The Aesthetic Awareness Display – a New Design Pattern for Ambient Information Systems

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ABSTRACT
Ambient Information Systems are designed as everyday, peripheral information sources that visualise useful data in a way that can be attended to when possible. Importantly these displays need to be designed to seamlessly fit into their environment and should not interrupt an individual from their primary task. The first Ambient Information System, known as the "Dangling String" was described in the literature in 1996. Since this time a number of different systems have been reported. In this paper we re-examine the concepts, definitions and background to this field that have developed over the last 20 years by performing a detailed narrative review of the field. As a result we provide a detailed discussion on the key design features or dimensions that have been used to help categorise and evaluate such displays. We also examine 36 previously reported Ambient Information Systems and categorise them in terms of an existing taxonomy of design patterns for such systems. A benefit of this taxonomy approach is that it helps us identify an underutilised design area for these displays and leads us to propose a new design pattern, known as the "Aesthetic Awareness Display" to assist in the design of these systems. This type of Ambient Display uses metaphors in order to encode a few data elements into an aesthetically pleasing display with the goal of raising general awareness about the data.

Categories and Subject Descriptors
User interface design, Visualization design and evaluation methods, Ubiquitous computing

Keywords
Ambient Information Systems; Ambient Displays; Design patterns; Informative Art, Calm Computing

1. INTRODUCTION
In our everyday life we constantly receive ambient information from our environment. This occurs through a range of mediums such as sound, light, temperature and air movement. For example, we can receive information such as the time of day through the amount of light shinning through a window, the time to wake up in the morning from birds tweeting, the running condition of an air conditioner by the quality of sound it emits or even the degree of excitement at a party from the chaotic din of background noise.

These "natural" ambient information sources generally sit in the periphery of an individual's attention. However, it also possible for a person to redirect attention to such peripheral information sources and focus more carefully on their content. This phenomenon is well known in visual information processing where the majority of the visual scene resides at the periphery of attention providing context to a much smaller focus of attention [13]. Uninteresting information sources such as a tree branch brushing against a window-pane might be ignored by an individual in preference for some other more critical and primary information source. However, attention can swiftly be directed to an alternative location if startling stimuli, such as sudden unexpected motion or rapid changes in light alert the individual to potentially valuable information in the periphery [46].

The "Cocktail Party Effect" [41] illustrates a similar phenomenon of selective attention in the auditory domain. This effect uses the analogy of a cocktail party, to highlight the ability of an individual to focus their listening attention on a single conversational source in a crowd of conversations [41]. For example, a background conversation where the individuals name is suddenly used.

While these ambient information sources are an abundant part of our natural environment they are less prevalent in our technological environments. Rather than sitting calmly in the periphery, traditional digital devices such as mobile phones, pagers and web browsers have been described as the enemy of calm [52]. This is due to their ability to demand immediate attention from the user.

Opposed to these interrupting, information devices is the notion of *Calm Technology* [52] that aims to deliver information by devices in an individual's periphery. A carefully designed, "calm" or non-alerting display situated in one's periphery, can provide a user with information in a similar way to natural ambient displays. Such digital devices that deliver information while residing in an individual's periphery are often referred to as *Ambient Information Systems* or *Ambient Displays*.

A typical definition of such systems is: *"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention"* [24]. Ambient Information Systems have also been described by some authors as Peripheral Displays, or "*displays that show information that a person is aware of, but not focused on*" [25]. A number of alternative definitions are provided in Table 1. While these definitions have similarities there is no uniformly accepted definition of Ambient Information Systems. Thus the first role of

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this survey paper is to highlight and compare the key features of Ambient Displays provided by various definitions. When we examine around 20 years of previous work in this field we also identify a wide variety of displays, each utilising different media and a range of data sources. Thus a further aim of this survey is to re-examine previous work in this field, particularly in relation to the various design dimensions, categorisations or taxonomies that have been described in this field. We also consider some 36 different displays that have been reported and categorise them in terms of a pre-existing taxonomy of design patterns for Ambient Information Systems [42]. This analysis of previous systems allows us to identify a new design pattern, which we describe as an Aesthetic Awareness Display and discuss in section 5. Finally we conclude by identifying outstanding gaps in this field that still require further research.

Table 1. Various definitions for Ambient Information Sources

Definition	Ref
"ubiquitous computing devices which monitor and display information in a peripheral, non- obtrusive way, and are meant to reduce demand on one's memory and overloaded senses"	[2]
"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention."	[24]
"An ambient display resides in the periphery of a person's attention. The display calmly changes state in some way to reflect changes in the underlying information it is representing"	[49]
"computer augmented, or amplified, works of art that not only are aesthetical objects but also information displays, in as much as they dynamically reflect information about their environment"	[44]

2. AMBIENT INFORMATION SYSTEMS

Many different displays have been developed since 1996 [52] that can be categorised as Ambient Information Systems. These include Informative Art displays [44], Digital Family Portraits [31] Ambient Mirrors [31], Tangible Bits [18], Invisible Displays [39] and Virtual Paintings [48].

An early example of an Ambient Information System is the ambientROOM [19]. The ambientROOM was designed to provide information to the user for background processing through a range of ambient mediums such as light, sound, motion and airflow. One example of an Ambient Information System that was installed into the ambientROOM is Water Ripples. Water Ripples reflected shadows of water on the roof of the ambientROOM. The ripples of the water were controlled by a hamster, if the hamster ran in its wheel the water ripples on the roof would vibrate and therefore visualise the activities of the nearby animal.

Another example of an Ambient Information System is the Informative Art display that aimed to visualise bus departures in real time [48] The display that was inspired by the art of Mondrian, visualised the movements of buses by manipulating a piece of art on an LCD screen. Each coloured square that made up the piece of Informative Art represented a bus, the size of each square would change in real time to represent the amount of time before a bus would leave a particular bus stop.

The Digital Family Portrait, another prominent display from the literature [31] which took the form of a photo frame that was also capable of delivering information to the user. The aim of the project was to create a device that could help the family members of an elderly individual become more aware of their elderly relative's activities, health and well being. Information about the elderly individual was visualised through a series of icons on the frame that would represent a range of metrics relating to their wellbeing. Such a system might be advantageous in relaying information to a family member that is some distance from their elderly relative.

These previous examples help to highlight some key features captured in various definitions for Ambient Displays (see Table 1). Namely, that such displays focus on displaying information in the periphery though novel means with an additional concern for producing an aesthetically pleasing display. These previous examples also demonstrate the diversity of such displays, a diversity that lends itself to further consideration. In the remainder of this section we look more closely at some of the clear distinctions that occur between these diverse Ambient Displays.

2.1 Tangible versus screen-based displays

The designs of Ambient Information Systems often differ from one another in relation to a number of physical design features. Most notable of these design considerations is the physical form of the display itself. Indeed two trends that have developed include the manipulation of a tangible-object for display versus a more traditional screen-based display.

Tangible Ambient Information Systems describe displays that utilise physical media in order to deliver peripheral information to the user. One of the first Ambient Displays, referred to as the Dangling String [52] or Live Wire has been cited as being the root of all Ambient Displays [28]. Dangling String was an Ambient Information System created by artist Natalie Jeremijenko which comprised of an 8-foot piece of plastic spaghetti that hung from the celling [52]. The Display, which used the physical medium of a moving string as well as the sound it emitted, was used to notify individuals of network traffic. There are many other examples throughout the literature particularly in relation to Tangible User Interfaces [19]. These displays are also sometimes referred to as Sculptural Displays [42].

Sculptural Displays usually have limited modalities for expressing information and this usually displays a single targeted piece of information [42]. Examples include "Show-me" [21] and The Power-aware Cord [15]. Both of these Ambient Information Systems aim to increase the awareness of a single metric to the user though sculptural changes to a tangible object. In the case of "Show-Me" real time water usage information is presented to the user through a series of LED lights. The Power-aware cord displays power consumption of a particular appliance by adjusting the brightness of a glowing cord.

An alternative group of Ambient Displays can be distinguished by their common use of LCD screen technology to deliver Ambient Media. While the use of an LCD display may seem contradictory to the concepts of Calm Computing, many of the displays that utilise an LCD display identity as being Ambient Art [44]. Such art displays can be integrated into any environment where wall art is commonly used [44]. Ambient Art does find itself suited to the use of LCD displays for information transmission due to the concept's focus on mapping layers of information onto existing pieces of art typically pictures or posters [44].

One such example that demonstrates the typical attributes of a screen based display but is also considered a piece of Ambient Art is the Butterfly/Dragonfly display [34]. Butterfly/Dragonfly is an

Ambient Information system that displays Australian Stock Exchange data in the periphery through the metaphor of Ambient Art. The display utilises the placement of butterfly and dragonfly symbols in order to visualise information about stock prices. The display is made ambient by placing the screen in a picture frame and then deploying it in a private office environment where similar artwork is present.

A potential advantage of screen-based displays over their more sculptural counterparts, is the ability for designers to adopt more complex information mappings or metaphors that can display multiple information sources. One such example of a screen based display that conveys multiple metrics to a user in this way is the MoneyTree [10] display. MoneyTree presents real time information about stock prices and volumes to the user on a screen based display using a tree metaphor.

2.2 Levels of Ambience

Another differentiating feature in the literature is the level of ambience or user interaction required for different Ambient Information Systems. In terms of interaction there are displays that require no direct input from the user in order to function or to be useful. These displays represent the purest form of Ambient Information Systems in that they act solely as a peripheral device to deliver information. The purposeful lack of interaction is a design feature of such fully Ambient Information Systems. In these cases, the emphasis is on creating a peripheral device that requires no interaction from the user. Such displays embody the concepts of Calm Computing, where a device avoids becoming the "enemy of calm" [52] by alarming or demanding input from the user.

Exemplifying these fully Ambient Displays where no interaction is required is the Mondrian bus display [48]. The display developed by Skog, Ljungblad & Holmquist is used to convey the movement of buses by modifying a piece of existing Mondrian art in order to create an Informative Art display. The display is fully ambient due as no direct input is required from the user to utilise the display. While the display is context-dependent, representing information about relevant bus arrivals, it can be used by simply glancing at the display where it resides within its public environment.

The majority of displays reported in the literature aim to be purely peripheral with no interaction required from the user. By contrast with these fully Ambient Displays are displays that require or intentionally enable some form of interaction. These more interactive types of display can be classified as being Semi-Ambient. These displays differ to their fully ambient counterparts in that while they do deliver information through the periphery they require direct purposeful input from the user to fully function, or at least become more useful and relevant when such interaction occurs.

One typical example of a semi-ambient display is the LumiTouch system [5]. The LumiTouch is a communication device in the form of a photo frame the can be used to communicate with another individual who has a LumiTouch Display. The LumiTouch incorporates interaction through a series of touch sensors along the front of the frame that can be pressed by the user. Such touch interactions are communicated to the other paired LumiTouch display to create communication between two individuals. While there are other possible methods of communication through the LumiTouch that do not require such direct interaction, it is clear that during such an interaction with a touch sensor it is no longer ambient or in the user's periphery for an extended period of time. This purposeful removal of the display from the periphery to centre of a user's attention in order to provide input differentiates such a display from a fully ambient display.

In reviewing the key features and definitions of Ambient Information Systems it is evident that such displays can be differentiated by physical form, either being more sculptural physical objects or utilising more traditional screen-based display technologies. Another differentiating characteristic is the level of ambience or interaction required for the display. However, the key design features that classify the various Ambient Displays are not consistently reported in existing literature. Given the range of such displays and the importance of defining the key design dimensions of Ambient Information Systems we now examine the previous taxonomies (see table 2) that have attempted to better classify the design dimensions of these systems.

Table 2. Previous design dimensions suggested for classifying Ambient Information Systems

Design Dimensions	Number of Dimensions	Year	Ref
Intrusiveness, Notification, Persistence, Temporal context, Overview to detail, Modality, Level of abstraction, Interactivity, location, Content and aesthetics	11	2002	[2]
Interruption, Reaction, Comprehension	3	2003	[26]
Personalized, Flexible, Consolidated, Accurate, Appealing	5	2004	[49]
Abstract, Non-intrusive, Public, Aesthetic	4	2005	[20]
Information Capacity, Notification Level, Representational Fidelity, Aesthetic Emphasis	4	2006	[42]
Distraction, Comprehension, Usefulness, Interoperability	4	2007	[34]
Abstraction level, transition, notification level, temporal gradient	9	2007	[50]
Abstract, Playful, Attractive	3	2010	[45]

3. DESIGN DIMENSIONS

A broad range of Ambient Information Systems and their characteristics were discussed in the previous section. Given this broad range of systems it is not surprising that further classifications of these systems has been proposed [27], [26], [42].

The intention of these more detailed classifications is to help understand the design space of Ambient Information Systems and so allow for better comparative analysis of the various types of systems. More formal design dimensions can assist in answering two key research questions, namely "How to design a good ambient display?" and "When is an ambient display good?" [34]. While these questions are simple in their premise there are numerous attempts throughout the literature to define the specific

design attributes that are required in order to create a "good" Ambient Information System. Many authors discuss ideal design dimensions and some formative examples of these dimensions for classifying Ambient Information Systems are summarised in Table 2. In the rest of this section we examine in detail four formal frameworks that have been created to help categorise Ambient Information Systems and highlight the similarities and differences of each.

3.1 Early Design Dimensions

The Ames and Dey design dimensions provide one of the earliest examples of a design taxonomy for Ambient Information Systems [2]. This taxonomy consisted of eleven distinct design dimensions (see table 3 for a description of these dimensions).

Table 3. Ames and Dey - early design dimensions [2]

Design Dimension	Description
Intrusiveness	Ambient Information Systems do not require constant attention from the user but convey information with differing levels of intrusiveness dependent on the significance of the data.
Notification	Displays can move from the periphery to the centre of the user's attention when required. Changes in information are conveyed subtly to the user.
Persistence	Information is shown on the display using an appropriate time scale and refresh rate.
Temporal Context	Contextual information is provided by the display if comparisons with past or predictions of future information are present.
Overview to detail	Displays show sufficient information in order for the user to gather knowledge at a glance. More detail is provided to the user if they pay attention
Modality	Displays provide information through a sensory channel that is not already overloaded
Level of abstraction	Information is conveyed through an abstract or indirect manner. The display's visualisation should be related to the nature of the information.
Interactivity	Displays employ an appropriate level of user interaction, without being overly demanding on the part of the user.
Location	The design of such a display addresses the location in which it will be installed.
Content	Displays convey information that users care about.

Dimensions such as "Intrusiveness", "Notification", "Interactivity", "Location" and "Content" describe attributes that commonly occur in the various definitions for Ambient Information Systems (see Table 1). The Ames and Dey taxonomy also includes concepts directly related to Calm Technology and User Interface Design evaluation. For example, emphasis is put on Intrusiveness and Notification in relation to such displays being non-alarming, which is a key concern of Calm Technology. Furthermore, several of the design dimensions such as Temporal Context, Overview of details and Content are similar to some of Nielson's usability heuristics [37]. Many of the eleven Ames and Dey design dimensions also overlap with the reported design goals of previous systems. For example, the design motivations given for the Breakaway display were noted as being abstract, non-intrusive, public and aesthetic [20].

3.2 Peripheral Display Dimensions

While the Ames and Dey taxonomy includes the dimension of Intrusiveness and Overview to detail they do not focus directly on a key aspect of Ambient Information Systems, namely that they sit on the periphery of attention. A further taxonomy was derived to help categorise the design of Peripheral Displays and this was subsequently integrated into a Peripheral Display Toolkit [25]. This taxonomy focused on cognitive psychology models of attention. It divided this key concept of attention into four main states: preattention, inattention, divided attention, and focused attention. Stimuli attended to in the early preattentive phase are processed without contextual reference, go unnoticed and as such do not affect the viewer's perception. By contrast during the inattention state, perceptual stimuli may affect behaviour even though they are processed subconsciously. The final two states, divided attention and focused attention, relate to perceived stimuli that are processed consciously and used either in multi-tasking fashion or a more singular focused task.

This taxonomy uses three dimensions, namely Notification Level, Transition and Abstraction to classify Peripheral Displays. In this taxonomy, Abstraction refers to way incoming data is transformed to meet the requirements of the output device [25]. It defines two distinct types of data abstraction used in displays, either degradation or feature extraction. Degradation involves ignoring some original data or reducing the fidelity of the data in some other way. Feature extraction concerns the refinement of data or derivation of new measures from the underlying data. This *abstraction* dimension might be described as the data mapping part of design for Ambient Information Systems and is a common step in Information Visualisation process [33].

In this taxonomy the *Notification Level* of the incoming data is further used to define the display and can be described as "demand action", "interrupt", "make aware", "change blind", and "ignore" [26]. A "demand action" notification requires that the user perform some action to stop the alerting, thus requiring the refocus of a user's primary attention to respond. An "interrupt" is of slightly lower priority and is characterized as an attempt to obtain the user's focused attention. The "make aware" data is of slightly lower priority but like the "interrupt" class of data will signify the need for divided attention from the user. The "change blind" corresponds to inattention, and as such should attempt to not distract the user's conscious primary attention. Finally, the "ignore" category represents data that should not be displayed, and should not correspond to any attention level.

Ambient Information Systems are peripheral displays that fall into the "make aware" notification level. Only very critical information would require the user to be alerted, to drop everything and attend to the displayed information. This is not in general the design goal of ambient displays. It does imply that Ambient Information Systems could change notification level based on the changes to incoming data over time. The lower notification levels correspond to less critical data and thus should be displayed in a manner that does not allow peripheral changes in the display to distract the user's attention away from their primary task.

The third part of this taxonomy describes the *Transitions,* such as fading or movement that are used to update the states of the information display. These should be designed to attract an appropriate amount of attention on the basis of the notification level of the underlying data, the sensory modality of the display and taking into account context such as the background noise in the area of the display. Abrupt transitions can be used for their alerting function when changes "demand action" or are designed to "interrupt". By contrast "minimally attended" displays such as those seen in Ambient Information Systems with "make aware" and "change blind" notifications should adopt subtler or repetitive transitions that are just noticeable but not distracting.

As can be seen from this discussion the Notification, Transition and Abstraction taxonomy while applicable to Ambient Information Systems also includes many additional displays that while peripheral are designed to act as alarms or to have alerting functionality. In these cases, the underlying data may even be categorized as critical to some divided attention task and as such displays might be more carefully designed to allow monitoring rather than having the vague goal of awareness that is described for many Ambient Information Systems. This monitoring is arguably outside the intended functionality of Ambient Information Systems.

One further noticeable shortcoming in this taxonomy for Ambient Information Systems is the decision to not include aesthetics as a dimension. Generally aesthetics is seen as an important design goal for Ambient Information Systems.

3.3 Interruption, Reaction, Comprehension

Another taxonomy that includes Ambient Information Systems is based on a review of typical user goals and constraints for notification systems [27] *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"* [27].

This categorization by McCrickard [27] has foundations in theories related to human information processing and was devised to provide an unifying model that can be used to guide evaluation for such notification systems. The taxonomy is based on the three dimensions of interruption, reaction, and comprehension. These dimensions are considered critical in interfaces designed to support divided attention or multi-tasking by users when monitoring real-time data [27].

Interruption refers to the expected level of distraction or intrusion required from some primary task to events in the background-monitoring task. Reaction refers to speed and accuracy of response expected to a given interrupting stimulus. Comprehension refers to the design criteria that assist remembering and allows the user to make sense of patterns in the display. Each of these three dimensions is rated on a scale from low (0) to high (1). Considering the maximum and minimum values of these three dimensions allows for the definition of eight idealised models or design patterns (see table 4).

For example, in this taxonomy Ambient Information Systems would be specified with a low level of Interruption, a low expectation for the user to react quickly and accurately but have a high level of comprehension or memorability so that any patterns can be recalled and processed at a later time. By contrast Alarms and Critical Information Monitors would be expected to have both a high interruption and level of reaction specified as part of their design goals.

Table 4. General models used to categorise Notification Systems [27]

Display Type	Interruption	Reaction	Comprehension
Noise	0	0	0
Ambient Media	0	0	1
Indicator	0	1	0
Secondary Display	0	1	1
Diversion	1	0	0
Information Exhibit	1	0	1
Alarm	1	1	0
Critical Activity Monitor	1	1	1

Once again this taxonomy covers a broader range of systems of which Ambient Information Systems covers a smaller part. It has the benefit of suggesting a cognitive process model that allows for design specification in terms of user goals and interaction constraints such as context, information complexity and cognitive workload. It also supports comparative evaluation studies to be carried out for systems that can be defined in terms of the three dimensions that make up the framework. However, like the framework for Peripheral Displays it explicitly excludes key criteria of Ambient Information Systems such as aesthetics and subjective satisfaction or enjoyment as primary dimensions [27]. A taxonomy more specific to Ambient Information Systems is discussed next.

3.4 Capacity, Notification, Representational Fidelity and Capacity

Probably, the most well known classification of Ambient Information Systems in the literature defines four key dimensions that can be used to help categorize these systems. These four design dimensions are: Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis [42]. Pousman & Stasko's taxonomy is effective in that it not only defines a specific set of design dimensions, but also allows each of these dimensions to be given an ordinal ranking (from low to high). Thus any particular Ambient Information System can be ranked on each dimension by choosing from the five categories of low, somewhat low, medium, somewhat high and high (see table 5).

In this taxonomy, Information Capacity relates to the number of information sources that an Ambient Information System can visualise at any one time. For example, a display that only displays one data element would receive a ranking of low for Information Capacity, while a display that encodes twenty or more data elements would receive a ranking of high.

Notification level represents the level to which an Ambient Information System can alert or interrupt a user. For this dimension the five categories can be understood as Ignore (low), Change blind (somewhat low), Make aware (medium), Interrupt (somewhat high) and Demand Attention (high). For example, a display such as the Water Lamp would have a low level of notification due to its ability to not interrupt the user unnecessarily

through its use of subtle light and shadows to convey data [53]. On the other end of the spectrum a display such as Mobile Bus could be rated as having a somewhat high level of notification due to its use of movement that could easily attract the attention of an individual [24].

Table 5. Mappings Notification level and Representational Fidelity design dimensions [42]

Level	Notification level	Representational Fidelity
High	Demand Attention	Indexical – Maps Photographs
Somewhat High	Interrupt	Iconic – Drawings, doodles
Medium	Make aware	Iconic - Metaphors
Somewhat low	Change blind	Symbolic – Letters and numbers
Low	Ignore	Symbolic – Abstract symbols

Representational fidelity describes how an Ambient Information System encodes the data it displays. This can range from very realistic representations using photographs or cartographic maps to the quite abstract use of symbols to represent the underlying data. For this dimension the five categories can be specified as symbolic - abstract symbols (low), symbolic – letters and numbers (somewhat low), iconic – metaphors (medium), iconic – drawings, doodles, (somewhat high) and indexical – maps and photographs (high). Examples exist throughout the literature of differing implementations of representational fidelity. A display such as the Information Percolator would have a low level of Representational fidelity due to its use of abstract symbols (bubbles) to convey data to the user [16]. The bus mobile is an example of a display that could be classified as having somewhat low representational fidelity due to its use of letters and numbers in order to deliver contextual information to the user [9]. The Butterfly/Dragonfly display uses the metaphor of a butterfly being positive and a dragonfly being negative in order to deliver information to the user [34], giving it a representation fidelity classification of medium due to its reliance on metaphors for information transmission. The InfoCanvas display is capable of exemplifying both somewhat high and high levels of representational fidelity through its ability to convey information through icons as well as photographs [49]

Aesthetic Emphasis, the final axis of this taxonomy represents the level of effort to which a display aims to be an aesthetic rather than simply a functional object. Once again, the categories of low, somewhat low, medium, somewhat high and high are used to position displays on this dimension. The measure is intended to relate to the designer's intention rather than being some absolute measure of a display's aesthetic worth. A display such as InfoPulse could be classified as having a low level of aesthetic emphasis due to its design not being overly focused on aesthetics [29]. Representing the opposite end of the scale, Informative Art displays such Butterfly/Dragonfly [34] have high levels of Aesthetic Emphasis due the levels of design effort put into making the display not only convey information but also be an aesthetic object.

The Pousman & Stasko's taxonomy has many overlaps with other taxonomies in terms of its design dimensions. However, it remains one of the best-known classifications specifically described for Ambient Information Systems. Arguably one of reasons it is well known in the field is the identification of various design patterns based on the four dimensions. In the next section we briefly review the concept of a design pattern before describing the original design patterns that were first used to classify Ambient Information Systems [42]. We will then extend this previous work by categorising Ambient Information Systems into these design patterns and then by updating the original work of Pousman & Stasko [42]. This process will help us identify a new design pattern based on this taxonomy that will be described in section 5.

4. DESIGN PATTERNS

One way to solve common design problems is to adopt, or adapt, a solution that has been useful in the past. This is true of Ambient Information Systems as it is in other design domains. Design patterns are intended as a more formal way of capturing good designs, or design practices, so they can be reused. They also help categorise designs to allow better comparison on various design features.

The approach of using formal design patterns is attributed to Christopher Alexander who described over 250 problems in architecture along with descriptions and solutions [1]. These problems and solutions together formed a "pattern language" for communicating good design practice. In architecture, such design patterns were identified at many scales and were frequently applied together to solve specific design problems. The second community to broadly adopt the notion of design patterns was the Object-oriented software industry where it has been extensively used [14]. The approach has also been described in other design domains such as auditory display design [3], computer game design [36] and even the more general field of creativity [35].

Based on the design dimensions of their taxonomy, Pousman & Stasko [42] used this approach to describe four particular design patterns that captured existing Ambient Information Systems. The four design patterns were known as; Sculptural Symbolic Displays (table 6), Multiple Information Consolidators (table 7), Information Monitor Displays (table 8) and High Throughput Textual Displays (table 9).

Symbolic Sculptural Displays are displays that typically display a single metric to the user through sculptural means [42]. A good example of a Symbolic Sculptural display is the Dangling String [52]. See table 10 for more examples of this design pattern.

Multiple Information Consolidators are displays that are able to deliver many pieces of information to the user. Displays that are considered as being Multiple Information Consolidators are typically screen based as this allows multiple data sources to be integrated into the display design. The InfoCanvas [49] is a good example of this type of display. See table 11 for more examples of this design pattern.

Information Monitor displays are Ambient Information Systems that are displayed as part of a user's desktop computer environment and might be considered by some to fall outside the novel types of media or integrated environmental displays more typically associated with Ambient Information Systems. The High Throughput Textual Display constitutes a display that uses simple graphics such as icons or text in order to deliver information to the user. Throughput Textual Display's are capable of conveying many metrics to the user but have little focus on aesthetics, again

placing them somewhat outside more typical Ambient Information Systems.

Table 6. Design Dimension mappings for the Sculptural Symbolic Display design pattern [42]

Symbolic Sculptural Display	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High				
Somewhat high				■
Medium				
Somewhat low		■		
Low	■		■	

Table 7. Design Dimension mappings for the Multiple Information Consolidator pattern [42]

Multiple Information Consolidator	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High	■		■	
Somewhat high				
Medium		■		■
Somewhat low				
Low				

Table 8. Design Dimension mappings for the Information Monitor Display pattern [42]

Information Monitor Display	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High		■		
Somewhat high	■			
Medium			■	
Somewhat low				■
Low				

Table 9. Design Dimension mappings for the High-Throughput Textual pattern [42]

High-Throughput Textual Display	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High	■			
Somewhat high				
Medium				
Somewhat low		■	■	
Low				■

Table 10. Examples of Sculptural Symbolic Displays

			Ranking 1 (low) …. 5 (high)			
Display	**Reference**	**Year**	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
Dangling String	[52]	1996	1	2	1	4
Water Lamp	[8]	1998	1	2	1	4
Pinwheels	[8]	1998	1	2	1	4
LumiTouch	[5]	2001	1	2	1	4
Power-Aware Cord	[15]	2005	1	2	1	4
Tea Place	[23]	2007	1	2	1	4
Follow the lights	[45]	2010	1	2	1	4
The Clouds	[45]	2010	1	1	1	4
Show me	[21]	2009	1	3	3	4
Breakaway	[20]	2005	1	2	3	4
MoveLamp	[11]	2013	1	2	3	4
PlantDisplay	[22]	2006	1	1	3	4
CareNet	[6]	2004	2	2	1	4
Information Percolator	[16]	1999	2	2	1	4
Digital Family Portrait	[31]	2001	2	2	1	4
Hello.Wall	[43]	2003	2	2	1	4
Bus Mobile	[9]	2003	2	4	1	1
Nimio	[4]	2005	1	2	1	4
Ambient Orb	[7]	2015	1	2	1	4

In the remainder of this section we re-examine existing Ambient Information Systems in terms of these four design patterns (see table 10). We do this by subjectively ranking Ambient Information Systems from the literature on each axis of the

Pousman and Stasko taxonomy. The design dimensions are subjectively ranked in categories from one to five (1 for low, 2 for somewhat low, 3 for medium, 4 for somewhat high and 5 for high).

The displays reported in table 10 embody the design features of Sculptural Symbolic Displays in that they all have a high level of aesthetic emphasis but low levels of information capacity and notification. Furthermore all the displays in table 10 are tangible, aesthetic objects as has been previously suggested for this design type [42].

By contrast, the displays in table 11 can been classified as Multiple Information Consolidators as they try to convey many metrics to the user through a display that is moderately concerned with aesthetics. Each of the displays that fall under this design dimension is screen-based. This suggests the utility of such screen-based displays to convey many data elements to the user.

While there are a large number of displays that fit the first two design patterns there is a lack of reported displays related to Ambient Information Systems that exemplify the design attributes of the Information Monitor and High-Throughput Textual design patterns. While these types of displays do exist they may be more generally reported outside the domain of Ambient Information Systems.

Table 11. Examples of Multiple Information Consolidators

			Ranking 1 (low) …. 5 (high)			
Display	**Reference**	**Year**	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
InfoCanvas	[49]	2001	5	3	3	3
Ambient Calendar	[40]	2008	5	3	3	3
Exercise Awareness Display	[12]	2008	4	3	3	3
Ambient News	[51]	2010	5	3	2/3	3
Research Wave	[17]	2010	5	3	2/3	3
Time Management	[38]	2011	4	3	1	3

5. AESTHETIC AWARENESS DISPLAY

In reviewing the literature and ranking existing Ambient Information Systems it is apparent that a number of systems do not fit either of the four design patterns described by Pousman & Stasko [42]. However, these Ambient Information Systems, (listed in table 12) all hold similar attributes when ranked against the axes of Pousman & Stasko's taxonomy. The displays covey too much information to be considered as Sculptural Symbolic Displays but not enough to be considered as Multiple Information Consolidators.

The unclassifiable displays typically have low information capacity, rely on metaphors for information transmission and are highly aesthetic. The examples of displays from the literature that embody these features (see table 12) are typically screen based and align to the goals of Informative Art, where only general awareness of the data is expected.

Table 12. Examples of displays that fall outside existing design patterns.

			Ranking 1 (low) …. 5 (high)			
Display	**Reference**	**Year**	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
Informative Art	[44]	2000	2	3	3	5
Mondrian Bus	[48]	2003	2	3	3	5
MoneyTree	[10]	2004	2	3	3	4
MoneyColor	[47]	2005	2	3	3	5
Butterfly/ Dragonfly	[34]	2007	2	3	3	5
Fisherman	[47]	2007	2	3	3	5
Celling Display	[50]	2007	2	3	1	4
Rabbit screen display	[30]	2009	2	3	3	4
Virtual Aquarium	[32]	2013	2	4	3	4
Persuasive Art	[32]	2013	2	3	3	5

Table 13. Design Dimension mappings for the Aesthetic Information Display pattern.

Aesthetic Information Display	**Info Capacity**	**Notification Level**	**Representational Fidelity**	**Aesthetic Emphasis**
High				
Somewhat high				
Medium				
Somewhat low				
Low				

Due to the high number of displays that do not fit within the currently defined design types we propose a new design pattern we describe as the Aesthetic Awareness Display. Aesthetic Awareness Displays are highly aesthetic displays that display a

moderate number of information sources to the user. Such systems use metaphors in order to encode data into the aesthetics of the display. Displays of this type are typically screen based but unlike Multiple Information Consolidators do not aim to deliver a high number of metrics to the user. Instead Aesthetic Information Displays focus on delivering a few metrics in an aesthetically pleasing display. In general, they represent a middle ground between Sculptural Symbolic Displays and Multiple Information consolidators.

6. CONCLUSION

In this paper we have used narrative review to reexamine the current state of design in the area of Ambient Information Systems, covering around 20 years of study since 1996. As a result we have highlighted the various design dimensions that have been associated with Ambient Information Systems over this period. Focusing on the well-used Pousman & Stasko taxonomy of design patterns [42] we update previous work categorising displays using this taxonomy.

A benefit of using such taxonomies is they help categorise the possible design space. As a result of our work we highlight a large number of displays that fall outside existing design patterns. These displays fall somewhere between Sculptural Symbolic Displays and Multiple Information consolidators. We thus describe a new design pattern called an Aesthetic Awareness Display. These displays typically provide a few key metrics using metaphors that create an aesthetically pleasing display.

While this further investigation is a good beginning we also recognize there is much more work that can be done in identifying and classifying ambient displays. We also acknowledge that the narrative approach for literature review we have taken is prone to errors in selection bias. We recognize that we have biased in our own literature selection by focusing on work related to implemented systems from the domain of Information Technology. In the future we would like to address this by conducting a more formal systematic review on the area. This review would including related areas from psychology such as peripheral displays and also cover displays that have been designed to address more general issues of divided attention.

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