THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

# Everyday encounters with data: Exploring engaging and collaborative interactive technologies

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# Everyday encounters with data: Exploring engaging and collaborative interactive technologies

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## ABSTRACT

This thesis addresses a variety of problems in human-computer interaction (HCI) centred around how users perceive, use and benefit from data. The work spans a number of application areas such as: medical work, shipping, emergency management, campus work conditions and practising amateur sports.

The first part of the thesis is devoted to a thorough investigation of data usage patterns and cooperation workflows in a Polish hospital. The author conducted extensive user studies to understand the rules and motivations governing how and why users interact with digital environments in this complex environment. The study enabled the authors to propose two models for modelling the hospital environment using fuzzy logic. These models may be used for facilitating surgery scheduling and optimising hospital operations. The thesis also includes a thorough account of the user studies conducted an an analysis of their results, which may be reused when designing future systems for similar environments.

Next, the thesis introduces and suggests how tabletop interfaces can be used in a variety of environments. The author investigates the implications of using a tabletop system on a ship's bridge and participated in studies of a tangible tabletop system for emergency management. Both applications showed added value of exploring data sets through tabletop systems in professional settings.

The author also conducted work in the field of persuasive systems. This work coffers system design targeted at limiting noise in quiet study spaces within campus environments. The author investigates how immediate feedback for dynamic user groups can be effective in changing behaviour through ambient displays.

This thesis concludes with a report on the author's most recent work on augmenting the experiences both for runners and their supporters during organised races. The author successfully developed a prototype of a computer-mediated communication system for providing feedback during races.

*The shapes, though, were similar,*
*And our new hands*
*Learned gem-tactics*
*Practising sands.*

# Preface

The main purpose of this thesis is to show my personal evolution as a researcher from an eager computer science student interested in social aspects of computing to a doctoral student in human-computer interaction (HCI). The reader will notice that the works included in this document are diverse and address different problems and a variety methods. However, I believe that all these papers share a common spirit of my fascination with understanding how humans use computers at different moments of their lives. I also hope that the reader can see that I feel that a carefully crafted mix of engineering, social science and design skills is required to embrace the mysteries of human-computer interaction. Having been educated as an engineer, I always try to include a strong empirical element in my work and I think this is one of the themes that emerge from this thesis.

Moreover, I hope that the reader will appreciate the fact that I have explored a set of complementary directions in my initial scientific efforts. Hence, all of the works included here have brought me to discover what kinds of questions I would like to ask in my future research. They have also allowed me to learn what work in science can look like and continue to fuel my scientific curiosity.

Most importantly, all the papers in this thesis are a manifestation of numerous hours spent discovering new fascinating things about the domain I grew to love. They allowed me to find me scientific role models and identify my own purpose in conducting studies. I think that by now I know what kind of research I would like to do and how it should benefit others. I am particularly fond of the fact that computers did not play the main role in this journey and the fascinating humans I met along the way are the greatest highlight of my time spent in research so far. I feel very lucky to have been able to experience this.

Paweł Woźniak
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I thank my family and friends for supporting me on the way to achieving my dreams. You have always been there for me and your help is invaluable. I apologise for being away for so long and promise to be with you all as much as possible.

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I am indebted to all the researchers with whom I collaborated and co-authored papers included in this work. I am grateful to t2i interaction lab's collaborators who constantly provide reliable support: Michael Schade, David NG McCallum and Barrie Sutcliffe.

I was fortunate to have the opportunity to work with and be inspired by a number of excellent master students including: Bartosz Koczorowicz, Lars Lischke and Benjamin Schmidt.

Last, but not least, I am grateful to all the members of my doctoral committee for support and appropriate supervision.

# Contents

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4. Woźniak, P. and Romanowski, A. (2013). Vertoid: Exploring the persuasive potential of location-aware mobile cues. In Proceedings of the 2nd Workshop on Techniques and Applications for Mobile Commerce, in print as part of Proceedings of the 2013 Federated Conference On Computer Science And Information Systems, published by IEEE.

# 1 Introduction

In this introductory chapter, I briefly present the research areas that are mentioned by works included in the later parts of this thesis. This is aimed to help the reader place my scientific output within a a context of research and benefit to society. I discuss works that are particularly important to the scope of this thesis in order to highlight what had the largest influence on my work.

## 1.1 Pervasive computing in medical care

The ubiquitous computing concept, originally developed by Mark Weiser [21] affected the field of human-computer interaction and other disciplines in computer science to a great extent. The vision of a future living space with pervasive embedded computation is both intriguing and useful as a paradigm of creating and designing for future technologies. A large part of this thesis is devoted to understanding how future changes in computational technology will affect the way humans care about their health.

Pervasive healthcare is a subfield addressing the use of ubiquitous technologies in a healthcare context. Most efforts focus on how patients can improve their lifestyles, their communications with their physicians and how systems can facilitate remote care. My work, however, falls into a different category. I investigated how clinical environments can be augmented using pervasive technology to make patient care more efficient and improve the user experience of the medical professionals. Doctors and nurses are a particular user group with an intrinsically complex relationship with interactive technology. They work in a goal-oriented safety-critical environment and this makes cooperating with them challenging and interesting.

Jakob E. Bardram contributed much foundation work in pervasive healthcare. Most importantly, he appropriated one of the core concepts of ubiquitous computing — context-awareness — to hospital work in [1]. Context-aware pills and beds inspired many researchers and a widely regarded as one of the future directions hospital work will take.

Electronic Medical Records (EMRs) are already used in many places and extensive and easy on-demand access to medical information will be a crucial element of medical care. Bardram also outlined key design considerations for hospital systems such as privacy, distributed computing, easy discovery and extensibility. An even deeper approach is presented by Bardram [2] in the form of Activity-Based Computing (ABC). This led to designing both a conceptual framework and software support (in the form of a Java framework) for facilitating hospital activities. The core concept is to understand the required interactions in the context of activities and how these activities relate to patients, professionals and objects (e.g. medical equipment, medication and surgical tools). The perspective also embraces collaboration as an necessity in hospital work. Bardram has also shown how deep insights can be gained from organising multiple workshops and prototype-testing sessions with physicians. The evaluation of the ABC framework illustrates how mock scenarios may benefit the design of hospital systems.

Another notable effort that influenced the work contained in this thesis was a study of how digital technology can mediate surgeries performed by Scupelli et al. [18]. They presented an extensive study of four surgery management systems in two hospital environments. The most interesting part of the work is how the researchers studied existing whiteboard-based systems to derive design insights for future improved and, possibly, digital solutions. They observed how the infrastructure created common information spaces and facilitated collaboration highlighting how physical spaces relate to the design of the information flows. In fact, finding digital representation of traditional healthcare environment artefacts is a recurring theme at it also surfaced in my work. Scupelli et al. also highlighted the need for customising systems, especially taking architectural considerations into account.

There are more examples of how engaging in deep conversations with medical professionals can yield a better understanding of how digital systems can support clinical activities. Frykholm et al. [7] conducted studies of multi-display system for supporting team consults in Swedish hospitals which show how one needs to support multiple interaction styles and parallel private and public access to patient information. They also show the challenges of pervasively integrating electronic medical records in clinical environments. One key element noted is that new medical tools need to be perfect or they will not be used. Doctors expect perfection from day one even for non-critical equipment. Most importantly, the study has shown that there is potential for delivering more information and providing a better overview of patient situation even in advanced environment. In a similar vein, Sarcevic et al. [15] examined decision-making in high-risk trauma cases and developed a clinical decision support system. Here, the speed of the activities was also a concern. The researchers reflected that rapid access to past cases may constitute a significant improvement in emergency cases. This is one of the key goal of the work contained in this thesis.

## 1.2 Tabletop computing

Tables are part of our everyday lives. We use them at home, at work, to play, to eat, and for collaboration. Over the last few decades, researchers have envisioned and designed interactive tabletops with computers integrated into furniture. This is a prominent way of making computers invisible [12]. Today, after approximately twenty years since its inception, research and development of technologies and products in the domain of interactive horizontal displays has reached a certain level of productivity. A question that still remains is how to design optimal tabletop experiences and in which domains interactive tabletops are most useful.

Tables provoke us to manipulate objects and rearrange them along with our thoughts. There is an intrinsic cultural tendency to be creative around tables (Schneider et al. [17] call it a "socio-constructivist flavour") and participate in collaborative activities. Building on that potential through applications in different domains is a challenge for human-computer interaction. How do we engage, inspire and educate users gathered around an interactive tabletop? This question is becoming more and more relevant as tabletop technology has accelerated and advanced devices are available from many suppliers. Microsoft PixelSense technology and an array of devices from MultiTaction now provide rapid access to tabletop development without the need of advanced programming skills. Even though an interactive tabletop is still a rather expensive gadget, it is now commonplace in research laboratories and public spaces such as museums and science centres. Indeed, many predict that public displays (which include horizontal displays) will be an important building block of 21st century computing [16].

Several past systems show how tabletops can be introduced to a variety of setting and enjoy relative success. A very important inspiration for the work covered in this thesis was G-nome surfer [19] — a system that has shown how tabletops may facilitate information discovery in highly specialised field such as genetics. Shaer et al. also show how classical interaction design methodology can be applied to designing complex tabletop interfaces. Their inquiry begin with a thorough study of habits and current practices of molecular and computational biologists. The researcher then built an extensive interface for browsing biomolecular data and conducted a data-rich evaluation process. This example shows that tabletops can be appropriated to benefit even very complex domains given that enough design effort is allocated to the activity. It also illustrates a key future challenge for tabletops and human-computer interaction in general — interacting with the emerging massive data sets.

Large amounts of data are generated through our daily activities: commuting, eating lunch, using mobile phones, and reading the bedtime story to the children. In a truly democratized society we should have access to the data we generate along with the tools needed to gain insight. There is an emerging need for aggregating data from different sources and presenting it in forms that will make it accessible for different stakeholders within social entities [20]. Consequently, pervasive computing systems will soon be

required to provide opportunities for users to rapidly explore big data in ad-hoc casual settings. From an infrastructure perspective, sensor networks have already begun to pervade everyday environments; many businesses and institutions are interested in exploiting sensor data. Moreover, the emerging area of citizen science in ubiquitous computing will require extensive support from interfaces for data exploration. Lay researchers will assemble systems from a variety of devices and even attempt creative reuse. Tools that require less technical expertise are likely to emerge, empowering users to perform advanced analyses in their backyards. Communities must be able control and understand the collection, aggregation, and sampling of data, thus enabling what Churchill [3] calls "data-aware design".

A key unsolved research question that emerges from the work contained in this thesis is how to use the potential of tabletops to harness the opportunities provided by big data and provide support for citizen science and civic engagement. One way to tackle the question is to address how tabletops may perform in various domains and gain new perspectives through design-based research. Two efforts of this kind are included in this thesis.

## 1.3 Persuasive systems

Using computerised systems to change behaviours and persuade users to perform certain actions is an established theme in ubiquitous computing. Initially called captology, it entered the human-computer interaction field as early as 1997 [6]. Perspectives on what to study and how to study persuasive technology have been discussed from the very beginning and there is still no consensus on an ultimate methodology to study these systems. Theoretical models have emerged that are often used to design persuasive systems. A model by B. J. Fogg that helps conceptualise what Fogg identified as key factors in behavioural change and design to accommodate for them. These include a set of behavioural triggers, elements of motivation and elements of simplicity. The designer must balance real-life conditions such as time, money and social acceptance to achieve the behavioural change goal. However, applying theory-driven models in persuasive systems is still disputed to a great extent and many argue for a design-based approach where the study of the users is the primary driving factor of the shape of the system [10]. This thesis shows a system which was developed in a design-oriented manner.

Human-computer interaction literature features several notable systems that show how persuasive technology can be used for the overall well-being of societies. A classic example is the power-aware cord by Gustafsson and Gyllenswärd [9]. The device represents the amount of power consumed by a device attached to an electrical socket through a glowing cable. The authors employ ambient feedback to nudge the user and make them recognise parameters, of which one is usually unaware. This is done with a clear intention of reducing domestic electricity consumption.

A more recent example by Nakajima and Lehdonvirta [13] showed four case studies where ambient mirrors are used to promote desired behaviours among users. Emotional engagement was important in all the case and users were presented with imagery that was to produce an emotional reaction. Most importantly, the work shows that persuasive ambient display are a versatile and effective solution for behavioural change as the authors applied them across a number of life spheres. These include dental hygiene, promoting reading books and environmentally-friendly behaviours (in fact,he author of this thesis has also tackled the issue of reducing greenhouse gas emissions in a work not included in this thesis [22]). Furthermore, the authors discuss the pros and cons of immediate and accumulated feedback which is a topic important for this thesis.

Another recent system that is largely influential for this thesis is The Clouds by Rogers et al. [14]. This installation combined visual cues with ambient displays in order to stimulate the users of an academic building to use the stairs instead of the elevator. The Clouds also included a result visualisation module available at a public screen. Rogers et al. presented a compelling study and outlined methodology that can be used in further studies. Furthermore, they illustrated how a persuasive systems can affect small communities and the importance of how news spreads along office spaces. The system uses just-in-time cues embedded in the physical environment and a physical, ambiguous ambient display for visualising the stair/elevator ratio. The fact that the researchers observed a significant effect in stair usage suggests that ambiguity in designing persuasive ambient displays may be beneficial.

## 1.4 HCI in sports

Providing support for physical exercise through digital means is an emerging topic in human-computer interaction. A researcher community willing to tackle problems faces by users practising sports and participating in sports events is now forming, which is confirmed by forming a special interest group at the last CHI conference. Several past developments in the area have influenced the content of this thesis.

Improving the experience of runners and creating digital support for running coaching is am often-addressed problem. One attempt was to help runners maintain cadence through auditory stimulation by de Oliveira and Oliver [5]. In TripleBeat, they provided significant evidence that mobile-device-based feedback methods can lead to increasing exercise performance. Furthermore, they hinted that social engagement as an important motivating factor can be mediated through social networks and elements of motivation can be provided by an interactive system. Finally, the system shows that user clearly recognise the additional value in providing extra information during an exercise.

Enhancing social relationships and promoting practising sport in group was a strong theme in work by Mueller et al. [11]. The researchers looked at how runners from Europe and Australia can be connected via digital means to create an experience of

running together. In what the authors call "mediated exertion", the authors aimed to create an engaging experience for social interaction between two individuals that cannot be together physically. However, they stress that while exercising can easily be a social experience, the ultimate decision whether or not to engage in excretion depends only on the individual. As a consequence, interactive system can facilitate and motivate the process, but they are unable to provide meaningful results without a concious investment on the side of the user. The work falls within a larger trend of exertion gaming (or exergaming).

Another important theme is sharing data with other during exercises and participating in organised events. Past research investigated the users attitudes towards broadcasting heart beat data. Curmi et al. [4] developed HearthBeat, which is a mobile-phone-based system for race participants that broadcasts hearth rate information. That information is then available through a social network. Those connected to the participant can then like the current status of the race and that is communicated to the runner through the vibration of the mobile device. Their study has shown that using biometric data can stimulate users to feel more engaged and the supporters felt closer to the participants. However, there are many unanswered questions in this domain. What form of feedback is most appropriate when running? How can supporters express the support they provide to emulate physical cheering? Is a mobile device the optimal way to track running (other solutions e.g. drones [8] have been discussed)? Some of these are dressed in later parts of this thesis.

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