Ambient Displays: Turning Architectural Space into an Interface between People and Digital Information

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Abstract. We envision that the architectural space we inhabit will be a new form of interface between humans and online digital information. This paper discusses Ambient Displays: a new approach to interfacing people with online digital information. Ambient Displays present information within a space through subtle changes in light, sound, and movement, which can be processed in the background of awareness. We describe the design and implementation of two example Ambient Displays, the ambientROOM and Ambient Fixtures. Additionally, we discuss applications of Ambient Displays and propose theories of design of such interfaces based on our initial experiences.

1 INTRODUCTION

Ambient \Am"bi*ent\, a. Surrounding, encircling, encompassing, and environing.
-Oxford English Dictionary
Display \Dis*play"\, n. An opening or unfolding; exhibition; manifestation.
-Webster's Revised Unabridged Dictionary (1913)

Nature is filled with subtle, beautiful and expressive ambient displays that engage each of our senses. The sounds of rain and the feeling of warm wind on our cheeks help us understand and enjoy the weather even as we engage in other activities. Similarly, we are aware of the activity of neighbors through passing sounds and shadows at the periphery of our attention. Cues like an open door or lights in an office help us subconsciously understand the activities of other people and communicate our own activity and availability.

Current personal computing interfaces, however, largely ignore these rich ambient spaces, and resign to focusing vast amounts of digital information on small rectangular windows. Information is presented as "painted bits" on flat screens that must be in the center (foreground) of a user's focus to be processed

(Fig. 1). The interactions between people and digital information are now almost entirely confined to the conventional GUI (Graphical User Interface) comprised of a keyboard, monitor, and mouse.

Ambient Displays takes a broader view of display than the conventional GUI, making use of the entire physical environment as an interface to digital information. Instead of various information sources competing against each other for a relatively small amount of real estate on the screen, information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movement, sound, color, smell, temperature, or light. Ambient displays are well suited as a means to keep users aware of people or general states of large systems, like network traffic and weather. We believe that this approach will be a critical step in moving beyond current interface limitations.

Ambient displays are envisioned as being all around us. They are suited for the home environment and everyday life. People have a need to feel connected to others, especially loved ones, and ambient displays can aid in this connection. Other well suited spaces include highly specialized environments where many streams of information need to be constantly monitored. Examples might include an aviation cockpit, an atomic power plant control room, or a car. Further, we envision ambient media stretching out towards everyday life, being incorporated into people's workplaces, and into future visions of wearable computers people might have on their bodies.

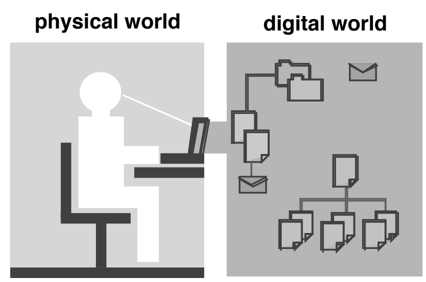

Fig 1. Personal Computing:

Looking through a small window

Two projects that explore the Ambient Displays concept are the ambientROOM and Ambient Fixtures. We will discuss their motivation, implementation, and application, and further attempt to tease out lessons we have learned through their creation.

2 RELATED WORK

2.1 Tangible Bits

Ambient Displays is part of our broader "Tangible Bits" vision that blurs the boundary between the physical and digital worlds to create an "interface" between humans and digital information in cyberspace. We are turning each state of physical matter - not only solid matter, but also liquids and gases - within everyday architectural spaces into "interfaces" (Ishii & Ullmer 1997).

The key ideas of "Tangible Bits" are concepts of graspable media and ambient media (Fig. 2). We are developing ways to:

- allow users to grasp and manipulate bits (digital information) with their hands at the center of attention, and
- enable users to be aware of background bits at the periphery of perception using ambient media.

2.2 Awareness in Human Computer Interaction

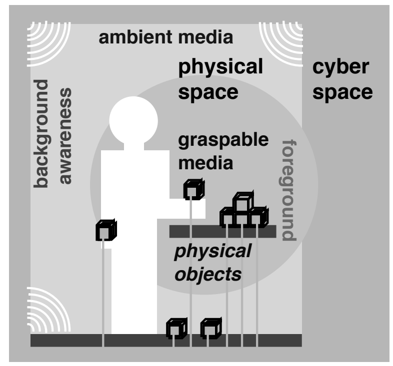

Fig. 2 Tangible Bits: Inhabiting a Digitally Augmented Architectural Space

Awareness is the state of knowing about the environment in which you exist; about your surroundings, and the presence and activities of others. Awareness is essential in collaboration to coordinate the activities in a shared workspace. Awareness support discussed in the Computer Supported Cooperative Work (CSCW) community has focused on the representation of the state of collaborators in a geographically distributed context. Technological devices such as remote cursors, multiple scroll bars, audio cues, and low framerate video have been proposed to support the awareness of remote collaborators' activities. Dourish and Bly's Portholes project (1992) is an example of an awareness support system using low resolution, low framerate video.

Our notions of ambient media were, in part, inspired by the Fields and Thresholds work of Dunne and Raby (1994) and the Live Wire of Jeremijenko (Weiser, Brown 1995). These projects explored a theme of peripheral awareness of external activity, especially of activity attributable to people. The AROMA project (Pederson & Sokoler, 1997) further investigates ideas of peripheral awareness. These researchers share many of our ideas, especially with respect to the use of subtle and abstract displays.

In this paper, we present a new kind of awareness support methodology, including, but not limited to, the "awareness" of people's activities. Rather, we extend them to include dynamic information systems, such as weather, stock values, and network traffic.

2.3 Cognitive Science Theories related to Ambient Displays

In designing the interface that humans use to access computation, the fundamental human issues of attention, perception, and mental representation come into play. In fact, these factors are central to how humans use an interface tool, yet, in the field of cognitive science, attention, perception, and representation building remain relatively illusive and mysterious.

In designing ambient displays, we have looked at two bodies of research about humans. First is the "ecological" perspective, as put forth by such psychologists as J.J. Gibson (1979) and Ulric Neisser (1972). Gibson and Neisser have written extensively about humans within the natural world. Their work, consequently, has focused on perception as an active task that humans engage in within their environment. Gibson introduced the theory of "affordances", which is central to our discussion of physicality and control.

The second body of literature that has driven our designs draws from attention studies in experimental psychology. Especially relevant is the notion of the "cocktail party effect"- the ability of a person to selectively move his or her attention around a busy environment (Cherry, 1953). One goal in designing ambient environments is to exploit this human capability. We also examined the divided attention studies of Treisman, Rensink, and others. Treisman's work shows that information can be processed, even if it is not in the foreground of a person's attention (1960). Rensink and others have tried to more systematically explore how attention can effect the perception of a scene (1997). While significant strides have been made in understanding the basic ways attention works, very few experimental results can be easily applied to complex, chaotic environments.

3 THE AMBIENTROOM

The ambientROOM is based on the Personal Harbor™ product from Steelcase Corp., a 6'x8' enclosed mini-office installation (Fig. 3). The ambientROOM surrounds the user within an augmented environment – "putting the user inside the computer" – by providing subtle, cognitively background augmentations to activities conducted within the room.

We developed the ambientROOM as a platform supporting the expression of online digital information with "ambient media" – ambient light, sound, airflow, and physical motion used as peripheral displays at the background of user attention.

Fig. 3 ambientROOM based on Personal Harbor™ (Steelcase)

3.1 Human Activity Awareness

People have a need to feel connected to others, especially, people they care about. Yet, some people argue that personal computing isolates people. Ambient media can be used to create a persistent, yet non-intrusive connection between loved ones, bringing people a sense of community through shared awareness.

Many of our prototypes are centered on this kind of information. Connecting people is an attractive, powerful application of networked technology that has shown its usefulness in forms like email, paging, and telephones. Our work extends these ideas by connecting people through their physical environment.

Water Ripples

One display in the ambientROOM allows the user to have some awareness of the activity of a distant loved one. For our first instance, we expressed the activity of a resident hamster in our laboratory, for which cage temperature, light level, and wheel motion had already been instrumented and displayed on a web page.

Initially, a small, motorized representation of the hamster was configured to vibrate as the hamster's wheel rotated. This type of display proved somewhat intrusive, so alternate display mappings were explored. Now, the hamster representation could be grasped by the user and pointed at the ceiling of the room. This action "transfers" the vibration to the motion of a solenoid in a shallow water tank. A lamp reflecting off of the water then produces rippling shadows on the ceiling.

Active Wallpaper

Another display also provides awareness of the physical presence of others. Electric field sensors are used to measure the level of human activity in a work area. This activity is represented by a pattern of illuminated patches projected onto an inner wall of the ambientROOM. When activity is low, the movement of these spots is minimal, but as activity levels increase, so does the motion of the spots, providing a visual display of remote activity.

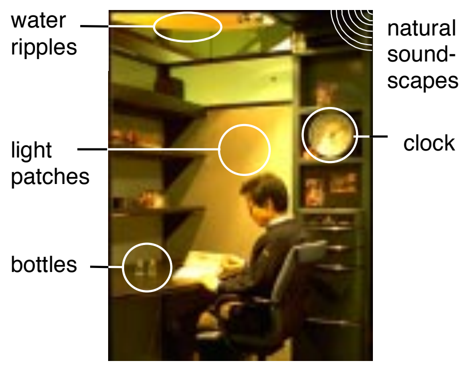

Fig. 4 ambient media displays and controls

Ambient Sound

Auditory displays have been implemented as well. A soundscape arises out of activity on the digital whiteboard in our group's workspace. When the board is in use, the sounds of the dry-erase pens rubbing against the board are transmitted into the ROOM in a low-volume, subtle way. This gives the inhabitant of the ROOM some awareness of activity in the central workspace.

So far, all of our examples have concerned awareness of a local event. However, we are particularly interested in relating global events to our local space.

3.2 Global System Awareness

The "awareness of people" application can be extended to monitor large systems of people, or behaviors that arise out of other large systems. Ambient displays could be suited to display general trends of stock values for a trader, network traffic information for a system administrator, and so on.

Another particularly interesting application to display is information about natural phenomena, such as atmospheric, astronomical, or geographical events. Displays such as these can give people an indication of the state of the world around them.

The ambientROOM contains a subtle but audible soundtrack of birds and rainfall, whose sound volume and density are modulated in conjunction with variations in room lighting. Thus, approximate quantities can be monitored with this display, for instance, the number of unread email messages or the level of a stock portfolio. Also, in this instance, the lighting in the ROOM changes according to the time of day.

It should be noted that GUI interfaces and ambient interfaces do not comprise a dichotomy of purpose and function. Subtle, background ambient displays are meant to co-exist with, and complement, foreground tasks. Also, background displays can move into the foreground, and vice versa. Users control this through their personal state of awareness, and sometimes, through physical controls.

3.3 Controls

To provide a means of controlling the ambient activity displays, several activity controls were deployed in the ambientROOM. Small physical bottles are employed as a graspable "containers" for digital content, such that opening a bottle "releases" information into the ROOM. One bottle contains information about the load on our computer network, and when opened, that data is represented in the ROOM as the sound of vehicular traffic.

A second activity control, a large wall-mounted clock with exposed hands, allows navigation through temporal events. A user recently absent from the room might wish to review activity displays from the past few hours, or skim forward in time to peruse anticipated events. In response to manipulation of the clock's time, the ambientROOM prototype shifts through the ambient sound and lighting displays of past hours.

We try to build controls to be self-explanatory. The gesture of opening and closing a bottle is a simple way of accessing information. The physical rotation of clock hands is equally simple and powerful. We envision that physical controls will be widespread in future environments, and will incorporate easy-to-use, gestural interfaces like the ones found in the ambientROOM.

3.4 Implementation

The implementation of the ambientROOM is designed to support quick prototyping. The ROOM is enabled with a host of products such as samplers, synthesizers, lighting-control boards, and software that allows easy synchronization of many media elements. Sensing and display in the ambientROOM are coordinated with Opcode's MAX software running on a Macintosh. MIDI-controlled dimmers adjust room lighting, a sampler manages sound playback, and rotation and electrical contact sensors monitor manipulation of the clock and bottle. An electric field sensing unit is used to monitor human movement in surrounding spaces. Video projectors augment the ROOM's clock, walls, and desk surface.

4 AMBIENT FIXTURES

Ambient Fixtures are standalone ambient media displays. We have taken concepts developed within the ambientROOM, and have moved them out into an open space, inhabited by many people. In the ambientROOM, the user is "inside the computer," while Ambient Fixtures allow us to externalize the displays and distribute them throughout an architectural space.

We have implemented two Ambient Fixtures: the Water Lamp and Pinwheels. The Water Lamp is an extension of the ceiling water ripples of the ambientROOM and the Pinwheels explore ideas of physical movement as a display medium.

4.1 The Water Lamp

The first ambient fixture we developed is the Water Lamp (Fig 5). A light shines upward through a pan of water, which is actuated by changing information. This action produces changing patterns of light projected onto the ceiling of a room.

Fig. 5 Design sketch of Water Lamp

The Water Lamp is composed of a wooden base, 3 aluminum support tubes and an acrylic water tray. There are 3 very small Shindengen 6V solenoids mounted above the water tray. These solenoids are controlled by a single circuit board. When actuated the solenoids tap on the surface of the water in the tray, causing ripples. The refracted light is shown as wave-like patterns on the ceiling.

The Ambient Fixtures are based upon a common control platform- the iRX 2.0 PIC Microcontroller Board designed at the MIT Media Lab by Robert Poor. The iRX board accepts commands over a serial input line from a computer to control each fixture. This allows us to distribute fixtures throughout our research space. TCL based software sends commands to the Fixtures. Information can be relayed from the internet or other networked information source and be routed to the appropriate fixture.

4.2 Pinwheels

The pinwheels evolved from the idea of using airflow in the ambientROOM (Fig. 6). We found that the flow of air itself was difficult to control, and hence, became a problematic tool with which to convey information. As an alternative, we found that the visual representation of airflow could be quite useful. The pinwheels spin at different speeds based upon their input information source.

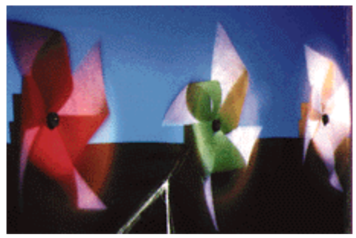

Fig 6. Array of Pinwheels

The pinwheels are made from folded fiberglass mounted on the shaft of a small Mabuchi 5.9V DC motor. Four pinwheels were connected to each iRX control board. Pulse width modulation controls the speed at which the motors spin.

Ambient Fixtures are especially suited to the display of information like natural phenomena, such as atmospheric, astronomical, or geographical events. For instance, an atmospheric scientist might map patterns of solar wind into patterns of Pinwheel flow in a room. Other users might want to be aware of tension in the Earth's fault-lines, giving an indication of earthquake activity. They could represent this through an array of Water Lamps. In ways like these, ambient media can provide a means for people to feel connected to the world around them.

5 DISCUSSION

Our explorations have given us insight into many research issues that arose in designing ambient displays. In this section, we will discuss some of these issues.

5.1 Mapping of information sources

In the presentation of ambient media, one of the key elements is the modality chosen to present a source of information. Information can be presented through any of the five senses, and the choice of which sense or senses to use at any given time is one of the first key choices in designing an interface.

The choice of modality for the background media should be considered with the person's foreground task in mind. For example, if a person is in their office performing a visually intensive foreground task- say, writing software- a visually based ambient display on the wall behind the person might not be as effective as an auditory display. Similarly, when a person is performing an intensive auditory task, like talking on the phone, ambient information might be better presented through non-auditory ways, or for example, in visual ways like shadows on a wall. However, if the modality and spatial configuration of a particular ambient display is substantially altered during the course of use, people may become confused about the display mapping being employed.

The mapping of data from information source to ambient display is a key consideration and challenge for ambient media. Whether it is sensors picking up activity of a person, or streams of data coming from dynamic natural systems, at the base level, almost all sources of information are represented by a computer as a stream of numbers. A designer of ambient media must transform the data into a display that successfully maps the information into a new form. The designer must decide how the source gets mapped and the location of where it gets mapped (i.e. where in visual, tactile, or audio space).

We expect that some styles of mappings will be more effective than others. For instance, many people reported that the sampled, looped sounds of water in the ambientROOM became annoying after months of repetition. In particular, sounds that are looped in some kind of discernable way tend to become annoying very quickly. In contrast, MIT Media Lab researchers Tom White and David Small (1997) created a project called "Stream of Consciousness" which employed a real stream of water flowing down a bed of rocks. The physicality in this project creates a kind of acoustic noise that most people seem to prefer.

Choices have also been made between abstract and literal displays. For the "active wallpaper" in the ambientROOM, fuzzy spots represent the movement of people. We also experimented with placing a far-infared camera in the space being monitored, and projecting its out-of-focus image on the wall of the ROOM. Many people thought the camera-based display felt intrusive, as the mapping was too literal and privacy had not been respected. Because of issues like this, we have focused thus far on more abstract display mappings. Still, we recognize that displays must not be so abstract that users cannot infer their meaning.

5.2 Thresholds / Transition from Background to Foreground

Ambient displays go largely unnoticed until some unexpected thing in the display makes it come into the foreground of attention. Depending on a user's state of attention, there exists a threshold where this background to foreground transition is made. In a few cases during our design explorations, it became apparent that the ambientROOM was too "busy". At times when all the displays were running at once, the ROOM was so full of brisk activity, that people had difficulty maintaining concentration on a foreground task. Many media elements going at once caused each display to exhibit a lower threshold for the background to foreground transition, creating an "information overload" effect.

In an effort to better control the output of our displays, experiments are being done that test the thresholds of each design instance, and how they change when used in conjunction with each other. These experiments examine changing modalities of background information based on a person's foreground task.

5.3 Learning effect

Ambient media likely has a learning effect: like driving a car, after a while, a person's perception changes based on his or her familiarity with the environment. Just like a car driver knows how to switch from the gas to the brake while turning the radio station, we expect a person in an ambient environment will learn how and where to look for information. The length of time a person spends in the environment will likely influence the person's facility for using it. We wish to further study how quickly a person can "get up to speed" in different kinds of ambient environments.

6 CONCLUSION

When ambient media is fully assimilated into future environments, appliances of all kinds may likely change. Air-conditioners may be computationally enabled to change the flow of air to convey information. Lamps bases may not only hold a light bulb in place, but will contain processors and motors so that the light can become a display medium.

The function of many common appliances may be extended to connecting people with information they otherwise would not be able to perceive, or at least not be able to get in such an easy fashion. We do not intend to distance people from their immediate environment even further. Ambient media should allow for further and increased coincidence of human interaction, rather than less. We seek to determine what kinds of interaction ambient media really promotes, and how we can design the media to promote human interaction, rather than detract from it.

We have discussed the motivation, implementation, and applications behind our ambient displays. We have also attempted to identify lessons we have learned through our work. Many more studies need to be done before a solid theory will arise, and hopefully, our work will help guide others along with us in this pursuit.

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