AMBIENT INFORMATION VISUALIZATION

1 Introduction

During the last 50 years, computers have gone from being room-sized machines specialized at performing advanced mathematical calculations to being smaller, more general information processing devices which we use for both work and leisure. Computers are also increasingly becoming embedded into artefacts in our surroundings.

In some respects, this development can be seen as a movement toward something resembling the *ubiquitous computing* scenario envisioned by Mark Weiser and colleagues at Xerox PARC, which foresaw a future where computation would be available everywhere (Weiser, 1991). Their vision was not primarily focused on the embedding of computers into everything, however, but rather on how the *use* of computers would evolve into a state where it became effortless and transparent, allowing the user to focus on the task at hand.

In order for us to be able to benefit from the computational power we embed into our environments, the computers will have to communicate, or output, the results of their computations to us somehow. The medium used by personal computers is primarily visual, possibly in combination with sound. However, as the number of computers increases, and they become embedded into our environments, the need for new ways to output information arises. As Weiser and Brown states in their paper on *Calm Technology* (Weiser & Brown, 1996):

if computers are everywhere they'd better stay out of the way.

The authors stress the importance of that computer use, in addition to the focused interaction computers demand today, also should be able to take a more peripheral role in the user's attention span. Rather than using a personal computer screen, placed on a desktop, as its only medium of communication, computer output should be available to the user where and when she needs it, in the same way as other, non-digital information presentation appear where it is needed.

Consider, for example, a train station; regardless of where you are in the building, a clock is likely to be somewhere within sight. This is no coincidence, but rather a conscious decision by the architect. Since most people visiting the sta-

Figure 1: Shinjuku district, Tokyo, Japan

tion building are either going somewhere with a departing train or are picking someone up at an arriving train, information about what time it is in relation to the scheduled arrival and departure times is of inherent interest to the people inhabiting the building.

Having computer displays everywhere, communicating information and seeking people's attention, could easily become overburdening. Think of places like New York's Times Square, Tokyo's Shinjuku (see Figure 1) or The Strip in Las Vegas: in all of these places, people are bombarded with commercial messages from a multitude of huge information displays, all competing for attention with flashing lights, blasting sound and their massive scale. They are all extreme examples of commercial centres created by the market economy, and as such extreme examples of information displays, but they still serve as a contrasting example to the more subtle display of time at the train station.

If information displays are to blend into their surroundings, they have to be carefully designed, taking into consideration factors like *what kind* of information is displayed, the *placement* of the display and *who the users are*. Furthermore, placing the presentation in an architectural context is likely to make the *aesthetics* of the presentation more important for how it is perceived.

The information presentation should be designed to accommodate the situation of use, which means that a peripheral placement of the display has different requirements than a desktop presentation where the user has her focused attention directed at it.

The use situation for a peripheral, public information display is likely to be subject to more distracting elements than its desktop counterpart, and a public display should accommodate this situation by providing a presentation that is as effortless as possible to read. Norman (1993) distinguishes two modes of cognition: *experiential* and *reflective* cognition, where the first is fast and effortless and the latter is slow and cumbersome, requiring the help of external support such as writing or books. Reflection requires concentration and, to quote Norman, "is best done in a quiet environment". A task that at first requires reflection can, however, become an experiential one, given enough practice. Revisiting the example of the clock, using it to tell the time is most certainly a reflective task for a beginner, but with practice the task becomes less difficult and eventually experiential. Adopting Norman's vocabulary, the display of information should be such that it makes use of experiential rather than reflective cognition.

How to present information graphically has been studied for a long time within the fields of graphic design and visualization. Norman says "*The power of the unaided mind is highly overrated.*" (Norman, 1993, p.43), and gives examples of how various problems become easier to solve when presented graphically. The external, graphical representation helps relieve the human mind of the effort to keep abstract things in memory and thus the problem becomes easier to solve.

The research field of visualization is devoted to the exploration of how graphics can be used as a means to exploit the special properties of visual perception in order to augment the human cognitive system. This is done by presenting data in ways that reveals hidden patterns or show relations that are not obvious to the unaided mind (Card et al, 1999). Computers, with their powerful number processing skills and capability to display interactive graphics, are very well suited for this purpose, and research within *information visualization* has during the last two decades explored ways of using computers to create interactive visual representations of abstract data. This rich knowledge of how to create efficient computer-based information presentation should be of great help when designing peripheral information displays that meet the needs of the ubiquitous computing scenario, like invisibility in use.

Applying the knowledge from information visualization to off-the-desktop information presentation is not always straightforward, however. For example, the move from the personal computing paradigm may limit the user's ability to interact with the data, which restricts the ways data can be presented. This new application area is likely to have a big impact on the requirements for information visualization, but fundamental principles on how to map data to visual structures should still apply.

1.1 Contribution

This thesis is an exploration of how the requirements for computer based information presentation change as it moves off the desktop and into the user's surroundings. The exploration is to a large extent carried out within the framework of *informative art*, which is a term denoting visualizations that use art and other decorative artifacts as a source of inspiration, both for the design of their appearance and for their role in the user's life. The assumption behind this design approach is that works of art—and 'art' here incorporates everything from paintings and sketches to posters and photographs—are frequently used as ornaments in our surroundings. These artworks are used to create a certain atmosphere or ambience at places where we spend our time. The purpose of informative art is to take the role art plays when it is used as ornament, and use it for the display of information.

The thesis also introduces the concept of *Ambient Information Visualization* (or ambient infovis, for short), which is a more generic term describing information visualizations that are explicitly designed to be displayed in the users surroundings rather than on a desktop screen. The move off the desktop and into the environment has a big impact on the design requirements of a visualization. The design space of ambient infovis can be mapped to a model describing its role in the

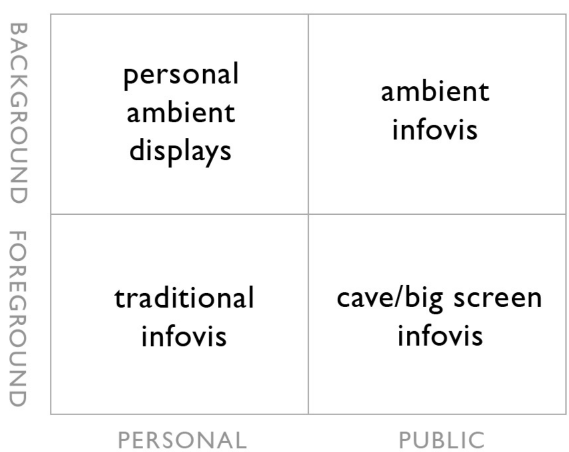

Figure 2: The design space of ambient information visualization.

individual user's *attention* span contrasted against how it is *accessed* in the environment. Using the access-attention-model seen in Figure 2, we see that ambient infovis resides in the background of the users' attention, since it takes place in the periphery; it is also public rather than personal. This places the design space in the upper-left quadrant of the model, whereas traditional infovis, which requires the focused attention of a single user, is placed in the lower-left quadrant. The Public/Foreground quadrant is occupied by visualizations that are design for focused, collaborative use—typically visualizations designed for large screens or so-called CAVES (Computer Animation and Visualization Environment). The last quadrant, Background/Personal, contain ambient and peripheral displays aimed at personal use, e.g. *InfoCanvas* (Miller and Stasko, 2002).

The access-attention model will be revisited at a later stage, when the design space of ambient infovis is defined more thoroughly and positioned against a background of related work within ubiquitous computing and information visualization. This definition is the topic of this thesis, which also answers the question:

> *What issues are of central importance when designing ambient information visualization?*

1.2 Thesis Structure

Section 2 describes the fields of ubiquitous computing ad information visualization and how they form the background for ambient information visualization. Section 3 lists the six papers that, together with this cover paper, constitute this thesis. Section 4 describes the research method. The results are summarized in section 5 and finally section 6 provides a discussion and a conclusion.

2 Background

Informative art is a concept that stands on two legs: ubiquitous computing and information visualization. They constitute the research background against which the work here should be seen. In the sections below, I will give a historical review of these three fields in order to position the project.

2.1 Ubiquitous Computing

In the early 1990s, Mark Weiser and his colleagues at Xerox PARC, devised a new computing paradigm called *Ubiquitous Computing* (or *Ubicomp* for short). This paradigm entails that in the future, computers will be everywhere and that computing access will permeate everyday life (Weiser, 1991). Inspired by the ideas of Suchman and other social scientists, who suggested that people work in a world of shared situations and that no action is isolated from its context (Suchman, 1987), the researchers argued that if computers are to truly become fundamentally integrated with our everyday lives and practices, they have to become effectively invisible in use—i.e., when you use a computer, you do not think of that you are actually using a computer but are fully focused on the task at hand.

The PARC researchers envisioned computers of the future to come in different shapes and sizes to accommodate the different needs that arise in the diverse usage situations that arise when the machines take the step off the desktop and into our everyday environments. They distinguished three different scales in which the computers of the future would be incarnated:

The smallest of these scales is the inch. Computers of this scale are called *tabs*, and are the computational correspondence to things like post-it notes, titles on book spines, or clocks—i.e. something that is specialized to solve one task.

Next comes the foot scale, where computers are called *pads* and correspond to things like sheets of paper, notebooks or magazines and are supposed to lay around wherever you may need them, like artifacts made of paper do today. Pads are used in ways similar to how we use paper—to sketch on, to read from etc.

The last and largest scale is the yard scale, with computers called *boards*. These computers work like boards; interactive bulletin boards or blackboards, but also as video screens.

Depending on what environment you are in, these devices appear in different quantities, but typically there are 100 or more tabs, 10-20 pads and one or two boards in any given room. Furthermore, all these devices should be able to communicate with each other and be aware of their location, e.g. know in what room they are in and what other computational devices are around them.

Weiser identifies three crucial technologies that are needed to realize the ubiquitous computing vision: cheap, low-power computers that include convenient display, a network that ties them together, and software systems implementing ubiquitous applications.

The work on Ubicomp at Xerox PARC continued throughout the 1990s, and spawned projects realizing parts of the vision, such as *PARCTAB*, *ParcPad* and *Liveboard*, which served as test bed devices for computers of different scales. The Tab was probably the most influential of the prototyping devices, bearing much resemblance to the cell phones and handheld computers of today. The devices were intended as technological explorations of how the ubicomp vision could be realized with available technology.

2.1.1 Design for Everyday Environments/Use

Much of the early research within *human-computer interaction* (henceforth abbreviated *HCI*) sprung from *human factors*, a discipline that had its origins in the industrial revolution. Industrial psychologists recognized that in order to reduce the probability of human error when handling machinery, the design of the interfaces needed to be dictated by how the human mind, rather than the machinery, worked. When applied within HCI. human factors came to deal with optimizing the design of computer interfaces in order to minimize human error, reduce ambiguity and increase the efficiency of use. This is a very task-oriented approach to interfaces, where computers are reduces to tools that are used to solve some task as efficiently as possible. As computers move off the desktop and into our everyday environments, however, the need for new perspectives arises.

Within the Ubicomp field, an increasing amount of attention has been spent on studying the way in which computers will come to permeate our lives. In the paper *At Home with UC: Seven challenges* (Edwards & Ginter, 2001), issues regarding the technical, social and pragmatic domains that have to be overcome in order for the "smart home" to become a reality.

Based on field studies of domestic life, Tolmie et al. published a paper called *Unremarkable Computing*, (Tolmie et al., 2002) in which they identify issues that are crucial when designing technology that is "invisible in use". They shed light on phenomena like activities that become invisible by virtue of having become routine—they are observable and identifiable, but to the people involved they are routine and hence carried out without reflection or thought on the activity itself. They stress the importance of not confusing invisibility in use with perceptual invisibility: ubicomp technologies of the future may well be *seen*, but they should have inherent qualities that enable them to become routine, and gain "invisibility status" that way. Important aspects to consider for designers involved in the creation of the future ubiquitous computing environments have been discussed by (Rodden and Benford, 2003) and concepts like *Everyday computing* (Abowd & Mynatt, 2000) also relate to similar issues. These approaches all have in common an approach where the designer studies the life and activities of people and let this ethnographic data inform the design of computational devices that support these activities.

Originating from a critique of the human factors-centered view of design that reigns within HCI, a range of alternative approaches to design has appeared on the research scene in the last few years. The assumption behind these approaches is that a lot of aspects that are crucial to the way we perceive computers will be overlooked if we adopt a strict human factors perspective for the design process. This will be especially unfortunate for the computational devices that are intended for our everyday environments, and these alternative design methods have to a large extent dealt with how to design for everyday environments.

An alternative method for gathering data about domestic life with the intent to influence design is to deploy so-called *cultural probes* in domestic environments. People use the probes to document different aspects of their life. The returned probes are then used as a source of inspiration for the design of new domestic devices. One such example is *the Drift Table* (Gaver et al., 2004) – a computationally enhanced sofa table that in addition to functioning as an ordinary sofa table also is equipped with a viewport through which you can watch aerial photography of England and Wales. The table surface is load sensing, so depending on how items are placed on the table, the aerial view will drift slowly in direction of where the load is heaviest. This drift table explores the concept of design for *ludic engagement*, where people are seen as playful creatures, or *Homo Ludens*.

When spending time in our homes, many of the activities we engage in are of a leisurely nature: they make us feel relaxed or engaged, or they simply allow us to dream away for awhile, depending on what we are in the mood for. These are aspects that are in focus when designing for ludic engagement, rather than more work-related aspects that usually direct the development within HCI.

> *"What if computing helped us pursue our lives, not just our work?"*

The drift table is one of many examples of design for domestic environments coming from the Royal College of Art. Another one is the *Placebo* project, where the designers placed experimental designs in domestic environments for some period of time and then came back to interview the people who had been living with the designs. Transcripts of the interviews are published, in unedited form, and without any attempt of interpretation from the authors, in (Dunne & Raby, 2001). The work is based on previous work like (Dunne, 1999), that describes a design methodology called *critical design*, which, in Dunne's own words strives to:

> *"explore fundamental issues about how we live amongst electronic objects. The most important elements of this approach are: going beyond optimization to explore critical and aesthetic roles for electronic products; using estrangement to open the space between people and electronic products; raising awareness of the electromagnetic qualities of our environment: and developing forms of engagement that avoid being didactic and utopian."*

Related to Dunne's critical design approach, is the concept of *Slow Technology* - technology that is explicitly designed to promote reflection and mental rest, rather than efficiency (Hallnäs and Redström, 2001). The authors argue that this focus is essential if we really want the use of computers to become integrated into our everyday lives. They foresee a movement "from use to presence" of computers, meaning that in the future computational devices will not be something that we *use* as much as something we *live with* (Hallnäs & Redström, 2002).

Continuing their work, the authors draw a parallel to design and architecture, where the birth of new materials or technologies have a way of affecting the way we design things. See for example how the use of reinforced concrete affected the way architects build things like houses and bridges. The same holds for the design of everyday things, where techniques such as bentwood and materials like plastic greatly affected the design of, for example, our furniture. The ubiquitous computing paradigm entails building computers into things, amplifying them and complementing their original functionality with new, interactive capabilities. Hallnäs & Redstöm consider computation as a material for design, and ask what properties it has, and in which way it will affect the everyday computational things of tomorrow (Redström, 2001).

2.1.2 Ambient Information Displays

In 1996, an new view on how to design interfaces for ubiquitous computers was presented in the paper *The Coming Age of Calm Technology* (Weiser and Brown, 1996), which described visions of how computers of the future would be able to "stay out of the way". Calm technology was described as technology that "engages both the center and the periphery of our attention, and in fact moves back and forth between the two". The authors argued that since humans only can focus their attention on a limited number of things at a time, and traditional computer interfaces require such focused attention from its users, a constant increase in the amount of computers requiring your attention will eventually become overburdening. The authors also argued, however, that humans have the ability to stay *attuned* to a lot of simultaneous information sources that reside in the periphery of our attention. By making use of this ability when creating computer interfaces, and explicitly design for the periphery of the human attention, we can accomplish the Ubicomp vision, where computer use becomes truly invisible.

In their paper on calm technology, Weiser and Brown states that

> *"Unlike virtual reality, ubiquitous computing endeavors to integrate information displays into the everyday physical world."*

The paper describes one such integrated information display, called *The Dangling String*. This was an art piece created by the artist in residence Natalie Jeremijenko, originally called *LiveWire*. The piece consisted of a plastic string, attached to a motor that would move according to the amount of traffic in the local area network, thus taking otherwise invisible information and giving it a physical manifestation in the room.

In the late 1980s and early 1990s, research on so-called media spaces was popular within HCI. The typical media space consists of a direct audio and video connection between two remote locations, intended to support collaboration between people in these locations. By keeping two (or more) spaces connected with a live video feed, even when it is not used for meetings or other work-related activities, an opportunity for keeping aware of the goings-on in other locations is created. This was explored in systems like *Portholes* (Dourish and Bly, 1992), which enables people to stay aware of the activities in several places; both public ones like lunch rooms or commons and the offices of friends and co-workers.

The *AROMA* system described in (Rønby Pedersen and Sokoler, 1997), provides the same kind of awareness information used in Portholes, but instead of displaying video images in a window on a screen, AROMA presents information using a set of more abstract output devices. The idea is both to make the information more peripheral by taking it off the desktop and placing it in the environment, and, by using abstract display methods, to provide just "enough" information and at the same time shield the privacy of the people being monitored. The system uses a camera and a microphone as input units and for output any of the four following: *speakers* playing wave sounds, a *Peltier element* changing temperature, a *merry-go-round* changing speed or a wall-mounted *monitor*, where clouds drift by at a speed depending on the amount of activity detected in the input data.

This way of presenting information in the users' environment, using modalities other than just vision has since been explored within the field of *ambient displays*. The term *ambient media* was coined in a paper from the Tangible Media Group at the MIT Media Lab that described the *ambientROOM* – a room that had a range of information displays integrated into its architectural structure. For example, the activity of someone close to you could be displayed as water ripples in the ceiling, the amount of e-mail in you inbox could be expressed as the sound of rain in the room (the heavier the rain, the more e-mail you have). They also describe displays that are not integrated in a specific room, but could be placed anywhere. These displays were called ambient fixtures and the examples described in the paper are called *WaterLamp*, which displays information by illuminating a tray of water from beneath and depending on some source of information, solenoids tap the water surface, creating patterns of water ripples in the ceiling. The second example is called *Pinwheels* and consists of an array of computer-controlled pinwheels mounted in the ceiling that spin according to some source of information, e.g. network traffic.

Another example of display design that strives to make use of out peripheral attention is the *Information Percolator* (Heiner et al, 1998), an ambient display that consist of 32 transparent, water-filled plastic tubes, each with an aquarium air pump mounted at the bottom. By releasing a short burst of air in a tube, a "pixel" is created that travels up the tube. The display is thus able to show any pixelated image of a resolution of approximately 32x25 pixels. The display was used for several applications, including a movement awareness display and a reminder clock.

With the goal to create general mechanisms for integrating ambient media with digital information, *the Ambient Media System* was developed at TeCo in Karlsruhe, Germany (Gellersen et al., 1999). The system connects hits on web pages to ambient devices in the environment, such as lamps, table fountains and a humidifier; thus integrating web awareness into the environment.

At Berkeley, the Group for User Interface Research has created a generalized mobile interface where six objects can be hung in strings from a "staging area" and, depending on some information, be lowered up to three feet. This interface has been used to create different ambient mobiles like the *Weather Mobile* and the *Bus Mobile*, which present weather and bus traffic information, respectively.

The *InfoCanvas* is a personalized peripheral display where the user can select the information she wants to monitor (e.g. stock portfolio information, weather, traffic data, news headlines, etc.) via a web-based interface and map it to a pictorial representation on the display (Miller and Stasko, 2002). A collage of such pictorial representations is then displayed on a peripheral display in the users surrounding, e.g. on the wall in an office, where it provides her with information "in a calm, unobtrusive manner".

The *Hello.Wall* is an ambient display consisting of LED-clusters forming light patterns that convey information. The display has three different modes and activation areas, one of which is ambient (Prante et al, 2003). Hello.Wall also has features connecting to the to the research on media spaces and awareness from the 1990's, where it is used to connect "commons" in two geographically dispersed offices by displaying abstract activity information.

On the consumer market, Boston based company *Ambient Devices* (www.ambientdevices.com) have commercialized the idea of ambient displays, and sells a set of different displays, including *Ambient Orb* and *Weather Forecast Beacon* The Orb can display a information ranging from stock market to weather to someone's presence on instant messenger whereas the Beacon only shows weather information for some location.

2.2 Information Presentation

The second "leg" of the foundation for ambient information visualization deals with information presentation. Humans have explored technologies for conveying information for a very long time—at least since the earliest findings of rock art, and probably even longer. In this section I give a brief account for the development of information presentation, with a specific focus on visual presentations, the ones that in modern day has become known as *visualization*, and with the advent of computers; *information visualization*. The research field of visualization is not new, but in order to understand its development, let us look at the definition of the term (from Merriam-Webster Medical Dictionary):

visualization - formation of mental visual images

The scientific field of visualization (which I, for brevity, use to encompass diverse areas like cartography, graphic representations etc.) has been devoted to studying the creation of visual means of *aiding human cognition*. The power of the human mind is enhanced greatly when provided with suitable tools (Card et al., 1999, p.1-2). Giving a thorough account for the development of tools for aiding human cognition is beyond the scope of this thesis; hence I will only visit a few milestones in the history of the field up until the present day.

Pictorial "languages" in the form of pictographs (rock paintings) and petroglyphs (rock carvings) from various cultures around the world are the earliest preserved examples of the way humans tried to record and convey information. This kind of rock art predates all written language and was commonly used to tell stories of hunting. Later cultures, like the Egyptian, developed these kinds of rock art into a proper pictographic language called *hieroglyphs*. The closest thing to a pictorial language that is still in use today is Chinese writing, whose logographic symbols have a pictorial background.

Around 1350 Nicole Oresme presented some graphical ways of visualizing theoretical functions and logical relations between tabulating values and so created the foundation for the bar-graphs of today. The scientific application of visualization began to develop more rapidly in the 1600's, with inventions like the Cartesian coordinate system and became gradually more advanced alongside the development within statistics, economics, etc. William Playfair is known for introducing the pie chart as well as the modern bar chart in the late 1700s and the 19^{th} century saw a virtual explosion in the development and use of different charts and graphs. This development slowed off in the early 20^{th} century which instead was a time for consolidation, with standards forming for when and how to apply different techniques.

During the second half of the 20th century came the computers, which with their innate number-crunching skills were very well apt to dealing with numerical data. Computer graphics has from its beginning been used for the visualization of scientific data. The rapid development of computers caused another creative explosion within the visualization field. As computers became more powerful they were able to process larger amounts of data of increasing complexity, and the enhanced graphics capabilities allowed for more advanced visualization techniques. This development gave rise to the field of *information visualization*. Information visualization has been defined by Card et al. (1999) as:

> *"The use of computer-supported, interactive, visual representations of abstract data to amplify cognition"*

This definition more or less presupposes the use of a desktop computer that allows for interaction with the information, changing point of view, rotating, restricting it etc. Building on the definition of visualization above, together with the definition of information as being "interpreted data", one could easily imagine a definition of information visualization that has nothing to do with computers, or even graphics. However, since the above definition by Card et al is commonly accepted within the field, I will adopt it for the discussion here.

2.2.1 Reference Model for Information Visualization

Card et al present a reference model for visualization (redrawn in Figure 3), which is a schematic view of how visualization is created by structuring of *Raw Data* into *Data Tables*, which then are mapped to *Visual Structures* which in turn can be explored from different *Views*. The core of this model is the mapping from Data Tables to Visual Structures, since that constitutes the move from Data to Visual Form, which obviously is a crucial step in the process of amplifying cognition.

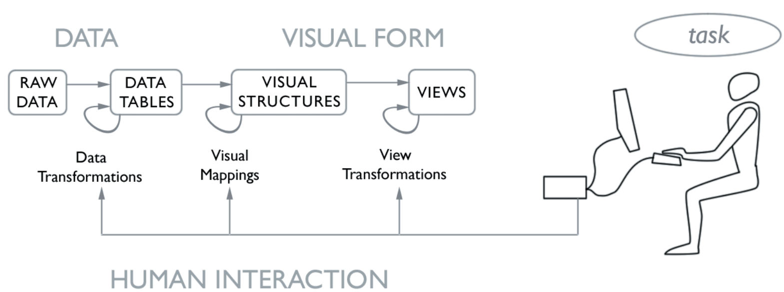

Figure 3: Reference model for Visualization, redrawn from Card et al (1999).

	Spatial	Q	O	N	Object	Q	O	N
Extent	(position)	●	●	●	grayscale	◑	●	○
	size	●	●	●				
Differential	orientation	◑	◑	◑	color	◑	◑	●
					texture	◑	◑	●
					shape	○	○	●

● good ◑ marginally effective ○ poor

Table 1: Efficiency of retinal properties for encoding of data, redrawn from Card et al (1999).

There are different types of data and Card et al adopts the division of data from (Mackinlay, 1986) into *Nominal* (unordered data such as {cat, dog, bird}), *Ordinal* (ordered data <small, medium, large>) and *Quantitative* (numerical data [0,10]).

Visual structures are defined to consist of *spatial substrate* (i.e., the visualization surface, onto which graphical elements are mapped), *marks* (i.e., graphical elements like points, lines, areas or volumes), and the *marks' retinal properties* (i.e., position, color, size, etc.). Not all visual structures are equally suitable to display different kinds of data. Table 1 shows a summary of how well suited different retinal properties (e.g. color, size or postition) of marks are to decode data.

2.2.2 Artistic InfoVis

The very first examples of information presentation like the rock art hunting stories mentioned above, were decoration as much as they were carriers of knowledge, and throughout the development of visualization as a field, aesthetics have been more or less an issue. If you consider examples from Edward Tufte's books *The Display of Quantitative Information* (Tufte, 2001) or *Envisioning Information* (Tufte, 1990)—they both provide a plethora of examples of how the most efficient visualizations have a quite aesthetic quality to them, even though they are not (necessarily) sprung from an artistic statement.

The visual appearance of the early visualizations of the computer age were limited by the graphics capabilities of the machines, but as computer graphics developed, these limitations gradually faded and indeed the new possibilities sometimes led to people getting carried away which resulted in effects such as careless use of colors, as noted in (Tufte, 1990, p.88).

As the discipline matured, however, the aesthetic appeal of visualizations gradually has gained renewed attention, e.g. in John Maeda's *Aesthetics and Computation Group* at the MIT Media Lab (the group has now changed names to *Physical Language Workshop*, but their focus on the aesthetics of computation remains. See also (Maeda, 2000)), and the Department of Art at Carnergie Mellon University gives a class on *Information Visualization as Artistic Practice*, which recognizes the aesthetic qualities that well-designed visualizations can have.

2.3 Ambient Information Visualization

The two fields of ubiquitous computing and information visualization form the background for the design space of *ambient information visualization*, which deals with the design of screen-based information displays that take peripheral roles in their users' environment. In other words, it is information visualization for ubiquitous computing environments.

This thesis explores how the knowledge gained within these two fields can be employed to create information visualization for everyday environments that have the necessary qualities to become integrated in the life and activities of its user.

2.3.1 Definition

The term Ambient Information Visualization is meant to encapsulate the role of the visualization in its surroundings. Let us revisit the definition of the word 'ambient' used in (Wisneski et al, 1998):

> *ambient* \Am"bi*ent\, a. Surrounding, encircling, encompassing and environing. (Oxford English Dictionary)

Arguably, the term 'peripheral' could have been used, which in some regards might have been more descriptive of the display's role in the user's environment, but since 'peripheral' word also has the negative connotation of referring to something of lesser importance, 'ambient' was considered more appropriate. Additionally, this includes the notion of the display contributing to the ambience of its location.

The other part of the term—information visualization—has been defined as :

> *"Use of interactive visual representations of abstract, nonphysically based data to amplify cognition"* (Card et al, 1999)

The combination of these two terms into the compound term *ambient information visualization*, should encompass the relevant aspects of both definitions and any possible synergy that might arise. A tentative definition may be:

Use of visual representations of abstract data to enhance a physical location with digital information

This tentative definition will serve as background to the papers described in the following two sections. We will return to this definition in section five to discuss how well it suits the work presented in the thesis.

3 Thesis

This thesis consists of six papers, plus this cover paper. In the following section I will present these six papers briefly, stating their main contributions and role in the thesis.

3.1 The Papers

I Informative Art: Using Amplified Artworks as Information Displays.
Redström, J., Skog, T. and Hallnäs, L. (2000)
Published in Proceedings of Designing Augmented Reality Environments (DARE) 2000.

II Informative Art: Information Visualization in Everyday Environments.
Holmquist, L.E. and Skog, T. (2003)
Published in Proceedings of Conference on Computer Graphics and Interactive Techniques in Australasia and South East Asia (GRAPHITE) 2003.

III From Usable to Enjoyable Information Displays
Ljungblad, S., Skog, T. and Holmquist, L.E. (2003)
Published as a chapter in the book: Funology: From Usability to Enjoyment. The paper in the thesis is an extended version of the book chapter.

IV Between Aesthetics and Utility: Designing Ambient Information Visualizations
Skog, T., Ljungblad, S. and Holmquist, L.E. (2003)
Published in Proceedings of the IEEE Symposium on Information Visualization (InfoVis) 2003.

V Subject to Change: Issues with Long-term Evaluation of Ambient Displays.
Skog, T., Ljungblad, S. and Holmquist L.E. (2005)
Unpublished.

VI Activity Wallpaper: Ambient Visualization of Activity Information
Skog, T. (2004)
Published (as poster) in Proceedings of Designing Interactive Systems (DIS) 2004.

Paper I introduces the concept of *informative art* - public information displays that use the language and role of art to communicate information. The concept is twofold and stands in part on the concept of Calm Technology, presented by Weiser and Brown, by moving the display of information off the desktop in order to peripheralize the interface. Another aspect of informative art is tied to the concept of *slow technology*, which strives to complement the reigning view of computer technology as tools, with the option that computational artifacts also can promote reflection and concentration. By gathering information from the environment and displaying it—in some processed form—an amplification of the both the art and the environment in which it is placed, is achieved.

Paper II describes four instances of informative art that were exhibited at SIGGRAPH Emerging Technologies 2001. The first example is called *Weather Composition* and presents weather information for six cities in the world in the style of a Mondrian composition. *Motion Painting* takes inspiration from op-artists like Bridget Riley in a visualization of activity information. *Stone Garden* visualizes earthquake information with what looks like a photograph of landscape art. *Soup Clock*, finally, is an abstract egg timer in the guise of an Andy Warhol silk screen print or painting of Campbell's soup cans. The main focus of the paper is the exploration of what makes successful visualizations for everyday environments through the design of a suite of examples. These examples serve to illuminate different crucial aspects of visualization design; the speed of animation, how the user ability to read a display changes over time, suitable balance between detailed information and overview, and aesthetic concerns.

Paper III was initially published as a chapter in the book *Funology: From Usability to Enjoyment* (Blythe et al., 2003). The version included in this thesis is extended with a section on related work and a detailed description of implementation and installation not included in the original book chapter. The paper describes the design and preliminary study of an "enjoyable" information display carried out in a university setting. The paper discusses the differences in requirements that arise when you are designing information displays that are supposed to be enjoyable rather than just efficient. The paper also provides an overview of the users' opinions on the display in general and how well it fits in as a part of their everyday environment.

Paper IV introduces the term *ambient information visualization*, as a superordinate term to describe the class of visualizations to which informative art belongs. With three previous Mondrian-esque visualizations as starting point, the paper describes the development of a fourth example, this time visualizing bus traffic information. The visualization is designed in an iterative process involving potential users, and the resulting display is subject to a brief evaluation in a university setting (c.f. Paper III). The results from that and previous evaluations, as well as exhibition installations are generalized to form four *lessons learned*, that serve as a summary of the experiences with designing ambient information visualizations.

Paper V describes a long-term evaluation of the display presented in Paper IV. As background, a number of previous attempts to evaluate ambient displays a re discussed, as well as possible, but yet to be explored, evaluation methods. We argue that, since ambient displays are integrated parts of the architectural surroundings in which they are placed, they have to be studied and evaluated *in situ*. The paper describes installations of the display and how the perception and use of the display varies with the physical location and the user group. The results highlight issues that could not have been unveiled in lab studies of the display, and that stresses the influence that the context has on the use of a display, and how use may change with the habits of the users.

Finally, paper VI describes the design of a new ambient visualization called *Activity Wallpaper*, which serves as an electronic "memory" for a place, by using sensors that collect activity data from the place – in this case an analysis of audio information – and then visualizing that information back into the space. The visualization is projected on a wall, which is the underlying reason for using wallpaper patterns as inspiration for the visualization. The paper included in the thesis is an extended version of the published one and describes a new activity analysis model that makes use of more sensors, which allows for a more diverse analysis of the activity or ambiance at the place that is being monitored.

4 Method

The six papers in this thesis describe the path from the initial experimenting with artistically influenced visualizations to an emerging framework for ambient information visualization. The work on which the papers are based was carried out at the PLAY studio at the Interactive Institute between the fall of 1999 and the summer of 2002, and from then on in the Future Applications Lab at the Viktoria Institute in Göteborg, Sweden.

The work on which the papers are based began with the idea of using art as inspiration for the design of information displays by employing its role as a decorative element in peoples' surroundings. The term we chose to denote such displays was *informative art*, which later was to be extended into *ambient information visualization* in order to encompass all peripheral visualizations, and not only those that build on an explicit artistic model.

The design space of ambient information visualization has been explored by the iterative creation of design examples (cf. Redström, 2001) with the purpose to shed light on what constitutes successful ambient infovis. The procedure has been to implement different mappings from information to "aesthetical" graphical structures, to test or evaluate these implementations, primarily by subjecting them to the scrutiny of users trying them out in different settings, and in that way gain knowledge about what constitutes viable mapping strategies and also to spawn ideas for new mappings. In addition to the exploration of mapping strategies, an important part of the work in this thesis is the study of ambient infovis *in use*. As the visualizations are designed to be a part of the user's environment, the context is likely to affect how the display is used. Hence we have conducted studies focused on how the displays fit into peoples everyday lives and how the use of the displays develop over time.

The design method used for developing the examples is a mix of methods from several disciplines. Some of the design examples has gone through what resembles the iterative refining of prototypes that is common within software engineering. Boehm, for example, introduced a so-called *spiral model*, in which each development cycle produces something that can be evaluated (Boehm, 1988). "Evaluation" within software engineering does usually not involve users, however, and Boehm's spiral model is not directly applicable within HCI. The model has, however, inspired other spiral methods that involve user testing and the spiral model is a straightforward way of breaking down a design process into different phases.

A crude description of the process traveling through a spiral model would be to divide it into four phases where the first consist of the design of a prototype, the second is some kind of user test to collect feedback, and the third step is to analyze the feedback to gain new knowledge about the prototype. Finally, the newly-found knowledge is used to infuse the development of a new prototype that—hopefully—is better than the first one. When this happens you have gone "full circle", but since the prototype is more refined, you have reached a higher level and hence the iteration of this process builds a spiral, and creates a spiral model. An alternative take on a spiral model, that in some respects is a better way of describing the research process used here is Verplank's spiral (see Figure 4). The model is described in (Holmquist, 2000) and shows how the development process moves from a "*hunch*" of something that might be interesting to explore, and as a first way of testing the hunch you do a *hack*, and then you *try it*. From this trial you form an *idea*, which can be used to sketch one or more *designs*, which can be developed into a *prototype*, this in turn can *tested* with users. Results from this (or these) test(s) are used to develop *principles* which develop into *plans* and finally *production* of something that goes on the *market*. As noted by Holmquist, the final two steps paradigms and industries are steps that are only applicable to a few, truly ground breaking inventions (e.g. the telephone or the car.) and thus I have chosen to adopt his use of the model, where the last arrow is dotted.

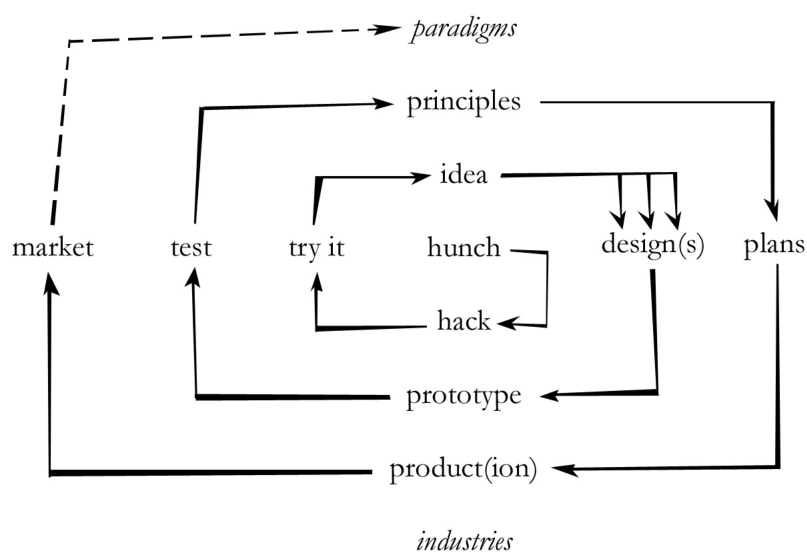

Figure 4: Verplank's spiral. Redrawn from Holmquist (2000).

The aim with the design of the examples and the evaluations has not been to create an exhaustive list of guidelines for how to design ambient information visualization, but rather to unveil aspects and issues of that are of crucial importance for how a visualization is used and perceived. Thus the examples serve as probes into the design space and are not part of a systematic exploration of all possible mappings in search of the best one according to some measure of efficiency.

4.1 Research

The idea for the informative art project was spawned by the Master's thesis *WebAware: Continuous Visualization of Web Site Traffic* (Siverbo and Skog, 1999), which also was published as a student poster at CHI 2000 (Skog and Holmquist, 2000). WebAware is a dynamic visualization of web site traffic, intended to provide people working in the company (or any workplace with an affiliated web site) a sense for what areas of the web site got the most traffic. In the visualization, each web page is represented by a dot, laid out using a visualization technique called Cyber Geo Maps (Holmquist et al, 1998) that distributes a tree structure in circles around the root, which made the entire web site look somewhat like a galaxy (see Figure 5). Whenever a web page was visited, the corresponding dot in the visualization would be highlighted. This highlight would then gradually fade away

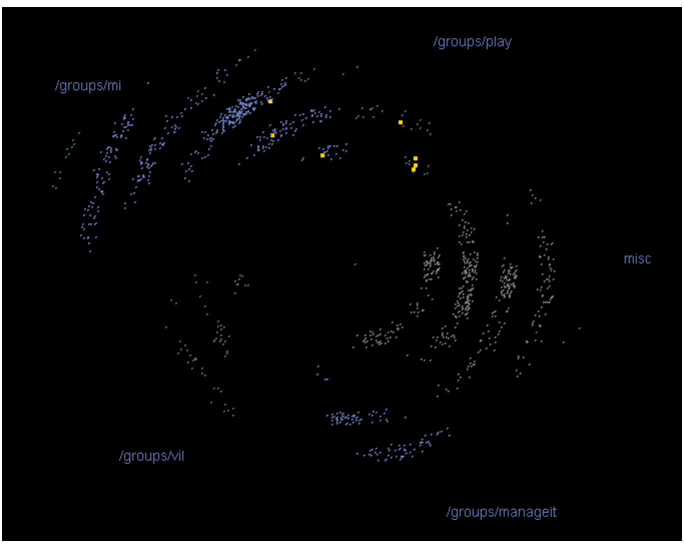

Figure 5: A Screenshot of WebAware, displaying six highlighted pages in the `/groups/mi` and `/groups/play` areas of the site.

(unless the page was visited again, in which case it would be highlighted again). The resulting visualization thus provide users with a dynamic picture of the web site traffic. We let people at our lab try the visualization and many of them found it aesthetically pleasing, so we experimented with different ways of displaying it in public areas of the office using a projector and plasma screen.

Having an aesthetic information presentation available in our everyday environments spawned the idea of actively employing items that we use for decoration as inspiration for information presentation. This chain of thought led us to art, and the idea of designing visualizations using well-known paintings as a visualization template, and thus the concept of informative art was born.

4.1.1 From Hunch to Hack

The first examples, or *hacks*, of informative art were developed in the winter of 1999-2000. The compositions of Dutch artist Piet Mondrian were used as inspiration for the first piece that was developed. The simple but characteristic graphic style seemed like a suitable template on to which information could be mapped in a fairly straightforward manner. The visualization we designed was of e-mail traffic (see Paper I) where quantitative information (the number of e-mails) was mapped to the size of colored fields. The color of the field was mapped to the time since a person last sent or received an e-mail. Making use of the same three primary colors as Mondrian, i.e. *blue*, *yellow* and *red*, a person could be "cool", "neutral" or "hot" respectively, depending on how recently he or she was involved in any e-mail correspondence.

The paper also describes an example that explores a simple mapping from information to the color of a field. The example is a clock contrasting objective and subjective time, where the subjective time is defined as some activity, e.g. the amount people passing through a door, so that the more people that would pass through the door, the faster the time would go (see Paper I). These early examples of informative art were running on wall-mounted flat-panel displays in a meeting room in our office (see Paper I, Figure 1).

4.1.2 Trying It & Getting Ideas

As a way of getting feedback on our designs—or, to use Verplank's term, to *try it*— we arranged a one-day exhibition at the Borås Art Museum in May 2000, on their yearly night of culture. We exhibited, among other designs (see Redström, 2001, p. 31) an altered version of the Mondrian visualization where the size of the colored squares were not controlled by the amount of e-mail traffic for some office worker, but from the amount of light let into the drawers of the *Chest of Drawers*

Figure 6: Three pieces of informative art at the Borås exhibition.

(described in Hallnäs et al, 2001; Redström, 2001). We also exhibited the clock of objective/subjective time, together with a new piece visualizing the amount of visitors to the exhibition (see Paper VI) as a pattern of colored fields where the color was determined by the amount of people entering or leaving the exhibition during one minute (see Figure 5).

These early examples yielded promising results in terms of how they were received, both by exhibition visitors and people at our lab, where we had examples running on wall-mounted flat-panel displays. Feedback from users, both at the lab and at the exhibition suggested that the mappings from data to supposedly aesthetical visual structures were comprehensible which indicated that the visualization could function both as information providers and decorative elements. The examples were not quite as exhaustive as we wanted them to be, however, and we also wanted to further explore the design space, both in terms of possible information sources and new visual structures.

This further exploration of the concept of informative art, was conducted through the development of a suite of new design examples for the Emerging Techtnologies exhibition at SIGGRAPH 2001. The examples explore new possible information sources, as well as the inherent possibilities of employing an artistic "template" for the display of information. Thus we designed four new examples, with four different sources of information, mapped to four different artistic templates. We chose to work with information that the exhibition visitors could relate to, and thus would be of interest to them. The examples, which all are described in greater detail in Paper II, were:

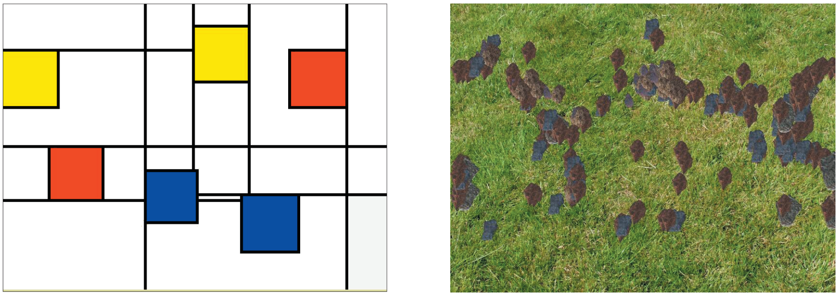

Figure 7 a & b: Weather Composition and Stone Garden

- *Weather Composition* (Figure 7a), which displayed weather information for six cities in the world using a Mondrian template. Information is mapped to the size and color of squares, which are laid out based on a world map. The motivation for the choice of information source was that weather is something everyone can relate to, and by choosing to represent cities from different continents, we got information that international conference visitors could relate to.

- *Stone Garden* (Figure 7b), which displayed earthquake data in a visualization resembling a picture of landscape art in the style of e.g. Richard Long. Information is mapped to the size of symbolic graphical elements and to the location of these elements form on the screen. Subsequently, as the number of symbols on the screen increases, they will form patterns that carry information in themselves. The choice of seismic activity as information source was based on the assumption that it was a topic of constant interest in Los Angeles, where the exhibition was held.

- *Motion Painting* (Figure 8a), which took inspiration from op-artists like Bridget Riley and abstract painters like Mark Rothko to visualize the activity in a room. Information is mapped to color of graphical elements (lines or dots, depending on the configuration of the visualization—which in turn highly affected the look of the display) and spatial mapping is determined by time which makes the visualization create activity patterns over time, where fluctuations in the activity can be seen. The information source here has an obvious connection to the place where the visualization is installed.

Figure 8 a & b: Motion Painting and Soup Clock

- *Soup Clock* (Figure 8b), which was an abstract egg-timer inspired by Andy Warhol's silk screen prints and paintings of Campbell's soup cans. The visualization counts down time until some pre-set deadline. Information is mapped to a pseudo random pattern of symbolic pictures (soup cans). At the exhibition, the soup clock was used to count down the time until the exhibition closed every night at 6 PM, and thus, like the motion painting, had an obvious connection to the setting.

The four pieces were exhibited for one week at the Los Angeles Convention Center in August 2001, to an international crowd, quite diverse in terms of background. We wanted to create a homely feeling to the exhibition and thus we chose not to use computer screens for the visualizations, but projected them onto hanging fabric (cf. Redström, 2001 p. 31). We also placed a couch, two comfortable chairs and a sofa table in our display space in order to create a kind of lounge space, where visitors could sit down for a while and see the project (Figure 9).

Figure 9: Picture from the exhibition setup at SIGGRAPH2001.

At this point, informative art had been exhibited in two different settings, to two different audiences, and although the concept had been well received, we felt the need to take the next step. Since the original inspiration for the project came from the art people use to decorate their surroundings, rather than art seen in museum and exhibition settings (although the two sometimes converge), we wanted to design an example that would let us explore how informative art worked in everyday use, where people had continuous access to a visualization.

Hence we adapted the Weather Composition exhibited at SIGGRAPH, so that instead of displaying the weather for six different cities, it displayed the current weather condition and a four day weather forecast for the Gothenburg region. A one-week study of this display was carried out at a local university, where we installed and ran the visualization on a wall-mounted 50-inch plasma display. The reception of the visualization was mostly positive, although the general consensus among the students seemed to be that a weather forecast was too static an information source to create an interesting display. When going from the spatial layout of the weather composition that was based on a world map, to the more arbitrary mapping used in this example, user's seemed to have greater difficulty comprehending the mapping—it was not as easy to find a mnemonic to remember the mapping.

4.1.3 Making Designs & Developing a Prototype

The suite of design examples in combination with the feedback from the user trials was a solid enough basis to start a serious reflection on what constitutes successful informative art visualization. It seemed reasonable that the results did not only apply to our artistically influenced visualizations, but also to the more generic class consisting of all visualizations aimed to take a peripheral role in the users' everyday lives. We chose to call this class of information visualizations *ambient information visualization* (ambient infovis, for short), to reflect their role as something blending into the surroundings, rather than something that requires the user's focused attention, like regular visualizations do. The foundations for ambient infovis are outlined in Paper IV.

The development of informative art continued through the design of a new display, again aimed at the university used for the study described above. The new visualization showed bus traffic information and was based on the Mondrian template, but this time we involved groups of potential users (i.e. university students, see Figure 10) in the design process, allowing them to give feedback on an initial design, which we then revised before the installation (see Figure 11 a&b). The visualization was running for two weeks on a 50-inch display at the university, dur-

Figure 10: Conducting a pre-study of the bus visualization.

ing which we conducted brief interviews with students spending time in the area around the display. The results from the study showed that the students in many cases were able to read the display, but that its placement sometimes hindered the use, since it was not always within sight when you were getting ready to leave, and hence was of no help.

The study helped us identify four *lessons learned* that serve as a summary of generic knowledge that we gained from our design examples and stress the importance of paying attention to issues regarding the *information source*, and *visual coding*. We found that the scope of the information source affects the relevance to the users (e.g. world weather has a much greater scope than e-mail traffic, and hence affects how the display works in different settings). The dynamics of the information source is another issue of great importance, where a balance must

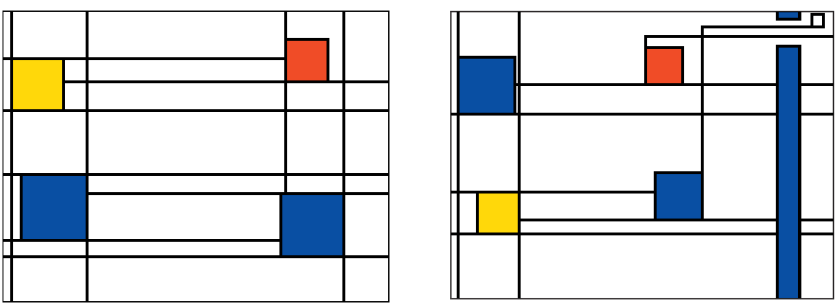

Figure 11 a & b: Intial design and redesign of the bus traffic visualization.

be struck in order to find the right amount of animation of the display (e.g. it has to change often enough for users to notice a change over time, but it should not be too animated or it will run the risk of distracting people). Regarding the visual coding, we found that using an artistic template for a visualization is not a hindrance for the comprehension of the display, and that letting some aspect of the information source (e.g. geographical features) affect the spatial layout of the visualization can be a helpful mnemonic for the mapping.

4.1.4 Testing the Prototype

Along the lines of many others, (e.g. Suchman, 1987; Dourish, 2000), we argue that the use of technology is inseparable from the context in which it is placed, both in terms of physical, architectural structures and the social structures and practices governing the use situation. When considering ambient and peripheral displays, which are explicitly designed to take their place as integrated parts of the users' surroundings, the context of use becomes even more crucial. So, in order to truly evaluate the concept of informative art, we needed to get usage data from real-life installations of a display.

Considering the results from the study of the bus display at the university, which did not see as much use as expected, we wanted to test it in another, less dynamic, setting, where people would have continuous access to the information, in order to find out how that would affect the use of the display. We also wanted to the test to run for an extended period of time to see how the use would change.

The second installation, was done in an office setting at a company with about ten users sitting close to the display (see Figure 12). The study lasted for a year, and to collect data from the users we started with on-site observations at the time around the installation and followed up these observations with iterative questionnaires that were e-mailed to the user group. We concluded the study with a final on-site observation and interview with our contact person, to see how the setting had changed during the installation. The display in the office setting saw much use during the initial stages of the study, but unfortunately the usage level dropped off significantly over time. This was mostly due to a general change of commuting habits of the users.

We also installed the display in our own lab, where it, at the time of writing, is still running. Data collection at the lab consisted of informal day-to-day observation of display use, completed with a questionnaire of a similar kind to the ones used in the company setting. This installation saw stable level of use from four users during the six months, an occasional use from one more sporadic bus traveler.

Figure 12: The bus display in an office setting (marked by white circle).

4.1.5 Principles & New Design

The lessons learned described above and the knowledge gained from studying the use of the bus display, now began to form *principles* for the design of ambient infovis. The last design example in the thesis, the *activity wallpaper*, addresses the important issue of working with information that is relevant to the prospective users. Another aspect that was in focus during the design was to work with information that maintains a strong connection to the place in which the display is situated, since our previous results had indicated that such a connection can strengthen the situatedness of the display, making it feel more as an electronic amplification or enhancement of the surroundings.

The visualization displays activity data, like in the previous examples *Exhibition Activity Monitor* from the exhibition at the Borås art museum and *Motion Painting*, from the SIGGRAPH exhibition. The visualization is inspired by wallpaper patterns and designed to be projected on a wall, so people spending time in the room can see a history of the activity in the room, reflected in the wallpaper pattern (see Figure 13).

The visualization also connects to fundamental mapping principles from information visualization in an attempt to adopt a reversed approach where the mapping is based on empirical results of how to map different data to the spatial layout and the retinal properties of the marks. The focus on aesthetics and integration is still retained with the influence of wallpaper patterns on the appearance of the visualization and color choices.

Figure 13: The Activity Wallpaper.

4.2 Discussion

In the previous section we have seen how the design examples maps onto Verplank's spiral, moving from the initial *hunch* to map information to artistic templates to the *hacks* that were the first examples of informative art. They were *tried out* at the Borås exhibition. The feedback helped the development of the *idea* of informative art, and the *designs* exhibited at SIGGRAPH. The *design* and *prototype* steps were iterated with the forecast composition and then the bus composition, and the latter was also the subject of a long-term user *test*.

This test and the aggregated knowledge from the earlier designed are summed up as *principles* for the design of ambient infovis that become manifest in the last example, the activity wallpaper, and that are further developed in this thesis.

The model is initially intended to describe the development of commercial products and for researchers, going further than the principles stage is hardly fruitful, although, as Holmquist remarks, some other part may pick up the thread and continue through the spiral.

In summary, the design examples and the evaluations describe the way from the initial hunch of combining information displays and art, to the concept of ambient information visualization. In the section below I will discuss the implications of the results presented in the papers.

5 Results

When designing ambient infovis the focus cannot be only on the input side of things, nor on polishing the output until it fits perfectly into a specific environment. The designer must take a holistic perspective from the very beginning and consider the interplay between the input and the output of the display and make sure that it is harmonious in order for the display to be regarded as an enjoyable part of the surroundings. Furthermore, a holistic perspective on the display itself is not enough: the holistic perspective must also be adopted on the display's role in the ongoing activities where it is situated. It can never become fully integrated in peoples' everyday lives unless it has the necessary properties that allow it to become *embodied* in the physical environment, as well as in peoples' lives and practices (Dourish, 1999).

The initial assumption, or hunch, to use Verplank's term, of this thesis was that the role of art as ornament or decoration in our everyday environments would be suitable for computational amplification, and this was also the reason for choosing the name *informative art*. The main motivation for the introduction of the term a*mbient information visualization* was to broaden the concept and not presuppose the use of an artistic template for the visualizations. Any developer of screen-based, peripheral information displays should be able to benefit from the findings. It was from these premises we arrived at the definition of ambient information visualization, given in section 2.3.1:

> *Use of visual representations of abstract data to enhance a physical location with digital information*

In the sections below, this definition will be scrutinized in the light of the results presented in the papers of this thesis.

5.1 Traditional Infovis vs. Ambient Infovis

The reference model for visualization described in (Card et al, 1999, p. 17; adapted here in Figure 1) describes how *Raw Data* is transformed into *Data Tables* which then are mapped to *Visual Structures*, which in turn can be presented in different *Views*. A central part of the model is the *Human Interaction* where the user can interact with the visualization to change any (depending on the visualization design) of the last three steps in order to ease the comprehension of the visualization.

With ambient infovis, however, the user cannot interact directly with the visualization, and thus has no way of manipulating the data or visual form, which means that how these parameters should change over time has to be defined ex-

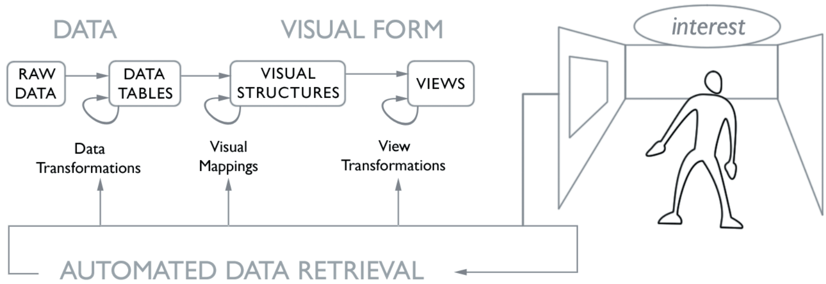

Figure 14: Reference Model for Ambient Information Visualization

plicitly by the designer. Furthermore, the use of ambient infovis is not necessarily task-driven but rather stems from an 'interest' in the information source. This is due to the fact that ambient infovis is not an application that is used as a tool to solve some task on a desktop computer, but rather a way of integrating information in the surroundings. To create a reference model for ambient infovis, these two parts of the infovis model will have to be changed.

5.1.1 Human Interaction vs. Automated Information Retrieval

Traditional infovis usually is a tool for looking at, and manipulating views of, a fixed data set, whereas ambient infovis is a means of presenting and overview of and providing awareness of dynamic changes in a data set or information source. This has fundamental implications for the design of the visualization and in the reference model for ambient infovis, seen in Figure 14, the 'human interaction' is replaced with a box labeled 'Automated Data Retrieval', indicating that any change in the appearance of the visualization is initiated by an automatic, iterative retrieval of data. How the data retrieval should be designed depends on several factors, like how often the information changes and how animated the final visualization should be (cf Lesson 2 from Paper III: *Rate of Change and Update Rate*).

5.1.2 Task-based vs. Interest-driven Use

In some instances it can be argued that ambient infovis is used as a tool; consider for example the Bus Composition, whose use can be quite tool-like. This kind of use is not inherent to the concept of ambient infovis, however, and if we consider examples like the Weather Composition or the Motion Painting, they serve more as enhancers of the users' awareness of some source of information, than as tools for some task. This "trait" of ambient infovis, acting first and foremost as awareness provider, led to the second change in the model; the change of from "task" to "interest" in the user's motivation for using the visualization in question.

5.2 Issues of Central Importance

There are some issues that, according to the results presented in the papers, stand out as being of vital importance in order for a visualization to fit the definition of ambient infovis. These issues concern *information source*, *mapping* and *use*.

5.2.1 Information Source

Issues regarding the information source are of obvious importance when designing ambient infovis. Not all information sources are suitable for this kind of presentation, for different reasons, as can be seen below.

Dynamics

In Paper IV, the importance of finding the "right" amount of dynamics for a visualization is stressed. A balance has to be struck between static and animation, where the visualization has to change often enough to be interesting but not so often that the display becomes distracting for people spending time around it. Finding an exact measure for what amount of dynamics is right is hard, or even impossible, since it is likely to change with the location of the display, the information source and the visual appearance of the display.

For example, the *Motion Painting* was running at a much higher update rate when displayed in an exhibition setting than what we found suitable for our lab, since the settings differed in terms of usage (one-time visitors at the exhibition vs. long-term regular users at the lab). Furthermore, the *Weather Forecast Composition*, was found to be too static, since the forecast information did not change more than a couple of times a day at most, which meant that the only thing in the visualization that was visibly changing during the day was information about the current weather.

Exact Information vs. Overview

One of the strengths of ambient infovis is that it can provide users with a quick overview of one or more, potentially quite complex, information sources. In Paper V, the most positive feature of the bus visualization turned out to be that the information was quick and effortless to read. The ability to convey information in an easily accessible way is an important step towards achieving the experiential cognition discussed in section 1.

Information Retrieval

How often the automatic information retrieval should be invoked depends on the dynamics of the information source. The visualization should retrieve data often enough to reveal any relevant changes in the information source. What constitutes a 'relevant change' in the information source depends, of course, on the source. In a less dynamic information source, that changes with intervals of a couple of minutes or more, all changes can be considered relevant. On the other hand, if the information source is highly dynamic as can be the case for the *Motion Painting* or *Activity Wallpaper*, may have to be toned down, in order for the visualization not to become overly animated.

5.2.2 Mapping

The mapping of information to graphical structures is crucial when designing ambient infovis. As noted in the introduction, the presentation should be such that it allows for experiential cognition. Even though quite complex tasks can become experiential given enough training, the mapping between information and visual form should ideally be simple and straightforward enough for the users to be able to remember it after a brief explanation.

Information and Aesthetics

Informative art had the explicit goal to work on two levels: first and foremost as information provider, but also as decorative element in the environment in which it is placed. To some extent this is true also for ambient infovis: even if the aesthetic aspect is toned down in the definition of the concept, the visualizations still will be placed in a certain architectural context, and the aesthetic appeal of the display is likely to affect how it is received by people spending time there. Except for the *Objective/Subjective Clock* and the *Exhibition Activity Monitor* all of the examples in this thesis use some kind of aesthetic inspiration for the visual design.

Graphical Properties of the Marks

In information visualization, much effort have been spent on finding suitable mappings between data and the graphical properties of the marks. Since the suitability of these mappings pertain to the human visual perception system, they hold true for ambient infovis as well even if it in some cases can be motivated to disregard the optimal mapping, e.g. in order to follow an artistic "template".

What should be in focus is that the resulting visualization is easy enough to read so that the most important information is available with a single glance at the visualization. The *Bus Traffic Composition*, for example, adheres to the infovis "rules" for mapping and maps the most important data in the hierarchy to the most powerful graphical property of the mark (cf Table 1): the *position* of the mark differentiates the buses, the *color* indicates the "catch status" for a bus and the *size* indicates the exact amount of time until the bus leaves (cf Card et al, 1999).

Graceful Degradation

Modern information technology has its limitations, and from time to time some link in the chain between the raw data and the user is likely to malfunction. As a designer of ambient infovis, it is important to acknowledge this, and design for these events. A visualization must have a way of indicating when it does not function properly, or users may lose their trust in the display (cf Paper V).

For example, should the visualization not be able to retrieve information from its source, this should be made visible in the appearance of the visualization. If it "freezes" and displays the last information that was in fact retrieved, or if it crashes all together, displaying error messages from the operating system, this is likely to affect the long term trust that users have in the display. For example, in Paper V, one user claimed to have lost trust and interest in the display after technical difficulties in the period following the installation of the display.

5.2.3 Use

In the beginning of this section I stressed the importance of adopting a holistic perspective on the design of ambient information visualization. Our studies of the use of the visualization show that there are aspects of the use that need to be considered during the early stages of the design process. These aspects include the interests of the prospective users, the size of the user group, and the placement of the display in the users' environment.

Relevance to Prospective Users

In order for people to want to use a display it has to display information that is relevant to them. For traditional infovis, or any desktop computer application for that matter, the designer can assume that the user have an interest in the information presented, or she would not have launched the application in the first place. Ambient infovis is placed in the users' environment and as designer, one cannot assume that everybody has an interest in the information. This has (at least) two major implications: firstly, not all information sources are suitable, and the designer should try and choose information that is relevant to as many users as possible in the location; and secondly, the visualization should be designed in a way that allows people who are not interested to ignore it; i.e. it should blend into the environment, and not alert the users attention.

The best way we have found to achieve this so far is to design displays that have a connection to the place in which they are placed, either by enhancing that place by making visible some, otherwise inaccessible, information (cf e-mail composition, activity wallpaper), or by relating information from that place with other places (weather composition).

Moreover, what information is relevant is something that is susceptible to change with the users' habits. Paper V describes how changes in the users' commuting habits had a big negative effect on the use of the bus visualization. The volatile nature of relevance is an issue that has to be acknowledged by designers of ambient displays if a stable level of use is desirable.

Placement & User Group Size

The study presented in Paper V, where the bus display is studied in different settings, shows that the placement of the display is crucial. If the visualization is not accessible to the user when she has a need for the information, she will not go out of her way to read the display, nor should she have to.

The study of the Bus Traffic Composition from Paper V shows that the visualization did not see much use in the university setting, mostly because of its placement in a semi-public area where people only occasionally spent time, and therefore did not have continuous access to the information. The same display saw significantly more use in the office and lab settings, where it was constantly accessible to a smaller group of users.

5.3 Summary

In this section I have presented what I believe to be the most important requirements for ambient infovis. A comparison with traditional infovis shows that moving visualizations off the desktop and removing the ability to directly manipulate and interact with the data set greatly affects how a visualization can be designed. The issues concern *Information Source*, *Mapping* and *Use*, which all affect the use and perception of a visualization in different ways, and hence must be regarded during the design process.

6 Conclusion

In this thesis, I have presented the design space of ambient information visualization, visualizations that are designed as a way of integrating information into everyday environments. The design space has been outlined in the intersection between the research fields of ubiquitous computing and information visualization.

The design space has been filled with a suite of design examples, whose design and evaluation have highlighted issues that are crucial to the successful design of ambient information visualization.

Our everyday environments are infinitely diverse and will thus all pose different constraints on how information presentations can be designed. A setting like a bedroom would call for extreme subtlety in the presentation whereas settings like Shinjuku, Times Square or The Strip mentioned in the introduction would require brute force and enormous size for the presentation not to drown in the surrounding noise. In between these extremes are settings that have other characteristics and peculiarities that have to be addressed by display designers. The issues of central importance presented in thesis should be general enough to be valid for the design of the vast majority of displays, and thus help to lay the foundation for a framework of ambient information visualization.

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