A Comparison of Spatial Organization Strategies in Graphical and Tangible User Interfaces

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ABSTRACT
We present a study comparing how people use space in a Tangible User Interface (TUI) and in a Graphical User Interface (GUI). We asked subjects to read ten summaries of recent news articles and to think about the relationships between them. In our TUI condition, we bound each of the summaries to one of ten visually identical wooden blocks. In our GUI condition, each summary was represented by an icon on the screen. We asked subjects to indicate the location of each summary by pointing to the corresponding icon or wooden block. Afterward, we interviewed them about the strategies they used to position the blocks or icons during the task.

We observed that TUI subjects performed better at the location recall task than GUI subjects. In addition, some TUI subjects used the spatial relationship between specific blocks and parts of the environment to help them remember the content of those blocks, while GUI subjects did not do this. Those TUI subjects who reported encoding information using this strategy tended to perform better at the recall task than those who did not.

Keywords
Tangible user interfaces, TUI, spatial memory, spatial organization, complementary strategies

INTRODUCTION
Tangible user interfaces (TUIs) have recently attracted attention as an alternative approach to GUIs for some application domains. However, beyond issues of speed of interaction there is little formal knowledge about the differences between TUIs and GUIs[9].

This experiment was motivated by our desire to understand the differing roles of TUIs and GUIs in complex problem-solving tasks. Researchers have observed that people modify their environment to aid them in thinking about problems[27][13]. Kirsh calls this modification "epistemic" action, which he contrasts with "pragmatic" action which is taken to solve a problem directly[15]. We hypothesized that epistemic action is more easily and effectively employed in TUIs than in GUIs.

Figure 1: A block is in the reader, while the other nine are in their initial positions

Understanding how people use TUIs as opposed to GUIs to help them think about complex problems is important for two reasons. First, it may help us develop a better understanding of what we gain or lose by moving from a GUI to a TUI for specific applications. Second, a thorough knowledge of how space is used differently in GUIs and TUIs may suggest design considerations for TUIs of which we are currently unaware.

To explore the differences between GUIs and TUIs in terms of epistemic action, we conducted an experiment in which we asked subjects to read a group of news summaries and think about how the summaries related to each other. For this task, some subjects used a TUI while others used a GUI. We designed the two interfaces to be as similar as possible, the GUI using on-screen icons to represent the summaries, the TUI using wooden blocks. To isolate the effects of spatial memory in the experiment, we made the tokens visually identical. The subjects accessed the summary associated with each block or icon by placing the token into a reader. While reading, most subjects moved the tokens around to help them think about how the summaries were related to each other. After the subjects finished reading, we measured their ability to remember the token with which each news summary was associated, and we interviewed subjects

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about their spatial layout strategies.

We observed the following:

- TUI subjects performed better at the recall task than the GUI subjects, remembering the locations of an average of 5 blocks, compared with 3.5 for the GUI case.
- Only TUI subjects used layout strategies which involved positioning tokens based on location within the space as a whole, rather than positioning relative to other tokens in the space. We call this strategy *reference frame based positioning.*
- Subjects who incorporated this reference frame based positioning scheme in their placement strategy were able to recall the associations between tokens and articles better than others.

RELATED WORK

Some work has been done to understand different ways that spatial arrangements of objects can be used to help us think. However, this work has not compared the strategies used with graphical objects in GUIs to those used with digitally augmented physical objects in TUIs.

Work by Kirsh [13][14] discusses a variety of ways that people use the space around them while solving problems. He divides this manipulation of one's environment into two types of action: epistemic and pragmatic. Epistemic action is action undertaken solely to help one think during the problem solving process. One of its common uses is to enhance memory and to simplify choice. For example, while solving a problem one might sort a group of objects into smaller groups to aid in remembering which objects share similar properties.

Zhang presents a study that shows the nature of the objects used in problem solving tasks can dramatically affect how people think about the tasks and how long the tasks take to solve [28]. He compares the time required to solve two variants of the "Towers of Hanoi" puzzle. This puzzle involves moving a group of rings from one of three pegs to another while keeping them sorted from largest to smallest diameter. In other words, a ring may never be placed on a peg if it will rest on a ring with a smaller diameter. The variants have the same rules as the standard puzzle. However, one uses oranges of varying sizes instead of the rings in the standard puzzle; the other uses coffee cups. Instead of placing these objects on pegs, they are placed together on small dishes. One can only remove the smallest object from a dish, and an object can only be added to the dish if it is smaller than those already on the dish. Zhang found that the puzzle involving oranges took more than twice as long as the coffee cups puzzle to complete, with six times as many errors [21]. The important difference here is that one can stack the coffee cups, but one can not stack the oranges. The process of stacking helps one keep track of which cup in each group is the smallest, and the order in which the cups were placed on the dish. This shows that the kind of the objects used in a problem-solving task can dramatically effect the nature and effectiveness of the way people use those objects to help them think.

There is also a variety of work on how people encode and use spatial information about their environment. Malone asked ten office workers to locate items in their offices in order to understand the different strategies people use for filing and retrieving information [18]. While his results suggested that office workers, particularly those with neat offices, were good at finding documents within them, more formal work on this question has suggested that it can be difficult to rely on location information alone for recall [7][16][20]. Dumais and Jones found that retrieving documents by name was more effective than using spatial information for retrieval [7]. Lansdale argues that memory of location can be quite poor in cases where documents are not organized according to some logical structure. In cases where a structure is imposed, subjects can use it to help determine the location of documents, and thus their performance at recalling location improves [16]. These results suggest that little spatial information is encoded automatically in the absence of an overall spatial organization scheme.

On the other hand, Mandler et al. have compared the performance of subjects at recalling object location when they are intentionally trying to remember location and when they are not. They found only a small decrease in recall performance when subjects were not told to remember object location. From this they concluded that much object location information is encoded automatically [19]. However, Naveh-Benjamin responds that location information is in fact not encoded automatically when subjects are just observing a spatial configuration rather than modifying it themselves [20].

Despite the disagreement in the literature about the utility of spatial information, recent work by Robertson et al. on the Data Mountain system suggests that spatial memory can be used to reliably improve performance in a task involving the retrieval of web documents represented by icons on the screen [22]. In the Data Mountain system, users employ a mouse to place web pages on the side of a "mountain" displayed on the computer screen in 3D. Robertson et al. found that when users were presented with a title, summary and thumbnail image of a document, they could retrieve it more quickly and with fewer errors with the Data Mountain system than with the Internet Explorer™ Favorites mechanism.

THE EXPERIMENT

Task

Subjects were asked to put themselves in the position of a newspaper editor who had to read ten short news summaries. Each summary was a 100 to 150 word excerpt from a top story in a mainstream online newspaper. They were told to take as much time as necessary to read all ten, and to look at each summary as many times as they wished. They also were told to expect a series of questions about how the summaries could be used in a newspaper afterward. The experimenter stated that subjects might want to consider how the summaries were related to each other, what the implications of each summary would be, and which readers would be interested in each summary, emphasizing that there were no correct answers. As we were interested in understanding how subjects' organizational schemes would develop and evolve over the course of the experiment, we were careful not to suggest any particular classification scheme for the summaries.

The subjects were divided into two groups: half of the subjects used a TUI to access the series of news summaries; the other half a GUI. The TUI consisted of a group of visually identical wooden blocks. When a block was placed in a reader device attached to the bottom of a computer monitor, the summary corresponding to that block appeared on the screen directly above it, as in figure 1. The GUI subjects accessed the same news articles by dragging and dropping an icon into a reader area displayed on the screen. When an icon was placed inside of this reader as shown in figure 3, the summary corresponding to that icon was displayed next to the reader.

While the subjects were reading the summaries, the experimenter observed where they placed the blocks on the desk or the icons on the screen. Immediately after a subject indicated that he or she was finished, he or she was asked to indicate which icon or block corresponded to each summary. The subject was prompted with the title of each summary in random order. The purpose of this task was to measure how well the layout strategy each subject used helped him or her remember with which summary each token was associated. After this task was complete, the subject was interviewed about how he or she organized the blocks or icons during the task. All subjects were asked about organizational strategies using the same set of scripted questions. The organizational strategies described in the “results” section come from the subjects’ reports about the strategies they employed. The final configuration of the blocks or icons was also recorded.

Experimental Hypotheses

Our hypotheses for this experiment were suggested by our experience with various physical token-based systems we have explored in our lab, including the mediaBlocks system[24], and by Kirsh's work on epistemic and pragmatic action.

Our hypotheses were as follows:

1. Subjects use more sophisticated strategies for laying out the physical blocks than for the graphical icons.
2. Subjects using the physical objects more accurately remember which token each summary is associated with than those who use graphical icons.

Subjects

Thirty-six subjects (18 males, 18 females) were paid $10 each to participate in the experiment. The subjects ranged from 18 to 49 (mean 26.7) years old, and reported using a computer between 2 and 40 (mean 21.9) hours per week. Despite this variation in weekly computer usage time, subjects reported using them for quite similar tasks, including electronic mail, word processing and accessing websites.

Experimental Procedure and Design

TUI Condition

In the TUI case, ten 2" x 2" x 0.75" wooden blocks were used to represent the news articles. Each block had a piece of paper on top which was used to cover up markings on the top of some blocks, to make them appear as visually similar as possible. Each block contained a digital identification tag and two strips of fuzzy conductive material on the bottom, as used in the mediaBlocks system [24]. The content of a block was accessed by inserting it into a reader device, which was attached with Velcro to the bottom left corner of a 21" computer screen.

The reader was designed so that the weight of the blocks would be enough to ensure electrical contact was made as the blocks were placed in the device. It could only accommodate one block at a time. The reader device only allowed wooden blocks to be placed into it if the diagonal face of the block was facing toward the subject. This ensured that proper electrical contact would be made with the block.

The experimenter demonstrated the use of these blocks to the subject, and then asked the subject to try using them. All subjects were able to use the blocks correctly on the first try, and reported no difficulty in understanding how to use them.

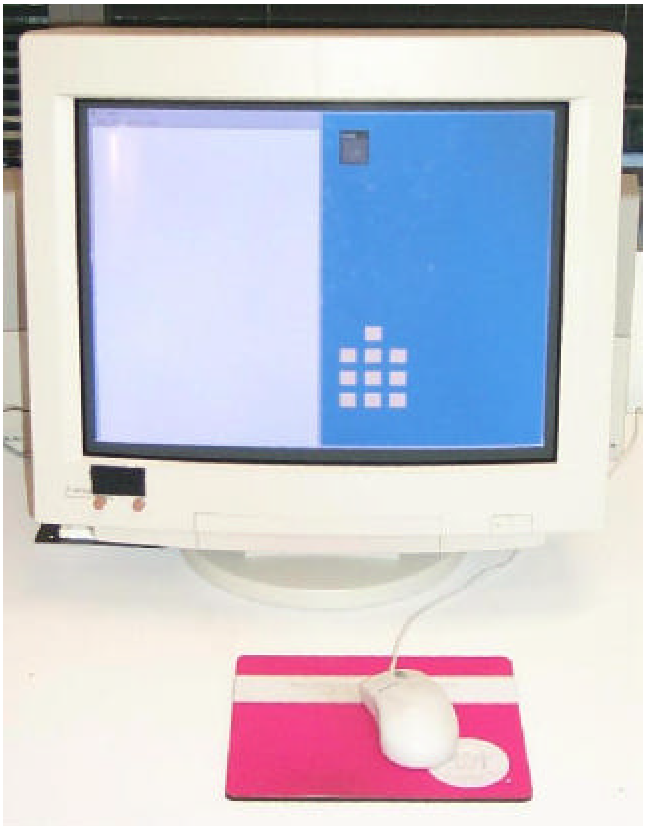

Figure 2 The GUI task with icons in their starting positions

When a block was placed into the reader, conductive strips inside of the reader connected with those on the block so the digital identification of the block could be read. Based on this identification number, the news summary corresponding to that block was displayed on the left half of the screen, directly above the reader device. The right half of the screen was not used in the TUI.

The task began with the blocks grouped to the left of the display as shown in figure 1. No items were on the desk except the monitor and the blocks. Subjects were told that they could leave blocks in any location on the desk when they were not in use.

GUI Condition

In the GUI case 10 visually identical 45x45 pixel icons were used to represent the news summaries. These icons were constrained to the right half of the screen in an area measuring 640x1024 pixels, while the summaries themselves occupied the left half of the screen. The screen was divided in this manner to prevent the text of the news summaries on the screen from occluding any of the icons. The content of these icons was viewed by dragging the icons into a graphical reader area at the top of the screen. As in the TUI case, subjects were told that they could leave icons in any location when they were not in use.

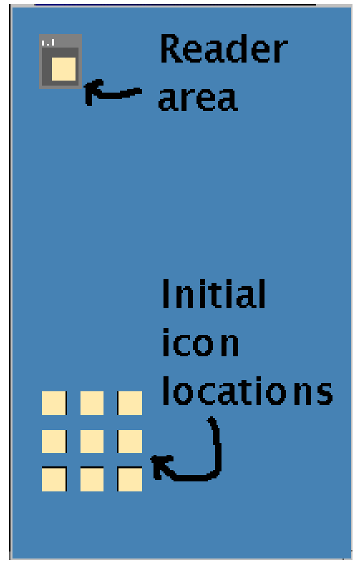

Figure 3 - The news summary associated with an icon is displayed when the icon is moved to the reader area.

Software was used to constrain the icons so that only one icon could be placed in the reader area at a time, to maintain consistency with the physical case. Users could not double-click on the icons to open the news summaries as one can in many common GUIs. We wanted to understand how users would choose to arrange the icons if they had to develop some sort of strategy for doing so. Allowing users to double-click to open them would have made it possible to view each article without moving the corresponding icon. We suspect that in this case subjects would have done quite poorly at recalling which icon corresponded to each summary, as a similar experiment revealed quite poor recall rates [16]. Instead, we relied on the drag-and-drop metaphor which is commonly used in today's GUIs, and which also maintained consistency with the TUI condition of our experiment.

Subjects participating in the GUI case were shown how to use the interface, and then were asked to try it themselves. Only one subject had difficulty using the interface at first, and after the experimenter explained that the left mouse button rather than the middle one had to be used to drag the icons, this subject did not have difficulty.

Design Considerations

Both GUIs and TUIs have a variety of characteristics that come "for free" which would greatly improve performance in tasks such as this one. For example, the icons on the screen could be annotated with short text labels which describe the summaries. The icons themselves could contain an image relevant to the summary. Summaries could be structured hierarchically in "folders" on the screen. In the TUI case, users could draw annotations with erasable pens on the tops of objects used to represent data. The three dimensional nature of the objects could be used in a variety of ways, such as stacking the objects on top of each other or storing them in different locations in the physical environment. In addition, graphical information about the physical objects in a TUI could be projected either from above [25] or below [23] the surfaces upon which they rest. In this experiment, we tried to take out as many of these factors as possible to focus on the issues of space so that we could begin to understand the differences between GUIs and TUIs in this regard. We insured that the objects a subject used, whether physical or graphical, looked as similar as possible, and that subjects had the same amount of space to work with while rearranging the objects in proportion to the size of the objects themselves.

Because the experiment involved a surprise spatial recall task, we used a between-subjects design. After performing one condition of the experiment, subjects learned that the experiment was focusing on their spatial organization strategies rather than their approaches to newspaper editing. Our pilot experiments suggested that subjects did not focus on the task of organizing the articles for a newspaper when they knew that a spatial recall task would follow. Rather they focused on memorizing the article locations according to some mnemonic. For example, one pilot subject alphabetized the stories based on their titles, treating the task as a memory task rather than an organization task. We were more interested in organizational strategies based on the content of the articles than simple strategies such as alphabetization. We expected that a strategy based on the content of the articles would have to evolve over time as the subject read more of the articles, where a strategy such as alphabetization would not. We felt that the process of revising strategies during the experiment was important to explore, because strategies might evolve differently in the TUI than in the GUI.

Limitations

While we controlled for a variety of factors between the TUI and GUI conditions of the experiment, we did not control for the extra rotational dimensions available in the physical interface. The wooden blocks we used were shaped such that the front and back were easily distinguished, so users would insert them correctly into the block reader. While it was possible for a subject to use the rotation of the blocks on the desk to encode information about them, we anticipated that subjects would tend to keep the front of the blocks facing toward them, so that they could be inserted quickly and easily into the reader. In practice, no subjects reported using the rotation of the blocks to encode any information.

In addition, we did not control for the organizational strategies that subjects were familiar with, or chose to use in the experiment. In one sense this was desirable because it helped us to understand what types of strategies subjects were inclined to use given the skills at their disposal. However, this decision also contributed to within-group variability, because the organizational strategies subjects used seemed to be an important factor in recall performance. While this limitation would not have been an issue in a within-subjects design, we believe that when coupled with our surprise recall task, a within-subjects design could have introduced more severe limitations. As discussed in the "Design Considerations" section, pilot subjects changed organization strategies when expecting a recall task. We were concerned that this change of strategies between the two trials would add noise to our data.

RESULTS

We found that TUI subjects performed significantly better than GUI subjects at the recall task. In addition, some TUI subjects employed spatial encoding techniques which relied on the position of the blocks within an external reference frame, while GUI subjects did not. TUI subjects who used this reference frame based positioning strategy did better on the recall task than those TUI subjects who did not. We discuss the findings in detail below.

Recall Task

Subjects in the TUI case remembered the locations of an average of 5.0 blocks (std. Dev. 2.85) With an outlier removed as discussed below, subjects in the GUI case remembered the locations of 3.47 blocks on average (std. Dev 1.23) Figure 4 shows this result. The bars represent standard error.

On the GUI portion of the experiment, one subject correctly recalled eight of the news story locations, placing him 2.68 standard deviations above the mean for GUI subjects. This is above the critical value of 2.50 (5% confidence interval) for a single outlier in a normally distributed sample of 18, as discussed in [1]. In a telephone conversation with one of the experimenters 11 days after participating in the experiment, this subject

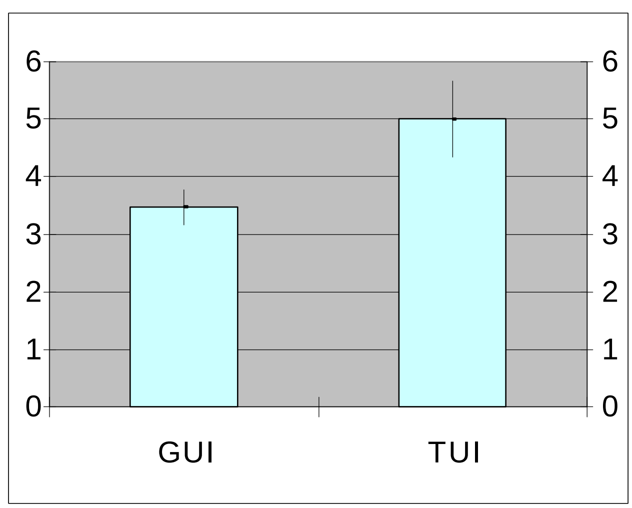

Figure 4: GUI and TUI object recall rates

was able to correctly recall the organization strategy he used in the task, complete with the location of the groups of icons on the screen and the stories associated with each group. Because of this subject's demonstration of this superb memory ability and his large deviation from the mean GUI score, we separate this datapoint in the remainder of our statistical analysis. This subject's organizational strategy involved grouping the stories into four categories. He did not report using any techniques different from the usual GUI grouping strategies described below.

We performed a one-way ANOVA and found the difference in performance between GUI and TUI subjects to be statistically significant ($p < 0.05$, $F(1,34) = 4.16$).

Spatial Arrangement Strategies

After the memory recall tasks, we asked subjects to describe their spatial layout strategies. Three GUI subjects reported that they adopted a layout strategy after reading only one or two stories, but later their arrangements of icons became less and less consistent as they found that some of the remaining stories did not fit well into the organization scheme they had devised. Because they did not adopt a new classification scheme after finding that their initial one was not sufficient, when they were done reading the articles they found the organizational structure of little assistance when remembering which story each icon contained.

In contrast, we observed that some TUI subjects appeared to frequently adopt new organizational schemes, or adjust old ones, in order to accomodate new stories. We would often see TUI subjects re-read the first three or four stories and rearrange them on the desk before reading the remaining stories for the first time. Other TUI subjects would read all of the articles once first, and then rearrange them on the desk by quickly checking the title of each one in the reader, and then moving it to an appropriate location on the desk.

Through our interviews of subjects, we found that three basic types of spatial encoding mechanisms were used, though at times they were used in concert with each other. These strategies were:

- Grouping - Subjects would place summaries with some property in common together in the space. e.g. Summaries only of interest to local audiences, or summaries about violence.
- Ordering - Subjects would rank summaries or groups of summaries along an axis, such as how the summaries made the United States look in the eyes of other countries.
- Reference frame based positioning - Subjects would place an object by itself in the space, in a location which meant something specific to that object, regardless of the spatial arrangements being used for other objects. For example, one TUI subject placed a summary about fires in the western United States far to the left of other summaries to represent that it dealt with the western part of the country. Another TUI subject reported placing an article about heart problems on the desk directly in front of his heart and placing a summary about arms sales directly in

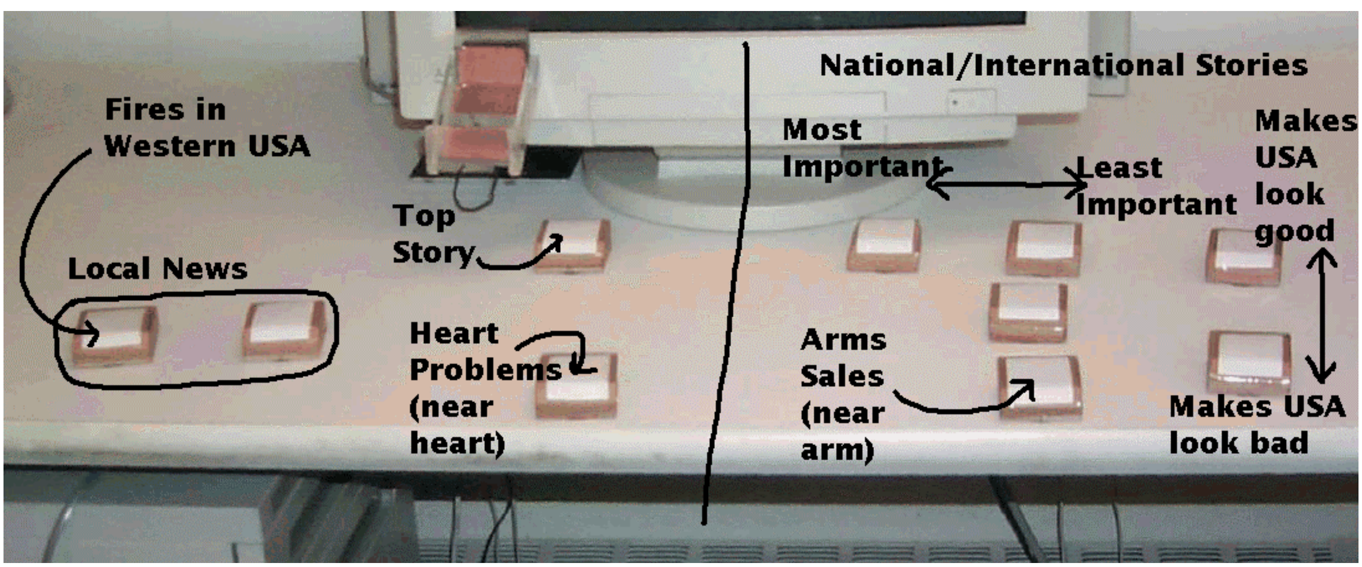

Figure 5 – Example final position of the blocks after the TUI task. Note the use of grouping, ordering, and reference frame based positioning.

front of his arm, taking advantage of the dual meaning of the word "arms."

Subjects in both conditions of the experiment employed grouping and ordering strategies. The results are summarized in tables 1 and 2. Eight GUI subjects used a grouping strategy. Seven of these eight used grouping exclusively, while the other one also sorted two of the groups' contents by importance from left to right. In contrast, ten TUI subjects used grouping, but seven of these ten employed it in combination with another strategy. All five subjects who used reference frame based positioning also used grouping.

Subjects grouped the summaries into categories such as "front page" "world news" and "local news" or "politics," "human interest" and "other." Subjects used ordering schemes based on various parameters including how interesting the summaries were, or the number of people they affected. Figure 6 shows a typical final layout of icons for a GUI subject. None of the subjects in the GUI case used a layout strategy which included reference frame based positioning. However, five TUI subjects did use such a strategy. This reference frame based strategy seemed to help subjects improve recall rates as well. The mean recall rate of subjects who incorporated this strategy was 8.2 (std. dev. 2.05) which is in contrast to the mean recall rate of 3.8 (std. dev. 2.05) for TUI subjects which did not use reference frame based positioning. Note that this mean is quite similar to the overall mean for GUI subjects. Figure 5 shows the final position of the blocks for a subject who used this reference frame based positioning strategy. The high standard deviation in the TUI data is due to the difference in performance between subjects who employed reference frame based placement strategies and those who did not. The correlation between the use of a reference frame based positioning scheme and performance in the recall task for the eighteen TUI subjects suggests that a reference frame based positioning strategy is an effective method for representing information using spatial layout in TUIs.

In both the TUI and GUI conditions, there were some subjects who encoded little or no information into the spatial arrangement of the tokens. Three TUI subjects and three GUI subjects placed each token very near where it was before they began reading it, in essence not using any spatial organization strategy at all. In addition, three TUI and three GUI subjects simply kept the tokens they had already read separate from those they had not. Finally, two GUI subjects and one TUI subject sorted the icons according to the order in which they had read them.

When asked about the layout of the objects, subjects who employed little spatial organization gave several explanations. One TUI subject said that "accessing the stories from the blocks was so easy that I felt no compelling need to organize them." A GUI subject said she was "storing them more mentally than spatially." Finally, a TUI subject mentioned that he was expecting to be quizzed on the details of the news summaries, so he had focused on memorizing them rather than on thinking about how the summaries might be used in a newspaper.

Strategy	Num. Subjects	Recall Rate
Little/no organization	8	3.38
3 groups (no ordering)	6	4.16
3 groups (ordering within 2)	1	3
4 groups (no ordering)	1	2
Only ordering	1	3

Table 1: Strategies and recall of GUI subjects

Strategy	Num. Subjects	Recall Rate
Little/no organization	7	4.14
3 groups (no ordering)	1	1
3 groups (ordering within all)	1	8
4 groups (no ordering)	2	3.50
Only ordering	1	4
4 groups (ordering within 1)	1	0
Reference frame based positioning along with 1-4 groups	5	8.20

Table 2: Strategies and recall of TUI subjects

DISCUSSION

We observed that TUI subjects performed better than GUI subjects at the recall task. We also observed that some TUI subjects employed reference frame based positioning effectively in the experiment. In this section we will discuss possible causes and implications of these results.

In the Results section, we reported that TUI subjects seemed more likely to change an organizational strategy to fit new stories as they read. One possible explanation for this difference is that it is easier to move tokens around in a TUI than in a GUI. With a TUI, subjects can manipulate objects with both hands at the same time. They can also slide groups of objects on the desk with one hand. As well, TUI users get instant, haptic feedback when they touch a physical token.

The models for GUI and TUI input suggest another key difference in usability. In the three-state model for graphical input[4], one must first grasp the physical input device, such as a mouse. Next, one must use this device to acquire the graphical object to be manipulated. Finally, one can manipulate the graphical object as desired. In the physical world, a two-state model is more appropriate: one simply acquires the physical object to be used, and then manipulates it[8]. The extra step required for this task in a GUI suggest that more time and mental effort is typically required to perform this task.

The separation between the mouse and the GUI screen may also make interaction with a GUI more difficult. When a user moves an icon on the screen with a mouse, the mouse itself moves in a horizontal plane, while the cursor moves in the vertical plane of the screen. MacKenzie and Iberall have pointed out that when the visual map and the proprioceptive map are not aligned, performance in object manipulation tasks can degrade [17].

Another issue that may complicate the process of manipulating objects in a GUI is the act of picking the mouse up off of the mouse pad. With most mice, the mouse pointer is only moved when the mouse is in contact with the surface beneath it. This means that just because the mouse pointer is at one side of the screen, the mouse itself and the hand guiding it are not necessarily at the corresponding corner of the mouse pad. Because the positions of the mouse cursor and the mouse itself are seldom correlated, the user cannot employ the position of the physical mouse relative to his or her body to help remember the positions of things on the screen.

These differences in interaction qualities between GUIs and TUIs may make users more likely to involve TUIs than GUIs in epistemic action. Epistemic action is a way to help offload thinking and memory tasks from the mind to the external world. In order for epistemic action to be worthwhile in a problem solving task, one must save more mental effort by encoding information in the physical world than one expends in the encoding process. Thus, the easier it is to manipulate objects in a problem solving task, the more frequently it will make sense to encode information in those objects to make the problem easier.

Another reason why TUI subjects may perform better at the recall task than GUI subjects is that people may be better at remembering where they have placed physical things than graphical icons, regardless of the organizational structure that they place them into. One aspect of this may be motor memory. While motor memory may be used to one's advantage in a TUI, the motions required to manipulate an object in a GUI change each time the user picks up the mouse and recenters it on the mouse pad, so memory of past actions seems less useful.

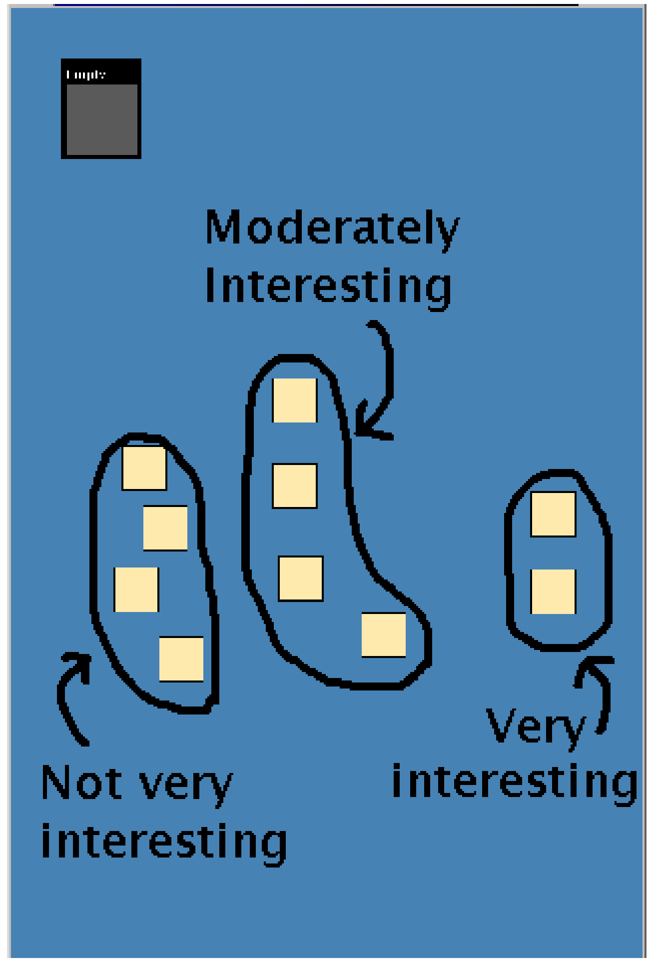

Figure 6: Positions of icons after the task. This subject only used a grouping strategy, though some GUI subjects also employed ordering approaches.

Another issue to consider is that one must pay explicit attention to the locations of nearby objects when moving things in the physical world. Thinking about avoiding other objects while placing an object in the physical environment may help the user remember location better, because more attention must be directed to the locations of nearby objects [Whittman Richards, personal communication]. To move an object on a desk, one must either lift the object off of the desk or slide it carefully around other objects to avoid disturbing their positions. In most cases, GUIs do not exhibit this behavior.

The use of reference frame based positioning in the TUI case seems to be important as well for developing a coherent spatial arrangement of the blocks. There are several reasons why this placement strategy may be more appropriate for TUIs than for GUIs. The first issue is that the visual and physical properties of objects are much more varied in the context of TUIs than in GUIs. Even in this experiment, in which we removed extraneous objects from the desk area which conceivably could have been used in a spatial organization scheme, one subject used the context clues provided by the computer monitor, by placing a block near its base to help him remember to put the corresponding story in the front page of his newspaper.

The human body can be a useful reference frame for TUIs as well. When a user places an object to his or her left in physical space, from the user's perspective this object is in a very different position from an object in front of the user. The center and right side of a computer screen are close together in comparison. With a standard desktop monitor, icons spread about the screen are all still in front of the user. This makes it difficult to use the position of the objects relative to the body to differentiate between them.

Because using spatial information seems to be easier in TUIs than in GUIs, TUIs may afford Kirsh's epistemic action to a greater degree than do GUIs. This conclusion is supported by the decisions of several of our GUI subjects in the experiment to abandon or not develop their spatial organization strategies when their original strategy did not appear satisfactory. In short, TUIs may make it easier for us to think about some problem solving tasks in ways that GUIs do not.

The differences between TUIs and GUIs observed in this experiment suggest some design considerations for TUIs. First, it can be useful for an interface to provide ways for the user to move and organize objects without these operations being interpreted by the TUI. Consider an interface in which a user places objects on a rack to perform an operation. A designer might choose to not have the system interpret the order of the blocks on the rack, so that the user could manipulate the order to help keep track of the task he or she was trying to accomplish.

As well, physical scale can be important in making a more usable TUI. Because GUI screens are so small relative to the size of our bodies, it is difficult to employ the reference frame our body provides to help us organize groups of objects in a GUI. TUIs which employ a small physical structure as a central part of the interface can fall prey to the same problem. However, TUIs which have a larger physical size can take advantage of the spatial reference frame of the user.

FUTURE WORK

This experiment poses several questions which we are interested in exploring. Some of our users said they did not feel a strong association between the blocks or icons and the content they displayed. Based on this we wish to explore how having labeled blocks and icons will affect the users' layout strategies. These labels would be removed before the recall task. We suspect that we may observe more consistent patterns of user behavior in this case.

As well, we are currently working on more sophisticated tracking technology for monitoring the positions of objects in TUIs. We are considering using this technology to perform further experiments in which the positions of several objects on the screen are directly mapped to the positions of several physical objects on a horizontal surface in front of the screen.

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