The Effects of Spatial Layout and View Control on Cognitive Processing

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Abstract
This study explores how spatial layout and view control impact learning. We performed a controlled experiment using a learning activity involving memory and comprehension of a visually represented story. We present our preliminary results comparing performance between a slideshow-type presentation on a single monitor and a spatially distributed presentation among multiple monitors, and method of view control (automatic and interactive). With the distributed layout, participants maintained better memory of the associated locations where information was presented. However, performance scores were significantly better for the slideshow presentation than for the distributed layout for the learning task.

Keywords
Learning, visualization, information processing, spatial memory, interactivity

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces—graphical user interfaces (GUI)

General Terms
Design, Human Factors, Performance

Introduction

Learning is a complicated phenomenon involving sense-making through the organization of many simple units of information [1]. Due to their many successes in making information easier to understand, visualizations are commonly used to help viewers learn new information [2]. When information is presented on a computer display, many design decisions affect how that information can be viewed. In this research, we are studying the effects of interactive view control and spatial layout on learning and cognitive processing.

Dynamic visualizations deliver a high amount of information within a limited amount of time, but individuals require different amounts of time to process the same information. Interactivity can help by allowing learners to control the delivery of information, easing the demand on working memory [3]. Interactive visualizations allows learners to represent and experience their internal knowledge structures visually [4, 5], and has been shown to improve problem solving and creativity [6]. Through interactive viewing, learners can control the order and duration in which information is viewed, but with costs of additional decision making and view-manipulation tasks.

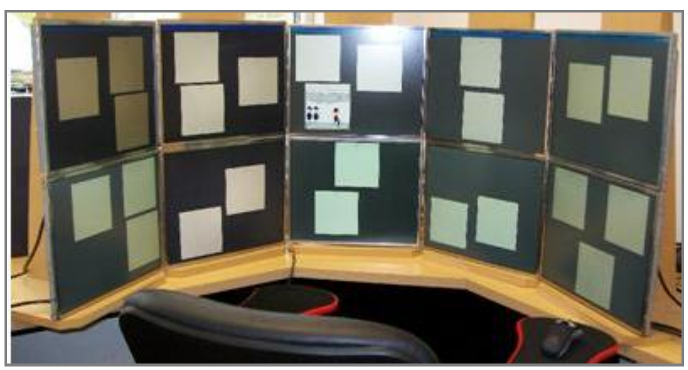

Figure 1. The ten-display workstation, showing the distributed layout condition.

This is closely related to the method of information layout supported by the computer display. Smaller displays (such as single, standard-size computer monitors) limit how much information is visible at a time, while larger workspaces afford persistent visibility of many items. Larger displays allow for spatial layouts of information to help users visualize relationships among pieces of information. Previous work has provided evidence that learners can use spatial locations to help recall the information associated with those locations [7, 8], but it is unclear when location alone is sufficient to provide benefits for cognitive processing.

We believe the benefits of large displays stem from both this persistent visibility and the distinct locations where information is presented. In this study, we

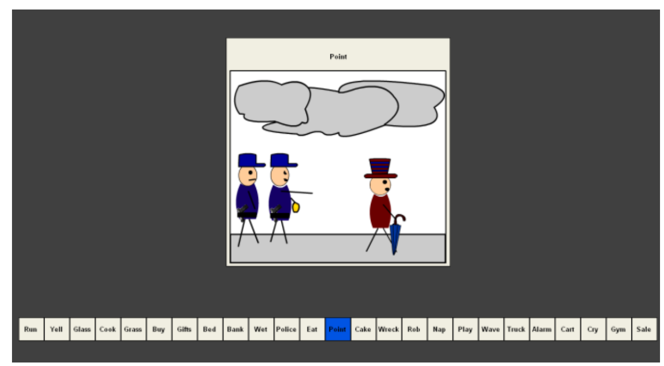

Figure 2. The slideshow layout. All images are viewed at the same location on a single monitor. Below the image location is a list of labels that correspond to the images. The title of the current card is highlighted in the list.

isolate the impact of spatial locations of information in an attempt to gain a greater scientific understanding of how users use space to aid learning and information processing.

In this work, we study how spatial distribution of information affects learning performance and learning strategies of abstract data. We present the preliminary results of a controlled study with a pictorial learning activity, in which we compared performance between a distributed presentation among multiple monitors (Figure 1) and a slideshow-style presentation on a single monitor (Figure 2). Additionally, we study the relationship between this presentation style and the method of view control—automatic or interactive. Preliminary results show that learners performed significantly better with the simpler slideshow presentation than with a spatially-distributed layout, suggesting that—in some situations—spatial presentations of information can have negative effects on cognitive processing.

Method

The primary research questions this study aims to address are:

1. How does spatial distribution of information affect learning performance and learner strategies?
2. How does viewing control affect learning performance and learner strategies?

Past research has found evidence that users were able to externalize memory and thought into space while using interactive, large-display systems to analyze information [e.g., 9]. We hypothesized that a distributed spatial layout would exhibit superior performance due to the increased variety in available positional cues. Further, we hypothesized that interactive, user-controlled viewing would improve task performance. We expected that interactive view control would improve learners' abilities to map information to locations in space, enabling the use of spatial indexing as a memory aid to improve performance. We suspected that the added element of interactivity would allow users to give further meaning to the space, strengthening the effectiveness of the information mapping.

Design

In a controlled study, we varied viewing mode and presentation style in a 2x2, between-subjects design. Currently, 24 undergraduate participants (11 male, 13 female) have completed trials. The two viewing modes we tested were *automatic* and *interactive control*, and the two presentation styles were *slideshow* and *distributed* layout.

In the automatic presentation condition, each card image was displayed for five seconds before it was hidden and the next image was displayed. The participant had no way of interacting or controlling the view of the cards. Cards were displayed from left to right for both the slideshow and distributed conditions. In the interactive control condition, participants used a mouse to manually control the order and duration in which card images were viewed. An image could be made visible by moving the mouse cursor over its title in the slideshow list or over its card in the distributed layout. The total amount of viewing time was limited to 250 seconds for both conditions. In both viewing modes, only one card was visible at any time, though the textual labels were always visible.

Figure 3. Examples of images used in story card dataset. From the top, the titles of these cards are: Bank, Police, Cake, Cook, and Eat.

In the slideshow layout, all cards were visible in the same location—on a single monitor directly in front of the participant (see Figure 2). Below the location where the cards are shown, a horizontal list always showed all the textual titles. In the distributed layout presentation style, the cards were distributed across all of the monitors of the display, so that every card had its own persistent location (see Figure 1). While only a single card was visible at a time, all the other cards were still visible as empty boxes with the textual titles visible. In this way, both conditions always had all titles visible and provided a spatial location corresponding to each image; however, these locations had much higher spatial variance in the distributed layout where the images themselves were displayed in different locations. This allowed us to isolate the effects of spatial location without the confounding effects of persistent visibility that is afforded by normal large-display workspaces.

In both conditions, the cards were ordered or arranged in the same predetermined organization—events were jumbled so that the stories were not presented in chronological order.

Procedure

To test our hypotheses, participants viewed a set of 25 event cards. The cards included simple, graphical representations of nine distinct characters in various situations along with single-word titles to describe the event. Figure 3 shows samples of card images. The cards portray simple events with the same characters so that a sequence of events may be interpreted as a story, with a sub-story for each other character. Participants were asked to determine the story and sub-stories based on the events viewed in the cards.

After viewing the event cards, we asked a number of questions to evaluate comprehension and memory of the information.

Prior to asking each participant the questions, we verbally administered a simple number-memorization test to help clear working memory of information about the story set before our real questions. This task took approximately one minute, helping to establish that the following questions would be answered based on information from long-term memory (memory research has found that retention in working memory is generally limited to around ten to fifteen seconds without active rehearsal [10, 11]).

Data and Evaluation

After viewing the panels, we verbally asked participants a series of questions to test their knowledge and understanding of the presented information. All responses were given verbally and trials were videotaped in order to aid scoring based on a prepared rubric. Questions were designed to evaluate simple detail recall as well as comprehension of the meaning of the events and stories. For questions based on memory of details, participants earned points for correctly recalling characters and details from the events shown in the story cards. An example of a recall question is: “What color was the cake?”

Other questions evaluated understanding, involving comprehension of the meaning of the events and stories. These questions required participants to do more than simply recall the images on the panels. Earning points for these questions required participants to explain relationships among the characters and events. An example of this type of question is: “Can you come up with a sub-story of events that link the boy with red baseball cap to the man with an umbrella?" The evaluation also included questions requiring participants to provide explanations beyond the information that was explicitly provided in the images. For example, we asked participants to hypothesize future events based on their understanding of the story. Additionally, we asked participants to predict the emotional states of the characters and explain their rationale. All scoring was calculated in accordance with the pre-determined scoring criteria.

We also asked participants to describe their strategies used to learn the story and to comment about their thought processes. Lastly, referring to the blank placeholders remaining on the display, we asked participants to recall the locations of any known events. Participants pointed to locations and described the corresponded events.

Results

Because the results of Shapiro-Wilk tests of normality for our metrics suggested that the data was normally distributed, we used a two-way factorial analysis of variance (ANOVA) to analyze the results. The analysis showed a significant main effect of presentation layout on total learning score, with $F(1, 20) = 4.89$ and $p < 0.05$. Performance was better with the slideshow-style presentation ($M = 67.58$, $SD = 16.77$) than with the distributed layout ($M = 49.0$, $SD = 22.6$). This is the opposite of the hypothesized effect of presentation layout. No significant effects on score were found due to viewing mode, with $F(1, 20) = 0.04$, and no significant interaction was found between viewing mode and presentation layout, with $F(1, 20) = 0.52$.

The analysis also found a significant effect on location recall (the number of event locations that participants could correctly recall after the questions) due to presentation style, with $F(1, 20) = 6.27$ and $p < 0.05$. This showed that participants were better able to remember the associated locations for events with the distributed layout ($M = 9.0$, $SD = 3.84$) than in the slide-show presentation ($M = 5.5$, $SD = 2.84$). However, the performance results suggest that these additional location memories did not support performance improvements, despite our observations that many participants were referring to locations to aid recall during questioning.

Discussion

These were surprising results with a number of possible interpretations. As no interactions were observed between presentation style and viewing mode, the results suggest that users did not suffer from problems interacting with the mouse in a larger space. We also know that the results were not due to poor spatial memory because participants demonstrated better memory of locations in the distributed layout conditions.

It is important to note that these results do not generalize to the claim that small displays are better than large displays, as our distributed layout condition lacked common large display features. That is, in order to isolate the effects of spatial location, we removed the benefit of persistent visibility of information. It is possible that participants scored higher in the slideshow presentation due to higher familiarity with small workspaces. It may be that it takes practice to establish effective spatial strategies when using larger workspaces; we leave this to future work. Or, perhaps spatial mappings are only useful when locations carry meaning to the data. For instance, when users organize information in the space, they can establish meaning for the locations.

Clearly, these results indicate a need for further work in order to answer some of the open questions established from this research. For example, the small size of this dataset may contribute to the effectiveness of the automatic presentation mode. With a larger dataset, interactive view control may become necessary as users need to refer back to information on demand. Another issue is whether the data representation affected the usefulness of spatial distributions. That is, this learning task was based primarily on graphical information that participants viewed and integrated into stories. It is possible that different results could be observed with a different data type, such as textual information.

As research in progress, we will continue to run participants for this study. Further, we have yet to analyze differences in strategies used in the learning task. We also hope to analyze eye-tracking data collected in this study to help us to further explain the interesting results of this study. We plan to extend this research to study additional forms of interactivity, such as organization or annotation. These results can help inform design guidelines for information visualization tasks where information processing is vital.

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