THE DESIGN OF IMPLICIT INTERACTIONS

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ABSTRACT

This work proposes and evaluates a theory and method for implicit interaction design. People rely on implicit interaction to communicate queries, offers, responses, and feedback to one another; this research posits that these interactions can be applied analogously to the design of interactive devices to improve people's ability to "communicate" with objects whose behaviors are dynamic and demonstrative.

This multiple-method research approach consists of three components. First, we present a theoretical framework and methodology for implicit interaction design. Next, we explore and experimentally evaluate the theory by applying it to two concrete challenges: the design of (1) automatic doors and (2) electronic whiteboards. Through these efforts, we are able to show the applicative value of the theory, evaluate its utility and begin to explore its broader implications for the wide range of interactive technology fields.

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HIDING IN PLAIN SIGHT

Understanding Implicit Interactions and their Implications for Design[1]

Imagine, for a second, a doorman that behaves like an automatic door does. He does not acknowledge you when you pass by or approach. He gives no hint which door can or will open—until you wander within 6 feet of the door, whereupon he flings the door wide. If you arrive after hours, you might stand in front of the doors for a while before you understand that the doors are locked because the doorman's blank stare gives no clue.

If you met such a doorman, you might suspect psychosis. And yet this behavior is typical of our day-to-day interactions not only with automatic doors but any number

[1] Significant portions of this chapter are currently accepted for publication in the paper, "The Design of Implicit Interactions," by the dissertation author, Wendy Ju, and Larry Leifer, in an upcoming issue of Design Issues. The dissertation author was the primary researcher and author for this paper.

of interactive devices. Our cell phones ring loudly even though we are clearly in a movie theatre. Our alarm clocks forget to go off if we do not set them, even if we've been getting up at the same time for years. Our computers interrupt presentations to let everyone know that a software update is available. The infiltration of computer technologies into everyday life has brought these interaction crises to a head. As Neil Gershenfeld observes, "There's a very real sense in which the things around us are infringing a new kind of right that has not needed protection until now. We're spending more and more time responding to the demands of machines." [Gershenfeld 1999]

These problematic devices are symptoms of our as-yet lack of sophistication in designing interactions that do not constantly demand the input or attention of the user. Many have suggested that more sophisticated artificial intelligence or elaborate networks of sensors may be the solution to the problem of obnoxious and overbearing machines. However, might it also be that we are missing more obvious solutions, ones hiding in plain sight in our everyday interactions with one another?

MOTIVATION

In *The Design of Everyday Things*, Don Norman pointed out that people are often unaware about how simple everyday objects fail even when they do so routinely.

> "Doors?" I can hear the reader saying, "you have trouble opening doors?" Yes. I push doors that are meant to be pulled, pull doors that should be pushed, and walk into doors that should be slid. Moreover, I see others having the same troubles–unnecessary troubles. There are psychological principles that can be followed to make these things understandable and usable.

By calling attention to the design principles violated by these doors, Norman enabled a generation of designers to understand how objects should be designed to help minimize error. It is for this reason that misleadingly designed doors are today given the honorific, "Norman doors."

The modern-day equivalent of the Norman door is the automatic door. Because people interact with automatic doors every day—entering stores, taking elevators, riding buses—it is often assumed that that our understanding of how automatic doors should be designed must be sufficient. Informal observations of people actually interacting with automatic doors, however, reveal that people repeatedly run into the same difficulties with automatic doors time and again. It is not only that people make slips—becoming startled, say, when they inadvertently trigger a door to open, or mistaking non-automatic doors for automatic doors. People actually make conceptual errors in interacting with doors. People make repeated runs at doors that won't open because they are unaware that they are trying to enter before or after store hours. People are startled at the direction the doors open, or the speed with which they open or shut. Anyone who has been whacked by a door that opens the wrong way or pinched by sliding doors that close too quickly understands that the experience can be frightening—and even lethal.

Automatic doors exemplify the broader challenges of designing the interactive systems that people face incidentally everyday: vending machines, ticket turnstiles on a bus or at a train station, information kiosks at a museum, auto-flush toilets, motion-triggered room-lights, and automatic automobile door locks. While the problems people face with automatic doors are easily classified using Norman's definitions of slips and mistakes, there are two key reasons that the design principles Norman presented for everyday objects like traditional doors (use knowledge in the world and in the head; simplify the structure of tasks; make things visible; get the mappings right; exploit the power of constraints; design for error; standardize) fall short of fully remedying the problems of automatic doors. First of all, automatic door behavior is dynamic—sometimes the automatic doors are willing and able to open, and sometimes they are not; sometimes the doors should welcome you in, and sometimes they should warn you away—so the proper affordance varies. Very often, the behavior varies in reaction to changes in the world that we can perceive—the driver of the car walks away from the car, and the car door locks—but sometimes it varies in reaction to changes that are subtler, like the time of day or the national security threat level. The challenge, then, of projecting intended use of dynamic systems to the user is akin to trying to design signage for doors that sometimes should be pushed and other times should be pulled; the solution requires intermittent rather than static cues, and needs in particular to pre-empt the mode errors that inevitably arise from having the same system behave differently in different situations.

The second reason why traditional design principles fall short for interactive systems has to do with the potential for autonomous action. Because automatic doors can act without explicit manipulation or triggering by the user, the door needs not only to show how it can be used, but must also demonstrate how it will act, and also hint at what the consequences of its actions will be. The manner in which doors automatically open and close can signal whether an elevator is full, that store hours have come to an end, or that the train is about to leave. Because the interactive system is actively signaling, it sets up changing expectations for how the interaction between man and machine; no longer are we considering only slips and mistakes on the part of the user, but also errors of commission and omission on the part of the device, when it acts or fails to act as expected. Thus, the *dynamic* and *demonstrative* capabilities of interactive systems represent new challenges to and opportunities for the design of everyday things.

The use of physical movement and other implicit means of signaling can be thought of as an extension to theory of affordances. Affordances are variously described as how people perceive the physical [Gibson 1979] or intended [Norman 1988] properties of an object that relate its potential for use. Gaver extended the notion of affordances into the realm of the interactive with the concept of sequential affordances, which are revealed over time [Gaver 1991]. Objects employing these complex affordances may be thought of as implicitly communicating potential for action through their dynamic behavior.

Consider the following two products:

Figure 1. Two interfaces utilizing capacitive touch: (a) touch lamp (b) Apple Power Mac G4 Cube

On the left in Figure 1, we have a touch-sensitive lamp, and on the right we have the Apple Power Mac Cube. The touch-sensitive lamp utilizes capacitive sensing so that any touch to its metal surfaces will turn the light on or off; the Power Mac, similarly, features capacitive sensing that allows a touch at the site of a glowing dot to turn the computer on and off. However, the Power Mac's button also incorporates some dynamic behavior; its glow pulses brighter and dimmer when the machine is off, inviting users to turn it on, and glows bright when the machine is on, indicating its state. The Power Mac's button draws the user's attention, and its finger-sized glow suggests the mode of proposed interaction. In contrast, the touch-sensitive lamp does nothing to communicate to the novice user how to engage with it. Both interactions are novel; neither features the normal on/off buttons or toggles present on many other lamps or computers. Both products could be described as subtle; it is not overtly obvious how to turn each on. However, they differ in that the Power Mac's glow implicitly communicates to the user that an interaction is possible and hints to the user how to initiate that interaction and what might occur next.

In the parlance of the design and human-computer interactions communities, the glow of the Power Mac's button is commonly referred to as an affordance—a perceived and actual property that indicates how the button is meant to be used—and the brightening response is referred to as feedback—a means of giving the action (in this case, of pressing the button) an immediate and obvious effect. These terms, made ubiquitous by Don Norman's *The Psychology of Everyday Things* [Norman 1988], successfully help designers map features to the principles they embody. However, while these terms are descriptive, they do not prescribe solutions; the designer still must figure out, for instance, how to use affordances or feedback to show users that they could touch any metal part of the lamp to turn it on.

This dissertation is based on the paradigm that because interactive systems are *dynamic* and *demonstrative*, their design can be enhanced using interaction techniques derived from human-human interaction. That is to say, the button's appearance and behavior changes over the course of the interaction between the button and the user, and the changes have an overtly (as opposed to incidentally) communicative function. The technique employed by the Power Mac's glow is an instance of a *cue* and its brightening response to one's touch is an instance of *system demonstration.* Both are implicit interaction techniques that have analogs in our everyday interactions with other people; people *cue* to invite an interaction and overtly *demonstrate* their actions to show us what is happening. This approach augments existing principles of design like affordances and feedback by suggesting techniques to achieve them: the touch-sensitive lamp, for instance, could demonstrate its function by glowing softly and could cue users by playing the sound of hands brushing metal.

Traditional human-computer interactions and human-machine interactions have focused on the realm of *explicit interactions*, where the use of computers and interactive products rely on the overt input and output common in command-based or graphical user interface-based interfaces. In these interfaces, the agency lies wholly with the user. *Implicit interactions,* on the other hand, are based on inputs and outputs that are jointly negotiated—the button that appears only to people authorized to press it, the computer desktop that makes some icons slightly larger and easier to click on based on its expectations of what will occur next. These types of interactions are an inevitable part of what some call "smart" products, products whose actions contain some degree of agency or of activity that occurs without the explicit behest or awareness of the user. These products will become increasingly important as human-computer interactions extend beyond the desktop computer into new arenas, arenas such as the automobile, the meeting room, or the home, where the driver is physically, socially, or cognitively engaged. In addition, these interactions are becoming more prevalent even in traditional computing interfaces as the body of users and application areas extends to situations where people are not able to exercise full agency and control—when users are novices or even distracted experts.

We humans have an abundance of experience employing implicit interactions in our day-to-day interactions with one another. We often employ them without conscious thought: we modulate our speaking volume based on ambient noise level, use smaller words when explaining things to children and hold the door open for others when we see that their arms are full. These accommodations do much to smooth our day-to-day interactions with one another and yet are made without explicit command. The success of these interactions relies less on extraordinary intelligence and more on sophisticated negotiation of changing contexts and subsequent behaviors. If designers could better understand implicit interactions and employ implicit interaction techniques in the design of our products and services, we could begin to resolve the strange psychosis that seems to afflict many of our new inventions by using insights present in our everyday interactions with one another.

BACKGROUND

The theory of implicit interactions posits that people rely on conventions of social interaction to subtly communicate queries, offers, responses, and feedback to one another, and that these interactions can be applied analogously to the design of interactive devices to improve people's ability to "communicate" with interactive devices. For example, the "offer" is one type of implicit interaction; it performs the critical function of alerting potential interactants to the possibility of a joint action [Clark 1996]. A deeper understanding of the dynamics and demonstrations present in human-human implicit interaction could greatly improve user interactions with interactive devices by enabling interaction designers to improve device intuitiveness

[Norman 2007], for example, or to enable "peripheral" interaction with devices that do not require a user's undivided attention [Buxton 1995].

Implicit Interactions in Human-Computer Interactions

The term "implicit interaction" was first coined in human-computer interactions by researchers working in the area of ubiquitous computing. Albrecht Schmidt, in his seminal paper, "Implicit Human-Computer Interaction Through Context," defined implicit human-computer interaction to be "based on the assumption that the computer has a certain understanding of our behaviour in the given situation. This knowledge is then considered as an additional input to the computer while doing a task." [Schmidt 2000] He observes that implicit interaction is based on perception and interpretation of the situation and context.

This approach of trying to gather background information about a user's context as a way of augmenting traditional human-computer interaction was a natural outgrowth of Marc Weiser's vision for "The Computer for the 21st Century." Weiser projected a future where computer technologies "disappeared" into the environment, changing in form to be embedded seamlessly into the daily lives of users [Weiser 1991]. In analyzing the ways that the projected "computer of the future" would differ from contemporary machines [Nielsen 1993], Jakob Nielsen found that "all previous generations of UIs, whether batch-, line-oriented, full-screen or WIMP, have all had one defining characteristic in common: They were all based on the concept of an explicit dialogue between the user and the computer in which the user commands the computer to do something."

Schmidt's concept of implicit interactions between humans and computers focused on the dynamics of interaction, the way that a computer in the world could surmise what to do in different contexts without explicit command from the user. This "background sensing plus interpretive model" approach is prevalent in the field of human-computer interactions (HCI): Intel's initiative into Proactive Computing [Tenenhouse 2000], Microsoft Research's work on Bayesian modeling of attentional foreground and background [Czerwinski 2000] [Hinckley 2005][Wilson 2005], and

Georgia Tech's Context-Aware Computing [Salber 1999] have been oriented on the technological issues of sensing, aggregating data, developing user and task models, and performing inference.

Another body of research that has been closely related to implicit interaction is ambient displays. Whereas the preceding research projects focus on providing implicit inputs to the computer, research on ambient interaction is largely focused on providing implicit outputs to the user [Wisenski 1998][Mankoff 2003][Streitz 2003]. A variety of research projects, such as James Fogarty's work on User Interruptibility [Fogarty 2005] and Adam Fass' Messydesk and Messyboard [Fass 2003], have sought to use information from sensors and models to control the degree of "ambientness" or "explicitness" information should be displayed with. One of the recurring tropes in this line of research is the idea that implicit interactions need to be "subtle," "invisible" or generally undemonstrative.

Implicit Interactions in Human-Human Interactions

The way in which implicitly interactive systems have been designed to date seems to imply that HCI researchers perceive that people interact with one another using very sophisticated a priori models about how to behave in every interactive situation. A quick review of how humans actually interact suggests otherwise.

Implicit interactions serve to enable what Herb Clark calls "joint actions" between two or more participants [Clark 1996]. Clark uses H.P. Grice's term "implicatures" to refer to the portion of what conversational "mean or infer beyond what is said," and the term "signals" to refer to demonstrations, indications, or descriptions that Clark states are also "essential to what speakers mean." These interactions may precede, prevent, or augment verbal or other explicit communication, but also work in their own right to achieve communication. Clark does not delineate between "implicatures" or "signals," so our term "implicit interaction" encompasses the superset of "implicatures" and "signals."

The implicitly communicative effect of body, space and motion was also observed by the cultural anthropologist Edward T. Hall [Hall 1966]; what he labeled the "hidden dimension" of human interaction is often referred to in popular parlance as "body language." Both Clark and Hall's choice of language—"implicature" and "hidden"—suggest the obscured nature of implicit interactions, but both also took pains to argue that the meaning of these communications is usually clearly, if not always consciously, intended and interpreted by the actors that formed or received them.

Research suggests that the ability to interact implicitly is not tied to specific contexts but in fact is a fundamental aspect of communication itself. Humans exhibit these abilities to interact implicitly and to interpret the implicit interactions of others from infancy [Beebe 1998]. Cognitive neuroscience studies of monkeys suggest that our ability to implicitly interpret the gestures and actions of others—to bridge 'doing' to 'communicating'—is due to the fact that the same neurons discharge when we see an action performed as when we perform the same action ourselves [Rizzolatti 1998].

Previous research indicates that nonverbal communication enables people to express feelings, emotions, motivations, and other implicit messages to one another [Argyle 1988]. Additionally, implicit cues often have a task-oriented communicative function as well. For instance, at a grocery market, a shopper's placement of grocery items on the check-out counter communicates to the grocery clerk what items the shopper wants to purchase; the shopper can further ground their communication by lifting and setting objects back down for emphasis and confirmation [Clark 2003].

The general essence of the research in implicit human-human interactions suggests not that people have sophisticated models for how to *act* in different contexts but rather that they have sophisticated models for how to *communicate*, which they use to negotiate action in a variety of contexts.

APPROACH

This dissertation explores the use of implicit interactions in the design of everyday interactive objects. This dissertation is premised on the theory that implicit interactions function through regular patterns of communication; hence, it hypothesizes that interactions designed in accordance with these patterns will be recognizable and effective. To test this theory, we first present a design methodology and framework intended to make our theory of implicit interaction generative and generalizable. Then, we apply the method and framework to create implicit interaction techniques and use them in the design of automatic doors and electronic whiteboards. As part of this process, we establish a deeper understanding of how implicit interactions function, and what responses these interactions affect. In total, this work on implicit interaction design lays the groundwork for an emerging area of applied design research [Buchanan 2001] focused on improving the interactions between people and computer-based systems embedded in the world.

Point of View

One of the themes of this dissertation is that implicit interactions share basic structural patterns and that people are used to recognizing and reacting to these patterns, *even when they are not consciously aware that they are doing so.* This paradoxical lack of awareness in effective communication is the crux of the power of implicit interactions—that information is transmitted with minimal effort or distraction on the part of the interactant. Because the patterns remain constant despite changes in actors or contexts, we hypothesize that by understanding how implicit interactions between humans help to manage attention, govern expectations, and decrease cognitive load, designers would be able to cross-apply solutions from one domain to another.

By outlining a design method that is useful in creating a broad class of interactions, we seek to complement technology-based approaches (which focus, for instance, on sensors and architectures that enable implicit interaction) and analysis-based approaches (which would investigate implicit interaction primarily through studies and controlled experiments of existing systems) towards implicit interaction design. This design-based approach has two main objectives: to be *generative*—that is, to guide designers in a constructive fashion in designing implicit interactions—and to be *generalizable*—that is, to suggest techniques and methods that are applicable to interaction designers working on a wide array of ubiquitous computing scenarios. Just as toolkits provide a common architecture and library for software developers working on similar classes of applications [Meyers 2000], we intend for the implicit interaction framework and methodology to help designers generate designs for similar types of interactions.

Methodology

The goal of this dissertation is to provide groundwork towards a generative technique for designers of interactive designs. To this end, our methodology is to suggest a framework for implicit interaction design, and to validate this framework through empirical application in diverse domains.

In this dissertation, we put forth a design framework for implicit interactions and then detail investigations in which we ask:

- Are assumptions of the framework valid?
- Is the framework useful for capturing observations?
- Is the framework useful for suggesting solutions?

As part of this broader effort to develop, validate and evaluate this design framework, we use a wide variety of theories and research techniques from other disciplines to develop, validate and assess specific designs, including field observation, controlled laboratory experiments, longitudinal studies, and web-based studies. This mixed-method research technique is typical of research in applied fields such as human-computer interaction [Mackay 1995], education [Greene 1989], or medicine [Cresswell 2004] where the flexibility to pose questions and receive answers in a context-appropriate fashion justifies the somewhat catholic approach to research. Because the selection of method and interpretation of results is a critical aspect of the design of this broader research, detailed explanations will be presented for each method that is employed in this work.

Terminology

Another consequence of the multi-disciplinary approach used in this design research is the terminology inherited from each field. Here we discuss the distinction between some easily confused terms used in this dissertation:

Implicit vs. Explicit

The term *implicit interaction* is somewhat problematic in that it sets up an expectation of a clear dichotomy between implicit and explicit interactions; this seems to beg the development of an "implicit litmus test," with features and rules that separate one type of interaction from the other. In actuality, the range from implicit to explicit interaction is more of a continuum, and, given the many factors that influence the implicitness/explicitness of an interaction, even the framework presented in this dissertation is an admitted over-simplification of the range of phenomena—albeit a useful one.

In the interest of providing useful oversimplifications–and ruling out unuseful ones, we provide the following table, highlighting the key differences between implicit and explicit interactions. The three primary criteria separating explicitness and implicitness are attention, exclusivity and grounding. Explicit events take place in the attentional center, whereas implicit events take place in the attentional periphery. The space of the attentional center is limited, and hence explicit actions exclude other focal targets. In contrast, the attentional periphery is both larger in area and less demanding of cognitive resources, and so implicit actions are non-exclusive; multiple actions can be observed and interpreted simultaneously. The distinction with regard to ground may be the most nuanced of these three criteria. Explicit interactions are based in commonly understood conventional meaning, whereas the meaning of implicit interactions is not conventional, but is calculable; that is, the receiver can figure out the meaning. We say that the meaning of implicit interaction is negotiated precisely because implicit interactions require some level of inference or interpretation on the part of the receiver.

Table 1. Key Differences between Explicit and Implicit Actions

	Explicit Actions	*Implicit Actions*
Attention	Occurs in center of attentional space	Occurs in attentional periphery
Exclusivity	Excludes other focal targets	Non-exclusive
Grounding	Based on conventional meaning	Based on calculable meaning

Two characteristics that do *not* distinguish implicit and explicit actions are clarity and intent. Based on the lay definition of explicit, one might think that explicit actions are those whose meanings are clear and consequently that implicit actions are those whose meanings are unclear. The purpose of this dissertation is to help interaction designers clearly interpret and signal implicit interactions, so clarity will not be a defining factor between implicit and explicit. Another tempting idea is to think that explicit interactions are those that are deliberate and that implicit interactions are those that are inadvertent. Because successful implicit interactions occur in the attentional periphery and are non-exclusive, it may be that a person inadvertently uses an implicit interaction, but inadvertence is not the cause but an effect of the implicitness. The set of actions that are inadvertent and have no meaning is far wider than the set of actions that are inadvertent and implicit.

Because our discussion focuses on communication between interactants, it does not make sense to talk about the implicitness or explicitness of various signals in a vacuum. Take, for example, the case of the beeping noise that a truck makes backing up. For those who grew up in a different culture, the beeps explicitly demand attention, but have no associated conventional meaning. For those who are familiar with such trucks, however, the beeps implicitly indicate that a truck is backing up—just as clearly as a motor sound implies motion. In terms of the signal, it doesn't make much sense to talk about whether it is implicit or explicit without knowing who is hearing it; in this case, the beeping truck is implicit in different ways for the two different receivers. However, we can speak of the truck employing an implicit interaction technique in the way that it overtly calls attention to its actions at the crucial moment when it is necessary for safety reasons to make sure people in the vicinity either look to notice it or know what to expect if they don't. The beeping is not an action taken for the benefit of the truck driver who is controlling the truck (who, ostensibly, would be cued by her own actions and the direction the truck was moving), but rather, it is an action intended for the other people who might inadvertently "interact" with the truck because the interaction was not initiated by them.

Tacit vs. Implicit

Another related distinction that people often wonder about is the relationship between implicit interactions and tacit knowledge. Tacit knowledge describes things that people know but cannot describe directly, such as how to properly hit a golf ball with a golf club. Implicit communications, on the other hand, relate to things that people communicate indirectly. Sometimes, the understanding of how to use and how to interpret implicit interactions is so innate and so tacit, that people are wholly unaware that they are using these techniques. This tacitness is the effect of effective implicit interactions and not the cause.

People's tacit understandings of different stimuli and their meanings can have an important effect on an interaction's implicitness. In the beeping truck example above, some people who hear the beep tacitly understand that a truck is backing up—tacitly because they may not even be aware why they know that to be the case—whereas other people have to consciously map the signal to the meaning ("Oh, that beeping means a truck is backing up.") and still others do nothing more than notice the signal ("What is that beeping about?"). Over time, stimuli that originally have no tacit meaning can come to be mapped "naturally" to accompanying actions and interactions. This is the case with the dinner bell in Pavlov's classic experiments with dogs. While the bell has no inherent physical relationship with the food being served to the dog, over time, the dog associates the bell with the food, so much so that just the ringing of the bell causes the dog to salivate.

There are admittedly many interesting aspects of the relationship between tacit knowledge and implicit interactions, but they are not explored in depth in this dissertation. The issue of tacitness depends very much on people's internal attitudes towards things in the world [Heidegger 1962], which are important but require different methods to interrogate than the externally communicated exchanges this dissertation is focused on. Thus, we focus on the role of attentional demand and initiative in implicit interactions.

Behavior vs. Technique

This dissertation will use the word “behavior” to talk about the actions and responses of people and animals and “technique” to talk about the actions and responses of systems and objects designed by people. Both terms imply action and some degree of intent. However, we differentiate the terms to describe human action and human-designed machine action both to clarify who is acting and also to remind the reader that although the behaviors and techniques being discussed are analogous, we are not claiming that they are the same. Just as a social response to computer technology does not necessarily indicate that people mistake computers for other people, the effectiveness of implicit techniques in machines does not imply that people mistake automatic doors for people, either [Reeves 1996].

Interactant

Because this dissertation commonly discusses interaction patterns in which either a person or a device is the “actor,” and because it is desirable to differentiate whether it is a person or non-person who is acting, we will use the word “interactant” when the actor in an interaction could be either a person or device.

ORGANIZATION

This dissertation is presented in five chapters including this one. As a guide to the organization of the remainder of this dissertation:

> Chapter 2 poses a framework for understanding implicit interaction, delves into the theoretical basis for its formulation and outlines the role of interaction patterns and techniques for designing interactive products.
>
> Chapter 3 presents the design and evaluation of gesturing doors to illustrate that people respond to implicit interactions from non-anthropomorphic interactive objects in a manner analogous to the way they respond to such implicit interactions with people.
>
> Chapter 4 presents the design and evaluation of an interactive whiteboard to explore the effect of employing implicit interaction techniques in novel user interfaces.
>
> Chapter 5 summarizes the thesis with a discussion of potential applications, limitations and principles of implicit interaction design.

CONCLUSION

This dissertation examines the hypothesis that interactive products can be designed by leveraging an understanding of the structure of joint action. Specifically, this dissertation seeks to examine *implicit interactions*, which are ways of communicating that go beyond conventional and verbalized interactions. This work presents a framework that allows designers to map and analyze interaction patterns so as to illuminate how implicit interactions function. This work does not seek to replace the designer or automate her process; rather it seeks to highlight how her observations and knowledge of human activity can inform the design of interactive products to come.

Chapter 2

SETTING THE STAGE

A Methodology and Framework for Implicit Interaction Design[1]

The prevailing approach towards designing interactive devices and other ubiquitous technologies is primarily ad-hoc. The engineer or designer programming the interaction employs "natural design," making reasonable guesses about what might work based on intuition. Designers in academic research contexts try to ground their intuition with data; in the area of implicit interaction, this often means using ethnography and contextual inquiry techniques to profile the specific domain in question, then to develop some system to link sensed context to desired behaviors, and finally to use computational and sensing technology to deploy this domain-specific knowledge in use. [Schmidt 2000]

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[1] Significant portions of this chapter were originally published in the paper, "The Design of Implicit Interactions," by the disseration author, Wendy Ju, and Larry Leifer, in an updoming issue of Design Issues. The dissertation author was the primary researcher and author for this paper.

While this approach is generative, it is rarely generalizable, for the knowledge about how to behave in one specific situation does not translate to any other.

The absorption with modeling human intelligence gives short shrift to the richness of human interactions. What if our true talent as human interactants is less a wealth of situation-specific intelligence so much as a measure of situation-independent suave? This chapter presents an implicit interaction design method and framework premised on the idea that knowledge about how to be courteous and communicative is as critical as context-specific knowledge or logic. The theory of implicit interactions posits that people rely on conventions of implicit interaction to subtly communicate queries, offers, responses, and feedback to one another, and that these interactions can be applied analogously to the design of interactive devices to improve people's ability to "communicate" with interactive devices. This know-how about how to communicate through behavior has the benefit of being generalizable, because it transcends context.

This approach is also generative, in that it specifies how designers can come up with solutions. In this respect, it is distinct from the approach that tries to achieve implicit interaction through broad principles. Alan Cooper and Robert Reimann's About Face 2.0, for example, provides the following guidance for designing considerate software: "Considerate software takes an interest. Considerate software is deferential. Considerate software is forthcoming. . . Considerate software doesn't ask a lot of questions. Considerate software takes responsibility. Considerate software knows when to bend the rules." [Cooper 2003] This is not bad advice—it is certainly general enough—but these guidelines do not actually help designers determine when an interactive system should take an interest, and when it should not ask a lot of questions.

In this chapter, we flesh out some of the basic implicit interaction techniques mentioned in the previous chapter by showing the method used to extract implicit techniques out of observed human-human interaction and by presenting a framework that helps explain how these different techniques work.

IMPLICIT INTERACTION DESIGN METHODOLOGY

Because implicit interactions occur outside of the user's notice or initiative, they can be challenging to design; it is insufficient to project what commands we might issue as users in situations where the command-and-control paradigm would not normally prevail. Instead, it is important that the designers of implicit interactions pay deeper attention to the interplay between interactants. Our design methodology for implicit interactions uses interaction patterns to help designers of objects model how to engage in everyday interactions with other people.

Interaction Patterns

The patterns of everyday interactions have been studied by those in other disciplines. Sociologists, for instance, represent what Erving Goffman calls the "strips of activity" as detailed narratives, setting the general context and describing specific behaviors [Goffman 1967]. Artificial intelligence researchers, such as Roger Schank and Robert Abelson, choose to use "scripts"—stereotyped sequences of actions that define well-known situations [Schank 1977].

Like pattern languages [Alexander 1977], these interaction patterns provide templates for solutions that designers can share with one another. However, whereas design patterns suggest high-level approaches to specific classes of design problems based on previous successful designs [Borchers 2001], our interaction patterns provide detailed instructions for the oft-implicit communications between actors and are derived from observations in the world. Because of both the interactive and the temporal component inherent in interaction, interaction patterns bear stronger resemblance to the "dances" [Hall 1984] or "silent language" [1973] between people described by Hall than to the more physical or technological patterns suggested by Alexander or Borchers.

In the scripted example below, we show two interaction sequences: one with a doorman and another, patterned after the first, with an automatic door that analogously mimics the doorman's implicit behaviors.

Setting: On a street sidewalk with a entrance to a building in the middle of the block.	Setting: On a street sidewalk with an entrance to a building in the middle of the block.
Roles: DOORMAN, PASSERBY	Roles: DOOR, PASSERBY
Sequence:	Sequence:
DOORMAN: [stands in front of door, wearing red uniform]	DOOR: [exists, with sign that says "automatic door"]
PASSERBY: [walks down street, in a path that will pass door]	PASSERBY: [walks down street, in a path that will pass door]
DOORMAN: [spots person walking down street]	DOOR: [sensors notice motion down the street]
PASSERBY: [notices doorman with red refinery in front of door, keeps walking]	PASSERBY: [notices door frame, keeps walking]
DOORMAN: [puts gloved hand on door handle]	DOOR: [makes a soft motor hum noise, as if preparing to open]
PASSERBY: [slows down a little, looks into doorway]	PASSERBY: [slows down a little, looks into doorway]
DOORMAN: [opens door slightly]	DOOR: [opens a little, jiggling its handle]
PASSERBY: [keeps walking past door, turns to look down street]	PASSERBY: [keeps walking past door, turns to look down street]
DOORMAN: [lets door shut, takes hand away from door handle]	DOOR: [lets door shut]

The doorman employs proactive, low-attention techniques to signal his capability for opening doors. He does this through *overt preparation*, when he puts his gloved hand on the door handle, and through an *enactment technique*, when he pulls the door open a little as a suggestion of his offered service.

An interaction designer designing an automatic door can use the doorman pattern to motivate questions such as how the door draws attention to itself, how it communicates its role as a portal, how it introduces its affordance. Such steps can sometimes be accomplished implicitly; the door's mere physical form serves to draw attention and communicate its door-ness. The designer can also look for clever ways to achieve the effects of each step: by opening a little when a person walks by, for example, the automatic door can simultaneously draw attention, define its role as a door and introduces its ability to open automatically by softly humming in overt preparation or jiggling its handle (as enactment). The interaction pattern helps designers to determine the roles, setting and sequence of the interaction to be designed. The interaction analogues allow the designer to imagine functionally equivalent actions, mapping the capabilities of the automatic door against the techniques employed by the doorman, without slavishly and literally replicating his actions.

FRAMEWORK FOR IMPLICIT INTERACTION

Implicit interactions enable communication without using explicit input or output. One way that an interaction can be implicit is if the exchange occurs outside the attentional foreground of the user. This occurs in traditional computing—when the computer auto-saves your files or filters your spam e-mail, for instance—as well as in ubiquitous computing interaction. The other way that an interaction can be made implicit is if the exchange is initiated by the computer system rather than by the user—if the computer alerts you to new mail or when it displays a screensaver. (It may seem counter-intuitive that something that grabs your attention could be implicit, but it is important to remember that the interaction is based on an implied demand for information or action, not an explicit one.)

This framework models interactions as the exchange between a person (sometimes called the user or actor) and an object (sometimes referred to as the computer, robot or, more generically, the system). This is limited to describing dyadic relations but provides a useful basis for modeling basic interactions.

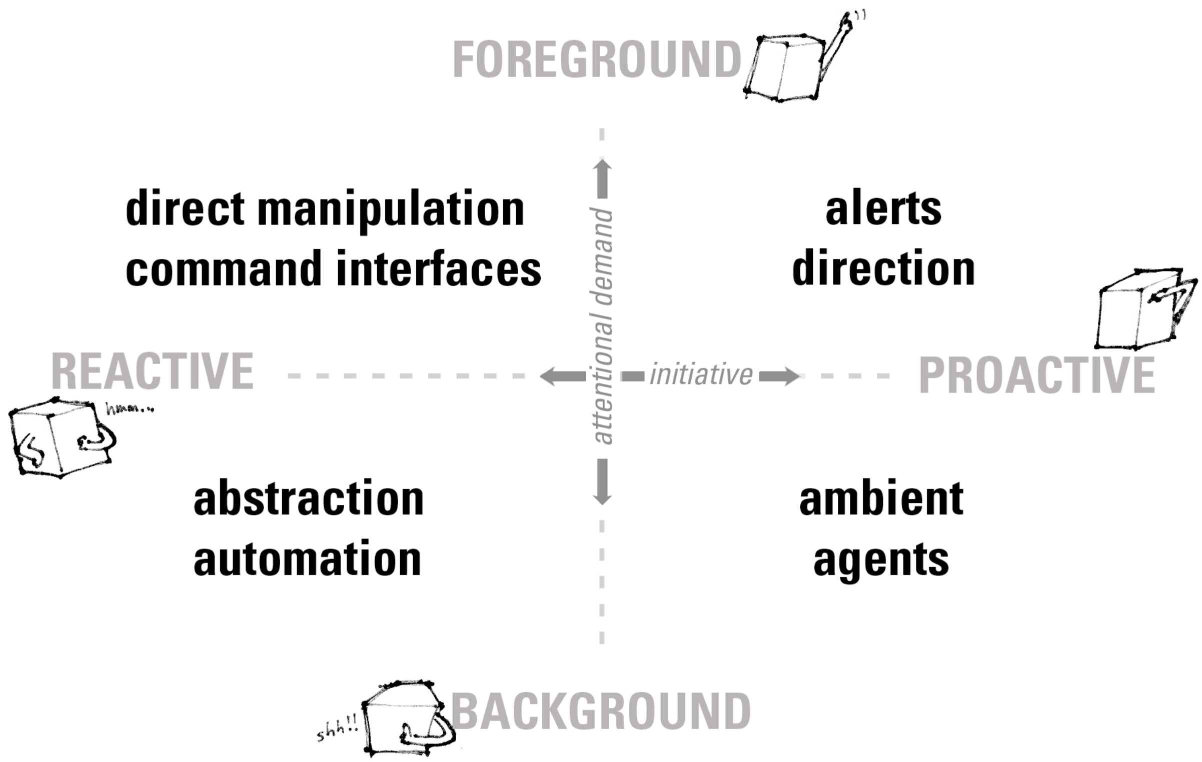


Figure 2. The Implicit Interaction Framework shows the range of interactive system behavior.

The implicit interaction framework (Figure 2) divides the space of possible interactions along the axes of attentional demand and initiative. Attentional demand is the attention demanded of the user by the computer system. Interactions that demand the user's attention are *foreground interactions* and interactions that avoid the user's attention are *background interactions.* Initiative is an indicator of who is initiating an interaction, and to what degree. The framework presumes the perspective of interactive system designers, so interactions initiated by the user are *reactive interactions* and interactions initiated by the system are *proactive interactions.* By characterizing interactions in this way, we are able to generalize about the capabilities and features of whole classes of interactions in a domain-independent fashion.

Figure 3 shows descriptions of interactions typified by each quadrant:

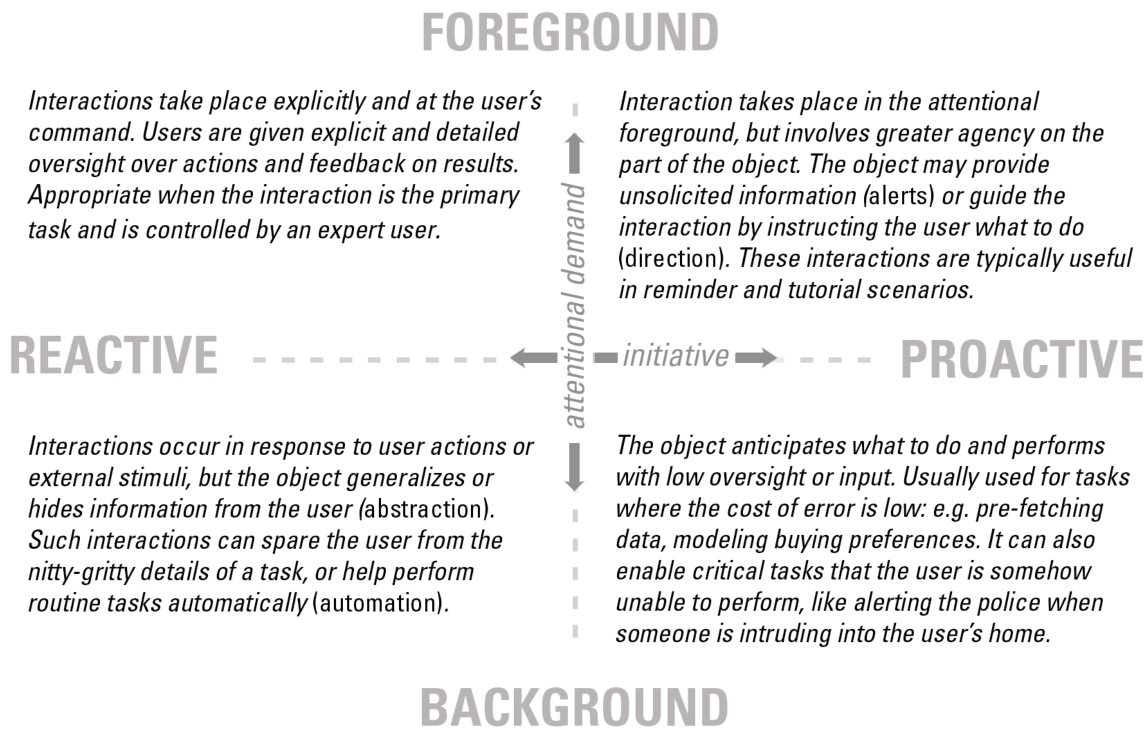


Figure 3. Characteristic interactions for each quadrant of the implicit interaction framework

The Framework in Action

To better understand the range of implicit interactions, let us consider this example: Our friend Terry sends us a link to a funny animation that can be found online. To play the animation, we need a Macromedia® Flash plug-in installed on our computer. The following cases show different ways that the plug-in can come to be installed:

> **CASE 1**: We see that the animation does not work. We deduce that we need the plug-in. We find, download and install the plug-in.

This is a classic example of explicit interaction. This is far from a unilateral activity on our part, for the computer is involved throughout this process, but we are actively engaged in diagnosing, deciding and performing each step along the way.

> **CASE 2:** We see that the animation does not work. We deduce that we need the plug-in, and ask the web browser to find, download and install the plug-in.

CASE 3: Our web browser alerts us that our animation does not work because we are missing a plug-in. We find, download and install the plug-in.

The second and third cases highlight the different ways interactions can be implicit. Case 2 is an example of *abstraction;* the plug-in installation occurs in the background, so that we don't have to actively and explicitly perform each step. Case 3 is an example of *alert*, where the interaction is implicit in that the system proactively diagnosed and informed us of the need for the plug-in. These cases illustrate how attentional demand and initiative affect the implicitness of the interaction.

CASE 4: Our web browser shows us that our animation does not work and offers to find, download and install the plug-in. We accept the offer, and the plug-in is installed.

CASE 5: Our web browser sees that we are trying to play an animation that we do not have the plug-in for, and lets us know that it is automatically finding, downloading and installing the plug-in.

CASE 6: Our web browser sees that we are trying to play an animation that we do not have the plug-in for, and automatically finds, downloads and installs the plug-in as a background process.

These three cases show increasing degrees of proactivity and *presumption* on the part of the web browser and decreasing degrees of attentional demand. In case 4, there is a fair amount of demand on our attention because we need to actively accept an offer. In cases 5 and 6, the plug-in is installed without any activity on our part, but the last case is more implicit because no feedback is offered. Although our actions in both cases are the same, the case 6 is more presumptuous because we do not have the opportunity to oversee and possibly cancel the task. This difference has important implications in practice because problems in the automatic download and install could slow a person's computer down miserably or tie it up in an error state with no escape or explanation.

> **CASE 7:** Our web browser anticipated that we might want to play a Flash animation someday and has already downloaded and installed the plug-in.

This last case is the most implicit interaction; in fact, with so much presumption and so little visibility, this last interaction may hardly be considered an interaction at all since there is no activity or awareness on our part.

There is a range of ways to accomplish the task of installing the Flash plug-in with different degrees of attentional demand and proactivity. Which is the best? It depends a lot on the situation: How capable is the user of installing this plug-in? How much control does the user want over disk space or network bandwidth? How concerned is the user about security? Just how funny is this animation Terry sent, anyway? Most plug-ins employ a design like the one in case 4 because it provides a happy medium.

As this example shows, although we speak of "implicit interactions," it is more accurate to speak of interactions being more or less implicit. Within the course of a task, different aspects of the interaction—the diagnosis, the action, the feedback—may be more or less implicit. Even though this example reflects a human-computer interaction, the issues raised around implicitness are reflective of the style of the transaction rather than the characteristics of the computer and hence transcend human-computer interaction to interaction in general.

Dimensions of Implicit Interaction

Now, let us examine the two dimensional variables in greater depth:

Attention

Attentional demand is generally described by the degree of cognitive or perceptual **focus**, **concentratio**n and **consciousness** required of the user. *Foreground interactions* make greater attentional demands on the user, whereas *background interactions* do not make such demands, and in fact, may elude notice.

A more complex definition of attentional demand also needs to account for spatiality (as Goffman did in drawing a distinction between "frontstage" and "backstage" interactions), [Goffman 1959] breadth (with many stimuli or just one), and intensity, among other things. This complexity reflects an increasing sophistication in understanding attention itself; cognitive neuroscientists are coming to believe that attention is actually a catch-all grouping of widely diverse mental functions and phenomena [Cavanaugh 2004]. However, a broad, commonsense understanding of attention is sufficient when we reason about our interactions with other humans, and so it is operationally sufficient to design with.

Attentional demand can be manipulated by adjusting the perceptual prominence of objects. This may be done through visual organization techniques, such as contrast, hierarchy and weight [Lupton 2004], as well as more dynamic means, such as pointing or placing. [Clark 2003] This type of visual display formatting has been most notably used to improve situation awareness in airplane cockpits [Andre 1991]. Interaction design research on the use of such techniques to present ambient information to users engaged in some other task is currently being pursued at the MIT Media Lab [Wisneski 1998] and Berkeley's Group for User Interface Research [Matthews 2004] among others.

Another way to affect the degree of attention demanded is through *abstraction*. By combining elements into a larger whole, the user is presented with less detail. *Chunking* is an example of an abstraction technique wherein experts are able to comprehend complex situations (such as the state of a chessboard) with greater ease because they are able to parse the scene into familiar subcomponents [Chase 1973]. Gestalt laws suggest that chunking leads to an "integrating of awareness" where people are able to identify a whole (say, a particular person's face) without being able to identify the details that make up the whole [Polanyi 1966].

This discussion of attentional demand may resonate with those familiar with Bill Buxton's concept of attentional ground [Buxton 1995]: "What we mean by Foreground are activities which are in the fore of human consciousness—intentional activities. Speaking on the telephone, or typing into a computer are just two examples." Buxton's definition of foreground overlaps only with the left half of the implicit interaction framework; he only considers the realm of user-initiated interactions—typing into a keyboard, or switching on a light. Hence, this definition conflates attention with intention, making it inadequate for describing device-initiated interactions—a cell phone ringing, or an automatic door opening. These interactions clearly take place in the foreground but are not at all intentional on the part of the user. Decoupling attention from intention gives us a separate dimension, *initiative*.

Initiative

The distinction of who initiates an interaction is a critical one in communication. If a waiter refills your coffee because you ask him to, that is a *reactive* response to your explicit request. However, if the waiter refills your cup because he sees that it is empty, the interaction becomes implicit; even if the *proactive* act of pouring the coffee might be in your attentional foreground, the waiter is responding to a projected request for more coffee. For our purposes, we are analyzing the interaction only on a pragmatic level. Sociologists such William Foote Whyte have commented on the ways that the server's actual motivations for action are complex and multi-layered—the waiter may also be responding to a desire for a tip, for instance, or to make her way around her circuit in an efficient manner [Whyte 1948]. This sophistication of analysis of the motivations of the server is not needed for the design of implicit interactions because the interactive machines we seek to design on the basis of this analysis do not have such complex and multi-layered motivations.

Initiative is salient in situations where actors are working together to accomplish a task. From the perspective of those championing direct manipulation or autonomy, joint action is suboptimal because it requires negotiation and coordination. However, it is far easier to think of successful examples of joint actions than terrific tools or perfectly autonomous objects. "Every day we engage in activities in which we have to coordinate with others to succeed," says Clark. "Face to face, we have systematic, economical and robust techniques of arranging for joint activities." [Clark 1996] One can even argue that we can experience readiness-to-hand in interaction with others; certainly we can contrast the ease and transparency with which we can buy a shirt at Macy's with the tortuous process of buying things in a foreign country with a different language and customs. In fact, it is possible to imagine optimal interactions at every point along the initiative continuum; the challenge is knowing what interaction is appropriate for the situation at hand.

Proactive objects operate in a realm of greater presumption, and so it is common that they need ways of seeing, discerning and reasoning about the world [Tenennhouse 2000]. This explains why most forays into proactivity, such as the research performed at Microsoft Research [Czerwinski 2000], University of Karlsruhe [Schmidt 2000], and Georgia Tech [Salber 1999], have been oriented to the technological issues of sensing, aggregating data, developing user and task models, and performing inference [Pantic 2006] [Crowley 2006]. And yet the solution for proactive interaction cannot lie in technology alone. People, for all their vaunted intelligence, make inference mistakes all the time, and are usually forgiven. Why is it, then, that interactive products such as the Microsoft Office Helper are so roundly criticized for guessing incorrectly what users are trying to do? It is probably because Clippy is untrained in the art of what Goffman calls "facework," sometimes called social graces, *savoir-faire*, diplomacy or social skill [Goffman 1967]. Since the days of expert dialogue systems, human-computer researchers have considered how *mixed-initiative* interplays between proactive and reactive actions, from both users and computers, can contribute to a project or an understanding. [Horvitz 2003] Similar negotiations are necessary on an interaction level to help systems communicate intended actions, and enable override.

When people go out on a limb, taking initiative in the face of uncertainty, they engage in compensating measures, hedging their actions with techniques such as overt subtlety (where actors make a show of how unobtrusive they are trying to be) or pre-emptive apology (where actors may bow their head, scrunch up their faces or raise their shoulders as they execute an action to indicate an apology if their initiative is unwelcome). One could easily imagine, for instance, that recent research on interruptions at Carnegie Mellon [Fogarty 2005] and Microsoft Research [Czerwinsky 2000] that have focused primarily on *when* to interrupt could be complimented by research on *how* to interrupt. There are conventional ways to act proactively, even in the face of uncertainty, and these are a matter of sociable design rather than technological intelligence.

INTERACTIVE TECHNIQUES

Three implicit interaction techniques which will be discussed further in this dissertation are *system demonstration, user reflection*, and *override*.

System demonstration

System demonstration is how the system shows the user what it is doing, or what it is going to do. This technique differs from the traditional conception of output in that it is not necessarily symbolic, overt, or immediate. System demonstration is a version of "presentation," a term that Goffman used to describe the expression interactants give and give off [Goffman 1967]. When the system "presents," it can implicitly draw the attention of the user in order to make a suggestion or request oversight.

Specific variations of system demonstration techniques include overt preparation and feed-forward. Overt preparation occurs when the system "shows" that it is preparing to take some action; these cues are generally read as an implicit offer (or threat). A doorman, for example, subtly offers to open the door for you by making a grand show of putting his gloved hand on the handle of the door. Feed-forward signals an impending action by presenting users with the projected outcome of the impending action. With the doorman, the slight opening of the door not only signals the potential for the larger action but also is usually performed to hint at the direction and speed of the proffered service.

The most challenging aspect of designing presentations is understanding how users will interpret them. It is possible to apply some design intuition here based on what implicit understandings people use to present to one another. For instance, as a rule of thumb, small-scale versions of an action (overtly leaning in the direction of the door) are implicitly understood as an offer or request to perform the full-scale action (leaving). As previously mentioned, pointing and placing [Clark 2004] are common ways that people use to present information implicitly; these techniques are easy to adopt in systems where speech or text are available for use in the interaction.

The design of system demonstrations requires testing with actual users to rule out false interpretations. Designing presentations for new actions also often requires several trials; users don't learn to anticipate an action until they have seen it occur several times. Indeed, people tend to exaggerate their presentations (speaking louder, making larger movements, moving slowly) when they think they are interacting with a novice rather than an expert, to make the communication clearer.

User reflection

User reflection is how the system indicates what it feels users are doing or would like to have done. Like system demonstration, user reflection is a version of "presentation" [Goffman 1967], but targeted at mirroring a user's actions to make it clear what the system "sees" or "understands." In verbal communication interactants take turns, and so one speaker may echo what the other said, as confirmation. In non-verbal interaction, user reflections can take place continuously, mirroring the action they are reflecting. In non-verbal interactions, the confirmation and feedback provided by user reflection is necessary because the actions being sensed by the system are not necessarily intentional.

User reflection functions to validate the inferred input; this validation corresponds with what Clark calls "recognition and uptake" [Clark 1996]. We separate this recognition and uptake into three varieties:

- *projections*, which reflect a user's intent, capability or desire ("Did you want to enter the door?"),
- *feedback,* which reflect a user's actions ("Were you walking towards the door?"), and
- *feedforward,* which reflect the consequence of a user's actions ("Did you want the door to open for you?")

By validating the user's intentions, actions and awareness of the consequences of her actions, the system can reduce the likelihood that it will act in an unanticipated or unwanted manner.

User Override & System Override

Override techniques enable users to interrupt or stop the system from engaging in a proactive action. This technique usually occurs after one of the previous two techniques (user reflection or system demonstration) alerted the user to some inference or action that is undesirable. Override differs from "undo" because it is targeted at countering the action of the system rather than reverting a command made by the user.

In order to have an override, there needs to be an inference or action to be overridden. When the override is preceded by a user reflection, the override is a correction of how the system interpreted (and reflected) the user's actions. When the override is a response to system demonstration, it is an interruption of the presented action. In our terminology, *user overrides* indicate override actions generated by the user, and *system overrides* indicate override actions generated by the system. The trajectory for an interaction involving user override goes from the proactive/foreground quadrant to the reactive/foreground quadrant.

Common variations on override are preemption (for instance, when you cover your cup with your hand to indicate that you don't want more coffee) and retraction (to overtly "cancel" a signal that may have prompted unwanted action.). "Blocking" behaviors—putting your hand in front of an elevator door to stop it, for instance—physically signal preemption. These are all variations of what Clark terms "repairs," ways of detecting and correcting problems in reception and communication between interactants [Clark 1996].

Overrides are often the simplest features that designers can create in an "intuitive" manner because they are borne out of a failure of commission rather than a failure of omission. When users see some unwanted action taking place, they often attempt to override the action in numerous ways; designers can observe these attempts to override and develop ways of recognizing and responding to the user's frantic override behaviors.

It is possible for the designer to design in affordances for overrides—handles and edges, for example, that the user can grasp or shields that the user can use to perform blocks.

CONCLUSIONS

We have presented a framework for implicit interaction that characterizes interactions based on attentional demand and initiative—factors that are pertinent to any interaction, regardless of domain. This framework and methodology can be used by designers as a lens on their interaction design problems, and can help them leverage existing linguistic, sociological or ethnographic techniques to the end of designing better human-computer interactions. The framework and method support the *theory of implicit interactions*, which posits that people rely on *conventions of interaction* to communicate queries, offers, responses, and feedback to one another. This basis in convention enables people to communicate efficiently with other people even in new, unfamiliar situations because they can use the common language of implicit interaction to negotiate the interactions. Furthermore, it allows implicit interactions to be applied to the design of interactive devices to improve people's ability to "communicate" with interactive devices.

Because implicit interactions have convergent features due to the constraints imposed by the human in the loop, knowledge about the interactions can be generated and generalized—key components to any area of academic research. This portability of solutions from one domain to another also enables design solutions to be passed from one design researcher to another, enabling designers of interactive objects to develop generalized interaction patterns for different classes of interactions.

Chapter 3

OPENING THE DOOR

Testing Implicit Interaction Response with Automatic Doors

In this chapter, we broaden the understanding of how implicit interactions inform the design of interactive systems by exploring the dynamic and demonstrative behavior of automatic doors to verify both (1) that changing the manner of a door's gestures towards passersby changes their interpretation of the door's approachability, and (2) that these different gestures will be interpreted in a similar fashion by a range of study participants, even when the door gestures themselves are novel and non-conventional. This exploration is conducted in two studies: (1) a between-subjects physical prototype study that uses "Wizard of Oz" techniques to see how actual passersby react to and interpret automatic door gestures; (2) a within-subjects video prototype study that asks participants to react to and interpret automatic door gestures that they see in a web-based video. Together, these studies form an empirical test targeted at both improving interactive system design and at testing the broader theory of implicit interactions.

RELATED WORK

Norman's use of doors as a symbolic entry into the realm of psychological design was replicated by Marc Weiser who invoked the notion of "doors [that] open only to the right badge wearer" through the use of hundreds of invisible computers embedded in the environment to sell his vision for ubiquitous computing [Weiser 1991]. For many, the key to enabling this "ubicomp" vision was to equip the user's environment with sensors and to provide user and context models that would enable the environment to anticipate the user's goals and action [Dey 1999][Paradiso 2000]. However, predictive modeling of behaviors is only the beginning to enabling seamless interaction with the everyday environment. The challenge of providing assistance without distracting users relies in some part on the technical design of sensor and hardware technologies that support implicit interaction [Schmidt 2000] but also requires attention to the interaction design that influences people's cognition and behavior.

Examinations of people's interactions with doors illuminate the critical role of design in providing clear and readily understandable cues to users about what kinds of interactions are being offered. Bruno Latour observed that people ascribe human agency to self-closing doors ("door grooms," in French parlance) because they have been designed to take over a human task; this encourages an anthropomorphic interpretation of the door actions despite the door's lack of human-like form [Latour 1992]. This suggests that designers can design interactive environments to signal both subtly and expressively, much as animators create subtle expressiveness in otherwise inanimate objects [Lassetter 1987].

The idea that the patterns of interaction used in implicit human-human interaction could be applied to human-object interaction is supported by research in the area of Gestalt psychology. The first psychological studies of how different stimuli affect people's interpretations of events was performed by Fritz Heider & Marianne

Simmel in 1944 [Heider 1944]; they found that people interpreted moving objects in the visual field "in terms of acts of persons." Subsequent studies by Albert Michotte experimented with showing people even simpler depictions of two moving balls, and found that while some movements elicited "factual" descriptions, others caused people to attribute motivations, emotions, age, gender and relationships between the two objects [Michotte 1962]. This finding complements more recent research by Clifford Nass and Byron Reeves, which indicates that people interpret computers and other media as social actors [Reeves 1996]. These studies suggest that neither voice nor facial features are required to trigger social attribution of actions. Indeed, the two studies following suggest that action and behaviors that are perceived to be autonomous is all that is needed to cause people to attribute social characteristics and motivations on objects.

STUDY 1: PHYSICAL PROTOTYPE PILOT

Study Design

As an exploratory pilot study, we employed a field experiment on gesturing doors. We used Wizard of Oz techniques [Dahlback 1993] to gesture a physical building door at participants who happened to be walking near the door during its deployment (*N*=48). The primary interests of this pilot study were (1) how people interact with the door and (2) how people interpret the dynamic motions of the gesturing door. We took note of whether the participants were walking toward the door or walking by the door at the time of their encounter with the gesturing door. Over a three-day period, we tried three different door trajectories: open, open with a pause, and open, then quickly close. Each participant only saw one of the door trajectories; hence, it was a between-participants study.

Materials

For this experiment, we selected one of a set of double doors that featured a large pane of glass that enabled people to see into the building. A human operator stood to the side of the door, out of view from passersby, and acted as a wizard, pushing the door using a mechanical armature attached to the door's push bar. We used gaffer's tape to

Figure 4. Wizard of Oz setup for gesturing doors study. A hidden door operator uses an armature to gesture the door.

hide the armature and Contact Paper to obscure the windows to the sides of the door to create the illusion that the door was opening on its own. (See Figure 4 for the experiment as seen from inside the building and see Figure 5 for the view from outside the building.)

The paper questionnaire contained two open-ended questions: “What did you think was happening when you saw this automatic door move?” and “Assuming it functioned properly, how did you interpret the door’s movement?” The questionnaire also included closed-ended questions that queried participants on 10-point scales with the following questions and anchors:

How did you *feel* about the door?

(1) very negative – (10) very positive

The door *seemed to intend* to communicate something to me.

(1) strongly disagree – (10) strongly agree

The door *seemed to think* when it communicated with me.

(1) strongly disagree – (10) strongly agree

The door was *reluctant* to let me enter.

(1) strongly disagree – (10) strongly agree

The door was *welcoming* me.

(1) strongly disagree – (10) strongly agree

The door was *urging* me to enter.

(1) strongly disagree – (10) strongly agree

Procedures

The procedure for the study required three to four experimenters. One was the door operator mentioned earlier. Another experimenter acted as a monitor, waiting casually outside of the building and surreptitiously triggering an alert to the door operator

Figure 5. Experimental conditions for gesturing doors study: Person walking (a) by and (b) towards the door. Note the monitor on the right.

Table 2. Frequency distribution of gesturing doors pilot study participants

	Open	Open with pause	Open, then close	Total
Walking by	11	7	19	37
Walking toward	2	4	5	11
Total	13	11	24	48

inside via walkie-talkie when pedestrians neared the door. The other experimenter(s) approached the pedestrians with the paper questionnaire after they had seen the gesturing door move.

Only those people who approached the door from the direction shown in Figures 1 and 2 were chosen to encounter the gesturing door because anyone approaching from the other direction might have seen the door operator and armature. Experimenters approaching people first queried participants to gauge whether they had noticed the door's motion before giving them a paper questionnaire. Some people declined to fill out the questionnaire; the most common explanations for non-participation were lack of time and inability to speak English. Most people (48 out of 64) opted to fill out the questionnaire and many even discussed the study with us at some length. Date, time, participant gender, and experimental condition were noted on the back of each questionnaire.

Data Analysis

The following studies use uniformity of participant interpretation as the standard for evaluation.

We used univariate analysis of variance (ANOVA) to analyze the data, using door trajectory as the independent variable and participant walking direction as a covariate. (Because participants were not randomly assigned to walking direction conditions, walking direction was not used as a full independent variable.) Each questionnaire item was analyzed as a dependent variable in an ANOVA.

In addition to the statistical analyses, we present descriptive statistics and observations from this pilot study that fed into the next iteration of this study design.

Quantitative Results

During the experiment, 64 people nearing the door noticed its motion; 48 of them opted to fill out the questionnaire. An additional 38 people did not notice the door's motion. Distributions of door motions and walking trajectories for participants who noticed the door move and filled out the questionnaire are reported in Table 2.

Door trajectory had a significant influence on valence of feelings toward the door, and perceptions of reluctance, welcoming, and urging on the part of the door. Walking direction had a significant influence on perceptions of the door as urging one to enter. These results are presented in Figure 6 and are further described in this section. Differences in sample sizes are due to non-responses by some participants to some questions.

Door trajectory significantly affected the *valence* (negative to positive) of participants' feelings toward the door, $F(2,44)=5.37$, $p<.01$: open ($M=6.62$, $SD=2.06$), open with pause ($M=6.55$, $SD=1.57$), and open, then closed ($M=5.06$, $SD=1.27$). Walking direction was not a significant factor.

Door trajectory also significantly affected how *reluctant* the door seemed to be, $F(2,43)=6.73$, $p<.01$: open ($M=1.67$, $SD=0.78$), open with pause ($M=2.18$, $SD=1.66$), and open, then closed ($M=4.25$, $SD=2.77$). Again, walking direction was not a significant factor.

Door trajectory also significantly affected how *welcoming* the door seemed to be, $F(2,44)=3.45$, $p<.05$: open ($M=5.92$, $SD=3.33$), open with pause ($M=6.73$, $SD=3.44$), and open, then closed ($M=4.00$, $SD=2.59$). Again, walking direction was not a significant factor.

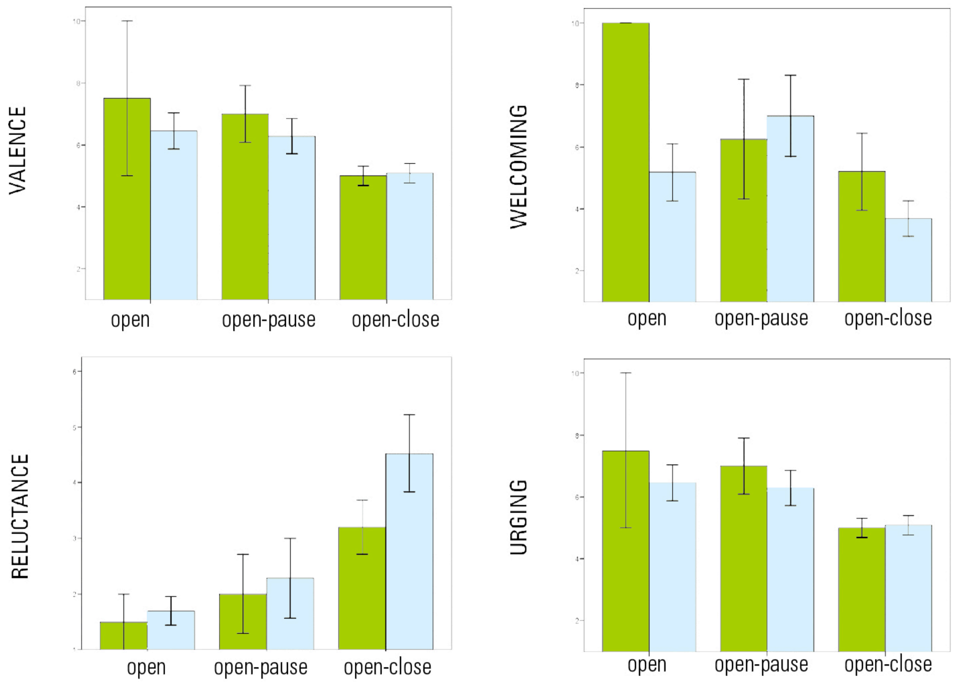


Figure 6. Mean Likert ratings for valence and perceived {reluctance, welcome and urging} for door trajectories

Finally, walking direction significantly affected how *urging* the door seemed to be, $F(1,44)=1.38$, $p<.05$: walking by ($M=3.57$, $SD=2.44$) and walking toward ($M=5.82$, $SD=3.31$). Door trajectory did not significantly affect perceptions of the door as urging one to enter the building.

There were no significant results for questions about apparent intention or apparent cognition of the door.

Qualitative Results

Written responses to the open-ended questions were too short for any meaningful response coding. The average length of response was 29 characters for the first question ($M=29.4$, $SD=14.8$), and 19 characters for the second ($M=19.0$, $SD=15.9$). The likely cause for the brevity of response is that participants filled the questionnaires out while standing, and on their way to another destination.

Discussion

The results of the pilot study were promising in that they suggested uniformity in interpretations of door motions. Even in the noisy world of people going about their everyday lives, people showed consensus in their responses to the door motions. Other insights gained from this pilot study came from qualitative observations and discussions with participants after they finished the questionnaire. One participant was a retail designer who was interested in the study because the door's motion caught his attention and made him curious about what was inside of the building; the goal of shops is to entice potential customers to walk through their doors.

One important observation for consideration in real field deployments of such systems is considering the people who did not notice the moving door. They tended to be walking and talking with others, talking on their mobile phones, listening to music players with headphones or walking very quickly, seemingly in a rush to some other destination. People are not always strolling idly down the street; they are often preoccupied, even during the summer on a nearly empty college campus.

One issue with this pilot field experiment was that participants who walked through the door also ended up seeing the door operator before they filled out the questionnaire. Fortunately, the majority of the data came from people walking by the door rather than toward it.

Another issue with this pilot field experiment was that participants who were unhappy with the door were also quite unhappy with the experimenter who requested their time to fill out the questionnaires. In particular, those participants who were walking toward the door and had the door shut in their faces seemed personally offended; several people were consequently unwilling to fill out a questionnaire "for the door."

STUDY 2: VIDEO PROTOTYPE EXPERIMENT

Based on the findings and identification of weaknesses in the pilot study, we decided to conduct a more controlled experiment to further test people's responses to door gestures. In the video prototype study, participants were shown 12 different types of gestures using video clips embedded in a web-based questionnaire.

As in existing research [Heider 1944][Michotte 1962], these studies engage participants in an "interpretative" role (where they are asked to read the interaction) rather than an "interactional" role (where they are asked to engage in the interaction). Although this method sacrifices some ecological validity, the video-prototype study enables better "participant" and door interactions and cleaner isolation of feelings toward the door rather than toward the experimenter or study. In addition, this video prototype could be run as a within-participants study, thus reducing the possibility that our inadvertent selection effects might be skewing our results across the conditions.

Study Design

This study added one new dimension, door speed, to the previous study design. Using a 2 (person walking direction: walking by vs. walking toward) x 2 (door speed: slow vs. fast) x 3 (door trajectory: open vs. open with pause vs. open then close) within-participants experiment design, we investigated the effects of both the door and the passerby's actions in this human-door interaction. Participants were recruited from a university community (N=51).

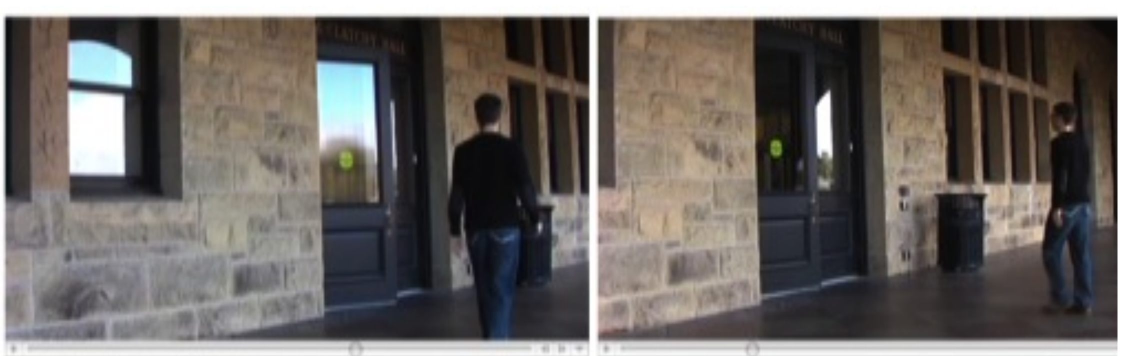


Figure 7. Video screenshots of person walking by (left) and toward (right) gesturing door.

Materials

We performed a web-based experiment in which participants were shown 12 web pages that each contained an embedded video of a human-door interaction and questionnaire items. The clips were randomly ordered to address ordering effects. These 12 videos included every combination of our three independent variables: person walking direction, door speed, and door trajectory. Like the pilot study, the videos showed door gestures performed by a hidden door operator. On each page, participants were asked to play the video, imagining themselves as the person in the video. To prevent participants from merely reading the person's reaction as opposed to imagining what their reaction would be, we chose a camera angle that hid the walker's face and ended the clip before the person walked through the door or physically reacted to the door's gestures. Video clips ranged from 4 to 9 seconds in length, were sized at 540 x 298 pixels, and were encoded using Apple Quicktime format. (See Figure 7.)

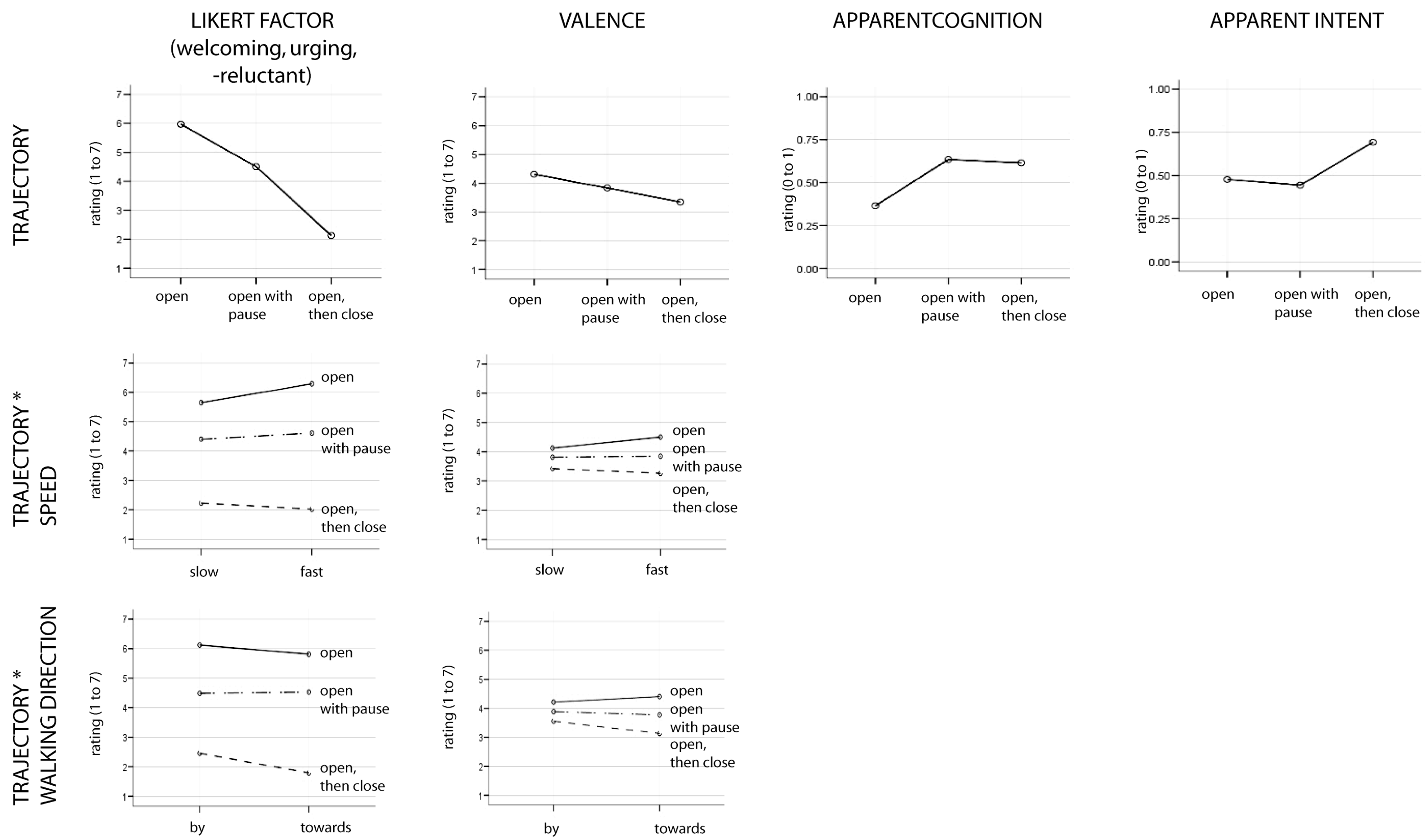


Figure 8. Mean values for significant and nearly significant main effects on responses toward gesturing door trajectories

Procedure

Participants who volunteered for the study were directed to the web page with gesturing door videos and questionnaire items. After watching each video, participants were asked to describe their experience with the door from the perspective of the person in the video, and to describe what they thought the door was communicating. They were then asked to rate the strength of their agreement or disagreement with three statements about the door, including how reluctant, welcoming, and urging the door seemed. These factors were the significant factors in the pilot study.

Data Analysis

Using Principle Component Analysis, we found that the three Likert indices (welcoming, urging, and reverse-coded reluctant) constituted a single factor, with *Cronbach's* α =.91. Therefore, we combined them into an unweighted averaged single factor, *approachability*. Open-ended responses were coded and averaged across coders for valence (negative, neutral, or positive), apparent cognition (0 or 1), and apparent intent of the door (0 or 1) by two independent coders who were blind to the experimental conditions. Inter-rater reliability was reasonable: *Cronbach's* α values of .714, .616, and .723, respectively.

Results

Unlike the pilot study, the video prototype study elicited far more descriptive responses to the open-ended questions. Average length of responses was 75 characters for the first question (M=75.1, SD=51.2), and 53 characters for the second (M=53.1, SD=42.1). This average far exceeds the lengths from the previous study, despite the fact that each participant filled out 12 times as many questions. Descriptions of the door included descriptions that implied apparent cognition and intent, e.g., "insulted, it acknowledged my presence but judged me and said no!" and, "The door wants me to come in, but doesn't want to appear more eager to have me enter than I am." Other types of descriptions did not express any apparent cognition or intent at all, e.g., "I wonder why the door blew open," and "I walked by a door and it slowly opened."

After all of the descriptions were coded and averaged across coders, we used a within-subjects full-factorial repeated-measures analysis of variance to investigate the effects of each of the three independent variables (person walking direction, door speed, door trajectory) upon each of the four dependent variables (approachability factor, valence of person's response, apparent cognition attributed to door, apparent intent attributed to the door). They showed highly systematic responses amongst participants.

The door's trajectory had the most far-reaching effects across all dependent variables: approachability ($F(2,30)=70.91$, $p<.001$), valence ($F(2,88)=43.31$, $p<.01$), apparent cognition ($F(2,50)=5.64$, $p<.01$), and apparent intent ($F(2,42)=3.59$, $p<.05$). In general, the door that opened and then closed before the person got to the door made the door seem more negative, more intentional, and less approachable, whereas the door gesture that simply swung open was read as approachable but not necessarily cognitive or intentional. (See Figure 8, Row 1.)

Several two-way interactions were significant or nearly significant. Faster door speeds showed a trend toward exaggerating the effects of door trajectory. It significantly influenced valence, $F(2,88)=6.55$, $p<.01$, and nearly significantly influenced approachability, $F(2,30)=2.61$, $p<.09$. Similarly, the walking direction of the "participant" showed a trend toward exaggerating the effects of the door trajectory. It significantly influenced valence, $F(2,88)=6.40$, $p<.01$, and nearly significantly influenced approachability, $F(2,30)=2.76$, $p<.09$. (See Figure 8, Rows 2 and 3.)

DISCUSSION

The core finding of this study is that people's interpretations of door gestures are highly coherent across several dimensions of door motion; despite the novelty of gesturing doors, untrained interactants "intuitively" read the gestures in systematic ways that were very consistent with the findings in pilot study 1. This finding suggests that people have a common understanding of door interaction and interpretation of the meaning of door gestures, possibly comparable to interpretations of human gestures [McNeill 2005]. This agreement supports the notion that door motion can provide an effective means of implicit communication.

Design Research Methodologies for Assessing Implicit Factors

Since one of the major obstacles to implicit interaction development is the Catch-22 that it is difficult to assess people's interpretations of implicit actions without distorting the effect by asking about them explicitly, the video prototype technique employed in this study is a methodological contribution to this area of research. The ability to use large numbers of online study participants and carefully simulated interactions allows us to predict how best to design an interactive system prior to building the whole system. While it will take more subsequent studies to see if people evaluating these interactions in an interpretative role are reasonable predictors of how people would feel in an interactive role, the coherence of these two studies is promising.

CONCLUSIONS

These two experiments seem to support the implicit interaction framework's assumption that the interaction trajectory used by doormen to communicate with passersby works analogously when applied to an automatic door. This suggests that the framework is useful for capturing observations about how doormen perform their task of opening the door, and the same framework is also useful for illuminating solutions for the design of automatic doors. The wide range of expression available with only one physical degree of freedom suggests that designers can create very rich interactive experiences with very simple actuation in ubiquitous computing environments. These findings support prior observations of Latour [Latour 1992], and more broadly, the research in *The Media Equation* [Reeves 1996], showing that people respond socially to interactive doors even when it is quite evident that the door is not a person. This work also extends the boundaries of the theory of Computers as Social Actors; unlike previous systems, which employed anthropomorphic visual or linguistic features, our interactive doors were able to elicit social response by using only interactive motion to cause attributed cognition and intent. If designers can convey different “messages” in such a highly constrained design space [Maclean 1991], it seems reasonable to extrapolate that even more information could be conveyed with more complex ubiquitous computing and robotic systems.

Designing interactions for interactive doors is a good reference design task for the engineering community because automatic doors are common and pervasive and because they are easy to adapt. If designers master the creation of expressiveness and better usability in the one degree of freedom robot that is the automatic door, then, it can be argued, we have a far better understanding of how to adapt more complex systems with the same traits. We have found preliminary support for the theory that, by taking initiative, the door’s actions are interpreted by people as an offering gesture. We intend to elaborate on this finding by using a wider variety of perceptual pull-cues and gestures.

While this study focused on doors, our broader goal was to experiment with providing interactive environments with implicit ways of offering to engage in joint action. We also hope to build on the theory of implicit interactions by applying the same implicit interaction techniques to more novel applications. Furthermore, the techniques explored here could be applied in interactive kiosks to proactively indicate to users what services are provided, in word processor interfaces to offer proactive assistance formatting letters or printing without use of insufferable talking paperclips [Xiao 2003], or in future work environments to provide selective access to different badge holders [Weiser 1991]. This research will assist designers of interactive devices by expanding the repertoire of implicitly communicative conventions that can be employed in the design of interactive systems.

Chapter 4

STANDING BY

Designing Implicit Interactions for Electronic Whiteboards

It is said that great service is invisible. This is a way of conveying the importance not only of fulfilling a need, but also, of doing so in a manner that is considerate of demands on a person's limited time and attention. Implicit interactions can be useful not only for enabling intuitive engagement with incidental interactions but also for permitting seamless support during extended ongoing activities. For instance, automobile passengers can assist drivers in way-finding, landmark spotting and hazard detection; competent navigators help the driver without distracting them from watching the road. Dental assistants support dentists by holding and passing instruments, removing tissues, saliva and other obstacles to the dentist's vision, performing background tasks like mixing cement or developing radiographs, and charting the overall progress during complex procedures. An important part of assistance lies in the implicit realm; expert assistants are alert to unspoken cues that help is needed and also exhibit corresponding implicit behaviors to remind people of their availability and to suggest specific offers to intervene.

In this chapter, we apply implicit interaction techniques to the task of supporting whiteboard collaboration. People who are engaged in design activity need their tools to be "invisible" so they can focus on interacting with their collaborators and developing their ideas. At the same time, the electronic whiteboard can better support interaction, for instance, if users have real-time access to features that allow them to distinguish different ideas, or to rearrange drawn figures on the board, or if they are made aware of relevant bits of previously generated information. System demonstration techniques, such as cuing, offering and engaging, are shown to be useful for initiating interaction, as well as providing ongoing low-level interventions, while a new set of user reflection techniques–projection, feed-back and feed-forward–facilitate the interaction by making clear to the user what aspects of their behavior are being perceived and acknowledged. We also discover an additional technique, override, which implicitly communicates a denial or correction.

METHOD

This endeavor applies design as a research methodology. By developing implicit interactions for the domain of whiteboard interaction, we provide a proof-of-concept that implicit interactions can be *designed,* rather than established through convention. In doing so, we discover specific techniques to form cues, offers and to exhibit engagement, which were previously established to be critical components of implicit interaction. Thus, by designing implicit interactions, we come to a better understanding of the phenomenon we seek to recreate.

This design consisted of two phases. In the first, formative, phase of the research, we studied a broad set of data detailing the behavior of people collaborating at whiteboards, in order to discover what users might desire help with and also to identify cues that might correspond with the different contexts in which help is needed. In the second, generative, phase of the research we created Range, an electronic whiteboard system that uses implicit interaction techniques to support design collaboration without interruption and performed preliminary evaluation of its ability to support design collaboration.

STUDY 1: WORKSPACENAVIGATOR

The formative portion of this research was part of the WorkspaceNavigator project [Ju 2004]. WorkspaceNavigator explored how knowledge capture and access tools enhanced design activity in physical design settings. It provided a unified interface for post-facto retrieval of multiple streams of data captured from the work environment, including overview shots of the work area, screenshots of in-space computers, whiteboard images and digital photos of physical objects. This system was developed, deployed and evaluated in two Mechanical Engineering design courses (ME310. Team-based Design Development and ME218B: Smart Product Design, Mechatronics) to identify features that best supported students in their design activity.

Motivation

One of the core goals of the WorkspaceNavigator project was to better understand the role of ad-hoc whiteboard sketching in collaborative design. Whiteboard sketching is an important aspect of design activity because it allows designers to externalize the concepts they are proposing so that they may more easily analyze and evaluate their ideas. Whiteboard sketches serve as a valuable form of communication from one designer to another, helping to *ground* their conversations in a common understanding of what is being proposed, what that proposal means and if that idea is desirable. While work groups of all types engage in shared sketching activity, it is of particular value to designers because of the unconstrained nature of their work. Whiteboards are a natural locus for collaborative design activity because they provide a large shared surface on which to propose ideas.

Figure 9. Initiation of ad-hoc whiteboard meeting

Sketches are deliberately and glamorously informal. Because the generation of ideas is part of a process in which participants suspend thoughts of what is true or untrue to consider what might be, the activity needs to occur in the context of a "bull session." These types of informal meetings, which are characteristically unstructured, denying of roles, interactive, and free from agenda, have been recognized as being valuable to the work process. The opportunity for informal meetings is one primary reason that co-located groups outperform distributed ones [Kraut 1992]. It is in these bull sessions that we feel that people are truly collaborating, rather than just throwing ideas "over the wall."

Previous research projects [Bly 1988][Tang 1989] [Rogers 2004] [Milne 2005] have studied design collaborators in interactive environments, but these studies are limited to observing a few hours of interaction rather than the weeks of activity that design projects usually entail. The studies that aim to evaluate the performance of various whiteboard systems in development are also informative, but the toy scenarios with which researchers necessarily initiate observable activity often differ from the scenarios collaborators might face in the wild. Another approach to understanding design collaborations is the analysis of design artifacts [Brink 1992][Maldonado 2007]. To date, these studies tend to focus on the drawn artifacts generated by collaborators rather than conversations and behaviors, which are the most important aspect of informal group work.

Method

To observe ad-hoc collaborative design behavior in-situ, we observed six physical design spaces, each of which had a whiteboard. These design workspaces are associated with two graduate courses in the Mechanical Engineering department. Both courses involved team-based design projects and had large laboratory spaces with specific areas designated for each team's use. The study and data collection took place over a period of nine months.

Users

We instrumented four dedicated project spaces used by teams of three to five people working on industry-sponsored projects to produce a final functional product prototype. The projects ranged from consumer products to automobile technologies. Each team had their own dedicated space that they were given rein to outfit as they saw fit. The duration of these projects was six months long.

We also instrumented a shared group space in the vicinity of these spaces where these and any other project groups could and would sometimes meet.

The other design space we selected was in a shared laboratory environment used by students working on team projects in mechatronic (mechanical-electronic) design. Students were assigned to work in teams of 3 or 4 people, building and programming interactive games from scratch to completion in 3.5 weeks. In this environment, the team's personal project spaces were outfitted with a lab bench, a computer, an oscilloscope and a power supply, but no dedicated whiteboards. Collaborators in these last two spaces all had free access to the shared whiteboard, day and night.

All the members of the project teams had substantive previous design collaboration experience. These design teams were chosen because we felt that their environments were sufficiently representative of actual work environments in many corporate environments, and that the designer collaborators were representative of actual designers in the "real world." Studying in a project-based learning environment allowed researchers free access to the physical facilities to maintain the system, helped to unify the project schedule which more readily enables comparisons across spaces, and mitigates the potential of intellectual property issues in the data collected.

Information from this study was not shared with course instructors and did not influence the academic evaluation of team performance.

System

Information from each design space was captured using a knowledge capture, access and reuse system made available to the students to augment their design activity.

The systems featured networked, multi-channel data capture. Design activity was captured using overhead web cameras and whiteboard drawings were captured using a commercially available system (http://luidia.com). Successive images from these inputs were analyzed to detect changes in order to filter potentially relevant time slices. Data was captured in 30 second intervals and logged to a database by a remote server. Data was time-stamped to enable cross-referencing of information from different data sources. For the purposes of this paper, none of the other channels of data captured are relevant.

The data capture system was always on, capturing data, although users could "blackout" capture by using their whiteboard pen to press a designated soft button on their whiteboard. Flat panel monitors installed next to each whiteboard gave users feedback about the data being logged.

Analysis Protocol

We would like to highlight that the data capture system, though “always on,” did not capture all the moments of design activity on the projects in question, even in the dedicated design spaces. In addition to periods of system downtime, significant gaps exist in the record because of our low temporal resolution, because of the “black-out” option and because the teams would often work elsewhere, particularly as their prototypes grew too large for the spaces. Also, occasionally it was difficult to make out what activity was taking place in the design space because of the density of objects in the camera’s view.

That said, the data corpus captured a large part of the conceptual design activity of many project teams. In the data log, we found a total of 37 identifiable whiteboard sessions by design teams. These were observed and analyzed by design researchers familiar with the course material and the design teams in question for regular patterns of interaction. Although each team had its own way of working, met at different frequencies and consulted each other on design questions of different granularity, we observed many behaviors common among the design teams and across the design environments. Representative sequences in which it was easy to make out behaviors and visually distinguish collaborators were chosen for illustration of these patterns.

Observations

From the wider set of findings based on the WorkspaceNavigator data [Ju 2006], we focused in on the interaction pattern of people engaged in ad-hoc whiteboard meetings. We found that design teams engaged in informal meetings would cycle between phases of drawing and analysis; these changes corresponded with changes in their physical proximity to the whiteboard. Users would stand close to the board when they were writing, further back when discussing written artifacts in detail or further back still when engaging in meta-discussion. The following is a detailed narrative of one typical instance of this behavior.

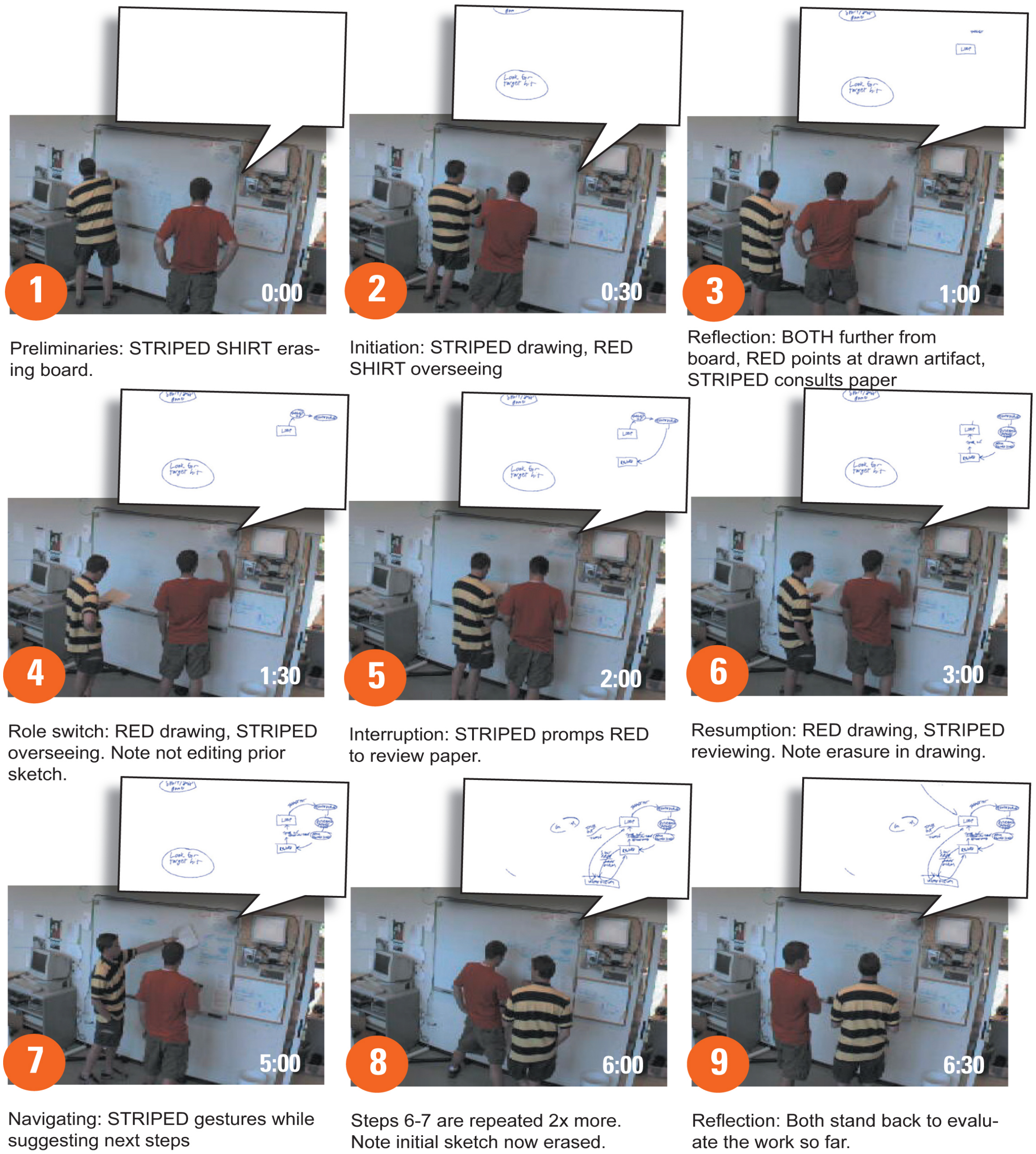


Figure 10. Typical interaction pattern in whiteboard design session. Two people working on a state diagram for an interactive game.

Set: Interaction in front of a whiteboard and the open space in front of it. Although there is often enough space for more than one group at the board, only one group seems to convene at a time.

Roles: Usually 2 people engaging in roles as "driver" (the person with the pen) and "navigator" (the person reviewing). Note that at a traditional whiteboard, it is possible for both people to drive simultaneously, but we never observed this behavior occurring in our data corpus. Other researchers studying pair programmers, however [Chong 2007], found that people did not engage in the turn-taking behavior we observed at the whiteboard.

Sequence:

(1) Preliminaries. Board is erased, participants take positions

(2) Initiation. STRIPED starts drawing. RED usually adopts critical stance (see Figure 10 for more examples)

(3) Reflection: After some period of generative activity, STRIPED pauses and steps back to analyze and evaluate. In Figure 10.3 Notice RED indexing aspect on board as STRIPED reviews paper in hand.

(4) Generation: Note role change between STRIPED and RED. Note that STRIPED now stands back and has adopted the critical stance. Also note that RED has forked from the initial drawing and started a new drawing in a new place on the board.

(5) Reflection: Similar to (3). STRIPED calls RED's attention to something on paper. Note both stand back from the board.

(6) Generation: Similar to (4). Note drawing has been erased and redrawn differently since (5)

(7) Review: RED steps back from board while STRIPED steps forward, commenting and gesturing in the space where nothing is drawn yet.

(8) Generation: Similar to (4). Notice original drawing from (2) now erased.

(9) Reflection: Similar to (3). RED and STRIPED both stand far back from the board.

Discussion

This interaction pattern highlights some specific aspects of whiteboard interactions that we found to be common:

a) The orientation and location of designers with regard to the board reflects design activity. Changes in proximity to the whiteboard correlate with design phases when designers are distancing from the ideas at hand and seeking perspective. This pattern is more apparent when people are standing because that enables them to move.

b) Ad-hoc meeting participants take on different roles at the whiteboard. While both participants are actively engaged in the design process, one adopts the role of the DRIVER, who wields the pen and consequently drives generation. The NAVIGATOR adopts a critical stance (see Figure 3) and analyzes and evaluates the proposed ideas as they are being generated.

c) The design process is iterative. Although the meeting collaborators did not generate many versions of their state diagram, the progression of board drawings in Figure 3, shows a significant degree of on-going revision, likely in response to the real-time feedback generated by the NAVIGATOR

Figure 11. Examples of "critical stance" by collaborators

d) "Props" such as external documents, maps, relevant hardware, etc. are usually held and referenced by the NAVIGATOR.

e) If there are additional people involved in the meeting (see Figure 4) they take on the roles of auxiliary navigators, contributing, though not so prominently, to the review and feedback.

f) A large percentage of the time at the whiteboard is spent talking and pointing, rather than drawing.

The last point is also shown in Figure 4, where we can see the STUDENT and the INSTRUCTOR discussing an issue. The STUDENT raises the issue with a sketch and uses the sketch to describe his issue. The INSTRUCTOR points to index his subsequent statements, but then a long period of discussion ensues wherein no drawing takes place at all.

These patterns serve to underline the fact that the process of creating the drawings is as important as the drawings themselves [Bly 1988]. In fact, in the case of collaborative design meetings, it seems clear that engaging in the iterative process of design, having a collaborative conversation about the many possible solutions and eliminating false leads, is more important than the drawn artifact. Based on these patterns and observations, we found the following areas for potential augmentation of the collaborative design process:

a) ambient display of information

b) changing of drawing tools for the generation phase

c) modification for the reflection and review phases

The fluid and improvisational nature of the interaction creates the need for augmentation of the collaborative process to be "invisible." Inserting a traditional computer interface into this dynamic would interrupt the flow of the collaboration in before-and-after studies of doctor-patient interaction during medical consultations, for instance, researchers have found that patient communication ground to a halt when doctors were perceived to be preoccupied with the task of operating the computer [Greatbach 1995]. Fortunately, our observations also indicate a correlation between collaborative phase and proximal distance to the whiteboard. This "proxemic" behavior, where physical distance correlates with metaphysical relationship, is analogous to the proxemic behaviors people exhibit with one another [Hall 1966]. In the following phase of research, we apply these findings to help make the proposed assistive whiteboard services less intrusive on the design activity.

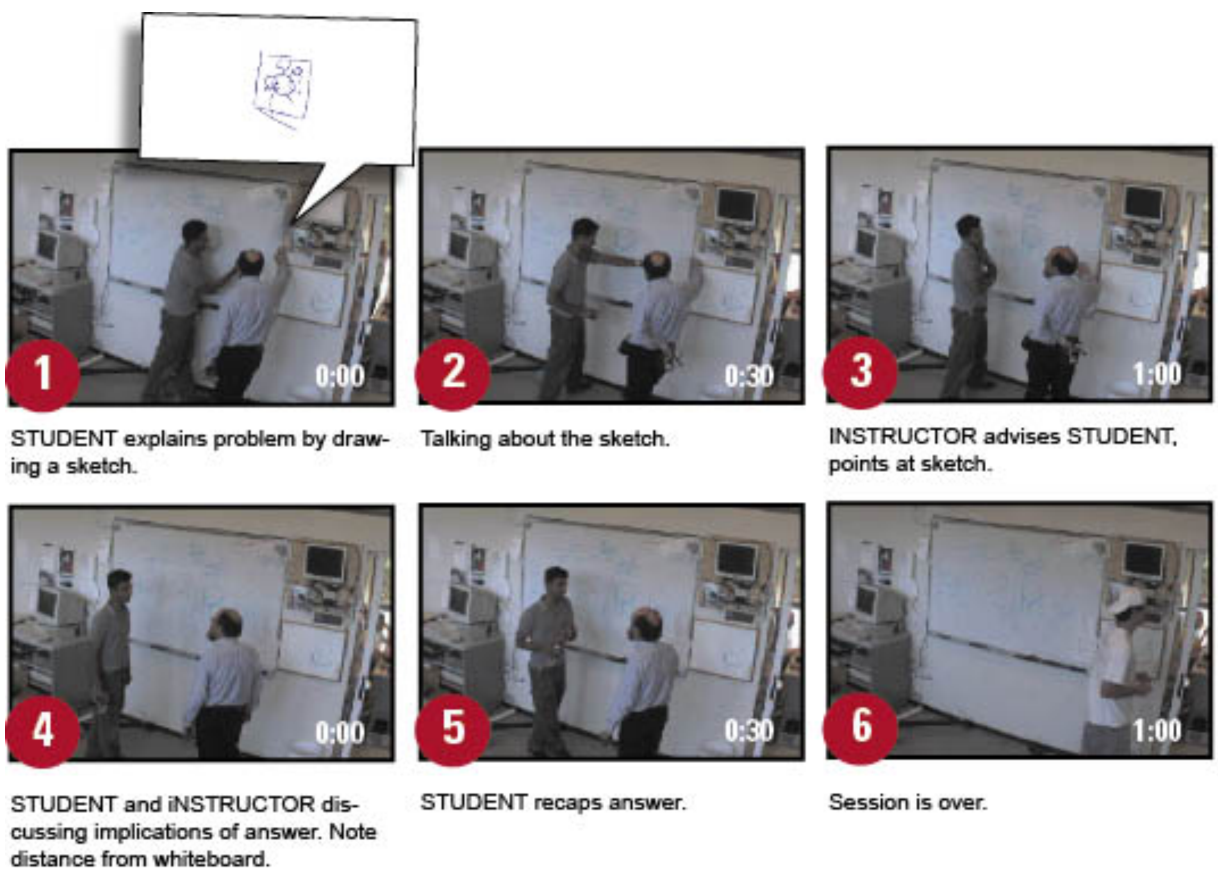


Figure 12. Student and Instructor interaction at whiteboard

Figure 13. The Range interactive whiteboard.

STUDY 2: RANGE

We designed Range, an electronic whiteboard system that uses user proximity as a form of implicit input to explore the role that proxemics [Hall 1966] can play in whiteboard interaction design. Using distance sensors mounted to the front of the board, Range alters its behavior to support (1) ambient display of information, (2) active sketching and writing, and (3) discussion and modification. Through iterative design, we developed presentation techniques to enable the whiteboard to transition between modes while enabling correction and override.

Related Work

Prior research and development on electronic whiteboards has created a wide variety of useful features for collaboration. PARC's pen-based electronic whiteboard, Liveboard [Elrod 1992], used a system called Tivoli to introduce interaction techniques for creating and manipulating ink based documents; the system used gestures to distinguish inkstrokes from gestures for selection, grouping and manipulation [Moran 1995]. While such *explicit* gesture based systems enabled fluid interaction, they required users to be familiar with the gestural language, a fairly high barrier to entry.

The Flatland whiteboard interface [Mynatt 1999] which was based on informal observations of whiteboard use in office settings, provided different sets of functionality adapted to the different types of thinking and pre-production tasks researchers observed people using whiteboards for: generating everyday content (such as task lists, sketches, and reminders), clustering of content (both persistent and short-lived), and a transitioning between semi-public and personal use. In their system, inkstrokes were automatically segmented and clustered, the physical proximity of the strokes is used as an *implicit input* signifying association, but task-specific adaptations required users to use *explicit input* to apply "behaviors" to inkstrokes and clear the board. A similar mix of implicit and explicit is found in François Guimbrietiere's PostBrainstorm Flow and Go technique where *implicit* recognition of different object types is used to create context menus with appropriate parameters but where users still employ *explicit* pen motions to indicate commands [Guimbretiere 2001].

Current work in ubiquitous computing is exploring the use of sensors to utilize information about the user's physical context as an implicit input. Both Thorsten Prante, *et al.*'s Hello.Wall [Prante 2003] and Daniel Vogel & Ravin Balakrishnan's interactive Ambient Public Displays [Vogel 2004] use the physical distances between multiple users and the display to adapt the display's operating mode. Range applies this concept of modifying interactive behavior based on the proximity of users and whiteboards to the context of active collaborative whiteboard use.

System Design

Range was implemented using a combination of pre-existing hardware and software tools and technology using sustained observation and iterative prototyping.

The Range whiteboard prototype employs a rear-projection SMART Board containing an SXGA+ resolution projector (1400x1050) and a Windows XP PC. Four SHARP GP2Y0A 150cm analog distance sensors were mounted to the bottom bezel of the board, and connected to the PC over USB via the d.tools hardware and libraries

[Hartmann 2005]. The software component of Range was written in C# using the Microsoft Tablet PC SDK and the SMART Board SDK.

The region in front of the board is divided into four zones, which we called intimate, personal, social, and public, after proxemic zones observed by Hall to be used by people in social settings [Hall 1966]. While Range is capable of sensing the presence of multiple people in front of the board if they are not standing in front of one another, our observational work suggested that use modes were based on the user closest to the board, and so the zones are defined accordingly. We settled on defining the intimate zone to be the region in which users stand to write at the board, testing with multiple users to increase the robustness of the zone definitions. The personal zone was set further back, at a distance (>15 inches back) where users were not "at" the board, but could easily reach the board for pointing and text manipulation. The social zone (>25 inches back) was out of touching distance from the board but with in easy viewing distance. The public zone comprises the distance beyond the social zone (> 40 inches back). Although we named the zones after Hall's proxemic zones, the actual distances for the zones were defined through iterative development by observing characteristic activities for each zone (action, negotiation, reflection), first observed by Gill and Borchers [Gill 2003] and where they usually took place in front of the board.

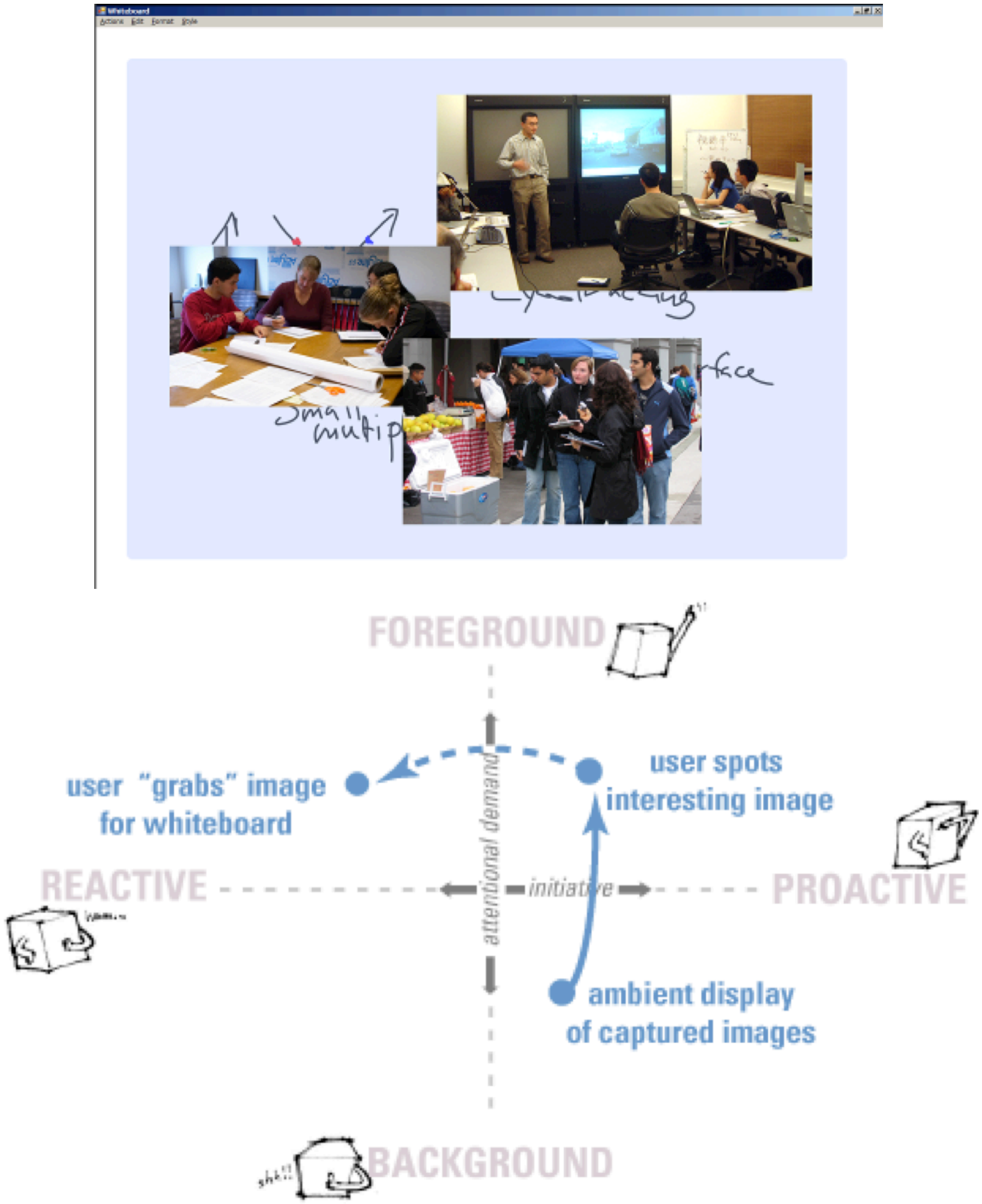


Figure 14 Transition from ambient to drawing space: *Left:* In ambient mode, Range displays photos of interest overlaid on top of any content on the board. These photos glide off the board when a user approaches, but can be "caught" for active use. *Right:* The trajectory of the system demonstration and override.

Features

We implemented three features in Range that use proximity as an implicit input: an automatic transition from ambient display to drawing space, automatic space clearing, and automatic ink stroke clustering.

> *Transition from ambient to drawing space:* When users are not engaged with Range, the whiteboard switches to ambient display mode, overlaying the existing whiteboard contents with a transparent blue backdrop and a stream of digital images of interest to the collaborative team (see Fig. 14). We used snapshots of previous whiteboard states and other photos of interest from an online photo sharing site to improve shared project awareness.
>
> As a user approaches a Range whiteboard in ambient mode, the backdrop fades and the displayed ambient content floats off to one side, allowing the user to re-engage the whiteboard contents beneath. If the user touches the departing content, it stops and becomes selected so that the user may move it to some place on the whiteboard of her choosing. We found in preliminary testing this "floating" to be important because it helped users to form a model of where the ambient images "went to." This metaphor also facilitated override; users found it "natural" to keep images by grabbing departing images.

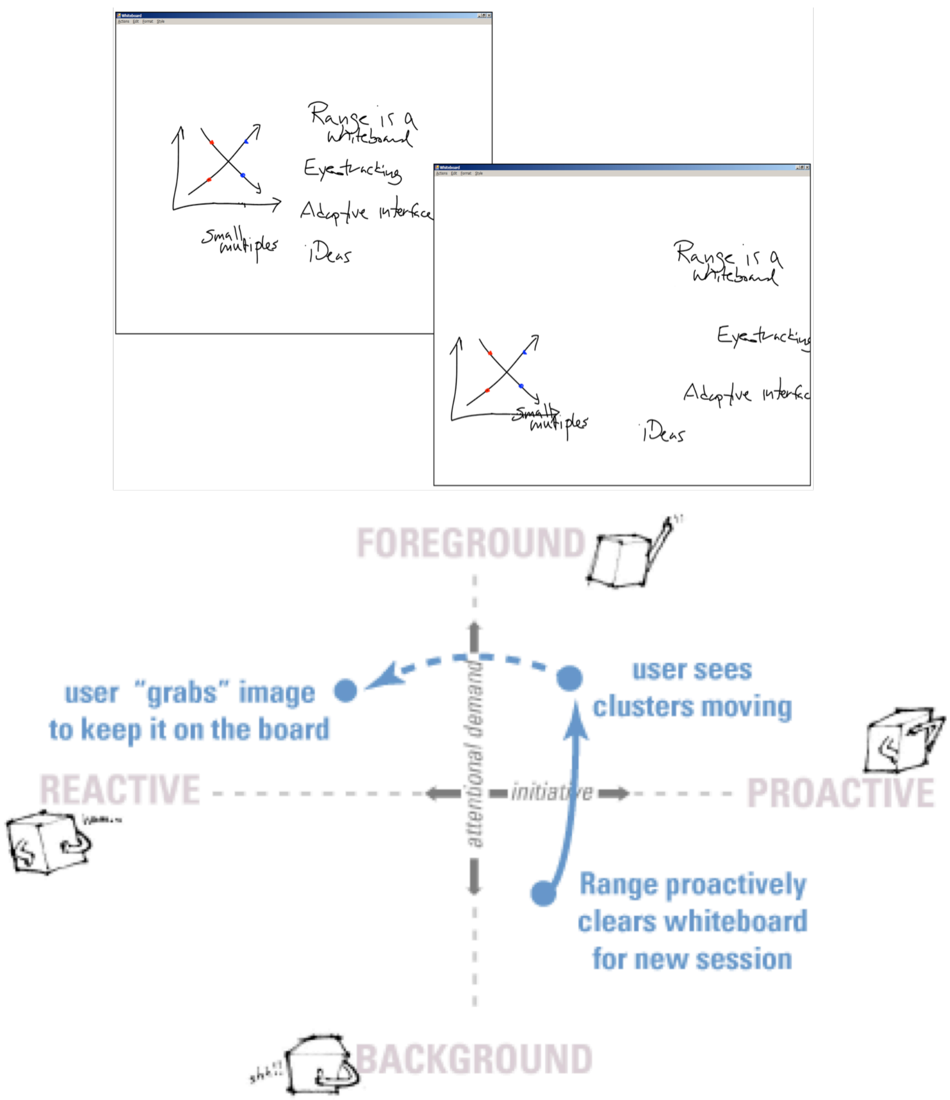


Figure 15. Making space. *Above:* Whiteboard before user approaches board. *Below:* The trajectory of System demonstration (solid line) and Override (dotted) used in making space.

Making space: In our first formative phase, we found that people often leave drawings or notes on the board; groups, in particular, would leave notes in order to provide shared persistent reference. However, a whiteboard full of writing discourages active whiteboard use, as users are hesitant to erase work. Copying content to another surface takes time, time that may kill a serendipitous, free-flowing conversation.

To address this problem, Range moves whiteboard contents out to the left and right of the board center when it senses a user approaching, clearing a space so that the user immediately has a blank space in which to write. The system reflects what it feels is the user's demonstration of her desire to start a new drawing session by overtly clearing the whiteboard for a new session. If the system's interpretation is incorrect, the user can repair the interaction by overriding the space-making gesture, holding clusters in place until the system stops trying to move them.

The data on the edges of the board are not affected during the board-clearing maneuvers; this "place-based exemption" was based on our observations that information that is meant to be persistent, e.g. phone numbers of colleagues, lists of upcoming events, tend to be placed on the outside edges of the board. Like the ambient display transition, we discovered that animating cluster relocation better supported user comprehension and override capability.

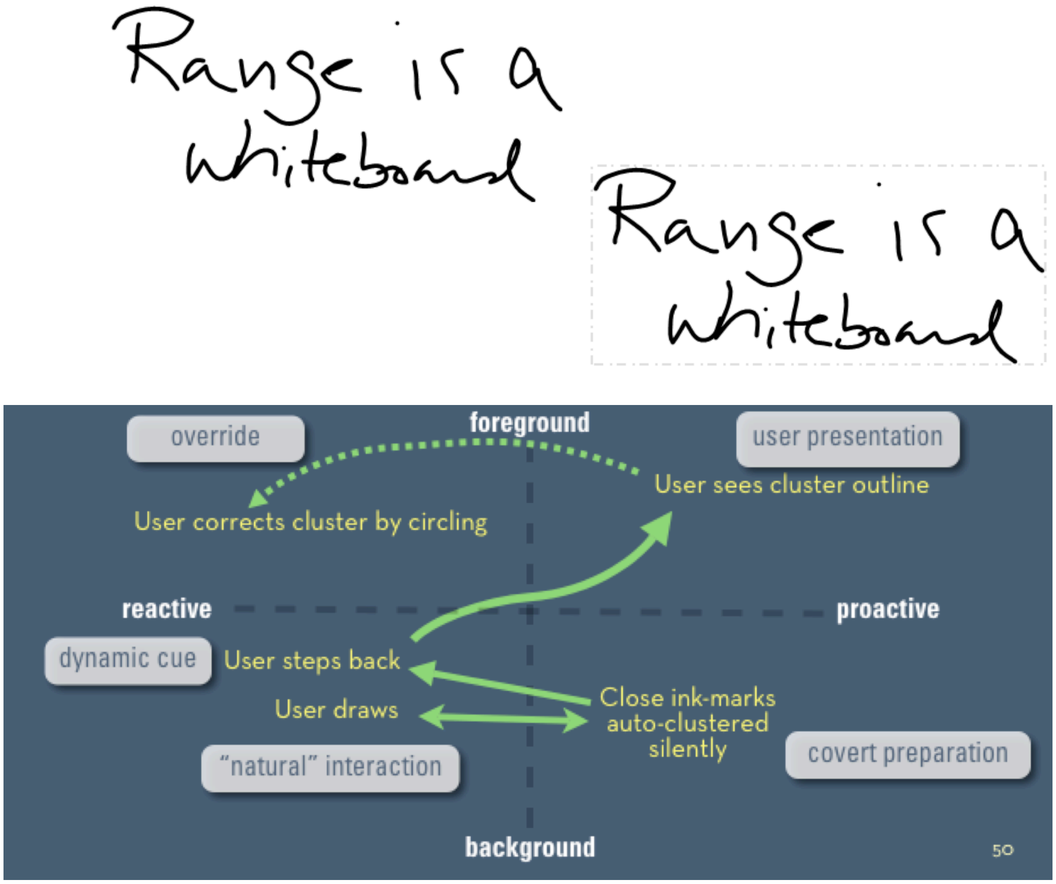


Figure 16. Clustering. *Above:* While strokes are invisibly clustered in writing mode, feedback about clusters is displayed when users are standing in the personal zone. *Below:* Framework trajectory for the user reflection and override.

Clustering inkstrokes: In order to move text and graphics around while maintaining coherency of the sketches, the underlying system needs to have some conception of the semantic units of whiteboard contents. To achieve this, we have implemented a simple form of stroke clustering, using the stroke's timestamp (time of creation) and location on the board (estimated by its bounding box).

One of the design tradeoffs faced by electronic whiteboard designers is whether and how to explicitly show users how their inkstrokes are being clustered and recognized; instant feedback allows users to correct mistakes but interrupts fluidity of idea generation, whereas lack of feedback can wreak havoc when semantically related inkstrokes are relocated or transformed incorrectly after the fact. Range uses the user's proximity as an indication of "when to interrupt" with information about how it has automatically clustered inkstrokes. The clustering occurs automatically as users write, but users are not shown the bounding box around their clusters until they step back into the personal zone. Following this metaphor, marker strokes read by the SMART Board are interpreted as inkstrokes when users are in the intimate zone and as manipulation gestures when the users are in the personal zone (see Fig. 16). Users can use manipulation gestures to move clusters or to correct the system's automatic clustering.

Users who tested our system informally during iterative development found that this zone-based implicit interaction was both more fluid and more intuitive than the explicit command-based or artifact-based models built into the current SMART Board system. Although they did not always "naturally" stand in the correct zone to write or manipulate drawings, the simple feedback of the cluster outlines let users know to stand closer or further; eventually, experienced users tended to stand in the appropriate locations without much forethought.

System Evaluation

In order to receive feedback on the design of Range and to identify potential improvements, we conducted a laboratory study in which 10 participants were asked to use the Range system on a series of short collaborative design exercises. Participants were recruited from an undergraduate course on communications and were asked to work in pairs. None of the participants had collaborated with one another prior to the study. None of the participants had much design experience. Four of the five pairs were mixed gender, featuring one male and one female participant; the participants in the remaining dyad were both male.

Protocol

Collaborators began with a warm-up task to help familiarize them with the digital whiteboard and with their collaborative partner. Their task was to brainstorm as many animals as they could with names beginning with the letter "M."

The pairs were subsequently asked to perform four design exercises in order to compare the utility of two versions of the digital whiteboard. The participants all received the following exercises, with the ordering mixed using latin squares to mitigate ordering effects:

> *Webpage design:* design a website for a web-based campus textbook swap service.
>
> *Remote control design:* sketch a design for a hand-held remote controller for the kitchen.
>
> *Space redesign*: remodel the current room to support a wide range of lecture, lab and lunch activity.
>
> *Game design:* design a storyboard for a "first-person rider" video game for youngsters who love horses.

The full descriptions of the exercises as they were presented to the students may be found in Appendix C. Screenshots shown in Figure 17.

Following each task, the written instructions stated, "You will have 10 minutes to work on this problem. During this exercise, you will use the whiteboard in [BLUE/GREEN] mode. You can use as many pages as you like, but the final solution must be presented on a single screen. We will let you know when you have 2 minutes left." Although participants were given up to 10 minutes for each exercise, they were permitted to end the exercise earlier if they felt the task was complete. The whole of the experiment lasted between 45 minutes and an hour for all the pairs.

In the directions for the first and third design exercise, the participants were instructed to use the whiteboard's "blue mode," and on the second and fourth, they were instructed to use the whiteboard's "green mode." The modes were selected by touching the blue or green buttons in the upper right-hand of the digital whiteboard screen; the corresponding button would "light up" when the mode was selected. Both the explicit mode selection and visual feedback were intended to reinforce in the participants which mode was being used for each exercise. The green mode featured more explicit controls of whiteboard functions, whereas the blue mode featured more implicit controls. The names "blue" and "green" were chosen to help prevent unwarranted bias in evaluation. Table 3 shows the key differences between blue and green mode:

Table 3. Differences in Experimental Condition for Range study

	Green mode	Blue mode
Implicit/Explicit	Explicit	Implicit
Ink-size toolbar	Toggles between extended and retracted mode when user taps on the toolbar in lower left of whiteboard.	Toggles between retracted and extended mode when user moves from intimate to personal zone.
Input mode	Toggles between write mode and move/select mode through use of buttons in lower right of keyboard.	Switches between write mode and move/select mode based on pen-pickup and user distance from board.
Clustering of ink strokes	Based on explicit selection of inkstrokes.	Based on implicit time/space distance algorithm.

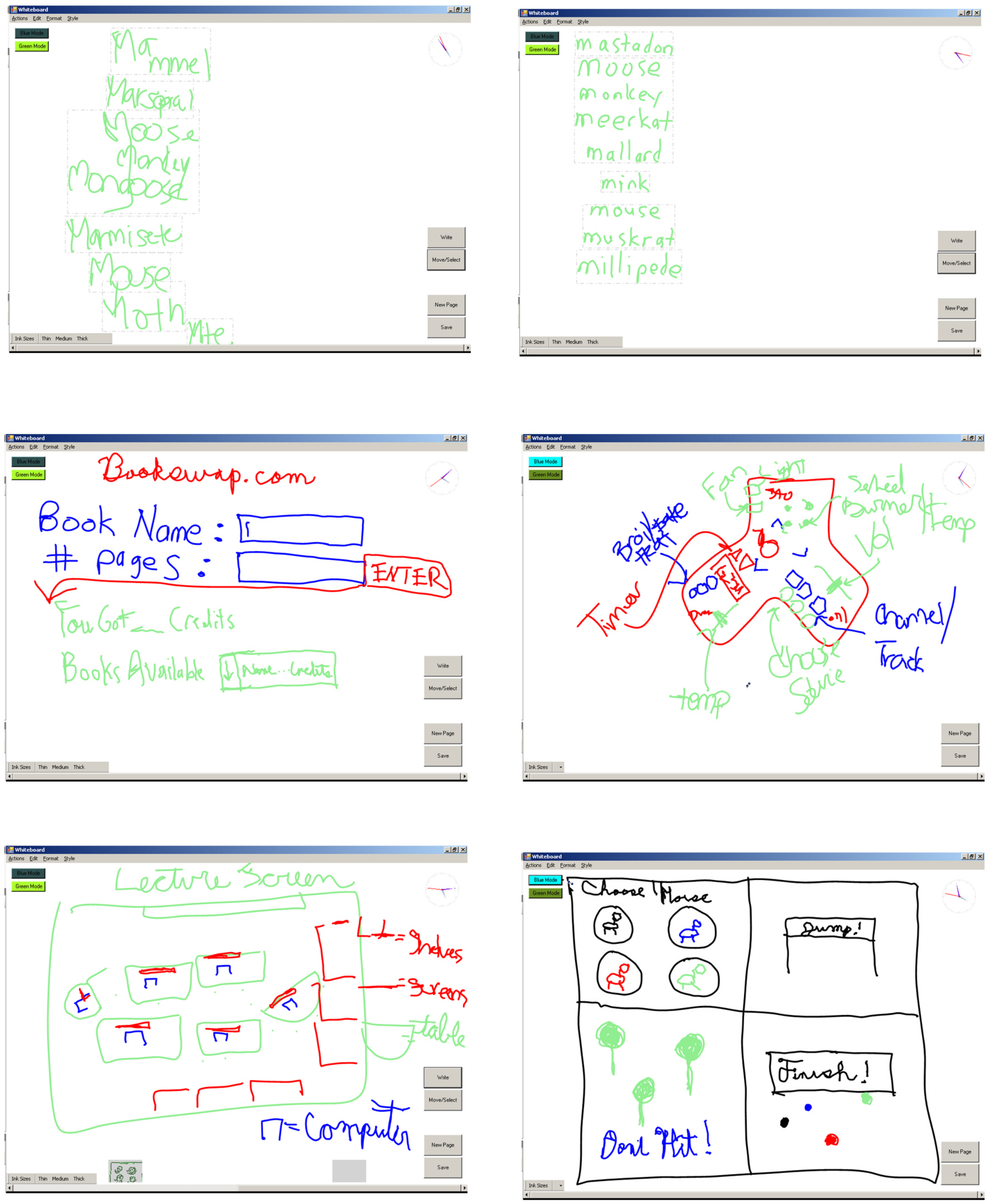


Figure 17. Screen captures from Range study: (a) & (b) Text from warm-up exercise. (c) Green-mode version of the website design task (d) Blue-mode version of the kitchen remote task (e) Green-mode version of the space design task (f) Blue-mode version of the Game design task

Following the exercises, students were asked to fill out a post-study questionnaire asking them about their experience with traditional and digital whiteboards, their preference for the blue or green mode on the whiteboard, their estimation of their own performances on the design exercises and their evaluation of their collaboration activity on the design tasks. The questions were generally posed in two parts, a close-ended five-point Likert scale question followed by an open-ended question that allowed participants to elaborate on what factors influenced their ratings.

Results

In this study, most participants evinced a clear preference for the explicit version of the Range whiteboard. Two participants, from different collaborative pairs, indicated a strong preference for the implicit Range system, rating it as the preferred/easiest to learn/easiest to use/least distracting/most natural choice, stating that they preferred the system because it "had less buttons," "look[ed] more like a normal whiteboard," allowed "more control," and enabled "faster transition into modes." Two other participants (also from different collaborative sessions) were similarly emphatic about their preference for the explicit version of the board, ranking it as the preference across the board and stating that "I didn't have to be right against the screen to write," that they preferred "directions on the board with icons", and that they liked that they could "stand wherever" without having to "worry about proximity to the board." However, while the remaining six participants were more nuanced in their assessment of the relative merits of the different versions of the whiteboard, showing some amenability to the implicit version of the board ("with some time I think I could learn its quirks and find it quicker"), by and large their ratings on the respective merits of the two whiteboard modes showed a strong preference for the explicit version of the board. Among the common criticisms cited for the implicit version of the whiteboard (in order of frequency) were:

a) Memory/visibility issues: A lot of the participants felt that having the explicit buttons helped them to learn and use the system. One participant who preferred the explicit system noted that "It had more buttons, more self explanatory" while another said "you knew you were on a specific setting and how to interact."

b) Distance calibration issues: Because the board used absolute distance thresholds as trigger points for mode changes, very tall participants who had to bend forward to write on the board were often standing in the "personal" zone rather than the "intimate" zone when they were writing. This triggered a lot of criticism: "Blue mode too sensitive to distance; required moving uncomfortably close to the board in order to write," said one participant; "I didn't have to be right against the screen to write," said another, about her preference for the explicit mode.

c) Spatial orientation issues: While most of the collaborators followed the spatial "driver/navigator" patterns noted previously in the chapter, a couple of the participants in this study showed more anomalous proxemic patterns (in one case because one participant had an injured leg, in another because the participant went out of his/her way to sit in a chair to cede control of the task activity to his/her partner). In these situations, the participants were quick to find that the whiteboard did not work properly: "Blue mode forced us to stand behind the other, which didn't feel as collaborative," "I had to focus on the blue mode's placement and body position"

One issue that seemed to affect participants perceptions was general latency and sensitivity issues with the Range software and SMARTBoard hardware itself; although these issues caused frequent slips in selection and writing as well as problems clustering, the participants seemed to feel it was more the "fault" of the whiteboard in implicit mode than in explicit mode, when they seemed to feel it was a matter of their own mastery of the tools.

Discussion

In his book, *The Design of Future Things*, Norman defines technology as “new stuff that doesn’t work very well or works in mysterious, unknown ways.” [Norman 2007] Perhaps, then, the problem with our design of Range is that it employed too much technology.

As researchers such as Heidy Maldonado[Maldonado 2007] have noted, numerous factors affect the successful employment of new technologies in design that may have little to do with the technologies (or the frameworks behind them) themselves. Another problem may have been our approach to testing; although it was easier to recruit and balance conditions using naïve students as designers, we now recognize that implicit interaction systems may require developers to focus on evaluation techniques that employ seasoned professionals, because the implicit interactions in question are built around patterns of behavior and interpretation that influence how people interpret actions. Experienced piano duettists may recognize their partner’s beating their hands in space as a sort of cue that aids in synchronizing timing, but a novice may gain nothing at all from the cue.

Given experienced designers, better interactive whiteboard technology, faster software response and further development and evaluation, it is possible that this “wicked problem” [Rittel 1973] of providing seamless design support at the whiteboard could be tamed through iterative refinement. It is apparent, however, that the size of this design challenge of adding implicit interactions to the already challenging task of supporting design collaboration was somewhat too ambitious for the purpose of validating our implicit interaction design framework. In many ways, Range has succeeded mostly in showing the pitfalls of developing technologies that are too clever by half.

CONCLUSION

In the previous chapter’s design exploration with gesturing doors, we utilized a pre-existing implicit interaction pattern, and validated that interaction built on established patterns carried social meaning even when people were interacting with non-anthropomorphic objects rather than people. In applying the implicit interaction framework to Range, we have gone further, attempting to establish novel and successful interaction patterns from individual techniques. The design of Range was a useful proof-of-concept exercise in using the implicit interaction framework as a method of developing new implicit features; the framework not only helped us to develop new and potentially useful features, it also helped us to more broadly characterize what was important about features that had been introduced to previous interactive whiteboard systems.

Given the difficulties we faced in evaluating Range, it is difficult to say from this evaluation whether the assumptions of the framework are valid. Our efforts to test the validity of the implicit interaction framework's assumptions that an implicitly interactive system would provide more seamless support for design collaboration were stymied by limitations of the technology we used, as well as by the methodological challenges of studying design activity. The design framework and the concepts of implicit interaction patterns and techniques help to frame the design effort conceptually, but do not remove the challenge of understanding the technical requirements and post-design testing and refinement required for any "technology design" project. That said, it seemed to us that the implicit interaction paradigm was valuable in focusing our attentions on the implicit cues people give off about the phase of their design activity, and that the framework itself was useful in suggesting solutions that would provide projection, feedback and feed-forward about the proactive actions of the Range whiteboard.

Chapter 5

MOVING AHEAD

Applications, Limitations and Principles of Implicit Interaction Design

This dissertation has explored the design of interactive systems that mimic our ability to use implicit interactions to work with one another. The primary goal of this work is to help interaction designers to understand how to create products, systems and experiences that make more intuitive sense to their users, so that the users can work more seamlessly, learn more quickly, act more skillfully and feel more comfortable in their day-to-day lives. This research is premised on the idea that human-human interactions have patterns with structural and communicative functionality that persist when these patterns are applied to human interactions with non-human partners.

CONTRIBUTIONS

The key contribution of this dissertation is the implicit interaction framework that gives designers a way to map the patterns and behaviors of implicit interaction observed in human-human interactions to the design of interactive systems. This framework enables designers to extend their intuitions of how to design everyday things to include objects that are dynamic and demonstrative. It identifies initiative and attention as two key factors in the design of implicit interactions, and makes plain the trajectory of actions in any interaction patterns.

From a disciplinary perspective, this dissertation provides designers with a deeper appreciation for the sophistication involved in many of our incidental interactions with one another, illuminating the role that the social sciences might play in making even very granular design decisions, such as when a graphical user interface should make a noise, or what color to make a door-frame. This view complements the more widely shared perspective that such work might motivate applications or clarify important contextual issues. Our ability to negotiate joint actions—to lead a friend by the hand, or to lift a table together—requires establishing common ground, a shared understanding, which we do by using a variety of behaviors that designers would do well to understand.

This dissertation also provides examples of applying implicit interactions to the design of interactive systems with research endeavors in two areas: public environments and collaborative workspaces. These research endeavors accomplished multiple ends: 1) They provided examples of implicit interactions, 2) they helped to establish the protocol for how to translate human behaviors into interaction patterns and techniques, 3) they motivated the development of new methods to evaluate implicit interactions, and 4) they helped to characterize typical responses to successful and unsuccessful implicit interactions. In addition, these projects validated the assumptions behind the implicit interaction framework.

APPLICATIONS

Although the importance of choreographing initiative and attention is a constant throughout human-computer and human-machine interactions, the patterns and techniques demonstrated in this dissertation will be most critical in situations where the explicit interaction model falls short: where the users and the designed systems are neither willing nor capable of being completely and autonomously in control. In such situations, the right action needs to be negotiated interactively. Examples of such application domains include:

Smart products. Airplane catalogs and electronics stores abound with devices that promise to make your life easier by automating various routine tasks: turning on your coffee machine, feeding your cat, watering your plants, taking out the trash. These products often have limited appeal because the effort required to figure out the range of what can be done, to set the relevant parameters, to understand what is set, and to predict what will occur is perceived to outweigh the likely benefit. Implicit interactions can help engage users without requiring a manual. By demonstrating what can be done, pointing users to relevant settings, making inferred information visible and projecting future actions, implicit interaction design can make the interaction as "smart" as the proposed action.

Automobiles. Most drivers seem unaware that they are the biggest variable in the safety of their car. Drivers are often inattentive, unskilled, and reckless to boot, and thus many of the most important innovations that are being integrated into cars have less to do with adding bells and whistles (in the manner of smart products) and more to do with trying to keep drivers from hurting themselves. Implicit interactions can help to choreograph the drivers' attention, to augment their sensing and control capabilities by providing feedback and on-going assistance, and to make drivers more mindful of their driving by reflecting their behavior back to them.

Interactive architecture. Architects often speak of a building's "program" but tend not to think of that program as reacting conditionally to different situations or people. The gesturing doors proposed in this dissertation are just one example of how buildings might interact with people; hallways could help guide different people to different places; wall displays could project information for tourists and lie quietly in the background for regulars. Implicit interactions can help make these functions possible without making the building incredibly irritating.

Human-robot interactions. Interactive robots have been heralded for their potential in domains ranging from manufacturing to elder care, but in all of these applications, the negotiation of action and autonomy is a constant issue. Implicit interactions can help mediate transactions between people and machines by helping robots to "read" the signals people implicitly communicate through their actions and by assisting the people in reflecting and demonstrating what it is that the robot is perceiving or proposing as an action… without requiring every user to be a script writer.

LIMITATIONS

One consequence of framing implicit interactions as conversations is that it represents interactions as a dialogue, such as one that a person may have with a partner, assistant, or agent. It does not presume *spoken* dialogue, but its structure tends to emphasize turn-taking and dyadism. This conversation metaphor tends to obscure interactions where the interactive system is less of a peer actor and more of an instrument, tool, or extension of one's self. It is easier, for example, to use the implicit interaction framework to model a scenario where I pass my partner a screwdriver than one where I steer a blindfolded friend to a surprise party. This is because the former scenario involves turn-taking whereas the latter involves something more like continuous control—and yet, in the latter scenario, it is still important to implicitly negotiate common ground between actors, for example, projecting changes in directions, and accommodating override (in case my friend's foot encounters an obstacle I don't see).

This seeming dichotomy—between the agent and the instrument metaphors—has been presented by Norman as a continuous spectrum. He cites, by analogy, horse riders who vary the amount of control or autonomy they have when riding a horse through the tension on the reins [Norman 2007]. In future work, it would be useful to understand how the implicit interaction framework needs to be expanded or modified to accommodate a wider range of interaction relationships, so as to better include those where the human interactant has more tightly coupled control and interaction with the interactive device.

Another limitation of this work is also related to the horse metaphor, which is the role of expertise and experience in the evolution of implicit interactions. Whereas this research has focused largely on interactions between “relative strangers,” the horse metaphor assumes highly knowledgeable users. People have ways of relaxing and abbreviating the structure of implicit communications with people they see everyday; at the same time, they also expect the range of possible interactions to expand over time. The same brief, civil greeting from a doorman might be perceived as rude if you’ve interacted with him daily for years. It could be similarly important to understand how people expect implicitly interactive devices to evolve their patterns of action over time to accommodate experience and expertise.

IMPLICIT INTERACTION TECHNIQUES

This research represents the beginning, rather than the definitive end of a line of research, so perhaps it is early to be proscribing the proper way to design implicit interactions. Nonetheless, we offer the following four proto-principles as key takeaways from this dissertation’s research:

Seek to understand existing patterns before designing new ones. Patterns of interaction are like patterns of conversation; they may be conventional, but the conventions have a purpose. As interaction designers, it is important to be attuned to these patterns and the work they accomplish in establishing common ground between interactants; it is not merely a matter of accommodating user habits but of recognizing and using what works.

Proactive demonstration helps people know what to expect. Interaction designers should remember that all actions also have a communicative component. They should design interactive systems so as to use action to signal as well as act. We might say “ahem” not only to get a person’s attention, but also to establish that information is going to arrive in audible format, and what voice to focus on.

Similarly, proactive demonstrations help users see what a system can do, and how it will do it, so that they might adapt their own behavior accordingly.

User reflection helps people see what a system notices about them. Sensing is a critical precursor to any dynamic response, but that response will confuse users unless they have some insight into what the system sensed to provoke that response. The designer has many options available in designing reflections. They can showcase what it is they sensed (feedback_, what it is they believe the user wants to do (projection), or what it is they plan to do as a consequence of the user's actions; (feedforward). Each of these provides recognition and uptake that is important in establishing joint actions.

Take people's reactions seriously. People tend to react sociallyto demonstrations of poor social skills. When we engage with people with bad social skills, we harbor negative emotions towards them, we impugn their intelligence and we wish to respond reciprocally with rude behavior ourselves—even when we can't say what is quite wrong with that person's behavior. Our reactions to socially inappropriate interactive objects, environments and systems are similar, so it is imperative that interaction designers learn to gauge these types of responses and behaviors when they are evaluating interactive systems and provide means of override.

FINALLY

In closing, the intent of this body of research is not to promote interactive technologies *per se* but to promote the humane design of such technologies. As interactive technologies move from the confines of desktop computers into toasters, cars and buildings, we are fast running into the limitations of the explicit interaction paradigm. In the real world, where people are not necessarily knowledgeable and are often distracted doing other things, it is important to engage users on their terms, offering services and providing assistance in a manner that is familiar and intuitive. By providing a theory and framework for implicit interaction design and by demonstrating the application of patterns and techniques of implicit interaction, this dissertation hopes to motivate interaction designers to better understand the sociology of objects and people. What matters most, in the end, is not how technology is changing our world or making new things possible. What matters most is how people are people, and how that is likely to remain the same.

As interactive devices continue to permeate our world, it is up to the interaction designers to correct their obnoxious habits, to make them more usable and useful. Designed well, implicitly interactive devices can allow us to reap the benefits of computation and communication away from the desktop, assisting us when we are physically, socially or cognitively engaged or when we ourselves do not know what should happen next. Designed poorly, these same devices can wreak havoc on our productivity and performance, creating irritation and leaving frustration in their wake. By taking stock of what it is we humans do when we work with one another, and using a bit of creativity in applying those lessons to the machine world, we can help make this next generation of interactive devices welcome in our world.

APPENDIX A

GESTURING DOORS PILOT STUDY QUESTIONNAIRE

PLEASE TAKE A MOMENT
TO TELL US YOUR THOUGHTS ABOUT THIS DOOR.

1. What did you think was happening when you saw this automatic door move?

something is wrong w/ the switch

2. Assuming it functioned properly, how did you interpret the door's movement?

It maybe ghosts, since nobody is near

3. How did you *feel* about the door?

☐ ☐ ☐ ☐ ☐ ☐ ☒ ☐ ☐ ☐

Very Negative — Very Positive

4. The door *seemed to intend* to communicate something to me.

☐ ☐ ☐ ☐ ☐ ☐ ☒ ☐ ☐ ☐

Strongly Disagree — Strongly Agree

5. The door *seemed to think* when it communicated with me.

☐ ☐ ☐ ☐ ☒ ☐ ☐ ☐ ☐ ☐

Strongly Disagree — Strongly Agree

6. The door was *reluctant* to let me enter.

☐ ☒ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Strongly Disagree — Strongly Agree

7. The door was *welcoming* me.

☐ ☐ ☐ ☐ ☐ ☐ ☒ ☐ ☐ ☐

Strongly Disagree — Strongly Agree

8. The door was *urging* me to enter.

☐ ☐ ☐ ☐ ☐ ☒ ☐ ☐ ☐ ☐

Strongly Disagree — Strongly Agree

9. Were you walking toward the door to enter the building?

☐ Yes, I was entering the building.

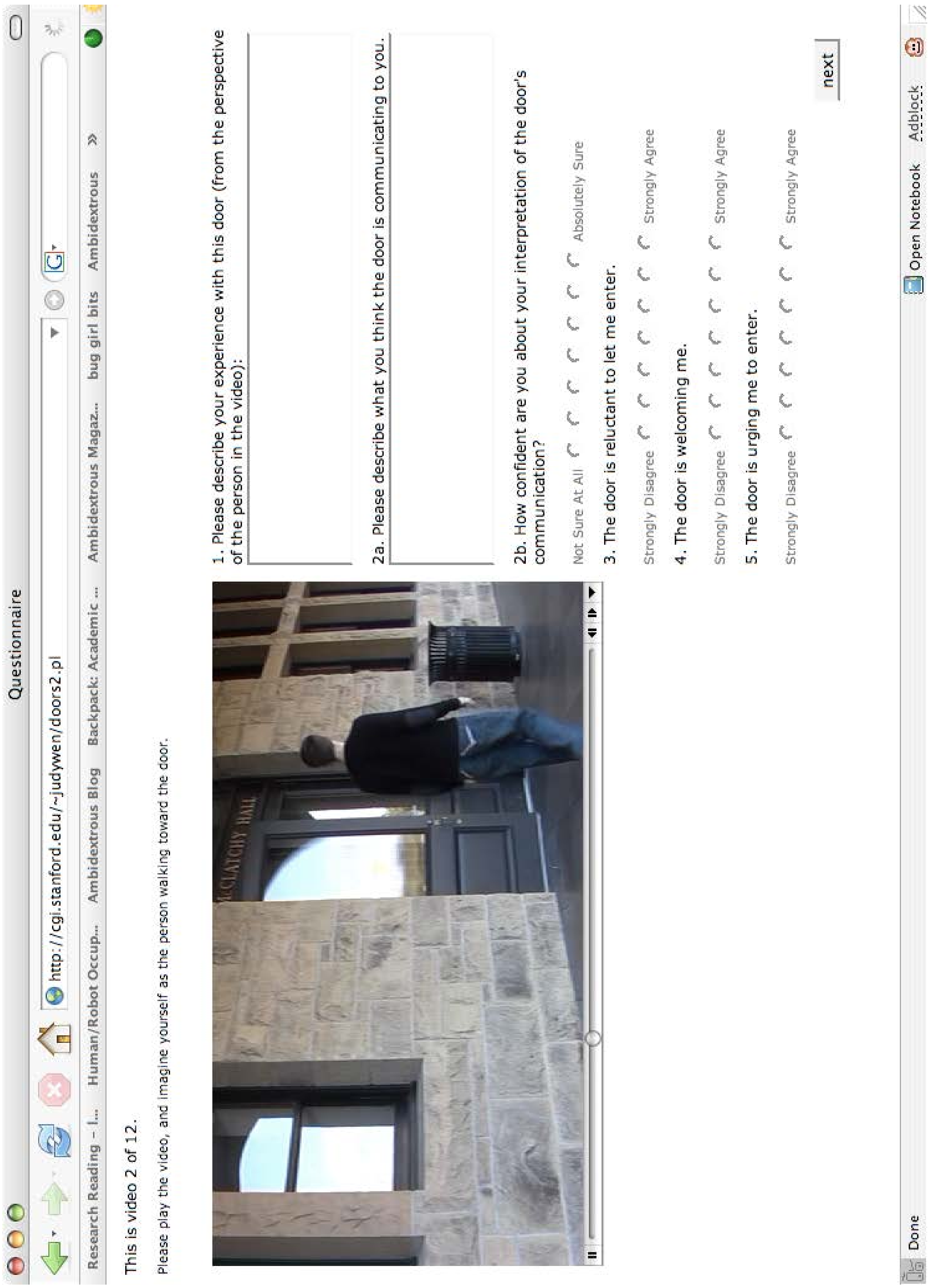
☒ No, I was just walking by the building. ☐ Other: ________

THANK YOU!

9:35 male
pave

APPENDIX B

GESTURING DOORS VIDEO PROTOTYPE STUDY QUESTIONNAIRE



APPENDIX C

RANGE STUDY PROTOCOL

0) Preparation:

Move table back, have chairs available but not in front of whiteboard

Set up camera. Make sure microphone is plugged in all the way!

Set up laptop capture system.

Double-check to make sure you are saving to a new log file on the computer.

1) Gain consent (x+01)

Distribute paper-based consent forms, and get participants to sign and initial.

2) Turn on camera.

Use new tape for each session, and make sure tape is on LP to get 90 minutes of recording time.

3) Provide general instructions. (x+03)

"Thank you for helping us with this study of our Range system. In this study, you are being asked to use our digital whiteboard system in a series of collaborative design tasks. The whiteboard has two modes, which we call the green mode, and the blue mode. You will be asked to use different modes for the different design tasks."

"To start out, I'd just like to familiarize you with this system."

Demonstrate:

-how to write

-how to change colors

-how to erase

-how to change line widths

-how to move inkstrokes (need to touch a line!)

-how to select inkstrokes (start from outside the box!)

-how to add pages

-how to move between pages.

-how to switch between blue and green

-how to change modes in blue.

-the clock.

4) Warm-up exercise, part I. (x+05)

The point of this first warm-up exercise is to give you a chance to explore how the board functions in both the blue mode and the green mode. Please feel free to ask as many questions as you like about how to use the whiteboard in either mode.

Please brainstorm as many animals as you can think of that start with the letter "m." You have 5 minutes.

5) Warm-up exercise, part II. (x+10)

Please use the next 2 minutes to order these animals by size, from smallest to largest.

6) Exercise 1. (x+12)

Ask if there are any more questions about the blue or green modes.

Now pass out exercise 1. MAKE SURE THEY ARE IN THE RIGHT MODE!

7) Exercise 2. (x+22)

While they read, capture the screen from the last exercise with a camera or a screenshot.
MAKE SURE THEY ARE IN THE RIGHT MODE!

8) Exercise 3. (x+32)

While they read, capture the screen from the last exercise with a camera or a screenshot.
MAKE SURE THEY ARE IN THE RIGHT MODE!

9) Exercise 4. (x+42)

While they read, capture the screen from the last exercise with a camera or a screenshot.
MAKE SURE THEY ARE IN THE RIGHT MODE!

10) Evaluation. (x+52)

Ask users to fill out questionnaire. While they read, capture the screen from the last exercise with a camera or a screenshot.

11) Define ranges (if there's time). (x+58)

Ask users where they would stand to a) write, b) move clusters, c) talk to someone at the board, d) stop using the board. Allow them to test this out before "record" ranges.

Also ask users to stand where their fingers just touch the board.

11) Wrap Up.

Remove and label the tape with the date, time, group name and "RANGE II."

Save computer captured movie.

Save the log file on the PC.

APPENDIX D

RANGE DESIGN EXERCISES

WEBSITE DESIGN TASK

Your team is being considered to design a website for a web-based campus textbook swap service. This service would allow students to exchange textbooks they don't need anymore for credits towards textbooks for classes they will take. Please create a sketch of a layout design for the website's homepage, and use arrows diagram pages that should be linked from this main page.

You will have 10 minutes to work on this problem. During this exercise, you will use the whiteboard in BLUE mode. You can use as many pages as you like, but the final solution must be presented on a single screen. We will let you know when you have 2 minutes left.

GAME DESIGN TASK

Your team is being considered to design a video game for youngsters who love horses. Specifically, the game will be a "first-person rider" in which players engage in adventures on horseback. Please create a storyboard (a series of frames that shows the narrative like a comic book) for the opening sequence of the game; diagram critical decision points and splits with arrows.

You will have 10 minutes to work on this problem. During this exercise, you will use the whiteboard in BLUE mode. You can use as many pages as you like, but the final solution must be presented on a single screen. We will let you know when you have 2 minutes left.

REMOTE DESIGN TASK

You have been hired as designers and human factors experts to make recommendations on the future (two to five year) directions in user-interface design for hand-held remote controllers for the kitchen. In particular, this manufacturer is interested in integrated, multi-purpose remote controllers that would be used to control the stove, the oven, and a sound system (because the company has found that people like to listen to music while cooking). Please create a sketch of this remote with call-outs labelling innovative features to show your client.

You will have 10 minutes to work on this problem. During this exercise, you will use the whiteboard in BLUE mode. You can use as many pages as you like, but the final solution must be presented on a single screen. We will let you know when you have 2 minutes left.

ROOM LAYOUT TASK

The iRoom (this room you are in) needs to be remodeled to be a multi-purpose space that supports a wider range of activity. Specifically, we would like to be able to support:

- Lecture-based classes of up to thirty people who face a single large screen display.
- Laboratory "breakout groups" where 5 smaller groups of 4-5 people could simultaneously huddle to work on team projects
- Group lunches of up to twenty people who face each other

We are willing to move the existing walls, but would like to reuse the furniture in the room as much as possible. Please draw ideas for room layout that might support this range of uses.

You will have 10 minutes to work on this problem. During this exercise, you will use the whiteboard in BLUE mode. You can use as many pages as you like, but the final solution must be presented on a single screen. We will let you know when you have 2 minutes left.

APPENDIX E

RANGE STUDY QUESTIONNAIRE

Thank you for participating in our study. Please answer each question carefully and truthfully.

1a. How often do you use a whiteboard?

O	O	O	O	O
ALWAYS	OFTEN	SOMETIMES	RARELY	NEVER

1b. What do you use the whiteboard for?

2a. How often do you use a *digital* whiteboard?

O	O	O	O	O
ALWAYS	OFTEN	SOMETIMES	RARELY	NEVER

2b. What do you use the digital whiteboard for?

3a. Which whiteboard mode did you prefer in general?

O	O	O	O	O
BLUE				GREEN

3b. Why?

4a. Which whiteboard mode was easiest to learn?

O	O	O	O	O
BLUE				GREEN

4b. Why?

5a. Which whiteboard mode was easiest to use?

O	O	O	O	O
BLUE				GREEN

5b. Why?

6a. Which whiteboard mode was the least distracting to the design task?

o BLUE o o o o GREEN

6b. Why?

7a. Which whiteboard mode felt the most natural?

o BLUE o o o o GREEN

7b. Why?

8a. Which whiteboard mode would you rather use in single-person use?

o BLUE o o o o GREEN

8b. Why?

9a. Which whiteboard mode would you rather use in a larger meeting?

o BLUE o o o o GREEN

9b. Why?

10. Please describe when the blue mode worked well, and when the green mode worked well.

For questions 11-15, please refer to your design task packet to remind yourself of that activity.

11a. In your own estimation, how did you and your collaborator(s) do on the warm-up design exercise?

O	O	O	O	O
POORLY				VERY WELL

11b. What factors do you feel contributed to your design performance?

12a. In your own estimation, how did you and your collaborator(s) do on the first design task?

O	O	O	O	O
POORLY				VERY WELL

12b. What factors do you feel contributed to your design performance?

13a. In your own estimation, how did you and your collaborator(s) do on the second design task?

O	O	O	O	O
POORLY				VERY WELL

13b. What factors do you feel contributed to your design performance?

14a. In your own estimation, how did you and your collaborator(s) do on the third design task?

o	o	o	o	o
POORLY				VERY WELL

14b. What factors do you feel contributed to your design performance?

15a. In your own estimation, how did you and your collaborator(s) do on the fourth design task?

o	o	o	o	o
POORLY				VERY WELL

15b. What factors do you feel contributed to your design performance?

16. How well did you and your collaborator work together?

O O O O O

POORLY VERY WELL

17. How well did you and your collaborator divide tasks?

O O O O O

POORLY VERY WELL

18. How well did you and your collaborator get along?

O O O O O

POORLY VERY WELL

19. How willing would you be to work with this collaborator again?

O O O O O

POORLY VERY WELL

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