Visual Search of Computer Command Menus

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UIR-R-1984-08

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ABSTRACT

Two experiments explored how users perform visual search to locate a target in a computer command menu. In Experiment 1, users searched for menu items while their eye movements were monitored. Visual search was well characterized by an unsystematic search model in which the user may search the same place more than once. This model predicted the distribution of search times, the lack of an item position effect, and the frequency of saccade directions. In Experiment 2, the unsystematic search model was used to describe the effects on search time of three menu-item arrangements and of practice. Initially, the arrangement of the menu, whether alphabetic, random, or categorical, influenced the time required by the search. But with practice, the user eventually learned the location of each item in the menu, rendering the arrangement of the menu unimportant.

MENU SELECTION AND VISUAL SEARCH

The design of human–computer interfaces presents many opportunities for the application of psychological theory and technique. The study of these systems can, in turn, be useful for driving the development of theory. An example is the study of user performance with menu-based command systems, in which a user selects a command from a set of choices displayed to him. Such menus have acquired widespread use in human–computer interfaces. Part of their attraction arises because the user need not recall the command he wishes to invoke, but merely recognize or identify it. Against this attraction is the requirement that he search for and find the target command. This requirement leads naturally to the question of how such a search is conducted. The answer has both practical implications for the design of menus and theoretical implications for understanding how people search for information on other computer and noncomputer displays.

To avoid confusion, it is important to realize at the outset that there are several distinct, though related, menu selection tasks that a user might perform: (1) Knowing an actual target item, search for it. (2) Knowing a characterization of the target, search for the first suitable item (satisfice). (3) Knowing a characterization of the target, find the most suitable item (optimize). And (4) browse among the items to see what is of interest. The present paper is concerned with the first of these, simple menu selection, because this task is a tactically advantageous starting point. But each of these menu selection tasks (and probably others) is important in some practical circumstances.

Models of Visual Search

Consider how a user might search a simple menu consisting of a vertically arranged list of words. Intuitively, it might seem that he would search the menu by starting at the top and reading down line by line until he reached the target. Rather surprisingly, this seems not to be the case.

Krendall and Wodinsky (1960) and Engel (1977) consider two idealized ways in which the users could perform a search: (1) *systematic search* (sampling without replacement) and (2) *nonsystematic search* (sampling with replacement). Both models assume the a priori probability p_1 of finding the target on any saccade to be constant throughout the search.

In systematic search, the user is assumed to have some means to keep from searching the same area twice, such as searching from top to bottom. (There are, of course, other systematic strategies that are not linear scanning.) The cumulative distribution $P(t)$ for the probability of finding a target in time $\leq t$ would then be given by:

$$P(t) = (p_1/\tau)t \qquad \text{for } t < \tau/p_1 \tag{1}$$

where p_1 is the probability of finding the target with one more saccade (assumed to be independent of t), τ the average time/fixation (including saccadic travel time), and t the time that has elapsed so far in the search.

By contrast, in nonsystematic search, the user is assumed to have no means of keeping track of where he has searched, even for the immediately prior position, although he is assumed to be able to confine his search to within a certain area. This model has been found useful in a variety of tasks (Krendall & Wodinsky, 1960; Williams, 1966; Howarth & Bloomfield, 1969; Engel, 1977; Carter, 1982; and others). For the unsystematic search model, the cumulative probability of finding the target using k or fewer saccades is:

$$\begin{aligned} P(k) &= 1 - (1 - p_1)^k \\ &= 1 - \exp[k \ln(1 - p_1)] \end{aligned}$$

We can re-express the cumulative probability of finding the target as a function of time, since the elapsed time is just k times the time/fixation, $t = k\tau$:

$$\begin{aligned} P(t) &= 1 - \exp\{[\ln(1 - p_1)/\tau]t\} \\ &= 1 - \exp[-mt] \end{aligned} \quad (2)$$

Empirically, we can approximate the actual cumulative distribution $P(t)$ by measuring $n(t)$, the number of trials on which the search time $\leq t$:

$$P(t) \approx n(t)/N \quad (3)$$

where N is the total number of trials considered. Combining Eqs. (2) and (3) gives us a linear equation for the ln of the proportion of trials on which the search required time $\leq t$:

$$\ln[(N - n(t))/N] = -mt \quad (4)$$

Selecting an item from a menu requires more than just the visual search. The various perceptual/motor actions involved in starting the search and making the selection are assumed to add a constant time t_0 to Eq. (4):

$$\ln[(N - n(T))/N] = -m(T - t_0)$$

where $T = t + t_0$ is the total menu selection time; t_0 is the time required by the nonvisual-search portion of the task, such as pushing the selection button; and $n(T) = 0$ for $T \leq t_0$. This last equation can be rewritten in a form convenient for the regression analysis of empirical data:

$$\ln[(N - n(T))/N] = -m(T) + C \quad (5)$$

where $C = mt_0$.

It can be shown that the mean search time is approximately equal to the reciprocal of the slope for Eq. (5); that is,

$$\text{Mean}(t) \approx 1/M \tag{6}$$

EXPERIMENT 1: DISTRIBUTION OF VISUAL SEARCH TIMES

The purpose of the first experiment was to compare empirical distributions for menu selection with those predicted by the systematic and unsystematic search models just discussed and to monitor users' average fixation time τ during the search.

Method and Procedure

Three users, all experienced with the "mouse" pointing device (a small device whose movement across a table causes a like movement of a cursor on a screen, see Card, English, & Burr, 1978), performed a series of menu item selections while their eye movements were monitored. The menu was an 18-item vertical list of command names, with surrounding border lines and additional horizontal lines separating the commands into groups of no more than four. The menu was displayed in black on a white background in a sans-serif-type font, using a bitmapped Xerox Alto computer and a raster display with 28.3 pixels/cm. Characters were 16 pixels × 8 pixels, including spacing. Lines were 2 pixels wide. Command names in the menu occurred about 1/2 degree apart, depending on preferred user seating distance.

Commands in the menu were arranged randomly. In order to be comparable with Experiment 2 (described later), individual target items appeared on 1, 2, 3, or 4 trials, and the menu remained constant across trials. The order in which the user was asked to select items was randomized, subject to the constraint that the user was never asked to select the same item twice in a row. There were a total of 43 trials.

Each user was seated about 50 cm in front of the display, with chin and head braced against a metal arm and a television camera focused so as to obtain a large picture of one of the eyes. Eye movements monitored in this fashion were recorded on videotape along with a signal designating the beginning of a trial and the target. From the videotapes it was possible to count the number of fixations per trial and code the direction of each individual saccade whether up or down from the previous point of regard.

Each trial began with the menu invisible. When the user pointed to the box at the top of the display with the mouse and selected it (by pressing a button on the mouse), one of the command names appeared in the box, the menu itself appeared, and a response-time clock was started. The user searched for the target item and selected it with the mouse, stopping the clock.

Results

The amount of time required to search the menu was proportional to the number of saccadic eye movements the user made to find the desired menu item, as required by both the systematic and unsystematic models. But other aspects of the search were better described by the unsystematic search model: (1) Search time was the same for all positions in the menu, as predicted by the unsystematic search model, and not increasing with lower position, as predicted by (the linear version of) the systematic search model. (2) Eye movements were equally distributed upward and downward, as predicted by the unsystematic search model, and not all in one direction, as predicted by the linear systematic search model. (3) The distribution of selection times was exponential, as predicted by the unsystematic search model, and not linear, as predicted by the systematic search model.

Eye fixation time. Search time was proportional to the number of saccadic eye movements the user made to find the desired menu item. The average times/fixation as measured by the regressions of menu selection time on number of eye movements were $\tau = 256$ msec, 303 msec, and 353 msec for the three users, respectively. The intercepts for the regression lines, that is, the contribution to the task of nonvisual search components such as mouse movement and reaction time, were 1265 msec, 1256 msec, and 977 msec for the three users. These are compatible with the roughly 1100 msec previously measured as typical for selection in other mouse selection tasks (Card, Moran, & Newell, 1983, Fig. 8.1).

Item position. Compatible with the unsystematic search model, there were no differences among the times to find items at different positions in the menu. Since it might have been expected that users would simply search the menu down from the top, it will be noted that the results are directly contrary to that expectation.

The mean selection time over all users and conditions was computed as a function of item position. To eliminate distortion caused by the unequal frequencies with which different item positions were designated as targets, only those 18 trials that were the first trials on which the user selected an item were used in the analysis. Although there was a small, statistically reliable increase in selection time with lower menu position of 26 msec/position (regression coefficient $\neq 0$, $F(1, 16) = 6.8$, $p = .019$), this increase is much smaller than the 250 to 350 msec/saccade necessary to indicate a linear search pattern. Moreover, the effect disappears, $F(1, 16) = 1.8$, $P = .195$ when a correction is made for the additional mouse movement time required for farther positions.

Eye movement direction. Eye movements were equally distributed upward and downward, as expected for an unsystematic search. Again this result contradicts what would be expected for a linear, top-to-bottom search, in which all of the eye movements should be downward. Only 57%, 56%, and 62%, respectively, of the three users' eye movements were downward (neglecting the first eye movement from the prompt to the vicinity of the menu). A binomial test showed that the observed proportions were within chance variation from being equal in number ($p = .35$, $p = .22$, and $p = .06$ for the three users, respectively). For two of the users, even the first-order contingencies (the proportion of times a downward eye movement is followed by another downward eye movement as opposed to an upward eye movement) were compatible with a random, unsystematic search ($\chi^2 = .953$, $p > .30$ and $\chi^2 = .025$, $p \geq 80$), but for one of the users an upward eye movement was followed by a downward eye movement 81% of the time, although a downward eye movement was about equally likely to be followed by either, causing a nonrandom pattern of contingencies ($\chi^2 = .14$, $p < .01$). This last result illustrates the fact that individual differences are quite possible in search strategy. It should be pointed out that the result indicates a search for the last user intermediate between systematic and unsystematic, but still closer to unsystematic.

Distribution of selection time. The distributions of selection times were exponentials as predicted by the unsystematic search model in Eq. (2). Figure 6.1*a* plots the empirically obtained cumulative distribution for one user, typical of the others. In Fig. 6.1*b*, the same cumulative distribution from Fig. 6.1*a* is plotted according to Eq. (5). Following the procedure of Engel (1977), p_1 and m have been estimated using Eq. (2) and regression analysis of plots similar to Fig. 6.1*b*. Both the idealized systematic and the nonsystematic models are plotted on Fig. 6.1*a* as lines. As a check, p_1 was also estimated for each user by the proportion of eye movements that found a target, $p_1 \approx N/N_f$, where N is the number of successful trials and N_f is the actual number of eye movements recorded less the one eye movement required to move from the starting box to the vicinity of the menu. The estimates of p_1 obtained by Engel's method and the eye movement method agreed within about 15%. (The estimate of p_1 by Engel's method was +11%, + 16%, and −7% different from that of the eye-movement method for the three users respectively.) Thus, whichever method is used to estimate p_1, distributions of selection times for the three users are clearly more similar to those predicted by the unsystematic search model.

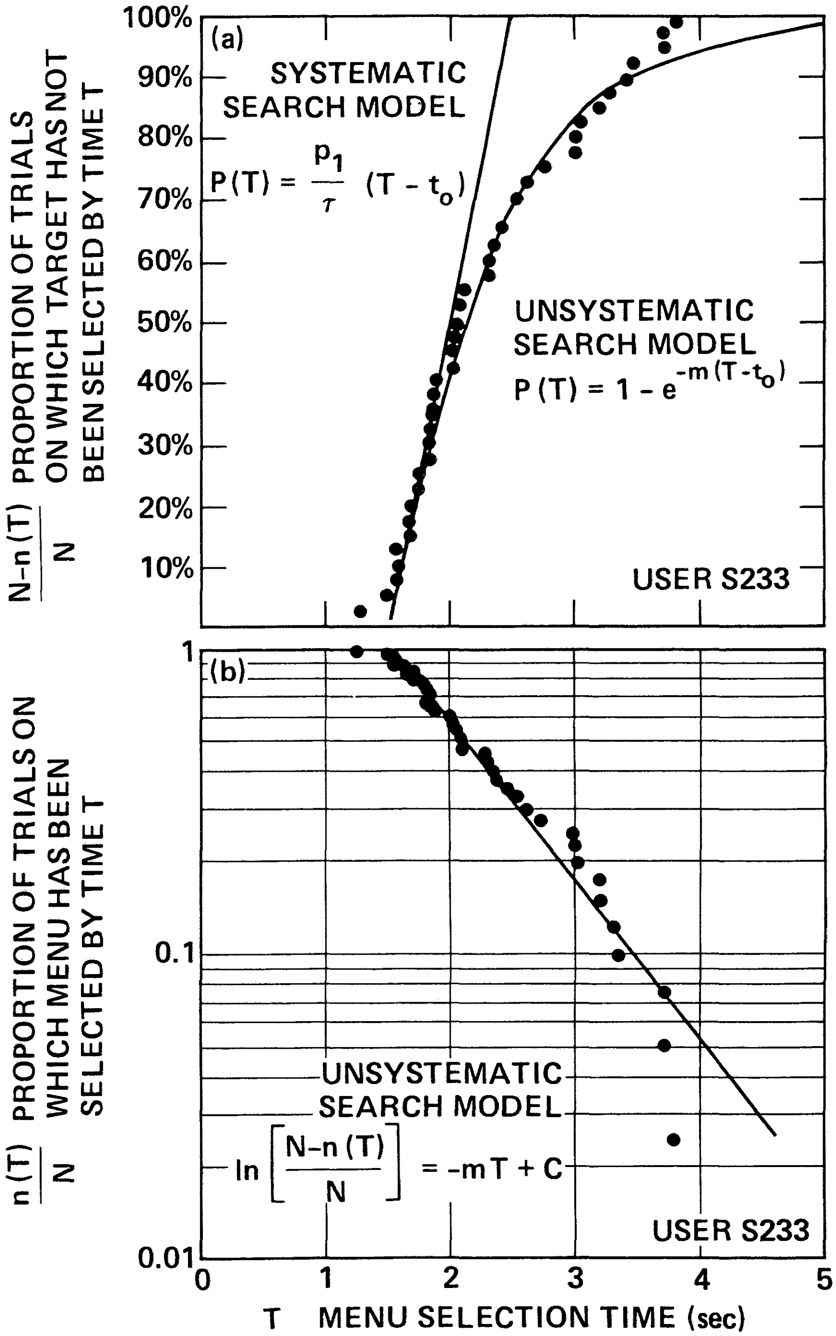

FIG. 6.1. Cumulative distribution of menu selection time for a typical user in Experiment 1, approximated by both the systematic and unsystematic search models: (*a*) Cumulative distribution in arithmetic coordinates. For this user, $\tau = 256$ msec/saccade, $t_0 = 1.56$ sec, $p_1 = .264$ (by Engel's method, solid line) or $p_1 = .303$ (40 trials/132 fixations, dotted line), $m = 1.20$. (*b*) Cumulative distribution plotted according to Eq. (5) and fitted by the unsystematic search model. $C = mt_0 = 1.87$.

EXPERIMENT 2: EFFECT OF MENU ARRANGEMENT ON VISUAL SEARCH

The results of the previous experiment imply that users search for items in a menu by means of an unsystematic search. The purpose of the next experiment is to use this model as a tool to understand the effect of menu arrangement and of practice on search time.

Method and Procedure

Twelve users, six with experience using the mouse, performed a series of menu item selection tasks. The commands were arranged in one of three orders: alphabetically, randomly, or categorically (words with related functions, such as *insert, delete*, and *replace*, or *get* and *put*, grouped together within the same box in the menu). Each of the three orders was tested with four different users, so as to guard against within-user asymmetric transfer effects (Poulton, 1974). In order to reduce the effects of any individual items, two lists of commands were used, each drawn from an actual system. Half the users in each arrangement condition received one command list, half the other. The experiment consisted of 12 blocks of 43 trials/block, resulting in 516 trials for each of the twelve users, or a total of 6192 trials.

To simulate the fact that items appear in real menu tasks with different frequency, individual target items appeared 1, 2, 3, or 4 times/block. The stimuli and procedures were similar to Experiment 1.

Results

The distribution of search time was approximated by the unsystematic search model, Eq. (5). Both menu arrangement and practice affected the model's m slope parameter.

Distributions of visual search time. In Fig. 6.2, the visual search time distributions of Experiment 2 have been combined (following Krendall & Wodinsky, 1960) over the four users for each condition. To make comparison easier, the distributions have been shifted to (have their regression lines) begin at zero by subtracting nonsearch response time as estimated by the regression (1.21 sec for the alphabetic order, 1.30 sec for the categorical arrangement, and 1.13 sec for the random arrangement). The distributions for the categorical and random arrangement conditions are not as good a fit to the unsystematic search model as those in Experiment 1 (Fig. 6.2*b*) and seem to be intermediary between the two idealized models. While it is possible under certain conditions for the Krendall and Wodinsky procedure of combining users to cause artifactual

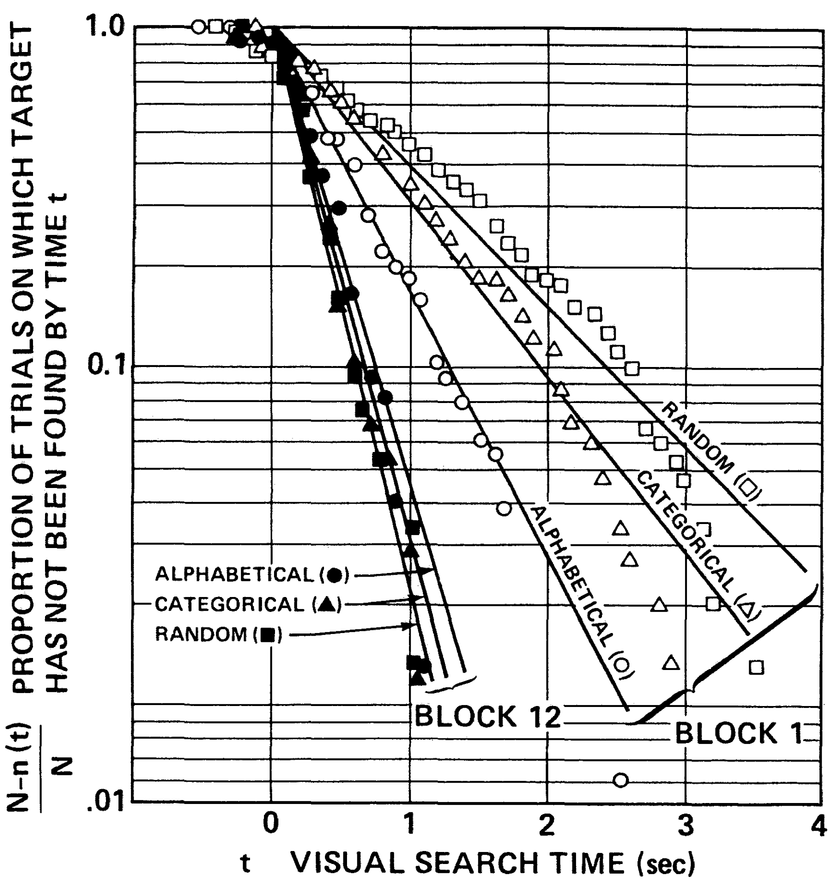

FIG. 6.2 Cumulative distribution of visual search time in Experiment 2 for three menu arrangements on Trial Blocks 1 and 12 (combined over users within each of the three menu arrangements).

bowing of the curve, examination of individual user distributions and debriefing interviews with the users suggested that some users may have had difficulty keeping motivation at a constant level. A subsequent experiment with improved motivational feedback and with warmup trials on a different menu produced good fits similar to those of Experiment 1. The approximation by Eq. (5) of the distributions displayed for Block 1 in Fig. 6.2 is sufficiently good that mean search times correlate .999 with those computed from Eq. (5): Mean$(t) \approx 1/m$. Error rates were 5% or less on almost all blocks.

Menu arrangement. The effect of menu arrangement was to change the slope of Eq. (5): the more information the menu arrangement gave the user about the likely location of an item, the steeper the slope in Fig. 6.2 (hence the shorter the mean search time). On Block 1, the alphabetically arranged menu required less time to search (.47-sec mean search time) than the categorical and random menus (categorical .85 sec, random .98 sec). The difference between the alphabetic search time and the categorical and random search times was reliable statistically [$t(6) = 5.06$, $p < .005$; $t(6) = 5.08$, $p < .005$], but the difference between the categorical and random search times was not [$t(6) = 1.54$, $p > .05$].

Practice. The effect of practice also was to make the slope of Eq. (5) steeper and additionally to eliminate differences among menu arrangements. Whereas users required an overall average .77-sec search time for Block 1, by Block 12 they required only .26-sec search time. There were no longer reliable differences in mean search time among the menu arrangements by Block 4. Figure 6.2 shows that for the twelfth block of trials (by which time the users had made over 500 selections), the distribution of search times for each of the menu orders was the same. We can use the model to characterize the nature of the learning that has taken place. The visual search time declines with practice from a range of .47 to .98 sec when the menu is unfamiliar to the user to a narrower range of .22 to .31 sec after it has been learned. This is so because the number of saccades necessary to find the target has decreased from a number in the range $k = 1.8$ to 3.5 (dependent on the particular menu organization) to about a single saccade (independent of menu organization): the user eventually learns the exact location of each item in the menu, and hence the organization of the rest of the menu becomes immaterial.

GENERAL DISCUSSION

The results of the present experiments imply that users' search for an item in a menu can be described by an unsystematic search model. The arrangement of the items and the amount of practice affect the m slope parameter of this model. It is worth noting that in previous studies the parameter m has also been found to vary with the area to be searched for the target (Krendall & Wodinsky, 1960) and the "visual conspicuity," that is, the amount of prominence of a visual object in its surroundings (Engel, 1977). Our task involved a computer command menu of moderate size (18 items). A larger menu list is likely to increase the differences in search time arising from different arrangements of the menu, a smaller menu to decrease them.

The alphabetical arrangement is but one way of giving the user partial information on regions of the menu more likely to contain the target. Other methods of doing this should also speed up search, but only if the user has the appropriate mental representation to take advantage of it. For example, Barnard, Morton, Long, and Ottley (1977) gave users a list of European countries arranged in one condition alphabetically, in another on a map of Europe. Selecting items from the map was faster for postgraduate engineering students but slower for Cambridge housewives, who were apparently not so well-versed in European geography. But the housewives were faster at selecting grocery products from a categorically organized list than from an alphabetic one, presumably reflecting their experience in shopping. In our study, the categorical arrangement provided little aid over the random arrangement, probably because the users little appreciated the categorical groupings. But when categorical groups well known to the user were employed in a later experiment, the search time was substantially shorter than for the categories employed in Experiment 2.

Engel (1977) has suggested the existence of an autonomous motor program for saccades that would lead to involuntary quasi-random search behavior with global voluntary control and cites the possibility based on Bouma and de Voogd (1974) of a similar autonomous motor program for saccades in reading. Our computer command menus, unlike many visual search tasks, have the feature that it may be possible to process them with either type of automatic program. Different menu selection tasks may favor the invocation of one or the other of these programs, perhaps to the surprise of display designers. For example, Young and Hull (1982) claim that users of the viewdata menu-based system sometimes skip about frames instead of reading them linearly and so miss information the frame designers assumed they would find. Certainly the assumption sometimes made that users will search menus linearly from top to bottom (e.g. Miller, 1980) is not tenable in general.

ACKNOWLEDGMENTS

Keith Patterson helped in the formulation of an earlier version of the reported experiments. Rachel Rutherford, Steven Locke, and Leslie Keenan helped code the experiment programs, run experiments, and analyze the data. I gratefully wish to acknowledge my appreciation to Michael Rothkopf, Steven Smith, and Ronald Kaplan for discussions on the models and analysis, and to Richard Young, Allen Newell, and Thomas Moran for comments on an earlier draft of the paper.

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