that making by hand, touch and manipulative activities, have a significant impact on creative thinking and imagination [22]. Emotional content can be translated from artist to artifact through physical making and can be perceived in the work as 'aura' or 'emotional charge'[5] frequently lacking in the product of the machine.

Future computing, which is distributed and pervasive, will become increasingly physical through increased human interaction [16]. This will provide greater opportunity to interrogate the ways in which materiality is experienced and translated into digital visual representations. Interfaces that exploit the complex multi-sensory stimulation, perceived through experience of the world, will extend the creative potential of technology within art and design practice. Metaphors drawn from physical objects, such as musical instruments and performative activities, such as constructing physical models or using dance and movement, can suggest new approaches to software development and interface design.

6. ACKNOWLEDGMENTS

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Art on the Physical-Digital Border

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ABSTRACT
The support of human creativity by information and communication technology is an important and interesting area of research. The existing research literature on creativity offers no clear indisputable theories or models to guide us. Our approach to this complex problem has been to go back to first principles and study examples of creativity in action. In this paper we present a case study of the creative practice of the Irish artist Enda O'Donoghue. His work is particularly interesting because of the way it straddles the physical-digital border or frontier. His creative practice involves not only manipulating paint atoms but also manipulating digital bits.

Categories and Subject Descriptors
J5 [**Arts and Humanities**]: Fine Arts.

General Terms
Design.

Keywords
The physical-digital border, creativity, artist case study.

1. INTRODUCTION
Our research focuses on the IT-based *support* of creativity and we are working on the design and development of what we term *creativity-support systems* [1]. We found that the existing creativity research literature although extensive provided us with little direct assistance in our research quest. Mayer ([6], p. 458) summarises our feelings when he suggests that "although creativity researchers have managed to ask some deep questions. They have generally not succeeded in answering them." In the face of this apparent theoretical confusion, our strategy has been to seek out and study first-hand examples of creativity in action; People engaged in various creative activities who are prepared to share the details of their creative practice with us. Our previous similar studies include [2,3]. From these descriptive studies we hope to discover valuable abstract and universal principles for creativity support that will ultimately contribute to our design efforts.

Examples of creativity are all around us, but it is often difficult to isolate and observe them. As a starting point we have chosen to study the creative practice of established artists. For the purposes of our research, artists have the advantage of clearly defined and usually fairly stable creative processes. However, we wish to emphasise that we are interested in the technological-support of a whole range of creative activities and not just those that take place within the artistic sphere. In our studies of artists, we have found those working on the "physical-digital border" to be of particular interest. By this, we mean that in their creative practices at certain points they are manipulating digital bits and at other times they are manipulating paint (or other) atoms. This border seems to be an interesting and fruitful artistic zone but it also has particular significance for those investigating the IT-based support of creativity. One such artist working in this border zone is Enda O'Donoghue who is the subject of this paper.

Why should we attempt to support creativity? Creativity is a defining human characteristic and a fundamental part of human development. There is a strong argument for supporting creativity because of its intrinsic value. However, recent studies have also highlighted the increasing economic significance of creativity. Florida [4] maintains that creativity is the driving force of economic growth; it is the decisive source of competitive advantage. We often underestimate the economic significance of creative industries. In Britain, for example, the music industry employs more people and generates more wealth than the car, steel or textile industries [5]. We believe that there are immense opportunities for new technological systems that support a wide range of creative endeavours. However, what we really need is the creativity to be able to design and develop these innovative creativity support systems.

2. RESEARCH METHODS AND FRAMEWORK
Enda O'Donoghue is an Irish artist currently living and working in Berlin, Germany. He originally studied computer programming before taking up visual art. He has a degree in fine art from the Limerick School of Art and Design and a Masters degree in Interactive Media from the University of Limerick, Ireland. As well as painting, he has worked and exhibited in a wide variety of media including photography, video, sound, installation, public art and interactive media. Examples of his artwork can be found on his website www.endaism.com. His particular skills and experience mean that he is perfectly at home on either side of the physical-digital border and indeed his artwork often exploits the anomalies and effects produced when a created object crosses this border. Recently Enda has produced a collection of paintings created from digital photographs "found" on the Internet (see figure 1),

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this artwork and the associated creative processes is the focus of this paper.

Enda’s creative process involves both work on the computer and work on the canvas. He performs the computer-based part of his creative process at his home while his painting takes place at a separate studio in Berlin. This is a deliberate separation. He particularly wants to keep the distraction of the computer out of his studio. We interviewed Enda sitting at his computer in his home and in his studio. The interviews were tape-recorded and later transcribed. Quotes from these recordings appear in *italics* in this paper. We also took various digital photographs mainly of his studio and his painting tools. Enda also provided us with previously captured photographs of the detailed stage-by-stage development of a specific painting entitled “on the one”.

Figure 1. An Enda O'Donoghue painting

While we are extremely interested in Enda’s paintings and the wider meaning of his art, our focus is deliberately on the creative processes of this artist. In particular, we were trying to capture and understand the interplay of when he was manipulating digital bits and when he was manipulating paint. In the next sections we describe in detail his creative processes.

3. ENDA’S CREATIVE PRACTICE

As you might expect Enda does not break his overall creative process down into separate stages. However, we have found it valuable to identify particular stages and then to attempt to describe these stages in detail. We have termed these stages: finding an image, manipulating the image and creating the painting.

3.1 Finding an Image

The images that form the basis of Enda’s paintings are all “found” on the Internet. With the development of photo-sharing sites, photo-blogs and moblogs (mobile phone weblogs) there is an ever-increasing online photographic gallery capturing every nuance of ordinary lives (see figure 2). These blogs can often be updated directly from a person’s mobile phone. Enda particularly values the images taken by phone-cameras because they are often of mundane or banal scenes and often of low resolution with associated image defects.

“Some of the mobile phones are getting higher resolution, it’s terrible. I reckon I am one of the few people that search for bad quality images.”

Enda’s interest in “found” images began when he found in a railway station a collection of blurred and faded Polaroid photographs. These mysterious photographs along with their associated image distortions formed the basis of a series of paintings. The next stage in the development of his painting style was a series of paintings based on random images “found” on the Internet. Recently Enda has concentrated on images of scenes from modern urban environments, for example, supermarkets, waiting rooms, travelling on trains and aeroplanes. These everyday scenes are at once familiar to anyone living in a modern urban environment but at the same time they are also unfamiliar in that they are someone else’s photos of someone else’s life.

“I suppose that is the concept behind the whole thing, it’s a kind of window through to other people’s lives, but also it gives you a little more distance and objectivity.”

Figure 2. A "found" image

When Enda finds an interesting image on the Internet he captures it on his computer along with associated information such as its web address, its title and its author. From his collection of captured images he will print out those that he thinks have potential to form the basis of a painting. These images are printed on a colour printer in his home at around postcard size. These postcards are then taken to his studio and mounted on a wall that contains 200-300 images under consideration. From this image wall a short list of 4 or 5 are selected and considered in more detail as the next possible painting.

“I pick them out every now and then, look at them, put new ones in and eventually decide to paint one.”

Before he starts work on a painting he contacts the author or owner of the image to ask permission for its use. This has led to an interest in such movements as creative commons and other organisations devoted to making material available in the public domain. If he does not get permission to use the image he does not paint that picture.

3.2 Manipulating the Image

After he decides on an image that he intends to paint and before he starts to actually paint, Enda engages in a short intermediate stage where he investigates possible visual distortions or degradations to the chosen image. These degradations or glitches are achieved by applying various filters in Photoshop that mimic digital distortions, what Enda terms "degenerative and erosive noise effects." Typical distortions are bands of contrasting colour, areas of blurring or overexposure and the misalignment of picture elements.

One technique that Enda uses to explore general ideas for digital distortion is to view websites and images through a program called a Glitch Browser. This piece of software deliberately introduces glitches into viewed images in a programmed way.

As a basis for his painting, Enda produces two A4 colour printouts as "working sketches", one is of the "found" image in its original form and the other is of the manipulated image incorporating various digital distortion effects.

"So I play around with them [the images] in Photoshop and the final painting is painted from the original and bits of the affected version."

3.3 Creating the Painting

"It's like building a jigsaw."

"And the strangest thing that happens is I can never really see how the final thing will come together until the last piece is painted in."

To start a painting, Enda produces a 35mm slide from the original "found" image and projects this onto a canvas (typically 150cm x 120 cm) using a slide projector. He then traces out the main elements of the image onto the canvas using charcoal.

Figure 3. A painting in progress

He also draws a grid onto the canvas and a corresponding grid onto his two working sketches (printouts of the original image and the modified image). This grid is for location purposes and also forms the basis for dividing up sections of the painting to be painted. Sections of the canvas are masked off using masking tape and each section is painted as a single entity (see figure 3).

"I mask areas out. So what happens is I am painting blindly, because I don't see what's happening [in the next section] or whether they line up or not."

"Each of these sections can almost work as a single unit. They are painted in one go, on the same day, so it keeps it quite fresh. When they work well each one is as rich as a little abstract painting."

Sections of the image are selected to emphasise distortion and introduce digital effects; often the distortion is created by selecting sections that cut across significant parts of the image. Part of Enda's creativity is undoubtedly in how he chooses a section and how he paints that particular section. Painting in these discrete sections tends to introduce large-scale banding and pixelation effects, but he also introduces other digitally influenced effects. Straight lines in the painting take the form of pixelated steps, a common digital defect known as aliasing or jaggies. To help him to achieve the regularity of these steps he uses plastic templates or stencils, a different template for each angle. To introduce small-scale pixelation effects he uses stamps made from rubber matting. He uses these tools to blend and stamp the paint while still wet. The final painting built-up step-by-step using this process is a rich mosaic of colour and texture. Photographs of the finished paintings (like those used in this paper) capture very little of this richness. The paintings really have to be viewed in their atomic form to fully appreciate their beauty and impact.

At present Enda does not sell his artwork through a gallery, instead he uses his website as a virtual gallery. This seems appropriate for someone with his IT skills. Ironically, it also means that the image that was "found" on the Internet returns to the Internet after the elaborate and painstaking process that has transformed it into a painting. The digital photo of the final painting probably looks little different from the original image (see figure 4). However, as we have described above, the digital photograph certainly does not capture the full beauty and richness of the actual painting.

Figure 4. The finished painting

4. IMPLICATIONS FOR CREATIVITY SUPPORT

Although the creative processes of artists like Enda O'Donoghue fascinate us, our ultimate objective is the design and development of creativity support systems. We have to attempt to develop abstract general principles on creativity support from our studies to be applied to the design of creativity tools. Our study of Enda's creative practice clearly requires more time and space to analyse the full range of implications, however, we can highlight here our most obvious findings.

4.1 Media Switching

Most artists working on the digital-atomic border are exploiting media switching in some way or other. For Enda, his creations begin as digital images and he converts them into arrangements of paint atoms on canvas, ironically imitating digital distortion effects in his painting style. Finally, his painting has a digital form again when he adds a digital photograph of his finished artwork to his virtual gallery.

The initial digital form of the image allows it to be captured in an instant and potentially viewed by everyone who has access to the Internet. Enda converts this image into a collection of paint atoms. Although the process of painting on canvas is around 500 years old it still has a number of marked advantages. A painting suggests permanence, originality and authenticity, which has a strong influence on perceived value. It is a stable wall-based form of representation that is widely accepted as "art". For Enda painting also allows him to exploit his undoubted painting skills that have been developed over many years. However, a painting's physical nature is a serious disadvantage when it comes to exhibiting his work. It can only be in one place at one time. By converting his painting back to a digital image, once again this image can be viewed (and bought) by potentially anyone who has access to the Internet. A final irony however, is that when reduced to an image on the Internet, Enda's paintings look little different from the original images, the impact and beauty of the painting is largely lost for those who are not able to view the physical artwork..

5. CONCLUSIONS

We have attempted to outline the creative practice of Enda O'Donoghue. His artwork occupies an interesting position on what we have termed the physical-digital border. Because of this position we believe his creative processes are of particular value in our investigation into the IT- based support of creativity. We need to analyse and reflect on our findings further and consider the design implications in more depth.

6. ACKNOWLEDGMENTS

We would like to thank Enda O'Donoghue .

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Mixed Reality Jockeying & Social Media

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ABSTRACT

In our proposed anthropological research project, we investigate contemporary mixed realities through innovative performance and artistic activities both on site (at the workshop) and online (MySpace). Specifically, we act as reality jockeys (RJs) working directly with the production, consumption and distribution of contemporary media, sound and the 'sensible' itself through social media technologies such as MySpace and Eyespot, and digital media production tools (sound recording, laptops, software, cameras).

Categories and Subject Descriptors

K.4.2

General Terms

Documentation, Performance, Experimentation, Human Factors, Theory.

Keywords

Mixed Reality, Virtuality, Distribution of the Sensible, Anthropology, Performance, Art, MySpace, Social Software, Reality Jockeying.

1. ORIENTATION

We are Legion is an aesthetic and anthropological research project involving a mixed reality changing room and a constructed band. Conceptually, our project experiments with and researches emerging mixed reality ecologies arising from the mass imbrication of the virtual (in the form of social software based activities) in the so-called 'real' physical world – think for instance of office workers hanging out on Facebook and MySpace whilst at work. *We are Legion* is at once a work of performance art *and* a penetrating investigation into the production, consumption and distribution of contemporary media, sound and the sensible itself (*le partage du sensible* – Jacques Rancière) through social media technologies such as MySpace and Youtube.

Social media productions are part and parcel of the domain of the visible, sonic, and sensible and are thus implicated not only in aesthetics but also in politics, to follow from Rancière's 2004 text *The Politics of Aesthetics* [1]. This is to say, social network activities in the form of MySpace, Facebook, Youtube living and the cultural experiences and artifacts they produce work to distribute or partition the world into that which can and cannot be seen, heard, said, felt, understood, and sensed.

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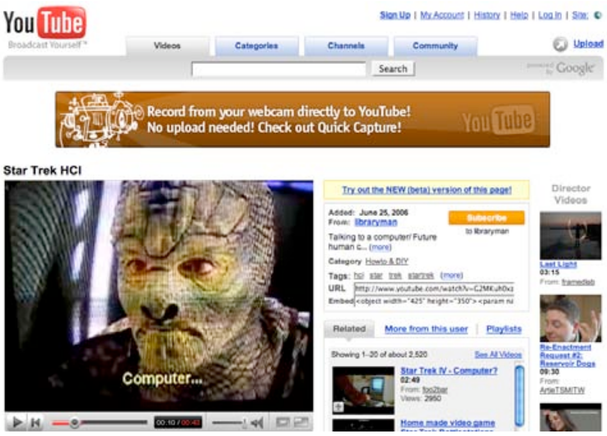

Figure 1. Screenshot of Youtube.com 'Star Trek HCI'.

Virtual regions of experience – such as MySpace or Youtube – as well as actual domains of experience – such as offices, cities and *Physicality 2007* – are very specific configurations of that which can and cannot be seen, heard, said, felt, understood, and sensed. Such experiential regions structure or order the field of virtual / potential and actual actions.

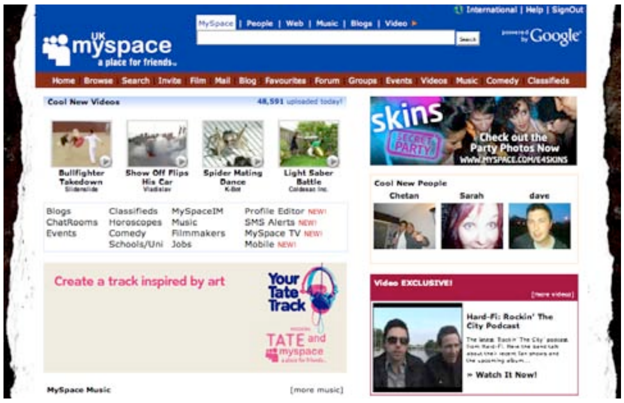

Figure 2. Screenshot of MySpace.com homepage.

RJ'ing by *The Hollywoods* involves the production of aesthetic acts "as configurations of experience that create new modes of sense perception and induce novel forms of political subjectivation" [2]. The intention is to instantiate a politics of aesthetics.

Rancière defines the politics of art as the endless recasting of what is perceptible, understandable and therefore artistically conceivable during a certain 'aesthetic regime,' defined as the politically

> determined configuration of knowledge and societal activities associated with a certain historical and political contingency [3].

RJ'ing enacts such an endless recasting through the practices of mashing up, employing movements and cuts across virtual and physical domains in order to stimulate border crossings and flows, resonances and disagreements.

2. PROJECT DETAILS

"Each technological extension involves an act of collective cannibalism. The previous environment with all its private and social values, is swallowed by the new environment and reprocessed for whatever values are digestible […] Our natural bias is to accept the new gimmick (automaton, say) as a thing that can be accommodated in the old ethical order" [4].

Frequently new technologies act as extensions of utopian visions, and are complicit in the transmission of power and the distribution of the sensible. The current horde of social software technologies is no different. Previous environments are gradually giving way to newer practices and values, after being consumed and digested for all that is transcodable into the new regimes of the sensible. The changing landscape of music and media promotion, distribution and consumption via MySpace is just one example.

Figure 3. 'White Bull' track from *The Hollywoods Debut* on MySpace.com.

We are Legion challenges hegemonic distributions of the sensible by engineering experiential encounters with online and physical environment(s) that involve 'mashing up' sounds, images, words, and other cultural productions used by MySpacers and individuals in real life settings (i.e. at an academic workshop). A key move in this project involves opening up flows into and out of traditionally obscure and exclusive cultural environments such as academic conferences, workshops, performance events and art exhibitions.

The researchers operate as RJs spinning their online, on site, and non-linear methods and intensities into and out of the physical space of a city and conference / workshop venue. The RJs take positions as nomadic guides and mapmakers, employing the malleability of the virtual in a return to affect and the actual, through remapping, resituating and remixing the sonic and sensible environment. Cultural artifacts (e.g. mashed up video and audio samples of *Physicality 2007*) act as points of departure for these investigations, agreements and disagreements.

By working online (using MySpace profiles and online mashup utilities) as well as on site, the RJs throw themselves into the fray of contemporary mixed realities, pulling subjects and objects from both online and physical locations into the mix. Social media artifacts produced in this maelstrom cut across spacetime boundaries of the actual *Physicality 2007* event to be continually used and remixed via the (paradoxically) more permanent virtual environment of MySpace. Space and time are breached also by the introduction and splicing in of artifacts from the RJs previous engagements (e.g. Digital Arts Week Zurich 2007) to *Physicality 2007*. In these ways, the fabric of 'physical reality' itself is continually called into question, made into the object of experimentation and analysis.

Figure 4. Video hosting on *The Hollywoods* MySpace page.

3. WE ARE LEGION CHANGING ROOM

The conference workshop event is used as source material for the production of social media artifacts. It functions as a sort of public changing room that brackets a local space within which we stage the birth and becoming of a multiple character that is the face, sound, and image of an academic event. This is done by involving and engaging workshop participants and activities in cultural productions on location[1]. The many academic productions are consumed and regurgitated – sound, voice, image, words, and actions - by the artists as RJs. Media content produced in this way is then fed into a specially created MySpace profile for *Physicality 2007*. There, these cultural artifacts are subjected to scrutiny and further remixing online by random audiences from the 190 million strong MySpace population. Such an intervention seeks to dissolve the borders

[1] Social media productions are enabled by portable media production kits including laptops and wireless net connections.

of the Ivory Tower, opening up flows between the Academy and society.

The entire *Physicality 2007* workshop is thus cast as the mixed reality changing room. *The Hollywoods* by their roaming and sampling presence at the workshop, and through their mashing up, uploading and downloading activities online, effectively transform *Physicality 2007* into a mixed reality environment of flux and flows, ruptures and sensation.

Figure 5. *The Hollywoods* band member in costume.

4. REALITY JOCKEYS IN AN AGE OF SOCIAL MEDIA

Figure 6. *The Hollywoods* on MySpace.

Hollywood is a self-perpetuating cornucopia of simulacra and decadence. *The Hollywoods* are the artists acting as RJs in an age of social media. Composed of fictional identities and costumed characters, *The Hollywoods* are a band with a MySpace profile. The band tours with the *We are Legion Changing Room*, alighting in each city with the mission of remixing the city through its various composite cultural artifacts, and remapping the visible, sonic, and sensible terrain. The use of costumes acts as a means of mashing up / splicing cultural identities and stereotypes, furthering the engagement with distributing the sensible.

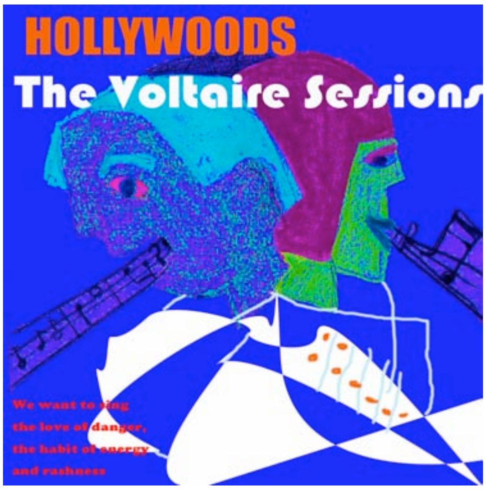

Figure 7. *The Hollywoods* album cover 'Voltaire Sessions'.

Each visit to a city is announced as a 'Secret Show' on MySpace to fans. Through MySpace and the secret shows *The Hollywoods* explore the unpredictable, celebrate volatility, and work to privilege the flux of knowledge, sense, and reality – opposing the stasis of (actual) being with the anxiety and movement of (virtual) becoming.

5. SUMMARY

We are Legion Changing Rooms, including the RJ machinery called *The Hollywoods*, instantiates a mixing of virtual and real lifeworlds in unexpected ways. This is a new participative research project investigating the production, distribution / mashup, and reception of creative vectors backwards and forwards along the virtual – actual continuum. In a sense, this project returns to an earlier notion of social sculpture, seeking to explore the ways in which mixed reality activities actively shape and sculpt the institutions and spaces of the world.

Check out the Hollywoods at http://www.myspace.com/hollywoodsband.

6. ACKNOWLEDGMENTS

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Physical Affordances Considered Harmful !?

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ABSTRACT

Frequently physical affordances are considered one of the main advantages of tangible interfaces or input devices, making interaction intuitive. This assumption may be overly simplistic – because physical objects have a multitude of physical affordances and properties, it is difficult for the designer to restrict these to (only) those that match with the digital system that they are connected with. This paper presents examples from a user study of children interacting with augmented books using physical paddles. These illustrate how children expected the digital augmentations to have physical 3D-behavior, encouraged by the possibility to interact in 3D space and by the (digital) visual feedback. The affordances of the physical interaction devices were rather deceiving, being a mismatch with the digital system's capabilities, and in effect intuitiveness of interaction broke down. Finally, a first cut at an analysis is presented of what our observations mean for the intuitiveness of tangible input elements and the use/virtue of physical affordances.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: Models and Principles, - *human factors*. H5.1 [**Information Interfaces**]: Multimedia Information Systems – *artificial, augmented and virtual realities.* H5.2 [**Information Interfaces**]: User Interfaces - *haptic I/O, input devices and strategies*.

General Terms

Design, Human Factors, Theory.

Keywords

Affordances, physicality, tangible, TUI, handles, augmented book, intuitive interaction, naturalness, augmentation.

1. INTRODUCTION

Frequently tangible user interfaces and physical computing in general are being argued for by alluding to their similarity with our experience from the physical world, being intuitive and allowing users to leverage their existing skills and experience [3, 4, 12, 13]. The physical affordances of tangibles are said to contribute to this intuitiveness. Observations from a prior project led me to regard the assumption that interaction guided by physical affordances of the natural world will transfer directly to the world of physical-digital ensembles as too simplistic. Physical affordances may on the contrary be misleading and deceiving, if physical representations are not closely mapped to the digital elements they are connected with – they may promise more than the system is able to do, and in effect increase the difficulties encountered.

The examples used here stem from a study with young children interacting with augmented books by manipulating physical paddles and paper sheets. The paddles in an on-screen view are super-imposed with animated characters from the book and serve to control their movements. This is very close to the notion of 'haptic direct manipulation' [10]. We found that children expected the augmented paddles to have physical 3D behaviors, expecting the 'physical effects principle' to apply [7], and employing what we referred to as 'physical metaphors' for their interactions [5]. Yet the system does not react (and cannot) as expected, and the children repeatedly struggled to achieve their aims. This obviously interferes with the 'augmented reading experience' which is the aim of the AR-book, system reactions being counterintuitive at times. The physical affordances here seem to be so strong in suggesting how to interact, that it is difficult for users to ignore them.

While our study involved children aged 6 to 7, this issue is likely to be of general relevance – adults may find it easier to disregard the affordances of physical input devices, to step back and analyze how the system reacts to their actions, but this would also mean that interaction is not intuitive (in the sense of being ready-at-hand [4]).

The final part of this position paper makes an attempt to shed more light on the underlying problem by discussing the paddles' role by applying several conceptual approaches to understanding affordances, intuitive interaction of tangibles, and direct manipulation. This analysis so far is not finished thinking yet, but points to the fuzzy role of the paddles, in-between being an interface, an interaction device, and a perceived interaction object...

2. CHILDREN READING AN AUGMENTED BOOK

The notion of an 'augmented book' [2, 3] inspires researchers and educators as a means to enhance books with interactive visualizations, animations, 3D graphics, and simulations, enhancing engagement and allowing for active manipulation and exploration of the content [17]. In terms of interaction technology, augmented books are midway between tangible interfaces and Augmented Reality, the interaction means being tangible and the view of the book augmented with digital images. There still is little known about the "how, what, and why" [17] of augmented books, their effectiveness, or the instructional support needed, and potential interaction issues or design criteria. This motivated the study done at the HitLab NZ which here serves as example.

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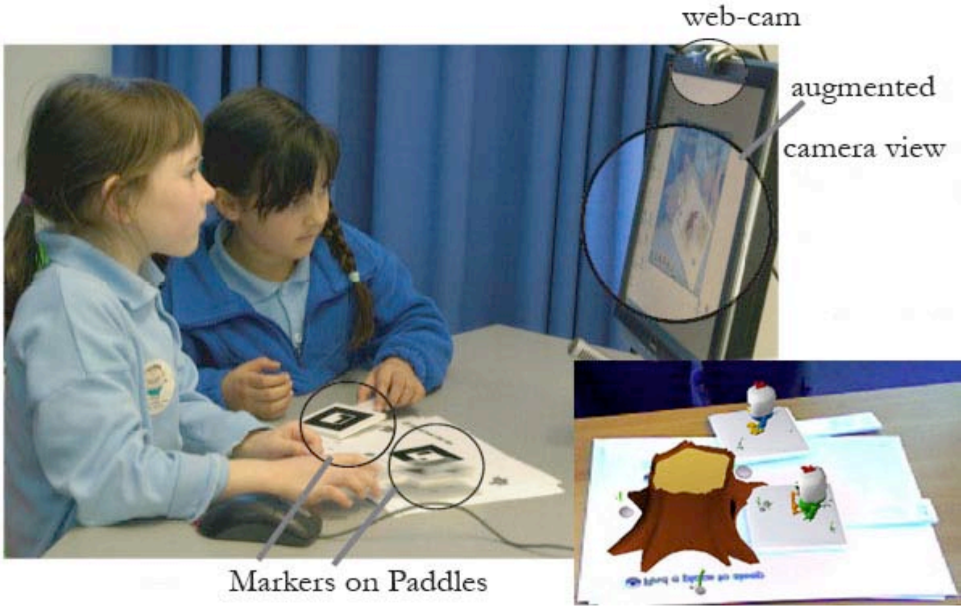

Figure 1. Set-up of system, with children engaged in interactive sequence (sneaking around the fox, the fox visible on-screen). Inserted image shows on-screen view of the chicks (sitting on the paddles) in front of a tree trunk (a marker on the page)

The study was designed to explore the use of augmented books for early literacy education. Children aged 6-7 interacted alone and in pairs with the AR-Jam storybooks (developed by the BBC). Two groups of children with different reading skills and socio-economic backgrounds participated in the study. The first trial involved children that had been identified by teachers as 'eager readers' (reported on in [5, 6]). As a contrast, the second trial involved children of the same age with reading skills below their chronological age [11].

2.1 The Augmented Books and the Study Design

The BBC provided the HitLab NZ research team with two augmented storybooks created for their AR-Jam project. These employ a combination of physical story pages and desktop interaction (screen, mouse), and alternate traditional narrated text pages with interactive sequences. On text pages (on-screen) the children can either read by themselves or listen to a recording. By clicking on buttons on the screen they can navigate through the story and start interactive sequences that have them interact with physical pages and paddles (see figure 1), seeing an augmented view on the monitor. The paddles serve as tangible input devices. They *represent and control* the main characters of the story while the paper pages constitute the setting (and other characters) for interactive sequences, organized as a series of physical pages.

The augmentation is based on AR Toolkit markers on the pages and paddles that are detected by a web-cam [3] and are replaced in the video image with computer-generated, animated 3D images. The augmented book thus becomes visible on the screen when pages and paddles are in camera view. The pages usually have 'hot spots', indicated by a grey outline. The markers are replaced on-screen with a relevant object for the story. Placing paddles on a hot spot triggers story events – in figure 1 (on the right) the chick will inspect a hole in the tree-trunk. A web-cam connected to the computer and positioned on top of the screen allows the technology to be used in most classrooms, being a low/no cost set-up. However, this does not provide a fully integrated view of real and virtual objects, unlike other AR-set-ups using head-mounted or hand-held see-through displays.

We used two storybooks. "Big Feet and Little Feet" tells the story of two little chickens, left outside the hen house in their eggs, who have to overcome several obstacles to escape a fox and find home. "Looking for the sun" has four insects (thus four paddles) that try to get to the sun. The chick story was specifically written for the AR-Jam, the other was adapted from a book by Rob Lewis.

Children from two local primary schools, ages 6 ½ to 7 (year 2), participated in the study at the Christchurch South Learning Centre (New Zealand). This corresponds to key stage 1 (age 5-7) in the UK system. For the first trial, avid and good readers were solicited from a nearby school in a middle-class neighborhood. Three pairs and three individual children each 'read' and interacted with one of the two stories (18 children in total). Supervised by the researchers, one child respectively pair at a time read and interacted with the storybook. Then, each child was interviewed individually. Analysis was open-ended, iteratively evolving and collecting categories and issues for further analysis. We employed both stories for wider insight into relevant design issues. The videos were analyzed collaboratively by the two researchers, iteratively collecting recurring issues and developing detailed notes of the children's interaction, transcribing talk and manual interactions.

As a contrast, the second trial involved children with reading abilities below their age who are hesitant about books. The trial was organized as part of one of the Learning Centre's 'book wizards' workshops conducted for a school serving a low-income socio-economic neighborhood. For this trial we used only the story about the two chicks, as we had identified a range of interaction problems with the other story. We further limited the trial to the pair condition (six pairs). Analysis followed the same approach as before.

2.2 Expectations of Physical 3-D Behavior

This paper focuses on one of the findings from this study, the children's expectations of the augmented paddles to follow physical laws of the 3-D world.

These expectations of 3D physical behavior seemed to be triggered by the tangible input devices in combination with the visual system feedback. The tangible input devices – paddles – have the physical affordance of allowing for manipulation in 3D space (Norman [15] talks about the 'real affordances' of physical objects in contrast to 'perceived affordances' that the user sees, on-screen objects having only perceived affordances). The augmented view provided on-screen reinforces the impression of interacting in 3D-space, because the markers'

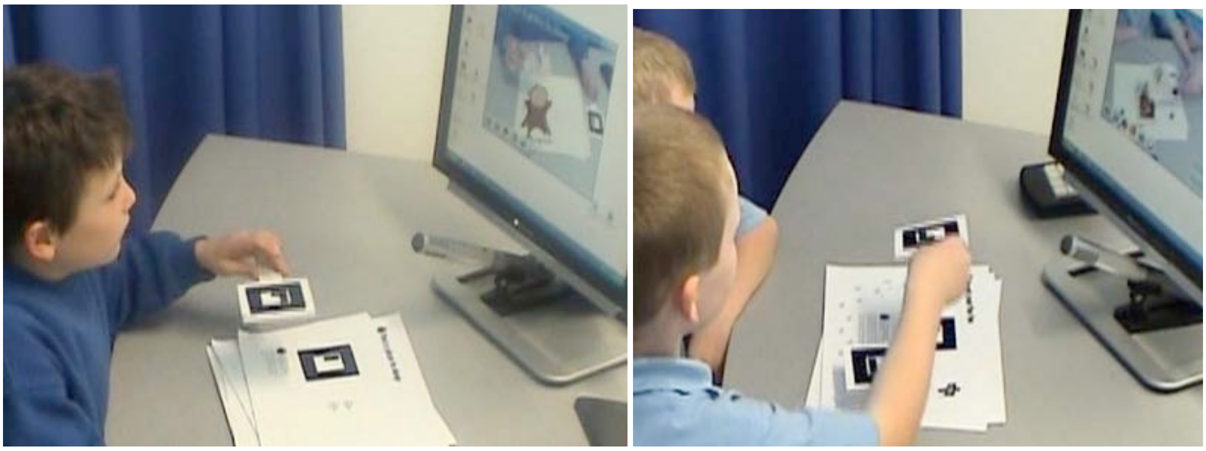

Figure 2 Trying to sit on top of the tree trunk and attempting to 'jump over' the fox

size and orientation are tracked and the digital objects (which on-screen are overlaid on the markers) are shown in the corresponding perspective view. Yet the story engine, that determines the effects of interaction, interprets the position of optical markers as a 2D point in the camera picture, ignoring orientation and height. A further limitation of the system is that markers need to be visible and paddles carry markers only on one side. Occlusion results in the virtual object disappearing. Objects can thus not be turned upside down.

We observed children attempting a whole range of 3D-interactions with the paddles, trying to make the digital characters (visible on-screen, on the paddles) act in 3D space. Evidence for these expectations of physical 3D behavior stems not only from the children's visible behavior, but can also be found in their talk. We saw children trying to let their chick sit on top of a (virtual) tree trunk by holding their paddle high above the tree visible on-screen. They tried to jump over obstacles, moving the paddle in an arch over the obstacle visible on-screen, (a meaningless motion for the software system). When aiming to make an object move off the paddle onto the ground, several children held their paddle in a slight angle and wiggled it, as if trying to let the object slide down, hoping for gravity to help. And quite often children would mimic a walking motion when moving the paddles, similar to the way they might move a doll during play. In the next sections a set of detailed examples from our notes and transcriptions from the videos is presented and discussed.

2.2.1 The Physicality of Cracking Eggs

An interactive sequence that had most children instantly refer to physical interactions with real objects was the story opening for 'Big Feet and Little Feet'. The story begins with the mother hen having forgotten to bring her eggs into the hen house at night. The children see eggs on their paddles. Bringing them closer to each other makes one chick say "Lets do it again" (this is intended by the system designers to provide a clue to children that the eggs need to be knocked against each other). We saw a wide diversity of different attempts at cracking the eggs open. For instance many children tried banging the paddles (which on-screen had the eggs sitting on them) face-down into the table or head-to-head into each other. Both interactions result in the markers being occluded.

In this example, two boys rather playfully attempt to crack the eggs. They repeat this interactive sequence a couple of times, enjoying themselves. Even though they are successful, this is often quite by coincidence (the markers being next to each other for the camera) and they do not identify the 'correct' way (even though they repeat this four times within 3 ½ minutes).

Ken and Tom have already cracked the eggs once and want to repeat the sequence. They start hitting the paddles against each other vertically in the air, markers facing each other (effectively invisible for camera). On the screen this looks as if knocking the eggs' heads against each other, a sensible action in the physical world. Having tried this a few times, they bang the paddles onto the table face down (the markers invisible). Ken starts, and Tom imitates him almost immediately.

After a while Tom takes the paddles and whacks one paddle, the marker facing downward, onto the other paddle, the marker facing upward. This has the paddle on top hide the lower one. The markers are only briefly visible during this motion. Somehow the eggs finally crack up. Tom says "Do it again" and Ken hits his paddle on the table. He then starts to smack his paddle against his own head, and Tom imitates him. They laugh loudly and exaggerate their movements, visibly enjoying themselves. After a while of doing this, Ken bangs his paddle with its edge onto the table.

In this short sequence we see a wide range of different actions one might do when trying to crack real eggs. Interestingly the children seem to identify the paddles as 'the eggs', even when holding the paddles in a way that occludes the markers, thus having no view of the eggs on-screen. Quick movements and fun experiments were rather typical for this sequence, and many children in their excitement forgot about the need for markers to be visible for the camera. Working through the story, the children usually became more aware of this need and tried to keep markers facing upward. Yet the many instances throughout story reading where the markers were occluded (by holding them in an extreme angle or by moving one paddle over a marker) shows that this is not natural behavior but requires conscious effort.

2.2.2 Jumping On and Over Things

Often children attempted to employ the third dimension in their interactions with the story elements. They for example tried to let the chicks sit on top of a tree trunk visible on-screen, to jump over a sleeping fox, or to let the chicks jump over a fence, moving the paddle in an arch that on-screen indeed arched over the fence. This example is from two boys, who just saw the tree trunk appear on-screen after the paper sheet with the corresponding marker is put on the table.

Ken asks his friend "so what do you do, climb on it?" and moves his paddle over the tree trunk. As nothing happens, he moves the paddle slowly towards *the tree trunk, and eventually the animations are triggered as he moves the paddle over the hotspot on paper.*

The spoken question provides us with additional evidence of children's expectations to be able to interact in 3D, analogue to the natural world. Figure two (left) shows a boy in the individual reader condition attempting to let a chick sit on the tree trunk, hovering with the paddle in the air, while staring at the screen. On-screen the chick is positioned above the tree trunk. This action does not trigger any events from the story engine – the children have to position the paddle onto the hotspot next to the tree trunk, which makes the chicks inspect a hole in it.

2.2.3 Letting Objects Slide Down

The tendency to refer to a physical world analogy posed a hurdle for most children asked to let the insect characters in the 'Looking for the Sun' story build a tower. The children need to make the insects stand on each other; the intended challenge being to find out in which order (smaller animals on top of larger ones).

The children struggled not only with finding the right order, but also with putting the paddle on the 'hot spot' next to the 'tower location' on the sheet in order to make their character jump onto the ground or onto the shoulders of another insect. We saw some children trying to make the insects slide or fall from the paddle, following laws of gravity. Children reading the other story, when required to let the chicks drop stones that they were holding, often held their paddle in a similar slanted angle, as if hoping for gravity to make the stone drop down. We here give a detailed example from the 'sun story' (Claws, Ant, and Scuttle are the story characters).

One insect is already on the ground and two girls now try to make another one stand on its shoulders. Alice takes a paddle and lays it directly onto the hotspot, upside down (the marker invisible for the camera). Then she tells her friend Clara: "No, get Claws". The tower tumbles down, and Clara fumbles for another paddle. Alice insists: "It should be Claws first". Clara takes the Claws paddle and holds it vertical, but visible for the camera (as if letting the insect slide down), explains "and then Ant", takes another paddle and holds it vertical again (as if sliding down), explaining: "then Scuttle". Figure 4 (left) shows this hand posture. Then Alice takes the next paddle with Scuttle, but holds it upside down and sideways (the marker invisible for the camera) onto the hotspot. She then turns the paddle around, holding it vertically upright (as if trying to let Scuttle slide down). Her friend Clara takes the paddle from her, holding it in a similar angle, and starts to wiggle the paddle until the insect finally jumps onto the tower, the marker being detected in the correct position. Alice now does the same with the next paddle, holding it first upside down, then upright and wiggling it.

They start to discuss in which order the animals are on the tower and which orders they already tried. Again, the tower tumbles and they have to start all over. Clara takes the paddle with Crab, waves it around, but doing so occludes the marker on the sheet with her paddle. Alice now tells her to "push him down", and takes her hand, tilting hand and paddle so the paddle faces downward (see figure 4, right).

Figure 3. Building a tower with the paddles

One child's behavior is copied by her friend and vice versa, something we already noticed with Ken and Tom. Children imitating each other could just as well be picking up a useful 'how to' behavior as be iterating the same non-goal-leading behaviors over and over again. Still, overall children seemed to profit from working with a partner, getting less badly stuck than individual readers [6], and showing more signs of play and enjoyment.

The rather coincidental successes of the girls (after some wiggling) reinforce their belief of having found the best way to make the insects jump off the paddle. At the end one girl verbalizes her current understanding by teaching her friend to "push him down" and demonstrates how to do things. This makes explicit the children's assumptions.

The sequence further shows some general difficulties with the system, as the markers are easily occluded, especially with excited children acting simultaneously. Furthermore the spatial order of the intended tower needs to be translated into sequential movement of paddles, a cognitive challenge that requires abstraction.

Additionally, several children attempted to stack the paddles, literally building a *tower* of paddles (figure 3). One child asked the researchers at the start of this interactive sequence "so do I put them all on a pile like that?", providing further evidence that the task of building a tower was interpreted to refer to the paddles. We give a short example.

Kathy takes the first paddle and aligns it with the marker on the sheet. The marker is recognized. She keeps the paddle in place and puts the next paddle on top of the previous one. The tower (of two insects) tumbles. Her friend Lea puts her hands in front of her mouth ('oh no' gesture). Kathy explains: "Oh, you have to get them right on top of each other" and aligns the paddles as 'tower'. Then she puts the third paddle on top, and takes the fourth, Lea reaches over and aligns the paddle tower.

3. DISCUSSION

We might conclude that interaction could be enriched by more explicitly exploiting physical analogue behaviors, using them as interaction metaphors. Some researchers have quite

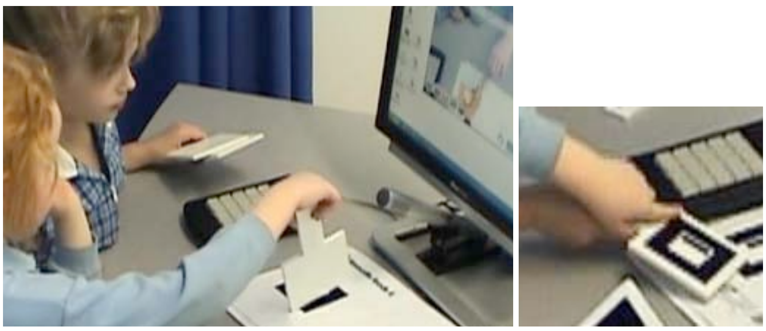

Figure 4. (left) Trying to let objects slide from the paddle by holding it slanted. (right) One girl grabs the other's hand, instructing her to "push him down" and demonstrating how to hold the paddle.

successfully developed interfaces based on the ‘physical effects principle’, such as a handheld calendar that scrolls to the next day if tilted [7]. But a more cautionary lesson is also recommended.

The tangible input elements (paddles) in our study worked rather too well in terms of encouraging physical interaction, users assuming physical world affordances and laws to transfer to the corresponding 3D objects. This inclination might be problematic for other tangible systems as well. Even though adults might be less inclined to expect physical-analogue behaviors, initial intuitiveness of interaction will break down at some point, shifting from ‘ready-to-hand’ to ‘present-at-hand’, because the input element is not transparent any more, becoming an object of investigation in itself [4].

In the remaining space I will attempt to get a clearer understanding of what our observations mean for the intuitiveness of tangible input elements (‘elements’ referring to their stand-in character in contrast to generic input devices) and the use/virtue of physical affordances. A range of concepts and analytical constructs from the literature are utilized in this attempt.

Beaudouin-Lafon’s [1] analysis of ‘directness and transparency of manipulation’ provides a starting point. Directness is split into three aspects, the *degree of indirectness* (spatial and temporal distance between tool interaction and effect), *degree of integration* (relation between degrees of freedom of the input tool and the interaction tool), and *degree of compatibility* (similarity between manual actions with interaction tools and reactions of the manipulated object). The paddles are input tools and at first sight appear to be identical with the interaction tools (the markers???) in the virtual interaction space, where they control interaction objects.

The physical affordances of the paddles provide complete freedom in manipulating them in 3D space. The virtual visualizations seem to follow these faithfully (while markers are visible). This indicates good compatibility. The definition of ‘degrees of compatibility’ does not address the expectations of physical laws, which would e.g. dictate that an object falls from a paddle if this is held in a steep angle due to gravity pulling against friction. What does compatibility mean in this specific context? Some indirectness is created by the need to look at the screen to see effects, but children usually focused on the screen, where indirectness ceases to exist, the virtual objects clinging to markers. Position and orientation of markers in the video image (interaction tools) are interpreted only as a 2D-position for the story engine. Identity of paddles with interaction tools thus only holds for the visualization and not for interactive behaviors. The paddles and markers thus fail in terms of integration, but do quite well in terms of indirectness (low) and compatibility (high, if the definition refers only to the similarity of the shape of movement). This conceptualization of directness thus does not cut to the core of the problem. It does however point to the fuzzy role of paddles – are they interaction object, interaction tools or just input devices?

One risk of exploiting physical-analogue behaviors, interpreting 3D positions of paddles, might be the long road of refining a simulated physics engine. The affordances of physical objects are potentially endless (cp. [14, 16]); we observed various unexpected interactions with the paddles, them being turned around, hit on edges, hit against each other, being piled, tilted and slanted, moved in an arch etc. The more of these physical behaviors the system detects and makes the digital world act in accordance, the higher the expectations rise. And the more confusing the eventual breakdown...

This may be quite similar to the experiences HCI gained with the use of metaphor, which inevitably break down at some point. Metaphors are useful in helping users to map familiar to unfamiliar knowledge. But relying too much and too literally on metaphors in interface design, making objects look and behave exactly like the physical entity used as analogy, has sparked a good amount of criticism (and often resulted in overly complicated interfaces) (cp. [18, pp. 61]). Different from on-screen interaction (including touch screens) 3D physical form with tangible input elements is not merely a metaphor, clearly represented in 2D space, limited to this space and representation format. We can differentiate between an object and its picture, can move between seeing the object in the picture and seeing a flat canvas with some colored patches. Knowing that the depicted object is just an optical illusion which does not have the same properties as the real object allows us to interact with it on two levels at once – taking it as a stand-in or as a reference for the depicted object while knowing it is just a picture.

Users have learned that desktop display metaphors are not to be interpreted literally and tend to be rather cautious in this regard nowadays. Tangible objects on the other hand have real physical affordances, and these are even more inviting than visual metaphors and raise expectations that are difficult to resist or to disregard. Norman [15] points out that the designer can manipulate real affordance (which only exist in the physical world), feedback to interaction, and perceived affordances independently of each other, and that sometimes it would be best to hide the real affordance. In the case of the paddles, there exists a mismatch between the real affordance of the paddles to be moved in 3D space, the visual feedback, which creates a perceived affordance for the user, seeing the augmented objects faithfully hanging onto the paddles in 3D space, and the actual system behavior. As Norman says: the “power of real and perceived affordances lies (*in the*) real, physical manipulation of objects” – but this also creates a risk of creating suggestions that are just too powerful.

Fishkin [8] in his categorization of tangible interfaces introduced *embodiment* (linking of input to output focus and the users’ impression that computing is embodied in the object) and *metaphor* as categories for analysis. Metaphor refers to whether the system effects are analogue to the real-world effect of similar actions – the ‘physical effects principle’ [7]. Metaphors can be by *noun* (similarity in form or appearance) and *verb* (similarity of the action). The children in our study are led to assume a very strong verb metaphor to be in place, albeit the designers have only implemented a noun and a weak verb metaphor (movement).

On a superficial level the paddles are close to the notion of ‘haptic direct manipulation’ [10]. Yet structural similarity of manual actions with effects repeatedly is ruptured. With the augmentation only on-screen, it is not clear conceptually *where* the interface is – on-screen, in the space of manual interaction, or in both arenas? The children seem to identify the paddles with the characters; the paddles for them are *the* interaction objects. While the visual mapping (attachment) of digital objects to paddles is simple and literal, the effects of users’ actions are less evident – the structure of input actions is only indirectly connected with the effects on interaction objects. The inherent feedback from the paddles conflicts with the augmented (functional) feedback on-screen [19]. This makes it difficult to discern the relation of actions to effects, the children e.g. thinking that it is the banging motion that makes eggs crack.

[10] distinguishes the basic syntax of interaction, which should be easy to explore when manipulating objects (syntax refers to basic actions like moving from A to B and seeing an effect related to A and B), and the semantics of interaction (referring to more detailed and domain-specific effects of actions). Intuitiveness thus is relative to domain knowledge, and ‘intuitiveness’ might have levels. Hurtienne and Israel [11]

recently discussed how intuitive interaction can be thought of as relying on several layers of knowledge (innate, senso-motoric, cultural, expertise) and proposed 'image schemas' as basic metaphors (relying on embodied experience) that can provide intuitiveness. Physical laws may be a simple example of 'semantic directness', referring to how the application context is mapped with objects and operations/manipulations. Because the children see 3D objects on-screen they expect them to behave like the same type of 3D objects in the physical world.

4. CONCLUSION

This paper re-analyzed findings from a user study of an augmented book highlighting problems resulting from a mismatch between the affordances of physical interaction devices, users' mental models, and the actual capabilities of the digital system. Children reading an AR book expected animated augmented objects (which they could move around via optically marked paddles) to follow laws of the physical world, waiting e.g. for gravity to let something slide down or trying to jump over objects. The tangible input elements (paddles) encouraged physical interaction rather too well, children attempting actions that the system could not detect or react to, resulting in repeated small breakdowns of intuitive interaction.

The affordances of physical objects are potentially endless. This means that even if we thoroughly user-test physical interaction elements, hoping to spot all behaviors users might come up with, we cannot be fully sure of covering all possibilities. An optimal physical object that *only* has the desired affordances may not exist. In the case study discussed, constraining movement of the paddles (e.g. mechanically) would be very complicated and – as I feel - would overly restrict the interaction and harm the playful experience.

The real affordances of tangible objects seem to be very difficult to resist; in our case study they were suggesting a strong 'verb' metaphor. The discussion so far points to the role of digital visualizations in enforcing children's expectations of physical world 3D-bevhavior. The augmented feedback on-screen creates a promise of 3D-ness, but the structure of manipulation is only indirectly connected with the effects on objects. Even though the mechanical manipulation of paddles remains intuitive, determining what exactly the results of movements are (or which element of a movement caused a particular effect) often is not intuitive, requiring investigative attention and 'present at hand'-ness.

This is so far just the start of an analysis, which is to be continued. As a side-result it is interesting to note that the theoretical/conceptual approaches employed in attempting to pin down the problem do highlight aspects, but fail to provide a straightforward explanation. We still seem to be lacking the conceptual vocabulary to clearly denote what we talk about.

5. ACKNOWLEDGMENTS

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The Role of Inverse Actions in Everyday Physical Interaction

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ABSTRACT
In this paper, we describe the concept of natural inverse actions. This is based on the way that certain actions on physical objects are naturally 'opposite' such as push/pull. If digital devices or tangible interfaces map these natural inverses onto inverse actions in the digital domain, then this often leads to more fluid or natural interactions. We describe the general concept and give an overview of experiments and techniques we have used to study this effect. In addition, we illustrate the role of inverse actions on both physical and tangible interaction for discussion purposes.

Categories and Subject Descriptors
H.5.5 [**Information Interfaces and Presentation**]: HCI; H.1.2 [**User/Machine Systems**]: Human Factors

General Terms
Design, Human Factors

Keywords
Inverse actions, natural interaction, exploration tangible interaction.

1. INTRODUCTION
The beauty of physical interaction ultimately lies on these two notions: the way we interact with the artifact, and, the design of the artifact itself. Undeniably, there are one thousand and one ways we can interact with things. If we consider today's physical devices such as mobile phones, computers, hair-dryers, and kitchen stoves for instance, we can interact with these devices in many different ways, but there are certain ways that just appear to be *natural* to us. Although the meaning of natural is debatable, especially on the issue of nature vs. nurture, we believe what makes an interaction natural is how we use our innate abilities to interact with artifacts.

As we believe the knowledge of today can benefit the design of tomorrow, we have studied everyday devices and consumer appliances. We are seeking to understand how the explicit and implicit designs of the physical objects enable the user to understand how to manipulate the devices. In particular, we wish to understand what makes our interactions with many everyday appliances successful, natural and fluid … and also when this fails. We have used more descriptive analysis and also have examined the relationship between the physical states of a device and those of the underlying logical states [8].

From our study, we found a set of physical design features and a collection of implicit design characteristics. And among all of the design features, we are particularly drawn to one particular design: *natural inverse*, solely on the fact that this feature triggers more interesting questions when it was discovered in the design of current tangible devices.

In this paper, we would like to draw attention to the role of inverse actions in everyday physical interaction, and discuss how the natural inverse may, or may not, be beneficial in the design of tangible interaction. This paper begins by introducing the concept of the *inverse action*. The following section presents results from two user studies that relate inverse action with human innate ability from the cognitive point of view, which take into account mental requirements and cultural influences. We will then outline and elaborate an analysis to a selection of current tangible devices with regard to *inverse action*. A discussion on the role of inverse action on both physical and tangible interaction will be presented at the end of the paper that we hope will invite feedback from the workshop audience.

2. INVERSE ACTIONS
Inverse actions are commonly exhibited in controllers such as dials. As with most dials, turning the rotary knob clockwise increases volume, turning it anti-clockwise decreases volume (figure 1a). Similarly with the Mini Disc controller, twisting the knob right advances the track, twisting it left moves the track back (figure 1b).

These inverse effects, like the dial, exploit natural physical inverse actions – if you push a cup across the table you can also push it back in the opposite direction. Until it falls off to the edge, opposite pressures have opposite effects. We are very familiar with this 'rule' as it is part of the natural world, and as we have learned about this effect since we were little.

Just as in graphical user interfaces (GUI) the existence of inverse actions acts as an 'undo' and so reduces the risk of exploration [4]. Rapid, reversible and incremental feedback in direct manipulation [14] allows user to make fewer errors and can be avoided more easily. However, with physical devices it is not just that an inverse exists, but that the inverse exploits a

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(a) Speaker volume control (b) Mini disc controller (c) Yoked buttons

Figure 1. Examples of today's devices.

natural physical inverse such as push/pull, twist clockwise/anti-clockwise, or push up/down. In the best cases this is intrinsic to the device (as in the speaker's rotary knob), but may also be made apparent using visual or tactile decoration. Figure 1c gives an example of the latter where two buttons are clearly linked by being 'yoked' together.

When a strong natural physical inverse is being exploited by in a device, people are drawn to invert unintended or exploratory actions even when they do not understand the underlying logical effects.

Natural inverse actions are especially important if the user does not have a perfect knowledge of the physical–logical mapping. This allows the user to experiment with the physical control and find out the logical functions the control supports, by reducing the chances of getting the actions wrong.

This experimentation is itself part of normal physical interaction with the world, as exemplified by Gaver's notion of sequential affordances of a door handle [7]. According to Gaver, the door handle alone doesn't afford turning, but once the handle is grasped, the exploration of pulling downward leads to tactile information (affordance of turning), which then leads to turning.

Note that this experimental action that leads to the sequential affordance depends critically on the inverse action – releasing pressure or lifting the handle inverts the effect of pressing it downwards. If the slight pressure on the door handle caused an immediate and less easily reversed effect, then it would not be possible to experiment – the world would appear fragile. Of course this is exactly what sometimes happens with electronic 'touch' switches. Note also it is important that the inverse is a natural one. After pressing down you do not have to explicitly think "I pushed down a bit, so will try lifting" – you just do it.

A particular case of finding out the logical functions a control supports is when the physical control may manipulate more than one logical function. The user can discover the different logical functions that lie under the physical appearance by inversing the actions. For example, some mobile phones have a small 'scroll' button that can be pressed up or downwards. This may control volume whilst in the middle of a call, or scroll through lists when searching the address book. Although this sounds very confusing it does not prove to be in practice. There is an immediate visual or audible feedback of the effect of the control, and if the effect is not as desired, the natural inverse makes it easy to correct.

The interaction is useful when inverse action exists, but it is also important that the user knows the inverse action exists. There are two ways of reinforcing the inverse actions to users: in a subtle form (decorations) and in an explicit form.

In a subtle form, inverse actions include additional features in order to provide additional information of the logical function that the physical form supports. The speaker control, which has been described earlier, has around it painted dots of different sizes that increase from one end to another, indicating to the user that the volume increases as he/she turns the knob clockwise, and reduces in the opposite direction.

Meanwhile, inverse actions can also be very explicit in order to deliver natural interaction. The best example is the tuning frequency of an old radio. Besides the manipulation of tuning the frequency by rotating the knob clockwise and anti-clockwise, it also exposes the position of the frequency that is pointed by a vertical line from a display as the user rotates the knob.

The naturalness of inverse actions' interaction may only be achieved when the user gets immediate feedback – for example, the sound of the speaker increasing and decreasing. Under certain circumstances, feedback may be delayed, for example in an electric cooker there is a lag due to the time it takes to heat the metal in the cooker's rings. Temporal locality is one of the features of physical interaction and not surprisingly these delays are not dealt with naturally. For example, many people will adjust central heating beyond the desired temperature to 'heat the room more quickly'. So strong is this effect it even applies to those who understand the system well and know it will not have the desired effect.

In addition, even in circumstances where the physical devices appear to exploit physical natural inverse, there are times when the inverse actions are constrained by the physicality of the device. For instance, although a toaster's slider appear to have an inverse effect to user, the inverse action is constrained, i.e. it is impossible in many toasters for the user to lift the slider back up … and even if you do lift it, the toast does not un-cook!

3. THE COGNITIVE SIDE OF INVERSE ACTIONS

We have taken into account mental requirements and cultural influences in our analysis to understand inverse action from the cognitive point of view. We define these two notions as follows:

- mental requirement - the level of mental effort one must put in,

- cultural influence - how our past experience with physical devices and appliances has shaped our understanding in interaction, which, among other factors, includes familiarity with particular artifacts from past experience, and different age group

Inverse action, we believe, is innate to human nature. If we observed humans who lived thousands of years ago, the natural inverse actions would be the automatic response movement when something goes wrong. At times, inverse action can also be thought of as reverse manipulation, as this action most of the time correlates to the reflex movement, thinking hardly exists in the process, thus requiring lower mental effort from the user.

As we humans are very used to the concept of 'opposite', we usually expect our action or performance to be able to, in some way, reversed – e.g. push-pull, in-out and left-right. The inverse action property reflects this natural and intuitive behaviour of the human being.

As noted previously, artifacts or devices with inverse actions make interactions becomes natural to users, thus, do not require learning or at least make it less difficult. As noted, this is especially important if the user does not have a perfect knowledge of the physical-logical mapping, when the inverse actions reduce the risk of getting the 'wrong' action.

To investigate this further, we performed an experiment, called the Cruel Design [5]. This was a simple target moving task, but where the mappings between two joysticks and their programmed functionalities were swapped around in different conditions. We purposely wanted to make the interactions difficult in order to observe how people cope when overshoots occur.

In some manipulations, the mappings were difficult to understand and remember (e.g. joystick up moves a target down), but the natural inverse action of pushing the joystick in the opposite direction always produced an opposite effect on the screen target. Despite the 'difficulty' of the mappings, users intuitively inversed their actions using the same joystick when there was an overshoot. This reaction could be seen to be automatic as the time frame is of the order of 200ms.

In others the mapping was easier to understand and recall, but the logical inverse actions were achieved by doing the corresponding action on the other joystick (e.g. up = right joystick, down = left). This made it easier to recall the right initial movements, but overshoots led to either the wrong automatic reaction or a deliberate 'thinking' period (of the order of 1 second or more).

Inverse actions also prove to be essential, in situations where the mappings are incoherent. In our study where we used the Cubicle – an existing tangible input device, to interact with an application on a screen. Because of the technology used (accelerometers), some of the orientation of the cube could not be determined meaning the users had great difficulty in understanding the relationship between the current state of the cube and that of the display (a virtual cube). However, the device did have a natural inverse action and this enabled users to construct *momentary mappings* which helped them to overcome breakdowns. We designed four mappings which all had the inverse property but differing in cognitive complexity. Despite breakdowns in the users' ability to create explicit mappings, users still could complete tasks, and found the whole experience enjoyable [9].

4. INVERSE ACTIONS IN CURRENT TANGIBLE DEVICES

Most tangible devices such as Phicons in metaDesk [16] and Senseboard [12] exploit inverse actions in such a way that they allow users to undo and reverse the actions. At one level, the invertibility is there by virtue of the physicality of the tokens being used to control the manipulation. However, it is not a necessary property of the augmented system but depends on there being a functional relationship between the state of the physical tokens and the state of the logical system. For example, Senseboard has been used to organise conference paper sessions. It is designed to show conflicts, but an alternative design might have had the users manipulating just some of the papers physically and others being reorganised by the system to maintain constraints. When a paper is moved by the user the system would reorganise the rest, but then it could easily be the case that moving a paper and then moving it back did not lead to the initial situation. The same thing occurs with a word processor if you move the cursor down and then up when at the bottom of the screen as the text will have scrolled.

For purely physical objects it is hard to design ones that do not support inverse actions, especially for small movements. However there are not such intrinsic constraints for tangible interfaces. While it is not difficult to design tangible interactions that obey the inverse action principle, it needs to be considered explicitly in design.

Although the above mentioned systems support inverse action, they do not have a real 'undo' in that they do not provide or represent the actual "path" of movements that have been made. Thus the user performs the reverse action(s) depending solely on what they can remember. One example that actually records and displays the history of the movement to allow inverse action is The Designers' Outpost [6], which is about organizing information of Post-it notes that are used as the physical media.

Although in some ways this is similar to GUI 'undo' (in direct manipulation, rapid, reversible and incremental feedback [14]), there are differences. Considering the parallels exposes several purposes of 'undo' or invertible actions in GUI systems that are usually elided.

i. to correct slips immediately,
ii. to allow 'homing' actions such as mouse movement or rapid cursor movement,
iii. to allow low risk exploration of alternatives,
iv. to 'turn back the clock' when after several actions some problem is found

In GUI, (iv) requires some form of multi-step undo menu, (ii) and (iii) are typically achieved using invertible actions, although using an explicit 'undo' button (iii) is possible, and (i) may be achieved using either invertible actions or undo depending on the erroneous action. Bellotti et al. [2] find existing sensing systems are still lacking in dealing with failure modes and errors by not providing sufficient undo for backward error recovery.

However, (iv) is most needed when there are large amounts of hidden state, or complicated computations so less relevant for tangible user interfaces (TUI). The focus in tangible interfaces is less about backward error recovery, restoring a past state, and instead more about forward error recovery, moving on from where you are towards a goal [1].

In tangible environment, the inverse action does not act in the same way as the typical inverse action in the physical world. The reason being is, the manipulation that takes place is not just physical, but is with a tangible object. Tangible objects are tied with digital functionality, in which the tangible state does not necessarily correspond to the underlying logical state. This is the case when although an object can be moved physically (or tangibly) from point A to point B and then moved it back to point A (inverting the physical effect), the underlying system does not necessarily return to the same state.

This has definitely created more complex functionalities in the design of tangible interaction, but the downside that we are facing at the same time is the confusion the user gets with regard to forward recovery, in which the past state is not recovered (see figure 2). In experiments with the Voodoo I/O Kit [16], subjects were allowed to reconfigure components such as sliders or knobs to play a game by 'pinning' them into a 2D sheet of conductive material. The authors proposed the concept of *appropriablity* in gaming devices [17], where an appropriable technology is one which allows users the freedom to define their own understanding of mappings between the

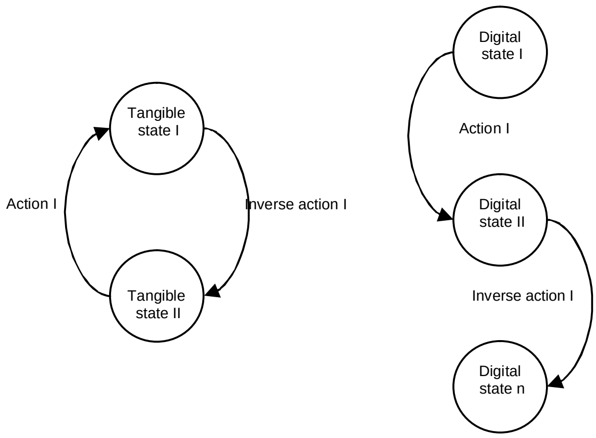

Figure 2 Confusion in tangible interaction

physical (or tangible) object and the underlying functionality. Subjects could place components in any orientation or position meaning that they could sometimes do the opposite of what one might be expect (e.g. moving a slider to the left moving an object to the right), however the physical and the logical settings always preserved natural inverse actions. Although it is not explicitly stated in the paper we believe the preservation of natural inverse actions made it easy for users to manipulate as (from personal observation) it was possible to layout the components without even noticing that they were 'the wrong way round' and yet still use the game effectively.

5. DISCUSSION

Inverse action design characteristic requires low mental requirement and does not depend on the conventional learnt understanding. When physicality adopts this particular design principle, it has proven to be very useful as shown in both of our user studies: the Cruel Design and the Cubicle. We observed that as the inverse action design principle exists, then there is coherency between the human innate ability and physical devices. This coherency makes an interaction come naturally to the user.

As much as the role of inverse actions is significant in the physical interaction, and even in GUI in the case of undo, the role of inverse actions in tangible interaction is still yet to be addressed. Table 1 simplifies the differences of the roles of inverse actions in these three types of interaction.

Looking at various electrical appliances, inverse actions can also be exploited in other kind of forms which has reversible effect, such as in bounce back, controlled state and compliant interaction [8]. Bounce back has an intrinsic reversible effect, which can be seen in most of PC's on/off power button. Controlled state refers to the form where the inverse action is constrained or limited (e.g. toaster), but reversible effect is possible by the means of a button to reset. Whilst the washing machine, an example of a compliant interaction, has to complete a full cycle before it can have the reversibility effect. As per what have been described, the reversibility effect in these forms may not be the same, as clear, or, as straightforward as in inverse action *per se*.

Table 1 The role of inverse actions in different types of interaction

Physical	GUIs	TUIs
Natural physical inverse allows experimentation on the physical control to explore the logical functions the control supports by reducing the chance of getting the actions wrong	Rapid, reversible and incremental feedback in direct manipulation reduces the risk of exploration	Invertibility exists on the physicality of the tokens being used to control the manipulation, but not necessarily affects the logical system in the same way

One of the benefits of inverse action that we have learned from this study is, it is extremely important to recover immediate mistakes especially in the act of exploration. And exploration is what it is all about in tangible interaction. Tangible prototypes and tangible devices always attract and invite users in their own special way to interact with them. The natural inverse would be important in the tangible interaction to give a positive encouragement, recovering from mistakes and to give users a sense of control [10].

6. CONCLUSION

Earlier in this paper we have mentioned that the beauty of interaction lies on two notions; the way we interact with object and the design of the object itself. Enhanced and augmented computationally-linked objects have, undeniably, transformed our experience in interacting with tangible artifacts. Marble telephone [3], I/O Brush [13], and Storytent [15], are amongst the tangible projects that have successfully promoted the idea of tangible interaction and made the interactions process more interesting. People from various backgrounds and age groups often express the interactions as fascinating, enjoyable and full of surprises. This positive experience, however, can turn sour if the flow of interaction is interrupted by events which are not expected and anticipated by users.

We have once proposed the idea of inverse actions to be considered in the design of tangible controls, due to the evidence shown by many of today's appliances that the interaction with are mostly successful and natural [10]. But as much as we would like to make it consistent in bringing and adopting the idea to tangible design, there are still much more questions we have to address with regard to the current design of tangible devices. Although consistency is already a complex issue [11] in itself, we open to the floor to discuss the role of inverse action in tangible interaction. Whether the fact that tangible is all about digital artifacts, hence it plays a different set of rule and yet some do lead to confusion, or whether the inverse actions in physicality is the best remedy to all reversibility problems, the question is still open up for discussion. We would expect the outcome to raise awareness of the reversibility issue amongst tangible designers, and eventually, in a bigger picture, to offer design techniques or methods to improve reversibility of actions.

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Adapt or be Adapted.

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ABSTRACT
Various user groups, e.g. people with a disability, could benefit highly from products or interfaces that could either be adjusted (adaptability) or adjust themselves (adaptivity) to the needs of individual users. Advances in technology are gradually enabling designers to create such products, but guidelines that help designers doing this are scarce. Designers need more insight in the implications of adaptivity on the form and content of their design in order to make good design decisions. In this paper we try to shed some light by giving an example from the *LinguaBytes* project, a three-year research program aimed at developing an interactive and adaptive educational toy that stimulates the language and communication skills of children between 1 – 4 years old with multiple disabilities. We will illustrate five example users from this heterogeneous user group with respect to their needs and skills (perceptual-motor, cognitive and emotional) and try point out how adaptivity and adaptability play a role in the design of one of our products.

Categories and Subject Descriptors
H.5.2 User Interfaces; D.2.2 Design Tools and Techniques

General Terms
Design, Human Factors, Theory.

Keywords
Tangible interaction, adaptivity, adaptability, interactive toys, multi-handicapped children, edutainment.

1. INTRODUCTION
In his model Emile Aarts [1] identifies five key characteristics of Ambient Intelligence (AmI): 1) embeddedness, 2) context-awareness, 3) personalisation, 4) adaptation and 5) anticipation. Aarts states that the former two elements mainly consider the 'Ambient' and the latter three the 'Intelligence', which we will address in this paper.

The 'Intelligence' elements of Aarts's model all involve adjustments of a system on different timescales, respectively from short to long. Following these stages, the system learns from the user and gradually adjusts its behaviour accordingly, eventually resulting in a state in which it can 'think ahead'. On the web we can already experience some examples that follow these stages. Amazon, for example (www.amazon.com), can be set by the user to initial personal preferences (personalisation); over time Amazon keeps track of the user's search queries and makes suggestions based hereupon: "other people also bought …" (adaptation); additionally, the user can rate items, react on Amazon's suggestions and use an assortment of tools to adjust the web service to his or her taste (personalisation, again); over time, your personal Amazon homepage fills itself with only those items that you're interested in and sends you e-mails that notify you of upcoming interesting items (anticipation).

Examples like Amazon have to date only scarcely emerged in the realm of physical products, although one can imagine the need for them. We will illustrate this need with an example from the *LinguaBytes* project [3, 9], showing how a physical product could become adaptive.

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Devina Ramduny-Ellis, Joanna Hare, Steve Gill & Alan Dix (Editors)

2. EARLY LANGUAGE DEVELOPMENT
The *LinguaBytes* project is aimed at developing an interactive and adaptive educational toy that stimulates the language and communicative skills of children between 1 – 4 years old with multiple disabilities. In the first years of a child's life stimulating language and communication is essential. This is especially the case with children with complex communication needs due to multiple disabilities. The foundations of early language acquisition are laid by early parent-child interaction [6, 7]. When early language development is distorted, as is generally the case with children with multiple disabilities, parent-child interaction does not start or progress normally. This doesn't only cause impediments in the child's linguistic skills, but also has repercussions on other skills (perceptual-motor, cognitive and emotional), since in this age the developments of all skills are interdependent.

Product design can play an important role here, since products can enhance the communicative skills of handicapped people, or offer alternatives for communication. This is known as Augmentative and Alternative Communication (AAC). Moreover, technological advances make it increasingly possible to design products that are adjustable to the needs and skills of individual users, or even adjust themselves. This is extremely helpful with this highly heterogeneous user group, since it enables tuning the product settings to each individual child, thus optimizing the learning settings.

3. INTERACTION DESIGN FOR TODDLERS
However, a first thing that should be taken into account with regard to interaction design, is that intelligent products for this

Figure 1. PC's were originally designed for office use

very young user group (age 1- 4 years) require radically different interfaces than the ones we know from the PC (a machine originally designed for office use, see Figure 1). Toddlers this young, let alone toddlers with multiple disabilities, do not yet grasp menu-structures, layered interfaces or icons. These are cognitively just too complex. The toddler's natural interaction style is one of exploration, of trial and error and of multiple senses. Additionally, PC's are often best suited for solitary use, whereas we specifically wish to stimulate parent-child interaction.

Therefore, we see Tangible Interaction [8] as a powerful design platform for *LinguaBytes*. The physicality of tangible interfaces offers several other benefits when designing for toddlers with multiple handicaps:

- physical objects help focus the toddler's attention;
- physical objects slow down the interaction speed, which benefits the parent-child interaction;
- since physical objects are three dimensional, they require less interpretation when teaching the toddler spatial relationships (in front of, behind, below, on top, etcetera) and tactual features (e.g. hard, soft, warm, cold).

However, in order to fully use these benefits of tangible interaction within the *LinguaBytes* project, it is necessary to create a product that can be tailored to the needs and skills of each individual user, since these vary greatly. The product we're developing should offer both the structure needed for proper language learning, and the flexibility to be able to adapt to the developmental level of the child.

4. ADAPTIVITY AND ADAPTABILITY

Now, in the course of the *LinguaBytes* project, we have found it necessary to slightly redefine the term 'adaptation' as used by Aarts. The three elements that define the 'Intelligence' part of AmI in Aarts's model are based on the flow of system adjustments over time. Within *LinguaBytes*, we have made another division, based on where the initiative to adjust the product lies: does the user adjust the product or does the product adjust itself? We make a distinction between 'adaptability' and 'adaptivity'. In the former, the initiative to adjust the product lies with the user, in the latter with the product itself (Figure 2).

One reason to distinguish adaptivity from adaptability is that they play different roles in people's perception of the *LinguaBytes* product. As we will illustrate shortly hereafter, the

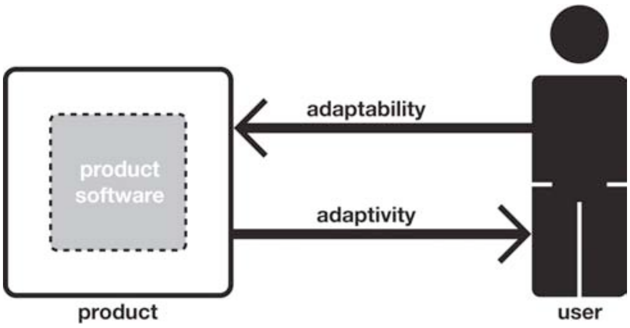

Figure 2. Adaptability: the user adjusts the product and Adaptivity: the product adjusts itself to the user

majority of the *LinguaBytes* user group is already dependant of *adaptable* products, since children with multiple disabilities often lack the physical skills to operate the 'usual' interfaces. Product adaptations are therefore often perceived as stigmatizing. *Adaptivity* in products however, including physical adaptivity, can enhance the child's sense of control, the sense of being able to do more with its body than felt possible, thus boosting its motivation and self-esteem [5].

The second reason to make this distinction is that we are currently still in the process of designing the *LinguaBytes* product and we need more information about elements that are involved in enabling a product to become adaptive (e.g. the user's characteristics, the desired interaction, the language development process, etc). Aarts's model can be used beforehand to set an outline of what kind of product it should be and how it should behave, but during the design process we have found ourselves in a loop in which each design decision has repercussions on both earlier and later design decisions. We have found it necessary to understand more about the course of the interaction: when should the user control the system and when should the system intervene? By dividing adaptation into adaptivity and adaptability we gain more insight in their relation and their influence on the design process.

We will illustrate the roles of adaptability and adapivity within design by describing five children from the *LinguaBytes* target group.

5. AN EXAMPLE FROM THE LINGUABYTES PROJECT

LinguaBytes is aimed at stimulating the language and communication skills of children between 1 – 4 years old with multiple disabilities through interactive and adaptive educational toys. One part of *LinguaBytes* involves reading interactive stories in which (new) words are offered to the toddler in an animated visual scene [4]. One of the stories we have created is a simple linear story about a boy and a girl, Tom and Tess, who visit the children's farm (Figure 3). All scenes are animated and supported by audio of a narrator and sound effects. The toddlers can 'read' the story on screen by moving a physical slider from left (first page of the story) to right (last page) over a physical representation of the story (Figure 4). To identify the user of the slider a personal identification tag is inserted in a slot in the side of the slider's housing.

In the following, we will describe how adaptivity and adaptability play a role for five example users from our target group (Figure 5), in order for them to read the story. We will use fictional names, but want to emphasise that the examples are actual participants of the *LinguaBytes* project.

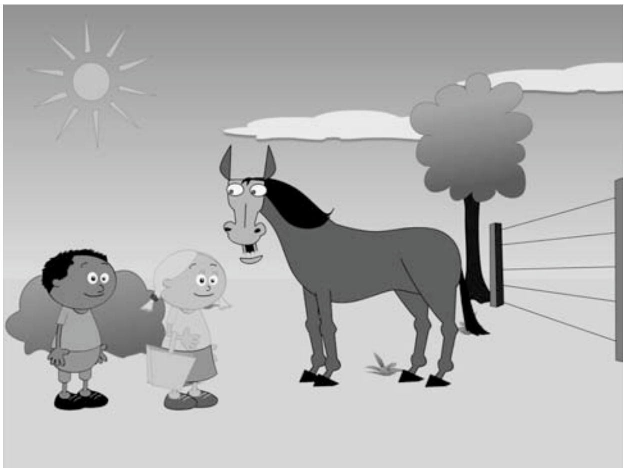

Figure 3. Screenshot from the linear story of Tom and Tess visiting the children's farm

5.1 Lisa

Lisa is 3;1 years old and has a developmental age (DA) of 2;4. She has hydrocephalus and trouble breathing due to a congenital defect of the windpipe. As an effect, Lisa has diminished vision. Her fine and gross motor skills are good, but usually she sits in a special, tailored chair during therapy. Lisa likes to inspect stuff from up close, picking up things and manipulating them.

5.1.1 Adaptability

As a result of Lisa's condition, it is important that both the screen and the slider are positioned close to her. The screen should be tilted so that ambient light doesn't cause too much glare. The slider should be placed right in front of her, fixed to the workspace, slightly to the right so she can handle it optimally. The graphics on the screen should have high contrast and move slowly.

These requirements can all be placed in Aarts's 'personalization' stage. They all involve the physical adaptation of the product in relation to the user within a space (Figure 6). We see this as physical adaptability of the product.

5.2 Dobson

Dobson is 2;11 years old with a DA of 1;6. His fine and gross motor skills are good although he has psychomotor retardation; but he can move around by himself, doesn't need special furniture and can manipulate objects like any toddler his age. He usually plays sitting on the floor. His problem is that he has an autism spectrum disorder. In his case this means that Dobson

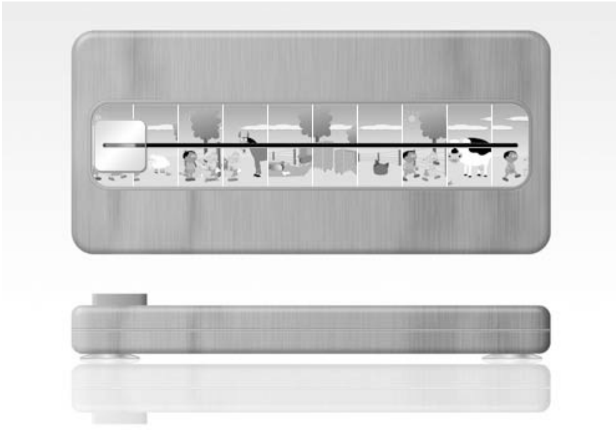

Figure 4. The linear story slider

is very reluctant to anything new or irregular.

5.2.1 Adaptability

Dobson would, contrary to Lisa and the following children, play on the floor so the screen should be used horizontally. The slider shouldn't be fixed to the floor so he could position it himself. However, Dobson won't use the slider as it is because he doesn't know it, nor will he pay attention to the story since it's not about people or situations he knows, but about two colourful drawn figures called Tom and Tess. For him to relate to the story, it would have to be about him, using real pictures. The narrator should be his mother or another safe voice.

Clearly, apart from the physical adaptability needed to suit the interaction styles of both Lisa and Dobson, the product should have emotional and cognitive adaptability as well. Moreover, due to the difference in Dobson's calendar age and developmental age, there is also a need for linguistic adaptability, since for Dobson the story should be less complex than his calendar age would suggest. This accounts for most of the children we describe here.

5.2.2 Adaptivity

To reduce the abovementioned difference between Dobson's calendar age and developmental age the product should very gradually change its content, e.g. by slightly altering the storyline, changing the characters or making the visual material more symbolic. These changes in content should be very subtle and well monitored. In short, in order for Dobson to develop the product should be highly adaptive.

5.3 Stanley

Stanley is a cheerful boy of 3;1 years old and has a DA of 3;1.

Figure 5. From left to right: Lisa, Dobson, Stanley, Emily and Gus

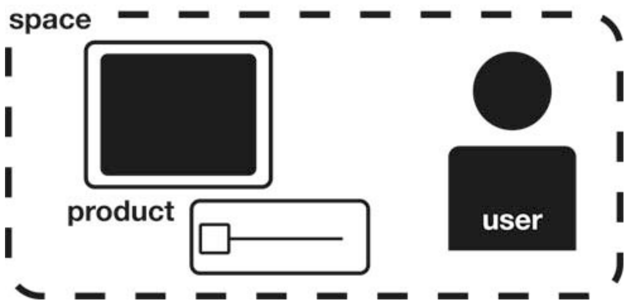

Figure 6. Product and User in context

He is diagnosed with infantile encephalopathy and has a cerebral palsy (CP) in the form of spastic quadriplegia. This means that he cannot speak, cannot walk on his own and needs special furniture. Also, Stanley has to concentrate really hard to have control over his arms and hands, due to the irregular tone of his muscles. His upper body tends to move involuntarily and his head can suddenly bob sideways. Due to his medication, Stanley drools unintentionally.

As a consequence, in order for Stanley to comfortably interact with our system, more adjustments will be necessary than just re-positioning. Due to Stanley's diminished control over his muscles, he has trouble letting go of the things he grabs. This means that if he uses the slider, he has difficulties in sliding the short distances between scenes. To avoid Stanley from sliding past the target, the slider will have to limit its range (Figure 7), keeping Stanley in control of the sliding action, but helping him by subtly adjusting its behaviour.

5.3.1 Adaptability

This would mean that when Stanley's identification tag is inserted in the product, the product would know how to behave by default. In terms of adaptability, this implies that Stanley's user profile can be set to a 'spastic quadriplegia/athetosis' preset, so that the product will know of his disturbed muscular control and behave differently.

5.3.2 Adaptivity

In terms of adaptivity this means that the slider should start reacting to Stanley's actions. It should contain sensors to detect and monitor Stanley's behaviour and sense when Stanley has the intention to interact or just can't let go of his previous action. Using a force sensor in the slider, a small motor to either block it or let it run freely, along with a sensor to detect the position of the slider could do this. At the end of each scene the motor would unblock, Stanley would be able move the slider until it is at the desired position. Then the motor would block

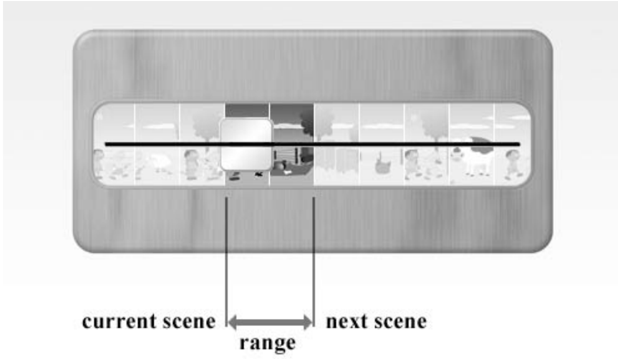

Figure 7. Slider range, adjusted to the allowed interaction

again, fixing the slider's position.

In the case of Stanley, we can conclude that the focus is no longer just on optimal positioning, but shifts towards the system's reactions on the user's behaviour (Figure 8) and Aarts's use of 'adaptation'.

5.4 Emily

Emily, a very smart and funny two year-old (her DA matches her calendar age), has spastic quadriplegia mostly resulting in dystonia and athetosis, which cause spasms, abnormal postures and uncontrolled writhing movements.

5.4.1 Adaptability

In the case of Emily it is no longer possible to optimally position the slider, since she continuously moves around. In order for her to be able to use the slider, it is first of all necessary to keep it clearly visible to her at all times, which essentially means that it should be positioned higher and so that it can be freely moved around, for instance by using the system of a balanced-arm lamp (Figure 9). This makes it possible to move the slider within Emily's eyesight and, when needed, move it towards her hand.

5.4.2 Adaptivity

However, if Emily wants to use the product more autonomously (which would be better for her self esteem) it should automatically follow her eyesight. Additionally, the slider should sense when Emily would try to manipulate it and give her a hand by approaching her hand and willingly slide autonomously upon her touching it. Just like a cat lifting your hand with its nose when it wants to be stroked. For this, it is necessary to be able to preset this in Emily's user profile (adaptability), and to use sensors and motors again to detect

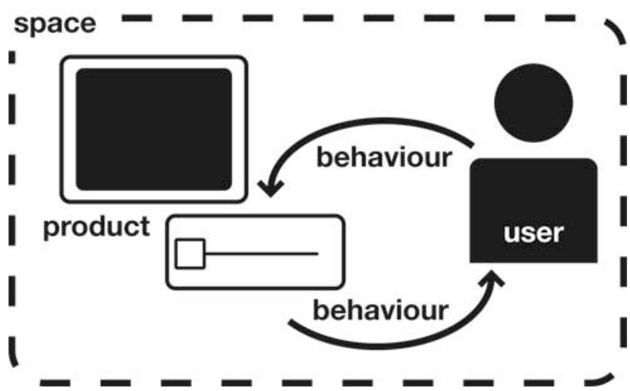

Figure 8. Relation Product-User through Behaviour

Figure 9. Story slider, mounted on the iMac balanced arm

Emily's behaviour and adjust the product's reactions. This can also be illustrated by Figure 8.

5.5 Gus

Gus is 3;4 years old with a DA of 1;5. He is diagnosed with infantile encephalopathy and spastic quadriplegia. Gus has the same physical challenges as Emily, along with severe vision problems and epileptic fits.

5.5.1 Adaptability

For Gus, the slider would have to behave as with Emily, but also offer additional auditory feedforward and feedback to help him focus his attention. This behaviour should be set in Gus's user profile.

5.5.2 Adaptivity

Gus's regular epileptic fits however, require the product to contain another form of behaviour. Due to his sudden epileptic fits, Gus's actions are often disturbed, even more than Emily's. Where even the behaviour of highly athetoid children has some predictability, Gus's fits are more irregular. These unpredictable mid-interaction losses of bodily control make it necessary for the system to adjust the flow of the interaction. Essentially, during a fit, the product should pause and wait for Gus to recover. When the product senses it has Gus's attention again, it could continue the scene, or decide to start over and play the scene again.

This kind of adaptivity requires not only that the product continuously monitors Gus's behaviour, but also try to detect patterns in, or recognize Gus's behaviour in order to make accurate interpretations and learn for future interactions. This long-term product adaptivity can be seen as Aarts's 'anticipation' key element.

6. ANTICIPATION, OR LONG TERM ADAPTIVITY

Of course, Gus isn't the only of the five examples in which anticipatory product behaviour is desired. One can safely say that all five children will develop into different users than they are now. Dobson will gradually be less suspicious of the slider and the content, Lisa will improve her motor skills and all children will improve their language or communication skills. They will grow taller and develop emotionally and cognitively; in short, they will all have developmental changes (perceptual-motor, cognitive, emotional and linguistic) that require the product to continuously monitor and adapt. These adaptations could be in the product ergonomics, in the linguistic content, the type of interaction, etcetera.

7. CONCLUSIONS

Clearly, the children described above illustrate the need for physical interfaces that are adjustable to their specific needs and skills; but how can we help designers create such systems? Based on our experience, we can identify three global design phases.

As a first step, we have found it essential to clearly map out all elements involved in the design problem. Take for example the element 'user'. Some questions that help explore this element are: who are the users, what are their characteristics (perceptual-motor, cognitive, emotional or linguistic), how do these characteristics develop over time, how can their development be measured or monitored? Other elements could be 'the product' (e.g. what is the goal of the product, which factors influence this goal?), the 'context of use' (e.g. where will it be used, what are the characteristics of this context?), 'technology', etcetera. Each design project will have different areas that should be mapped out in detail.

In the second phase the designer should map out the relationships between elements. Helpful questions during this process include: which elements influence each other, how do they influence each other, what is the hierarchy of these influences, which influences are needed and which should be filtered out? This phase will help the designer determine his design space. Based hereupon the designer can identify generalizations that can be turned into default product characteristics and settings.

In the third phase the designer can start with the difficult part: designing the interaction, while looking at the required adaptive behaviour, the desired space for adaptability and the consequences these have for the design. Obviously, this will be an iterative process, since adaptive product behaviour inevitably requires parts of the design to change, and parts of the initial design guidelines as well. During the design process, the designer should anticipate himself, in order to grasp the product's desired anticipatory behaviour.

We find using the distinction between adaptability and adaptivity a helpful tool for doing this. It can help the designer define what behaviour (of both the user and the product) is desired, what the default should be, and consequently what flexibility for adaptability and adaptivity should be designed. Whereas we find Aarts's model to be an excellent theoretical definition of AmI in general, we consider our method to be a more practical tool during the design of specific AmI applications.

8. LINGUABYTES STATUS QUO

The method we have described here has definitely helped us design our first prototype *KLEEd* [2]. We are currently building the second prototype of the *LinguaBytes* product, called *KLEEd+*, a modular system containing a re-designed version of the slider described here, among other elements. We will test the system in September 2007 in two different child rehabilitation centres in The Netherlands.

9. ACKNOWLEDGMENTS

We thank the Phelps Foundation and the consortium of additional sponsors for funding the *LinguaBytes* project, and Aadjan van der Helm, Chet Bangaru and Shriek Alers for their help in creating the *KLEEd+* prototype.

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BodyPaint: a physical interface

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ABSTRACT
This paper describes a multi-person, movement controlled on-screen pen prototype that is used to explore two types of physicality in technology design: (1) full body interaction with technology, and (2) physical interactions between users. First we describe the motivations behind the system, and then the system and the experimental context, the latter aimed at articulating trade-offs between a technological setup and a group's ability to negotiate an interaction among themselves.

Categories and Subject Descriptors
H.5.3 [**Group and Organization Interfaces**]

General Terms
Performance, Design, Human Factors, Theory

Keywords
CSCW, Physicality

1. INTRODUCTION
Although the term ‘physicality’ may have fewer usages than the term ‘embodiment’ which has fourteen [1], physicality covers a wide range of perspectives. In this paper we will delve into two aspects of physicality: (1) full body interaction with technology, and (2) physical interactions between users. We explore these through an interactive multi-person paint program prototype in which three users control a single on-screen brush with their movements, both of their limbs and in space. Using a motion capture system linked with video that enables us to track the position of participants' entire bodies in 3-dimensional space, we are able to use precise body movements to control the program as well as to evaluate both qualitatively and quantitatively a group's physical interactions in a given circumstance. After outlining our motivations for choosing these aspects of physicality to study, we will describe the experiment and preliminary results.

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2. BACKGROUND
A number of projects have recently moved beyond locative mobility employed in location-based applications to explore the possibilities of using finer movements to interact with technology -- the Nintendo Wii being the most well-known example. Unlike the Nintendo Wii which utilizes a direct mapping of movements performed onto a character on-screen, our program attempts to explore how abstract movements can control an entire system.

The ethnographic study that motivates the second question in this study builds on compared interaction around a paper-based patient medical record system to a computer-based one in an intensive care unit [2]. We specifically looked at physical interactions – that is: group formation, upper-body orientation, gesture and object manipulation, and posture. Analysis of the usage of the paper-based system demonstrated the importance of physical interactions in seamlessly negotiating conversation. It also showed that Kendon's F-formation [3], a framework describing non-verbal behavior in group interaction, fit well. However, this was not the case with the computer-based system where the group was forced to separate due to the position of the display, as in figure 1. This caused a break down in communication. The separation prevented members from participating in the interaction, removing physical interaction as a viable means of communication. The inability of group members to monitor each other's physical (non-verbal) interactions caused a reduction in parallel work and less integration with those switching between reviewing/taking notes and the group conversation.

Figure 1: Group interaction around a computer-based medical record system

The solution to static display devices is generally to use mobile devices that allow people to configure themselves as necessary. However, it is not clear from our ethnographic research whether this will solve the problem. We conjecture, looking at different content, that no central source of orientation, and an inability to monitor what information others are using -- will decrease group cohesion and thus, the effectiveness of the interaction. The experiment described below aims to understand more precisely whether mobile hand-held devices, such as Emanotech's new device MedTab [4], can solve the problems articulated above. We would therefore like to test how physical interactions differ when a group of three performs a cooperative task using a large, wall-projected display versus having a shared screen displayed on a personal hand-held device that each participant holds individually.

3. Experimental Design

3.1 Setup

Each participant wears a hat, one glove, a belt, a shoulder pad, and shoe covers fitted with reflective dots whose 3-dimensional coordinates can be tracked by a Vicon motion capture system within a 3 x 3 meter area, illustrated in figure 2. The large display is projected 50 cm in front of the motion capture space. The hand-held displays are standard PDAs. In both cases, the display are created through a java program running on the main computer and projected or sent as appropriate.

Figure 2: Experimental Setup

3.2 Task

Participants cooperatively control one on-screen pen with their body movements in a drawing program. Each can manipulate either the x-component, y-component, or speed of the direction vector by changing the angle of their hand to their hip and the color, width, or line type by moving in space. They are asked to do the following exercises: (1) draw their dream house; (2) draw an animal that is a cross between their three favorite animals. The order of exercises and display types are randomized.

3.3 Evaluation

Participants are videoed and log files kept of their head, torso, and foot movements as well as their absolute position in space. To evaluate our first research focus, full body movement interaction with technology, we use video analysis to investigate how the system is learned and operated. For our second research focus, use of physical interactions between users, the following are analysed: (1) changes in group formation by visualising each participant's position and orientation; (2) completion times; (3) number of times and degree that participants turn their heads, upper-torso, or whole body (feet) towards each other; (4) conversation analysis. Visualisations will be rendered to examine each of the above categories individually. In addition, all data will be fed into Replayer, an application that allows simultaneous viewing of different media at any given timestamp.

4. Preliminary Results

As of the writing of this abstract, only a preliminary experiment has been completed to test the usability of the drawing program and provide initial feedback from the participants. Two pairs of students (instead of trios due to current space constraints) used the program with the wall projection. Although we are unable to evaluate all of the criteria proposed for the full experiment, we would like to suggest some preliminary comments upon our two proposed themes: full body interaction with technology, and the use of physical interactions.

Both pairs found the program very engaging and after 1.5 hours we had to request that they finish the first exercise. The students, even those who did not understand the concept of vectors, had no problem controlling the system. The ease of learning the system, which usually took about 10 minutes, stemmed in part from the simplicity of explaining it with body movement. One participant could demonstrate to the other, bypassing and the abstraction needed for speech. Immediate feedback also proved very useful to participants in figuring out how to operate the system. Even less intuitive movements such as moving the hand left to go up and right to go down were learned after only 2 or 3 mistakes. Surprisingly, we did not see any difficulties navigating the small space. Despite focusing almost exclusively on the screen, participants never collided or showed any behavior signifying an unawareness of the location of the other participant. In preparation of the full experiment, we are considering the most appropriate way to articulate the advantages of the physical movement in the enjoyment of the task and ability to complete it.

Figure 3: Drawing produced by two participants

Although we were unable in this preliminary study to compare both experimental conditions, large screen display versus hand-held devices, we had a number of surprising results in the first condition. Contrary to expectation, physical interactions, significant in mediating group interaction without technology, did not generally play a role in the interaction. Participants used the immediate feedback on the screen to guess what their partner was doing. Only at the beginning, before the participants were completely aware of how their partner's actions affected the on-screen brush, did they glance at each other to check what the other was doing. They did, however, glanced, or rather stare, at their partner when s/he produced something unexpected on the screen and did not heed a verbal warning to change. Likewise, participants only turned towards one another as a means to indicate that a discussion of strategy was needed. We see then, that physical interactions are important for resolving mis-understanding, when mutuality is not achieved. This is consistent with an ethnomethodological understanding of intersubjectivity [5], or, how people come to understand in what context the actions of another should be interpreted. This result suggests that we should focus less on quantitatively trying to measure physical interactions, and rather delve into how this experiment might help us understand how technology affects intersubjectivity and mutuality.

5.ACKNOWLEDGMENTS

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Kinesthetic Empathy Interaction – Exploring the Possibilities of Psychomotor Abilities in Interaction Design

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ABSTRACT

This paper outlines a PhD project that focuses on bodily interaction. The project is grounded in interaction design informed by psychology, sports psychology, kinesiology, cognitive science and phenomenology and explored within the context of competitive sports, leisure/fun and education. As the project is in its initial stages this paper presents the approach of the project and outlines some of the core questions that are going to be addressed in the future work.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and presentation**]: User Interfaces – *interaction styles, evaluation/methodology.*

General Terms

Design, Experimentation, Theory.

Keywords

Interaction Design, Kinesthetic Empathy Interaction, Kinesthetic Interaction, psychomotor abilities, design.

1. INTRODUCTION

There is an increasing interest within the interaction community to address the body's central role in interaction design. Interaction design as defined by Terry Winograd [16] has grown out of the tradition of HCI where the primary focus has been on an efficient interaction between man and machine mediated by an interface. There is a growing interest aimed at shaping technology that enables interaction to become an experience in itself [12].

Instead of seeing interaction only as mouse clicks, interaction designers are working with entire interactive and social spaces as well as physical artifacts. Designing for these new contexts calls for novel ways of interaction.

The scope of this PhD project is to substantiate and broaden design research within interaction design community by exploring the possibilities of Kinesthetic Empathy Interaction. Throughout the process I wish to get a better understanding of the following:

How we are aware of our own movements?

How technology can enhance bodily movement skills?

How we plan complex movements?

How our own movements relate to others?

How we plan our movements according to our surroundings?

How we acquire new movement skills?

How we perceive through bodily movement?

How tacit knowledge is embedded in the body?

How interaction design can be informed by Kinesthetic Empathy Interaction?

The experimental layout of the PhD project will be grounded in the following three venues, competitive sports, leisure/fun, and learning environments (such as schools), all targeted at children. By doing design cases within these venues the project explores, both from a theoretical point of view and through empirical studies, the boundaries and possibilities of Kinesthetic Empathy Interaction. The expected outcome is general knowledge about how interaction designers can include the different dimensions of the body when designing, so that the body is naturally integrated in interactions with artifacts and spaces as well as in the design process. The contribution will be in the form of design methods and approaches for designing with and for the human body reflected and exemplified the three design cases.

2. EXPLORING THE POSSIBILITIES OF PSYCHOMOTOR ABILITIES

The mystery of body and mind has long occupied researchers within fields such as phenomenology, psychology and cognitive science.

The traditional psychological approach is that the relationship is dualistic. The faculty of reason is separate from and independent of what we do with our bodies. Which means that reason must be independent of perception and bodily movements. Intelligence is here seen as the ability to think abstractly, combine and solve mental problems. The theory was put forth as a way of distinguishing humans from animals, before the emergence of the evolutionary theory, which showed that human capacities grow out of animal capacities [9].

Today it is becoming a well-known and generally accepted thesis that human beings perceive, learn and experience through bodily movement [9, 10]. George Lakoff and Mark Johnson states in the Philosophy In The Flesh that "Our sense of what is real begins with and depends crucially upon our bodies,

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especially our sensorimotor apparatus, which enables us to perceive, move and manipulate...”. In that way our bodies are the foundation for the way we experience and interact with our surroundings.

2.1 Kinesthetic Interaction

The way we perform and the activities that we choose to engage in are highly dependent upon the neurological feedback we receive from the body. We use various sensory feedbacks to determine an adequate response to our surrounding environment. This is similar to the way we use the five senses smell, sight, touch, hearing and taste. For example, as the way we use sight in order to know when to stretch out our arm and catch a ball [13, 15].

The anatomic definition of kinesthesis or kinesthesia is the perception of the position and movement of one’s body parts in space. If you close your eyes and then place your index finger on your nose, you are utilizing your kinesthetic sense. Kinesthesis is part of the sensory capacities dealing with bodily perception and is part of the somatosensory system. The somatosenory system is conscious bodily perception which includes all skin sensation, proprioception, and the perception of the internal organs. When talking about Kinesthetic Interaction, the proprioception is often included because both kinesthesis and propriorception deal with the perception of bodily movement. The difference between the two is that kinesthesis is kinetic motion, while the proprioception is the sensory faculty of being aware of the position of the limbs and the state of internal organs. It is the bodily intelligence that allows us to react intuitively without having to think about every single movement [13, 14, 15]. Through Kinesthetic Interaction with artifacts and spaces, focus is on the awareness of the body, the perception of the body’s movements and how these interact and influence each other, an example of this type of interaction is the BodyBug designed by Jin Moen [11].

Figure 1. BodyBug

The BodyBug is a small digital device that can move up and down a metal wire attached to one user or suspended between two users. The device senses the users movement and responds by moving up and down the wire. The meaning of the bodyBug is for the users to generate new and otherwise unexplored movements. By utilizing the body’s capability to engage in bodily interaction, you invite the user to explore and challenge the body through a kinesthetic experience based on emotional and physical input, thus enhancing the body’s kinesthetic potential [11].

2.2 Introducing psychomotor abilities

The focus on psychomotor abilities is a yet unexplored area within kinesthetic interaction. Motor activity is much more than learned movements executed in space and time. When talking about motor learning, it is mandatory to be aware of both the physical and the psychological aspects of the term [5].

While the common factor between the two is movement, the physical aspect of motor learning is neurological based. The nervous system has a motor component and it is the motor nerves that activate muscle contractions, which makes us move. So when a person has performed a specific movement enough times a nerve pathway is formed and the movement becomes automated. A lot of our coarse motor skills are automated. When walking, we don’t have to think about lifting up the foot and setting it back down again, it’s happens automatically.

The psychological aspect of motor learning, known as psychomotor abilities, is the cognitive part of the motor system. Psychomotor skills results from organized muscle activity in response to stimuli from the environment. Whereas the physical part of motor learning is concentrated around reflex actions, psychomotor skills are complex movement patterns that have to be practiced [1, 3, 5].

To get a better understanding of psychomotor abilities it is profitable to look at the term in context. For a soccer player to excel at the game, it is not enough for him to be able to kick the ball precisely or kick it hard. He also needs a sophisticated insight into the game. He continuously needs to be able to decode and react on his teammates and opponents movements around the field, and from that choose an adequate responds [4, 5, 6].

When engaged in any form for sport, the notion of psychomotor abilities will be more or less present. In a sport like fencing, like any other combat sport, elements such as tactics and psychomotor abilities are of greater importance than any other skill. It is not only vital to know how to execute a certain action, but also to know where and when to apply it. This is the empathic part of our innate bodily intelligence [2].

3. THREE TYPES OF KINESTHETIC INTERACTION

Kinesthetic Empathy Interaction is focused around specific and controlled movement patterns executed in relation to other people and the surrounding environment. This differs from what Jin Moen has done with the BodyBug in the way that the bodyBug generates free movements not necessary specific to the surrounding environment. Kinesthetic Interaction can be divided into three categories, individual, joint and opposed, the last two are variations of Kinesthetic Empathy Interaction.

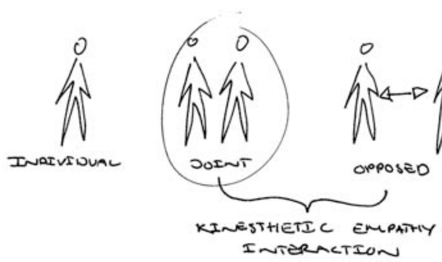

Figure 2. Three types of Kinesthetic Interaction

Individual kinesthetic interaction is where one person is interacting with a space or artifact. The BodyBug is an example of this type of interaction. Joint interaction is where two or more people collaborate through Kinesthetic Empathy Interaction to reach a common goal. It is crucial for the players to be able to read, react and build on each other’s actions. Opposed interaction is where two or more people are battling to reach the same goal. Tactics plays a huge role and is the most complex of the 3 types of interaction. The players not only have to focus on the goal but also on thwarting the opposite player or players. It is crucial for the players to be able to indicate intent without the signals being intercepted by the opponents.

3.1 Designing for Kinesthetic Empathy Interaction

When designing for Kinesthetic Empathy Interaction, the values embedded in the users psychomotor abilities should be taken into consideration. Some of the skills defined as being part of ones psychomotor abilities are: timing, tactics, sense of surprise, response ability, speed (slow, fast), type of action and level of attention [2]. The object of psychomotor ability is to organize muscle activity in response to stimuli from the environment, and is done by combining several of these skills at the same time. When designing for Kinesthetic Empathy Interaction one should be careful to solely focus on one of the elements, because there is a significant risk, that the type of interaction achieved becomes fragmented and doesn't encompass the body as a whole. The key to designing for Kinesthetic Empathy Interaction is to open up for the users to access several skills and plan which combination makes for the most optimal response to a given situation.

Furthermore for an artifact/installation to remain relevant it should be able to change as the users continually becomes more and more skilled. Otherwise the users will quickly lose interest in the product.

3.2 Bounce – an analog example of Kinesthetic Empathy Interaction

The playground equipment Bounce is an example of how psychomotor abilities can be utilized when generating bodily interaction.

The motivation for the project was children's decreasing level of physical activity throughout the day. The advancement of TV, computers and other sedentary activities take up more and more time, which leaves little time for physical development. As described earlier humans explore and experience through the body. The goal of this project is to explore how artifacts can encourage physical activity and help children explore and challenge their bodies while engaging in meaningful experiences with other children. By exploiting the users innate psychomotor ability, the interaction becomes intuitive and easy to decode.

In short terms, Bounce is best described as a cross between a swing and a bumper car. It is opposed interaction where three players battle each other by bouncing into one another. The object of the game is to hit the other players by swinging a bounce unit into theirs while avoiding being hit (See figure 3).

Each player stands on bouncing unit. By utilizing the whole body the player can control the movements of the unit and bounce it into the other players. Due to the fact, that each unit is suspended by four ropes a unit can swing freely within 360 degrees area, unlike a regular swing that only swings back and forth (see figure 4). The player can control the unit's movement by utilizing the whole body. For example, to instantly stop a unit the player stretched both arms out to the sides and the unit will stop completely (See figure 5). The type of game strategy is very similar to that of a fencing match. Tactics play a significant role and it is crucial for the player to be able to decode the other player's movements and from that know when to attack and when to avoid being attacked. Just like fencing the act of surprise is the key to becoming a skilled player.

Figure 3. Two kids bouncing into one another.

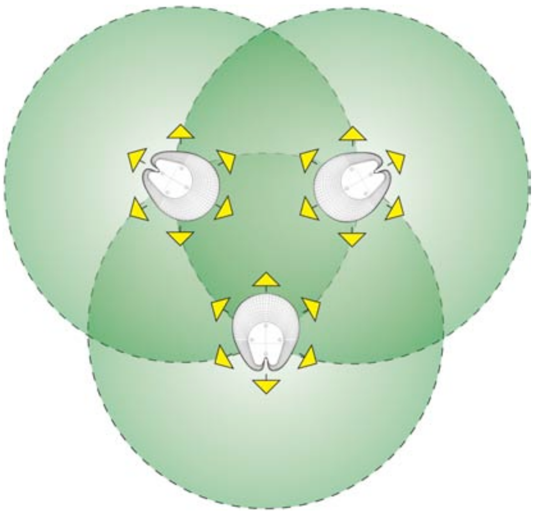

Figure 4. Swing radius for each of the bouncing units.

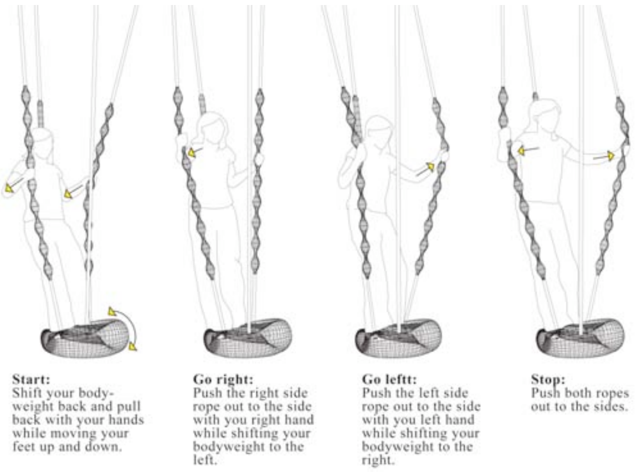

Figure 5. The diagram describes how to control a Bounce unit.

The future work of this project is to enhance the experience of playing with Bounce by adding a digital layer to each unit. By adding “hit zones” using lights along the sides of each unit, the users will be able to see who has been bounced the most and where the hits have been made. When two units hit each other the lights will go out in the area where the hit is made. When all lights are knocked out on a unit the person has lost. The digital layer calls for at more sophisticated insight into the game. It’s will no longer be enough just to hit the other units without them hitting you too hard, you also a have to pay attention to where you aim your hits, whilst protecting yourself.

4. THE EXPERIMENTAL LAYOUT

The approach of the PhD project is to do experimental design cases that can provide me with feedback to what Kinesthetic Empathy Interactions is or can be and how we can design for it. The experimental studies are going to be executed within the research center, Interactive Spaces (www.interactivespaces.net). Interactive Spaces is a trans disciplinary research center where computer science, engineering, media studies, design and architecture are intertwined in several different projects. In order to understand interaction design, it is vital to explore and discover the potentials of interactions and one way of doing this is to build working prototypes. By making actual working prototypes we are able to test how the designs work in “real life”, real domains and in the hands of real people. By making the prototypes it becomes possible to uncover otherwise hidden potentials and afterwards find new ways of utilizing this knowledge. Not by doing extensive quantitative experiments but instead collecting information from qualitative experiments and by doing proof of concepts. The purpose of the project is to uncover a field of potential within the world of sports and drawing the gathered knowledge into unexplored contexts that ultimately will broaden the field of interaction design.

By introducing interaction design into the field of sport I wish to explore how Kinesthetic Empathy Interaction design can enhance the training of athletes, by practicing the generation of complex movement patterns and tactics. The experiences and information gained will then be used as grounds for creating fun interactive bodily experiences. Finally this will be utilized in the context of education to explore how to create fun learning experience by exploiting the body as a tool of interaction.

5. DISCUSSION

By studying field such as psychology, sports psychology, kinesiology, cognitive science and phenomenology I hope to get a better understanding of how the body works, not just anatomically by also how mind and body relate. This ongoing research will help me form and design the three cases. These will then work as exemplification and clarification of how mind and body relate through Kinesthetic Empathy Interaction.

In the first design case, I will be drawing on already existing knowledge of how psychomotor abilities are used in sports and drawing that knowledge into the field of interaction design to design training devices that will improve athletes performances. The sole purpose of the installations/artifacts will be to enhance the athlete’s skills. I wish to get a betting understanding of how specific bodily skills can be trained and improved in a controlled environment by added a digital layer to the athlete’s daily training routines. The knowledge that I gather from that case will then help me shape the next experiment.

By doing a design case within the context of leisure/fun the goal for the user will change from improving a specific skills to acquiring new skills through play. It is very important for children to get a versatile and broad motor training [8] and Kinesthetic Empathy Interaction can be one way of accomplishing this. In this case fun will be the motivating factor for engagement. By drawing on the already known elements of psychomotor ability and on the knowledge of how athletes plan complex movement patterns I wish to explore how to encourage playful psychomotor learning, by the means of Kinesthetic Empathy Interaction.

Children in learning environments such as schools often spend most of their time sitting still while receiving instructions or working on assignments. When a human sits still for too long their cerebral cortex (outer layer of the brain) falls asleep and the brain won’t be able to process new information. Movement is the only way to wake the brain again and it is therefore crucial to get bodily movement incorporated seamlessly into both existing and new learning environments. Interactive technologies can contribute in developing these new types of learning experiences that actively engage the children in the learning process by utilizes the body as a tool for interaction. In this design case I wish to explore how Kinesthetic Empathy Interaction can be used in a teaching environment by drawing the objectives of the world of sports and play into the environment. By utilizing Kinesthetic Empathy Interaction, the schooling will be focused around the children’s natural way of utilizing the body.

Kinesthetic Empathy Interaction is one way of looking at bodily interactions founded in cognitive science and the field of sports. It is a way of utilizing kinesthetic interaction as a mean of reaching a higher goal. The bodily interaction gives meaning to or enhances a situation, such as described in the three cases. This could be transferred to other contexts as well. For example, in museums and science centers, where interaction designer are working on shaping technology that enhances and actively engages the users in the experience. One way of getting the users actively involved in shaping their own experiences is to build the interaction on the users inherent bodily movements.

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Embodied interaction in authoring environments

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ABSTRACT
How can we make it more appealing for young people to learn about and understand digital technology and computing concepts? We use both a different kind of interaction and a different kind of content to convey computing ideas such as *subroutines*, *modules*, *abstraction*, *classes*, *objects* and *debugging*. A crucial notion is embodied interaction, the idea that the child's interaction with the system should, in part, use her whole body, and not just fingers and eyes. In order to explore this approach we use the magic mirror, a device constructed from an interactive whiteboard and a camera such that when the child stands in front of it, the image she sees is her own but changed or augmented. For example it may show her in costume, or as a non-human creature. As she moves, so does her image. This device can be used as part of a lesson in which children create sequences of movements that can be recorded by the system and then manipulated in various ways to create more complex entities. The proposed work cuts across several disciplines, including education, psychology and computing, and will consider: in what ways can embodied authoring in principle (and in practice) be used to explore computing concepts, and, for each way, what advantages and disadvantages might it offer over traditional methods? In this paper we elaborate on the ways in which embodied authoring can support programming, explain the detail of the approach and report on some preliminary prototyping work we have undertaken.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *graphical user interfaces, input devices and strategies, user-centered design.*

General Terms
Design, Human Factors, Languages.

Keywords
Embodied interaction, Programming, Software Authoring.

1. INTRODUCTION
Digital technology plays an increasingly important role in our lives. Given the importance of software and digital products, there is a need for people who can develop these products, both at professional and end-user levels: not only students undertaking Computer Science studies and careers but also other professionals able to use packaged software as well as produce their own computational solutions [4]. However admission and retention rates to computer science university courses are falling [20], enrollment is male dominated [20] and although there is a thriving community of end-user programmers, there are serious concerns about the dependability of the software which they produce [4]. Thus there is a need both to foster the development of computational thinking [23] in young learners and to motivate them to study computing subjects by improving the perception of computing, especially for girls.

We suggest that there are three issues that conspire to make computing concepts difficult to learn i) context: the problems and scenarios to which the concepts are applied are often not very motivating, ii) abstraction: some of the concepts are presented in too abstract a fashion and iii) great attention to detail is needed in order to make something appealing work.

A number of researchers have grappled with the issues above. A prominent strand of this work has sought to make the learning of computing a playful and creative endeavour: for example, Lego Mindstorms (http://mindstorms.lego.com/), and the Scratch programming language (http://scratch.mit.edu/), whose website indicates how young people are appropriating the language to create programs of real interest and meaning to them. With respect to gender issues, there is a growing body of work which acknowledges the role of women in the computing field, e.g. the Grace Hopper Celebration of Women in Computing (http://gracehopper.org/2007/).

And finally, there are concerted moves toward extending the notion of computing, and its overall reach: VL/HCC 2007's doctoral consortium, entitled, "Broadening the Audience for Comptational Thinking, is a prime example, (http://vlhcc07.eecs.wsu.edu/consortium.html).

2. EMBODIED AUTHORING
If the underlying computational concepts were to be introduced in a dramatically different way, the story would be different. A key to this change is modifying the interaction medium. We will employ embodied interaction [6] to make computing concepts more accessible, and increase the appeal and collaborative potential of the scenarios within which these concepts are introduced. Embodied interaction, i.e. using the physical world as a medium for interacting with digital technology, is a new form of naturalistic, multi-modal interface that can support co-located communities of learners through a variety of different interaction devices.

Our approach to introducing computing concepts combines embodied interaction with social constructivist and constructionist theories of learning [17, 21, 5, 18]. Through

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acting and recording animation scenes instead of programming complex character animation episodes, young people will be involved in an authoring process, where, by turns, they will be both designers and critical consumers of their own and other children's applications. This process will be embedded in scenarios in which there is scope for discussion and collaborative, imaginative play.

This research programme is investigating the ways in which embodied interaction can be used to explore computing concepts and, for each way, the advantages and disadvantages it might offer over traditional methods.

There are at least four ways in which embodiment, or more generally any interaction modality, can be used in programming[1]:

- By supporting non-coding activities. A non-coding activity is task necessary for the execution of the program but that does not involve programming or scripting. Capturing data or creating a graphical element that the program will use in its execution are examples of such auxiliary activities. The auxiliary activity can be performed in a different interaction modality to the rest of the programming activity. For example, a textual programming language might use graphic elements created in a graphic modality or data inputted as an audio recording. Technological innovations have allowed some programming activities to become auxiliary, for example GUI front ends can now be produced in a graphical environment (by drawing them) instead of programming them.
- As the interface medium. The interface medium is the way in which the programmer interacts with the program. Usually the interface medium is keyboard and mouse but programmers could also interact with the program via speech recognition for example.
- As the programming environment. The programming environment provides a set of tools to support the programming activity. Some examples of programming environment tools are coding editors, output windows, visualisations of the program, automated testing facilities, etc. Programming environments nowadays are usually graphical, even for textual programming languages. Logo and its tangible turtle [17] are an example of a textual programming language combined with a programming environment employing tangible elements.
- As the programming language itself. In this case the lexical elements of the language are expressed in a particular modality. Traditionally programming languages are textual but there are also visual and even tangible programming languages. One could think of a tangible programming language within a graphical programming environment, or of a textual language within a tangible environment, although this might not make much sense in practice.

So far we have identified one way in which embodiment can be used to explore computing concepts, the acting and recording of animation scenes. This can be considered as a non-coding activity which can replace a programming task (the coding of animation scenes). We believe there are several benefits of employing embodied interaction in this way for educational applications: it can make sophisticated authoring tasks more accessible to a wider audience, it can establish a link between computing and other parts of the curriculum such as drama, English and the performing arts, it could help to improve interest in computing degrees and careers and could also enable a more active interaction in the physical sense.

1 In the discussion that follows, we will consider the concept of interaction modality in its widest sense, so we can talk of a textual modality, a graphical modality or a tangible modality.

3. ACTING AND RECORDING ANIMATION SCENES

The main idea behind the approach is the possibility of acting and recording movements. This is done through a combination of small paper markers (similar to barcode labels) placed on different parts of a person's clothing, a webcam and a large screen. This arrangement works as a magic mirror where the user will be able to see a reflection, however this reflection can be in the form of a character of her choosing (see Figure 1).

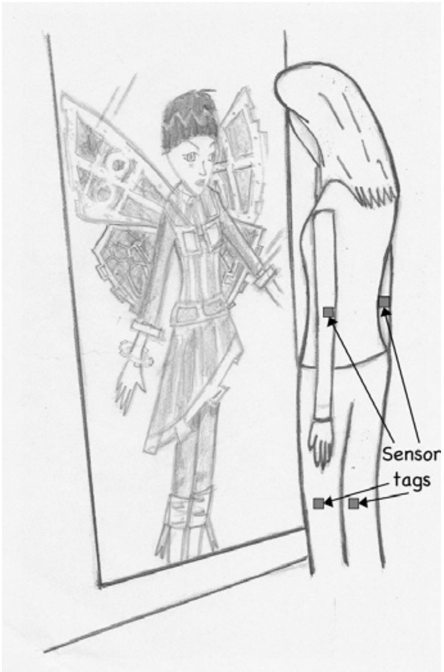

Figure 1. The Magic Mirror.

Additionally, users will be able to record their movements as if they were recording a film with a video camera. However there is an important difference: when users employ a video camera they record concrete scenes, when they use the magic mirror they record movements. Movements are more abstract than concrete scenes because they do not need to be associated with a particular character, background, place in a scene or size, among other characteristics. In this sense, movements can be considered as animation libraries that can be used for authoring purposes. Movements can be instantiated to different characters, duplicated, speeded up, played backwards, connected to create composite movements, etc. The authored applications can be populated with several instances of movements and each one of these instances can be associated with specific behaviours when users interact with them. Young people will be able to manipulate them to build their own applications and in so doing, they will have to familiarise themselves with important computational thinking skills such as *abstraction, modularisation*, identifying and working with *abstract entities (classes)* and their instantiations (*objects*, etc.).

The manipulation of movements will be performed with an editor that follows conventions similar to those of commercial authoring environments such as Flash [7] and will employ an embodied-style interface medium such as the one used for the Eye-toy [11] or the Nintendo Wii [19]. This form of interface will be compatible with the magic mirror and will enable a concurrent interaction mainly via their body movements or a remote control. Concurrency and the public aspect of large screen-based applications, which are shared characteristics with the magic mirror, give this approach strong collaborative potential [8, 1].

The proposed approach will therefore comprise two parts, a platform for developing applications (the Stage Platform), and the actual applications that will run on the platform. The platform will include the magic mirror to record movements and an editor to manipulate them. The applications developed for the platform could be environments to create simulations, video games, authoring environments for creating free-form playful applications or game authoring environments, among others. We are particularly interested in the latter two environments as they allow plenty of scope for imaginative play within the authoring (construction) process.

The Stage Platform will be similar to other generic platforms and tools like the DART Toolkit [15], the standard toolkit for programming augmented reality applications, in that it will be open (and we will actively encourage) for other research groups to use it. We believe that there is a need for a platform to enable developers to build applications with an embodied style of interaction and the Stage Platform can respond to that need similarly to the way the DART Toolkit provided developers with a tool to build Augmented Reality applications.

As part of our research programme, we intend to build a pair of authoring environments related to subjects such as drama, English or dance, for example. We believe the latter is important as performance art subjects usually involve role playing, social interaction and narrative, and these activities have been found to be particularly appealing to girls [3, 10].

Both the platform and the authoring environments will be developed using a learner-centred design process [14, 9] that will involve users, stakeholders and potential beneficiaries.

The authoring environments to be developed will be fairly specific so that, from the outset, young people focus on the environment's application area, making authoring activities implicit aspects of the task rather than the main, explicit part of it. This approach has proven to be effective for recent authoring and scripting environments [13, 2] and has also the added value that a good deal of basic functionality and libraries specific to the environment's application area can be built in to the authoring environment, providing enough support for young people to create more powerful applications but at the same time leaving them enough room for a sense of challenge and the chance to be creative.

3.1 A Sample Scenario

The sample scenario that follows is about young people creating their own dance mat-like games [12] collaboratively and through embodied interaction with Dance Along, a game authoring environment that could be built for the platform.

Dance Along: The students from year 7 are looking at the Maori people in history and the dance teacher has linked the class activities to this topic by practicing the Haka dance. A small group of students in this class (Caitlin, Camila and Jon), who are looking at design abstraction and modularisation in ICT, are interested in creating a dance mat-like game to help the rest of the children learn the Haka. They use the Dance Along game authoring environment to recreate one of these dances and then dance along to it. First, they act and record a basic sequence of dance moves using the magic mirror. Then they edit these dance moves (figuring out the global design of the choreography, creating and assigning characters to dance moves, connecting and duplicating the dance moves), interacting with the moves editor concurrently, each using a wii remote control to create a complex dance with 40 characters. Finally they invoke a built-in functionality for giving feedback and producing a score for players (this works by comparing the trajectories of players dancing along with those of the programmed characters). Then they invite Chloe, who is also in year 7, to see the movie of the dance and then dance along to it. Chloe chooses the character she wants to be and then dances in front of the magic mirror as if she were that character. When the dance finishes she looks at her score and watches the movie of her dancing as the character and realises that she didn't do that badly in the Haka. Chloe is so impressed by the game that she asks Caitlin, Camila and Jon to teach her how to use the Dance Along environment to create her own dance games. They show her how to record scenes and how to design a choreography by manipulating dance moves stressing that some of the key concepts are designing the dance in a modular way, understanding the difference between the abstract library of moves and their concrete instantiations and assigning parameters to moves.

The scenario illustrates the main characteristics of our approach, an embodied style of interaction [6], fostering computational thinking skills by an active process of construction (not only of a piece of software but also of a plan of action and strategies) [17, 18] and the mediating aspect of the environment to provoke collaborative encounters [5].

The scenario also exemplifies the sorts of authoring environment that can be developed for the platform, the types of application that young people can create with the authoring environments, and the ways these applications can be played. In this case it illustrates a game-authoring environment, but the platform can also be used to implement authoring environments that can be used to build more free-form playful applications. This versatility will be helpful in evaluating the approach in a variety of contexts. Also, in this case, both the authoring process and the game play are performed with an embodied style of interaction. This is the ideal situation, but it could also be the case that the constructed software is played as a conventional desktop application.

3.2 A Proof-of-Concept Prototype

The STAGE system includes an input device, the "magic wand", and an interface in the form of a "magic mirror". After testing and evaluating the many options for the elements of the STAGE system, the best current candidates were chosen and implemented.

The Magic Wand uses the Nintendo Wii Remote and Belkin Bluetooth 2.0/EDR USB Adapter, with WiinRemote, GlovePIE and Widcomm Bluetooth as software interfaces. The Magic Mirror uses the Trust Megapixel USB2 Webcam with ARTag as the C++/OpenGL marker tag detection library. The user interface is written in Java 6.0 using the standard Swing widgets.

Current functionality includes changing Magic Mirror characters and backgrounds, and limited possibilities for Story Grid manipulation. The recording of scenes does not provide significant challenges but presenting fluid and anatomically plausible movements may require motion capture techniques [16].

As part of our ongoing learner-centred design process, we have conducted workshops with school teachers and have obtained very positive feedback on the potential of the system.

4. CONCLUSION

This paper sketches a research programme for investigating the ways in which embodied interaction can be used to teach and learn computing concepts and for each way what advantages and disadvantages might it offer over traditional methods. It presents a tentative analysis of the ways in which embodied interaction can be used in authoring and programming, explores the potential of a specific approach, the acting and recording of movements, and briefly describes a prototype built as a proof of concept.

Future work will consider a full implementation of the platform as well as educational applications similar to the one described in the scenario of Section 3.1. Additionally, the research will explore some of the other ways (described in Section 2) in which embodied interaction can be used in programming.

5. ACKNOWLEDGMENTS

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Multimodal Interface for Ambient Edutainment

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ABSTRACT
This article presents a design exercise how to use Modality index of Barbe and Swassing (1979) in the design of multimodal interfaces for an Ambient Interactive storybook. Modality Index, and other learning theories such as Multiple Intelligences by Gardner (1985) consider the fact that people learn in different ways. In this paper we extend this not just into the delivery and content of an edutainment title, but also into the Multimodal Interface. We base our experiment on Multimedia Multimodal Ambient Interactive Story System (MM-AISS), which extends existing interactive storybooks into the open space of a living room. MM-AISS targets children between 3 – 8 years. In this paper we present guidelines for Multimodal interfaces from the point of view of an educator and a producer of an edutainment title. In our work we don't see physicality purely represented by kinaesthetic modality. It is one element of the whole, determined by the relationship between visual, auditive and kinaesthetic modality.

Categories and Subject Descriptors
H5.2. User Interfaces. H.5.1 Multimedia Information Systems; I.2.1 Applications and Expert Systems

Keywords
Interaction design, Multiple intelligences, Modality index, Multimodal interfaces, Ambient Intelligence, Interactive storybook

1. INTRODUCTION
Ambient Intelligence (AmI) is a paradigm that refers to electronic environments that are sensitive and responsive to the presence of people (Kleisterlee, 2002). Home entertainment systems are going to be one of the main beneficiaries of Ambient Intelligent Systems. MM-AISS explores how to extend one of the success stories of edutainment, interactive storybooks, into AmI. In these systems user interfaces are needed that can capture our natural speech and body movements.

2. BACKGROUND
We base MM-AISS on (1) Ambient Intelligence spaces, (2) Interactive storybooks and (3) Multimodal, tangible and speech interfaces.

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We see MM-AISS as one interconnected system, in which a living room is equipped with a wide screen; tablet PCs are on coffee tables; desktop PCs on another table. Interaction is moved away from a desktop PC and is conducted in the comfort of an armchair (or in our case dancing in the middle of the room). Microphones and speakers are embedded in many objects. Personified characters are augmented into toys. Additional cameras track users' body language, face expressions and eyeball movements. Intelligent characters, either in digital or physical form, interact with users. Interaction is done by speech, writing, user's movement, touching and moving objects.

Ambient Intelligent Systems are very interesting challenges for Multimedia producers and educators. They offer new and exiting possibilities for the content. An interactive storybook is a genre in a digital storytelling, which is melange of literature, visual art, cartoons, Multimedia, and computer and non-computer games and activities. Children move forward and backwards as easily as browsing a classical book. Additional activities like interactive games and puzzles give depth to Interactive storybooks so children spend hours exploring them.

Stories and activities in MM-AISS can be experienced from a sofa with a tablet PC or standing in the middle of the room, watching action on a wide screen.

2.1 Learning style theories
The idea of the Multimodal interface in MM-AISS is based on the positive experience of using learning styles in the development of Multimedia educational and edutainment titles. Educators and course developers, at the start of the development phase of an educational Multimedia title, in order to create delivery methods that will enhance learning, consider the fact that people learn in different ways. They have different learning styles that will influence how they learn, how much they learn, and how in depth they learn. The simplest classification of learning styles deals with auditory, visual, and kinaesthetic learners. The basic idea in this sense is that the preferred mode of learning in people tends to be one of those three mentioned above. Simply, it means that some people learn better by listening to what is presented, some by seeing, and some by actually doing and practising the materials.

Learning style theories state that students prefer one way or style of learning to another. Many learning styles testing instruments have been developed to measure different learning styles. Most known are:

1) **Swassing Barbe** Modality index (SMBI) (Barbe and Swassing, 1979).
2) **Witkin's** (1971) Group embedded figures tests.
3) **Gardner's** (1985) Theory of Multiple intelligence, which recognises linguistic, logical, kinaesthetic, musical, interpersonal and intrapersonal intelligences.

Barbe and Swassing (1979) recognise three modalities: visual, auditive, and kinaesthetic. Individual's dominant modality is that channel through which information is processed most efficiently. Beside a dominant modality, many people evidence a secondary modality upon which they can rely. A secondary modality is not so efficient as its dominant counterpart. Mixed modalities occur when no single modality is clearly dominant. Barbe and Swassing (1979) state that the proportion of persons with mixed modalities is larger among adults than children. They suspect that cognitive maturity and the opportunity of practice in all three modalities are the principal reasons that mixed modalities occur. They acknowledge that the manner in which an individual is most comfortable receiving information is not always consonant with the way in which information is most efficiently received and processed. To optimise the learning process it is not enough to find out what the preference of the learner is. Designing courseware according to modality preferences of learners might motivate those learners but it does not automatically mean that the information processing will improve. Another consideration Barbe and Swassing (1979) is that a modality may come in different grades:

(a) dominant modality;

(b) secondary modality; and

(c) mixed modality.

Barbe and Swassing (1979) developed a test to assess modality strengths of children: the SMBI (Swassing Barbe Modality Index).

3. DESIGN OF MULTIMODAL SYSTEM BASED ON BARBE AND SWASSING

The learning style theories do not imply only that humans have different preferences to learn better if someone shows us a picture, explain to us verbally or shows us in gestures, but also which activity and task is more appropriate. Multimedia educational and edutainment applications already successfully present content with text, sound, video and animation, illustrations etc. Course developers of computer based learning present content to users with different types of activities, which best suit their learning styles and their knowledge.

In MM-AISS we want to explore how to support these differences in learning styles with the Multimodal interaction. Multimodal interface in MM-AISS allows user to interact with the system depending on his/hers learning style. By these we mean the access of the content with different modalities. This approach to Multimodal interfaces differs from the existing approaches (Nigay & Coutaz, 1993, Raisamo, 1999, Oviatt, 1999). Multimodal interfaces are usually treated as pure mathematical treatment of humans' input output modalities into computer hardware input and output devices.

Below we present main characteristics of a user with visual, auditive, and kinaesthetic dominant modality and how Multimodal input and output in MM-AISS support particular modality.

3.1 Kinaesthetic modality

A user with dominant kinaesthetic modality (Barbe and Swassing p. 44-45) learns better by doing, prefers stories where action occurs early, remembers best what was done and like to tries things out. Such student attacks problem physically, moves hands and holds hands up and gestures when speaking.

For users with dominant kinaesthetic modality MM-AISS encourages them to work on activities that are conducted in the open space of a room, by using construction kits and other tangible e-things. Users are encouraged to touch tangible objects and to write on a tablet PC. Digital sound recorder allows him to record his answers. User with dominant kinaesthetic modality gestures and makes face expressions when speaks. Virtual (Intelligent) teacher communicates with the user through body language. Virtual (Intelligent) pupils encourage user to help them by explaining what the user has just learned, to talk with them and to act out scenes with them.

Preferred Multimodal input for a user with dominant kinaesthetic modality is tangible objects and writing.

3.2 Auditory modality

User with dominant auditory modality (Barbe and Swassing p. 44-45) learns better by verbal instructions from others and self. He likes to learn by dialogue, plays and movement of the lips. Problem solving is done through talking the problem out. He tries solution verbally and talks to himself through the problem.

For users with dominant auditory modality MM-AISS presents material verbally (reading aloud) and with discussion. System encourages users to solve verbal problems by talking to himself and through music. Virtual (Intelligent) teacher repeat questions and answers many times and gives other verbal explanations. Virtual (Intelligent) pupils discuss problems with user.

Preferred Multimodal input for a user with dominant auditory modality is speech.

3.3 Visual modality

User with dominant visual modality (Barbe and Swassing (1979) p. 44-45) learns better by seeing or watching a demonstration. Sometimes stops to stare into space to imagine scenes. He thinks in pictures and plans in advance. Facial expressions are good index of emotions. Such student is impatient when extensive listening is required and deeply affected by visual displays.

For users with dominant visual modality MM-AISS allows them to organize their own space, with a lot of posters and other visual material. Mathematical and other activities are presented visually on different screens with many colours.

Virtual (Intelligent) teacher presents material visually with graphs, and visual examples, encourages user to draw and to imagine scenes.

Preferred Multimodal input for a user with dominant visual modality is writing and drawing.

4. SHORT DESCRIPTION OF THE MULTIMODAL INTERFACE IN MM-AISS

This description is based on the activity "Basic Math" (see figure 1). The goal of the MM-AISS is that user has:

- Multimodal input, which suits user's dominant or mixed modality,
- Multimodal output, which suits user's dominant or mixed modality,
- Activities, which suit user's dominant or mixed modality,
- Activities and tasks, which suit best his/hers current knowledge and capabilities.

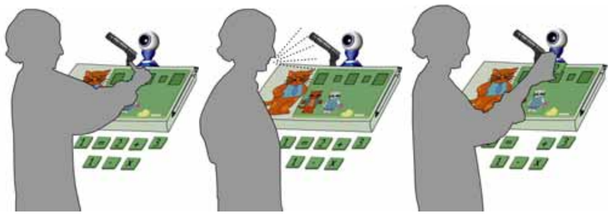

Figure 1. Three suggested solutions for Barbe and Swassing dominant modalities experiment

4.1 Multimodal input

MM-AISS allows users to interact with the system either by speech, handwriting or tangible objects. These three inputs are best suitable to three Barbe & Swassing dominant modalities. System also uses video camera to capture gestures, body language and face expressions. User is free to choose at any time the Multimodal input device. In MM-AISS user interact with the system:

- Writes the answers >> Electronic handwriting.
- Verbally answers the questions >> Speech recognition.
- Puts tangible thing on a tablet PC >> Tangible e-blocks.

4.2 Multimodal output

System interacts (communicates) with the user (Multimodal output) via virtual (digital) characters (teacher and two pupils) and additional visual material. Two virtual pupils have special role with users who have dominant kinaesthetic modality as they encourage user to explain to them the content that s/he has just learned. Additional visual displays (tablet PC) present questions visually with images and graphs.

4.3 SMBI test

In MM-AISS user first conducts SBMI test (Swassing & Barbe modality index) that establish his/her dominant or mixed modality (visual, kinaesthetic or verbal). The system captures with video camera and microphone users gestures, face expressions and other parameters, which are then used for fine-tuning of the SBMI.

4.4 Activities

System presents content and activities according to the dominant or mixed modality. For example for the user with dominant kinaesthetic modality, the teacher gesticulates a lot and encourages activities, which are done in the middle of the room, with the user with dominant

4.5 Guidelines

For the purpose of the design we developed guidelines. In Table 1 we first describe the characteristics for users with specific dominant modality and then how we plan to support them in our design.

5. DISCUSSION

There are known problems with low recognition rates for electronic handwriting and voice recognition respectively. Snape et al (1999) report of low rates in speech recognition with children. Read et al (2002) also report on low rates in hand writing recognition with children. We are also aware that such rational approach limits more creative use of technology in the design process.

6. CONCLUSION

In this paper we present guidelines how to use pedagogical theories of Modality index in the design of a Multimodal interface. We believe that such system and their applications can be fun and enjoyable, because it allows users to interact with the systems in their preferred modality. The system also offers educational designers possibilities to recognise user’s modality, and create activities to develop skills for specific modalities.

7. FUTURE WORK

Work is currently underway to design the system. Wizard of Oz technique is going to be used to prove the concepts of the prototype. We are planning to test our conceptual prototype in an observational study with main stakeholders: teachers, parents and children. In the later phases of the project we plan to develop a working prototype.

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<table>
<tr><th>Kinaesthetic modality</th><th>Auditory modality</th><th>Visual Modality</th></tr>
<tr><td colspan="3">General characteristics for users with specific dominant modality</td></tr>
<tr><td>Learns by doing.
Prefers stories where action occurs early.
Remembers best what was done.
Images are accompanied by movements.
Attacks problem physically.
Moves hands, holds hands up.
Tries things out.
Gestures when speaking.</td><td>Learns by verbal instructions from others and self.
Learns by dialogue, plays and movement of the lips.
Problem solving.
Talks problem out
Tries solution verbally
Talk self through the problem</td><td>Learning by seeing
Watching demonstration
Sometimes stop to stare into space to imagine scenes
Thinks in pictures
Plans in advance
Facial expressions are good index of emotions
Impatient when extensive listening is required
Deeply affected by visual displays</td></tr>
<tr><td colspan="3">How MM-AISS supports user with specific dominant modality</td></tr>
<tr><td>Encourages activities which use open space of a room,
Activities include many e-blocks, e-models, construction kits, and other tangible e-things,
Encourages touching tangible objects,
Encourages to write,
Encourages to record his answers,
Encourages to prepare a report,
Encourages to act out scenes</td><td>Material is presented verbally and with discussion.
Activities support reading aloud
Encourages problem solving verbally
Encourages problem solving to talking to him self
Encourages problem solving through music.</td><td>By allowing students to organize their own space.
Space is full of posters
Mathematical and other activities are presented visually.
Space is full of post its.
Wide screen and other small screen on the wall.
System is presented with many colours
Instructions are read out.</td></tr>
<tr><td colspan="3">The role of Virtual (Intelligent) teacher</td></tr>
<tr><td>Communicates with the user also with body language (gestures, face expressions - Type of animation that animates him\her)</td><td>Encourages verbal repeating
Questions and answers are accompanied by verbal explanations.</td><td>Presents material visually with graphs, and visual examples.
Encourages user to draw
Encourages user to imagine scenes</td></tr>
<tr><td colspan="3">The role of Virtual (Intelligent) pupils</td></tr>
<tr><td>Virtual (Intelligent) pupils encourage user to help them by explaining what the user has just learned, to talk with them and to act out scenes with them.</td><td>Virtual (Intelligent) pupils discuss with user problems.</td><td>NA</td></tr>
<tr><td colspan="3">Preferred Multimodal input for a user with specific dominant modality</td></tr>
<tr><td>Tangible bits (e-blocs, and other augmented elements)
Writing.</td><td>Speech.</td><td>Writing and drawing</td></tr>
<tr><td colspan="3">Table 1. Guidelines for Multimodal system in MM-AISS based on Barbe & Swassing modality index</td></tr>
</table>

A Place-theoretical Framework for the Development of Ubicomp in Urban Places

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ABSTRACT

This article is based on the research with the same name that is being carried out at the school of Architecture of the University of Sheffield. It discusses the physicality of Ubiquitous Computing (Ubicomp), introducing some analytic resources for thinking about problems and possibilities in the incorporation of IT into the design of public spaces. Some concepts and the result of an experiment are summarized, drawing up final conclusions and suggesting new researches.

Categories and Subject Descriptors

J5: Computer applications: Arts and Humanities: Architecture

General Terms

Design, Theory.

Keywords

Ubiquitous Computing, Pervasive Computing, Architecture, Urban Design

1. INTRODUCTION

Ubiquitous computing is the model of human-computer interaction through which information processing capabilities are accessed within the environment. By embedding devices and pervading resources of Information Technology (IT) in quotidian scenes, everyday objects and their spatial resources became interfaces to detect and react to people's activities. In accordance to those concepts, physicality of Ubicomp systems can be expressed by the set of physical characteristics that can act as part of that interaction. It comprises the study of the environment and of IT components to disclose their complementary spatiality in order to assemble them into integrated systems.

Proceedings of the second Workshop on Physicality
Physicality 2007, 2-3 September 2007, Lancaster University, UK
Devina Ramduny-Ellis, Joanna Hare, Steve Gill & Alan Dix (Editors)

2. INITIAL CONCEPT

It is assumed here that the main purpose of the built environment is to provide support to dwell. In this sense, "place" means a differentiated and qualified space that supports dwelling and IT is regarded as being able to improve dwelling when applied as Ubicomp system. In other words, the meaning of Ubicomp physicality is to support dwelling as an integrated resource with the physical environment.

3. QUALITIES OF THE PLACE

Malard [1] has studied the qualities of place. From Heidegger [2] she assumed that place is equipment to dwell. Souza [3] commented that Heidegger extended this meaning to open and public spaces, by considering that they provide inhabitability to support human activities [4]. Thus, public place is understood here as space qualified to support dwelling. Investigating about dwelling, Korosec-Serfaty [5] proposed three fundamental physical characteristics:

Figure 1: inside/outside definitions

3.1 Setting up an inside/outside:

Changing space into place is a process of qualification and differentiation. Differentiation is the process of choosing, defining, marking and building places. It is achieved by doing some work in the place, for instance, by implementing markers and signs, building walls, planting trees and the like. Setting up an inside/outside is a question of establishing boundaries that qualify the space. Dwelling is to be inside (in a place) as opposed to being outside (in the infinite space). Qualification is the assignment, the in-order-to, the involvement of the place with man's activities. Man creates places by differentiating and qualifying spaces to perform his activities. Therefore, all built environments are submitted to this process of setting up an inside/outside, this limit of territory which also is the process of distinguishing what is private from what is public (figure 1). By demarcating and differentiating dwelling places, humans put down roots and establish existential connections with them. Therefore it may be concluded that the phenomenological dimension of the dwelling process, which consists of setting up an inside/outside, causes qualities as territoriality, identity and privacy.

3.2 Visibility: The hidden and the visible

From the opposition inside/outside emerges the characteristic of visibility. Any dwelling can be both, closed or open, visible or concealed, at the same time. Because the dwelling is open to the outside and, at the same time, encloses the inside, it conceals and shows, it is secrecy and display. The phenomena related to this dimension are privacy and preservation of identity (Figure 2).

Figure 2: control of visibility

3.3 Appropriation

Appropriation of the dwelling is acting and taking care. It is to be connected with some place, its present, its past and its future. Appropriation also is related to the quality of ambience, which is the need of being comfortable while living. Almost all qualities of the place-object are, to a certain extent, related to ambience. Nevertheless, to be properly appropriated, places need to be comfortable, in terms of layout, temperature, ventilation, illumination and the like.

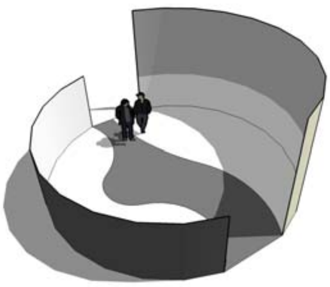

Figure 3: different internal areas: appropriation

4. QUALITIES OF PLACE

Those latter three characteristics proposed by Korosec-Serfaty could be encompassed by four basic concepts that are the qualities of place [1, 6, 7]: Territoriality, Privacy, Identity, and Ambience.

Territoriality is the process in which an area is maintained in order to preserve and protect an individual or group. The actions to protect an area are termed territorial behaviour. Territorial behaviour includes all the devices that use the space with that aim. The territorial quality is related to human purposes when humans give a sense of appropriation to the space, generating marks to identify the place boundaries. At the same time, it generates marks, delineating the space, granting identity, showing to the members of a community who live inside how they can recognize their limits. The social interaction inside a territory is ruled by the dominant group in order to improve their defence.

Privacy is the selective control of the access to a person or a group. It can be described as a control process of interpersonal events, permitting to take part in the social life, controlling by denying or permitting the web of relationship established by the social collective. Desirable levels of privacy can be established by means of spatial, verbal and cultural behaviour. Normally, the common sense of privacy is obtained by using spatial elements to separate activities, or even using time, scheduling activities in order to separate them.

Identity is the set of beliefs, ideas, general qualities that make us sense we are at the same time unique and able to share social life values. Individually, identity promotes differentiation and individual distinction. Collectively, it gives elements that the individuals recognize as patterns to integrate a person into a group.

Ambience is a quality related to all those facts that turn the place into an enjoyable interior. It reaches a subjective dimension, in which one can experience emotional responses to a place. To observe this quality we need to interpret how people are willing to maintain the place, how they care to correctly use the equipments located in it, etc.

An analysis of the spatial phenomena related to the qualities of place will make clear how those qualities are related to the physical elements and people's activities. However, we need to establish some terms in order to clear a referential group of words to refer to it.

5. ELEMENTS OF THE PLACE

This study has the hypothesis that Information Technology can integrate place's spatiality when its elements perform in consonance with place's topological structure. The elements of that spatiality were inferred from topological characteristics that were set out through many other studies about places and placeness[8-13]. Thus, elements of the place are topological arrangements of events that happen in the place and they can be referred to as centrality, internal directions, enclosure, internal area and entrances. Note that events are human activities that include the actual organization of the physical characteristics, as a register of past transformations. It means, for instance that a wall can be regarded as an event, despite not looking as "happening now", it is a result of what happened in the past.

Looking at figure 4, an interior is defined by delimitating a chosen internal area (2) from the exterior. This delimitation implies in creating an enclosure (5) which involves an internal volume. A differentiated territory from the outside is created in this process. The quality achieved by this differentiation is territoriality. Once defined as the interior, its appropriation by people will generate centrality (1) that means a set of central points organized which identifies the internal area and help to organize hierarchies of events supporting the internal movements with best orientation. The events that happen inside the internal volume of the place can be meaningfully aligned in directions (3 and 4). The peculiarity of this alignment, in terms of visible characteristics, confers identity to the interior. The way people use, maintain and preserve that interior while appropriating it by their activities confers ambience. The visible form of the enclosure, from the outside, and the peculiarity of its internal surfaces will confer identity to the place. The means by which the enclosure permits that the interior is visible or not and accessed or not from outside determines its privacy. The controlled connections with the outside are made by entrances (6), which visual aspects contribute to the identity. In the entrance, the issues related to the control of the fluxes contribute to privacy. Therefore, centrality, internal directions, enclosure, internal area and entrances are the primal components of the place, defined by the more stable and recurrent events that happen in it.

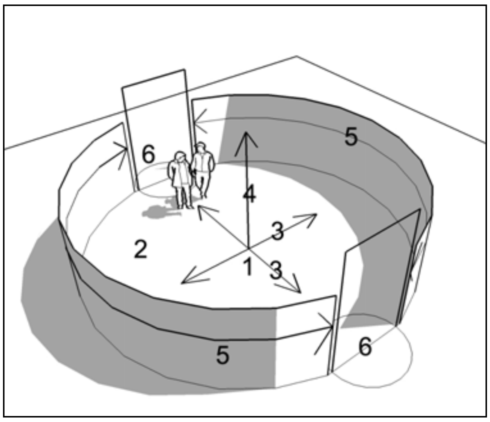

Figure 4: the components of the places

6. ELEMENTS OF UBICOMP

Components and functions of generic IT device, as a classification considering their spatial attributes were firstly clarified by Steve Shafer in his seminal paper "*Ten Dimensions of Ubiquitous Computing"*[14]. McCullough [15], inspired by Shafer's list, has enumerated later ten essential components and functions by which Ubicomp can be studied. His description is a means to clarify to architects and designers how they could refer to IT applied in the environment. To McCullough [15], the components of Ubicomp are:

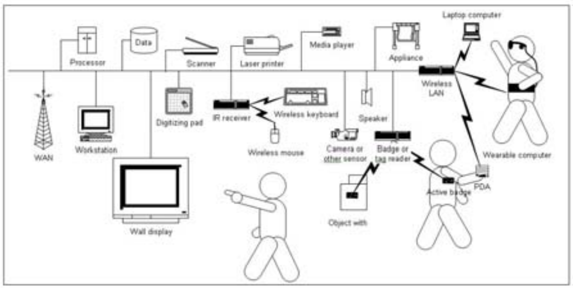

Figure 5: Representative Elements of Ubiquitous Computing according to Shaffer[17] in 1999

microprocessors, sensors, process and devices for tagging; links to communicate; actuators; control process; displays; determination of fixed Locations; software models; and tuning process.

Analysing both classifications of McCullough and Shafer in terms of spatial characteristics, it is possible to list their properties considering four categories, according to the relationship of the components and the place. So, an Ubicomp system has *elements to sense the place; elements to modify and actuate in the place; elements that represent the place; and the place itself, as a referential matrix*.

7. TOPOLOGY OF UBICOMP ELEMENTS

The four latter categories of Ubicomp were studied relatively to the physical properties of places. A table was used to specify the four place's qualities and its related physical characteristics. Then, each Ubicomp component was analysed accordingly with its potential applicability, by the study of its technical features and how it can interfere over spatial instances. Table 1, in the end of this article, exemplifies this process.

8. UBICOMP SPATIALITY ANALYZED

Spatiality of Ubicomp describes each component relating its features to the topology of the place and describing how it can potentially interfere on the qualities of territoriality, privacy, identity and ambience. A following brief summarization can exemplify it, according to those components:

Components to sense the place are all components and processes that sense modifications in the environment in terms of changes in some type of energy, transforming it into processed data and dispersing it to connected servers. Those components include microprocessors, sensors, tags, and communication links and all the spatial procedures where they are organized. To exemplify this category, we refer to the sensors, which function is to detect action in the place. They are electronic devices used to measure a physical quantity such as temperature, pressure or loudness and convert it into an electronic signal of some kind. They can act on place's territoriality by detecting when moveable elements are inside or outside of pre-established delimitations. They can act on privacy by sensing proximity, invasion, permitting surveillance and informing when an action is needed to react against invasion. They can interfere on place's identity when they provide visual identification of users, according with user's status given by electronic tags. They can also permit users to visually identify specific elements according to embedded electronic tags. In terms of appropriation, sensors can act on Identity by sensing mechanical movements in the adjustment process when people tune the system, permitting to know the user preferences while appropriating the place. Also interfering on the ambience, they can help to collect information about changes in temperature, pressure, light, permitting automatically trigger action to tune the system.

Components to modify the place are a group of elements to physically actuate in the place. They interfere in the environment physically by delivering some types of energy, and are named actuators, controls process and displays. To exemplify this category we mention the actuators. Probably, the idea of actuators is the most popular among architects who sometimes dare including robots and programmed mechanisms in their projects. An actuator is the mechanism by which an agent acts upon an environment. The agent can be either an artificial intelligent agent or any other autonomous being. They can interfere on territoriality by the servo mechanic adjustment of territorial enclosure as doors, walls, ceilings and canopies, floors, directions in the internal area, fences, and delimiters. Openness and visual barriers also can be controlled by servomechanisms, providing adjustments in privacy. With the adjustment of the visibility of some elements, they can act on the identity by changing enclosure shapes and textures. Adjustments of physical elements according to conditions demanded by user's occupation, weight, physical efforts, movements, can also act on identity, interfering on appropriation of the place. Finally, when they act providing self cleaning functions and self adjustment of comfort conditions, like openness, wind and sound barriers, they interferes on the ambience.

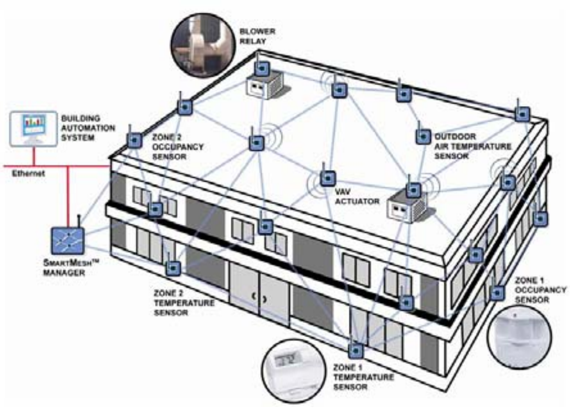

Figure 6: Wireless sensors control and monitor occupancy, temperature and air flow in a building. By Dust Network Inc..

Components to represent the place are a group of elements that represent the place in terms of model to adjust the whole system by processing data, simulating and predicting patterns of modifications in the environment. They include the techniques related to determining fixed location, designing and using software models and all tuning process of the system. Fixed Locations corresponds to strategic positions in the place through which information will be gathered or delivered or there will be an action caused by other IT components that can modify the place. It is a referential point to the representation of the whole IT system. Software model is a list of prescribed behaviours that the system can deal with. It informs mainly how sensing and acting has a closed correspondence, prescribing expected outcomes. Some models can include artificial intelligence, accumulating information about the environment and the users by learning them.

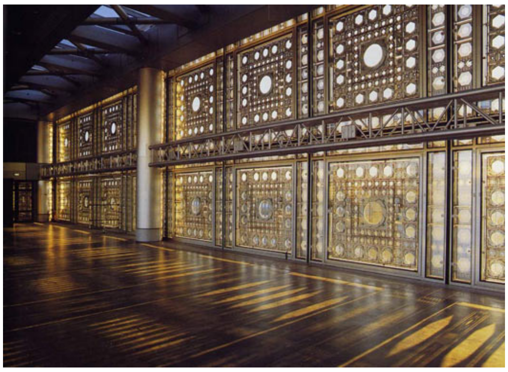

Figure 7: interior of the building "Institute de Monde Arabe". Visibility and ambience controlled by actuators.

Figure 8: Detail of the facade of the "Institute de Monde Arabe" showing an actuator to control the openness in the façade.

The tuning process refers to all sorts of services and devices that enable tuning the IT gears in the place. Such adjustment comprises defining scales of sensitiveness, accuracy of software models to represent the phenomena (events), and adjusting the physical presence of gadgets in located position. The place itself is a referential matrix, with the aforementioned components. It includes the events organized though the topology of the place. It consists of a set of parameters that guide this analysis.

Figure 9: Los Angeles Traffic control, an example of model of place. As vehicles pass in the designated zones they are counted and measured for speed and direction. The representation of those zones is a model of the place.

9. SUPPORTING PROJECTS

The results of three different urban projects are now being analyzed in order to draw a conclusion about the limits and contributions of this framework to the creation of urban projects supported by Ubicomp. The first project (project A) was for the international contest of urban requalification of Gwangbok Street, South Korea, 2005. The second project (project B) was the urban requalification to Fargate Street, city of Sheffield, United Kingdom, 2006. The Third (project C) was the urban recast to the central area of the campus of the University of Sheffield, 2007. All projects had a common starting point that was to consider the application of IT as a means to contribute in the solution of spatial conflicts. Those urban areas were analyzed through the "*reading space*" technique proposed by Malard [1], observing conflicts originated from lack or malfunctioning of spatial elements in local activities. The conflicts were interpreted as interfering directly on the qualities of territoriality, privacy, identity and ambience. The architects of project B and C will be interviewed focusing their experience whilst using the framework. Project A intended to reconnect the street with a broader range of events that surround it in the neighbourhood. Busan is the city of the Korean Festival of Cinema, which attracts people all over the country to its celebrations. Originally Gwangbok Street was a calm commercial path that existed during the Korean middle ages. It has become nowadays a busy and congested street with many conflicts. The illegal parking at street obstructs it continuously causing conflicts with pedestrian activities. By its turn, pedestrian activities interfered over each other. The facades show a lack of maintenance that, together with many areas difficult to clean, interferes on the ambience. Also a wide variety of different types of urban furniture did not offer a sense of identity. Thousand of placards make Gwangbok to look as many other congested streets in Asia, nothing special, but a lack of identity. In addition, the city council was aiming to transform Gwangbok Street in a cultural pole, surrounded by a cast of buildings, open-markets, museums and other facilities in the range of walking distance.

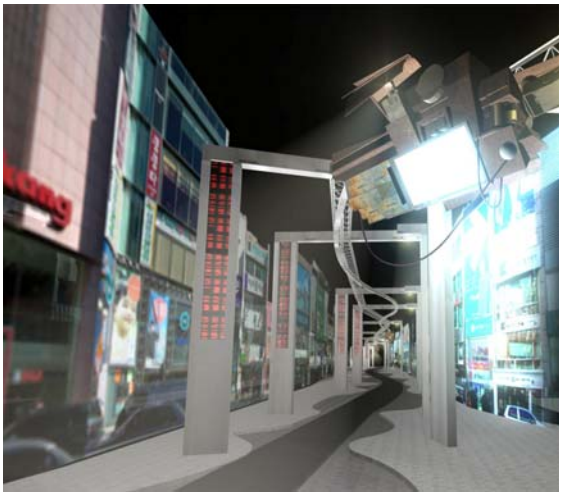

Figure 10: Busan project, refurbishment of commercial street, South korea, 2005

The project consisted of eight movable actuators, gadgets named "robots". Each robots includes 1 Laser projector, 1 display message board, 2 big screen televisions, 2 video cameras, and 3 IBM's Everywhere projectors. The laser projectors aimed to produce special visual effects in exhibitions and parades at nighttime. The luminous message board would broadcast news about activities in the street and around, information about local museums, events and so on. Televisions would permit watching small clips, ads, footages from the place, real time sequences, and others. Video cameras would gather material to be mastered and after broadcasted through the Robots. The IBM's Everywhere projector would combine projection with detection on arbitrary surfaces, converting walls and floor in an crude interactive touch screen. Each Robot would move under rails over the street, sustained by 34 structural portals. The Robots were made in molded polycarbonate and structural aluminum. They would be controlled by the Interaction Research Centre, situated inside the 4 towers along Gwangbok street. But the interaction, position, movement and lights of the Robot would be also modified by users through internet.

In the occasion of Busan International Film Festival or when required the Robot can spread information, ads, clips, games and quizzes about the movies exhibited, interacting with the public and attracting their attention. In order to be a pervasive mechanism for declaring, representing, and querying the physical relationship between people, places, devices, and things, the Robot would need a continuous research. The Interaction Research Centre would be an organization which main concern is designing, experimenting and maintaining systems, software and hardware, in order to produce new improvements on interactive urban devices used at Gwangbok Street.

Figure 11: Project B; Fargate Street at Sheffield, UK.

Project B was a refurbishment of an old commercial street at the centre of Sheffield. That street was bombed in the Second World War, and many buildings were rebuild. A report containing a list of conflicts affecting the qualities of the place was made to assist the architects design. The solutions comprised interactive walls, a ring for amusement, playing with local images and a kiosk for tourism information.

Project C was an urban recast of the public space at the Campus of University of Sheffield. Many conflicts were detected, from the lack of delimitations in the territory, causing confusion in people's orientation, to the diversity of entrances and circulations reinforcing the transient character of occupation to the place, and so on. Two different systems of integrated solutions were designed, using IT devices and small physical interventions. In comparison with project A and B, the solutions were spatially less intrusive and the devices were more accurately specified.

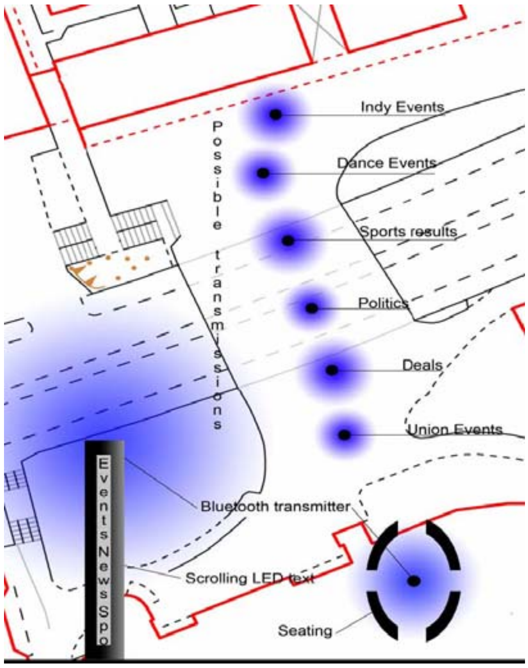

Figure 12: Project C; Area at campus of the University of Sheffield.

10. Conclusions and future researches

Some points can be roughly inferred about the use of the framework by the architects in those projects:

A) The framework was introduced accomplished to the groups of architects in project C. It was partially accomplished when applied by the group in project B and was not applied at all in the project A. Project A was, as a matter of fact, inaccurate in terms of specifications of devices and rationale, being expensively intrusive, demanding extreme physical adaptations;

B) The technical specifications to the components of Information technology used in the projects became more concisely prescribed with the framework application. There was more reliability in their description as an integrated system with the place. At the same time, drawings to express the functioning of solutions became more abstract and hard to grasp;

C) The solutions designed solving each conflict through the use of the framework have provided more integration with each other. It means that each solution given interfered positively over the others and has helped to solve a bigger number of other detected conflicts;

D) There was a more rational use of technical resources of Information Technology to solve the conflicts addressed; justifications of the design were made with explicit references to place characteristics.

E) Once the solutions were designed more coherently as a system, they seemed to offer more flexibility for the design of new components and gadgets of Ubicomp. Their specifications were more related to located particularities, permitting a range of diverse technical solutions.

These observations have suggested that new researches could emphasize Ubicomp Design as a sort of problem-solving process, wondering how the design of the embodiment of IT, its physicality within the environment, is already attached to the place. It has also suggested that the design of Ubicomp systems requires new better approaches in the graphical representation of the solutions, requiring new researches to connect the fields of Design and Computer Sciences.

Table 1: sample of analysis of Ubicomp components relatively to the place.

Territoriality	**Privacy**	**Identity**		**Ambience**
Interiority and exteriority How can generic IT components be related to spatial situations of interior/exterior position of people/elements in the place? This column describes general situations where IT components could affect the quality "territoriality".	**Visibility** How do IT components relate to spatial situations of visibility of people, activities and spatial elements, considering a definition of interior/exterior and helping the quality "privacy"? This column describes some general applications related to visibility in what visibility is involved with the quality "privacy".	**Visibility** How can the visible appearance of the place be related to IT components? This column tries to describe process in which the visibility of the place could be transformed into useful information to generate spatial outcomes.	**Appropriation** This column describes how IT components could help to transform the way the users use the place into useful data to understand how they appropriate of the spatial elements. The outcome of using such information is suggested as an application related to identity, which is either spatial related.	**Appropriation** This column describes how information gathered in the process of appropriation of the place by the user could be related to IT components. All the actions to take care, maintain and preserve the place (including cleansing, maintenance, adjusting environmental comfort, etc.) are here considered in terms of a spatial output to reinforce the quality "ambience".

11. Acknowledgments

Our thanks to Dr. Chengzhi Peng, from University of Sheffield, for his support during the development of this research.

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Physicality of Domestic Aware Designs

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ABSTRACT
The design of computer-supported spaces within the home must address the strong relationships between the social "dynamic" and the digital "static": technology must often find a fixed location within the home but must not obstruct the activity and flow of home life. This paper presents our experience addressing this physical link whilst exploring the setting of a domestic aware space. Our work reflects how a negotiation of physical resources needs to be undertaken in three contexts: social, technological and the built environment of the home. Managing the intersection of these three contexts might help with the social acceptance to this type of pervasive approach.

General Terms
Design, Human Factors.

Keywords
Awareness, intrusiveness, physicality, sensing technology.

1. INTRODUCTION
Laboratory-based aware designs are characterized by the amount of technology used to collect activity from the user's surroundings including the user's activity itself. However, when designing for the nature of the home designers struggle to make technology "invisible" and often the physicality related issues are overlooked. We are exploring the social acceptability of technologically constrained domestic-aware designs with a closer consideration of physicality. For example, our aware design avoids tagging people and uses a smaller number of invasive technologies. Our design attempts to get the most from sensors to support the system awareness. Our framework offers a top-down approach to the design of aware-based services out of laboratory. It starts with the technology requirements for the nature of the aware design followed by the intersection of the physicality issues to the home's fabric, technology and the user's psychology – *what* technology can provide sufficient awareness for the ubicomp design, *where* buildings might accept technology, *how* technology could live within the setting and *why* technology might coexist with the social dynamics. Thus, for the workshop we hope to trigger people's thoughts about the importance of taking account of physicality in ubicomp designs when considering real settings.

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As previously stated, aware designs must negotiate the physicality of social and technological spaces. Technology needs a physical location, however, it has not always succeeded in negotiating a place within the building's architecture, nor with the dweller. On the one hand, usually technology demands a relatively "static" location with particular physical characteristics, such as its XYZ coordinates, to fit the goals for which it was selected. Accordingly, the home's fabric may not gracefully meet the physical requirements of technology and often it has to be invasively accommodated. The accommodation of a simple webcam within the home for monitoring purposes is a clear example. The webcam often needs a space in one of the room corners to get the widest possible view. If wired then there are cabling issues and if wireless there are fixing constraints due to size and weight. On the other hand, the dynamics of domestic activity impose some restrictions regarding the magnitude of technology that can become integrated. For instance, the dynamic organization and movement of furniture, either during cleaning tasks or to change the room's aesthetic, may restrict the type of technology that can be used to augment those artefacts.

Research on wireless/Bluetooth communication and better sensing technologies is being done to reduce, for example, intrusiveness issues within the home, and to increase the user's acceptance. Research has partially addressed technological issues with better sensitive [1] and collaborative proposals [2]. However, in spite of these efforts, there are still concerns about how these integrative spaces can be achieved seamlessly.

In this work, we describe our experiences whilst designing an activity-aware space for a domestic setting. In particular, we expose how the physical requirements of technology, the physical resources that the dwelling can allow to be augmented and the physical aspects of the inhabitants' affairs restrict the design of aware spaces.

This paper begins with a brief review of what we believe are requirements for aware designs in general. Section 3 then shows how physicality is reflected in our activity-aware room prototype and how physical issues were addressed in our context-aware design. Section 4 discusses the physicality intersection of buildings, technology and society. Section 5 proposes an ideal scenario in which the design of aware systems would be more focused on understanding and processing the user's context and less dependent on the building's physicality. Finally, conclusions are given in section 6.

2. PHYSICALITY OF AWARE DESIGNS
For a system to be cognizant of people's affairs it needs to technologically pervade the environment in which the user lives [3]. Designs often begin by considering what people might need and how these needs might be supported. This is then followed by the exploration and selection of candidate technology. Once technology has been identified its incorporation into physical

spaces should be assessed considering issues of physicality around: technology requirements, building settings and social integration.

In order to clarify these physical issues, consider a scenario in which the user's location is part of the context being monitored, and that we attempt to attach technology everywhere within that context.

Thus we need to identify the physical requirements of the context-gathering technology. For instance, from the context-location scenario, we need to consider the form factor and weight of sensors. For example, the physical requirements of incorporating a webcam are different than those for a temperature sensor. Additionally, the physical resources needed for the sensing technology to communicate its findings must be accounted for.

With respect to the building, designs must take into account the particularities of the physical space. Is the system intended for the home or for the workplace? This will affect the facilities available to hide technology. For example, can the receivers of an ultrasonic system be hidden using false walls? Is the incorporation of sensing technology altering/modifying the building's functionality? That is, are sensors installed on windows and doors limiting their use? To what extent, are nails or tape allowed to fix sensors on artefacts?

Finally, we need to explore how these design requirements can be harmoniously situated within the local social setting. Is the proposal respectful of the user's well being? For example, is the household task of cleaning being affected due to the existence of wires on walls or floors? Or additionally, does the sensor technology limit potential uses socially assigned to artefacts? For example, sensors may be attached to radiators to sense temperature but culturally these artefacts are also used to dry clothes.

Thus using the definition: "*the physicality of an object is shaped by the physical properties of that object*" given by Reeves [4], we could say that the physicality of aware designs is shaped by the intersection of the physical requirements of three contexts: social, sensing and buildings. Figure 1 summarizes the three aspects of consideration when designing aware spaces.

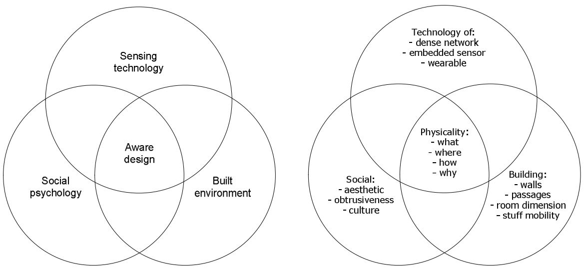

Figure 1. Mapping physicality to aware designs.

Next we describe our experience in addressing the intersection of these physical issues: the *what*, *where*, *how* and *why* of our context-aware design.

3. THE ACTIVITY-AWARE ROOM's PHYSICALITY

Here we describe how physicality is reflected in our aware design. To that end, we first introduce the characteristics of the activity-aware room. Following this, we present some of our issues of physicality around each of the three contexts: social, technological and built environment.

3.1 The activity-aware room

The activity-aware room was envisaged as a computational tool to respond to the social needs found by Swan and Taylor [5]. In this research people ask for support with household work and childcare. Until then, most research was focused on supporting the monitoring and automation of appliances. We argue that these offerings are not alleviating domestic workload as most of the parent's work is still done by hand. For example, cooking, tidying up, and making beds are activities that might not be replaced or augmented with technology yet. Thus, we could argue that parents cannot avoid attending to these tasks. Nevertheless, it is clear that parents cannot automate caring for their children. Therefore, it seems that these two elements, housework and childcare, have nothing in common but the sharing of time. That is, parents need to organise their time to attend both tasks.

It is these two observations, that technology is not ready to support some of the people's activities and that attendance to housework reduces the time available to childcare, that inspire our activity-aware room. It aims to support parents with information about the child's activities while they are attending to household chores. Additional evidence to motivate the activity-aware room design is the data about children's accidents within the home, shown in figure 2. So, a more general goal of our activity-aware room is: "The monitoring of children's activities, being aware of environmental circumstances that might represent a risk to the child".

Thus the tool should inform the parent about any potential hazardous activity. As we know, young children learn from exploration and potentially risky activities, and these experiences might lead to accidents.

	0 - 4
	Home
(Suspected) poisoning	1,214
Acute over exertion	540
Bite/sting	356
Chemical effect	198
Crushing/piercing	1,815
Electric/radiation	20
Fall	11,200
Foreign body	1,672
Other/unspecified	778
Striking contact	4,094
Suffocation	136
Thermal effect	1,269
TOTAL	23,292
UK National Estimate	477,486

Figure 2. UK child accidents, 2002 [6]

Using the information from figure 2, we might attempt to augment those household artefacts that are associated with the largest numbers of accidents.

Considering *what* sensing technology is available to address the awareness to the social support, we selected the following: proximity, motion and IR beam break sensors. Without dwelling on the technicalities of the sensing technologies used, we show in figure 3 the activity-aware version of two of the commonest spaces in the home, the living room and the kitchen.

In relation to the selection of sensors, we could say that the appropriateness of the technology can be based on two criteria: availability and communication capabilities. Sensing capabilities have remained relatively constant for the last few years [7], but substantial work has been done in improving their communication capabilities. For example, research is being carried out around different communication technologies, such as Internet/Ethernet, wireless/Bluetooth, X.10, and so on, which will allow technology to be embedded in social spaces more easily.

We conclude this section saying that the selection of technology is not a problem as such but there are many challenges when considering *where* it should go. Thus, the physicality of buildings must inform the design. The encircled sensing points in figure 3, represent the technology that was accommodated within our activity aware room prototype.

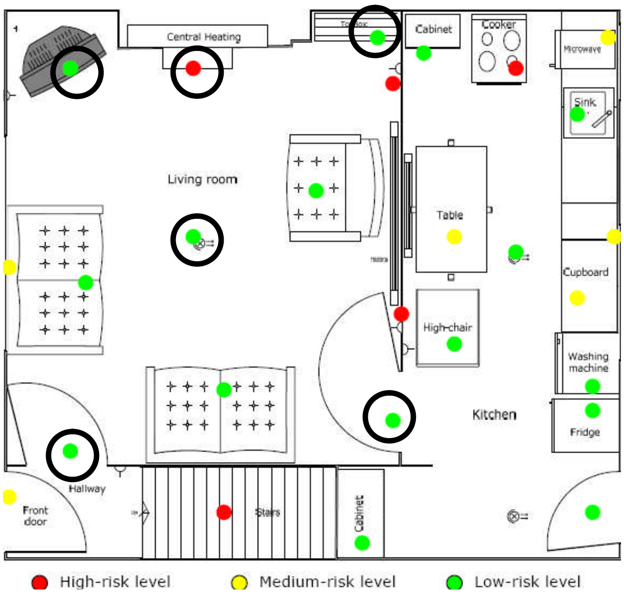

Figure 3. Kitchen and living activity-aware-rooms showing locations/artefacts that might be monitored. Those circled are the sensing points in the finally setting.

3.2 Physical issues to the aware room

It is well known that existing homes were built without considering a place for computer technology [8]. But the question is: to what extent can a successful negotiation between sensing technology and the physical fabric still be achieved to support the aware design? Using our activity-aware design, we describe our experience with physicality when embedding technology in artefacts, the social issues that intersect with physicality and the resulting awareness constraints for our prototype.

Figure 4. Examples of accommodating technology on artefacts.

3.2.1 The Physicality of augmenting artefacts

After deciding what technology could satisfy the sensing requirements of the aware room, we explore how this could be accommodated within the home. As shown in figure 3, we know where to attach sensing technologies, i.e. in relation to particular artefacts within the room. The question now is *how* we can tag these artefacts. This is a twofold task. Firstly, we need to examine the facilities offered by artefacts to accommodate the sensor. Secondly, we need to consider the requirements for the technology's communication. With regard to the former, proximity sensors were "easy" to attach to the TV and radiator using tape, while beam-break sensors required a stronger fastening item such as a nail, for instance. With regard to the latter, our sensors needed wired communication and so required a hidden cabling path as well as consideration of the length of cabling. Here, it is easy to see how some architectural offerings can address some technology constraints. For example, when cables can run beneath the carpet, designers might face fewer social and aesthetic complaints. But, how can we conceal a wired connection to a motion sensor which needs to rest around the lamp at the centre of the room?

3.2.2 Social aspects with physical issues

Leading on from the technology accommodation issues, now is the time to answer *why* (or whether) a particular sensing technology should go onto a particular artefact or in a particular position on (or within) the artefact itself. This is often a social issue. As it is known, the home is a valued space for its occupants and, thus, whatever the purpose of the technology, if it is too obtrusive or if it alters the relationship of dwellers and dwelling, technology can be rejected. But why are aesthetic concerns so important for aware designs? The answer is that if we fail to accommodate the technology appropriately then we will also fail to adequately sense and represent the user's environment. For example, home inhabitants like to move mobile furniture such as sofas either to clean beneath it or for re-decoration. Therefore, we must be cautious when considering augmenting these artefacts. Another more radical change for mobile objects is that they may just be transient elements of the room and sooner or later be removed entirely. In our experience, we saw the "disappearance" of an armchair and its replacement by a decorative table. Here it is clear that the re-arrangement of social spaces usually has an aesthetic element.

Another social aspect is in relation to the information being sensed, proximity, weight, or voice for example. Where exactly should the sensor live? How could we be sure that, for instance, the person is in the line of sight of the sensor or at the right position? Considering our activity-aware room, which is sensing young children's activity, the accommodation of the sensor on the TV was done considering the average height of a four year old child. However, this cannot be fixed for this type of aware design, even considering the same child's growth. What if the ideal height for the sensor location is in the middle of the TV's display?

Finally, if for parents the presence of invasive technology is strange, for curious children it can represent something very interesting. Thus, we found children trying to pull or play with the sensors and cables.

3.2.3 Effect on Awareness due to Physical Issues

So far, we have discussed issues of physicality around aware designs and used our activity-aware room to illustrate them. Using this experience, we could argue that physicality also affects the environmental information that can be gathered. This will also affect our understanding of users' affairs. If the system has a weak context representation, it will be not be aware of the user's needs and therefore will fail to offer appropriate support.

4. DISCUSSION

In this paper we claim that careful consideration must be given to issues of physicality that exist around the setting-up of pervasive technology within the home. There are three elements to consider: sensing technology, the nature of the home and the inhabitants' psychology.

Rodden and Bendford [9] say that in order for technology to find a place within the home, the home itself needs to change to accommodate this technology. We argue that we cannot wait decades for the new generations of homes to be ready if we want to explore different ubiquitous experiences out of laboratory. We need to socially negotiate existing building spaces in order to explore supportive capabilities of technology.

Technology can then be moved into domestic spaces in sufficient quantity to explore its viability in every-day use [10]. The sufficiency of technology, however, needs to be assessed in respect to how obtrusive it is with regard to the family's activity. That is, the extent to which the deployment of technology can affect, modify or alter the inhabitants' activities. Here is where the intersection of the "static" technology and the social "dynamics" comes into play. Consider, for instance, a weight sensor that is hidden under the sofa. If this technology has wired communication to the host computer then cabling issues will arise. Furthermore, if the family decides to move the sofa to undertake, say, a cleaning task we cannot prevent this dynamic activity just to reduce cabling issues or to accommodate another technological constraint like adjusting the sensor's position.

Thus, after considering these issues of physicality around aware designs, our domestic setting allowed only seven sensing points from the twenty-seventh originally considered. Two beam-break sensors were accommodated on each of the living room doors, a motion sensor was installed in the centre of the room and four proximity sensors went to the TV, fireplace, toy box and radiator.

Within this constrained setting, we recorded activity from a single family. After data processing, the system is able to differentiate between adults and children with an accuracy of ninety-five percent at the room level. Two additional families were invited to interact within the activity-aware room and with the collected data we are currently assessing the mobile interface that parents can use to receive collaboration and to interact with the system.

5. AN IDEAL SCENARIO

We have seen from our experiences that two important elements of aware designs are the accommodation of sensing technologies within the home and the technology's communication capabilities. We would suggest that if these two considerations were combined with current research, we could envisage embedding services in domestic network-appliances. What we imagine are artefacts, appliances, furniture, and so, that have been industrially embedded with sensing technologies such as distance or thermal sensors, in a similar way to the existing fridge, which has an embedded touch screen and a webcam. Each of these ideally embedded artefacts would have at its back panel a standard socket connector from which the sensor-signal could be obtained. This universal socket would accept an Ethernet connection. Alternatively, a wireless/Bluetooth transmitter could be used to communicate with a host computer. An additional way of getting the sensor signal would be using the house power line if the artefact supported X.10 communication.

Users would then need only to attach a transmitter to each of the home artefacts they are wish to. The system would be able to add any of the available signals to establish a global context model. Using the host computer or a mobile device, users could then select what aware service they are interested on.

6. CONCLUSION

We have seen that there is a physical relationship between the three aspects of aware designs: social, technology and buildings. We have illustrated, using experiences with our prototype activity-aware room, how physicality issues have to be considered and addressed in order for designs to actively support inhabitants. Finally, we have presented a futurist scenario in which some of the physical constraints could be reduced if sensing technologies were directly embedded within appliances, furniture and so on.

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The role of physical artefacts in agile software development team collaboration

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ABSTRACT

Agile software development promotes feedback, discipline and close collaboration between all members of the development team, and de-emphasises documentation, 'big design up front' and hierarchical processes. Agile teams therefore tend to be co-located and multi-disciplinary, including developers, testers, users and interface designers (among others). They rely heavily on face-to-face communication and simple physical artefacts to support interaction and exploration of requirements. However in this current age of globalised software development, co-located teams are infeasible in many cases and several organizations are trying to implement agile working in a distributed setting. A key question for these teams is how and whether to replicate the physical artefacts used by co-located teams, and several of them have developed digital equivalents. However, this has been accomplished without a clear understanding of what is gained and what is lost by moving from the physical to the digital. This paper draw on empirical studies of 7 mature XP teams to expand on these issues and describe the use of physical artefacts by XP (eXtreme Programming) teams.

Categories and Subject Descriptors

D.2.9 [**Software Engineering**]: Management – *programming teams.*

General Terms

Design, Human Factors.

Keywords

distributed cognition, distributed software development

1. Introduction

Mature eXtreme programming (XP) teams are highly collaborative and self-organising. Since 2000, we have been conducting a series of observational studies, and have to date collected data from 7 mature XP teams, most of whom are co-located. In our studies, we have observed that these teams make significant use of physical artefacts. These range from a furry dog that is used as a 'floor control' token in team meetings to an artificial cow 'moo'ing toy, and from a traffic cone to denote integration activity to a lava lamp to show whether the current software has any bugs in it. While the use and physical realization of these artefacts vary across teams, we have found two simple artefacts that are used consistently across all our teams. These two artefacts are the story card and the Wall. Story cards capture and embody the user stories (requirements) which form the basis of implementation, while the Wall is a physical space used to organise and display the cards being implemented during the current development cycle (called an iteration). Figures 1 and 2 show example story cards and the Wall from two different teams.

The difficulties of maintaining co-located teams has led to various (understandable) attempts to translate the physical artefacts into electronic versions for ease of distribution. However there has been little discussion about the impact that this change may have on collaboration and co-ordination activities, and other characteristics of successful XP teams. Our aim is to understand what is gained and what is lost through different translations, and thereby to advise distributed agile teams how they might maintain (some of) the advantages of co-location, and how they may compensate for any significant properties they lose.

The next section briefly introduces XP, section 3 looks at the use of the story cards and the Wall in co-located teams, section 4 considers distributed agile working, and describes the compromise devised by one XP team we have studied, and section 5 concludes with some issues and questions.

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2. EXTREME PROGRAMMING

XP (Beck, 2005) is an agile development method, and all agile methods conform to an agile manifesto. The emphasis of the agile manifesto (http://www.agilemanifesto.org/) is different from that found in traditional software development: individuals and interactions are valued over processes and tools; working software is valued over comprehensive documentation; customer collaboration is valued over contract negotiation, and responding to change is valued over following a plan. To support the need for close collaboration and interaction, XP teams (including testers, customers and developers) are often co-located.

Some may contend the detail but the sense of XP practice is captured in this description by Cockburn [2002, p29, original emphasis]:

> *It calls for all the developers to sit in one large room, for there to be a usage expert or 'customer' on the development staff full time, for the programmers to work in pairs and*

> *develop extensive unit tests for their code that can be run automatically at any time, for those tests always to run at 100% of all code that is checked in, and for code to be developed in nano-increments, checked in and integrated several times a day. The result is delivered to real users every two to four weeks*[1]
>
> *In exchange for all this rigor in the development process, the team is excused from producing any extraneous documentation. The requirements live as an outline on collections of index cards, and the running project plan is on the whiteboard. The design lives in the oral tradition among the programmers, in the unit tests, and in the oft-tidied-up code itself.*

While its acceptability is contested, many organisations have successfully adopted the approach, and its popularity is growing.

3. THE USE OF STORY CARDS AND THE WALL BY CO-LOCATED TEAMS

In our work we have articulated the workings of co-located XP teams, and how they rely heavily on interactions between team members and their environment rather than on documentation (Sharp and Robinson, 2004; Robinson and Sharp, 2005).

Two key mechanisms that are used consistently by these teams are the story card (an index card typically no bigger than 5x7 inch on which the users' requirements are written) and an area of physical space where the story cards are organised and displayed which we call 'The Wall'. Photographed examples of these two artefacts are shown in Figures 1 and 2.

Figure 1. Example 'Wall's from two mature XP teams

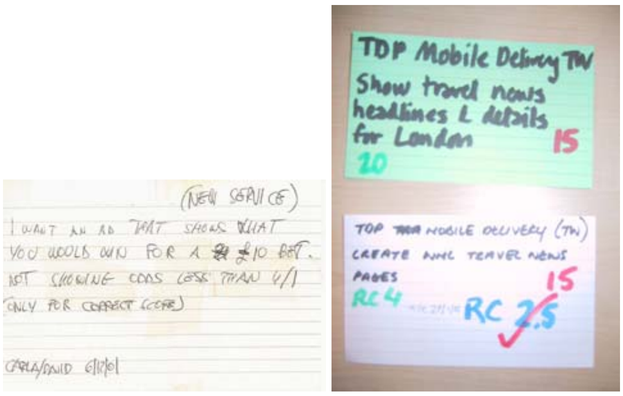

Figure 1. Example story cards from two mature XP teams

[1] This chunk of development is called an 'iteration'; many companies have one-week iterations

User stories are the mechanism used to communicate user requirements to the development team. They represent "units of customer-visible functionality", and have become a central focus of many agile teams. The efficacy of story cards is supported by the team's environment, including the Wall. The Wall is an 'informative workspace' where the cards are displayed and is the central focus in all team meetings. In explaining the Informative workspace primary practice, Beck states (2005, p39) "Make your workspace about your work" and goes on to say that "An interested observer should be able to walk into the team space and get a general idea of how the project is going in fifteen seconds". He mentions the fact that many teams do this by putting story cards on a wall. Cockburn (2002, p84) echoes this idea through his definition of 'information radiators'. An information radiator "displays information in a place where passersby can see it". It should have two characteristics: information changes over time; and it takes very little energy to view the display. Thus, a wall where story cards are displayed in a public place conforms to the idea of both an informative workspace and an information radiator.

But there is much more information being communicated through the disciplined use of these artefacts than at first it appears. The different coloured writing on the cards, the different colour of the cards, and their positioning on the Wall all have significance within the development process. For example, the left hand Wall in Figure 1 is arranged so that the blue cards (story cards) are above the corresponding white cards (task cards) which represent a more detailed analysis of the story. The right hand Wall shows many cards at the bottom of the area, which indicates that most of the planned stories have been implemented during this iteration. Of course, you need to understand these rules of display and use in order to make correct sense of the images, but once you know the rules, then interpretation is easy. It is also true that the team must be disciplined in their use in order to maintain such a rich communication mechanism.

In Sharp and Robinson (2006) we used the distributed cognition framework (Hutchins, 1995) to investigate in detail the structure and use of story cards and the Wall in one of our teams. In Sharp and Robinson (2007) we analysed cards and the Wall associated with two further teams. They work in different commercial organisations developing different systems, yet we found significant similarities between their use of these two artefacts. Although simple, teams use the cards and the Wall in sophisticated ways to represent and communicate information that is vital to support their activities.

From this analysis, the following observations emerged:

1. The simple nature of the card and the Wall means that there is little transformation between different media. In addition, the role of the mediating artefacts is largely restricted to process issues. For example the cards and the Wall aid in handling plans and goals but lack detailed information. This means that no artefact substitutes for more meaningful high-bandwidth discussion between people. In fact, the scarcity of information encourages this behaviour.
2. The information flows are simple and open, thus promoting situational awareness amongst the team.
3. The XP team works in an information-rich environment. Information is both easily accessible and immediately relevant and applicable.

A key property of the artefacts used by our co-located teams is that they are physical, and the two key artefacts mentioned above are paper-based.

4. PHYSICAL VERSUS DIGITAL ARTEFACTS

So what is it about the physical nature of these artefacts that makes such a difference? Research in the agile arena is limited, but other researchers have investigated the role that paper and other physical artefacts and activities have in co-ordination and collaboration. As Luff et al. (1992) have noted, paper has an 'ecological flexibility' which allows it to be used as a focus for discussion, and for the co-ordination of social interaction. Luff et al. also point out that paper can be more easily interweaved into ongoing collaborative activity, as opposed to screen-based documents which cause interaction to be more localised and fragmented.

Levy (2001) comments that physical artefacts communicate a sense of permanence, while Sellen and Harper (2003) investigated the role of paper in two workplace situations. They found that even when very sophisticated electronic support tools are available, workers still rely on paper artefacts for certain collaborative tasks. They examine particularly the role of paper in coordination, information gathering, discussion and archiving group information. Whittaker and Schwarz (1999) compared two software development teams: one using an electronic schedule and the other using a physical wallboard schedule. They found that the medium used for the schedule had a major impact on the co-ordination problems faced by the teams and that large, publicly visible displays promote awareness and encourage collaborative work in a way that electronic systems do not. Bellotti and Rogers (1997) also found that paper persists in a newspaper production office even when much content is created and delivered online. They identified visibility, communicativeness, status, permanence and task-adaptedness as properties of physical representations.

It would seem, then, that there is evidence to suggest that the physical medium affects co-ordination and collaboration activities in a wide range of domains.

5. DISTRIBUTED AGILE WORKING

The difficulties of maintaining co-located teams has led to various (understandable) attempts to translate the physical artefacts into electronic versions for ease of distribution. However there has been little discussion about the impact that this change may have on collaboration and co-ordination activities, and other characteristics of successful XP teams. In Sharp and Robinson (2006) we identified potential breakdowns in XP teams. One of the breakdowns identified involved a co-located team that used an online software system to store and maintain stories rather than physical story cards and Wall. The breakdown may have had various causes but it is noticeable that shortly after the study was completed, the team adopted physical story cards. This example does not appear to be unique. Beck (2005, p45) states that "every attempt I've seen to computerize stories has failed to provide a fraction of the value of having real cards on a real wall". Cockburn (2002, p84) comments that "Hallways qualify very nicely as good places for information radiators. Web pages don't. Accessing web pages costs most people more effort than they are willing to expend, and so the information stays hidden."

We have observed one co-located team who used a tailor-made electronic system to support their activity, but who reverted to index cards and a physical wall shortly after we concluded our study. We have also observed one team where the customer could not be co-located with the rest of the team, who used a combination of electronic records and paper-based artefacts to support collaboration. This latter team will be described in more detail below.

One of the teams we studied involved testers who were located offshore (in India in fact), and a customer (user[2]) several hundred miles away (but in the same country). In this team, the developers were co-located and maintained a physical Wall and used physical story cards. However in order to facilitate communication with their distributed team-mates, they also maintained a wiki which captured the stories and their status. At the end of each iteration, the physical 'Wall' was photographed and the photograph included in the wiki records. On the whole, this system worked well and both the co-located team members and the distributed team members were satisfied, although the overhead of maintaining two records of activity were commented upon.

Figure 3 The physical Wall

At a time when offshoring, outsourcing, homeworking and distributed team working is becoming more prevalent, and hence the pressure to abandon physical artefacts in favour of electronic forms of communication which do not rely on co-location is mounting, this issue becomes more pertinent. Given the emphasis of XP on co-location, it is important to identify how best to maintain the benefits of using a lightweight approach, while also continuing to benefit from distribution.

There are different issues faced by teams who are distributed but all located in the same time zone and those that are globally distributed, but they all face the problem of how to maintain the informal but disciplined collaboration and co-ordination structures that are a hallmark of agile teams. Lee et al (2006) studied 22 globally distributed software teams and suggest some coping strategies for others wishing to adopt agile processes. One set of strategies addresses task awareness and they suggest frequent visits between sites, use of shared project documents and project management tools. Ramesh et al (2006) studied three organisations who have adapted their practices to support agile globally distributed projects. One of the areas they identified concerned the need for more formal communication to facilitate knowledge sharing, e.g. by maintaining a project repository. Neither of these pieces of work addresses the more detailed day-to-day co-ordination and

[2] In XP, the term 'customer' is used to refer to a 'super user', and hence the terms are often used interchangeably. There are clearly different roles being merged, and the role of the customer is a well-known problematic area in XP. We do not discuss it further here.

collaboration activities that the story cards and the Wall support. However some experiences have been suggested by others, including the use of video and web conferencing (e.g. Danait, 2005), instant messaging (e.g. Hogan, 2006), and staggered round-the-world stand-ups (e.g. Braithwaite and Joyce, 2005). These approaches can successfully support some aspects of distributed working, but it is not yet established how this experience compares to the use of physical artefacts.

6. CONCLUSIONS

Practitioners will continue to be pragmatic and to make distribution successful, but the work we have been conducting indicates that teams grappling with a distributed situation need to understand and be aware of the issues around physicality if they are to maximise the benefits of agile working. It is clear that just translating cards into a database or spreadsheet format, and replacing the Wall with a static display will result in a poorer atmosphere of co-ordination and collaboration than the physical artefacts encourage. Two issues which we feel teams grappling should consider are:

1. *Interaction styles*. A key danger of translating these mechanisms into an electronic form is that activity may become 'hidden', and less easily accessed by all. There are several new and emerging interaction technologies that provide a very different user experience than that experienced via desktop systems, and which might provide a more appropriate interaction style to support co-ordination and collaboration in XP teams (e.g. see Sharp et al., 2007). For example, large displays and gesture-based interaction may be a suitable medium for the Wall; tangible interfaces may be an appropriate way to support planning activity (e.g. see Liu et al, 2005 for a prototype tabletop tailored to XP). Other technologies integrating the flexibility of paper with the mobility of pervasive systems are being investigated at present (e.g. CoPADD, 2006). But although moving to a different kind of interaction may provide a more comparable user experience, it may also be at the cost of simplicity and accessibility.
2. *Integration with the real work*. A key characteristic of any mechanism to support agile working must be that it is part of the real work, and doesn't distract from the main goal of producing correct software. By this we mean that no extra effort is needed to keep the mechanisms up-to-date and effective.

However, there are many more detailed issues to be addressed in this area, and I look forward to a stimulating and informative discussion at Physicality 2007.

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Enabling prediction in virtual environments: lessons from the physical world

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ABSTRACT
Our personal work environments provide essential tools for developing ideas and communicating them to others. The transition from purely physical work environments to partly virtual environments has provided incredible opportunities for augmenting the capabilities of individuals. Virtual work environments can be designed to have fundamentally different behaviour to physical work environments, but what effect can this have on our ability to predict and make use of them?

This paper focuses on the role of prediction in personal work environments as a means to control and inform our future actions. It discusses the benefits of physical information technologies in managing personal work and the shortcomings of existent digital information technologies for this purpose. Approaches to improving virtual work environment design are discussed and new tools to aid in informing and controlling future action are suggested.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation (e.g., HCI)**]: User Interfaces (D.2.2, H.1.2, I.3.6) – *Evaluation/methodology*.

General Terms
Human Factors

Keywords
Personal information management, personal information, distributed cognition, reminding, task management, virtual environment design.

1.INTRODUCTION
Computing technology provides the means to automatically manipulate information in response to real-time stimuli. Unlike other technologies which facilitate the creation of representations, computers can create representations unique to an almost limitless number of variables. Digital information technologies can react to us and to the world far faster than we can, a feature we constantly exploit when using them.

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The dynamic nature of digital information technologies allows them to represent virtual environments in a way we can freely experience, yet these virtual environments can exhibit behaviour which is radically different from the physical world. Clearly such virtual environments are dependent on a physical implementation at some level, but this dependency can be abstracted from users of the environment to a striking degree. For example, while a human user must experience the linear progression of time while interacting with a virtual environment, time within the virtual environment can be manipulated freely. Similarly, the continuity of appearance which characterises most physical artefacts need not be maintained in virtual representations of objects.

This freedom from all but the most fundamental of physical constraints allows unprecedented levels of flexibility for designers of virtual environments. This freedom, however, is a hindrance as well as an advantage: features of physical environments which we wish to see in virtual environments must be designed and implemented from scratch.

This paper looks at the design of virtual environments for personal work. Unlike the shared information repositories of the World Wide Web (WWW) and similar resources, personal information collections have deep connections with the individuals who create them. Our personal work environments are not passive repositories for information; we rely on them to help manage our time, inspire and motivate us. This paper argues that personal work environments can benefit substantially from analogy to the physical world in ways that environments for shared information do not. Drawing from research in the field of Personal Information Management (PIM) discussion is made of the strengths of physical information technologies for information-centric work and their implications for virtual environment design.

2.PHYSICAL AND DIGITAL INFORMATION TECHNOLOGIES
The ongoing tension between physical information technologies and computer-based digital information technologies has been a subject of much research [16, 22, 13, 20]. Landauer charts the massive shift towards digital information technologies in US public and private sectors from the 1960s to the 1990s [16]. Clearly computers have become commonplace at work and at home in the Western world, but throughout the development of the modern personal computer, design has been oriented towards organisational productivity. The inception of the now-prevalent 'desktop metaphor' can be found in a system very much oriented towards office work [23]. Designing virtual work environments to support office work may be a good way to sell computers to

organisations, but it is not clear how suited existent digital information technologies are to knowledge work when compared to their physical alternatives.

In their definitive book, The Myth of the Paperless Office, Sellen and Harper discuss the ways in which physical information technologies vastly outstrip the capabilities of digital ones in the context of the office work environment [22]. They highlight the interactional advantages of paper over computer-based alternatives and the co-evolution of information handling methodologies and work practices with physical information technologies. Again in the context of knowledge work, Kidd highlights the value of physical representations of information as visible evidence of activity during highly internalised tasks [13]. Kidd also notes the overhead many digital information technologies introduce to unconstrained activities, such as jotting down ideas, when compared to physical information technologies. Kaye et al., in their investigation of personal information collections, note the difference in meaningfulness that physical information instances can have compared to digital ones [12]. An example given is of a researcher who maintains a large digital archive of papers, but ensures that those papers with special emotional value are stored in a physical form.

The picture painted by literature on the subject suggests that digital information technologies cannot hope to completely replace physical information technologies in the offices of the near future. Work practices have come to incorporate computer-based tools, but physical information technologies are still prevalent in knowledge work practice. The overall message is that information-centric work has many subtleties and nuances which physical information technologies support, but which digital information technologies do not. The study of physical information technologies is therefore a excellent source for understanding the needs of individuals engaged in knowledge work. As shown in [22], a work environment free of physical information technologies is not a reasonable goal, but understanding the strengths of physical information technologies can helps us better exploit the untapped potential of digital information technologies.

3.PERSONAL INFORMATION

The personal work environment is a concept taken from the field of Personal Information Management (PIM). This paper focuses on knowledge work in virtual environments, so the idea of a personal work environment is closely related to the idea of personal information and personal information collections. In the context of PIM, personal information is defined by a direct relationship between an individual and their stored information; personal information is not necessarily private as such, but there is a distinct feeling of ownership by the individual over the information in their collection [17]. Lansdale's original use of the term Personal Information Management defined future retrieval and use of stored information as the primary goal of PIM activity [17]. As such Lansdale outlines the processes of information acquisition, categorisation and retrieval as basic to PIM activities. Barreau developed this definition further to include maintenance of collections and output of information in useful forms [2]. These influential definitions place the functional problems of what information to store, and how to ensure it can be retrieved, at the centre of PIM activity.

Knowledge work clearly requires communication with others if its products are to be shared, but it also requires communication with ourselves in the future. Ensuring that we perform future activities in an effective and timely manner is an important part of personal work. These needs are evident in a second area of PIM research pertaining to managing tasks and remembering to perform actions. Malone observed the reminding function of information instances in physical work environments [18]. More recent work has also investigated the relationship PIM has with reminding oneself to take action and in the ongoing management of activities within the personal work environment [3, 24]. As noted in [11], these two areas of concern within PIM overlap to a large degree; the way individuals organise their information and the way in which they access it play a significant role in how they manage their time and the activities they must perform.

The value an individual derives from their personal information is based not only on the explicit facts it contains, but also on the relationship they have developed with their information and the environment in which it resides. In this respect personal information is very different from the shared information accessed via the WWW – the selection and organisation of information adds value to the collection which is unique to the individual who created it. The information we externalise into our personal work environments need not contain explicit details of our ideas and intentions. Our internal knowledge of our ideas and intentions provides the context for understanding our personal information. This hybrid of internal and external information is what makes other people's notes and organisational structures often so difficult to interpret; essential information required for understanding remains in the mind of their creator. This tacit knowledge, so essential to personal work, may be in a form which cannot be externalised, even if the desire to do so were to arise.

4.PERSONAL WORK ENVIRONMENTS

At a basic level, personal work environments enable information-centric activities by allowing individuals to externalise their ideas in symbolic form. The relative stability of many substances in the physical world has permitted the creation of information technologies which provide persistent storage for symbolic information. Stable information technologies allow us to communicate our ideas to others across time and space, but they are also crucial in supporting our personal conceptual processes. Engelbart describes how the sophistication of the tools and methodologies employed in external symbol manipulation define the type of conceptual work we can engage in [8]. Simple artefacts, such as a pen and paper allow us to represent and manipulate ideas more complex than possible in the mind alone. Hollan, Hutchins and Kirsh describe how work environments provide the means to externalise some of our ideas and intentions, placing a portion of the burden of undertaking complex conceptual processes on the environment [10]. As parts of our cognitive processes are externalised into our work environments, the environments themselves should be considered an essential component of our thought processes.

Environments for personal work must go beyond basic repositories for information if they are to exploit the full potential of the individuals who use them. As described in the previous section, our personal information is made valuable by the implicit meaning it has for an individual as well as the explicit facts it contains. The intimate knowledge we develop of our personal work environments and the activities we engage in within them justifies and motivates a different approach to the design of virtual environments for personal work. In particular, this paper questions the importance of future use as a motivator for the storage and organisation of personal information.

Being able to retrieve instances of information we have included in our personal information collections is clearly necessary, but research suggests that this is rarely an issue for most individuals who employ virtual environments for information storage. Barreau and Nardi observed that individuals rarely have problems finding information instances amongst their frequently-used information [3]. Similarly Broadman and Sasse observed that individuals rarely fail to find information within their personal collections [5]. Alvarado et al. note that "despite people's large and complex information repositories, most information activity involved simply accessing information and did not involve the user exerting effort to find information" [1].

Recent trends in digital information search technologies offer the means to rapidly access digital information instances with the minimum of recalled detail about them. Should these trends continue then bridging the gap between the intention to access a digital information instance and actually accessing the instance will become insignificant. This is radically different from physical information technologies which are often specifically designed to overcome this barrier. Predefined categories and indexes are features of large collections of physical information, necessitated by the static nature of physical information technologies. No such schemes are necessary to retrieve digital information – provided the retrieval dimensions available suit what you know about the desired target.

Instead of enabling future use of information, this paper argues that controlling future action as the outstanding need to be met by virtual environment design. Reminding ourselves to take action and informing ourselves of what needs to be done are essential aspects of effective work, yet support for these needs in existing virtual environments takes little advantage of the lessons physical environments can teach us.

5.REMINDING AND FUTURE ACTION

Individuals do not often have problems finding personal information instances they seek, but remembering to look for them in the first place often is a problem. Malone gives equal importance to both finding information and reminding functions in his study of PIM in paper-based personal work environments [18]. He distinguishes reminding from finding by noting that, unlike looking for items, being reminded of a task or activity requires no intention to be reminded. Put another way, for reminders to be useful they must direct our attention without relying on us seeking them consciously.

We often encounter items which trigger memories of activities we must perform. Sometimes we purposefully devise reminders for ourselves based on predictions we make about future situations we are likely to encounter. Other times we are reminded of important information simply by an association we make with an item we encounter. Barreau and Nardi report on the reminding function of file placement in virtual environments, noting that "With a file in a specific location, the user knows he will see the file and be able to use it as a behavioural trigger to remind him to take some action." [3]. Bauer, Fastrez and Hollan highlight the reminding function individual information instances, and structures within them can have, even when such instances are not explicitly sought [4]. Whittaker and Sidner employ the term 'opportunistic reminding' to characterise the reminding functions of items in commonly viewed groups [24]. This is best illustrated by the example of an email inbox which contains multiple messages: if such a grouping is viewed frequently, as is likely for an email inbox, then any visible items are likely to receive some attention and hence create the opportunity to remind. Kirsh describes the benefits of having multiple items visible in the work environment; each provides the possibility of opportunistically discovering a useful piece of information while engaged in tasks within the space [15].

In this way consistently experienced aspects of a work environment can benefit the individual in controlling their future action. The location of items within a personal work environment can be used to indicate their importance and to affect the probability that we will encounter them experientially in the future, and hence be reminded to take action and informed of what action to take.

The obvious question raised by this reasoning is why individuals would choose to rely on passive, static methods to remind ourselves to take action. Fertig, Freeman and Gelernter note the drawbacks of reliance on passive reminding functions – namely that there is no way to guarantee that the reminding takes place at all. They highlight the virtue of placeholders for outstanding work in their Lifestreams concept for personal electronic environments which can serve to explicitly map out future events and commitments [9]. Going beyond reminders tied only to a specific time, such as an alarm clock, Dey and Abowd employ contextual information about the location of multiple individuals to decide when a reminder should be brought to a user's attention [7].

Active reminders, tied to predefined circumstances (a time, place, individual or combination thereof), offer many possibilities for managing one's time and activities. Crucially, however, all such active reminders rely on an explicit definition of the circumstances under which a reminder should take effect. This is appropriate for coordinating activities with others, but far less important for controlling and informing future action of the self. Not all knowledge work we engage in is planned in advance, nor do our activities necessarily justify the effort required to explicitly define all the steps required to achieve a task. Kidd notes the problems digital information technologies may present in requiring that all information items be assigned an explicit label or location [13]. This may not be possible if the meaning of the item in question has not yet been established, just as explicitly defining the circumstances under which you should be reminded to act may not be possible for unconstrained and open-ended activities.

Managing personal tasks and informing ourselves about what action to take in the future are not activities always subject to explicit definition in advance. The information necessary to decide on appropriate action resides both in the personal work environment in explicit form and in the mind of the individual who makes use of the environment. The combination of the two is necessary for efficient, meaningful, personal work. Control over our future actions is a part of this, but precise control is only possible in circumstances with precise variables, such as a time or location. Passive reminding mechanisms, common in physical work environments are clearly valued in virtual work environments [3, 24, 18, 15] and provide low-cost, flexible ways to inform and control future action.

6.REPRESENTATIONAL CONSISTENCY AND PREDICTION

The ability to generate dynamic representations of information is a key feature of computing technology. The virtual environments which can be implemented in computing technology can adapt to an individual's needs in real time. In a moment fundamental changes in the representation of a virtual environment can be effected. This dynamism has numerous benefits, not least the rapid navigation of information sources, personal or shared. Digital information search technologies allow the rapid and continuous refinement of search queries. Digital information presentation technologies allow the representation of information to be instantly and continuous modified, even translated into other languages.

Dynamic, reactive digital information technologies are powerful tools, but implicit in the dynamic system is the need for an individual to explicitly request certain types of information before they are provided. This does not match well with the requirements of passive reminding which relies on individuals being able to predict future states of their work environments and future experiences they will have within them. Dynamic representations suit circumstances when shared information is being sought, but this dynamism makes prediction of future states difficult.

The need to physically move around an office provides numerous opportunities to have predictable encounters with artefacts and information. Norman provides the example of placing a book which must not be forgotten when leaving the house against the front door, making it unlikely that you will leave the house without tripping over the book [19]. In comparison, existing virtual environments for personal work provide limited opportunities for predicting future experiences we might have. Objects are frequently represented in different ways; one moment an information instance is represented as an icon, the next a full-screen page of text. Seemingly minor actions in virtual environments can have huge effects on their representation: buttons for closing windows are often right next to buttons which make them occupy the whole screen.

The material structure of physical information technology artefacts provides a basic set of properties with which we can interact. The physical artefacts we use in our work environments tend to be stable in appearance and spatial location. These properties enable a rich vocabulary with which we represent problems and communicate with ourselves in the future; not through explicit messages, but though implicit meaning we encode into the spatial arrangement of artefacts [14]. The top-down realisation of existing virtual environments results in some types of object being treated differently from others, even if their representations appear similar. For example, the virtual position of an icon may be preserved between sessions, but the position of a window may not. This issue relates to what Roth et al. refer to as the "basic currency" of user-system interaction [21]. Properties and objects are assigned differing levels of importance by the designer of the virtual environment. The meaning an individual places on a given aspect of a representation is not guaranteed to be respected by the behaviour of the environment.

7.APPROACHES TO IMPROVING VIRTUAL ENVIRONMENT DESIGN

Given the shortcomings of contemporary virtual environments for passive control over future action, what approaches might we take to improving virtual environment design for personal knowledge work? Previous sections of this paper have discussed the advantages of physical information technologies and physical work environments for knowledge work, so it might appear natural to suggest incorporating aspects of physical information technologies into the design of digital information technologies. Such replication, however, would not necessarily create digital artefacts which meet the same needs as their physical counterparts.

As Lansdale points out, the practices observed in physical work environments are products of the constraints of physical technologies and will not necessarily serve the same function in virtual environments [17]. The previous section noted that the overheads that physical information technologies place on interaction mean that certain actions and experiences are likely to be repeated, providing opportunities for prediction. Yet, introducing similar overheads to interaction with a virtual environment does not appear to be a sensible way to aid prediction. Digital information technologies allow us to obviate many constraints which apply to physical information technologies; simply replicating the behaviour of physical artefacts risks undermining the strengths of digital information technologies. Kirsh describes the need to identify the deep structure of physical work environments in order to best replicate their strengths in a virtual environment [15]. Identifying this deep structure would involve abstracting its properties from the surface representations found in existing work environments. A detailed understanding of the abstract needs of knowledge workers would provide a basis to better realise virtual environments suited to their activities, however this is a very demanding goal. Kirsh underlines the distributed nature of information in work environments, especially information used to coordinate activities, such as that being discussed in this paper. This distributed information, part explicit, part implicit makes modelling such complex systems very difficult.

The ecological nature of personal work environments makes a complete understanding of individual needs appear to be an impossible goal. The co-evolution of work environments, information technologies and user practices provides the opportunity to introduce new artefacts and behaviours into existing virtual environments. If suitably integrated these artefacts could provide opportunities to improve existing environments without the need for substantial global changes in environment behaviour.

8.IMPROVING CONTROL OVER FUTURE ACTION IN VIRTUAL ENVIRONMENTS

Passive reminding mechanisms rely on predictions we make about information instances we will encounter in the future. These mechanisms need to be low cost and flexible; precise controls over future action can be achieved through active reminding mechanisms, but this is not appropriate for fluid, open-ended processes. Physical information technologies meet well with this requirement as information intended to guide future action can be encoded using ad hoc spatial arrangements, such as piles. The flexibility to encode such information in contemporary virtual environments is less evident. Generic file/folder hierarchies provide only basic tools to add semantic information to information instances, usually a single label for items and categories alike. Despite this, research suggests that users will employ even these basic tools to decompose tasks and control their ongoing work. Jones et al. observed individuals employing complex folder hierarchies to represent tasks and employing compensating strategies to gain control over the presentation of these structures [11].

Enriching the semantic information which can be easily added to information instances and organisational structures is one method to increase the opportunities for passive reminding strategies in virtual environments. For example, providing mechanisms to visually emphasise items or groups, hence making them more likely to gain a user's attention. Improvements in information retrieval technologies, discussed in the third section of this paper, make supporting future access to information instances a less important consideration in the design of organisational tools, providing latitude for changes to support task decomposition and passive control over future action.

While improving the means by which semantic information can be directly added to digital information instances is an appropriate strategy, it can only match some of the flexibility that physical information technologies provide. Another important feature of physical information technologies which supports opportunistic reminding and task decomposition is the ability to quickly create ad hoc categories and groupings [15]. While engaged in a task, it is easy to group physical items to encode temporary working information into information instances which is relevant for only a short time. For example, creating piles of paper documents to denote which have been read and which still require attention.

Equivalent information can be encoded into information instances in existing virtual environments using a variety of methods, such as the position of windows on the screen or the order tabs in a web browser. However, these methods do not guarantee the persistent storage of this information if the relevant properties were not considered worth maintaining by the designer of the virtual environment. Likewise, only properties of items which are consistently represented in different views are apt to be good choices for encoding temporary working information. This forces users of virtual environments to encode such information in variables which are both consistently represented and subject to persistent storage. Hierarchical relationships between items and the names assigned to categories and items are often the only properties available for this purpose. Compensating strategies, such as prefixes on the names of folders to control their order [11], are evidence of the demand for greater control over the representation of organisational structures in existing virtual environments.

This paper suggests that the lack of rapid, flexible mechanisms to add semantic information to information instances in virtual environments limits the control that individuals can exercise over their future action. Single-inheritance hierarchies have become an established part of contemporary virtual environments and provide a solid and absolute system for the organisation of digital information instances. Many functions of personal information collections, however, go beyond simply enabling future access to information instances. New tools could complement existing organisational structure by providing short-to-medium term mechanisms to encode additional semantic information into existing information instances. Such tools would not need to handle the volume of items which current file browsing tools support; instead they could be designed to handle a relatively small number of items specifically related to a given activity. It would not be necessary to replace existing structures for the organisation and storage of items; underlying file hierarchies could remain in place and provide an initial source for semantic information about items aliased into new views.

Tools designed to facilitate the creation of transient, task-specific views of information instances could provide a diverse tool set for individuals to inform their future actions and decompose problems. These views would be quick to create and dismiss, making them useful for both short and long term activities. By breaking free from the wide range of functions which generic tools for organising information instances must perform, more latitude can be given for functions designed to add rich semantic information to items. As in the physical work environments, when engaged in a knowledge-based tasks, only a small portion of the information instances within a personal information collection are relevant to the task at hand. Specialised views of underlying organisational structures could provide similar benefits in existing virtual environments. Limiting the number of items included in a view would provide greater consistency in the representation of the items, creating more opportunities for users to rely on passive reminding mechanisms.

This approach does bring with it risk of fragmenting personal information between different tools. Broadman, Spence and Sasse note the problems that accompany the maintenance of multiple hierarchies between disparate tools [6]. Creating further semantic structures on top of existing ones could reasonably be expected to add to this problem. A way to address this issue would be to integrate the new tools with existing ones, providing a way to creating views which bridge between different applications and provide a common space to organise items and plan activities. Although not an easy task, this approach could help mitigate some of the problems associated with the fragmentation of personal information.

9.CONCLUSIONS

Personal work environments provide a context in which we can externalise our ideas and intentions. This external information need not always have explicit meaning – we use it to communicate with ourselves as well as with others. The value of personal information collections lies in the meaning we can derive from the combination of external information and internal knowledge. This fundamental difference between information for oneself and information for others is what necessitates special attention to personal information needs.

Virtual environments offer huge potential for supporting personal work. The flexibility designers of virtual environments enjoy provides the possibility of creating radically different ways of engaging in personal work. This flexibility, however, comes at a cost: almost all aspects of virtual environments are subject to design and implementation, so designers must explicitly define how the environment should be represented and how it should behave. Existing virtual environment design has tended to play to the strengths of digital information technology, emphasising dynamism and rapid information access. This paper has shown how this trend can potentially limit the usefulness of virtual environments for personal work.

Access to our personal information is an important need in personal work environments. Enabling future access to stored information has often driven the design of physical information technologies. Digital information technologies make access to specific information instances effortless by comparison; organisational structures and representations can be created on-the-fly in response to the needs of a user. While solving this problem, however, digital information technologies not automatically meet all of the needs of individuals engaged in personal work.

Personal work necessitates control over what information we access in the future. Digital information technologies offer powerful tools to actively remind us to act, but only if we can first make our intentions explicit. This paper argues that personal work activities, especially those involved in knowledge work, are not frequently subject to such explicit definition. Passive reminding methods require no such explicit definition, but rely on the prediction of future states of work environments to be effective. Physical information technologies offer strong support for passive reminding due to their stability and the easy with which ad hoc information can be added to items through spatial arrangements. These low cost and unobtrusive mechanisms provide effective ways for individuals to decompose problems and take control of their future actions.

This paper suggests the integration of new artefacts into existing virtual environments to provide mechanisms to help individuals control and inform their future actions. Tools which facilitate the addition of ad hoc semantic information to existing information instances and structures have the potential to imbue digital information technologies with some of the abstract properties which make physical information technologies so effective for personal knowledge work. By creating new semantic layers on top of existing structures these tools can specialise in support functions appropriate to informing and controlling future action.

10.FUTURE WORK

As part of the author's PhD research project, an ethnographic study is planned to investigate the role of personal organisational structures in controlling, informing and motivating future action in personal work environments. This will involve the development and evaluation of tools designed to facilitate the low cost addition of semantic information to information instances and structures as discussed in this paper.

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Instantiating Your Imagination: Creativity across different levels of reality

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ABSTRACT
Virtual reality offers a bridge between what is physical and what is imagined, which allows opportunities for designers to explore alternatives that would not be feasible in the physical world. This paper aims to address the issue of whether this manipulation of constraints is likely to be beneficial to their overall creativity, and looks at the effectiveness of popular systems such as Second Life for supporting creative design.

Categories and Subject Descriptors
H.1.2 [**Models and Principles**]: User/Machine Systems – *human information processing*; H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems – *artificial, augmented, and virtual realities*.

General Terms
Design, Experimentation, Human Factors, Theory.

Keywords
Creativity, virtual reality, physicality.

1.INTRODUCTION
Creating a novel object is far from trivial, and designers are often known to externalise aspects of the task in order to assist them with their work. Traditionally, this has been done with models and sketches, which have been shown to help facilitate certain features of the process, such as restructuring a design [9]. This is also supported by theories of distributed cognition (e.g. [13], [4]), which suggest that aspects of a task may be embodied in objects so that part of the task is processed externally to the mind of the person performing it.

However, the domain of virtual reality may have much to offer to designers in place of these more conventional tools. For example, it offers visualisation of 3D shapes and scenes from many viewpoints, storage and fast prototyping of designs, as well as possibilities for collaboration and dissemination of the whole product, all of which are advisable if a system is to follow the 'create, donate, relate' systems model [7]. Although there are clear advantages to such a system in some scenarios, the unique nature of virtual reality poses some challenges for supporting creativity appropriately.

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2.THE NATURE OF REALITY
Imagine that you, as a designer, had been asked to invent a new form of car. If you were given a selection of building blocks or basic shapes to help you create your design, you might well choose some circular objects that would roll along, and quite literally fall into the trap of trying to re-invent the wheel. Starting from this point, it seems unlikely that any wildly radical ideas would immediately present themselves. However, if you now imagine that you were designing in a space without the constraints of gravity, the results may be very different. A wheel would no longer offer the same advantages, and a flying machine may be a more suitable solution.

Many theories of creativity agree that a creative product is one which is both original, or novel, and practical, or fitting for its purpose (e.g. [3], [1]). In the above examples, a car which rolls along the ground may be highly practical in the real world, but it is not hugely original. A flying machine may be more original, but not very practical. Finding an optimal solution requires creative 'leaps' or 'thinking outside the box', which may be hindered by the strong affordances offered by physical shapes.

The nature of virtual reality offers some of the features of physical objects, such as the ability to see and manipulate them, but with the possibility of removing some of their natural constraints, and arguably allowing for greater exploration. For example, if a person is presented with two cubes and asked to combine them into a single form, they may be able to imagine merging the shapes so that they overlap (Figure 1), but it would be difficult to achieve this with physical entities. In a virtual environment, however, this may be done easily, and may result

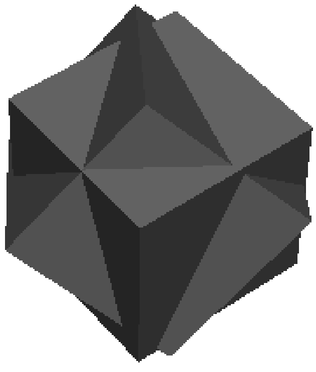

Figure 1. A complex shape produced by merging two cubes

in more unusual and complex shape combinations. In this way, the virtual world offers the possibility of bridging the gap between the mental and physical spheres. However, it remains to be seen whether this results in more creative inventions. The question therefore is this: in designing creativity support tools in virtual reality, are we looking to use the non-physical features of the software to their best advantage, or limit how much they naturally impede creativity? In order to answer this question, it is necessary to first understand the differences between a physical environment which is ruled by constraints, and a purely imagined scene which is open to exploration.

3.EXPLORATION VS CONSTRAINT

On first thought, it could easily be assumed that greater exploration would be of benefit to designers looking for more original ideas, whereas constraints would make their job more difficult. However, on further consideration, the issue is less clear. If a designer is left to imagine freely, there is potentially more freedom to invent unusual designs, but this is a difficult task, and it has been shown that prior knowledge or exemplars in particular may encourage people to conform to existing constructs [8] [11]. Although the search space for ideas is theoretically wider, there is a tendency not to explore beyond established norms unless pushed to do so. Instead therefore, it may be that imposing stricter constraints on designers would force them to think in different ways in order to fit the requirements of the task, and therefore arrive at more original solutions which may not have occurred to them otherwise.

Geneplore: The Exploration Account

One cognitive model which advocates the importance of exploration to the creative process is the Geneplore model of Finke, Ward and Smith [3], which proposes a cyclical process of idea generation and interpretation (Figure 2). This model was partially inspired by a series of experiments conducted by Finke [2], in which participants were presented with three 3D shapes, and asked to combine them to form a single 'invention' in a given category. In some of these experiments, participants were asked to create a form before being given the category, with the aim of forcing them to generate a structure free of interpretive bias which must then be explored.

Finke found that the use of these 'preinventive forms' increased the overall creativity of the resultant designs (as rated by independent judges on scales of originality and practicality),

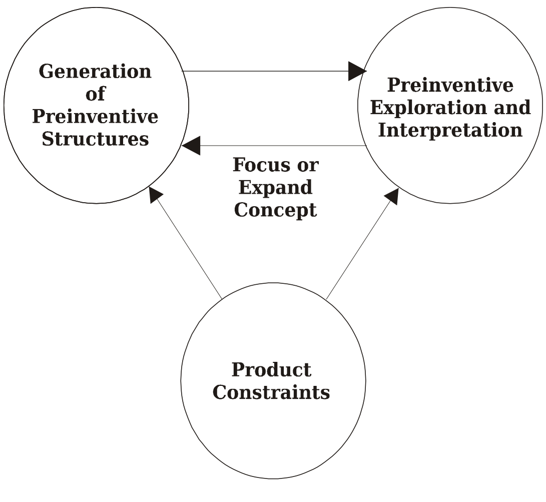

Figure 2: The Geneplore model (Finke, Ward & Smith, 1992)

which supports the argument that exploration is a critical part of the creative process. However, his experiments were conducted purely with mental synthesis of shapes, and his participants were never presented with physical objects to work with. For the Geneplore model to hold, it would be expected that the same results would also be seen using tangible forms, or that mental synthesis would yield more creative designs due to the increased exploration that is possible in this environment. Therefore, it was necessary to test these hypotheses before continuing into the virtual domain.

Mental vs Physical Synthesis: The Role of Constraint

An experiment was conducted to replicate Finke's research as closely as possible, with an added within-subjects condition of whether shapes were presented in physical form or not [5]. However, in contrast to the original studies, no significant effect of preinventive forms on creativity was seen. Instead, using preinventive forms was found to increase originality at the cost of practicality, so that any benefit was essentially cancelled out. Also, there was no significant effect of the physicality of the shapes on either the creativity of the designs, or on their originality and/or practicality, but there was an interaction effect noticed, whereby designs were found to be more practical using mental synthesis when no preinventive forms were made, and more practical using physical shapes when the preinventive forms were used.

This suggests an alternative account for Finke's results. Instead of the increased creativity being due to the increased exploration offered by the preinventive forms, it is possible that the effect is instead due (at least in part) to the added constraint imposed by having a pre-determined shape that the invention must conform to. This means that participants were forced to come up with more original ideas in order to fit the category, and their practicality suffered as a result of this. The interaction effect may support this theory, as it could be taken to show that the affordances offered by the physical shapes made a design more practical by imposing additional constraints on the participant that suit the form to be used, whereas when there is no form to follow then the participants are more capable of thinking of practical examples from their own knowledge base and making a design that incorporates these.

If these results are to be believed, then this would suggest that there are indeed constraints due to the nature of the physical shapes that could be manipulated in virtual environments to produce the most suitable setting for creative design. The fact that there was no significant difference between the mental and physical synthesis tasks on creativity or its components is encouraging, as it means that it may be easier for a virtual environment to bridge the gap between them. However, there is still the consideration that there are aspects of the software that affect the creative process in themselves, and this should not be overlooked.

4.VIRTUAL PHYSICALITY

Issues of immersion and presence are important areas of research in the field of virtual reality, and much work has been done on assessing and enhancing these factors. This may involve the use of features such as ambient sound, haptic feedback or depth and perspective in graphical displays, and it has also been indicated that as well as improving the user experience, this increased immersion may also lead to improvement in task performance. For example, a study by

Pausch, Shackelford & Proffitt in 1993 reported a 42% reduction of time taken to perform a visual search task with head-mounted displays as opposed to standard computer displays [6]. It does not necessarily follow that this will result in an increase of quality as well as speed when it comes to creativity, but if varying the level to which the virtual environment mimics the real world could affect a user's level of presence or immersion, this may have implications for their performance in creative synthesis tasks.

Exploratory Studies

As a first test for this theory, a number of exploratory studies were run using desktop systems. To begin with, a simple environment was built using Java3D (Figure 3) to allow the manipulation of shapes in a pseudo-3D scene through mouse control. In this environment, the following operations were possible:

- Moving the shape on a 2D plane
- Rotating the shape in 3 dimensions
- Zooming the shape (moving it on the z-axis)

In addition, it was possible for the experimenter to apply a simple 'gravity' to the scene, whereby shapes always fell to the bottom of the screen, or apply 'solidity' to the shapes, to prevent them from passing through each other. The user was not able to change the viewpoint or move themselves around the shapes in any way using this system. Participants were given 3 shapes (similar to the ones presented in the studies discussed earlier) and a simple synthesis or generation task, in four conditions:

- Gravity off, solidity off
- Gravity off, solidity on
- Gravity on, solidity off
- Gravity on, solidity on

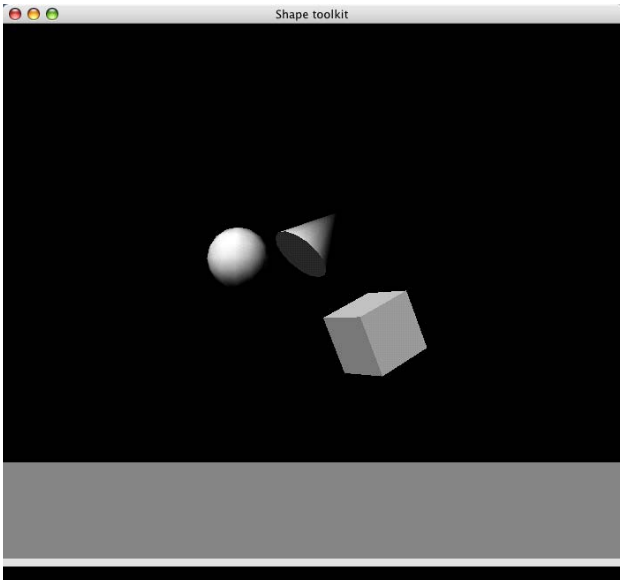

Figure 3: The Java3D environment

It would be understandable to make the assumption that the fourth condition would be the easiest for participants to handle, as it is the closest to the physical world that they are most used to. However, most participants actually found the first condition preferable, as it allowed for greater freedom of movement in all directions. In this condition, shapes would remain where they were placed, and this condition is arguably more comparable with standard graphics packages or 3D modeling software. The hardest condition for participants to work with seemed to be the third, as shapes would all fall to the 'floor', but would fall through each other, meaning that in order to be grouped into a single shape they could only be lined up along the floor, not stacked. This strongly affected the types of shapes that were made, and participants would often have to re-think their ideas as they found they were no longer possible. While this was frustrating to them at the time, such a scenario may potentially lead to more creative discoveries if the earlier theories are to be believed.

However, an environment where participants are fixed in place is not ideal for comparisons with normal physical interaction, as one of the advantages of physical shapes is that they provide a true three-dimensional view. For comparison, a similar scene was put together in the classic VRML environment (Figure 4), which easily allows for a number of styles of movement through mouse interaction, via a 'tool-bar' at the edges of the scene. In this environment, the following operations were possible:

- Moving the shapes on a 2D plane
- Rotating the view
- Panning or planning the view
- Turning or rolling the view
- Resetting the view
- Moving towards and away from the shapes

The user was not able to rotate the shapes individually. There was no 'gravity' to the scene, and the shapes were able to pass through each other. Participants were presented with three shapes, and encouraged to experiment with changing the view before assembling the shapes into a single form.

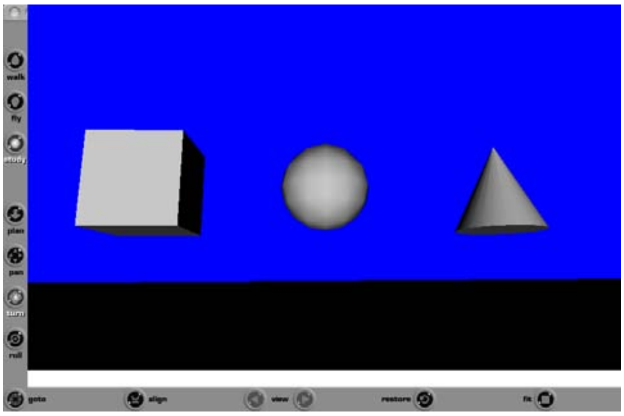

Figure 4: The VRML environment

In this environment, participants manipulated the shapes without too much difficulty, but orientating themselves around the scene was found to be rather more complex, with one person complaining that rotating the whole view made them 'dizzy'. Adding a 'horizon' to the scene was found to be helpful, but participants still found it difficult to orientate themselves, and often needed to reset the view. Some people found the tool-bar useful, as it allowed a variety of actions without the need for remembering a large number of mouse or key combinations, although others found the many different options confusing, as the differences between the styles of movement were often hard to grasp.

One issue that occurred in both environments was that participants found free rotation in 3D to be very difficult to grasp, particularly using a standard mouse which is not designed for such a task. This phenomenon is supported by a study conducted by Ware and Rose, who found that a virtual object such as a cup could take an average of 13.4 seconds to rotate accurately [10], while a similar task would only take a second or two with a real object. The increased cognitive load caused by the complexity of this task may make comparisons between virtual and physical shape manipulations difficult.

Therefore, in order to compare virtual manipulation of objects against physical or mental synthesis effectively, it seemed necessary to find a system that had the best features of both environments – a physics engine that could be manipulated, the ability to change the view easily while being able to orientate oneself, the means to present shapes to the user, and so on. Due to the difficulty of manipulating shapes accurately in 3D, it also seemed highly desirable to find a system that participants already had familiarity with.

Real Life, Imaginary Life and Second Life

Second Life, as the name suggests, sells itself as a complete alternative world, where 'anything is possible'. A highly popular online virtual community with over 8 million users to date, it has a strong focus on creativity, with users building and selling objects for money, all of which are made from primitive 3D shapes (or 'prims'). The system uses the well-known Havok physics engine, and shapes can be easily marked as 'physical' (meaning that they obey the laws of physics) or 'phantom' (meaning that they will pass through other shapes), and other behaviours can be added to any object via the use of scripts. Currently around 1 million US dollars are spent in the system each day, so finding ways of using the virtual environment to maximise creativity could prove to be highly profitable for its users.

Results from exploratory pilot studies with this system were encouraging, with many early expectations proving true. As with the Java3D environment, gravity was found to be an additional constraint on the task, particularly since the physics engine was much more realistic, as participants found that they could not always make the shape combinations that they had originally conceived – for example, a sphere placed on a curved or slanted surface would roll off if not restrained in some way.

Novice users adapted to the system reasonably quickly, finding it helpful to see their own avatar in order to orientate themselves, and to be able to walk around the shapes as well as change the viewpoint. The 'build' mode also provided guides for rotation, allowing users to rotate on a single axis at once, which some found much easier than the free rotation supported by the other systems. However, while the large number of operations available was thought to be useful, the amount of key combinations and menus that were needed made it slow for first-time users to find the manipulation they required. Nevertheless, on the whole participants found Second Life more enjoyable to use than the previous two environments, possibly since it was a more novel, feature-rich system.

Therefore, in order to be able to explore the differences between mental, physical and virtual synthesis more fully, an experiment was designed to extend the previous study by adding a third within-subjects condition of virtual interaction, taking place in Second Life (Figure 5). For the virtual trials in this experiment, gravity was not activated, and the shapes were able to pass through each other. Participants were recruited who already had some experience with the environment, in order to reduce the novelty effect and the cognitive load caused by learning the controls, but they were still naïve to the experiment. A training phase consisting of some basic manipulation and synthesis tasks was included before the virtual trials, to ensure that all participants were comfortable with the controls. As well as taking measures of the originality and practicality of the resultant designs, participants also completed two post-test questionnaires to assess their perceived level of presence in the virtual world during the task. This was based on Witmer and Singer's Presence Questionnaire, and paired with their Immersive Tendencies Questionnaire [12].

Figure 5: Interacting with shapes in Second Life

Although data is still in the process of being collected from this experiment, some interesting trends already appear to be emerging, particularly from the presence questionnaires. On aspects such as the quality of the visual display, their capabilities within the system or other features of the environment, participants rated their experience highly, which fits with the positive impressions given by the pilot studies. However, on questions relating to how natural the interactions felt, its consistency with the real world or how well they felt they could move or manipulate objects, the virtual trials scored poorly. Despite being non-novice users, participants indicated that the control devices interfered with their abilities to perform the task, and that they could not strongly concentrate on the task instead of the mechanisms used for it. This was true even when they had said that they had no trouble concentrating on tasks or switching attention to a task, and were feeling mentally alert, according to their immersive tendencies questionnaires, and during the training phase it was remarked that the task seemed difficult. However, no noticeable effect on the reported ease or enjoyability of the tasks in comparison to the mental and physical trials has yet been seen, so it may be that the low levels of presence and immersion could be due to the nature of the short tasks, and do not impact on the resultant designs. Since these have not yet been rated by independent judges though, this remains to be seen.

If the complexity of the task does not impede the creativity of the designs produced, then it may be that the features of the virtual environment can be manipulated in order to increase levels of presence within it. Therefore, the next logical step will be to further explore the physical constraints that can be manipulated in virtual environments such as Second Life, and see if the predictions from the exploratory work are found to hold true.

5.CONCLUSIONS

While there are still many unanswered questions that remain, the outlook for virtual reality as a creativity support tool remains positive, particularly if their features can easily be manipulated to better suit the domain and the users. At this time there are still many benefits to using more traditional sketches or physical models in some circumstances, as they still offer strong advantages in terms of convenience and familiarity, but the popularity of Second Life may be an indication of things to come. While skeptics argue that such environments are little more than fads, as systems like this become more familiar and interactions with them become more natural for its users, it may be that they will become more suitable platforms for creativity.

In particular, for a system to be effective, it needs to incorporate the best aspects of both mental and physical environments, which does not necessarily mean it should aim to mimic the physical world perfectly. Second Life may not be the perfect tool for all types of creativity, but it does offer the possibility of prototyping creativity support environments using its physics engine and scripting features, and making it available for testing by a large number of people, so that perhaps the most creative outcome of the system is a novel way for supporting creativity itself. However, the final tests for any support tool will always be how much its users like it, and the quality of the final products; as to this, only time will tell.

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A Model-based Approach to Describing and Reasoning About the Physicality of Interaction

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ABSTRACT
In this paper we consider the use of the ASUR interaction model and notation to capture and reason about some physical aspects of interaction. Using a running example of three alternative techniques for interacting with Google Earth, we present the ASUR model and notation and then show how the three techniques can be modelled. We finish with a discussion of the potential value and limits, for describing the physicality of the interaction, of the resulting models of these three techniques.

Categories and Subject Descriptors
H.5.2 [User Interfaces]: Evaluation methodology, Interaction styles, User-centred design

General Terms
Design, Experimentation, Human Factors, Languages, Theory.

Keywords
Mixed Interactive Systems, Interaction Modelling, Information flow characterisation, Design Analysis, tangible user interfaces, gestural interaction.

1. INTRODUCTION
Compared to a decade ago, user interface design now has to take much more seriously the physical aspects of interaction, due to the emergence of new physical devices and new contexts of use, plus associated enabling technologies (wireless networks, service oriented distributed systems architectures, etc.). This change is particularly evident in the area of Mixed Interactive Systems (MIS), viz. that family of systems consisting of:

- Augmented Reality systems (AR) enhance interaction between the user and his/her real environment, by providing additional computer capabilities or data,
- Augmented Virtuality systems (AV) make use of real objects to enhance the user's interaction with a computer.

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A large number of descriptive models are available to support the design of traditional human-computer interaction, covering different aspects such as the task, the abstract interaction technique, its context of use and the relationship to its implementation in software. However few descriptive models have been produced to describe the specificities of MIS, particularly the physical aspects of interaction. Among them, the TAC paradigm [10] and MCPrd architecture [9] are specific to Tangible User Interfaces. Notations, such as the Mixed Interaction Model [2], have been developed to support the exploration of the design space; MIM offers descriptions of MIS from the point of view of the modalities involved. More recent work links design and implementation by projecting scenarios on to software architecture models [3] or combining Petri Nets and DWARF components [8].

ASUR is an interaction model we have developed to provide designers with support for exploring, comparing and reasoning about the design of MIS systems. ASUR descriptions involve the identification and characterisation of artefacts, resources and relationships between entities involved in the user's interaction with an MIS. In this paper, we first introduce ASUR and then consider its advantages and limits for capturing and reasoning about the physicality of interaction. For both the description of ASUR and the discussion of the handling of physical aspects of interaction, we use as examples and as a case study three mixed interaction techniques we have developed for navigating Google Earth [7].

2. ASUR: SUPPORTING MIXED INTERACTIVE SYSTEM DESIGN

2.1 A simple example: the GE-Steering Board
Google Earth presents satellite pictures of the Earth, mapped on a sphere representing the Earth. The position of the point of view on these pictures can be modified, thus supporting navigation in the four cardinal directions and in terms of altitude. In addition, the orientation of the point of view, initially a birds-eye view perpendicular to the surface of the globe, can also be modified, thus providing the user with a pseudo 3D view on these images. Modifying this position and orientation of the point of view is normally via a mouse or keyboard key. We have developed an alternative interaction technique: the GE-Steering Board. As described in [4], this interaction technique makes use of pattern-based video-tracking of a board that the user holds in front of him/her. This board represents the position of the point of view on the images. When the board is in a specific and predefined cubic area, the "neutral zone", the position of the point of view remains static.

Moving the board above this zone results in moving the point of view in the direction of the top of the currently displayed image; this means that the picture displayed on the screen will be shifted downwards and pictures on top of the displayed pictures will be revealed. Motions of the pictures upwards, to the left or to the right and zoom in and out on the pictures can be obtained similarly. Finally when the board is in the neutral zone, rotating it along an axis perpendicular to the screen results in a rotation of the globe area: this corresponds to a modification of the orientation of the North direction. A rotation of the board in this neutral zone along a horizontal axis, parallel to the screen, results in a modification of the angle between the point of view and the globe surface tangent: this corresponds to a modification of the viewpoint. This technique is illustrated in Figure 1, where one can note the presence of the camera in front of the screen to detect and position the board.

Figure 1: User navigating Google Earth with the GE Steering Board.

2.2 Goals and Principles

ASUR adopts a user-system interaction point of view to describe mixed interactive systems [6]. ASUR is intended to help in reasoning about how to combine physical and digital "worlds" to achieve user-significant results: it supports the identification of objects involved in the interaction, and at the boundaries between the two worlds, and information exchanges among them. The model is helpful in expressing the results of the requirements analysis and addressing the global design phase of a mixed interactive system. In connection with the ASUR model, complementary design tools have been developed and are under development to cover additional aspects of the design of MIS: links with software architecture design, task analysis, focus-group outcomes and simulation. Thus, ASUR now fits into a suite of models and into a development process.

In this paper we will limit ourselves to the use of the ASUR model to the description of one task, viz. Google Earth navigation. Modelling this interactive situation with ASUR then requires identifying the components involved:

- an "S" component depicts the computer system, including computational and storage capabilities and data acquisition and delivery. An S_{object} represents the object of the task, such as the Google Map in our example. S_{info} and S_{tool} represent additional digital elements relevant to the task or used to achieve the task; the current example does not involve any.
- a "U" component refers to the user of the technique.
- "R" components denote physical entities involved in performing the task. An R_{object} designates the real focus of the task: in our case study, the object of the task is digital and no R_{object} are required. An R_{tool} plays the role of intermediary entities required to perform the task, such as the board in our case.
- "A" components refer to adaptors, used to bridge the two worlds. A_{in} components convey data from the physical to the digital world, such as the camera in our case study. A_{out} components carry data from the digital to the physical world such as the video-projector in our example.

Components are not independent and relationships exist among them:

- Data exchanges (arrow) express physical and/or digital information flows and associations among the components. For example, the user can perceive information displayed by the projector ($A_{out} \rightarrow U$).
- Physical proximity (double line) represents a form of physical coupling between two entities: in our example, the user is holding the board.
- Trigger (double line arrow) express that a physical setting must be reached between components A and B so that component C can transfer data to a component D. This will be illustrated in section 3.1.
- Representation (dashed arrow) is used to associate a physical entity with its digital equivalent. This is especially interesting when specifying Tangible User Interfaces.

Figure 2 presents the ASUR modelling of the GE-Steering Board. Note that this graphical representation captures only some features of the model. It would typically be complemented by characterisation of the components and their relationships, such as the physical location where the information carried by the component is perceivable or modifiable, the dimensionality of communicated information, etc. (this is further discussed and illustrated in [6]).

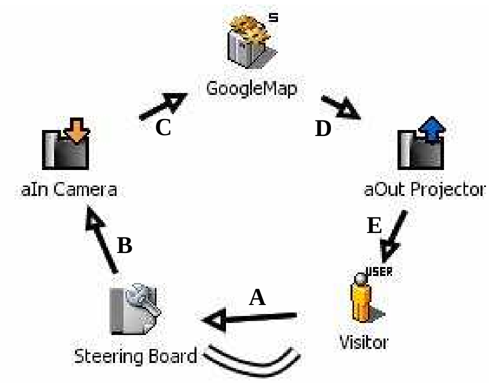

Figure 2: ASUR modelling of the GE-Steering Board.

Although ASUR captures the basic features of an interaction, it does not have the expressive power to say very much about the user's interactive activity or experience. This aspect is presented in the next section.

2.3 Refining the Interaction Description

The basic ASUR model described above can be augmented with additional information. We have refined the basic model to offer a means of characterising the physical aspect of the designed system, to support the description of relationships between a user's expectations, the physical artefacts and system behaviour and to support reasoning about the impact on the user's experience of manipulating the physical artefact. This refinement is presented here as part of the ASUR model, but we believe that such a refinement would also be useful to enrich other existing MIS modelling approaches.

2.3.1 Interaction path definition

We refer to the term "Interaction Path" to depict the activity that is created by a user manipulating or perceiving a physical or digital entity. Along an interaction path, information is thus exchanged and this exchange can be either direct or mediated by other entities and intermediate information exchanges. An interaction path is thus made of:

- Two or more participating entities: users, adaptors, real and system entities (e.g. carriers, contextual, digital …) corresponding to the ASUR components U, A, R and S.
- One or several information channels, corresponding to ASUR relationships.

Channel, participating entities and overall interaction path are further described with a first set of properties: they are briefly introduced and illustrated in the following sections. Further examples and explanations can be found in [5].

2.3.2 Interaction path properties

Channels are first characterized by the **medium:** it is the means by which the information is transmitted. It may be any physical characteristics used to communicate the information (light, vibration, pressure, etc.) or properties of a digital connection. The medium of channel A is the physical configuration of the board & the hands that grasp it. The medium of channels B and E is visual, and channels C and D have a digital medium and are no longer illustrated in the following examples.

Channels are also characterised by the **representation:** it is the coding scheme used to encode information onto the medium. It might be a set of predefined values, a sentence, an image, the position of an artefact, etc. The representation of channel A is a set of specifiable positions of the board. The representation of channel B is a set of specifiable forms of the visual field of the camera (in fact corresponding to the positions of channel A. The representation of channel E is a satellite picture.

Participating entities can be differentiated according to their **method of modification:** it refers to the method of affecting the medium. It might be light modulation, tremor, etc. Concerning channel A, the method of modification is the user's hand/arm/body motion. Channel B is modified as a consequence of the changes to the board via channel A and channel E is the light modulation generated by the video-projector.

Participating entities can also offer different **sensing mechanisms:** the devices or processes used to capture the state or changes of the medium. It may be a camera, microphone, or any sensor. In our case, the sensing mechanism of channel A is not applicable (i.e. the board's position is directly caused by hand manipulations). It is the camera CCD and tracking algorithm for channel B, and the human visual sense for channel E.

Finally, the interaction path is associated with an **Intended User Model** that describes what the user should know about the interaction. It includes the information intended to be communicated (IUM content) and any other required information (IUM context). Channel B, C and D are not entitled to be refined by these properties. The IUM-content of channel A is that a motion of the board corresponds to a motion of the satellite pictures. However the IUM-context includes the knowledge of the existence and position of the neutral zone.

This refinement offers a rich, structured characterisation of the interaction as a mixed phenomenon, with physical and information properties. We further illustrate our approach via two other interaction techniques for navigating Google Earth.

3. TWO OTHER EXAMPLES

3.1 The Google Earth-Stick

The second interaction technique we developed is called the GE-Stick. It consists of a prop, built to look like a joystick, held in the user's hand and a board representing a compass rose (cf. Figure 3). To perform the translations of the satellite pictures, the user has to bring the prop close to one of the four directions represented on the compass rose (top, bottom, right and left). Bringing the prop close to one of the two areas present in the middle of this compass rose and tilting the prop up or down modifies the orientation of the point of view. Finally, there are two buttons on the prop: one can be turned with the thumb and forefinger to modify the orientation of the North axis and the second can be slid up or down to change the zoom. In a specific and predefined position, the "neutral zone", these buttons have no effect. This technique is based on Phidget sensors: the prop includes an RFID reader, a potentiometer and a slider; on the reverse side of the board, RFID tags are fixed to detect the position of the prop on the board.

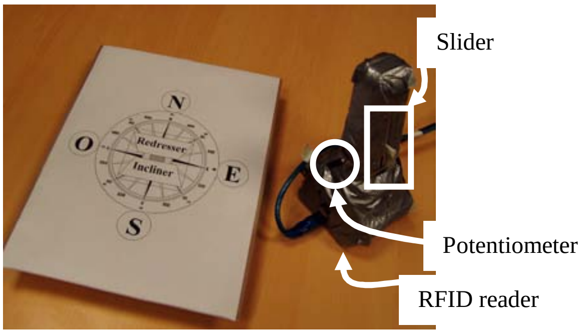

Figure 3: The GE-Stick.

In terms of ASUR, each of the four "cardinal" translations, tilt and pan commands are physically located on the board: seven R_{tool}, with a physical proximity link between them will be used to depict this situation. The prop is a group of three sensors (RFID reader, potentiometer and slider) and is represented in ASUR with a physical proximity link between three adaptors for input. The Google Map is still the object of the task (S_{object}) and the video-projector is the unique Adaptor for output used to perceive the images. In terms of data exchange, the user can act on the RFID reader, slider and potentiometer and each of these adaptors will then transmit the data captured and transformed to the Google Map. Perception of the map by the user is done through the video projector. Finally, ASUR triggers are used here to depict that when the RFID reader comes close to one of the board regions, the region will transmit some data (basically its ID) to the RFID reader.

We do not focus here on the further characterization of the digital channels involved in this model (E1, F1, G1, H1). When analyzing the remaining channels, we identify that different **media** are used in this solution: physical force in channel A1, C1 and D1, radio frequency in channels B1x, and visual in channel I1. The **representation** is the same for channels A1, C1 and D1: a set of predefined sensor positions (6 in A1, 3 in C1 and D1). The representation of each B1x channel is a single value corresponding to the ID of the tag, and channel I1 representation is still a satellite picture. The **method of modification** of channel A1 is a physical motion of the user's hand grasping the prop. It is limited to the thumb motion in channel C1 and the correlated motions of two fingers of the same hand in channel D1. Each B1x can affect its medium via RF modulations and I1 through light modulation generated by the video projector. Finally the **sensing mechanism** is not applicable for A1, an RFID reader for B1x, electronic sensors of some sort for C1 and D1 and the user's visual sense for I1.

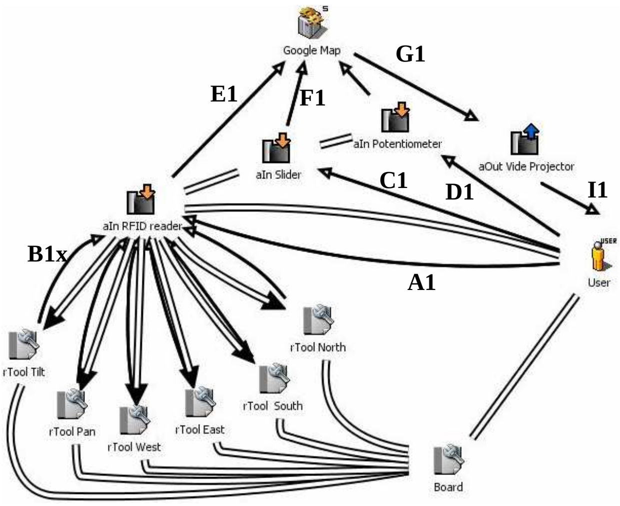

Figure 4: ASUR modelling of the GE-Stick

The **IUM** is not relevant for channels B1x. The IUM-content of channel A is the specification of a direction in which to move the satellite images; the context is that the prop must be close enough to the board, or conversely the prop must be far enough to avoid this link. IUM-content of channel C1 (resp. D1) is that elevating (resp. rotating) the slider (resp. potentiometer), zoom out (resp. rotate) the satellite images and conversely.

3.2 The Google Earth-Shake

This third interaction technique, called the GE-SHAKE, is based on the use of the Shake, a small Bluetooth interaction device that contains a 3-axis accelerometer, gyroscope, 3-axis magnetometer, a vibrotactile actuator, 2 capacitive sensors (used as virtual buttons), and a physical button [12].

In the default mode, tilting the device along the longitudinal axis of the Shake, triggers horizontal translations of the satellite images. Vertical translations of the images are obtained by tilting the Shake along the other axis. Pressing the Shake button toggles the device to rotation mode. Tilting the Shake in this mode, results in a rotation of the images, i.e. rotation of the orientation of the North direction or modification of the orientation of the point of view on the Earth. A press on one of two virtual buttons on the Shake is converted into Zoom In and Zoom Out respectively. In addition, this technique supports vibrotactile feedback through the SHAKE, based on the changing terrain height as a user navigates around Google Earth. Real-time display of selected data streams is also possible, provided by the OpenInterface framework for interaction technique development [10] as shown in figure 5.

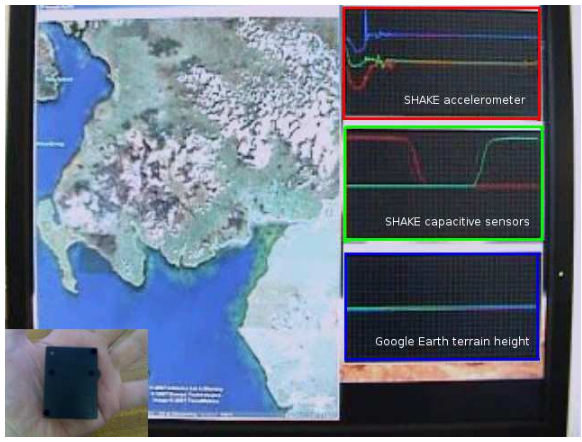

Figure 5: The Shake device, used to navigate Google Earth.

In terms of data exchanges, the Shake-button captures and transforms data before sending them to inform the mode (E2) which will have an influence on the behaviour of the map (H2). All other sensors capture and transform data to directly inform the S_{object} component Map. The map is then rendered on the screen, where the user can perceive it.

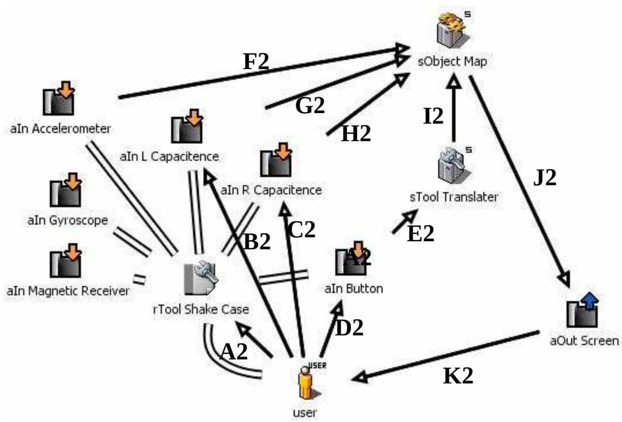

Figure 6: ASUR modelling of the GE-Shake

As in the previous examples, we do not focus here on a further characterisation of the digital channels (F2, G2, H2, I2, J2). Channel K2 has the same properties that channels I1 presented in the previous example. The **medium** of channels A2 and D2 are here again physical forces while it consists of an electric field in channels B2 and C2. The **representation** of channel A2 is the acceleration applied on the case on the different axis. The representation of channels B2, C2 and D2 is a set of two states: pressed or not for B2 and C2, pressed a specifiable amount of time for D2. The **method of modification** is a user's hand gesture for channel A2. In the case of B2 and C2 it is an electric field while D2 relies on a user's thumb pressing the physical button. The **sensing mechanism** is an accelerometer in the case of channel A2, capacitance for channels B2 and C2 and a button mechanism for channel D2. Finally, the **IUM-content** of channel A2 is that moving the Shake will move the Earth. The IUM-context is the current value of the mode. The IUM-content of channels B2 and C2 is that pressing a virtual button will change the altitude. The IUM-context is the association between the button and the command. Concerning channel D2, the IUM-content is the mode selection but once again, the IUM-context is that the user has to know which mode was selected before.

4. DISCUSSION

In this section, we discuss some positive aspects and limits of the current state of our modelling approach.

4.1 Advantages

4.1.1 Highlighting the architecture of the interaction

Building these models can facilitate the communication inside the necessarily multidisciplinary design group involved in the design. Indeed, it provides a graphical support to present an interaction technique and the lightweight notation used to represent these models allows non-experts to quickly understand what it is about. In the context of emerging interaction techniques, it is important to be able to provide a common, well understood communication language.

In addition, this graphical representation highlights the set of components that are involved in the interaction and their relationships. Object domains were initially confined to computer systems and represented in some domain specific format, such as a class diagram. Using ASUR constitutes an initial form of a language allowing the description of domain concepts that are both digital and physical.

Adapters clearly identify the physical-digital frontier: to articulate one world in the other, a designer can first focus on the definition, selection and/or implementation of adequate adapters. To guide this part of the work, the nature of data the adapter has to perceive is expressed in the representation property and the sensing mechanism is also mentioned.

In terms of interaction, this model clearly represents the number of facets that make up the user's interaction. Too many channels directed towards the user may indicate a potential "interaction overload". Looking more precisely at the description of these channels may also reveal incompatibilities between them [6].

4.1.2 Pinpointing differences

ASUR facilitates a comparison of MIS design solutions. For example, the total number of physical entities involved in the system might be an important design aspect in a mobile context: juggling with a number of artefacts while walking or driving might be problematic. For example, the GE-Stick model features a physical representation of each available command while the GE-Shake and the GE-Steering Board models do not. Implementing the GE-Stick will thus ensure that all the features are clearly observable, but may be more difficult to manipulate.

The nature of entities involved in the interaction channel may also have an impact on the future use of the system: the ASUR modelling of the GE-Shake and GE-Stick captures the fact that the user is carrying an artefact to which sensors are attached: using them in a public space might be dangerous if the sensors are fragile; it is even more problematic with the GE-Shake since the Shake is very small and wireless. As opposed to this situation, the GE-Steering Board only places a physical artefact in the user's hand: it might just be a piece of paper, cheap, reproducible.

Similarly, the nature of the data exchanges is refined and useful to distinguish mixed interaction techniques apparently similar. For example, with the GE-Shake, pressing the virtual buttons or the physical button is required to zoom in, out or change the mode: channels B2, C2 and D2 thus have the same representation (a set of states). But the model also express how this "button pressing" is achieved and in this specific case there are two different ways for sensing that the button is pressed: one is based on an electrical properties, the other on an articulatory action. This difference might be of importance especially in situations where users are wearing gloves such as in a medical context.

4.1.3 Adopting different points of view

ASUR includes the notion of interaction groups, viz., a set of entities and channels that together have properties that are relevant to a particular design issue. We can use interaction groups to capture and analyse design alternatives of MIS from different points of view. For example, we can identify entities and channels related to particular kinds of feedback, linking the response of the system to actions of the user. Two forms of this grouping are particularly relevant: semantic feedback (supporting an understanding of the interaction) and articulatory feedback (supporting successful physical performance).

Grouping for coherenc*e* among properties consists of joining together elements with related properties in order to generate a coherent effect, such as visual continuity or forms of interaction consistency. This could be based on participating entities properties or channel properties or combinations of them.

Action and effect grouping refers to a relationship among elements that promotes a user's belief that their actions cause some change in the system. Such a grouping thus applies a constraint on the subset of the elements of the ASUR model that compose the interaction channels. For example, low latency in a feedback group may be needed to promote a belief in a causal link.

More details about these groupings can be found in [5].

4.1.4 Evaluating

Based on this approach, several aspects can be taken into account to lead a predictive evaluation of the designed solution. So far, these considerations have not been assessed by user experiments and so constitute a set of hypotheses that require empirical verification.

First of all, the Intended User Model (IUM) and more specifically its context can be characterised as empty or not. Since it represents a set of beliefs the user must have to perform the interaction, it is anticipated that a non empty IUM-context will require further design cycle to provide the user with additional feedback or help. Alternatively, it can suggest that the user's workload with this technique will not be negligible and that a training period will be required.

Secondly, the IUM-Content depicts the concepts to which the channel is related. It is thus possible to compare the concept with the action to perform. In our example, the main concept is the Google Map displayed on a screen. Carrying a square in the hand and moving it to move the Google Map is probably better in terms of user's experience than the mouse-click.

The third aspect which might be worth considering when leading a predictive evaluation on the basis of our approach is the length of the interaction channels. The effect of the mediators involved in the overall interaction path can have a negative effect if the distance is too long, resulting in feedback delays.

Finally, evaluating such systems can no longer only take into account performance criteria. User's experience must be measured; integration of the physical and digital pieces must be assessed, etc. We believe that a composite evaluation is now required. By decoupling the different aspects of MIS systems (physical vs. digital, adaptor vs. mediating entities, etc.) the ASUR modelling approach facilitates the identification of the dimensions of a composite evaluation and will contribute to the elaboration of a composite evaluation process.

4.2 Limits

The framework presented here still suffers from a lack of precision in some respects. Indeed in our example, a similar arrow is used to describe the fact that the user presses a button (U→Ain, Figure 6) or moves the board (U→R_{tool}, Figure 2). It is thus crucial to be able to complete this description on order to better distinguish these different forms of physical action.

Furthermore, in the case of the GE-Steering Board, several modes could be thought to link the motions of the board to the motion of the Google Map: the current version is modal, an alternative could be absolute i.e. a given position of the board in the room would be associated to a given location on the map. The physical actions would be approximately the same. The description in the current state of our modelling approach would also be the same. But the link between the physical activity and the behaviour of the application would be different and not expressed. The effect of the physical actions on the digital application needs a better description.

The previous aspect is linked with another lack of the current model: so far, all we can say in the model is that the user will move the hand and that a camera for example will be in charge of capturing this motion; the concrete description of the gesture is not yet supported. Nevertheless, a wrist rotation along an axis perpendicular to the arm is very difficult and should only be used for motions of small amplitude. Refining the description of the physical actions is an important future development.

Further improvements are also required to better describe the representation property of the interaction channels. Indeed, the satellite picture can be presented according to different points of view as addressed by an ASUR properties, but can also include 3D graphics, a modified orientation of the north, etc. It is also the case with the three predefined positions of the slider and the potentiometer: the model specifies that they exist but not how to reach them nor their size and relative position.

Similarly, the method of modification is not sufficiently precise. Turning the potentiometer or translating the slider of the board should be better distinguishable at a design level in order to informs the choice of the correct technology: sliding to modifying the altitude and rotating a button to change the axis of the Earth make perfect sense but is not expressed in the current model. In addition, better describing the rotation / translation / motions axis is also important.

Finally, the description so far is only a static description of the mixed interaction setting. Adding the description of the techniques at a dynamic level is needed to better express the link between the physical actions and their digital counterparts.

5. CONCLUSION

In this paper, we have presented our modelling approach to take into consideration significant aspects of the design of interactive systems that merge physical artefacts and actions and digital resources and capabilities. This approach is useful to describe mixed interactive situations, to compare them, to identify differences and to establish a first set of predictive evaluation. Further work is required to covers the different limits identified in the last section.

We do hope to be able to address part of these perspectives during the forthcoming workshop and we are especially interested in investigating possible means of description of the physical motions achieved by users. We believe that it is one of the mainstays of the development of design tools, method and theories of Mixed Interactive Systems. It would definitely help addressing some of the limits identified in this paper and also constitute a solid basis for a framework for exploring the wide possibilities of physical aptitude of users.

The second dimension of the design of MIS we would like to address, is the study of the impact of the description of these physical activity onto the software architecture and implementation. A component-based approach is widely accepted now, but the granularity is still assessed empirically, in an ad hoc manner. Guiding this decomposition on the basis of the physical actions performed by the user could prove to be worthwhile.

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Physical Interaction: The Basis of Human-Computer-Interaction

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ABSTRACT

In this paper, I consider physical interaction with respect to the semiotic human-computer-interaction model by Foley and van Dan, Buxton, and Nielsen and the definition of human interaction by Watzlawick and the Virtuality Continuum by Milgram and Kishino.

The concept of tangible interaction and physicality has seen a shift from its literal meaning in terms of physical objects and their manipulation towards a holistic interaction approach which also incorporates body movements, human behavior and social communication by means of tangible artifacts. But we might have lost some valuable characteristics of tangible interfaces, most importantly leaving the social and verbal communication channels free for the main task (overall problem [11]) and the communication with other people. In this context I especially criticize the use of gestures and emotion sensing in tangible interfaces.

This position paper is intended as a basis for a discussion on the integral aspects of physical interaction and the differentiation to other types of interaction, e.g. verbal or social interaction.

Categories and Subject Descriptors

H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces: Theory and methods.

General Terms

Design, Human Factors, Standardization, Theory.

Keywords

Physical interaction, tangible interfaces, semiotic human-computer-interaction model, Watzlawick, virtuality continuum, hybrid objects.

1. INTRODUCTION

At the 2006 Physicality workshop, a lot of contributions were concerned with the very meaning of physicality in the context of human-computer-interaction. But a consensus could not be found about what physicality is. Does physical interaction rely only on physical objects or does it also involve the human body as “input device”, e.g. by means of gesturing? Is physical interaction the same as tangible interaction, or is it a broader approach to HCI? Is physical interaction primarily mechanical interaction or does it also involve acoustical, visual, thermal, or even electromagnetic interaction? What is the opposite of physical interaction? Is it social interaction, or is it virtuality?

Figure 1. Deterministic interaction with physical objects.

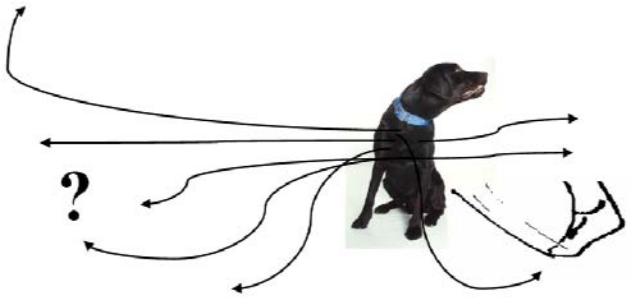

Figure 2. Non-deterministic interaction with intelligent objects.

Every user interface needs a physical part in order to be controllable by the user. Even standard desktop PCs have physical interaction devices, e.g. mouse and keyboard, but certainly nobody would refer to operating a PC as physical interaction.

Because physicality is in every interaction, it is necessary to look whether it is only a bridge between the users mind and the digital model, e.g. in terms of input/output devices. Or if the model is also represented (externalized) physical, if physicality provides extra means for controlling the digital system, and if it

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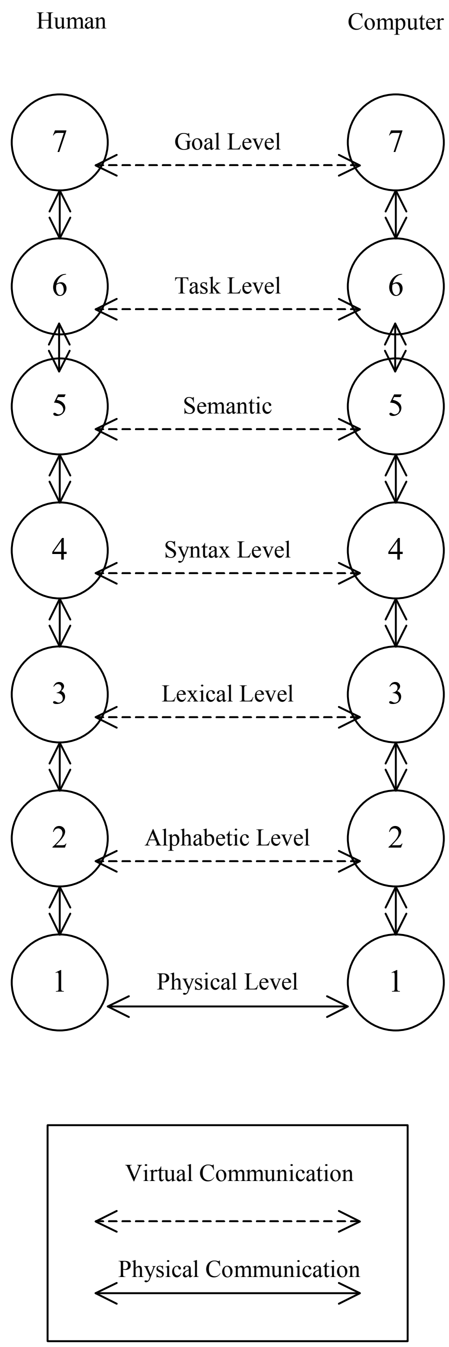

Figure 3. Overview of the protocol model. [8]

meaningfully interweaves system, problem domain and physical controls.

In this paper I try to find references to physical interaction and existing definitions. Firstly I refer to Watzlawick's [14] fundamental considerations on human interaction and communication to differentiate exchange of information and physical energy. Secondly, I take a look at the semiotic interaction model by Foley and van Dan [2], extended by Buxton [1] and Nielsen [8] in order to show that physical interaction is the base of all human-computer-interaction. Thirdly I refer to the Virtuality Continuum (VC) by Milgram and Kishino [7]. Lastly I list some characteristics of physical interaction which make it distinguishable from other forms of interaction and propose steps for increasing physicality in technical systems.

2. STONES AND DOGS

Consider the following example by Paul Watzlawick: "When you are walking and kick a stone, energy will be transferred from the foot to the stone, the stone will start rolling and will finally stop at a place that is completely predetermined by the amount of energy transferred, the shape and weight of the stone, and its surface characteristics.

Now consider the object being kicked is a dog, the dog could jump and bite you. In this case the relation between the kick and the bite would be fundamentally different because the dog would doubtlessly use its own energy resources and not the energy transferred by the foot kick. What is being transferred here is not energy but information. In other words the kick would be a kind of behavior that communicates something to the dog and the dog responds with an appropriate but different kind of behavior." [14, p. 30]

Watzlawick's point is that humans categorize objects of their environment in intelligent (non-deterministic) and deterministic objects in order to allocate attention resources. Those objects, which may respond non-deterministic, which are intelligent and less predictable, require more attention and awareness than primitive non-intelligent objects. The interaction with both types of objects differs fundamentally. In the case of *physically manipulating* passive, deterministic objects (figure 1), the *energy* which is transferred during the interaction is not interpreted or understood by the object. Predicting the responses to manipulations is possible entirely by considering physical laws, which makes it more or less easy. In the case of manipulating or *communicating* with intelligent objects (figure 2), the transferred energy is *interpreted* by the object. Predicting the response of intelligent objects is far more difficult, because their inner state and the basis of their "decisions" is never entirely known, the range of possible responses increases dramatically and can even make it unpredictable.

Various models of human information processing see communication and linguistic processing on higher cognitive levels than sensorimotor actions [6, 10]. Because the sensory equipment of the human is too slow for fast object manipulations in the physical environment, humans simulate the behavior of deterministic objects on an *internal dynamic world model*. This allows fast and efficient *skill-based* performance without conscious attention and control. "The total performance is smooth and integrated, and sense input is not selected or observed – the senses are only directed towards the aspects of the environment needed to update and orient subconsciously the internal map. The man looks rather than sees." [10, p. 101] In contrast, simulating the interaction with non-deterministic objects on an *internal dynamic world model* would in many cases lead to an inefficient strategy of trial and error. Instead it requires *rule-based* behavior which is typically consciously controlled and thus requires more cognitive resources than *skill-based* behavior.

If we take this to human-computer-interaction, we could assume that the more (sub) tasks can be performed entirely physically, the less the cognitive load is. On the other hand, the more tasks require the generation of (linguistic) symbols in an explicit syntax, the higher the cognitive load is.

From studies like the towers of Hanoi experiment by Swendson [12] we know that verbal (command based) interfaces require longer operation times than direct manipulative interfaces, but evoke a deeper understanding of solution. In long-term use, command-based interfaces may be more effective than physical ones.

For example moving an object from A to B is a physical task, it requires and allows no interpretation by the object. Moving an icon on the desktop is a physical metaphor for this (direct manipulation). But issuing a verbal or nonverbal syntactical command, e.g. “move that there” at the command line, or selecting items in the menu tree generates unnecessary linguistic noise for an otherwise entirely nonverbal action.

From this point of view, a single mouse click, which is interpreted by the system as the communication of the user’s mental focus, and also gestures, which require an instance that is able to interpreting the body movements and body signals, is not entirely physical interaction. Both create symbols and follow certain syntax.

From an ethical point of view one could criticize that systems which make intensive use of interaction skills acquired in human-to-human communication, e.g. gestures, body signals, or language, could direct our attention more and more away from humans towards machines and computers. Human communication is a valuable and sensitive skill which should not be used in user interfaces without care and considering alternatives. One could speculate that the more social communication a system requires, the more it acts as a communication partner, the more it is binding the user emotionally.

3. THE PHYSICAL LAYER

In reference to the OSI-model for computer networks [4] and the prior models of Foley and van Dan [2] and Buxton [1], Jacob Nielsen [8] developed a semiotic human-computer-interaction model which comprises of seven levels: *goal level, task level, semantic level, syntax level, lexical level, alphabetic level* and *physical level* (see figure 3). Each layer has its own characteristics with respect to intuitive interaction. The *goal level* describes the goal of the user (e.g. writing a letter), from which the actual task is derived (*task level*, e.g. write some lines of text). The *semantic level* defines the functionality of the system, sequences of user actions and system responses. The *syntax level* defines interaction tokens (words) and how to use them to create semantics. The *lexical level* describes the structure of these tokens (words), made up from elements from the *alphabetic level*. The actual exchange of these tokens occurs at the *physical level* by means of user actions and I/O elements, e.g. displays and input devices. The knowledge required to operate on the interaction layers increases from bottom (physical) to top (task)

The *interaction problem* [11] is defined by the *physical, alphabetical, lexical* and *syntax layer,* whereas the *goal level, task level, semantic level* belong to the *overall problem* [11]. Buxton [1] recommends careful differentiation between the layers and appropriate mappings between them. This helps to prevent ‘apples and oranges’ types of interfaces.

Each application and digital system has its own characteristics with regard to the information or energy exchange between these layers. It is possible to design systems for the same tasks, which differ strongly on the lower levels. For example, compare the written command `delete file` with moving a file icon into the trash. Whereas the first version requires twelve distinct keystrokes which in turn generate two interaction tokens (words), the second requires a mouse click, release and continuous hand/mouse movement which generate three words (select/drag/release, file). This example illustrates that digital systems might be designed towards more or less interaction over the physical layer.

One could say an interface is more physical if more traffic occurs on the physical level and less traffic on the layers above. Whether this increases usability of the whole system is another question.

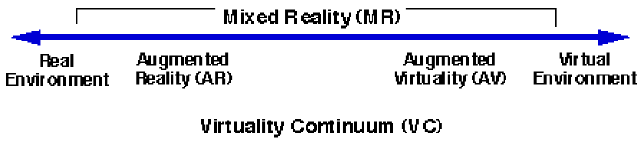

Figure 4. “Virtuality Continuum” by Milgram and Kishino. [7]

4. REAL AND THE VIRTUAL ENVIRONMENTS

The extent to which real (physical) and virtual environments are mixed can be described in terms of the *virtuality continuum* (figure 4, [7]). Environments consisting solely of real objects appear at the left end of the continuum, those consisting solely of virtual objects at the right end. Between these extremes is a *Mixed Reality* with environments with varying ratios of real and virtual elements.

Common instruments to incorporate physical objects in virtual environments (*Augmented Virtuality*) are *Passive Haptic Displays*, or *props.* They provide physical handles to virtual objects, typically matching their shape and appearance.

With respect to this continuum, physical interfaces are those to the left.

Physical objects are persistent. Once you place them anywhere, they will not move until further energy is transmitted. This is a unique quality of physical objects. Virtual objects, displayed on screens which you can turn on and off, are much less persistent and thus require to allocate more attention resources than for physical objects.

5. CHARACTERISTICS OF PHYSICAL INTERACTION

The characteristics of physical interaction can be summarized as follows. An interface is more physical:

- The higher the bandwidth is on the physical layer and the lower the bandwidth on the higher layers of the interaction problems.

- The fewer is the number of linguistic symbols used in the interface, in terms of labels, buttons, and spoken dialogues.
- The higher the ratio is between physical and virtual objects in the interface in terms of numbers of objects and their importance.

From this some instructions can be derived for increasing physicality in human-computer-interfaces:

- Provide physical handles for as many virtual objects and functions as possible, but
- Avoid physical clutter [13] which may arise by the extensive use of physical objects (e.g. by means of flexible hybrid objects [5])
- Allow the construction of complex interaction tokens by manipulating physical objects (e. g. moving and arranging objects)
- Limit the use of linguistic symbols in the interface (e.g. written or spoken language)
- Use physical constraints to limit the degrees of freedom of the interaction and to communicate the application logic [13]
- Use the user's concepts of the physical world (image schemas) and their metaphorical extensions for the design of the interface (e.g. containers, in-out, more-less) [3]

Following Norman's beliefs on the return of mechanical controls [9], I personally think that physicality has the potential to ease human-computer-interaction dramatically, provide deeper skill-based access to digital models and functions and thus broaden the effect of human work and creativity. I think we are only at the beginning of a development in which hybrid physical/virtual objects [5] will play a more important role in everyday's work and life than personal computers.

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Sketches, Drawings, Diagrams, Physical Models, Prototypes, and Gesture as Representational Forms

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ABSTRACT

What is the role of physicality when interacting with different representations? Representational forms differ in type of representation (e.g. sketch, diagram, 3D model) and in the way they are materialized. These variations influence the properties of a representation and suggest or enable different usages, interaction styles and variations in meaning, even if they represent the same object, idea or concept. Here we present a literature survey summarizing knowledge about the properties of representational forms such as sketches, drawings, diagrams, physical models, and also of gesture.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: Models and Principles, - *human factors*.

General Terms

Design, Human Factors, Theory.

Keywords

Representational form, sketches, diagrams, models, prototyping, gesture.

1. INTRODUCTION

Representations are made to represent something else. Therefore representations are never identical with the represented, always underspecified, designed with a specific purpose in mind, and usually connected with conventialised practices [31]. We have to discern in particular between sketches, drawings, diagrams, different kinds of prototypes, and graspable models and also gesture, which can be interpreted as a perishable type of representation.

In computing we are used primarily to sketches, engineering drawings, and diagrams. But in other disciplines a much wider range of representations is employed, often in parallel, not competing, but complementing each other. For example, within architectural practice relevant representational forms encompass conceptual models (being abstract and lightweight), plans, sketches, diagrams, and models of different sizes and materials [6]. In design, art, and architecture often a multitude of different media are created in parallel, looked at simultaneously, put next to each other, and connected with each other. This is because different techniques of representation and different media allow the exploration of different aspects of a design idea. Furthermore often they are suited for different phases of the design process. Representations direct the focus of discussions and thereby can take the role of an implicit vehicle of facilitation. This means that the choice of representation can influence the discussion focus – representations are not neutral, but need to be chosen carefully in accordance to aims.

Different representational forms of one and the same design, such as schematic construction drawings, sketches, and physical models, can be interpreted as variations or 'modulations' [10] which each have different characteristics and suggest or enable different ways of usages, interaction styles and variations in meaning.[1] Different media or modulations differ in the type of feedback they provide to interaction, and the ease of conducting certain actions on or with them. Furthermore the type of representation chosen interacts with its medium (being on paper, on-screen, physically embodied etc.). Thus, for example, even what in terms of the definition of 'a sketch' might be the same representation type, is modulated with the choice of a different medium of embodiment.

This paper starts an exploration of the differences between representational forms. This refers mostly to physical instantiations of these representations, leaving out of consideration e.g. digital sketches. In physical representational forms the representation is embodied in its medium [32], and thereby representation, storage medium, and display are always connected with each other. With digital representational forms, this connection is broken – the representation 'floats' on the display, which turns into a physical object in its own right. This influences both the affordances of interaction and the feedback received by the user. While there have been a range of studies comparing e.g. digital with physical sketches [2, 11], there seems to be much less discussion about the properties of the representations themselves and the differences of the way they are materialized, let alone a systematic comparison of representational forms. Here, I am summarizing results of a literature survey on this question, which was conducted as part of my PhD thesis [12].

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[1] Glock [10] borrows the term 'modulation' (or 'key': the metaphor of musical modulation of a melody) from Goffman, referring to the transformation of an object that attains a different understanding by being reframed.

2. TYPES OF REPRESENTATIONS

2.1 Visual Graphic Representations

2.1.1 Sketches and Drawings

Purcell and Gero [25] summarize design research knowledge on the function of drawings. They conclude that drawings and sketches usually embody abstract design ideas and allow for imprecision regarding material attributes of the designed object. This density, ambivalence and unstructuredness of drawings is important in early design phases. Studies have shown that words predominantly activate conceptual and abstract knowledge, while images activate perceptual knowledge, for example about materials, forms, and analogue cases. Purcell and Gero [25] suspect that the work in design teams is successful because the integration of sketching and discussion in teams automatically activates both types of knowledge.

Drawings and sketches enable us to put different representational levels next to each other, to mix them and connect them [7]. Textual annotations can be added, alternatives sketched in, highlighting and marks added, and details inserted. These different elements of a drawing are typically connected with lines, which for example graphically denote which part of a larger drawing is detailed in a corner. This next-to-each-other is a source of ambiguity, as the different levels do not need to be coherent and complete. Some lines may look more definite and others are clearly tentative and vague. To some extent these things can be done on engineering drawings, despite of formal rules for draughtsmen [11]. As long as the drawing is not analysed by software, it is up to the human reader to tweak apart informal and formal elements and to interpret their relation.

Ambiguity really seems to be one of the most important properties of sketches. Allowing for imprecision is essential to the process of idea generation, as studies into effects of the introduction of CAD in construction planning have shown. CAD systems force the designer to start from concrete, exactly specified details, building up larger elements from core elements. Sketching on the other hand can start from a holistic picture and slowly become more precise [2, 11]. CAD, because it is based on numeric data, requires exact data input. If one wants to be ambiguous while sketching digitally, one needs to make this explicit - but explicitly invoking a different mode might interrupt the process of sketching…

2.1.2 Diagrams

Diagrams are a specific type of drawing, since their interpretation and manipulation is heavily conventualized and formalized. They offer a rather small scope of action and little ambiguity, but similar to sketches, take their powers from human perceptual intelligence and situated seeing [13, 14, 28]. Just as sketches and drawings, diagrams are selective representations. The ability to see spatial representations not just sequentially, but simultaneously, allows for perceptual inferences, which would require a whole series of inferences if employing a language-based representation. This holds in particular for transitive, symmetrical or asymmetrical relations [33]. Yet negations or contradictions are notoriously difficult to represent in a diagram.

So-called 'secondary notation' [24] supports legibility of diagrams. This concerns for example the layout and spatial arrangement of elements, which in addition to the logical connections provide information by guiding the order or flow of reading and emphasizing structure. For example diagrams of circuits will often have the input on the top left and the logical flow will continue to the bottom right, analogue to normal text flow. With pneumatic circuits this is partly reversed, and usual practice has the elements receiving input (from a user pushing a

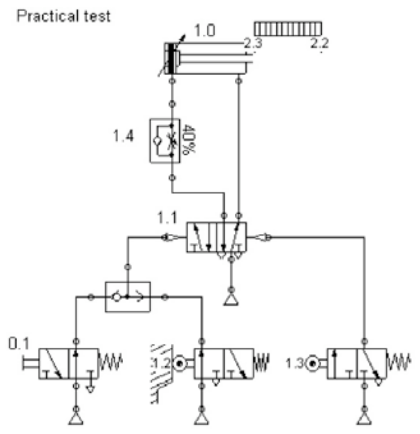

Figure 1. Diagram of a pneumatic circuit

button or an object triggering a sensor) on the bottom and the 'output' elements (pistons) in the top row (see Figure 1).

Reading of diagrams needs to be learned and trained, and requires a lot of expertise due to its condensed and abstract nature. Direct perception (without explicit translation effort, employing perceptual inference) of spatial representations such as diagrams requires experience and confidence with the application area, the type of representation and reading conventions.

2.1.3 Graphic representations on paper and on screen

Moving graphic representations onto computers change the medium of display. This also changes the way we can interact with them and how we can perceive them. Besides of screen resolution, which may cause eyestrain, the size of the monitor is a key variable. Studies of draughtsmen in architecture who were shifting from drawing on paper to CAD emphasize the loss of overview and context [2]. The professionals complained about loosing context of where the current section they were working on is located on the overall plan and about loosing sense of scale. When working on the big printouts which used to be put onto slanted tables or hung onto walls, they could physically view the entire plan from a distance and zoom in bodily while keeping a peripheral overview. Even when rolling the plan up or folding it, it seemed easier to keep aware of which piece of the plan they were currently looking at.

2.2 Material Models

Material models come in a variety of types that differ in how accurately they represent the thing modeled, and how exact or open they are to interpretation. Models can look rather sketchy or 'ready for production'. This is reflected in the literature on prototyping, which differentiates a wide range of different types of prototypes (mock-ups, functional or paper prototypes, low-fi and hi-fi …). Much of this literature originates from research about design practice in engineering from the past 10 years. Design research only rather recently started to discuss the role of physical prototypes – but we must remember that the acknowledgment of the role of sketching was comparatively recent [25]. For a long time sketching and diagrammatic thinking were thought to be 'just a practical proficiency' and not an essential part of the thinking process in design.

Different types of prototypes possess different degrees of openness or ambiguity [26]. 'Impromptu prototypes' (objects being at hand, that get employed ad-hoc) are spontaneously used as a helper for explaining or testing an idea, and are rather short-lived. They are "conduits for design conversation, not fixtures" and thus serve as a direction-guiding medium of

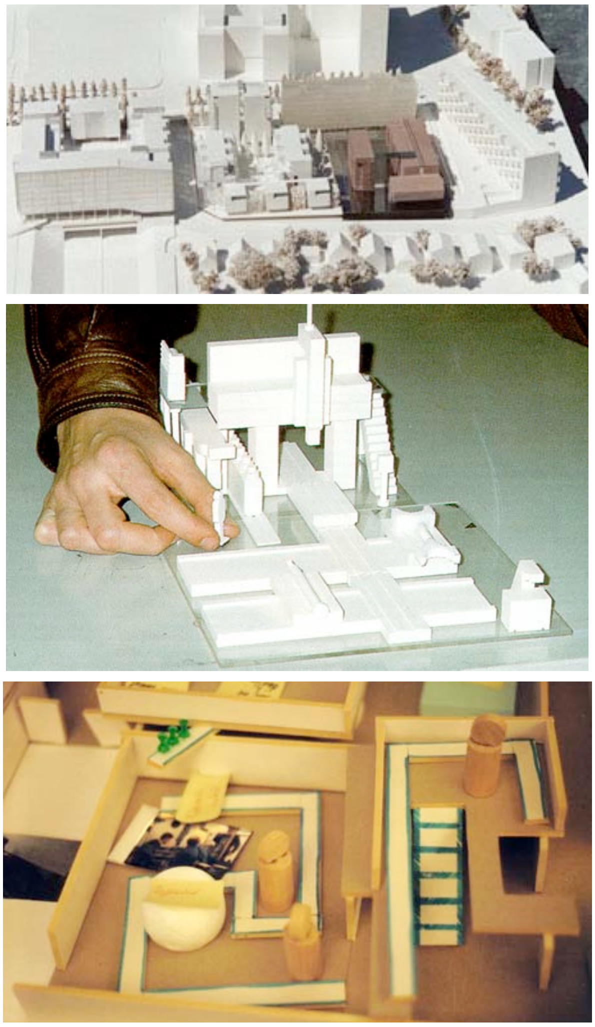

Figure 2. (top) Architectural model. (middle) Model used for production planning [29]. (bottom) Cardboard model used during participatory design sessions to envision new work practices in a plant.

conversation. In a similar way we tend to employ anything at hand for building “thinking props” when trying to understand and reconstruct processes and mechanical or logical principles. Seen out of context, these tinkered objects are meaningless for an outsider. “Embodiment prototypes” on the other hand already contain central aspects of the final structure. They are semi-permanent and to a large degree resolve ambiguity. They thus offer an (almost complete) plan for the production of the final product.

Creating models and prototypes forces us to differentiate, correct and control our ideas successively, for example in construction design in mechanical engineering [27]. In particular models embody abstract ideas, allowing for feedback from the model and thereby potentially uncovering errors in the designers’ mental models – ideas can be implemented and instantaneously tested [20]. While all kinds of external representations allow for feedback and dialogue with the representation (see Schön’s [30]’s discussion of sketching as a ‘conversation with the material’), material models provide feedback of a specific kind, implicitly invoking physical laws. Specific types of models (such as Fischertechnik ©) lend themselves to simulation or test of behavior (restricted to the elements of the construction set) [7]. Yet if these pose constraints that are irrelevant within the application domain, this can restrict the action space too much.

While CAD for other reasons (like supporting distributed design, digitizing designs, and thereby shortening the road to production) has taken over in many design areas, it has also resulted in increased effort in rapid prototyping technologies. These are expected to re-enable a direct assessment of designs (e.g. being able to assess a form by taking the object in one’s hand or walking around it) and enabling distributed design teams to talk about the same thing [9].

Architects throughout the design process often create a variety of models of different sizes and materials [6]. Usually several physical models are created, where one for example explores the effects of chosen materials, another depicts structural decisions, and the next model serves to experiment with sources of lighting. Specific attention is put on the materials used. The search for ‘the right material’ often takes a long time and, in doing so, inspires new ideas. In making use of various materials, models can be extremely rich and inspiring [6, 16].

2.2.1 Spatial or enactive knowledge

Another aspect of physical models is that they help to activate spatial and kinaesthetic knowledge, being ‘enactive’ representations [11]. For this reason, physical mock-ups, low-tech prototypes and design games with cardboard models are widely used in participatory design [3, 18, 21, 23, 29]. They can be employed in performative ideation and role play sessions, taking the role of props that ease staging ideas, or triggering ideas in bodystorming [16, 18, 34, 23]. Real artifacts or mock-ups that work as ‘things-to think with’ can also support reflective conversations [3. 23].

Models in particular allow us to discern spatial relationships – firstly they model spatial relations (without transforming modalities, because space is represented as space), and secondly we can move around the model, take different perspectives, turn the model around, move and manipulate it. Models thereby allow us a rather intuitive understanding of geometrical and spatial relations. For this reason physical models are still popular e.g. in archaeology, reconstructing how by-gone buildings might have looked like.

2.2.2 Ambiguity and the restriction of action space

Yet material models in some aspects restrict the space of action more than sketches (even if these models are sketchy and open-ended). They materially embody domain specific constraints through physical affordances, and symbolically through cultural and perceived affordances, suggesting particular actions [22]. Models enforce greater precision when positioning objects than a sketch would do. A brick can be put on one spot only, and one needs to decide for one – even if exemplary and rough – spatial relation, there is no way to just ‘allude’ to and sketch it.

Not being able to be ambiguous in terms of positioning makes it difficult to represent alternative solutions in parallel, but at the same time can provide more clarity (sketches often contain many ‘nonvalid’ and outdated objects). It can force people to make concrete suggestions – a valuable property for negotiations. Furthermore it is easier to rearrange objects when they can be grasped (often as a whole group) and moved, instead of needing to be redrawn (digital sketches in this regard do better than physical sketches, allowing for copy and paste manipulations).

With physical models one needs much more effort than with a sketch or a drawing to do anything similar to putting different representational levels next to each other, mix and connect them [7], e.g. having a detail view next to an overview. As sketching of evocative connecting lines is very difficult to achieve within a physical 3-D model, and detail views and alternatives are difficult to represent. Some work has been done

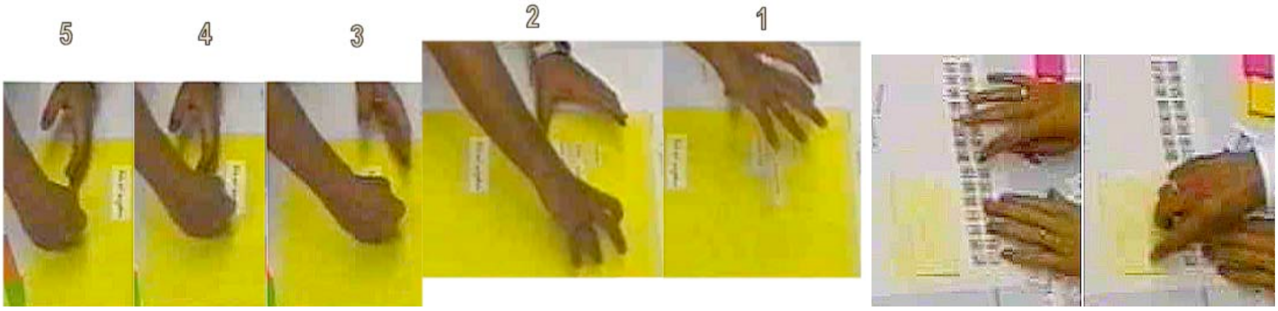

Figure 3. Gestural explanations of spatial relations and gestural mimicking (both taking reference to a visual representation)

on physical annotation of models. Annotations can be written on notes and laid into the model [23] or be represented with pins in the model, which are electronically tagged and connected with digital text or recordings [6].

Material objects, in restricting the action space, also help to focus on the remaining options. They present a basic vocabulary, which suggests starting points and topics for discussion. Taking a prototype into a meeting that went in circles, would shift the focus “from separate mental models (…) to the external material model that all can see, touch and manipulate” [1]. The model confronts with reality – it can’t be discussed away and doesn’t’ disappear, even if temporarily forgotten about.

2.2.3 *Spatial Configurability*

Media with the property of spatial configurability [8, 15] ease reversal of simple actions and quick successive testing of variations. Most studies seem to point out that physical representations, in particular if they consist of a set of elements that can be moved about, provide advantages for rapid and intuitive interaction because of their configurability. With a paper prototype [21] the paper slips, and with a magnetic whiteboard [37] the magnetic slips for medical staff and patients in a ward can be moved around to quickly test alternative solution ideas or to simulate a process. Sketches or things written onto a fixed medium need to be redrawn, slashed through, and annotated with pointers.

Spatial configurability also is used to visually highlight things. Paper cards for not yet assigned work tasks are pinned slanted sideways to the edge of a project planning board [36]. Magnets on the ward planning board that represent soon finished surgeries are attached diagonally [37]. Here the standard structure, which is almost like a diagrammatic language, and the (allowed) deviations together result in an easy legible picture.

If we think of spatial configurability as a typical property of physical models, it becomes clear that a method like paper prototyping stands halfway between graphic representations and physical models. The manipulable elements carry graphic representations on them, and there is no real three-dimensionality. Most of the examples just mentioned in fact are only ‘2 ½ D’ – they are more than two-dimensional because we can lift elements off the surface and place them over each other while still being able to access what’s underneath, but they are nevertheless flat. The two lower pictures of physical models in figure 2, both from participatory planning in industrial domains, do exploit three-dimensionality, indicating height of objects, distance, and including human figurines (thereby providing a reference to bodily experience of the place discussed about).

2.3 Gesture

Gestures also can be interpreted as a possible representational form and externalisation – the gesture creates a transient and fading image for perception. Hutchins describes the effect of drawing lines with the finger on the navigation chart: “The memory of the trajectory of the fingers decays with time, but it seems to endure long enough that several of these can be superimposed on one another and on the perceptual experience of the chart” [13, pp. 156].

Gestures can imitate a series of events, mimic an object, demonstrate spatial or temporal relations, measure something, point to objects, and organize conversation. Tang [35] found that gestures made up about 35% of actions during a design session. Gestures in the design discussions of construction engineers often serve to represent a construction idea or to visualize the interplay of parts, acting as a ‘substitute for a sketch’ [10; cp. 19].

Bühler [4] already pointed out that motoric processes are an important element of imagination, even for adults. For children the manipulation of the play object creates the required inner impulses to continue with play and ease identification. Adults tend to need only the movement impulses or inner imaginations (like mental rotation), but if our imagination does not suffice, we often use our bodies to simulate the goal object.

Figure 3 (from [12]) shows two examples of gesture used in design discussions from paper prototyping the interface for a ticket vending machine. On the left (images read from right to left as numbered) the gesture indicates areas of the screen where specific content could be organized. The gestures in the right image-set mimic interaction with the interface (the user types on a virtual keyboard on a touch screen and sees the typed text in the small window above it). These video stills also demonstrate how gesture is often tied to the physical surrounding, using it as a frame of reference and integrating elements of the environment into the expression.

What results is a multi-modal, multi-layered expression (or representation). Hutchins and Palen [14, p.38-39] argue: “space, gesture, and speech are all combined in the construction of complex multilayered representations in which no single layer is complete or coherent by itself. (…) Does gesture support speech? Clearly it does, but no more so than speech supports gesture. [...We saw] the creation of a complex representational object that is composed through the superimposition of several kinds of structure in the visual and auditory sense modalities. Granting primacy to any one of the layers of the object destroys the whole.”

Gesture even seems to share characteristics with language. It sometimes precedes linguistic naming, and often is imitated and shared by conversation partners, turning into a ‘standard phrase’. Especially mimetic and descriptive gestures tend to be repeated, appropriated, and adapted by conversation partners [17], e.g. mimicking the form of a building can result in the gesture later-on being used as a stand-in for the building. Mimetic gestures often precede the linguistic term and may help to activate tacit knowledge, easing mental access for the correct word (‘gestural foreshadowing’). Koschmann and LeBaron [17, p.271] therefore say that gestures are ‘material signs’ which embody the knowledge being articulated.

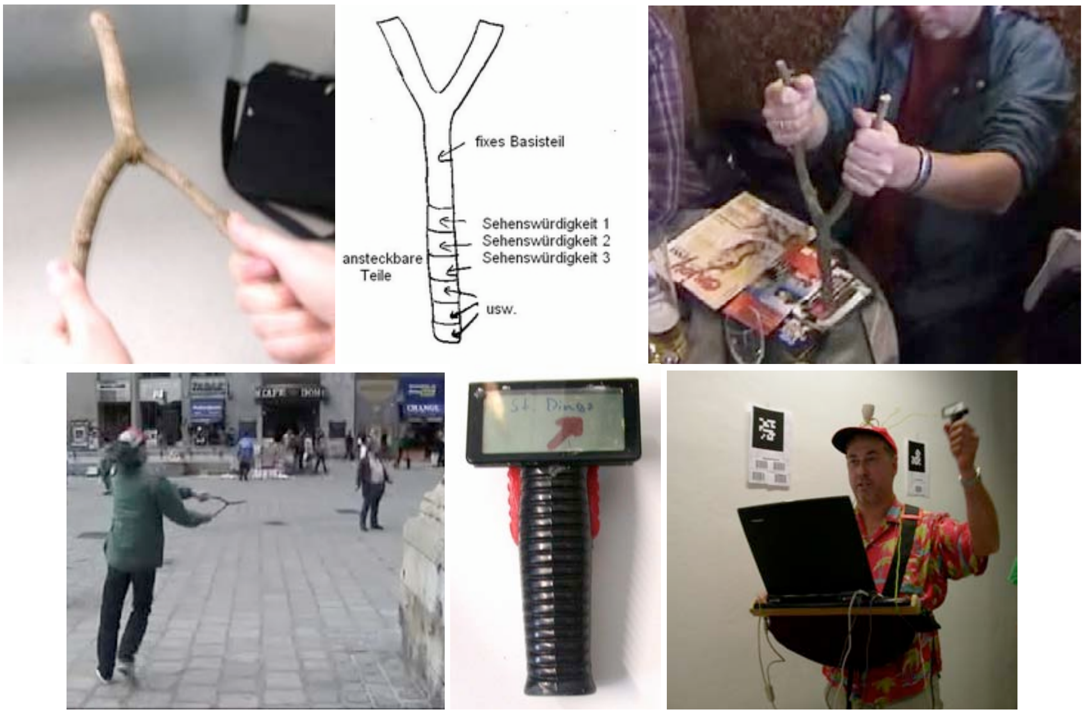

Figure 4. Evolution of a material model / prototype / mock-up in a student design exercise.

Students had the idea of a mobile tour guide that 'nudges' tourists to sites they are interested in, while allowing them to stroll through the city serendipitously. The initial guiding idea of functionality and form factor was inspired by a 'water divining rod' (top left). The envisioned functionality was sketched, extending the rod with plug-on parts (top middle). Then students used a rod when creating a video prototype, which also had them in-situ emulating use of the device (reading codes for interesting sights, and being nudged to a particular object of interest). This experience led to more insight into the usability and social appropriateness of the form factor, simplifying the form factor to a simple handheld device which would vibrate and hold a display at the top (bottom middle shows a mock-up). The functional prototype has no resemblance to the envisioned device, but provides a simulation of interacting with such a device, allowing initial insight into the user experience of the interaction process.

In comparison with sketches or fixed models gestures have the advantage of being able to represent movements and time-based processes. Spatial and time-based imagination, enactive and kinaesthetic knowledge do not need to be translated into a medium that is not time-based and spatial. The transience of gesture here turns into an advantage, and one can quickly represent a series of alternatives, without creating 'representational garbage'. Yet it is difficult to represent larger relationships with gestures. The sequential nature of gesture, its 'linearity' which it shares with spoken language, allows us to demonstrate and perceive only one part of a bigger relation at once. Persistent graphic objects, in contrast, "can be visually taken in simultaneously, at a glance (…) modalities of interaction that are fundamentally different from the sequential order of speech and action" [31, p. 271].

3. CONCLUSION

This paper has attempted to collect and summarize some of the current knowledge about the properties of different representational forms. The focus has been in particular on understanding the different properties of physical models or prototypes in comparison to graphical representations such as sketches. This discussion is far from complete, and far from satisfying, as I am aware.

A particularly intriguing issue in summarizing evidence from literature has been the degree of ambiguity that different media afford in comparison to the freedom of action they allow for. Other issues have been the kinds of interactions a particular representation allows for, as well as the types of knowledge it activates or allows to express (cp. Figure 4). With a physical model it is more difficult to make annotations than on a sketch. The gesture of showing by demonstration can orient itself much closer to a physical model, while it needs to divert from the sketch where the planar nature and invariance of the sketch does not support the demonstration.

Something that is fundamentally changed by transferring sketches to digital form is the medium, changing the ways we can interact with it. This is essentially true for all representations. Any representation that is affixed to a sheet of paper can be moved around, handed over physically, creating visible reminders. Gestural references to physically embodied representations are easy to decipher, because the spatial relation is clear – unlike the text that scrolls off the screen.

Interpreting gesture as a kind of representation may first seem surprising, but in discussing the materiality of representation we should also be aware of the physicality of the people that create or perceive representations – in performative activity the body turns into a representational medium. Gesture has long been neglected as something that merely adds to and accentuates speech. Thus emphasizing its unique qualities of being able to show temporal things and its interrelation with the external representations it might engage with and refer to, highlights aspects that we might be missing in other representational forms.

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Physicality and Digitality: Parallelisms at a Material Level

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ABSTRACT

What is the striking difference between doing in a purely non-digital world and doing through, on, at and with digitally augmented physical entities? The work described in this article sets out to explore the nature of the physical and digital world at a *material level*. To contemplate the two worlds in direct parallel and to understand and discuss the physical world on an abstract level, the philosophical work of Peter Unger is introduced. This framework is then used to understand the digital world at a similar abstract level. In the wake of that, two main concepts are being coined, namely *Physicality* and *Digitality*. Each of which captures the essence of the two worlds, including their individual defining *basic qualities*. Through an increase in understanding of the two terms we hope to inform designers and researchers about the intermixture of the two worlds.

Keywords

Physicality, digitality, parallelism, materiality, spatiality, locality, framework, embodiment.

1. INTRODUCTION

Being in the business of information processing, one never seems to stop being amazed at the sheer amount of data presented to us by our surrounding world every living second. The amazement seems only surpassed by our ability, as human beings, to process, filter and utilize this data in all aspects of navigating the world - in using, in traveling, in experimenting, in learning, in living, or to put it short: in *doing*. The intriguing thing about humans *doing* in an entirely physical context is that we, to some extent seem to, just *do*. It seems that we go about our daily business with such a profound confidence in the intrinsic properties of the world, that the complexities of *doing* are subconsciously disregarded in favour of the assumption that one simply *can do*. Alas, the aforementioned ability to *do* for some reason falls short when applying it to most non-trivial, multi functional digital entities surrounding us. Instead of trust in the ability to simply *do*, there is, at a very fundamental level, a somehow foreign feeling of distance, even alienation. The confidence with which we normally navigate the world disappears, making way for uneasiness and insecurity. Consequently, ones demeanor is best described as reluctant.

At first sight, we should by now have had every chance of getting acquainted with the computer and familiarized ourselves with the new and enhanced environment. It has, though, been a subject to prolonged discussion and deliberation [5, 6, 3, 9], why we repeatedly struggle to adequately comprehend the computer and its associated new domain, or more precise, the digital world which has been brought to life through its existence. What we deem necessary to be adequately comprehended is the fundamental nature, to some extent the possibilities and limitations and lastly the special characteristics of this reasonable new digital world.

The question is, as of now, how come there is such a striking difference between *doing* in a non-digital world and *doing* through, with, on, at, etc. most of these digitally augmented entities? Thus, the overall subject driving the development of our work, is a question about difference. More specifically, in accepting that such differences exist, the obvious follow-up questions are; what *are* these differences and what do we do about them? We shall, coin two main concepts, *Physicality* and *Digitality*, capturing the essence of the two worlds, that is, the physical and digital, respectively. Our work takes as its starting point, a focus on what it is in the physical world that enable us to do as we do. It is based on the claim that there exists a set of basic qualities inherent and ubiquitous to the physical world. These qualities are at the core of what we understand as the essence of the concrete physical world, here designated Physicality. Further, it is through the unconscious knowledge of and trust in these qualities, we as humans are able to *do* in the physical world. Digitality, then, would similarly capture the true essence of the purely abstract digital world. The construction of the digital world is based on the ways in which we have formulated our mathematical universe and on the possibility to embody and more easily operate on this very same abstract world through the use of computers. We claim that this abstract digital world must too hold a set of basic qualities inherent and ubiquitous to it. We will clarify both terms in greater detail after the presentation of our theoretical foundation, see section 3. The choice of a purely abstract level, at which we contemplate the digital world, should be kept in mind throughout the discussions to come. Contemplating these two worlds separately, that is, Physicality and Digitality, is meant to enable designers and researchers to discuss their differences at a much more fundamental level than previously possible. Entailing them to better understand the intermixture of two and the consequences it has. Our overall model is depicted in Figure 1. To push further in our endeavours, we shall at this point present a conceptually sound

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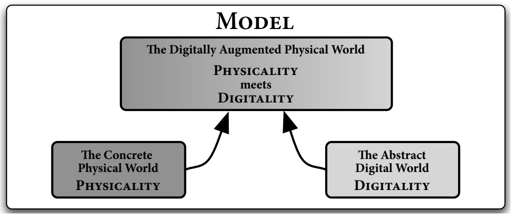

Figure 1: We *separately* contemplate the concrete physical world and the purely abstract digital world to better understand the two's intermixture.

base, from which to build, at an appropriate level, a common understanding of our main concern, namely the nature of the physical.

2. THEORETICAL FOUNDATIONS

The intrinsic nature of the physical world is quite an illusive thing to investigate. We are, as fallible beings, bound to this one world and are limited to it with respects to both individual knowledge and experience. Hence, there are probably as many perceptions of it as there are people perceiving, each perception as incomplete and possibly partially erroneous as the next one. Though this may seem a stark and unnerving realization, it is really outshone by how little we pay heed to it in our lives.

The physical world is the main context of our existence, the one we are all born into. We live and learn in it, around it and about each other through it. Whatever we choose at any given point in time to do, we do it through interaction with the physical surrounding us. One could say that we are truly conversant in the *language of physical.* That it is the primary mode of expression of our body, the one we use in interacting with the surrounding world. It is through this language we interrogate the world [8], we talk to it; it talks back. In relation to this, we define *Conversancy* as being deeply familiar and highly skilled with, what we above have called, *the language of the physical.* As such, the subject of Conversancy is closely related to the term *familiarity* as coined by Paul Dourish in his work on Embodied Interaction [1]. In relation to the three levels of design defined by Norman [7] the concept of Conversancy pertains primarily to the visceral and behavioural level. It is an in-depth knowledge about sending and interpreting signals to and from the physical. We don't know about each and every thing we may encounter during a journey through the physical world. We do know, through our Conversancy, though, that we will be able to sense and interpret it, in a way that is sufficient for us to make basic meaning of it. So, what is it in the intrinsic nature of the world, that supports us in this Conversancy?

2.1 The Scientiphical Metaphysic

With background in the above considerations, we present here some of the work of contemporary philosopher Peter Unger. In his magnum opus, *All The Power In The World* [13] as well as in a preceeding journal paper [12], Unger continues the long line of philosophers contemplating the nature of physical reality. Although the overall purpose of his exploration, which is to develop what he denotes a *Humanly Realistic Philosophy*, is in its entirety greatly beyond the scope of this work, he is preoccupied with questions so very central to also our enterprise:

> So, we should wonder: To what extent, if any at all, do we have a philosophically adequate conception of physical reality? However any of our conceptions may have originated, do we have a conception well enough related to the human mind for it to ground a metaphysic in terms of which physical reality can be understood, at all well, by us very limited human thinkers? [13, p. 5]

In the quest for further knowledge on these fundamental issues, Unger sets out by sketching the metaphysic dominating contemporary academic philosophy [13, p. 6]. This metaphysic, denoted by Unger as *The Scientiphical Metaphysic*, a combination of the words scientific and philosophical, giving way to the term *scientiphicalism*, is a philosophy aligning with the relative insight gained from classical physics the previous centuries.

Unger starts out by making the claim, that the world consists of physical stuff, or *matter.* This matter, which is independent of minds (it need not be sensed to exist), is differently distributed in space at different times. The distribution at any given time is determined by the earlier distributions proceeding in line with the world's basic natural laws. These are all physical laws. He continues, that some of the world's matter is, at certain times, configured so as to compose various complex physical structures and systems, some of which are (or are serving to constitute) living entities. Among these living material entities, there are those that are thinking, feeling, experiencing physical entities. Unger further holds, that he is such a living, thinking entity, and so are you. Turning from this to hierarchy, Unger gives an inductive definition on the construction of the world. Every concrete entity in our world is a wholly physical entity. Either it is a basic physical thing or it is a physical *complex.* Such complexes are themselves wholly constituted of things that are all wholly physical entities, ultimately being wholly composed of basic physical constituents. Accordingly, the scientiphical metaphysic Unger describes, makes the claim that all the powers, or the propensities, of any physical thing, are physically derivative dispositions. Probabilistic or not, these dispositions all physically derive fully from the simpler properties of the complex's simpler physical constituents, their powers and their relations. Unger claims, that this holds as well for entities, which are not so clearly physical, such as himself and you. The consequence is, as described, that the powers of any physical complex, including ourselves, will physically derive from the naturally basic properties and basic relations of the complex's basic physical constituents. Unger divides these naturally basic properties into three categories: *Spatiotemporals*, *Propensities* and *Qualities.* Now, he does not make any endorsements as to the reality of these specific categories and neither will we, just to say that this specific categorization wholly and fully covers the needs for his and more than covers the needs for our endeavour.

The first group, called the spatiotemporal properties, or the Spatiotemporals, have grossly to do with only shape, size position and duration. Apart from these general terms, the category also allows more specific properties, as "being perfectly spherical" or "being exactly one cubic millimeter".

The second group, the Propensities, some of which have earlier been called Powers or Dispositions, depending on the philosopher, concerns how things will be in the future. So if, for example, an electron has unit negative electric charge, it is propensitied to attract, say, protons, who have unit positive charge, which conversely is propensitied to *be* attracted by the electron, and so on. So, for any physical entity to exert influence on some other physical entity, they must have *opposite* corresponding propensities. Also, if we consider a perfect sphere, we may say, that it was propensitied to *be* spherical just one moment ago. This does not mean, though, that Spatiotemporals and Propensities are the same thing, they are, in the terminology of Unger, quite distinct and also equally fundamental and indivisible. The only thing he does state, is, that there is a strong dependency among the two.

The third and last group, Qualities, is to a first approximation what quite a few philosophers have called phenomenal properties. Here, Unger means, for example phenomenal blue, the phenomenal smell of chocolate and phenomenal loud. Unger here diverges from common belief, in that he takes these Qualities, not necessarily to be anything but approximatively equal to phenomenal properties, which are purely mental qualities. He claims and argues, quite rigorously[13], for the existence of such Qualities, like the Spatiotemporals and Propensities, as intrinsic to matter. So, the Qualities argued by Unger does have some relation with the phenomenal properties. It is not one-to-one, though, since other arguments apart, they are generally non-mental and hence need not be mentally apprehended (ever) to exist.

So, what Unger gives us, is a metaphysic that allows us to contemplate physical reality as consisting of material having *ever present* basic intrinsic properties separated into categories concerning its spatial and temporal extent, its propensities and its qualities. It is based on this that we can speak of the transparency of the complexities pertaining to our daily doing or the ability to *just do* in our physical world. They allow for us to develop a trust in the physical world, that is founded not on specific material pertaining to specific objects and situations, but to the way that *any* of this material *at a minimum* is and will be.

2.2 The Truly Universal Machine

The theoretical foundation for the computer as we know it today, was lain by Alan Turing with his description of the *Turing Machines* [11] in 1936. It was the preliminary culmination of the mathematical research into universality and the boundaries of computability. Around the same time, other researchers made similar discoveries in this field, some of which were proven by Turing himself, to be at best equivalent to Turing machines in expressive power. The general acceptance of this equivalence, that no computing machine can be more powerful in terms of expressive power, than can be constructed as a Turing machine, came later through the formulation of the *Church-Turing thesis* by Stephen Kleene in 1943 and can be formulated as: *Every 'function which would naturally be regarded as computable' can be computed by a Turing Machine.* A Turing Machine can be abstracted as a *finite control* and a paper tape of finite length divided into cells, each holding a finite number of symbols. Computation is performed by the finite control analyzing the tape cells one at a time, and moving the tape forward and backward, all in accordance with simple unambiguous rules. The real expressive power came, though, with Turing showing that it is possible to construct a Turing machine simulating other Turing machines, a Universal Turing machine [4, 11]. The consequence is a statically defined machine, a universal Turing machine, capable of simulating every other Turing machine. In other words, a machine capable of computing anything which is theoretically computable.

The practical foundation, then, for the computer as we know it today, was primarily lain by the formulation of the *von Neumann architecture* by John von Neumann in 1945 [14]. Neumann treated programs in the same way as data. In doing so, a machine based on the von Neumann architecture can easily change the program, and can do so under program control. So what von Neumann advocated was a universal computing machine capable of acting upon a finite set of basic instructions and some amount of memory for representing both data and programs. The latter constructed as *algorithms* of the commands of the instruction set. The most interesting fact in relation to the theoretical foundation, is that a machine built using the von Neumann architecture, is equivalent to a universal Turing machine [10]. Virtually all modern computers are based on the von Neumann architecture entailing their universal basic nature and extreme versatility in use. Each of these computers is in principle capable of performing the tasks of *any* other computer in accordance with the aforementioned Church-Turing thesis.

2.3 Turing In Relation To Unger

What can be extracted from the former section, is that aside from current (and earlier) performance issues, the nature of the digital as represented by the computer as we know it today, is primarily derived from the nature of the universal Turing machine. It is crucial here, to notice that the actual performance and memory limitations of some given device, be it a supercomputer or a GPS device, does not have any impact on the intrinsic nature of the computer, and hence the digital, itself. There is truth, of course, in the claim that the smaller a device gets in terms of memory, the "less" Turing complete it is in terms of limits on the tape length. But this does not impact the way itself, that Turing machines compute, it only impacts on the set of computable problems. Given this universality, no matter what properties and qualities the digital world might possess, they are all present in and applicable to each and every digital device we might encounter. The former fact is crucial, if we are to conclude and say anything in general relative to the nature of the digital world.

Relating the nature of the universal Turing machine itself to the basic qualities as put out by Unger in section 2.1, we can also draw some abstract parallels. That is, in relation to the first group of qualities, the Spatiotemporals, Unger is referring to those basic qualities having primarily to do with temporality and materiality, i.e., the passing of time and having physical *substance*, as directly derived from the Latin word *substantia* meaning "standing under" (Oxford English Dictionary). Considering again the nature of the universal Turing machine, we can, at an abstract level, also speak of substance and passing of time. We can say that, that which is defined in the *language* of the universal Turing machine and represented by the words on the tape of it, makes out the substance of the digital realm. It is, as with physical matter the primary constituent of the digital, "standing under" everything else. Taking the next group defined by Unger, that is the Propensities, we see that these have to do with dispositional characteristics, i.e., having to do with change and potential. A world without such propensitive properties would, per definition, be entirely static. Considering the universal Turing machine again, it is partially defined in terms of causal progression, and thus in terms of change and potential. Change in the universal Turing machine is governed by the machine's transition function. On the basis of this, it makes sense to speak of propensitive properties in terms of this function. The transition function, however, is not a Propensity or Propensities of the digital world *itself*. Rather, it is merely the mechanism *effectuating* the dispositional characteristics of the binary substance. The transition function *and* the dispositional characteristics are in unison that which constitutes the Propensities of the substance of the digital world.

Turning to the last of the three categories defined by Unger, we come upon the category of Qualities. These having, as stated, a close relation to our phenomenal perception of things. As such, these are also somewhat harder to deduce the existence or nonexistence of in the digital world solely by considering the universal Turing machine. Such basic qualities would, in the digital world, be fully constituted by the substance of which it is made. But we can only at this point say, that the digital world at least *may* have something resembling Qualities primarily relating closer to our perception of it.

So, comparing the nature of the digital to the nature of the physical, there is an interesting discrepancy. On the one hand, we have a material concrete physical world, whose intrinsic nature is reasonably opaque to us, but with the help of Unger in section 2 we have found that it can be largely, but probably not completely, defined by some set of basic qualities. On the other hand, we have a physically immaterial abstract digital world, whose intrinsic nature, by us being the constructors, is completely transparent to us. Utilizing the concepts of Unger, we shall see that this digital world, as with the physical, also have a set of basic qualities pertaining to the intrinsic nature of it. We have further argued, that it makes sense to divide these into the same three categories used by Unger in contemplating the intrinsic nature of physical reality.

3. TWO WORLDS

Based on the former to sections, we define our two parallel terms, *Physicality* and *Digitality*. They are meant to cover what we deem to be the intrinsic natures of the physical and digital world, or at least, since what we present may not be exhaustive, a *subset* the natures relevant for our endeavour.

3.1 Physicality

Firstly, we coin the term Physicality as being the intrinsic nature of physical reality as it is covered in section 2. This physical reality we refer to, then, is in itself external to us and its existence is independent of us perceiving it. However, it is still the main context of our existence. It is the place in which we live and through which we communicate. In short, in and through which we *do*. Our awareness and comprehension of it follows through our sensing it, as embodied beings, with our five physical senses. It is one of the elements comprising the totality of our lived experience, another being what we might call mental reality, that is, systems, laws, beliefs, ideologies, etc. that are consciously as well as subconsciously fabricated by us, in our minds. We are, as embodied beings, able to *do* in physical reality because we are conversant with it. That is, we are able to interpret signals, or language, from our physical reality sufficiently correct that we can make meaning of what is going on. It is by ways of the properties and consistency of Physicality, that we have achieved this Conversancy. A property of Physicality is that it has an open set of basic qualities pertaining to the material it represents. These are abstracted from the work of Peter Unger, as described in section 2.1. As part of Physicality, these basic qualities are responsible for our perceptions of that which we encounter through our meeting with physical reality. It is those we have grown accustomed to and those on which we rely in our daily dealings. As such, they carry a lot of responsibility with regards to establishing the Conversancy, on which we so fundamentally rely.

3.2 Digitality

Secondly, in direct parallel with and at the same level of abstaction as Physicality, we define the term Digitality. We define it as being the intrinsic nature of the abstract digital world as it is covered in section 2.2. The digital, or virtual, *reality*, that is, the ways in which we are presented and interact with the purely digital world, is created through and upheld by a digital computer or multiple communicating digital computers. Thus, it is as such a *runtime* phenomenon. It is this runtime phenomenon we are faced with in our daily encounters with digitally augmented physical entities. However, what we are faced with is *not* in its entirety the purely digital world itself, but a polluted picture of the true nature of the digital world. A picture in which the physical world is the polluter. Given the equivalence between most modern computers and a universal Turing machine, it is abstracted that the term Digitality pertains *solely* to the intrinsic nature of such universal Turing machines. This entails that the term Digitality describes and relates exclusively to the abstract world unfolded by the universal Turing machine, that is, unfolded by its transition function together with the structurally meaningful words on the tape, and not the specifics of the actual physical machine. One should think of the essence of Digitality as one would think of the essence of a purely mathematical universe, that is, as a world only existing in the mind of the contemplator.

In terms of the basic qualities derived from Unger, we have it that Digitality, as with Physicality, has a set of basic qualities which can be divided into the three categories of what is denoted Spatiotemporals, Propensities and Qualities. These are, as a consequence of the definition of Digitality, governed by the basic characteristics of the nature of the universal Turing machine and what it entails. It is these basic qualities which constitutes Digitality. It is furthermore through an increased understanding of these and upon those we should come to better understand and eventually become accustomed with the intermixture of the two worlds.

4. THE BASIC QUALITIES

We have identified two sets, see Figure 2, of basic qualities, the first of which pertains to the physical world and the second of which pertains to the digital world. That is, we have identified a small subset of what we deem to constitute Physicality and identified a similar small subset of the governing part of Digitality.

4.1 Basic Qualities of Physicality

We continue by explaining the qualities[1] and their, in our

[1]We only delve into a subset of the qualities mentioned in

Physicality	Digitality
PHYSICAL MATTER	BINARY SUBSTANCE
SPATIAL EXTENT	NON-VOID EXTENT
SPATIAL POSITION	UBIQUITOUS
SPATIAL LOCALITY	REFERENTIAL LOCALITY
STATE	STATE
EXITANCE	-

Figure 2: The basic qualities of the two worlds.

context, intended meaning.

Physical Matter All physical objects are constituted by some physical substance, more specific, physical material, or in the words of Unger and as being one of the Spatiotemporals, matter. Having, or being, matter is the most primary of the physical prerequisites and also the "language" of the physical world. Information and action is communicated and performed physically materially in the physical world. The information made out and conveyed by the physical object itself is solely constituted by its physical material and this truly unique information in itself cannot be represented by any other physical object. Physical material is unique and exists thus only at one place at any given point in time. There is a finite (constant) amount of energy available in the universe and some of this energy is manifested as physical matter. When a physical object made out of physical material annihilates, it is transformed either into one or more other physical object(s) and/or energy thus preserving the energy-matter equilibrium. Conversely, when a new object is made, it is created out of pure energy and/or the annihilation or combination of one or more other object(s).

Spatial Extent All physical objects constituted by physical matter, are all cohesive bodies occupying an individually defined amount of physical space. Thus, every instance of physical material has a measurable extension within our physical reality. Spatial extent is defined in terms of distance in this physical spatial reality. Because this space is perceived as being tridimensional by us, so is spatial extent. There is a linear relation between an object's *amount* of material, i.e. its countable size, and its spatial extent, and this relation gives that the more of a certain kind matter, an object is made out by, the greater the spatial extent of the object. The aforementioned size could denote the number of atoms comprising the total amount of physical matter. The basic quality of Spatial Extent, obviously, belongs to the group of basic qualities which Unger denotes as a Spatiotemporals.

Spatial Position Any physical objects within our physical world have a position in relation to the space it occupies. Every physical object has a *unique* position. The quality of Spatial Position also belongs to the group of basic qualities which Unger would denote as a Spatiotemporals.

Spatial Locality The basic quality of Spatial Locality is based on a basic principle stemming from physics denoted the *principle of locality.* It describes that all objects are only influenced by or can only influence its immediate surroundings. That is, every physical object can only be influenced by objects local to its physically spatial position. Accordingly, every physical object can only influence other physical objects that are local to its physically spatial position. In terms of Unger, then, we have that all physical matter, at the utmost basic level, possess opposite corresponding Propensities. The basic quality is always two-way, that is, if a physical object is spatially close to another, then that other physical object is correspondingly spatially close to the first.

It is difficult to intuitively grasp how a physical world without the above basic qualities would be like, probably because they are so integrated into our phenomenological reality. The basic qualities might also, at first glance, appear as uncomplicated, straightforward and as a matter of course. This is primarily due to the fact that we, as human beings, either take them for granted or on a daily basis fail to mentally notice them. Viewed against the basic qualities of Digitality their importance should become clear.

4.2 Basic Qualities of Digitality

The digital world is *binary.* The interesting fact here is, that the digital is completely described and manipulated by an unambiguous language. The digital is physically *immaterial.* The digital has a *measurable size* in terms of bits, that is, ones and zeroes. The digital is a chain of *causal* events manifested by the transition function associated with the universal Turing machine. What we have found through these immediate properties, is a list of basic qualities of Digitality relating thematically to the previously identified basic qualities of Physicality.

Binary Substance All things digital are constituted by some digital substance, more specific, binary substance. A digital entity is a body of binary substance. It may be as simple as a one or a zero, or it may be arbitrarily large. Common for all binary substances part of Digitality is, that they have a binary structure (arrangement) which is interpretable and meaningful for the transition function of the universal Turing machine. Having, or being, binary substance is the most primary of the digital prerequisites and also the "language" of the digital world. Information and action is communicated and performed digitally binarily in the digital world. The information made out and conveyed by the digital entity itself is solely constituted by its binary substance and this unique information in itself cannot be represented by any other piece of binary substance. Binary substance is unique and there exists, thus, only one of it at any given point in time. There is a theoretically infinite amount of potential for binary substance[2]. When an entity made out of binary substance annihilates, it is either transformed into one or more other binary entity/entities or it simply completely disappears. Conversely, when a new binary entity is made, it is created from *nothing* and/or the combination of one or more other binary entity/entities.

Non-Void Extent All digital entities constituted by binary substance, are all bodies having the spatiotemporal basic quality of having some measurable and countable size, and hence some binary extent. As with the extent and matter of Physicality, there is also in Digitality a linear relation between the extent of an object and the amount of binary substance it is made out by. This extent is in Digitality not spatially defined and would thus be spatially zero-dimensional.

Referential Locality Binary substance is Propensitied

Figure 2, due to the the limited extend of this article. For an even more detailed description and explanation, we refer the reader to have a look at our work described in [2].

[2]Actually, not entirely infinite as defined by the tape of the Universal Turing Machine, as this is defined to be finite. This finiteness, though, is expressed as $\lim_{n\to\infty}$ for n being the length of the tape and thus practically unlimited [4].

to be binarily influenced by, and to binarily influence other binary substance. To exert the Propensity to binarily influence, the influencee needs to be referentially local to the influencer. That is, the influencer needs to be able to *refer* to the influencee. By virtue of the universal Turing machine, this will, at the basic level of the digital world, always be the case, though, not necessarily on all other levels [2].

Ubiquitous By ways of the nature of the basic quality of Non-Void Extent, we have that there is nothing in Digitality pertaining to any such digital entities as having a unique specific position, or placement, in the digital universe. The only position, in terms of our spatial three dimensional understanding, digital entities have is the physical position of the device on which they are associated with[3]. For the purely digital world no such similar concept of position exists. Instead, they all have the Spatiotemporal basic quality of being Ubiquitous in the digital world, that is, in the spatial zero-dimensional digital world.

The above listed basic qualities of Digitality may seem, on the one hand highly abstract and difficult to fully comprehend. On the other hand they are simple derivatives from even simpler basic properties of the nature of the universal Turing machine, its transition function and the chosen language of formulation. Some of them have or appear to have a strong resemblance to those of Physicality and others are truly unique to the world of Digitality[4].

5. CONCLUSIONS

The *key* finding must be that Digitality and Physicality, despite sharing direct similarities and some figurative equivalent parallels, are in some areas *fundamentally different.* Not only are the two worlds of dissimilar nature, but their various differences, splitting them apart, are far from neutral. What have become most evident is, that a greater part of the differences identified in Physicality and Digitality owes to fundamental differences on the most basic level at all, on that of materiality. On the subject of materiality, we touched upon the primary constituents of existence. For Physicality, this means physical material, extent and position. These three are both quite individual concepts and at the same time mutually defining. These are, among others, what defines anything and places it in, as a spatially constructed particular, our physical reality. It is further upon the consistency of these basic qualities we have become conversant with and base our trust in the physical world. On digital "materiality", this means binary matter, non-void extent and being ubiquitous, we see that although Digitality has a materiality somewhat similar to that of Physicality, there are also defining differences. The major difference being the incongruous nature of their individual materialities.

What we have provided is a framework capable of contemplating the physical and digital world in direct parallel. The primary tenet of our framework is to think of binary substance in terms how it *offers* itself to be understood by ways of what it *is.* This follows the connecting thread of Peter Unger's work in his approach to describe how the physical world offers itself to be understood by ways of how it is, independently of us. Having this, one is tempted to say, "objective" knowledge of the two worlds, should allow for a better basis in contemplating how we eventually come to understand them. In consequence, we suggest that designers should think of computer applications in terms of binary substance as being a parallel to physical matter. This stems from the fact that physical matter is that which governs the world in which we are born and the world we have become strongly familiar with. In short, the world in which we have become able to *just do* based on our Conversancy with it. We further suggest to think of the world in which these computer applications are being used, as a cross field of two *sovereign* worlds, each contributing to this cross field their own unique qualities, merits and shortcomings. This way of thinking and set of concepts to support it, should also allow designers to analyze existing applications and systems and, perhaps more importantly, develop new and improved applications and systems which would allow us to become conversant with and *just do* in the aforementioned cross field.

[3]A small note should be made here. The binary substance *does* have some position/extent, which could be described in terms of its position on the tape of the Turing machine. The "head" of the Turing machine must move to the position of the binary substance if it needs to be read or changed. But at the level of abstraction at which we consider the digital world, the time it takes to move the head is abstracted away. Consequently, all binary substances are equally close, thus rendering that concept of position redundant.

[4]A thorough and in-depth discussion of the individual qualities and they affect upon one another can be found in our worked described in [2].

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Mutable Matter - Exploring the Physicality of the Nanoscale

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ABSTRACT
Visions of lively, mutable matter in public imagination add to the urgency to explore the physicality of nanotechnology. While decision-making orientated public engagement has been reluctant to address this task, artists and scientists are in the process of using sensuous engagement and symbolic practices to communicate the curious materialities of the smallest level of life and their relationship with the scale we can sense as humans. Building on such efforts, the project Mutable Matter works with a combination of and playful tactile engagement and dialogue may help people communicate and visualise ideas about the nanoscale, but also allow them to give direction to the form of the engagement.

Categories and Subject Descriptors
A.m MISCELLANEOUS

General Terms
Performance, Design, Experimentation.

Keywords
Physicality, nanotechnology, sensuous engagement, art, lively matter, public engagement, symbolic practices.

1. INTRODUCTION
How can one have a sensual understanding of nanotechnology - or, more generally, of the alien [6] mechanics of the nanoscale? That is one of the questions I have been asking myself in relation to my project, 'Mutable Matter', for which I am developing a series of activities reflecting the agency of matter at different scales.

Nanotechnology, more than other 'new technologies', is not only throwing up questions about the boundaries of matter/data, organic/inorganic, inertia/liveliness that have been affecting the 'macroscale', but also questions of visualisation [6]. Unfortunately, sensuous engagement with the nanoscale is rarely the subject of nanotechnology themed public debates. The reason for this lack of prominence may be that the science behind nanotechnology is not considered 'interesting' for 'the public' [1][5] or 'too complicated'. While it is undoubtedly important to 'make visible… the assumptions, values and visions that drive science' [14], as it is the aim of recent public engagement with new technologies, I wonder if also a different kind of understanding could be promoted by 'making visible' the invisible matter of the scale these technologies are operating on. What questions would participants ask about nanotechnology if they could experience 'nano' through sensuous engagement?

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2. UNSUPPORTED IMAGES OF LIVELY MATTER
The scientist Richard Jones criticises that there is a tendency to set up nanotechnology as a 'hard', 'solid', 'inorganic' technology to contrast it with mutable, 'soft, wet and floppy' biotechnology [4]. In the public imagination, however, the incomprehensibly small products of nanotechnology do not come across as 'solid' or inert: they are thought of as moving, replicating, and reacting to their environment. In public engagement reports, participants often talk about engineered matter 'doing things' as if out of its own agency – contrarily to the promised control of the manufacturers. Matter at the nanoscale is believed to 'refuse to be the raw material' [2] for human aspirations, breaking free like the infamous herbicide resistant golf course lawn [8] or computer viruses. To many researchers, such undesirable visions are to blame for a misconception of nanotechnology [11]. But are these visions really so counterproductive? From personal experience, delving deeper into popular nano worlds has had the effect that I cannot perceive anything as solid anymore. Combined with a diet of 'nano' product catalogues and description of 'nano' future scenarios, statements such as 'most of nature exists on the nanolevel' [4] have begun to create the image of a lively inorganic wilderness in my mind, which is quickly becoming more populated by anything from sticky propeller-bearing bacteria-bots to antibacterial 'nano' kitchen ware.

Could it not be that the boundaries between matter, technology, information and the everyday have become blurred in the public consciousness as they have always been at the smallest level of life? Finally, it seems, people have started to think of themselves as part of a world of lively matter, and they are making enquiries about its mechanics, its agency. What does it do? Why does it do it? What are we in relation to matter? How does matter perceive us? And most importantly: how does the matter that we are interact with the matter that we are not – and can we still draw these boundaries? Have people unknowingly started to think at the quantum level? Inspired by recent efforts in philosophy to draw attention to the intentionality of matter and to promote a 'weird vision of reality' [3], I am arguing that offered images of the physicality of nanotechnology – or nanolevel technologies - are not ‘weird’ enough and do not support or match what people already understand.

3. SENSUAL ENGAGEMENT THROUGH IMAGES

My first point of call in my search for alternative engagement forms was a website put together by a research group of the Technical University of Vienna [9]. The site contains some animations and photographs, but mostly images produced by a scanning tunnelling microscope (STM) which explain the group’s work to ‘outsiders’. Thanks to one of the website’s animations, scanning tunnelling microscopes are what I have come to imagine as the nanoscientist’s ‘record player’, as they have a sharp tip, ideally ending in one atom, that runs over a surface, thus ‘reading’ it. A photograph shows, that in comparison to a fragile record player, an STM is enormous, heavy, almost archaic in feel, and one wonders how such a bulky and clumsy-looking piece of machinery is capable of exercising such precise work. And work it is: in addition to the photographs of the STM, an animation illustrates the amount of labour (adjusting, monitoring, comparing etc) that goes into interactions with the atomic scale.

The first impression I had of the surface images was how regular the surfaces were and how round the atoms looked. Is this how they ‘look’ or how they are rendered by the machine for our eyes? The second impression was how strikingly their arrangements looked like different weaves of fabric. In fact, the same descriptions used in textiles (‘herringbone’) were applied to corresponding atom patterns [9].

The arrangements of atoms looked delicate, yet dense and impenetrable. Paradoxically, the rigid and regular looking order of atoms on these surfaces induced a certainty that there are different laws at this scale. Very quickly, I started to look for patterns, and when a pattern was disturbed, the desire for an explanation arose, and also the wish to know why there are different kinds of patterns in the first place. Other questions came to mind such as: what is in the space between atoms? And: what makes me see atoms in this particular way - surely, atoms consist mostly of empty space and do not have a coloured shell that resembles frog spawn or sweetcorn as these images want to make me believe?

From the commentary on the website, I was also able to find out what scientists can read from those images: which positions atoms ‘prefer’ in an alloy, which bonds between atoms are stronger in which particular combinations, and what other kinds of activities atoms engage in, for instance, ‘bouncing’, ‘getting stuck’ or ‘wandering about until they find … islands where they are readily incorporated’ [9]. I am told which atoms represent which elements, why the atoms have different colours, and why it is so intriguing that they arrange themselves in certain formations. Last but not least, it is illustrated how these images help us understand how things work in the ‘macroworld’: how the knowledge about corrosion resistance, pollution absorption or material structure in the ‘nanoworld’ affects the design of materials such as car catalysts or steel. Examples such as these render clearer how STM images help scientists to gain a different understanding of the processes at the nanoscale and thus enable them to make changes to previously established solutions to problems. I would maintain that not only scientists can arrive at a different, sensual understanding of matter at the nanoscale. Also, with regard to current engagement exercises, could these images act as a platform where both scientists and non-scientists engage not only in meaningful dialogue with each other but also with matter?

4. EXPLORATION THROUGH SYMBOLIC PRACTICES

The method I am exploring in my own project is hands-on interaction. Quite a few examples are already out there. For example, the internet abounds in nanotechnology themed computer games, such as the Science Museum’s ‘Duckboy in Nanoland’ [10] where the player can navigate ‘Duckboy’ through easy obstacle courses based on classical mechanics, which mischievously turn into far more difficult enterprises half way through when the classical mechanics are replaced by quantum mechanics. The more artistically inclined can visit ‘NanoArt’ [7], a website run by the scientist / artist Cris Orfescu, where STM scans that can be downloaded and transformed into artworks. These transformations can happen on the computer, from a printed image, or in the form of ‘large scale’ nano-themed sculptures. The potential of sound has also been explored:

the scientist/artist team James Gimzewski and Victoria Vesna has put together an art installation called ‘Blue Morph’ [12] through which visitors can see, listen and interact with a butterfly in the making – paradoxically by stopping to move and make noise themselves. The sounds they can hear as well as the nanoscale patterns of the butterfly’s wings are derived from ‘feeling’ the pupa surface with the help of an atomic force microscope. The scale transitions of ‘Blue Morph’ are changing the visitors’ perception of the world as they know it: butterflies become noisy creatures, and their colourful wings become an ‘optical illusion generated by the very precise surface arrangement of the biomaterial which produces structural colour via this nano-patterning’ [12]. By listening to the amplified nanoscale, the visitors are made aware of the limits of their senses, but also of their active (p)re-interpretation of information given out by their environment. A few years earlier, the same team initiated the ‘nano’ exhibition at the Los Angeles County Museum [13] during which visitors had the chance to explore ‘nano’ at human scale through a variety of interactive installations. In the installation ‘Atomic Manipulation’, for instance, visitors could ‘move, manipulate, and reorient individual ‘atoms’ in actions that emulate the operations of the Scanning Tunneling Microscope’ [13]. So visitors actually got to manipulate matter on the atomic scale – symbolically, of course, but nevertheless!

It would be interesting to hear the reflections of the people who participated in these projects, especially as most of the featured interactions were explicitly devised for playful exploration and not for giving authoritative answers. In my own work, I am therefore combining playful tactile engagement with dialogue to engage in a mutual research process with participants. In ‘Mutable Matter’, phenomena that are characteristic for the nanoscale, such as viscosity, Brownian motion, ‘stickiness’ [4] are enlarged to human scale with comparatively primitive means such as magnets, modelling clay, thick liquids, polystyrene balls and fans. The choice of familiar materials is an important part of the project, as I am hoping that participants will feel more inclined to propose changes to the ‘experiments’ that allow them to communicate and visualise their own ideas about the nanoscale. If there is something the participants cannot portray with the materials on offer, they can mention it in the dialogue, so that their ideas can be discussed. The ‘experiments’ are a series of short interactions with the materials and first start off behaving according to the mechanics we sense at 'our' scale, but then progressively start to create a (sensual) link with the nanoscale – and back, to suggest how these seemingly distinct or distant spaces relate to each other. Throughout these 'experiments', dialogue is encouraged and recorded. When a session finishes, the participant - so far, the 'experiments' are envisioned to take place on a 1-to-1 basis – is encouraged to give additional feedback and to visit and leave comments on the project blog space to where project developments are regularly updated.

During the first trial – the project is only going live towards the end of the year – I had the feeling that the continuous moving between the human and the nanoscale had the effect that the symbolic 'matter' I handled became increasingly strange. Suddenly I expected the play-dough I used for the trial to exhibit properties it does not normally have. Was that a good effect – it could be interpreted as a successful merging of spaces – or was that something that could become a major obstacle to what I am trying to do? Only further experimentation will tell. Of course what I experienced may not be experienced by other people, but if it is and proves to be too distracting, changes to the project will be made.

Despite the potential open-endedness of the project, I am opening myself to the criticism that the experience is not first hand and not neutral, because the symbolism is subjectively chosen and will predetermine certain outcomes or, worse, give a distorted scientific view of the workings of matter (but then, how immediate and neutral are scientific observations?). Like other designers of symbolic engagement, I emphasise that I am myself experimenting and trying to understand which, in return, might encourage other people to challenge what I am offering and to start experimenting with the resources that they deem appropriate.

5. CONCLUSION

Engagement with the physicality of the nanoscale has been very limited. Images of lively 'inorganic' matter in the public consciousness are counteracted rather than supported in public engagement. In this paper, they are more positively and provocatively re-interpreted as a tacit curiosity (or even knowledge) about the goings-on at the level where 'most of nature' [4] operates. Projects and even large scale exhibitions addressing the physicality of the nanoscale exist, but are not integrated, for instance, into decision-making orientated nanotechnology engagement. Examples such as BlueMorph, NanoArt, or the STM gallery were initiated by individual scientists or scientist/artists who wanted non-scientists to understand and explore their work. Visually or physically struggling with the mechanics of the nanoscale, it is felt, can prompt audiences to ask different sorts of questions and help them visualise these through different sets of imageries. The project 'Mutable Matter' attempts to push further the theme of sensual engagement by inviting people as co-creators of visions of the physicality of the nanoscale. The mutual, playful, open-ended investigations into these invisible materialities are intended to speak out against the claim that 'nano' science is too difficult and 'intangible' for 'the public'. Moreover, by trying to evoke the 'nanoworld's' imbeddedness in the visible and tangible through symbolic practices, the project is trying to unsettle established perceptions of distance between the spaces of 'nano' and 'macro', thereby challenging the assertion that an understanding of the nanoscale is irrelevant to people's everyday lives.

But most of all, I am promoting the view that by sensuously and dialogically addressing the curious material and non-material complexity that discussions of nanotechnology are starting to expose, different worlds can be imagined.

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