Interactive Public Ambient Displays

by

Daniel John Vogel

A thesis submitted in conformity with the requirements
for the degree of Master of Science
Graduate Department of Computer Science
University of Toronto

Abstract

Interactive Public Ambient Displays

Daniel John Vogel

Master of Science

Graduate Department of Computer Science

University of Toronto

2005

We develop design principles and an interaction framework for sharable, interactive public ambient displays that support the transition from implicit to explicit interaction with both public and personal information. A prototype system implementation that embodies these design principles is described. We use novel display and interaction techniques such as simple hand gestures and touch screen input for explicit interaction and contextual body orientation and position cues for implicit interaction. Techniques are presented for subtle notification, self-revealing help, privacy controls, and shared use by multiple people each in their own context. The results of two user studies are also presented, and future directions discussed.

Acknowledgements

Returning to academics after a ten year hiatus can be daunting. But, from the moment I first inquired about the program, my return was made significantly easier through the help and encouragement of Ron Baecker. When Ravin Balakrishnan gave me a tour of the DGP lab and demonstrated research using novel interaction techniques with unconventional input and display devices, I knew that this was what I wanted to do. I feel incredibly lucky to have worked with Ravin as an advisor in such a great lab with so many talented students and faculty. And, I am also thankful to all of my family and friends who have encouraged and supported me throughout.

Previously Copyrighted Material

Much of the material included in this thesis has previously been published in the proceedings of the *ACM Symposium on User Interface Software and Technology,* and has been included herein with their permission and permission of my co-author. The ACM copyright notice applies only to those sections previously published in journals of the ACM (see Bibliography, Vogel & Balakrishnan 2004):

Table of Contents

List of Tables

List of Figures

1 Introduction

As the vision of ubiquitous computing edges towards reality, an increasing flow of information will likely be available anytime and anywhere (Weiser, 1991; Weiser 1993; Weiser & Brown, 1996). A new conduit for information is emerging in the form of inexpensive large-scale displays placed in public, semi-public, and private spaces like airports, schools, shopping malls, offices, and homes. Currently these large displays are typically used to display advertisements or news, essentially creating super-sized broadcast televisions.

Beyond simply broadcasting information to the multitudes, this creates an opportunity for exchanging specific information with individuals as they pass by. As data exchange networks solve privacy issues and mature into a trusted platform for distributed personal information access, these public displays could be used to access our personal information securely and easily. With these ubiquitous gateways to our information, we may no longer have to carry around personal devices like PDAs or laptops to access all our personal information.

Realizing this vision, however, has its challenges. How should we present useful information in an already crowded environment without overloading users' senses? How do we maintain privacy while offering personal information in a public space? What techniques could be used to notify and communicate with users in a minimally intrusive, socially acceptable manner? How can a public display be effectively shared by several users for personal interactions while still providing some semblance of privacy to the individuals concerned? What kind of input and interface technologies do we need to develop to allow for effective interaction with large public displays?

For the most part, researchers have been tackling these issues somewhat separately. This includes research on techniques for peripheral awareness and notification (Huang & Mynatt, 2003; Greenberg & Rounding, 2001; MacIntyre et al., 2001), ways to represent information in public, semi-public, and private spaces using ambient displays (Skog & Holmquist, 2003; Prante et al., 2003; Stasko, Miller, Plaue, Pousman, & Ullah, 2004), explicitly interactive public displays (Russell, 2002; Churchill, Nelson, Denoue, & Girgensohn, 2003; McCarthy, McDonald, Soroczak, Nguyen, & Rashid, 2003), whole body and hand interaction (Krueger, 1990; Baudel & Beaudouin-Lafon, 1993), and privacy and sharing issues when working on large displays (Izadi, Brignull, Rodden, Rogers, & Underwood, 2003; Shoemaker & Inkpen, 2001).

Our research explores many of these issues collectively by identifying a set of design principles and developing an interaction framework for publicly located ambient displays that seamlessly move users from implicit interaction with public information to explicit interaction with their personal information. Our design goal is for a single display to fluidly serve the dual role of public ambient or personal focused display depending on the context inferred from a few key variables, including an individual's level of attention to the display, and the relationship of available information to an individual currently near the display.

We explore our design ideas via a prototype sharable, interactive, publicly located ambient display that enables access to both personal and public information. Our display and interaction techniques exploit implicit contextual cues such as body orientation and user proximity to the display, and explicit actions such as hand gestures and touch screen input. We recognize that our prototype is not the definitive solution for a system implementation; rather it is our hope that it takes us closer to realizing more sophisticated and useful sharable, interactive, public ambient displays.

To test and evaluate the design principles and framework as applied to our prototype system, we conducted two user evaluations. We first ran a preliminary exploratory evaluation with four participants. It touched on all aspects of the system, including ambient display comprehension. This allowed us to get initial feedback about our interaction and visualization techniques as well as aiding our design of a follow-up formal user study.

Afterwards, we conducted a follow-up formal user study in two parts. The first examined novice user exploration and discovery similar to the preliminary study, but without emphasis on ambient display comprehension. The second part observed performance and usability of an experienced user in a task-based interaction scenario.

1.1.1 Contributions

The main contributions of our work span the theoretical, embodied in our four phase interaction framework, and the applied, shown in our techniques for fluid transitions, novel interaction gestures, self-revealing help, support for multiple users, and evaluation methodology.

Four Phase Framework

We developed an interaction framework which covers the range from distant implicit public interaction to up close explicit personal interaction, with four continuous phases with fluid inter-phase transitions: Ambient Display, Implicit Interaction, Subtle Interaction, and Personal Interaction.

Fluid Transition Techniques

Our framework encourages a seamless experience with phase changes occurring in a smooth way, which we demonstrate in our prototype system. We use visualization and display techniques like transparency, dissolves, smooth animation, and minimal disturbance of the main display elements. Fluid transitions are made more effective through simple, logical implicit interactions like returning to a previous phase by simply turning away from the display.

Novel Interaction Gestures

We use a set of simple, coarse grained postures and gestures in our prototype system representing a departure from the typical way in which free space gestures are designed and implemented. An initial tense hand posture is used to signal a discrete gesture or the beginning of a continuous gesture. Responsive on screen feedback with visual cues communicates that a posture has been recognized and reminds users how to complete a gesture.

Self-Revealing Help

Our system avoids an extensive instruction or training period for learning our free space hand gestures through a self-revealing help system. We present a technique for teaching three-dimensional hand gestures consisting of a looping help video showing a mirror user performing a posture and gesture sequence in which they appear to control the actual system interface.

Techniques for Supporting Multiple Users

We support several users sharing the display regardless of what phase each individual is in. We use a variant of explicit space partitioning in which users do not explicitly claim a static region of the screen. Instead, each user's space partition contracts and expands along a thin, vertical area allowing several users to share even a moderately sized display. We also present techniques for reaching for information beyond other users and ways to display personal information safely by exploiting natural body occlusion.

User Evaluation of Interactive Ambient Displays

To our knowledge, we are the first to test an interactive ambient display in a user evaluation. Our evaluation combines observational user study techniques with a simulated task-based scenario in an attempt to approximate a real world usage setting.

1.1.2 Thesis Overview

This thesis is based on work already published by Vogel and Balakrishnan (2004). This extended work provides a more in-depth survey of background material, an expanded discussion of the theoretical framework and design principles, results from an additional follow-up formal user study, and an extended discussion of future work. A five minute video which demonstrates the prototype system is published in the proceedings and also available online[1].

In chapter 2, *Background*, we examine relevant prior work relating to peripheral awareness and notification, ambient displays, explicitly interactive public displays, whole

[1] Video available online at http://www.dgp.toronto.edu/~ravin/videos/uist2004_ambient.avi

body and hand interaction, and privacy and sharing issues when working on large displays.

In chapter 3, *Design Principles and Interaction Framework*, we present a set of principles to guide our research, and a theoretical framework of four interaction phases emphasizing fluid transitions and supporting multiple users.

In chapter 4, *Prototype System*, we describe a prototype system guided by our design principles and demonstrating our four phase interaction framework.

In chapter 5, *User Evaluation*, we discuss our findings from two user evaluations including the formal analysis of interaction in a task-based scenario. We also identify design implications based on the user evaluation findings.

In chapter 6, *Conclusions and Future Directions*, we summarize our work with its contributions and discuss future work for enhancing our prototype, experimentally testing theories and principles in isolation, and future directions for interactive public ambient displays.

2 Background

Our work builds on and combines a variety of related work in current HCI research. We have grouped the relevant background work into five main areas: *peripheral notification and awareness*, *ambient displays*, *explicitly interactive public displays, whole body and hand interaction,* and *privacy and sharing issues on large displays*. Peripheral awareness and notification systems give us a sense of the general state of one or more information sources and will notify us if something urgent or important requires our attention. They are typically situated in a user's immediate personal environment, on a secondary display, or within their main focal display itself. Ambient displays are a subset of peripheral displays which emphasize aesthetic design and integration with the surrounding architectural environment. We are mainly interested in pixel based ambient displays. Explicitly interactive public displays typically act like kiosks or public terminals with a single user controlling the entire display for a period of time. These are designed for foreground activities like browsing and selecting information rather than conveying ambient information. Whole body and hand interaction leverages the rich and powerful vocabulary we use to communicate in the real world as input to a digital application. Finally, techniques and strategies are examined for sharing a single public display among several users and ways to address privacy issues.

To compare and contrast the representative systems in each research area which we review in detail, we identified five dimensions useful for comparison (shown in Table 1). We chose these dimensions to highlight qualities relevant to our work – ambient displays that transition from implicit to explicit interaction and from public to personal information with multiple users.

The five dimensions are:

1. *Interaction*: Does the system support implicit or explicit interaction? Implicit interaction refers to indirect, naturally occurring input like walking up to a display. Explicit interaction is what we use when manipulating a mouse or using an intentional hand gesture.

2. *Input*: What input devices are supported or required?

3. *Information*: Does the system provide general, public information only, or can it also supply personal information for specific individuals or groups of individuals?

4. *Multiple Users*: Does it support multiple users on a single display and if so, how does it support them? Typically systems use *time based queuing* or *explicit space partitioning* to support multiple users on a shared display.

5. *Location*: What kind of space is the system located? Public or private space?

		Interaction	Input	Information	Multiple User	Location
Peripheral Notification & Awareness	Semi-Public Awareness Displays	some explicit	touch	public	no	public
	Notification Collage	explicit	wimp, touch	public	single[1]	public, private
	Kimura	explicit	wimp[2]	personal	single	private
Ambient Displays	Informative Art	none	none	public	no	public
	Hello.Wall	implicit, explicit	body, pda	public, personal	queue[1]	public
	Info Canvas	none	none	public, personal	no	private
Interactive Public Displays	Plasma Poster/Place, YeTi	explicit	touch	public	queue	public
	BlueBoard	explicit	touch	public	queue	public
	Pro-Active Displays	implicit	body	public	queue	public
Whole Body and Hand	Videoplace	explcit	body, hands	n/a	no	n/a
	Charade	explicit	hand gestures	public	no	n/a
Privacy and Sharing	Dynamo	explicit	wimp	personal	space partition	public
	Single Display Privacyware	explicit	wimp	public, personal	different views[3]	n/a

Table 1. Comparison of systems in related research areas
See text for a description of the five dimensions and five research areas.

[1] *single = single user, queue = time based queuing, space partition = explicit space partitioning*
[2] *wimp = Typical GUI interface using Windows, Icons, Mice and Pointers*
[3] *each user receives a different view of the display (using LCD shutter glasses)*

2.1 Peripheral Awareness and Notification

There is often a requirement (and a compelling desire) for us to monitor an increasing amount of available digital information sources. We already have time sensitive content like online auctions, weather reports, traffic conditions, new email, and instant messaging. But more information sources are becoming available with increased breadth and significance like the interruptability and availability of co-workers for informal chats, public transit schedules and delays, or time-sensitive offers from online merchants (Cadiz, Czerwinski, McCrickard, & Stasko, 2003). But continually monitoring so much information is a significant cognitive load which may prevent us from accomplishing important foreground tasks. One strategy for staying aware of a large amount of information is to deliver it to our periphery – typically perceptual or auditory. This gives us a sense of its general state, and if something urgent or important requires our attention, we can have it brought to our attention through a notification mechanism (Weiser & Brown, 1996).

Video-Based Awareness

Before we discuss peripheral awareness, we must acknowledge an important related area of research in awareness for informal communication through “always on” video links. An early example is Galloway and Rabinowitz’s (1980) Hole-In-Space art installation. The artists created a two-way, life-size video and audio link between two public sidewalk locations in New York City and Los Angeles for three evenings. In a more applied example, Olson and Bly’s The Portland Experience (1991) describes the results of using video, audio, and computing links between research labs in Portland and Palo Alto from 1985 to 1988. A live video and audio link was established between common public areas of both labs to enable informal interaction and formal group meetings. The notion of awareness is not discussed directly, but the authors propose a categorization of the project process and communication style they wished to support. One category was *open process, synchronous communication* activities, in which lightweight and informal interaction was important.

Building on the results of The Portland Experience, Dourish and Bly (1992) explored awareness with the *Portholes* system. The Portholes system was a multi-site awareness service which managed video capture images and meta-information across networked sites. The video capture images were taken from individual offices and common areas. Desktop clients allowed users to view these images along with audio snippets, short user messages, and direct email links to get an informal indication of "what was going on" in the different lab locations. A usage survey found that users accessed the client a few times per day (it was not an always on awareness application). The VideoWindow system (Fish, Kraut, & Chalfonte, 1990) uses life-sized wide-aspect ratio displays to connect two remote spaces for informal conversations. Interaction is implicit – simply walking up to the display and speaking initiates an interaction. Jancke, Venolia, Grudin, Cadiz, and Gupta (2001), represent more recent research into large screen, public video awareness displays.

Video awareness applications such as these raise fundamental issues regarding privacy. Hudson and Smith (1996) describe a trade off between privacy and awareness. The more an individual transmits about their activity, the more potential there is for awareness. However, transmitting information about activity may violate an individual's privacy. Hudson and Smith offer a video processing technique called *shadow-view*, which provides awareness of motion and context, but hides areas of theoretically sensitive high activity. Boyle, Edwards, and Greenberg (2000) investigate other techniques to maintain privacy while still offering a level of awareness using personal always on, live video links.

Peripheral Awareness

There are a broad range of strategies and techniques to provide peripheral awareness and notification. Examples include small desktop displays like scrolling tickers, secondary displays dedicated to peripheral information, and ambient displays in the form of physical objects or large aesthetically designed digital displays placed in an architectural environment. We will discuss ambient display systems in the next section and restrict our discussion here to other types of peripheral awareness and notification systems.

Researchers have found certain mechanisms for awareness to be effective. For example, McCrickard, Catrambone, & Stasko (2001) found that animated textual displays did not overly distract people from certain primary tasks. They found that in place animation like fading performed well for the identification of items in notification scenarios, but motion-based animation, like scrolling, was better for comprehension and memorability.

Cadiz et al. (2002), studied peripheral awareness and notification with Sideshow. Sideshow displayed peripheral information along a thin vertical strip located at one side of the user's Windows™ desktop. Users could subscribe to different public and private information sources and customize how the information was visualized. This system was used and evaluated by over 11,000 employees. From the usage data and follow-up surveys, they found that users wanted to have an alert option to notify them, in addition to a peripheral awareness display.

Psychological Theory for Peripheral Awareness

But how do we remain "aware" of peripheral information while attending to a primary foreground task? Filter theories such as Treisman's *attention attenuation* model (1960) suggest that we can only process a limited number of sensory and memory inputs at one time. In studying auditory attention, Treisman proposed that physical characteristics like a speaker's tone and semantic key word triggers are used to select one message for full processing while a limited number of other messages are attenuated for partial, parallel processing. This filtering of attention is also applied to visual perception. Neisser's synthesis theory (1967) suggests that there are two processes governing our visual attention. First there are automatic, quick, and parallel *preattentive* processes (which include the visual periphery) and afterwards there are *attentive* processes (focal) which are controlled and serial. The preattentive processes scan the visual field and filter salient regions to be processed partially or entirely by the attentive processes in a similar fashion to Treisman's attenuation model.

Attentive filtering allows us to monitor a large amount of background information through *habitation* and *dishabitation* (Gray, 1975). Habitation occurs when we learn to ignore a stimulus as it becomes familiar and predictable – it fades into the background.

But when there is a significant change in a background stimulus, dishabituation occurs. The stimulus becomes more relevant, and our preattentive processes permit it to enter our conscious as attenuated messages, or if very significant, it is selected for full processing. This subtle shifting of priorities in background stimulus enables peripheral awareness and a significant change supports notification mechanisms.

We now review three peripheral awareness systems in more detail using a combination of secondary peripheral displays and large public displays, semi-public displays from Georgia Tech, Notification Collage from the University of Calgary, and Kimura also from Georgia Tech.

2.1.1 Semi-Public Awareness Displays

Huang and Mynatt (2003) built a *semi-public awareness display* prototype combining four different awareness applications together on a single large display (Figure 1). The applications are: *Reminders* showing a text slideshow of recent help requests, *Collaboration Space* for asynchronous brainstorming in a mini-whiteboard style interactive space, *Active Portrait* displaying individual activity over time as a dynamic group photo portrait, and *Attendance Panel* for graphically showing expected attendance at upcoming events. The system uses a large touch enabled display located in a common area of their lab.

After deploying the system in their lab for two weeks, they administered a survey to investigate usage patterns and reactions. They found that users preferred persistent displays offering "opportunistic glances" rather than interactive applications like the Collaboration Space. This is partly attributed – somewhat surprisingly – to the difficulty users had with the electronic whiteboard pen input required by the Collaboration Space. Another relevant finding was that users were receptive to harmless personal information being displayed, like who is attending what event in the Attendance Panel. We also display a similar type of harmless personal information in our system. Reaction to the Active Portrait suffered because of visual design and technical problems. This application faded people in or out of a group portrait based how recently they used their keyboard. The intention was that it would communicate who was in the lab or how recently they left. Unfortunately, users could not translate the different levels of transparency into an occupant’s recently and keyboard input was found to be poor indication of activity.

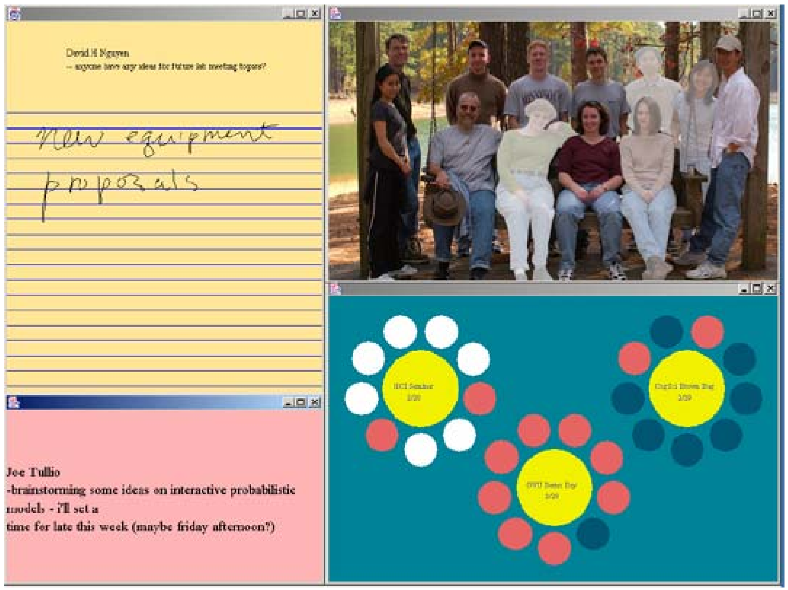


Figure 1. Semi-public awareness display (from Huang & Mynatt, 2003)
Clockwise from top left: a) Collaboration Space; b) Active Portrait; c) Attendance Panel; d) Reminders.

Huang and Mynatt’s work managed to combine four different applications (or information sources) onto a single, large public awareness display which is an important contribution. However, the design execution of the display does not provide for effective peripheral awareness, and since this system is intended for a public environment, more care could have been taken in its aesthetic design. We will discuss examples of more architecturally integrated public peripheral displays in section 2.2, Ambient Displays.

2.1.2 Notification Collage

The Notification Collage (Greenberg & Rounding, 2001) is a system for users to communicate awareness through a network of desk mounted peripheral displays and public large displays (Figure 2). Based on a collage metaphor, this system enables co-located and distributed lab members to post various types of media onto a real time collaborative display surface. Items are positioned randomly with newer items covering older ones. While aesthetics was not a factor in the information presentation, the use of this system as a peripheral awareness display tool was found to be effective.

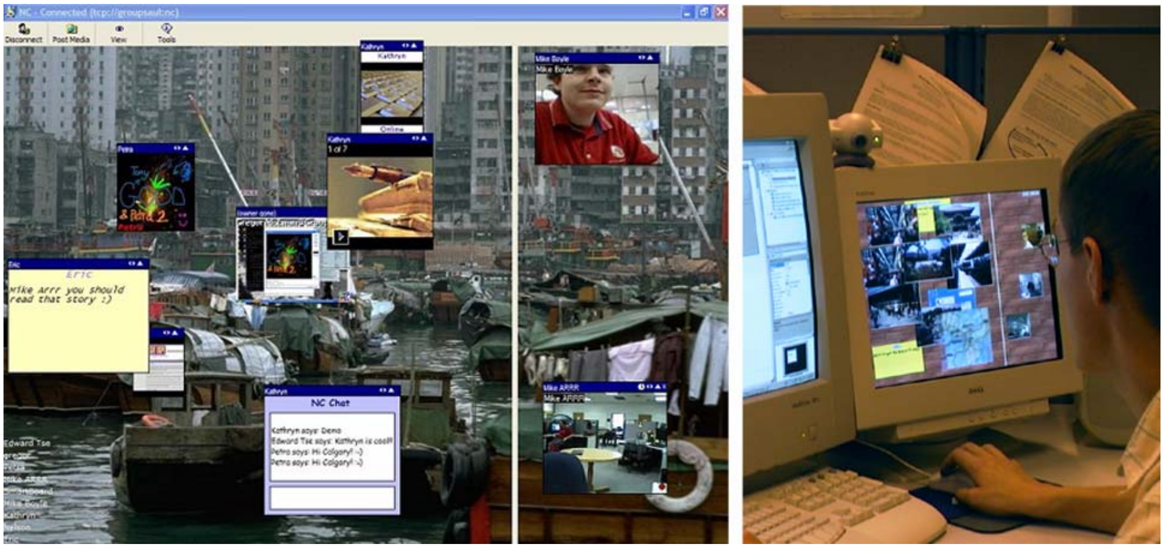


Figure 2. Notification Collage (from Greenberg & Rounding, 2001)
From left: application screen capture, right: a secondary personal display.

The type and content of media items included live video from a desk-mounted video camera, photo slide shows, short text notes, desktop screen captures, and user activity levels. The authors reported how users handled privacy issues caused by live streaming video, especially for those working from home, but they did not report on any privacy concerns resulting from having their current desktop captured and posted to the display. The content of a user's desktop could be very personal and private, so it should be expected that there would be privacy concerns.

Observations during a bootstrapping study in the authors' lab revealed unexpected usage patterns for the personal and public displays. Even if the large pubic display was visible to a lab member, they chose to run the Notification Collage on their personal secondary display. Yet, the public display still had a role as a "conversation starter" for people near by, and functioned as a satellite interaction point for users away from their personal display. Telecommuters also used the large public display as a communication channel to contact individuals near by – creating casual, social conversation much like co-located individuals do when occupying the same public space.

The Notification Collage demonstrates an effective way to blend video-based awareness, informal information sharing, and desktop peripheral displays. Our current prototype system does not support video links between remote locations, but we acknowledge this as an important area of future work for publicly located ambient displays.

2.1.3 Kimura

Kimura (MacIntyre et al., 2001) is an augmented office environment using interactive peripheral displays to enhance a worker's ability to manage several different projects and tasks. The peripheral displays are large projected displays on nearby walls in the worker's personal office – approximately the size of large whiteboards.

Figure 3. Kimura augmented office environment. (from MacIntyre et al., 2001)
From left to right: a working context, system installation view.

The peripheral displays show visualizations of different work activities, or *working contexts*, in the form of a visual collage of images (often screen captures) gathered from activity logs. For example, a project paper working context would include images taken from web pages, images, emails, and text documents accessed while working on the paper. In addition to images taken from activity logs, a working context may also have time-sensitive notifications like a printer icon to signal competition of a large print job or a co-worker's picture indicating availability for an informal project meeting. The authors designed the working context collages to have a sketchy look and use stacking, colour, and transparency to signify recently accessed or important documents.

The worker uses these background peripheral representations of working contexts to monitor status and notifications. By selecting a working context, the system returns the user's workstation back to the corresponding configuration of applications and documents. When a working context is selected, the representative collage on the peripheral large display moves closer to the location of the primary desktop display. The authors refer to this as a *near-periphery display*.

Users can also manipulate the working contexts while standing at the wall display similar to interaction with a large interactive whiteboard. The authors provide typical digital whiteboard functionality on the large peripheral displays based on the Flatland system (Igarashi, Mynatt, Edwards, & LaMarca., 1999). They allow users to move, delete, and manipulate the working context collages, and add annotations using digital ink.

Kimura's usage of wall sized, peripheral awareness displays to provide context for conventional desktop computing is an intriguing idea. Unfortunately, fluid movement between the desktop display and the peripheral working contexts is an important design problem which is not discussed in detail. Also, the authors do not discuss how the transition from peripheral background display to foreground interactive whiteboard is achieved fluidly – such a transition between implicit and explicit interaction is a core contribution of our work.

2.2 Ambient Displays

Ambient displays are considered to be a proper subset of peripheral displays (Stasko et al., 2004). An ambient display communicates with us primarily on the periphery of our attention, working in the background while we attend to foreground activities. By existing in the background, we can monitor low priority information sources without experiencing cognitive overload – we can get the essence of the information state with a quick aural or visual *glance*, or simply through gestalt background communication (Mankoff et al., 2003). To remain in the background, ambient displays are often permanently located within an architectural setting. Therefore, the aesthetics of an ambient display are very important so that it accentuates a space, rather than invading it (Holmquist, 2004).

Ambient displays can be characterized as pixel and non-pixel displays. A pixel based ambient display uses a conventional digital display, typically a large plasma screen or LCD projector. Non-pixel displays have the advantage that they do not look like a computer and can easily blend into the architectural environment. AmbientRoom (Ishii & Ullmer, 1999), the Dangling String (Weiser & Brown, 1996), and the Information Percolator (Heiner, Hudson, & Tanaka, 1999) are examples of research in non-pixel ambient displays. Ambient Devices is a company manufacturing non-pixel ambient displays like the "Ambient Orb" for the consumer market (www.ambientdevices.com). Two disadvantages of non-pixel ambient displays are that they have less bandwidth for conveying information – they typically communicate a single information source – and they are limited in how they receive and react to user input.

Three relevant examples of pixel-based ambient display research are Informative Art from the Future Applications Lab, Fraunhofer Institute's Hello.Wall, and Georgia Tech's InfoCanvas. Informative Art and InfoCanvas use standard digital displays, while Hello.Wall uses a custom large, very low resolution pixel style display.

2.2.1 Informative Art

Skog, Redström, Holmquist, and other researchers from the Future Applications Lab of the Viktoria Institute demonstrate ambient information visualizations with aesthetics adapted from art works (Redström, Skog, & Hallnäs, 2000; Skog & Holmquist, 2003; Skog et al., 2001, 2002, 2003; Skog, 2004; Holmquist, 2004). They argue that when creating visualizations for non-desktop spaces, the displays must not only provide information, but also make an attractive addition to the environment. A balance between aesthetics and utility must be found to create effective ambient displays. Their strategy to find this balance is by iteratively designing large display visualizations inspired by actual works of art.

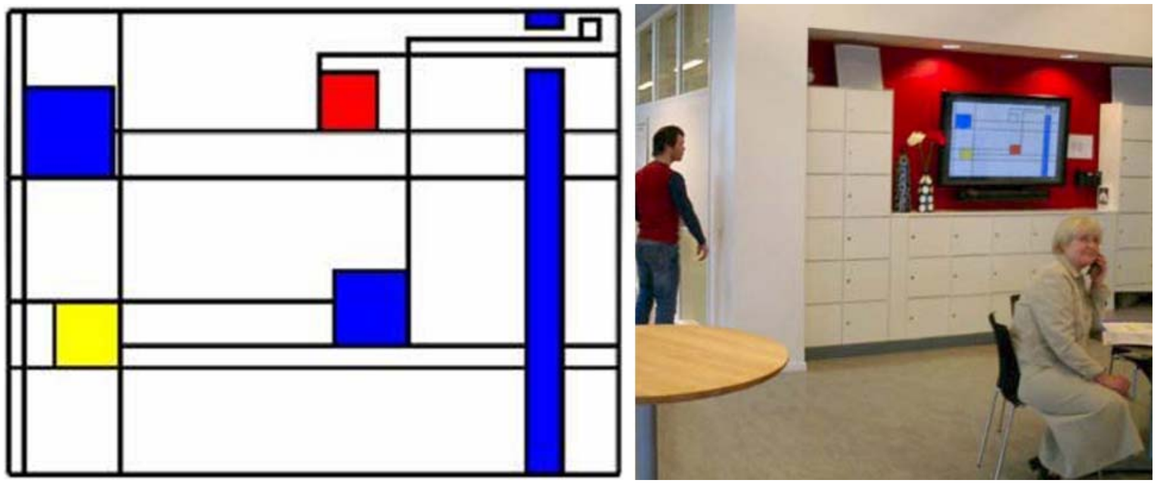


Figure 4. Informative Art ambient display (from Skog & Holmquist, 2003)

Redström et al. (2000), first created ambient displays based on work by Andy Warhol ("soup clock") and Bridget Riley ("motion painting"). Motion painting uses vertical stripes of colour to convey activity levels in a room, this inspired one of our ambient displays showing branch office activity. Other early prototypes used Piet Mondrian inspired information visualizations for email (Redström et al., 2000) and world weather conditions (Skog et al., 2001). Other work includes a visualization of activity levels in a café using an original design inspired by wallpaper designs (Skog, 2004).

Skog et al. (2003) conducted an in-depth study of the design and evaluation of a Mondrian inspired visualization for transit at a university (Figure 4). They manipulated the abstract geometric shapes found in the artist's original painting style to visually convey bus departure times. For example, the size of Mondrian's characteristic squares represented the amount of time before a bus leaves and a square's position indicated the direction in which the bus is traveling.

A preliminary design for the ambient display was evaluated by interviewing eight students which identified several ambiguities and opportunities for improving the usefulness of the information. Revisions included making the display more representational, becoming slightly more map-like. It remained abstract, but some squares represented geographic areas like the downtown and a major river. The revised design was displayed on large plasma screens in a public area close to the exit of the main building of the university. The authors also placed an information card near the display to explain the meaning of the visualization. It is interesting that this explanation was not incorporated into the design of the display itself – this inspired us to design a display that would not need such a literal "decipher key."

After fifteen days of operation, they conducted interviews with seven people to assess the comprehension of the display. The authors used a three step comprehension scale with each step a requirement for the next (Holmquist, 2004). The first comprehension step is for the user to know that *something* is being visualized and the display is not a decorative object. The second step is that they knew *what* was being visualized. Did they know it visualized bus departure times? The final step is to comprehend *how* it was visualized. Did they know what the size, location, and colour of the shapes meant? Skog and Holmquist claim that it is only after reaching the third step that the ambient display has real utility for users. From the interviews, they found that three out of seven users knew how to read the display.

Informative Art's successful combination of aesthetics and utility is a key contribution, and their technique for evaluating comprehension seems to be taking the right approach. A three step comprehension scale provides a simple yet effective way to evaluate the success of ambient displays. We apply a variant of this three step technique in our preliminary user evaluation discussed in chapter 5. Other techniques have been proposed for evaluating the effectiveness of ambient displays like Mankoff et al.'s (2003) set of ten heuristics. But Mankoff et al.'s heuristics are somewhat subjective and they emphasize the evaluation of non-pixel ambient displays. Regardless, some researcher's projects like Stasko et al.'s (2004) pixel-based InfoCanvas display (discussed in section 2.2.3) have used Mankoff et al.'s heuristics as a partial evaluation.

2.2.2 Hello.Wall

"Hello.Wall" (Prante et al., 2003; Streitz, Röcker, Prante, Stenzel, & Alphen, 2003) is a large ambient display coupled with a hand-held device, supporting three zones of interaction for distance dependent ambient interaction and notification (Figure 5). The intended purpose of the display is to communicate "atmospheric aspects" of an organization through abstract representations of public and private codes. Atmospheric aspects include such things as the level of stress, frustration, or success among different groups of people in a company. Although the authors do not provide detail how these feelings are sensed by Hello.Wall, they do describe how individuals add private codes to identify a project team and how to retrieve information from the display using a hand-held device (Figure 5 right). For example, their UbiComp Video (Prante et al., 2003) shows a new project team gathering at the Hello.Wall to design a unique graphic code for identification and then associating this code with team members. If a team member passes the display later, the team code will be shown on the Hello.Wall. The authors hint that additional codes could indicate a team message is waiting, or that the team is nearing a deadline. Regardless of the viability of this system’s intended use, the technology, design, and the three zone interaction model are relevant to our work.

Figure 5. Hello.Wall interactive ambient display (from Prante et al., 2003)
The detail on right shows a hand-held device used to interact with display.

The Hello.Wall is an attractive, custom built 1.8 m by 2.0 m display with a total of 124 pixel-like light cells. Each cell is an LED cluster with a short-range transponder. The short-range transponder is used by a hand-held device to query the contents of a particular cell. The hand-held device is also used to display specific information to the user, since the Hello.Wall is not able to display text or any detailed graphic images. Requiring users to carry a hand-held device to perform most of the information retrieval and interaction limits the universality and seamless interaction of this system. In addition to having transponders in each cell, Hello.Wall has integrated sensors that detect the presence of hand-held devices within two distinct distance ranges.

The researchers use this distance information to trigger different display and interaction modes. There are three display and interaction modes depending on the presence or absence of an individual in three distance-based zones of interaction: *ambient* (far distance), *notification* (medium distance), and *interactive* (close distance).

The ambient mode is a “stand-by pattern” which communicates general information when no individual is detected near the display. The light cells form abstract patterns which represent such things as the number of people still in the building or current office activity levels.

The notification mode is entered as an individual passes close to the wall. The light cells form a personal or group pattern as a notification signal to that user. Although this is not explained in the paper or video, it seems that users are able to associate “secret” notification patterns with certain triggers – like a new voice mail message. The authors allow users to “borrow the display,” where a hand-held device is used to query the display for the meaning or content of a notification.

The interaction mode is entered by moving very close to the display. Here the user can query or send information to individual cells of the display using the hand-held device. The authors do not elaborate on what content would be sent or queried, but one can imagine that this may function as a type of storage system or perhaps seeking more detailed information related to a notification code from the previous mode.

While Hello.Wall is closely related to our work and suggests an exciting possibility for implicit interaction, it has some shortcomings. The implicit interaction based exclusively on distance fails to acknowledge other orientation and movement cues that may indicate the appropriateness of entering a certain mode. The heavy reliance on a hand-held device for most of the interaction and information retrieval seems to reduce the importance of the large ambient display. Perhaps the biggest shortcoming is that the display supports a single user at a time in the notification and interaction modes. Since Hello.Wall occupies a public place, there will be times when multiple users are within the notification zone at one time – it is not clear how it can deal with this situation.

2.2.3 InfoCanvas

InfoCanvas (Miller & Stasko, 2002; Plaue, Miller, & Stasko, 2004; Stasko et al., 2004) is a personal, pixel-based ambient display which emphasizes aesthetics, user customizability, and enables the simultaneous conveyance of multiple pieces of information concurrently.

This system uses a thematic pictorial scene with objects in the scene representing the current state of information sources. For example, a beach theme consists of a background picture of the seashore and available objects like sailboats, beach balls, and sun bathers. An object, or objects, can convey the current state of an information source using a variety of techniques. For example, translating an element along a straight line shows the current value of an information source within a certain range. Or, a graphical attribute like colour can be adjusted to symbolize different information source states. The different objects are placed in the scene and positioned or altered to convey the current state of about five to fifteen user-selected information sources. The effect is that the display shows a continually changing picture from which a knowledgeable user can decipher the current state of a range of information sources.

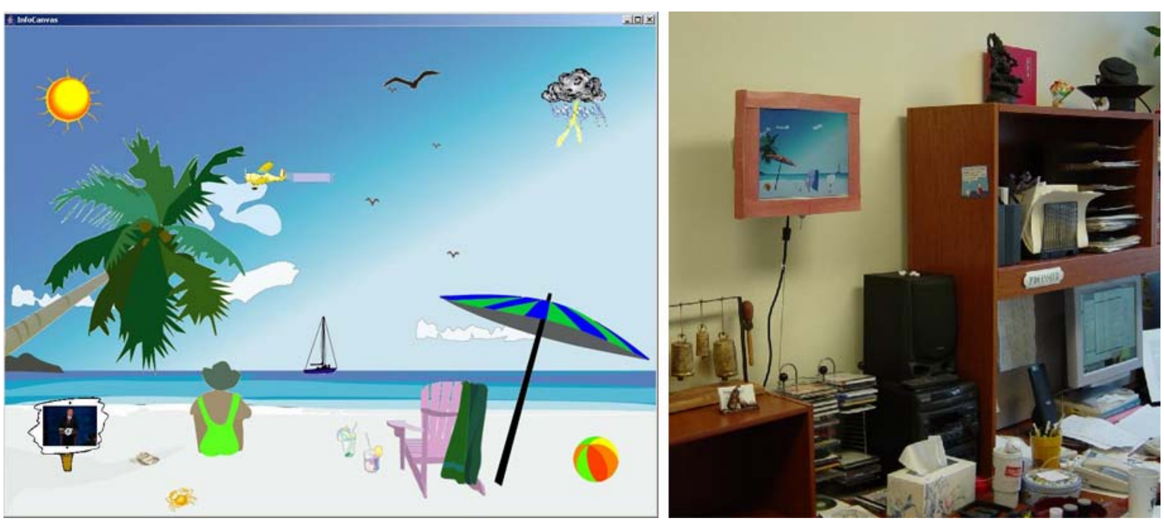


Figure 6. The InfoCanvas (from Miller & Stasko, 2002)

The initial versions of the system provided ways for a user to interactively “paint” information sources into their graphical scene using brushes and clipart (Miller & Stasko, 2002). But the authors found that this highly customizable paradigm was too open-ended and difficult to use in practice. So, later versions provided a selection of pre-set themes for users to compose their InfoCanvas scene (Stasko et al., 2004).

Regardless what technique is used to create the display, the strategy to communicate the status of multiple information sources in one display has some limitations. Using such representational objects requires users to learn which portions of the scene convey information and which are merely decoration. The strong symbolic meanings of objects in the scene may in some cases help, but in other cases hinder comprehension depending on how abstract the object to information source mapping is. For example, Plaue et al. (2004), assigned the weather forecast to the actual weather shown in the sky, a very literal representation. But they also used less direct representations like the height of a kite representing airfare price, and completely disjoint relationships like traffic conditions represented by the colour of a woman's bathing suit. It may be that purely abstract representations like Skog and Holmquist's Informative Art (2003) are more effective since we do not already have some preconceived notion of what the object represents.

2.3 Interactive Public Displays

Interactive public display research using large displays has largely focused on explicit ways for users to interact. In some sense, these interactive public displays act like kiosks or public terminals with a single user controlling the entire display for a period of time. They are designed for foreground activities like browsing and selecting information rather than conveying ambient information.

Brignull and Rogers (2003) studied users interacting with a large public display called the *Opinionizer*. This was a simple system installed at two cocktail parties where users could post their "opinions" on a selected topic. A keyboard connected to a single large display allowed users to post "opinions" which were displayed in a stylized manner. Similar to the zones of activity in Hello.Wall (Prante et al., 2003), Brignull and Rogers identified three spaces of activity based on proximity and level of engagement: peripheral awareness, focal awareness, and direct interaction. They found that people moving towards higher-engagement phases faced bottlenecks tied to a fear of social embarrassment. To overcome these bottlenecks, people needed to be motivated and informed about the benefits and usage of the public display. If they felt it was easy to use and provided a tangible benefit, they were more likely to interact.

Also relevant are large displays using explicit interaction for remote group collaboration. Ishii’s TeamWorkStation (1990) introduced the idea of a shared drawing surface fused with a video overlay on a standard desktop monitor, making collaborative activities seamless and social. ClearBoard (Ishii & Kobayashi, 1992) demonstrated a remote collaborative drawing program on a large display emphasizing eye contact between the collaborators. ClearBoard is aesthetically beautiful in its design and execution. The author’s describe it simply as “talking through and drawing on a transparent glass window.”

Three research examples are now discussed in more detail: IBM’s BlueBoard, FXPAL’s Plasma Poster, PlasmaPlace, and YeTi, and McCarthy et al.’s Pro-Active Displays.

2.3.1 BlueBoard

BlueBoard (Russell, 2002) is an interactive public display designed for individual information access and short-duration “side-by-side” collaborative sessions developed by IBM research (Figure 7). The system recognizes users via an explicit “badge in” with an RFID tag, after which all interaction is exclusively touch screen. One or more users may badge in at the same time, but they all share a single, collaborative session. When no one is in a session, the display plays back web pages as an attract loop. This attract loop is designed as a foreground, attention grabbing effect rather than as a peripheral ambient display.

Figure 7. BlueBoard (from Russell, 2002)

The authors identified three design principles to achieve their dual design goals of individual and collaborative usage. First, they wanted to represent each user currently using BlueBoard in the display. Second, they wanted to provide appropriate applications and tools. And third they recognized the importance of keeping personal information private while making public information available for all users. The first and third principles are especially relevant to our work. We discuss how we represent users of our system in a more abstract manner and how we balanced the mix of personal and public information in chapter 4.

To study how people used BlueBoard, the authors conducted an observational field study during a workshop with over one-hundred attendees. They found interesting patterns of behaviour for collaborative and individual use. For example, they observed many examples of people learning how to use some aspect of the system by simply observing others. Also, in multi-user collaboration settings they witnessed many instances of hesitation when a user had to reach across another user's implied physical space. We took this into account with our prototype system's socially acceptable reaching technique discussed in chapter 4. Only when one user had emerged as the leader, would this reaching action be done without hesitation, in fact it was an assertion of leadership. A final observation saw many users forget to "badge out" in sessions where they did not retrieve any information, possibly exposing their personal information to others. This exposes a problem with such an explicit sign-in and sign-out requirement.

BlueBoard's strength is how it enables users to identify themselves and access and share personal information. The reliance on the explicit "badge in" and "badge out" may be for technical reasons, but perhaps it is not the most fluid and seamless way to identify a user. Pro-Active Displays (McCarthy et al. 2003; 2004), discussed in section 2.3.3 below, demonstrate a fluid user identification technique, but for a more lightweight purpose.

2.3.2 Plasma Poster, PlasmaPlace, and YeTi

Three versions of an evolving system from the FXPAL research group, Plasma Poster (Churchill et al., 2003b), PlasmaPlace (Churchill, Girgensohn, Nelson, & Lee, 2003a), and YeTi (Yamada et al., 2004), emphasize light-weight, explicit interaction techniques with public displays. Their motivation is to "close the gap between online and offline encounters and content sharing" between individuals within a group like an office or conference. The systems share a common form factor of a vertically mounted (portrait oriented) plasma display with touch screen or trackball input limited to single user interaction (Figure 8). The content shown on the display is published using other back-end systems, so the public displays only provide capability only for browsing, reading, and annotation.

PlasmaPlace (Churchill et al., 2003a) sought to create a presence for online bulletin board discussion forums like CHIplace and CSCWplace in the physical space of their associated conferences. The display's user interface consisted of a trackball or touch screen with interaction broken into two modes: content area selection and browsing within a selected content area. The content shown on PlasmaPlace was a combination of re-purposed postings from the online forums and photos and blogs from conference attendees – all content was posted using a website accessed from other computers.

The interaction techniques and functionality of PlasmaPlace were explicit and extremely simple. In the CHIplace version of PlasmaPlace, the trackball buttons were used as previous and next navigation to cycle through all content items, and the trackball was used to scroll through the selected item. Similarly, users of the CSCWplace version touched onscreen buttons or thumbnails to select and navigate content items. When no one was using the display, it entered an attract loop where it cycled through content items, showing each for about sixty seconds. The authors comment on the choice for the attract loop's update speed: "too fast and it's distracting, too slow and it appears static and not dynamic." Interestingly, analysis of usage logs from the conferences found only 5% of users viewed the online bulletin board discussion forum, while 62% viewed images taken at the conference.

PlasmaPlace's sister system, the Plasma Poster Network (Churchill et al., 2003b), was designed to digitally augment casual conversations and serendipitous information sharing in an office environment. An exploratory field study revealed that current content sharing practices in office environments included informal chats in hallways and viewing corkboards mounted in places where people were waiting, passing time, or performing a low-concentration task. The authors noted that although corkboards mounted in hallways were often glanced at, people seldom stopped to read postings. Based on this initial study, the Plasma Poster Network was designed to display content sampled from the company intranet and posted by individuals. The authors located the system in waiting areas like the kitchen and in high traffic locations like a hallway and foyer.

The interaction style of the Plasma Poster Network was similar to PlasmaPlace with a neutral attract mode, and two explicit, single-user, touch-based interaction modes for reading content items and navigating and selecting from available content items. The authors refer to the usage of these modes as four forms of engagement: *peripheral noticing*, *active reading*, *navigating and browsing*, and *messaging*. Though not a strict progression of interaction modes, these model how a user increasingly becomes engaged with the content and the device. The analysis of a six month usage study revealed that 62.4% of the users spent time in *active reading*, 36.3% in *navigating and browsing*, and only 1.3% in *messaging* (where they sent interesting items to others). They also found the amount of interaction was tied to the display's location; 67.9% of user activity took place on the kitchen Plasma Poster.

Figure 8. Yeti (from Yamada et al., 2004)
PlasmaPlace and Plasma Poster displays use the same form factor, but the interface differs somewhat.

YeTi, the “Yesterday Today Interface” (Toshiya et al., 2004) adds new functionality like user annotations, content recommendations, and techniques for communicating awareness (Figure 8). Networked YeTi displays were placed in FXPAL offices in California and Japan sharing a central content repository. The separation of time and distance between users prompted the inclusion of techniques to “foster an informal sense of co-presence among distributed office colleagues.”

Scribble annotations are one example of a technique to foster informal co-presence. While viewing a content item, a user may write a short comment with their finger and send it to the content author or add it as an annotation. Awareness of who is using the display is accomplished by capturing short segments of video when someone activates the display – the authors refer to this as *reading awareness*. These video segments are then made available when others view the same content item later, creating a sense of awareness of who viewed that item. Although the authors had concerns about privacy and surveillance with the video capture, in practice this proved to be of little consequence. Some users turned the camera away to remain anonymous, but most did not mind.

A three month usage study revealed similar results regarding the four forms of engagement with 60.6% of activity spent in active reading, and 0.9% messaging. In addition, 14% spent time looking at annotations like the captured video segments and scribbles.

This long-term body of work presents compelling techniques for light-weight explicit interaction with large displays to connect geographically separated groups. Their survey findings suggest basic usage patterns and suitable locations for these types of displays. Using short video capture segments to convey reading awareness bears some similarity with the video-based awareness work discussed earlier in section 2.1. If the display was able to recognize users, this awareness "usage trail" could be built in a more exacting way, but the subtlety and spontaneity of viewer reactions would be lost.

2.3.3 Pro-Active Displays

Examples of public displays which do not require explicit interaction are McCarthy et al.'s Pro-Active Displays (2003; 2004). They react implicitly to people in their proximity using RFID tags. The authors designed three pro-active display applications for a conference setting, AutoSpeakerID, Ticket2Talk, and Neighborhood Window. AutoSpeakerID was used during the question and answer period following a paper or panel presentation. When the attendee approached the microphone to ask their question, their name and affiliation was displayed on a large screen for other attendees to see. Located in informal gathering areas of the conference, Ticket2Talk and Neighborhood Window displayed information about individuals or groups standing near the display as "conversation starters."

Figure 9. Pro-Active Displays (from McCarthy et al., 2003; 2004)
From left to right: AutoSpeakerID, Ticket2Talk

Among the authors' design goals are two that are relevant to the design of a system like ours. The authors state how they want their Pro-Active Displays to "fit within the common practices at conferences … following the precept of calm technology" and "respect the privacy – notably the varying desires for publicly revealing content – of the attendees" (McCarthy et al., 2003). The visual design of these displays employed techniques like smooth dissolves and slow animation to remain calm and unobtrusive – something we also incorporated into our design. To respect privacy, they required attendees to "opt-in" to the system by requiring them to explicitly create profiles and activate an RFID tag. This gave them control over the content being shown and allowed them to opt-out at any time by removing the RFID tag. Of special note is that they felt it necessary to create a "kill switch" to hide the AutoSpeakerID display in case offensive material was shown.

The seamlessness and simplicity of the Pro-Active Display's user identification is an important contribution, and using this to implicitly interact with a public display is a compelling application.

2.4 Whole Body and Hand Interaction

Enabling users to interact with a computer using their entire body is an attractive and practical choice for many applications. In the real world, we use many facets of body language to communicate with each other using a rich and powerful vocabulary. However the current standard input modalities of mouse and keyboard prevent us from using the additional communication channels afforded by the rest of our body. Significant research has focused on technical issues surrounding the tracking and recognition of hand and body movements to enable this style of interaction. Two relevant surveys include Mulder’s (1994) overview of techniques to track and recognize body and hand movements and Gavrila’s (1999) survey of computer vision techniques for body and hand recognition. Certainly these technical issues must be solved before reliable and usable whole body and hand interaction is possible without cumbersome hardware and specialized, intrusive garments. We will review research which focuses on whole body and hand interaction styles and applications, rather than the underlying enabling technical issues.

Two-handed whole-hand interaction is an active research area. The Ames Virtual Environment Workstation (Fisher, 1990) is an early example of a Virtual Reality system incorporating whole hand input tracked via tethered DataGloves. This system used hand postures to issue commands; for example, pointing a finger triggers a flying birds-eye viewpoint of a virtual environment with the flight speed controlled according to the distance of the finger to the body. Cutler, Frlich, and Hanrahan (1997) built a system to manipulate three dimensional models using both hands on a stereoscopic “responsive workbench.” They use a six degree-of-freedom tracker attached to each “pinch glove” – these gloves detect pinching between opposing digits. Using this hybrid whole-hand input device, they developed two-handed interaction techniques exploiting Guiard’s (1987) bimanual control theory (we briefly discuss Guiard’s theory as it relates to areas of future work in chapter 6). Cutler et al’s techniques include: coordinated symmetric interaction, for example a *slide-and-turn tool* which rotates a three dimensional model when both hands are moved as though turning an automobile steering wheel; and coordinated asymmetric interaction, as in their *free rotation tool* which uses the non-dominant hand to specify an axis of rotation and the dominant hand controlling the amount of rotation.

Sturman and Zeltzer (1993) offer a design method for “whole-hand” human computer interaction. Their five stage iterative process is composed of two major parts: evaluating the feasibility of using whole hand input, and analyzing the application and tasks for possible whole-hand input techniques. Perhaps the most compelling part of their work is the definition of a whole-hand input taxonomy. They partition hand actions into *continuous* features and *discrete* features. Continuous features are quantities derived from the degrees-of-freedom of the hand. Discrete features are interpreted as input tokens. A token can be a posture denoting a specific configuration of the degrees of freedom of a hand, or a gesture denoting a particular motion of the hand or the fingers. We use this taxonomy for describing the gestures used in our prototype system.

Another important facet of body language is eye gaze. The ability to track the gaze of a subject's eye was first demonstrated by Mason (1969, in Jacob, 1995). Although eye tracking has become reliable and affordable, it is not a standard consumer input modality. For the most part, eye tracking has been used for behavioural and psychological studies. When used to control input to a computer, gaze has often been applied in situations where the user has no alternate mode of input, like disabled persons or fighter pilots (Jacob, 1995). But there are early examples of systems using gaze as an alternate or optional input modality like Bolt's Gaze-Orchestrated Dynamic Windows (1981). Bolt's system enabled a user to use gaze to select and control many "windows" dynamically displayed on a wall-sized display. These were not application windows in the (now) conventional sense, but rather snippets of real-time remote video channels.

Recent work demonstrates using explicit and implicit eye gaze to create *attentive interfaces*. Shell, Vertegaal, and Skaburskis (2003) have created appliances like an attentive television that pauses or plays according to gaze, paintings that record salient areas of interest and a large display mirror which "artistically visualizes attention" (Skaburskis, Vertegaal, & Shell, 2004). The Eye Tracking Research and Applications symposium provides a good overview of the eye tracking area of research.

Multi-modal interfaces which combine different modalities like gaze and voice, or voice and gesture, are also relevant. While it may make sense to pause an attentive television when looking away, it is unlikely that we want an attentive lamp to turn off the moment we look away from it. Therefore, Shell et al., (2003) use simple speech commands like "turn on" and "turn off" to be used in concert with gaze – using gaze to define the subject and speech the desired action. This technique is a refinement of the style of multi-modal commands used in Bolt's (1980) landmark "Put-That-There" system. This system uses finger pointing and very simple gestures combined with speech to interact with a large wall display. By uttering a command such as “create a blue square there” while pointing, the user could unambiguously define the location where the square was to be created. This leverages the strengths of both input modalities – words like “square” and “blue” are relatively unambiguous, but specifying a location to create the square is difficult to describe using only speech.

We now discuss two example systems demonstrating the application of whole body and hand input. VIDEOPLACE is a pioneering and playful example of whole body input. Charade examines a presentation system controlled entirely by single hand gestures.

2.4.1 VIDEOPLACE

Beginning in 1969, Krueger (1977) has explored *Responsive Environments*, real time interactive computer mediated spaces. Krueger describes a Responsive Environment as “an empty room in which a single participant’s movements are perceived by the computer which responds through visual displays and electronic sound” (Krueger, Gionfriddo, & Hinrichsen, 1985). Krueger saw his work as an attractive alternative to controlling computers using a programming model which was common at that time. Instead, a Responsive Environment allowed people to interact with computers using the same perceptual process used in the real world.

The PSYCHIC SPACE Responsive Environment created in 1971 and presented as an interactive art work, is a precursor to VIDEOPLACE (Krueger et al., 1985). PSYCHIC SPACE used hundreds of pressure sensors mounted in the floor to track the movement of a participant’s feet. By walking around the room, the participant could control computer generated images shown on a large 2.5 m by 3 m screen. Krueger created different playful and exploratory interactions based on this unique input modality.

One PSYCHIC SPACE interaction allowed participants to control the movement of a small sprite on the screen. Part of this interaction involved navigating their sprite through a maze revealed on the screen. Of course there were no physical boundaries in the room, so the participant (after a few minutes) usually attempted to step right to the end point of the maze. But the system thwarted such “cheats” in forty different entertaining ways such as elastically stretching the boundary of the maze, moving the maze, or destroying the participant's sprite.

Figure 10. VIDEOPLACE *(from Krueger, 1990)*
From left to right: drawing interaction; Critter; two person remote interaction.

Krueger's VIDEOPLACE Responsive Environment enabled whole body and hand interaction techniques with a large display in the 1970s (Figure 10) (Krueger et al., 1985; Krueger, 1990). This system recognizes different postures and actions of a user's full body silhouette captured by a single video camera in a darkened room. A large display shows the real time silhouette of the user (typically full size) along with computer generated imagery resulting from computer vision analysis of body and hand movement. Krueger argues for providing full body and hand input in VIDEOPLACE:

> "When people see their image displayed with a graphic object, they feel a universal and irresistible desire to reach out and touch it. Furthermore, they expect the act of touching to affect the graphic world."
> (Krueger et al., 1985)

Over thirty different demonstration interactions were created to investigate different styles of whole body and hand input. These were lightweight, simple and playful. For example, a drawing interaction enabled users to draw a line by simply extending one finger. Closing their hand enabled movement without drawing, and holding up all five fingers erased the current drawing. These simple posture based commands are reasonably intuitive and incorporate a simple clutching mechanism. Another playful example is Critter, a simple set of interactions with a computer generated character. A small spite based character follows your silhouette around the screen. If a hand is held out, the Critter jumps on and proceeds to climb up the user's silhouette, and celebrates if it successfully reaches the top of the head. The Critter can be caught by encircling it with joined hands or coaxed to dangle precariously from a single finger. This demonstrates Krueger's emphasis on interactions that are exploratory – his aim was to create environments that reacted in logical ways without needing to learn a set of commands.

Not all input mappings between position and effect where absolute as they are in the drawing and Critter interactions. For instance in a two person remote interaction, one user is displayed at a smaller scale where they can dangle and swing from a string held by the other full size user. The swinging motion is triggered by the suggestive side-to-side motion of the user's body.

Although VIDEOPLACE was primarily used to experiment with these light-weight and playful interactions, the author also refers to more practical development tools they created also using whole body and hand input. In Krueger et al. (1985), several practical applications are described including computer aided instruction and "computing by hand." He also prophesizes that the keyboard will be replaced with voice input, and video monitors will be removed from the worker's desk and replaced by wall-sized displays. In fact, Krueger argues for the benefits of standing while working in general, claiming that "Overcoming the sedentary tyranny of existing systems is one of VIDEOPLACE's ongoing goals" (Krueger, 1990).

Also worth noting is Krueger's companion system, VIDEODESK, which uses more refined bimanual whole hand input. In a drawing demonstration, the selection of a RGB colour is controlled by adjusting the red level with one hand, green with the other, and blue through the movement of both hands. The system also supports multipoint control using multiple fingers, for example using thumb and forefinger to designate spline control point positions. Two handed interaction with a digital desk oriented display continues to be an active area of research – Hinckley (1997) provides many more examples.

Krueger's ideas have inspired more technically evolved systems, like Maes, Darrell, Blumberg, and Pentland's (1995) ALIVE system. This system also uses computer vision to enable full body, "partial 3D" unencumbered interaction with a very large display. It is partial 3D because although the system can infer a rough approximation of the person's distance from the display, it can only get depth information for hands in certain non-occluding, ideal situations. Like VIDEOPLACE, it uses the silhouette of the user to simplify image processing, thus it can not recognize hands if they are directly in front of the body. Unlike VIDEOPLACE, it recognizes simple hand gestures and even a kicking gesture performed with the foot. Like an enhanced version of Krueger's Critter, the purpose of ALIVE is to interact with an autonomous agent in a natural way.

Krueger's ground breaking work is still relevant today. We have moved beyond having to write programs to interact with computers, now we can interact through a graphical interface with keyboard and mouse. Certainly this is a significant improvement, but the dream of effortless, natural interaction with a large display remains elusive.

2.4.2 Charade

Baudel and Beaudouin-Lafon's (1993) Charade system explores free-hand gesture interaction for controlling a presentation slide show. Using a tethered data glove to track single hand movements, the system recognizes a set of sixteen free-hand gestures representing commands such as advancing to the next slide, returning to the table of contents, and highlighting an area on the screen. When not performing a gesture, the system tracks the hand's position reflected by a cursor on the display.

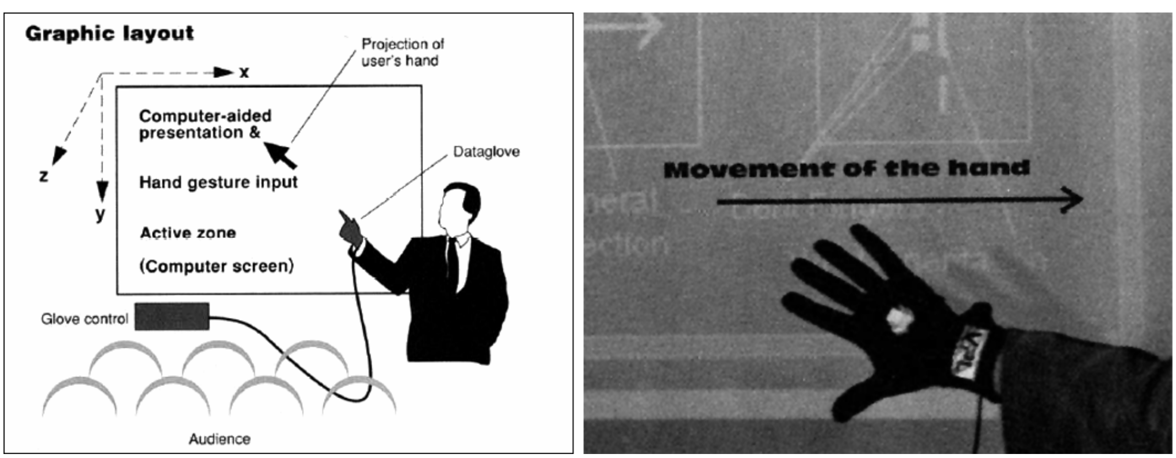


Figure 11. Charade (from Baudel & Beaudouin-Lafon, 1993)

They argue for three expected advantages of free-hand gestures as an input technique: they are *natural*, they are *terse and powerful*, and they are *direct*. We use hand gestures to interact in our world already, raising a hand to hail a taxi cab is a simple example, and thus free-hand gestures would seem to be natural. A gesture can issue a command and define multiple objects in one continuous movement creating a terse phrase. As Buxton (1986) also argues, this can reduce interaction complexity by chunking operations in a more meaningful manner. Finally, by eliminating intermediate transducers such as a mouse or joystick, the user can interact directly with the digital objects.

However, Baudel and Beaudouin-Lafon also recognize that there are limitations to free space gestures intrinsic to gestural communication itself and due to limitations of current recognition technology. Two major problems of free space gestures are user fatigue and their non self-revealing nature. Learning gestures is problematic since there are no onscreen widgets to click and explore (this is the same problem in command line interfaces). Our work looks at ways to make gestures self-revealing without resorting to an extensive training period in chapter 4.

Limitations of current technology and recognition include lack of comfort due to the tethered glove required at that time, and perhaps more relevant to our work are two related problems: immersion syndrome and segmentation difficulty. Immersion syndrome is caused when every hand movement is interpreted as a hand gesture. Segmentation is the difficulty in deciding which portions of a continuous hand motion constitutes a single gestural command.

The authors ran a usability study to observe how the system is used and what the recognition success rate was. They found two types of common errors: system errors where postures were not correctly recognized, usually due to out-of-tune tolerances, and user errors resulting from hesitation during the performance of a gesture. Hesitation was most prominent in new users. Analysis also showed that recognition rates improved from 72 to 84% for first time users to 90 to 98 % for experienced users.

Based on their experience, the authors present guidelines for designing gestural command sets which are usable and natural. They suggest using an active zone in which all gestures are executed. If the hand is not in the area defined by the active area, no gestures are interpreted. This addresses some aspects of “immersion syndrome” by making the user’s intention explicit. A second guideline is to segment each gesture into start and end positions defined by wrist orientation and finger positions (which we refer to as hand postures). The authors claim that depending on a user's skill and training, from thirty to eighty different postures could be recognized. The third guideline for a usable gestural command set refers to classification by combining posture and dynamic phase. They suggest moving the hand after the start posture to distinguish among different commands.

The final four guidelines address the naturalness of gesture command sets. The authors recommend using hand tension for start positions to make the user's intention explicit. Gestures should be fast, incremental and reversible with liberal onscreen feedback. Commands should favour ease of learning by compromising between natural gestures that are easily learned and complex gestures that provide more control. Finally, hand gestures should only be used for appropriate tasks. Symbolic gestures like holding your hand up to say "stop" can be used for a corresponding command like "pause," while non-symbolic gestures can be used for more abstract commands like "save" and "change font." They caution against using indirect selection gestures similar to menu navigation in non-gesture interfaces since this detracts from the directness of gestural input (they suggest using speech input in this case).

Baudel and Beaudouin-Lafon's exploration of hand gestures presents a compelling demonstration application and a reasonable set of guiding principles. We adopted the spirit of many if their guidelines. For example, they suggest combining posture and dynamic phase to define a command which we mostly do, however we use a dynamic phase to denote an input parameter for a subset of our gestural commands. Our aim was to reduce some of the complexity and dexterity required by the Charade gesture set – our main critique of the work.

2.5 Privacy and Sharing on Large Displays

Sharing multiple displays among several users has been explored in projects such as Rekimoto's pick and drop (1997), Streitz et al.'s i-Land (1999), and Stanford's iRoom (Johanson, Fox, & Winograd, 2002). They present interaction techniques for multiple users to control and interact with common, public information across multiple displays spanning different sizes and personal and private contexts. They include ways for exchanging information between a personal device like a laptop or PDA, with one or more common shared displays. Hello.Wall (Prante et al., 2003; Streitz et al., 2003), which we discussed earlier in this chapter, is another example of a system that uses a personal device to display private information in conjunction with a large shared display.

Systems which primarily have a *single* display shared among multiple users are referred to as Single Display Groupware, first defined by Stewart (1998). Authors have argued that there are benefits in allowing users to collaborate around a single display surface rather than using a combination of personal and shared displays (Shoemaker & Inkpen, 2001).

Two systems which explore techniques for sharing and exchanging public and private information on a single large display are Izadi et al.'s (2003) *Dynamo* system and Shoemaker and Inkpen's (2001) *Single Display Privacyware* technique which we now discuss in more detail.

2.5.1 Dynamo

The Dynamo system (Izadi et al., 2003) stresses explicit controls for sharing and privacy when collaborating on a single common display using conventional input devices. The system is designed for instant-on casual interaction and is typically located in a common space where people are likely to gather informally. Users interact using mice and keyboards, or using the input devices on a personal device like a laptop. Once connected, users can manage the common display as a communal resource by "carving out" an area to use individually or collectively with others (we call this method of sharing *explicit space partitioning* and we use a variant of this technique in our system). Users can easily move information from their own personal device to the public display and vice-versa. Information may be left on the display for extended periods of time for others to pick up or view later.

The authors contribute visualization and interaction techniques to enable this style of communal sharing. For example, they make use of colour and picture icons to identify and differentiate between the users currently using the display. Each user is assigned a colour to identify their information space and their input cursor/pointer. Available functionality is made immediately apparent through the use of floating palettes. These palettes contain icons denoting an operation or state. Many functions are performed by dragging a symbolic iconic link between different spaces. For example, dragging a key icon from your own personal space to another user's personal space enables this user to access your information.

Figure 12. Dynamo (from Izadi et al., 2003)

Similar to Greenberg and Rounding's (2001) Notification Collage, Dynamo provides techniques for posting media items to the shared surface like notes, pictures, and videos. A unique feature is for these media items to be enclosed in a package which can only be opened and viewed by a certain user when they access the display at a later time.

The authors solicited feedback from over 65 users using a prototype version of the system. They found that users had trouble with the drag and drop paradigm at first, but after explicit instruction they were able to use this technique effectively. They also found that people liked the idea of simultaneous interaction on a shared surface with one participant saying "it's much more sociable than using laptops around a table."

The Dynamo system presents several simple and effective techniques to address the control and display of personal information on a single, large public display. However, the focus on using conventional input devices limits the possibility for deploying this system in public or even semi-public places, and reduces the fluidity of a "walk up and use" scenario.

2.5.2 Single Display Privacyware

Shoemaker and Inkpen (2001) present a different solution for showing private information within the context of public information on a single shared display. In their system, LCD shutter glasses are worn by each user to present different versions of the shared display – essentially creating multiple private output channels. This allows each user to see only their private information, such as a note or comment for example, in the context of common public information, such as a street map. They refer to their technique as Single Display Privacyware. Although their system provides a high degree of privacy within a public context, it requires each user to wear special LCD shutter glasses, and display system refresh rates limit the number of simultaneous users to a small number, probably less than five.

The techniques used in Shoemaker and Inkpen's system addresses three key problems they identified with typical Single Display Groupware systems: the *screen real estate problem*, the *awareness overload problem*, and the *privacy in context problem*.

The screen real estate problem and the awareness overload problem are caused by the duplication of tool palettes, menus, cursors, and home areas of each user on a single display. With so many widgets on a single display it easily becomes cluttered. With Shoemaker and Inkpen's system, each user sees their widgets and an appropriate balance of other user's widgets to provide awareness information with minimal clutter.

The privacy in context problem follows from the requirement for placing private information near public information. With typical Single Display Groupware this simply is not possible without sacrificing the privacy of the information. Using the multiple private output channels in Shoemaker and Inkpen's system, users are free to place private information wherever they wish without fear of others viewing it.

Although using LCD shutter glasses solves the problem of displaying private information in the context of public information, requiring users to wear specialized hardware undermines the practicality of this approach.

3 Design Principles and Interaction Framework

Our environment has already begun to fill with the first generation of large plasma or LCD displays. We see them in public, semi-public, and private spaces like airports, schools, shopping malls, offices, and homes. Currently they broadcast generic public information, typically in a pseudo cable news channel format or as animated, graphic advertisements. But with simple and immediate interaction techniques, the displays could become responsive to us; and as data exchange networks mature into a trusted platform for distributed personal information access, these public displays could be used to access our personal information securely and easily. Our research examines how large, public displays can be used to exchange specific information with individuals as they pass by.

Realizing this vision, however, requires overcoming several issues. As more large public displays are added to an already crowded environment, we risk overloading users' senses. If the display has urgent information for a user in its vicinity, the notification method must be done in a minimally intrusive, socially acceptable manner. Since public places are inhabited by many people, we need to consider how a public display can be effectively shared by several users at the same time. Input and interface techniques and technologies need to be developed to allow for effective walk-up-and-use interaction with large public displays. Assuming we can access personal information through a secure network, we still need to maintain privacy when users view such information on a large, shared public display.

A first step in our research is to address these issues collectively by identifying a set of design principles and developing an interaction framework. We created this theoretical basis with an overall design goal in mind: the creation of a shared, single display to fluidly serve the dual role of public ambient or personal focused display depending on the context and relationship between users and the information available from the display. By anchoring our research prototype in a theoretical foundation, our experimentation with different interaction and visualization techniques are more systematic and justifiable. It also kept us focused on dealing with the issues that need to be overcome with this type of system.

Although the findings of our user evaluations (discussed in chapter 5) have suggested some level of validation for our choice of design principles and framework, it is far from definitive. Additional design iterations in parallel with a longitudinal field study would be useful to seek more confidence in the validity of our principles and framework. Experimentally testing theories and principles in isolation (see chapter 6) would also lend more credibility to our choices. This would follow more closely with techniques such as Heiser, Phan, Agrawala, Tversky, and Hanrahan's (2004) validation of design principles applied to computer generated instructional illustration design. They identified design principles through empirical research, and then validated them with an empirical user study comparing their prototype system (built using the identified principles) against a base case of human generated good instruction design.

3.1 Design Principles

In conceptualizing a system for public ambient display interaction, we identified eight design principles which we feel should be adhered to. Our principles are motivated by prior research and by our own experiences. Our design principles do not necessarily correspond one-to-one with the issues we listed above, but taken together, they work to address them collectively. For example, Calm Aesthetics, Comprehension, Subtle Notification, and Immediate Usability all work together to address the issues relating to overloading a user's senses and providing socially acceptable notification. While Short-Duration Fluid Interaction, Immediate Usability, and Shared Use suggest how a public display can be effectively shared by several users at the same time.

Although our design principles and interaction framework consider the design of the ambient display visualization itself, we emphasize interaction and visualization techniques to support the transition between public ambient and personal focus. Design principles for pure ambient display visualization could be derived from Mankoff et al.'s (2003) ten heuristics for evaluating ambient displays and/or Skog and Holmquist's (2003) work in ambient display design.

Calm Aesthetics

Ambient displays provide information in the user's periphery and are typically placed in a permanent location becoming part of their environment (Skog & Holmquist 2003; Skog et al., 2003; Weiser & Brown 1996). Thus, one must carefully consider the aesthetics of the displayed information, and how the interface subtly reacts to input and fluidly signals state changes. For example, Churchill et al. (2003a), found an overly reactive display too distracting, while a slow one felt static and unresponsive.

Comprehensibility

The information communicated by the ambient display must be comprehensible, even if rendered in an abstract manner (Skog et al., 2003; Holmquist, 2004). It may not be immediately understandable, but users should be able to discover meaning through subtle interaction. As Gaver, Beaver, and Benford (2003), argue having some ambiguity in the display, at least initially, can draw users into interaction. An interactive display should reveal meaning and functionality naturally.

Subtle Notification

The display should notify and communicate with passers-by in a socially acceptable manner based on their level of attention and openness to receiving more information. From Hudson et al.'s (2003) work on interruptibility of individual workstation users, we hypothesize that cues such as user's walking speed and direction, gaze, conversation, and proximity to the display could be used to determine the interruptibility tolerance of a potential user.

Short-Duration Fluid Interaction

To maintain the ambient nature of the display, interaction should be designed to support short duration activities. This suggests tasks for quick information queries rather than involved activities. Initiating and ending an interaction should be fast and seamless, without requiring explicit sign-in or sign-out, to encourage "crossing the threshold to participation" (Brignull & Rogers, 2003). For instance, simply walking away from the display should end any explicit interaction with personal information.

Immediate Usability

Prior training should not be required to use the display. To encourage learning by exploration, responsive display techniques can lead users into subsequent phases of interaction. If some explicit interaction techniques are difficult to discover, the system should demonstrate these techniques at appropriate times. Since the display will be in a permanent public place, regular inhabitants of the space may also discover functionality vicariously, by observing other users (Brignull & Rogers, 2003).

Shared Use

To take advantage of a large display and considering the realities of the number of people in public places, multiple users should be able to share the system either individually or collaboratively whether interacting implicitly, explicitly, or simply viewing the ambient display. Sharing techniques must be minimally disruptive to other individuals using the display and the display must feel as though it is available for use at some level regardless of the number of people in its proximity. The system needs to consider the three key problems with sharing a single display with multiple users: the screen real-estate problem, the awareness overload problem, and the privacy in context problem (Shoemaker & Inkpen, 2001).

Combining Public and Personal Information

Rather than exclusively showing public information, when appropriate weave an active user's *harmless abstracted* personal information into the ambient display. By harmless, we mean information that one is not too concerned about others viewing – like free/busy time slots in a meeting calendar – as opposed to sensitive personal information like the body of an email. For instance, Huang & Mynatt (2003) found that users of their semi-public awareness display were receptive to displaying harmless personal information such as their expected attendance at upcoming events. Abstracted personal information refers to how information content and presentation is simplified or transformed so that others could not comprehend it in any detail. But caution should be exercised when displaying any type of personal information in a public space. Palen’s (1999) research in shared calendars found that the patterning and sequencing of benign information can still compromise the integrity of underlying information. For instance, she describes a scenario where an employee of a financially unstable company discovered that layoffs were imminent based on the unusual amount of all-day bookings of conference rooms by the human resources department (Palen & Dourish, 2003).

The trade-off in displaying harmless abstracted personal information to gain awareness and personal utility is an important issue. Palen and Dourish (2003) suggests that “Active participation in the networked world requires disclosure of information simply to be a part of it.”

The best way to combine public and private information is to place personal information in the same context as corresponding public information – similar to what Shoemaker and Inkpen (2001) enabled with their Single Display Privacyware system. For example, an individual’s personal calendar events could be displayed on the same timeline as common public events in a single ambient display.

Privacy

Tan and Czerwinski (2003) showed that people tend to be more voyeuristic with large displays and Palen’s (1999) discussion of group calendar privacy indicates that “information considered totally innocuous to some is considered personally private to others.” Thus, techniques should be provided that discourage other users from eavesdropping and the display of personal information should be controlled by the user. For example, a user should have an easy way to explicitly hide their notifications and minimize their implicit interaction, perhaps with an explicit start and stop command like Jancke et al. (2001). Our principle of shared use suggests that the system must support privacy in a reasonable way, without completely undermining the utility of a multiple user system – essentially there is a trade off (or balance) between privacy and shared use.

3.2 A Framework for Interaction Phases

In addition to our design principles, building upon previous research we developed an interaction framework (Churchill et al., 2003a; Brignull & Rogers 2003;

Prante et al., 2003; Streitz et al., 2003). It covers the range from distant implicit public interaction to up-close explicit personal interaction, with four continuous phases with fluid inter-phase transitions: Ambient Display, Implicit Interaction, Subtle Interaction, and Personal Interaction (Figure 13).

We differ from the three zone model used in Hello.Wall (Prante et al., 2003; Streitz et al., 2003) in that we do not rely solely on physical proximity to delineate different phases, we do not require a hand-held device for personal interaction, we emphasize fluid transitions between phases, and we support sharing by several users each within their own interaction phase. By dividing Hello.Wall's "interaction zone" into the Subtle and Personal Interaction phases and by generalizing the notion of a "notification zone" into an Implicit Interaction phase, our framework suggests a wider range of implicit and explicit interaction techniques.

Our four phase interaction framework bears some similarity to Hall's theory of Proxemics (1966). Hall defined a succession of four zones of interpersonal distance across cultures: Public, Social, Personal, and Intimate. However, our framework is concerned with how people relate to information on a large display. We discuss future work in chapter 6 to explore whether Proxemics applies to human-computer distance as well.

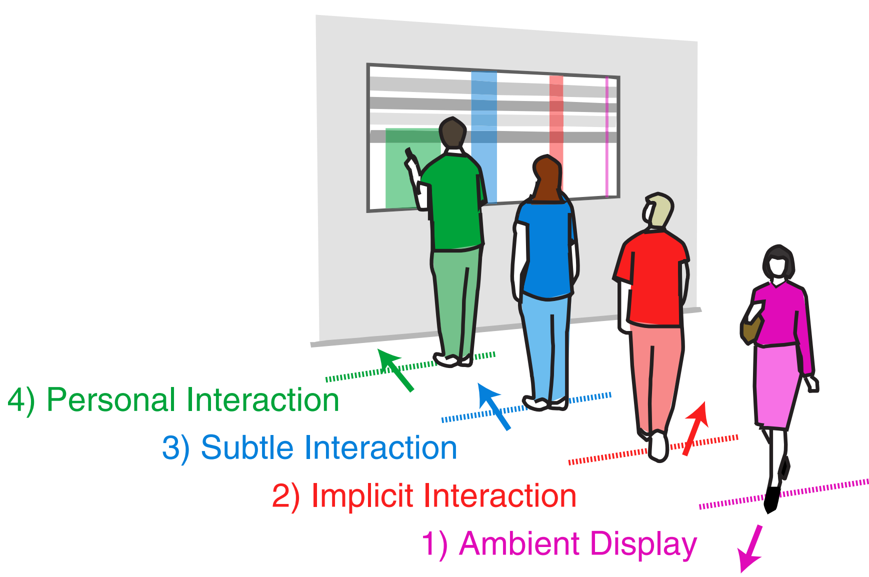


Figure 13. Four phase interaction framework
Four interaction phases, facilitating transitions from implicit to explicit, public to personal, interaction.

3.2.1 Ambient Display Phase

The neutral state is that of an ambient information display, showing a range of categorized information simultaneously with updates occurring slowly (Skog & Holmquist, 2003; Skog et al., 2003; Weiser & Brown, 1996). The ambient display forms a central context anchoring all subsequent interaction, so it is important that other phases do not radically alter or obscure it. Users should be able to get a sense of the overall information space with a quick glance.

3.2.2 Implicit Interaction Phase

The system state shifts to an implicit interaction phase with peripheral notification when a user passes by. The system should recognize the user’s body position and orientation and use this information to infer their openness to receiving information – a measure of that user’s interruptibility (Hudson et al., 2003). If they appear to be open to communication, the system should subtly react by showing an abstract representation of the user on screen. The user is notified in a subtle manner if there is an urgent personal or public information item that requires attention. These techniques help to draw the user closer to the display, leading them to enter the next interaction phase (Kortuem, 2003). While this inference is done implicitly, the user should also have a way to explicitly signal that they wish to be left alone.

3.2.3 Subtle Interaction Phase

When the user approaches the display and provides an implicit cue such as pausing for a moment, the system should enter the subtle interaction phase. More detailed descriptions of the notifications and/or the current state of the available public information are displayed. The public information is also augmented with personal information relevant to the particular user and information context, if such information exists. For example, the organization’s event calendar could be augmented with a user’s own meetings and appointments. The duration of this phase would be about one minute: just enough time to select an information item to investigate in more detail.

To this point, the user has only interacted implicitly, but now they should be able to use simple explicit actions to select and navigate an information source. Since this phase is meant to be used for a very short time and viewed from more than arm's length from the display, simple hand gestures and some explicit body movements might be used for interaction. By remaining distant from the display, the user does not obscure it, thus allowing sharing of the display by multiple users. This also allows users to view the display in its entirety when navigating the information sources. The information shown in this phase can be personal, but should be not be something that a user is highly protective of.

3.2.4 Personal Interaction Phase

After an information item is selected, the user should be able to move closer to the screen and touch information items for more details, including personal information. While gestures are useful for interaction from a distance, direct touch is suited for accurate, up-close interaction. Since the user is close to the display, their body can help occlude the view of their personal information from others. While body occlusion is not a secure way to protect very sensitive personal information, there is a class of personal information that would be appropriate for this simple privacy technique, even if another user intended to eavesdrop. This personal interaction phase is a smooth extension to the previous phase, with all previous gestures still usable. This phase should support longer duration interaction, say 2–5 minutes, and should be designed such that the disruption to the rest of the display is minimized, allowing simultaneous use by multiple people.

3.2.5 Transitions between Phases

A key feature of our framework is how it maintains a seamless experience with phase changes occurring in a smooth way. Users initially signal a phase change using implicit interaction such as body movement, body location, and head orientation, and then gradually become more explicit with gestures and touch (Kortuem, 2003).

Phases should be entered and exited with minimal disturbance to the display, but with enough calm feedback so that it's clear a new phase has been entered. The phases should also keep interaction consistent. For example, a user should be able to signal an exit from any phase with a consistent action, such as simply turning and walking away. To manage these transitions, we sub-divided the four main phases into six states (Figure 14). The ambient display phase has two states: INACTIVE for users who are out of range, and HIDDEN for users who have explicitly requested that the display not notify them. The subtle interaction phase has two states: SUMMARY when viewing the notification details, and SELECTED when the user has selected an information source to query

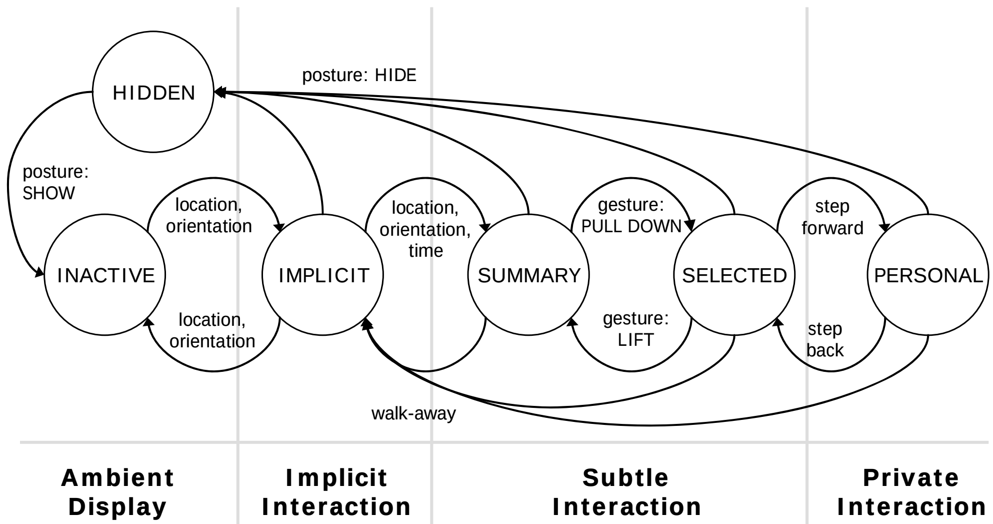


Figure 14. State transition diagram
Showing transition events between phases and states within phases.

3.2.6 Supporting Simultaneous Phases for Multiple Users

Another key feature of our framework is that it supports several users sharing the display regardless of what phase each user is in. Typically, sharing a large display is done through time-based queuing (Churchill et al., 2003a; Russell, 2002) or explicit space partitioning (Izadi et al., 2003). We build on the latter, but without users explicitly claiming a static region of the screen. Depending on the interaction phase they are in, each user's space should contract and expand. Using transparency, other users could see through a user's space to the public information beneath (Harrison, Ishii, Vicente, & Buxton, 1995). Also, the system should allow users to reach beyond their own space to access information. Such interaction should, however, not interfere with the fundamental role of the system as an ambient display that must remain useful for others at a distance.

4 Prototype System

Conventional public information sources such as bulletin boards are common in high traffic locations of many office buildings. However, these displays contain only public information and have no comprehension of the users in the immediate vicinity. As an extension to these displays, we built our prototype system with generic information suitable for an office corridor environment. Our techniques are generally applicable beyond this environment and the information sources could easily be adapted to other locations such a hotel lobby, an airport, or a shopping mall.

Our prototype realizes our design principles and embodies our four-phase framework for seamless implicit to explicit, public to personal interaction. Our work focuses on fluid movement between the different interaction phases, techniques for supporting multiple users, subtle notification, privacy controls, and self-revealing help. Our prototype user interface illustrates one way to realize our design principles and interaction framework. Although our user feedback described in chapter 5 is encouraging, we are not claiming that our prototype is eminently usable at this stage.

A five minute video demonstrating our prototype system is available as part of the published proceedings which include Vogel and Balakrishnan (2004) and also online[2].

4.1 System Hardware

We use a 50 inch plasma screen, which provides a high-resolution display platform for easy prototyping of different information layouts and animations. A SMART

[2] Video available online at http://www.dgp.toronto.edu/~ravin/videos/uist2004_ambient.avi

Technologies (www.smarttech.com) touch sensitive overlay supports up-close interaction using fingers. A Vicon (www.vicon.com) motion tracking system provides high resolution location and orientation data for the user's head, body, right hand, and selected fingers, in a tracking volume approximately 2.5 m deep from the front surface of the display, 2.2 m high (i.e., from floor to ceiling), and 5 m wide (i.e., 2.5 m on each side of the display).

Although the Vicon system requires us to place small wireless passive markers on body parts we wish to track, it is our belief that advances in computer vision techniques will obviate the need for markers in a few years. While the inconvenience of using markers and a specialized motion tracking system does detract from the overall usability and implementation simplicity of our prototype, this technology allows us to explore advanced interaction techniques today, *before* marker-free tracking becomes widely available. As such, this hardware should be viewed simply as an enabling technology for our prototype, rather than one that would be used in a future real implementation of our interface ideas. This system also provides a simple way to identify individual users through registered marker sets. We discuss other tracking options and user identification techniques in the "future work" section in chapter 6.

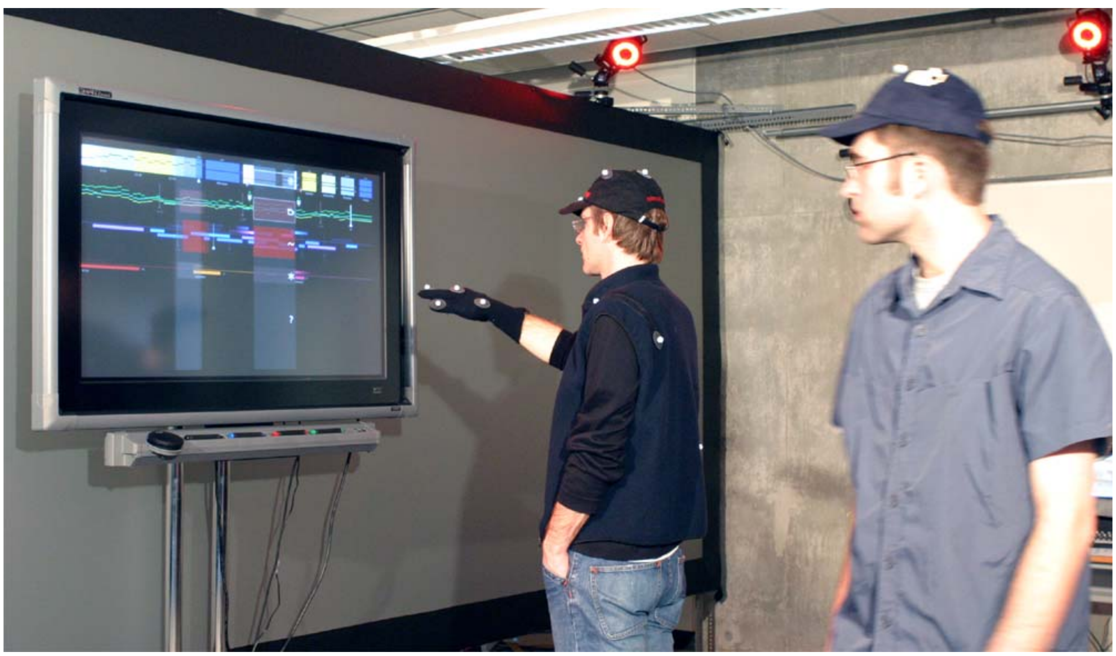


Figure 15. Prototype sharable interactive ambient display

4.2 High-Level Description of the Prototype

The default ambient display consists of a series of visual elements representing four information sources, each a horizontal "stripe" spanning the width of the screen (Figure 16). As a user enters the tracking volume surrounding the display, their body location and orientation are translated into an abstract representation of that user and their associated information displayed in the form of a vertical bar. Where the user's vertical bar intersects with each horizontal ambient visual element, a notification flag is shown whose transparency, colour, and dynamics are influenced by its current level of importance. If the user faces the screen and lingers for a moment, additional detail is presented for each notification flag and the ambient visual elements augment their public information with information specific to that user. Using simple hand gestures, the user can select an information category to further query. Within the selected category, additional hand gestures and body movement allow the user to query the entire ambient display space. Stepping very close to the display transitions the display into a finer level of detail and touch interaction. Figure 17 to Figure 21 show the contents of the display at each interaction phase.

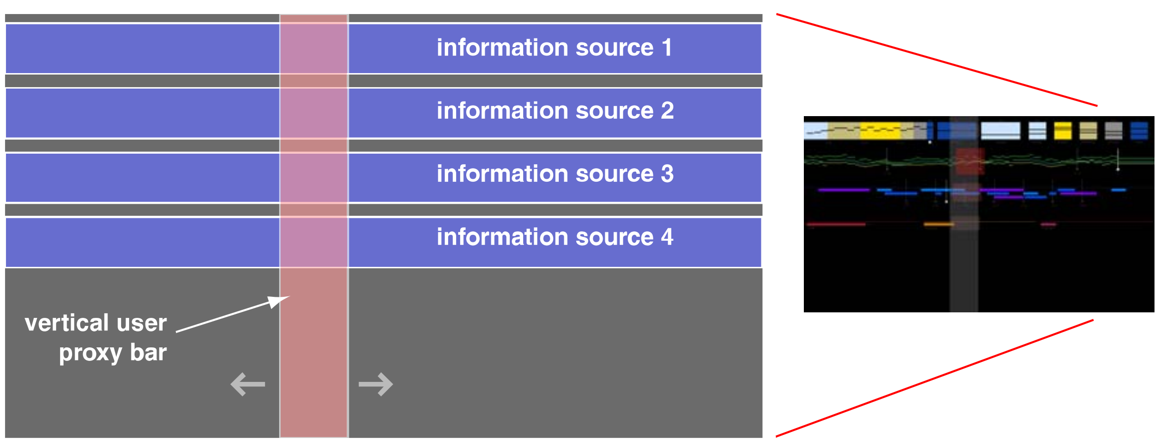


Figure 16. Information source stripes and vertical proxy bar
The vertical proxy bar moves left to right according to the user's body movement in front of the display.

Multiple users can initiate their own phases of interaction on the display at the same time. The design of our prototype also keeps the majority of the display elements accessible to other users even as one or more users have entered into deeper interaction phases. Also, privacy gestures can be performed at any time to hide the notification and querying display elements. This also allows the user to observe the public ambient display up close if desired, without entering the interactive phases.

4.3 Display and Interaction Techniques

In the following sections we describe techniques used in the prototype system that exercise our design principles and realize our four-phase interaction framework. Although we discuss them in terms of our framework for continuity, it is important to note that many of these techniques are used in several phases and can function simultaneously when different people use the display in different phases.

4.3.1 Techniques for Ambient Display Phase

The ambient display phase functions on the periphery with minimal interaction when users are distant from the screen or have asked to have other interaction phases hidden. Our prototype ambient display presents four information sources suitable for an office environment: current weather conditions and forecasts; activity levels in branch offices; an event and appointment calendar; and public and personal messaging. We selected these information sources because they were representative of type information found in conventional information sources like personal organizers (calendar, messaging), website portal pages (weather, messaging), and office awareness systems (activity levels). We note that these categories and their presentation heuristics are only examples selected from many possible candidates, In particular, a production system should focus more time on privacy design, building for example upon Palen’s (1999) work on calendars.

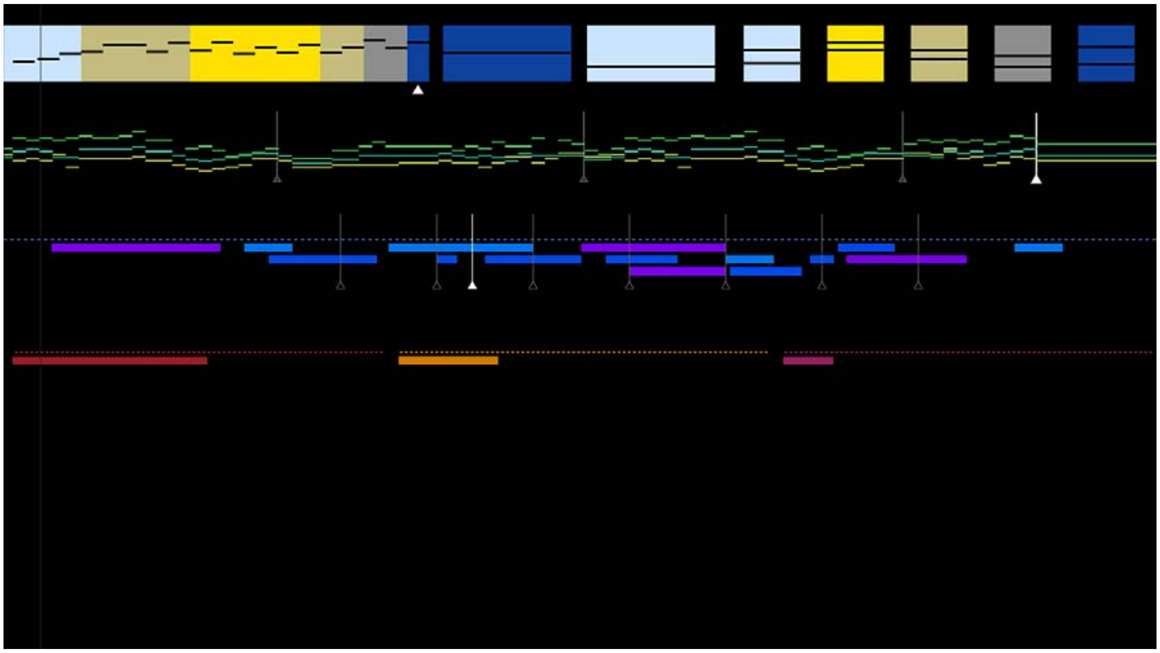


Figure 17. Ambient Display Phase
Four information sources make up the ambient display, each occupying a horizontal "stripe" spanning the width of the display (see Figure 22 for a detail view).

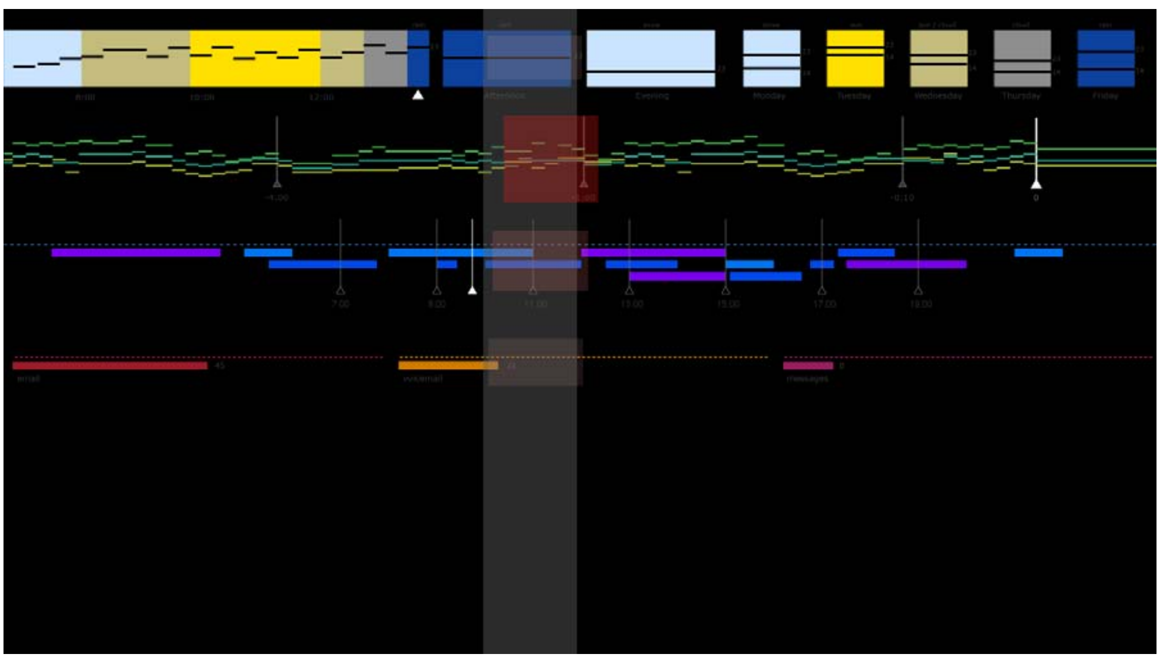


Figure 18. Implicit Interaction Phase
A semi-transparent vertical user proxy bar with notification flags is shown on the ambient display when a user moves near the display (see Figure 23 for a detail view of the proxy bar)

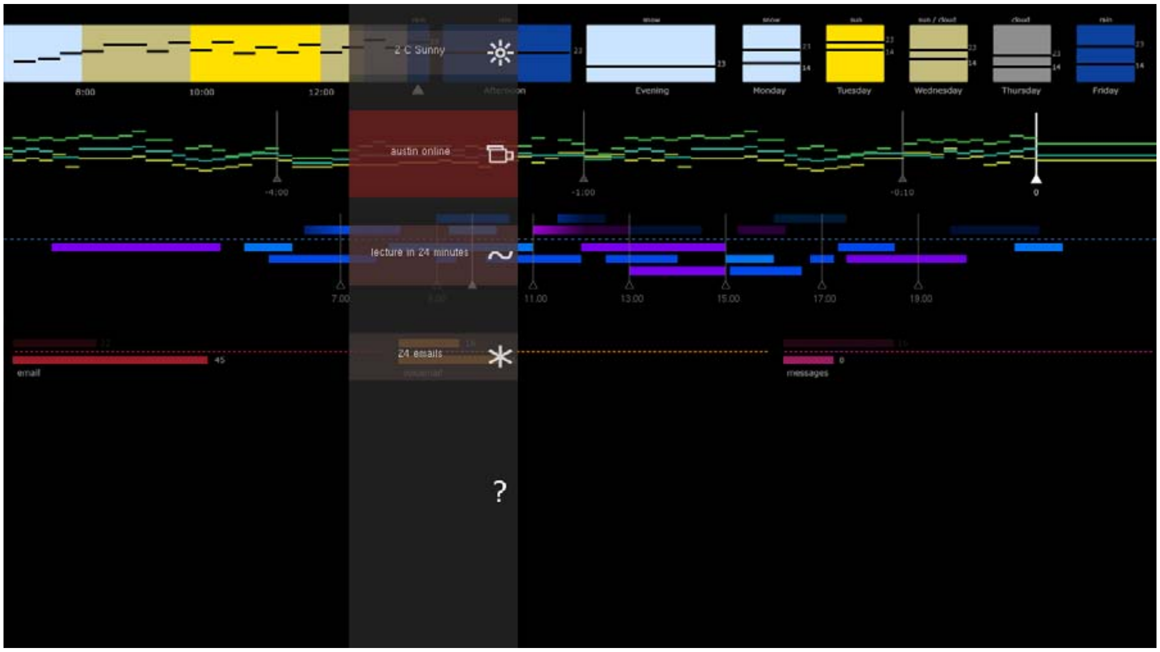


Figure 19. Subtle Interaction Phase, SUMMARY Sub-Phase
If the user pauses for a moment while facing the display, the proxy bar widens, overview information for the notification flags are displayed, and some personal information augments the ambient display (see Figure 24 for a detail of personal information augmentation)

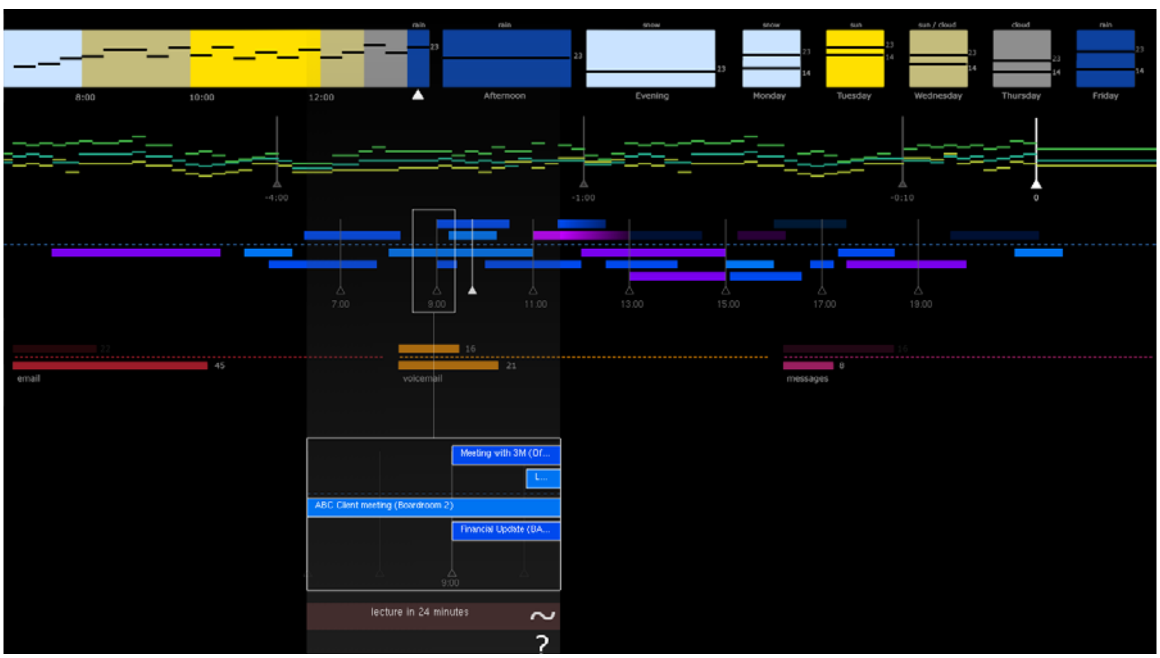


Figure 20. Subtle Interaction Phase, SELECTED Sub-Phase
When the user selects an information source, the proxy bar transforms into a detail panel at the bottom of the display with a selection point providing a zoomed view of the information source. (see Figure 25b,c for a detail view of the detail panel and selection point)

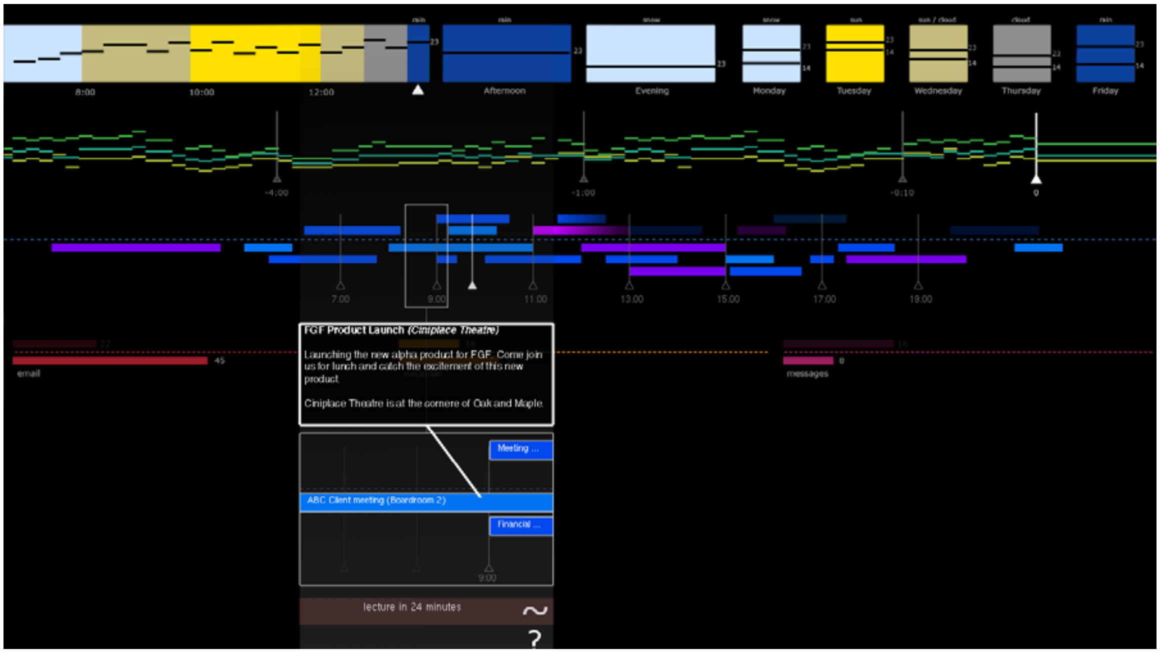


Figure 21. Personal Interaction Phase
By stepping closer to the display, information in the detail panel can be queried using touch screen input. Touching an event in the detail panel opens a full description in a "balloon" above (see Figure 25a for a detail view of the detail panel and description "balloon")

Layout and Design

The ambient information is displayed in an abstract manner using pleasing colour combinations and simple geometric shapes. Our *calm aesthetics* design principle led us to choosing this unobtrusive "designer look" which also provides a consistent, versatile way to represent various information sources — similar to the "informative art" designs presented by Skog et al., (2003). Each information category occupies a horizontal "stripe" spanning the width of the display (Figure 22 & Figure 17). Many information sources can be organized by time, so we exploit the ubiquitous left to right progression of time which this horizontal orientation suggests. We positioned the ambient information stripes in the upper half of the display with the screen itself mounted high (screen top is 2 m off the ground). This allowed users to see the ambient information even when other users are interacting with the system in closer proximity, as per our *shared use* design principle.

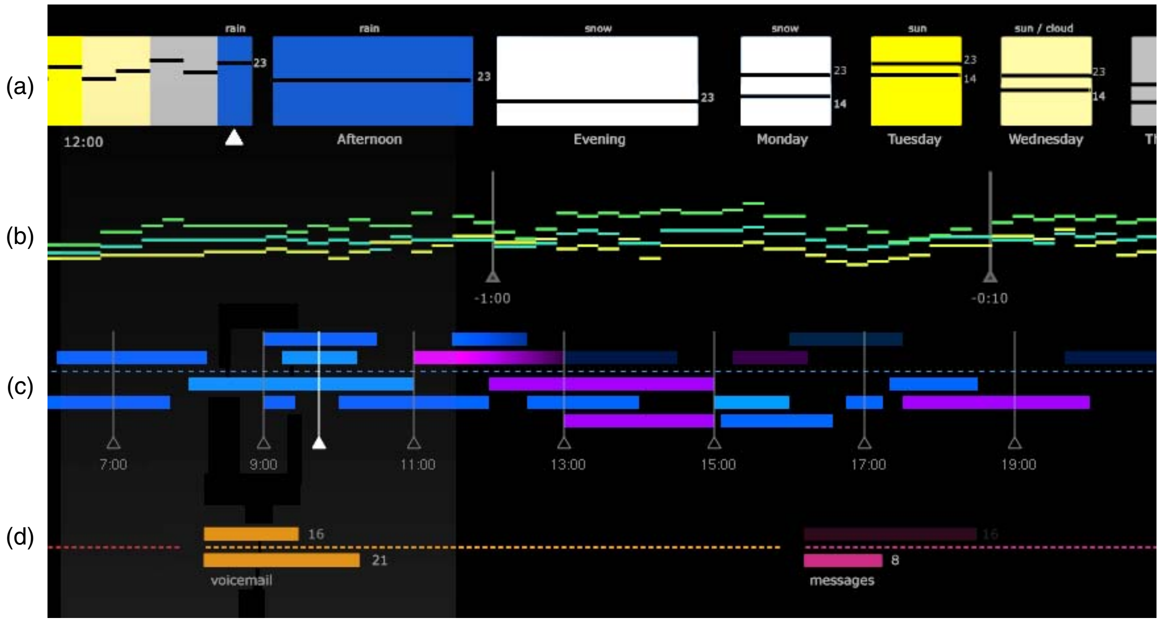


Figure 22. Detail view of the information sources
From top to bottom: (a) weather, (b) office activity, (c) calendar, and (d) messaging.

Proximity Reveal

As a first step towards fulfilling our *comprehension* design principle, we included an implicit technique for the ambient display phase to reveal information. As a user approaches the screen, additional text labels for the information sources fade in to view. This allows us to remove unnecessary text-clutter from the distant display, yet take advantage of descriptive labels when users are near enough to read them. This simple implicit interaction also demonstrates to the user how the display reacts to their body position, creates a fluid bridge to signal the beginning of the transition from the ambient phase to the implicit interaction phase. This draws them closer to the display and helps them discover the next phase of interaction, thus contributing to the system's *immediate usability*.

4.3.2 Techniques for Implicit Interaction Phase

This phase is initiated as a user walks past the screen. It has two functions: notify the user of any urgent information and demonstrate to the user that the display is interactive.

User Proxy Bar

We use the user's body location, body orientation, and head orientation to communicate with the user through a semi-transparent vertical "proxy bar" (Figure 16 and Figure 23). The width of the proxy bar is a function of the user's body orientation and its opacity a function of head orientation. This has the effect of minimizing the proxy bar when the user is facing completely away (no attention), maximizing when they look directly at the display (full attention), and a mid-sized width if the user is facing parallel to the display (peripheral attention). The proxy bar moves horizontally across the length of the display in a viscous but responsive manner according to the user's movement in front of the display. This calm style of movement keeps the display functioning on the periphery until the user initiates an explicit action.

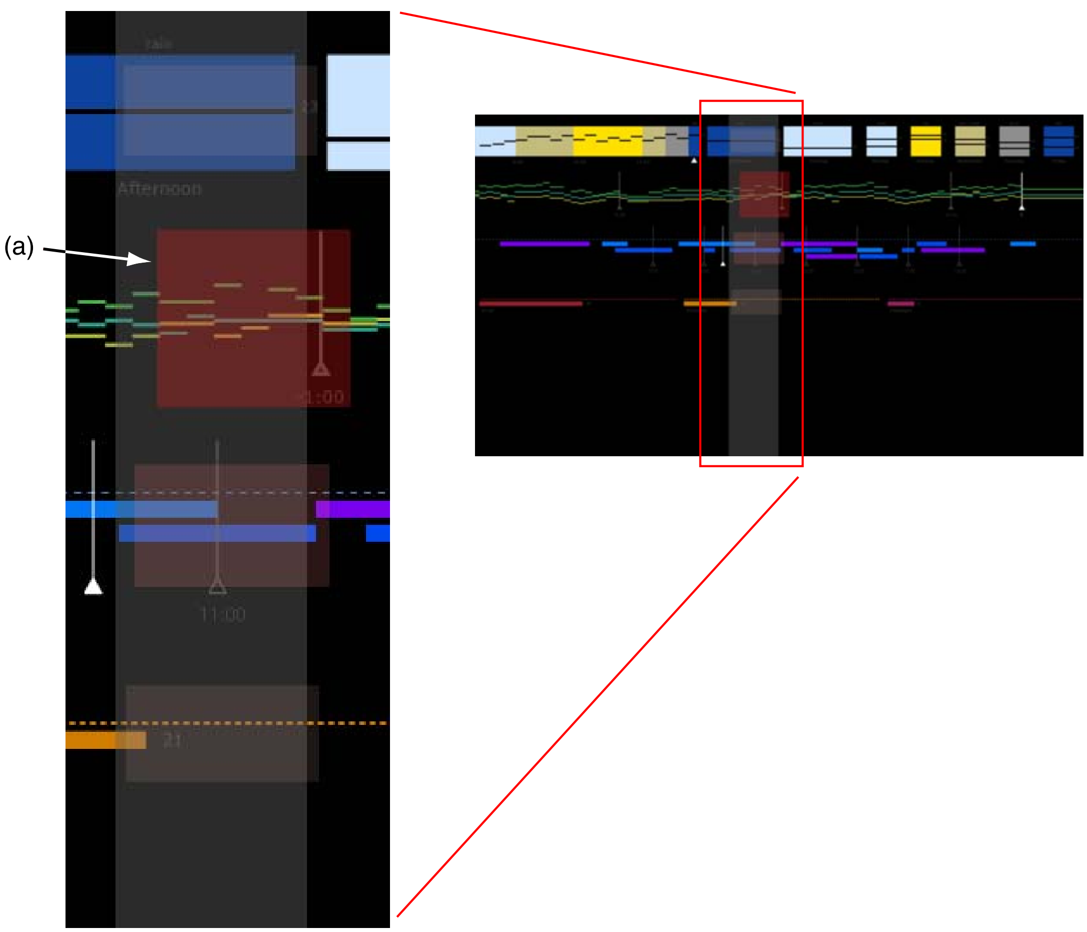


Figure 23. Detail of vertical user proxy bar
(a) Shows a notification flag with high urgency. Other notification flags are shown above and below, not that these indicate lower urgency since they are more transparent and de-saturated.

Peripheral Notification

At each intersection of a horizontal information stripe and the vertical user proxy bar, a notification "flag" conveys the current level of importance of the underlying information source to that user. For example, the messaging information source may notify the user if their inbox has reached a certain number of emails. Like the user proxy bar, the notification flags are designed to be calm and peripheral, but they are intentionally more pronounced if notification is intended. As an item becomes more urgent, the colour saturation, opacity, and size of the flag increase. Also, an urgent notification flag's movement moves more out-of-phase with the user proxy bar to increase visibility in the user's peripheral vision. Since the flags are anchored to the proxy bar, their width and opacity are also influenced by the user's body and head orientation.

Hide and Show Actions

Two complimentary hand postures are used to hide and show the display of a user's own proxy bar. The *hide* action is performed with a *palm away* posture consisting of an open hand pointing up with palm facing the display (Figure 27d), analogous to the commonly seen "stop" gesture used for traffic signalling in real life. The *show* action is performed with the *palm facing* posture which is an open hand pointing up with palm facing the user (Figure 27e) (similar to the "go" gesture in real life). These postures can be invoked in any interaction phase. We discuss the details of our posture and gesture set, as well as a self-revealing posture/gesture demonstration system, later in the paper.

The hide and show actions provide a privacy mechanism to stop the system from tracking an individual and suppress the display of notification information. Jancke et al., (2001) identified this as an important technique with their public, video-based awareness display where they installed physical "stop" and "start" buttons.

4.3.3 Techniques for Subtle Interaction Phase

The user enters the personalized subtle interaction phase by facing the screen and standing still for a moment within a certain threshold distance (1 m). Upon entering this phase, the user's proxy bar widens, overview information for the notification flags are displayed, and some personal information augments the ambient display. We refer to this initial state as the SUMMARY state (Figure 14 & Figure 19). From here, the user begins interacting in a more explicit manner using hand gestures to select an information source for querying, thus entering the SELECTED state (Figure 14 & Figure 20). To exit this phase, the user either moves closer to the screen to enter the personal interaction phase or turns and walks away to return to the implicit interaction or ambient display phases.

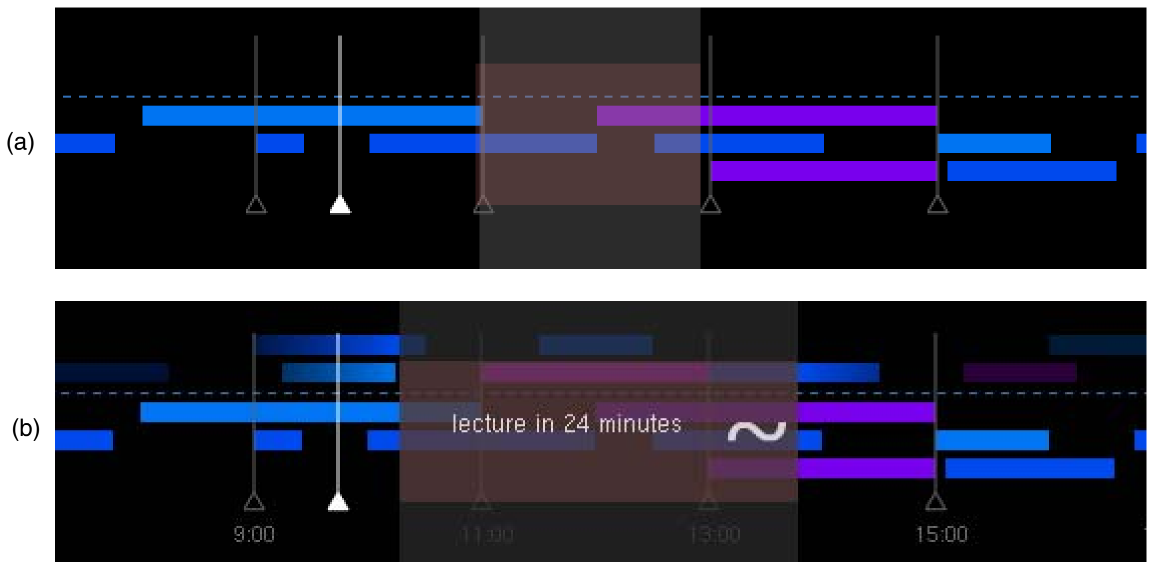


Figure 24. Augmenting public information with personal information
(a) public calendar events in the ambient phase. (b) personal events added above the dashed line after the user enters the subtle interaction phase.

Displaying Personal Information

Near the widened proxy bar, a magic lens (Bier, Stone, Pier, Buxton, & DeRose, 1993) inspired technique is used to *combine public information with personal information* (Figure 24). For example, the calendar displays personal events using the same ambient display techniques on the same time line as public events. To maintain *shared use*, personal events are shown with full opacity in the area near the proxy bar and high transparency elsewhere (Harrison et al., 1995). Viewing personal information beyond the immediate space of the bar is achieved with the reach and shifting techniques discussed below. Not all information sources require augmenting: for example, branch office activity and weather have no personal aspect, whereas sources like the calendar and messaging do.

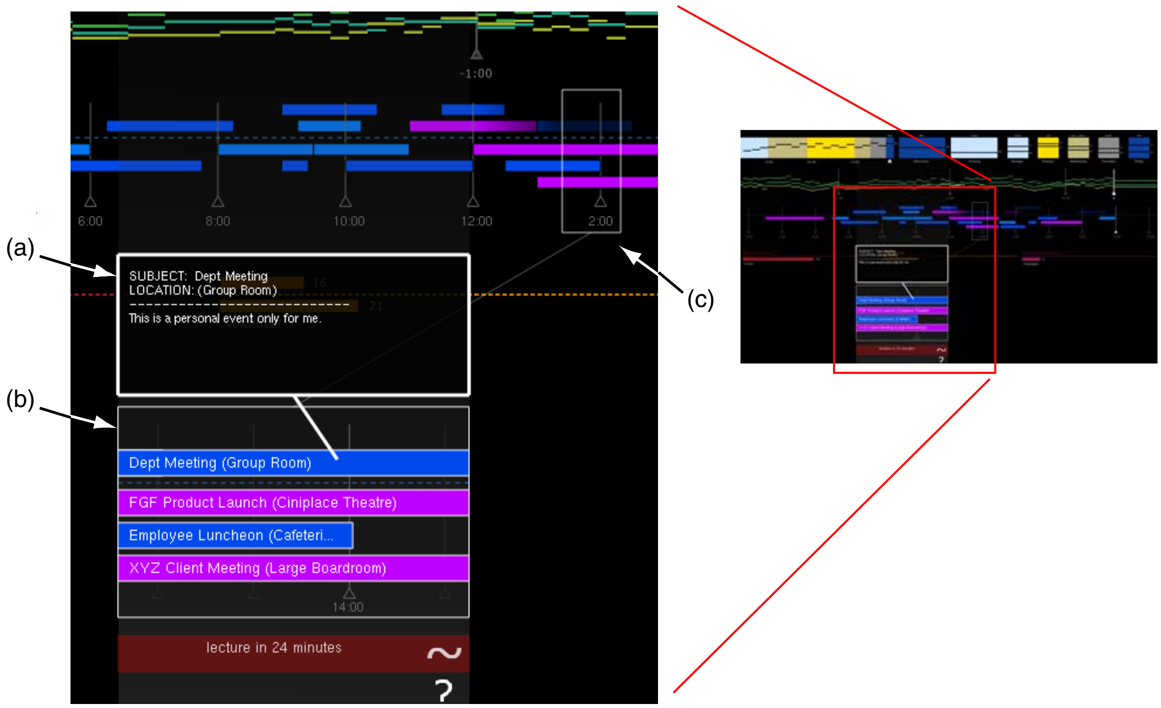


Figure 25. The detail panel and selection point
The detail panel, (b), displays a zoomed view of information located at the selection point, (c). The user can touch items in the detail panel to view more detailed information in the description area, (a).

Information Exploration

By forming an open hand with palm facing down (*palm down* posture, Figure 27a) the user selects an information category to explore in more detail (Figure 21). Essentially, the notification SUMMARY state acts like a large menu. Movement up and down vertically highlights items, and selection is done with a downward *flick* gesture (Figure 27a). The exploration is aborted by moving significantly to the left or right, or by changing the hand posture. We provide liberal visual feedback to guide the interaction (Figure 28): potentially selectable items are highlighted; while moving, "sticky" menu items follow the hand suggesting that the item can be flicked down to be selected; and display hints indicate how to cancel or complete the actions. Providing responsive on screen feedback in a gesture based system is important, as demonstrated by systems such as Bolt's "Put-That-There" (1980), Charade (Baudel & Beaudouin-Lafon, 1993), and ALIVE (Maes et al., 1995). For example, even in Bolt's early work, the shapes responded visually when they "heard" their name, clearly indicating to the user that their voice command was successful.

We also experimented with more conventional methods such as pointing at the screen, and a finger-controlled marking menu. Pointing from afar proved to be too difficult to control. The finger-controlled marking menu was easier to control and very efficient in terms of screen space, but was not intuitive for first time users and difficult to explain in an *immediate usability* scenario.

Return to Overview

To return back to the notification SUMMARY (Figure 19) when currently viewing detailed information in the SELECTED sub-phase (Figure 20), an open hand pointed out with palm facing up (*palm up* posture, Figure 27b) together with an upward *flick* gesture is used. A display hint is shown when the posture is initiated. The return gesture is complimentary to the select gesture. It reinforces a consistent conceptual model of items being "brought down to see detail" and "lifted back up to return to overviews" – something that our user studies later confirmed.

Reaching and Shifting

After an information source is selected, a detail panel is shown in the lower portion of the display (Figure 25). The detail panel provides a zoomed view combining both public and personal information together similar to the SUMMARY sub-phase. A square in the information source above, which we call the selection point (Figure 25c), indicates the location where the detail information is retrieved from. The user can navigate the source information by moving their body laterally to the portion of the display that interests them, which we call "shifting." This repositions both the selection point and the magnified area. Alternatively the user can use a *reach* technique to reposition the selection point, while maintaining the location of the magnified area. Similar to category selection, an open out-stretched hand is used, but this time with palm facing to the left (*palm vertical* posture, Figure 27c). Moving the hand left and right adjusts the selection point on the information source (Figure 26). Flicking up cancels and returns the selection point to its previous position and flicking down locks the position of the selection point.

These two methods for positioning the selection point deal with *sharing* the display and contribute to *immediate usability* of the system. When another user is physically blocking left or right body movement, the *reach* technique allows users to reach for information beyond the obstructing user. When there are no other users nearby, the lateral body movement is a natural action for selection considering how the body has been controlling the proxy bar in previous phases – our user studies later confirmed this.

Figure 26. Using the reach gesture to access information beyond other users
The user on the left uses a hand gesture to move the selection point (shown by arrow b) of the current information source beyond the obstructing user. The zoomed view of the retrieved information is shown in the detail panel (shown by arrow a) (see also Figure 25)

4.3.4 Techniques for Personal Interaction Phase

By stepping closer to the display, the user enters the personal interaction phase where information in the detail panel is queried using touch screen input. By standing close to the display, more personal information can be displayed safely by using a small font size and exploiting natural body occlusion. The phase is exited by stepping back to the subtle interaction phase, or turning and walking away to return to the implicit interaction or ambient display phases.

Touch Screen Interaction

In our prototype, we have implemented interactions in the personal interaction phase for the calendar information category only. In this case, touching an event in the detail panel opens a full description in a “balloon” above (Figure 25a). We imagine using similar techniques for other information categories like office activity where personal interaction could open a video link for casual conversation, or in messaging where personal messages could be reviewed.

4.3.5 Hand Posture and Gesture Interaction

As seen in the previous sections, much of the explicit selection and manipulation interaction is achieved using simple hand postures and gestures. Hand-based interaction allows users to remain at a distance so they can view the public ambient information content and their personal information simultaneously.

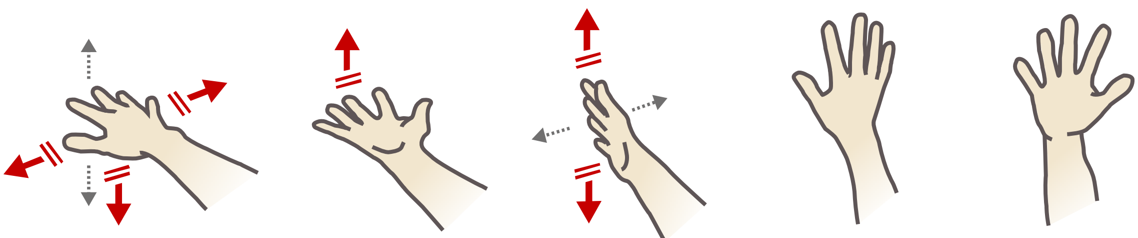


Figure 27. Postures and Gestures

Large red arrows indicate discrete gestures and small grey dashed arrows indicate continuous gestures. (a) Palm Down: continuous vertical gesture highlights items. A downward flick gesture selects an item. Left or right flick cancels. (b) Palm Up: an upward flick returns to the SUMMARY. (c) Palm Vertical: continuous horizontal gesture adjusts the selection point’s position. A downward flick locks the location and an upward flick cancels. (d) Palm Away posture triggers the hide action. (e) Palm Facing posture triggers the show action.

All of our postures are based on an open hand to prevent other common positions, like pointing, from being mistakenly interpreted. To facilitate robust recognition, and enhance performance by users, we deliberately use coarse grained open hand postures that rely only on large (usually 90 degree) differences in wrist and elbow angles (Figure 27). We currently use only a subset of possible gestures leaving room for future expansion.

Our postures are intentionally tense, in that they require momentary stiffness in the hand muscles to be achieved. This is similar to how Baudel and Beaudouin-Lafon (1993) designed the gestures in the Charade presentation control system. They used tense postures at the beginning and end of a gesture to form one continuous motion. We use a different technique in which a user holds a tense posture for a moment signalling the beginning of a discrete or continuous gesture.

Our recognition is done by first looking for the required posture based on the marker inputs from the user's hand. If a user's hand is held such that it falls within certain tolerances for finger and hand position and orientation, then a posture dwell time clock is started. After the posture is held for the required dwell time (we used one second in our prototype) it is considered recognized. The posture can then be used to invoke discrete gestures that trigger on/off actions equivalent to clicking a button, and continuous gestures that vary a continuous parameter.

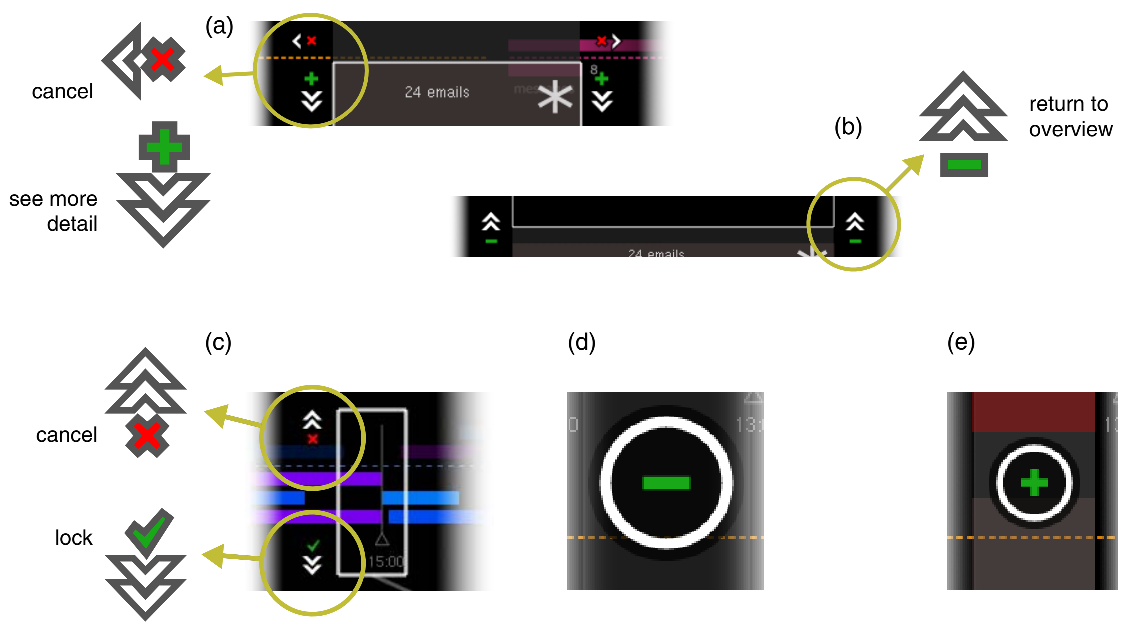
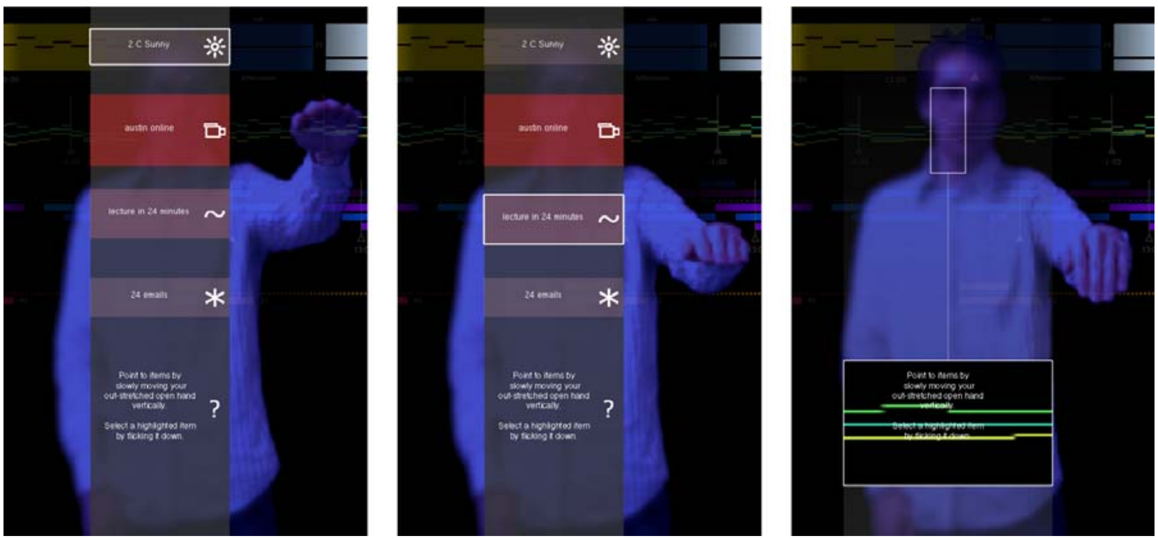


Figure 28. Visual cues providing information for imminent or possible actions (a) select information category. (b) return to SUMMARY. (c) reach action. (d) hide. (e) show.

We provide visual cues to indicate that hand-based interaction is about to be initiated or to remind users what actions are available for a particular posture. Baecker and Small (1990) and Baecker, Small, and Mander (1991) present a taxonomy of questions that need to be answered by the interface, including four that are relevant in this situation: Transition, "where have I just come from?"; Choice, "what can I do now?"; Feedback, "what is happening?"; and Demonstration, "what can I do with this?". They argue that these questions should be answered visually (see also Baecker, 2002). For example, while in the process of initiating the *palm away* posture, a symbol is faded in to indicate that the display is about to be hidden (Figure 28d). This provides feedback to the user that the recognition is working and an action is about to performed. If the imminent action is not desired, it can easily be aborted by changing the posture. For postures already invoked, the range of possible further actions are indicated via small icons (Figure 28a,b,c).



(a) (b) (c)

Figure 29. Self-revealing help using looping video sequences
In this example, an action with the palm down posture is demonstrated during the subtle interaction phase. (a-b) show continuous vertical movement with the palm down posture highlighting items. (c) shows the result of selecting the item with a downward flick action.

4.3.6 Learning Gestures through Self-Revealing Help

Systems using postures and gestures typically rely on an extensive instruction and training period (Lee & Xu, 1996), but our design principle of *immediate usability* precludes imposing such burdens on the user. Beyond keeping our postures and gestures simple and consistent, we also implemented a self-revealing help mechanism.

After a certain length of time in which a new user remains at some stage of an interaction phase without action, our help mechanism begins. This shows a looping video sequence of a user demonstrating the available action as though they were in a mirror (Figure 29). Baecker (2002) argues for the benefits of “showing instead of telling” through various kinds of dynamic visualizations to augment text instructions, including screen capture presentations and structured digital video demonstrations. A screen capture demonstration mimics an interaction through a captured, animated portrayal of that interaction and a structured video demonstration shows users how to accomplish desired tasks. Baecker suggests that these styles of dynamic help are particularly useful in answering demonstration questions.

Our technique can be thought of as a local screen capture demonstration combined with a subtle layer of structured digital video demonstration. The display behaves and reacts as though user in the video demonstration was actually controlling it. Also, brief text describes the posture and gesture that is being demonstrated. When the real user is ready to regain control of the interface, they initiate the instructed posture/gesture or any other available action.

After the user successfully performs the action, the help video will take longer to be triggered the next time the user remains at the same stage of that interaction phase. We used a four second time interval for first time users and twelve seconds for users after they successfully performed the action.

4.3.7 Supporting Multiple Users in Different Phases

Our interaction techniques use transparency, position, and duration so that the maximum utility of the display is preserved for other users. For example, the display screen itself is mounted high enough so that users can see public ambient information over the heads of users close to the screen. Notification icons and the SUMMARY sub-phase are transparent so that the ambient information can still be seen beneath. Longer duration phases like personal interaction only occupy the lower portion of the screen. The thin, vertical footprint used for the user proxy bar allows several users to share even a moderately sized display effectively.

We experimented with techniques that allowed a user to take over a larger portion of the display, or to squish, crop, or move the ambient display, but these techniques either created too much disruption, violating our *calm aesthetics* principle, or obstructed the display for too long, violating our *shared use* principle. If a user wished to interact for a longer period of time, secondary long-duration “kiosks” could be added similar to the PlasmaPlace system (Churchill et al., 2003a).

5 User Evaluation

To test the effectiveness of our techniques, we conducted two user evaluations of our prototype. We first conducted a preliminary user evaluation which was exploratory in nature and touched on all aspects of the system including ambient display comprehension. We used this to get initial feedback about our interaction and visualization techniques as well as aiding our design of a follow-up formal user study. The follow-up formal user study was conducted in two parts with the same participant completing both. The first part examined novice user exploration and discovery, and the second was a task-based interaction scenario after the participant became a more experienced user. Both parts of the second formal study focused on the evaluation of user interaction rather than ambient display comprehension.

To our knowledge, a user evaluation of this sort has not been applied to the evaluation of an interactive ambient display. Previous work in evaluating ambient displays has focused solely on comprehension and visualization. They include Mankoff et al.'s (2003) set of ten heuristics for evaluating the effectiveness of ambient displays with emphasis on evaluating non-pixel ambient displays and Skog and Holmquist's (2003; Holmquist, 2004) survey-based approach to evaluate comprehension using a three step model. Our work combines observational user study techniques with a simulated task-based scenario in an attempt to approximate a real world installation setting.

At the conclusion of this chapter we discuss future design refinements for our prototype based on the user evaluation findings.

5.1 Preliminary User Evaluation

Our preliminary user evaluation touched on all aspects of the system including ambient display comprehension. The evaluation was exploratory in nature and somewhat informal. We recruited four participants, two women and two men, who work in an office environment, had no prior knowledge of our project, and were fluent with various computational media. Our evaluation had two stages, the first without the tracked glove and the second with it. Each user evaluation lasted for a total of approximately twenty minutes per participant.

In the first stage of the evaluation, each participant was told that they would be using a system that tracked body movements while they donned a special hat and vest that had the markers required for tracking their head and body movements. They were asked to "talk-aloud" as they explored how their movements influenced the display and how they interpreted what was shown. No other instructions were given.

During this first stage, we wanted to see if they would initiate the subtle phase of interaction and/or the help sequence, and if they realized that they could use hand interaction to select more information. This is why a glove with markers for hand tracking was not used in this first stage of the evaluation – we did not want it to be obvious to participants that hand input was a part of the system. We were also interested if participants understood the meaning of the ambient display using the three levels of comprehension as defined by Skog et al. (2003), and Holmquist (2004). Although the visual design of the ambient display was not the primary focus of our work, we wanted to see if *interacting* with a somewhat naively designed ambient display would increase comprehension regardless.

In the second stage of the evaluation, the user was given the glove with hand tracking markers and asked to continue exploring the display. We began the second stage of the study after they found the self-revealing help and attempted to initiate the hand gesture without the glove. Here, we were interested in whether participants could perform the gestures, found the reactive gesture hint icons helpful, discovered how to navigate the timeline, and initiated the direct interaction touch-screen phase of the system. In our prototype, we did not implement help sequences for the actions associated with the *palm* *up* and *palm vertical* postures, so the tester acted in a wizard of oz fashion by demonstrating these actions at the appropriate times.

5.1.1 Findings

We discuss our findings for both stages of the study together grouped by ambient display and interaction comprehension, initiation of phases, learning gestures, and navigating the timeline.

Comprehension

Skog et al., (2003) and Holmquist (2004) have developed a framework for evaluating ambient displays according to three levels of comprehension (Figure 30). The three levels are: 1) That something is being visualized; 2) What kind of information is visualized; 3) How the information is visualized. Each level is a prerequisite for the next. Only after making it to the third level is the ambient display useful to the user.

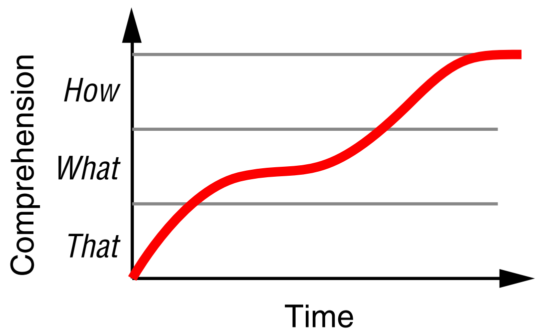


Figure 30. Ambient display comprehension levels (from Holmquist, 2004)

We observed that participants immediately understood that their body position was controlling the vertical bar and realized that some kind of information was being visualized (level one). Three of the participants noticed the notification flags with one making a connection between the four notification flags, the four horizontal information displays (level 2), and red meaning "high priority" (level 3).

After the participants learned to approach the display to initiate the notification SUMMARY sub-phase, they correctly recognized the kind of information shown in the weather, calendar, and messaging displays (level 2). This was no doubt due to the short text in the notification overview. This suggests that a few words of text describing the current state of a display, like "15 degrees, sunny" can be effective in conveying what kind of information is being visualized. Three participants made comparisons to the type of information found in a PDA or day timer. One described it as a "PDA that you don't have to carry around." Two users recognized the calendar as having a timeline with events or meetings placed on it (level 3). Deciphering the weather display posed more of a challenge, with no users correctly translating the colours and shapes into a five-day forecast and current weather conditions. We feel that a more evolved design for the weather display would increase the third level of comprehension.

Initiation of Phases

After exploring movement from a distance, participants naturally moved towards the display for a closer look. When the overview panel opened, all realized that the icons and brief text related to the horizontal information displays. One person commented on movement as happening in "a pleasing non-direct way." However, we noticed that the subtle interaction phase was sometimes exited by mistake when participants stepped too far back or turned their body too far. This caused them to become increasingly tentative in their movements since they didn't know exactly what the exit thresholds were. A visual indication of when a threshold is being approached would likely remedy this problem.

Somewhat surprisingly, participants did not expect the screen to be touch enabled. When the tester informed them of this, three of the participants discovered that they could touch the items in the detail panel to retrieve additional information. Some participants also attempted to select other areas of the display by touching, but all continued to use the gestures to perform previously used actions.

Learning Gestures

All participants recognized from the help sequence that they could select more information using their hand in the *palm down* posture, in fact half the participants attempted to initiate these gestures without the special glove during the first part of the evaluation.

Once given the special glove, two of the users were able to select an item almost immediately, but the others had difficulty because they either moved their hand too erratically or didn't manage to hold their hand within the required threshold posture. To reduce these problems, the system could give feedback indicating when a user is moving their hand too quickly for recognition. Alternatively, when they appear to be close to initiating a posture, feedback could show how to correct their posture or the system could adopt that posture as the correct initiator for that user.

Navigating the Timeline

Three users discovered that they could move their body laterally ("shifting") to adjust where the detail panel was drawing information from. They appeared to have no trouble controlling this movement with their body, although the dwell time required to lock the detail panel caused some problems. For example, if the user wished to approach and touch the display after positioning it at a certain horizontal location, the natural left and right rocking motion while moving forward caused the detail panel to move side to side. One way to remedy this would be to use forward motion as a trigger to exit the shifting mode.

After demonstrating the *reach* technique, users were able to use this as well; and when the tester stood beside the user, "blocking" their movement, they understood the value of reaching.

5.1.2 Conclusions

Our findings from this preliminary user study revealed some promising aspects of the system like the self-revealing help, the style of movement of the user proxy bar, and the ambient visualization techniques. It also revealed potential shortcomings with the style of gestures and thresholds between phases and modes. To more fully explore these promising aspects and shortcomings, we conducted a formal user evaluation as a follow-up study.

5.2 Formal User Study

We conducted a formal user evaluation spanning both novice user exploration and discovery (similar to the preliminary user study discussed in the previous section), and a task-based walk by interaction scenario with an experienced user. This study focused on the evaluation of user interaction rather than ambient display comprehension.

We recruited six participants who work in office environments, one woman and five men. All were quite conversant with computers, but had little if any experience with non mouse-and-keyboard interaction styles. The evaluation consisted of two parts: the first evaluated novice exploration and the second studied task-based usage. All participants completed both parts. The study time for each participant was approximately fifty minutes total – about fifteen to twenty minutes during the exploratory portion and about twenty to twenty-five minutes performing the task-based scenario with a five minute instruction and training period. We recorded audio and video of both parts of the study as well as logging the events, durations, and positions of the user during the second part of the study.

It is important to identify the limitations of our study. Although six participants is thought to be a reasonable number for usability studies (Nielsen, 2000), the task-based part may have benefited from including more participants. But, since our quantitative analysis is secondary to observational analysis and we are not claiming any statistically significant effects, we feel the smaller size of our study is reasonable. A similar argument could be made for the relatively small number of tasks. We felt that it was important to keep the total duration of the study to about 45 minutes since it required walking, standing, and arm motions. We also did not perform any discourse or conversational analysis beyond studying the talk-aloud comments made by each participant.

5.3 Formal User Study Part One: Novice Exploration

The first section was essentially a repeat of our previous two stage preliminary user study, but the ambient display was simplified to show four identical calendars information sources each a different colour (see Figure 31). This focused participants on how they were interacting with the system, rather than adding the additional cognitive load of trying to comprehend four different ambient displays. As before, we conducted this section of the study in two stages, first without the glove and the second with the glove. The user was given no prior instruction and was encouraged to simply explore the space and the display. We wanted to confirm and refine our findings related to comprehension of the interaction (exclusive of the ambient displays themselves), initiation of phases, and learning and performing gestures.

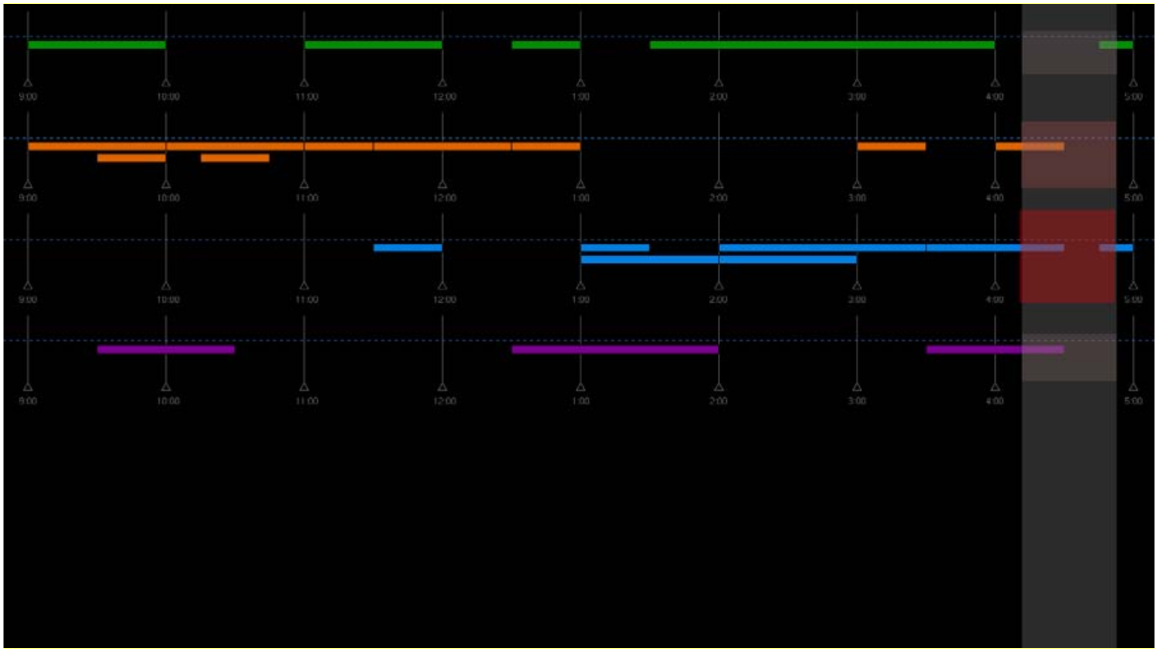


Figure 31. Ambient display layout for formal study
The ambient display was simplified for the user evaluation to show four abstract calendar information sources, each in a different colour. Note that in part one, the calendars had identical event data, but in part two the calendar data was different (shown here).

5.3.1 Findings

Comprehension

Our observations regarding the degree to which participant's comprehended the interactive portions of the ambient display echoed those of the first preliminary study. For example, all participants immediately recognized that the user proxy bar was moving with them and five out of six noticed the red notification flags, but did not necessarily comprehend their meaning. One participant commented, "It lets me know it sees me, and tells me I can move in for more information." Within a few minutes of initiating the Subtle Interaction Phase, all participants saw that the ambient display was visualizing a calendar of appointments.

One user commented that they found the concentration of the ambient visualization in the top of the display "uncomfortable" as they were used to interactive interfaces concentrated at the bottom of a display. This may have been attributed to this participant's shorter physical stature. The height at which our display is mounted is biased towards taller individuals; a vertically larger display would allow us to adjust the height of the ambient information depending on the height of users in the surrounding space.

Initiation of Phases

We confirmed many of our earlier findings regarding how users initiated different interaction phases. We saw participants naturally approach the display, but not all within the same time span. Although one participant walked directly up to the display and triggered the overview menu within 20 seconds of the start of the study, the other five spent a considerable time exploring interaction from a distance before approaching the display. One participant was especially timid in approaching the display – it was almost five minutes before they entered the subtle phase. The other five participants approached and discovering the subtle phase after two to three minutes.

A curious observation is that half the participants missed opportunities for entering the subtle phase at an earlier time. When they stopped moving near the display, the did so for just under the required dwell time of three seconds – often repeating this “near miss” several times. This could be remedied by giving a visual indication that entering the subtle mode is possible and the dwell time countdown has started.

As in the preliminary study, we witnessed participants having difficulty with the thresholds of the subtle interaction phase. In addition to exiting unintentionally, we witnessed participants grappling with forming a conceptual model explaining how the subtle phase was entered. Two participants initially associated a specific location on the floor with triggering the subtle phase, with one of these participants also believing they had to approach along a very specific path before standing in that location. After further exploration, all participants eventually stated that they thought the subtle phase was entered when you stood still near the display. But even though this was stated, one participant lapsed to their specific path, specific location conceptual model for the task-based part of the study.

Two out of six of the participants favoured a location very close to the display, close enough to be in the personal interaction mode. These were also the two participants who tended to touch the display initially.

Learning and Performing Gestures

Again, we saw promising results regarding the self-revealing gesture help video. All participants understood that the video was instructing them to do “something with their hand,” and similar to what we observed before, all participants attempted to perform the gesture using their bare hand without the glove. But in this study, two of the participants felt the video was instructing them to touch the screen in a certain way rather than perform hand movements in free space.

The two participants who began touching the display did so during the first stage of the study, when they were not wearing the special glove. This may be attributed to these participants understanding that their hand could not possibly be tracked without attached markers like on the hat and vest, so the only logical option was to touch the screen. When the glove was given to them in the second stage, one of these participants backed up and tried performing the instructed hand gesture in free space immediately, but the other persisted in touching the screen. We also had a third participant who expressed a desire to interact through touch rather than free space gestures – even though they initially performed the free space gesture using their bare hand.

After the participant’s were given the glove in the second stage, four could initiate the gesture almost immediately. But, three out of these four had trouble remembering how to complete the gesture to select an item.

This tendency to forget a multi-part gesture demonstrates a shortcoming of our self-revealing help mechanism. We observed participants quickly understanding how various gestures were initiated, but then not knowing what they had to do next. In addition, we witnessed several instances of participants forgetting how to complete a gesture even after performing it successfully several times. The problem is that our self-revealing technique demonstrates the entire gesture at once, and then disappears as soon as the gesture is initiated by the user.

Two participants also stated they did not know how to “exit” the self-revealing help video. They failed to realize that they exited by initiating the instructed gesture, either because either they did not have the glove in the first stage of the study or their initial posture was not triggering the gesture correctly.

One of the participants who tended to touch the screen also felt that *they* were controlling the display during the help video. In fact, their touches only appeared to control the display when they coincided with selections in the demonstration video. Our current implementation of the self-revealing help mechanism completely takes over the OVERVIEW menu and manipulates the menu exactly as though the user was doing it – this demonstration may be too close to the users actual control feedback.

As in the first study we witnessed participants initially using quick, erratic movements in an attempt to “get the gesture working.” This leads us to believe that there is a human tendency to move our hands very quickly to communicate commands and, if the desired result is not achieved, to perform quick repetitions of the same movement multiple times.

Initiating a gesture using a tense posture held for a moment seems not to be natural at first, although we saw that it can be learned quickly. One participant commented that he became physically tired while learning because he was concentrating so hard on trying to get the gesture right. All participants became proficient enough to select an information source using the palm-down gesture and return to the overview menu using the palm-up gesture after about three minutes of practice. We could also see their initially overly stiff, outstretched arm relax to a more comfortable position as they became more proficient.

Another characteristic we observed was the participant’s tendency to point at items on the screen with the index finger, or even with the tips of all fingers while performing the palm-down or palm sideways postures. This seems natural because the purpose of many interactions in our system is to select information from choices shown on the screen, or to move a widget which is already positioned at some location. Unfortunately, our choice to use an indirect, relative position and motion for the postures and gestures seemed to be unnatural at first – even though theoretically it is more flexible and scalable. Prior work suggests that relative mappings of hand gestures are superior to absolute ones (Bowman, 1999; Hinckley, 1997). We also found that in the second task-based part of the study, most participants adjusted to using the relative gestures.

Time Line Navigation and Touch Interaction

A curious behaviour is that when told that the display reacted to touch, and after the participant initiated the personal interaction phase, the first place that the participants touched the screen was inside the large, empty black square reserved for showing the detailed description of a selected event (see Figure 25a). Two commented that they thought this was a place to draw or write. But, immediately after this, they touched the calendar events shown in the detail panel below. This may signify that an empty space is a natural affordance for writing or scribbling with touch based interaction, rather than the more button-like affordances associated with mouse clicks.

Three out of six participants discovered shifting on their own. One participant used a simultaneous shifting and reaching technique and another participant instantly understood that navigating the timeline could be done in two ways: with the reaching gesture or using body shifting. We also saw many instances of a participant shifting to a position, then immediately stepping forward to enter the personal phase. This caused the detail panel to jiggle left and right due to the user's natural side-to-side movement as they stepped forward. This behaviour could be remedied if shifting was exited through a forward step in addition to a dwell position timeout.

5.4 Formal User Study Part Two: Task-Based Interaction

The second part of the study required each participant to perform sixteen simple information retrieval tasks. We wanted our participants to be experienced users for this part, so we took time after the exploratory portion to answer any questions and explain techniques for performing gestures and initiating phases before beginning the sixteen tasks. We also had each participant perform four practice tasks as a warm-up. This training and warm-up period lasted approximately five minutes.

To simulate walk by interaction, we asked participants to begin each task at the same position on the far left side of the display and end at another position at the far right side of the display (Figure 32). We did this to approximate the situation in which the display was mounted in a hallway, and to regularize the approach paths across tasks and participants. We instructed the participants to complete each task as efficiently and expediently as possible. As before, the ambient display presented four different coloured calendars – but this time the calendars each had different data.

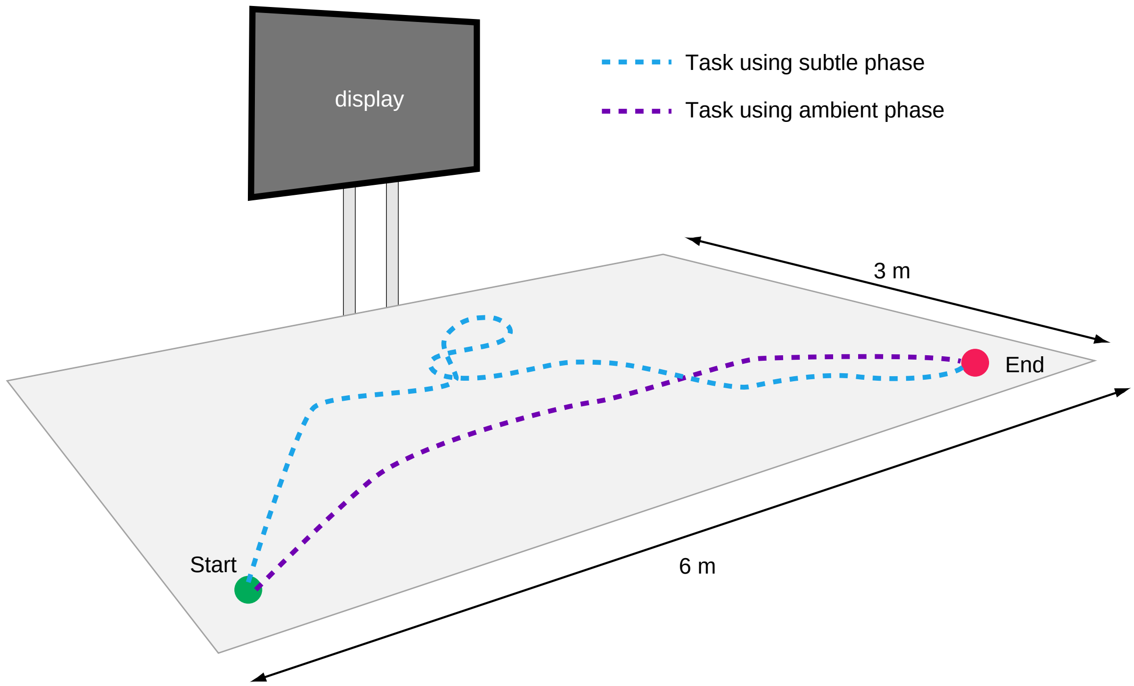


Figure 32. Room layout for task-based part of study

We designed the tasks so that there were four tasks for each of the four different interaction phases. For example, a task like “tell me which calendar is most important” required the use of the implicit interaction phase, since the user needed to see his or her proxy bar with the notification flags. A task like “tell me the description of the green personal task at 4 o’clock” required the participant to enter the personal phase (see Table 2 for all sixteen tasks). The eight tasks requiring the retrieval of calendar event information gave us ample opportunity to observe how users navigated the menu and calendar timelines refining our observations from the earlier preliminary study. We presented the tasks to participants in a randomized order to decrease confounding effects due to learning or fatigue.

Ambient Phase Tasks	
1.1	Which calendar is busiest in the morning?
1.2	Which calendar is busiest in the afternoon?
1.3	Which calendar appears to have the fewest events?
1.4	Approximately what time is the latest green event?
Implicit Phase Tasks	
2.1	Which calendar is most important right now?
2.2	Which calendar is most important right now?
2.3	Do you have any important notifications?
2.4	What is the status of your notifications right now?
Subtle Phase Tasks	
3.1	What is the name of the green public event at 12:30?
3.2	What are the names of the blue public events at 11:30 and 4:45?
3.3	What is the name of the orange personal event at 10:00?
3.4	What is the name of the purple event at 3:30 and orange event at 3:00?
Personal Phase Tasks	
4.1	What are the descriptions of all the blue events starting at 2:00?
4.2	What is the description of the purple event at 9:30 and the green event at 9:00?
4.3	What is the description of the orange events starting at 11:00 and at 4:00?
4.4	What is the description of the orange personal event starting at 12:00?

Table 2. Formal study tasks

During each task we recorded the length of time to complete, the participant's closest distance to the display, and regular samples of the participant's position along with their head and body angle. We also logged the times of certain events: initiating and ending a gesture, entering a phase, touch screen events, self-revealing help usage, and the start and stop of lateral body shifting.

5.4.1 Findings

Postures and Gestures

We observed that participants became more proficient and relaxed in performing the gestures during the task-based part of the study. While most were initially very stiff and deliberate with their postures and motions, as they became more comfortable with the system they adopted a more relaxed technique. Posture recognition continued to work well due to our forgiving tolerances.

Four out of six of the participants noticeably transitioned from an absolute pointing style of gesture to a relative gesture for menu selection and reaching. Although this transition may be partly attributed to the brief training and warm-up period, it was apparent in the beginning of the second part of the study that participants still tended to initiate gestures with an absolute point rather than a relative posture. It is encouraging to see that relative gestures can be learned easily.

However, participants continued to struggle with some aspects of the gestures. In spite of becoming more proficient with the relative gestures over the course of performing the tasks, three out four of the participants still forgot how to complete some gestures at the beginning (most noticeably the reaching gesture).

Almost all users had trouble with the posture dwell times. At several instances throughout the sixteen tasks, participants would forget to hold their open-hand posture for a moment to initiate the gesture. We also observed all participants wishing to initiate a gesture immediately when they approached the display, before the OVERVIEW menu opened and the subtle phase entered. Since our system requires the menu to be completely open before the posture is recognized, this led to confusion and frustration. Participants expected the system to be instantly responsive, instead of these perceived lag times.

Selection and Timeline Navigation Patterns

We observed four out of six of the participants using their body position to make initial course adjustments followed by refinements using their hand. This was most pronounced in tasks requesting events which occurred in the early morning or late afternoon (the extreme left or right of the display). As these participants approached the display, they moved so that their user proxy bar was positioned near the required time (see Figure 33). Then, they used the reaching gesture to move the selection point to the exact time. Using the body to situate the context for the hand is similar to Guiard’s (1987) Kinematic Chain model for bimanual control. We discuss future directions with regard to this observation later.

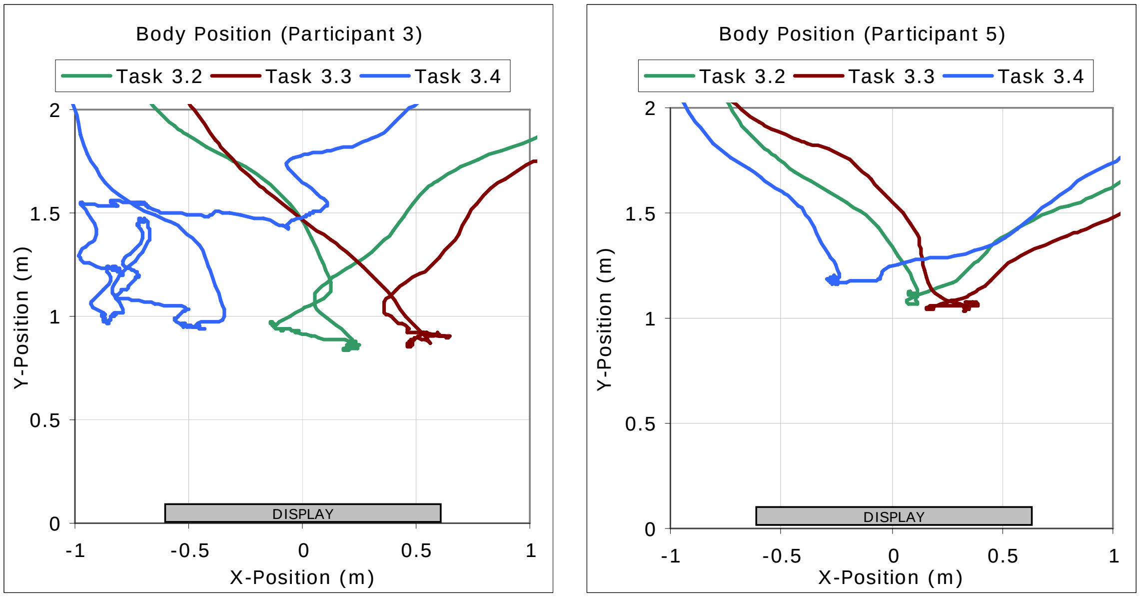


Figure 33. Visualization of body context position
Visualization shows body positions of two participants during tasks 3.2, 3.3, and 3.4. Task 3.2 requests two events with the first at 11:30 AM, task 3.3 requests an event at 10:00 AM, and task 3.4 requests an event at 3:00 PM. The lines indicates the body path taken by the participant during the task (recorded in metres), the grey rectangle indicates the display position.

However, we also observed two participants approaching the display in exactly the same way each time, and appeared to always start the session at the exact centre of the display.

Only one participant used body shifting exclusive of any hand reaching for some tasks. We also saw two participants simultaneously shifting and reaching, but we were not sure if this was wholly intentional or not. Three of the participants occasionally triggered the shifting mode accidentally when they took a step forward to enter the personal phase. Their natural side-to-side motion as they stepped forward was enough to surpass the distance tolerance and started shifting.

We observed four out of six participants using the reach gesture to retrieve the names of different events using a variant of kinesthetic tension (Buxton, 1986, Sellen, Kurtenbach, & Buxton. 1992). These participants held the reach gesture still for a few seconds to read an event name, then continued the gesture to move to another time and read a second event name. This is interesting because it suggests that kinesthetic tension applies not only to isometric muscle movements like holding a button down, but also to isotonic muscle movements where a muscle is held still in the absence of significant resistance.

Movement Between Personal and Subtle Phases

Five out of six participants stepped forward and backward to repeatedly enter and exit the personal phase when retrieving event descriptions in tasks 4.2 and 4.3. Task 4.2 asked participants to retrieve event descriptions at two different times on the same calendar (requiring a shift or reach gesture) and task 4.3 asked for descriptions of events on two different calendars (requiring a return to the OVERVIEW menu and selection of a different calendar). For both these tasks, we observed these five participants follow the following pattern (see also Figure 34):

1. Stand more-than-arms-length away in the subtle phase to select the calendar and the timeline location.
2. Step forward into the personal phase to get the description of the event by touching the screen.
3. Step back again to the more-than-arms-length distance and select the new calendar or timeline location.
4. Step forward once again into the personal phase and touch the screen to get the description.

The tendency to move back and forth from more-than-arms-length to a close distance may be attributed to the space required to perform the hand gestures, and the difficulty of seeing the entire timeline when standing too close. But since one participant in the study remained close to the display throughout the retrieval portion of tasks 4.2 and 4.3, an alternative explanation may be applicable. One such explanation could be the association of personal information with a close distance and more public information with farther distances.

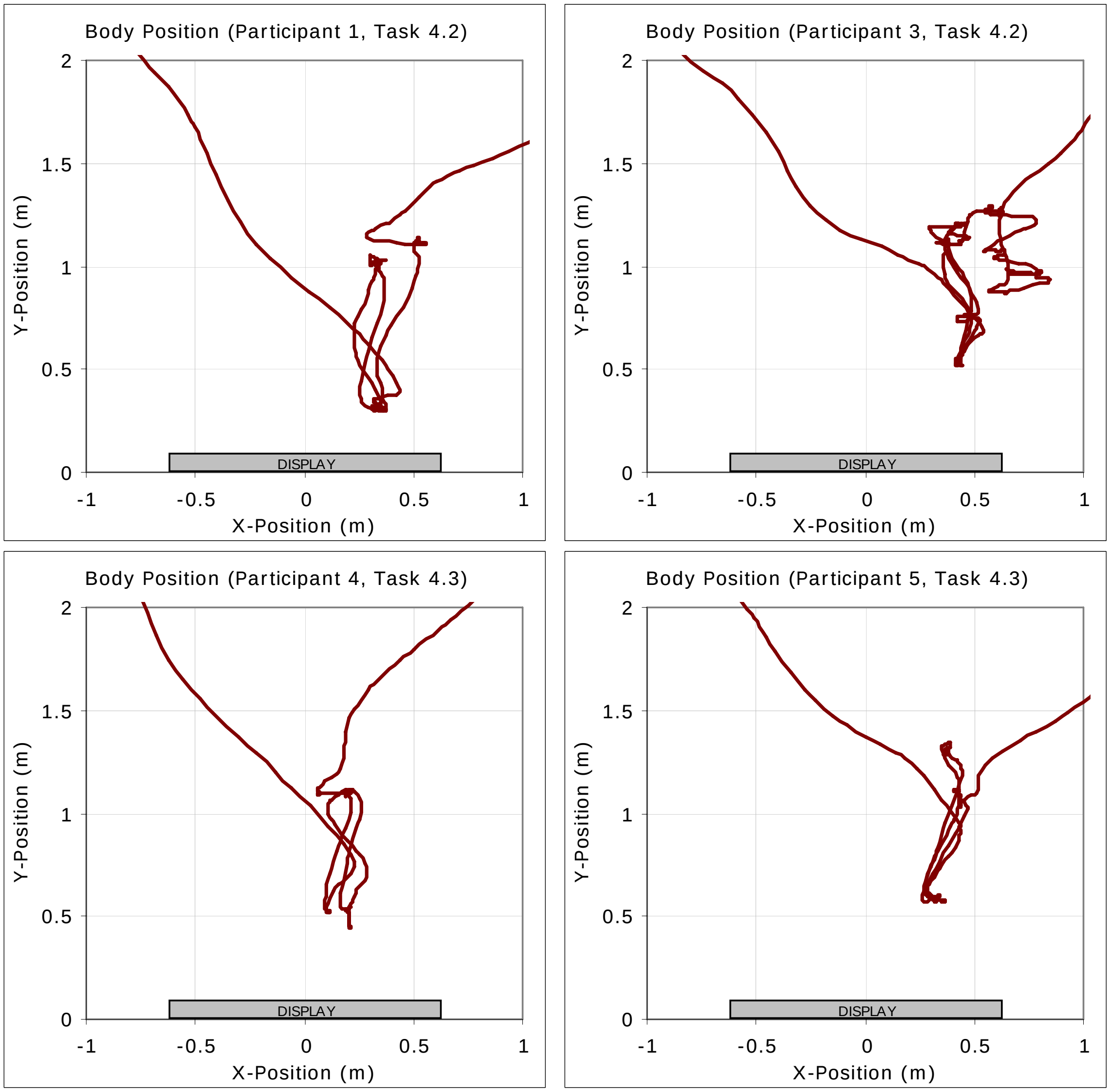


Figure 34. Visualization of body position showing back and forth motion
Examples of back and forth motion for four participants in tasks 4.2 and 4.3. The red line indicates the body path taken by the participant during the task (recorded in metres). The grey rectangle indicates the display position.

Average Task Duration

The average task duration time followed a general trend predicted by our four phase framework. Tasks designed for the ambient and implicit phases were very short with total times averaging just less than 8 seconds (Figure 35). Tasks requiring the subtle phase averaged 37.5 ±3.4 seconds and tasks requiring the personal phase took 56.8 ±4.3 seconds. However, this observation may not be terribly surprising given the design of our prototype. Ambient and implicit tasks require no hand gestures, while the subtle and personal tasks do. Touching the screen to retrieve a description will also naturally increase the duration of tasks requiring the personal phase.

Minimum Distance to Display

The minimum distance between participant and display during a task also followed a trend predicted by our four phase framework. Although participants occasionally performed the ambient and peripheral tasks close to the 2.7 m maximum distance possible in our experimental set up, the average distance for these two tasks was closer to 2.0 m (Figure 35). This is because some participants initially approached closer, but after doing one or two of these types of tasks they realized they did not need to walk very close to get results. The subtle tasks were performed 1 m from the display and personal tasks at a distance of 0.5 m.

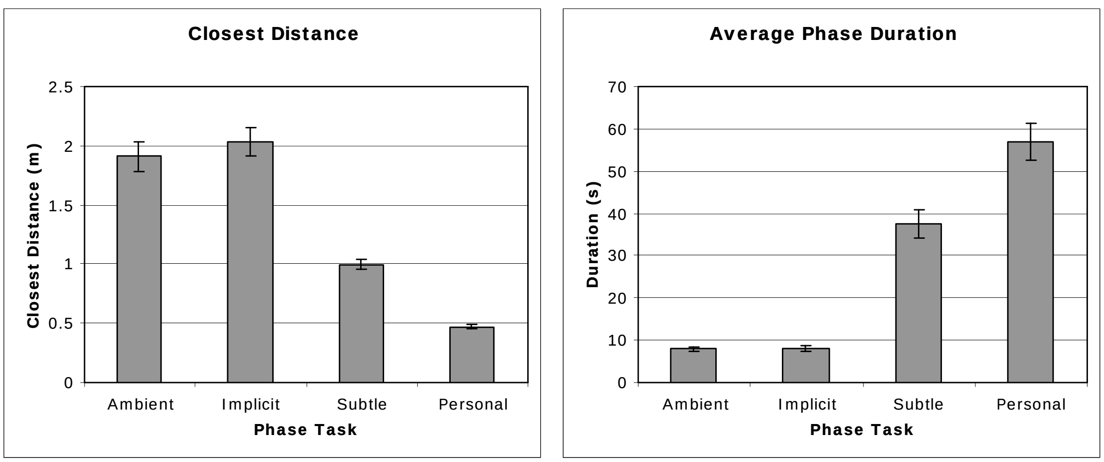


Figure 35. Closest distance to display and average phase duration
(left) Closest distance from participant to display for the four different types of tasks.
(right) Time to complete task according to required phase for task.

5.5 Design Implications

The results of our user studies suggest several refinements to our prototype system:

Visual Feedback

By making the display even more visually responsive, we could reduce interaction ambiguity enabling users to form a more accurate conceptual model of the system.

Although our system incorporated responsive visual feedback when a posture was recognized or a gesture mode was about to be entered, additional feedback would address observed difficulties with phase initiation and posture tolerance. As a user satisfies preconditions for entering a phase, such as distance and body angle thresholds, subtle visual feedback could be shown in the display. Perhaps this visual feedback could take the form of an iconic shape with colour intensity communicating the degree to which they are within the thresholds. For example, this could communicate that a user is very close to exiting their current phase if they standing near a distance threshold.

Visual feedback could also convey dwell times (or latency times) which we use in several places to exit or initiate an action. We observed several participants miss a phase change because they could not tell how close they were to satisfying the required dwell time. We also noted how users struggled with the shifting technique because they had no indication how long they had to stand still to turn it off. Visual feedback showing a simple graphic countdown timer would give an indication how close they are to satisfying a dwell time. We have already incorporated this type of visual indication for posture recognition where a symbol fades in to full opacity as a posture is held for the required dwell time. Another example of this type of visualization is from EyeCatcher (Hansen, Andersen, & Roed, 1995), an eye-gaze interface, where pushing a button requires fixating for a moment. EyeCatcher buttons provide visual feedback by animating an eye slowly closing as the user stares at it. When fully closed, the dwell time is reached and the button is pressed (Figure 36).

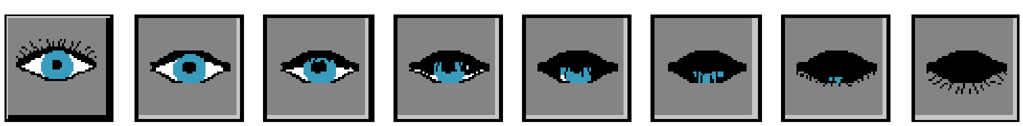


Figure 36. Visual indication of dwell time (from Hansen et al., 1995)

Likewise, more visual feedback should be used to assist users when learning gestures. We observed in both studies that new users tended to move erratically and repetitively when having difficulty with gestures. This could be counteracted by visually indicating that they are moving too fast and the system can not understand what they are doing. Another type of useful gesture feedback would be to communicate how close a user is to achieving a certain posture. Designed correctly, this could help users to improve their postures bringing them closer to an ideal posture.

Threshold and Dwell Time Tuning

We saw several problems with interaction parameters like position thresholds, posture tolerances, and dwell times. We already discussed using visual feedback to communicate how close a user is to satisfying these parameters, but the parameters should also be tuned. There are two ways to do this: determine a single optimum value for each parameter, or customize each parameter as individuals interact with the system. The results from our study demonstrated that our dwell time values for subtle phase initiation and shifting timeout were too long, but the distance tolerance for initiating shifting was too small. We could adjust these parameters to new optimum values given these observations, but we could also customize these parameters for individual users using simple heuristic algorithms. For example, if a user exits the subtle phase twice in a short time period by stepping too far back, we can assume they are exiting by mistake, and increase the distance tolerance by some reasonable amount. A similar strategy can be applied to hand posture and gesture tolerances, customizing them for each individual.

To counteract the problem introduced when new users move erratically and repetitively while learning gestures, we can adopt what seems to be a more natural, quick, and erratic gestural style. However, this may introduce ambiguities in the segmentation and classification of gestures. One reason why we adopted the still, tense hand postures to signal the beginning of a gesture was to allow easy segmentation and ensure the user intended to perform the gesture.

Self-Revealing Help System

Although our self-revealing help technique is successful communicating to new users that a gesture is required and how the gesture is performed, it is not effective in assisting the user while they learn the gesture. Currently, as soon as the user initiates the gesture, the help video fades away. What is needed is an incremental technique that teaches the gesture in stages. This incremental help technique could also be used to give help "mid-gesture" if they appear to be having trouble based on a long pause. When the experimenter demonstrated gestures wizard-of-oz style using an incremental technique, the learning rate was very quick (although this is also partly attributed to the fidelity of a human demonstrator).

We had participants who could not figure out how to exit the self-revealing help and one who thought they were controlling the display when in fact the self-revealing help was demonstrating an interaction sequence. Our current technique where the self-revealing help completely takes over the display and manipulates it exactly as the user does may be too realistic. A better design would be to make it clear that the system is currently in a help demonstration mode by transforming the visualization of the actual user interface in someway – perhaps by changing the colour or size. To avoid confusion surrounding how to exit the help mode, the video could pause and fade away after a demonstration – effectively restoring the display back to the user's control. In fact, one participant commented that they "wished the help video was shown once and then stopped to give me a chance to try it out."

6 Conclusions and Future Directions

In this thesis we have presented a new style of interactive public ambient display combining peripheral notification with implicit and explicit interaction for accessing both public and personal information. Our research focused on fluid movement between different interaction phases, techniques for supporting multiple users, subtle notification, privacy controls, and self-revealing help.

We built a prototype system driven by a set of design principles and an interaction framework that fluidly moves from implicit interaction with a public ambient peripheral display to explicit interaction with their personal information in a more focused manner. Implicit interaction was enabled by sensing contextual cues such as body orientation and position, and user proximity to the display. Hand gestures and touch screen input support explicit interaction.

We conducted a preliminary user evaluation and a formal user study to test the effectiveness of our prototype system. The results of these studies not only indicate that our techniques are discoverable and appear to be usable, but also identified areas of improvement in the execution of the prototype and revealed directions for future research.

Before summarizing our contributions and discussing future work, it is important to recognize the limitations of our research. 1) We rely on specialized hardware and passive markers for motion tracking purposes, discussed in chapter 4. The level of tracking required for the kind of subtle and responsive interaction in our prototype is not currently possible without markers and specialized hardware. We present ideas for simpler, current tracking techniques in the future work section, which could be used for a system built for simplified interaction and coarser feedback. 2) Our self-revealing help techniques presented in chapter 5 are effective for the kind of simple gestures and postures used by our system. As we discuss in the future work section, more refinement and research into a generally applicable self-revealing gesture technique remains to be done. 3) We have not focused on the design of the ambient display itself. Further research should explore the design of ambient displays suitable for use with our interaction framework in a wide range of different scenarios. 4) In chapter 4, we acknowledged that the type and amount of information presented in the display could benefit from more in-depth analysis with regards to personal privacy. 5) In chapter 5, we acknowledged that the number of participants in our user evaluations could be increased if there is a desire to find statistically significant results.

6.1 Contributions

The purpose of this work is not to present the definitive solution for a system implementation; rather it is our hope that this work takes us a step closer to realizing more sophisticated and useful sharable, interactive, public ambient displays. Therefore, our contributions span the theoretical, embodied in our four phase interaction framework, and the applied, shown in our techniques for fluid transitions, novel interaction gestures, self-revealing help, and support for multiple users. We now summarize the contributions discussed in the previous chapters.

Four Phase Framework

In chapter 3, we describe a four phase interaction framework which covers the range from distant implicit public interaction to up-close explicit personal interaction, with four continuous phases with fluid inter-phase transitions: Ambient Display, Implicit Interaction, Subtle Interaction, and Personal Interaction. It emphasizes fluid transitions between phases and supports sharing by several users each within their own interaction phase. Although our framework does not rely solely on physical proximity to delineate different phases, we recognize that proximity to the display is often a key differentiator between personal and private interaction. Our formal user study described in chapter 5 showed that users positioned themselves at different distances for personal or more public interactions.

6.1.1 Fluid Transition Techniques

Our framework encourages a seamless experience with phase changes occurring in a smooth way. This is partly achieved by visualization and display techniques used in our prototype discussed in chapter 4 like transparency, dissolves, smooth animation, and minimal disturbance of the main display elements. A specific example combining several visualization and display techniques is the vertical user proxy bar. It is a consistent anchor element throughout the four phases – it smoothly adjusts its shape and transparency as different phases are entered and exited, always remaining on screen in some form or another. Fluid transitions are also enabled through simple, logical implicit interactions. For example, simply turning away from the display returns the user to the ambient display phase.

6.1.2 Novel Interaction Gestures

The simple, coarse grained postures and gestures used in our system represent a departure from the typical way in which free space gestures are designed. We use an initial tense hand posture to signal a discrete gesture or the beginning of a continuous gesture. Our design also includes responsive onscreen feedback with visual cues communicating that a posture has been recognized and reminding users how to complete a gesture. In our user studies described in chapter 5, we found that these postures and gestures are simple enough to learn quickly and most users can master them after about five minutes of practice. We also found that selection of position and rotation thresholds are critical to successful recognition.

6.1.3 Self-Revealing Help for Gestures

Our system avoids an extensive instruction or training period for learning our free space hand gestures through a self-revealing help system described in chapter 4. Past work in this area has concentrated on self-revealing two dimensional stroke-based gestures using marking/pie menus (Kurtenbach & Buxton, 1991; Hopkins, 1991; 1998) or recently using a self-revealing stroke extension technique (Hinckley, Baudisch, Ramos,

& Guimbretiere, 2005). We present a technique for teaching three-dimensional hand gestures using a looping help video of a mirror user performing a posture and gesture sequence in which they appear to control the actual system interface. Baecker (2002) has argued for the benefits of video and animation based help, and our user studies showed that with our self-revealing help technique, users could initiate a gesture easily and most could learn how to do it proficiently. We discussed refinements to our technique based on observations of our user study, primarily concerning the difficulty of learning multi-part gestures and a possible solution by using an incremental help system.

6.1.4 Techniques for Supporting Multiple Users

Another significant feature of our work is how it supports several users sharing the display regardless of what phase each individual is in. In chapter 4, we discuss a variety of techniques. We use a variant of explicit space partitioning where users do not explicitly claim a static region of the screen. Instead, each user's space partition contracts and expands depending on the interaction phase. The thin, vertical footprint used for the user proxy bar allows several users to share even a moderately sized display effectively. Notification icons and the SUMMARY sub-phase are transparent so that the ambient information can still be seen beneath. Longer duration phases like personal interaction only occupy the lower portion of the screen. When another user is physically blocking left or right body movement, the *reach* technique allows users to reach for information beyond an obstructing user. Finally, since personal information may be shown in the presence of other users, we required users to stand close to the display, where more personal information can be displayed safely by using a small font size and exploiting natural body occlusion.

6.1.5 User Evaluation of Interactive Ambient Display

To our knowledge, a user evaluation incorporating an exploratory and task-based scenario, which we describe in chapter 5, has not been used to evaluate an interactive ambient display. Previous work in evaluating ambient displays has focused solely on comprehension and visualization. They include Mankoff et al.'s (2003) set of ten heuristics for evaluating the effectiveness of ambient displays with emphasis on evaluating non-pixel ambient displays and Skog and Holmquist's (2003; Holmquist

2004) survey-based approach to evaluate comprehension using a three tier model. Our work combines observational user study techniques with a simulated task-based scenario in an attempt to approximate a real world installation setting.

6.2 Future Directions

The research and results described in this thesis have provided us with a wealth of theories and principles to explore in more detail, possibilities for enhancing our prototype system, and new directions to explore relating to the broader research area of full body large display interaction. Of special note, and of particular interest, is research relating to informal, remote collaboration using interactive ambient public displays, and challenges arising from our work such as relative vs. absolute gestures, techniques for interaction without an explicit clutch, and incremental self-revealing gestures.

6.2.1 Enhancements

At the conclusion of chapter 5, we discussed design refinements to our prototype based on the results of our user study. This included improving the visual feedback, tuning dwell times and thresholds, and improving the self-revealing help system. Here, we present other enhancements.

Remote and Collocated Collaborative Use

While we have emphasized sharing a display as a way for multiple users to work as individuals without bothering each other, the system could be extended to allow collaboration between multiple users. This includes techniques for two users collocated in the same space and time, or distributed at remote locations or different times.

Providing awareness of individuals in distributed organizations, and tying this to techniques for initiating informal and fluid remote collaboration is a natural application of interactive public ambient displays. Prior work such as FXPAL’s Yeti system presented ideas for connecting users asynchronously in different locations using informal video recordings (Yamada et al., 2004) and Greenberg and Rounding’s Notification Collage (2001) provides similar techniques. Similar ideas could be adopted for our system where users can leave video messages for public or private viewing. Our peripheral notification techniques could be used to notify users in different locations when they are both near a display and the subtle phase could lead these individuals to an informal video chat, or spontaneous collaborative review of project documents – perhaps similar to the VideoWindow system (Fish, Kraut, & Chalfonte, 1990) or ClearBoard (Ishii & Kobayashi, 1992).

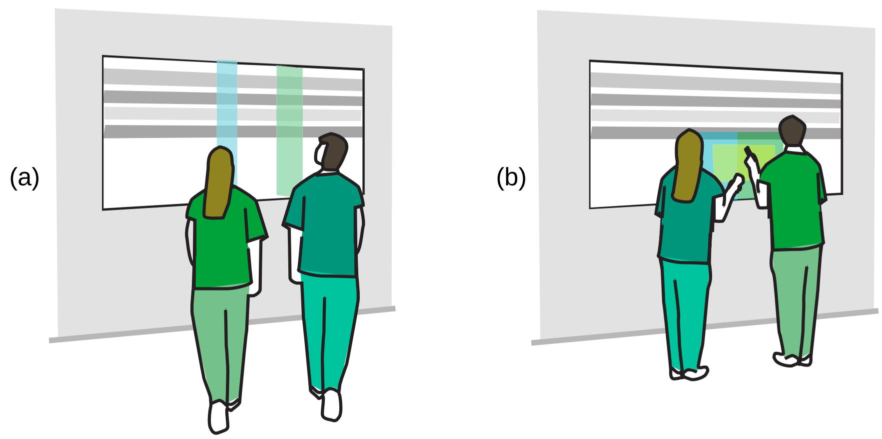


Figure 37. Sketch of collaborative interaction style
(a) Individual users with separate proxy bars. (b) Proxy bars joined to form a single collaborative space.

For users collocated in the same space and using the system at the same time, information sharing techniques simplified from those presented in the Dynamo system could be used (Izadi et al., 2003). For example, if two users are viewing calendar information at the same time and wish to find a meeting time common to both of them, they could "join" their proxy bars and enter a collaborative mode allowing them to view their combined calendar data (Figure 37). To enable this style of interaction, we may need to design techniques for individuals to authorize this collaborative mode.

Ambient Display Information Sources

The information sources we selected for our prototype were chosen to be representative of the type of information required by workers in an office environment. Additional information sources could be discovered and designed through field research in other, more specific, locations and usage scenarios. For example, what types of information would be appropriate for a hotel lobby, airport terminal, hospital corridor, subway platform, or school cafeteria? The style of information visualization could also be more tailored to a specific scenario or environment, as long as it remains calm and unobtrusive.

Personal Phase

Our prototype did not focus on the possibilities that touch screen interaction affords in the personal phase. When in the personal interaction phase, touch could be used to deliver a wide range of functions customized for a certain information source. For example, the office activity information source could provide a way to initiate an information video link between two of these systems in different locations. If this system is replicated in multiple locations, it would be interesting to explore how these locations can communicate implicitly and explicitly with each other. For example, the system could show versions of user proxy bars on remote as well as local screen (without notification flags).

6.2.2 Theories and Principles

The findings from our user study suggest several theories and principles relating to full body large screen interaction using free space gestures that could be experimentally tested in isolation. In addition there are formal theories relating to inter-personal distance that may have application to our framework.

Relative vs. Absolute Gestures

We witnessed users initially struggling with relative gestures and then becoming more comfortable over time. Even with this initial difficulty, we suspect that using relative gestures to control selection widgets on screen is more effective than pointing with the hand. Prior work has shown that pointing at a distance with laser pointers is inaccurate and difficult (Myers et al., 2002) and arguments for indirect mappings between hand positions and object selection in virtual environments have been made (Bowman, 1999; Hinckley, 1997). We are not aware of any studies on the performance of selection from a distance using finger pointing compared with selection by relative hand movement.

Techniques for Interaction without an Explicit Clutch

One challenge in manipulating and controlling an interface with true, whole hand free space gestures is the lack of a suitable “clutch” to engage or disengage gesture recognition or tracking location. This has been a recognized problem in eye tracking interfaces where dwell times are typically used to signal an event in the absence of an explicit clutch. Ware and Mikaelian (1987) tested the performance of different clutch mechanisms, including dwell time, as early as 1986. The evaluation and design of different clutching techniques for free space whole-hand interaction is essential to creating effective interfaces of this type.

Body to Hands Functional Kinematic Chain

Researchers investigating two handed interaction have referenced Guiard's Kinematic Chain (1987) for asymmetric bimanual control since it was first published. Hinckley (1997) provides an excellent overview of two handed interaction and a concise summary of Guiard's relevant work. We observed users positioning their body to provide a context for a reaching hand gesture in our task-based user study. Although it seems to be a logical extension to bimanual control, to our knowledge no research has explored how we use our body to provide context for our hands in a full body tracked interface. Applying Guiard's model in this scenario, the body seems to act as the proximal element and the hands the distal element. In fact, this may suggest an interface using a hierarchy of contexts, starting with gaze, then the body and finally the hand. An experimental study testing this phenomenon in isolation would be an interesting investigation.

Isotonic Kinesthetic Tension in Free Space

We observed several participants in our formal study using a variant of kinesthetic tension in free space (Buxton, 1986; Sellen et al., 1992). They would hold their hand still for a moment to maintain a mode. This suggests that kinesthetic tension applies not only to isometric muscle movements like holding a button down, but also to isotonic muscle movements where a muscle is held still in the absence of significant resistance. This hypothesis could be investigated and fine-tuned in isolation. It could prove to be a useful technique for free space interfaces.

Proxemics Applied to Human Computer Interaction

Our four phase interaction framework shares some similarities with anthropologist Edward Hall's theory of Proxemics (1966). Proxemics explains why we interact and react differently depending on distance. Hall argues that humans have evolved a culturally dependent perception of interpersonal space beyond pure sensory input. He defined a succession of four zones of interpersonal distance across cultures: *Public*, *Social*, *Personal*, and *Intimate*. We are careful about who we allow into our personal and intimate zones and will effect how we interact in these situations. Hall found that the boundaries between these four zones are surprisingly well defined, though they vary across different cultures. For example, the Intimate zone is North America is less than 0.5 m; the Personal zone is just more than arms length, ranging from 0.5 m to about 1.25 m.

Human Computer Interaction researchers have done some examination of how Proxemics relates to mediated interactions. Harrison, Ishii, and Chignell (1994) examined how remote users sense inter-personal space in video-mediated collaboration, the OfficeWalker system (Obata & Sasaki, 1998) is a video-based virtual chat system based on Proxemics, and Reeves and Nass (1996) found that the inter-personal distances in Proxemics extends to our reactions towards video representations of people. All of this research explored human to human interaction mediated through a computer or television. To our knowledge no one has explored the natural distances we use to engage with a large computer interface when not sitting at a desk. For example, what distances do we adopt for different types of content (like public vs. personal) or different types of applications (like social vs. utilitarian, or browse vs. create)? The results of our task-based user study showed participants moved back and forth between the personal and subtle phases when accessing detailed “personal” information and more public overview information. There are several plausible explanations, but one is that Proxemics does apply to human to computer interactions. A focused study could explore this in more detail.

This type of formal study presents a key problem – can we observe different interaction phases empirically through observational analysis, by reviewing video recordings of interactions, for example? Hall’s work relies heavily on observation, so there may be opportunities to apply his techniques.

6.2.3 Future Work

Longitudinal Study

Our prototype and user evaluations were encouraging, so a logical next step is to create a prototype system for use in a real environment over an extended period of time. There are two major challenges with this: 1) replacing our specialized Vicon motion tracking system with one suitable for deployment in an actual environment, 2) identifying users in a way that does not require explicit sign-in/sign-out type actions. Stereo computer vision, sonar, or a pressure activated floor could give us the approximate location of a body in the surrounding space. Identification of users may be done using active RFID tags, computer vision face recognition, or active badges (Want, Hopper, Falcão, & Gibbons, 1992). Three dimensional hand posture recognition is a difficult problem, and it would be difficult to track even our simple posture set without the marker based tracking system we currently use.

Self-Revealing Gestures

As more and more systems attempt to leverage the naturalness and expressivity of a gestural interface, generalized techniques for self-revealing gestures could be an important piece of the solution. Past work has already argued that in context visual demonstrations and animation are more effective ways to present help to users (Baecker, 2002; Baecker & Small, 1990; Baecker et al., 1991). These techniques could be general enough to apply to all gesture modalities: variants of three dimensional free-hand gestures with and without graspable tools and all two dimensional stroke-based gestures activated by a pen, mouse, finger(s), and other pointing devices.

Although the effectiveness of our self-revealing gesture system is encouraging, as we discussed in chapter 5, it would benefit from refinements like making the system incremental so it teaches gestures in stages and assists users in completing a gesture. We believe these types of refinements would be relevant to other gesture modalities as well. Using marking/pie menus is one successful technique for teaching non-representative two dimensional stroke gestures (Kurtenbach & Buxton, 1991; Hopkins, 1991; 1998). But this may also be extended into three dimensions, perhaps using a free-hand or finger activated marking menu. Graphical “follow the stroke” techniques demonstrated by the Scriboli systems “pig tail” (Hinckley et al., 2005) are essentially a variant of the self-revealing video style gestures we present here. Design techniques for the display of suggestive graphical diagrams communicating the direction of movement of gestures could be generalized.

Full Body Interaction

Our work with implicit and explicit interaction afforded by full body tracking suggests possible applications to more traditional software domains. The Charade presentation system (Baudel & Beaudouin-Lafon, 1993) discussed in chapter 2 touches on this, but it remains very explicit and confined to single hand gestural interaction. When interacting with a very large display, the proximity of the user could affect the mode of the display. For example, a large display drawing application where tool palettes and other interaction widgets fade away as the user stands back to observe the drawing in its entirety. Different body stances or foot positions could control application modes fluidly. Parameter selection could be mapped to relative positions of the hand against the body or arm for example. Similar to our prototype application, a blend of full body and hand gestures could be used for course operations at a distance, and direct touch interaction when working accurately close to the display.

Bibliography

Baecker, R. M. & Small, I S. (1990), Animation at the Interface, in *The Art of Human-Computer Interface Design*, ed. B. Laurel, Addison-Wesley Publishing Company. p. 251–267.

Baecker, R.M., Small, I. S., & Mander, R. (1991). Bringing Icons to Life, In *Proeedings of ACM SIGCHI CHI '91*, New Orleans, LA, May. p. 1–6.

Baecker, R.M. (2002). Showing Instead of Telling. In Proceedings of the 20th annual international conference on Computer documentation, Toronto, ON. p. 10-16.

Baudel, T. & Beaudouin-Lafon, M. (1993). Charade: remote control of objects using free-hand gestures. *Communications of the ACM*. 36(7) (July 1993). p. 28–35.

Bier, E., Stone, M., Pier, K., Buxton, W., & DeRose, T. (1993). Toolglass and Magic Lenses: The see-through interface. In *Proceedings of the 20th annual conference on Computer graphics and interactive techniques*. p. 73–80.

Bolt, R. (1980). Put-that-there: Voice and gesture at the graphics interface, In *Proceedings of the 7th annual conference on Computer graphics and interactive techniques*, July 14-18, Seattle, WA. p. 262–270.

Bolt, R.A., (1981). Gaze-Orchestrated Dynamic Windows, *Computer Graphics* 15(3). p. 109–119.

Bowman, D. (1999). *Interaction Techniques for Common Tasks in Immersive Virtual Environments: Design, Evaluation, and Application.* PhD Thesis, Georgia Institute of Technology.

Boyle, M., Edwards, C. & Greenberg, S. (2000). The Effects of Filtered Video on Awareness and Privacy. In *Proceedings of the 2000 ACM conference on Computer supported cooperative work, CSCW 2000*, Philadelphia, PA. p. 1–10.

Brignull, H., & Rogers, Y. (2003). Enticing people to interact with large public displays in public spaces. In *Proceedings of Human-Computer Interaction INTERACT '03,* IOS Press. September 1. p. 17–24.

Buxton, W. (1986). Chunking and phrasing and the design of human-computer dialogues, In *Proceedings of the IFIP 10th World Computer Congress, Information Processing '86*. p. 475–480.

Cadiz, J., Venolia, G., Jancke, G., & Gupta, A. (2002). Designing and deploying an information awareness interface. In *Proceedings Conference on Computer Supported Cooperative Work , CSCW 2002*. p. 314–323.

Cadiz, JJ., Czerwinski, M., McCrickard, S., & Stasko, J. (2003). Providing elegant peripheral awareness. In *CHI '03 extended abstracts on Human factors in computing systems*, April 5-10, Ft. Lauderdale, FL (Workshop). p. 1066–1067.

Churchill, E., Girgensohn, A., Nelson, L., & Lee, A. (2003a). Weaving Between Online and Offline Community Participation. In *Proceedings of Human-Computer Interaction INTERACT '03*, IOS Press, September 1. p. 729–732.

Churchill, E., Nelson, L., Denoue, L., & Girgensohn, A. (2003b). The Plasma Poster Network: Posting Multimedia Content in Public Places. In *Proceedings of Human-Computer Interaction INTERACT '03*, IOS Press, September 1. p. 599–606.

Cutler, L. D., Frlich, B. & Hanrahan, P. (1997). Two-Handed Direct Manipulation on the Responsive Workbench. In *Proceedings of the ACM Symposium on Interactive 3D Graphics*. p. 107–114.

Dourish, P. & Bly, S. (1992). Portholes: supporting awareness in a distributed work group. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, May 3-7, Monterey, CA. p. 541–547.

Fish, R., Kraut, R. E. & Chalfonte, B. (1990). The VideoWindow system in informal communications. In *Proceedings of the 1990 ACM conference on Computer-supported cooperative work, CSCW 1990*, Los Angeles, CA. p. 1–11.

Fisher, S. (1990). Virtual Interface Environments. *The Art of Human-Computer Interface Design*. B. Laurel, ed., Addison-Wesley Publishing Co., 1990. p. 423–438.

Galloway, K. & Rabinowitz, S. (1980). Hole in Space, Art Installation in New York and Los Angeles. Retrieved January 15, 2005, http://www.ecafe.com/getty/HIS/index.html.

Gaver, W., Beaver, J., & Benford, S. (2003). Ambiguity as a resource for design. In *Proceedings of the ACM Conference on Human Factors in Computing Systems*. p. 233–240.

Gavrila, D. (1999). The Visual Analysis of Human Movement: A Survey. *Computer Vision and Image Understanding*, 73(1), Jan. p. 82–98.

Gray, J. A. (1975). *Elements of a two-process theory of learning*. London: Academic Press.

Greenberg, S. & Rounding, M. (2001). The Notification Collage: Posting Information to Public and Personal Displays. In *Proceedings of the ACM Conference on Human Factors in Computing Systems.* p. 515–521.

Guiard, Y. (1987). Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain Model. *Journal of Motor Behavior*, 19(4), p. 486–517.

Hall, E. T. (1966). *The Hidden Dimension.* New York: Doubleday, 1966.

Hansen, J. P., Andersen, A. W., & Roed, P. (1995). Eye-gaze control of multimedia systems. Y. *Anzai, K. Ogawa and H. Mori (Eds.) Symbiosis of human and artifact*, Amsterdam. p. 37–42.

Harrison, B., Ishii, H., & Chignell, M. (1994). An Empirical Study on Orientation of Shared Workspaces and Interpersonal Spaces in Video-Mediated Collaboration. *Ontario Telepresence Technical Document: OTP-94-02.*

Harrison, B., Ishii, H., Vicente, K., & Buxton, W. (1995). Transparent layered user interfaces: an evaluation of a display design to enhance focused and divided attention. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, May 07-11, Denver, Colorado, p.317-324.

Heiner, J., Hudson, S., & Tanaka, K. (1999). The Information Percolator: Ambient Information Display in a Decorative Object. In *Proceedings of the ACM Symposium on User Interface Software and Technology*. p. 141–148.

Heiser, J., Phan, D., Agrawala, M., Tversky, B., & Hanrahan, P. (2004). Designing better visual interfaces: Identification and validation of cognitive design principles for automated generation of assembly instructions. In *Proceedings of the working conference on Advanced visual interfaces.* Gallipoli, Italy. p. 311–319.

Hinckley, K. (1997). *Haptic Issues for Virtual Manipulation*. Ph.D. thesis, University of Virginia.

Hinckley, K., Baudisch, P., Ramos, G., & Guimbretiere, F., (2005, In Press). Design and Analysis of Delimiters for Selection-Action Pen Gesture Phrases in Scriboli. To appear in *Proceedings of the ACM Conference on Human Factors in Computing Systems*.

Holmquist , L. (2004). Evaluating the Comprehension of Ambient Displays. In *Extended abstracts of the 2004 conference on Human factors and computing systems.* p. 1545–1545

Hopkins, D. (1991). The Design and Implementation of Pie Menus. *Dr. Dobbs Journal*. Dec.

Hopkins, D. (1998). *Self-Revealing Gesture Interfaces* [Video]. Talk at Interval Research Corporation.

Huang, E., & Mynatt, E. (2003). Sharable displays: Semi-public displays for small, co-located groups. In *Proceedings of the conference on Human factors in computing systems*, April 05 – 10, Ft. Lauderdale, FL. p. 49–56.

Hudson, S. and Smith, I. (1996). Techniques for Addressing Fundamental Privacy and Disruption Tradeoffs in Awareness Support Systems. In *Proceedings of the 1996 ACM conference on Computer supported cooperative work, CSCW ’96*, p. 248–257.

Hudson, S., Fogarty, J., Atkeson, C., Avraham, D., Forlizzi, J., Kiesler, S., Lee, J., & Yang, J. (2003). Modeling user behavior: Predicting human interruptibility with sensors: a Wizard of Oz feasibility study. In *Proceedings of the conference on Human factors in computing systems*, April 05 – 10, Ft. Lauderdale, FL. p. 257–164.

Igarashi, T., Mynatt, E. D., Edwards, W. K., & LaMarca, A. (1999). Demonstrating Flatland user interfaces (demonstration). In *Extended Abstracts of ACM Conference on Human Factors in Computing Systems*, May 15-20; Pittsburgh, PA.. p. 27–28.

Ishii, H. (1990). TeamWorkStation: Towards a Seamless Shared Workspace. In *Proceedings of Conference on Computer-Supported Cooperative Work, CSCW '90,* October 7-10, Los Angeles, CA. p. 13-26.

Ishii, H., & Kobayashi, M. (1992). ClearBoard: a seamless medium for shared drawing and conversation with eye contact. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, May 03-07, Monterey, CA. p.525-532.

Ishii, H. & Ullmer, B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the SIGCHI conference on Human factors in computing systems, SIGCHI’97*, Atlanta, GA. p. 234–241.

Izadi, S., Brignull, H., Rodden, T., Rogers, Y., & Underwood, M. (2003). Dynamo: a public interactive surface supporting the cooperative sharing and exchange of media. In *Proceedings* of *ACM Symposium on User Interface Software and Technology*. p. 159–168.

Jacob, R.J.K. (1995). Eye Tracking in Advanced Interface Design. In Barfield,W. and Furness, T.A. (Eds) *Virtual Environments and Advanced Interface Design*. p. 258–288.

Jancke, G., Venolia, G.D., Grudin, J., Cadiz, J.J., & Gupta, A. (2001). Linking Public Spaces: Technical and Social Issues. In *Proceedings of the SIGCHI conference on Human factors in computing systems, CHI 2001*, Seattle, WA. p. 530–537.

Johanson, B., Fox, A., & Winograd, T. (2002). The Interactive Workspaces Project: Experiences with Ubiquitous Computing Rooms. *IEEE Pervasive Computing Magazine* 1(2), April-June 2002.

Kortuem, G. (2003). Mixed initiative interaction: A model for bringing public and personal artefacts together. *Disappearing Computer Workshop* [Position Paper].

Krueger, M. (1977). Responsive Environments. *American Federation of Information Processing Societies 1977.* (46) p. 423– 429.

Krueger, M., Gionfriddo, T., & Hinrichsen , K. (1985). VIDEOPLACE—an artificial reality. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. p. 35–40.

Krueger, M. (1990). VIDEOPLACE and the Interface of the Future. *The Art of Human-Computer Interface Design*. B. Laurel, ed., Addison-Wesley Publishing Co., 1990. p. 417–422.

Kurtenbach, G., & Buxton, W. (1991). Issues in Combining Marking and Direct Manipulation Techniques, In *Proceedings of the 4th annual ACM symposium on User interface software and technolog*, Hilton Head, SC. p. 137–144.

Lee, C., & Xu, Y. (1996). Online, interactive learning of gestures for human robot interfaces. In *Proceedings of IEEE International Conference on Robotics and Automation*. p. 2982–2987.

MacIntyre, B., Mynatt, E., Voida, S., Hansen, K., Tullio, J., & Corso, G. (2001). Support for multitasking and background awareness using interactive peripheral displays. In *Proceedings of ACM Symposium on User Interface Software and Technology*. p. 41–50.

Maes, P., Darrell, T., Blumberg, B., & Pentland, A. (1995). The ALIVE system: full-body interaction with autonomous agents. In *Proceedings Computer Animation '95*, April 19-21. p. 11-18, 209.

Mankoff, J., Dey, A., Hsieh, G., Kientz, J., Lederer, S., & Ames, M. (2003). Peripheral and ambient displays: Heuristic evaluation of ambient displays. In *Proceedings of the conference on Human factors in computing systems*, April 05 – 10, Ft. Lauderdale, FL. p. 169–176.

Mason, K.A. (1969). Control apparatus sensitive to eye movement. U.S. Patent #3,462,604

McCarthy, J., Nguyen, D. Rashid, A., & Soroczak, S. (2003). Proactive Displays and The Experience UbiComp Project. In *Adjunct Proceedings of The Fifth International Conference on Ubiquitous Computing (UbiComp 2003).*

McCarthy, J., McDonald, D., Soroczak, S., Nguyen, D., & Rashid, A (2004). Augmenting the Social Space of an Academic Conference. In *Proceedings of ACM Conference on Computer Supported Cooperative Work, CSCW 2004,* November 6-9, Chicago, IL. p. 39– 48

McCrickard, S., Catrambone, R., & Stasko, J. (2001). Evaluating Animation in the Periphery as a Mechanism for Maintaining Awareness. In *Proceedings of INTERACT 2001*, Tokyo, Japan, July, p. 148–156.

Miller, T., & Stasko, J. (2002). Artistically conveying information with the InfoCanvas. In *Proceedings of AVI, Workshop on Advanced Visual Interfaces*. p. 43–50.

Mulder , A. (1994). Human Movement Tracking Technology. *Technical Report, NSERC Hand Centered Studies of Human Movement project,* Burnaby, BC, Canada: Simon Fraser

University, 1994. Retrieved December 2004 from www.cs.sfu.ca/~amulder/personal/vmi/HMTT.pub.html

Myers, B., Bhatnagar, R., Nichols, J., Peck, C., Kong, D., Miller, R., & Long, C. (2002). Interacting at a distance: measuring the performance of laser pointers and other devices. In *Proceedings of the SIGCHI conference on Human factors in computing systems,* April 20-25, Minneapolis, MN. p. 33–40.

Nielsen, J. (2000). Why You Only Need to Test With 5 Users. *Alertbox,* March 19. Retrieved January 15, 2005, from http://www.useit.com/alertbox/20000319.html.

Neisser, U. (1967). *Cognitive psychology*. New York: Appleton-Century–Crofts.

Obata, A. & Sasaki, K., (1998). OfficeWalker: a virtual visiting system based on proxemics, In Proceedings of *ACM conference on Computer supported cooperative work CSCW'98*, November 14-18, Seattle, WA. p. 1–10.

Olson, M. & Bly, S. (1991). The Portland experience: a report on a distributed research group, in Greenberg, S. (1991). *Computer-supported cooperative work and groupware*, Academic Press Ltd., London, UK, 1991.

Palen, L. (1999). Social, individual and technological issues for groupware calendar systems. In *Proceedings of the ACM Conference on Human Factors in Computing Systems*. p. 17–24.

Palen, L. & Dourish, P. (2003). Unpacking "Privacy" for a Networked World. In *Proceedings of the conference on Human factors in computing systems*, April 5 – 10, Ft. Lauderdale, FL. p. 129–136.

Plaue, C., Miller, T., & Stasko, J., (2004). Is a picture worth a thousand words?: an evaluation of information awareness displays, In *Proceedings of the 2004 conference on Graphics interface*, May 17-19, 2004, London, Ontario, Canada. p. 117–126.

Prante, T., Röcker, C., Streitz, N., Stenzel, R., Magerkurth, C., Alphen, D.V., & Plewe, D. (2003). Hello. Wall - Beyond Ambient Displays. In *Video and Adjunct Proceedings of UBICOMP Conference* [Video].

Redström J, Skog T., & Hallnäs L. (2000). Informative Art: Using Amplified Artworks as Information Displays. In *Proceedings of DARE 2000, Designing Augmented Reality Environments, ACM, 2000*, Elsinore, Denmark.

Reeves, B. & Nass, C. (1996). *The Media Equation: How People Treat Computers, Televisions, and New Media Like Real People and Places*. Stanford, CA: Center for the Study of Language and Information; Cambridge (England); New York: Cambridge University Press, c1996.

Rekimoto, J., (1997). Pick-and-Drop: A Direct Manipulation Technique for Multiple Computer Environments, In *Proceedings of ACM Symposium on User Interface Software and Technology*, 1999. p. 31–39.

Russell, D. (2002). Large interactive public displays: Use patterns, support patterns, community patterns. *CSCW Workshop on Tabletop and Large Displays.*

Sellen, A., Kurtenbach, G. & Buxton, W. (1992). The prevention of mode errors through sensory feedback. *Human Computer Interaction*, 7(2). p. 141–164.

Shell, J., Vertegaal, R, & Skaburskis, A. (2003). EyePliances: Attention-Seeking Devices that Respond to Visual Attention. In *CHI '03 extended abstracts on Human factors in computing systems*, April 5-10, Ft. Lauderdale, FL. p. 770–771.

Shoemaker, G., & Inkpen, K. (2001). Single Display Privacyware: Augmenting public displays with private information. In *Proceedings of ACM Conference on Human Factors in Computing Systems*. p. 522–529.

Skaburskis, A., Vertegaal, R., & Shell, J. (2004). Auramirror: Reflections on Attention. In *Proceedings of ACM Eye Tracking Research and Applications Symposium 04,* San Antonio, TX, 2004. p. 101–108.

Skog, T., Holmquist, L.E., Redström, J. & Hallnäs, L. (2001). Informative Art. In *SIGGRAPH 2001 Conference Abstracts and Applications* (Emerging Technologies exhibition).

Skog, T., Ljungblad, S. & Holmquist L. E. (2002). Bringing Computer Graphics to Everyday Environments with Informative Art. *SIGGRAPH 2002 Conference Sketches and Applications.*

Skog, T., & Holmquist, L. (2003). Informative art: Information visualization in everyday environments. In *Proceedings of GRAPHITE*. p. 229–235.

Skog, T., Ljungblad, S., & Holmquist, L. (2003). Between aesthetics and utility: Designing ambient information visualizations. In *Proceedings of 2003 IEEE Symposium on Information Visualization*. p. 30–38.

Skog, T. (2004). Activity Wallpaper: Ambient Visualization of Activity Information. In *Proceedings from Designing Interactive Systems (DIS) 2004* (Poster)

Stasko, J., Miller, T., Plaue, C., Pousman, Z., & Ullah, O. (2004). Personalized Peripheral Information Awareness through Information Art. In *Proceedings of UbiComp 2004.*

Stewart, J., Raybourn, M., Bederson, B, & Druin, A. (1998). When two hands are better than one: Enhancing collaboration using Single Display Groupware. In *Proceedings of ACM Conference on Human Factors in Computing Systems*. p. 287–288.

Streitz, N.A., Geißler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P., & Steinmetz, R. (1999). i-LAND: An interactive Landscape for Creativitiy and Innovation. In *Proceedings of ACM Conference on Human Factors in Computing Systems (CHI '99),* Pittsburgh, Pennsylvania, May 15-20. p. 120–127.

Streitz, N., Röcker, C., Prante, T., Stenzel, R., & Alphen, D. (2003). Situated interaction with ambient information: Facilitating awareness and communication in ubiquitous work environments. *Human-Centred Computing: Cognitive, Social, and Ergonomic Aspects.* Lawrence Erlbaum. p. 133–137.

Sturman, D. & Zeltzer, D. (1993). A Design Method for Whole-Hand Human Computer Interaction. *ACM Transactions on Information Systems,* Vol 11. No 3. July. p. 219–238.

Tan, D., & Czerwinski, M. (2003). Information voyeurism: Social impact of physically large displays on information privacy. In *Proceedings of the conference on Human factors in computing systems,* April 05 – 10, Ft. Lauderdale, FL. p. 748–749.

Treisman, A. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology*, 12. p. 242–248.

Vogel, D. & Balakrishnan, R. (2004). Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In *Proceedings of ACM Symposium on User Interface Software and Technology*. Santa Fe, NM. p. 137–146.

Want, R., Hopper, A., Falcão, V., & Gibbons, J. (1992). The active badge location system. *ACM Transactions on Information Systems.* 10(1). p. 91–102.

Ware, C. & Mikaelian, H. H. (1987). An evaluation of an eye tracker as a device for computer input. In J.M. Carroll & P.P. Tanner (Eds.) *CHI + GI 1987 Conference proceedings*, SIGCHI Bulletin, ACM. p. 183–188.

Weiser, M. (1991). The computer for the 21st century. *Scientific American.* 265(3). p. 94–104.

Weiser, M. (1993). Some computer science issues in ubiquitous computing. *Communications of the ACM*. 36(7). p. 74–83.

Weiser, M., & Brown, J.S. (1996). Designing calm technology. *PowerGrid Journal.* 1(1).

Yamada. T., Shingu, J., Churchill, E., Nelson, L., Helfman, J., & Murphy, P. (2004). Who cares?: reflecting who is reading what on distributed community bulletin boards. In *Proceedings of ACM Symposium on User Interface Software and Technology*, Santa Fe, NM. p.109–118.