A Taxonomy of Ambient Information Systems: Four Patterns of Design

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ABSTRACT
Researchers have explored the design of ambient information systems across a wide range of physical and screen-based media. This work has yielded rich examples of design approaches to the problem of presenting information about a user's world in a way that is not distracting, but is aesthetically pleasing, and tangible to varying degrees. Despite these successes, accumulating theoretical and craft knowledge has been stymied by the lack of a unified vocabulary to describe these systems and a consequent lack of a framework for understanding their design attributes. We argue that this area would significantly benefit from consensus about the design space of ambient information systems and the design attributes that define and distinguish existing approaches. We present a definition of ambient information systems and a taxonomy across four design dimensions: Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis. Our analysis has uncovered four patterns of system design and points to unexplored regions of the design space, which may motivate future work in the field.

Author Keywords
Ubiquitous Computing, Ambient Display, Peripheral Display, Notification System, Taxonomy, Design Guidelines

ACM Classification Keywords
Visual Interface Design, Tangible Interfaces

1. INTRODUCTION
From the very first formulation of Ubiquitous Computing, the idea of a calmer and more environmentally integrated way of displaying information has held intuitive appeal. Weiser called this "calm computing" [35] and described the area through an elegant example: a small, tangible representation of information in the world, a dangling string that would wiggle based on network traffic. When information can be conveyed via calm changes in the environment, users are more able to focus on their primary work tasks while staying aware of non-critical information that affects them. Research in this sub-domain goes by various names including "ambient displays", "peripheral displays", and "notification systems". The breadth of the systems in these broad categories is quite large. We seek to disentangle the terminology used to describe and categorize the wide array of systems in order to provide a common language for discussing research therein.

An ambient display can represent many types of data, from stock prices, to weather forecasts, to the presence or absence of colleagues. Maintaining awareness of co-located and distant work and social groups has been a long-term research thread in the area of Computer Supported Cooperative Work (CSCW) [5, 8]. The Tangible Media Group at the MIT Media Lab, directed by Ishii, also helped shape the field of ambient computation. They coined the term "tangible media," citing inspiration from Weiser's vision [35] and from Pederson and Sokoler's AROMA system [29] and developed AmbientROOM [17] and Ambient Fixtures [6, 18]. These systems use ambient displays to make people aware of both group activity and other information such as network traffic. Recent work in Ambient Intelligence has brought techniques from Artificial Intelligence to ambient systems, spearheaded by the Disappearing Computer initiative of the European Union [31]. This research thrust seeks to imbue ambient systems with contextual knowledge about the environment. The Roomware project has resulted in smart architectural spaces that support information conveyance (and group collaboration) [33].

Researchers have developed systems that use a multitude of everyday objects to display information. Examples include lights of various sorts [2, 17], sounds [25], shadows [8], artificial flowers [18], mobiles [24], and office-décor water fountains [12, 16]. Further research has sought to use framed photographs [26] and larger artistic pictures to represent information from the world in an art-like manner [14, 30, 32]. There are also peripheral display "modes" of a user's main desktop, including screensavers like What's Happening [36], information bars and menus such as those leveraged in Sideshow and Irwin [6, 22], and alternate panes, like Apple's Dashboard [3]. As one can see, the design space is large.

All these systems provide a rich history of system design principles, approaches, and decisions, but accumulating theoretical and craft knowledge has been stymied by the lack of a unified vocabulary to define and describe these systems. In this paper we propose a set of design choices that developers of ambient information systems must confront to build successful and compelling systems. First we set out a definition of an ambient information system that is a synthesis of the varied definitions given in published research. We hone the intuitive set of

AVI '06, May 23-26, 2006, Venezia, Italy.

characteristics that distinguish ambient systems from other ubiquitous computing research systems. Next, we propose a set of design dimensions for ambient information systems. The four dimensions of system design elucidate the main decisions one confronts when designing an effective ambient system. Finally, we explore the clusters across dimensions to uncover four coherent combinations of system designs, which work as design patterns for the field. The results also identify new ways of combining the design attributes to explore new possibilities for ambient information systems.

2. AMBIENT INFORMATION SYSTEMS

Many different terms have been used to describe the types of systems we discuss in this paper. Three of the most commonly used terms are "ambient display," "peripheral display," and "notification system." But how does one differentiate these terms? Based on general understandings, we claim that:

- all ambient displays are peripheral displays,
- some notification systems are peripheral displays (some notification systems are not peripheral but are instead the object of focused work and attention)

The words of researchers themselves likely best explain their conceptions of the systems that they have built. Below, we present germane definitional quotes.

- Ishii *et al*: "[**In Ambient Displays**] information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movement, sound, color, smell, temperature, or light. Ambient displays are well suited as a means to keep users aware of people or general states of large systems, like network traffic and weather." [17]
- Matthews *et al*: **Peripheral displays**, then, are displays that show information that a person is aware of, but not focused on. [24]
- Matthews *et al*: "**Ambient displays** might be defined as those that are "minimally attended" (e.g. just salient enough for conscious perception) while **alerting displays** are "maximally divided" (e.g. slightly less salient than focal tasks). [24]
- Stasko *et al*: **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 is often paramount. **Peripheral displays** refer to systems that are out of a person's primary focus of attention and may communicate one or more pieces of information." [32]
- Mankoff *et al*: "**Ambient displays** are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention… They generally support monitoring of non-critical information." "**Ambient displays** have the ambitious goal of presenting information without distracting or burdening the user." [20]
- Rounding and Greenberg: "The [notification collage] is designed to present info[rmation] as lightweight and **peripheral** objects. It does not demand the full attention of its users: rather it can be attended to in passing, where people collaborate should the need or desire arise." [14]
- McCrickard *et al*: "Often implemented as ubiquitous systems or within a small portion of the traditional desktop, **notification systems** typically deliver information of interest in a parallel, multitasking approach, extraneous or supplemental to a user's attention priority." [21]
- McCrickard *et al*: **Notification systems** are defined as interfaces that are typically used in a divided-attention, multitasking situation, attempting to deliver current, valued information through a variety of platforms and modes in an efficient and effective manner [21].

The easiest way to explain the differences between systems is to look at the design motivations that informed them. Ambient displays are those that have pointed aesthetic goals and present a very small number of information elements. These systems are a proper subset of peripheral displays, which can appear either in the environment or on secondary or even primary computer displays. Notification systems' design motivation results from divided attention situations. As such, they can be equal to a primary work task in their attentional needs or be secondary. When notification systems are designed to be secondary to a primary task, the systems are appropriately defined as peripheral.

In this paper, we propose the term *ambient information system* as the unit of study and define the behavioral characteristics of such as systems as follows:

- Display information that is **important but not critical**.
- Can **move from the periphery to the focus of attention** and back again.
- Focus on the **tangible**; representations **in the environment**.
- **Provide subtle changes** to reflect updates in information (should not be distracting).
- **Are aesthetically pleasing** and environmentally appropriate.

3. PREVIOUS TAXONOMIES

A small number of research papers that describe ambient information systems also include extended discussions of the design dimensions that motivate and contextualize their work. The authors provide dimensions to compare and contrast their systems to others in order to explain their design rationales.

Matthews *et al* use the dimensions **notification level, transition,** and **abstraction** to characterize systems in this space [24]. They developed the Peripheral Display Toolkit [23] that helps people to develop ambient information displays more easily. Their concept of notification level means the relative importance of a particular data stream. Transitions are the programmatic changes to the display, based on the data. Transitions include fading, scrolling, or animation effects. They define abstraction as the mapping that takes a piece of numerical or ordinal data and turns it into something that the ambient display can use, something "more easily interpreted with less [user] attention."

Matthews et al segregate notification level into five levels: *Ignore, Change Blind, Make Aware, Interrupt,* and *Demand Attention*. The gradations run from low, a system ignoring the change in the data, to high, a system demanding attention in a way that must also be explicitly dismissed. They propose categories of transition: *interrupt*, *make aware*, and *change blind*. Finally, they bifurcate abstraction into *feature abstraction* or *degradation.*

McCrickard *et al* introduce a different set of three dimensions to classify notification systems: **interruption, reaction,** and **comprehension** [21]. Interruption is defined psychologically, similar to Matthews' notion, "as an event prompting transition and reallocation of attention focus from a [primary] task to the notification." Reaction is defined as the rapid response to a given stimulus, while comprehension is the long-term notion of remembering and sense-making.

McCrickard *et al* then plot the design space as a 3-tuple of interaction, reaction, and comprehension (IRC). Each dimension is assigned a rating of high (1) or low (0), creating models like 0-1-0. They label these models with meaningful names like "Ambient Media, 0-0-1" "Indicator, 0-1-0" and "Critical Activity Monitor, 1-1-1." Eight models serve as the corners of a design space. The resulting space, it should be noted, is larger than the design space of ambient information systems as we discuss in this paper because it contains games, secondary displays, and critical activity monitors (which by our definition, are notification systems that are not also peripheral systems). McCrickard also classifies a set of 14 extant systems in the design space on the three dimensions.

Both of these taxonomies deal thoroughly with interruption and detail some of the criteria for categorizing systems along this design dimension. We extend this analysis to other dimensions of data representation, flexibility, and aesthetics. This more holistic view points out design trade-offs between aesthetic emphasis and and flexibility, and between a system's information display style and display capacity.

Mankoff *et al* proposed a set of heuristics for evaluating ambient systems [20], which may also assist system builders. The heuristics attempt to give guidance for the formative evaluation of ambient systems, but they also can be viewed as high-level design guidelines, such as *"The display should be designed to give 'just enough' information. Too much information cramps the display, and too little makes the display less useful."*

4. DESIGN DIMENSIONS OF AMBIENT SYSTEMS

Designers of ambient information systems make decisions about how much information to display, what specific aspects to depict, and how exactly to display it, transparently or abstractly, on a monitor or via a decorative sculpture. We present four design dimensions that capture the space of ambient information systems. The dimensions can be thought of as design choices or design questions that system builders must answer. The dimensions are:

- **information capacity**
- **notification level**
- **representational fidelity**
- **aesthetic emphasis**

We rank 19 research systems and three consumer ambient information systems on each of the four axes. Each axis is divided into 5 bands, from low to high. We place systems into groups based on information from published conference and journal proceedings, including images and videos of systems in use if available. The 19 systems we chose are not intended to be an exhaustive list of all ambient information systems in the research literature. The 19 systems are representative of the breadth of the field and we feel that attempting an exhaustive list, while amplifying completeness, would not significantly alter the design dimensions.

Research systems that we analyzed include: Bus Mobile [24], Dangling String [35], Digital Family Portrait [26], InfoCanvas [33], Informative Art [30], Information Percolator [16], Irwin [22], Kandinsky [11], Kiumra [19], Lumitouch [5], Notification Collage [14], Scope [34], Sideshow [7], Table Fountain [12], Water Lamp [8], and What's Happening [36]. We include three consumer systems that fit our definition of ambient information systems, Ambient Devices Ambient Orb [2], the My Yahoo! web portal [27] and Apple's Dashboard [3].

Figure 1 shows the four dimensions for our analysis, and each of the 19 systems placed into a group along each. Thin colored lines trace the rankings of systems on each axis, similar to a parallel coordinates plot. Each axis has values that range from low to high through five grades. The dimensions of notification level and representational fidelity have more descriptive axis labels that will be explained in detail below.

4.1 Information Capacity

Ambient information systems are created to convey information to users—information that typically is important to a user's sense of wellbeing and general awareness, but not critical to their work or personal life. Information capacity represents the number of discrete information sources that a system can represent. Some systems are capable of displaying a single piece of data such as the current price of a stock index. Others can display the value of 20 (or more) different information elements on one screen. We rank systems from "Low" to "High" on this design dimension.

Information elements are discrete information "nuggets". For example, if a system monitors campus shuttle buses, each bus is a single nugget. If the system can represent both the time to a location and a direction of travel, then there are two nuggets of information for each bus that is monitored.

Information capacity makes visible the design trade-off between space and time. A designer can increase the information capacity of a display by increasing the space for information to be presented or by creating a display that transitions through a set of views over time. If a system is designed with multiple views or uses scrolling, we rank it in the top tier, since the number of pieces of information that it could display is arbitrarily large.

A further caveat about information capacity is necessary. Some of the analyzed systems such as InfoCanvas, Sideshow, and Dashboard are user-configured and user-customizable. This means that these and other systems could potentially be made to display hundreds of elements. Instead of attempting to calculate a theoretical maximum throughput for the display in these cases, we use the system designer's naturalistic portrayal in their published work to determine the "everyday maximum." Each of these systems is also in the top tier of information capacity.

The design dimension of information capacity has a barbell distribution. Five of the 19 systems display a single information element and are ranked "Low". Conversely, there are eight systems that display from ten to 20 information elements, with some systems having the potential to display more and these are ranked "High." Only a few systems take a middle-ground approach, attempting to display a small number (from two to ten) of information elements.

The systems with low ratings on the attribute of information conveyance are those that are physical displays. Fountains, glowing lights, and office-decoration sculptures afford designers only so much flexibility for changes.

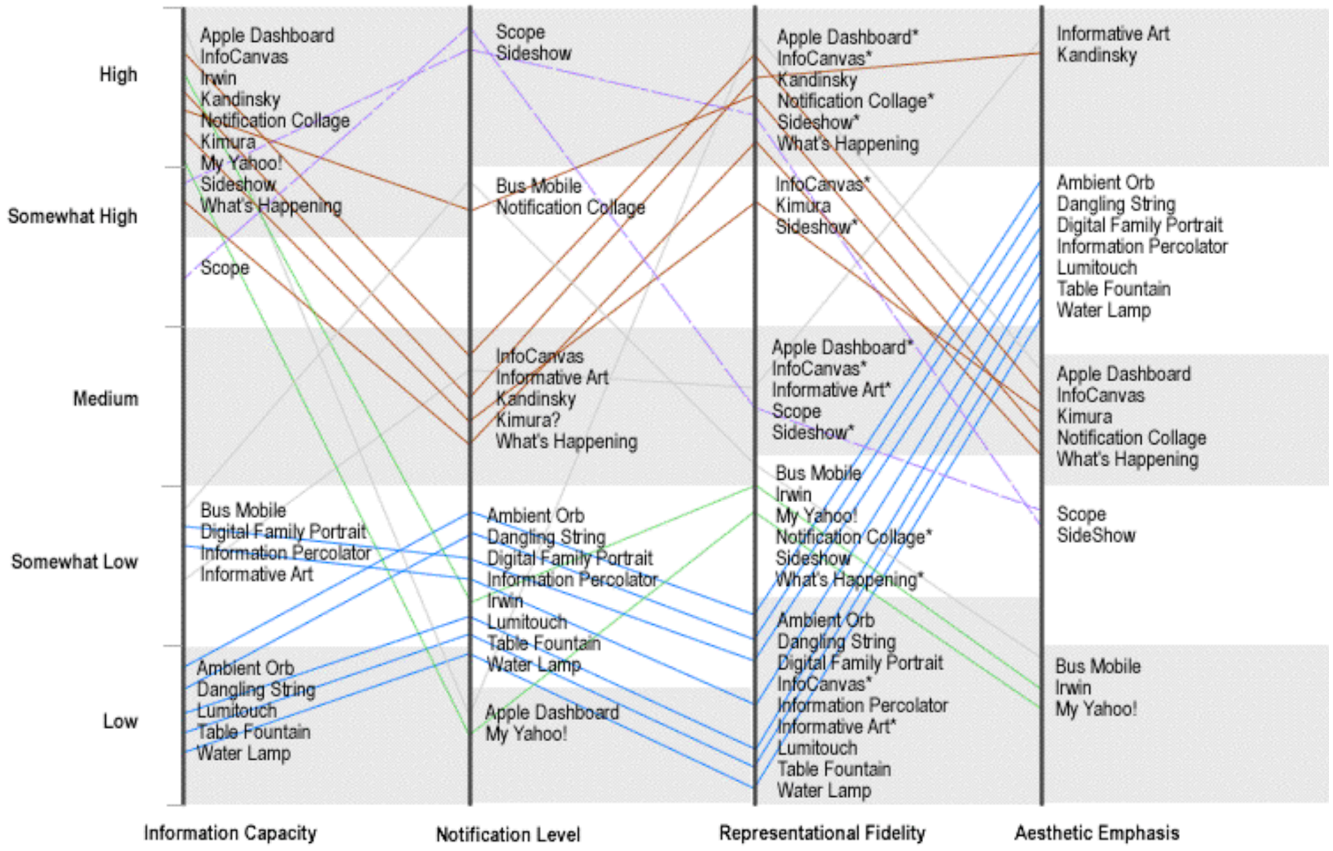

Figure 1: Parallel Coordinate plot of 19 existing ambient information systems across four design dimensions. Colored lines trace each system's ranking along the design dimensions. Different colors are used to denote groups of systems which are similar as explained more fully in Section 5.

Since the number of changes possible is small, the total number of information nuggets that can be represented is correspondingly small. The systems with high information conveyance are those that are presented on LCD screens. The systems that run at full screen (instead of as a small section of a focused main monitor) are ranked the highest.

4.2 Notification Level

Notification level is the degree to which system alerts are meant to interrupt a user. Notification level is a design attribute that is present in the two taxonomies of ambient and peripheral information systems we reviewed earlier. Matthews *et al* subdivides notification level into five categories: ***ignore, change blind, make aware, interrupt,*** and ***demand attention***. For our analysis we adopt those categories but replace the lowest level of system alert function, ***ignore*** (a degenerate case) with ***user poll***. Systems such as Apple Dashboard and My Yahoo! do not always appear in a user's environment and must be explicitly called to the fore.

Notification level can be thought of as the "ambience" of the systems in question. Some systems in the ambient space are quiet, and afford opportunistic glances to the information, while others provide more strident alerts by blinking, flashing, beeping, or even opening dialog windows. Systems that provide unobtrusive change blind or make aware notifications to the user are at the core of the ambient information system design space. Systems that *interrupt* users with alarms or that *demand attention* (by launching system dialog windows) are not subtle, so are further from the core concept of ambient information systems, though, as Matthews *et al* argues, the smooth transition from more subtle to more jarring is an interesting design direction for ambient system designers.

Notification level is the designer-intended level of alert. We do not take pains to distinguish between systems that are proven to be "change blind" through user experimentation versus those that merely claim change blindness. We remain agnostic here about the techniques used for ensuring subtlety including slow animation, scrolling, and fading (these implementation details are at a lower level of design rationale). Once the decision has been made to produce a system with *change blind* transitions, the designer must then produce system transitions that meet the goal in the specifics of the system. Our analysis focuses on the high level decision on the part of the designer or design team.

The distribution of systems here shows a good fit to our definition of ambient information systems. It is apparent that most ambient information systems adhere to the central notion of subtle visual or representational changes. The vast majority of ambient information systems fall into the *change blind* and *make aware* transition categories (somewhat low and medium). Few systems are designed to interrupt users or demand attention.

Two that do however are Scope and Sideshow. Note that most systems that are physical displays do not have make-aware or interruption-level alerts, much less demand attention alerts. The Bus Mobile does enable make-aware transitions, when, for example, the last bus of the day approaches.

4.3 Representational Fidelity

Representational fidelity describes a system's display components and how the data from the world is encoded into patterns, pictures, words, or sounds. Some systems reproduce the information being monitored in a very direct way, while others are much more abstract in their representation. Matthews *et al*'s taxonomy characterizes this design choice as *abstraction*, but only distinguishes two sub-types, feature degradation and feature abstraction. We consider this design dimension to be rich and complex, so we will try to tease apart the many different types of abstraction that appear in ambient information systems.

Representational fidelity can be described in the language of *Semiotics*, the branch of Philosophy that deals with signs, sign systems (such as natural languages) and their meanings. As such it has an accepted vocabulary for the elements of a symbolic representation. Semiotics can help analyze the way that particular signifiers—words, pictures, sounds, and other things—stand for the things they represent.

A semiotic **sign** is made up of three parts [28]. The object is called the **signified**; it is the physical thing or idea that the sign stands for. The **signifier** is the representation of the object, which could be a word, a picture, or a a sound. The **sense** is the understanding that an observer gets from seeing or experiencing either the signified or its signifier. The signifier and the signified need not have any direct relationship. However, both the signified and the signifier create the same sense in the head of an observer; seeing a log aflame and seeing the word "fire" create the same meaning for a person.

Ambient information systems, in the vocabulary of semiotics, contain one or more signs. Each sign has its object, information in the world, and its representation, the lights, pictures, or sounds used to signify that information. Many ambient information systems contain multiple signs—each picture element standing for a different piece of information.

The theory of Semiotics also helps to explain the notion that some signs are transparent, easily understood, while others are metaphorical and still others are abstract. Signs can be **symbolic**, **iconic**, or **indexical**. Symbolic signs are those that are completely arbitrary. For example languages are arbitrary, for the word *"bachelor"* has no more natural relation to an unmarried man than does the word *"foobar."* Symbolic signs are those signs for which a code, or rule-following convention, is required to understand. Language characters and numbers are all symbolic, as are abstract visual representations (the color red standing for "danger"). Iconic signs are those signs that have an intermediate degree of transparency to the signified object. Iconic signs include metaphors as well as doodles, drawings, and caricatures. Icons represent their objects by having some similarity or resemblance to the object or to an essential aspects of the object. Indexical signs are those that are directly connected to the signified. Examples include measuring instruments, maps, and photographs.

We have subdivided the three main categories of representational fidelity to distinguish between ambient information systems. We propose five groups, ranked from indexical (high) to symbolic (low):

- INDEXICAL: measuring instruments, maps, photographs
- ICONIC: drawings, doodles, caricatures
- ICONIC: Metaphors
- SYMBOLIC: language symbols (letters and numbers)
- SYMBOLIC: abstract symbols

Some ambient information systems have displays that do not afford representational flexibility, because of the constraints of the display. For example, the LiveWire system and the Ambient Orb cannot represent language symbols, nor can they convey indexical forms like photographs. However, some flexibility is present. The systems might map information in an arbitrary way, remaining fully abstract (representing stock increases with the color green and losses with the color red), or it could map information more metaphorically, as would be the case if LiveWire were connected to information from a seismograph or ocean tides. As one can see, the question concerning representational flexibility requires one to consider both the display and the information that is displayed.

The InfoCanvas is a very flexible system when considering representational fidelity. The InfoCanvas uses all five types of representational fidelity. It uses abstract symbols, such as the color red standing for traffic being stopped, metaphors, like a cartoon drawing of a cloud representing cloudy conditions, and also photographs and words of news stories, which are fully indexical. We show this ability for a system to straddle multiple representational forms by duplicating the system in each category and noting them with an asterisk (see Figure 1). Systems which are designed to represent information at multiple levels of fidelity are: Apple's Dashboard, InfoCanvas, Informative Art, Notification Collage, Sideshow, and What's Happening. In these cases, we draw the parallel coordinate plot to the top-most tier of representational fidelity for each system.

The majority of systems however, only afford a single level of representational fidelity. Many of the sculptural displays only afford symbolic, that is abstract, representations, while a smaller number afford text and photographic representations.

4.4 Aesthetic Emphasis

The final dimension concerns the relative importance of the aesthetics of the display. Some system designers seek to build displays and artifacts with sculptural or artistic conventions. For these systems, being visually pleasing is a primary objective. Others however place relatively little focus on aesthetics and typically focus more on information communication ability. Since aesthetic judgment is at its core a subjective phenomenon, we do not judge systems on their relative artistic merits. Instead we attempt to rank ambient information systems by our perception of the importance given to aesthetics. There is often a tradeoff made between communication capacity, representational fidelity, and aesthetics, a relationship that we explore in this section.

Ambient information systems are intended to be visible; positioned on a shelf, hung on the wall, or placed as a small sculpture on a desk, the systems are seen not just by a user, but also by co-workers, colleagues, or family members. There are a

multitude of approaches when it comes to building aesthetically pleasing devices. One approach is to build systems that mirror existing artworks by a particular artist, as is the case in Kandinsky and Informative Art. A second approach is to design a display that is representative of a particular style or art movement. InfoCanvas, through its use of themes, allows the display to take on characteristics of Asian water-color paintings, for example.

We rank systems on the design dimension of aesthetic emphasis as low, somewhat low, medium, somewhat high and high. Note again that we are not assessing the degree to which the systems are successful as art. We are providing a subjective measure of how much the system designers focused on aesthetics and how much they emphasized aesthetic considerations in their research and design decisions.

Most systems that we analyzed had medium or somewhat high degrees of aesthetic emphasis (12 of 19). The decisions of designers to strive for visually pleasing displays is most clear in the cases where the display is intended to leverage the work of existing artists. The physical ambient information displays are often sculptural in their design decisions. They attempt to set themselves off from the rest of the environment, often on pedestals or stands. Their capability to display much information (information capacity) is often limited by their design clarity and austerity. We consider this design trade-off in the next section.

Systems that we ranked at the middle of the spectrum of aesthetic emphasis are those which are not intended by their designers to be art worthy of contemplation as art objects. But they are explicitly intended to be viewed as calm pleasing objects and displays. Apple's Dashboard widgets have a clean design sense about them, as does Kimura, What's Happening and the Information Percolator. The systems that are ranked low on aesthetic emphasis are Scope, Sideshow, Bus Mobile, Elvin, and My Yahoo!. These systems put information conveyance at a higher priority than being aesthetically pleasing. They are still calm and environmentally appropriate, but their designers did not emphasize their aesthetic qualities. Cleary, some systems that are early-stage prototypes like Bus Mobile, may not have the aesthetic polish of more finished systems.

5. FOUR DESIGN PATTERNS

In this section, we introduce four design patterns for ambient information systems, after Alexander's pattern language for architectural studies [1]. The design patterns illustrate four coherent combinations of the four design dimensions previously presented. We have already pointed out trends and clusters that are present in each particular design dimension. However, there are fruitful conclusions for system designers as we consider the interaction between the design dimensions to form design patterns.

Considering the clusters of systems in each dimension and the correspondences that are visible in the parallel coordinate plot, we find four main archetypes in existing ambient information system design: **Symbolic Sculptural Display, Multiple-Information Consolidators, Information Monitor Display**, and **High Throughput Textual Display**. Figure 2 shows the pattern of each archetype across the dimensions.

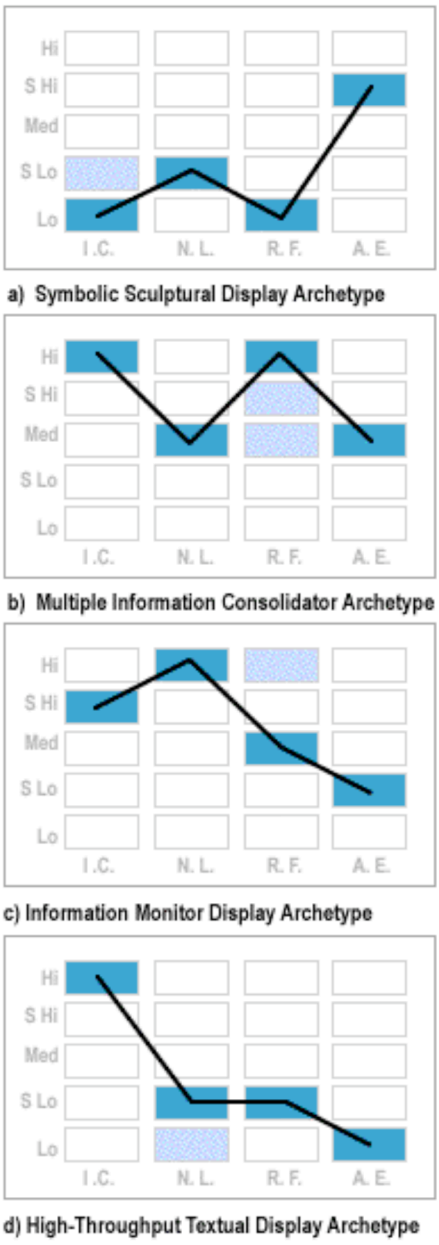

Figure 2: a-d System design archetypes shown in the context of the design space. Heavy boxes indicate core design decisions, while light boxes show alternate choices.

Symbolic Sculptural Displays are ambient information systems that display very few pieces of information, usually a single element. They represent information in an abstract sculptural way with light, water, or moving objects. They are intended to be decorative objects for a home or office setting and as such are highly aesthetic in their design (see Figure 2a). This design pattern is a core of ambient system design, and accounts for six of our analyzed systems: Ambient Orb, Dangling String, Digital Family Portrait, Information Percolator, Lumitouch, Table Fountain, and Water Lamp. The Digital Family Portrait combines multiple information sources and so truly represents more information than the other members of this type.

Multiple Information Consolidators are ambient systems that display many individual pieces of information in a consolidated manner. They are typically screen-based in order to convey much information and make users aware of changes to that information (usually by blinking the visual representation of a certain element). They are reasonably aesthetically motivated, but all clearly demonstrate the trade-off between aesthetics and customization and information capacity (see Figure 2b). Systems which illustrate this design pattern are: Kandinsky, Kimura, InfoCanvas, Notification Collage, and What's Happening. Kandinsky departs from the other systems in that it is explicitly modeled on the fine art of Kandinsky, and as such is highly stylized and design-focused. It does so at the expense of flexibility, since it can only display photographs in its slots.

Information Monitor Displays are displays that are a peripheral part of a user's computer desktop. As such, they afford different interactions and design choices. They display multiple sources of information, and do so usually by visual metaphors. They are capable of notifying users in multiple ways about changes in the source data, including subtle awareness, interrupting, and even demanding user attention when necessary (i.e., requiring the user to switch focus to dismiss a notification). The systems achieve aesthetics, but their primary purpose is not good looks (see Figure 2c). Examples of this design archetype include: Scope, and Sideshow.

High Throughput Textual Display systems are those that use text and very simple graphics (icons) to denote information. They are capable of representing voluminous information, but do not draw attention with interruption-level notifications. These systems are not primarily as concerned with aesthetics as they are with information conveyance (see Figure 2d). These systems are simple but efficient for certain types of tasks. Examples of this design archetype are: Elvin, and My Yahoo!.

The four design archetypes cover nearly all of the analyzed systems, but do not cleanly categorize three systems. Apple's Dashboard system is most similar to a Multiple Information Consolidator. It fails being a pure example of this archetype because of its inability to alert users to changes in information – it requires users poll the system by calling up the transparent pane via a hot key. The Bus Mobile is an early stage prototype, and as such is not concerned with aesthetics to a large degree. With a higher degree of aesthetic emphasis, it might be closer to a Information Monitor Display (albeit a physical instead of screen-based system). Informative Art is quite unlike the four design archetypes. Informative Art has high aesthetic emphasis, but low information capacity (e.g. 5 or 6 city's weather forecast information). It is metaphorical and abstract in its information mapping fidelity.

6. EXTENDING THE PATTERNS

The four patterns for system design can help designers to make appropriate choices as they develop new ambient information systems. The design patterns can be used as models so a designer can decide to build "an *information monitor display* for a home health awareness application", or "a set of *symbolic sculptural displays* for work-group collaboration". Further, the designer may be depart from the pattern, by building up a system's range of possible *notification levels*, or by choosing to trade *aesthetics* for increased *information capacity*. However, our analysis also points at what has not yet been explored. The four design patterns show four coherent combinations, but they are not the only possibilities for building useful ambient systems. Combined with longer-term trends in the fields of Ambient Intelligence and Ubiquitous Computing, new archetypes for system design are emerging. We note possibilities here, which change both the dimensions and the four design patterns.

We do not expect the information capacity for ambient systems to increase by dramatically. Though scrolling or time-divided ambient systems (What's Happening, Elvin) can already display data elements numbering in the hundreds, simultaneous visual displays are usually limited to 25 or 30 elements by readability and user learnability. Ambient information systems will not turn into information visualization systems showing thousands of data points. However, contextual sets of information may be useful for ambient systems in specialized environments. Systems which display contextual sets of information like that of the Bus Mobile (all of the buses on a college campus) or Scope (email and calendar data) would increase the number of systems in the middle portion of this design dimension.

We also expect to see changes to the design dimension of representational flexibility. Designers have begun to explore the affordances of abstract and symbolic mappings between information sources and their representations. We see this continuing, with new systems focusing on personally relevant symbolic representations, and utilizing metaphors from the natural and built worlds. Another shift that we foresee is the designers creating systems where multiple information sources and aspects interact to affect a single part of the representation. This is apparent already in Digital Family Portrait where the size of the butterflies represents "activity," even though activity is not the reading from a single sensor, but it instead a reading from multiple sensors in a home. Informative Art also has aspects of this approach, changing both the color and dimensions of squares based on two different aspects of weather.

As regards aesthetic emphasis, we foresee a more radical change. We predict further exploration of the space of truly artistically motivated ambient information systems. These generative artworks use information from the world to drive their behavior and ask (and answer) art questions as well as technology questions. Though most of these works are outside the academy (they are shown in galleries instead of computer science conferences), Bolen and Mateas' *Office Plant #1* [4] is a sculpture that characterizes the mood of a user's email stream and conveys it via transformations of a robotic plant. These systems are going to create a new design space above the top tier that we depict in this work.

7. CONCLUSIONS

In this work we synthesize a definition that distinguishes research in ambient information systems from that of notification systems and peripheral displays. We propose four design dimensions, rank systems to show clusters, and uncover four design patterns on which system developers may model their system designs. Future work will expand the four dimensions to include aspects of the social interaction and impact that system have on the behavior of individuals and groups.

In this work we point toward open areas in the design space, and we point to new design directions that may fill these gaps. Future work may also turn this taxonomy into an evaluation framework for ambient information systems.

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