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.

Copyright is held by the author/owner(s). *Pervasive '07 Workshop: W9 - Ambient Information Systems.* May 13, 2007; Toronto, Ontario, Canada.
This position paper is not an official publication of Pervasive '07.

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

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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