

Navigational Techniques to Improve the  
Display of Large Two-Dimensional Spaces

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## Abstract

Often the components of a problem can be arrayed on a two-dimensional information space (e.g., abstract tree or Hypertext) far too large to fit onto the display screen of a workstation. With current navigation techniques it is often difficult for users to keep track of their location or to move rapidly to remote locations in the space.

We developed two similar direct-manipulation techniques that both use a map-window--a miniature of the entire information space--with a wire-frame box to aid users in remembering their location. The first technique allows the user to rapidly "roam" over the information space by moving the location of the wire-frame box. The second allow for "zooming" as well as roaming.

A controlled experiment compared the above techniques to scroll bars for determining whether a target word was in a large balanced binary tree of words. The experiment also examined the merit of the map window.

Map windows significantly improved user performance, and the roam and zoom techniques were significantly faster than the scroll bars. Our observation of subjects and their verbal protocol indicated that a paging feature on the scroll bars--allowing rapid movement of the screen a page in any direction--was advantageous.



# **Introduction**

Often the components of a problem can be arrayed on a two-dimensional information space. Sometimes the information has a visual analog that makes the meaning of the information space clear to the user; a city map or a cat-scan medical image, for example. At other times, information can be represented as a two-dimensional logical graph consisting of arcs and nodes; for example, structure charts, data flow diagrams, PERT charts, Hypertext graphs, and spatial databases (Herot, 1980).

If the two-dimensional information space fits completely onto a display screen, there is no navigation problem. A user can point to any location using one of the computer's pointing devices and is never lost because he can always see the complete information space. But what if the information space is considerably larger than the display screen? What if the user wishes to navigate and examine a graph consisting of 10,000 nodes and arcs?

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## **Research Description**

While moving a cursor on a single screen is relatively well-understood, navigating in a two-dimensional information space consisting of hundreds of screen-size pages has not been so well studied. What navigational techniques allow a user to locate and view both nearby and remote regions in a large, two-dimensional information space?

We developed two similar direct-manipulation techniques that both use a map window--a miniature of the entire information space--to aid the user in remembering his location. The first technique allows the user to rapidly "roam" over the information space. The second allows for "zooming" into the space as well as roaming. The zoom technique is especially well-suited for hardware implementations that can support such a feature.

A controlled, between-subject experiment compared the above techniques to scroll bars for determining whether a target word was in a large balanced binary tree of words. Both horizontal and vertical scroll bars were used to allow two-dimensional movement. This three-by-two experiment additionally examined the merit of map windows.

Map windows significantly improved user performance, and the roam and the zoom techniques were significantly faster than scroll bars. Our observation of subjects and their verbal protocol indicated that a paging feature on the scroll bars--allowing rapid movement of the screen in any direction--was advantageous.

The following section contains a brief summary of previous work in this area. Next, the two navigational techniques are described. The controlled experiment is then described along with results, conclusions, and recommendations.

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## Previous Work

In this section, we first look at applications where navigation in one direction is used, then at more general two-dimensional applications, and previous uses of map windows.

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### Single-Page Navigation

Card, Moran, and Newell (1983) compared four pointing devices (a mouse, a joystick, text and step keys) for the task of searching for known words in a single page of text completely displayed on a computer screen. They did not study whether similar results would be obtained with many screens of text. Card et al., found that user performance in these tasks could be predicted by Fitts's Law (Fitts, 1954; Welford, 1968), "which says that the time to move the hand to a target depends only on the target's distance and its size." Their study showed the mouse performed best among the four devices they tested for this restricted task involving a single page of text.

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### Multiple-Page Navigation

Text files are frequently much too large to be displayed on a single screen. Moving to the proper region in the text complicates the task of finding individual words and phrases. A large text file is commonly thought of as a scroll that passes under the screen. The screen is thought of as a viewport that can be moved on top of the underlying one-dimensional information space.

Scrolling is usually accomplished using the available pointing devices, in addition to their pointing function. For example: cursor (or arrow) keys are commonly used to scroll a viewport up or down one line at a time, typically with a repeat option; or paging keys move a viewport up or down one page (or a portion of page) each time they are pressed.

Scroll bars (as introduced in the Smalltalk system: Kay, 1977) allocate some of the display screen specifically to aid the scrolling process. Scroll bars indicate both the current position in the file and how much information there is above and below, or to the left and right. They also allow rapid movement to remote regions of a file.

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### Two-Dimensional, Multiple-Page Navigation

A great deal of information is conceptually thought of as two-dimensional, and has long been represented on paper. A computer-displayed, two-dimensional information space has several advantages over paper, including being potentially infinite in the size of both dimensions. Its restriction, however, is the limited size and resolution of the display screen.

Several navigational techniques are common; the techniques differ in two areas: 1) in the ease with which they allow diagonal or curvilinear movement (the problem on a classic "Etch-A-Sketch," for example), and 2) in the ease in which they allow rapid access to remote regions of the space. Typically, users navigate within a spreadsheet, for example, with cursor keys and scroll bars to move horizontally or vertically among the cells (Hayes, 1985). Microsoft Windows supplies horizontal and vertical scroll bars to move its viewport window over a large underlying, two-dimensional space (Microsoft, 1985). MacDraw allows two-dimensional navigation with a "hand" that grabs the space and scrolls it under the viewport. We did not specifically study navigation using the cursor keys or the hand, since, while good for fine-focusing, we observed that they were unsuitable for movement to remote regions.

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## Map Windows

If the size of the information space is large (or unknown), the user can easily become lost. Maps, however, help users keep track of their location (Baird, 1979) and should greatly improve the total interaction. In thinking about maps to aid navigation, we considered how we use a large road map in a car. While the map usually covers everything we want to see, we typically focus on a smaller local region--and fold the map up to show just that region. Variations of map windows are often found in computer games, CAD/CAM and drafting packages, and VLSI tools such as ICARUS (Card, Moran, and Newell, 1983, Ch. 10). A map window should either take up little valuable screen space or the effort needed to show and hide it should be minimal.

# The Two Navigational Techniques Studied

## Objectives

The objective of these two navigational techniques is to allow easy access to various locations in a two-dimensional information space, including both near and far perpendicular and diagonal motion. These techniques are application-independent; they can be used for a general class of computer interaction problems that involve locating current position and moving through a two-dimensional information space considerably larger than the display screen. While their functions differ, the techniques share an underlying mental model and a considerable overlap in interaction style.

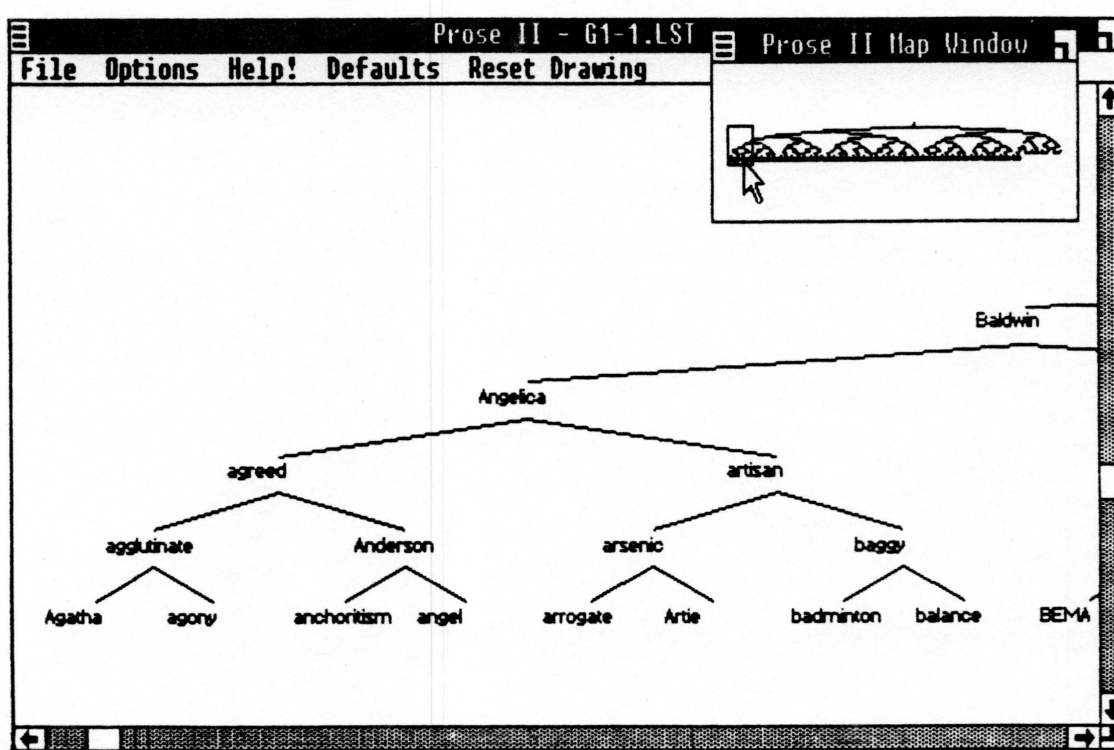


Figure 1. A typical display screen in our experiment.



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## Map Window

Figure 1 illustrates the display for Prose II. The design for this tree-based structure editor is the result of work on previous editors and ideas by the Writing Research Group at the University of North Carolina (Smith, 1983; Smith et al., 1985). In the upper right hand corner of the screen is a small window--the map window--showing in miniature the entire two-dimensional information space. A rectangle (called here the "wire-frame box") inside the map window denotes the portion of the information space that is shown in the main display. This main display becomes a viewport into the larger information space.

The map window takes up screen space, but in return provides a clear notion of where the user--or more to the point, his current viewport--is within the information space. Further, it allows direct manipulation (Schneiderman, 1987, Ch. 5) of the viewport within the space. For many applications, the tradeoff of screen space for better navigation is worthwhile. If screen space is critical, the map window can be made to only appear when desired.

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## Zoom Navigational Technique

To change the location or the magnification factor of the main display, the user moves the cursor--using a mouse--into the map window, presses the mouse button, drags the cursor down and to the right, and releases the button drawing a new wire-frame box in the map window. The original wire-frame box disappears. As in the previous case, the magnified contents of the new box are shown in the main display. If the new box is within the old, the user has zoomed in. This technique allows a user to zoom out, or roam around the screen. The user can also zoom into the space by drawing a wire-frame box within the main display itself using the right button on the mouse. We dedicated a mouse button to zooming in our implementation, giving us immediate access to the zoom feature, and more precise control over the magnification and size of the image in the main display.

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## Roam Navigational Technique

Both roaming and zooming within the information space may be useful in a single implementation; however, for many applications it may be either too slow for the given hardware-software combination, or inappropriate for the users' task. To this end, we have an alternate navigational technique that allows roam but not zoom. Like the zoom technique, a map window is provided and a wire-frame box within the view denotes the location and size of the main display. However, with the roam technique the magnification is fixed at full resolution and the dimensions of the wire-frame cannot be changed. Instead of drawing a new wire-frame box, the user "grabs" the existing box with the mouse button, drags the box to its new location, and "releases" it. The main display then shows the region of the information space within the new location of the wire-frame box.

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## Experiment

**GOAL:** The purpose of the study was to evaluate the usefulness of the roam-and-zoom techniques by comparing them to scroll bars (both horizontal and vertical), and to evaluate the effectiveness of map windows.

**HYPOTHESES:**

- 1) Each of roam and roam-and-zoom would be better than the scroll bars, both with and without the presence of the map windows.
- 2) Each of the techniques with the map window would be better than without.

We believe these two hypotheses are predictable. A back-of-the-envelope Fitts's Law calculation would tend to support the first hypothesis for rapid movement on the screen. Grabbing one object on the screen is likely to be much faster than grabbing and moving two. Further, the total distance needed for movement, and the different sizes of the grabbed objects would both tend to suggest slower times for scroll bars. The one exception would be if a preponderance of movements required only horizontal or only vertical movement. The map windows provide "contents." Roaming to unknown locations in the space should be faster because the subject only has to move to a location, not also find it.

**SUBJECTS:** Six computer science graduate students were used as subjects in the experiment--three males and three females, with ages ranging from 23 to 26. The experience of these subjects ensured that mouse manipulation or the task of searching for words in the dictionary did not overwhelm the effect of the navigational techniques. We judged them all to be excellent English speakers.

**APPARATUS:** An IBM Personal Computer AT (tm) with an IBM Enhanced Graphics Adapter and Display and a Microsoft mouse were used throughout this experiment. This monitor has a resolution of 640x350 pixels. The structure editor used in the experiment was written using the Microsoft Windows Software Development Kit. The zoom technique was implemented in software, without any special hardware assist.

The study was conducted in a well-lit office isolated from external sound. Subjects were comfortably seated in front of the computer and were allowed to adjust the location and angle of the monitor, and the location of the mouse. The experimenter sat behind and to the right of the subjects and used the computer's keyboard to control the experiment. Times were recorded manually using a stopwatch.



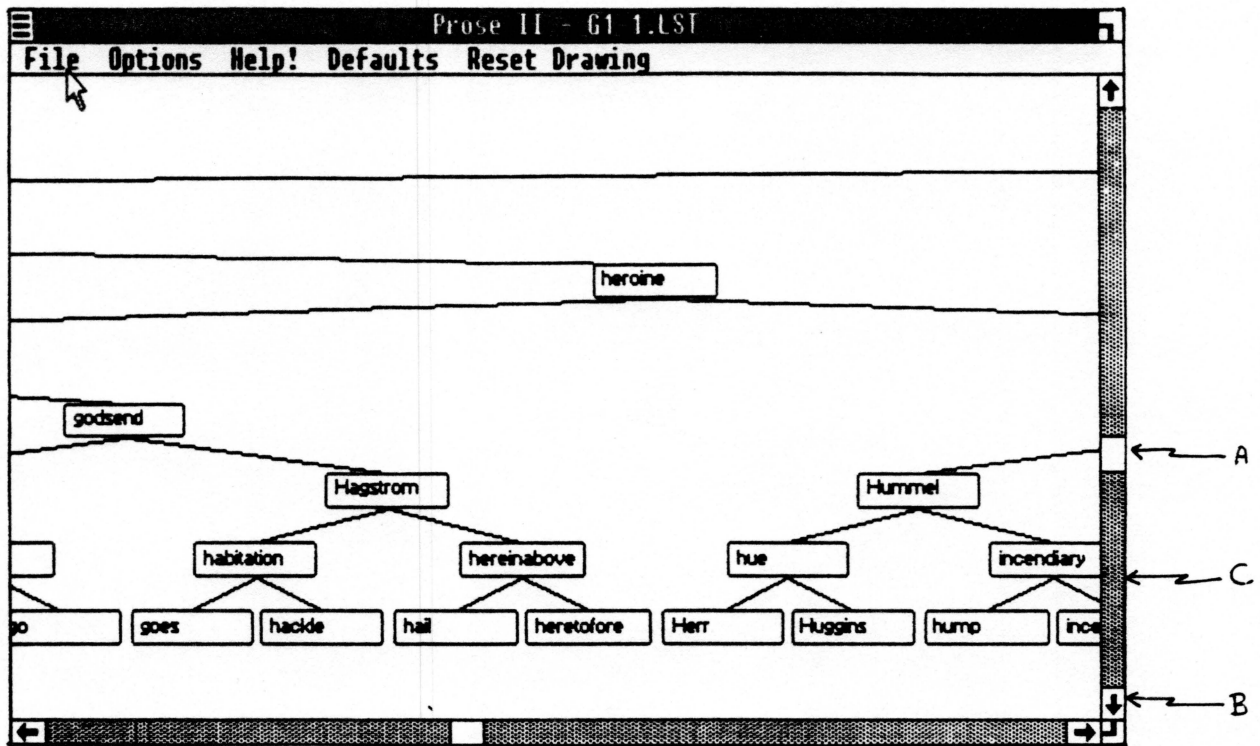


Figure 2. Scroll bar features, as implemented in the Prose II editor.

The scroll bars used in the experiment appear along the bottom and far right of a display window (see Figure 2). The location of the viewport in the underlying two-dimensional information space can be controlled using three techniques. First, the mouse can be used to grasp the scroll (a) and move it to a new location, changing the viewport to the corresponding location in the information space. Second, one of two small arrows (b) at either end of the bar can be clicked with the mouse. This causes the main display to "scroll" in the direction indicated by the arrow, for a distance equal to the size of a node in that dimension. Finally, if the region between the bar and the arrow is clicked (c), the bar moves one page (the size of the main display) in the direction of the arrow.

The three navigational techniques were each used with and without map windows to determine the significance of displaying, in miniature, the entire information space. However, both the roam and zoom techniques require the presence of the map window on which to operate. Therefore, when the map window was not desired, it was displayed empty, that is, without a miniature of the underlying information space.

As can be seen from Figure 2, the map window, while detailed enough to show the span of the binary tree, is unable to display the labels of the individual nodes. Thus, users cannot locate exact words using the map window; they can only move to a general region in the tree using their spatial and cognitive abilities.

**TASKS:** The effectiveness of a navigational technique may depend on the amount of "cognitive resources" available to perform the task (see Card, Moran, and Newell, 1983). To fully evaluate a technique, two different sorts of tasks were used: the first task required the subject to navigate in order to solve a reasonably complex cognitive problem, while the second task allowed the subject to fully concentrate on navigation.

Task One required the subject to find a word in a balanced binary dictionary tree in which the labels of the nodes were dictionary words. Thus the subjects were navigating through the dictionary tree while doing the cognitive task of word recognition and binary search.

Task Two required the subject quickly to move the viewport from displaying the apex node of a binary tree to displaying the rightmost leaf node--and back--five times. Thus, the subjects could fully concentrate on the navigational task.

**PROCEDURE:** On being admitted to the office, the experimenters greeted the subjects, gave them a brief description of the experiment and its purpose, and obtained background data from them. They were then shown how to use the scroll bars, roam technique, and zoom technique in varying order. Each subject was trained and tested on Task One, followed by Task Two. Throughout the experiment, observations and verbal protocol were manually recorded. Subjects were instructed to "work as quickly as possible without making errors."

For each technique the following procedure was used. First, four training trials were given using the technique with the map window to familiarize the subject with the technique. Then, four training trials were given with or without the map window followed by a brief rest break with eyes closed (to avoid eye fatigue), followed by five timed trials. After a one minute break, four additional training trials were given, followed by an eyes-closed rest break and five timed trials.

An individual trial for Task One proceeded as follows: the subject was shown a 3x5 card on which the target word was written. After about four seconds, the subject was asked "Ready?" and then a verbal "Go" signal were given and the stopwatch started. With the cursor in the center of the screen, the subject placed his or her hand on the mouse, manipulated the image in the viewport until the region in the tree where the word either was or should have been was displayed, and said either "Yes" or "No" to indicate whether the word was or was not in the tree. The experimenter then said "Good," recorded the time and whether the correct result was obtained.

After completing all the Task One training and trials, a three-minute rest break was given followed by Task Two. Again six groups of trials, one for each navigational technique with and without the map window, were given. No additional training was used, since Task Two followed directly from the Task One trials.

An individual trial for Task Two proceeded as follows: the subject started with his or her hand off the mouse. A "Ready?" followed by a "Go" signal were given and timing begun. The subject manipulated the mouse to move the main display first from the apex node, to the rightmost leaf, then back--five times. The subjects were again instructed to work as quickly as possible without making errors. Only trials in which every target node was correctly located were counted. The same binary tree was used for all trials for a given technique in Task Two.

DESIGN: The study was organized as two different three-by-two between-subject experiments, one for Task One and one for Task Two. The independent variables were the navigational technique (roam, zoom, or scroll) and the presence or absence of the map window. The dependent variable was error-free response time.

For Task One, each of the six subjects completed five trials for each combination of navigational technique with or without the map window. Thus there were a total of 60 data points for each pair-wise comparison. For Task Two, each of the six subjects completed three trials for each combination of technique with or without the map window. There were therefore a total of 36 data points for each pair-wise comparison.

CONTROL: The order of the navigational techniques for the presence or absence of the map window was controlled to avoid learning effect. For all trials in Task One and between groups of trials in Task Two, the dictionary trees were varied to avoid having learning about individual trees affect the comparison of techniques or evaluation of the map window.

The dictionaries contained 280 words, selected at random from an online public-domain dictionary, but controlled for character length, number of syllables, and familiarity. About fifteen nodes of the tree were visible in the main display at one time. The target words were chosen so that about half actually were in the displayed trees. They were presented to the subjects in a random order to insure there was no known linguistic or spatial pattern in their order.

ANALYSIS: We used the Differences of Means method to analyze the trial data, since we were testing for significance involving sample differences. The critical value of  $z$  was compared in a standard table for one-tailed tests, since we were testing the hypotheses that our navigational techniques were better than scroll bars, or that navigation performance was better with a map window than without.

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## Results of Task One

Six subjects were run with a total of ten trials for each technique, five with and five without the map window. All the subjects run were able to successfully complete the experiment. The results are summarized in Table 1, below. Of the 180 timed trials, eight were discarded due to subject error.

Several of the results are significant: the use of a map window was found to be significantly better than without (95% confidence); the roam-and-zoom technique and the roam technique were found to be significantly better than scroll bars (both with

95% confidence). The experiment design did not provide for enough data points to allow pair-wise analysis of each of the individual techniques when showing the map window as compared to when it was hidden.

	Roam alone	Roam-and-Zoom	Scroll Bars	Total
	mean/SD/CV	mean/SD/CV	mean/SD/CV	mean/SD/CV
with map window	23.8/12.3/.5	21.3/8.9/.4	27.6/12.7/.5	24.2/12.2/.5
no map window	25.4/10.8/.4	27.9/13.6/.5	31.8/17.6/.6	28.3/14/2/.5
Totals	24.6/11/5/.5	24.7/12.3/.5	29.7/15.7/.5	

Table 1. Each cell in this table contains the mean time, in seconds, to determine whether the target word was present or not, the standard deviation (SD), and the coefficient of variance (CV), respectively.

## Observations from Task One

A wide variety of subject search strategies were observed. Some subjects followed a single path from the apex of the tree to the target nodes. Others went directly to the leaf nodes in the general region they expected the target word, and then systematically searched left or right and finally up until the word was located. Both of these search techniques required sequential movement, jumping movement, orthogonal movement in horizontal or vertical directions, and diagonal motion.

Having the entire tree displayed in miniature in the map window was clearly beneficial. Even though only the shape and not a node's label was visible in the map window, it still allowed a subject to move to the correct location based on what he could infer from the shape of the tree. For example, this greatly helped in locating the leaves of the tree.

With the aid of the map windows, we observed users quickly locating nodes and displaying them in the main display to see their contents. Without the map window, subjects would often take several attempts to move to a particular node and view its contents.

Because the map window was fixed, as the size of the search tree increased, the size of the individual nodes appearing in the map window and the size of the wire-frame box denoting the main display became quite small. Therefore, for very large trees, subjects had difficulty "grabbing" the wire-frame in roam mode, and drawing boxes of the correct size when zooming. With the zoom technique, some subjects overcame this by zooming in the main display.

Grabbing the wire-frame box was particularly difficult when the subject only wanted to move the main display a small amount in one direction. Two roam trials were rejected because the subjects tried to use the scroll bar's page-up or page-down



option, which appeared to be available on the screen. Several voiced the need for a sequential option with both the roam-and-zoom techniques. A smaller gain for the mouse might also help this problem. Several subjects mentioned that the gain was set higher than that at which they were adept.

## Results of Task Two

Table 2, below, summarizes the results of Task Two. Of the 108 trials, three were discarded due to subject error.

Several of the results are significant: the use of a map window was found to be significantly better than without (99% confidence); both the roam technique and the roam-and-zoom technique were found to be significantly better than scroll bars (99% confidence and 99% confidence, respectively).

	Roam alone	Roam-and-Zoom	Scroll Bars	Total
	mean/SD/CV	mean/SD/CV	mean/SD/CV	mean/SD/CV
with map window	18.1/3.6/.2	19.6/4.9/.3	35.7/9.2/.3	24.1/11.5/.5
no map window	27.3/11.8/.4	30.8/15.5/.5	46.0/13.4/.3	35.2/17.8/.5
Totals	23.1/12.3/.5	24.0/13.1/.5	41.7/15.2/.4	

Table 2. Each cell in this table contains the mean time, in seconds, to determine whether the target word was present or not, the standard deviation (SD), and the coefficient of variance (CV), respectively.

## Observations from Task Two

Using the page-down feature when appropriate appeared to be advantageous. Subject six discovered that the page-down feature would move the main display from showing the top of the trees to showing the bottom layers. Thus to move from apex to rightmost leaf with scroll bars required moving the cursor to the vertical scroll bar and hitting the page-down region, moving the cursor to the horizontal bar and adjusting the main display location until the rightmost leaf was in view.

Users often missed locating either the apex or rightmost leaf node on their first try. With the map window present, the primary difficulty seemed to be manually manipulating the main display rather than difficulty knowing the target location. Without the map window, additional error occurred when users tried to navigate by interpolating the target location relative to the sides of the empty map window.

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## Discussion

From the results of the above experiments, we can draw two conclusions: first, map windows are a significant advantage when moving in a large two-dimensional information space, particularly one that is unknown to the user; and second, the roam and the zoom techniques are superior to scroll bars for roaming in a large two-dimensional space.

We did not have sufficient data points to determine conclusively whether roam alone was better than roam and zoom together. A simple keystroke model calculation might indicate that fewer mental cycles (Card, Moran, and Newell, 1980 and 1983) and fewer hand motions would actually be needed with the roam-and-zoom technique. But we suspected that the zoom technique required more time to be spent thinking about the level of zoom, because a bad zoom is costly (in time and mental effort) to recover from, and the choice of the exact location of the starting point is often difficult and time-consuming.

From observation, the "paging mechanism" of the scroll bars proved valuable. No users used the scrolling mechanism; however, we believe that a significantly faster scrolling mechanism on the scroll bars would have resulted in its seeing more use. Unfortunately, the hardware needed for this performance improvement is often costly.

A great deal of learning seemed to take place during the trials in Task Two where the dictionary was not changed within sets of trials for a given technique, with or without the map window. This would suggest, as one might think, that the map windows are more useful in relatively unknown, or complex information environments.

We can envision specialized two-dimensional navigational situations in which neither of these techniques are ideal. For example, some applications might require only local or only orthogonal movements, or others might involve only a relatively small information space. But given the goal of a technique for general-purpose, two-dimensional navigation, both techniques seem more than acceptable.

We felt the key function missing from our roam and zoom techniques was a sequential paging mechanism, similar to that found in the Microsoft Windows scroll bars. Such function is easily added.



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