On Ambient Information Systems: Challenges of Design and Evaluation

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1 Abstract

The rise of the Internet, the ever increasing ubiquity of data, and its low signal-to-noise ratio have contributed to the problem of information overload, whereby individuals have access to more data than they can assimilate into meaningful and actionable information. Much of the success of Web 2.0 has been achieved after an effective tackling of this problem. Ambient Information Systems take the battle into the physical world by integrating information into the physical environment in a non-intimidating and non-overloading fashion. After two international workshops on Ambient Information Systems, we outline our vision for the field, consolidate a new definition, identify the key concerns of the research community, and issue a call to arms for future research.

2 Introduction

Various multimedia and Internet technologies have fueled strong cravings for information within our culture. Today the average American spends more time using various information communication technologies (ICTs), such as personal computers, cell phones, iPods, television, radio, etc., than any other activity throughout the day (Papper, 2005). About 30% of the day is spent with such ICT usage as the *sole* activity versus 20.8% spent on work activities, while an additional 39% of the day is spent using ICTs along with some other activity (ibid.). Such frequent use of ICT stems from an emergent desire to be constantly informed, and always aware of what is occurring around us. Anecdotal evidence supporting both the pros and cons of this hunger for information have been discussed, with some touting the advantages of being always connected versus others claiming a pseudo-attention deficit disorder emerging among the populace (Richtel, 2003). Regardless of the possible benefit or detriment, the world is moving toward greater and greater quantities of information being made available; the important question is *how* people can effectively manage so much information without feeling overloaded. Similar problems have been addressed for Internet users with information

filtering, aggregation, and personalization (cf. Brusilovsky et al. 2007), but since Ambient Information Systems (AIS) are deployed physically in the world around us they require different ways of thinking about how to handle information overload.

Recently there has been a shift in the way people interact with digital information from the exclusive domain of the desktop computer to the laptop, phone, and handheld video game console. As display and computing technology continue to become widely available, it is inevitable that users will be able to interact with information on everyday household devices that up to now have not had this capability. However, it could be that if digital information is allowed to constantly interrupt in all aspects of our daily existence, our lives could become more confusing and difficult. Smoothly integrating an abundance of information into the environment around us in such a way that it is available in a calm, non-intrusive, ambience is the central goal of AIS research. Successful AIS require consideration of information modeling and filtering techniques, the societal impact of information technology, the psychology of human attentiveness, user experience, and emerging technologies and materials. AIS is inspired by a number of earlier movements, and overlaps with many paradigms, including *ambient displays* (Wisneski et. al., 1998), *peripheral displays* (Matthews, 2007), *slow technology* (Hallnäs, 2001), *glanceable displays* (Stasko, 2007), *informative art* (Holmquist, 2003), *unremarkable computing* (Tolmie, 2002), and *calm technology* (Weiser, 1995). AIS make use of existing artifacts and physical spaces to integrate information so that is minimally distracting, but in some way perceivable even when not being directly concentrated upon. The classification of AIS are not restricted to the application of visual displays (as with peripheral displays), a particular level of efficiency (as with glanceable displays), scale of implementation (i.e. a single artifact vs. a large system of artifacts), or any particular type of hardware or software platform. Some recent AIS research investigates delivering information beyond the visual sense, using smell (Kaye, 2004), touch (Hemmert 2009), and sound (Hazlewood, 2008).

After two successful workshops on Ambient Information, with twenty oral presentations, two half-day discussion sessions, and engagement with a growing community of researchers, we have decided that it is time to consolidate the recent work of the

community in this journal special issue. Our goal in this work is to use our engagement with the community to refine a definition of AIS, examine the issues that arise in terms of design and evaluation, and provide a set of challenges for furthering research in this domain. In the following sections, we structure our definition by stating and elaborating the essential qualities of AIS. We follow by describing particular issues in both designing and evaluating this form of information delivery. We finish by laying out a series of grand challenges, which we feel are essential to further AIS research.

3 Refining A Definition of Ambient Information Systems

It is tempting to try to understand AIS technologies by thinking about possible information devices that could exist exclusively in the periphery of attention, but in daily life our focus of attention shifts frequently and there is no clear distinction between the periphery and non-periphery. Various information sources are constantly competing and shifting in and out of our field of attention, so it is misleading to consider any artifact as being exclusively ambient or non-ambient. Instead, AIS distinguish themselves in that they are designed in such a way that they may facilitate at least some degree of *ambient interaction*. More specifically, ambient interaction is a *property*, which allows some technologies to continue to provide at least some level of information transfer when not in the center of a person's awareness. This property may, or may not, be expressed within a particular artifact's design. Accommodating ambient interaction requires that information be integrated into the environment in such a way that it blends in, and does not cause unmanageable amounts of distraction. The degree to which an information source can facilitate interaction from the periphery is tied directly to its ability to be non-intrusive, intuitive, and easily ignorable when more important matters need addressing.

3.1 Levels of Attention

Artifacts can facilitate ambient interaction at varying levels depending on their relationship with the environment and the perceiver. In terms of interaction, a person's field of perception can be broken down into three realms of attention: primary, secondary, and tertiary (shown in Figure 1), and different designs can facilitate interaction differently within these fields. For example, let us imagine an author writing a

piece of text with a word processor. The word processor is designed to exist exclusively in the *primary* realm of attention while in use – it has no overt ambient character. By comparison, an instant messaging application, which might also be active, has some ambient capabilities and may facilitate interactions in the *secondary* realm of attention. As the instant messenger application sits on the edge of the screen one can subtly perceive the animations caused by people logging in and out. From the state of the avatar associated with each of those people, one can gain a low-level understanding of the status of all the contacts. These cues can be perceived indirectly, and one does not have to break attention from the primary focus of the word processor to access some of its information. In this scenario, the *tertiary* realm of activity occurs away from the screen. There are people walking the halls, doors opening and closing, vehicle traffic outside, the smell of coffee, cold air from the vent, and the sunlight shining brightly through the window. These sensations provide information (useful or not) about the overall environment.

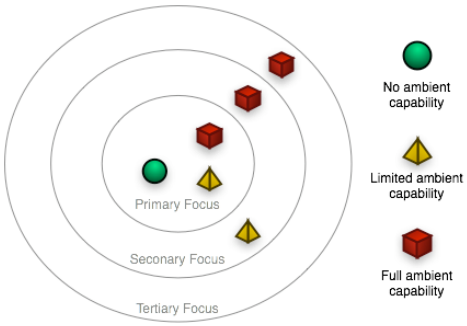

Figure 1: ***Artifacts can facilitate different levels of ambient interaction, allowing them to exist in different realms of attention***

One of the goals of AIS research is to better understand these secondary and tertiary realms of attention so that we may make better use of them in the AIS design process. In order to reduce ambiguity over the concept of ambience we prefer not to consider AIS as existing exclusively in any one of these realms of attention. We prefer to think of good *ambientness* in a technology as its ability to shift forwards and backwards between these realms of attention. Some implementations may have features that enhance or reduce this ability. For example, the instant messenger application has a *limited* ambient capability. It can be used directly in the primary realm of attention, and can shift into the secondary realm and still provide a level of information. However, it is not clear that it can offer

anything from the tertiary realm.

3.2 Integrated vs. Embedded

We believe it is important to understand a distinction between *embedding* information into, and *integrating* information with, the environment. Embedding involves attaching a new information artifact on, in, or next to an existing space or artifact. For example, Samsung has proposed a smart-fridge, which combines a tablet computer and a refrigerator. The tablet has been *embedded* into the refrigerator, and can provide useful information, but does not constitute *integration* since the original components can still be considered separately from one another. In contrast, Figure 2 illustrates a project entitled "Open Source", which exemplifies full integration between information and the surrounding environment (Mehin et. al., 2004). The designers propose the use of a special color-changing concrete impregnated with a thermo-reactive pigment that reacts to digitally controlled heating elements hidden inside. This project suggests using this concrete to create a large community space that changes based on the activities taking place. In such a space it is difficult for people to distinguish the community space from the information it delivers. From a person's perspective, the information is the space and vice versa.

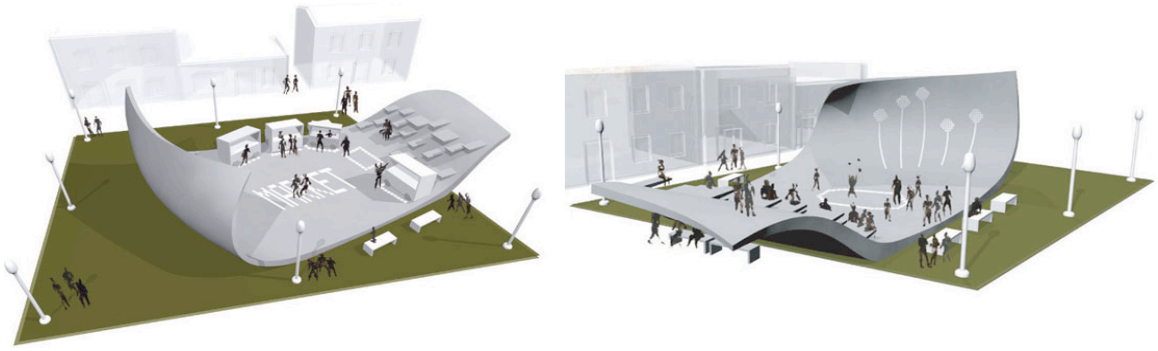

Figure 2: Open Source[1]. A conceptual design for a community square in which color changing concrete is used to display information based on the activities taking place.

3.3 *Non-invasive, Ignorable, and Low Cognitive Load*

One of the major goals of AIS is to saturate the environment with pieces of potentially

[1] http://afshinmehin.com/open_source.htm

useful information without overwhelming people with more information than they can handle. To avoid overload, the information must be designed to be noticeable only when it is relevant to the observer, and nearly imperceptible otherwise. As an example, consider the History Tablecloth (Figure 3, left), which is an electronically enhanced tablecloth designed to cover a kitchen or dining room table and provide a general notion of how the space is utilized by illuminating in the places where objects are placed (Gaver et. al, 2006). When an object is placed on the tablecloth a visual halo appears that expands very slowly, and when items are removed the halo begins to fade away. The effect is that people are able to see not only where things are, but also where they had been. People using the table over time can begin to understand more deeply how they make use of this particular surface in their home. The effect of the tablecloth is that people may notice the patterns it displays when they are considering their use of their dining room table, but people are still able to carry on their typical dinner activities, and ignore the tablecloth's information if they do not find it of any use.

Figure 3: The History Tablecloth[2] (left) has a pattern of embedded electroluminescent material that begins to glow when objects are placed upon the surface. When objects are removed the pattern begins to fade slowly. The SmartSwim UV Intensity Bikini[3] (right) uses UV sensitive materials to warn against excessive exposure to the sun.

Another good example where information is provided at minimal cognitive cost to the observer can be found with Solestrom's SmartSwim UV Intensity Bikini (SmartSwim, 2008). This is a typical bikini adorned with special beads that turn dark based on the

[2] http://www.equator.ac.uk/var/uploads/proposals_tablecloth.gif
[3] http://infosthetics.com/archives/uvbikini2.jpg

mount of UV rays they are subjected to. UV rays are the major factor that leads to harmful sunburns, not the brightness of the sun, as some may believe. In this example, the bikini wearer and those around her can be constantly aware of their risk of acquiring sunburn, with no distraction.

4 The Design of Ambient Information Systems

The design of AIS is highly complex due to the large number of different dimensions (cultural, spatial, aesthetic, technical, etc.) that have to be accounted for when presenting information ambiently. The ambient property of an AIS is not "used" so much as simply perceived and digested in the background of our awareness, and the experience of an ambient display is largely a result of its interaction with its surroundings and its references to cultural practices and preconceptions (Offenhuber, 2008). If information is successfully delivered in an ambient way, we do not expect that anyone would consider the information provided for longer – or any more deeply – than a sign on the road as it passes by. However, the way the information is presented is paramount to its plausibility as an ambient source. The success is in the details, in this case, the design of the medium in which the information is presented.

In the context of AIS, the value of proper design goes beyond simply making the information functional or beautiful, and contributes to both the *integration* of information into the environment (so as to be ambient), as well as one's *interpretation* of the information (so that it is perceived and digested appropriately). As discussed earlier, integration requires a blending between an existing artifact or physical space, and a new information medium. Any artifact or physical space has an existing set of inherent aesthetic attributes. The ways in which we can manipulate and appropriate these attributes have been studied at length in the disciplines of design and architecture, but are new territory for most technology related disciplines (e.g. Human-Computer Interaction).

Forlizzi, et al. (2001) alludes to the growing necessity for deeper analysis of information aesthetics by pointing out that the value of information technology is measured less exclusively in terms of its functionality in solving problems of interest. Now that computational technology is being applied beyond the – mostly utilitarian – business

environment, we have begun to see traits such as *desirability* become just as relevant as *usefulness* (p. 141). Technologists have to consider not only whether their implementation works, but also whether it "goes with the couch" (ibid.). Without appropriate aesthetic considerations the technology will always "stick-out," making true ambience more difficult.

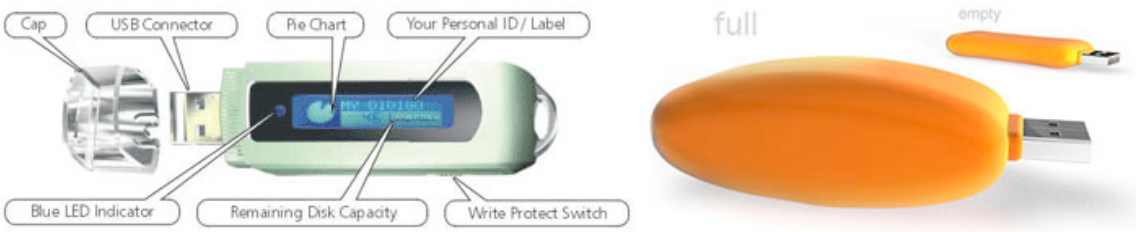

Figure 4: ***Comparison of the "SmartDrive[4]" (left) and "Flashbag[5]" (right)***

Proper design considerations are also important in determining how information is perceived, and simply presenting information as-is is not a sufficient condition for the success of an AIS. There is a symbiotic relationship between information and the medium used to deliver the information (McLuhan, 1967). McLuhan posits that the aesthetic characteristics of a particular information medium will have a significant effect on one's understanding (or interpretation) of the information presented. This relationship between information content and media means that the design attributes for a particular information technology (i.e. AIS) are not necessarily trivial or subjective, and have a serious impact on the success or failure of a particular implementation. However, the proper use of such attributes in terms of ambient information design has not been thoroughly explored. As an example where different design strategies have been applied to convey the same information, consider Dima Komissarov's Flashbag (Figure 4, right) and Didigo's SmartDrive (Figure 4, left), two flash storage devices that advertise their free capacity. The Flashbag is surrounded by a small rubber bladder that inflates as it "fills up" with data (Kormissarov, 2006). The designer states that the purpose of the Flashbag is to allow people to perceive how much space is left on their drive by sight and touch. In contrast, the SmartDrive provides similar functionality through the use of an E-ink display that shows a pie chart representing the available storage space (Didigo, 2006).

[4] http://www.ubergizmo.com/photos/2006/1/didigo-smartdrive.jpg
[5] http://www.plusminus.ru/flashbag1.jpg

Both devices convey how much storage space is available, but their choice of information presentation gives the products different levels of ambientness. We would argue that the design attributes of the Flashbag allow it to facilitate ambient interaction on more levels and in a more intuitive manner with lower cognitive load of interpretation than the SmartDrive. The Flashbag allows one to be aware of data storage capacity simply by the way it feels inside the pocket, or by glancing at it from across the room, where the SmartDrive requires a specific, intentional, visual inspection of the embedded display.

5 The Evaluation of Ambient Information Systems

In an HCI laboratory, any kind of measured task completion has some confounding effect on what is being measured. With typical information technologies, researchers are able to account for the effects of artificial environments, or tasks, by separating out the effects of the lab setting from the valuable bits of information that are independent of the simulated environment. For example, a researcher can single out a particular research problem (e.g. sharing information between two people), develop a solution for solving that problem (e.g. a new data sharing paradigm), and measure how well people are at applying the solution to successfully evaluate the solution (e.g. time taken to discover a function or feature, awareness that a file has transferred, ease of accepting/viewing an incoming file). The researcher can construct a set of tasks for the user to complete, and if the results are good, the researcher knows that when a person needs to share information with another person using the provided software, there is a strong possibility that the person will know what to do. With AIS technologies however, we cannot understand their effects until we can be sure that the observer is in no way perceiving them directly. To perform an HCI lab study on an AIS implementation, a participant would have to be introduced to the AIS so as to understand its function, and then asked to conduct a separate task that would distract them enough to *force* the AIS into their peripheral attention. But what exactly do the results from such a study tell an AIS researcher other than that people are *capable* of detecting some level of ambient information? The ability of such a study to inform researchers as to how AIS integrate into the environment, and whether or not people can make good use of them, is questionable since *having the distractions of one task obscure an information channel is not the same thing as having that information live naturally in the periphery*. The lab scenario is akin to asking if one is capable of concentrating on two

conversations at the same time, but this is a very different proposition to asking whether or not they can or will make use of extra information transmitted to them by an AIS that is embedded into the environment (such as the ability to process and use SmartSwim's UV levels). Traditional HCI user interface evaluation methodologies can tell us about the quality of a specific AIS implementation (i.e. *could* it work), but because AIS are designed to be subtle, and primarily used indirectly in everyday environments, these methodologies do not give enough insight to help predict how one of these technologies is experienced in an actual context of use (i.e. *does* it really have any effect).

This is not to say that typical usability methods are unnecessary. Usability studies tell us whether or not certain features are possible, for example, whether a person is at all capable of detecting subtle changes in movement, shape, or color, of a particular design. However, by their very nature, these technologies cannot function as intended until they have properly blended into the fabric of the observer's everyday environment, and to say anything meaningful about AIS will require researchers to go beyond simple usability by moving out of the lab and conducting studies in-situ. In order to progress research in this domain, new frameworks and evaluation methods which focus on studying the use of AIS in the wild have to be constructed to give researchers deeper insights on how people make use of the information provided. Some good examples of existing in-situ research on studies of AIS include (Stasko, 2005), where highly personalized information displays were observed in participant's offices, (Hsieh and Mankoff, 2004), where a usability/distraction/awareness framework was used to evaluate an AIS developed to filter email, and most recently, Matthew's thesis (2007), which provides a great deal of useful information regarding the design and evaluation of peripheral displays. However, this area of study still suffers from an overall lack of research due in part to the difficulty involved in creating user studies for this class of technology (Carter and Mankoff, 2004).

6 Future Directions for Ambient Information Systems

From our engagement with the community, we can see that furthering research in AIS requires several challenges be addressed in both designing and evaluating implementations.

6.1 Challenges for AIS design

Even though we have many of the tools necessary for building AIS implementations, including sensors, smart materials, and communication protocols, a greater understanding of the issues specific to *design* needs to be developed so that we can understand how these tools can be applied to construct technologies that facilitate ambient interaction. We propose the following challenges be tackled in order to expand our thinking about AIS technology:

- Analyze the relationships between design attributes (i.e. the visual mechanisms, tactical qualities, sounds, smells, metaphors, cultural aspects, etc.) used to present information, and their use in the development of different AIS implementations. For example, in what ways might tactile sensation facilitate an ambient awareness of storage capacity as with the FlashBag?

- Develop new AIS design methods derived from perspectives and approaches employed by different academic disciplines. The development process conducted by an industrial designer may be very different from how an HCI researcher, or a digital artist, but these different processes may inform each other if the knowledge and processes could be successfully shared across disciplines.

- Experiment with novel types of content in everyday living. On the beach it might be useful to know the current UV level, as with the UV Sensitive Bikini; likewise AIS seems ideally placed to provide for the growing public awareness and demand for information about personal carbon footprints and energy consumption.

- Discover new applications of ambient information. AIS that inform us about weather, stocks, and email traffic have obvious utility, but new forms of information may also be useful if presented in an ambient fashion. For instance, the History Tablecloth allows people reflect on the use of a table within the home (i.e. eating, studying, socializing, etc.). This information may be drawn upon when people are deciding how to rearrange their home, plan a party, or remember where their spouse usually keeps their keys.

6.2 Challenges for AIS evaluation

Currently there are few widely accepted metrics for evaluating the success of AIS. As we have discussed, these technologies are unusual in their use, and typical HCI evaluation methodologies do not tell us all that we need to know to adequately judge the success of AIS. It is important not only to know if information is perceived, but we also need to know whether people appropriate the information at all. We suggest that AIS researchers focus the development of evaluation methodologies that can:

- determine if onlookers perceive information provided by an AIS as intended, and whether they are able to appropriate the information provided
- describe how, and to what extent, people's behavior are being influenced by the information provided by an AIS
- measure the level of distraction produced by an AIS in different circumstances
- characterize the effects of a given AIS in terms of user experience

7 Conclusion

We envision a world in which every object and surface is capable of providing at least some additional layer of information. The only way this will be acceptable is if the information can be presented without overwhelming or annoying the people we are trying to inform. In this work we have developed a definition of Ambient Information Systems, and discussed issues in both the design and the evaluation of such technologies. We have issued a set of challenges that we believe must be undertaken to further the growth of AIS research. However, it is clear that this list is not exhaustive and in time new challenges will be exposed. We hope that more researchers will see that AIS are a viable and important technology that will become increasingly necessary in a society with growing appetites for information, and step up to the challenges we have set forth.

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