Designing Computers As Public Artifacts

Saul Greenberg
Department of Computer Science,
University of Calgary
Calgary, Alberta Canada T2N 1N4
+1-403-220-6087
saul@cpsc.ucalgary.ca

Cite as:

Greenberg, S. (1999). **Designing Computers As Public Artifacts**. *International Journal of Design Computing*: Special Issue on Design Computing on the Net (DCNet'99), November 30 - December 3, University of Sydney. http://www.arch.usyd.edu.au/kcdc/journal/

Abstract

In this paper, I explore the notion of designing *computers as a public artifact*. As a public artifact, information held by the computer can be seen, heard, and acted upon in an easy and natural way by the people inhabiting the area around the computer. I explore what I and others mean by computers as public artifact, and tell anecdotes that illustrate situations where computers have been used in public ways. I recast these as lessons learnt, and derive from them a list of design points. I include an example of a public artifact we are now building called the *dynamic photo*, and show how it responds to these particular design points.

Keywords: CSCW, ubiquitous computing, ambient displays, media spaces.

Introduction

The design of traditional computers is---with few exceptions---oriented towards single person use, where one computer is crafted to be used by one person at a time. Reality shows that this view of computers is rather naive, because it does not recognize that the computer acts as a public artifact used by several nearby people. Bonnie Nardi, for example, noticed that users of spreadsheets often work collaboratively over the same computer, where local experts typically provide over-the-shoulder assistance to the actual person who is trying to get their work done [Nardi 1993]. Similarly, educators often have groups of children working together around a single computer. Even though the children have to share the single mouse and keyboard, they engage in conversation over what they see, and direct the person who is currently holding the mouse [e.g., Code 1995; Inkpen, Booth, Lawe and Upitis 1995].

My particular interest is in reconsidering the design of computers as a public artifact. By *public artifact*, I mean that:

> information held by the computer can be seen, heard, and acted upon in an easy and natural way by the people inhabiting the area around the computer.

There are, of course, many non-computer public artifacts that surround us. Obvious examples include public surfaces such as bulletin boards that publicize posted announcements, PA systems that broadcast messages over a building, a television set positioned in a living room. More subtle

examples include the surface of a telephone (where families often leave sticky notes to other family members), refrigerator doors (a place to publicize drawings of children: see Buxton 1996), and pictures hanging on a public wall so they can be seen by all.

In this paper, I explore what I mean by computers as public artifact. I begin by discussing related ideas that include some notion of the computer as public artifact. Next, I list a series of anecdotes that illustrate situations where computers have been used (or failed to have been used) in public ways, and the lessons learnt from these situations. I then describe dynamic photos, a partially implemented example of a public artifact. I close by summarizing several design points that we need to think about when considering computers as public artifacts, and indicate how the dynamic photo example responds to these points.

I caution that the ideas expressed here are still in the early stages. They are somewhat scattered, incomplete, and (in many cases) formed from subjective experiences. Similarly, the system described at the end is just in its formative stages and is incomplete. Instead of providing answers, my purpose in this paper is to encourage discussion in the design community about computers as public artifact, and to begin this discussion by speculating on design issues.

Related Ideas

There are a variety of ideas in the literature that contribute to the notion of computers as public artifact. Each idea either contains some aspect that considers a device as a public entity, or focuses on a particular property that affords public behavior around a device.

Weiser [1991] suggested that the history of computing can be thought of occurring over three waves. The first *mainframe* wave had one (very expensive) computer shared amongst many people. However, this sharing was not a public thing: through batch processing, people first took turns having exclusive use of the computer, while later versions provided time-shared systems that gave each user the appearance that they were the sole user of the computer. The second (and current) wave is *personal computing*, where one person typically has one computer e.g., a workstation or laptop. While sharing does go on internally (through email, groupware, and other software packages), the computer itself is designed to be viewed and used by one person at a time. The third wave, just beginning now, is *ubiquitous computing* where one person has many computers [Weiser 91]. Of particular interest to me is that ubiquitous computing implies that our many computers will be doing very different things. Some will be crafted as quite personal devices, such as the personal digital assistants (PDAs) that are now available. Other devices will be quite public, such as large wall sized displays seen and used by groups. What is important is that ubiquitous computing allows for computers to become untethered from their owners i.e., while one person can have many computers, many people can also share one (or more) computers. Because of this, I contend that some of these devices will be designed to be seen, heard and used by many people. That is, ubiquitous computing embraces the notion of computers as public artifacts.

Related to the idea of ubiquitous computing is *calm technology* that "engages both the center and the periphery of our attention, and that moves back and forth between the two" [Weiser and Seely Brown 1996]. Most of today's computers demand that they be in the center of our attention: they only work if we are looking at the screen. In contrast, technology that supports peripheral attention means that we can sense what is going without attending to it directly. This technology becomes 'calm' when it recedes into the background, becoming almost invisible unless some event attracts attention to it or when a person consciously decides to bring it into the center of their attention. This idea is part of our everyday lives: we easily and often unconsciously ignore, hear, or act on

background sounds; we notice and selectively attend to motion seen by peripheral vision; our eyes linger on particular things as we scan our surroundings; and so on. However, I contend that an interesting phenomena happens when computing devices are designed for the periphery: whatever they display will diffuse into the surrounding space. If these devices are located in a public space, they can be peripheral not only to a particular user, but to all who inhabit the space.

Computers that act on the periphery can manifest themselves in a variety of ways. As *everyday sounds*, information is translated into caricatures of naturally occurring sounds that are played (either continuously or discretely) when appropriate [Gaver 1986]. As *large displays*, information is projected onto a public screen. This can be done by having a conventional desktop interface appear on the large display, or by portraying information in a more abstract form as a mural [Winograd and Guimbretiére 1999]. As *tangible bits*, information appears as an everyday physical object or architectural surface [Ishii and Ullmer 1997]. Finally, as *ambient display media*, it appears as physical things that have ambient properties i.e. that somehow surrounds us: light, sound, airflow, and water movement [Ishii and Ullmer 1997]. I contend that all these manifestations are much more amenable to considering the computer as a public artifact when compared to traditional computers. Sounds can be heard by people not in line-of-sight; large displays are viewable at a distance; tangible bits imply that the many (perhaps redundant) objects that populate a space can exude information; and ambient display media creates a shared information ether.

There are a variety of example systems that illustrate these concepts and how they work as public artifacts. The Dangling String, created by Natalie Jeremijenko, is a plastic string attached to an electronic motor that hangs from the ceiling [Weiser and Seely Brown 1996]. The motor is connected to a nearby Ethernet, so that the motor (and thus the string) twitch whenever a network packet goes by. Its motion and sound increases with network traffic. Nearby people see the string, and people in nearby offices and out of line-of-sight can hear it. Ishii and Ullmer's ambientRoom [1997] translates web site hits to the sound of raindrops hitting the roof of their specially designed room. While they do not discuss its public properties, it is self evident that all people in the room or close to it hear the rain. Similarly, they reflect light patterns onto the ceiling of a room which in turn can be detected by all those in the room. Jancke, Grudin, and Gupta [1999] position a large display on a side wall in a seminar room, where the visuals show both the seminar presenter and the local audience who is attending remotely. Remote people are represented as a mural of individual icons, photos, or video stream. Their evaluation of their setup indicates a tension between making things readily observable in the foreground (but risking distraction) vs. part of the background (and therefore missed). Somewhat related, in the AROMA project Pederson and Sokoler [1997] map activities of people into abstract representations which are in turn displayed on a variety of devices. Their examples include how activity is mapped onto the rotational speed of a merry-go-round, the sound levels of a sea shore soundscape, and the speed of drifting clouds on a large public display. As with the previous systems all will be seen and heard by people in the space. Of course, there remains questions on whether people in the space can perceive and interpret the public information appropriately, but this (hopefully) is what good design will solve.

Experiences

I formed the notion of computers as public artifact over time through a series of personal experiences. Several of these are recounted below as stories, along with my thoughts about what I learnt from them. I will begin with stories concerning the use of traditional everyday computers and objects, followed by stories of how we found ourselves using a media space containing specially-designed devices.

Experiences with everyday computers and objects

The first set of anecdotes describes experiences using everyday computers and objects. While each story and lesson differs, they all illustrate how: the public use of a device is heavily affected by how they fit within the ecology of the space; how they are perceived by the people who inhabit the space; and the normative practices that have evolved around them.

The traditional computer as isolator. My home office is typical of many. The computer is located on a desk in a crowded space (our spare bedroom). When I (or anyone else) work on the computer, my back is to others who enter the room. Thus there is no public face to this computer. Other people who enter the room cannot see what I am doing because my body is in the way. They do not look at what is on my display unless I invite them to do so, as it is somehow considered a private space. They (and I) view the computer as something that isolates: it is difficult to attend to both the computer and the visitor at the same time, and it is difficult for visitors to know what I am doing.

Lesson. The traditional computer inhibits public interaction around it. Consequently, I began to seriously reconsider the role of the computer in my home because it was starting to get in the way of how I interacted with others: this sensitized me to be aware of what was happening in the episodes below.

Playing games: Computers *vs.* Nintendo. My children and their friends also use the computer in my office for playing action games. They typically crowd around the computer. They jostle each other for space for control of the joystick and so they can see the display. When there are many children, some are physically pushed out of the small space, and eventually sit away from the computer. When parents enter the room, they cannot share what the children are doing unless they move some of the kids away from the screen.

In contrast, I have seen the same set of children play similar action games on a Nintendo set connected to a television located in a living room. Their play is quite different. They are comfortably scattered around the television, and they sit in locations and positions relative to the television that reflects their degree of involvement. The children often invite us (the parents) to watch them play, and we often do so: sometimes lingering for a few moments, sometimes sitting on the couch and watching for a longer time, sometimes even getting involved as players! As we walk by, we also notice what they are doing. We comment on games that are especially violent, or on maneuvers that are particularly clever.

Lesson. A device (computer or television) can, in spite of similarities of what it is used for, afford or inhibit public interaction by how it is located and positioned in our world. The television-as-video-game was far better as a public device because people position televisions for public use. This meant that with television: there was room for people to scatter around the display comfortably, both on the floor and on couches; the display was easily seen by all; the living room was already crafted as a natural thoroughfare; and as people walked through the room, they could notice what was going on and could (if desired) join into the game playing at various degrees.

Getting messages: email *vs.* answering machines. Retrieving email from a computer and listening to messages on an answering machine are conceptually similar acts. Yet when I do this at home, my family perceives these quite differently: email is seen as me doing work at home, while listening to the answering machine is seen as part of everyday family activities. These differing perceptions were odd, for my email and the answering machine both contained work and non-work

messages. On reflection, what actually happened was that email reading had no public face: I would disappear into the home office (see first anecdote above), and people did not share in any way with the email-reading activity. Even when people were in the same room they could not tell what I was doing, for the textual nature of email meant that it had to be looked at directly. In contrast, the answering machine had a very public face. Because it was located in the kitchen, all saw me move towards the device and activate it. Because it produced sound, all could hear the messages as they were being played, and all could comment on particular messages if desired.

Lessons. The computer as public artifact can be designed or positioned to let others know that people are about to use it (as the case when I move towards the answering machine and pressed its buttons), and that even seemingly personal information can be broadcast into the public space if appropriate (as when others hear my messages). Another lesson is that the ambient properties of a device's medium contributes to its public face: in this case, we saw that text on the screen does not afford easy sharing, while voice broadcast from the answering machine projects its information into the public space around it.

Making private work public. My graduate student laboratory is equipped with various workstations as well as a very large rear-projected Smart board with attached computer. Each student has their own workstation, and the Smart board is typically used for group discussions. One day, one of my student's computer broke down. Because the other workstations were in use, he continued his programming on the large Smart board over the next few days. Whenever I entered the lab during this period, I noticed what my student was coding, and we would often discuss the material that he was working on. On reflection, I realized that I rarely did this when he worked on his own computer.

Lesson. Exactly the same information, when made public, creates opportunities for interaction between people.

Experiences with a media space

This next set of stories come from a special media space designed by myself and Hideaki Kuzuoka [Kuzuoka and Greenberg 1999]. As with most media spaces, the system creates an 'always-on' video and audio channel between our offices. Unlike most media spaces, the video/audio/camera was located within an integrated small device called an *Active Hydra* unit, as pictured here. The unit could also detect the proximity of people to it, and other devices, called surrogates, could surround it to represent the activity of others. The role of these additional devices will be discussed shortly; a complete description of how the devices are designed, implemented, and how people interact over them is found in [Greenberg and Kuzuoka 2000]. For the stories below, what is important is that the system was built to support casual interaction between a local person and their remote collaborator, but we had not designed it (at least not explicitly) to be a public artifact used by several local people.

Creating a media space with a public face. The size of the Active Hydra unit meant that it could be easily positioned. In my case, I located it on my desk to the right of my computer. Although I had not realized it at the time, this position also meant that it was easily visible to visitors to my office. I observed that visitors would come in, notice the other person, and even wave or talk to the remote person. Over time, I found myself introducing visitors to my colleague via the media space as if he and I were actually sharing the office. This observation is similar to those of other media space users, who also noticed that visitors would sometimes come into a person's office only to talk to the other person visible in the media space [Dourish, Addler, Bellotti, and Henderson 1996]. In sharp contrast, I have used a media space that was seen as a video window on my computer display. Unlike the 'public' media unit located off the desk, the screen was perceived as a personal place. I rarely introduced visitors to others, and visitors did not interact with the remote person unless invited to do so.

Lessons. Media spaces are a particular variation of computers as public artifact: instead of publicizing information, the media space can become a public surrogate of remote people. In spite of this difference, the importance of earlier lessons of device location and positioning still apply. A new lesson is that remote people can become part of the local space through their public surrogates, to the point that the people around the surrogate react to the remote person using near-normal social practices.

Balancing awareness and privacy. Another aspect of the Active Hydra system above is that it tried to balance awareness and privacy by controlling what people could see in the media space [Greenberg and Kuzuoka 2000]. Our Active Hydra unit included an a ultrasonic sensor (seen as the two circular devices on top of the box pictured above) that measured how close a person was to the unit. We then adjusted what people could see and hear as a function of distance: when both were close to their units, they could see and hear the remote person clearly. As they moved further away, sound was disabled. Being further away switched the video into a glimpse mode, where only a brief flash of the remote office would be visible every several seconds. While both Kuzuoka and I were quite comfortable with 'always-on' video, we realized the importance of the privacy features when visitors were in the office. In my case, I had students come in for discussions, where it would have been inappropriate for Kuzuoka to overhear our conversation or for us to hear Kuzuoka in his office. However, the way I and the visitor sat in our office relative to the unit meant that audio was turned off, and he could not overhear our conversation. As well, it was fairly obvious when sound was on and off because our units (which had a cheap audio connection) produced a faint ambient noise when on.

Lesson. There are situations where we need to control the public face of computers. While this could be done explicitly by pressing buttons or equivalent (which also exists in this system), it is perhaps better done by having the devices react appropriately to implicit acts of people as they move through the environment (see also Buxton's [1997] discussion of *reactive environments* and *ubiquitous media*).

Balancing awareness and distraction. Another part of our media space are a series of devices that would indicate the activities of others [Kuzuoka and Greenberg 1999, Greenberg and Kuzuoka 2000]. One of

these devices was based on
a motorized dragonfly, purchased from a hobby store and pictured here. We modified the device to indicate activities (collected via sensors) of remote people: the dragonfly would be still if the remote person's office was empty; would flap its wings slowly if a person was in the office; and would flap its wings as quickly as possible if the person made large motions, such as when they entered or left the office. The device was problematic because it proved distracting: the quick flapping of wings generated sounds loud enough to be annoying, and the large motion of its wings made it hard to resist looking at it. Even the more subdued sounds during slow flapping proved intrusive over long term use. In contrast, we created other devices that were much quieter and had smaller motions. For example, a small toy figurine (pictured at the bottom of the Active Hydra unit) activated by a servo motor would rotate to face the front if a remote person was present, and towards the back if that person were absent; if the person moved about the office, the figure would rotate slightly. The result was a unit that balanced awareness and distraction: while its sounds and motions became part of the background sounds and sights, it was easy to notice changes in another's activity status.

Lesson. Devices with public faces must be carefully crafted to balance the information they provide at the periphery of a person's attention against the danger of being distracting, where they force themselves into a person's center of attention.

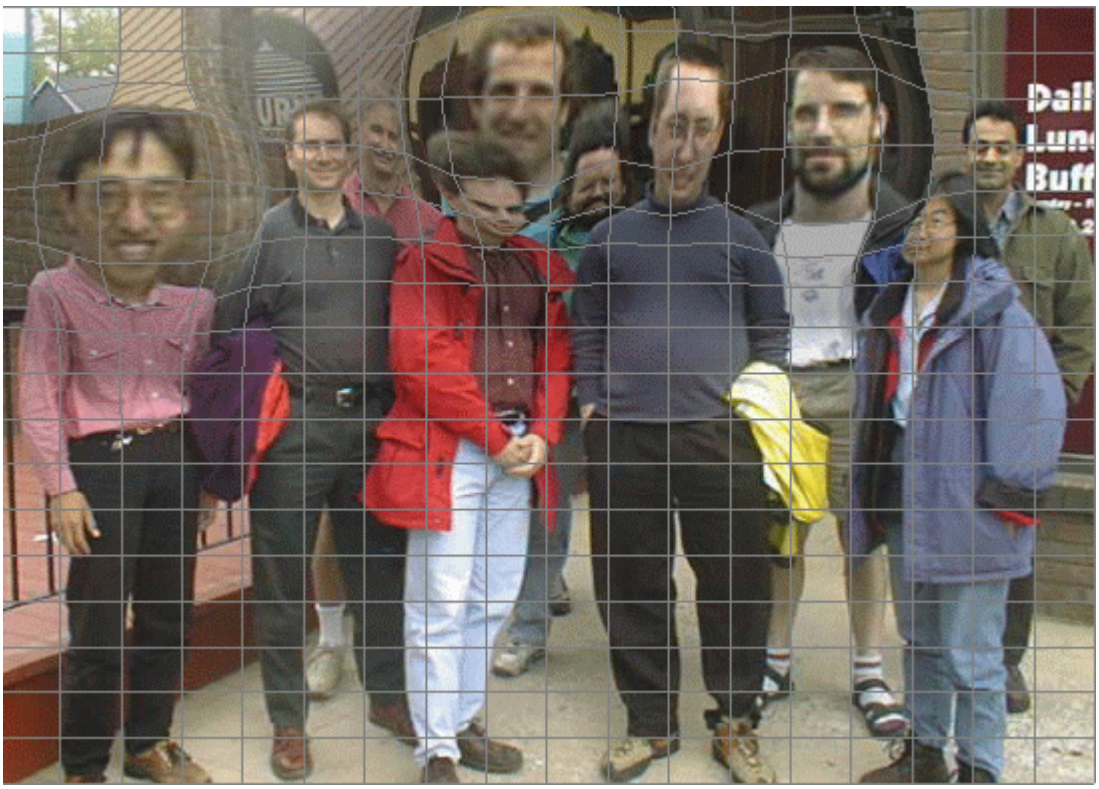
Example: Dynamic Photos

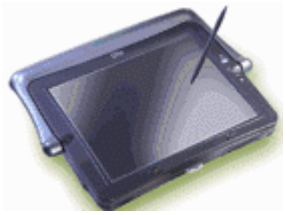
I am building a novel system called the *dynamic photo* (at time of writing, only small parts of the system are implemented and it is untested). Because I wanted this system to serve as a public artifact, I based its design on the insights gained from the previously discussed lessons. In this section, I will describe the system, using it as an example of how a public artifact can be built. In the subsequent section, I will discuss (after presenting a summary of the previous lessons) how the features of dynamic photos were derived from a lesson's design points.

The goal of the dynamic photo is to provide people who inhabit a shared space with information about the availability of other people (usually intimates) that are located elsewhere, and to let people move from that awareness into conversation. The groups could be office staff and telecommuters, dispersed families, even a clique of close friends (adults, teens, children). One idea, simulated in the figure below, is based on the notion of a photograph of the group hung on a wall in a public space (a shared office, a living room). The difference is that the photo is dynamic: it modifies itself to show the availability of the people in the image. If anyone walks up to the device and strokes a particular person in the image, the image is then replaced by a live video connection to that person.

To create the dynamic photo, we used the elastic presentation system built by Sheelagh Carpendale [Carpendale, Cowperthwaite and Fracchia 1995]. This system applies distortion effects to regions within an image. We simply loaded the system with an image of the people we were interested in, and indicated points on people's faces where the distortion would occur as a function of availability: the more available someone was, the larger their face in the image (as with the previous media space work, information on availability would be captured by sensors).

The three images below illustrate what the dynamic photo could look like for a given group of people and different levels of availability over time. (Note that we used the elastic presentation system to manually craft the fisheye effects in these photos; however, it is fairly straight-forward to do this automatically, where effects are applied in response to information received from sensors positioned at remote locations). This first image illustrates the undistorted image, which is what a person would see in the photo if no one was present or available for conversation. The second image shows what one would see when only one person was available: that person clearly stands out of the crowd. The third image shows a more complex scene when four people are available. The grid lines in the image are a graphical aid that help people visualize the degree of distortion [Carpendale, Cowperthwaite and Fracchia 1995].





To make the dynamic photo into a public artifact, we do several things. First, we display the image on a device that could be hung on wall: we are currently using a touch-sensitive Cleo CE machine with a 16x20cm display (www.vadem.com/cleo.com) as pictured on the right and on the very first image in this document. While not ideal (it is somewhat small and the screen is not very bright), the Cleo has several advantages. Its size and form factor resembles a picture frame, it is light enough to be hung on a picture hook, and it includes wireless capabilities. This means that people can easily position the device-as-photoframe within the public space so that it visible to all (the very first image above shows the Cleo hanging in a shared office an displaying a dynamic photo---note that this is a simulated scene). Next we add sound, where changes in state of a person's availability would be accompanied by subtle ambient sounds (perhaps distinctive everyday sounds associated with that particular person such as the low murmuring of their voice, or of footsteps approaching or fading away [Gaver 1986]). Finally, we remove security. Anyone can walk up to the photo, stroke the image of the person, and transform it into a video conversation. Of course, others can see that person approach the photo, and can see / hear any conversations over it in a way that is similar to how people interact with the Active Hydra unit.

Design Points

In this section, the lessons are recasted here as design points and summarized below. Each point is annotated by how the dynamic photo example has the potential to satisfy the design objective.

1. Computers can be untethered from their 'owners'. Consequently, we would expect some of our devices to become a group resource, where they are seen, heard and used by many people.

   In the dynamic photo example, the Cleo machine that implements the picture and frame is

not owned by anyone, and its location in the public space makes it a resource to the group.

2. Computing devices designed for peripheral attention diffuse their output into the surrounding space. When these devices are located in a public space, they can engage not only a particular user, but all who inhabit the space.

   As a dynamic photo hanging on a public wall, it should be positioned so that it maximises its use at the periphery. All should be able to see it, either directly or when walking by. Similarly, its sound level should be loud enough to be heard (but barely) by all.

3. Computers can manifest themselves as forms amenable to being a public artifact: sounds, large displays, tangible objects, and ambient display media including air, water and light.

   The dynamic photo uses a tangible form factor of 'device as picture frame', and a screen size that resembles that of photos hanging from the wall. However, the current Cleo device is not the perfect vehicle: it is too small; its sound is not particularly good; its screen is not bright enough to be seen over distance (especially in well-lit areas); and the visual clarity of the display is sensitive to the viewing angle.

4. The form of a device can have very different properties that affect their public face. Some require line of sight, while others do not (e.g., large displays *vs.* sound). Some are seen or felt uniformly by all who inhabit the environment, while others decay over distance (e.g., air motion *vs.* sound/large display). Because of physical constraints, some realistically allow only one or two of them to exist in the shared space (e.g., large displays) while others allow a multiplicity of devices (e.g., small tangible objects).

   It is entirely reasonable to have many dynamic photos within a single public space. The only constraint is on the sounds they produce, for while images do not compete with one another, sounds do.

5. Devices can afford or inhibit public interaction by how they are located and positioned in our world. Thus we must pay attention not only to the device, but how it is positioned within our world.

   As already mentioned, positioning the photo is instrumental to how it is used. If located within a person's private space (such as a cubicle), it is only available to that person and his or her visitors. In contrast, locating the photo in a hallway means it is available (perhaps inappropriately) to all who walk by.

6. Computers can be designed or positioned to let others know not only when a person is using it, but also when people intend to use them.

   We can notice others glancing at the photo. We can see when a person gets up and approaches the photo, and how they stroke the image to initiate communication with the remote person.

7. Publicizing information and work activities of people creates new opportunities for interaction between them.

   As a media space, the dynamic photo publicizes not only the activities of others, but also

how local people are using it (see point 6 above). This creates an opportunity for other local people to exchange information about the people in the photo, and to join conversations that are about to start or that are in progress.

8. Seemingly personal information can be broadcast into the public space if appropriate, for it gives others an indication of that person's activities and allows them to react to that information.

   The dynamic photo takes personal information --- the sensors that collect what another person is doing --- and abstracts this information to provide a public notion of availability. (See also point 10 for protecting privacy by balancing how personal information is publicized).

9. One application of computers as public artifact is as a media space, where we have to consider how remote people can be positioned, seen and heard so that they become part of the local space.

   It should be clear that the dynamic photo implements a media space. However, it is somewhat restricted in that the view of the group in the image is replaced by a video image of a single person when a connection is made. Thus it only partially satisfies this point.

10. There are situations where we need to control the public face of computers for privacy reasons. This could be done explicitly by pressing buttons or equivalent, or by having the devices respond appropriately to implicit acts of people as they move through and use the environment around the computer.

    We envision crafting the dynamic photo system so that remote people can control whether their availability is displayed to others, as well as who can access to this information. Perhaps it also implements something similar to the Active Hydra unit. When a person strokes the face of another, a video connection is established only if the remote person is made aware of the desire for communication and approaches their equivalent photo. When one person moves away from the photo, the connection terminates.

11. Devices must be crafted carefully to balance the information they provide at the periphery of a person's attention against the danger of being distracting, where they force themselves into a person's center of attention.

    There are many things that need to be fine-tuned in the dynamic photo: its size, the degree of the distortion effect (as large distortions may involve large movements of the image), the volume and composition of the sounds.

There is one further point worth making that is implied by many of the other points. Computers as public artifacts must be crafted to fit the ecology of the physical environment [Nardy and O'Day 1999]. They are not just screens and windows. Rather, they are devices whose form factor must match the surroundings of the public space, and whose location and position are adjusted (perhaps many times) by the people who inhabit that space until it matches their needs and desires.

Summary

In this paper, I considered the design of computers as a public artifact. I argued and gave examples

of why information held by particular computing devices should be seen, heard, and acted upon in an easy and natural way by the people who inhabit the space around the computer. I also suggested several aspects that are important to designing such devices.

I did not present answers to how this can be done. Rather, my goal is to sensitize other designers to think about the role of computers as public artifact, to begin the discussion by compiling this initial list of design points, and to provide a novel example of a system that tries to address these points (albeit imperfectly).

Acknowledgements. This research was partially supported by Microsoft Research and by the National Science and Engineering Research Council of Canada. I am indebted to Sheelagh Carpendale for providing her elastic presentation system as a way to create dynamic photos, and to my collaborator Hideaki Kuzuoka for his work on the Active Hydra unit. Discussions with Anoop Gupta helped spark some of these ideas.

References

Buxton, W. (1997). **Living in Augmented Reality: Ubiquitous Media and Reactive Environments.** In K. Finn, A. Sellen and S. Wilber (Editors.). *Video Mediated Communication.* Hillsdale, N.J.: Erlbaum, 363-384.

Buxton, W. (1996). **Absorbing and Squeezing Out: On Sponges and Ubiquitous Computing**, *Proceedings of the International Broadcasting Symposium*, November 13-16, Tokyo, 91-96. http://www.dgp.toronto.edu/OTP/papers/bill.buxton/sponges.html

Carpendale, S., Cowperthwaite, D. and Fracchia, D. (1995) **3-dimensional pliable surfaces: For the effective presentation of visual information.** In *Proceedings of the ACM Symposium on User Interface Software and Technology*, 217-226, ACM Press.

Code, K. (1995) **Equality issues in computer-based collaboration: Looking beyond surface indicators.** In *Conference on Computer Supported Collaborative Learning* (CSCL'95), 67-74, Lawrence Erlbaum Associates.

Dourish, P., Addler, A., Bellotti, V. and Henderson, A. (1996) **Your Place or Mine? Learning from Long-Term Use of Audio-Video Communication.** *J. Computer Supported Cooperative Work*, 5(1), 33-62

Gaver, W. (1986) **Auditory Icons: Using Sound in Computer Interfaces.** *Human-Computer Interaction* **2**(2) 167-177.

Greenberg, S. and Kuzuoka, H. (2000) **Using Digital but Physical Surrogates to Mediate Awareness, Communication and Privacy in Media Spaces.** Personal Technologies, **4**(1), January, Elsevier. In press.

Inkpen, K., Booth, K., Klawe, M. and Upitis, R. (1995) **Playing together beats playing apart, especially for girls.** In *Conference on Computer Supported Collaborative Learning* (CSCL'95), 177-181, Lawrence Erlbaum Associates.

Ishii, H. and Ullmer, B. (1997) **Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms.** In *Proceedings of ACM CHI 97 Conference on Human Factors in Computing*

Systems, 234-241, ACM Press.

Jancke, G., Grudin, J. and Gupta, A. (1999) **Presenting to Local and Remote Audiences: Design and Use of the TELEP System.** MSR Tech Report 99-71, Microsoft Research. http://www.research.microsoft.com/coet/

Kuzuoka, H. and Greenberg, S. (1999) **Mediating Awareness and Communication through Digital but Physical Surrogates.** *ACM CHI'99 Video Proceedings* (7 minute video) and *Proceedings of the ACM SIGCHI '99 Conference Extended Abstracts* (two page summary). ACM Press.

Nardi, B. and O'Day, V. (1999) **Information ecologies: Using technology with heart.** MIT Press.

Nardi, B. (1993). **A small matter of programming: Perspectives on end-user computing.** MIT Press.

Pedersen, E. and Sokoler, T.(1997) **AROMA: Abstract representation of presence supporting mutual awareness.** In *Proceedings of ACM CHI 97 Conference on Human Factors in Computing Systems* 1997, 51-58, ACM Press.

Weiser, M. (1991) **The Computer for the Twenty First Century.** *Scientific American*, 94-110, September.

Weiser, M. and Seely Brown, J. (1996) **Designing Calm Technology.** *PowerGrid Journal*, Version 1.01, http://www8.electriciti.com/1.01/

Winograd, T. and Guimbretiére, F. (1999) **Visual Instruments for an Interactive Mural**, In *Extended Abstracts: ACM Conference on Human Factors in Computing*, 234-235, ACM Press.