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Representation Matters: The Effect of 3D Objects and a Spatial Metaphor in a Graphical User Interface

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ABSTRACT
As computer graphical user interfaces (GUIs) are loaded with increasingly greater numbers of objects, researchers in HCI are forced to look for the next step in constructing user interface. In this paper, we examine the effects of employing more "natural" representations in GUIs. In particular, we experimentally assess the impact of object form (2D iconic versus 3D realistic) and layout (regular versus ecological) have on target acquisition time. Results indicate that both form and layout significantly affect performance; subjects located targets more quickly when using interfaces with 3D objects and ecological layouts than they do with 2D objects and regular layouts. An interface with an ecological layout, realistic objects, or both may be an improvement over traditional interfaces.

Keywords
3D interface, graphical interface, spatial metaphor, icon, ecological layout, regular layout

INTRODUCTION

What is the next step in the evolution of the graphical user interface? One possible step is the move from predominantly iconigraphic, 2D representations to more realistic, 3D representations. The implicit assumption underlying the increasingly popular attempts to develop compelling 3D environments is that users will find it natural and intuitive to navigate virtual spaces (e.g., Reeves and Nass, 1996).

The specific advantages, however, of realistic 3D GUIs are unclear. Moreover, it is also unclear which attributes about a realistic 3D GUI would make it more useful. Note that we do not use the term 3D in the sense of a virtual reality display, but we are talking about a normal, everyday desktop computer screen. Clearly, a 3D GUI should not merely be the traditional GUI enhanced with the depth dimension. In the natural 3D world, there are many different factors that "codify" objects. Many of these factors are visually salient attributes that have us to recall objects. If we transfer these factors onto the interface, the interface is more likely to involve a non-regular placement, differing external shapes, enhanced color, landmarks, connectivity, and potential semantic associations than is a 2D GUI. In general, 3D GUIs may provide more dimensions to distinguish and identify objects. The more redundant dimensions available to the user, the greater the chance of the user being able to choose an attribute to which to relate. As a result, users might find and recall the objects more quickly in such a 3D GUI than in a 2D GUI. In this study, we examine whether and which factors of a 3D GUI affect how quickly users can acquire target objects in a laboratory experiment.

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THEORETICAL BACKGROUND

Placement

There is an large amount of research stating the importance of location having a direct effect on the recall of information. Mandler et al. (1977) and Hasher and Zacks (1979) indicated that people automatically encode spatial information. When recalling where a file is located, people want to expend the least amount of cognitive efforts as possible so they can focus on the tasks they want to accomplish once they retrieve the file. If forming spatial associations is a pre-attentive process, designers should use this to their advantage when creating interfaces.

Kaptelinin (1993) showed that experienced users do not need to read menu item names while working with the system. As novices, they primarily rely on the names of the menu items to accomplish simple tasks. After the learning period is over, the location of the item names seems to be encoded and the selection actions start to become automatic. Moyes (1995) and Kaptelinin (1993) both agree that users focus on local attributes initially (e.g. icon form) but over time switch to identifying attributes which are global, or require the user to consider the interface as a whole (e.g. the icon's relative position among all other icons on the screen).

Hess et al. (1994) also noticed the effect spatial placement has on recalling information. In their study, they showed that spatial separation of items on a screen aids memory for a task requiring that the items being monitored be available separately in memory.

Individual object locations are not the only concern in this study. More importantly, this experiment will focus on the effects of object layout, or how individual objects are placed in relation to each other. In particular, we are interested in the effect an office-like metaphor will have on user performance. Ecology, the study of the habits of living organisms and their interactions with their environment, can be applied to the office metaphor. Ecological considerations are important as people draw important cues from their immediate environment and develop knowledge of the space over time and through the experience of interacting with it. Benyon and Höök (1997) refer to many various types of spatial metaphors for which designers use to represent vast amounts of information.

Van der Veer (1989) suggests that adequate metaphors can facilitate the learning process. In turn, the learning process facilitates automatic actions and; hence, the cognitive load has been reduced.
The idea of organizing information by spatial metaphors have been advocated by many (Bolt, 1979; Cole, 1982; Malone, 1983). Although such an idea seems to be in agreement with the general theories, such as method of loci, some laboratory studies have not supported spatial interface advantage. In particular, Jones and Dumais had subjects read news articles and file them based on a certain condition (name only, location only, name and location, or name and location separate). The subjects were then given a passage from one of the ten articles (per condition) and were given three guesses as to where they had previously filed it. The performance of the subjects led to the conclusion that the location only condition did not have any significant advantage over the name only condition. The results also indicated that in the location and name combined condition, the article was more easily found. These results demonstrate that more semantic information provided for the objects (name plus location) will aid in the retrieval process. It is important to recognize that there are two cognitive processes involved in this study: the recognition task and the recall task. Jones and Dumais take measurements from both of these tasks which requires the subjects to not only recall the spatial location of where the article has been filed, but also from which article the passage was contained. However, in this experiment, we focus only on the recall task.

Objects in an ecological layout not only have their individual locations, but also form connectivities that make physical sense. For example, in the office metaphor, a monitor is on the desk and the hardware is attached to the monitor and the keyboard and the mouse are attached to the hardware. We propose these connections will facilitate target acquisition.

External Shapes

Another characteristic of realistic objects is the differing external shapes. The 2D iconic representation has a "framing" effect. The rectangular box surrounding each of the icons gives them a uniformity which does not help to differentiate the icons. Having different shapes is a desirable quality when a distinguishable feature is needed quickly.

Color

Color is another important feature of a realistic object. There is a large amount of research about when color is helpful and when it is distracting and which colors are better to use than others. A particularly interesting review of comparing the usefulness of color against various achromatic codes (size, shape, etc.) gave evidence that a color-coded target was more accurately identified than the codes monochrome, size, shape, and brightness (Christ, 1975). However, if color is not the target, then color becomes a shortcoming and a distraction on the screen.

Landmarks

Landmarks are inherent in any situation. The difficulty in developing a good test to study landmarks is the fact that landmarks are a personal discrepancy. We expect that unchanging features on a GUI such as a table or a bookshelf in the form of what can be called visual landmarks will improve a person's memory for where things are located. Groupings of any kind, be they caused by a rim or window around objects or by spatial separation could be considered landmarks and might improve performance.

Landmarks may serve as external memory aids and we know that external aids to memory are often employed when other, intervening, cognitive events might interfere with the processes of learning and recall, when accuracy is at a premium, and when memory load is to be minimized to facilitate the allocation of attention to other activities. It seems that, in general, individuals prefer to use external aids to memory rather than rely upon their own internal memory. This suggests that the effort occasioned by the use of external memory props is less demanding than the cognitive effort required to encode and retrieve information from internal memory sources (Findlay et al., 1988). However, Jones and Dumais (1986) did not find any significant data relating to landmarks.

Semantics

Rothkopf et al. (1982) improved upon the claims of Mandler et al. (1977) and Hasher and Zacks (1979) by stating that location provides especially privileged cues and that not all content-correlated background stimuli are equipotent cues in associative learning. Lansdale et al. (1987) also stresses the important factor in the utility of a cue enricher which seems to be the ability of the subject to form a meaningful association with the relevant document. The more semantic information provided related to the object, the more cues a person has from which to extract a useful meaning. In 1996, Lansdale et al. discovered even though there were many differences between cues subjects used when describing characteristics of an object they recently saw, they were consistent with cues which they had previously used.

METHOD

To examine the relative contributions of different factors distinguishing two styles of interfaces (3D, ecological and realistic vs. 2D, regular and iconic), we operationalized two independent factors. The first, "layout," varies from regular object placement with no landmarks and no connectivity ("regular") to non-regular placement with landmarks and connectivity ("ecological"). The second, "object representation," varied from similar shape, simple color, and shallow potential semantic associations ("2D iconic") to different shapes, complex color, and rich potential semantic associations ("3D realistic").

In order to test the hypotheses described above, the interfaces developed were the best representations for a traditional 2D iconic interface and a new 3D realistic interface. The interfaces were based on the interfaces used in a pilot study (Selker et al, 1997).

Design

There were many issues which had to be taken into account when designing the interfaces used in the experiments. We attempted to make each of the two styles of interface resemble the most typical features of their own class. The 2D iconic representations were in 8-bit color and were surrounded by identical rectangular boxes.

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The regular layout consisted of rows and columns typical to a user interface. The ecological layout portrayed an office metaphor in which the computer monitor and hard drive were located in the center of a desk with a bookshelf on the desk to the left of the computer. The ecological layout contained the 3D interface attributes previously described. The desk and the bookshelf served as visual landmarks while the computer monitor had connectivity with the hard drive which were also connected to the keyboard.
In order to account for the size discrepancies between the 2D and the 3D icons and also the difference in the placement of the icons, Fitts' law (Fitts, 1954) was used to calculate a regression slope to normalize our results.

The four experimental conditions were: 2D with regular placement (Fig. 1), 2D with spatial placement (Fig. 2), 3D with regular placement (Fig.3) and 3D with spatial placement (Fig. 4).

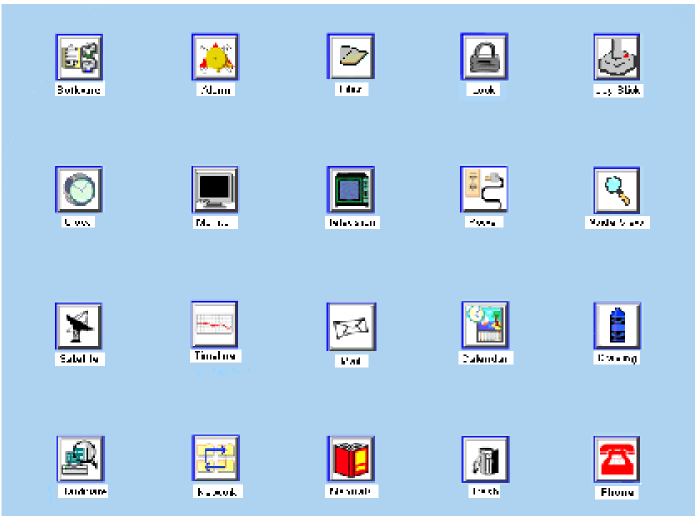

Figure 1: 2D Regular

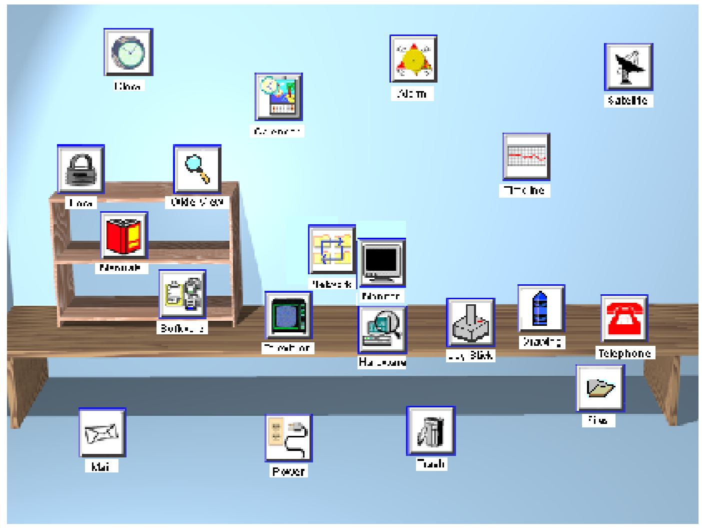

Figure 2: 2D Ecological

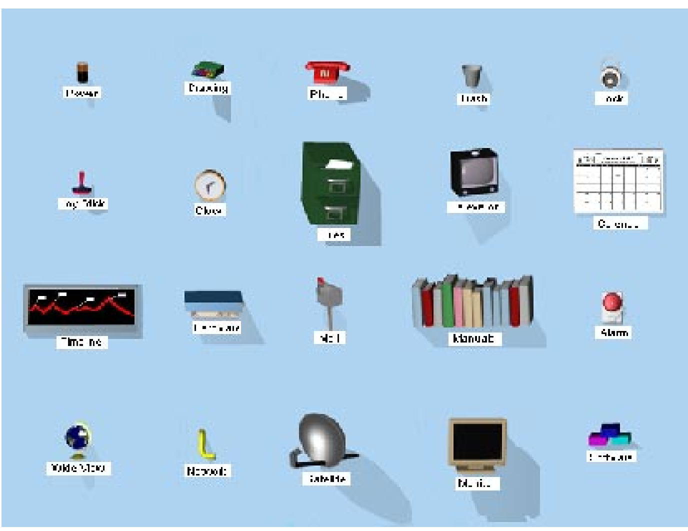

Figure 3: 3D Regular

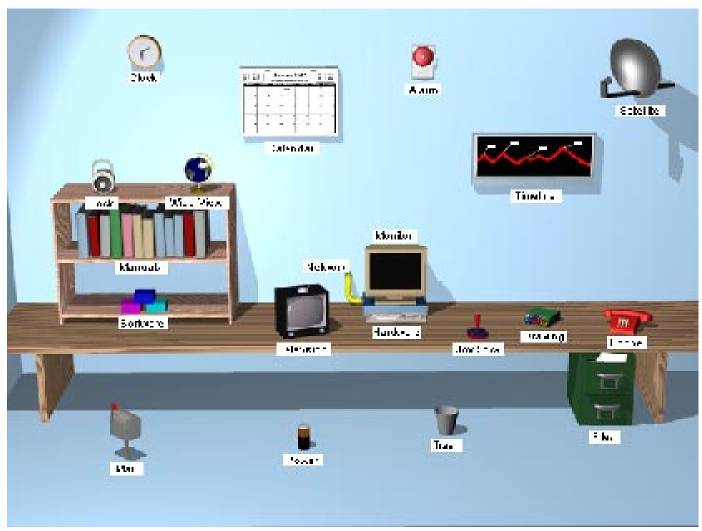

Figure 4: 3D Ecological

The test was written in Macromedia's Lingo and displayed using Director on an IBM desktop computer with a standard mouse.

Subjects
Twelve subjects were used. Nine were male and three were female. All used computers on a daily basis.

Procedure

The experiment used a balanced, within subjects design. The subjects were asked to find an object as quickly as they could and then select the object by using the mouse to click on the object or the object's label. The subjects were assigned by a Latin square equally into one of four groups where each group consisted of a different order of the four conditions.

There were ten objects to locate per condition and three trials within each condition with the sequences varying per trial. The subject repeated the same test on a separate day (within a twelve to thirty-six hour time period).

The test consisted of an instruction screen which was followed by the name of an object to find. When the subject was ready, they were asked to click on a "GO" button so as to position the cursor in the center of the screen. Once the subject clicked on the object or its label, the test continued to the next object. The refreshed scene forces the subject to get reoriented to the interface and does not give way to any advantages for neighboring objects. Errors were recorded along with the time it took to find each object.

Also, after the second day of the test, the subjects were given pictures of the four conditions and were asked to rate the pictures on a scale of 1 to 5 (1 easy; 5 hard) based on how hard it was to find the object they were looking for in each condition.

RESULTS

We were interested in whether object representation (2D iconic or 3D realistic) and layout (regular or ecological) would impact the time it takes users to search for and click on objects. To start, we examined whether other differences among the four conditions might impact our participants' performance. In particular, the distance to a target (amplitude) and the size of a target (width) can determine the time it takes to acquire a target, as described by the well-studied Fitts' Law. A transformation of this ratio (amplitude / width), called Fitts' index of difficulty, has been shown to be linearly related to target acquisition time.

To rule out the possibility that any differences in performance between experimental conditions were due to differences in Fitts' index of difficulty, we examined the mean of the indices across the ten targets for the four conditions. These means were 1.68, 1.62, 1.69, and 1.63 for the 2D Regular, 2D Ecological, 3D Regular, and 3D Ecological respectively. A descriptive analysis provides a measure of the comparability of the groups. A 2 (2D versus 3D) by 2 (regular versus ecological) analysis of variance on the indices revealed no significant main effects or interactions. The statistic for the explained variance is $F(3, 36) = .040$, p nonsignificant. These analyses suggest that the four conditions are not meaningfully different in their average Fitts' indices of difficulty.

We also examined the variance of the ten targets across the four conditions. The standard deviations were .41, .54, .78, .48 for the 2D Regular, 2D Ecological, 3D Regular, and 3D Ecological, respectively. A test of heteroscedasticity revealed no significant differences in the distribution of indices across conditions; Levene statistic $(3, 36) = 1.91$, p nonsignificant. This analysis suggests that the four conditions also share similar variance in the Fitts' indices of difficulty.

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To examine the impact of object representation and layout of subject performance, we looked at the mean completion times over the three trials and two days by each of the four conditions. These results are illustrated below in Figure 5.

Mean Completion Time (sec.) with Standard Error Bars

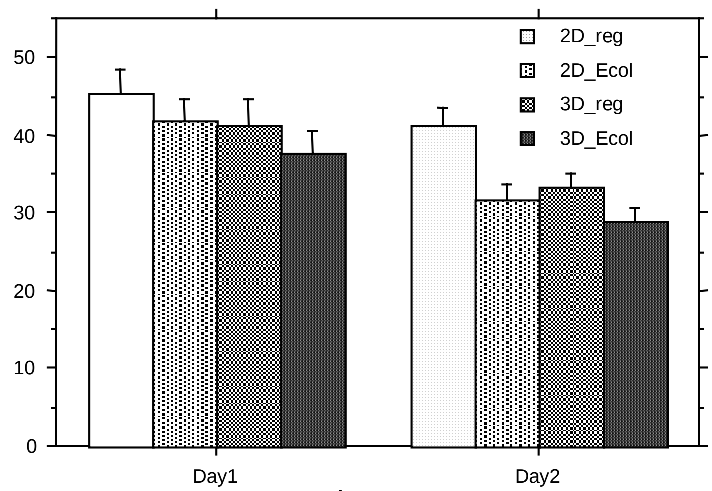

Figure 5

We analyzed these data with a 2 (object representation) X 2 (layout) X 2 (day) X 3 (trial) repeated measures analysis of variance with the order of the experimental conditions as a four level between subjects factor. The Fitts' indices of difficulty were added as a covariate to control for any possible variance accounted for by target size and distance.

This analysis revealed a main effects for object representation and layout; for object representation $F(1,8) = 41.02$, $p < .001$, and for layout $F(1,8) = 45.60$, $p < .001$. Subjects found objects more quickly when they had 3D realistic representation than they did when they had 2D iconic representations. Similarly, subjects found objects more quickly when the objects had an ecological layout than they did when they had a regular layout. The interaction between object representation and layout was not significant; these factors aided performance indepently. Subjects performed best when objects had a 3D realistic representation in an ecological layout and worst when objects had a 2D iconic representation in a regular layout.

Other effects were also significant in this analysis. The main effect for trial was significant; $F(2,16) = 234.96$, $p < .001$. Subjects tended to perform better on latter trials than they did on earlier trials. The main effect for day was also significant; $F(1,8) = 11.99$, $p < .01$. Subjects tended to perform better on the second day than they did on the first. The interaction between day and trial was significant as well; $F(2,16) = 58.69$, $p < .001$. In general, the effect of trial was greater on the first day than it was on the second day. The day factor also interacted significantly with the layout factor; $F(1,8) = 18.94$, $p < .01$. Generally speaking, the day factor had a bigger impact for the ecological layout conditions than it did for the regular layout conditions (Fig. 6).

Finally, the interaction among order, trial, object representation, and layout was significant; $F(6,16) = 9.05$, $p < .001$. We can offer no meaningful interpretation of this result. All other main effects and interactions, including the effect of the covariate, were not significant.

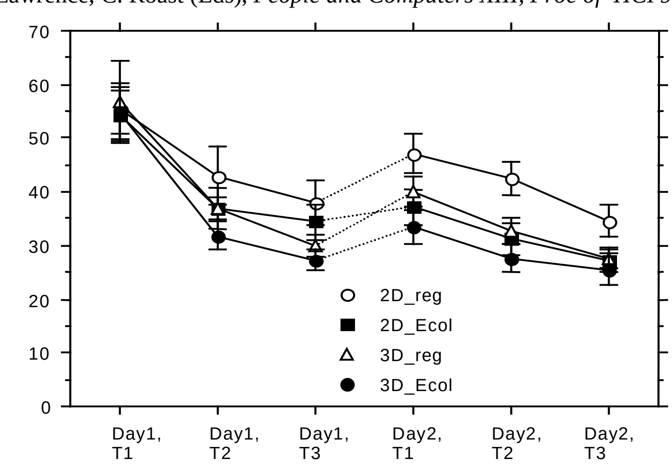

Figure 6

DISCUSSION

The results indicate a user will search for and acquire objects more quickly if they are presented with a 3D ecological, realistic interface rather than a 2D regular, iconic interface. Specifically, an ecological layout (as opposed to a regular layout) and a 3D realistic representation of objects positively affected experimental task performance.

Interestingly, the effects of ecological layout and 3D realistic representation are additive. That is, the subjects' performance was better when either the ecological layout or the 3D realistic representation was present, and they performed best when both were present. Moreover, the interaction between these factors was not significant; their contributions to the interface are independent.

These results have important implications for interface design. For tasks which require identifying and learning the place of objects, 3D realistic interfaces along with ecological layouts will provide increased performance time. Interface designers can draw upon either factor. In applications where a regular layout is necessary, 3D realistic objects may still be useful. In applications where 2D icons are necessary, an ecological layout could still improve the usability of the interface. In other words, these results suggest that an interface need not be completely 3D to be an improvement over the traditional 2D iconic interface.

We would like to explore the other issues in the 2D versus 3D comparison. We hope independently investigating shape, color, landmarks and connectivity will provide insights into factors that can support the 3D realistic ecological representation as a favored desktop interface.

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