HUMAN FACTORS, 1992, 34(3), 351–367

The Influence of Hypertext Linking Structures on the Efficiency of Information Retrieval

MICHAEL F. MOHAGEG,[1] *Silicon Graphics, Inc., Mountain View, California*

Hypertext systems parse documents into components connected by machine-supported links. This study investigated several usability issues relating to linking configurations in an information retrieval application. A HyperCard™-based geography data base was used as the information domain. Linear, hierarchical, network, and combination hierarchical/network linking were of particular interest. In addition, the number of required links (two, four, or six links to reach the answer) and task type were the task variables studied. Task type refers to expert programmers' judgments as to whether a task is best suited to a hierarchical or network linking configuration. The intention was to identify the task situations under which each linking structure excels. Results indicated that users of the hierarchical linking structure performed significantly better than those using network linking (on average requiring 49 s less per task). Subjects using the combination condition performed no worse than those using the hierarchical condition, yet the combination condition provided no consistent advantages. Hence, for novice users of a system, no performance gain results from the inclusion of network links (in isolation or in combination with hierarchical).

INTRODUCTION

Hypertext and hypermedia have been viewed as the future environments for creating, organizing, and disseminating on-line documents. In recent years a great deal of attention and discussion have been devoted to these on-line environments. Most of the discussion concerning these systems has been of a complementary nature. However, with few exceptions (Cecala, Mohageg, and Watkins, 1989; Gordon, Gustavel, Moore and Hankey, 1988), no solid empirical evidence exists to support or refute the utility and usability of hypertext and hypermedia. It is reasonable to ask a fundamental question: are hypertext environments appropriate for performing typical computer-based tasks such as information retrieval? From a human factors standpoint, efficiency and satisfaction of task performance should be regarded as indicators of usable systems. The current study attempts to answer several questions concerning the utility and usability of hypertext environments within an information retrieval context.

Hypertext and Hypermedia Defined

Hypertext and hypermedia are methods of on-line information management and/or presentation in which textual documents are

[1] Requests for reprints should be sent to Michael F. Mohageg, Silicon Graphics, Inc., 2011 N. Shoreline Blvd., P.O. Box 7311, Mountain View, CA 94039-7311.

parsed into many nodes. Usually each node contains a single concept, data element, idea, or chunk of information. The nodes are connected to one another using links. The links create an interconnected network of nodes. Links may connect related nodes within the same document or between documents. The important characteristics of hypertext systems are as follows (Conklin, 1987; Halasz, 1988; Smith and Weiss, 1987; Tompa, 1989):

- Information is parsed (modularized) into smaller units called *nodes*. Depending on display technology limitations, application, information format, and designers' specifications, the nodes may be of various data types and sizes.
- The presence of links (or the ability to create links) between nodes provides users with preconstrained or random access to the network.

Hypermedia systems are identical to hypertext systems with one additional characteristic: in addition to text, each node in the network may contain animation, graphics, audio (digitized or synthesized), video, executable computer programs, or others forms of information.

The links used to connect hypertext nodes are of two types (Conklin, 1987; Halasz, 1988): organizational and relational. Organizational links provide for the arrangement of nodes through the use of conventional organizational schemes, such as hierarchical, alphabetical, and functional organization. The most popular organizational scheme is hierarchical (or tree) organization, which arranges nodes in a general-to-specific fashion. As a user traverses the nodes, he or she moves to progressively more specific topics. For instance, in searching for London in a hierarchical organization, a user might move from the world to Europe, then to England, and finally to London. A strict hierarchy will allow movement in only two directions: either up one level (more general) or down one level (more specific). System organizations exist with variations to this theme (e.g., jump to the top node in a tree), but most include the basic general-to-specific configuration.

Newly popularized relational links go beyond the rigid general-to-specific structure. Relational links are established based on some user- or author-derived dimensions and are presumed to be beneficial for task performance or system use. Relationships between nodes may be of any type users or designers see fit. For instance, a link may be established between nodes because they contain contradictory information or because one node supports information in another. A link may be created simply because one node contains information that may be of interest to the reader of the current node. In relational linking there is no regard for node location in an organizational sense. A significant amount of time and effort must be invested in creating relational links, especially given that no universally acceptable automated linking methods exist. Designers (or users) must determine the relationships of interest and establish the links. Some hypertext systems allow for user configurability; however, most systems require users to employ designer-established relational links. Relational linking has been purported to be the essence of hypertext because of its relevance to task performance and flexibility (Conklin, 1987).

Rationale and Approach

Hypertext advocates claim that the most salient advantages of these systems are the modularity of information and nonlinear access to information through linking. These characteristics decouple the logical progression from the physical layout of the document (Smith and Weiss, 1987) in a purportedly advantageous fashion and allow browsing in the data base. Browsing is an often-mentioned advantage of linking and is seen as an augmentation to other search mechanisms (e.g.,

string search or query language; refer to Bates, 1986, and Thompson and Croft, 1989, for detailed discussions of the benefits of browsing).

Browsing with the use of relational links is of no value if it fails to enhance performance and satisfaction in some measurable fashion over conventional linking structures. The issue of enhanced performance is especially questionable with commonly available hypertext systems, which use designer-established links and provide little or no user configurability. Designer-established relational links are likely to fall short of fulfilling the needs and informational requirements of all retrieval tasks, even for a single information domain. It may be impossible to predict all potentially useful relationships that could exist among the nodes. Hence the following questions are raised regarding information retrieval in a system of linked nodes:

(1) Do relational links have performance advantages over existing linking structures, such as linear and hierarchical?
(2) In situations in which task requirements are not perfectly matched (or served) by relational links, will a negative effect result from including these links?
(3) In a condition such as that described in Item 2, will organizational links suffice (as the default linking structure), or is the conventional linear structure more appropriate?
(4) Do linear text, hierarchical linking, and relational linking lead to equal performance?

METHOD

On-line Data Base

An on-line HyperCard™-based geography data base called *GEO* was created specifically for this experiment. *GEO* contains 187 nodes providing detailed information about the six countries of North Africa: Algeria, Egypt, Libya, Morocco, Tunisia, and Western Sahara.

GEO contains information pertaining to the demographics, economy, education, geography, and government of each country. The nodes provide varying levels of detail regarding each of the topics. Each node is an individual entity, and its information is meaningful in a stand-alone fashion. However, all nodes have relationships with other system nodes and provide richer information when these interrelationships are exploited.

Information parsing. The bulk of the information was extracted from the "Country Study" series of geography books published by the U.S. Government Printing Office in conjunction with American University (e.g., Nelson, 1986). In the creation of *GEO*, the section, subsection, and sub-subsection entities in the country study books were converted into individual nodes. Titles of created nodes were not differentiated by font, color, alphanumeric coding combinations, or any other mechanism for signifying order or levels of specificity/generality.

Each node was confined to a text area of 19 lines × 64 characters to eliminate experimentally uncontrollable scrolling rates. Some information reduction and/or paraphrasing was required to properly fit the original text into the newly created nodes. However, no significant alterations to the information resulted: all critical information was maintained, and no false information was included.

Independent Variables

Linking structure. Linking structures are methods used to connect nodes of information in the network. These links allow for browsing through the system in search of desired information. Four linking structures were studied: linear, hierarchical, network, and combination linking structures.

The linear structure connected nodes in a fixed order but maintained the hierarchical grouping of sections and subsections as found in books (Figure 1). Information was divided into six chapters (corresponding to the six

countries of North Africa). Within each chapter, information was organized as illustrated in Figure 1. Chapters were composed of five sections, each of which had five subsections. In the linear structure users paged from one node to another, as in a standard word-processing document. The top node (North Africa) was accessible from any location.

The hierarchical linking structure, depicted in Figure 2, maintained a nested relationship among the nodes. This structure provided a strict hierarchy; however, the top node (North Africa) was accessible from any location. As with the linear configuration, the organization of material within each country was identical, and all nodes (at every level) contained textual information. The difference between hierarchical linking and linear link-

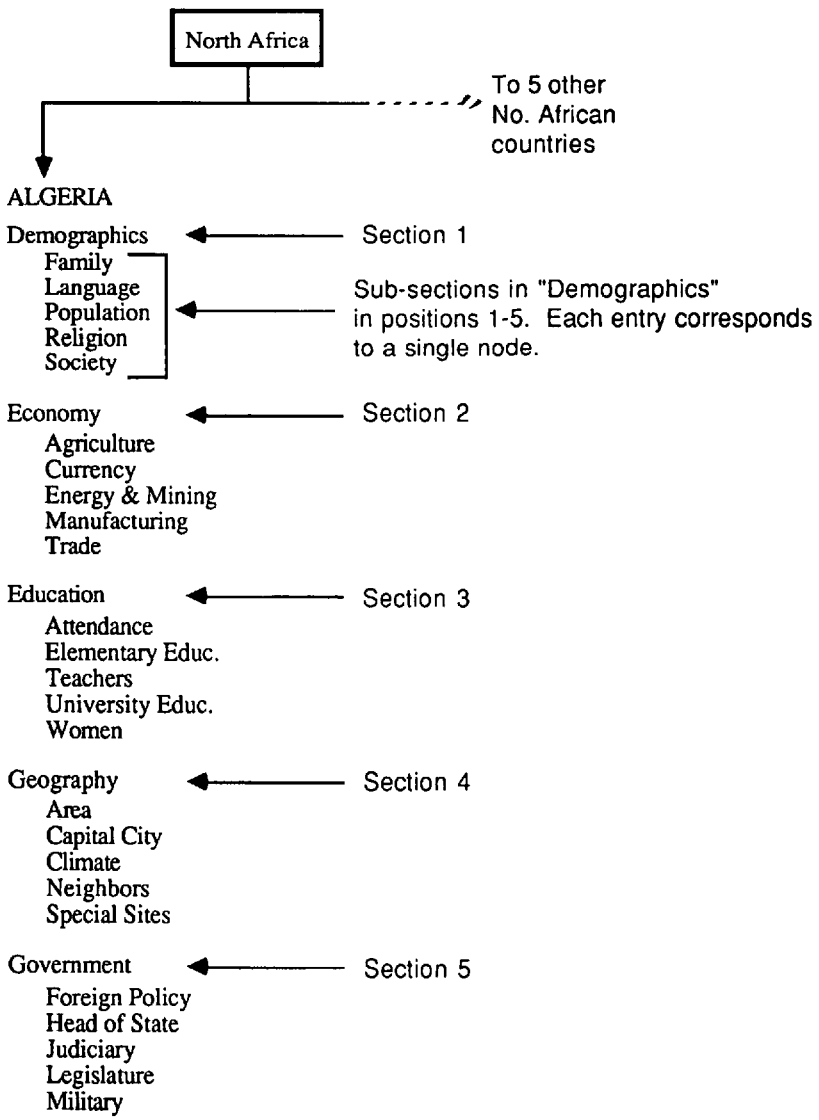

Figure 1. *Information organization in the linear linking structure.*

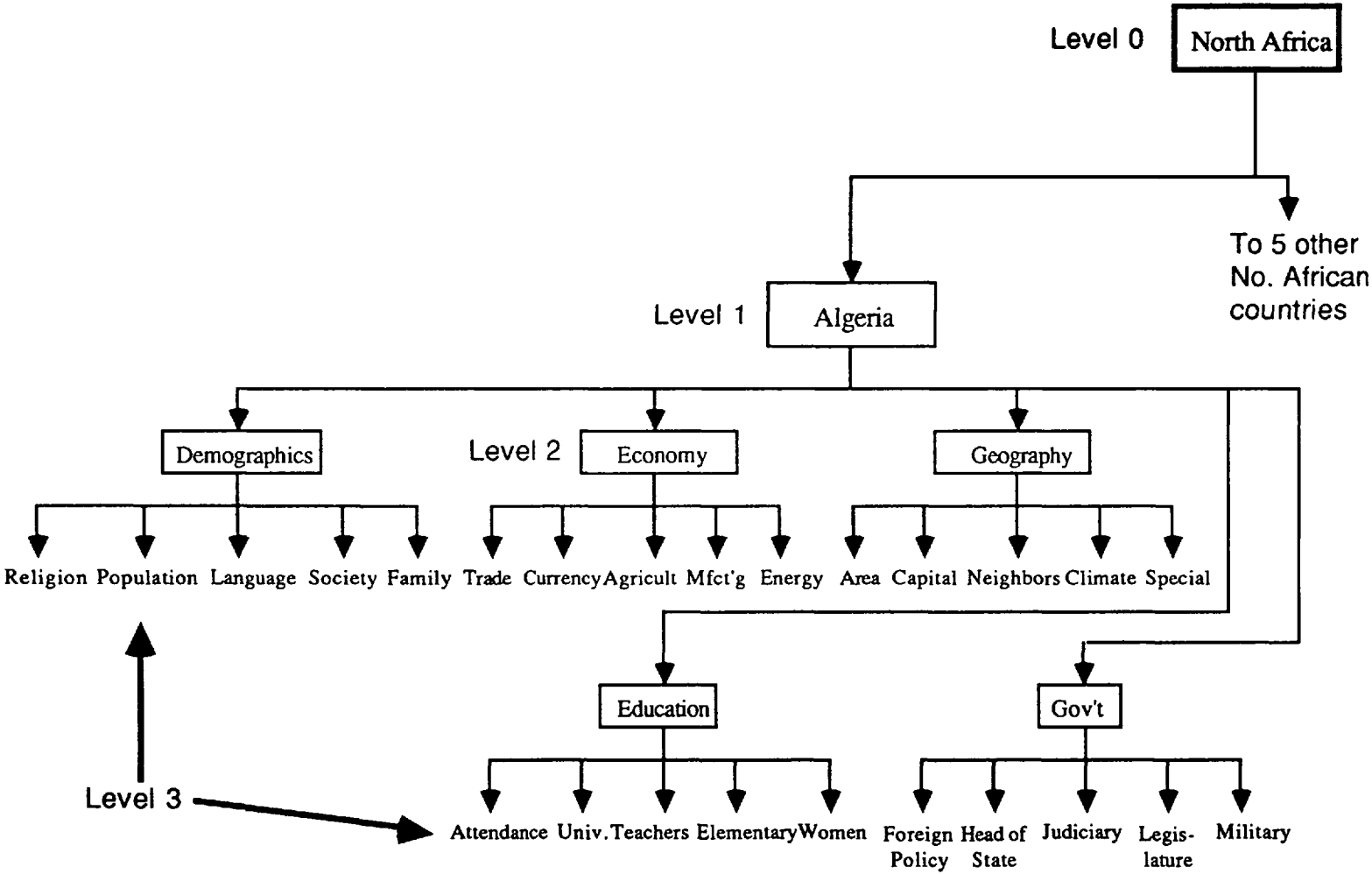

Figure 2. *Information organization in the hierarchical linking structure.*

ing is the immediate availability of all options associated with a particular chapter or section, which presumably allows for more efficient movement within the document. Options within each chapter and section were organized alphabetically as determined by the menu panel design guideline offered by Paap and Roske-Hofstrand (1988).

Network structure provided relational links established on the basis of key word searches (a common method of deriving relational links). The titles and general subject matter of all system nodes (e.g., economy) were defined as key words. Key words in a given node referred to information contained in other nodes. A link was established from the key word to the referent node. A sample node in the network linking configuration is illustrated in Figure 3. Links are established solely on the basis of reference-referent relationships, regardless of locations in hierarchical terms.

The combination linking structure was the combination of the previously described hierarchical and network structures. In effect, users had access to two types of linking and twice as many options as did users of the hierarchical or network structures alone. Some hypertext experts (e.g., Conklin, 1987) believe that such a two-tiered configuration of organizational plus relational links is more beneficial than each in isolation.

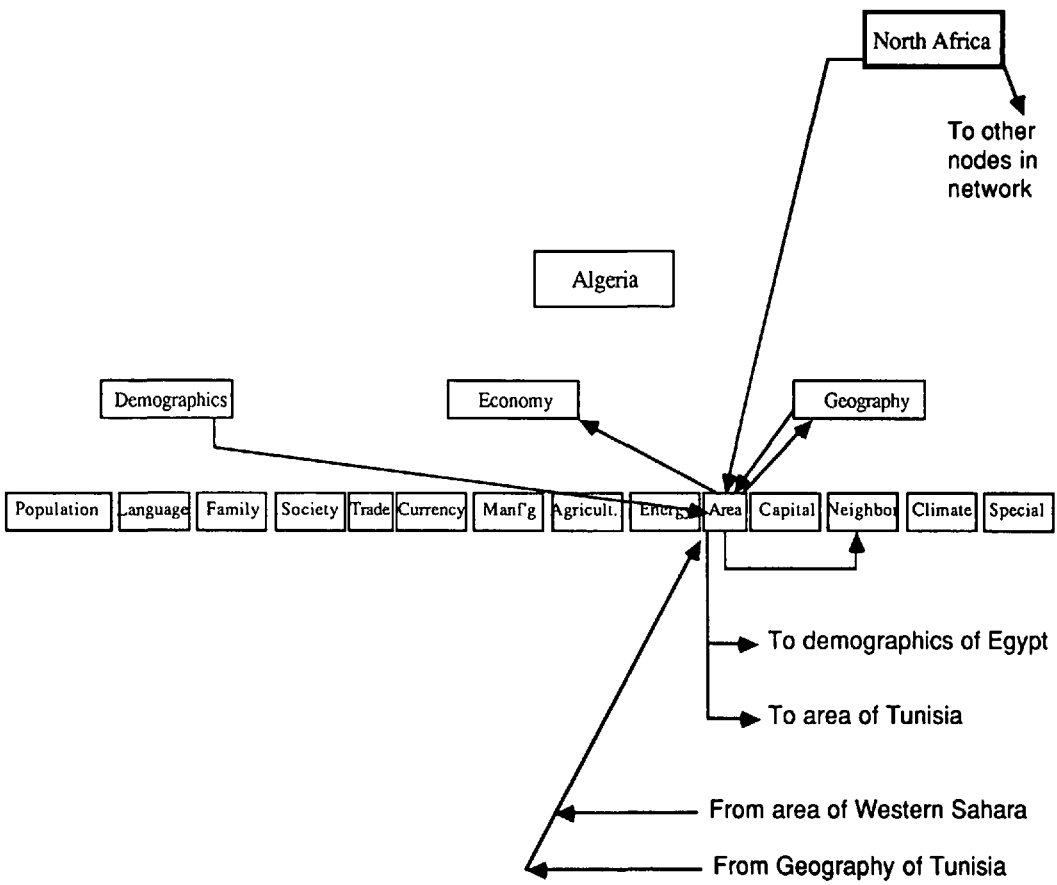

Figure 3. *The Area of Algeria node in the network linking structure. Multiple links connect this node to various nodes throughout the document with no regard for their locations in hierarchical terms.*

Number of required links. The number of traversed links is the minimum number of required traversals (during browsing) to answer a particular retrieval question. There were three levels: two-, four-, or six-link tasks, a representative range for realistic task performance, given the other high-powered search mechanisms available (e.g., string searches). Answers to two-link tasks were found in a single node, whereas four- and six-link tasks required access to pieces of information in two separate nodes. The number of links is meaningfully applicable to only the hierarchical, network, and combination structures. The linear structure served as a control.

Task type. Task type refers to data base programmers' judgments of whether retrieval tasks were best performed with the hierarchical or network linking structures. It was hypothesized that because of the inherent differences between the hierarchical and network structures in available links at any given node, certain tasks may be logically suited to the hierarchical structure, whereas others may be better suited to the network structure. Therefore, a pilot study was conducted using 12 data base programmers as expert judges. The data base programmers were experienced users and creators of data bases; all were familiar with hypertext. The experts performed 18 retrieval tasks on both the hierarchical and network structures and rated the ease of performing the task on each structure; additionally, the experts provided forced-choice preference judgments. Experts tended to judge tasks based on perceived level of effort required during retrieval (e.g., time or links required to reach the answer) and availability of links suited to task requirements. A binomial test was used to assess whether a task was reliably judged to be easier on the hierarchical or network structure. The resulting task types were labeled *hierarchical tasks* and *relational tasks.*

Experimental Design: Experiment A

A three-way mixed factors factorial design was used for data collection: 4 Linking Structures × 3 Levels of Required Links × 2 Task Types. Linking structure was a between-subjects variable, and number of required links and task type were within-subjects variables.

Experimental Design: Experiment B

In Experiment A, all tasks were constructed to require the same number of link traversals on the hierarchical, network, and combination structures. However, a significant benefit of relational linking is the ability to access information with no regard for levels in the hierarchical sense. For instance, moving from the top of a hierarchy to a leaf node may require traversing four links, whereas the identical trip may require a single link using relational links. Therefore, a second experiment—Experiment B—investigated the performance of various linking structures under circumstances heavily favoring the network structure. A two-way mixed-factors factorial design was used for data collection: 4 Linking Structures × 3 Levels of Required Links. The number of required links were two-, four-, and six-link tasks for the hierarchical configuration, whereas in the network configuration the same tasks required one, two, and three links. Because all tasks were judged to be best suited to the network linking structure (relational tasks), task type was not relevant. Data for Experiments A and B were collected during the same session. The order of task performance was completely randomized.

Apparatus

Equipment. An Apple Macintosh II equipped with a 20-inch Sigma Designs SilverView™ monochrome monitor (model A91F19F), an extended keyboard, and a

mouse constituted the host system. Subjects used the *GEO* data base to perform the retrieval tasks.

Subjects

Sixty-four subjects (48 men and 16 women) ranging in age between 18 and 37 years (mean = 22) participated in this study. All were paid volunteers. On a pre-experiment questionnaire, most subjects categorized themselves as PC users with average experience. However, subjects ranged in experience from basic software users to highly experienced programmers; all were familiar with the operation of mouse-based interfaces. A few subjects had heard of hypertext, but none had seen or used a hypertext system.

Dependent Variables

Numerous dependent measures were used in the study; however, four are of particular interest here.

Task completion time (solution time). Task completion time (TCT) is the time difference between the start and completion of a retrieval task. The beginning of the task was defined as the time at which the subjects entered the data base; the end was marked by the time subjects accessed an on-line answer sheet. All subjects read about and completely understood the retrieval task and then pressed a button to enter the data base; thus TCT reflects solely the solution times, with no contamination from time required to read about and understand the task.

Number of errors. This measure is the number of incorrect responses. These errors were classified in a binary fashion: any answer but the correct one was considered an error.

Deviations from the optimum path. The optimum path was the shortest route through the network (for each linking structure) to reach the answer to each task. The number of required links (two, four, or six) reflects the number of link traversals in the optimum path. Deviation was defined as follows:

$$\frac{\#\text{ of total nodes accessed}}{\#\text{ of relevant nodes accessed}} \quad (1)$$

A low deviation ratio (the minimum value is 1.0) indicates that few irrelevant nodes were accessed; a high ratio indicates the opposite.

Uncertainty measures. Frick and Miller (1951) and Miller and Frick (1949) used information theory to quantify the predictability of response patterns of rats moving in a maze. In particular, they evaluated the contingent uncertainties in navigational behavior given the occurrence of a specific event, such as a trip to the food tray.

In similar fashion, information theory was used in the current study to describe the uncertainty associated with the path to reach the answer to each retrieval task on each linking structure. Given 16 subjects per linking structure, the probability associated with each path, p_i, for any task was

$$p_i = \frac{\#\text{ of subjects using path } i}{16} \quad (2)$$

The total uncertainty (U) for completing this task in a particular linking configuration is

$$U \text{ bits} = -\sum_{i=1}^{n} p_i \log_2 p_i \quad (3)$$

for n paths. The assumption is that variability of navigation (used paths) should be reduced for linking configurations that facilitate finding information.

Uncertainty measures and deviation ratios may appear quite similar, but actually they measure different aspects of navigational difficulty. A deviation ratio provides a measure of deviation from an author-defined optimum path. This path for reaching an answer may indeed be the quickest route to task completion, but it may not be the most obvious or

most traveled path. Hence the uncertainty measure provided an understanding of the number of different paths taken in answering a question.

Procedure

The 64 subjects were randomly assigned to one of the four linking structures. All participants completed a questionnaire to determine their level of computer expertise and test their knowledge of North Africa. Subjects were excluded from participation if they correctly answered more than 25% of the questions related to North Africa. Most of these questions concerned simple geographical facts, such as, "What is the capital city of Libya?" On average subjects participating in the study correctly answered 4% of the questionnaire questions; most could answer none (range, 0–1 questions of 8 answered correctly). Hence all participants were considered novices in the information domain. After a 15-min training period and three practice tasks, subjects completed nine retrieval tasks. These tasks included detailed questions such as "What percentage of the Egyptian labor force is employed in the agriculture industry?" After reading and understanding the retrieval task, subjects pressed a button to enter the data base and navigated through the system in search of information to satisfy the query. Task completion time started when subjects entered the data base. Subjects pressed another button to access an answer sheet once they had found the answer to a task. Task time was halted when the subject accessed the answer sheet. During user navigation, the system collected data concerning the nodes each subject visited, time spent at each node, and type of link used to maneuver (applicable only for the combination structure). Finally, subjects were solicited for comments, debriefed, and paid. Data collection required 45 to 75 min per subject.

RESULTS

Experiment A

Experiment A yielded the results of retrieval tasks requiring equivalent numbers of links on the network and hierarchical structures. From a task performance view, an optimum information retrieval system will yield low task times and errors as well as low deviation ratios and uncertainty values.

Task completion time. A three-way analysis of variance (ANOVA) was used to test the effects of linking structure, number of required links, task type, and their interactions on TCT. The Greenhouse-Geisser ϵ correction factor for violation of sphericity was calculated for appropriate within-subjects variables and concomitant interactions. This approach was adopted for all ANOVAs in both experiments. Corrected p values are listed for appropriate F values; the nominal degrees of freedom were maintained at original levels. Refer to Greenhouse and Geisser (1959) and Huynh and Feldt (1970) for further detail on ϵ.

Linking structure, $F(3,60) = 4.59, p < 0.01$, and required links, $F(2,120) = 152.25, p < 0.01$, yielded significant effects. Newman-Keuls post hoc tests (overall $\alpha = 0.05$) failed to show a significant difference between the hierarchical and combination configurations, which had mean TCTs of 109.21 s and 115.78 s, respectively. However, these two structures yielded significantly shorter TCTs than the network and linear systems: mean of 149.35 s and 155.56 s, respectively. No significant difference existed between the network and linear structures. The two-link tasks required significantly shorter TCT than four-link tasks, which required significantly shorter TCT than six-link tasks. The task type main effect was not significant, $F(1,60) = 1.07, p = 0.31$, indicating fairly equivalent difficulty for the task types.

The Linking Structure × Required Links, $F(6,120) = 3.11, p < 0.01$, and Linking Struc-

ture × Task Type interactions, $F(3,60) = 3.38$, $p < 0.05$, yielded significant effects. Figure 4 presents the Linking Structure × Required Links interaction. A Newman-Keuls post hoc test (overall $\alpha = 0.05$) revealed no differences among the structures for two-link tasks. For four-link tasks the linear structure had significantly longer task completion times than did all other structures, which failed to differ significantly. Finally, for six-link tasks the linear and network configurations required significantly more time than did the hierarchical or combination structures, with no reliable differences uncovered between linear and network or between hierarchical and combination. The linear regression equations for each structure are as follows (based on means):

Linear: $TCT_L = 19.375 + 34.05$ links, $r^2 = 0.99$
Hierarchical: $TCT_H = 2.80 + 26.60$ links, $r^2 = 0.98$
Network: $TCT_N = -21.896 + 42.813$ links, $r^2 = 0.96$
Combination: $TCT_C = 11.031 + 26.188$ links, $r^2 = 0.98$

The network structure exhibited higher β-weight values than did the hierarchical ($t = 2.73$, $p < 0.01$) and combination structures. No other differences were uncovered.

The Linking Structure × Task Type interaction is depicted in Figure 5. For relational tasks a Newman-Keuls test (overall $\alpha = 0.05$) failed to reveal differences between the combination and hierarchical structures or between the network and hierarchical structures. However, the linear configuration yielded significantly longer TCTs than did all others, and the combination structure produced significantly shorter TCTs than did the network structure. Of particular interest is the absence of a difference between the network and hierarchical systems. Recall that expert judges determined relational tasks to be particularly well suited to the network configuration. For hierarchical tasks no differences were found between the network and linear structures or between the hierarchical and combination structures; however, the former pair produced significantly longer TCTs than did the latter pair. Hence for hierarchical tasks the network configuration yielded detrimental effects, compared with the hierarchical and combination structures.

Errors. A total of six retrieval tasks were performed on each of four different structures

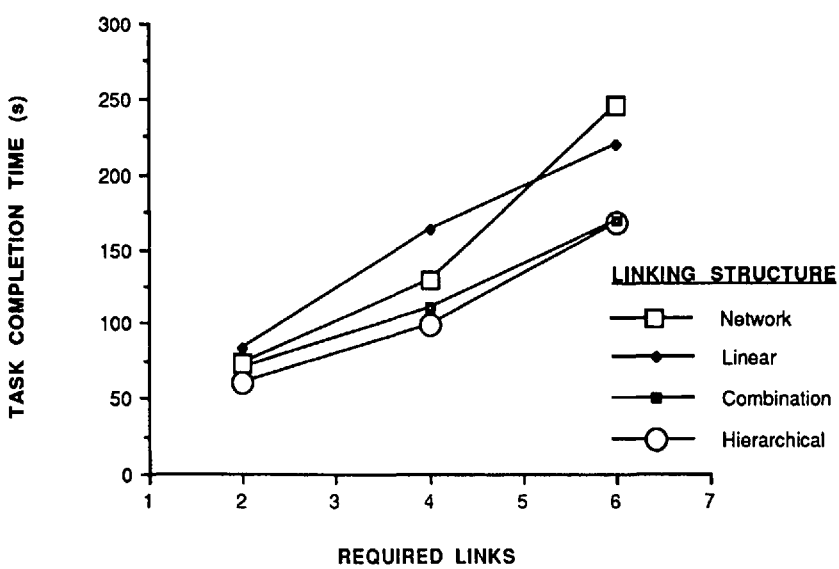

Figure 4. *Linking Structure × Required Links interaction for task completion time (Experiment A).*

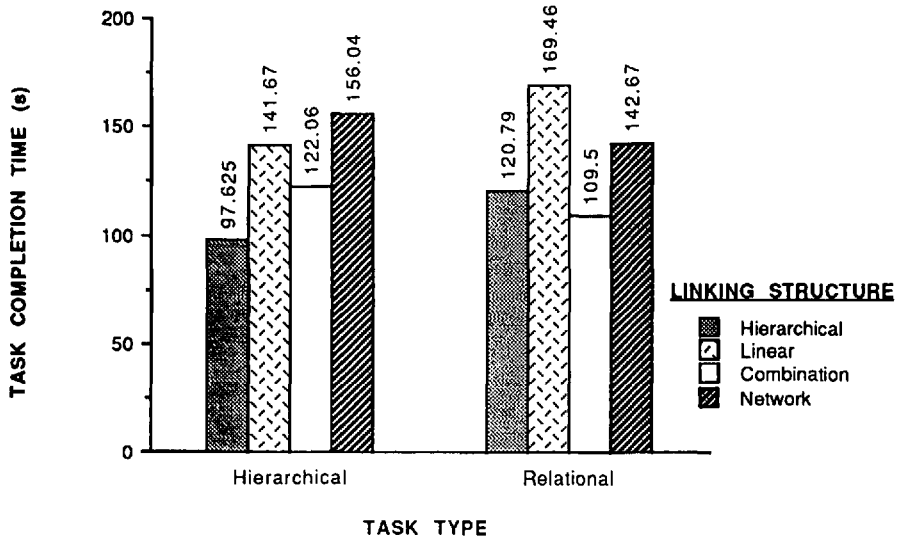

Figure 5. *The Linking Structure × Task Type interaction effect for task completion time (Experiment A).*

16 times, yielding a total of 384 tasks. However, only 18 errors occurred, resulting in a 4.6% error rate. The frequency of errors for the structures was quite low, and no statistical analyses were conducted.

Uncertainty. Attneave's (1959) bits to χ^2 transformation was used to investigate the differences in uncertainty. There were no significant differences between the hierarchical and combination structures, but both yielded significantly less uncertainty than did the network structure ($p < 0.0169$ for three paired comparisons). Additionally, two-link tasks had lower associated uncertainty than did four-link tasks, both of which exhibited lower uncertainty than did six-link tasks. Task type failed to produce a significant difference in uncertainty.

Figure 6 presents the Linking Structure × Required Links interaction. No differences existed among the structures for two- and four-link tasks; however, the network configuration yielded significantly higher uncertainty than did the others for six-link tasks ($p < 0.005$ for nine paired comparisons, overall $\alpha = 0.05$). The hierarchical and combination structures exhibited no differences at any level of required links.

Deviations from the optimum path. A three-way ANOVA was used to analyze the deviation data. Task type and required links failed to produce significant main effects (at $p < 0.05$), but the linking structure main effect was significant, $F(2,45) = 4.63$, $p < 0.05$. A Newman-Keuls post hoc test found the hierarchical structure to have significantly higher deviation ($D = 2.01$) than did the network and combination structures ($D = 1.50$ and 1.48, respectively), which were not significantly different. At first glance this finding seems somewhat inconsistent with the results for task completion time and uncertainty: although the hierarchical structure produced lower task times and uncertainty, it also exhibited significantly higher deviation. The Linking Structure × Task Type interaction (Figure 7) further explains this seemingly contradictory result. No differences existed (at $\alpha = 0.05$) among the mean deviations except that the hierarchical structure yielded significantly higher deviation for relational tasks. Detailed explanations

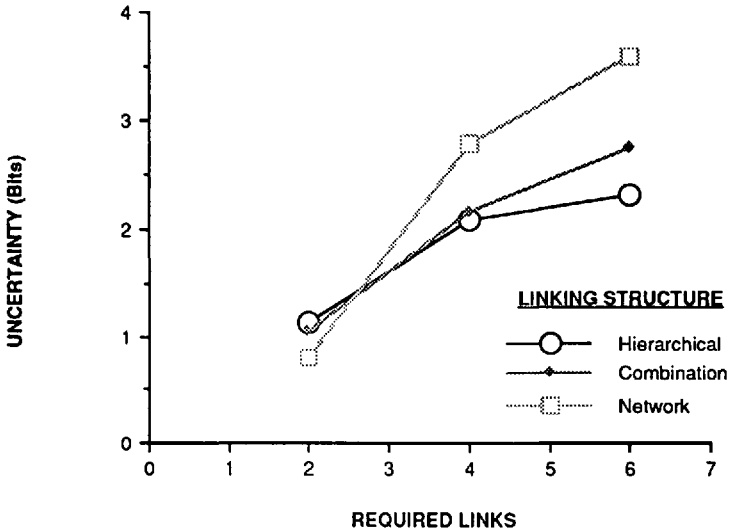

Figure 6. *The Linking Structure × Required Links interaction for uncertainty (Experiment A).*

of this finding appear in the discussion section.

Experiment B

Experiment B yielded results of retrieval tasks requiring half as many links in the network structure. In Experiment B, number of required links is referred to as 2/1-link, 4/2-link, or 6/3-link tasks. The number before the slash indicates the minimum number of links required for task completion in the hierarchical structure; the number following the slash indicates the number of links required to complete the same task in the network structure.

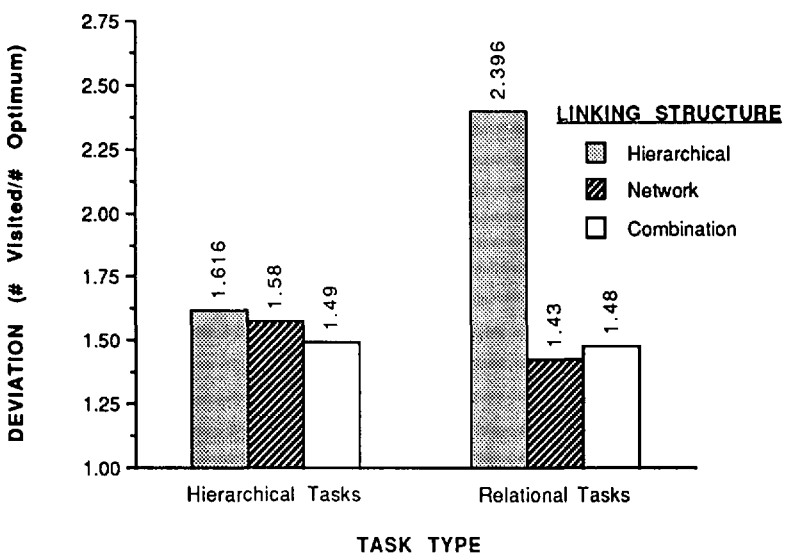

Figure 7. *The Linking Structure × Task Type interaction effect for deviation (Experiment A).*

Task completion time. A two-way ANOVA was utilized to test the effects of linking structure, number of required links, and their interaction on TCT. The linking structure, $F(3,60) = 6.37$, $p < 0.01$, and required links, $F(2,120) = 55.49$, $p < 0.01$, main effects yielded significant F values, as did the Linking Structure × Required Links interaction, $F(6,120) = 3.77$, $p < 0.01$. For the linking structure main effect, Newman-Keuls post hoc tests (overall $\alpha = 0.05$) showed that the network configuration yielded significantly shorter TCTs than did both the hierarchical and linear structures. The network and combination structures yielded no significant difference. For the required links effect, no differences were uncovered between 2/1-link and 4/2-link tasks; 6/3-link tasks produce significantly longer TCT.

Figure 8 illustrates the Linking Structure × Required Links interaction. A Newman-Keuls post hoc analysis revealed that for 2/1-link tasks the hierarchical, network, and combination structures showed no difference, but the linear configuration yielded significantly longer TCT. No differences were detected for 4/2-link tasks. For 6/3-link tasks, the hierarchical and linear structures produced no difference; however, both had significantly longer TCT than did the network and combination structures. The combination structure exhibited a longer mean TCT than did the network configuration.

Errors. As in Experiment A, too few errors occurred for statistical analysis.

Uncertainty. A test of the differences in uncertainty among the linking structures showed that the combination structure yielded significantly higher uncertainty than did the network configuration ($p < 0.0169$ for three paired comparisons). No other differences were detected among the linking structures. Additionally, 2/1-link tasks had lower associated uncertainty than did 4/2-link tasks, both of which exhibited lower uncertainty than did 6/3-link tasks.

Figure 9 presents the Linking Structure × Required Links interaction. No differences existed among the linking structures for 4/2-link or 6/3-link tasks; however, the combina-

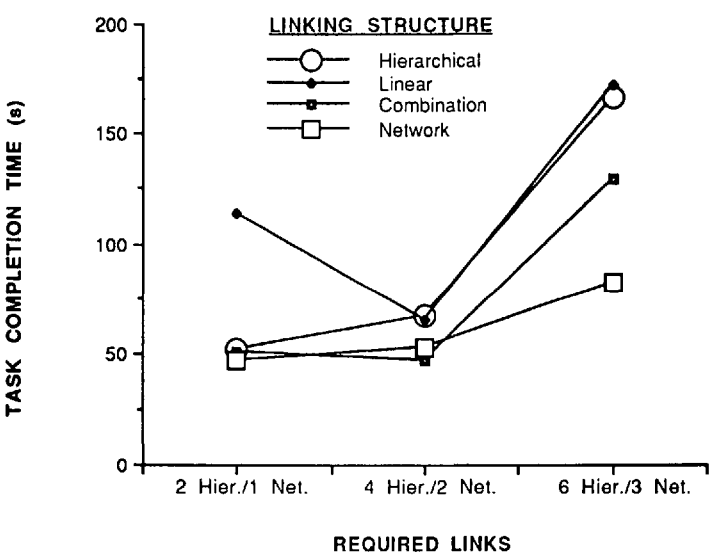

Figure 8. *Linking Structure × Required Links interaction for task completion time (Experiment B). Demarcations such as "Hier./1Net." indicate that two links are required in the hierarchical structure and one link in the network.*

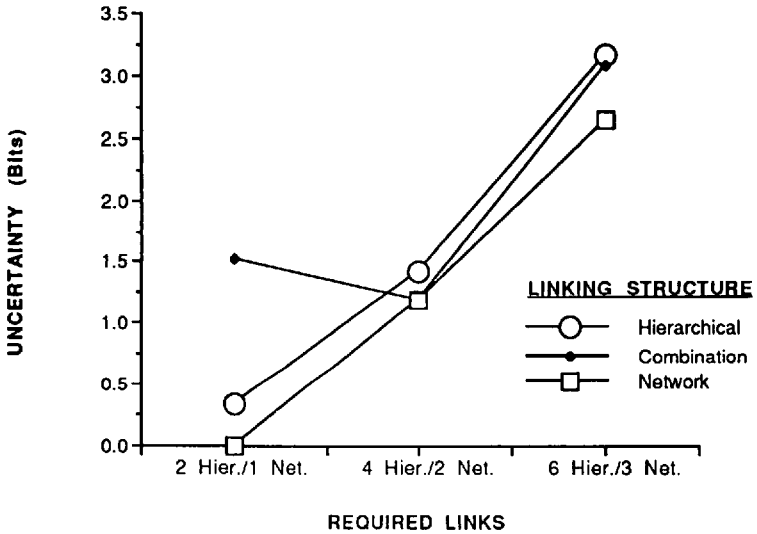

Figure 9. *Linking Structure × Required Links interaction for uncertainty (Experiment B).*

tion configuration yielded significantly higher uncertainty than did the others for 2/1-link tasks ($p < 0.005$ for nine paired comparisons). The hierarchical and network structures exhibited no differences at any level of required links.

Deviations from the optimum path. A two-way ANOVA was utilized to test the deviation data. Linking structure, $F(2,45) = 5.75$, $p < 0.01$, produced a significant main effect. A Newman-Keuls post hoc test detected a difference between the network (mean = 1.33) and combination (mean = 1.93) structures; all other pairs failed to produce significant differences. A post hoc test of the significant Linking Structure × Required Links interaction, $F(4,90) = 3.78$, $p < 0.05$, yielded no differences among the structures for 2/1-link or 4/2-link tasks. For 6/3-link tasks the combination and hierarchical configurations produced significantly higher deviation.

DISCUSSION

Task Completion Time

Where identical numbers of links were required to reach answers (Experiment A), the hierarchical and combination linking structures were superior to the network and linear structures. The hierarchical linking structure is believed to be superior because of its sufficient navigational predictability. Search of the hierarchical data base was driven by structure; because available links were identical at similar levels in the hierarchy, users could formulate structure-based strategies for their search. Most subjects commented positively on the convenience of structure predictability. Conversely, network links were established purely on informational bases (a key word search) and forced the user into an information-driven search pattern. Available links at each node were highly variable because the nature of the information and corresponding links were inconsistent from node to node. Subject task performance indicated that tasks were better performed using a structure-driven approach than an information-driven one.

In Experiment B all tasks were relational, as determined by judges, and required half as many links in the network structure. Thus the task situations heavily favored the network

configuration. However, only six-link tasks (three links in network structure) yielded significant differences between the hierarchical and network configurations. These results indicate that there are no TCT advantages in network linking unless the linked terms are well suited to task requirements *and* these links considerably reduce the overall number of link traversals (i.e., from six to three). However, if the important linked terms are identified prior to system design, there may be no need to embed them in text or force the user to move through nodes in search of the information. Perhaps an easily accessible list of key words or important terms will suffice.

Uncertainty

Uncertainty was highly correlated with TCT ($r = 0.86$ in Experiment A, $r = 0.85$ in Experiment B), indicating the sensitivity of this newly applied measure to the independent variables. In Experiment A the network structure exhibited higher uncertainty than did both the hierarchical and combination structures, owing largely to the exceptionally poor performance of the network structure for six-link tasks. The consistent structure of hierarchical linking allowed for less erratic navigation through the system, whereas the unpredictability of the network structure led to nonuniform navigational patterns.

In Experiment B no reliable difference existed between the hierarchical and network structures. This absence of a difference was consistent across number of required links. The network structure did not show lower uncertainty despite the fact that it required half as many links, and the combination condition provided no advantages over the hierarchy. It is interesting that the uncertainty value was not simply a function of the number of available links (i.e., more links lead to higher uncertainty). The combination structure offered twice as many links at each node than did the network or hierarchical links, but it still produced fairly low uncertainty in Experiment A.

Deviation from the Optimum Path

The exceptionally high deviation uncovered for the hierarchical structure in Experiment A was attributable to relational tasks. When considered in combination with TCT and uncertainty results, this finding was quite surprising. Subjects traveled to significantly more (and perhaps unnecessary) nodes in the hierarchical configuration with very high speed, as evidenced by the short TCT, and deviated to the identical nodes, as indicated by low uncertainty. A review of search tendencies for performing relational tasks uncovered an interesting navigational pattern. For the six-link relational task, subjects were required to access information from two nodes to complete the task satisfactorily. Both targets were leaf nodes within two separate chapters; thus users were required to travel down the hierarchy in one chapter, return to the home node, and navigate down the hierarchy in the second chapter to reach the final target node. In defining the optimum path for this task, I assumed that subjects would use the Home key to directly access the top-level node in the hierarchy. This single link eliminated the need for retracing three steps upward in the hierarchy. However, 44% of subjects using the hierarchical configuration failed to make use of the Home key, opting instead to retrace their steps in the hierarchy. This navigational behavior is attributable either to the subjects' poor understanding of the Home key or their preference for retracing steps to maintain a sense of orientation. The latter explanation seems more viable, considering that other subjects using the hierarchical structure who were exposed to identical training materials effectively utilized the Home key.

In Experiment B network structure yielded less deviation than did the combination

structure, mainly because of its advantages for six-link tasks. Also, users seemed unable to employ network links usefully in the combination structure for tasks requiring numerous traversals. For the six-link tasks, significantly fewer network links (45) were traversed than were hierarchical links (82), $z = 3.37$, $p = 0.001$. This may indicate that users experiment with network links only when they perceive minimal risk, as in situations requiring few links. However, users may be reluctant to use unpredictable network links when significant navigation is required (or if they believe such to be the case).

Conclusions

Linear linking. Clearly, the linear linking structure is a less efficient alternative than the other structures. The linear structure included in this study lacks highly sophisticated navigation features. For instance, each node of the system has an entry in the table of contents, but users cannot click on the entry to access the node. Although many systems provide such options, the intent of the current study was to measure performance given use of specific linking structures. The provision of immediate access to nodes through a table of contents would defeat this purpose. Additionally, specific node titles may not have always corresponded to retrieval task requirements; hence, users would have been required to enter the system and browse the document in search of the target information. Therefore, although the linear configuration was not augmented with sophisticated searching mechanisms (neither were other structures), the basic linear organization of nodes, as seen in many systems, was maintained.

Hierarchical linking. Hierarchical linking structures should be implemented for most hypertext (or text-intensive) data bases used for information retrieval. A debate as to whether a strictly hierarchically organized document should be labeled *hypertext* is found in the hypertext literature. This taxonomical issue is certainly minimal (and perhaps irrelevant)—the task performance issues of such systems are more salient concerns. Additionally, the recommendation of using hierarchical links does not exclude the use of other linking structures as augmentations; however, the necessity of the hierarchy as an underlying baseline organizing structure is obvious.

Network linking. Implementation of network links was based solely on key word searches. This is a common method for link generation, but it is not the only strategy for creating such links. Results of the current study imply that the use of network (relational) links in isolation from organizational linking should be strongly discouraged. Their inclusion should be in combination with organizational linking; the hierarchical structure proved suitable for organizational linking. Additionally, care should be taken in the establishment of network links. A critical issue will be for designers to identify task-relevant key words given that network links not suited to task requirements prove detrimental, not harmless. Experiment B illustrated that these links are beneficial only when task-relevant network links are capable of saving users many steps (or traversed links).

The potential extra costs of network linking, both during system development and in requiring system resources, may not be justified by the performance gains for information retrieval tasks. In fact, under certain conditions network links show a negative effect on task performance. These statements, however, must be interpreted in light of the subject population of the current study; subjects were novices to both the information domain and the *GEO* system. The utility of network linking may be higher for domain experts or experienced system users. Conceivably, users could learn an underlying hierarchical struc-

ture after considerable exposure. Subsequent to this exposure, users may feel more at ease and confident in using relational links to navigate within the document. Additionally, domain experts may immediately find utility in relational linking. They may recognize that certain linked words lead to desired information, whereas novice users may fail to recognize the utility or importance of particular links.

Combination linking. In terms of task completion time only, the combination configuration yielded performance as good as that for the best structure in each experiment. Thus if task completion time were the most salient consideration, the combination structure would be the structure of choice. The data fail to support overwhelmingly the use of combination linking, yet combination linking may prove to be advantageous over time. That is, although no differences may exist for a few tasks, over a period of performing many tasks, access to both types of linking may be beneficial, especially in terms of task completion time. Ultimately the decision to include both hierarchical and network links is likely to be determined by the information domain and the designers' ability to identify useful key words. Hierarchical links should be emphasized and network links should receive secondary emphasis.

ACKNOWLEDGMENTS

The author would like to thank Harry L. Snyder and William H. Muto for their insights, guidance, and assistance during the course of the experiment. This paper is based on the author's doctoral dissertation, which was sponsored by a graduate internship grant from the Texas Instruments, Inc., User Systems Engineering Laboratory.

REFERENCES

Attneave, F. (1959). *Applications of information theory to psychology: A summary of basic concepts, methods, and results.* New York: Holt.

Bates, M. J. (1986). Terminological assistance for the online subject searcher. In *Proceedings of the Second Conference on Computer Interfaces for Information Retrieval* (p. 7). Alexandria, VA: Defense Technical Information Center.

Cecala, T., Mohageg, M. F., and Watkins, R. (1989). *Human-computer research annual technical report* (Tech. Report CSC-TR89-014). Dallas: Texas Instruments, Inc., Computer Science Center, User Systems Engineering Laboratory.

Conklin, J. (1987). *A survey of hypertext* (Report STP-356-86). Austin, TX: Microelectronics and Computer Technology Corp.

Frick, F. C., and Miller, G. A. (1951). A statistical description of operant conditioning. *American Journal of Psychology, 64*(1), 20–36.

Gordon, S., Gustavel, J., Moore, J., and Hankey, J. (1988). The effects of hypertext on reader knowledge representation. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (pp. 296–300). Santa Monica, CA: Human Factors Society.

Greenhouse, S. W., and Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*(2), 95–111.

Halasz, F. G. (1988). Reflections on NoteCards: Seven issues for the next generation of hypermedia systems. *Communications of the ACM, 31,* 265–283.

Huynh, H., and Feldt, L. S. (1970). Conditions under which mean square ratios in repeated measurements designs have exact F-distributions. *Journal of the American Statistical Association, 65,* 1582–1589.

Miller, G. A., and Frick, F. C. (1949). Statistical behavioristics and sequences of responses. *Psychological Review, 56,* 311–324.

Nelson, H. D. (Ed.). (1986). *Algeria: A country study.* Washington, DC: U.S. Government Printing Office/American University.

Paap, K. R., and Roske-Hofstrand, R. J. (1988). Design of menus. In M. Helander (Ed.), *Handbook of human-computer interaction* (pp. 205–235). Amsterdam: Elsevier.

Smith, J. B., and Weiss, S. F. (1987). A hypertext writing environment and its cognitive basis. In *Hypertext '87 Proceedings* (pp. 195–213). New York: Association for Computing Machinery.

Thompson, R. H., and Croft, W. B. (1989). Support for browsing in an intelligent text retrieval system. *International Journal of Man-Machine Studies, 30,* 639–668.

Tompa, F. W. (1989). A data model for flexible hypertext database systems. *ACM Transactions on Information Systems,* 7(1), 85–100.