Workshop at Pervasive 2007
Designing and Evaluating Ambient Information Systems

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Layout by Heekyoung Jung

Preface

The concept of calm technology, introduced by Mark Weiser, has led researchers from several disciplines to explore new and unconventional ways of conveying information. Some well-known examples of such novel information techniques include Ambient Devices' Stock Orb, Koert van Mensvoort's Datafountain, Violet's Nabaztag, Jafarinami et al.'s Breakaway, Mynatt et al.'s Audio Aura and Digital Family Portrait, Mankoff et al.'s Daylight Display and BusMobile, and Natalie Jeremijenko's Dangling String. Applications such as these, that publish information in a non-intrusive or calm manner are Ambient Information Systems.

The *1st International Workshop on the Design and Evaluation of Ambient Information Systems* was held in Toronto, Canada, on May 13th 2007, in conjunction with the 5th International Conference on Pervasive Computing. The goal of this workshop was to bring researchers together to discuss this domain of growing interest in both pervasive computing and human-computer interaction. This domain is described by mechanisms that are minimally attended and perceivable from outside the range of a person's direct attention, providing pre-attentive processing without being overly distracting. Developing new technologies such as these poses new and difficult challenges. These technologies display information outside of a person's direct attention, which is a space that is not currently well understood, making it difficult to evaluate their effectiveness. A great deal of care is required to design studies which accurately observe the effect of ambient devices, particularly since the test subjects are not meant to observe them directly. After all, how does one provide a subject with a device and say, "I want you to use this, but please do not think about it?" Our workshop sought to gather perspectives from researchers in the field on these and other problems. Eleven excellent submissions were accepted which describe works-in-progress, frameworks, taxonomies, methodologies, evaluation paradigms, and case studies, and are published here.

We would like to thank the Program Committee for their numerous contributions to this workshop and Heekyoung Jung for creating the workshop's website and for assembling this booklet. We would also like to thank our keynote speaker, David Rose of Ambient Devices, and all of the authors of position papers, the participants at the workshop's discussions, and the workshop attendees.

"The most profound technologies are those that disappear. They weave themselves into the fabrics of everday life until they are indistinguishable from it." - Mark Weiser

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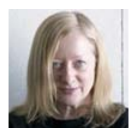
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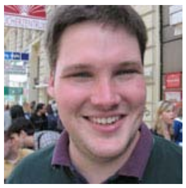

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Sunny Consolvo is a member of the research staff at Intel Research Seattle. Her focus is in applying human-centered design to ubiquitous computing. She is currently working in the areas of ubiquitous technologies to encourage people to be more physically active. She is also investigating the social implications introduced by behavioral monitoring technologies. Sunny has recently worked with location- enhanced technologies and aging in place.

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A time to glance: Studying the use of mobile ambient information

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ABSTRACT

Recent work by our group at Motorola Labs has focused on applying the principles of ambient interfaces to the domain of mobile communications. Our methods incorporate both formative ethnographic studies and field evaluation of prototypes to investigate how people make use of ambient information in the course of everyday communication. Our goal is to enable applications that provide rich presence information for close friends and family that is appropriate to their particular tasks and social conventions. In this paper, we briefly summarize the results of two prior field studies of ambient awareness on mobile phones: shared motion presence and music listening history. We then discuss our current efforts in context-aware photo sharing on the phone. Together, these studies provide insights about how people understand, use, and contextualize presence information. We also show how this information helps people stay connected and strengthens relationships. We hope to use these insights to establish how contextual information can be gathered, synthesized and displayed to more effectively promote connectedness.

Keywords

Ambient information, mobile devices, field studies, photo sharing, presence

INTRODUCTION

To date, researchers have found some success in the development of ambient information tools for such environments as the home and office. These settings are characterized by situations where there is a high potential for users to be distracted from their primary activities by any number of environmental or social sources. Ambient interfaces allow these sources to communicate information in a lightweight, non-distracting manner and can be attended to selectively by users. We see similar benefits gained by applying ambient interfaces to the mobile space. Whether in transit or a foreign environment, there is a need for users to maintain contact with friends and loved ones despite having limited attention or a limited ability to interact with their devices (*e.g.*, while driving) [11]. For us, ambient mobile interfaces include additional information that is displayed in the context of normal use of the device that informs a user about the state of others or his/her environment.

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We see ambient mobile communications as a means of maintaining connectedness with close friends and family with minimal interaction. By viewing small pieces of real-time contextual information about one another, people can feel a greater sense of presence despite hectic schedules or geographic distance. This information could include music listening history, location/motion, recent photos taken, or one's current mood. In addition, the lightweight interactions of viewing this information can enable more focused, opportunistic communications.

By studying how people make use of a diverse range of shared contextual information, we ultimately hope to build interfaces that will combine and display the information that is most relevant to the needs of friends and loved ones for managing and maintaining their relationships. To this end, we conduct field studies examining when and how often people check this information, how they interpret it, and whether they use it to strengthen relationships (*e.g.*, to initiate further communication with a phone call).

In this paper, we will review the results of some of our work on mobile ambient communications, reporting on field studies of both motion presence and music sharing prototype applications. We will also discuss our current work on ambient photo sharing, as well as some future directions we plan to explore in the coming months.

RELATED WORK

Our work has been influenced by several existing systems. WatchMe [6] allows people to view the current location and mode of transportation of a contact and send him/her a lightweight "smile". The Socialight [7] suite of

Figure 1 A message inbox with Music Presence information.

applications allows a user to remotely "tap" a contact by making his/her phone vibrate for some length of time. In addition, users can register for notifications when a friend is within some threshold of distance from them. Systems such as those developed by Vetere [11] and Kaye [4] allow intimate users to communicate in lightweight ways throughout the day.

While our focus is to support existing close relationships between people, other systems use context such as proximity to allow users to access information about less familiar others in their environment. DigiDress [8], allows users to browse public profiles of people in their vicinity providing for potential communication with strangers.

PAST PROJECTS

We believe that the best way to understand ambient mobile applications is to observe their use in real social situations. Over the past year and a half, we have been implementing and field testing ambient mobile presence applications. In this paper we will describe two of these applications, Music Presence and Motion Presence, and then discuss the situations in which they were used by our participants.

Music Presence

The music presence system allowed mobile phone users to see title and artist information for songs that their friends were playing at home. We conducted a preliminary field study with a group of four college-aged friends in the Chicago area to test the concept using a rough prototype implementation. All participants installed an Audioscrobbler[1] plug-in for their music-playing application of choice. A server would monitor the stream of songs played (as recorded by Audioscrobbler) by each participant and send SMS messages to each of their friends whenever they played a new song. At any time, participants could open the messaging application on their phones and see a list of the latest songs played (as seen in Figure 1). Messages started with the initials of the friend followed by

[1] Now named Last FM: http://www.last.fm

Figure 2. The Motion Presence Java Application

the song title and artist name, allowing them to be seen at a glance from the messaging application. Many phones also display the most recent message on the external display, so in these cases, participants could see a part of the message without having to open the messaging application.

Participants used the service on their own phones for one week. In addition, they left voicemail diaries documenting their use of the system, and participated in two brief interviews during the study, with a longer final interview at the end of the study.

Motion Presence

The Motion Presence application (Figure 2) detected when a user was in motion between places (*e.g.,* driving home from work or walking to the grocery store), and conveyed this information to close family or friends through an augmented phone book application. Whenever a user entered this phonebook, they could see at a glance if their close family or friends were in one place or moving between places and the amount of time that they had been in that state. We used GSM cell ID information to determine when a participant was in motion, and these changes matched well with participants' own concepts of "moving."

We deployed this application to a total of 10 users from the Chicago area, three couples and one group of four friends. To understand use of the application and explore privacy concerns raised by sharing motion information, participants used the application for two weeks, left voice mail diaries, and participated in two interviews with researchers. The application and study are further explained in [3].

WHEN PARTICIPANTS CHECKED PRESENCE

Our work in mobile presence for music and motion has taught us a great deal about how presence information is used in a mobile setting. There are three types of occasions when users in both of our studies checked their presence applications: micro-moments, when bored, or when seeking interaction. Most use of both systems either occurred on weekdays when participants did not consider themselves to be "busy" or when they had a specific purpose for viewing the information.

Micro-moments

We often found our users checking on the status of others in small breaks during the day, similar to the breaks that Anttila and Jung noticed in mobile media usage [1]. These micro-moments are characterized by short (~10 second) time periods when attention can be taken away from a current task. For two of the participants in the music study, this even occurred when short conversational breaks occurred in light conversations with others. Caroline[2] was spending Father's day with her family and "we were just casually talking…it's appropriate to check then." Dean also checked on the music playing of his friends. He told us that "when I wasn't doing anything, I might be with people but not actively engaged in conversation, then I could like go through [the messages]". In these cases, our participants were using idle time or pauses in social interaction to learn more about their friends' music tastes as well as to infer other information (*e.g.*, whether they were home, their mood, *etc.*).

Abigail reported checking her phone during these micro-moments at her data entry job where "I stare at a computer all day, so I figure it's better to stare at my phone. So I'd constantly go to my purse and check [the music that my friends were playing on] my phone."

Likewise, in the Motion Presence study, Participants often needed a distraction from their current task and saw the Motion Presence application as an entertaining source of diversion. Harold reported looking at the application "at work when I don't feel like doing my actual work." Other users saw the application as a game and would try to catch each other moving or not moving throughout the day. Chris: "I looked at it mainly out of curiosity, mostly it was a game for me this afternoon to see if I could find a time when I could see her moving." George reported checking for his "own amusement."

These micro-moments provided an escape from current tasks, even if just for a second, and helped users get through tasks that challenged their concentration.

Boredom

While checking presence information during micro-moments can be seen as offering a quick distraction from a current task, our participants also checked for longer periods of time when they considered themselves to be bored. These interactions typically involved a prolonged interaction with the application, looking into past history to try to learn more about the other participants.

In the music study, Bianca reported that "it was only when I was bored that I like went out of my way to see what they were listening to or like cared a lot" and "If I was like…doing anything more interesting then checking it, like eating or at work or watching a movie on TV. But if I wasn't doing anything that exciting like on the computer checking my email, I would always check it."

We also noticed our Motion Presence participants checking the application when they were bored. Several of our participants lived away from the city center and had to take busses or trains to get home. These participants frequently reported checking the application on public transportation as a way to pass the time. Individuals within our group of four friends often checked for when other members of the group were leaving work or going out to lunch. These interactions helped them to learn more about each other and in some cases led to topics for later communication.

Purposeful

As we had hoped, many interactions with these systems served a greater purpose than curiosity. Often users had specific tasks that they wanted to accomplish, such as determining if a friend was at home or trying to coordinate arriving at a location at the same time. In these cases, participants would check the status of others to determine the best course of action.

Music context was commonly used as a proxy for location context. Since only participants' home computers could broadcast music context information, seeing that a friend was playing music meant that they were at home (or had left their audio player running). Early in the study, Bianca said "[I'm] bored because nobody could go out and do things this weekend, so there's nothing for me to do now. But maybe if someone is listening to music, I'll know they're home…I was thinking if maybe they played music, I could call them because I know they'd be home." Caroline reported looking at the application for this same purpose: "I did pay attention to [timing] because I did wonder 'oh, are they home right now?'"

Abigail knew that her friend Bianca was out for the night and "wanted to see what time Bianca got home, so I was looking at her messages then to see when she'd gotten back from going out."

Checking to see if a friend was home could be seen as a simple example of what Ling and Yttri call micro-coordination [5]. They describe micro-coordination as a set of coordination tasks that are required in daily life, such as deciding on a place or time to meet, determining transportation to a given location, or locating someone else in a busy park. Participants in the Motion Presence study used the application for many coordination tasks throughout the day.

We saw our participants use the application to give themselves more time to spend in their current location. Ebony would check the status of her partner towards the end of the day to see if she had left work yet. "If she didn't leave yet, that means I can go do whatever I'm doing, like

[2] All names in this paper are pseudonyms.

at work stay later." James also described using the application in this way: "If you knew someone was going to go pick you up or if someone was going to go someplace and you knew that and you know about what time, you could see if they were actually on their way or if they were running late. … Kind of lets you know when you should be ready for things like that."

Other participants used motion information to try to arrive at the same place at the same time. Harold and Ian were going to meet for lunch. Harold originally was going to call Ian when he was leaving, but then reconsidered: "I'll call you, or I'll just see that you're moving!" Later that week when they were actually getting together, Harold reported using that information: "I could tell when he was leaving work by when he went off of 'not moving.' … It was like, ok, I saw that he was already on his way and we'd get there about the same time."

These purposeful uses show that much can be inferred from simple presence information. Oftentimes it is not necessary to share precise data like location that can lead to many privacy concerns. Something as simple as music playing or being stationary could be enough for a close friend of family member to be able to discern one's location or activity while still allowing people to feel like they have not exposed information that could be misused by casual friends or strangers.

Not for weekends

We found our participants mainly used these applications during weekdays when their schedules were busier and were often tying to meet or communicate with friends or family. In fact, one participant in the Music Study said that she sort of forgot about the system over the weekend, but it became important when she "had rehearsals [Monday and Tuesday] and I was really bored so I took out my phone like every two minutes looking at it."

In the Motion Presence study our participants also used the application less frequently on weekends. For participants that lived with their significant other, they often spent most of the weekend with them and therefore didn't have a need to use the application. For friends, weekend time was either spent with family or scheduled in advance such that participants knew when their friends would be available and when they were all meeting to go out. Ian said that he "knew where my friends were going to be all day. So I had no reason to know where they were or what they were doing or to contact them."

This data shows that mobile presence is most useful when a person's time is scheduled, but prone to variations (*e.g.*, the exact time they leave work). On weekends, a participant would either be unavailable or have their plans made in advance. In either case, the application was not needed. When participants could not use the information for purposeful interaction, were not bored, or did not desire a distraction, they simply did not view the information presented on their phones.

CURRENT WORK

Currently, we are investigating the use of contextually relevant photographs displayed on the idle screen of the phone. Using the ZoneTag [2] system and friend/family relationships created on Flickr[3], we display three types of photographs as rotating feeds on the idle screen. The first feed includes public photographs from Flickr taken in the zip code where the user is currently located. The second feed contains the recent photographs that their friends have taken while the final feed covers photos taken in a particular city, such as all photos taken in Chicago.

We hypothesize that we will see our participants using these photographs to learn more about their surroundings. In addition, they will use them to initiate conversation topics with their friends about not only the photos that their friends have shared, but also about photos taken in their vicinity. We predict the same types of use from our previous system will be evident in this new application. These uses may include employing the presence display as a distraction while engaged in long tasks, as a relief from boredom, and as a means to determine where a friend is or what they are doing based on their shared photos.

DISCUSSION

We believe that ambient mobile presence applications have several affordances that allow for interactions different from more traditional in-home ambient applications. Since mobile devices are nearly always in their owner's possession, mobile applications can provide continuous updates to presence states throughout the day and allow users to receive the most recent information available about others. As a result, no matter where a person is, they can check the current status of others and make real-time decisions about availability, activity, or location based on the information provided.

This indirectness of data used in our studies allows for a larger variety of information to be sent with fewer privacy concerns since there is still a large amount of plausible deniability. By contrast, most home presence applications have provided direct information such as physical presence in a room [10] or explicit messages left for others [9, 4].

Also, because mobile applications are always available, they allow for increased interaction opportunities when one is bored or looking for a distraction throughout the day. While moving from one location to another, people often have little else to keep them occupied. Mobile presence applications provide a constructive way to feel connected to others as well as coordinate while on the go.

Finally, mobile phones are unique in being able to provide a large amount of rich context that can be shared with others.

[3] http://www.flickr.com

Many phones today are able to determine their location through GSM cell ID or GPS, capture rich media such as photos and videos, and are aware of the media that a user is playing. This rich context provides many opportunities to share this information and allow for a greater sense of awareness as well as increased availability management. Having this information is increasingly important as people lead more hectic lives while maintaining a strong desire to feel connected to others.

QUESTION

For us, a question we continually face is "How ambient is ambient in a mobile setting?" Is information that appears in the course of a normal phone interaction (e.g. an augmented phone book) enough to be considered ambient? What about information that is always visible on the idle screen or the external display? This leads us to a larger question of "What types of ambient affordances should a phone provide?" We hope that through this workshop we can explore some of these questions with others as well as explore the differences between mobile and home-based ambient applications.

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Ambient Interfaces that Motivate Changes in Human Behavior

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ABSTRACT

Peripheral or ambient displays move information from the periphery to the center of human attention and back. Our research group is interested in the interaction and interface design goal of how to best design ambient displays that help users to understand and change their behavior. We have found that there is often a disconnect between a person's perceived and actual behavior, and we hypothesize that appropriately designed ambient displays can address this problem.

Choosing physical activity as our first domain of exploration, we have developed the IMPACT system, which monitors physical activity throughout the day and provides feedback to the user in the form of detailed and abstracted displays. To date, we have explored abstraction and symbols, agents and avatars, and speech and sound user interfaces as display modalities that can present appropriate amounts of information in a lightweight fashion without being too distracting.

INTRODUCTION

People who engage regularly with technology interact with hundreds of visual, auditory, and multimodal displays each day. Some of these displays demand full attention; others can be interpreted with just a glance. The latter set of displays has been described *calm technology,* [7] or *peripheral* or *ambient displays* that move information from the periphery to the center of human attention and back. If we can leverage design methods to reduce the time it takes to extract information from a display, we can focus more quickly on how to design ambient displays that help users become more aware of and ultimately change their behavior.

Ambient displays receive varying and unpredictable levels of attention. Understanding what design variables might minimize the demand for attention, and help people to become more self-aware through information interactions, is a rich area for exploration. While many novel ambient display designs have been proposed for everyday environments [2, 3, 4, 7, 8], most are point designs in a space that have rarely been systematically evaluated for effectiveness or even desirability [6, 1]. Furthermore, little is known about how interactions over time with an ambient display might potentially contribute to increased use of peripheral awareness and ultimately, change in human behavior.

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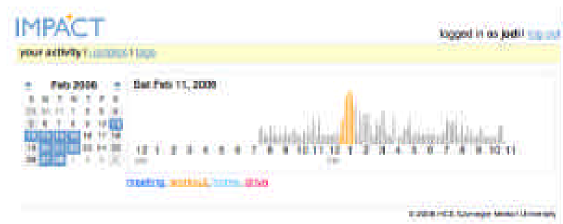

Figure 1. Prototype of a reflective visualization, indicating the amounts of physical activities conducted while performing everyday activities.

Our research group is working on systems that use peripheral displays on context-aware devices to sense and provide information about the self, to improve decision making. and to inspire positive changes in human behavior. We have found in our research that a gap exists between perceived and actual behavior. We reason that an appropriately designed ambient display can deliver information in real time to help people develop a better awareness of their behavior. We believe that the difference between real and perceived behavior can diminish and that real behavior can be improved.

Our first domain of exploration has been physical activity. We have created the IMPACT system, which stands for Improving and Motivating Physical Activity Using ContexT. This system monitors physical activity throughout the day and provides feedback to the user in the form of both detailed and abstracted displays. Figure 1 shows a visualization of a day of activity.

We are interested in the interaction and interface design research goal of how to best design ambient displays that help users to understand and change their behavior. We are investigating several design themes, including the use of abstraction and symbols, the use of agents and avatars as peripheral displays, and the use of speech and sound user interfaces as ambient displays.

APPROACH

We have identified a 5-part framework for designing activity monitoring and feedback systems: Activity: what phenomena need to be monitored? Sensing: what is the appropriate technology for monitoring these phenomena? Modeling: How should the sensed data be analyzed and modeled? Feedback: What are appropriate methods for presenting feedback to users? Effect: What is the effect of presenting feedback to users?

Activity: what phenomena need to be sensed?

We have conducted initial ethnographic studies of women who have set goals to lose weight and upheld or failed to uphold those goals. We have also instrumented a randomly chosen subset of our subject pool with pedometers, accelerometers and heart rate monitors. We have learned what barriers exist to being more active, and how data from pedometers is not seen as inherently useful. We also understand how to better contextualize and understand activity.

Sensing: Identify sensing technology

The physical nature of health-related activities poses a challenge to the kind of sensors that will be successful in monitoring activity. Sensors placed on the body need to be non- or minimally intrusive, need to blend seamlessly into the lives of the users, and be inexpensive, accurate, robust and be low-power devices.

Modeling: Detecting trends and progress towards goals

The sensing data collected from our subjects is used to iteratively create models of user activity to better understand hourly, daily and weekly variations in activity over time and how users' self-motivation causes changes in their monitored activity.

Feedback: Identify and evaluate appropriate feedback mechanisms

We are currently working on several types of ambient displays that we hope will provide users with the appropriate information to monitor and possibly change their behavior. These include the use of abstraction and symbols, agents and avatars that look like the user, and speech and sound user interfaces.

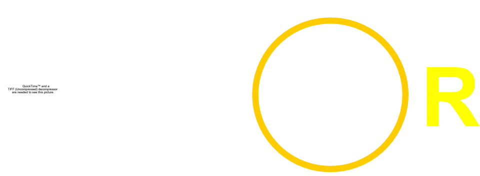

Figure 2. Comparison of a simple and direct and complex and indirect symbol to indicate the presence of a restaurant.

Abstraction and symbols

As interface designers, we have been researching how simple and complex interfaces effectively convey information to users. During the workshop, we will use the themes of simplicity, complexity, direct, or indirect symbols to help brainstorm the visual components of ambient displays. For example, Figure 2 shows a comparison of two icons indicating a restaurant: a McDonald's icon and a more generic restaurant symbol. Although the complex symbol conveys more information, it could be potentially distracting if it is not the target of an information interaction. In some contexts, the simple generic (indirect) symbol would be easier to perceive, but may need to be decoded to offer the right amount of information. On the other hand, indirect, highly abstract symbols can be useful for preserving privacy and maintaining an aesthetic design.

Agents and avatars

Agents and avatars that look like the user can serve as effective ambient displays. For example, one of the first thing one does when observing a group photo is to look for one's face in the group. Our group has done some initial research on the use of agents that look like the user for providing assistance with computer tasks. So far, we have discovered the users follow advice from agents that look like themselves [5]. In the workshop, we hope to discuss and extend our initial findings in this area.

Speech and sound

Auditory attention differs significantly from visual information, and is currently underexploited as a form of ambient display. In a pilot study, we designed auditory notifications in the form of speech and sound that contained specific and generic information, and asked users to rate their effectiveness, attention demand, and likeability. We found that speech interfaces were generally found to be more informative and that sound interfaces were generally found to be better at capturing attention. While initial, our results have implications for the design of auditory ambient displays.

Effect: Evaluate the effects of monitoring and feedback

Our final task is to determine the effects of our monitoring and feedback system. Longitudinal studies of these ambient systems need to be conducted, in order to understand their effectiveness in changing behavior, and to understand how comprehension at the periphery might change after using such a system for an extended period of time.

CONCLUSION

In this paper, we presented the IMPACT system, and a five part framework for the development of contextually aware systems that provide the user with information about the self. We are interested in the design and long-term use of this information in the form of ambient displays. We have found that there is often a disconnect between a person's perceived and actual behavior, and we hypothesize that appropriately designed ambient displays can address this problem. To date, we have explored abstraction and symbols, agents and avatars, and speech and sound user interfaces as display modalities that can present appropriate amounts of information in a lightweight fashion without being too distracting. We hope to eventually provide useful guidelines for what types of design features create the most appropriate and actionable ambient displays for use in mobile contexts.

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Competing for your Attention: Negative Externalities in Digital Signage Advertising

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ABSTRACT

In this paper, we propose to model attention consumption of advertisements as a negative externality. We examine the methods of maximum permissible values, fees, and tradable certificates to cope with the negative effects. We propose to integrate auctions for tradable attention certificates with auctions for advertising slots on digital signage. This method allows us to implement tradable certificates with relatively low transaction costs. It enables us to define a maximum amount of attention that is consumed at a certain location at a certain time. It is guaranteed to stay within these limits while causing only minimum costs for advertisers.

Keywords

Advertising, attention, digital signage, negative externality, auctions.

INTRODUCTION

If you watch a science fiction movie today, like Blade Runner or Minority Report, a recurring theme is that public space is full of advertisements, all crying for your attention. We find that this property alone often makes the future look bad and uncomfortable. Even today, if you enter places such as Shibuya Crossing (Fig. 1) or Times Square (Fig. 2), you face an overkill of advertisements, letting the vision presented in the movies seem ever more realistic. In theory, people can personally regulate to how much advertisement they are exposed by only going to certain places or ignoring the advertisements. But in practice, people are forced to go to certain places (which are then preferred by advertisers) and the ignorance of advertisements leads to an arms race causing advertisers to design their advertisements ever more attention drawing. But is this development of ever more advertisement a fate we cannot escape? Certainly, this question is not only a technical but also an economical one. If we look at Internet advertising, recent developments are promising. At first, advertisements in the Internet were relatively static images, presented throughout the text, that could easily be ignored. New technological developments, like animated gifs and Flash, led to the spreading of animated advertisements. These used the fact that the property of animations to draw attention is hard-wired in the human brain. Thus, animated advertisements can hardly be ignored. This development culminated in spam mails, aggressive pop-up windows and screen filling animations, which attracted the dislike and even hate by many users. As countermeasures, spam filters, pop-up blockers and ad blockers were developed, so that the situation merely looks like a war between advertisers trying to sell their products and users trying to protect their attention.

But unknown to many users, most money is today made with a much less obtrusive kind of advertising: Those little, decent “Sponsored Links” shown on the right of a result page when you search for something at Google. Few people are really annoyed by these advertisements, and some even consider them useful when they present them with information they really searched for.

The interesting question now is whether in public space we have to go through the same development as in Internet advertising and live in spaces that distract us and cause bad emotions, of if we can skip this phase and directly go to decent, targeted advertisements. If we manage this, we could live in a world where decent advertisements are embedded into the image of the city, resulting in a place we really love to live in (Fig. 3).

Figure 1: Shibuya crossing in Tokyo.

RELATED WORK

In [6], the concept of using auctions to sell advertising space on digital signage has been introduced. In that work, context information is gathered in terms of the Bluetooth IDs found by a Bluetooth sensor. This information is then provided to the different advertisements, which use it to generate their bids for having them shown on a digital display. The advertisement with the highest bid is then shown for one advertising cycle. In [3], the bidding strategy is extended such that the advertisement with the highest utility for the advertiser is shown. The utility is calculated by multiplying the probability that the user will buy the advertised product with the profit the advertiser would make. The auction mechanisms used for Internet advertising, for example by Google, are analyzed in [1]. The problem of negative externalities and its possible solutions are explained in [7]. A general overview of research on situated public display is provided in [5]. Emotions related to Digital Signage are discussed in [4], where it is argued that those emotions are reflected back on the organization that installed the advertisement. In calm technology [8], attention should move seamlessly between the center and periphery of your attention. But the intent of advertisers is that their advertisement should always be at the center of your attention.

Figure 2: Times Square in New York.

NEGATIVE EXTERNALITIES IN ADVERTISING

Obviously, for each individual person, attention is a limited resource. If attention is spent for one task, for example looking at an advertisement, less attention is left for other tasks. Thus, each advertisement you look at causes some ‘attention costs’ to you. On the other hand, the advertisement may convey some useful information for you and thus cause a certain benefit. If the benefits are higher than the costs, you are happy that you have seen the advertisement. If, however, the benefits are less than the costs, you may become unhappy or even angry about the advertisement. Thus, there would be a certain optimum amount of advertisements such that the average benefit is maximized. Unfortunately, if the market is not regulated, the amount of advertisements is much higher that the optimum amount.

This is simply because advertisers don’t pay for the use of your attention. Thus, the costs that occur because your attention is used are external to the advertisers calculations. This is called a negative externality. In this case, the only cost that influences advertisers calculations is advertising space, finally resulting in every public space being covered by moving, colorful electronic advertisements crying for your attention.

In principle, there are three methods to cope with negative externalities: Maximum permissible values, fees and tradable certificates. Each of these methods requires that the amount of attention consumed by an advertisement can be quantified somehow.

PREREQUISITES: A METRIC FOR ATTENTION

Unfortunately, in order to control the consumption of attention in public spaces, we need to measure it. It is obvious that a perfect metric cannot be achieved, and the more exact we measure the consumption of attention, for example using EEG, fMRT, eye trackers etc., the more expensive it is. A relatively simple method to measure the amount of attention that is consumed by different categories of advertisements is measuring dual-task performance [2]. With this technique, test persons would have to do a primary task, for example solving mathematical or geometric problems. At the same time, they would be presented different kinds of advertisements. The degradation in primary task performance would then allow to draw conclusions on the distraction by the advertisement. It is important to note that for our case it is not that important that the metric is exact, as long as we have any metric. Advertisers would over time try to cheat the metric and attract as much attention as possible with a low metric value. Examining the cheating strategies of advertisers would us then allow adapting the metric itself to better cope with reality.

Figure 3: Regulated Advertising at the Prinzipalmarkt in Münster.

MAXIMUM PERMISSIBLE VALUES

The usual method to cope with advertisement today is maximum permissible values. In many cities, the amount and style of advertisements is strongly regulated. To conserve the cityscape, for example, many cities require advertisements to be in certain colors and shapes (Fig. 3). In some countries, advertisements on highways are prohibited. With maximum permissible values, regulators can be certain about the amount and style of advertisements, but they cannot be certain about the costs caused to advertisers by the regulations. To some advertisers an attention-attracting advertisement might be worth much more than to others. By requiring each advertiser to attract the same maximum amount of attention, this method is ineffective and does not result in the optimal distribution of attention among advertisers.

FEES

An alternative method would be to charge a certain fee for each unit of attention that is attracted. This way, if an attention attracting advertisement is worth more to one advertiser than to another, he could simply pay more fees. The difficulty with this method is how much to charge for one unit of attention. The correct fee would be equivalent to the costs that are induced to society. This value is very difficult to determine. Unfortunately a difference in attention that brings only little extra benefit to the advertiser may cause great costs to society, for example causing an accident. Thus, a small estimation error determining the fee could result in far too much advertisement and large cost for society. Progressive fees that become more expensive the more advertisement is already there could partly compensate for this, but are also difficult to determine. Thus, in theory, fees could result in a optimum advertising amount for society, but are too difficult to handle.

TRADABLE CERTIFICATES

An approach that combines the advantages of maximum permissible values and fees are tradable certificates. In this approach, for each location in a city a certain amount of attention can be consumed, which is represented by certificates. These certificates are then sold in an auction, resulting in the advertiser valuing attention most getting the most of it. This approach is useful when the value of goods are different for different players but these values and the costs to society are unknown. Both conditions hold in our case. With tradable certificates we can be sure that no more attention is consumed that the amount of certificates we sold, and the distribution among advertisers is optimal.

The main problem with this approach is the high transaction costs in executing the auction, rendering the approach impracticable for current analog advertising schemes. With digital signage however, the auction could be executed automatically by software agents without any human intervention. When auctions are used to sell advertising space on digital signage anyway, auctioning the certificates would only add little complexity to the process.

AUCTIONING ADVERTISING SPACE

One promising approach for selling advertising space on digital signage are auctions. Depending on the context, advertisements bid different amounts to be shown. Such auctions have evolved as the predominant approach of selling advertising space on the Internet. Both big players in this field, Google and Yahoo, use second price auctions on keywords [1], where advertisements can bid to be shown when the user searches for a certain keyword. Even on the Internet, this bid can be different for different times of day or locations of the user. Because the advertisements are already tailored to the user, there is a relatively high probability that the user is really interested in the advertisement. Thus, the advertisements are usually designed relatively calm, mostly consisting only of a headline, a text block and a link. Because of its huge success in Internet advertising, it is quite probable that this approach will also become dominant in digital signage advertising. The process of auctioning advertising space for digital signage is depicted in figure 4. In analogy to Internet advertising, one hope would be that if the advertisements are tailored to the time, location and audience, they can be designed relatively calm.

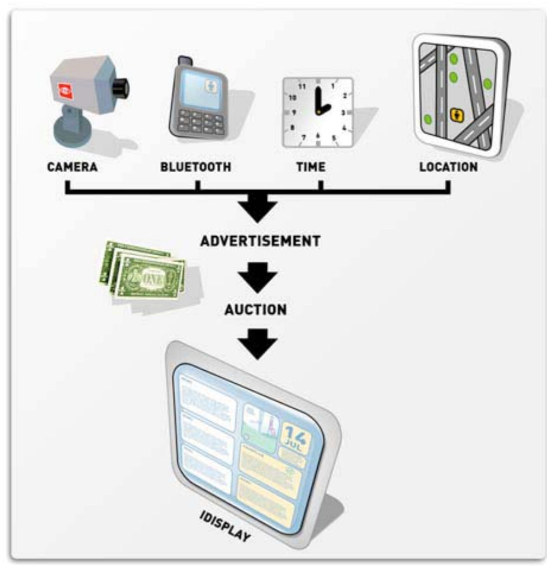

Figure 4: Auctioning advertising space on digital signage. At the start of each advertising cycle, context information is gathered from different sensors. This context information is then provided to the individual advertisements, which use it to generate their bids. In an auction, the available advertising slots are then sold to the highest bidders. For the duration of the advertising cycle, the selected advertisements are shown on the display.

AUCTIONING TRADABLE ATTENTION CERTIFICATES

If we accept that attention is a scarce resource where the costs of use should be internalized to the advertisers calculation, there would be two scarce resources that have to be distributed among advertisers: Advertising space and user attention. We present a first simple approach of an combined auctioning process for advertising space and public attention.

As a first step, public space would need to be subdivided into advertising regions. These regions should be of the right size such that in principle it does not matter where exactly within this region attention is consumed, as long as the total attention consumed within the region is below a certain level. This could be a crossing or a place, for example. Then, for each region, maybe depending on the time of day, the maximum amount of attention consumed would be defined. According to this maximum amount, a corresponding number of certificates would be provided on a central server implementing the attention marketplace.

On each individual digital sign, advertisements would then bid for advertising space using the process depicted in figure 4. Once the space is distributed among the advertisements, the advertisements shown would then decide in which form they would present themselves. The same advertisement could show itself in black and white, color, with animations or as a movie, for example. To generate their bid, they could use a bidding strategy similar to the one for the auction for advertising space. Thus, advertisements would determine the utility of having themselves presented in a particular way and make the corresponding bids for attention certificates. One advertisement for example could have a high utility for being shown as a static image, but only a little higher utility for being shown as a movie. Another advertisement could have a low utility for being shown in black and white, but a high utility for being shown with animations. Then, the first advertisement would bid a lot for a few certificates, while bidding only little for more certificates. The second advertisement would bid the same high amount for as many certificates as necessary to present a movie. Once all bids are set, the central marketplace then sells the available amount of certificates and each advertisement is told how many certificates it bought. Each advertisement then selects the right way to present itself given the amount of attention it can consume, and the advertisements are shown on the displays.

CONCLUSION AND FUTURE WORK

In this paper, we proposed to model attention consumption of advertisements as a negative externality. We examined the methods of maximum permissible values, fees, and tradable certificates, to cope with the negative effects. We proposed to integrate auctions for tradable attention certificates with auctions for advertising slots on digital signage. This method allows us to implement tradable certificates with relatively low transaction costs. It enables us to define a maximum amount of attention that is consumed at a certain location at a certain time. It allows us to stay within these limits with minimum costs for advertisers.

We believe that controlling the amount of advertising in public spaces is an important challenge for science with huge effects on life quality in developed societies. We believe that our approach of auctioning tradable attention certificates has great potential to hold advertising in public spaces within bounds.

Important questions, some of which can be solved by the pervasive computing and ambient information systems community are:

1. How can technology support economic methods to cope with negative externalities in advertising?
2. How need combined auctions of advertising space and attention certificates be designed?
3. How can attention consumption be measured and how can attention certificates be designed?
4. Can the proposed techniques be transferred to other domains than advertising?
5. How do the proposed techniques relate to the use of peoples attention for Ambient Information Displays?

To conclude, we want to draw your attention to the central question of this paper, which we believe got far too little attention by the community up to now:

HOW CAN THE DIGITAL SIGNAGE ADVERTISING MARKET BE REGULATED SUCH THAT ATTENTION IS NOT OVERCONSUMED?

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Assessing the Suitability of Context Information for Ambient Display

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ABSTRACT

With the advance of pervasive technology, information from both the physical and virtual world is increasingly accessible to developers. Context-aware applications may consume relevant aspects of this information as they support user tasks. When conveying information to people, the mechanism for presentation must be carefully considered. As ambient devices are centred on the notion of calm-technology, it is logical that certain types of data lend themselves to ambient display more easily than others. In this paper we present our initial investigations into the properties of contextual information best suited for display using ambient technologies. We present the feature set extracted from our investigation, and apply examples that satisfy these criteria to our prototype ambient device, the visual calendar.

Keywords

Context, ambient devices, pervasive computing

INTRODUCTION

The boundary between personal computing and consumer electronic devices is becoming increasingly blurred, resulting in an environment in which technology is blended with everyday objects [1]. In addition to easing the path through which data from the physical world may be combined with data from the virtual world, application developers are afforded new opportunities for interacting with users outwith the bounds of the traditional personal computer.

Our recent work has focused on the development of frameworks that support the collection and distribution of *context information*, and on raising the level of abstraction over data that is available to applications [2]. Early applications that we developed made use of web pages, mobile devices, and wall-mounted displays to present information to and interact with users. We are presently investigating the use of ambient displays, and examining how they afford different opportunities for presenting context information to users in comparison with existing approaches.

Our notion of an ambient display is based around Weiser's idea of calm-technology [3]. With respect to this tenet, we take the view that ambient displays should be designed to be unobtrusive, with interaction completely driven by the user. They should be experienced as a tool that the user may refer to in the process of completing a task if he or she wishes.

Information manifests itself in many forms. It may appear in a single or number of discrete events, or flow as a continuous stream. Values may be relatively static or highly dynamic over time. The range covered by data may take the form of a finite set of values or have unbounded scale. Information must be appropriately represented for it to be understood by the user. This implies the need for a strong correlation between the nature of information and its presentation medium. As ambient devices adhere to the concept of calm-technology, it follows that certain types of data are more appropriate for ambient display than others.

In this paper we present our initial research towards identifying properties of context information that are well-suited for presentation via ambient technology. We consider the mapping between information and realisation by existing devices, and the need to "ask the right question" of the information. Throughout this paper we use examples of readily available sources of information to motivate discussion, and apply examples of information that match these properties to a prototype ambient device, the visual calendar.

This paper is structured as follows: In section 2 we discuss the mapping between information and display in existing ambient devices. Section 3 presents our initial investigation into the properties of context information best suited for ambient display. Section 4 describes the application of different types of information to a prototype ambient display. Finally, in section 5 we summarise our work and present a question designed to motivate discussion at the workshop.

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RELATED WORK

There are many examples of ambient devices that aim to communicate a wide rage of information to users without placing significant demands on their attention. This section examines some well-known examples, and discusses the relationship between information source and display technology.

Ambient Devices' Ambient Orb [4] is a glass ball that changes colour to display variance in data obtained from internet sources. The Orb has many modes, which makes it an interesting case study. As an example of an intuitive and useful mapping, the Orb will change colour from green, through yellow, to red to indicate current traffic congestion levels. A less complete visualisation is the mode that displays changes to a stock portfolio, which is restricted to indicating performance swings of up to 2.5%. External information, namely the starting value of the stocks, is required for the interpretation to be fully meaningful. Finally, the Orb's weather forecast mode uses 11 different colours to indicate temperature intervals between -10 and 100 degrees Fahrenheit. When there is a chance of precipitation the Orb pulses. This more complex visualisation demonstrates that the Orb is not well matched to the problem of conveying weather information.

van Mensvoort's DataFountain [5] uses three water fountains to provide a visual comparison of the Yen, Euro and Dollar currency rates. Whilst it is an aesthetically pleasing display, and is straightforward to deduce the relative position of each currency, the scale on which the fountains operate is not visualised. The nature of the presentation medium greatly reduces the precision at which the data can be interpreted.

Jafarinaimi et al.'s Breakaway project [6] uses a morphing sculpture to encourage people with desk jobs to take breaks throughout the day. Information gathered from sensors in the user's seat drives changes to the shape of the sculpture. The sculpture is designed to mimic the human body - when upright, it indicates that the body is refreshed; when slouching, it represents that the user has been sitting for an extended period of time. The sculpture reflects a good mapping between information and its visualisation. The intention of the sculpture is more easily interpreted than, say, a numeric display of the time spent seated; providing a visual clue that suggests the user takes a break.

Ardern's Powerpoint [7] is a mains socket augmented with a set of LEDs that indicate the amount of energy consumed from the outlet. As the power consumption increases, the number of lit LEDs increases, and their colour changes on a spectrum between green and red. The intention is to increase user awareness of power being drawn by various appliances. Despite the fact that this mapping is intuitive, the decision to place the display on the wall socket may be questioned. There is an assumption that the socket is in full view and not, for example, behind a sofa or a bookcase. However, the idea of a central view for recording and displaying information is touched upon.

Finally, Stasko et al's InfoCanvas [8] allows people to specify mappings between information of personal interest and pictorial representations. These are realised in the form of a digital painting. The artefacts in the painting move, morph, or change colour to represent changes in state. Some mappings are intuitive, such as changes in colours representing traffic conditions. Others mappings, such as those involving scalar data types, are difficult to interpret visually without the presence of a scale. The InfoCanvas example employs a kite at varying highs to represent rise and fall of stock prices. Without a clear indicator as to the exact values being represented, the stock price cannot be read.

FEATURES OF CONTEXT DATA SUITABLE FOR AMBIENT DISPLAY

Context information can be derived from any data that describes the current state of a system, its users, and their surrounding environment. Examples of such data are user location, current task(s), goals, environmental conditions (temperature, weather, light conditions), capabilities of the system, and so on. When a user is the end point for delivery of context information, the presentation mechanism must be carefully considered. We hypothesise that ambient technology is only suited to conveying certain types of context information to the user. This section discusses five properties of context information that should be considered when selecting an appropriate presentation medium.

Precision is the first property that we consider. Ambient displays do not lend themselves to accurately conveying information with a fine granularity. A continuous range of values needs a scale to be fully understood. Without a scale, interpretation can only be approximate and precise comparison between different states is difficult. Linear scales may be represented where accuracy is not important, but other scales, such as logarithmic, may be more difficult to interpret. Where values are described from some offset, such as stock price fluctuations, the user needs to have an understanding of the base-level for that offset to make sense. Ambient displays cannot clutter the visualisation with scales for values or keys with labels, which increase the cognitive load on the user. Information should be instinctively interpretable without the requirement for extra indicators to enable understanding. Context data needs to be rounded or smoothed before displaying in a calm-manner. A small, discrete set of values are far simpler to map to a visualisation. Attempts to display a large number of related values with fine resolution are inherently more open to user reasoning error.

Criticality influences how aware the user must be with respect to changes in the state of information. If the user must pay significant attention to the information, the device should not be regarded as ambient. Similarly, if a change in information state requires immediate user attention, this too should not be regarded as ambient. Presented information must not be mission critical; it should be supportive of but not integral to the tasks at hand. If ignorance of information will cause the user's task to fail, the information should be presented in a more intrusive manner. The principle of calm-technology behind ambient displays makes them a poor mechanism for conveying data that must be acknowledged or acted upon.

The **periodicity** of context information is another factor in choosing appropriate presentation. Information that is repeated often is suited to ambient display. In some sense, repeated data is linked to the property of criticality. If the user misses a particular assertion, a future event in the sequence may be observed. Users should not be left wondering if they have missed a rare event. For example, train departure times between the user's local station and home may be a good example of repeated data.

The **interpretability** of context information is another factor. Information usage should be considered *a priori* in order to provide a representation that does not strain the user's cognitive load. Information is only appropriate for ambient display if it can be visualised in a way that lends itself to easy interpretation. An example of this is a system designed to show bus timetables. Displaying the raw data provides too much information: the user needs to aggregate times of buses with the current time and the time it will take to get to the bus stop. It is more appropriate if the data is pre-processed and conveyed in a personalised manner. Note that we do not imply the display of bus timetables is not useful, only that it is not ambient.

The final characteristic we consider is **self-descriptiveness**. When displaying context information to the user it is important to provide a stand-alone representation. The user should not require information beyond what is displayed to fully comprehend its meaning. We motivate this using two of the AmbientOrb applications discussed in section 2. The stock performance application provides an example of an incomplete representation of context information, where the user's interpretation is restricted by the need to know the starting price for the day. This can be contrasted with the traffic congestion application, where the user requires no external information to understand its meaning. The self-descriptiveness and interpretability properties of context information are closely related.

We observe that data-driven processes can be well-supported through the use of ambient displays. This encompasses situations where the aggregate of information from multiple sources is considered useful to the user, and the individual information not so. Aggregated data should be displayed in the form that is most meaningful for the task at hand. For example, a system that takes multiple inputs to predict weather patterns may be of most use to the user by answering the question: "should I carry an umbrella with me today?" Boolean outputs such as these are examples of context information well-suited for ambient display.

THE VISUAL CALENDAR EXAMPLE

We have designed a prototype ambient device called the Visual Calendar, which provides users with a personalised display of context information. The device is similar in principal to the InfoCanvas [8], and takes the form of a digital picture in which artefacts are placed that visualise context information relevant to the user.

The visual calendar is realised using a widescreen display. It provides a view of the state of the world relevant to the user's current context through animated icons and symbols. Context information is selected and processed to ensure that it adheres to the feature set identified in the previous section. This is illustrated in figure 1.

Artefacts in the foreground of the picture move from right to left as time advances. They may take the form of either a representation spanning the horizontal axis, or may appear as a number of discrete values.

Figure 1: The timeline of the visual calendar.

The background of the picture is used to represent contextual data viewed as a Boolean question. When artefacts in the background are present, they indicate that a condition is true; they disappear when the condition is false. Reducing context information to a Boolean representation satisfies the *precision* and *interpretability* properties we outlined above. It is the responsibility of the developer to ensure that the question being asked of the context information is appropriate to satisfy the other properties.

In our scenario, buses on the road represent the approach of a bus on the user's route home from work. The visualisation takes into account the time required for the user to walk to the bus stop, and the estimated time the bus will reach the bus stop. Buses move along the road on the display from right to left, each bus disappearing from view once it is no longer possible for the user to catch it. Note that this representation satisfies each of the criteria we set out. The visualisation of the bus travelling along the road provides adequate *precision*. No explicit scale is required, as the user can interpret meaning from the position of the bus on the road. Missing a bus is not important when others will follow. This satisfies the *criticality* property of the system. The timetable and user location data have been pre-processed from their raw forms into a personalised version. This yields a satisfactory degree of *interpretability* as the system includes the time the user takes to get to a bus stop. Simplicity of visualisation further meets this requirement. The representation is also *self-descriptive*, requiring no external information to be understood. It is important to note that this representation may not be suitable for all users at all times. For example, if the next bus is the last (*criticality*), or there are only 2 buses a day (*periodicity*).

Figure 1 also illustrates the use of the visual calendar to display traffic congestion, and person location information. The three buildings in the background represent home, office, and school. When a family member is sensed in one of these locations, their image appears in front of the building. The cars travel along the road indicating current and predicted traffic congestion on the route between the user's work and home. The number of cars on the road indicates the current level of congestion, while cars stacked closer together on the right edge of the road indicate that congestion is expected within the next hour. Historical data is used to predict congestion based on the day of the week and the time of day. We believe that the number of cars on the road clearly conveys whether there is congestion to the user. There is no need to apply a fine-grained scale in order to make the representation meaningful. As with the example of the buses, if you miss a time period when the roads are clear, another will follow. The nature of traffic flow follows this repeated pattern, satisfying our criticality and periodicity properties. Interpretability is eased by pre-processing traffic reports for the user's route home from work. The resultant visualisation, which uses cars, is simple and self-descriptive - cars are a symptom of congestion and therefore aid user understanding of the representation.

Finally, the three images in the upper-half of the display represent weather forecasts for now, rest of today, and tomorrow. These well-known representations satisfy all five of the properties identified in this paper.

CONCLUSION

Increased availability of information from both the physical and virtual world provides developers with new opportunities for supporting user tasks. Ambient devices, based around the notion of calm-technology, are one approach to exposing such information to users. In this paper we hypothesised that only certain types of context information are suitable for display via ambient technology. Our initial research into the properties of information that fit this display modality has identified precision, criticality, periodicity, interpretability and self-descriptiveness as key factors. We illustrated our findings using a prototype ambient device, the visual calendar.

We posit that it is important to consider the above properties when deciding if an ambient device provides an appropriate choice of display for exposing context information to the user.

Based on our recent work with context information, we have witnessed a clear trend between the need to "ask the right question" of the information and the ease in which it can be presented using ambient technology. The question we bring to the workshop is: **"to what extent can views of information be adapted to render it suitable for ambient presentation?"** The complex interplay of factors involved in choosing adequately processed data for visualisation via ambient display will benefit from cross-collaboration between computer scientists, visual and interaction designers and psychologists.

ACKNOWLEDGMENTS

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Urban Score: Measuring Your Relationship with the City

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Introduction

In this paper, we introduce a new ambient display, *personal steganography,* and the concept of the *urban score.* Strictly speaking, the ambient display itself is a particular rendering of a value of the same name. As we will explain, the two are intricately linked. This ambient display does not convey stock prices, bus schedules, remind you to buy milk, or any other such useful bits; it gives the user a feeling--perhaps even just a hint--about their connection to the city they are walking in and its other inhabitants.

We argue that the display shown in Figure 1 is both an efficient display of a great deal of information and is well designed for its ambient task. Its task is to convey, likely helpful information to the user in a way that is both unobtrusive and always present. What cannot be depicted in Figure 1 is that this display is not typically shown at full brightness and it is always at the lowest level of the window stack or "in the background" on your PC. It is a resource that the user can draw on when they "aren't doing something else" or when they are between other actions. We in no way mean to criticize the display, its many brethren, or its authors.

Rather, we want to argue that there is another task of interest that, while it shares some constraints with Google's widgets in Figure 1, opens up a different and important design territory. This task is more closely related to exploring a new city or "neighborhood, walking into a restaurant or bar to "see what it's like", or chatting with a friend about local political events. The task is feeling the pulse of a city. The idea of the urban score is that somehow measures and conveys that pulse.

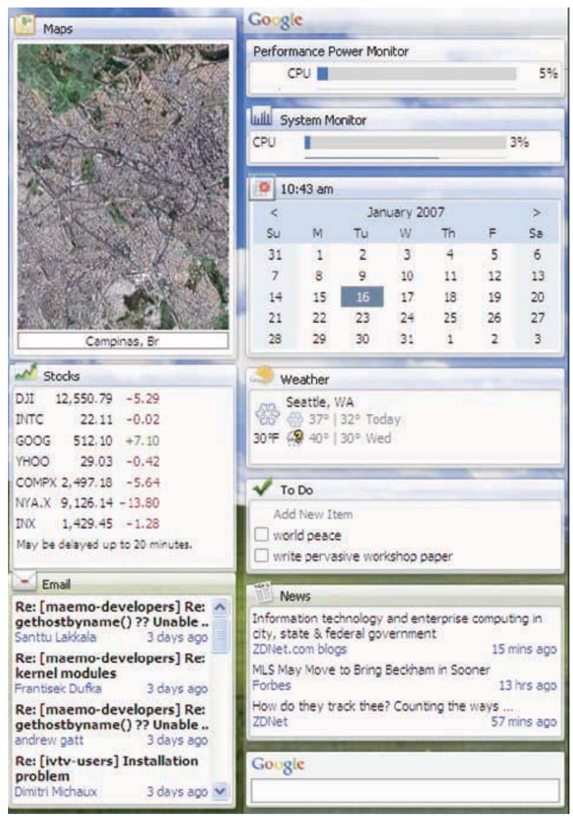

Figure 1: Typical set of Google widgets

Computing Your Urban Score

Any mention of an urban "score" quickly leads to a discussion of the rulesets used to calculate such a number (or set of values) and this discus-

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sion often is followed by more vehement arguments about which set of inputs or outputs more validly describes one person's urbanity versus another. We encourage this argument and seek to foment it. We would like to see many designers come up with their own metrics of urbanity and have users compare, use, and find those metrics that suit their tastes; we want to encourage people explore what it means to be urban through these low-intensity displays. In the next two section we will discuss two categories of designs that we are proposing for an urban score.

It seems clear from recent work in industry and academia [1-5] that some type of sensing will be available on almost everyone's mobile device in the foreseeable future. Thus, our designs assume that many different sensors will be available for applications to use.

The Dosimeter

One urban score design avenue that we have been considering is taken from the world of nuclear engineering and radiology, the dosimeter. The idea is to make an ambient display for a mobile device such a phone or Ultra-Mobile-PC (UMPC) that measures your "dose" of the city. This display could be a background or a screen saver in the simplest case. In any case it should be unobtrusive and require little, if any, of the user's active attention or input.

Figure 2: Classical worn dosimeter. The badge changes color based on amount of exposure to radiation

In our first variant of the dosimeter, we measure airborne pollution that the user is exposed to. Many pollutants, such as carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, and fine particulate matter can now be measured with cheap, handheld instruments [6-7] and we expect that these sensors will be easily integrated either into a mobile device's packaging or into small attachments.

This simple urban score is a display that shows the total and highest amounts of pollutants a user is exposed to over the course of the day. This could be displayed as simply a mixture of background colors, with no text at all, making it very low-demand in attention terms. Although there are certainly communities who would find this type of ambient information both useful and important, it fails, in our view, to spark a debate about how one is experiencing the city. This type of design might even be better as a more direct, non-ambient, display by compiling information from many users into standard maps showing the geographic relationship to exposure levels.

A second design that is superior in our view, is the dosimeter that measures the amount of a city's "vibe" as your urban score and then gives a more ambiguous ambient display we called a *personal steganographic* ambient display. The name comes from steganography which is the art and science of writing hidden messages in such a way that no one apart from the intended recipient knows of the existence of the message; this is in contrast to cryptography, where the existence of the message itself is not disguised, but the content is obscured. A typical steganographic application is to high messages within images via alter low order bits of pixels, etc. In our approach we alter small portions of what appears to be a regular image. The alterations are subtle and occur over long periods of time making them hardly perceptible to the casual untrained glancer. However, to the person who knows how to read the display, a wealth of information is stored within it.

The image shown in figure 3 is one example of a personal steganographic display. It shows a view of the skyline of Shanghai, PRC and has many easy to manipulate dimensions. For this example, the figure shows only two of the possible ways to modulate this display, the height of the tower at the left and the number of smaller build-

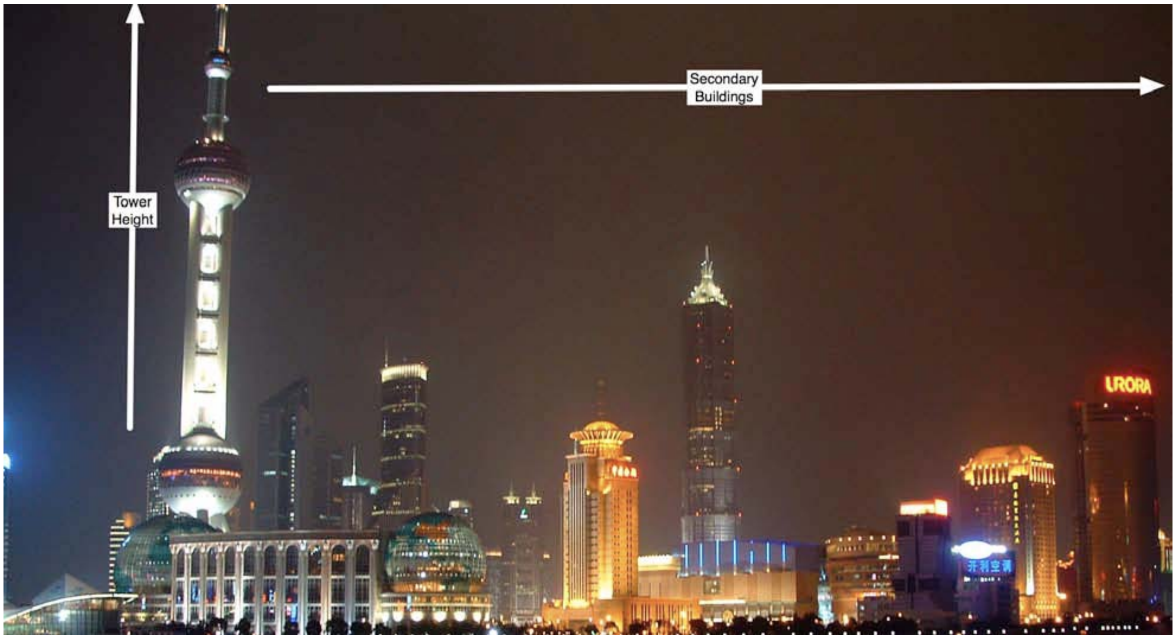

Figure 3: Example of a Personal Steganographic display of an Urban Score measuring the city "vibe" of Shanghai, PRC.

ings shown. These and many other properties could be easily layered within the image.

In our effort to promote conversations, even arguments, about life in the city, we claim that it is better to entangle the notions of the display, the measurements taken, and the mapping between them. This encourages exploration and opens up new avenues of dialogue. We claim that there are any number of metrics that one could measure about the city, the user, or other people that could be used as fodder by designers. We will demonstrate here a simple, two-dimensional, easy-to-implement display that could be generated in real time on a mobile device at any time.

For this urban score, we map the height of the tower to the number of other people that you have encountered over some interval. Are you "out on the town" or "stuck at home?" This can be measured easily with bluetooth scanning. Even though only a small fraction of people turn on their bluetooth radio and make it visible for scanning, we can safely assume that this proportion is roughly constant so that seeing twice as many bluetooth phones indicates roughly the twice the number of people. Naturally, this part of the urban score can be manipulated to include well-known persons, be they friends [8] or strangers [9].

The second dimension, shown as number of secondary buildings in Figure 3, a running average of your proximity to the city's "center" for some spatial definition. The latitude and longitude could be easily measured by GPS, now common on mobile devices, or by some approximation based on visible beacons [10] which has the advantage of working indoors. We also would include in this measurement altitude, as this is often connected with city center locations such as San Francisco's Starlight Room, Tokyo's Roppongi Center, and Paris' Jules Verne Restaurant on the Eiffel Tower. Given some average over a 24 hour period of proximity to the city center, differing amounts of the secondary buildings in Figure 3 would be exposed, perhaps with the most buildings being exposed when one is distant from the city center and fewest when one is "in the center" or vice versa.

An effect of this display is that commuters who live out of town would see the city unfurl or disappear as they went through their day. The skyline would remain "distant" on the weekends if they do not venture into the city for non-work activities. A slight variant of the measurement computed here would be to take the geographic centroid of a set of friends' movements and measure from this point. If there is a "standard hangout" for the gang, it would become the center of the city for that group of people and the display would change accordingly.

Personal Stegonographic Designs

In Figure 4 we demonstrate two envisioned personal steganographic view of an urban score for San Francisco, USA. The views exaggerate a wide range of changes. In reality, a very small handful of changes would be subtly occurring at any given time. For example, the sky color change could indicate air quality with the smoke from building representing sulfur dioxide (SO_2) specifically. The crane could indicate the arrival of new buildings as you approach your "center" of the city. Strangers and familiar strangers are captured by the birds - both flocking and perched. There are also balloons, airplanes, boats, flowers, and tents whose number and appearance can map to specific elements of an urban score. Similarly with animals (grazing) and people (walking, picnicking, and sunbathing.

Figure 4: Example of a Personal Steganographic display of an Urban Score for San Francisco, USA.

Iconic Designs

An alternate approach is shown in Figure 5 using a more iconic representation of various elements to "render" an urban score. In this example as you move from suburb to city the screen "slides" to reveal the urban image (top). The sky color shows air quality comparing air quality where you are now with sensors in the city. Familiar strangers are represented by people and unfamiliar strangers by birds.

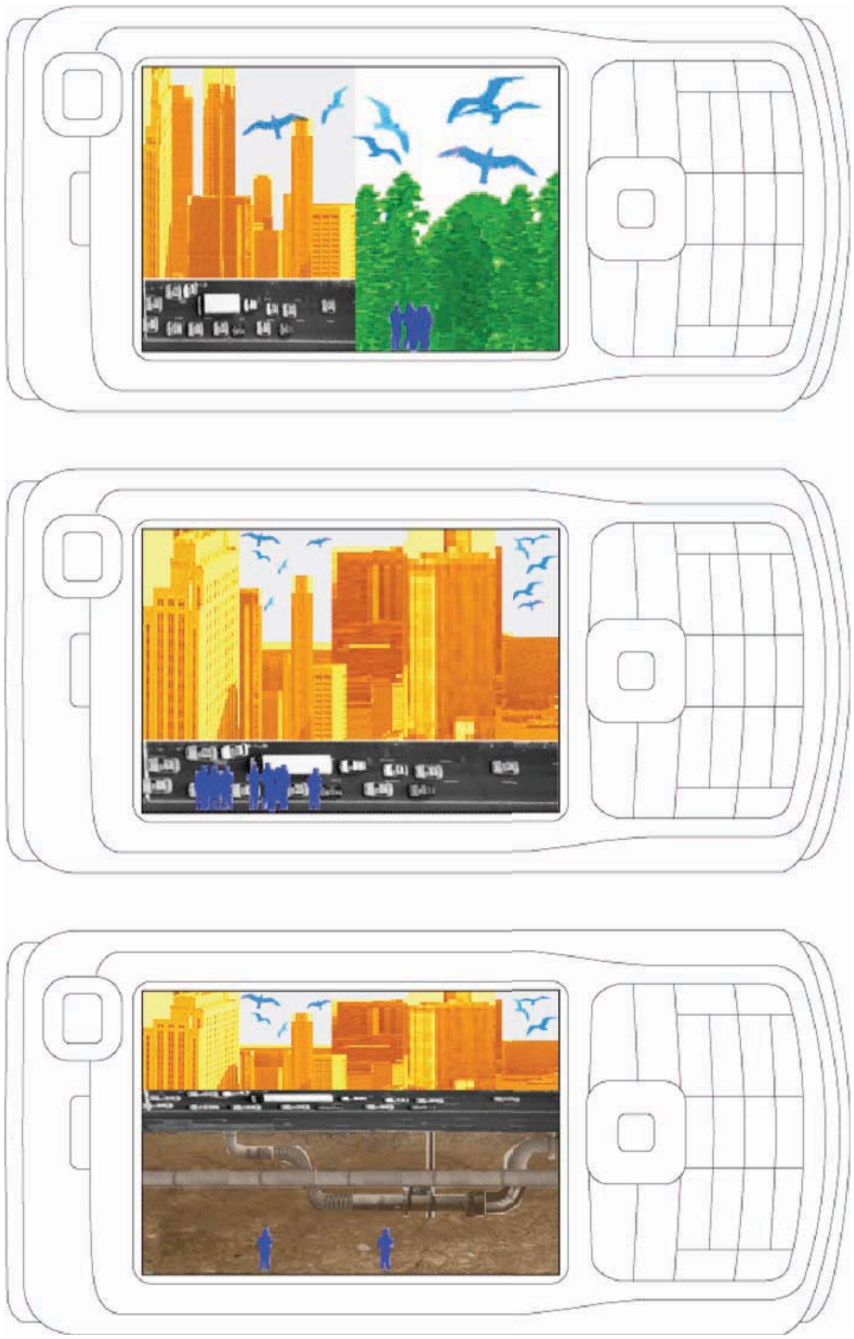

Figure 5: Example of an icon display of an Urban Score

Clouds

We would argue that a key factor that differentiates cities, especially major ones, from towns or the rural environment is leadership, "being ahead of the curve." It is hard to imagine fashion trends coming "to" New York, London, Los Angeles, Paris, or Milan. Similarly, musical trends often coalesce around cities' both large densities of musicians and people eager for new experiences: Hip-hop in New York city, R&B and soul in Detroit, downtempo in London and Manchester, and hair-metal on Los Angeles' Sunset Strip. Films are routinely shown only or make their debuts in major cities, to say nothing of the film festivals. Part of living in a city is the stimulation, even excitement, brought by new things happening in front of your eyes.

For the Cloud type of visualization, again we seek to score what is latent in the experience of a city. A naive Cloud visualization, such as the one shown in Figure 6, would be to take the tags of the songs that people near you are listening to on their mobile devices and form a tag cloud. These tags are usually categories or the names of artists, but experience with last.fm (music) and flickr.com (images) shows that users will tag in useful and unexpected ways. User contribution also implies wrong or distasteful contributed tags; note the misspelled tag in Figure 6 "electroic" is more popular than say "chill." Also the tag "czilaut kompletny" (really "chillout completely") is a joke on (easing of? mistranslation of?) slavic or eastern european languages that represent a significant fraction of the listeners to this type of music.

The relative size in Figure 6 indicates the number of times one of the authors listened to songs with that tag, however in an urban score it would be more interesting to map size to the preferences or current selections of those people nearby. This could be easily sensed among people with Apple iPhones, Microsoft Zunes, or bluetooth enabled devices that share music information. In Figure 4, the position of words is not a controlled dimension, it is alphabetical. Of course this dimension could be easily controlled as well, in the simplest case putting words radially closer to the center if that tag was sensed "recently." With this measurement and visualization, a user walking down 5th Avenue could get a sense of what the world is listening to and why they live "in the city."

A More Aggressive Cloud

We dubbed the visualization shown in Figure 6 naive because it can really show very few of the properties that make cities trendsetting. It is, or soon will be, possible to do this for music, as

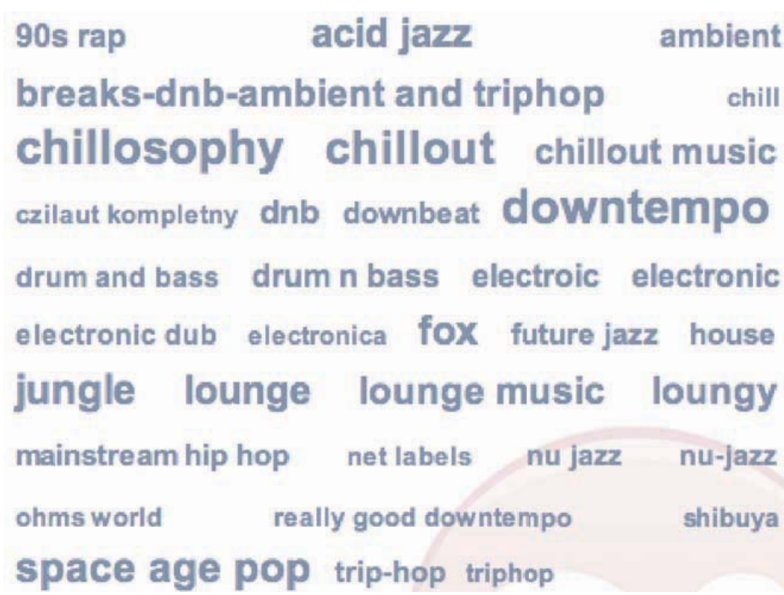

Figure 6: Simple cloud tag visualization. Words shown are tags of music listened to by one of the authors over a two month period. Tags were entered by many users. **Image by http://last.fm***.*

shown, and perhaps photography as cameras emerge with networking capabilities. This is insufficient in our view to get a view of the complexities of the trends in the world's cities.

We propose a new scheme based on credit card sales transactions. In its simplest form, the music tags in the figure would be exchanged for goods/services recently purchased by those nearby or perhaps the names of stores they patronized. This would present a much more accurate portrait of activities in the city and all the data is collected already (by credit card companies) and is already available to most users on the internet. Almost needless to say, though, this presents a privacy problem of the highest order. If this were actually the desired design it is likely that a technical scheme could be devised to "hide" a single user's data amongst the great multitude, ala mix routers [11]. This would allow meaningful clouds to be generated without exposing an individual's behavior. Even still, it seems unlikely to gain wide acceptance due to the perceived privacy invasion

Evaluation Opportunities

In this section we will give a brief overview of some of the evaluations of an urban score that we think might be interesting research contributions to the community.

- Measuring the different "uses" that a mobile device takes on. This evaluation would compare a personal steganographic urban score visualization with a more functional one, such as in Figure 1. Within a subject, it seems clear that news and weather have value, but how does that value (both by usage and perception) differ from the value of the urban score? When? How does this tie in with the idea of promoting “wonderment” in cities [12]
- Measuring the different properties of the urban score that create the highest interest or usage level. This could be done easily by measuring perceived satisfaction and usage and varying the properties sensed without changing the display or vice versa.
- Measuring the degree to which an urban score influences action, especially in contrast with traditional advertising. Assuming one could do location based advertising, for example, is that more effective at causing people try to a new restaurant versus an urban score that "suggests" that people in some area have some unusual or unexpected property?
- Measuring the degree to which people want to view their own urban score and compare it to others. Is it possible that there could be agreements on rules such that one could have a "most urban person in Rome" contest?
- Measuring the front-stage vs. back-stage [13] behavior with data that is being publicized about a user. Do users try to manipulate the system in some way (say by *not* playing Vanilla Ice on their iTunes so it will not appear in the "recently played" list) so as to present a particular *face* to others that see their data? Even in aggregate data? Do people use urban scores as a way publicize their interests in a particular band, restaurant, or way of life?
- If the urban score is a complex amalgam of many sensed features, it might be interesting to have users use the system for a while and see what mental model they build up about the system and how they feel when the system's true working is revealed. Their mental images of how such a system works is likely to yield insights into what an urban score system *should* do.

Conclusion

In this paper we have introduced the notion of an urban score, partly a low-attention display and partly the basis on which that display rests. This "score" allows users to put their finger on the pulse of a city, to get a feeling of those around them, and question assumptions about their urban life. We have introduced the idea of a personal stegonographic ambient display. We have suggested a variety of mostly personal stegonographic visualizations of the urban score to kick-off the debate about what an urban score should measure and how it should be visualized. Two of these displays, the dosimeter category, attempt to show you how much of the city you have consumed, via inhalation or inebriation. The last two focus on understanding those that are near you - a common situation in densely populated areas. These two cloud visualizations could be generated from easy to sense values and provide insights into a community. With these designs have try to highlight our significant concern for designing usable, thought-provoking systems that protect the users privacy.

We hope that these thoughts can be a spring-board to others.

Research Question For The Workshop

What's your urban score?
What would you like it be?

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Ambient Information Systems: Evaluation in Two Paradigms

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ABSTRACT
We take two paradigms for information systems development, functionalism and social relativism, and apply their assumptions to the evaluation of ambient information systems. Ambient information Systems research, we posit, comes from two distinct paradigms and this has confounded a single evaluation framework from emerging. Instead, different groups of researchers have specific (if implicit) philosophical commitments about people and the social world, and these commitments have led to two research paradigms. We explain our view of these evaluation paradigms, and note a single area of focus for each evaluation framework. For functionalist evaluations, the questions circle around what to measure (and how to measure). For social relativist evaluations, the questions are practical but also theoretical; are we even asking the right questions? If so, how could we answer them?

ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

GENERAL TERMS
Ambient Information Systems, Human Factors., Longitutidnal Evaluation, User Study, Design

INTRODUCTION
Every technology product has, if one looks deeply, a delicate and complicated relationship with its users, and the environments in which users live and work. Ambient Information Systems, those systems that display important but not critical information on aesthetically pleasing and subtle displays, are no different [12]. In fact, when compared to systems that users employ for work tasks, they almost certainly have this character. Evaluating Ambient Information Systems (AISs) is a process of explaining how often an AIS is used, how much it improves the life of users, and how the system is appropriated into the rhythms and practices of users. AISs are built by designers from different research paradigms. Designers subscribe, either implicitly or explicitly to a set of practices and commitments about the world that make up a research paradigm [7]. These research paradigms shape the ways in which designers of systems view the world, including their assumptions about the nature of the social world and the goals of technology intervention. The paradigms also influence the evaluation questions that are asked, the metrics by which success will be judged, as well as the methods they will employ in measuring these phenomena.

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In some research areas, all or nearly all the practitioners have a consistent world view, and have wide agreement on their assumptions. This leads them to agreement on what matters for design, as well as what counts as success (success metrics), and evaluation methods. In contrast, AIS design and evaluation is complicated because the devices and systems that are produced span two differing research paradigms. We believe that some research teams have particular commitments and beliefs on the status of the world, while others subscribe to a different set of beliefs. Let us explain a bit what we mean by the idea of a research paradigm, and specifically the two paradigms that we feel that researchers in our community use in their work. Paradigms, as we the authors understand them, can be implicit or explicit, so some researchers may not have consciously or publicly joined a paradigm, though we claim the paradigm still impinges on their work, the systems they build, and the ways that they evaluate those systems. We follow Hirschheim and Klein, who explained four different theoretical frameworks for the entire space of information systems development [7].

Their analysis of the philosophical and social science commitments of research communities mirrors Burrell and Morgan, sociologists who sought to explain the commitments of Sociological research [1]. The first spectrum represents the reality of the social world and whether (and how) it can be understood. On one extreme are the realists (empiricists), who believe in a stable, perceptible, and explainable social world, and who are scientific in their explanations. At the other extreme are those theorists who believe the social world to be socially constructed, and use anti-rationalist explanations (at its most extreme, where the social world could be described as imaginary, this is philosophical Solipsism). A second spectrum concerns explanations of behavior in social experiences. We feel that this spectrum of control and regulation versus transformative change (even revolutionary change) is not as applicable to the design community for AISs, so we will not dwell on it here. Four quadrants fall out of the crossing of the two spectra. They are: Functionalism, Social Relativism, Radical Humanism, and Radical Structuralism.

We posit that two paradigms, Functionalism and Social relativism are relevant to researchers who build and study Ambient Information Displays. Functionalism is the earliest paradigm for system's research, and has guided the work of engineers and developers. Hirschheim and Klein claim that Social Relativism came about as a reaction to the functionalist research paradigm. Social relativism contains phenomological and hermenutic philosophical positions, where the social world is understandable only by investigating the everyday "felt lif" of a particular group, and the ways that they use signs and sign-systems to negotiate these meanings. Hirschheim and Klein, as well as Burrell and Morgan before them, claim that the four paradigms are mutually exclusive and irreducible; they claim that the two paradigms cannot be joined in a synthesis that would combine the best elements from each. This may make it impossible to create a single paradigm for design and evaluation of AISs.

AISs appear to us to be built by research groups from the Functionalist paradigm or the Social Relativist paradigm. This paper will work to explain how these two paradigms address the messy issues surrounding evaluation of AISs. Many researchers have already noted the difficulty in designing, running, and analyzing the results from evaluations (as we note in the next section). Our hope here is to use the opposing research paradigms to hone in on a single evaluation framework under each paradigm. The evaluation frameworks that we propose for each paradigm does not change the basic shape of evaluations of ambient systems. Successful evaluations are by and large longitudinal in their character, taking a view of technology that unfolds over weeks and months, not minutes. These evaluations predominantly take place in situ, situated in authentic work and home environments. As opposed to short laboratory-based studies, these long-term and situated evaluations of technology aim for rich narratives and ecologically valid results, no matter the particular paradigm chosen.

RESEARCH PARADIGMS

First we should explain in greater detail the two paradigms that we find operating in the space of ambient information systems. These paradigms are "the most fundamental set of assumptions adopted by a professional community" [7]. The assumptions in a paradigm concern the very nature of what a particular community (and therefore a researcher in that community) can see, because the assumptions filter the social world based on concepts and objects that are governed by the paradigm. Said another way, joining a paradigm requires a commitment from members about ontology, the kinds of entities that exist in the social world. Paradigms also concern epistemology, the way that knowledge can be gathered. Further paradigms make claims about methodology, how research is done research, and the nature of human beings, whether they are mostly volitional (free to chose their actions) or constrained by external forces and events. Paradigms, as we have already hinted, are potentially unconscious and part of the unquestioned background of research practice.

The paradigm of Functionalism is the oldest and still most common research paradigm in Computer Science and Information Systems development [7]. Functionalism states that the social world is real, stable, teachable, and rationally understandable. The paradigm commits to the existence of mental phenomena in the lives of people. People are rational beings with free will, and their fundamental social driver the coordination, regulation, and control of social situations (this is opposed to understanding the social conflict as primarily a class struggle of owners of capital versus laborers, an assumption by those who subscribe to a more structuralist paradigm). System design in this paradigm can be thought of as "instrumental reasoning" and the role that the developer plays is "systems expert." The expert moves through the analysis process by decomposing goals into hierarchical tasks, and then proceeds to develop a system that supports "rational organizational operation and effective and efficient project management." [7]. The goal of the developer is to increase efficiency and effectiveness. Hirschheim and Klein claim this is the oldest and most ingrained paradigm in IS development, and we feel that it has continued to be important to HCI, ubicomp, and ambient information system research.The paradigm of Social Relativism is a more interpretivist research paradigm. Researchers who subscribe to this paradigm have different commitments, different understandings about the world, and their roles as analysts and developers reflect their beliefs.

The Social Relativist paradigm takes reality as socially constructed, and therefore potentially different for different people. The social world is complex, full of traditions, social conventions, and cultural norms, which are not purely rational. People are embedded in the social world, which is ever-changing, and in some real sense continually reinvented by individuals and groups. On this shifting ground, social practices may never be fully rationalizable, nor is rationality the only way to understand human behavior. The systems developer who takes on this paradigm is more accurately described as a "facilitator" and attempts to tease out some (potentially limited) order by a process of sense-making [7]. The goal of the developer is to help a given population achieve consensus on their shared understanding of a confusing (and potentially unknowable) reality.

We will now move the discussion to the view that each paradigm brings to evaluation, in the context of AISs. We are not judging these paradigms on their relative value, and our aim is not to show one paradigm as a better fit for AIS design and evaluation. However, a clear understanding of the paradigms coupled with how those paradigms find expression in the evaluations of ambient information systems may help the evaluator ask clearer, more germane questions, design better studies, and, we hope, get more compelling results from those studies.

FUNCTIONALIST AIS EVALUATION

Inside the functionalist research paradigm, AIS evaluation has a particular character. We summarize our conception of that character here. An AIS is designed to convey information in a way that is calm and not disruptive or distracting. An AIS is designed to be helpful for the important but not critical information in our lives, and to increase our awareness. In this paradigm, researchers know what they are looking for, and the only puzzle is to find it. A successful AIS would increase a user's perception of her awareness of the information displayed. This increase in awareness would improve her quality of life and decrease her feelings of stress and anxiety (or at least those stresses caused by not having this information at the ready). The question then becomes: *How do we measure these constructs in user's heads?*

The evaluation of an AIS is most often done in an authentic situation, such as in the home or office setting. Evaluations are often longitudinal, so that the evaluators can be sure that results are not skewed by the "novelty effects" early on. Surveys and other self-reporting measures can be used to gather feedback on measures concerning efficiency and effectiveness of the system. The evaluators measure the sense of usefulness, anxiety, distraction, and perceived time savings. An example of this evaluation technique is the evaluation of the InfoCanvas by Stasko *et. al.* [14] Stasko and his team deployed a consolidated information display, the InfoCanvas, into eight participant's offices for a period of one month. They interviewed participants with a pre-intervention, midpoint, and end-point feedback sessions. These sessions consisted of a battery of Likert-scale questions surveys to determine if and how much user's perceptions were changing over the course of the study. The sessions also contained more open-ended questions, which sought to gather narratives of situations where the system came in handy. These qualitative data points were intended to bolster the claims from the quantitative measures and their trends throughout the study. Other studies that are in this paradigm, and that therefore follow this evaluation framework (but in a laboratory setting) are McCrickard, *et. al.*'s and Matthews, *et. al.*'s studies of design for the periphery of computer screens [11, 9].

The evaluation framework of functionalism requires that members of the research community who subscribe to this set of commitments come to a clear set of metrics. That work is, from our reading in the field, ongoing, but certain metrics have gathering consensus. We list some candidates here, with a short discussion:

- **Heightened Awareness** An AIS will make information available for quick and opportunistic glances
- **Time Saving** The hope is that AIS are convenient for users, saving them time in their routines
- **Anxiety / Stress** An AIS should decrease the anxiety and stress that comes from having to actively find and monitor information sources. If a user feels little stress from monitoring a particular data source, then an AIS that includes this information is of little value.
- **Distraction of presentation** An AIS should have more payoff in heightened awareness and time savings than it has detriment being distracting. We note that distraction can mitigate over time, so a evaluation should last long enough for the system to become routine.
- **Learnability of mappings/representations** An AIS is often evaluated on the success of the mapping between data and presentation. A system that remains hard to decode is not a success.

Is this a complete list, or should other important metrics be added? The functionalist paradigm for AIS research hopes to find a consistent set of metrics through which developers can make claims about the success or failure of their ambient systems. The list of metrics should also be measurable in a consistent (and generalizable) way. New methods for getting at these perceptions can be developed. Also, observational data could potentially be used to get past the perception to the actual participant behavior for metrics like counts of "glances per day" (see Shen for an interesting attempt at this [13]) and "distracted by display."

SOCIAL RELATIVIST AIS EVALUATION

For researchers in a social relativist framework, AIS evaluation is conceived differently. In light of their philosophical commitments and orientation, the AIS intervention needs to be studied in light of complicated and harder to measure topics like work practices and rhythms, appropriation, and adoption of systems into the lives of participants. These evaluations are of similar setup when compared to functionalist evaluations. They are long-term, *in situ* studies by and large, but the focus of the evaluation, driven by the philosophical commitments, is quite different. Researchers in this paradigm might believe that it is impossible to look inside the heads of users and participants. Or, slightly less categorically, they might believe it impossible to know precisely if and when they've found something. The most one might be able to say is that the evaluator might have been able to note moments of reflection and contemplation in the lives of participants. Carter, *et. al.* note "The central problem facing developers of peripheral displays is that metrics for success are not well defined. One [expert interview] participant summarized the issue saying 'most technology that is out there is about maximizing efficiency' that is often not the case with peripheral displays, causing designers to 'reevaluate [standard] systems of evaluation'." [2] If, as Carter claims, AISs are not about maximizing efficiency, then what are they about?

One place that many researchers have looked for answers to this question is phenomology, a philosophy that operates firmly in the social relativist paradigm. Hallnas and Redstrom characterize their design and evaluation of an AIS for weather data for multiple cities in a way that is not on the previous list of metrics that matter for evaluation [6]. Instead, they draw on phenomological philosophy, and propose the notion of *presence* as key to analyzing and evaluating AISs. They contrast presence with *use* or *function*. Hallnas and Redstrom note "Having encountered problems such as how to evaluate a certain design and how to describe what constitutes good design in these areas, we came to question the relevance of some of the basic assumptions in human-computer interaction." [6] McCarthy and Wright, though they are focusing on system evaluation in a wider domain that just AIS, claim that the felt life and emotional quality of system interaction are of key importance [10].

The methods for evaluation in a social relativist paradigm are narrative and ethnographic in their main approach. These techniques rely on the evaluator being, himself or herself, the tool with which data is gathered. The evaluator, attempting to stay open to various kinds and modes of appropriation attempts to find the ways (if any) that participants are making the AIS part of their lives. These evaluations are hardly ever comparative in their execution, and can be concieved of not experimental interventions. However, the goal is not generalizable results, but, instead, a consensus between the users and the developers themselves around the use of the AIS. Techniques beyond ethnography that are used by researchers in this paradigm are bringing users into the evaluation, making the evaluation part of the experience of using the system [8]. Other approaches that are undertaken are probes (cultural and technical), experience sampling methods, and other methods to spark and stimulate reflection by users on the system under evaluation [3, 4]. AISs can be evaluated in the social relativist paradigm from multiple angles and perspectives in a kind of triangulation. This can even stretch toward mixed methods research, which blends quantitative (historical or demographic), qualitative, and participatory evaluation to find multiple corroborative data points from which a holistic portrait of use emerges.

The social relativist paradigm for AIS evaluation hopes to answer the question of how exactly, to what degree, and to what ends, users integrate AISs into their lives. Answers to this question are at a level at which only descriptive statistics can be gathered, and instead, rich narratives chart the appropriation of the technology into the lives of users. Gaver's work with the History Tablecloth epitomizes, for us, this approach [5]. The ongoing questions for this research paradigm consist of work to extend the paradigm, to define its course, and to refine the methods utilized by the community.

CONCLUSION AND FINAL QUESTIONS

In this position paper we have proposed that there are two different paradigms of research at work in AIS design and evaluation. We note that they may be mutually exclusive, governed by philosophical commitment of the researcher more than pragmatic or practical strategy. As such, we attempted to give our views on the paradigms, the entities they focus on, and the way that these paradigms find expression in the evaluation of systems. Now we take up two specific areas, one in each paradigm, where open work remains for the researchers who are committed to that paradigm. We propose a more focused and nuanced vision of evaluation questions for practitioners in each paradigm.

For the Functionalists: *Is the list of measures for evaluation complete? If not, what is missing? How can we achieve agreement on how to study these measures as user's enage with ambient information systems?*

For the Social Relativists: *Are the concerns we mention for evaluation ever going to achieve closure? Will phenomology, a philosophical position that many researchers in the area appeal to, be able to provide deep insight? What specific evaluation questions seem germane given this philosophical framework? How can they be answered?*

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Intrusive and Non-intrusive Evaluation of Ambient Displays

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ABSTRACT
This paper addresses two problems: "What are the appropriate methods for evaluating information systems?" and "How do we measure the impact of ambient information systems?" Inspired by concepts in the social and behavioral science, we categorize the evaluation of ambient displays into two styles: *intrusive* and *non-intrusive*. Furthermore, two case studies are used to illustrate these two evaluation styles. An intrusive evaluation of *MoneyColor* shows that the correct disruptive order for ambient displays is animation, color, area and shape. A non-intrusive evaluation of *Fisherman* proposes an effectiveness measurement, and reveals three issues to improve the effectiveness of ambient displays.

Keywords
Ambient displays, intrusive evaluation, information visualization, human computer interaction

INTRODUCTION
Ambient displays to some extent come from the ubiquitous computing dream, which was first proposed by Weiser [1]. Following his dream, many pioneers of ubiquitous computing have created a plethora of overlapping terminology (for example, disappearing computing [2], tangible computing [3], pervasive computing [4], peripheral display [5], ambient display [6], informative art [7], notification system [8], or even ambient information system [9]). The differences between some of these terms are not obvious. In this paper we use the term "ambient displays" generically.

Research on ambient displays is still immature, and there is no universally accepted definition available. Ishii et al. [3], Matthews et al. [5], Stasko et al. [9] and Mankoff et al. [6] all propose their own definitions. Here we follow Stasko [9]: "ambient displays typically communicate just one, or perhaps a few at the most, pieces of information and the aesthetics and visual appeal of the display are often paramount".

Many ambient displays have been designed and developed but less progress has been made in the evaluation of these displays. However, good evaluation methods can judge the quality of the design to provide a basis for making improvements, and we believe that evaluation methods should be a priority for researchers.

This paper focuses on two issues: "What are the appropriate methods for evaluating information systems?" and "How do we measure the impact of ambient information systems?" These questions are difficult and will take some years of effort to settle. In this paper we propose a concept that may play a role in the answers. More specifically, two evaluation styles, intrusive and non-intrusive evaluation, are proposed in the next section. Following this, we illustrate the styles with two case studies.

INTRUSIVE AND NON-INTRUSIVE EVALUATION
Many researchers have realized the importance of the evaluation of ambient displays. Mankoff et al. [6] proposed a heuristic evaluation for ambient displays. Pousman et al. [9] proposed a four design dimension to guide in the evaluation of ambient information systems. McCrickard [8] proposed an IRC framework to evaluate the notification system. Shami [10] et al. proposed the CUEPD evaluation method to capture context of use through individualized scenario building, enactment and reflection.

McGrath [11] categorized eight normal evaluation methods in the social and behavioral science and classified them by two dimensions: "Obtrusive vs. Unobtrusive" and "Abstract vs. Concrete" (See Figure 1).

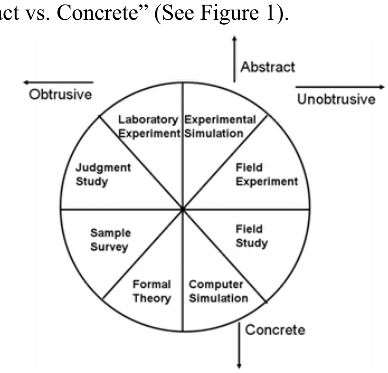

Figure 1. Evaluation Methods and Classification

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These eight evaluation methods are applied broadly in behavioral and social science, but can be used in information visualization and even ambient displays.

Inspired by McGrath's classification, we proposed two new terms "intrusive" and "non-intrusive" for ambient display evaluation.

Intrusive Evaluation — is where the user's normal behavior is consciously disrupted by the evaluation experiment. This kind of evaluation often consists of usability tests in a laboratory environment for a short period. Most such experiments are conducted using well established evaluation techniques in information visualization (for example, questionnaires and interviews).

Non-Intrusive Evaluation — is where the user's normal behavior is not consciously disrupted by the evaluation experiment. This often focuses on actual use in a general environment (*in situ*) over a long period. Currently, few existing evaluation techniques can be applied successfully in this manner.

Intrusive and non-intrusive seem more like endpoints on a continuous range than buckets for evaluation methods. The difference between these two evaluations is the level of user involvement. Intrusive evaluation seems to be good at quantitative measurement of parameters, but non-intrusive evaluation may be not. On the other hand, intrusive evaluation may have higher cognitive load, which leads to affect the validity of results, but non-intrusive evaluation can have better results by having lower cognitive load.

Two case studies are described in the next section to illustrate these two evaluation styles.

TWO CASE STUDIES

In this section, we describe evaluations of two systems: *MoneyColor* and *Fisherman*. Both systems represent real-time information as well as decorating the architectural space. Both are designed for the public sites.

The data used in *MoneyColor* is stock price and volume from the Australian Stock Exchange. More specifically, our experiment used BHP-Billiton[1] price and volume data.

The *MoneyColor* display is inspired by the art of Hans Heysen [12] an Australian watercolor painter of the early 20th century. Paintings in the style of Heysen form a peaceful background, and are often used simply as decoration in Australia, from homes to boardrooms.

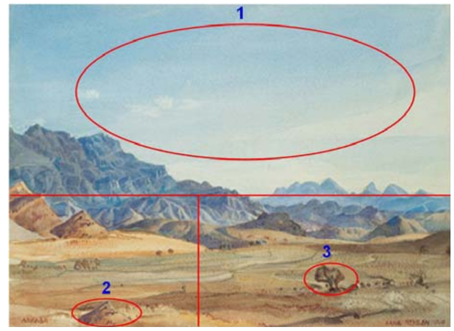

Figure 2. Metaphor of *MoneyColor*

There are three metaphors in *MoneyColor* (see Figure 2):

1. The color of the sky represents the general stock index. The darker the sky, the lower the general stock index.
2. The position of a specific mountain represents the current BHP stock price. The higher the position of the mountain on the image, the higher the stock price.
3. The size of the tree represents stock volume. The larger the tree, the greater the stock volume.

MoneyColor is aimed for use by stock holders and brokers.

The data source used in *Fisherman* is statistics. More specifically, we use three parameters of the NICTA[2] website: the number of hits on the web page; the bandwidth of the web server, and the number of pages viewed.

There are three metaphors in *Fisherman* (see Figure 3):

1. The level of fog in the mountain represents the number of hits on the web page. Heavier fog indicates fewer hits.
2. The number of trees represents the number of viewed pages. The more trees, the more pages viewed.
3. The position of the boat represents the bandwidth of the server. The higher the position, the higher the bandwidth.

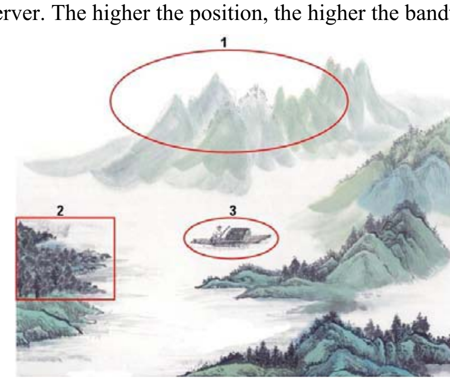

Figure 3. Metaphor of *Fisherman*

[1] BHP-Billiton is a large mining company based in Australia; price movements in BHP-Billiton are very influential on the Australian Stock Exchange.

[2] National ICT Australia, an Australian Government research laboratory.

Intrusive Evaluation of *MoneyColor*

The general evaluation aim of *MoneyColor* is to explore the way in which different factors disrupt the user. More specifically, we want to determine the order of disruptiveness of the following factors:

- *Animation*: the image morphing technique
- *Color*: the change in hue.
- *Area*: the change in the size of the tree
- *Position*: the change of the location of the mountain.

We hypothesize that the correct disruptive order for ambient displays is: animation, color, position, then area. This hypothesis is loosely based on the results of Cleveland and McGill [13] on the order of visual cues for effectiveness in graphical presentation.

The experiment was conducted in a visualization laboratory. Eighteen (nine female) subjects participated in this experiment. Subjects ranged from 21 to 35 years (10 masters, 6 PhD and 2 Post-doc). Seven subjects knew nothing about ambient displays and the remainder had some knowledge; none were experts.

The experiment use *Square-Click,* a simple game that dynamically assigns a random location for a black square (size 80*80 pixels) every second. Subjects need to mouse-click the black square within one second of its appearance (see Figure 4). If successful, the black square will be assigned to a new random location and the user scores 1. If not, the black square will be assigned a new location after one second and the user scores 0.

The experiment used a standard PC with two standard 19 inch monitors with a resolution of 1024*768, and one LogiTech QuickCam Pro4000 web camera together with face detection software. A mouse was the only user input device. The monitors, camera, chair, and desk were arranged as in Figure 5.

There were two user tasks in this experiment. The primary task was to play *Square-Click*; this ran for two minutes on the "focus" monitor, after which the user score was recorded. The secondary task was to obtain information about BHP stock via *MoneyColor* on the "peripheral" monitor. Participants were encouraged to not only get a good score in the primary task but also get BHP stock information.

The experiment included fifteen tests. Each test had *Square Click* system plus *MoneyColor*, but focused on different factors:

- Test 2-3: "color" with/without animation;
- Test 4-5: "position" with/without animation;
- Test 6-7: "area" with/without animation;
- Test 8-9: "color and position" with/without animation;
- Test 10-11: "color and area" with/without animation;
- Test 12-13: "position and area" with/without animation;
- Test 14-15: "color, position and area" with/without animation.

Each test lasted two minutes and was followed by a two-to-four minute break, so the entire experiment lasted around one and a half hours. Testing of all 18 subjects was conducted within three weeks.

A questionnaire was also used at the end of each test to collect additional information, with three Likert-scale questions:

- Does the value of the parameter change?
- How does the value of the parameter change?
- How much does the value of the parameter change?

Further, the face detection software is used to record whether subjects look at *MoneyColor* or not.

Figure 4. Square Click

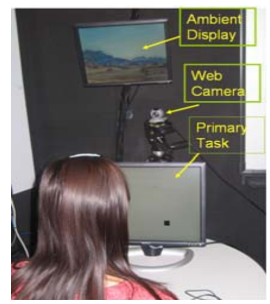

Figure 5. Actual Settings

Non-Intrusive Evaluation of *Fisherman*

The general aim for this experiment is to discover the relationship between *comprehension* and time. We hypothesize that the comprehension of subjects to *Fisherman* increases with time.

This experiment was conducted in a public corridor opposite to an elevator, close to a public facilities room. The display was in a purpose-built frame, which also enclosed an IR sensor and a camera[3]. Furthermore, the *Fisherman* metaphor was described on an A4 size paper on the new frame (see Figure 6).

Every person passing by *Fisherman* was a subject of this experiment. These people are mainly researchers. Most have some knowledge of ambient displays but none is an expert. The whole experiment lasted six months.

Subjects were randomly chosen to fill the questionnaire and subjects were not allowed to look at the display during answering questions. Three questionnaires were scheduled within the six months. Each questionnaire was mainly to

[3] Since the system included a sensor and camera in a semi-public place, legal opinion was obtained to ensure that the system complied with privacy legislation.

measure three attributes: *comprehension*, *usefulness* and *aesthetics*.

The comprehension questions were:

CQ1: Does *Fisherman* convey any information?

CQ2: How many types of information are represented in *Fisherman*?

CQ3: What kind of information does *Fisherman* represent?

CQ4: Have you ever noticed changes in *Fisherman*?

The usefulness questions were:

UQ1: Is *Fisherman* useful to you?

UQ2: Why?

The aesthetic questions were:

AQ1: Do you think *Fisherman* is visually appealing?

AQ2: If possible, would you put *Fisherman* in your home/office?

AQ3: Why?

The IR sensor and camera recorded the number of people passing the display and the number of people who turned their face toward the display.

There was no specific primary task designed for the subject; almost all the subjects were engaged in a normal everyday primary task such as using the elevator or the facilities room. Subjects shifted focus to the display to obtain information; this was a secondary task.

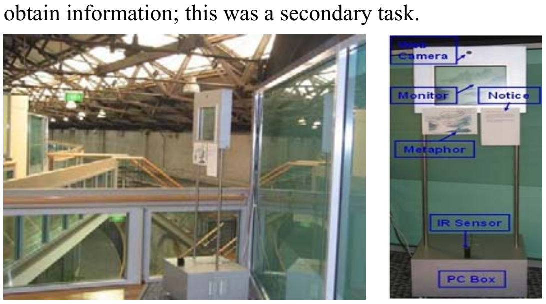

Figure 6. Implementation of Fisherman

Results of the Intrusive Evaluation of *MoneyColor*

A within-subject experimental design was used with non-fixed ordering of the experimental tests. Three parameters are analyzed:

- *Mean Comprehension Rate* (MCR) is derived from the answers given in the questionnaire; it measures the correctness of the information that subjects recalled about the information on the peripheral display. A larger MCR indicates better understanding of the ambient display.
- *Mean Self-Interruption* (MSI) counts the number of focus shifts to the peripheral screen prompted by the subjects themselves; a larger MSI denotes a more curious or nervous subject.
- *Mean Display-Distraction* (MDD) counts the number of focus shifts to the peripheral screen caused by display distraction; a lower MDD denotes a calmer ambient display.

The difference between Mean Self-Interruption (MSI) and Mean Display-Distraction (MDD) is not subtle. As a gross simplification, we assume any glance after a display update contributes to the Mean Self-Interruption (MSI).

Two major results are discussed below.

MCR	Test 2-3	Test 4-5	Test 6-7	Test 8-9	Test 10-11	Test 12-13	Test 14-15
Animation	0.84	0.67	0.83	0.80	0.60	0.54	0.53
Static	0.83	0.65	0.80	0.74	0.58	0.58	0.52
p	0.05	0.04	0.04	0.03	0.05	0.05	0.05

Table 1. Mean Comprehension Rate in Each Test

Table 1 shows that the value of Mean Comprehension Rate (MCR) with animation is higher than without. Furthermore, this difference is significant ($p<0.05$).

Also, Table 1 reveals that color (Test2-3) has the highest Mean Comprehension Rate (MCR) and position (Test4-5) achieves the lowest (as a single factor).

	One Visual Cue	Two Visual Cues	Three Visual Cues
MCR	0.771	0.633	0.531
p	0.123	0.081	0.069

Table 2. Relationship between MCR and visual cues

Table 2 shows that the value of Mean Comprehension Rate (MCR) decreases with the increase in the number of visual cues. However, this result is not significant and requires further study.

A statistics correlation method was used to calculate relationships between Mean Comprehension Rate (MCR), Mean Self-Interruption (MSI) and Mean Display-Distraction (MDD) and results showed that Mean Comprehension Rate (MCR) is directly proportional to Mean Display-Distraction (MDD). However, there is no obvious relationship between Mean Comprehension Rate (MCR) and Mean Self-Interruption (MSI) (see Figure 7).

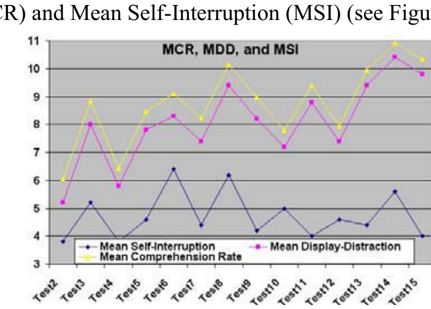

Figure 7. Relationship between MCR, MDD and MSI

Results of Non-Intrusive Evaluation of *Fisherman*

A standard deviation (STD) statistical method is used to analyze results. Three parameters are analyzed in the non-intrusive evaluation of *Fisherman.*

- The *Mean Comprehension Rate* (MCR), based on the answers from the comprehension questionnaire (CQ1-CQ4). A larger MCR indicates better understanding of the display.
- The *Total number of Subjects Passing by* (TSP) *Fisherman* in one day, measured using the IR sensor.
- The *Total number of Subjects Looking at* (TSL) *Fisherman* in one day, measured by the facial detection system.

It is clear that TSL ≤ TSP, but TSP also counts subjects passing by *Fisherman* without looking at the display. Thus we propose an effectiveness measurement ES as:

ES=TSL/TSP

Two major results on effectiveness are discussed below.

	1st MCR	2 MCR	3 MCR
CQ1	90.1%	100%	100%
CQ2	72.7%	76.9%	79.9%
CQ3	45.5%	76.9%	78.4%
CQ4	45.5%	69.2%	69.9%

Table 3. Results of Mean Comprehension Rate

Results from Table 3 show that Mean Comprehension Rate (MCR) in each question increases with time. This result supports our hypothesis that comprehension of *Fisherman* increases over time.

Table 4 shows the mean effectiveness value with standard deviation in each week (the first value in each cell is the mean effectiveness value; the second value is the standard deviation). From Table 4, it seems that effectiveness decreases over time.

	Week 1	Week 2	Week 3	Week 4
Sep., 05	34.8%/0.1	32.9%/0.2	16.9%/0.12	16.7%/0.1
Oct., 05	8.4%/0.03	9.0%/0.04	8.1%/0.03	7.2%/0.01
Nov, 05	7.4%/0.03	6.1%/0.02	5.7%/0.03	5.3%/0.02
Dec., 05	4.3%/0.02	4.7%/0.01	4.1%/0.01	Holiday
Jan., 05	Holiday	4.1%/0.01	3.9%/0.01	4.1%/0.01

Table 4. Mean value of effectiveness in each week

Discussion of Intrusive Evaluation of *MoneyColor*

The intrusive evaluation of *MoneyColor* shows that animation is the most disruptive factor. In fact, Table 1 shows that we can order the factors by disruptiveness as follows: Animation, Color, Area and Position. This result differs from the finding of Cleveland and McGill [13] (that the correct order for quantitative data is: position, area, color and animation). However, Cleveland and McGill investigated displays that demand full user attention, while we are investigating ambient displays. Thus this result shows a clear distinction between ambient and focal visualization.

Conclusion 1. The correct disruptive order for ambient displays is animation, color, area and shape.

Results in the *MoneyColor* evaluation (Figure 7) also show that more display distraction gives the better performance in comprehension. On the other hand, there is no obvious relationship between self-interruption and comprehension. Part of the reason is that display distraction is caused by the change of data source, whereas self-interruption depends on the personality of the subjects. Thus subjects have a better chance of identifying changes in *MoneyColor* by display-distraction than by self-interruption. This result is consistent with Matthews' finding on distraction (which she called "notification") [5]. Our result further adds weight to the hypothesis that different levels of display-distraction may affect the comprehension of ambient displays.

Conclusion 2. Better control of the level of display-distraction seems to enhance the level of comprehension for ambient displays.

Discussion of Non-Intrusive Evaluation of *Fisherman*

Results in the evaluation of *Fisherman* show that the effectiveness in *Fisherman* is quite low. Three reasons are reached to explain this:

1. *The data source does not interest users* — many subjects comment that the data source used in *Fisherman* was not related to their everyday activities. A typical comment: "I felt the display was interesting rather than directly useful, as the information represented here is not relevant to me. Visualizing statistical information of NICTA internet traffic has not affected my internet usage (it didn't bring any personal advantage to me). I'd like to see information about my activity that doesn't affect my privacy". This kind of comment implies the following conclusion:

Conclusion 3. Customization of data source can improve the comprehension of ambient displays.

2. *Lack of reference in the visual metaphor* — some subjects have difficulty interpreting information from the small changes in the metaphor used in *Fisherman*. A comment from one subject was: "I notice the color, the number of trees and the position of the boat changing but I can't get precise information from this change. Also I can't tell the difference between small percentages of change in these three metaphors. There is a lack of reference for the difference between heaviest and heavier fog." These comments imply:

Conclusion 4. Metaphors for quantitative measurements need some clues to be interpreted well.

3. *Subjects need a better way to interpret ambient displays* — ambient display is a new type of

visualization style and most subjects still prefer to access information by focal displays. A typical comment: "I only look at the display a couple of times a day and it seems to act as a cue for conveying information. But I still like normal visualization styles". This comment indicates that users need better support to interpret the information from ambient displays.

Conclusion 5. Users need better support information from ambient displays.

A significant question in many evaluations is: "When a test should be conducted?" Most researchers answer this question based on experience, but this evaluation attempts to use the pre-defined *effectiveness* measurement to determine the optimum time for the evaluation. Our case study has shown that the evaluation of *Fisherman* should be delayed until the value of *effectiveness* becomes stable. This is because a stable *effectiveness* value for *Fisherman* means that the display itself integrates into the environment and will not draw unusual attention from users: this meets the definition of non-intrusive evaluation of ambient displays.

Conclusion 6. Non-intrusive evaluation cannot be tested until the display integrates into the environment.

CONCLUSION

This paper focuses on discussing two questions:

1. "What are the appropriate methods for evaluating information systems?"
2. "How do we measure the impact of ambient information systems?"

To answer the first question, we present two evaluation styles: intrusive and non-intrusive evaluation. Two case studies are conducted by applying these two styles and six conclusions are draws from these two case studies.

Answers to the second question are mainly derived from the non-intrusive evaluation styles. We simply propose a quantitative effectiveness measurement to quantify the impact of *Fisherman*. As we believe the more subjects like the display, the better impact of the display.

This work is still in progress. Our future plans include more experiments to gain experience in the two evaluation styles. We aim to define the strengths and weaknesses of each style.

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Explorations and Experiences with Ambient Information Systems

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ABSTRACT
We have developed a series of ambient information systems and used each in our research lab for extended periods of time. The systems use technologies such as RFID, RSS, and Phidgets to help present information on devices ranging from tangible and tactile objects such as children's toys to peripheral displays running on wall-mounted LCDs. This article describes the motivation, design goals, and implementation issues for four systems: Ambient Trolley, Pirate Island, AuraOrbs, and InfoCanvas. A key capability provided in most of the systems is the consolidation of multiple types of awareness information into one display. We conclude the article with reflections on our experiences and questions about how one would evaluate such systems.

Categories and Subject Descriptors
H.5.m [**Information Interfaces and Presentation**]: Miscellaneous.

General Terms
Design, Experimentation, Human Factors.

Keywords
Ambient information system, ambient display, peripheral display, evaluation, RFID, Phidgets, LCD

1. INTRODUCTION
Within the Information Interfaces Lab at Georgia Tech, we have been exploring the design and use of a variety of ambient information systems [7] over the past few years. Our approach to each project has begun with the identification of a need or problem by people in our local community. We have coupled work on addressing these problems with a desire to explore the use of new technologies. The projects described herein, for example, have employed Phidgets, RFID tags, RSS feeds, and flat panel picture frame style displays.

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One of the common threads across all the projects is that each has focused on communicating *awareness information* to our lab inhabitants. Awareness information is sometimes called "discretionary information" and it involves information that is important to people but is not their primary focus at that time. For example, information about tomorrow's weather forecast, traffic on the ride home, or a colleague's presence in the office can all be considered awareness information. Information like this has become much more available recently because of widespread network access and increased distribution of data by information providers, much of this occurring through the WWW.

All of the systems described here have been deployed in our lab and have been in use for extended periods of time. We believe that only through long-term use like this can one adequately understand the benefits, problems, and general issues of such systems.

In the sections that follow, we describe four particular systems developed, the Ambient Trolley, Pirate Island, AuraOrbs, and the InfoCanvas. The sections explore motivations for the project, design rationale, technologies employed to build the system, and some reactions to its use. We conclude by reflecting upon our experiences with all the systems and the further research questions they raise.

2. AMBIENT TROLLEY
The Georgia Institute of Technology has trolley service between various locations around campus and to the subway station in a nearby neighborhood. Our lab is located a moderate distance from the main campus, so many people use the trolley to commute to classes and meetings held there. Fortunately, a trolley stop is located directly in front of our building and thus it receives a lot of use by our lab members. Trolleys, shown in Figure 1, are scheduled to arrive every 5-10 minutes, but due to surface street traffic, trolley arrival times are inconsistent and one cannot plan on a trolley being at a stop at a predetermined time.

Because our lab is on the third floor and it has no view of the trolley stop, it is difficult to know when a trolley is nearby and thus when one should rush to meet it. The first ambient information system we describe is an attempt to help people gain

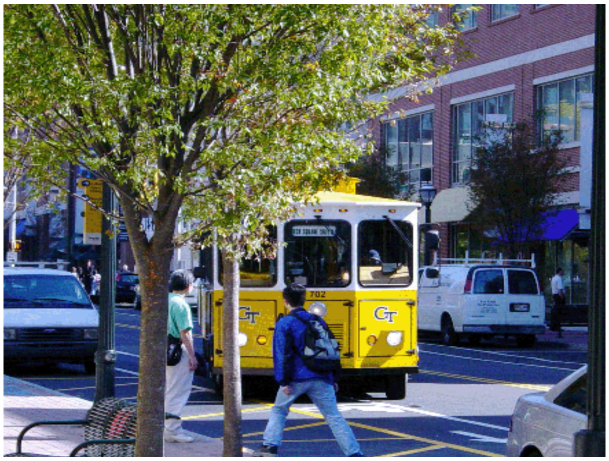

Figure 1: Actual trolley running on campus.

an awareness of the trolley's position and suggest a good time to leave the lab to meet the trolley.

In the Ambient Trolley project, we built a novel physical interface to indicate to building residents the amount of time before the next Trolley arrives at the stop outside our building. We modified an O-gauge model railroad trolley car to run along a 6-foot length of track suspended from the ceiling near the entrance to our lab (see Figures 2 and 3). Small labels at the midpoint and two endpoints of the track indicate the amount of time estimated until the trolley arrives: 8, 4, and 0 minutes from left to right. The trolley's position is updated every 60 seconds to reflect the new arrival estimate. In the event that the estimate is greater than 8 minutes, the car is positioned at the left-most endpoint. To meet the bus, users typically must leave their desks when the model indicates 2 minutes.

The trolley car is controlled from a PC hidden nearby. A Phidgets [2,3] interface board is used to control various lights and motors on the trolley car, as well as relaying input from endpoint switches to the controller application. At regular intervals, the application retrieves a simple web page containing estimated arrival times based on GPS data provided by NextBus [4]. The

Figure 2: Ambient Trolley up-close.

Figure 3: Configuration of Ambient Trolley showing tracks and positional markers used to indicate distance from trolley stop.

HTML is then parsed for the next predicted arrival and this value is used to reposition the trolley. The controller application itself is rather plain, allowing a user to start or stop the display, indicating the current arrival time depicted by the trolley, and providing access to diagnostic functions like moving the trolley car along the track manually.

We experimented with several positioning mechanisms to determine which provided the most reliable visual estimates of the indicated time. In the original prototype, user intervention was required to calibrate the amount of time needed for the trolley to move from one end of the track to the other. In practice, this proved problematic as users were not able to consistently indicate the same endpoints—in effect, each time the display was restarted the physical positions of 0 and 8 minutes changed. To address these concerns, we added hardware switches to fixed endpoints of the track, and calibration was handled entirely by the controller application. The trolley could then be repositioned by moving the motor in the appropriate direction for a duration equal to $1/8^{th}$ of the total end-to-end calibration time multiplied by the absolute difference in previous and current values. For example, if the estimate changes from 5 to 3 minutes, the motor must run for $1/4^{th}$ the total calibration time.

Unfortunately, this did not solve all of our positioning problems. Users noted that the trolley seemed to "drift" from its calibrated positions. Typically, this meant that the trolley failed to reach the 0 endpoint when it should have. We noted that there was slight variation in the speed of the motor in the forward and reverse directions, causing some of the faulty motion. Additionally, drift tended to occur when the motors were moved for long durations. Over the course of a day, these small drifts compounded and became perceptible enough that the display was considered unreliable.

Two solutions were attempted. In the first, we attached a light sensor to the underside of the trolley car and added a series of white and black markers to the track bed. The idea was that the light sensor would be able to detect the exact locations of all non-end point values (1-7). However, this proved impractical due to changing ambient lighting conditions in our lab throughout the day. The final solution returned to the timed positioning approach, but enhanced the algorithm by adding special cases. If the new value is either of the extremes (0 or 8), the trolley is moved until the corresponding end switch is tripped. Due to more drift observed on longer motions, if the new value is greater than half the distance of the track, the trolley first repositions to the far end and moves back to the new position. All other cases rely on the original strategy where a short burst in the corresponding direction is used to approximate the value. Anecdotally, the trolley display now seems to depict arrival times reasonably well enough to be usable. Remaining discrepancies are no worse than those caused by inaccurate GPS predictions.

The Ambient Trolley appears to be a fairly self-explanatory representation of the information being portrayed and most passers-by appear to "get it." Unfortunately, the GPS data driving the system is only moderately reliable and this can undermine people's confidence in the display. Ambient information systems are clearly prone to this kind of problem. In terms of interest and appeal, many viewers smile or chuckle when observing the Trolley for the first time, a fact that is pleasing to us as designers. Viewers have commented, however, that the blue cord connecting the Trolley to the computer does detract from the aesthetics of the system.

3. PIRATE ISLAND

Our next system, Pirate Island, is an attempt to explore how fun and playfulness can be combined with useful information conveyance. A child's LEGO-like construction set for a pirate island makes up the setting of this physical display. Figure 4 shows the island. Various aspects of the island have been motorized to provide animation to represent transformations in awareness data being monitored.

This project and the two others described later in the article illustrate one of the primary design goals of our work with ambient information systems, a desire to consolidate multiple pieces of awareness data within one system. Many ambient displays developed previously have focused on one particular nugget of information. In contrast, we wanted to explore whether multiple data streams could be combined into one coherent display and whether people viewing the display could easily digest all the different information.

Figure 4: Pirate Island Information Display.

Each of the four moveable parts on Pirate Island (circled in Figure 4) communicates a different piece of information and they are drawn from three fundamental information types: continuous values, categorical values, and binary values. Both the cannon, on the far left, and the compass in the middle of the figure are able to communicate continuous values. The cannon rotates on a continuum of 180 degrees in relation to the current temperature value. The compass is a simple clock, portraying the hour of the day. The pirate climbing the ladder, to the right, signifies a simple binary value, in this case the presence of precipitation. He faces the ladder when the value is 0 (sunny conditions) and outward when the value is 1 (rain is occurring). Finally, the flag above the pirate illustrates categorical values and currently is mapped to traffic conditions. The flag stands upright when traffic is normal, at 45 degrees to the right when traffic is slightly congested, and at 90 degrees when traffic is severely congested.

Pirate Island uses Phidgets to help control the display, much like the Ambient Trolley. The application program controlling Pirate Island is minimal. It exposes the actual values being depicted by the physical display and allows a user to start and stop the Phidgets.

4. AURAORBS

Another type of awareness information sometimes communicated to people through peripheral or ambient displays is presence information. Communicating the presence/absence of colleagues or friends has been a common theme in CSCW applications [5], one example of which is video-based media spaces. Transmitting video, however, raises numerous privacy concerns. Some researchers suggest that the video stream be filtered to mask out potentially sensitive information [1]. Our next system adopts this strategy by using an ambient information display to communicate presence information.

In a shared community like our lab, it is not uncommon for someone to wonder whether another (absent) person has been there recently, whether they have been in yet that day but stepped out, and so on. Similarly, people may wonder whether an office with a closed door simply means the person is not present or if the person is present but working privately.

We have built an ambient information system that communicates people's presence along with a few items of local interest such as weather forecasts and traffic conditions. The system's interface runs on a large 42 inch flat panel display on the wall of our lab as shown in Figure 5. It uses abstract geometric shapes and colors to represent the awareness information. We use RFID technology to identify people's presence and RSS feeds to gather the weather and traffic information.

RFID uses radio frequency signals to identify objects. An RFID system consists of two primary components - a tag and a reader. We use passive tags that have no battery of their own and make use of the incoming radio waves broadcast by a reader to power their response. Each member of our lab has a tag such as a key fob, a card, or a flat disk and each tag has a unique signal that identifies it to the reader.

Figure 5: AuraOrbs display deployed in the laboratory.

In the AuraOrbs system, we have mounted an RFID reader on the pole of a wire shelf near our lab entrance. Lab members swipe their RFID tag past the reader when they enter and exit the lab. Software running on a computer connected to the reader detects each swipe event, determines who the person is, and updates the information display. The display control system also monitors the RSS feeds and updates the view as appropriate to the most recent information received.

The AuraOrbs display follows the style of an abstract painting. Figures 6 and 7 show two example system views. Each person in the lab is represented by a unique-colored sphere. When an individual arrives and badges in, their sphere appears at a random position on the display. When the individual leaves and badges out, their sphere changes into a circle outline of that same color. The radius of the circle then begins to slowly shrink and will eventually disappear after two hours. This visual representation allows viewers to determine who is "in" and whether a person was recently present but has now stepped out. If a person badges out and then back in shortly thereafter, a new sphere is created. Thus, a number of hollow circles means that a person has been in and out frequently in the recent past.

The background color of the view portrays weather information. The left edge of the background indicates temperature, more specifically, today's forecasted or measured high as compared to tomorrow's forecasted high. If tomorrow's high temperature will be much warmer, then the left edge of the display is bright red. If tomorrow's temperature will be much colder, the left edge will be blue. The color is smoothly interpolated between these two extremes to encode the forecasted difference with an in-between purple color indicating a high temperature tomorrow equal to today's high. The right edge of the background is used to encode tomorrow's forecasted conditions. Yellow indicates sunshine, gray indicates clouds, and black means rain is coming.

The number of wavy lines through the display simply indicates the number of traffic incidents on highways frequented by several members of the lab. More lines indicate more accidents and a likely slower commute home.

We designed the display to be simple and to allow a viewer to quickly learn the relevant information at a glance. The background colors have natural correspondences and were intuitive to all. The number of wavy lines is easy to detect as well. Learning the mapping from sphere colors to individuals took about a week of use with a reminder legend posted next to display. Thereafter, the legend was removed and lab members were able to remember the mappings. This symbolic color-to-person mapping provides a level of privacy in that only our lab members who know the mappings can determine details of any individual's presence. In our case privacy like this is not a

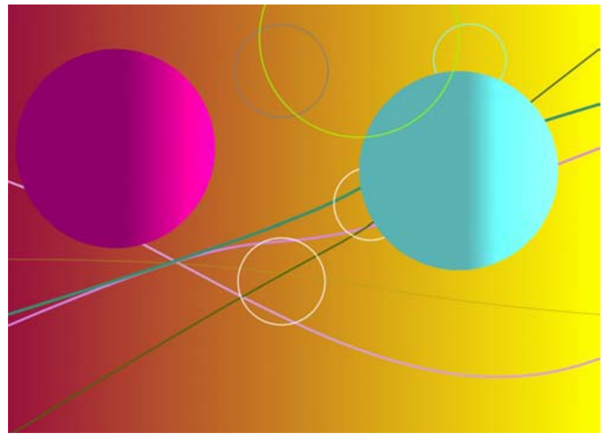

Figure 6: Example AuraOrbs display showing two people present (pink and blue spheres) and five recent departures (circle outlines). The display also indicates that tomorrow will be moderately warmer than today (reddish left edge) and sunny (yellow on right). Five traffic incidents (wavy lines) have recently occurred on local roads.

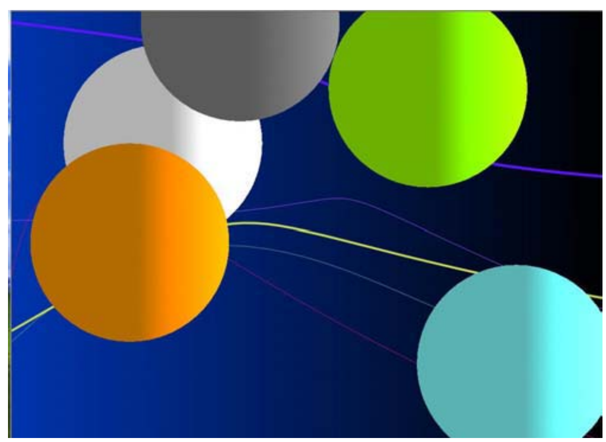

Figure 7: Another example AuraOrbs display indicating much different weather than that of Figure 6. The display shows that tomorrow will be much colder than today (blue left edge) and rainy (black on right). Five people are present.

concern, but one could easily imagine situations where tracking of specific people's movements by outsiders would be problematic.

Aesthetics were also a concern in the design of the display. Since it is so large and prominent in our lab, we wanted a scene that would be attractive and appealing. While individual artistic tastes vary widely, the display has largely been viewed favorably.

The AuraOrbs system is implemented using MFC, OpenGL, and XML DOM libraries. A simple control interface allows users to manage the visual mappings and add new individuals and RFID tags. Details of monitored data such as forecasted temperatures and traffic incident locations can be overlaid on the display. Furthermore, changes in data are logged and a time slider allows a user to quickly go back-and-forth in time to rapidly see movements and changes in data. Although we have not implemented it yet, one can easily imagine a touch or voice interface that would allow this type of more in-depth information to be summoned on demand.

Lab members appear to enjoy having the AuraOrbs display running in the lab and find the information it communicates useful. The chief problem with the system is people forgetting to swipe in or out when arriving or departing. Other, more automated tracking technologies could help this problem, however. The display clearly has piqued the interest of outsiders and we have fielded many questions regarding its purpose. One observer commented that he does not know the mappings of colors to individuals (as is appropriate for someone outside the lab), but the background color weather mappings are still useful.

5. INFOCANVAS

The InfoCanvas is an ambient information system that communicates information via a flat panel LCD that has had the bezel removed and replaced by a picture frame. The system thus acts like an electronic picture in which the scene can be controlled and made to change. An example of the InfoCanvas running in an office is shown in Figure 8. A variety of scenes exist, most exhibiting a kind of clip art style.

The main idea of the system is that different objects in a scene can be set to represent different items of awareness information of interest. When the underlying data being monitored changes, then

Figure 8: Example deployment of InfoCanvas.

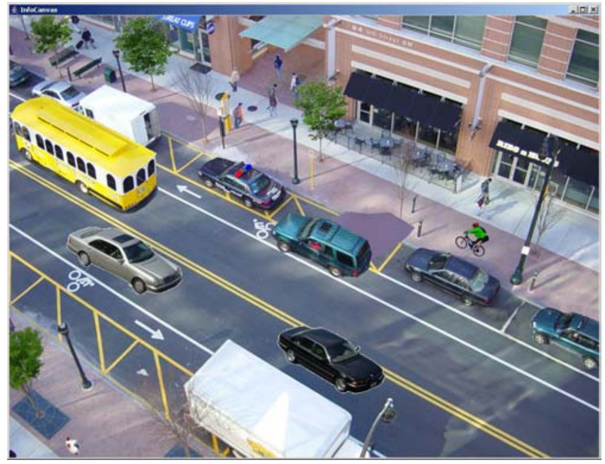

Figure 9: Sample InfoCanvas scene. Colors, appearance, and positions of objects such as the cars, lights, people, trees, etc., all indicate the present state of information of interest.

the corresponding object's representation in the scene is updated appropriately. Objects can change appearance, color, position, and size, or can be made invisible to represent different data states. For instance, in the example scene shown in Figure 9, the number of cars on the street could indicate stock performance that day or the level of traffic on a drive home. The position of the bicyclist could indicate tomorrow's forecasted high temperature or the current time of day.

Details about the system are described elsewhere [9], but a more recent longitudinal study of the system deployed for use by eight local technology workers uncovered some interesting findings [8]. For instance, the use of seemingly strange abstract, symbolic mappings such as a crab's position on the beach representing a stock value was appreciated and often adopted by participants. A key factor in this was that the person using the display was able to personalize the mapping from data of interest to an object of choice. This personalization made the representation more meaningful and relevant to the individual.

The system was viewed most favorably by people in the middle of a spectrum of information consumers. At one extreme, people who normally kept aware of very few pieces of discretionary information just did not have a basic need for it. At the other end of the spectrum, people who wanted to know precise details about many different information items, such as current prices of 10-20 stock values, did not find the symbolic representations detailed enough and they used the display as a simple alert to gather more detailed information from other sources. In between these two extremes were the majority of study participants who identified 5-15 items of information that they typically maintain awareness of from day-to-day. These people found the system to be both useful and enjoyable on the whole.

6. DISCUSSION

One of the key questions that has emerged from our experiences building and using the systems above is how to evaluate the systems. Ambient information systems are not meant to assist some finite, concrete task that can be easily measured and assessed as is often the case for other computer applications. Rather, an ambient information system's success seems to lie in some combination of 1) effectiveness in promoting awareness in some data of interest and 2) a level of enjoyment and satisfaction in the person or persons who are using the system.

Studies of systems in this space are challenging because any explicit evaluation efforts of an examiner draw more attention to the ambient system than it would normally receive, thus its peripherality is compromised and one must question whether realistic use is being examined. While certain aspects of an ambient information system such as its perceptual affordances can be measured in a laboratory study [6], we feel that evaluations of systems as a whole must be longer-term examinations of actual use in real-world situations. It is important to study deployed working systems in their proper context to understand how they are being perceived and how they are affecting the people in that environment.

Another problem or challenge with ambient information systems is that they typically consist of special purpose hardware and software that is difficult to create and can malfunction or break easily. Therefore, we conclude with another important question that must be answered for this field to grow — How do we transition ambient information systems from special purpose "toys" to more everyday information appliances?

7. ACKNOWLEDGMENTS

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Towards a Taxonomy for Ambient Information Systems

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ABSTRACT
We propose a set of design dimensions that constitute the axes of a taxonomy for ambient information systems. The dimensions are based on an investigation of a wide range of research projects and related papers. We rank 19 ambient information systems on each axis to demonstrate the utility of the taxonomy. We further discuss other similar taxonomies and compare them to our approach.

Keywords
Ambient information systems, peripheral displays, design guidelines, taxonomy

INTRODUCTION
Terms for ambient information systems have been defined by several researchers using slightly different characterizations [14,21]. We decided to adopt the definition by Mankoff *et al.* [20], as it reflects our comprehension of ambient information systems.

“Ambient displays are aesthetically pleasing displays of information which sit on the periphery of a user’s attention. They generally support monitoring of non-critical information. “

As ambient information systems can also cover other modalities, such as olfactory and auditory ones, we use the term ambient information systems instead of ambient displays (cf. [25]).

Researchers and designers increasingly create ambient information systems for different application areas, each with very special requirements. Thus, a wide variety of designs has emerged, varying from screen displays to tangible products. The design choice depends on a series of factors, such as the number of information sources. Examples of the diversity of ambient information systems are flashbag [16], a USB flash drive that inflates when storing data on it, data fountain [22] that visualizes currency rates with the height of the fountain, interactive waterfall [9] displaying movement of people in front of the display or ladybag [18], which visualizes the emotions of the user through the bags LED screen.

There are many different design variables comprising various characteristics. For clarification we summarize the most significant ones in a taxonomy. According to Fishkin [8] it is important to balance the number of dimensions. Whereas more dimensions increase the descriptive power, few dimensions may provide simplicity and clarity. Hence, a meaningful taxonomy has to include a deliberate number of design dimensions.

In addition to supporting designers in their design decisions, a taxonomy can be a useful tool for categorizing existing ambient information systems, pointing out developments and trends in this area.

APPROACH
At the time we developed the taxonomy suggested in this paper no similar taxonomy for ambient information systems was available. There was, however, a colorful landscape of various ambient information projects showing manifold characteristics. Additionally, some researchers in this field had suggested heuristics and guidelines for ambient display design. These together with an investigation of existing research projects provided a basis for developing our new taxonomy.

Starting from an analysis of 51 research projects we compiled a list of typical characteristics of ambient information systems. (The entire list of projects can be found in [17].) Examples of characteristics derived from this step were input, output and location to name just a few. Each item of the resulting list of characteristics represented a possible dimension for the taxonomy. With regard to our goal of a balance between simplicity and descriptive power we decided to reduce the number of potential dimensions by further analysis and selection. The challenge was to identify those characteristics that had the greatest influence on design and were significant for the entire list of collected projects.

This goal was approached by investigating previously published heuristics and design guidelines for ambient displays. The results of this investigation combined with the identified characteristics provided an established basis for the design dimensions of the taxonomy. Below we discuss the references that we used to define these design dimensions.

Ames and Dey developed a set of design dimensions for ambient displays based on their experience [2]. They

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suggest the following dimensions: *intrusiveness*, *notification*, *persistence*, *temporal context*, *overview to detail*, *modality*, *level of abstraction*, *interactivity*, *location*, *content*, and *aesthetics*. Based on these dimensions, which can also serve as a tool for both designing and evaluating ambient information systems, they described a number of research projects on ambient information systems.

Matthews *et al.* describe three key characteristics, derived from a survey of existing peripheral displays and cognitive science literature [21]. They further developed a toolkit to support the development of peripheral displays, which facilitates the incorporation of the key characteristics. The characteristics they found are: *abstraction*, *notification*, and *transitions*. They also suggest five levels of notification, namely "demand action", "interrupt", "make aware", "change blind", and "ignore."

Brewer introduced guidelines to govern the design process of ambient displays [5]. The suggested guidelines are a set of questions that designers have to consider, as for example, "*How quickly does the information change?*" and "*Is the information already displayed in some way or is it intangible?*"

Mankoff *et al.* proposed a set of heuristics for evaluating ambient displays [19]. Although their motivation was to provide a low-cost evaluation technique, these heuristics can also guide designers of ambient displays. The proposed heuristics highlight important aspects of ambient information systems without directly corresponding to design dimensions.

Many definitions of design implications are published in the introductory sections of articles about research projects on ambient information systems. Thus, we also included these sections in our analysis to supplement the list of potential design dimensions. The last step was an aggregation of the dimensions found during the investigation of ambient information projects and the analysis of research articles. We obtained the final set of dimensions by applying the model for the taxonomy on our list of projects and by reconsidering the dimensions in an iterative process.

DESIGN DIMENSIONS

As a result of our analysis we identified nine significant characteristics serving as design dimensions for ambient information systems. The dimensions are as follows: *abstraction level*, *transition*, *notification level*, *temporal gradient*, r*epresentation*, *modality*, *source*, *privacy* and *dynamic of input*. Each of the dimensions is divided in different stages using metrics to specify their characteristics.

Abstraction Level

As ambient information systems sit on the periphery of user's attention, data has to be represented in a way that users can read the information "at a glance" [6]. Abstraction supports this requirement, since it reduces the amount of displayed elements. It encodes data in a way that allows easy and comfortable monitoring of data. Almost every previous work refers to the necessity of this characteristic. The metric is *low*, *medium*, and *high.*

Ambient information systems that use a *low level of abstraction* map the source data to the displayed information in a direct or slightly abstracted way. They display data in a one-to-one relation to the real world. An example of this is Wattson [6], an electricity meter that displays energy consumption. Another example is the Short Term Weather Forecast – Window [27], which uses real-time projections of the outside weather conditions. A *medium level of abstraction* enables easy comprehension of the encoded data. This level provides a good balance between degree of abstraction and comprehension. Systems that use a *high level of abstraction* apply a strong encoding of data. There is no obvious relation to the real world. It depicts information as symbolic design items.

Transition

In accordance to changes within the data source, the displayed information has to switch from background to foreground awareness to attract user's attention. This may be accomplished by different means, for example by smooth changes in colors or a sudden increase of audio frequency. Depending on the speed of transition, we define the appropriate metric as *slow*, *medium,* and *fast*.

Ambient information systems that define themselves within the first stage of the metric feature a very *slow transition* from one state to another. The user only recognizes big and global changes in the data realm. Systems that use *medium transitions* change the state of display information more abruptly. This makes it easier to recognize changes than in the case of slow transitions. *Fast transitions* immediately lead to changes in the display whenever the source data changes.

Notification Level

The notification level depicts the degree at which a system alerts the user or even forces him to interrupt his primary task. For many systems, there is a tight relation between the dimension of transition and the dimension of notification level. A system that is defined to have a high notification level should use abrupt and fast transitions from one state to another (e.g. flashing, beeping, etc). In case of low notification levels transitions should be subtle and calm. We adapted the levels of notifications from Matthews *et al.* [21], which they derived from literature about cognitive psychology. Accordingly the metric is *ignore*, *change blind*, *make aware*, *interrupt*, and *demand attention*.

Temporal Gradient

Most ambient information systems present continuous information that changes its state over time. There are only a few systems that also visualize the history of temporal changes. The vast majority just depicts a discrete value and presents one state at a time. Temporal gradient defines,

Figure 1. Examples for ambient information systems that we ranked on our design dimensions. Top row: Progress Bar [24], History Tablecloth [10], Weather Patterns [11], Forecast Umbrella[23], Datafountain [22], Nimio [5], Informative Art [13], Flashbag [16]. Lower row: Power Point [3], AuraOrb [1], Wattson [6], Power-Aware Cord [12], Ladybag [18], Hello.Wall [26], Interactive Waterfall [9], Nabaztag [29].

whether a system features a history view of the displayed data or not. The metric is history and current.

Representation

Representation describes the output device used as ambient information system. Many systems have been developed that rely on a screen for output (e.g. [11,13]). Others are integrated in existing physical objects (e.g. [23,29]). We encountered three main categories of output devices to represent data which finally serve as corresponding metric, namely *physical*, *integrated*, and *2D*.

Physical representation describes artifacts or devices that had been developed solely for the purpose of being an ambient information system. Systems that use *integrated representations* are objects that previously existed. They have some initial purpose or functionality and had been augmented with technology to additionally provide ambient information. Such ambient information systems are often integrated into everyday items. *2D representation* depicts systems that display information by means of traditional screen technology, such as LCDs.

Modality

Ambient information systems are not limited to visual information design. Information can also be embodied by other modalities, such as audio or movements of objects. According to this we suggest the metric *visual*, *tactile*, *olfactory*, *auditory*, and *movement* for this design dimension.

Source

This dimension refers to the location of the information that is displayed by an ambient information system. The source can be divided into three categories, which serve as the metric: *local*, *distant*, and *virtual*.

For ambient information systems that have a *local source* the position of the system itself and the source of information are located in the same environment. An example is the Power Aware Cord [12] which visualizes the consumption of power in a home environment. The display (the power cord) and the data source (consumed power) are located in the same environment. A *distant source* relates to a geographically large distance between the location of the display and the data source. Nimio [5], a system that visualizes distributed activities, represents an example for an ambient information system that relies on a distant source. Systems that retrieve the data from the virtual world (e.g. the Internet) are classified as *virtual source*.

Location

This dimension refers to the location or context of the output device (i.e. the ambient information system). We found three common classes of location. Accordingly the metric is *private*, *semi-public*, and *public*.

Dynamic of Input

The dynamic of the input (i.e. the velocity of data changes) has an important impact on the design of ambient information systems. Depending on the nature of the source, incoming data can change quickly or slowly. This dynamic has to be considered when choosing the data source [19] as it has relevant influence on design issues. The metric is *slow*, *medium*, and *fast*.

A *slow dynamic* of input stands for a rare change of the data coming from the input source and results in rare updates in the display. A *medium dynamic* of input means a regular change in the input source. A *fast dynamic* of input relates to fast changes in the input source. As the changes are very fast, the display has to be designed by means of appropriate transitions and notification levels.

UTILITY OF THE TAXONOMY

To demonstrate the utility of the taxonomy we ranked 19 ambient information systems along the axes represented by our design dimensions. Since an exhaustive list of projects would go beyond the scope of this paper, we decided to select a representative cross-section of available ambient information systems. The projects presented on the workshop website[1] served as a basis for this selection, which we complemented with others to assure an equal distribution along all axes and variables.

[1] http://informatics.indiana.edu/subtletech/

	Transition			Notification Level					Temporal Gradient		Abstraction Level			Representation			Modality					Source			Location			Dynamic of Input		
	Slow	Medium	Fast	Ignore	Change Blind	Make Aware	Interrupt	Demand Attention	History	Current	Low	Medium	High	Physical	Integrated	2D	Visual	Tactile	Olfactory	Auditory	Movement	Local	Distant	Virtual	Private	Semi-Public	Public	Slow	Medium	Fast
Progress Bar	■				■				■			■		■			■							■	■			■		
History Tablecloth	■				■				■				■		■		■					■			■				■	
bench	■				■				■				■		■			■					■			■			■	
Weather Patterns	■				■					■			■			■	■					■					■	■		
Forecast	■				■					■			■		■		■							■	■				■	
Dollars & Scents	■				■					■			■	■					■					■			■		■	
Informative Art	■				■					■			■			■	■						■	■	■			■		
Data Fountain		■			■					■			■		■						■			■			■			■
nimio		■				■				■			■	■			■						■		■				■	
flashbag		■				■				■		■			■		■							■	■				■	
Short-term Weather Forecast Display		■				■				■	■					■	■					■			■				■	
Power Point		■				■				■		■			■		■					■			■				■	
AuraOrb			■			■				■	■			■			■							■	■				■	
Wattson			■			■				■	■			■			■					■			■				■	
Power Aware Cord			■			■				■		■			■						■	■			■				■	
Ladybag			■			■				■		■			■		■					■				■			■	
Hello.Wall			■			■				■			■			■	■					■				■			■	
Interactive waterfall			■			■				■			■			■	■					■					■		■	
Nabaztag			■				■			■		■		■			■			■	■		■	■	■				■	

Table 1. Ranking of 19 ambient information systems along the axis of our taxonomy.

AuraOrb is a notification system that uses social awareness cues such as eye contact to display notification messages [1]. Datafountain makes money currency rates from the internet visible through different water fountains [22]. Hello.Wall displays information of social spaces via light patterns [23]. History Tablecloth shows how long an object has been left on a table by a halo that increases with the course of time [10]. Interactive waterfall detects people's movement in front of the display, which shows ripples of virtual watercolors representing the activity level [9]. Nimio is a system of a series of physical objects which glow in different patterns and colors while action is around one of the Nimios [5]. Progress Bar measures long-term goals and wishes. It creates an emotional link to the passing of time [24]. Power Point visualizes the amount of power consumption with the goal to improve energy awareness [3]. Weather Patterns is a permanent light installation for York Art Gallery, which communicates changes in weather conditions outside the gallery [11]. Power Aware Cord is an electrical power strip, which visualizes the energy consumption through glowing pulses, flow and intensity of light in the cord [12]. Forecast umbrella is a glowing umbrella, which reveals information about the probability of rain through changing intensities of light [23]. Ladybag visualizes non-verbal emotions by displaying emoticons on the bag's LED screen [18]. Wattson is an aesthetically designed device, which displays a household's consumption of power with the aim to improve energy awareness [6]. Flashbag is a USB flash drive, which enlarges with the increasing amount of saved data [16]. Informative Art adapts well-known art to present different kind of information in an aesthetically pleasing way [13].

After ranking each project, we reordered the list to better reveal specific patterns and to point out trends. Results of this analysis are discussed in the last section.

RELATED WORK AND DISCUSSION

Defining a taxonomy is a difficult task, especially for a relatively new field, such as ambient information systems. There are different approaches for developing the design dimensions, depending on the requirements and expectations. Therefore different taxonomies might be helpful or appropriate in different situations. Below we will discuss two taxonomies and compare them to our approach.

Pousman and Stasko recently proposed a taxonomy for ambient information systems [25]. It is based on four design dimensions, namely *information capacity*, *notification level*, *representational fidelity*, and *aesthetic emphasis*. In their paper they classify 19 research systems and three consumer ambient information systems along these dimensions. The metric for each dimension ranks from low to high. The resulting diagram shows the distribution of existing ambient information systems along the four axes by pointing out trends and clusters. Pousman and Stasko further derived four design patterns from this taxonomy. They claim that these patterns provide fruitful conclusions for system designers.

The main difference between the taxonomy proposed in this paper and the one developed by Pousman and Stasko is the number of design dimensions. As stated earlier a low number of dimensions assures the simplicity and clarity of the taxonomy. This is clearly an advantage of their taxonomy. The drawback of including only few dimensions is a lack of descriptive power by neglecting important design dimensions, such as modality. This decreases its value as a design or evaluation tool for designers of ambient information systems. The motivation that guided our design process was to develop a taxonomy that balances simplicity and descriptive power. We therefore decided to keep all nine dimensions that resulted from the analysis process. Another difference to Pousman and Stasko's taxonomy are the metric attributes used for the design dimensions. Similar attributes support a simple visualization. However, specific metrics for each design dimension further contribute to the descriptive power of the taxonomy.

Rohrbach and Forlizzi [28] conducted a taxonomy of information representation and its effectiveness, based on an analysis of a wide range of ambient displays. They further reviewed literature from cognitive psychology and investigated the use of visual variables in static designs. Following this approach they created a list of design variables for ambient displays, such as *abstract*, *realistic*, *2d*, and *3d*. In a final step they derived design principles that are applicable for ambient display design. Due to the large number of design variables this taxonomy is extremely valuable for the design process, but may not be suitable for pointing out current trends and potential areas for further research. The design dimensions, which Rohrbach and Forlizzi call design variables, further relate to the information that ought to be communicated through the ambient display, while our taxonomy emphasizes the ambient information system as a whole.

CONCLUSIONS

There are different approaches and motivations for developing a taxonomy. Our goal was to develop a number of design dimensions that provide a balance between simplicity and descriptive power. Another requirement was to identify dimensions that represent a reasonable aggregation of design variables suggested in research projects and related publications. We found out that analyzing a wide range of research projects provided a good basis for an initial list of potential design dimensions. To assure their significance and relevance, we further analyzed guidelines and heuristics for ambient display design. The final set of dimensions was created by an iteratively ranking of the research projects on each axis and redefinition of the dimensions. The design dimensions are: *abstraction level*, *transition*, *notification level*, *temporal gradient*, *representation*, *modality*, *source*, *privacy*, and *dynamic of input*.

In a following step we ranked 19 ambient information systems according to our taxonomy. Through rearranging the list of systems we were able to reveal specific patterns. For example we noticed that transition and notification level are closely related to each other. A slow transition always correlates with a change blind notification character. Medium and fast transitions typically go along with systems that feature the notification character "make aware". Another correlation was revealed between abstraction level and representation. Ambient information systems that are embodied by 2D representations tend to have a high abstraction level. The reason for this is that otherwise the system would not comply with the definition of ambient information systems. However, for integrated and physical representations no correlation with the abstraction level can be identified.

The taxonomy of ambient information systems also shows current trends and points out potential areas for future research. For example, most systems only display current data. The taxonomy shows only two systems that also provide a history of displayed data. An immanent observation is that almost all systems are based on visual embodiment as modality. There are only few systems that use movement and hardly any systems that feature tactile, olfactory or auditory characteristics.

Moreover we observed that all systems from our list feature change blind, make aware, and interrupt characteristics for the dimension of notification level. This is due to the requirement that ambient information systems should not distract users from their primary tasks. Some systems have multiple characteristics within one design dimension, because of their multiple purpose nature (e.g. Nabaztag and Informative Art).

Finally, we want to raise a concluding question: How does the number of design dimensions influence the value of a taxonomy for ambient information systems and which of the presented taxonomies might be best for which situation?

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Towards Designing Persuasive Ambient Visualization

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ABSTRACT
This paper discusses an alternative application area for ambient information systems, coined as 'persuasive visualization'. It investigates the recent evolution of ambient displays, from simply aiming to inform people about data patterns towards increasing awareness of themes underlying the data. Accordingly, this paper proposes the potential of ambient display techniques to encourage users to modify their behavior. First, the evolution of past ambient display applications is analyzed according to their persuasive capabilities and environmental contexts, ranging from large-scale installations towards more personalized applications of ubiquitous and wearable computing. Accordingly, ambient displays could become a useful platform for unobtrusive, aesthetic applications that can augment our awareness and encourage positive behavior modifications relating to socially relevant issues.

Keywords
persuasive technology, ambient display, information visualization, wearable computing

INTRODUCTION
The concept of *ambient visualization* or *ambient display* is defined as a category of data representations that conveys time-varying information in the periphery of human attention. According to Mankoff's evaluation model [12], an ideal ambient display should adhere up to eight different heuristic principles that are founded from functional, effectiveness and aesthetical considerations. Most ambient displays are similar to classic data visualization techniques in the focus on conveying meaningful visual patterns to augment the understanding of the dataset. However, ambient displays and data visualizations are different in that ambient representations can be quite ambiguous and non-intuitive to interpret. In other words, ambient metaphors "may not be immediately understandable, but users should be able to discover meaning through subtle interaction." [17]. Accordingly, by including aspects of *ambiguity* in their designs [5], multiple, potentially competing, interpretations are created, which can stimulate user engagement and augment the user experience [5]. Ambient displays thus aim for more artistically inclined and emotionally engaging ways of data representation, going beyond simply 'informing' people of specific data patterns. An ambient display tends to be calm, non-obtrusive and opportunistic, revealing meaningful information only for interested users who are willing to invest time and effort. The value of interpreting an ambient display by long-term or repeated exposure is further enhanced by its general lack of direct user interaction, such as the exploration, filtering or selection of information.

Because such a display is able to convey information in a subjectively pleasant way over a relatively long period of time, this paper claims that particular ambient display techniques have the potential to be used for persuasive applications. Persuasive technology uses specific techniques to encourage behaviour, belief or attitude change by providing personalized messages at teachable moments, at the right time and right place, when a person is receptive to information [4]. Persuasive applications are different from normal feedback displays in that they require active involvement of those being monitored in attaining a desired behaviour change. Various persuasive techniques are founded on increasing human awareness, often by informing people explicitly of relevant aspects that sustain or underlie specific attitudes or behaviours. An ambient display could increase human awareness by conveying such relevant issues within a relevant and timely environmental context. It can make important influential factors visible and tangible, to allow people to better understand their personal attitudes. Furthermore, the aesthetic and opportunistic qualities of an ambient display allow for a long-term sustained usage, and reduces the risk to "nag" or annoy users.

This paper proposes that ambient display is currently changing character and is becoming increasingly persuasive. It investigates the evolution of ambient display techniques from relatively large-scale spatial installations towards more personalized applications in the realm of ubiquitous and wearable computing. Accordingly, it discusses various design and evaluation considerations for a new visualization direction, coined as *persuasive visualization*, which aims to modify human behavior by augmenting the awareness of people within an appropriate context and in a non-obtrusive way.

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Figure 1. Spatial ambient display examples (see also [15]). Left: a plant display showing the traditional country flowers in relation to what products people buy in a coffee shop (Designers: Huong Nguyen et al.). Right: a wallpaper style display capturing real-time environmental parameters in three computer labs (Designers: Mitchell Page et al.).

SPATIAL AMBIENT DISPLAY

Most ambient displays take form as large-scale, spatial installations placed within public settings. Such displays tend to represent dynamically changing, non-critical information that is relevant to their actual environmental context (e.g. time, location and people), such as the weather [8] or local bus schedule [12]. Because of their physical context, such displays are closely integrated within the architectural setting. They stimulate the human senses in a direct way, including vision (e.g. projections), sound (e.g. data sonification), touch (e.g. wind fans, temperature changes) or smell (e.g. odor emitters) [18].

Figure 1 shows two typical spatial ambient displays, developed as part of an undergraduate studio design course at the University of Sydney [15]. On the left, a collection of flowers represents the country of origin of products as they are purchased at a local coffee shop. On the right, an organic-style wallpaper displays the real-time network usage and sound levels within four computer labs, while rhythmically alternating light bulbs convey the waiting time of the printing and plotting devices placed below. Although not noticeable on first sight, these ambient displays were initially motivated by persuasive intentions. For instance, the coffee shop installation aimed to change unsustainable shopping behavior: by indirectly increasing the awareness of the amount of foreign products purchases, it was expected that customers would choose more local products that require less transportation costs and lead to less environmental impact. Similarly, the wallpaper concept aspired to influence the decisions of students of which computer lab to go to, for instance the one that is the most quiet, least occupied, and with the fastest network. However, these persuasive considerations have not been clearly translated, as they were diluted by concerns about the physical adaptation to the environmental context, the general acceptability by users and a desire for artistic originality. Because the display designs concealed the true intentions and their environmental contexts were too broad for accurate interpretation, the resulting persuasive impact was low.

Figure 2. Ambient display artifact examples. Left: an egg shaped USB device that wiggles and moves in reaction to emotions communicated during online chat conversations (Designer: James Kim); Right: a working computer mouse that changes temperature hot/cold depending on the input of textual humans emotions (Designer: Irene Chen).

AMBIENT DISPLAY ARTEFACTS

More recent ambient display applications focus on producing small-scale physical artifacts. Although influenced by physical computing, product design and electronic gadgetry, the design of these data-driven objects still largely follows traditional ambient display heuristics. The prototyping of these displays has become possible due to the recent appearance of community-driven physical computing platforms (e.g. Arduino, Processing), which aim to reduce the technical complexity of programming micro-electronic devices for the enthusiastic interaction designer. Existing ambient display artifacts vary from elaborate robotic plants that convey the recycling behavior of people [9], to simple color-changing objects such as the Ambient Orb, commercialized by Ambient Devices Inc. Figure 2 shows two typical ambient artifacts developed by postgraduate students. On the left, an egg-shaped and color-changing device wiggles and rocks in different motion typologies in reaction to the human emotions depicted during an online chat conversation. On the right, the fabric surface of a working computer mouse changes temperature (i.e. hot or cold) depending on the emotions detected in textual computer documents.

Both examples show how ambient display artifacts aim for alternative, non-graphical (or non screen- or projection-based) ways of communicating information. They demonstrate more explorative design approaches that are more inspired by digital, interactive art works than traditional data mapping algorithms. By deliberately exploring the borders of human's cognitive perceptive capabilities through infotropic stimulation by way of motion, light, or temperature, these displays deliberately provoke unpredictable interpretations. However, because the objects are more directly related to their environmental context, the resulting interpretations are more narrow than for spatial installations. Whereas typical ambient displays focus on conveying simple but meaningful patterns within datasets, ambient artifacts 'utilize' the data to communicate a more elaborate, subjective message. In other words, the representation of patterns *within* the data is overturned in favor of interpretative meanings that *underlie* the data.

Instead of augmenting knowledge about a dataset, such displays aim for changing subjective attitudes of users. The dataset is then reduced to a medium, used as a real-world context and justification for the existence of the artifact. Such displays do not aim for objective observation, but rather provoke personal interpretation, quite similar to good works of art. As ambient artifacts convey underlying messages related to real-time data, they are able to inform and involve people. It is this capability to stimulate higher level reasoning based on information that forms the persuasive potential of ambient display applications.

WEARABLE / UBIQUITOUS AMBIENT DISPLAY

From building facades to small artifacts, from mobile devices to electronic fashion, information access seems to be reaching the borders of technology miniaturization. At the same time, information becomes increasingly related to the actual environmental context of the user, such as the actual location, situation, activity or social status. The most recent advances in ambient display target the *ubiquitous* or *pervasive* paradigm, or the use of computational devices that enhance the experience of everyday life by interfaces that are embedded within the physical environment [6]. Several potential benefits of ubiquitous computing have been described that demonstrate how technology can support activities and values that are fundamentally different from those that are existing today [3]. Whereas most ubiquitous computing research efforts focus on improving sensor analysis and context recognition performance, only few research projects exist that focus on how such context-related information can be fed back to the users. 'Wearable visualization', the use of wearable computing technology to represent information, is a recently emerging application area based on insights from ambient display and electronic fashion. A wearable visualization uses small computers that can be continuously worn on the human body to communicate information, either to the wearer herself, or to other people in the wearer's vicinity. It differs from more common visual applications on mobile devices in that wearables are specifically designed to be unobtrusively integrated within the user's clothing. By merging visualization with fashion, clothing is considered as a sort of public display that is meant to 'signal' an interpretable meaning [11]. Because of its continuous and public setting, a wearable display can potentially alter the experience of the wearer or of other people present in the immediate vicinity. Ultimately, those onlookers might even be experiencing the presence of the wearer differently. Wearable visualization shifts the context in which people perceive and interpret information from space and architecture (i.e. spatial ambient display), or object affordances and product usability (i.e. ambient artifact), towards the presence of the user herself, who constantly shifts her contextual setting depending on location, activities or time of day.

Figure 3. Wearable ambient visualization. Left: a light-emitting basketball jersey showing game-related information (Designer: Mitchell Page, [14]); Right: a wearable folding device conveying activity information (Designer: Monika Hoinkis, [16]).

Dissimilar to fashion, which is ultimately decided by the wearer, a wearable display determines its visual presence autonomously, depending on sensor-depending instructions. As the wearer thus looses the power to determine her visual presence, such display can become a useful tool for persuasive purposes: to influence the display, the wearer will ultimately need to alter her behavior. Figure 3 shows two wearable ambient displays. On the left, *TeamAwear*, an electronically-enhanced basketball jersey that is capable of displaying publicly available sports data related to the wearer (e.g. fouls, score, time clocks)[14]. On the right, a fashion-neutral wearable device that creates fabric folds depending on environmental data related to the wearer, such as the amount of movements, sounds and social contacts over the time span of a day [16]. The designs of both displays were inspired by the ambient display concept: they both attempt to convey information through "subtle changes in form, movement, sound, color, smell, temperature, or light" [18], are based on 'non-critical' dynamic data streams, can be observed in the periphery of human attention, are meant for a non-expert audience, and are designed with attention to visual aesthetics to increase their general acceptance by the public. Both displays contain subtle persuasive qualities, aiming to alter the behavior of the wearers to some degree. For instance, the TeamAwear's original design hypothesis consisted of providing additional information to the players in a non-intrusive way. By wearing these jerseys, it was expected that players would make better in-game decisions and thus experience a more challenging game-play. However, although the players felt more confident, the highest impact was reported by the referees, coaches and audience members. Similar to an ambient display, the folding display was specifically designed to become understandable over time, only by those people that had extensive exposure to the display, or were personally informed by the wearer about the used data mapping algorithms. Here, the design deliberately used an ambiguous metaphor of fabric folding to 'encrypt' the data in time and effort for obvious privacy reasons. In contrast to the large-scale context of spatial ambient displays, wearable visualizations represent information within the environmental context of the wearer, with the aim to alter the experience of that context for the wearer and any onlookers. Because of its close relationship to the context, wearable visualization seems to be an ideal platform for persuasive applications.

PERSUASIVE VISUALIZATION

Sustainable living, energy conservation, water management, health prevention trust, social integration, and ethics are only a few examples of potential application areas that often utilize information presentations to increase people's awareness and change their behavior. Imagine being able to ambiently represent the true environmental impact of products, the energy consumption of activities, or the health risks of food items at the exact moment when such decisions are made. Different from other feedback approaches, and because of the ambient qualities, such display should be able to not unnecessarily disturb the user during this activity. Such displays would allow people to make more informed decisions while buying specific products, eating fast food, taking a shower or choosing the stairs or the elevator, but avoid the tendency to nag or annoy users. Such displays should be different from traditional feedback methods, in that they personally involve the user when he or she wishes to do so. Ambient display could become an ideal platform for this task, in its focus on real-time data, context dependency, aesthetics and personal interpretation.

Background

Several visualization projects already exist that directly or indirectly aim to encourage human behavior modification, and could be classified under the term "persuasive visualization". For instance, the original Bus Schedule visualization was evaluated by measuring whether more students were logging off the university computers in tact with the bus schedule after the display was installed [12]. DiMicco et al. [2] conducted a behavioral study to examine how a shared graphical display of individual speaker-participation rates impacted the behavior of a group during a collaboration task. A visualization of the power consumption of radiators helped people understand and reflect upon their energy usage [7]. Several creative design interventions in public space aimed to promote energy awareness, increasing awareness and provoking responses and discussion [10]. A short evaluation study showed how a subtle plant display positively influenced the recycling habits of students [9]. The impact of this display resulted in more than just informing people about their recycling habits, as people effectively changed their recycling behavior. Morris [13] recently developed a social network visualization with sensor-generated and self-reported data, to foster awareness and empowerment of social health. Other researchers developed a semi-graphical mobile phone application to encourage physical activity [1]. These examples prove how socially relevant information can be represented in persuasive ways. They shift simple information representation towards augmenting human awareness of underlying principles, and ultimately aim to encourage behavioral changes. However, it is still undefined whether the unique qualities of ambient displays are more suitable for such purposes than direct feedback or self-reporting methods.

Design and Evaluation Considerations

The goals and expectations of persuasive visualization require that the current assumptions and heuristics of ambient display need to be reassessed. For instance, the concerns about aesthetic quality should reach beyond adapting the design to its environmental setting. Instead, a persuasive visualization could be assessed on how it 'convinces' or 'encourages' behavioral change, alters opinions and attitudes, augments human awareness or leads to 'reflection' or 'discussion'. New evaluation methods are required to objectively measure behavioral change. As novelty and curiosity might initially be the major factors that drive behavioral changes, longitudinal studies are required to assess user compliance and long-term sustained effects. However, traditional long-term behavior and attitude capturing methods, including self-monitoring techniques such as diaries and retrospective reporting, have typical low success rates. They either require physically carrying around a diary or the retrospective completion of reports at the end of the day. The effort of carrying around a diary results in a low long-term user compliance. Retrospective reporting is relatively unreliable due to recall bias and cognitive errors. In addition, the continuous self-monitoring ultimately might even influence the behavior change more than the displays, either positively or negatively. However, alternative evaluation opportunities exist in measuring behavioral changes over random intervals, or by monitoring the direct effects of behavior changes, instead of the attitudes themselves.

Ethical Considerations

A persuasive visualization is different from an ambient display in that people need to rely on and trust the information shown, so that they are willing to alter their behavior. Whereas all visualizations should be trustworthy, no real danger is involved when an international weather diagram is miscomprehended. However, an ambient local bus schedule might immediately loose its functionality, and probably never recover, when people stop trusting its accurateness. Naturally, this concern shifts even further when people should become willing to modify their personal behavior based on what they understand from the display, for instance when purchasing more healthy food products, conducting a more sustainable lifestyle or making social contacts. This issue becomes even more evident for persuasive purposes that rely on personal data, such as health information or physiological sensor readings, which could potentially lead to adverse behavior changes.

CONCLUSION

This paper discussed a recent shift in ambient information systems, which can be coined as a focus towards 'persuasive visualization'. It identified a recent tendency of ambient displays to become smaller, more personal and more persuasive, and showed how ambient displays increasingly aim beyond informing people to instead communicate subjective phenomena that underlie the dataset. Such displays utilize data to justify the relevance and significance of the representation by focusing on the meaning of the data, instead of detecting any patterns hidden inside it. By presenting such higher-level information in a continuous and non-obtrusive way, ambient displays have the potential to encourage people to alter their attitudes or behaviors while maintaining an enjoyable user experience.

Following questions remain: What are the design considerations for a persuasive ambient display? How can ambient characteristics augment persuasive capabilities? And how can persuasive quality be accurately evaluated?

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Interstitial Interfaces for Mobile Media

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ABSTRACT
Mobile devices make ideal *personal* ambient information systems given their ubiquitous adoption by users and their rich context knowledge of users' activity. However, we believe that unlike traditional systems, the mobile device acts more as an *interstitial* information appliance, allowing users to consume relevant information at-a-glance primarily during the interstices between other activities. In this paper, we motivate a discussion on how such usage behavior can impact the design, display and delivery characteristics of ambient information systems for mobile devices. We focus not just on design issues (information selection, rendering abstractions, impact evaluation) but also on the ecosystem concerns (provisioning costs, business models) that often prove critical to developing commercially-viable solutions.

Keywords
Ambient interfaces, mobile media, information awareness, presence, context-awareness

INTRODUCTION
Ambient information systems help users stay connected to relevant but non-critical information in a non-intrusive way. Mobile handsets make ideal personal ambient information appliances due to both their penetration among the global consumer population and their rich contextual knowledge. The always-on, always-connected nature of handsets could conceivably enable "what's happening" style interfaces [1], allowing users to remain up-to-date with their community information anytime, anywhere. However, this potential is underutilized because a number of mobile interfaces offer a 'miniaturized browsing' experience that is at odds with users' desire for a 'passive awareness' interface – one that exposes them to a breadth of relevant information but with minimal interruption. By definition, browsing requires a degree of user attentiveness (in querying, navigating and selecting content) that lends itself better to a *lean-forward* tethered PC experience than to a *lean-back* mobile one.

What then constitutes an effective ambient interface for the mobile device? In our experience, users expect mobile phones to act as an *interstitial* information appliance – one that allows them to grab an 'information bite' quickly and opportunistically during the interstices between other activities (e.g., while standing in the airport security line or waiting for friends at a restaurant). Therefore, in this paper we explore the key design issues that need to be addressed when architecting mobile ambient information systems for interstitial consumption of content. These include:

- *Information Selection* – What kinds of information will be viewed as "value-add" by a mobile user *and* will lend themselves to interstitial consumption?
- *Rendering Abstractions* – What primary visualizations of ambient interfaces will enable mobile users to balance breadth of awareness with cognitive overload?
- *Evaluation Metrics* – How do we measure the impact of such systems on end users? Can we qualitatively identify factors that enhance (or disrupt) interstitial consumption?
- *Pragmatic Concerns* – What service provisioning costs and business models should we factor in, when creating 'commercial' mobile ambient information appliances?

Many of our insights on these issues, and on potential solutions to them, have been influenced by our experiences with SCREEN3 [2], the 'zero-click' ambient interface currently deployed on over two million handsets worldwide.

RELATED WORK ON MOBILE AMBIENT DISPLAYS
Research on ambient information systems has yielded a rich and diverse variety of design approaches. These have been covered exhaustively in papers such as [3][13] but can be coarsely segmented into *specialized ambient displays* (e.g., Ambient Orb, Water Lamp [4]) which are aesthetically-pleasing representations of small (and often single) datasets, and *information monitors* that tend to unify multiple data sources under a single awareness interface.

The latter can be segmented further into *distributed display architectures* (e.g., Eye-Q [5]) where a primary display is augmented with a secondary display that interoperates seamlessly with the primary, and *primary display adaptors* (e.g., Sideshow[6]) that repurpose an existing primary interface for ambient information delivery. Under this categorization, we view mobile devices more as information monitors than as specialized ambient displays. Both the monitor-based approaches are viable for mobile phones. However, the distributed display architecture approach pre-supposes the development and existence of an 'accessory' ecosystem – this is likely to happen only over much longer

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time horizons. By contrast, the primary adaptor solution can co-exist easily with currently-supported mobile hardware.

Our classification of mobile phones as information monitors gains further credibility in the light of recent user studies by Schmidt [9] that show how screensaver-like visualizations of 'communication meta-information' can help users track the strength (or lack thereof) of their social ties. This meta-information includes data on frequency of communications, identity of the initiator, last in-person encounter (based on proximity) and other contextual cues. Their work also explores design cases which attempt to tie various technical capabilities of the device (e.g. GPS, Wi-Fi, accelerometer) to what can be presented via the ambient display The focus is on utilization of the mobile device as a sensor which inherently provides rich, *personalized* information that can be used both to drive content on the ambient information display and to influence how it is presented to the user.

Many desktop-resident ambient information systems (e.g., "What's Happening" [1], Apple Dashboard [7], and Yahoo! Konfabulator [8]) have also pointed out the desirability of a passive *click-free* (lean-back) user experience. These zero-click experiences become particularly important for mobile interfaces given device input constraints – industry reports show that the proportion of engaged mobile users decreases in almost geometric progression with the effective "click-distance" of the relevant item from the main screen.

Finally, we note commercially-available technologies such as Widsets (Java-based widgets) [10] and the SCREEN3 (0-click idle screen interface) [2] provide ideal vehicles for mobile interstitial consumption experiences. All of these factors collectively influenced our thinking and guided our exploration of basic design principles for mobile ambient information systems.

DESIGN PRINCIPLES

We begin by defining the dimensions of an effective mobile interstitial display. We borrow heavily from Pousman and Stasko's taxonomy of ambient information systems [3] which identifies four dimensions of design – information capacity, notification level, representational fidelity and aesthetic emphasis. In particular, we refined the definition of 'ambient' and its dimensions to better characterize the mobile domain and to introduce additional elements that are unique to the mobile ecosystem.

Information Capacity

This denotes the *nature* and *amount* of information that can be effectively depicted on an ambient display. The passive nature of these systems and the low interruption-tolerance of mobile users suggest that interstitial information systems are best used to convey non-critical, delay-tolerant content for casual consumption. Deployment experience and user studies indicate that environmental information (e.g., local weather), general news (e.g., sports, entertainment) and updates from the user's primary social group (e.g., music and motion presence) are viewed as being appropriate for interstitial consumption. From the mobile perspective, the amount of information conveyed can be characterized by factors like the ***channel bandwidth*** (number of concurrent information channels supported as ambient interfaces), the ***information density*** (ratio of information value to message size) and ***hysteresis*** (rate of decay in perceived value of item over time).

In our experience, effective mobile experiences may be able to support channel bandwidths of 3-5 channels*, with content characterized by a high information density coupled with a low hysteresis (1-5 hours). However, future work may discover ways of conveying more information in a glanceable manner. High information density (e.g., a sports score, or a stock quote that conveys high-value information in just a few bytes) is especially important for mobile devices, given the relatively high cost of cellular bandwidth and the limited cognitive bandwidth display real-estate available to users. Emphasis on 'hysteresis' is also a function of the high cost of data delivery to the handset. To conserve valuable bandwidth and battery, mobile information appliances often resort to 'cache-and-render' models that leverage periodic bulk transfers to the mobile device (in lieu of expensive incremental or continual real-time information updates).

Notification Level

Notification levels reflect the degree of interruption that is acceptable to users. It is typically dependent on the user's interest in his current task – which varies from inattention to divided attention to more focused attention. Accordingly, researchers [12] have identified five notification levels for peripheral displays namely *ignore*, *change blind*, *make aware*, *interrupt* and *demand attention* ordered by their increasing intrusion into user consciousness. However, Pousman and Stasko observe that ambience is best-served by change-blind and make-aware style notifications only.

We agree with this philosophy. In general, high levels of interruption are especially heinous in mobile environments where device constraints and the likelihood of users being otherwise engaged, combine to make such alerts annoying – leading to users questioning the utility of such interfaces, and potentially tuning out *all* notifications subsequently. However, interstitial consumption may require switching between different notification levels based on known or predicted level of user attention. By default, 'idle screen' behavior should be seen as user inattention – less intrusive alerts suffice. However, a user action (e.g., click through) indicative of user engagement in the content may be perceived as divided or focused attention – more intrusive alerts (e.g., to arrival of fresh content) may then be acceptable within that interstitial consumption 'session'.

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* This is not an empirical figure, but a relative measure based on our evaluation of a specific implementation of a mobile ambient interface (SCREEN3). In particular, this takes into account screen real estate limitations of mobile devices and cognitive user experience.

Representational Fidelity

The taxonomy for representational fidelity [3] focuses on the diversity of symbols and notation used in depicting the information on the ambient display. High bit and bandwidth costs restrict the symbolic flexibility of mobile interstitials to basic text and minimalist symbols. However, *synthetic media* approaches (e.g., avatars) could leverage the fact that such devices are rich in graphics capability even if network bits remain expensive. Limited representational fidelity enhances *glanceability* since the user does not have to master a complicated set of notations in order to interact with the information system.

A second aspect of representational fidelity (from a mobile perspective) focuses on *nesting* – i.e., allowing the user to "snack" superficially on a number of content channels but then enabling him to drill down further to obtain additional details on items of specific interest.

Aesthetic Emphasis

Aesthetics is essentially viewed as a subjective discussion [3] where focus can vary from the innovativeness behind physical artifacts that blend into the user environment to the ability to use other means to *communicate* the information effectively. From the mobile device perspective, we rate aesthetics in terms of the success of the user interface in maximizing the user's "ambient bandwidth" – i.e., how well does the interstitial ambient interface adapt to the user's current need for information such that the user is able to tradeoff breadth of information with depth of detail at any given time. Given resource constraints, an aesthetically-pleasing interface must avoid clutter and yet be relevant.

We see different 'modes' of ambience (rendering abstractions) in existence today that translate to mobile devices with different levels of success.

- *Carousel* – interface limited to a small segment of available real estate. Is ideal if *sequential* access to information can be tolerated. Is good for low item counts (allowing users to scroll through items quickly to locate specific content) but can be adapted for higher counts with intelligent design. E.g., SCREEN3 [2].
- *Widgets* – interface is ideal for scattered usage over larger display real estate. [7, 8,10] Is ideal if *parallel* access to information sources is desirable. Is good for moderate item counts, though user action may be desired in order to "select" from large populations of available widgets for display at a given time.
- *Clouds* – can be rendered within a carousel or as a widget. These abstractions adapt to real estate available but focus on displaying *aggregate* data rather than details [11]. Such "heat maps" are ideal for huge item counts where user interest is likely to be in the overall trend rather than in individual samples.

Based on our experiences with SCREEN3's carousel mode, we see value to a comparative study of such 'ticker-style' interfaces that use wipe-based transitions for ambient information visualization. Different classes of tickers can be envisioned – *continuous scrolling* (steady rate), *discrete scrolling* (employing scroll➔pause➔scroll cycles) and *serial presentation* (no scrolling, just item replacement). Our initial thoughts favor the use of discrete scrolling since this allows users to consume sufficient information without additional effort on their part – also giving them sufficient time to react to information by clicking-through for details.

Fairness

We augment Pousman and Stasko's taxonomy with the dimension of *fairness*, as a way for passive interfaces to support a larger information capacity without active user navigation. It's quite common in channel-oriented mobile systems (e.g. SCREEN3 below) for the number of channels to exceed the display capacity[†] of the device, and for the number of items per channel to exceed what can be shown to the user at one time. The definition of fairness for ambient information systems parallels its usage in distributed systems – namely that every 'channelized' information item will have fair access to "face-time" with the user – even if the user does not actively navigate to it directly. The carousel model adopted by SCREEN3 is a good example of a fair ambient information system with a non-weighted, round-robin selection scheme. However, one can imagine a number of alternative ambient interfaces that support fairness. We note that fairness becomes particularly important in commercial systems where many third-party providers of such ambient content have a vested interest in having their content seen by the user at some point. This is different from the case where users elected to receive specific content of interest – i.e., the user knows the content exists and can navigate to it if desired, while in the earlier case users remained unaware of its existence unless they 'stumbled' upon it by accident.

Privacy Concerns

The mobile phone is a deeply personal device, thus naturally privacy concerns arise when talking about a medium on which to display contextualized and possibly personalized information that may be viewable by others. As much as ambient visualization is a central means for user awareness, the fact that in certain situations, it may be publicly viewable raises concerns about how the information needs to be presented. A lot of this concern is with protecting the user from undesirable situations [13]. Ambient interfaces (particularly multimodal ones), are not as familiar in terms design and hardware ergonomics compared to the PC for example. Therefore, it makes sense to adopt an approach where any personal information is tagged as sensitive (e.g. communication meta-information such as call lists, contacts etc.) and filtered out when

[†] Here, display capacity represents the 'viewing window' provided to the user within the available display real estate. It could equal the physical display size (for full-screen ambient interfaces) or could be some subset of it that is specifically allocated for ambient usage.

displaying ambient information. It may also be possible to achieve finer-grained access control by utilizing more dynamic, contextually-triggered filtering. There is certainly a lot of scope for future work in this area, which should be considered an integral part of the design process rather than an afterthought.

Figure 1: SCREEN3 user experience

THE SCREEN3 CONCEPT

Our exploration of mobile ambient interfaces was motivated primarily by our experiences with using the SCREEN3 technology [2] developed at Motorola for mobile handsets. SCREEN3 targets the idle screen of mobile devices as the ideal delivery point for news, weather, sports, entertainment and other updates. The SCREEN3 client (on the handset) supports multiple channels of information (e.g., one for sports, another for community updates), and multiple items per channel. A SCREEN3 media gateway (server) manages different content feeds, allowing the client to obtain the freshest information for each feed (channel) of interest (pull-based, with the capability of WAP push).

The SCREEN3 model's emphasis has been on providing users with a zero-click, lean-back experience for lazy content consumption – with the ability to transition to a more lean-forward, interactive experience as desired.

These different degrees of user engagement are supported by a "bite–snack–meal" approach to information delivery as shown in the figure. The "bite" contains headline-quality information for content items, enabling users to consume it at a glance (passive awareness). For items of interest, users can easily transition to a lean-forward (more interactive) experience by clicking through to receive a "snack" – typically a cached extended summary for the headline article. For more information, users can then click through the snack to request a complete "meal" – typically a link to a network repository containing the complete article with richer media attachments that the user can browse online or download for consumption.

SCREEN3 currently adopts a carousel model for displaying information bites – the carousel can be navigated manually (to enable scrolling through the channels, or through items within a channel) but is typically animated, automatically scrolling through channels and items in sequence for a true zero-click consumption experience. The server caches client state in order to decide what updates need to be delivered to the mobile device. However, the content being displayed remains still fairly static in terms of both its applicability to the user (i.e., it may be a channel that the user subscribed to in the past, but hasn't actively in recent times) and its visualization on the device.

EFFICACY MEASURES FOR INTERSTITIAL SYSTEMS

User interactions convert "ambience" into "intent". This tipping point is of value from a business perspective, as it bridges content and commerce. Where passive viewing a news item represents casual interest in something, actively interacting with it might indicate sufficient interest in the topic or item to merchandise related goods and services. Identifying user interests can also provide personalization of ambient information. This improves not only system efficiency (ability to prioritize fetching and caching of content that is likely to be of more interest to this user) but also the hit-rate (user click-through) for interstitial consumption of related content.

The latter is particularly important on mobile devices. Display constraints limit the information capacity, allowing only a few items to become visible in any limited time window. Further, interstitial consumption patterns imply that the *face-time* afforded to ambient information systems is usually limited to short 'windows of opportunity' in between other user tasks. Thus, items must now compete for the user's attention within a given opportunity. Item *selection* becomes key to either holding the users' interest (thus providing opportunities for other items to be shown) or losing it (thus ensuring that he or she remains unaware of the existence of items that *are* relevant and interesting).

So how can we measure the impact of ambient information systems? We propose various measures that reflect different degrees of user engagement and for different rendering abstractions (e.g., carousel-based, widget-based)

- *Attention Measures*. Identifies the minimal level of engagement with ambient information. E.g., time spent by user in scrolling through channels, or time for which an item was in focus with user present at device. While the notion of an attention measure could apply equally well to PCs and TVs, the fact that the phone is a personal device on which content consumption is a deliberate decision, is likely to provide "clean", high quality attention data. As shared devices, both the PC and TV suffer from the "who's watching" drawback (according to an industry statistic, over 50% of the time, the TV is on with nobody watching). Simple context enablers can disambiguate mobile-in-the-pocket and mobile-to-one's-ear situations, and allow more accurate measurements of content viewing on the handset.
- *Action Measures*. Identifies a higher level of user engagement related to a specific item or channel, particularly since the user is potentially aware of possible

delays in fulfillment such as for network downloads. E.g., user click-through (bite➔snack➔meal) or hide➔reveal transitions for specific widgets [7] [8] [9].

- *Transaction Measures*. Identifies potentially the highest level of user engagement related to an item or channel E.g., {see concert notice (on music channel) ➔buy tickets or read interesting headline (on news channel) ➔blog it).

Transaction measures are more interesting from a business perspective since they translate more directly to commerce. However, they are also a more difficult measure to evaluate since the correlation between point-of-viewing (on ambient interface) may be temporally or spatially distant from the point-of-purchase (e.g., at a later time, on a potentially different application). Correlations may be simplified in cases where the transaction is driven directly off the ambient interface (e.g., via menu actions).

More complex solutions can involve correlating *short-term* activity history to *long-term* monitored user behaviors. For instance, short-term history can link an ambient display item to the user (e.g., click-through captured showing user viewed extended information about concert on the ambient display). The long-term observations (across devices and domains over a longer period of time) can be analyzed to infer that a subsequent user activity was influenced by this recently viewed item – e.g., a weather item indicating rain in the forecast was viewed some time before the purchase of an umbrella was recorded on the user's credit card. In general, we view handsets as ideal devices for gathering the raw data required for deriving such metrics. It inherently provides a source for fresh, personalized user data.

QUESTION FOR DISCUSSION

This discussion was motivated by a single but multi-faceted question: *What differentiates the design of a mobile ambient information system that emphasizes **interstitial** consumption of content?* We believe these systems are useful, are viable (given existing technologies) and are of commercial interest (both for differentiating devices with an enhanced user experience, and in creating opportunities that convert ambience to action and ultimately to commerce). With this paper, our goal is to initiate deeper discussions on design issues and key applications for such systems.

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