Perifoveal Display: Combining Foveal and Peripheral Vision in one Visualization

Figure 1: A user is standing in front of the Perifoveal Display. Two depth cameras track the user's head direction. At the focal point more detailed information is shown. The data becomes increasingly abstracted the further away it is from the user’s focus. In the periphery changes in brightness and movement indicate changes in the data perceivable by the user’s peripheral vision.

ABSTRACT
The Perifoveal Display (see Figure 1) is a visualization display for complex, real-time, dynamic data such as stock market data, traffic or control room as well as virtual 3D environments. The system takes advantage of the unique properties of the human perceptive system which is capable of perceiving a high degree of detail in the foveal area, but has a unique more subliminal type of perception of movement and brightness in the peripheral area. The Perifoveal Display varies how data is visualized based on the user’s viewing direction. Data in the center of the user’s focus is displayed in a lot of detail. Important data changes, which fall into the periphery are highlighted by movement and change in brightness as well as amount of detail and size. The results of our user study showed that the system is able to support the user while observing complex data.

INTRODUCTION
In today’s information age an increasing number of jobs as well as many consumer activities require that a user keeps track of massive quantities of dynamic data. Machines are able to process information at a much faster rate and visualize this information on huge high resolutions screens. The information on those screens is typically presented with Graphical User Interfaces (GUI) that have been invented for small screens. At this point in time, people and their limited perceptual system are the bottleneck when it comes to processing all this information.

Figure 2: Only about 6° of our vision system represent the focus. In this foveal area we can read text with an update rate at around 4 Hz. 180° of our vision system falls into the periphery where we can see sudden movements with up to 90 Hz [1].
To address this issue we propose to create interfaces that take the unique strengths and limitations of the human perception system into account.

The human eye has a relative small focus area – the foveal vision – and a huge range of out of focus space – the peripheral vision. Within the line of sight – the focus – we can see complex shapes, sharp contours, colors, and we can read text. This focus area is only about 6º of our 180º vision system (see Figure 2). Images that fall into the periphery are processed in such a way that we do react in response to sudden changes and fast movements. This helps us to consciously perceive much more information than we are able to focus on (e.g. Figure 3). If something is moving in our peripheral area it results in subliminal tension, almost forcing us to look in that direction to decode using our focused vision what it is. This human instinct could help people monitor and operate huge real-time data visualizations. A user interface built on top of this instinctive behavior could help humans keep track of important changes in large data visualizations.

Modern GUIs do not take this feature of our peripheral vision into account. GUIs are designed for small computer screens where a user can sit in front of the screen and does not need have problems with choosing an area to focus on, since each point on the screen can easily be reached with simple eye movements. Each area on the screen has the same visual complexity and consists of detailed images and text. Traditional GUIs are intended for usage scenarios in which the user actively chooses where to look.

In scenarios where the user does not previously know what to look at and has to monitor a real-time visualization of complex data such as stock markets, industrial plants, hospital patients, network traffic, street traffic or air traffic the traditional GUI needs to be reconsidered. In such systems traditional GUIs tend to produce information overload or put the user under a lot of pressure not to miss any important event, which finally can end in human failure [2]. The motivation for exploring the Perifoveal Display is in order to help them react more efficiently to sensitive data changes.

**RELATED WORK**

In monitoring professions people are frequently using multiple displays to visualize all the relevant data. But in other fields the trend is to enlarge displays as well. Researchers have explored many different ways in which larger sized displays could increase productivity. For a digital brainstorming tool Guimbretière et al [3] have tested pen-based interactions on a large high-resolution display. In a study to test why larger displays increase productivity on large-scale visualization tasks Ball and North [4] separated peripheral vision and navigation and found that physical navigation leaded to improved productivity.

The way our vision systems works is that certain ambient stimuli provoke our attention. The peripheral vision is not simply a reduction of information; it is a complex vision system that helps us perceive the surrounding world. A study determining face perception [5] shows that human faces pop out in contrast to schematic or animal faces. Once a stimulus in our peripheral vision has provoked our attention, it is important to show the provoking information at the spot where the ambient stimulus has happened, since this represents the natural behavior of our vision system.

Our vision system supports two different ways of seeing the world: one lets us see visual complex content in the foveal area while the peripheral vision leads our attention instinctively to movement and brightness changes outside the foveal point. From this perspective there are many works that explore the possibilities of using the full range of vision by creating Focus Plus Context Screens [6] or combining hand-held and wall-sized displays [7]. But there is more to the peripheral vision, than creating a bigger space. The peripheral vision system is our emergency system, it reacts to fast motion or motion that has rapid changing patterns and there are explorations to understand what this behavior can mean for the Computer GUI [8], or how this behavior can be used in combination with multi resolution displays [9] or with head-up displays [10]. The biggest problem however is to avoid visual noise with systems that support the user without distracting him. There are systems such as the AmbientRoom [11] that address the visual noise problem with ambient displays, but these systems work as ambient display only and do not change their content to complex information, once they become the focus of attention after the peripheral vision system has successfully drawn our attention to the display. The Perifoveal Display changes the content dynamically related to the users head position from an ambient display in to the expected complex information. It addresses the described problems.
**USAGE SCENARIOS**

In general the Perifoveal Display system can be used in situations where an operator needs to monitor a large amount of data. Data of such magnitude that it cannot be perceived with a traditional GUI at once. The peripheral vision needs to be addressed in the right way, so that the user can perceive a maximum amount of information with little mental effort to keep the reaction performance and concentration at a high level. The subliminal instinct that is triggered with the Perifoveal Display can be used in many scenarios. We will discuss three different usage scenarios in more detail.

**Stock market:** In the stock market usecase, one needs to keep track of a lot of numbers on many screens placed around the user. In order not to loose track of major changes, one has to move the head around and look at all the numbers nearly simultaneously in order to generate a mental model of the market. With the Perifoveal Display a user can determine beforehand what kind of changes are relevant for his task and can therefore get individualized highlights. To prevent too high losses he could set the loss threshold at a certain percentage and would get warned as soon as the stock falls under this threshold. This does not need to be general for all stocks but can be adapted to each one.

**Hospital monitoring:** Another use case could be the monitoring of a hospital. In such a use case the data could inform about the patients’ status. Some patients need more attention than others. As a whole it can be important to see the activity on each ward, this would represent an abstracted vision on the hospital. Then, if a specific patient needs direct attention, if he is having a stroke for example, the Perifoveal Display would grab the user’s attention to get more information about what is going on and directly initiate the right procedures.

**Traffic control:** Traffic control is a highly stressful operation and needs the operator’s attention at any point in time. With more and more vehicles on our roads the need for road traffic monitoring and control has become larger. Especially in a city environment or on highways it is necessary to see if traffic congestion arises. With the large amount of data which can be accumulated such as vehicle speed, road usage, accidents, construction zones and more a system such as the Perifoveal Display could help the human operator to detect inconsistencies and initialize procedures to prevent traffic congestion or redirect the traffic flow.

**CURRENT PROTOTYPE**

The Perifoveal Display helps a user monitor and operate real-time large data sets by giving the user highly detailed information in her focus and abstracting the information in the periphery. Important changes in the data set (such as when a stock falls under a certain threshold) that fall into the periphery draw the attention of the user by moving and by changing their brightness. The Perifoveal Display continuously calibrates the data visual presented on the screens to the user's view direction.

**Setup:** The Perifoveal Display system consists of four monitors that are arranged around the user and two consumer depth cameras (see Figure 1). The system could easily be expanded to a larger number of displays such as a video wall. Each depth camera tracks the user’s head and head direction in front of its two monitors. The space is calibrated so that the monitors are defined in relation to the camera. For each depth camera the head direction estimation is performed using the algorithm presented by Fanelli et al. [12]. This results in a head pose and direction estimation in camera space. Calculating the ray-plane intersections of the head direction with each of the monitors leads to a pixel position on the screens. This is used as focal point. If multiple users are detected the system chooses to track the tallest and closest person.

**Visualization:** In our prototype we visualize stock market data. The individual stocks are aligned in a grid on all four screens. In the focal area each individual stock is color-coded based on its current trend. Red meaning the stock falls; green meaning the stock goes up. Using a quad tree structure data points are summarized the more distant they are from the focal point.

The color and the numerical representation fades away until there is only grayscale color areas representing the information. If a data point changes in the periphery the corresponding rectangular area changes its brightness (white - the stock goes up, black - the stock goes down) and transitions into an animated brightness variation. Additionally, an animation of a circle moves around the changed data point to attract the user’s attention.

![Figure 4: Different detail steps when facing the display at different distances. From top left to bottom right: The user can see a detailed graph of the stock when in less than 75cm proximity to the screen. Within 1 meter distance he can see the color-coded stock value. Within 1.5 meter away the display shows through colored triangles the trend of the stock. At 2 meter or farther only an abstracted view of changes in the data is visualized.](image-url)
Additionally, the user’s distance to the screens gives another level of information detail to the system. The farther a person is away from the setup the more abstracted the overall visualization is (see Figure 4). At 2 meter distance the system only presents the abstracted information of the data changes. Only when coming closer it will reveal trends in the stock: green and red triangles indicating if the stock goes up or down. Stepping closer will show the individual stock price and the lowest level gives the graph of the stock over the past days.

The Perifoveal Display separates dynamically based on a user’s head position two different GUIs, one that is similar to a traditional computer GUI and one that is highly optimized for the peripheral vision. These two GUIs fade seamlessly into each other to generate an undistinguished experience, making use of the full 120° human sight with no need for scanning screens with the head. The GUIs are interwoven in such a way, that the peripheral GUI guides the eye to the point of focus, by visually narrowing down the point of interest, when moving towards it.

Since the system can encode information into ambient representations, the human eye can recognize such information in the corner of the eyes, but does not get distracted when focusing on the information.

**USER STUDY**

We performed an informal user study in which we asked participants to test the Perifoveal Display. Participants had to detect changes in the data for three different conditions and answer a few questions.

**Participants:** For our evaluation we recruited 15 unpaid participants through email lists. Participants were between 23 – 55 years old, with a mean age of 25; 8 men and 7 women. Participants came from many different academic backgrounds but most from the xxxx xxxxxxx xxxxxxx community; 12 graduate students, one faculty and two visitors. The minimum requirement for the participation was an intact peripheral vision. Within those 15 people three wore glasses with temples in such a shape, that they prevented the peripheral vision to work properly. We excluded those participants from the quantitative evaluation but recorded their results for the questionnaire.

**Measures:** As qualitative measures, we quantified the participants’ cognitive load through 10-point scale self-assessment questions for all individual tasks. Additionally, we asked for short answers on the following questions:

1. “How much cognitive load did you feel while fulfilling the task?”
2. “Has fulfilling the task been pleasant?”

As quantitative measures, we assessed the task performance, which was defined as the amount of changes in the data a participant could detect.

**Experiment Procedures:** For the user study, we did not include the distance dependent change of detail. Participants stood in a 70 cm distance to the screens so that they could easily see each point on the screens just by turning the head. Participants were introduced to the system and had time to try each task out for training. We showed stock market data to the participants that have been organized as a big amount of individual numbers represented within a visualization in the form of a table with rows and columns spanned over 4 screens. The market data was static and only one number at a time with a randomized position has been changed in a randomized timing within one minute time frame. Nine number changes were performed within this one minute time frame. The challenge for the participants has been to find all nine number changes within the tasks. An indication for a perfect working GUI would be that all 9 number changes were easily found by the participant with minimal mental effort.

**Conditions:** Based on this setup, we performed the task of detecting changes in three different conditions which were presented in random order to prevent biasing or a learning effect.

1. The first condition showed the plain stock market data without any visual assisting, meaning that the data were shown in complete detail on all four screens.
2. The second condition showed the changes in the stock market data by a two second visual brightness change in the cell around the changed number. This condition represented a balance between visual distraction and peripheral vision assistance.
3. The third condition showed the stock market data with the Perifoveal Display system, whereby numbers changing in the focus point were represented like in the second condition.

After each participant finished the tasks, we performed a semi-structured interview and asked about the cognitive load related to each given condition using a 10-point scale. 10 represents the highest cognitive load and 1 the lowest.

**EVALUATION**

**Qualitative measures:** The interviews have shown, that the assistive effect of the Perifoveal Display gave the participants a feeling of security not to miss any number changes. Some comments illustrate this:

“I have had a low cognitive load, it has been almost automatic. I had the feeling I wasn't missing anything, and that relaxed me.”

“I have had little cognitive load, I felt pretty relaxed and could do something else while looking for changes.”
Some comments for the second condition have been: “I have had a medium cognitive load. This one works well if you don't have many screens.”

“I have had some cognitive load. I had to really pay attention.”

“I was alarmed and could not do anything else.”

The first condition showed that no assistive system leads to complete information overload:

“Did not see any changes give up quickly.”

“Stress because I felt like I was missing a lot.”

I have had some cognitive load. I felt like I needed to scan all the moments”

These comments are well supported by the average points given by the participants. With a scale from 1-10 whereby 10 represents the most cognitive load the average perceived load with the Perifoveal Display is 3.83, the second visual assisted condition reaches an average of 4.42 and the non visual assisted first task reaches 8.17.

On the other hand, we asked the participants if the task was pleasant to perform.

The following answers were given for the Perifoveal Display:

“Felt more in control.”

“It was pretty relaxing to be honest.”

Some comments for the second condition have been:

“I like these games.”

“Much easier, but I still had to be concentrated to keep up with the changes.”

With the average points given on a scale from 1-10 whereby 10 represent a very pleasant feeling, the Perifoveal Display reaches 5.83, the visual assisted second condition reaches 4.75 and the non assisted first condition reaches 0.91 points.

**Quantitative measures:** From 9 changing numbers within the 4 screens, 7.5 numbers have been found using the Perifoveal Display, 6.83 numbers have been found using the visual assisted second condition and 0.75 numbers have been found using the non assisted full detail everywhere display.

The three participants with glasses that have temples which obstruct the peripheral vision have had the following average results:

The Perifoveal Display reaches an average of 4.7 cognitive load, the visual assisted second condition reaches an average of 3.34 and the non assisted task 8.67. The Perifoveal Display has been most pleasant with an average of 7 points, the visual assisted condition reached 6 points and the non assisted condition 2.

Participants with temples that prevented peripheral vision have recognized 5 number changes with the Perifoveal Display, 7 number changes with the visual assisted condition and 1.33 numbers using the non assisted condition.

**CONCLUSIONS**

The evaluation suggests that there is an advantage using the Perifoveal Display for tasks where a user has to keep track of a high amount of real-time data. Our results show that a user perceives a lot of stress when using the full detail everywhere display. The bigger the information, the more mental stress the user has. The Perifoveal Display guides the user to data changes and gives a save feeling not to miss any changes, which leads to a more relaxed work situation. This gives the user the possibilities to use his mental performance for other tasks or stay concentrated for a longer amount of time. We believe that the Perifoveal Display can help prevent human related errors and in extreme cases catastrophes, since the task of monitoring a huge amount of data can be minimized to a small amount of cognitive load using the subliminal instinct that helps to recognize the world around us for multiscreen GUIs.

The evaluation suggests that the Perifoveal Display uses the instincts that our vision system provides. We saw that the Perifoveal Display is not working when the peripheral vision is being blocked by certain styles of glasses.

Why is the Perifoveal Display working better than a normal GUI? A trader or a traffic supervisor has a lot of stress with keeping track of all the changes in his system, since he needs to scan all his screens continuously with his eyes. With the Perifoveal Display there is no need to balance between visual guidance and well readable information in one GUI. The Perifoveal Display separates the visual guiding system from the well readable focus and therefore does not have such limitations. It can take the task of continuously screen scanning from the user and support the user with an assisting visual system that gives the user the relaxing feeling not to miss any important event. Since the concentration level can be lower and the user feels more secure using the Perifoveal Display fewer errors will occur. This can have positive influence on network, street and air traffic as well power plant supervising and stock market trading.
FUTURE WORK
Based on the kinect sensing mechanism using infrared laser beams to scan the scene, we have recognized errors capturing the depth images with two kinects. Some projects [13] have proven that it is possible to use many kinects looking at the same spot. It would also be interesting to interweave the acoustic sense into the Perifoveal Display, therefore extending it to a 360° multimedia surround vision and sound system (e.g. Figure 5). A user would get detailed information about the data in the focus area but could keep track of the complete 360° environment through sophisticated alerts. Even changes in the back of his head could grab his attention.

We see a use case for the Perifoveal Display in computer games or augmented reality applications, in which the technology can be used to enlarge the field of view. Once something in the enlarged field of view is of interest, the user turns around until it comes into sight and into focus.

This system is also useful in an automotive environment to warn the driver about dangerous conditions which he would not see without an assistive system or would see too late to prevent an accident. The big advantage of the Perifoveal Display used in such an use case would be, that the focus of a driver never gets disturbed by the assistive visual system.

ACKNOWLEDGEMENTS

REFERENCES
7. Sanneblad, J. & Holmquist, L. E. Ubiquitous graphics: combining hand-held and wall-size displays to interact with large images

Figure 5: In a possible extension of the Perifoveal Display a user could be surrounded by screens therefore creating a 360° display. This could be combined with a 3D audio system to create a multimedia environment.