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Patterns in information search for decision making: the effects of information abstraction†

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This paper reports on a study of abstraction in an information retrieval interface, where users had access to both detailed data and to two higher levels of abstraction of the data, in a multiple attribute alternative ranking situation. Through an experiment with a total of 76 subjects we found that, when they were not constrained by any built-in structure in their choice of information, there was a spectrum of use which combined various proportions of top-down search with opportunistic episodes (non-top-down branches to view various information attributes). We developed a measure of the degree of top-down search used, and found that this measure correlated positively with an increased propensity to use a compensatory decision strategy. Users also tended to reduce their use of top-down search in favour of more opportunistic search as they moved through the stages of the decision process. The degree of top-down search correlated significantly with a tendency to search within alternatives, but did not correlate with user domain experience. An implication of our findings is that, in order for a data retrieval interface to be implemented successfully, users should not be constrained by the system to follow a built-in search strategy, but should be allowed to develop their own search strategies through the use of a flexible interface.

1. Introduction

The use of computers to support decision making continues to expand rapidly, encouraged by the much more widespread availability of advanced technology in the form of inexpensive hardware, flexible software, user-oriented interfaces, and network and multi-media capabilities. These allow decision support systems (DSSs) to provide information to decision makers in a wide variety of formats and output modes. Recent advances in communications technology have also made available to users large amounts of information on diverse topics, accessible at many sites and in a number of forms. But these new technologies currently outpace an understanding of how the information they provide can be accessed, selected, organized, and presented through suitable interfaces in supporting and/or influencing decision making (Benbasat & Nault, 1990).

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In considering DSS design, Zmud (1983) has suggested several guidelines for DSSs which can help improve the chances of success of the system. These include: capturing and reflecting the way decision makers think; supporting multiple decision processes and multiple decision styles; ease of learning and convenience of use; and helping decision makers to structure and think about the situation at hand. To provide information in a manner that meets these guidelines requires an understanding of the basic problem-solving cognitive processes which decision makers tend to follow. A generalized state-space representation which is often used in the context of artificial intelligence (Newell & Simon, 1972) implies a series of successive problem and plan decompositions and refinements, starting from high-level goals which are successively refined into achievable actions. These may be expanded at the same level of abstraction before moving to lower, more detailed levels in the planning and goal hierarchy, thus implying an overall top-down strategy. An alternative view (Hayes-Roth & Hayes-Roth, 1979) is that planning and problem-solving are opportunistic, heterarchical processes where interim plans and decisions can lead to further decisions at either higher or lower levels of abstraction. More recent empirical studies (Ullman, Stauffer & Dietterich, 1986; Visser, 1987; Guindon, 1990; Davies 1991) have hinted that the nature of the human decision-making process is more likely to be a combination of these two alternatives. In particular in one such study, Davies (1991) suggests that the computer program design process can be characterized as an "hierarchical goal-directed task with random opportunistic excursions caused largely by simple cognitive failures."

Another related type of study into problem solving processes does not involve the creation of models, computer programs, or the like, but instead concentrates on a more limited area of the decision-making process where the user arrives at a choice or ranking of multiple alternatives, through the retrieval and assimilation of data that are provided to describe certain attributes for each of the alternatives. Much research has been carried out on this topic (Payne, 1976; Svenson, 1979; Klayman, 1983; Ford, Schmitt, Schechtman, Hults & Doherty, 1989; Todd & Benbasat, 1991), since it is closely related to how database information can be retrieved and displayed for use in decision making. An empirical method used to analyse these information search strategies is called process tracing. We used this approach in our experiments, described in a following section.

Models have been developed to describe the associated choice/ranking strategies that decision makers use. These can be classified generally (Minch & Sanders, 1986; see their paper for a more detailed description) as either "High Processing" or "Reduced Processing" strategies. A High Processing strategy implies that an exhaustive search is carried out over all available data on each alternative, and that the decision strategy is compensatory. That is, the advantages of choosing or ranking an alternative solution on one dimension are traded against the disadvantages on another. If a Reduced Processing strategy is used, alternatives may be rejected or accepted based on much more limited data, even though more is available, and strategies are non-compensatory. That is, no attempt is made to balance an advantage on one dimenson with a disadvantage on another dimension. Payne (1982) developed a cost–benefit approach which suggests that a factor affecting the selection of a particular decision strategy is that decision makers make a trade-off between accuracy and effort in choosing/ranking among such multiple alternatives; this has been supported by empirical studies (Johnson & Payne, 1985; Jarvenpaa, 1989). Todd and Benbasat (1993) found that decision makers tend to prefer decision making strategies which require a lower expenditure of effort, and they suggest system design approaches should be used that provide tools to minimize the effort required to use more desirable strategies.

Previous research into the use of decision making strategies for alternative choice/ranking problems, where available information is accessed at will by the decision maker, has not evaluated the impact of hierarchical data structures. Since many computer-based decision making applications involve information retrieval through constrained structures such as hypermedia and menu systems, it is of great interest to understand how the decision maker's search and decision strategy preferences would be manifest with hierarchical data structures in the absence of such constraints. We believe that a great deal may be learned by studying such strategies, since this could be helpful in the provision of decision support in a more natural fashion which suits the user's importance structures, rather than forcing the user to adapt to a system's particular data display structures. In this paper, we will make use of previous findings of cognitive behaviour relating to hierarchical structures constructed during user computer-based design processes, extending these to considerations of the multiple alternative choice/ranking decision process. In particular, we will examine the cognitive behaviour of users who can access information at will at different abstraction levels without any system-imposed constraints in terms of the ability to move randomly about the data hierarchy. We will discuss the uses of information abstraction and the results of an exploratory study we undertook to develop an understanding of the information search strategy and the decision strategy used, and whether these strategies were related.

In the remainder of this paper, we review the form and application of information abstraction, and describe the design of an experimental interface to evaluate its effects. Then we discuss an experiment where data were collected on the activities of 76 subjects while they used an interface to solve an alternative ranking problem. An analysis of the data is then presented, followed by conclusions and implications of the study.

2. Information abstraction

Information abstraction involves the recoding of information in a reduced or condensed form (Posner & Rogers, 1978). Abstraction is probably the most powerful tool available for managing complexity, since it allows observers to deal in an hierarchical manner with high level concepts and understand them before proceeding to consider details or to classify different chunks of information according to their similarities (Ossher, 1987). In a complex problem solving environment, decision makers can be assisted by reducing the compleixty of the information being presented. This may occur implicitly while assimilating information, or explicitly through the arrangement of information on an external display medium. Our senses take in a great deal of information, but only a small part of this is reflected in our learning and responses so, as decision makers, information retrieval normally involves a great deal of abstraction of what we find important in solving the problem at hand. In developing an interface, it therefore seems appropriate to let the user take advantage of previously abstracted information which may be helpful in developing a more rapid and comprehensive understanding of the problem. At the same time, it is important to avoid forcing use of a mode with which the decision maker is not at ease, and information at all levels of abstraction should be readily accessible when needed, in keeping with the design principles suggested by Zmud (1983). There are many applications of abstraction to problem solving, including composite model support (Gerlach & Kuo, 1990), conceptual model design (Archer & Kao, 1993), computer program design (Davies, 1991), problem diagnosis (Rasmussen, 1985), and systems analysis methodologies (Burch, 1992) among others.

A hierarchy is a natural way to represent relationships among pieces of information in many situations. Representing these on a computer screen so that they provide the maximum assistance to the viewer can be a significant challenge. For example, Furnas and Zacks (1994) used a form of tree structure to provide additional information to the user who is searching for information; commercial software frequently uses tree structures to represent relationships such as the availability of files in a directory system. There are several other forms in which such hierarchies can be represented. One is through an enforced top-down structure such as a menu system. This normally allows viewing at only one level at a time. Another is a structure which shows all relationships from top to bottom at one time, allowing the user to choose information from any node at any level. Displays of child or parent relationships among attributes at the various levels are also likely to be useful. In our study, we chose to make the information at all levels equally evident and readily available to the users. The same attributes and relationship structures were available for all the alternatives, and users could easily switch among alternatives at will, with simple mouse button pointing and clicking. This allowed users to evolve their own individualized search strategies, giving them the choice of either using or not using the explicit hierarchical structures displayed in the data. At the same time, there was nothing to inhibit them from changing their search strategies during the problem-solving process.

The organization of the information display will affect the search strategy chosen by the user, since this can influence the amount of effort and the probability of errors (Payne, 1976; Sundstrom, 1987). Decision makers are highly adaptive in selecting search strategies (Johnson & Payne, 1985). Payne (1982) suggested that decision makers focus on trade-offs between accuracy and effort in making decisions, so that the decision maker will attempt at the same time to maximize accuracy or decision quality and to minimize effort. Todd and Benbasat (1991; 1993) showed that decision aids which reduce cognitive effort in pursuing particular search strategies will encourage users to follow these strategies, and that improved accuracy may not play a predominant role in search strategy selection. A major implication is that interface design has the potential for influencing decisions.

Our research considers preferential multi-attribute multiple alternative ranking problems, where a decision maker ranks a number of alternatives, each of which is described by a common set of attributes (Keeney & Raiffa, 1976). We chose to use a limited number of alternatives, where decision makers were able to examine in detail and to rank each alternative. This avoided introducing the additional dimension of how many alternatives would be examined and what strategy would be used in examining these alternatives (e.g. Johnson & Payne, 1985) if a large number of alternatives were available. Nevertheless, this is of interest to us in future research. In the experiment we performed, subjects were asked to rank a set of alternative apartment choices. Because such choices are subjective and depend on individual subject preferences, it is not possible to measure the quality of the alternative rankings developed by the subjects, but our study was oriented towards the process of developing the rankings rather than the actual final rankings, in any case.

Tabular data displays supporting the type of decision problem we chose have been organized in previous studies by alternatives, by attributes, or by a matrix displaying both alternatives and attributes (Jarvenpaa, 1989). If data are organized by alternatives, then the attributes for a particular alternative are present in one display, encouraging the examination of the attributes of a particular alternative before moving on to another alternative. When attribute organization is used, the values of a particular attribute are displayed for all alternatives, and this encourages processing information on a particular attribute at a time. In a matrix organization, all the attributes for all the alternatives appear in one display, and this makes it simpler for users to process information in either direction. In our study, we have added a third dimension—information abstraction. Here, for each alternative presented, the attributes are displayed in three classes: low, intermediate, and high abstraction levels. It is very simple for the user to move among these abstraction levels, but as yet there is no theory to predict the patterns of these movements, or what impact this may have on decision-making strategy.

The particular interface design we chose is oriented towards alternative processing because information abstraction tends to be useful mainly in this context. We used a computerized extension of the Payne (1976) format for ranking apartment alternatives, to provide the appropriate information attribute and abstraction displays. When there are many alternatives to be considered, information abstraction can help users to eliminate undesirable alternatives easily if they choose that particular strategy, without having to retrieve more detailed information. It is also easier for the user to gain a more general understanding of an alternative of information is available in abstracted form. Information search by alternative was the least-effort search strategy in our case because attributes were organized by alternative, and attributes for a particular alternative at any level of abstraction could be accessed simply by pointing and selecting by mouse. If the subject chose to use an attribute search strategy, the selection of a series of the same attribute across multiple alternatives would require two key clicks for each attribute accessed; one press to select the alternative and another to select the attribute. According to Jarvenpaa (1989), the natural desire to minimize effort and errors helps to explain why researchers (Huber, 1980; Russo & Dosher, 1983) have found that individuals tend to choose less attribute processing when using verbal data than when using numerical data. In our case, the data format was predominantly verbal. We believe that such an interface is congruent with the tendency of most users to prefer alternative processing for such a task, and it will also lead to a higher likelihood to make use of information abstraction, since attribute processing is less conducive to movement among different levels of abstraction.

3. Measures of search patterns

In our experiment, subjects were free to follow search patterns in three dimensions. They could retrieve information by attribute within an alternative, moving upwards or downwards in abstraction level within the alternative, or they could move "horizontally" to search by attribute among alternatives. Since many subjects do not follow a pure search strategy of any type, the following were used as measures to determine relationships among search strategies (top-down vs. opportunistic search, and alternative vs. attribute search) and decision strategies (compensatory vs. non-compensatory).

(a) *Search Direction* (*SearchDirn*) indicates the subject's preference for search by alternative or by attribute, as defined by Payne (1976), and refined by Todd and Benbasat (1991). This is essentially a measure of "horizontal" or "among alternative" search strategy preference, which has been found to correlate with decision strategy (Payne, 1976; Cook, 1993).

$$\text{SearchDirn} = \frac{\text{AttRuns} - \text{AltRuns}}{\text{AttRuns} + \text{AltRuns}} \times 100$$

Here, AttRuns is the number of attribute runs. Each attribute run consists of two or more accesses of the same attribute across two or more alternatives. AltRuns is the number of alternative runs; each alternative run consists of two or more accesses to different attributes within the same alternative. When SearchDirn has a value of -100, the subject is using pure alternative search; when it is 100, the subject is using pure attribute search, and values between these end-points will be referred to as mixed search. When SearchDirn $= -100$, this implies a minimum of movement among alternatives; the search visits each alternative once. When SearchDirn $= 100$, the search visits an alternative to access only one attribute each time.

(b) *Average Attributes Referenced* (*AvAttr*) refers to the average number of available attributes among the four alternatives in a scene which were actually accessed during the problem-solving exercise. This measure is referred to as "search depth" in the process tracing literature (e.g. Ford *et al.,* 1989), but we will not use this term in this paper to avoid confusing it with vertical search among abstraction levels. AvAttr is defined as

$$\text{AvAttr} = \sum_i \sum_j n_{ij}/4$$

Here, the summation extends over the 19 attributes in each of the four alternatives, where $n_{ij} = 1$ if that attribute was accessed one or more times, and $n_{ij} = 0$ otherwise. This measure is useful because, in previous process tracing studies (Payne, 1976; Svenson, 1979; Klayman, 1983), it has been observed that the number of attributes accessed indicates whether the subject is using a compensatory or noncompensatory decision making strategy. Searching a large proportion of available information is an indication of a compensatory strategy, while noncompensatory strategies typically utilize a low proportion of available information. A low variability in the number of attributes accessed among the alternatives is also an indication of a compensatory strategy, and high variability is an indication of a non-compensatory strategy (Svenson, 1979). Both AvAttr and its standard deviation can therefore assist in determining relationships between decision strategy and information search strategy. It seems logical that a more organized and complete data analysis would tend to be more top-down in nature, leading to a positive relationship between the use of top-down search and the likelihood of using a compensatory decision strategy.

(c) *Degree of Top-Down Search* (*TopDown*). Since, as a number of researchers in the characterization of the design process have observed (Ullman *et al.,* 1986; Visser, 1987; Guindon, 1990; Davies, 1991; Archer & Kao, 1993) that movement among abstraction levels is likely to be neither purely top-down nor purely opportunistic, if a particular individual has a tendency to use top-down depth first search, that person will exhibit a propensity to use a type of search which is on a continuum somewhere between pure top-down search and a highly opportunistic search. In the literature, however, there is no clear definition of what is pure top-down and what is pure opportunistic search. For our purposes, since most menu systems are organized in a top-down manner, we define a pure top-down search to be a strategy that strictly follows a hierarchical tree menu structure. Any transitions that violate this structure are opportunistic transitions. A measure of the degree of top-down search, which can be used to classify and analyse individual performance is:

$$\text{TopDown} = 100(\text{topdown transitions})/(\text{total transitions})$$

Here, a transition represents the movement between two successive attribute accesses from the same alternative (whether or not these retrievals are interrupted by retrievals from other alternatives). We considered transitions to be "top-down" if they are congruent with transitions within a menu system. That is, they can be realized as a movement along the normal path of a menu system. Otherwise we classed transitions as "opportunistic". A standard menu system can be compared to a series of calls and returns from sub-routines. For example, in a menu system, accessing an attribute at the lowest level would require a call from the second level. To access a sibling attribute at this point would require a return followed by a call. Accessing subsequent siblings at the same level is congruent with menu, or top-down access. However, accessing non-sibling attributes at the same level in a menu system requires two returns followed by two calls, but going directly to non-sibling attributes at the same level is not possible in a menu system and is therefore opportunistic. The general rule is that any single transition which would be represented by more than one call in a menu system is opportunistic. A transition is opportunistic if (a) it does not enter the structure at the highest abstraction level of a given alternative, (b) it moves downward to lower level attributes in a different category, or (c) it moves directly from one category of attributes to another. The total number of transitions is the number of transitions observed for a particular alternative. TopDown would have a value of 100 for a pure menu-type attribute search, and 0 for a purely opportunistic search. In keeping with other measures previously defined, this measure is based on transitions aggregated for all four alternatives examined during the scene analysis by each subject.

4. Methodology

The objectives of this study were (a) to determine whether users use top-down information search when they are not forced by the interface design to do so, (b) to classify the patterns of information search that users prefer to use, (c) to determine whether a propensity for top-down search is related to the decision strategy used, and (d) to determine whether the use of a top-down search strategy will change over the duration of the problem-solving process.

4.1. EXPERIMENTAL INTERFACE DESIGN

A view of the experimental system's display (data access interface) is shown in Figure 1. The problem which each subject was asked to solve was similar to a decision problem first described by Payne (1976), and since used by other researchers. In this problem, each subject assigned a score of 0 to 10 to each of four alternative apartments which reflected his or her evaluation of their relative values. When a particular attribute was retrieved for a certain alternative by pointing and clicking the mouse, that attribute was displayed only for a limited amount of time. The Appendix is a listing of a sample set of attribute information used in one such alternative. Each of the four intermediate level attributes (Environment, Rental, Location and Interior) is a generalization of the most important information from its subsidiary low level attributes. The top level attribute (Overall) highlights certain

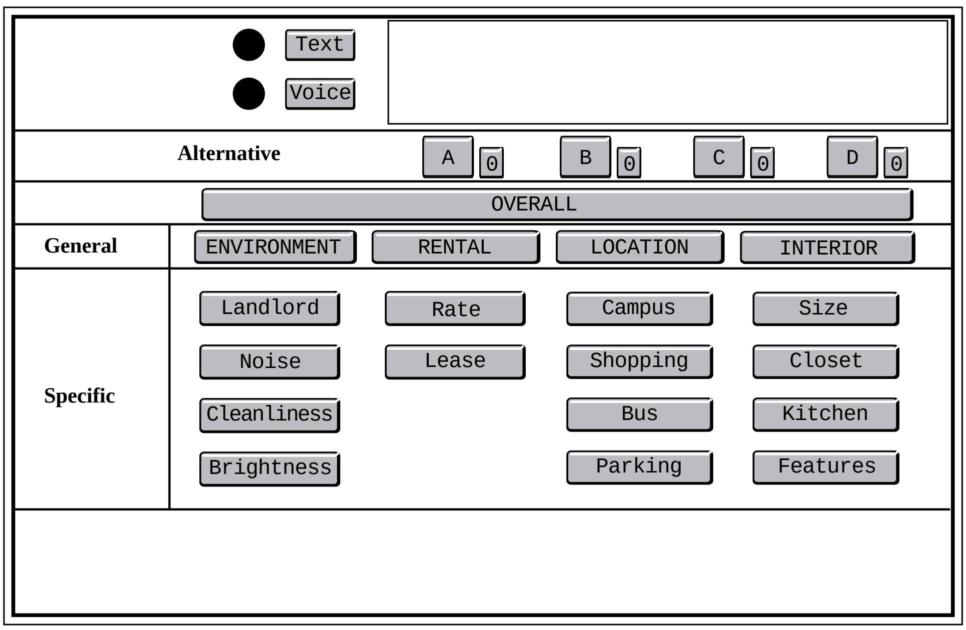

FIGURE 1. The data access interface.

overall information. These attributes represent three increasingly general levels of abstraction of apartment information. The information given is primarily qualitative, of the type typically seen in housing advertisements, and most does not lend itself to quantification. When an alternative A, B, C or D has been selected by clicking the appropriate display button, all information obtained by selecting a particular attribute will then pertain to that alternative only. The scores assigned to any of the alternatives could be adjusted at any time by the subject, by clicking on the small scoring buttons just to the right of each alternative's button. We refer to a set of four alternatives as a Scene. Half the subjects used one scene and half used another scene, both selected randomly. The alternatives (apartments) in each case had attribute values which varied randomly but within a reasonable range. The technique of hiding information until it was specifically requested, and then only displaying it for a short length of time, removed any ambiguity about whether or not a particular unit of information was actually being observed at that time. This is especially useful for recording two or more repeated accesses of an attribute, and of assessing the importance and sequencing patterns of attribute retrieval. Each retrieval was time stamped and recorded by the system for further analysis. More detailed information on the experiment is available from the authors in a working paper (Archer, Sigmund, Wollersheim & Yuan, 1994).

Prior to using the interface, subjects watched an automated demonstration of the interface, and then were given an abbreviated problem to solve. Following this, subjects solved a problem of a magnitude similar to the final problem to be tackled. This gave subjects a sufficient exposure to learning and using the interface that their information search and problem-solving strategies would tend to stabilize. Finally, a problem was solved from which the data obtained were analysed in full, for the purposes of this study.

4.2. SUBJECTS

User experience is the individual characteristic which is most likely to have an impact on patterns in decision making tasks. A survey of process tracing studies by Ford *et al.* (1989) found that the level of domain experience often affected certain measures such as the number of attributes searched. In studies of design activity (Jeffries, Turner, Polson & Atwood, 1981; Davies, 1991), differences have been observed between the straegies of experienced and inexperienced subjects in the use of top-down approaches. In our experiment, we drew upon two different levels of students for subjects; MBA students who were experienced in apartment search, and high school students who had no experience in ranking and selecting alternative living accommodations.

Seventy-six subjects participated in the experiment. Forty-eight were MBA students, all of whom had experience in searching for and selecting living accommodation (an average of 6.5 times per student). The remaining 26 subjects were students at a nearby high school, six of whom had some experience in searching for living accommodation, while the remainder had no such experience. Of the total of 76 subjects, 38 were male and 38 were female. Subjects were relatively familiar with computers and graphical user interface interactions. All were paid for participating.

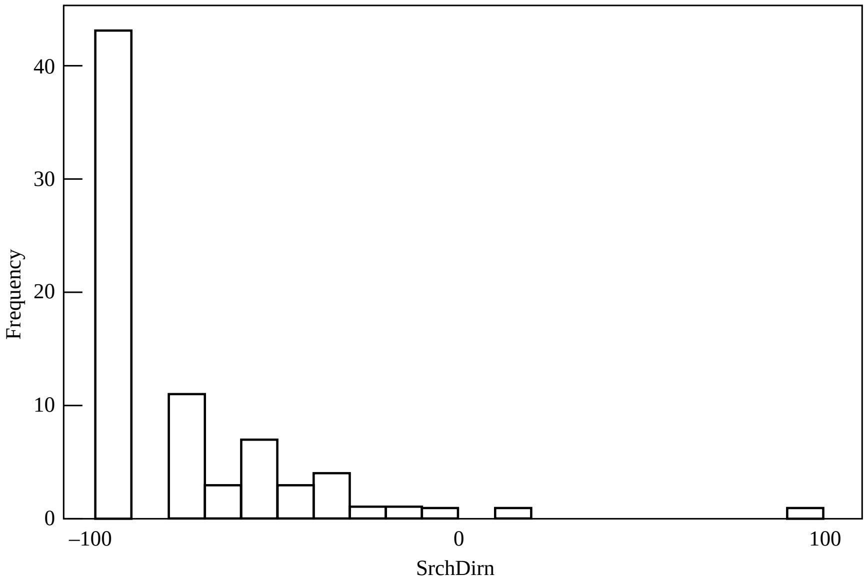

FIGURE 2. Search direction measure (SearchDirn) frequency distribution.

5. Data analysis

Attribute selection patterns were analysed from all 76 subjects, based on the three search pattern indicators described in a previous section.

5.1. SEARCH DIRECTION ANALYSIS

Figure 2 is a histogram of SearchDirn. Clearly, a relatively large number of the subjects (57%) used a pure alternative search (SearchDirn $= -100$), which is to be expected from an interface which favours this approach. But surprisingly, we found that 43% used a mixed search ($-100 <$ SearchDirn $< +100$), except for one subject, who used a pure attribute search (SearchDirn $= +100$). The search patterns of subjects tended to be consistent among the four alternatives, in agreement with the findings of other research (Payne, 1976). Relationships between search direction and topdown search strategy are discussed in a following section.

5.2. TOP-DOWN ANALYSIS

A histogram of TopDown is displayed in Figure 3. TopDown had a mean value of 64.8, a median of 64.1, and a standard deviation of 19.2. Its minimum and maximum values were 20 and 100 respectively.

Among the 76 subjects there were two relatively ill-defined groups of subjects which exhibited primarily top-down or primarily opportunistic behaviour, separated by a middle group which tended to a moderate combination of the two approaches. For the purpose of this discussion, we divided the subjects into three groups: (1) a group of 13 which exhibited primarily opportunistic search behaviour, with measured TopDown values of less than 50, (2) a group of 41 with an intermediate search strategy and TopDown measures falling in the range of 50 to 75, and (3) a group of 22 following a primarily top-down search strategy, and with TopDown

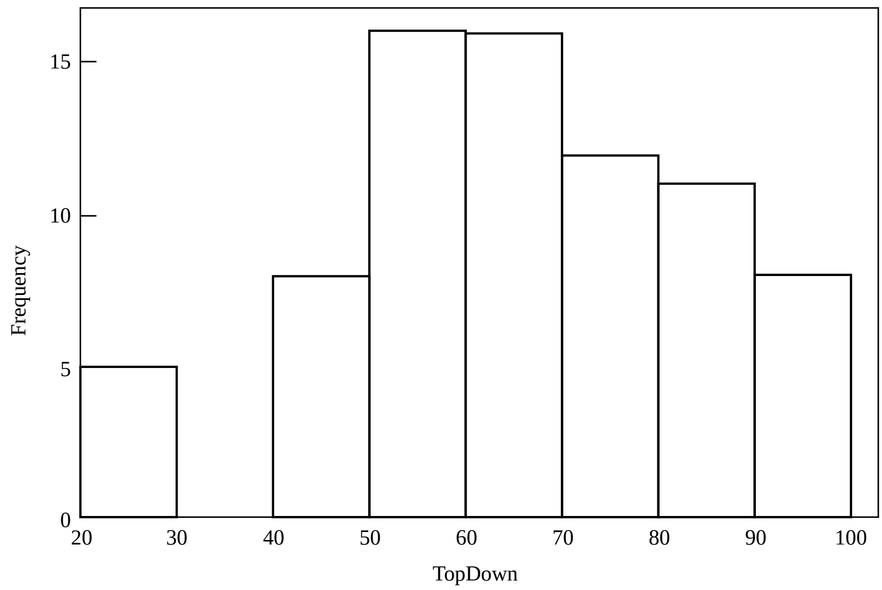

FIGURE 3. Top down measure (TopDown) frequency distribution.

measures greater than 75. For the Opportunistic group, TopDown had a median of 40.7, a mean of 35.5, and a standard deviation of 10.6. Among this group were seven who began accessing attributes at the lowest abstraction level, and continued at that level for most accesses, four who used some form of top-down breadth-first search (generating a number of opportunistic complicated patterns in terms of top-down analysis). The Intermediate group had a median TopDown measure of 61.8, a mean of 61.9, and a standard deviation of 7.8. The 22 subjects in the TopDown group had a median TopDown measure of 87.0, a mean of 87.6, and a standard deviation of 6.7. However, only three from this group exhibited almost pure top-down strategies (TopDown $>$ 95) and only one had a TopDown score of 100. Figure 4(a), (b) and (c) shows three actual transition diagrams drawn from the TopDown, intermediate and Opportunistic groups respectively. Transitions are represented in the diagrams by directed arcs, with each arc labeled according to whether it was Top-down (T), or Opportunistic (O), according to our definition.

5.3. PATTERN CHANGES DURING THE SEARCH PROCESS

Davies (1991) observed that the top-down strategies adopted by computer program designers tended to vary over time in the degree of opportunism exhibited. To determine whether this effect was also present in information search, we divided the transitions in each alternative into three time stages, with each stage containing one third (as close as possible) of the transitions among the attributes in the alternative. The value of TopDown was calculated for each stage of each subject's activities. Treating results from the 22 subjects in the TopDown group, the 41 in the Intermediate group, and the 13 in the Opportunistic group as a three level factor, and the three stages of the information search as three levels in a second factor, a two-way analysis of variance on TopDown was carried out. Interactions were not

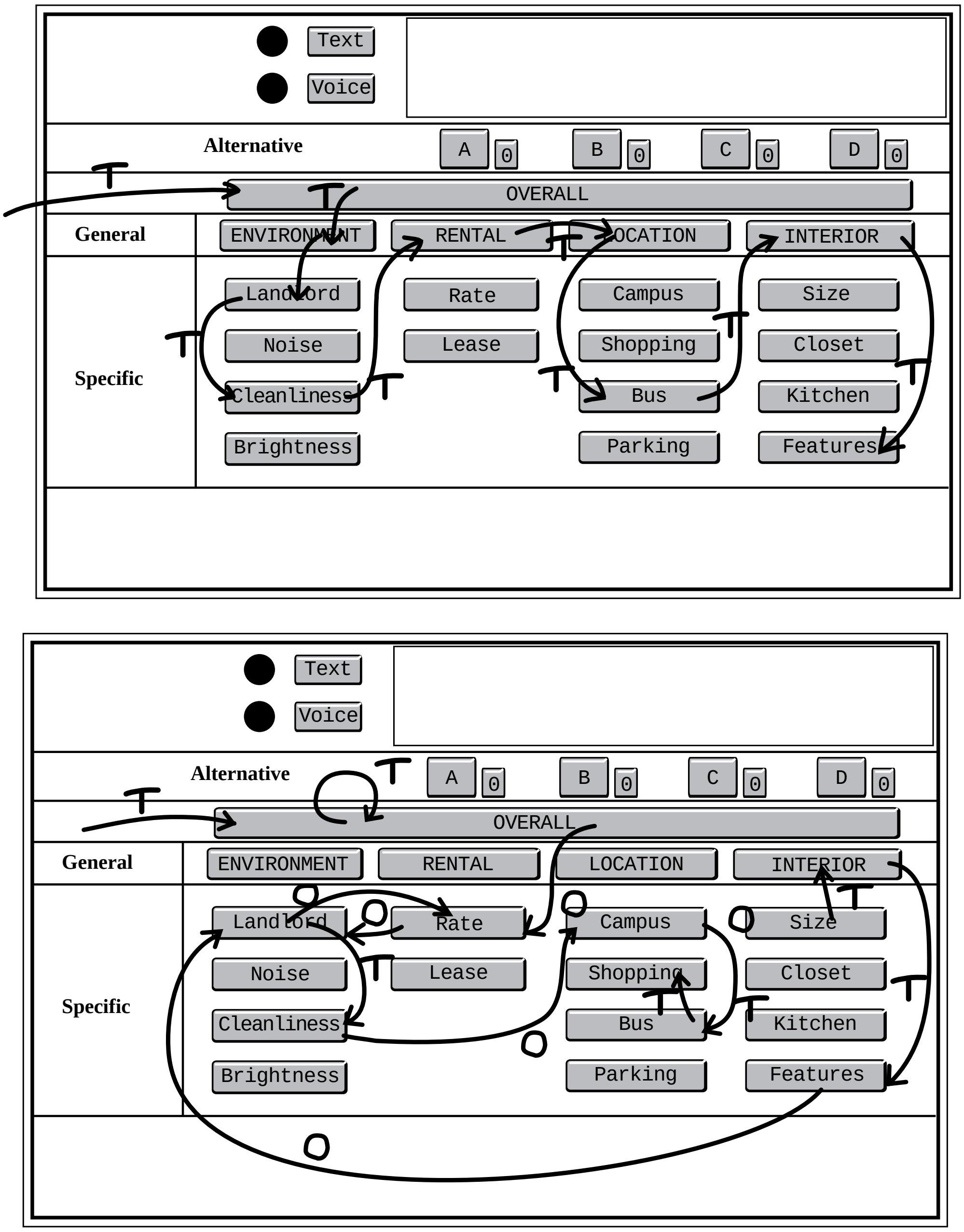

FIGURE 4. (a) Strongly top-down search pattern; (b) intermediate top-down/opportunistic search pattern; (c) strongly opportunistic search pattern.

significant, but both main effects were significant. For the three subject groups, $F = 148.2$, $n_1 = 2$, $n_2 = 219$, $p < 0.001$. For the three information search stages, $F = 16.2$, $n_1 = 2$, $n_2 = 219$, $p < 0.001$. A plot of the results appears in Figure 5. There is a consistent difference among the three subject groups throughout the search

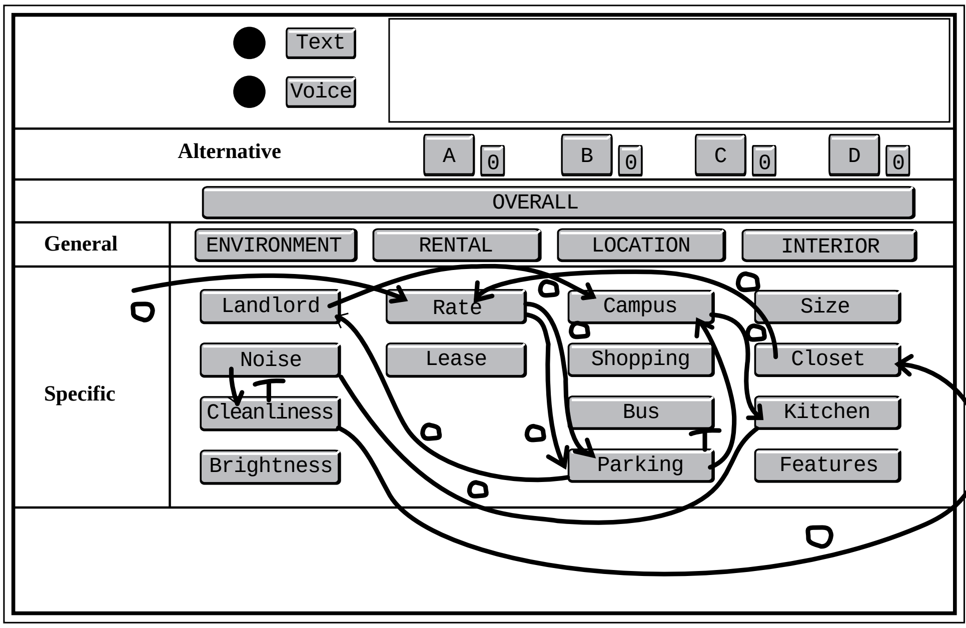

FIGURE 4. (*Continued*.)

process. An analysis of differences among the factor level means (as plotted in Figure 5), using the Tukey pair-wise test with a 95% family confidence interval indicated that all pair-wise differences among the three subject groups were significant. However, the differences between the first and second and between the second and third stages in the information search process were not significant, although there was a significant difference between the first and third stage means. This indicates that even the basically opportunistic subjects became significantly

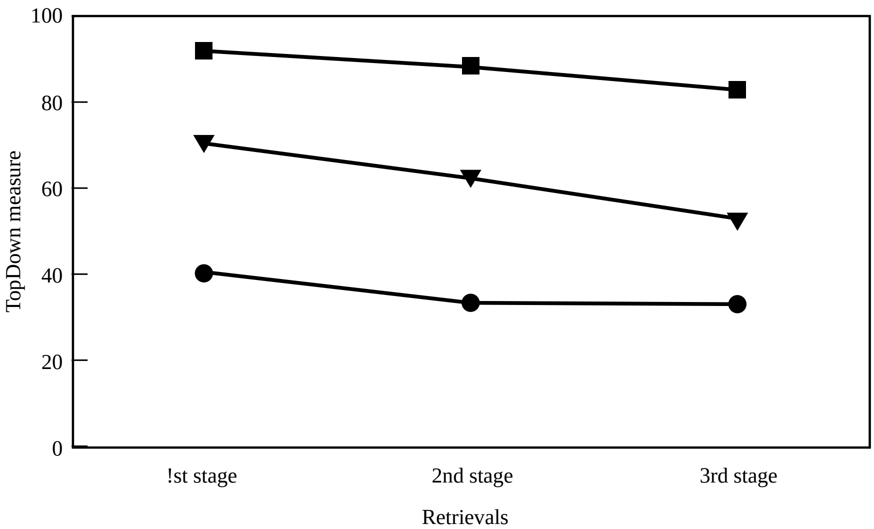

FIGURE 5. Top-down dependencies; ■: Topdown; ▼: Intermediate; ●: Opportunistic.

more opportunistic as they moved through the search process. The lack of significant interactions shows that, on average, the degree of top-downness did not affect the tendency to become more opportunistic as the end of the process was approached, although of course in the extreme case, a totally opportunistic search cannot become more opportunistic.

An explanation for this observed tendency is that a user will retrieve and analyse data in a more organized and top-down manner during the early stages of the search, but will become increasingly opportunistic as the search progresses, in order to selectively pick out certain attributes, to repeat retrievals of data which may have been forgotten, or to evaluate specific attributes against the user's current and evolving opinions of the relative value of the alternatives being considered.

5.4. OTHER RELATIONSHIPS

A multiple regression of TopDown was performed against the independent variables Experience, SrchDirn, AvAttr and its standard deviation SdAttr. Experience was not significant ($p > 0.10$), indicating that being an expert or non-expert in the domain did not affect the search approach. This may be due to a lack of difference between the basic knowledge and perceptions of all of the subjects with respect to housing information, rather than differences in housing search experience. But the implication of this result is that the individual user's needs for information determine the search approach used and we cannot assume, for example, that expert users should be supplied with an interface which forces a top-down or any other approach. On the other hand, we note that user experience was found to be important in an analysis of top-down strategy in computer program design (Davies, 1991). It is possible that the difference in our findings may be partly due to fundamental differences between problem solving through information search or problem solving by creating a computer program or model.

We found in the same regression that AvAttr was significant ($F = 14.50$, $n_1 = 1$, $n_2 = 71$, $p < 0.001$), but SdAttr was not significant. The F value given is the partial F-ratio for AvAttr. The coefficient for AvAttr was positive, which indicates (Cook, 1993) that a variable (TopDown in this case) is positively correlated with compensatory decision strategies. That is, pursuing a compensatory decision strategy is congruent with a top-down information search strategy. To demonstrate the relationship between AvAttr (the average number of attributes accessed) and TopDown, the AvAttr values were divided into four quartiles ($2.0 \Leftarrow \text{AvAttr} < 5.81$, $5.81 \Leftarrow \text{AvAttr} < 8.62$, $8.62 \Leftarrow \text{AvAttr} < 11.0$, $11.0 \Leftarrow \text{AvAttr} \Leftarrow 14.0$) and the average TopDown values in these ranges plotted against the four quartiles of AvAttr in Figure 6. It is clear from this figure that subjects who accessed attributes in the high range (in the fourth quartile, the average number of attributes accessed was 13, or 70% of the maximum possible) exhibited a much stronger top-down search strategy than individuals accessing fewer attributes.

SrchDirn was significant ($F = 4.37$, $n_1 = 1$, $n_2 = 71$, $p < 0.05$), with a negative coefficient. This indicates that search direction (among alternatives) is related to top-down search strategy (within alternatives), with a more top-down search being related to a more alternative-oriented search. An implication of this in interface design is that, while decision strategy used (compensatory vs. noncompensatory)

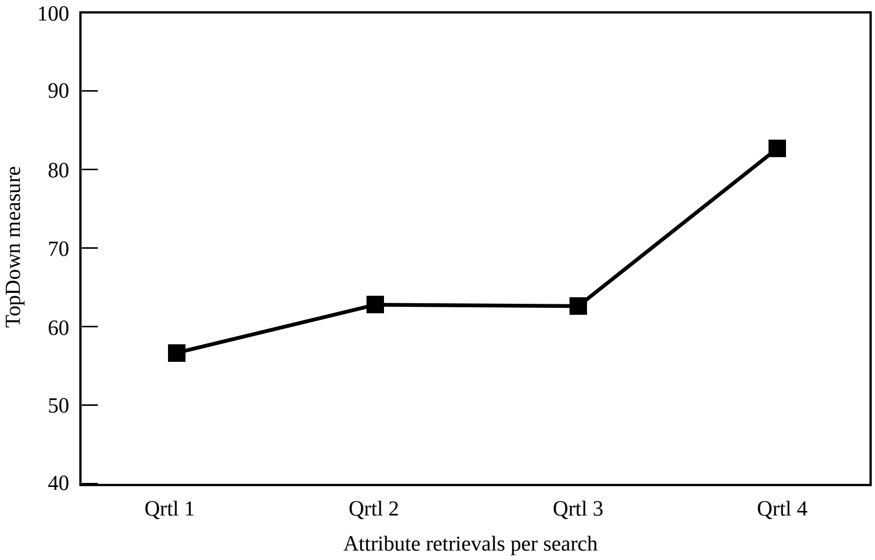

FIGURE 6. Relationship of top-down measure to number of attributes accessed.

may depend upon the number of alternatives presented to the user (Payne, 1976), with a consequent effect on between-alternative (or attribute) search strategy, this may also carry over into a corresponding effect on the within-alternative (top-down) search strategy. Although further studies are required to confirm this, we can anticipate that, since a larger number of alternatives tends to lead (Payne, 1976) to more noncompensatory decision strategies, this will also lead to more opportunistic within-alternative searches.

6. Conclusions

In this study, the data presented to the subjects at the lowest abstraction level were representative of the type of information typically retrieved from a database. The higher levels included data which was abstracted from the lower levels, and tending to be of more general importance. Our findings indicate that the majority of the subjects used the higher abstraction levels to some extent in retrieving and evaluating information, and that most of these subjects used top-down search at least part of the time. The most important findings are that the propensity to use top-down search (a) was directly related to a tendency to use a compensatory problem solving strategy, (b) became less over the time of the search in favour of a more opportunistic approach, (c) was related to the likelihood of using an alternative search strategy, and (d) was independent of domain experience.

Given the conclusions that have been reported in studies of continuously creative processes and decisions involved in work such as computer programming, we should expect certain similarities to be exhibited in the overall creative process involved in making decisions on alternatives suggested by an existing set of data. In this study, we have observed that decision makers tend to behave in much the same way as program or model creators. That is, when data are structured hierarchically, most users tend to access the data part of the time in an hierarchically top-down manner, punctuated by opportunistic episodes where attributes are accessed as the need arises, rather than in a completely organized hierarchical manner. On the other hand, we found that domain experience did not significantly affect the search approach. These findings have implications in terms of the design of decision support systems. The first is that hierarchical data structures can be helpful in decision-making based on data retrieval. The second is that users should not be constrained to access the data hierarchically, since this would tend to interfere with their tendencies towards branching into opportunistic episodes. This could affect the decisions made, since users prefer a least effort approach (Todd & Benbasat, 1993) and would be less likely to access as much information in a constraining environment.

Abstraction does not appear to have direct application in the provision of information for standard automated database systems, where search is almost invariably by attribute, the searches are deterministic in nature, and the attributes tend to be very well defined. On the other hand, tools which allow users to build abstractions according to their own specifications, and tools which assist in making decisions according to abstracted information, are likely to be useful in the realm of alternative search. Such searches are typical with document-type data, e.g. with applications in literature search, job application evaluations, executive support systems, etc.

This study of the effect of information abstraction on information search patterns and decision making poses questions which open interesting avenues of research. The increasing interest in creating more usable systems (Nielsen, 1993) can benefit from this and other studies which are designed to improve our understanding of how users interact with these systems. The following are some areas relating to information abstraction which should be examined in more detail.

(a) Decision quality should be examined in the context of different types of problems, where abstraction can be critical to giving the user an overview of the problem, without causing overload effects from either quantitative or verbal information. Quantitative information is often abstracted in such forms as objective functions or statistical results, just as qualitative information is abstracted in verbal form. At the same time, we should be careful to select problems which continue to move closer to the less structured type of business problems, to open the scope and relevance of this type of work.

(b) The impact of abstraction on user performance and preference should be compared over differing numbers of alternatives to verify its relationship to the use of compensatory and noncompensatory decision strategies, and to determine its usefulness in helping to evaluate or eliminate alternatives when noncompensatory decision strategies are used.

(c) Techniques need to be developed which will support the generation of information abstraction hierarchies which do not improperly bias or pre-dispose decision makers. We also need to understand how the presence or absence of detailed information can help alleviate such problems, and in what situations users prefer to use abstractions independently of lower level information.

(d) The rapidly growing use of Internet information sources has led to a variety of methods for information search in a highly cluttered and confusing environment.

The use of information abstraction in available data structures (e.g. through hypermedia in World Wide Web) should be studied to determine the most effective way it can be used to improve searching for, and presenting, available information.

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Appendix†: data for one apartment choice

Attribute	Data
Overall	One bedroom basement apartment, rather low priced, good condition.
Environment	Moderately quite and well maintained.
Landlord	Visits frequently.
Noise	Near an elementary school.
Cleanliness	Virtually spotless.
Brightness	Dark, with one medium and two small windows.
Rental	Rather low priced with a long term lease.
Rate	$265 per month plus $65 for utilities.
Lease	Twelve month lease.
Location	Downtown Hamilton.
Campus	Twenty minute drive to campus.
Shopping	Large shopping centre is two blocks away.
Bus	Stop for buses going to campus is one block away.
Parking	Outdoor parking.
Interior	Small one bedroom apartment; living room, kitchen, full bath, two closets.
Size	8×10 foot bedroom, 12×12 foot living room.
Closet	One closet in the bedroom, and one in the hallway.
Kitchen	Dishwater and dishes available.
Features	Coin operated laundry available.

† Extracted from Archer, Sigmund, Wollersheim and Yuan (1994).