A Taxonomy of Information Representations and Their Effectiveness in Ambient Displays

A Design Sketch

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Abstract
People who engage regularly with technology interact with hundreds of visual, auditory, and multimodal displays each day. These ambient displays move information from the periphery to the center of human attention and back. If we can leverage design methods to reduce the time it takes to extract information from a display, taking advantage of information comprehension on the periphery, both human and financial resources could be greatly maximized.

In this design sketch, we present an initial taxonomy of information representation for ambient displays. Inspired by an analysis of existing ambient and peripheral displays, we have derived generalizable design principles from the taxonomy that can be applied to situations of divided attention in a number of contexts.

Keywords
Human-Centered Design, Interaction Design, Peripheral Displays, Ambient Displays, Visual Design, Information Architecture, Design Taxonomy

Project/problem statement
People who engage regularly with technology interact with hundreds of visual, auditory, and multimodal displays each day. These displays, which have been described as *calm technology* [16] or *peripheral* or *ambient displays*, move information from the periphery to the center of human attention and back. If we can leverage design methods to reduce the time it takes to

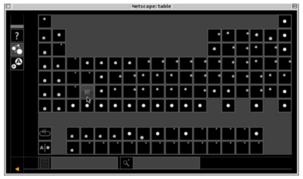

Figure 1. In this example of an ambient display, more than one hundred elements are compared and placed into one of seven groups based on similar reactivity amounts. The reactivity level of each element is represented by a moving dot. All elements that are placed in a similar group move at the same speed. Groups that are more reactive move more quickly than those that are less reactive. As a result, temporal patterns are visible, enabling comparisons to be made. A specific layer of data is shown that can be combined with color, sound, and scale to provide additional information. Limiting the amount of temporal changes is vital to the successful communication of content.

Observing the use of visual variables applied to various content and contexts may lead to the development of generalizable design principles that can be evaluated for desirability and effectiveness [13].

extract information from a display, taking advantage of information comprehension on the periphery, both human and financial resources could be greatly maximized.

Ambient displays receive varying and unpredictable levels of attention. Understanding what design variables might minimize the demand for attention in information interactions is a rich area for exploration. While many novel ambient display designs have been proposed for everyday environments [6, 7, 8, 16, 18], most are point designs in a space that have rarely been systematically evaluated for effectiveness or even desirability [4, 10]. Furthermore, little is known about how interactions over time with an ambient display might potentially contribute to long-term changes in attention allocation and increased use of peripheral awareness.

As designers creating ambient displays, our overall goal is to better understand how to derive design guidelines for displays that are used in situations of divided attention. We hope to create generalizable design principles for ambient displays that can support a variety of usable and accessible designs. We are investigating several design themes, including the use of movement, abstraction, scale, and background manipulation; the phenomenon of moving from the periphery to the center of attention, and the social and aesthetic uses of these displays, among others.

Background

Team members and their roles

One interaction designer and one communication designer have undertaken this project. They have also engaged the help of a communication design student to create sketches of some of the emerging peripheral display design variables and concepts.

Project dates and duration

The project began in January 2004 and is ongoing. The work is part of a 5-year NSF-funded project related to managing human attention.

Context of Project

Within the larger research project, a group of social scientists, computer scientists, and designers is attempting to understand how human attention, as a finite resource, can best be utilized. The audience we are working with is a group of home healthcare workers who provide home visits to nearly 600 residents distributed throughout twelve neighborhoods in a large metropolitan city. The work of this group is conducted largely by landline telephone and home visits. Visits are comprised of both social and caregiving activities. The healthcare workers struggle to stay in regular communication with family members, other staff members, doctors, and pharmacists. Their communication environment is impoverished, and they could greatly benefit from appropriately designed information systems.

The social scientists in our group are investigating how an economic market might be created for human attention, where incoming messages might be ranked or “priced” so that, for instance, important messages from physicians might take priority over sales calls. The computer scientists in our group are creating machine-learning models of the workers’ basic tasks and determining when they are most interruptible. The designers in the group are designing ambient displays to present critical information with the right amount of detail in a way that does not take all of the worker’s attention.

Figure 2. In this example of a peripheral display, the position of the standard gear shift provides the greatest amount of information. Visual variables are unnecessary in this application. They simply serve as a form of redundancy.

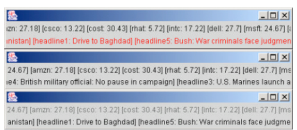

Figure 3. Screen real estate is a major consideration of the University of California, Berkeley Ticker Device, which is an example of an ambient display. Visual variables, such as color and value, are used to convey information. When coupled with temporal variables such as duration, and pacing, hierarchical importance is perceived. Visual representations are abstract. For example, the meaning of the color red needs to be learned. However, the use of design variables is concrete. Interaction with the device matches viewers' expectations [11].

Challenge

One of the challenges in our project has been to integrate the work of social science and computer science with the work of the designers. For example, creating machine-learning models takes a very significant amount of training data—instances collected from the people who will use the system. The approach of the design team has been twofold: to conduct basic research related to peripheral displays, and to create a visionary design as the theoretical and technical work evolves. This paper reports on the basic research we have conducted to date.

Solution

Process

Our basic research is exploring the use of design variables as a means of developing effective ambient and peripheral displays. By creating an initial taxonomy of design variables, we hope to address the following questions:

- What design variables are most and least effective in gradually shifting attention from a primary task to an information seeking task [detection]?
- At what time should such a shift be initiated [task type/onset/interruption]?
- Should variables be adjustable [interaction]?
- Can variables contribute to learning and remembering information [representation]?

To begin the process of creating the taxonomy, we collected examples of a wide range of existing ambient and peripheral displays. Examples are illustrated in Figures 1–4. These examples range from things that are observable in the world (for example, the dividing line on a highway or a gear shift in an automobile) to ambient displays that are the work of other designers and researchers (for example, A Peripheral Display Toolkit, designed by researchers at the University of California, Berkeley, and An Interactive Poetic Garden, designed by researchers at the MIT Media Lab) [11, 17].

We also reviewed literature on perception, attention, and a series of experiments found in psychology literature that examines the onset of information in two-dimensional displays. Of particular interest were issues of spatial proximity [3] and display size and location, use of relatively unstudied design variables such as transparency and subtle motion [1], and supporting cognitive processes at the instance of presenting new information by creating an "interruption lag" — the analog of white space in a peripheral display [14].

Solution

The next step was to examine and articulate the design variables found in this diverse set of examples. Informed by research done on visual variables in static designs [2, 5, 9, 15], we created an initial list of design variables found in these displays. From this set, we extracted a list of design variables that have the greatest potential for communication of abstract information through concrete representations of content. Figure 6 shows the organization of the taxonomy. The design variables are shown in Figure 7. We are currently exploring particular design variables alone and in combination in laboratory studies of ambient displays. For example, one fruitful technique for detection is to highlight the background that the information sits on using a "light circle," rather than the information itself (Figure 5).

Studying a diverse range of display examples and relevant readings helps us construct a taxonomy of design principles that are applicable to various content

Figure 4. The Interactive Poetic Garden of the MIT Media Lab is an example of an ambient display. It uses a wide variety of visual, temporal, and aural features to convey a range of information through layering. Temporal scaling of parts provides qualitative information by enabling comparisons to be made. Although the display of content mimics a familiar environment, making information easy to perceive and manipulate, the effectiveness of communication methods needs to be evaluated using complex information [17].

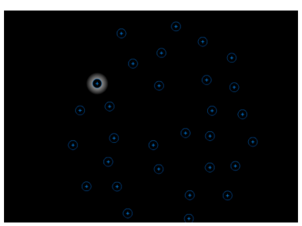

Figure 5. The "light circle" study examines background manipulation as a means of creating a subtle cue for directing attention.

and contexts. Simple geometric studies that focus solely on one or two particular variables, such as variations in speed and color, indicate the grouping and hierarchy of variables. However, we're discovering that our process needs to include the application of design variables to specific content and contexts for their use and effectiveness to be tested and evaluated.

Results

Our next step is to apply the design principles to the construction of displays that communicate specific content in a particular context to a clearly defined group of people. Information conveyed to caregivers currently serves as a basis for the application of the design principles.

Our exploration thus far has lead to numerous discoveries. Examination of our findings enables us to project the outcome of our efforts. We predict that:

- the shifting of attention should be guided by an appropriate change in stimulus determined by the information's level of urgency. As the representation of information moves from qualitative to quantitative forms, the amount of attention needed to perceive information rises.

- visual, temporal, and aural representations should logically match information stored in viewers' memories. (For example, a strong match: red=hot; weak match: square=hot.) Representations that look and feel according to viewers' expectations require less learning than those that do not.

- to ensure an accurate understanding of content, the representation of complex information should utilize patterns. Repetitions can be understood as patterns either separately or in combination with one another (for example, a color pattern may describe certain information while a movement pattern may depict other content).

- complex information should be presented sequentially, in layers, as the complexity of information increases. People have the ability to perceive and process a greater amount of information via multiple channels/modalities than by any single means. People recognize patterns more easily by inspecting complex images one after the other, rather than simultaneously, because changes in images become visible through temporal transitions.

- the granularity of information should correlate to the amount of content that is visible. A sparce amount of information indicates generalities, while dense bodies of information imply that the viewer will gain specific details.

- the acquisition of information should match the needs and desires of viewers relative to specific content and contexts. For example, private inforrmation about a patient viewed in a public context could make use of abstraction to convey critical information.

We anticipate evaluating the use and effectiveness of the design principles by studying the interruption of viewers incited by the application of design principles, the reaction of viewers to visual changes, and viewers' comprehension of content [12]. We will also evaluate the representation of information, examining the success of the design principles in communicating nominal, ordinal, and interval/ratio amounts of content.

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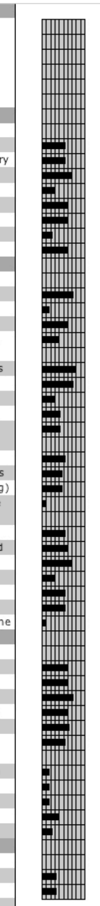
	standard gear shift			classical abacus			periodic table atomic mass			periodic table reactivity			gas gauge			vitals monitor			Panther Exposé		
temporal variables		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*
pacing (acceleration/deceleration)		0			0			0				1			1			1		0	
duration		0			0				1		0				1			1		0	
simultaneity		0				1			1			1		0				1			1
direction			1			1		0			0				1			1		0	
speed			1		0			0				1			1			1		0	
frequency		0			0			0				1			1			1		0	
***collision**		0			0			0			0			0			0			0	
***attraction**		0			0			0			0			0			0			0	
***repulsion**		0			0			0			0			0			0			0	
***biomimetic**		0			0			0				1			1			1		0	
***vibration**		0			0			0			0			0			0			0	
other modalities		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*
auditory information			1			1			1			1		0				1		0	
haptic information			1			1		0			0			0			0			0	
information type		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*		*No(0)*	*Yes(1)*
qualitative			1		0				1			1			1			1			1
quantitative		*0*				1			1			1		*0*				1			1
task description (after McCrickard)																					
notification	no apparent notification — no change in visual or auditory field			no apparent change in notification without explicit movement by user			notification dependent on user interaction; action occur based on activity			notification dependent on user interaction; action occur based on activity			gradual change in notification by position of needle			two types of changes provide notification: distinct change from a learned normal curve, and approaching a limit for each variable			changes in window layout show when new information is coming in		
reaction	current position of gear shift provides info about next possible positions			position of abacus beads provides information			visual, temporal, and aural changes prompt user activity			visual, temporal, and aural changes prompt user activity			position of needle relative to ticks gives low-level knowledge			overall appearance of curve gives low-level knowledge about reading			simultaneous views give low-level sense of the information		
comprehension	process becomes intuitive with experience			maps to existing knowledge of mathematics			maps to existing knowledge of the periodic table			maps to existing knowledge of the periodic table			when needle points to E, tank is empty. Never know the actual gallon amount			information trends are learned over time			process becomes intuitive with experience		
notes about examples																					
What do the features in each example mean? What is the most successful variable in each example?	The position of the device provides the greatest amount of information. Visual variables aren't necessary in this application.			The position of the abacus parts provide mathematical information. Color, shape, and texture are extraneous variables.			Temporal scaling of parts provide qualitative information by enabling comparisons to be made. The image indicates one specific layer of information which can be combined with color and sound. Contrast and clarity enables the components to be assessed properly.			The movement of parts are grouped into seven sets. Temporal patterns are visible, enabling comparisons to be made. This is one specific layer of information which can be combined with color, sound, and scale. Limiting the amount of temporal change is vital to its success.			The position of the gauge pointer provides vital information. Information is typically monitored while performing other activities. Therefore, the simplicity, clarity, and contrast of visual variables determines the success or failure of the device.			Position and movement provide information. Since the monitoring of several bodily functions appear similar in movement, color and numerical information distinguish individual parts. Repetitive movements are perceived as patterns which convey consistency.			Simultaneity is the main feature of this device. It enables viewers to see all open documents on the desktop at one time. This is achieved through a reduction in the visual size of all documents. Importance is not gauged since hierarchy is not indicated visually. Aside from the initial change,		

Figure 6. The taxonomy of design variables was derived from an analysis of existing ambient and peripheral displays. Examples range from displays observable in the world to studies constructed by designers and researchers. Based on our initial review of the examples, which were supported by literature readings, we created a list of design variables and defined their use. Next, we noted evidence of the design variables in the examples and plotted our results. Our findings point to a set of variables that are used more frequently than others and that some variables are used often as groups. Notations of evaluation methods and key features of each example are listed along the bottom of the diagram. A partial list of design variables and the displays we studied is shown here.

Figure 7. The design variables in our taxonomy, their definitions, and the frequency of their use in the examples we studied, are shown here.



descriptions	totals	intended goals
		variables used to convey information/incite interaction
		visual variables (whole)
color hue often contributes to whether each example attracts the attention of viewers or functions in their periphery	10	**color hue**
color intensity often contributes to whether each example attracts the attention of viewers or functions in their periphery	10	**color intensity**
value is a frequently used variable, providing differentiation between each example and their surroundings	13	**color value**
in most examples (primarily screen-based) the whole cannot be examined separately from its parts	5	**transparency**
in most examples (primarily screen-based) the whole cannot be examined separately from its parts	11	**blur/clarity**
in most examples (primarily screen-based) the whole cannot be examined separately from its parts	11	**resolution**
texture of the whole is more meamingful, in terms of being able to make comparisons, than that of individual parts	4	**texture**
variable refers to the location of the device in relation to the user—in most cases this contributes to its functionality	11	**location (of the whole not parts)**
		visual variables (parts)
large amounts of information can be conveyed and compared by representing complex concepts via abstract shapes	14	**abstract**
realistic representations often used to convey sparse amounts of information—comparisons difficult to make	3	**realistic**
2d representations most often used in screen-based examples in combination with temporal variables	11	**2d**
3d representations aren't utilized in screen-based examples—often convey information through touch and movement	7	**3d**
amount of info a factor in most examples which is often distributed via layers, temporal, aural, and/or tactile variables	15	**amount**
location of variables is not simply pleasing but conveys important information in most examples	14	**location**
proximity of variables not simply an aesthetic decision but often conveys important info and enables comparing	5	**proximity**
differentiation among similar content is used frequently—often implies a value system and/or designates a focal pt.	8	**hierarchy**
some examples clearly force viewers to move through information via a particular route—system appears fairly closed	8	**occlusion**
due to limited space, visuals must function well at a small size in most examples—size also conveys info/hierarchy	10	**size**
shape is used as a form of differentiation among content—abstract shapes are often used to convey concrete concepts	9	**shape**
orientation most important when text is used—it also mimics human behavior in some instances (ex. left/right reading)	9	**orientation**
movement in and out of information (less and more complex) seldom utilized in these examples but proven valuable	1	**macro/micro**
hue, value, and intensity often appear together as visual variables—color is the least effective due to color blindness	10	**color hue**
intensity is a variable consistently used with hue—the greater variation in intensity, the easily differences are discerned	11	**color intensity**
value is a frequently used variable, affecting legibility and providing differentiation	13	**color value**
most often used to enable multiple levels of information to be seen	5	**transparency**
clarity is more often a factor than blur—due to limited screen real estate, the clarity of information is important	10	**blur/clarity**
mostly applicable to screen-based examples, resolution is often a factor combined with clarity (real estate issue)	10	**resolution**
visual texture isn't utilized in screen-based examples—texture functions as support information rather than stand-alone	1	**texture**
		temporal variables
often combined with duration, pacing is a rhythmic movement that enables patterns to be distinguished	11	**pacing (acceleration/deceleration)**
the length of time an action is performed conveys important information, often qualitiative as a stand-alone	11	**duration**
visual, aural, and/or temporal variables (frequently in abstract form) are often combined—used frequently throughout	14	**simultaneity**
visible in both 2d and 3d representations of information—often mimics human behaviors (left to right, top to bottom)	11	**direction**
the rate at which information appears/disappears affects how easily a person can perceive and process information	12	**speed**
many examples repeat information in even intervals to emphasize importance and solidify meaning	10	**frequency**
few examples use the collision of parts to convey information—often used in combination with attraction and repulsion	3	***collision**
few examples mimic attraction behaviors in their movement of parts to convey information—used with repulsion	3	***attraction**
few examples mimic repulsion behaviors in their movement of parts to convey information—used with attraction	3	***repulsion**
some examples mimic known behavioral movements (appears alive) to convey specific content characteristics	7	***biomimetic**
similar to pacing in its rhythmic nature, vibration often doesn't vary, and intervals of duration are short (often tactile)	4	***vibration**
		other modalities
useful in the sense that it can easily be used in combination with visual and temporal variables or as stand-alone	6	**auditory information**
used primarily in 3d examples to convey limited information—often used to perform an action	6	**haptic information**
		information type
		qualitative
		quantitative
		task description (after McCrickard)
		notification
		reaction
		comprehension