Informing the Design of Proxemic Interactions

Proxemic interactions can help address six key challenges of ubicomp interaction design and how devices can sense or capture proxemic information via five dimensions—distance, orientation, movement, identity, and location.

Nicolai Marquardt and Saul Greenberg
University of Calgary

Social scientists and others in related fields describe *proxemics* as people's cultural perception and use of personal space to mediate their social interactions with others in everyday situations.[1] Although proxemics emphasizes distances between people, other attributes are also relevant, such as orientation and body language. Yet, despite people's understanding of proxemics, only a handful of interactive systems in ubiquitous computing have applied proxemic relationships to interaction design in a holistic way.[2,3] This is surprising, given that one promise of ubicomp is to situate technology in people's environments, where it leverages, exploits, and becomes integrated into everyday practice.[4]

We recently proposed the idea of *proxemic interactions*,[5,6] describing how devices could have fine-grained knowledge of nearby people and other devices and exemplifying how we might exploit that knowledge to design interaction techniques. Here, we take a step back to focus more on proxemic theory and its potential to address six key design challenges of ubicomp interaction:[7] revealing interaction possibilities, directing actions, establishing connections, providing feedback, preventing and correcting mistakes, and managing privacy and security.

Ubicomp and Embodied Interaction

Almost 20 years ago, Mark Weiser proposed ubicomp as the next era for interacting with computers.[8] He foresaw network-connected digital technologies available in our everyday environments in a variety of form factors and sizes to suit the task at hand. Given today's availability and use of such devices—smartphones, tablet computers, net-aware digital cameras, photo frames, interactive whiteboards, and digital tabletops—it might seem that we've realized his vision. But the vision went beyond devices.

Weiser predicted that computing technology would move into people's everyday surroundings, embedded into all kinds of everyday objects and spaces, where it would be seamlessly accessible:[8]

> *The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life, until they are indistinguishable from it.*

To partially realize seamlessness, Weiser and John Seely Brown also proposed technology that "engages both the center and periphery of our attention."[9] These parts of Weiser's vision—the seamless interaction, disappearing technology, and seamless transitions between foreground engaging activity and background peripheral perception—are still missing from people's everyday experience with ubicomp technology.

Paul Dourish later expanded on the concept of situating technology in people's everyday environment as *embodied interaction*.[4] Dourish brought together the core ideas of

Published by the IEEE CS ■ 1536-1268/12/$31.00

phenomenology theory, social computing, and tangible user interfaces, emphasizing the importance of designing technology that exploits human skills and experiences.[4] Extending the ubicomp vision, embodied interaction thus aims to build technology that's seamlessly integrated into people's everyday practices. People shouldn't act *on* technology but rather *through* technology to perform the task at hand.[4] Context-aware computing relates to this by providing devices with knowledge about the situation around them so that they can infer where they are in terms of social action and then act accordingly.[10]

Challenges in Designing Ubicomp Systems

We've identified six core challenges related to designing embodied and seamless ubicomp interactions, inspired by Victoria Bellotti and her colleagues' design considerations for sensing systems[7] and augmented by other analytical and reflective ubicomp discussions.[2,11–13] We can't cover all ubicomp design challenges here, so we focus on those most relevant to proxemic interactions.

Challenge 1: Revealing Interaction Possibilities

In *The Psychology of Everyday Things* (Basic Books, 1988), Donald Norman appropriated James J. Gibson's notion of affordances to describe how an object's visuals can suggest how you might use it. Traditional GUIs exploited affordance to design interface elements that suggested their use and possible actions. These GUIs worked because they could assume that they were in the foreground of a user's attention—that is, that the person was watching the screen. Yet this can't be directly applied to ubicomp, which aims to integrate technology into the everyday environment such that it "disappears" or is present in the just-perceptible periphery of our attention and can fluently grab our attention as needed.[8] This introduces the following challenge: how to design technology to reveal appropriate interaction possibilities not only when the technology is in the background of a person's attention but also when it transitions into the foreground.[2,12,14]

Challenge 2: Directing Actions

Input to a single traditional device is straightforward, because such input usually comes through a dedicated input device, such as a mouse, keyboard, or touch surface. In ubicomp, however, input can be detached from a particular device. Possible actions can be performed through speech, gestures, or eye gaze, for example.

The device must somehow discern whether the action is a directive to the system or is just part of a person's everyday actions (for example, a voice command versus a conversation, or a command gesture versus a movement made while doing other things).[2,7] The problem of directing the actions to a particular device is even more problematic when there are large quantities of devices present in the local ecology, because the system must discern which device (or set of devices) should respond to a person's directed action.

The device must somehow discern whether the action is a directive to the system or is just part of a person's everyday actions.

Challenge 3: Establishing Connections

Device connectivity is a significant ubicomp challenge.[12] Technical issues aside, ubicomp's ad hoc nature means that people must somehow (seamlessly) control how one device connects to another device in a way that reflects their interaction needs while still safeguarding privacy and security (for example, to transfer digital content from a personal smartphone to a large public screen).

This challenge is compounded by the potential and perhaps unpredictable interplay between numerous digital devices. Some might be personal (a smartphone), belong to the inhabitants of a space (a home's picture frame), or be public (such as a public wall display). Their form factor also affects their mobility, which in turn can suggest different factors affecting how they should establish connections.

Challenge 4: Providing Feedback

Appropriate feedback is a mainstay of traditional GUI interaction design. Yet as ubicomp interfaces move away from the traditional desktop computer setting, it becomes even more important to provide feedback about the application's current status, its interpretation of user input, or its errors.[2,7,11] To complicate matters, ubicomp systems must consider that people's attention in regards to the ubicomp technology might switch between foreground and background.[14]

Challenge 5: Avoiding and Correcting Mistakes

When mistakes or errors happen, the system should provide options for a person to correct these mistakes.[2,7] Many ubicomp systems use some kind of sensing technology to monitor people's actions, so such errors and misinterpretation of sensor data are even more likely to occur in ubicomp settings than with traditional computers.

Challenge 6: Managing Privacy and Security

In ubicomp, as the number of potential interactions with technology increase, so do the risks to privacy and the need for greater security.[13] The question is how can the system protect privacy-sensitive information and handle the access to information, while at the same time not getting in the way of all

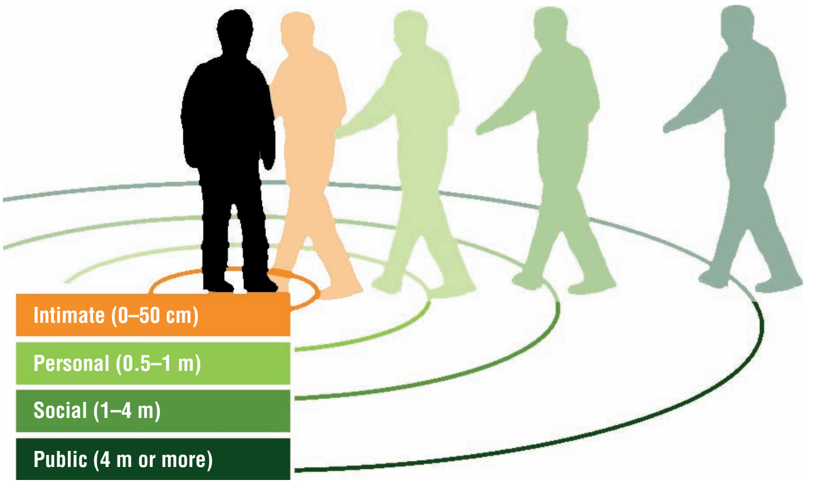


Figure 1. Edward Hall's proxemic zones. Hall correlates physical distance to social distance between people and categorizes it into four discrete zones.

the positive offerings of ubicomp mentioned in challenges 1 through 5?

Proxemic Theories

Before examining techniques based on proxemic interaction that can mitigate these challenges, let's first review proxemic theories and the use of personal space relevant to ubicomp design.

Distances and Discrete Zones

Anthropologist Edward Hall introduced proxemics as a theory for studying the interpersonal spatial relationships between individuals.[1] His theory—while emphasizing social and cultural differences—generally describes how people perceive, interpret, and (often unconsciously) use the microspace around them, and how this affects their interaction and communication with other nearby people.

He details how people interpret and use proxemic cues, especially distance, to mediate relations to other people. In particular, he correlates physical distance to social distance between people. As illustrated in Figure 1, he categorizes this into four discrete distance zones, ranging from: *intimate* (0–50 cm), *personal* (0.5–1 m), *social* (1–4 m), and *public* (> 4 m). These collective distances, which Hall calls the *dynamic space*, characterize a progression of interactions ranging from highly intimate to personal to social to public.[1] The exact ranges of these interpersonal distance zones depend not only on cultural factors but also on other factors such as age, gender, or personal relationship.[15]

Environment: Fixed and Semifixed Features

Hall also identified two other factors that influence people's use of the microspace around them.[1] *Fixed features* include the immobile properties of the space: the layout of buildings and rooms and of walls, doors, and windows. *Semifixed features* include the spatial layout of elements in the space that can be moved (such as furniture, chairs, or tables). Hall noticed that the layout of the fixed features, as well as the arrangement of elements in the semifixed feature space, influence our use and perception of personal space, where particular layouts can be *sociofugal* (separating people) and *sociopetal* (bringing people together), as also earlier observed by Humphry Osmond.[16] A simple example is how chairs in a living room can be brought together into a sociopetal small circle to encourage intimate chat.

Although others have critiqued Hall's classification of personal space as being overly simple (for example, comments published with Hall's article[17]), his work has become a seminal theory for studying personal space. As we discuss next, other theories add new perspectives to extend Hall's original *distance-centric* view.

Orientation

Orientation generally describes how people face toward or away from each other. Robert Sommer studied people's preference of spatial seating arrangements and relative orientation around a table depending on the task at hand.[18] He found that for most people, their seating position depends on the task: face-to-face seating for competitive tasks, side-by-side seating for cooperative tasks, and side-by-side or corner-to-corner seating during conversations. Others have identified patterns in which people's orientation toward one another depends on the conversion and social status.[19]

Compensation, Balance, and Privacy

People constantly adjust their use of space to fit the presence of, and interactions with, others. This includes how people react to and try to overcome "invasions" or "violations" of their personal space. Some theories describe people's adaptation to given spatial circumstances, and how they try to maintain a certain comfort level or equilibrium in these situations. For example, the *intimacy equilibrium model* assumes that when people interact, they strive to maintain an overall balance toward a desired optimal proxemic distance.[20] To achieve this balance, people might try to adapt proxemic variables such as distance, orientation, or eye contact. For example, when a person stands too close to us, we might step back to maintain the equilibrium. If we can't change one of the variables in this particular situation (for example, if we're forced to stand close to others in an elevator), then we can change another variable to compensate (changing orientation to avoid eye contact in the elevator).[20]

Another predictive model formalizes equilibrium as an *optimal proxemic distance*, where it adds proxemics variables including identity and familiarity of the other person, and the type of interaction.[21] People also use personal space as a method to protect a certain level of privacy. Irwin Altman reframes this use as a *dynamic boundary regulation process* that controls privacy.[22]

Figure 2. Five dimensions of proxemic interactions: (a) distance, (b) orientation, (c) movement, (d) identity, and (e) location.

Proxemic Dimensions for Ubicomp Interaction

These proxemic theories describe many different factors and variables that people use to perceive and adjust their spatial relationships with others. Although these theories describe people's relations to people, not devices, we can still use them as a first-order approximation to apply proxemics to ubicomp design.

As part of this approximation, we offer five device-oriented proxemic dimensions—inputs and states that devices can hold about proxemics relationships—most relevant to operationalizing proxemics in ubicomp interaction (see Figure 2).[5,6] That is, they describe relationships not only between people but also all entities in ubicomp ecologies: people, digital devices, nondigital objects, and features of the surrounding environment.

Distance is the first dimension. This is the measurable distance between entities in the space (people, devices, and objects), and we can represent it in many ways. For example, the distance can be precise (such as 2.3 meters) or crude (such as "zone 1"), given as an absolute position or relative distance between entities, or provided continuously (as changes are detected) or discretely (as the entity passes from one zone to another).

Orientation provides information about which direction an entity is facing. For people, this includes gaze, face, and body and limb orientation. For devices or objects, this might require a well-defined front (for example, a display's front-facing side). Orientation can be relative between two or more entities, or absolute when relative to a fixed point in the environment. We can describe it in both qualitative ("facing toward") and quantitative ("at a 90-degree angle") terms.

Movement describes changes in distance and orientation over time. Thus it can describe an entity's sequences when moving through space and even its velocity.

Identity uniquely identifies entities in the space. This can be exact (such as "Fred and Jane") or can discriminate between entities ("person 1 and person 2") or between categories (a "person" and "phone").

Finally, *Location*, in contrast to distance, describes the qualitative aspects of the place in which the interaction occurs. That is, it characterizes the location (such as home versus office), describes fixed or semifixed features (such as room layout and furniture position), and provides meta-information (such as social practices and context of use).

Addressing Ubicomp Design Challenges

We now revisit each design challenge, where we speculate—using examples drawn from the literature—how knowledge of proxemics (as gathered by the five dimensions) can mitigate problems inherent in each of the six design challenges. These examples are merely a starting point for exploring the potential of future proxemic interaction designs.

Revisiting Challenge 1: Revealing Interaction Possibilities

To address this challenge, a system must offer possible actions[2] that afford seamless transitions from background to foreground interaction.[14] This concept is somewhat similar to how people approaching each other exchange greetings and begin communicating through various signals (eye gaze, body language, and speech), where signals and possible actions vary appropriately across this greeting phase. Similarly, ubicomp should "greet" other entities by revealing interaction possibilities that match what's possible at the moment. Several strategies could help accomplish this.

Reacting to the presence and approach of people. At the most basic level, if a system can sense the presence and approach of people, it can use that information to reveal possible interactions.

Various systems do this but only as a binary measure: if the system detects a person, it marks the person as present; otherwise, it marks the person as absent. In response to this binary measure, systems trigger an appropriate action. For example, smart light switches can use motion detectors to infer presence and turn lights on and off in response.[14] Or a desktop computer screen can use a proximity sensor to determine a person's distance from the display, and from that either activate the screen or go into a power-save mode.[6] Both systems reveal interaction possibilities implicitly: the first by illuminating the room, and the second by showing that the desktop computer is on and ready to go.

Other systems detect and use presence information to explicitly reveal interaction possibilities. Consider *ActiveBadges*—identity tags worn by individuals—where the badge (and thus a particular person's) location is tracked at a room level in a building.[23] Its inventors exploited this presence and identity information to offer personalized computing services at that person's current location—for example, where their desktop computer display would "follow" them to other rooms and appear on nearby screens. Similarly, the EasyLiving system selects custom media content when sensing a person's presence in a particular room at home.[24]

Another popular example is a large screen that senses when a person enters a room, where the display not only turns on but tailors its contents to suggest its offerings.[3,5] For example, with the large-screen media player we developed,[5] the display senses when a person crosses a threshold into a room and presents a splash screen offering several different videos. The system intentionally displays only a small number of videos using large graphics to make it appropriate for viewing at a distance. If one person seated on a couch is already viewing a video when another person enters, the system displays its information differently, where it reveals what's being viewed with minimal disruption to the primary viewer.

In terms of our dimensions, this media player exploits both relative distance and identity to reveal appropriate interaction possibilities compared to just a binary notion of presence—that is, it considers the room as an ecology. It uses people's approach across a threshold (the doorway), their distance from the screen, and their presence relative to other fixed features in the room (such as the couch).

Transitioning from awareness to interaction. People exploit proxemics cues as they greet and engage in social interaction. You might have peripheral awareness of another person from a distance, but you'll become increasingly aware of that person as he or she turns toward you and approaches. You'll then begin to interact when the person enters an appropriate proxemic region. Some public ambient displays apply a similar mechanism to engage people, where they trigger actions to attract a passerby's attention and progressively show more information and interaction possibilities as the person approaches and attends the display, ideally leading to foreground interaction by direct touch.[3,5,25] The idea is that the passerby notices the public display as it implicitly reacts to the person's presence and captures his or her attention and interest. If the person then moves closer and faces the display, the system reacts to that show of interest.[3] The media player prototype,[5] for example, adjusts the number of videos, their size, and the associated text as the person approaches the display to reveal more selections and information. A system such as this exploits distance, orientation, and movement to infer a person passing by a distance, turning toward the display, approaching it, and finally standing directly in front of it.

In the physical world, we know what's available by looking around us. In ubicomp, we need to visualize otherwise hidden offerings on a device's screen.

Spatially visualizing ubicomp environments. In the physical world, we often know what's available simply by looking around us. In ubicomp, we need to explicitly visualize otherwise hidden offerings on a device's screen (or screens), such as when one device is within range of another, its relative location, and what can subsequently be done between them.

For example, Hans Gellersen's Relate Gateways project places icons at the device's screen border to represent the type and location of surrounding devices relative to that device's position.[26] Our media player also visualizes the spatial relationships to nearby personal devices: if a person points his device toward the large screen, a graphic appears as a ray-cast projection on that screen, indicating its position and orientation.[5] As the mobile device approaches and is oriented toward the large display, increasing detail about that device, its contents, and its interaction possibilities are revealed.

Revisiting Challenge 2: Directing Actions

While challenge 1 concerns how a ubicomp system can reveal interaction possibilities to a person, challenge 2 addresses how a person can direct input actions to a particular device.

Using discrete distance zones for interaction. Similar to how people tend to move closer to others when interacting (to begin a conversation, for example), systems might accept user input only when the person appears at a certain distance relative to the device. Thus, to address a particular system, a person might have to approach and move closer to it.

Some ambient display systems do this by realizing Hall's discrete proxemic zones as thresholds that adjust interaction possibilities according to the zone in which a person appears.[3,25] Hello.Wall introduced the notion of *distance-dependent semantics*, where an individual's distance from the wall defined the possible interactions.[25] Although information on the large display can be seen from afar (challenge 1), a person had to move closer to actually interact with it (for example, to transfer information from a mobile device).

Daniel Vogel and his colleagues extended this concept by defining four proxemic zones of interaction around the large display.[3] From far to close, these ranged from *ambient display*, to *implicit*, then *subtle*, and finally to *personal interaction* with the interactive calendar application. Each of these zones allowed particular kinds of interaction with the display's contents. Similarly, Wendy Ju also defined four zones around an interactive whiteboard, where she allowed certain actions only when a person was standing close to it.[2] Our media player shows yet another promising approach, where each interaction zone explicitly supports different input modalities that are appropriate to the person's distance from the display.[5] When afar, people interact via pointing (ray-casting); when close by, they use hand gestures or direct touch.

Considering attention and orientation. Instead of relying only on distance, the system can use other measures to infer a person's focus. This is the premise of attentive user interfaces (AUIs) that are designed to "support users' attentional capacities."[27] In one class of AUIs, the system reaction depends on whether a person is directing his or her attention to the device as detecting eye gaze,[27] which in turn can be considered a fine-grained measure of orientation.

Our media player also exploits orientation as a measure of attention.[5] When a person turns away from the video screen (to read a magazine or talk to another person, for example), the system pauses video playback, and resumes when the person turns back toward the screen. In other work, we show that our proxemic-aware presenter also uses orientation as an indication of attention.[6] If the presenter is facing toward the audience and away from the large display, a standard slide deck is shown. However, when the presenter turns towards the display, small navigation controls and speaking notes become visible at the side of the screen closest to the presenter.

Considering location features. Ubicomp systems are often embedded in people's everyday environments, surrounded by other physical objects and social meanings that comprise the ecology of that place. Inspired by research in context- and location-awareness,[10] our next concept emphasizes the importance of interpreting the physical setting in which an interaction takes place.[4] In particular, people's relationships to fixed and semifixed features[1] can be indicators for directing actions to a particular ubicomp system.

Researchers have considered the geometric relationship of people to semifixed features to determine which screen is activated to display information to a person.[24] Similarly, in our media player, the ubicomp system not only monitors a person's proxemic relationship toward a device but also to that person's distance to other fixed and semifixed features in the ecology.[5] If a person selects a video and then sits on the couch, the system assumes the person is ready to watch the currently selected video and begins video playback. However, if the person instead moves to the doorway, the system assumes the person is no longer interested and shuts down. In both cases, the person's distance to the screen is the same, but his or her location in the room's ecology is different. These examples are a starting point of how to consider people's relationships to fixed and semifixed features in the environment.

Considering motion trajectories. Going straight toward another person—or quickly passing by—are also proxemic cues that we implicitly interpret in everyday interactions with others. Similarly, ubicomp systems can interpret people's and device's motions for directing actions. For example, Vogel's ambient display ignores people quickly passing by but reacts to (and gathers input from) people walking straight toward it.[4] Motion cues can be quite fine-grained, where a system can exploit distance, orientation, and velocity as well as how each changes over time.

Adapting to nearby devices. A system's interpretation of a person's actions can also depend on the number of other nearby devices that it senses. To illustrate, a user of the gesturePen, designed by Colin Swindells and his colleagues, triggers interaction between two devices by pointing her pen to the device with which she wants to interact.[28] We can extend this to help a user choose between numerous devices by applying a distance- or identity-based filtering technique to limit the number of possible pointing targets—for example, the system could require the person to move closer to the target until it can discriminate the desired device.

Revisiting Challenge 3: Establishing Connections Between Devices

As suggested by our last example, people must somehow control how one device connects to another device in a potentially large ecology of devices in a way that seamlessly supports their interaction needs while still safeguarding privacy and maintaining security. People do this naturally—the way we greet and move closer to one another via proxemics is essentially a negotiation to establish connections for communication.

The way we greet and move closer to one another via proxemics is essentially a negotiation to establish connections for communication.

Connection as a consequence of proximity. We can exploit distance, identity, and even orientation to determine proxemic relationships between devices, and then establish connections between only those that are in close proximity. As opposed to directly connecting two devices with a cable, such wireless connections facilitate the spontaneous and lightweight transfer of information. Existing systems now do this, although most do so as a binary function (for example, "close" is "connected").

> Assuming a system knows a person's physical orientation and distance, it can adjust the provided output as needed.

Jun Rekimoto and his colleagues' combination of near-field RFID communication and wireless networks allows interdevice communication only when two mobile devices are in close proximity.[29] Alternately, physically bumping two devices together can activate a connection: the accelerometer signal produced by bumping identifies the devices,[30] and bumping can only occur as a consequence of direct touch.

Another strategy exploits people's proximity to one another, where they communicate to synchronize an act that establishes the connection. One example is when both people simultaneously shake their handheld device.[31] Similarly, a stitching gesture can be used, where one person starts a gesture on one device, which is then continued on the other, but this can only happen if the devices are nearby.[30]

Progressive connection process. Although the systems just described are binary in nature, progressive connection processes are also possible. Christian Kray's *group coordination negotiation* introduced spatial regions around mobile phones to establish and break device connections or initiate data transfer.[32] As a device moves across three discrete regions, a preview of a media transfer is first displayed, where transfer begins only after moving into a closer region.

Our proxemic media player is somewhat similar, but it uses a continuous rather than discrete progression over distance.[5] When a person holds a handheld media player, a subtle notification on the large screen indicates the connection possibility. As she moves closer to the screen, she sees the two devices connect, where the large display progressively reveals more information about the handheld's video content as icons. As the two devices move within touching distance, a touch interface appears that lets the person transfer digital media either through pick and drop or by touching the handheld to one of the icons revealed on the large display.

Revisiting Challenge 4: Providing Feedback

We can also leverage proxemics to provide continuous feedback about a system's status or any errors that occur.

Adjusting feedback output. Because of the embedded nature of many ubicomp systems, often there's no graphical display for showing feedback to the user. Instead, output can be via lights, sounds, speech, or physically moving objects (as in many tangible user interfaces). Assuming a system knows a person's physical orientation and distance, it can adjust the provided output as needed.

The Listen Reader, for example, adjusts the volume of the audio output depending on a person's proximity to a digitally augmented book.[33] Similarly, in our media player, a person sees large preview thumbnails of available videos when at a distance.[5] The screen continuously shows more content as the person moves closer.

Selecting the appropriate feedback modality. Furthermore, a system can select the most appropriate output modality for a person (such as visual versus audible) based on his proxemic relationship. For example, when the person is facing away from a large screen, the system might use an audible signal as a notification. When the person is standing closer to the system and is facing the screen, visual output might be used instead.

Proxemic-dependent revealing of feedback. Details presented to a person can vary depending on his or her distance or orientation relative to the system. Helen Ai He and her colleagues, for example, introduced distance-dependent semantic zoom in an augmented-reality energy viewer for the home.[34] The system adjusts energy-use feedback based on the viewer's proximity to rooms or appliances in a room (detected through fiduciary tags). When a user holds the viewer outside a room's doorway, the system displays that room's energy use. When the person moves into the room, it displays each appliance's energy use on-screen as a colored glow; as the person moves closer to a particular appliance, details of that usage appear first as a text overlay and then as a graph.

Revisiting Challenge 5: Preventing and Correcting Mistakes

Our next design challenge addresses the question of how a person can correct errors, such as those that occur when a system misinterprets a person's action or when the person performs an unintended action.

Inverting actions. One technique that lets a person correct a mistake is performing the inverse/opposite action. The system implicitly responds by reverting to the prior state. For example, in Vogel's ambient display setting, when a person moves closer to the screen, it reveals personal calendar information.[3] If the person didn't want this information made public, he would just step back to make the information disappear. Other proxemic dimensions can be exploited as well. For example, if facing the screen triggers an action, a user could undo that action simply by turning away.

Explicitly undoing actions. Ju presents an opposing strategy to undo actions.[2] Her application runs on the interactive whiteboard, where it implicitly responds to people's actions. This can easily result in an unwanted action—for example, it might automatically move a cluster of ink strokes to the side of the display to free up space. If this was an unwanted action, the person would move closer to the screen (instead of stepping back, as in Vogel's system) to grab the cluster of ink strokes to keep it from moving.

You could also combine both techniques to override the system. In fact, Vogel used both in his system: a person can either use a set of simple hand gestures to trigger or stop certain system functions, or the person can just step back from the screen—both have the same effect.

Using proxemic safeguards. As a safeguard mechanism, actions with a high impact (such as those that delete information or reset the system) could be restricted to occur only when a person is in very close proximity to the device. For example, while a person can manipulate information on an interactive whiteboard from a large distance using remote gestures, she would have to move directly in front of the screen to delete data via direct touch.

Alternatively, actions with high impact could require a certain proxemic relationship in multiple dimensions. For example, to delete something, a person might have to simultaneously be in close proximity to the screen, stand oriented toward it, and look at the screen. The action could also be tentative and undoable as the person remains close but committed as he or she moves away.

Revisiting Challenge 6: Managing Privacy and Security

Next, we review techniques that apply proxemics for managing privacy and security in ubicomp systems.[13]

Proximity-dependent authentication. Access to ubicomp systems can be granted depending on the sensed proximity of people, devices, or other objects. Jakob Bardram discussed proximity-based user authentication allowing access to computers when approached by a person.[35] The system is implemented through authentication tokens (such as pens) that wirelessly authorize a person's access once he or she is close to the computer.

The *tangible security* approach uses the measured proximity between pairs of tokens to authenticate access.[36] For example, a person obtains access to a cell phone only as long as the physical *security token* he carries remains in close proximity. If the phone is lost, strangers can't access its contents because they don't have the security token. Furthermore, Rekimoto combines near-field sensing techniques (such as RFID or infrared) with wireless network communication to seamlessly establish device-to-device connections.[29] Near-field communication initiates the wireless communication channel. That is, a person must not only bring his device close to the other device but also make sure that they're in line of sight to establish the connection.

Distance-dependent information disclosure. Another strategy uses the distance between entities to determine the amount of information shared between them. This approach suggests that "distance implies distrust"[37] and similarly that closer proximity implies trust.

For example, distance-dependent disclosure RFID tags vary information transmitted between the tag and the reader depending on the distance between them.[38] The closer the tag is to the reader, the more information is revealed. Similarly, Vogel's public calendar reveals a person's personal calendar information only when the person moves very close to the display.[3] The information disappears immediately once the person steps back away from the display.

Proxemic-aware privacy mechanisms. Although these approaches consider distance as a factor affecting access, the techniques could be further refined by considering other proxemic dimensions such as orientation, identity, or location. A person's body, face, or gaze orientation can affect the amount of information shared. For example, privacy-sensitive information shown on the display of a proxemic-aware mobile device could be visible when the person is looking at the screen but hidden when he or she looks away. Alternatively, the information might disappear once the system notices another person looking at the display. By considering the identity dimension, a system could use relaxed privacy and security settings when a person is alone but could switch to more restrictive settings when it detects another nearby person or device. By considering location, a mobile ubicomp device could adjust its security settings depending on the type of environment, using higher-level settings in an open office but lower-level security when at home.

By considering the identity dimension, a system could use relaxed privacy and security settings when a person is alone.

Considering people's expectations. Altman's theory considers personal space as a protection mechanism for maintaining a certain level of privacy.[22] This could be leveraged to design systems that respect people's expectations of personal space. That is, the ubicomp system can influence the simultaneous interactions of multiple people in a way that maintains such levels of privacy for everyone involved.

To illustrate, let's revisit Vogel's public ambient display.[3] When people move closer to the display, they get more details from their personal calendar visible on-screen. Thus, people stand next to each other viewing their personal calendars. When considering Altman's theory of balancing privacy through proxemics, the system could separate the large screen interaction areas of the two people. For instance, the areas for viewing personal calendars could require a minimum distance between people.

Despite our belief in the importance of considering proxemic theories and people's expectations of personal space in interaction design, as a contradicting possibility, you might imagine interaction designs that deliberately *violate expectations of proxemics*. Violating a person's personal space as defined by proxemics might not always cause a negative reaction.[39] Depending on a ubicomp application's context and design, deliberate violations of personal space (such as requiring people to stand close to each other) might be an integral part of the user experience (for example, in games or public interactive-art installations).

Overall, we've concentrated on a few example systems and techniques to illustrate how we might address certain ubicomp challenges. Our goal was to inspire design thinking—not provide a complete review or catalogue of solutions. By focusing on how we can apply knowledge in the five proxemic dimensions to ubicomp interaction, we hope to create a new perspective on using proxemics when designing new ubicomp systems that react seamlessly and appropriately to people's expectations.

Furthermore, a single technique might serve different purposes across these challenges. For example, progressively revealing information as a person approaches a display reveals interaction possibilities (challenge 1), affords actions being directed to it (challenge 2), can establish a connection (challenge 3), provides system-response feedback (challenge 4), can be used to prevent and correct mistakes by inverting actions (challenge 5), and lets people manage privacy and security by simply moving to adjust the visible information (challenge 6). We believe this is one of the strengths of proxemics: if we develop techniques with social expectations of proxemics in mind, we can likely apply them as a universal way to mediate many ubicomp challenges.

REFERENCES

1. E.T. Hall, *The Hidden Dimension*, 1st ed., Doubleday, 1966.
2. W. Ju, B.A. Lee, and S.R. Klemmer, "Range: Exploring Implicit Interaction through Electronic Whiteboard Design," *Proc. Conf. Computer Supported Cooperative Work* (CSCW 08), ACM, 2008, pp. 17–26.
3. D. Vogel and R. Balakrishnan, "Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users," *Proc. Symp. User Interface Software and Technology* (UIST 04), ACM, 2004, pp. 137–146.
4. P. Dourish, *Where the Action Is: The Foundations of Embodied Interaction*, MIT Press, 2001.
5. T. Ballendat, N. Marquardt, and S. Greenberg, "Proxemic Interaction: Designing for a Proximity and Orientation-Aware Environment," *Proc. Int'l Conf. Interactive Tabletops and Surfaces* (ITS 10), ACM, 2010, pp. 121–130.
6. S. Greenberg et al., "Proxemic Interactions: The New Ubicomp?" *Interactions*, vol. 18, no. 1, 2011, pp. 42–50.
7. V. Bellotti et al., "Making Sense of Sensing Systems: Five Questions for Designers and Researchers," *Proc. 20th ACM Conf. Human Factors in Computing Systems* (CHI 02), ACM, 2002, pp. 415–422.
8. M. Weiser, "The Computer for the 21st Century," *Scientific Am.*, vol. 265, no. 30, 1991, pp. 94–104.
9. M. Weiser and J.S. Brown, "The Coming Age of Calm Technology," *Beyond Calculation—The Next Fifty Years of Computing*, P. Denning, R. Metcalfe, eds., Springer, 1998, pp. 75–85.
10. B. Schilit, N. Adams, and R. Want, "Context-Aware Computing Applications," *Proc. Workshop on Mobile Computing Systems and Applications*, IEEE Press, 1994, pp. 85–90.
11. G.D. Abowd, E.D. Mynatt, and T. Rodden, "The Human Experience [of Ubiquitous Computing]," *IEEE Pervasive Computing*, vol. 1, no. 1, 2002, pp. 48–57.
12. J. Bardram and A. Friday, "Ubiquitous Computing Systems," *Ubiquitous Computing Fundamentals*, J. Krumm, ed., CRC Press, 2010, pp. 37–94.
13. M. Langheinrich, "Privacy in Ubiquitous Computing," *Ubiquitous Computing Fundamentals*, J. Krumm, ed., CRC Press, 2010, pp. 95–160.
14. W.A.S. Buxton, "Integrating the Periphery and Context: A New Model of Telematics," *Proc. Graphics Interface* (GI 95), Canadian Information Processing Soc., 1995, pp. 239–246.
15. J.R. Aiello, "Human Spatial Behaviour," *Handbook of Environmental Psychology*, D. Stokols and I. Altman, eds., John Wiley & Sons, 1987, pp. 359–504.
16. H. Osmond, "Function as the Basis of Psychiatric Ward Design," *Mental Hospitals Architectural Supplement*, vol. 8, no. 4, 1957, pp. 23–27.
17. E.T. Hall, "Proxemics," *Current Anthropology*, vol. 9, nos. 2/3, 1968, pp. 83–108.
18. R. Sommer, *Personal Space: The Behavioral Basis of Design*, Prentice-Hall, 1969.
19. T.M. Ciolek, "Spatial Arrangements in Social Encounters: An Attempt at a Taxonomy," *Man-Environment Systems*, vol. 8, no. 2, 1978, pp. 52–59.
20. M. Argyle and J. Dean, "Eye-Contact, Distance and Affiliation," *Sociometry*, vol. 28, no. 3, 1965, pp. 289–304.
21. E. Sundstrom and I. Altman, "Interpersonal Relationships and Personal Space: Research Review and Theoretical Model," *Human Ecology*, vol. 4, no. 1, 1976, pp. 47–67.
22. I. Altman, *The Environment and Social Behavior: Privacy, Personal Space, Territory, and Crowding*, Brooks/Cole Publishing, 1975.

23. R. Want et al., "The Active Badge Location System," *ACM Trans. Information Systems*, vol. 10, no. 1, 1992, pp. 91–102.

24. B. Brumitt et al., "Easy Living: Technologies for Intelligent Environments," *Proc. Handheld and Ubiquitous Computing* (HUC 00), 2000, pp. 12–27.

25. T. Prante et al., "Hello.Wall—Beyond Ambient Displays," *Adjunct Proc. Ubicomp*, 2003, pp. 277–278.

26. H. Gellersen et al., "Supporting Device Discovery and Spontaneous Interaction with Spatial References," *Personal Ubiquitous Computing*, vol. 13, no. 4, 2009, pp. 255–264.

27. R. Vertegaal and J.S. Shell, "Attentive User Interfaces: The Surveillance and Sousveillance of Gaze-Aware Objects," *Social Science Information*, vol. 47, no. 3, 2008, pp. 275–298.

28. C. Swindells et al., "That One There! Pointing to Establish Device Identity," *Proc. Symp. User Interface Software and Technology* (UIST 02), ACM, 2002, pp. 151–160.

29. J. Rekimoto et al., "Proximal Interactions: A Direct Manipulation Technique for Wireless Networking," *Proc.* Human-Computer Interaction (INTERACT 03), IOS Press, 2003, pp. 511–518.

30. G. Ramos et al., "Synchronous Gestures in Multi-Display Environments," *Human-Computer Interaction*, vol. 24, no. 1, 2009, pp. 117–169.

31. L. Holmquist et al., "Smart-Its Friends: A Technique for Users to Easily Establish Connections between Smart Artefacts," *Proc. Ubiquitous Computing* (Ubicomp 01), Springer-Verlag, 2001, pp. 116–122.

32. C. Kray et al., "Group Coordination and Negotiation through Spatial Proximity Regions around Mobile Devices on Augmented Tabletops," *Proc. Tabletop*, IEEE Press, 2008, pp. 1–8.

33. M. Back et al., "Listen Reader: An Electronically Augmented Paper-Based Book," *Proc. SIGCHI Conf. Human Factors in Computing Systems* (CHI 01), ACM, 2001, pp. 23–29.

34. H.A. He, "One Size Does Not Fit All: Extending the Transtheoretical Model to Energy Feedback Technology Design," MSc thesis, Dept. of Computer Science, Univ. of Calgary, 2010.

35. J.E. Bardram, "The Trouble with Login: On Usability and Computer Security in Ubiquitous Computing," *Personal and Ubiquitous Computing*, vol. 9, no. 6, 2005, pp. 357–367.

36. Y. Chen and M. Sinclair, "Tangible Security for Mobile Devices," *Proc. 5th Ana. Int'l Conf' Mobile and Ubiquitous Systems: Computing, Networking, and Services*, Inst. for Computer Sciences, Social-Informatics and Telecommunications Engineering (ICST), 2008, pp. 1–4.

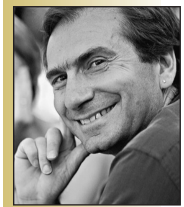
37. K.P. Fishkin, S. Roy, and B. Jiang, "Some Methods for Privacy in RFID Communication," *Security in Ad-Hoc and Sensor Networks*, Springer, 2005, pp. 42–53.

38. N. Marquardt et al., "Rethinking RFID: Awareness and Control for Interaction with RFID Systems," *Proc. ACM Conf. Human Factors in Computing Systems* (CHI 10), ACM, 2010, pp. 2307–2316.

39. J.K. Burgoon and J.L. Hale, "Nonverbal Expectancy Violations: Model Elaboration and Application to Immediacy Behaviors," *Comm. Monographs*, vol. 55, no. 1, 1988, pp. 58–79.

the AUTHORS

Nicolai Marquardt is a PhD candidate in the Department of Computer Science at the University of Calgary. As a member of the Interactions Lab, he's working on novel interactive computer systems and interaction techniques. In particular, his research of proxemic interactions focuses on how to exploit knowledge about people's and devices' spatial relationships in interaction design. Marquardt received his MSc in media systems from the Bauhaus University in Weimar. Contact him at nicolai.marquardt@ucalgary.ca.



Saul Greenberg is a full professor and Industrial Research Chair in the Department of Computer Science at the University of Calgary. His research interests include human-computer interaction, computer-supported cooperative work, and ubiquitous computing. Greenberg received his PhD in computer science from the University of Calgary. He received the Canadian Human Computer Communications Society (CHCCS) Achievement award and was elected to the ACM CHI Academy for his overall contributions to the field of human-computer interaction. Contact him at saul.greenberg@ucalgary.ca.