Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users

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ABSTRACT
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. Initial user feedback is also presented, and future directions discussed.

Categories and Subject Descriptors: H.5.2 [**User Interfaces**]: Interaction styles; H.5.3 **[Group and Organization Interfaces]**: Collaborative computing.

Additional Keywords and Phrases: ambient displays, interactive public displays, subtle interaction, ubicomp.

INTRODUCTION
As the vision of ubiquitous computing [27-29] edges towards reality, an increasing flow of information will likely be available anytime and anywhere. 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, offices, and homes. 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 ways to represent information in public, semi-public, and private spaces using ambient displays [8, 9, 15, 22, 23], techniques for subtle ambient communication and notification [3, 7, 10], explicitly interactive public displays [4, 20], techniques for interacting with large displays [5], privacy and sharing issues when working on large displays [12, 21], and evaluation methodologies [16].

Our research explores many of these issues collectively by identifying a set of design principles and developing an interaction model 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 that is 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 (Figure 1). 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.

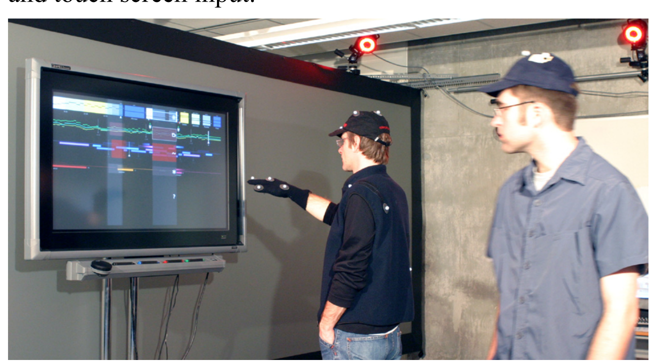


Figure 1. Prototype sharable interactive ambient display.

UIST '04, October 24–27, 2004, Santa Fe, New Mexico, USA.

RELATED WORK

"hello.wall" [19, 24] is a large ambient display coupled with a hand-held device, supporting three zones of interaction for distance dependent ambient interaction and notification, communicating "atmospheric aspects" of an organization through abstract representations of public and private codes. Our four phase framework extends this work, and we compare the two in more detail later in this paper.

Brignull and Rogers [2] studied users interacting with large interactive public displays, identified three spaces of activity. and provided interaction guidelines. PlasmaPlace [4] emphasizes light-weight interaction and blending of online and physical spaces for a single user. BlueBoard [20] is an interactive public display that recognizes users via an explicit "badge in" with an RFID tag. It encourages collaboration, but allows only a single interaction session at a time. A field study showed interesting results regarding how people collaborate on a large public display.

Skog et al [22, 23] demonstrate ambient information visualizations with aesthetics adapted from actual works of art. AmbientRoom [11] and the Information Percolator [8] provide examples of non-pixel ambient displays.

Mankoff et al [16] offer a set of ten heuristics for evaluating the effectiveness of ambient displays with emphasis on evaluating non-pixel ambient displays.

Kimura [15] is an augmented office environment using interactive personal peripheral displays to manage "working contexts." The Notification Collage [7] is a system for users to communicate through a network of desk mounted peripheral displays and public large displays. Sideshow [3] is a peripheral notification application for use on a Windows™ desktop. InfoCanvas [17] provides another example of a personal, peripheral ambient display.

Huang and Mynatt [9] built a *semi-public awareness display* prototype combining four different information sources together on a single display surface. Their evaluation showed users preferred persistent displays offering "opportunistic glances" and were receptive to harmless personal information being displayed.

Dynamo [12] enables collaboration on large interactive displays using a WIMP interface, stressing explicit controls for sharing and privacy. Shoemaker and Inkpen [21] discuss techniques for showing private information within the context of public information using shutter glasses.

DESIGN PRINCIPLES

In conceptualizing a system for public ambient display interaction, we identified the following design principles:

Calm Aesthetics: Ambient displays provide information in the user's periphery and are typically placed in a permanent location becoming part of their environment [22, 23, 29]. 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 [4] found an overly reactive display too distracting, while a slow one felt static and unresponsive.

Comprehension: The information communicated by the ambient display must be comprehensible, even if rendered in an abstract manner [23]. It may not be immediately understandable, but users should be able to discover meaning through subtle interaction. As Gaver et al [6] argue, having some ambiguity in the display, at least initially, can draw users into interaction. An interactive display should reveal meaning and functionality naturally.

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 work on interruptibility of individual workstation users [10], 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" [2]. 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 [2].

Shared Use: To take advantage of a large display, multiple users should be able to share the system either individually or collaboratively whether interacting implicitly, explicitly, or simply viewing the ambient display.

Combining Public and Personal Information: Rather than exclusively showing public information, when appropriate weave an active user's *harmless* 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.

Privacy: People tend to be more voyeuristic with large displays [25], and Palen's discussion of group calendar privacy indicates that "information considered totally innocuous to some is considered personally private to others" [18], 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.

A FRAMEWORK FOR INTERACTION PHASES

In addition to our design principles, building upon previous research [2, 19, 24] we developed an interaction framework. 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 2). We differ from the three zone model used in Streitz et al's hello.wall [19, 24], in that we do not rely solely on physical proximity to delineate different phases, we do not require a handheld 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 Streitz et al'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.

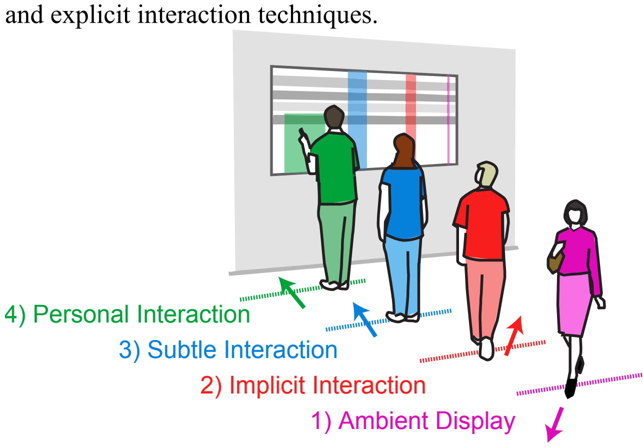


Figure 2. Four interaction phases, facilitating transitions from implicit to explicit, public to personal, interaction

Ambient Display Phase

The neutral state is that of an ambient information display, showing a range of categorized information simultaneously with updates occurring slowly [22, 23, 29]. 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.

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" [10]. 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 [13]. While this inference is done implicitly, the user should also have a way to explicitly signal that they wish to be left alone.

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 harmless, in that it should not be something that a user is highly protective of.

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.

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, then gradually become more explicit with gestures and touch [13]. 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 3). 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: OVERVIEW when viewing the notification details, and SELECT when the user has selected an information source to query

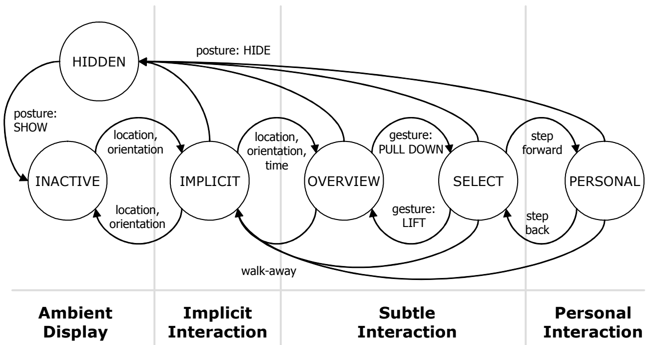


Figure 3. State diagram showing transition events between phases and states within phases.

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 [4, 20] or explicit space partitioning [12]. We build on the latter, but without users explicitly claiming a static region of the screen. Depending on the interaction phase they're 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. 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.

A 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 initial user feedback is encouraging, we are not claiming that our prototype is eminently usable at this stage.

System Hardware

We use a 50" plasma screen (Figure 1), which provides a high-resolution display platform for easy prototyping of different information layouts and animations. A SMART 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 8' deep from the front surface of the display, 7' high (i.e., from floor to ceiling), and 16' wide (i.e., 8' 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 of this paper.

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. 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.

Multiple users can initiate their own phases of interaction on the display at the same time. 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 to hide the notification and querying display elements. This allows the user to observe the public ambient display up close if desired, without entering the interactive phases.

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.

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 categories of information 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 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 work on calendars [18].

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 [23]. Each information category occupies a horizontal "stripe" spanning the width of the display (Figure 4 & Figure 5a). 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 6½' 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.

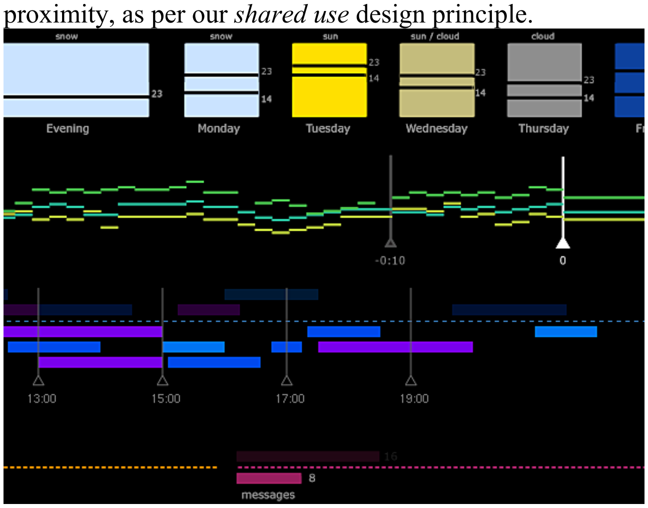


Figure 4. Detail view of the information sources. From top to bottom: weather, office activity, calendar, and messaging.

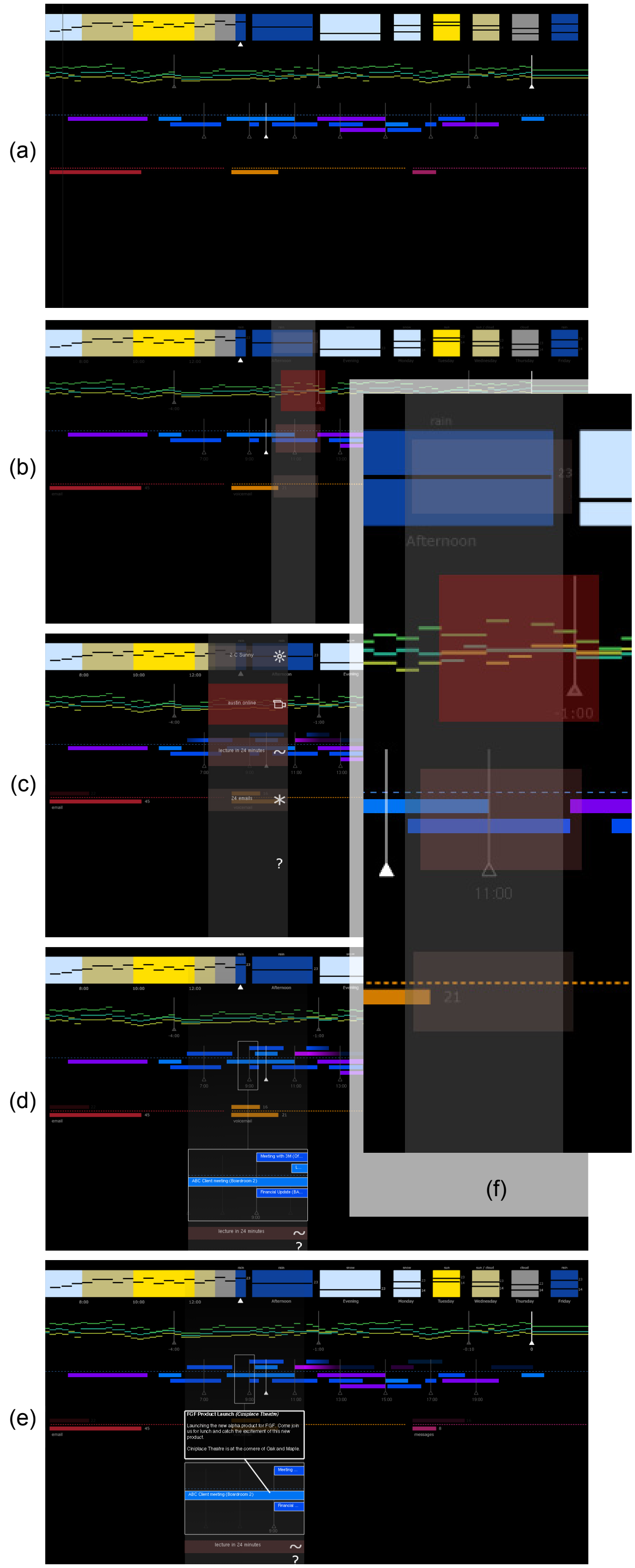
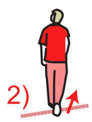


Figure 5. Progression of different phases on prototype display. (a) Ambient Display. (b) Implicit Interaction. (c) Subtle Interaction OVERVIEW. (d) Subtle Interaction SELECT. (e) Personal Interaction. Detail Inset: (f) user proxy bar.

Proximity Reveal

As a first step towards fulfilling our *comprehension* design principle, we included a 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. This draws them closer to discover the next phase of interaction, thus contributing to the system's *immediate usability.*



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

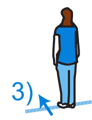
We use the user's body location, body orientation, and head orientation to communicate with the user through a semi-transparent vertical "proxy bar" (Figure 5b,f). The width of the proxy bar is a function of the user's body orientation and its opacity a function of head orientation. This has the effect 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.

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 increases. 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 8d), analogous to the commonly seen "stop" gesture used for traffic signaling 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 8e) (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.



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 (40"). 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 OVERVIEW state (Figure 3 & Figure 5c). From here, the user begins interacting in a more explicit manner using hand gestures to select an information source for querying, thus entering the SELECT state (Figure 3 & Figure 5d). 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.

Displaying Personal Information

Near the widened proxy bar, a magic lens [1] inspired technique is used to *combine public information with personal information* (Figure 6). 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. 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.

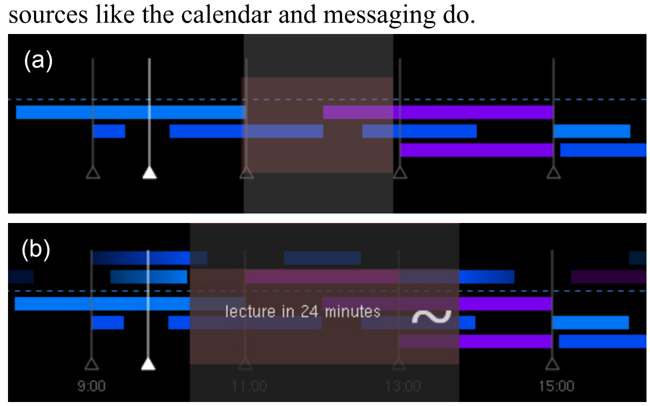


Figure 6. Augmenting public information with personal information. (a) public calendar events in the ambient phase. (b) personal events added above the dashed line.

Information Exploration

By forming an open hand with palm facing down (*palm down* posture, Figure 8a) the user selects an information category to explore in more detail (Figure 5d). Essentially, the notification OVERVIEW state acts like a large menu. Movement up and down vertically highlights items, and selection is done with a downward *flick* gesture (Figure 8a).

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 9): 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.

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 OVERVIEW (Figure 5c) when currently viewing detailed information in the SELECT sub-phase (Figure 5d), an open hand pointed out with palm facing up (*palm up* posture, Figure 8b) 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 informal user test later confirmed.

Reaching and Shifting

After an information source is selected, a detail panel is shown in the lower portion of the display (Figure 5d). The detail panel provides a zoomed view combining both public and personal information together similar to the OVERVIEW sub-phase. A square in the information source above, which we call the selection point, 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 8c). Moving the hand left and right adjusts the selection point on the information source (Figure 7). 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 informal user study later confirmed this.

Figure 7. Using the reach gesture to access information beyond other users. (a) detail panel. (b) the selection point.

Techniques for Personal Interaction Phase

By stepping closer to the display, the user enters the personal interaction phase where information in the detail display 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 display opens a full description in a “balloon” above (Figure 5e). 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.

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.

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 postures that rely only on large (usually 90 degree) differences in wrist and elbow angles (Figure 8). We currently use only a subset of possible gestures leaving room for future expansion.

Our recognition is done by first looking for the required posture based on the marker inputs from the user’s hand. 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.

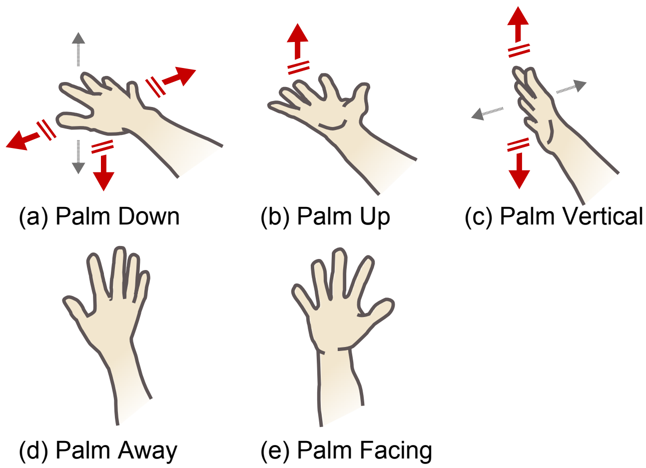


Figure 8. Postures and Gestures. Large red arrows indicate discrete gestures and small grey dashed arrows indicate continuous gestures. (a) *Palm Down*: continuous vertical gesture highlights items. A downward flick gesture selects an item. Left or right flick cancels. (b) *Palm Up*: an upward flick returns to the OVERVIEW. (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.

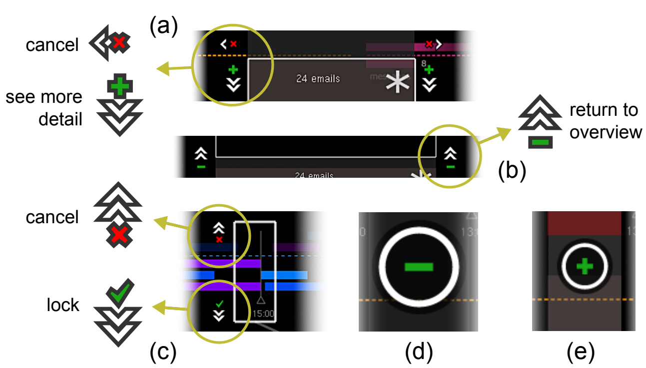


Figure 9. Visual cues providing information for imminent or possible actions. (a) select information category. (b) return to OVERVIEW. (c) reach action. (d) hide. (c) show.

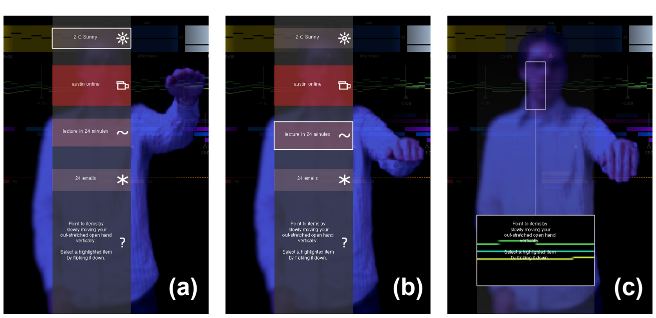


Figure 10. Self revealing help using looping video sequences. In this example, actions with the *palm down* posture is demonstrated during the subtle interaction phase. (a-b) show continuous vertical movement with the *palm down* posture highlighting items. (c) shows the result of selecting the item with a downward flick action.

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. 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 9d). 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 9a,b,c).

Learning Gestures Through Self Revealing Help

Systems using postures and gestures typically rely on an extensive instruction and training period [14], 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 in an interaction phase without action, a help mechanism initiates showing a looping video sequence demonstrating the available actions (Figure 10). The user regains control of the interface by initiating the instructed posture/gesture or any other action.

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 OVERVIEW 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 [4].

INITIAL USER FEEDBACK

To test the effectiveness of our techniques, we conducted informal user evaluations of our prototype. We recruited four participants who work in an office environment, had no prior knowledge of our project, and were fluent with various computational media. Our evaluation had two parts.

In the first part, 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 part, we wanted to see if they understood the meaning of the ambient display using the three levels of comprehension as defined by Skog et al [23], 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 part of the evaluation – we did not want it to be obvious to participants that hand input was a part of the system.

In the second part of the evaluation, the user was given the glove with hand tracking markers and asked to continue exploring the display. 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.

Comprehension: We observed that participants immediately understood that their body position was controlling the vertical bar. Three of the participants noticed the notification flags with one making a connection between the four notification flags, the four horizontal information displays, and red meaning "high priority." After the participants learned to approach the display to initiate the notification OVERVIEW sub-phase, they correctly interpreted the weather, calendar, and messaging displays. 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."

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 direct 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 display 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 display was drawing information from. They appeared to have no trouble controlling this movement with their body. 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.

DISCUSSION AND FUTURE WORK

Our prototype and informal user evaluation 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 doesn't 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 [26]. 3D 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.

Our prototype did not focus on the possibilities that touch screen interaction affords. 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.

While we have emphasized sharing a display as a way for multiple users to do their own thing without bothering each other, the system could be extended to allow collaboration between multiple users. 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.

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. The touch screen discussion above mentioned one such idea with video links, others may include showing versions of user proxy bars on remote as well as local screen (without notification flags).

CONCLUSION

We have demonstrated 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. 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. Initial user feedback indicates that our techniques are quickly discoverable and appear to be usable. Our prototype was 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, taking us a step closer to realizing more sophisticated and useful sharable, interactive, public ambient displays.

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