Search by Uncertainty:
Menu Selection by Target Probability

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Abstract
Subjects searched a simple three level hierarchical filing system to locate hypothetical documents. Search was guided only by a numerical index. The index was either (a) the probability that the document would be found by selecting one of the alternatives, (b) a frequency count of possible hits available by selecting one of the alternatives, or (c) a bargraph of the likelihood that each of the alternatives would lead to the target document. The three indices were calculated using either (a) joint probabilities or (b) probabilities normalized across the alternatives at each level. An analysis of search patterns indicated that subjects tended to follow highest probability paths for the first traversal. If the target was not found, they engaged in a local search at the bottom of the hierarchy. If the target was still not found, they attempted to follow the second highest probability path down. Results indicated that subjects made the fewest deviations from the best path when probabilities were normalized. Furthermore, bargraph displays uniformly resulted in the fewest deviations from the best path. When subjects redirected their search, they could either move up the hierarchy one level or restart at the top. Subjects with high spatial visualization ability were more likely to move up one level, while subjects with low spatial visualization were more likely to restart the search. Finally, if the target was not found after several attempts, search patterns began to reveal considerable redundant random search behavior and checking of paths. Techniques are suggested to reduce inefficient search patterns.

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Menu search has been increasingly important (a) as first time users encounter unfamiliar menus and (b) as menus become extremely large and diverse. In such menus users do not have complete certainty that the selections they make will lead to the desired target. Indeed, in each menu frame they often rely on intuition, inferences, and shear guessing. Whalen and Mason (1981) investigated three defects of menu systems that results in uncertainty: miscategorization of items, ambiguous category labels, and synonymous labels. Even with perfect menus, users often face uncertainty due to the lack of complete knowledge about the menu structure. Consequently, menu search in the midst of choice uncertainty is an important problem to be reckoned with.

Previous research has investigated the reduction of uncertainty as users acquire knowledge about the menu system. Seppälä and Salvendy (1985) found that users were able to move around through a data base with greater speed as they acquired knowledge of how the data base was structured. Billingsley (1982) and Norman and Schwartz (1987) demonstrated that users can benefit from studying a global tree diagram of the menu.

Other work has investigated the effect of hierarchical structure on performance in menus with choice uncertainty. For example, Norman and Chin (1988) varied the breadth of menu choice as a function of depth. They found that menus having the greatest breadth at the bottom of the hierarchy resulted in superior search performance due to the fact that choice uncertainty was reduced by explicitly displaying broad menus of target items.

However, it has not been clear just how users deal with the problem of choice uncertainty in searching a menu. How is search guided by user's assessments of probabilities that items lead to the desired path? How do users redirect search when a target is not found in its most likely location?  Is search optimal in the sense that users minimize the number of menu traversals to find a target? Is search systematic in the sense that users do not redundantly recheck paths for the same target? Finally, what search patterns or strategies do users use and to what extent are they affected by individual differences?

Search Process

It is assumed that when users are uncertain about menu items, they assign subjective probabilities to the items to guide their search. In general, we assume that users select the item with the highest subjective probability and proceed to the next level in a hierarchical menu. The process is repeated until the desired item is reached or until it becomes sufficiently clear that a wrong path has been taken. At this point, users may either backtrack to the point where they
suspect that they took a wrong turn or restart the search from the beginning and move to the point where the wrong turn may have occurred. Most likely this is a point at which there was considerable uncertainty in the choice. Thus, if users were fairly sure about a choice, that frame would not be a good point to reposition search. But if the choice were a toss-up, then that frame would be a good candidate for redirection.

It is expected that users will vary in their tendency to backtrack level by level versus restarting the search at the beginning. When the search is restarted, users have the opportunity to review and reselect all items in the path. When users backtrack, they may have to remember the items selected up to the current position in the menu. Restarting is more efficient in terms of the number of selections that have to be made when the wrong turn was closer to the top of the hierarchy. Backtracking is more efficient when the wrong turn is closer to the current level than the top.

While search is expected to be guided by probability, there may be points at which it is more efficient to check low probability items before checking more probable items. For example, when the user has traversed down to the bottom of a branch in the menu hierarchy and checked the most likely item, it may be expedient to check low probability items at the same time. Thus, users may switch to a local search mode regardless of the subjective probabilities.

**Probability Menus**

While there is no lack of real world computer menus that suffer from choice uncertainty, they are not necessarily good candidates for research on menu search processes. The reasons are twofold: (a) the subjective probabilities of items leading to targets will vary from user to user and (b) with continued exposure to the menu users will reduce the uncertainty by acquiring knowledge of the menu structure. To alleviate these problems in the present study, content-free menus were generated which listed only the probabilities that targets would be found by selecting each item. Subjects were asked to search for a hypothetical file in a hierarchical filing system. To aid in the understanding of the menu system, a mental model of hierarchical filing was given. Files were described as being located in folders and folders were located in drawers of file cabinets. Subjects were told that the only information they had were probabilities of where the file might be. Searches began by selecting a cabinet, then a drawer, and finally a folder. Once a folder was selected, the subject was told whether or not it contained the desired file. If it did not, the subject continued to search. At any level the subject could decide to switch cabinets, drawers within the same cabinet, or files within the same drawer (See Figure 1).
It should be noted that it is not usual for databases to provide numeric indices to guide search. Such values may result from the number of occurrences of keywords in a file or some other evaluation function. Since the form in which such information is displayed may have an effect on search, the index in the present experiment was presented as either (a) the probability that the document would be found by selecting one of the alternatives, (b) a frequency count of possible hits available by selecting one of the alternatives, or (c) a bargraph of the likelihood that each of the alternatives would lead to the target document. Figure 2 shows each of these forms. Furthermore, the numeric index was calculated using either joint probabilities or probabilities normalized across the alternatives at each level. Figure 3 shows the difference between the joint and normalized probabilities for a 3x3x3 hierarchical tree.

Method

Design
The experiment involved a 3X2 factorial design in which subjects were randomly assigned to each of the six treatment combinations. The two factors were (a) the method of presentation having three levels (probability, frequency, and bargraph) and (b) the method of calculation of probabilities having two levels (normalized and joint).

Subjects

Forty-eight subjects, twelve males and thirty-six females, were recruited from introductory psychology classes at the University of Maryland. Subjects received extra credit for their participation. Eight subjects were randomly assigned to each of six independent groups.

Materials

Three level hierarchical menus were presented to subjects on a computer display. In each frame, the probabilities of a given path leading to the target were presented. In the top menu frame, the subjects were presented with a set of "Cabinets" which represented paths to the middle level. Each cabinet was listed with an accompanying probability. When subjects selected a
cabinet and reached the middle level, they were presented with a set of "Drawers" which represented paths to the bottom level. A "Change Cabinet" button was also displayed that would return then to the top level. When subjects selected a drawer and reached the terminal level, they could select a "File Folder" to see if the target document was contained therein. Both a "Change Cabinet" and a "Change Drawer" button were displayed at the terminal level. If they did not find the target, subjects could select a "Change Cabinet" button which would reposition them at the top of the menu or they could select the Change Drawer button which would reposition them in the middle level.

The probability information was presented in six different ways depending on the assigned treatment condition. The first factor in the experiment was the method of presentation of the probability information. This information was presented as (a) a probability (e.g., ".40"), (b) a frequency (e.g., "40"), or (c) a bargraph (e.g., "****"). (See Figure 2). The second factor in the experiment was method of calculation of the probabilities. Probabilities could be calculated in one of two ways: "Normalized" or "Joint". The normalized probability condition presented probabilities that summed to 1.00 in every frame. Joint probabilities were dependent on previous probabilities and summed to 1.00 only at the top level. All levels thereafter had probabilities that were multiplied by the probabilities of the previous items. (See Figure 3).

Twenty menu, similar to that shown in Figure 3, varying in item probabilities were generated. A target was defined in each menu structure. Targets varied in their path probabilities across the menu structures. Eight orders of presentation of the twenty menu structures were generated and presented in each condition, one per subject.

The menu system was presented on an Apple Macintosh Plus computer with a nine inch monochrome monitor. All menu selections were made by moving a mouse driven cursor into selectable fields and pressing the mouse button.

Subjects' spatial ability was measured using the VZ-2 cognitive test (Ekstrom, French & Harmon, 1976).

**Procedure**

Subjects were instructed as to the nature of the menu task. The VZ-2 was then administered. Subjects were given three minutes for each half of the test. Instructions were then read to the subjects which described the conceptual model of the menu hierarchy in terms of file cabinets, drawers, folders, and target documents. Subjects were instructed concerning the use of the mouse and method of selecting items in the system. Three practice searches were presented. Finally, subjects were asked if they had any questions and were then started on the actual task.
Results

Performance on the search task was measured by (a) the number of selections to locate targets, (b) the type of reposition move either to the middle level (i.e. "Change Drawer") or to the top level (i.e., "Change Cabinet"), and (c) deviations from the optimal search path. The following sections present the results for (a) the effect of the type of presentation and method of calculation, (b) the effect of spatial visualization ability on performance, and (c) patterns of search strategies.

Effect of Type of Presentation and Method of Calculation

In examining the effect of type of presentation and method of calculation on performance, the first measure of overall performance that was considered was the number of total moves the subjects made. Figure 4 shows the mean number of move to find a target for each condition (top panel). Neither type of presentation, \( F(2, 42) = .75, p > .05 \), nor the method of calculation, \( F(1, 42) = .03, p > .05 \), had significant effects on total number of moves, nor was there a significant interaction, \( F(2, 42) = .59, p > .05 \).

A second measure of performance is the number of times subjects changed levels (Figure 4, middle panel). The number of times subjects issued a change of level command that repositioned search at the middle level (i.e. "Change Drawer") was not significantly affected by the type of presentation, \( F(2, 42) = .29, p > .05 \) or the method of calculation, \( F(1, 42) = .14, p > .05 \). Furthermore, there was no significant interaction, \( F(2, 42) = .41, p > .05 \). The number of return to the top of the menu (i.e., "Change Cabinet") was not affected by either of the two factors. Neither the effect of type of presentation, \( F(2, 42) = .13, p > .05 \) nor the method of calculation \( F(1, 42) = .05, p > .05 \) were significant. There was no significant interaction, \( F(2, 32) = .21, p > .05 \).

After finding no significant effect for type of presentation or method of calculation on these measures, a more in-depth analysis of the data was performed which examined the path that subjects followed. Interest lay in evaluating the subject's ability to use probability information about the location of the target.

The evaluation of the subject's search considers all the moves up to the first time the subjects redirected their search. Redirection occurred when subjects exhausted a menu path and then changed level using a "Change Drawer" command, which took the subjects to the previous
level in the menu, or a "Change Cabinet" command, which took the subjects back to the start. In analyzing the moves prior to the first change of level, subjects were considered to have followed the highest probability path if they chose the option with the highest probability at the first and second levels and chose the highest probability option of the third level first. After choosing the option with the highest probability in the third level, subjects could examine all the other choices in the third level, regardless of their probability, in order to save time. When subjects had completed this local search without finding the target, a "change of level" command was executed. There were cases where returning to the first level and choosing the second highest probability option did not give the subject the path with the second highest probability. By examining Figure 3, one can see that returning to the first level and choosing the second highest probability achieves a probability as high as .06 (.20 x .50 x .60). However, if the subject returned to the second level and choose the second highest probability, a probability of .13 could be achieved (.70 x .30 x .60). In grading the subject's performance, either strategy as a high probability path.

The mean number of times subjects deviated from the highest probability path ranged from a zero in the Joint-Bargraph condition to 2.125 in the Joint-Probability condition as shown in the bottom panel of Figure 4. The type of presentation of probability information significantly affected path, (F(2, 42) = 5.00, p < .05.) A Scheffé test for pairwise comparisons between levels in the presentation factor was conducted. The Bargraph resulted in significantly fewer deviations than the Probability method of presentation, (F(2, 42) = 9.63, p < .05.) A significant effect was found for method of calculation of the probability, (F(1, 42) = 5.83, p < .05), with the normalized probability method yielding a lower number of deviations from the high probability path. There was no significant effect for the interaction, (F(2, 42) = 3.16, p > .05.).

**Effect of Spatial Visualization Ability on Performance**

The VZ-2 was administered because it was expected that subjects' spatial visualization ability would affect how efficiently they would be able to navigate the menu. That is, subjects with good spatial visualization ability would navigate the menu more efficiently than subjects with poorer spatial abilities. Scores on the VZ-2 ranged from seven to nineteen with a mean of 13.2 and a standard deviation of 3.3. The results indicated significant negative correlations between VZ-2 scores and (a) total number of moves (r (46) = -.423, p < .05), (b) total number of search redirection moves (r (46) = -.491, p < .05), and (c) deviations from the best path (r (46) = -.379, p < .05). Subjects with higher VZ-2 scores made a fewer number of total moves, returns to start, and deviations than did subjects with lower VZ-2 scores as shown in Figure 5.
Patterns of Search Strategy

Following a failure to locate the target, the decision to reposition search at the start or one level up represents an important difference in search strategy. The number of times each subject chose level one or level two as the level to reposition their search was recorded and a t-test was performed to determine whether a subject was significantly more likely to return to a given level. When subjects who followed the highest probability path returned to a previous level, they returned to the second level 66 percent of the time (a total of 67 times) while returning to the first level only 34 percent of the time (a total of 35 percent of the time). The preference for the second level is significant, (t(paired)=-3.773, p<.05.)

Discussion

The fact that users of menu selection systems make navigational errors, misinterpret labels, and lack a knowledge of how items are clustered indicates that users must somehow manage choice uncertainty. In highly familiar, well-practiced menus, users are virtually certain that their choices will take them to the desired items. In unfamiliar menus with vague or ambiguous item labels and unexplored branches, users are less than certain, but not totally without guidance. Search in an uncertain menu environment is neither totally certain nor totally random. Users are able to guide and to redirect search based on educated guesses and subjective probabilities. The experiment reported here explored the way in which users search in probabilistic menu structures. The logic for the experiment was that given a set of menu items, users assign subjective probabilities to the items and make their selections accordingly. Search progresses as a function of the assigned probabilities. Results indicate that almost without exception, users check the highest probability path first. If the target is not found, they perform a local search among the terminal level items in that menu. If the target has still not been found, they redirect search to either the top level menu or to a previous level. Subjects who have low spatial visualization ability are more likely to redirect search to the top level and completely start over again. At this point users generally take the next highest probability path, but as search progresses, it becomes less and less systematic and subjects find themselves rechecking the same paths.
Redundant Search

In the present menu it was easy to forget what had been previously checked since the menu items (Cabinet A, B, and C; Drawer A, B, and C; and File A, B, and C) did not serve as highly meaningful semantic markers. In real world menu systems, it is more likely that users will be able to tag items that have already been checked. However, even in highly meaningful menus, users may not be able to remember particular combinations of items and paths that have been checked.

A design change that could facilitate search would be to mark files that have already been checked, mark drawers whose files have all been checked, and mark cabinets whose drawers have all been checked. Thus, as users traverse the menu, items become marked when all of the subitems have been checked. Although such marking does not preclude inefficient search, it could serve to prune the tree and eliminate redundant search. In the present case, a systematic trial-and-error search unaided by probabilities, would have resulted in an expected number of selections of 14.8. The observed mean number of moves was 19.3. Thus, marking could have increased performance by 23%.

Optimizing Search

If users assign subjective probabilities to items that truly contain diagnostic information about the location of targets (as opposed to random probabilities or uniform probabilities), these probabilities can be used to guide search. The problem may be that users themselves are ill-equipped to use such probabilities. A solution to the problem is to have the computer perform a search using an optimal method. This would require the user to explicitly assign probabilities or at least rank order all of the menu items or a subset of the menu items. Of course, it would be ludicrous to rank all items throughout menus in a system. Instead, users could rank items only as required by an interactive search routine. On the first path down the tree, users would rank the items in all of the menus. On the next, they would not need to re-rank menus that they had already seen. Whenever a new menu was entered, the system would solicit a ranking from the user. In the present case, the optimal use of probabilities would have resulted in an expected number of moves at 11.1, a 42% improvement over observed performance. Further research is needed to evaluate the tradeoff between the added time and effort of ranking items and the efficiency of a computer directed search.

Spatial Visualization

Spatial visualization ability has been isolated as a key factor in explaining individual differences in proficiency using computers particularly in the use of menu search of databases.
(Vicente, Hayes, & Williges, 1987). The present study helps to localize this effect in the
tendency to redirect search either at the top of the hierarchy or at a next level up. Subjects with
low spatial visualization ability tended to redirect search back to the top. It was as if they could
only handle a one directional search downward. The real world analogy would be as if one were
trying to find napkin rings in a department store: the shopper goes to the third floor to the linen
department but cannot find them; so he or she returns to the front door of the store to start
another search only to return to the third floor and to the china department where the napkin rings
are kept.

In contrast the high spatial visualization subjects were more likely to redirect search by
moving up one level. By moving up just one level rather than to the top every time, the total
number of moves is reduced. For example an exhaustive search in a 3x3x3 menu tree requires
26 moves when the user always redirects search to the top, as opposed to 20 moves when the
user redirects to a previous level when appropriate, a 22% savings.
References


Author Notes

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Select Cabinet

- A .6
- B .3
- C .1

In Cabinet-A
Select Drawer or Change Cabinet

- A .3
- B .6
- C .1

In Cabinet-A Drawer-B
Select Folder or Change Cabinet  Change Drawer

- A .1
- B .6
- C .3

Figure 1. Depictions of cabinets, drawers, and folders at the three levels of the hierarchical menu task.
Figure 2. Depictions of the three types of indices used to guide search.
Figure 3. The two methods of calculation, normalized and joint, and their effect on the tree structure.
Figure 4. The mean number of total moves per search to locate a target (top panel), number of starts (middle panel), and number of deviations from the best path (bottom panel) as a function of method of presentation and the method of calculation.
Figure 5. Mean number of total moves per search to locate a target (top panel), mean number of returns to start (middle panel), and mean number of deviations from best path (bottom panel) as a function of spatial ability as measured by the VZ-2.