Between Aesthetics and Utility: Designing Ambient Information Visualizations

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Abstract

Unlike traditional information visualization, ambient information visualizations reside in the environment of the user rather than on the screen of a desktop computer. Currently, most dynamic information that is displayed in public places consists of text and numbers. We argue that information visualization can be employed to make such dynamic data more useful and appealing. However, visualizations intended for non-desktop spaces will have to both provide valuable information and present an attractive addition to the environment – they must strike a balance between aesthetical appeal and usefulness.

To explore this, we designed a real-time visualization of bus departure times and deployed it in a public space, with about 300 potential users. To make the presentation more visually appealing, we took inspiration from a modern abstract artist. The visualization was designed in two passes. First, we did a preliminary version that was presented to and discussed with prospective users. Based on their input, we did a final design. We discuss the lessons learned in designing this and previous ambient information visualizations, including how visual art can be used as a design constraint, and how the choice of information and the placement of the display affect the visualization.

CR Categories: B.4.2 [Input/Output and Data Communications] Input/Output Devices – Image display; H.5.1 [Information Interfaces and Presentations]: Multimedia Information Systems; H.5.1 [Information Interfaces and Presentations]: Evaluation / methodology – Screen design; I.3.8 [Computing Methodologies] Computer Graphics – Applications

Keywords: Ambient information visualization, informative art, ambient displays, calm technology

1 Introduction

Information visualization can augment human cognition in many ways, and has proved useful in professional application areas such as scientific visualization and business management. But what are the potentials of information visualization in everyday life? Could infovis techniques be used to support "mundane" activities, such as catching a bus or finding out what the weather will be tomorrow? There are many places where there is no immediate access to a computer, but where information visualization might be used to provide time-critical, localized, or otherwise important information. In this paper, we explore how ambient information visualization can take infovis out of the desktop computer screen and into the real world.

Figure 1: An example of ambient information visualization: a visualization of bus departure times, inspired by the artist Piet Mondrian

Designing information visualizations for off-the-desktop use is different from designing for other electronic media, such as interactive software or web sites. One cannot simply put up a computer screen in a living room or a train station and run some standard visualization software. First of all, we cannot expect potential users to be immediately familiar with the visualization techniques involved. Thus, even more than with ordinary information visualization, it will be necessary to carefully design the mappings in the visualization so that they can be grasped quickly and are easy to read, even from a distance. Second,ly aesthetic concerns become a major issue when a visualization is integrated with a larger environment. It will be necessary to design visualizations that not only provide useful information efficiently, but also blend in with the surroundings and are appealing to look at. Furthermore, ambient infovis should contain only a minimum of animation, since the human eye has a tendency to automatically be drawn to moving images, which could prove to be a major distraction [Sekuler and Blake 1994]. These two conflicting concerns – aesthetics and utility – must be reconciled to create truly useful ambient information visualizations.

In previous work, we have been drawing inspiration from famous artists when designing information visualization, creating so-called *informative art* [Redström et al. 2000, Holmquist & Skog 2003]. By basing our visualizations on well-known artistic styles, we hope to create ambient information visualizations that literally look "good enough to hang on the wall", while still providing useful information. In this paper we will describe the iterative design of our most recent example, a dynamic visualization of bus departure information inspired by the Dutch artist Piet Mondrian. The visualization was designed in collaboration with prospective users and deployed at a local university (see Figure 1). Based on this experience, we outline important criteria for the successful design of ambient information visualizations, and how their design relates to that of traditional infovis applications.

2 Ambient Information Visualization

Information visualization is commonly defined as "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition" [Card et al. 1999, p. 7]. By *ambient informa-*

tion visualization, we mean information visualization applications that do not reside on the screen of a desktop computer, but in the environment or periphery of the user. Using ambient information visualization, dynamically updated data sources can be presented in new environments, where a traditional computer display may not be suitable.

Using the physical environment to present information has been explored previously, in particular in *ambient media* [Ishii et al, 1997]. In ambient media, information displays are designed to present information in the periphery of the user's attention. For example, the authors introduced a lamp that uses different intensity to indicate variations in an information source. Closely related to this is the term *calm technology*, which was coined to define technology that moves between the periphery and the centre of the user's attention [Weiser and Brown, 1995]. When correctly designed, calm technology should become a natural part of the user's everyday surroundings. An example of calm technology was the *dangling string*, an installation where a hanging piece of wire would shake more or less depending on the traffic in the local network.

Many ambient displays have been based on physical constructions, but this puts limitations on the flexibility of the display and the complexity of the information that can be shown. A natural choice would therefore be to use computer graphics for ambient displays, but the cost, size and capabilities of computer screens has been a hindering factor. However, display technologies are rapidly advancing and becoming more affordable, and therefore it should soon be possible to hang a high-resolution display on a wall as if it was a poster or a painting. In the future, technologies such as electronic ink and color-changing textiles may make it possible to display computer graphics on almost any surface, even wallpapers or curtains [Jacobson et al. 1997, Holmquist and Melin 2001].

Several peripheral displays using computer graphics have been presented recently. A common approach seems to be to take information from traditional wall-hung art to inform the design and use of such displays. *InfoCanvas* are specialized computer displays that provide awareness of some source of information using images, creating a form of "virtual paintings" [Miller and Stasko 2002]. *Information collages* are automatically generated, aesthetic collages in the style of certain artists that reflect dynamic information [Fogarty et al. 2001]. *Digital family portraits* mimic the appearance and function of a picture frame, placing updated information about the health of an elderly family member in the border of the photo [Mynatt et al. 2000]. Our own related work in informative art will be further discussed in section 3.

Ambient information visualizations present new challenges to the application of established infovis techniques and evaluation methods. For example, an important criterion for information visualization in science and technology is *display effectiveness*, where time, accuracy and cognitive workload are measured [Nowell 1997]. Such a measure of effectiveness is relevant when applied to systems that are designed to perform work-related tasks. Ambient information visualizations, on the other hand, will be *lived with* rather than used, which means that traditional measures of effectiveness may not necessarily be the most relevant [Hallnäs and Redström 2002]. More specifically this suggests that factors such as calmness and appearance might be just as important issues for an everyday application as effectiveness is for professional tasks. This in turn means that new evaluation criteria, based on long-term usage studies rather than lab experiments, may need to be developed.

3 Informative Art

Informative art is a subset of ambient information visualization, in that it is situated in an everyday environment rather than on a computer screen. In the design of informative art we were inspired by the appearance and function of paintings, posters and other objects that people use to decorate their living spaces [Redström et al. 2000]. Previously, we have created several examples of informative art, inspired by artists ranging from Andy Warhol's pop-art, Bridget Riley's op-art and Richard Long's landscape art [Holmquist and Skog 2003]. Data sources that were visualized included the passage of time, the movements of people in a room, and world-wide earthquake activity.

The most fruitful template for informative art so far has proved to be the Dutch artist Piet Mondrian, who did a number of recognizable works in an artistic movement called "De Stijl" (literally, "the style"). In the section below we will describe three previous generations of informative art, all inspired by Mondrian.

3.1 Previous Mondrian Designs

Within De Stijl, Mondrian created a characteristic and immediately recognizable style of painting. His most famous compositions consisted of arrangements of colored fields and black lines over a white background. In these works, he used only three primary colors, namely red, yellow and blue. This style is immediately recognizable, and its surface characteristics are easily reproduced with computer algorithms (in fact, some of the earliest experiments in computer graphics-based art mimicked some of Mondrian's black and white compositions [Noll 1995]).

We found the characteristic look of Mondrian's compositions to be a good basis for an abstract information visualization. The use of three easily distinguishable colors together with geometrical shapes seemed ideal for our purposes. We have so far used Mondrian's style to visualize dynamic data concerning e-mail traffic, current weather, weather forecasts, and most recently bus departure times. Typically, data has been mapped to the size, position, and color of the fields in a composition, giving us three possible dimensions to use for visualization, although not all were used in all examples.

3.1.1 E-mail

The first example of informative art can be seen in Figure 2. It is a dynamic display of e-mail traffic, designed to be situated in an office [Redström et al. 2000]. Each of the colored fields in the visualization represents the e-mail traffic for one person. The size of a field is mapped to the amount of e-mail sent and received by that person during the last 24 hours. The *color* of the fields carries no information, but is randomly appointed at start-up. Every field has the same *position* every time, so by time it may be possible to differentiate between the different persons in the office. However, in this case we were more concerned with the overall impression of activity in an office, rather than that of individual users, which is why there is no immediate way of determining which field represents which person.

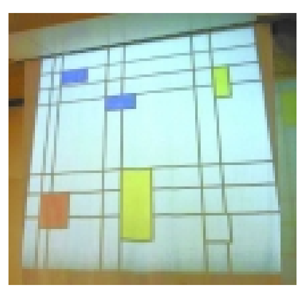

Figure 2: A Mondrian-inspired visualization of e-mail traffic.

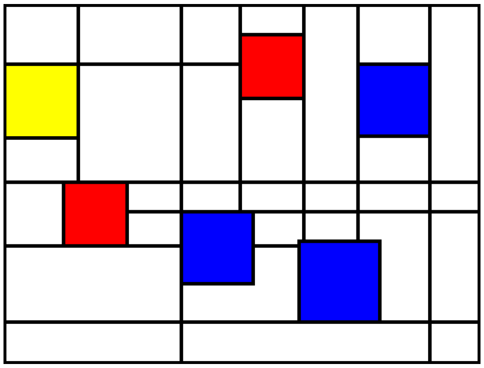

Figure 3: A visualization of the current weather in six cities around the world

3.1.2 World Weather

A second example of a Mondrian-inspired visualization was one of four pieces exhibited at the Emerging Technologies section of SIGGRAPH 2001 [Skog et al. 2001]. Here, we displayed current weather information for six cities around the world, which was taken in real-time from a web page. Each city is represented by a colored square, whose *size* is mapped to the current temperature in the city. The higher the temperature is, the larger square gets. The *color* of the square is mapped to weather conditions, where *yellow* means sunny or clear, *blue* means downfall, i.e. rain or snow, and *red* means overcast.

The distribution of the squares is loosely based on a world map metaphor. Each square's *position* in the visualization roughly corresponds to that city's placement on a world map, with Europe in the center. The cities shown here are, in the top row, from left to right: Los Angeles, Gothenburg (in Sweden) and Tokyo. The bottom row shows Rio de Janeiro, Cape Town and Sydney. This mapping turned out to be quite easy to learn for visitors at the exhibition, and we felt that the visualization gives a good overall view of the weather situation in the selected cities.

3.1.3 Local Weather Forecast

This visualization is an altered version of the one described in section 3.1.2. This visualization was adapted to show a weather forecast for the local Gothenburg region, taken from a web page [Skog et al. 2002]. Each square represents the weather of one day. The *size* and *color* are mapped to temperature and weather respectively, as in the example above. The *position*, however, does no longer give geographical information, but indicates what day the weather forecast is for. The left-most square in the upper row shows the current weather condition and the right-most shows the forecast for the next day. The forecast for the following three days is shown, from left to right, by the squares in the bottom row.

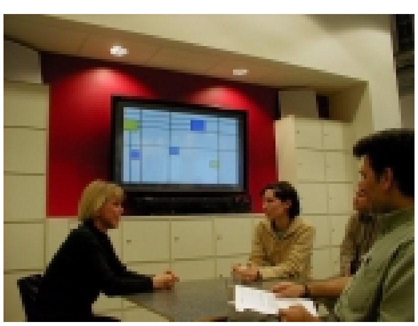

Figure 4: Informative Art visualization of a local weather forecast, running in a university setting

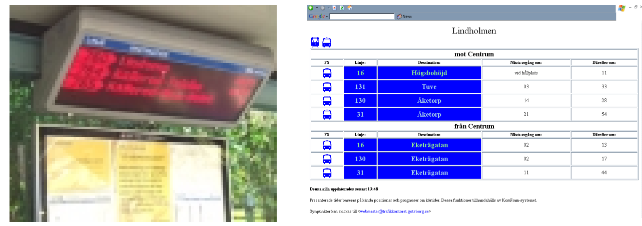

Figure 5: LED-display showing bus & tram traffic information (left), and the same information displayed on a web page (right).

This prototype was installed for evaluation purposes on a large plasma screen at a university in Gothenburg (Figure 4). We first asked students what sources of information would be interesting to have visualized by informative art, and weather information was one of the most common suggestions. The visualization was then created and we had it running at the university for an evaluation period of one week. We found that students were able to learn to use the visualization after a brief introduction, but we also identified several problematic issues in the design. For more information, see [Ljungblad et al. 2003].

4 Designing an Ambient Information Visualization of Bus Departure Times

During the design of the weather forecast visualization (above), another of the most frequently requested data sets was public transportation information. At the time, there was no source providing reliable data of this kind. Timetables could have been used, but since a timetable does not provide actual real-time data, and since the buses to and from the university often were delayed due to passenger overload, we decided not to use this data for the visualization.

In early 2003, however, the local transit authority started providing a new web-based service keeping track of buses and trams in the public transportation network. This service uses the transit authority's sensor system, installed to keep track of buses and trams in the city. This information is available for commuters at larger bus stops, in the form of large text-based LED-displays, indicating how many minutes remain before the next bus or tram arrives (see Figure 5). The web site has a page for each bus/tram stop in the network. In turn, each page contains traffic information for all bus/tram lines trafficking that stop, showing when the next two buses/trams are due to arrive at that stop.

When this information was made available on the web page (Figure 5) we saw this as an excellent opportunity to create a new visualization for the students at the university. Almost at the same time, a new bus line was added (line 16), connecting the university and the central parts of the city. Many of the students have started to depend on this particular bus for their commute to and from the university. With over 300 students and teachers regularly spending time in two main open areas, we considered the departure times of this bus line to be a suitable source of information to visualize in this space.

4.1 Preliminary Visualization

We created a visualization that shows the departure times of the buses on line 16, two in each direction. Several ambient displays of local transport data have previously been presented, e.g. in the form of a hand-held display that the user could bring along while going to the tram stop [Lunde and Larsen 2001] or a physical "mobile" where numerical indicators attached to strings would move up and down to show bus departure times [Mankoff et al. 2003]. For our visualization, we again chose to use Mondrian as inspiration to create an informative art installation.

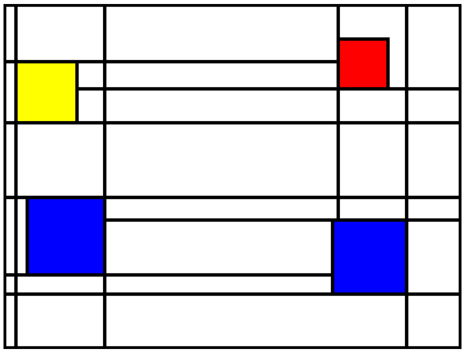

Figure 6: Preliminary visualization of bus traffic

We let each bus be represented by a colored square. The size of the square shows the amount of time before the bus leaves the university bus stop, so that the less time remains, the smaller the square is. The *color* is used to shows intervals of time it would take to catch the bus from the position of the display. The timing used for these mapping were based on our own experiments of walking from the university to the station. Again we mapped information to Mondrian's three primary colors, where:

- *Blue* means you have plenty of time before the bus leaves.
- *Yellow* means it is time to pack your stuff and start walking to the bus stop.
- *Red* means you're in a hurry. You may have to run to catch the bus.

We used the *position* of each square to indicate where the bus is headed. The squares are laid out so that the two squares on the right hand side represent buses traveling *towards* the city center whereas the squares on the left hand side represents buses traveling *from* the city center.

4.2 Feedback from Users

In order to get feedback on the preliminary visualization we interviewed three groups of students (a total of eight studets; five male, and four female) who all used the bus for their commute to the university. We ran the visualization on a laptop, using real, online data. The use of size and colors to indicate departure times seemed intuitive and the students understood it quickly. They also seemed enthusiastic about having this type of visualization available. They were aware of the web page containing the same information, but rarely used it.

The students helped us identify a number of problems with the proposed visualization. The most important issues were:

- *Direction*: The students found it hard to identify what buses were traveling in which direction. It seemed our use of position to indicate direction was not intuitive.
- *Connection to the physical world:* During the interviews, we noted that the students used the visualization as an abstract map of the bus stop, in order to make some sense of which bus was heading in which direction. They asked on what wall the display would be situated, using the physical surroundings as a point of reference. Since we had not taken this into consideration when designing the visualization, the readings turned out to be ambiguous and arbitrary.
- *End stop*: During rush hour traffic, an extra bus is used to offload the regular bus service. This extra bus runs as a shuttle between the university and the central station. Students traveling past the central station stop wanted a way to differentiate the two lines, so that they did not risk ending up on the wrong bus.
- *Relevance*: Two of the students pointed out that there was no need to show buses that when it is too late to catch them.

4.3 Redesigning the Visualization

Based on the input from the students, we chose to change the visualization in a number of ways. The resulting final visualization can be seen in Figure 7.

We chose to adapt the map-like connection to the physical world suggested by how the students tried to read the preliminary visualization. In the redesigned version, we added a blue line in the right hand side of image, to represent the river running through Gothenburg. The area to the left of the blue line acts as an abstract map of the bus stop. The two squares on the left now represent the buses traveling *from* the city center and the ones on the right represent buses traveling *to* the city center. In contrast to the first version, the squares are also arranged vertically according to the direction of the bus, so that for the squares on the left the, closest bus is represented by the square at the bottom, whereas the reverse is true for the right-hand side. The resulting visualization was intended to give a more intuitive impression of buses running in both directions along the river.

Furthermore, in order to differentiate the rush hour extra buses from the regular buses, we decided to add a black line, indicating the final destination of the buses traveling towards the city center.

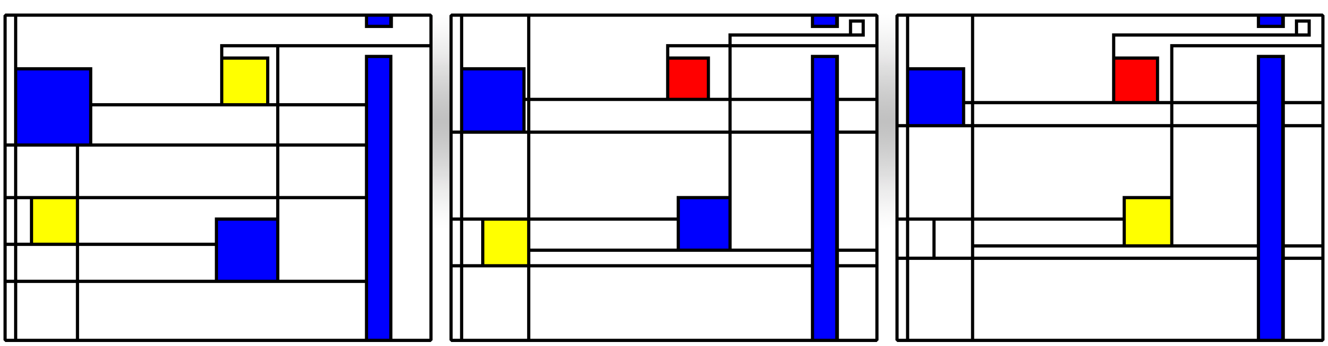

Figure 7: Three screen-shots (*A*,*B* & *C*) from the revised version of the bus traffic visualization. *A* shows the "regular" mode, where both buses heading towards the city centre (the two squares on the right) have the same final destination. *B* & *C* shows the visualization when one of these two squares represent a shuttle bus, which runs between the university area and the central station (represented by the small white square in the upper right corner).

As can be seen in figure 7, the bottom square has a line that starts in the upper right corner, and ends up in a small white square that represents the central station. The top square has a line that starts in the upper left corner and that ends up at the edge of the screen, indicating that it continues past the central station bus stop. None of the remaining lines in the visualization carry any information.

In order to deal with the problem with the visualization showing buses that it is too late to catch, we decided to represent such buses with white squares. This means that the squares are still there, but they are less visible than squares of other colors. The reason for not removing squares representing these buses altogether was that it would be too disruptive to the visualization as a whole.

A final modification was introduced soon after we started running the visualization at the university. The database server running the application at the transit authority turned out to have a lot of down time, and we realized that we had to add some kind of mechanism to indicate breakdowns. We did this by changing all the squares' colors to black whenever the server went down. The black squares would then indicate that there was no reliable data available for the application.

5 Preliminary Evaluation

The visualization of bus departure times is currently running at the university, on a plasma screens in a public area close to the main exit (as seen in Figure 1). The over 300 teachers and students at this department of the University will pass the display every day. Our plan is to let the application run for an extended period of time, to get long-term usage data. When we did our first study, it had been installed for 15 days, but effectively running only for about 10 days, due to server breakdown at the public transportation network and other technical problems.

There have been comparatively few evaluations performed of ambient displays in use, although some heuristics have been developed to influence the design of such displays [Mankoff et al. 2003]. We believe that it is difficult to capture the value of an ambient information visualization using traditional usability measures, and in particular that they have to be studied *in situ* and in actual use rather than in a lab environment. Therefore our approach has been to conduct on-site interviews to see if and how the visualization is taken up and used by the people in the area. We have tried to provide open-ended ways for people to use the visualization, so that the usage is *natural* rather than forced for the sake of evaluation. The authors themselves do not belong to this department of the university and are not regular visitors to the area where the display is installed, and should thus have minimal influence on the use of the visualization.

When we first set up the visualization, a caption with instructions for how to interpret the information was placed next to the screen. Unlike for our previous evaluation (the weather forecast, above),

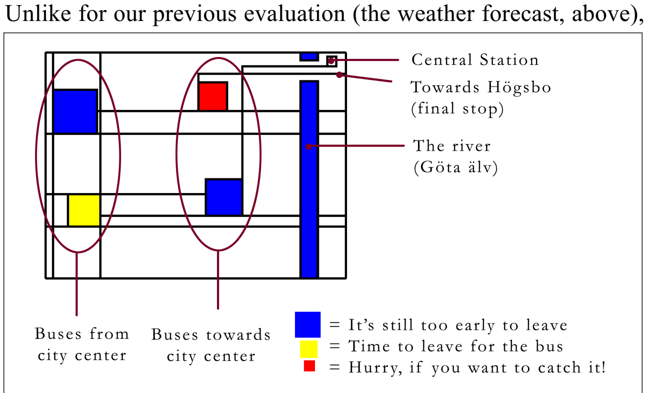

Figure 8: The caption placed next to the screen.

we did not arrange any public presentations. Instead, about 30 handouts with instructions were placed on a shelf immediately beside the display. Furthermore, the IT University added a news item on their homepage about informative art which included instruction on how to read the visualization. Thus, while noone was directly instructed or asked to use the display, information on how to use it was readily available for those who wished to do so.

We conducted our interviews during the afternoon on an ordinary weekday. Seven people were asked for an interview, when passing by or staying in the area of the display, three men and four women. Out of these, one woman was not interviewed, since she only made sporadic visits to the University. We wanted to involve only those who were constantly spending time in the area.

5.1 Results

5.1.1 Comprehension

When trying to assess the comprehension of our ambient information visualization, we used the broad framework of a three-step scale, where each step is a pre-requisite for the next:

- *That* something is visualized – does the subject know that the display is an information visualization and not simply decoration?
- *What* is visualized – can the subject tell us what data the visualization reflects?
- *How* the data is visualized – can the subject read and interpret the visualization correctly?

Only when reaching the third step does a person have enough understanding to actually *use* an ambient information visualization.

Out of the six persons who were interviewed, one person did not know *that* some data was visualized on the display. This person did not travel with the bus line in question. The reminding five people knew *that* the display visualized dynamic data, and also *what* was visualized, i.e. departure times for bus line 16. All of these five subjects traveled with this line with some regularity.

Two people knew *what* was visualized, but did not know *how* to read it. However, both of them could explain that the colors on the "buses" represented something like "hurry", "leave now" and "there is time left". One of the two pointed out one square and suggested that it represented a bus that probably went to the town, which was correct. Therefore, although they did not have sufficient understanding for practical use of the visualization, they had still picked up some of the essentials.

Out of the five, three people knew *how* to read the visualization. One of the three first claimed that she was unable to read it, but in fact, when asked to explain the visualization, she could read it correctly.

5.1.2 Use

Two of the three persons that knew *how* read the visualization, had also used it to catch the bus. One of them had used it three times and the other once. Both of them said that they planned to continue using the display, providing it would continue to provide reliable information. One of them commented that it was great to get "information at a glance" and that it was particularly good in this place.

The person who could read the visualization, even though she thought that she could not, said that she was on her way to use it once. At the time she did not have the "energy" to get herself into it, and because she already had her outdoor clothes on, she simply left for the bus instead. She said that she would like to use the display, mainly if she was going home. If she was planning to con-

Visualization	Scope	Rate of Change	Display Update
E-mail	office	variable	once/minute
World Weather	world wide	hours	once/minute
Local Weather Forecast	city	days	once/minute
Bus Traffic	nearest bus stop	~every 30 seconds	every 15 seconds
Bus Traffic revised	nearest bus stop	~every 30 seconds	every 15 seconds

Table 1: Overview of the information sources used for our examples

tinue the trip, she would rather use the website provided by the public transportation, where more detailed information could be found.

The two people who knew *what* was visualized, but did not know *how* to read it, believed that they would not use the display in the future. Both of them usually did not look at any timetables, unless they were staying late, something they had not been doing lately. One of them preferred more exact, number-based information, and suggested that people might need different amount of time to get to the bus, which he thought the current visualization did not support.

6 Designing Ambient Information Visualizations: Lessons Learned

In this section we will briefly discuss some of the lessons we have learned from designing several generations of ambient information visualizations. A summary of the development and features of our Mondrian-inspired informative art can be seen in Table 1 and Table 2.

6.1 Table 1: Information Source

The choice of what information to visualize is obviously important when designing ambient information visualizations, as it would be in any infovis application. But unlike ordinary infovis, where users can be expected to actively seek information, ambient information visualization *provides* users with this information in their everyday environment – whether they ask for it or not. This means that whereas we can rely on users of desktop infovis applications to actively work with an application, and to be prepared to give it their full attention for some amount of time, this is not always the case for ambient infovis applications. In particular we found that information used in ambient infovis has to have a relevant scope and a suitable rate of change.

6.1.1 Information Scope and Relevance to Users

The scope of the information used in our examples of informative art range from covering an office (e-mail traffic visualization), to encompassing the entire world in (world weather visualization). The bus visualization, which spans a local bus stop, was somewhere in between: it goes outside the user's immediate surroundings, yet it concerns something that potential users are very likely to be familiar with. We feel that ambient information visualizations must be designed so that the scope of the information is clearly linked to the placement and possible users of the display.

World weather has relevance to *users* from all over the globe (or at the very least in the six cities being visualized). This made it suitable in an exhibition situation, were visitors were likely to come from many different countries. The e-mail example, on the other hand, was really only relevant to the people working in the particular group whose e-mail was being visualized. Both of these examples therefore worked well as illustrations of the concept of ambient infovis, but neither was compelling enough for it to see continued real-world use.

The bus visualization, on the other hand, is relevant to a *place*, in this case the area around the university bus stop. This means that all visitors to the place where the visualization was situated were potential users of the display. To a similar extent this was true for the weather forecast, which was relevant to the local city area. But the bus visualization has proven to be by far the most compelling of our designs so far, which is probably related to the fact that it also helps in carrying out a certain activity (catching the bus) which is not so much the case for the weather visualization.

Lesson 1: By finding information that is relevant to the place where the ambient display is located, every person spending time at that place becomes a potential user.

6.1.2 Rate of Change and Update Rate

All our ambient infovis examples have been based on dynamic data, but update rates have varied. We found that the selected information source should have a suitable rate of change – so that on the one hand, the display changes often enough that users perceive it to be dynamic, but on the other hand, not so often that it becomes a source of distraction.

On the worldwide weather display, even though the update was based on real-time weather data, hours could pass between perceivable changes. The weather forecast could be perceived as static, since it only changed a few times per day, when the new forecast became available. People would thus sometimes believe that the visualization was "broken", since there was no perceivable change. Also, because of the low rate of change, there was no "urgency" to the information, and in the case of the weather fore-

Visualization	Size	Color	Position	Geographical Metaphor
E-mail	amount of e-mail	-	-	-
World Weather	temperature	weather condition	location of city	world map
Local Weather Forecast	temperature	weather condition	day of week	-
Bus Traffic	time until bus leaves	time intervals	direction of bus	-
Bus Traffic revised	time until bus leaves	time intervals + breakdowns	direction of bus	city landmarks + bus stop

Table 2: Overview of the visual encodings used in our examples

cast it was actually sufficient to look at it once per day to get all information it had to offer.

The bus visualization, on the other hand, was based on real-time data that changes quite often. Furthermore it provides time-critical information that directly helps the users with an everyday activity. However, since the buses run very frequently during the daytime, many users would simply not bother checking when a bus was due – they would just go to the bus stop, expecting a bus to come. This situation changes during the evening and our impression is that the visualization will see more use when the buses are less frequent.

Although the rate of change in the information source is something that cannot be changed, the update rate of the display is under the control of the developer. Our experience indicates that it would be fruitful to include some minimal amount of animation to the display of data that changes with a low frequency, to make the users aware that the application has not frozen. This might have promoted the impression that the weather displays were showing real-time dynamic data. On the other hand, for information that has a very high rate of change, e.g. a stock market index, it can be necessary to slow down the update rate so that the viewer is not distracted by continuous fluctuations in the visualization.

Lesson 2: The rate of change in the information should be frequent enough to promote relevance, but the developer can affect the visual appearance by slowing down the changes or adding a small amount of animation.

6.2 Table 2: Visual Encoding

When designing informative art, it may be necessary to make trade-offs between the aesthetical template and the visual encoding. There is no question that in some sense, adhering to a visual template that has been determined without concern to the information that is to be visualized can be restrictive. At the same time, this approach has the advantage of making the designer of the visualization "see through the eyes of an artist", which might be a good way for even a person with little visual design training construct a visualization that has aesthetic appeal. In our experience, using an artistic template does not necessary make the visualization less *useful*.

6.2.1 Using an Artistic Template to Visualize Information

As can be seen from the table we have been able to visualize a quite diverse data set using the style provided by Mondrian. In practically all of these examples we have used a mapping from some quantitative data to the size of colored fields. This mapping has worked quite well, even though it is not ideal for temperature, since the centigrade value for the freezing point is zero, and there is no simple way of making the area of a square indicate a negative value.

Nowell [1997] suggest that no more than five or six colors should be used in coding a display and that color-coding should only be used for the information that is most directly relevant. We used the three primary colors that are a characteristic of Mondrian's compositions as important information carriers in our visualizations. The colors were used to indicate discrete data classes, such as types of weather conditions and, in the latest example, specified time intervals. This has worked quite well, although occasional users expressed a dissonance between their own associations to colors and our mapping (e.g. in our weather visualization blue means "rain" whereas many users associated it with "blue skies" [Ljungblad et al. 2003]).

But most interestingly, a side-effect of using Mondrian as a template has been that all our examples use bold and easy-to-read encodings to visualize a limited amount of information. We have been forced to carefully design the mappings to fit with the limited template. This has led to simplified visualizations, which once learned can be read very quickly, and at some distance from the display, even in busy environments. This might not have been the case if we had started from scratch, and without the visual template we could have been tempted to cram too much information into the display.

Lesson 3: Basing a visualization on an artistic style need not hinder – and might even support – the readability and comprehension of an ambient infovis installation.

6.2.2 Using the Spatial Layout as a Mnemonic

In our Mondrian examples we have used different strategies for the spatial layout of the colored squares. The arbitrary spatial mappings used in the e-mail and local weather forecast visualizations (described in section 3.1.1 and 3.1.3, respectively) tended to be harder to remember than the ones where we used a geographical metaphor as a basis for the spatial layout of the graphical components.

The first example that used a geographical mapping was the world weather visualization described in section 3.1.2. Although no visual cues to the mapping were given, we found that the spatial mapping in that example was of great assistance for viewers to help them remember the mapping. The users would of course need to learn which six cities were represented, but once this had been done it worked both ways, since the visualization also act as a mnemonic to indicate in which areas of the world the cities were located.

The latest example, where we let actual geographical landmarks be represented in the visualization, has rendered the best results so far. With the representation of the river as a point of reference, the viewers could easily derive which bus was which. The visualization became a sort of abstract map of the bus stop, without breaking the adherence to the visual style of Mondrian. This builds somewhat on lesson 1, where we found the relationship to a specific place to be useful.

Lesson 4: Letting features of the information source affect the visual encoding, thus providing a mnemonic to remember the mapping, is a good way to support the comprehension of the display.

7 Conclusions and Future Work

In information visualization, aesthetics can almost be considered an added bonus, or at least a bi-product when striving for readability and effectiveness. In ambient information visualization, on the other hand, aesthetics is considered a primary property, both in the design and during use. When designing ambient infovis, it may even be necessary to go against established infovis guidelines in order to adhere to an artistic template. For instance, the bus visualization is not entirely consistent in its coding, since the representation of the river has the same blue color as the squares representing buses. Additionally, some of the black lines carry information, whereas others do not. However, we did not find this inconsistency to be a problem in our user studies, and the design was still considered intuitive.

Graceful degradation is an important issue for ambient information displays. Since an ambient information visualization is usually not interactive, it is crucial that applications have a way of indicating when they are not functioning, or have trouble retrieving data, so that users can rely on the display as a source of accurate information. In our bus example we let black squares indicate that the server was down, and that no reliable data was available. It is particularly worth noting that this consisted a noticeable break with the artistic template, something that should make it easier for users to conclude that something is wrong with the application.

It is also important to make the most crucial information available at a glance. The bus visualization uses redundant coding – both color and size – to represent time to departure. From our preliminary study it seems that people tend to use the color, rather than size, to determine the time to departure. One reason for this might be that color is said to yield faster result than e.g. shape, when used redundantly with other encodings [Nowell, 1997]. The size of the squares, on the other hand, in principle gives a more exact indication, but in practice, it is very difficult to translate the visual size into an accurate measure of departure times. In forthcoming studies it will be interesting to see if people will be able to use the size of the squares to better estimate time, and thus getting a more precise reading of the display.

Our ambient information visualization of bus departure times is currently running at the university, and we plan to conduct a long-term study of the uptake and use of this application. We are concerned with issues such as how the understanding of the display changes over time, and how it takes its place in everyday life. One measure would be to determine how likely knowledge of the interpretation is to be lost over time – i.e., once a person has gone "up" a step on our three-step scale (*that – what – how*) how likely is she to go "back" and forget this knowledge? The design of the mappings must be intuitive to be both easy to learn and easy to remember, and this will probably have a noticeable effect on the uptake and comprehension of the visualization. Therefore, it would be interesting to study and contrast the use of two different ambient information visualizations that show the same data but use different mappings and artistic styles.

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