Proxemic Interactions:

From Theory to Practice

Synthesis Lectures on Human-Centered Informatics

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Proxemic Interactions:

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ABSTRACT

In the everyday world, much of what we do as social beings is dictated by how we perceive and manage our interpersonal space. This is called proxemics. At its simplest, people naturally correlate physical distance to social distance. We believe that people's expectations of proxemics can be exploited in interaction design to mediate their interactions with devices (phones, tablets, computers, appliances, large displays) contained within a small ubiquitous computing ecology. Just as people expect increasing engagement and intimacy as they approach others, so should they naturally expect increasing connectivity and interaction possibilities as they bring themselves and their devices in close proximity to one another. This is called *Proxemic Interactions*.

This book concerns the design of proxemic interactions within such future proxemic-aware ecologies. It imagines a world of devices that have fine-grained knowledge of nearby people and other devices—how they move into range, their precise distance, their identity, and even their orientation—and how such knowledge can be exploited to design interaction techniques.

The first part of this book concerns theory. After introducing proxemics, we operationalize proxemics for ubicomp interaction via the Proxemic Interactions framework that designers can use to mediate people's interactions with digital devices. The framework, in part, identifies five key dimensions of proxemic measures (distance, orientation, movement, identity, and location) to consider when designing proxemic-aware ubicomp systems. The second part of this book applies this theory to practice via three case studies of proxemic-aware systems that react continuously to people's and devices' proxemic relationships. The case studies explore the application of proxemics in small-space ubicomp ecologies by considering first person-to-device, then device-to-device, and finally person-to-person and device-to-device proxemic relationships. We also offer a critical perspective on proxemic interactions in the form of "dark patterns," where knowledge of proxemics may (and likely will) be easily exploited to the detriment of the user.

KEYWORDS

proxemic interactions, proxemics, embodied interaction, location and orientation awareness, natural user interfaces, ubiquitous computing, human computer interaction

Contents

Acknowledgments

Many people participated in the intellectual foundations of this book. Our own efforts in Proxemic Interactions started several years ago, where we (Saul Greenberg as supervisor and Nicolai Marquardt as Ph.D. student) set this as a Ph.D. topic. As our work developed, so did the interest of other people in our Interaction Laboratory at the University of Calgary. When Marquardt created the Proximity Toolkit for rapid prototyping of proxemic systems, other students and researchers in our lab embraced it. They quickly developed their own projects on proxemics, ranging from quick and dirty explorations to full-blown research efforts. During this time, we developed a graduate course on the topic: students researched sub-topics, built systems, and added to our database of relevant background literature. The result was a research sub-culture, where Proxemic Interactions became an on-going topic of conversation and research. This rich environment added considerably to our own thinking about Proxemic Interactions.

We thank our collaborators and co-authors of joint publications which formed the basis of the content covered in this book. In particular, we would like to thank Till Ballendat, Sebastian Boring, Robert Diaz-Marino, Jakob Dostal, Ken Hinckley, Jo Vermeulen, and Miaosen Wang. We also thank all the other researchers and developers whose work we cite. Their work stimulated our own thoughts, and showed different ways of approaching and leveraging the idea of proxemics to interaction design. Dan Vogel and Ravin Balakrishnan's seminal paper and video on interactive public ambient displays (ACM UIST, 2004) was particularly inspiring: they planted the seed that eventually led to our own research explorations.

Videos

This book describes highly interactive systems built both by ourselves and others. Yet print is a poor way to show the dynamics of these systems. Fortunately, a subset of these systems is also illustrated by videos, many available on the Internet. We include a list of various videos produced not only by ourselves but by selected others, along with URLs to those videos. We highly recommend that readers look at these videos. When a video is available, we indicate that in our text by (see video: system name).

System or interaction technique name	Source
Tip-Me-Lens	Aseniero et al., 2013
http://grouplab.cpsc.ucalgary.ca/Publications/2013-TipMeLens-Report2013-1040-07	
Proxemic media player	Ballendat et al., 2010
http://grouplab.cpsc.ucalgary.ca/Publications/2010-ProxemicInteractions.ITS	
Shoulder surfing protection	Brudy et al., 2014b
http://grouplab.cpsc.ucalgary.ca/Publications/2014-MediatingShoulderSurfing.CHIVideos	
Spalender name	Chen et al., 2012
http://grouplab.cpsc.ucalgary.ca/Publications/2012-Spalendar.AVI	
Greetings Robot	Heenan et al., 2014
http://grouplab.cpsc.ucalgary.ca/Publications/2014-HRIGreetings.DIS	
Proxemic remote control	Lido et al., 2013
http://grouplab.cpsc.ucalgary.ca/Publications/2013-MobileProxemicControl-CHIVideo	
Proximity toolkit	Marquardt et al. 2011
http://grouplab.cpsc.ucalgary.ca/Publications/2011-ProximityToolkit.UIST	
Gradual engagement	Marquardt and Ballendat et al., 2012
http://grouplab.cpsc.ucalgary.ca/Publications/2012-GradualEngagement.ITS	
GroupTogether	Marquardt and Hinckley et al., 2012
http://grouplab.cpsc.ucalgary.ca/Publications/2012-GroupTogether.UIST	
Microseismic visualizer	Moustafa et al., 2013b
http://grouplab.cpsc.ucalgary.ca/Publications/2013-Microseismic-CHIVideo	
Proxemic Peddler	Wang et al., 2012
http://grouplab.cpsc.ucalgary.ca/Publications/2012-ProxemicPeddler.PervasiveDisplays	
ViconFace	Diaz-Marino and Greenberg 2010
http://grouplab.cpsc.ucalgary.ca/Publications/2010-ProximityToolkit.CHI	
Ambient display	Vogel et al. 2004
http://www.dgp.toronto.edu/~ravin/videos/uist2004_ambient.avi	

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Figure 2.3: **From:** Want, R., Hopper, A., Falcão, V., Gibbons, J., 1992. The Active Badge Location System. *ACM Transactions on Information Systems* 10, 91–102. DOI: 10.1145/128756.128759.

And **From:** Schilit, B., Adams, N., Want, R., 1994. Context-Aware Computing Applications, in: *IEEE Workshop on Mobile Computing Systems and Applications*. IEEE, Los Alamitos, CA, USA, pp. 85–90. Copyright © 1994 IEEE. DOI: 10.1109/WMCSA.1994.16.

Figure 2.4: **From:** Ju, W., Lee, B.A., Klemmer, S.R., 2008. Range: exploring implicit interaction through electronic whiteboard design, in: *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW '08*. ACM, New York, NY, USA, pp. 17–26. Copyright © 2008 ACM. Used with permission. DOI: 10.1145/1460563.1460569.

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Figure 2.8: **Based on:** Streitz, N., Prante, T., Röcker, C., Alphen, D. van, Magerkurth, C., Stenzel, R., Plewe, D., 2003. Ambient displays and mobile devices for the creation of social architectural spaces, in: *Public and Situated Displays—Social and Interactional Aspects of Shared Display Technologies, The Kluwer International Series on Computer Supported Cooperative Work*. Kluwer, Dordrecht, pp. 387–409. DOI: 10.1007/978-94-017-2813-3_16.

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Figure 3.2: **From:** Hall, E.T., 1966. *The Hidden Dimension*, 1st ed. Doubleday, Garden City, NY Used with permission.

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Figure 3.4: **From:** Marquardt, N., Hinckley, K., Greenberg, S., 2012. Cross-device interaction via micro-mobility and F-formations, in: *ACM Symposium on User Interface Software and Technology, UIST '12*. ACM, New York, NY, USA, pp. 13–22. Includes video figure. Copyright © 2012 ACM. DOI: 10.1145/2380116.2380121.

Figure 4.1: **From:** Marquardt, N. and Greenberg, S., 2012. Informing the Design of Proxemic Interactions. *IEEE Pervasive Computing*, 11(2): 14–23, April–June. Copyright © 2012 IEEE. DOI: 10.1109/MPRV.2012.15.

Figure 6.20: **From:** Chen, X., Boring, S., Carpendale, S., Tang, A., Greenberg, S., 2012. SPALENDAR: Visualizing a Group's Calendar Events over a Geographic Space on a Public Display, in: *Proceedings of the 11th International Working Conference on Advanced Visual Interfaces, AVI '12*. ACM. Copyright © 2012 ACM. DOI: 10.1145/2254556.2254686.

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Figure 7.25: **From:** Aseniero, B.A., Tang, A., Carpendale, S., Greenberg, S., 2013. Showing Real-time Recommendations to explore the stages of Reflection and Action (No. 2013-1040-07). Technical Report #2013-1040-07, Department of Computer Science, University of Calgary, Calgary, Alberta, Canada. Includes video figure.

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CHAPTER 1

Introduction

"When you walk up to your computer, does the screen saver stop and the working windows reveal themselves? Does it even know if you are there? How hard would it be to change this? Is it not ironic that, in this regard, a motion-sensing light switch is 'smarter' than any of the switches in the computer […]?"

Bill Buxton, "Living in Augmented Reality" (Buxton, 1997)

Over the last two decades, Mark Weiser's (1991) vision of *Ubiquitous Computing* (ubicomp) as the next era of interacting with computers has increasingly become commonplace through the rising number of digital devices present in people's everyday life. *Ubicomp ecologies* are emerging (e.g., Figure 1.1), where people regularly use their portable personal devices (e.g., phones, tablets), interact with information appliances (e.g., digital picture frames, game consoles), and collaborate with large surfaces (e.g., digital whiteboards) within a given context. But Weiser's vision went beyond the mere *individual* devices. He predicted seamlessly accessible technologies of calm computing that "weave themselves into the fabric of everyday life, until they are indistinguishable from it" (Weiser, 1991) and "engage both the center and periphery of our attention" (Weiser and Brown, 1996). Unfortunately this vision does not yet exist, for there are still considerable problems that make interaction with devices in such ubicomp ecologies far from seamless. In practice, using multiple devices in *concert* is often tedious and requires executing complicated interaction sequences (Cooperstock et al., 1997).

For example, consider the digital ecology of the living room shown in Figure 1.1. While the devices within it are network-enabled, actually configuring, interconnecting, and transferring content between these devices is painful without extensive knowledge. Even when devices are connected, performing tasks between them is usually tedious—for example, navigating through network and local folders to find and exchange files. In practice, people rarely go through the effort. This means that, from a person's perspective, the vast majority of devices are blind to the presence of other devices. What makes this even more problematic is that these devices are also blind to the non-computational aspects of the ubicomp ecology, which may affect their intended use. Devices do not recognize *people* that are present, such as whether only a single person is interacting with the device vs. a group of people that could work collaboratively over those devices. They do not recognize *non-digital* objects, such as a person holding a physical object in their hand that could determine the intended interaction with the device. They do not recognize *spatial relations*, such as a person sitting on a chair facing a screen from a distance, from which we could infer that the person's attention is focused on the screen. And devices also do not recognize the *spatial layout of the environment* (e.g., position of walls or doorways), which could help to determine if another wirelessly connected device is in the same or an adjacent room, or to know when a person is entering the room through a door so the system can activate itself.

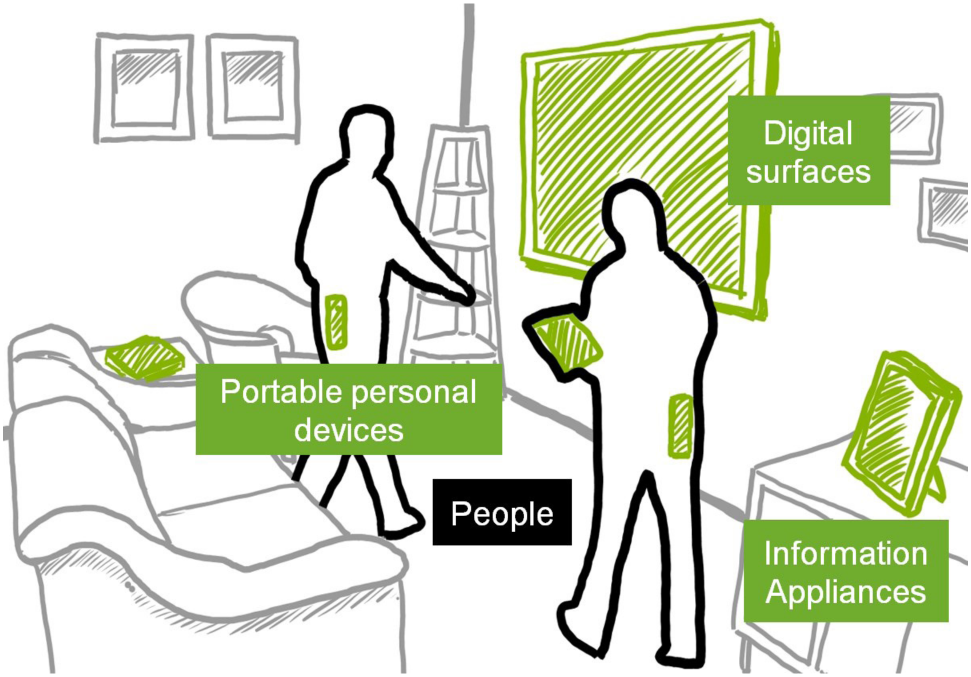

Figure 1.1: People, devices, and non-digital objects are part of a small-space ubiquitous computing ecology (Ballendat et al., 2010).

This book argues that computational knowledge of spatial relationships between people and the devices or objects around them could be leveraged in ubicomp interaction design. However, we first need a better understanding about how people use the space around them. A seminal theory analyzing and describing people's use of interpersonal space when interacting with others is Edward Hall's *proxemics*, introduced here but presented in more detail in Chapter 3.

1.1 PROXEMICS

In everyday life, the spatial relationships between ourselves and the other people or objects around us are important for how we engage, interact, and communicate. People often use changes of spatial relationships—such as interpersonal distance or orientation—as an implicit form of communication. For instance, we keep certain distances to others depending on familiarity, we orient toward people when addressing them (e.g., see the informal circles of collaboration in Figure 1.2), we move closer to objects we are interested in, and we stand or sit relative to others depending on the task at hand. *Proxemics*, a term coined by anthropologist Edward Hall, is one of the seminal theories about people's perception and use of interpersonal distances to mediate their interactions with other people (Hall, 1966).

Figure 1.2: People often implicitly adapt proxemic variables (e.g., distance or orientation) when interacting with others, as shown in these small group formations during conversations.

Hall's studies revealed patterns in how certain physical distances correlate to social distance when people interact. Other observations further refined this understanding of people's use of spatiality. For example, spatial features of the environment (e.g., location of walls, doors, furniture) influence people's use of proxemics. A person's orientation relative to others is another driving factor in how people greet and communicate with one another. Overall, proxemics mediate many aspects of social interaction. For example, it influences casual and serendipitous encounters (Kraut et al., 1988), is a nuance in how people greet one another (Kendon, 1990), and is a major factor in how people arrange themselves for optimal small group collaboration via spatial-orientational maneuvering (Kendon, 2010; Sommer, 1969).

1.2 PROXEMICS APPLIED TO UBICOMP INTERACTIONS

The key idea elaborated in this book is that we can leverage information about people's and devices' fine-grained proxemic relationships for the design of novel interaction techniques in ubicomp ecologies.

The overarching goal of this book is to inform the design of future *proxemic-aware devices* that—similar to people's natural expectations and use of proxemics—allow increasing connectivity and interaction possibilities when in proximity to people, other devices, or objects. Toward this goal, we explore how the fine-grained knowledge of proxemic relationships between the entities in small-space ubicomp ecologies (people, devices, objects) can be exploited in interaction design.

For example, in Figure 1.3 left, we see that one person in the room has a spatial relationship with other room entities: people, the devices (the whiteboard, the tablet, the mobile devices carried by both people, the various information appliances in the room), and non-digital objects (room boundaries, furniture). What can we do in terms of interaction if the ubicomp ecology knew about these spatial relationships? For example, in Figure 1.3 right, the ecology may detect that the person holding their tablet is approaching the digital whiteboard. As a consequent, it may automatically connect the tablet and the whiteboard, readying it for information sharing and exchange. The whiteboard may show progressively more detail about the information it is displaying as the person approaches it. Both tablet and whiteboard may show interface features allowing information from one device to be easily transferred to the other. Interaction methods can be tuned to best fit how far away the person is from the whiteboard, e.g., pointing while at a distance, touching when within reach. This book will explore these and many other possibilities.

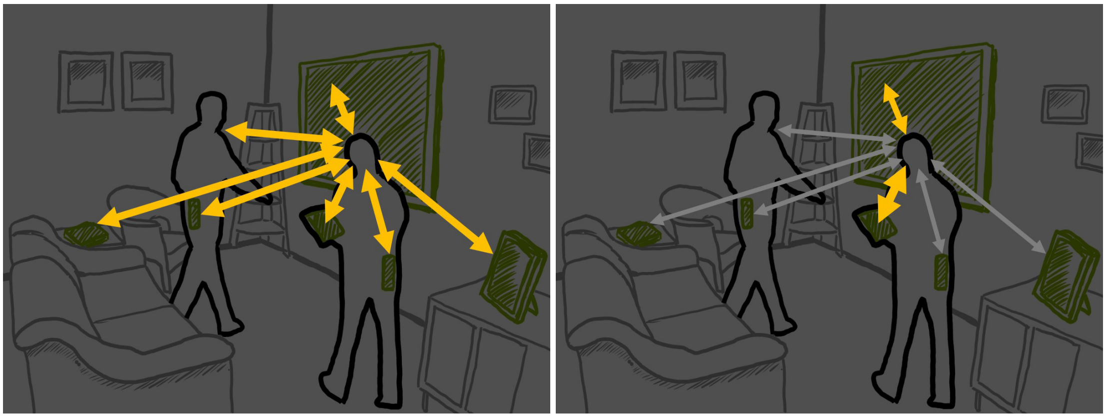

Figure 1.3: Interactions in ubicomp ecologies (cf. to Figure 1.1): (left) many possible interaction possibilities around a person, where (right) knowledge about proxemic relationships can be leveraged to identify devices more likely for possible interactions.

Over a decade ago, Vogel and Balakrishnan (2004) seminal research started exploring the use of proxemic relationships to drive people's interactions with large public displays (see video: ambient display). Other early pioneers continued in this vein, such as Ju et al.'s (2008) use of proxemics to mediate between implicit and explicit interactions. Yet despite the contextual rich information of proxemics and the opportunities presented by people's natural understanding of them, so far only a relatively small number of research installations incorporate knowledge about spatial relationships within ubicomp interaction design. Of those systems that do, most do not yet consider the fine nuances of distance, orientation, movement, location, and identity in people's and devices' proxemic relationships. Thus this book delves into Proxemic Interactions more deeply, where it explores further nuances and applications of proxemics to ubicomp interaction design.

In order to keep the scope of this book manageable, we primarily focus on the study of applying proxemics to interactions in *ecologies of people and devices* in *small space ubicomp environments*. This includes small- to medium-sized indoor rooms, such as a living room at home, or meeting rooms at the office. Figure 1.4 provides an example room layout and its entities. Later chapters in this book will selectively focus on proxemic relationships between the following entities:

- People (single person to small groups, i.e., 1–4 people)
- Large interactive digital surfaces (e.g., whiteboard)
- Information appliances (e.g., digital picture frames)
- Personal portable devices (e.g., phone, tablet computer)
- Non-digital objects (e.g., magazines, pens)
- Fixed features (e.g., walls) and semi-fixed features (e.g., furniture) of the environment

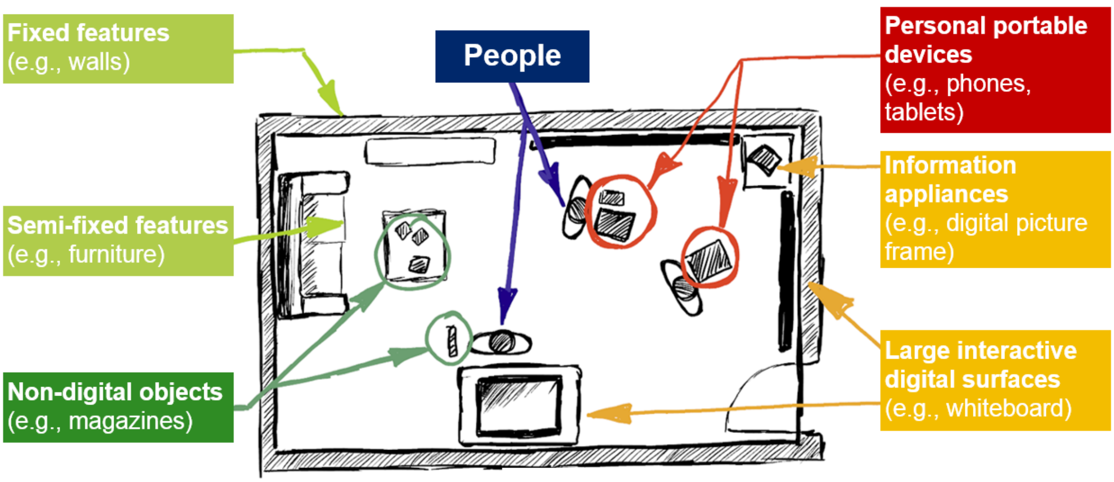

Figure 1.4: Ubicomp ecology with multiple people interacting with personal portable devices, information appliances, large digital surfaces, and non-digital objects.

Within this context, we ask how we can exploit the fine-grained knowledge of proxemic relationships (which we operationalize in Chapter 3 as distance, orientation, movement, location, and identity) between people, digital devices, non-digital objects, and the surrounding environment to mediate ubicomp interactions. In particular, the book is divided into two parts that elaborate two primary themes.

1. Part I. We operationalize proxemic theories for ubicomp interaction design in the framework of Proxemic Interactions.

2. Part II. We describe the design and implementation of three explorative case studies probing into the design space of Proxemic Interactions in small space ubicomp ecologies—and therewith applying the operationalized proxemic theories.

There are, of course, important topics this book does not cover in detail. First, we recognize that ubicomp systems designed for public spaces and building- and city-wide deployments could also leverage proxemics. While this book can help inform some of that design, we leave it to others to pursue the nuances of those different spaces. Second, Proxemic Interactions require our computers and devices to somehow sense spatial relationships between entities in the environment: people, devices, and even non-digital objects. There are various technologies and infrastructure that can perform that sensing, and these are used by the various systems described in the book. However, we do not elaborate on the sensing technologies for various reasons: space is limited; the various technologies currently used are all limited in their own way, and we expect new technologies to be introduced in the near future. Even so, the pointers we provide to source references should suffice for those interested in using, reproducing, or researching such sensing systems.

1.3 AUDIENCE FOR THIS BOOK

The primary audience for this book is ubicomp developers, human-computer interaction researchers, interaction designers, and indeed anyone interested in novel ways of interacting with technology.

The book provides sufficient background to bring you, its reader, up to speed. If you have no knowledge of proxemics and just passing knowledge of ubiquitous computing, the first part of this book will explain what proxemics is and how it relates to ubicomp design. If you do have expertise in the area, you will find that the details provided along with pointers to related work will give you a rich intellectual basis for considering and applying proxemics to both research and product design.

The book is based on various social theories of proxemics, which by themselves may be insufficient to guide design. Consequently the book operationalizes proxemics as dimensions that can be sensed and managed by a computer, which will help you as a practitioner, developer, or interaction designer apply proxemics to your own system creation. Part II of the book gives three case study designs along with myriads of novel interaction techniques based on proxemics. These make Proxemic Interactions design concrete. Overall, we hope this will inspire and inform your design processes for building ubicomp systems.

PART I

Proxemics and Ubiquitous Computing

In this first part of the book we investigate proxemic theory and how it can be operationalized for ubicomp interaction design. First, in Chapter 2 we survey related work in ubiquitous computing and context-aware computing, and review previous work considering spatial information for ubicomp interfaces. Next, in Chapter 3 we lay out the foundation of Proxemic Interactions in ubicomp, with a survey of seminal theories of proxemics and personal space. In Chapter 4, we operationalize proxemics for ubicomp through the Proxemic Interactions framework, which identifies five key dimensions of proxemic measures most relevant for ubicomp interaction design. Last, in Chapter 5 we describe how to leverage proxemics in system design to mitigate six particular ubicomp interaction design challenges.

Author Biographies

Nicolai Marquardt is a Lecturer in Physical Computing at University College London. At the UCL Interaction center he is working in the research areas of ubiquitous computing, physical user interfaces and interactive surfaces. In particular, his research of Proxemic Interactions focuses on how to exploit knowledge about people's and devices spatial relationships in interaction design. He graduated with a Ph.D. in Computer Science from the Interactions Lab at the University of Calgary, and joined Microsoft Research in Cambridge and Redmond as an intern during his graduate studies. Together with Saul Greenberg, Sheelagh Carpendale, and Bill Buxton he is co-author of *Sketching User Experiences: The Workbook* (Morgan-Kaufmann 2012). See: http://www.nicolaimarquardt.com.

Saul Greenberg is a Full Professor and Industrial Research Chair in the Department of Computer Science at the University of Calgary. While he is a computer scientist by training, the work by Saul and his talented students typifies the cross-discipline aspects of Human Computer Interaction, Computer Supported Cooperative Work, and Ubiquitous Computing. He and his crew are well known for their development of toolkits, innovative system designs based on observations of social phenomenon, articulation of design-oriented social science theories, and refinement of evaluation methods. He is a Fellow of the ACM, received the CHCCS Achievement award, and was elected to the ACM CHI Academy for his overall contributions to the field of Human Computer Interaction. Together with Nicolai Marquardt, Sheelagh Carpendale and Bill Buxton he is the co-author of *Sketching User Experiences: The Workbook* (Morgan-Kaufmann 2012) as well several other books on Human Computer Interaction. See: http://saul.cpsc.ucalgary.ca.