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An Evaluation of Information Visualization in Attention-Limited Environments

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Abstract

People often need to quickly access or maintain awareness of secondary information while busy with other primary tasks. Information visualizations provide rapid, effective access to information, but are generally designed to be examined by users as the primary focus of their attention. The goal of this research is to discover how to design information visualizations intended for the periphery and to understand how quickly and effectively people can interpret information visualizations while they are busily performing other tasks. We evaluated how several factors of a visualization (visual density, presence time, and secondary task type) impact people's abilities to continue with a primary task and to complete secondary tasks related to the visualization. Our results suggest that, with relaxed time pressure, reduced visual information density and a single well-defined secondary task, people can effectively interpret visualizations with minimal distraction to their primary task.

1. INTRODUCTION

People need information. Many decisions and actions are based on information gathered from a variety of sources. The weather dictates what people wear and whether they carry umbrellas. Stock prices influence investments. Traffic information helps decide which routes to take and which not to take. With the advent of the internet and wireless technology, these and other information resources are readily available on computer desktops, cell phones, handheld computers, in-dash vehicle displays, and elsewhere.

With the availability of this information comes the problem of presenting it in an effective manner. The field of *information visualization* investigates methods for addressing this problem using graphical representations that capture and reflect important aspects of the information [3, 22]. Information visualizations can enable users to quickly assimilate large amounts of data, and empirical evaluation has led to improved designs over time [4].

However, the evaluation of information visualizations has focused almost exclusively on situations in which users explore the information as their only task. In reality, using a visualization is quite often not a person's sole or primary task. Computer users have long used visualizations such as email tools and system load monitors to keep track of information while performing other tasks. Today, as information invades our desktops, it is important to understand how best to communicate this information in an effective manner, with minimal negative impact on the user's other tasks.

This paper explores the use of information visualizations as secondary displays (*peripheral visualizations*). In general, a person's attention will be focused on some primary task, but at times may divert partial attention to a secondary task that involves gathering information from a visualization. This may occur through peripheral vision or shifts in visual focus, but the primary focus of attention should remain on the primary task. Hence, only limited attention can be devoted to the secondary visualization task. For example, a student may want to work on a collaborative assignment while watching for chat messages from his colleagues, or an investment professional may want to monitor stock prices while sending email to her clients, or the driver of a vehicle may want to look at map directions while driving.

In order to design information visualizations intended for secondary tasks, more understanding is needed about the utility of visualization in multiple-task situations. It is suspected that such visualizations are distracting, but little is known about the degree to which they distract users and whether users can overcome these distractions and interpret the peripheral visualizations. Similar to standalone information visualizations, we expect that peripheral visualizations will have some benefits in terms of user performance for assimilating information. However, we also expect that the design of peripheral visualizations will need to be different from standalone visualizations. For example, a typical goal in information visualization design is to maximize visual information density [24]. But in peripheral visualizations, increased visual density may result in additional distraction and decreased user performance.

We attempt to address two primary questions with this work:

How quickly and effectively can people interpret an information visualization while busily performing other tasks? That is, we want to learn whether people can partially switch from their primary task to the secondary visualization task when an information visualization is presented.

How can peripheral visualizations be designed to reduce distraction while maintaining awareness? For example, a visualization that contains more data points has the potential to better show clusters and trends in the data, but it seemingly becomes more difficult to quickly focus on individual data points and can cause distraction.

In answering these questions, we hope to establish guidelines for the presentation of information visualizations in the periphery. This research has the potential for long range impact in many domains. For example, studies have shown that integrated in-vehicle systems do decrease the attention of the driver to the driving task, but do communicate information more effectively than non-integrated systems [9]. Effective methods for the timing, placement, and representation of information in in-vehicle information systems could impact safety issues and help prevent serious accidents.

2. RELATED WORK

Many of the guidelines we used in defining our experiments stemmed from early research on perception in user interfaces. Some of the earliest evaluations examined the perceptibility and readability of rapid serial visual presentations (RSVPs) of letters, strings, and words [10, 13]. More recently, researchers have been examining the effectiveness of graphical displays when presented for short times, focusing on changes in visual features like color and orientation [19, 23, 6]. Others considered the effects of visual attributes such as texture, luminence, dimensionality, and motion in the visual display [8, 11, 12]. This work required participants to quickly interpret complex visual displays, resulting in guidelines for the use of color in display design.

While perception plays a part in the understanding of information in the periphery, also important is the ability to transition attention between tasks quickly and easily. All the previously mentioned evaluations considered the viewing of displays as the sole task of the user. However, in multi-task environments, users would be balancing attention. In recent years, several research teams have examined the effects of displaying information or attracting attention to displays in the periphery [2, 7, 17, 18, 21]. For these studies, the researchers conducted dual-task experiments in which participants performed some central tasks while various types of displays showed different types and amounts of information. This information was used in answering questions or performing secondary tasks. In general, the displays in the periphery were textual [7, 17, 18] or simple graphical [2, 21] displays.

Our research follows a similar experimental design, but differs in that we are focusing not on textual or simple graphical displays but on visualizations that use many factors (color, shape, position) to communicate information.

3. EXPERIMENTS

In conducting the experiments, we examine how various factors affect the ability to assimilate information from displays in the periphery. Specifically, we focus on three factors: visual information density, visualization presence time, and the type of task the user wants to accomplish with the information.

Little work has been done to assess the various effects visual information density may have on information assimilation, particularly in multi-task situations. We speculate that the recommended density may depend on the use of the data. For example, displaying many data points may be beneficial for recognizing patterns in the data, while displaying fewer data points may be more helpful for determining a specific value or datum.

We also want to determine what effect, if any, the presence of visualizations may have on primary task performance. For peripheral displays, presence time becomes important when it may interrupt or distract from a primary task. Determining limits and recommendations for presence time is particularly important in safety critical systems such as industrial machinery, monitoring stations, and vehicle operation. It is desirable to only show the important peripheral information for an amount of time that will not interfere with the primary work task, yet enable the secondary tasks.

Experimental design

This 2 (time) X 2 (density) X 2 (task type) experiment was designed to determine relative performance on tasks in a dual-task setting. Twenty-eight students participated in the experiment for class credit. Participants performed six rounds of playing a video game (primary) and answering questions (secondary) about the visualization that appeared.

The questions asked participants to note in which quadrant (upper left, upper right, lower left, lower right) of the

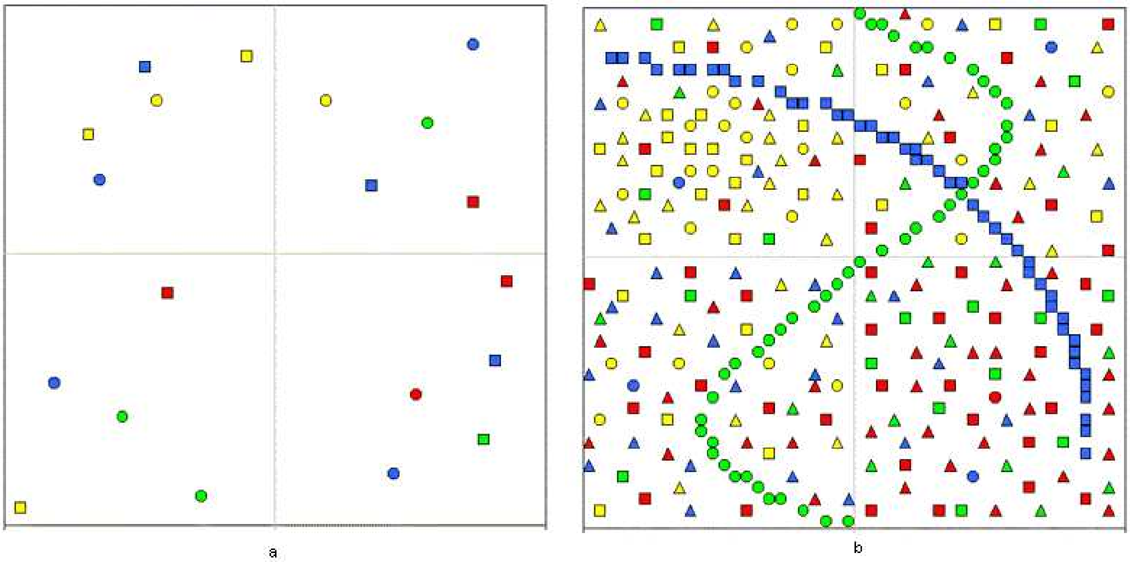

Figure 1: *Sample information visualizations used in the experiment. Figure a shows a low density visualization while b shows a high density visualization, both representing the same distribution of data.*

visualization a target was located. The target was either a single item (e.g. red square) or a cluster of items (e.g. green objects). In each round, participants viewed either a high or low density visualization. High density visualizations contained 320 objects and low density visualizations contained 20 objects. Figure 1 shows the high and low density visualizations. These mock visualizations were designed to mimic common information visualizations such as the Spotfire starfield [1] or maps of landmarks. While the lack of real underlying data may have made the task more difficult, we believe that it was necessary to ensure uniform understanding by all participants.

Each round started with the presentation of the question that the participant would answer using the visualization. The question was then removed and participants then played a simple game as in the pilot study. After 15 seconds of playing the game, the visualization appeared on the screen. Incorporated in the visualization was the answer to the target question. The visualization remained visible for either one or eight seconds, depending on the test group, and then disappeared. Participants then played the game for an additional 10 seconds. The target question then reappeared along with 4 multiple choice answers. See Figure 2 for a screenshot of the experimental setup.

The time the visualization was present varied between participants: either one or eight seconds. The visualization density (low = 20 objects, high = 320 objects) and question type (find single item, find cluster) were both within-subjects variables. Each participant saw both high and low density visualizations and each saw both types of target question.

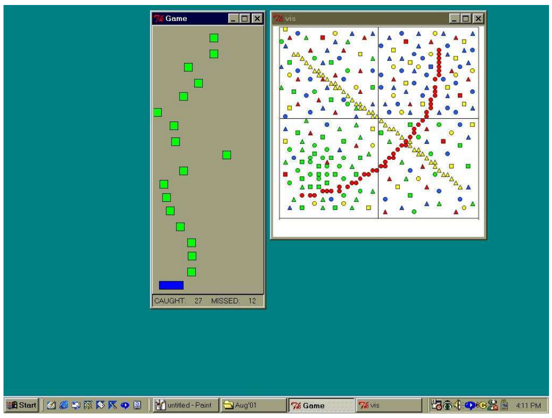

Figure 2: *Game and visualization seen by participants in the experiment. The visualization was only present for either one or eight seconds. Before each round, participants were given a question that they used the visualization to answer.*

For each round, all participants played the same game, saw the same visualization, and tried to answer the same question. The only things that varied in a given round were the density of the visualization and the time the visualization was visible. To measure primary task performance we measured the percent of blocks caught both for the time before the visualization appeared and for the time period after it appeared (including while it was visible). We refer to this as *performance*. The expectation was that presenting and removing the visualization may be disruptive to playing the game and we wanted to determine if there was a significant disruption; hence we chose to look at performance before the visualization appeared compared to after it appeared. For the secondary task performance we measured the *correctness* rate for answering the questions.

4. RESULTS

The results of this dual-task experiment include measures of performance on the primary task as well as measures on correctness in the secondary task. We compared different conditions using paired-sample t-tests. Analyzing these measures separately allows us to examine the issues described previously: the effect of visualization presence on game performance, the effect of visualization density on information assimilation, and the effect of visualization density on game performance. We expected to find that the presence of the visualization would impact performance on the game. We also expected that locating a single item will be easier in the low density visualizations, and locating a cluster of objects will be easier in the high density visualizations. The following sections summarize the results of the experiment.

Performance We found no main effect between performance before the visualization appeared and after the visualization appeared for either the one-second group or the eight-second group. This is somewhat unexpected because in a pilot study, the presence of the visualization resulted in over 10% difference in performance. Comparing performance on rounds with high density visualizations to rounds with low density visualizations indicates a main effect in the one second conditions, $t(13) = -2.46$, $p < 0.029$, with low density visualizations ($M = 0.604$, $SD = 0.091$) yielding better performance over high density visualizations ($M = 0.568$, $SD = 0.071$). No main effect on performance for density was found in the eight second condition. When we compared performance on rounds with the secondary task of locating a single object to rounds with the secondary task of locating a cluster of objects, we found a main effect in the one second condition, $t(13) = 2.410$, $p < 0.031$, with performance higher when locating a single object ($M = 0.6$, $SD = 0.084$) as compared to locating a cluster ($M = 0.572$, $SD = 0.076$). There was no main effect for question type in the eight second condition. See Figure 3 for a representation of mean performance after the visualization has appeared.

Correctness To examine whether the order (high density then low density or low then high) in which participants saw the visualizations affected correctness (answering questions), we compared them within a single time condition. We found no main effect on correctness for the two orderings in either time condition. However, we did find a main effect for time, $t(13) = -5.252$, $p < 0.0002$, with subjects in the eight second condition ($M = 0.94$, $SD = 0.083$) answering more questions correctly than subjects in the one second condition ($M = 0.571$, $SD = 0.233$). Comparing correctness on high density visualizations to low density visualizations reveals a main effect in the one second condition, $t(13) = -2.5$, $p < 0.027$ ($M_H = 0.452$, $M_L = 0.69$) as well as in the eight second condition, $t(13) = -2.687$, $p < 0.019$ ($M_H = 0.88$, $M_L = 1.0$), with people answering more questions correctly with low density visualizations. Comparing correctness on 'find single item' questions to correctness on 'find cluster of items' questions reveals a main effect in both the one and eight second groups. In the one second group we have $t(13) = -2.219$, $p < 0.045$, with more questions answered correctly on 'find cluster' questions ($M = 0.69, SD = 0.332$) than on 'find single item' questions ($M = 0.452, SD = 0.28$). In the eight second group we have $t(13) = -2.687$, $p < 0.019$, with more questions answered correctly on 'find cluster' questions ($M = 1.0$, $SD = 0.0$) than on 'find single item' questions ($M = 0.881$, $SD = 0.166$). We also wanted to examine whether density affected correctness for different question types. For the one second condition with 'find single item' questions we find a marginal effect for density, $t(13) = -2.09$, $p < 0.057$, with people answering more questions correctly with the low density visualizations ($M = 0.643$) than with the high density visualizations ($M = 0.32$). The same comparison in the eight second group produced a main effect, $t(13) = -2.463$, $p < 0.029$, with more questions answered correctly with low density visualizations ($M = 1.0$, $SD = 0.0$) than high density visualizations ($M = 0.75$, $SD = 0.38$). No main effect was found for density in answering 'find cluster' questions in either the one or eight second conditions, with $t(13) = -0.486$, $p < 0.635$ ($M_H = 0.643$, $M_L = 0.714$) for the one second group. Participants answered all 'find cluster' questions correctly (100%) in the eight second condition for both densities. See Figure 4 for a representation of correctness based on density, within a question.

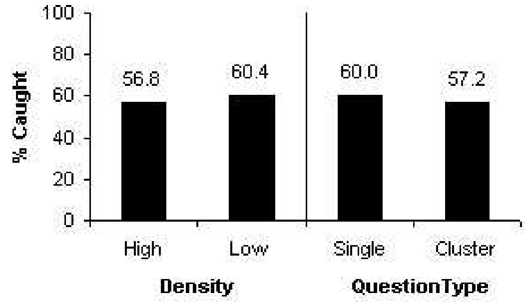

Figure 3: *Average performance (ratio of blocks caught to total blocks) for the 1 second conditions, based on high vs low density and single vs cluster question type.*

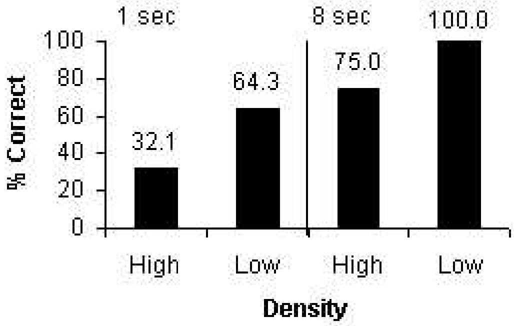

Figure 4: *Correctness based on density for the single-item question. There are significant differences in both the one and eight second conditions.*

5. DISCUSSION

The following list summarizes the results of this experiment.

Peripheral visualizations can be introduced without necessarily hindering primary task performance. The primary task we considered required consistent attention, and it appeared that participants were able to allocate this attention for visualizations presented for either one or eight seconds. This is important as it suggest that people are able to perform non-trivial dual tasks with some efficiency, and gives hope for peripheral visualization design for similar scenarios such as highway driving. It is important to note that if the primary or secondary task required more thought and reasoning, then performance might be affected by a visualization, as was seen in the pilot study and prior work that considered document editing as the primary task [17].

Interpreting complex visualizations within one second in a dual-task scenario cannot be done effectively, but with relaxed time constraints can be very effective. Despite prior work that suggests that the presence of certain visual attributes can be recognized in well under a second [11], we found that in dual-task situations participants perform poorly when only shown a visualization for one second. However, when given eight seconds, they completed the tasks almost perfectly. The longer duration gives users freedom to choose when to task switch, such as at times when their primary task situation is momentarily stable and requires less attention.

Lower density displays can result in performance that is as good or better than high density displays in a dual-task scenario. We found this to be true both when participants were finding single items and finding clusters of items. Note that in our experiments, the cluster-based task was fairly simple: participants were told that a cluster of information existed and they merely needed to identify where. However, as tasks become more numerous and difficult, participants are more likely to become distracted from the primary task as we saw in our pilot study. That presents a unique challenge of breaking down a visualization task into a series of sub-tasks that can be completed independently with low density visualizations and reassembled mentally. This variant of the "chunking" problem, initially studied by Herb Simon [20], has important ramifications for the domain of peripheral information visualization.

Finding clusters of visually similar items is easier than locating a single item. Locating a cluster of items of a single color resulted in more correct answers than locating a single colored shape. This result directly supports prior work by Pomerantz that suggests when dealing with separable dimensions (such as shape and color), divided attention tasks would take longer [19]. Recall that locating the single item involved both color and shape, which makes it a divided attention task.

6. CONCLUSIONS AND FUTURE WORK

Our work has focused on presenting peripheral information to people while they are busy performing some other task that requires significant amounts of attention. We focused on the factors of visual information density and presence time, with information representation the next logical factor to consider. Researchers including Cleveland and Mackinlay have experimentally established visual order-of-precedence rules for standalone visualizations [5, 16], but corresponding rules for visualizations in the periphery are needed. In addition, if the concept of information chunking with low density visualizations is to support increasing quantities of information, then new low-effort peripheral interaction strategies will need to be explored to enable peripheral information navigation with minimal distraction.

A better understanding of the effects of visualizations as secondary displays will impact the increasing development of desktop information management tools. Computer users have long used visualizations like email tools and system load monitors to keep track of information while performing other tasks. As systems like Letizia [15] provide users with additional information on our desktop to help with browsing and communicating, it is becoming increasingly necessary to identify methods for effectively communicating this information with minimal disturbance to other tasks.

With further study, we see this work impacting off-the-desktop situations as well, such as displays in factories and vehicles. In these situations, good guidelines for developing visualizations as secondary displays shift from being beneficial to interpret the visualization peripherally to being essential to do so. Prior studies have looked at the use of icons and other simple visual displays in in-vehicle systems [14]. However, as the information available while driving increases, designers must be ready with safe, effective methods for communicating it to drivers.

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