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# An extended fisheye view browser for collaborative writing

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This study investigated information-seeking tasks and associated cognitive issues in the context of interacting with an evolving collaborative hypertext. Fisheye view browsers were used to facilitate exploring in a large information space. The fisheye view browser was extended to incorporate word frequencies. The effects of the fisheye view browser and the changing document were tested with a $2 \times 2$ factorial experiment. Multivariate tests found a significant interaction between the two factors and a significant main effect of the fisheye view browser. The users who had access to the word frequency information performed their tasks more effectively than the users without access to word frequencies. This work implies that several aspects of an evolving hypertext might also be usefully incorporated in an associated fisheye view browser.

## 1. Introduction

Computer-supported cooperative work is a forum that combines the understanding of the nature of group working with the enabling technologies of computer networking, systems support, and applications. Four major classes of cooperative system are: (1) message systems; (2) computer conferencing; (3) meeting rooms; and (4) coauthoring and argumentation systems (Rodden & Blair, 1991). Coauthoring and argumentation systems aim to support and represent the coordination and argumentation involved in group working. The collaborative authoring of documents represents the product of a process of coordination among coauthors' work. Studies in human–human cooperation reveal the importance of creating an environment where the cooperation can be based on argument and the resolution of different perspectives (Clarke & Smyth, 1993).

The shared group memory paradigm provides a simple framework for understanding the nature of cooperative work and incorporating specific mechanisms to support different aspects of coordination and collaboration. One example of using this paradigm in traditional artificial intelligence is the Blackboard architecture. Within this paradigm, it is possible to reduce some decision-making complexities for collaborators on when, what and with whom to communicate. In addition, the shared group memory paradigm also provides the basis for investigating cooperative work from the perspective of open systems.

Hypertext systems represent a major group of computer-supported collaborative writing systems. Hypertext systems demonstrate some appealing features for collaborative writing. For instance, hypertext systems have been used to facilitate



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early stages of collaboration such as brainstorming and planning (Conklin & Begeman, 1988). Some hypertext systems provide support to organize the writing work of individual coauthors and merge their contributions at later stages of collaborative writing (Delise & Schwartz, 1987). Some hypertext systems can provide timely, appropriate communication support for collaboration, in accordance to the positions of coauthors in activity spaces, for all stages of writing (Streitz, Hannemann & Thuring, 1989; Haake & Wilson, 1992). On the other hand, interacting with the non-linear presentation of information chunks in hypertext has been known to incur a considerable cognitive overhead (Wright, 1991). The changing of the organizational structure and the content of a collaborative hypertext increases the cognitive load even more. Users need to rationalize the changes made by other coauthors and fit the changes into their own cognitive models associated with the shared group memory. A fisheye viewer to the shared group memory may help to facilitate users' interactions with the evolving public workspace.

The fundamental motivation of using fisheye views is to balance the display of local details and the overall organization of a large information space. The occurrence of a word in a chunk of information conveys information on the content of the chunk. Section 2 presents the background of collaborative writing and a review on the design and development of computer-supported systems. Some problems particularly associated with collaborative writing processes are identified in Section 3, based on experience of using a collaborative hypertext system, called the MUCH system. Section 4 gives the formation and extension of fisheye views related to a collaborative hypertext. An experiment was conducted to investigate the impact of the extended fisheye view browser on interacting with an evolving hypertext. The method and results of the experiment are presented in Sections 5 and 6. Section 7 discusses the implications of the results. Section 8 includes the conclusions and recommendations for future work.

## 2. Collaborative writing

The nature of cooperative work in general and of collaborative writing in particular has been an active issue in many disciplines such as social psychology, education, philosophy and computer science. For instance, two philosophies of collaborative writing are: (1) the neo-Romantic and (2) the neo-Classic (Ede & Lunsford, 1990). Neo-Romanticists emphasize the individual nature of collaborative writing and argue that collaborative writing is essentially individual-based. Neo-Classicists stress the social nature of collaborative writing and suggest that collaboration activities are significantly influenced by cultural and social factors.

Kraut and Egido developed a framework for scientific collaboration based on the empirical evidence that physical proximity is a fundamental factor that influences how scientific collaboration is initiated, advanced and maintained (Kraut, Egido & Galegher, 1988). Physical proximity influences ways of meeting research partners, defining problems, planning projects, and communicating with co-workers. The framework emphasizes the role of informal communication between collaborators in terms of its frequency, productivity and cost.

Discourse theorists have identified some patterns that writers tend to employ on every level of text. Readers depend on the help of structural patterns to recognize the type of text and its integrative role. Empirical studies of reading comprehension reveal that discourse is easier to comprehend when it is presented in well-defined structures and when clear signals of shifts from one part to the next are available (Charney, 1987).

van Dijk and Kintsch's theory on the organization of text suggests the existence of micro- and macrostructures. Research in discourse comprehension suggests that readers build hierarchical representations of the text they read (van Dijk & Kintsch, 1983). Readers are much more likely to remember general information at the top of the hierarchy than specific and low-level details. High-level propositions are reflected in the hierarchy and they are easy to remember as they are linked and referenced frequently in the discourse.

On the other hand, theories and models of collaborative writing are only sparsely available to the practitioners of computer applications. Some collaborative writing systems are essentially based on individual writing models, such as peer-evaluation, where coauthors serve as a general audience and take turns drafting (Fish, Kraut, Leland & Cohen, 1988; Ede & Lunsford, 1990; Hahn, Jarke, Eherer & Kreplin, 1991). Other computer systems for collaborative writing take the Neo-Classical approach. These approaches directly address the inherent problems of collaborative writing. Kraut, Galegher, Fish and Chalfonte (1992) applied the contingency theory to collaborative writing in their empirical research on the relationship between task requirements and the choice of communication media. Morgan and Murray (1988) related their studies of collaborative writing to the theory of cognitive dissonance, which was developed by the psychologist Leon Festinger (1957). Insights in an interacting group can be reached via an iterating cycle: occurrences of cognitive dissonance and achieving of consonance with a greater degree of understanding (Morgan & Murray, 1988). An empirical account for the relationship between cognitive dissonance and insights in collaborative writing can be found in Morgan *et al.* (1987).

The theory of cognitive dissonance was developed a few decades ago (Festinger, 1957). Cognitive dissonance may occur when people cannot relate new knowledge to their existing knowledge. Cognitive dissonance is a motivating factor in its own right. For instance, cognitive dissonance occurring in a learning or problem-solving process increases people's desire to explore further information in order to fit the new knowledge into existing cognition. According to the theory, the existence of dissonance will motivate a person to try to reduce the dissonance: the person's knowledge structure may be re-organized as a result of the rationalization. Collaborative writing is expected to have more occurrences of cognitive dissonance than individual writing and these dissonances may spark more insights into the work. When coauthors are interacting with a shared workspace such as a collaborative hypertext, an information-seeking tool with respect to the structure and content of the workspace becomes particularly important. The impact of a fisheye view browser of a collaborative hypertext on exploring desired information will be further discussed in the following sections.

Hypertext systems that aim to support collaborative writing activities can be divided into two generations according to the underlying theoretical basis used and implementations derived from the theory. The first generation of hypertext systems do not explicitly deal with interactions arising in collaborative writing processes.

These systems depend on established collaboration patterns for the effective use of functionalities of the systems. There are some initial conditions that have to be satisfied. For instance, KMS deals with one collaborative writing problem by making the assumption that in general the number of frames significantly outnumbers the number of collaborating authors so that it is unlikely that more than one author finds that they are working on the same frame at the same time (Akscyn, McCracken & Yoder, 1988). Turn-takings in NoteCards rely on established conventions among coauthors (Irish & Trigg, 1989).

The second generation of hypertext systems are more closely connected with theories related to collaborative writing and provide explicit support to some activities identified in corresponding models. The implementation of the Neptune system, particularly, includes mechanisms to resolve the clash of multiple perspectives in collaborative writing (Delise & Schwartz, 1987). Neptune uses the concept of *context,* a collection of nodes and links that have to be evolved consistently, to facilitate versioning transitions between the individual workspaces and the shared workspace. Some basic mechanisms such as conflict detection in terms of versioning trees are provided to facilitate the mutual intelligibility of coauthors' work. The SEPIA system is by far the most comprehensive hypermedia system developed in terms of its theoretical basis and the associated activity spaces supported (Streitz *et al.,* 1989; Haake & Wilson, 1992). SEPIA emphasizes that the planning, translating and reviewing involved in collaborative writing are not subsequent stages, in that there is empirical evidence that they can also occur in other orders. In SEPIA, collaborative writing processes are supported within a framework of four activity spaces: (1) planning space, (2) content space, (3) argumentation space, and (4) rhetorical space. The system helps to monitor and organize interactions among coauthors. Two modes of interactions among coauthors are provided, on the basis of coauthors' relative positions in these activity spaces, in order to make smooth transitions from one mode to the other.

These approaches provide useful insights in solving problems associated with cooperative work. In the following sections, experiences and lessons learned from using a hypertext coauthoring system called Many Using and Creating Hypermedia (MUCH) are presented. Based on these problems and lessons, a model of a particular aspect of collaborative writing with a dynamic hypertext is developed. An existing browsing tool has been extended with respect to the model. An experiment was conducted towards testing the usability of the tool.

## 3. Experiences with MUCH

The MUCH system aims to support collaborative writing with hypertext (Rada, Wang & Birchall, 1992). In practice, using the MUCH system revealed some problems that are particularly related to interactions with a dynamic hypertext document among multiple users. These problems highlighted the need for information not only on the artifacts being developed, but also on the processes which interweave the activities of each individual user. This understanding led to an extension of the existing browser implemented in the MUCH system. Interrelationships among tasks, users, and different searching and browsing tools in earlier versions of the MUCH system were investigated (Rada & Murphy, 1992).

### 3.1. THE MUCH SYSTEM

The MUCH system supports three groups of tasks: (1) collaborative hypertext authoring; (2) desktop publishing; and (3) hypertext-to-hypertext conversions. The semantic model of the MUCH system is based on semantic networks and this semantic model is represented in the form of hypertext with a hierarchical outline browser.

The user interface of the MUCH system consists of an outline window on the left-hand side and a node content window on the right-hand side (see Figure 1). The outline window shows a hierarchical view to the underlying semantic network. In the outline window of Figure 1, the numbers in front of node headings are the occurrences of the word *environment* in corresponding nodes. Users choose the word of interest from a list in the small window with the title of "Word Index". The underlying semantic network is organized such that the traversal mechanisms of the MUCH system can generate filtered views according to users' needs.

The development of the outline window was based on the fisheye view paradigm (Furnas, 1986; Fairchild, Poltrock & Furnas, 1988; Noik, 1993). A fisheye viewer visualizes the organization of an information space as a graphical network. A fisheye viewer displays information elements in detail near a focal point and displays only the more important landmarks further away. The positions of information elements in the graphical network are determined by computing a degree-of-interest value for every element, and displaying only those elements that have sufficient degree-of-interest values for a given criterion. The degree-of-interest value for an element

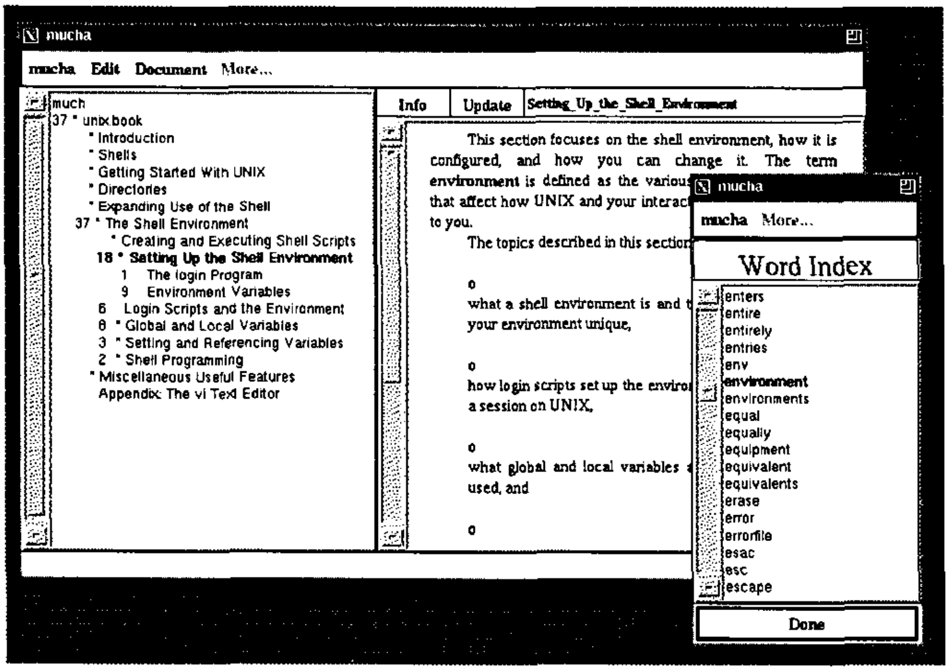


FIGURE 1. The interface of the MUCH system. The screen shows a split window with a fold/unfold outline on the left. Users choose a word from the alphabetically-sorted list in the Word Index window in the lower right corner to display its frequencies in the outline.

increases as the *a priori* importance of the element increases, and decreases as distance increases from the location of the element to the current focal point of the user. The formation of fisheye views will be discussed in detail in Section 5.

In a collaborative authoring setting, collaboration depends on the ability of one collaborator to learn easily what changes were made during the previous session by other coauthors (Irish & Trigg, 1989). The MUCH system has two component managers: the locking manager and the monitoring manager. Asynchronous accesses to the shared data repository, i.e. the collaborative hypertext, are controlled by locking mechanisms. Once a permission to a writing request is granted by the locking manager for a node, notification will be given to the users who make subsequent writing requests to the node. For example, in its simplest form, a notification could be a one-line message:

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This node is being editing by user@host.
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Other users may act accordingly on this information. The active author can use a pushbutton called update to trigger the propagation of the latest changes to the display of other users reading the same node.

### 3.2. PREVIOUS EXPERIENCES

The MUCH system provides some basic support in the understanding of what other coauthors are doing with the same part of the hypertext. Historical and status information on users and their actions is made available to the monitor manager, including time-stamps showing when operations were conducted and the names of users who invoked the operations. Two types of historical information are stored for each node: update records and selection credits. The two types of historical information on the current focal point are displayed in a pop-up window upon pressing the INFO pushbutton on the node content window. The pop-up window is labeled as "Node Information" (see Figure 2). Recorded information for each node includes the name of the creator, the time of the creation, the selection history (the number of times users visited the node), and the editing history (the name of coauthors who invoked update operations on the node). The selection credit is used to give the node a collective assessment of interest. Previous experience gained from the use of MUCH in coauthoring a variety of types of document, including academic papers, position papers, project proposals and deliverables, development notes, and manuals, suggests that a node heading plays a more significant role in getting high scores in selection credits than the content of a node. The node information associated with each node provides information in order that one coauthor can learn what changes are made by other coauthors.

The hierarchical view in the MUCH system is used as the major browsing mechanism. However, this global view, which consists of a network of node headings, is a high-level abstraction of the underlying hypertext. Three types of problem were particularly associated with this high-level abstraction and lack of finer-grained access points:

1. It can become increasingly ineffective for users to judge the relevance of a

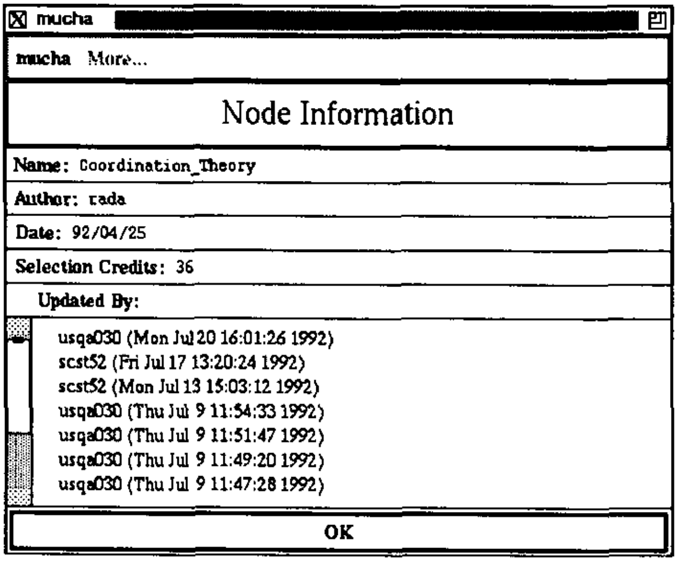


FIGURE 2. Access and evolutionary information of a node. This node has been accessed 36 times by users other than the creator of the node, Rada. The node has also been updated by two other users.

group of nodes farther away from the top of the hierarchy based on the outline of node headings. An additional dimension for balancing local details and the global structure in the display could be helpful.
2. Experience of using the MUCH system reveals that the hierarchical outline and node headings are often found insufficient in providing informative navigational guidance.
3. There is no mechanism for the users to find out what changes have been made in finer granularities, nor are there mechanisms to record the rationale behind these changes.

These problems may influence the collaboration among coauthors. The developers of the NoteCards system identified three types of processes in collaborative writing with hypertext: (1) substantive processes, (2) annotative processes, and (3) procedural processes. Most existing hypertext systems in this direction mainly deal with substantive processes (Streitz *et al.*, 1989). Users not only need to know who has made changes to a particular node, but also need to rationalize the new information introduced to the current understanding of the content domain and rhetorical status. In fact, users reported that it is usually difficult to appreciate how a new node of information added by others will fit into the evolution of a hypertext document being collaboratively written. According to the theory of cognitive dissonance, people would be motivated to seek additional information in order to rationalize or explain away the gap so as to reduce the magnitude of dissonance. The existence of cognitive dissonance has been regarded as a positive and intrinsic factor that promotes collaborations in order to achieve more profound coherence. In an attempt to help users in this content, the fisheye view browser, based on the organizational structure of a hypertext document, was extended to incorporate word frequencies.

## 4. Extending fisheye views

Previous experience of using the MUCH system suggests that the cognitive complexity of interacting with a hypertext document space can be influenced by a number of factors. What types of modification are allowed in the hypertext space—structural changes, local content changes, or both? Are coauthors allowed to modify the nodes created by other coauthors? How frequently is a single node likely to be modified by different authors? To what extent are the structure and the content of the hypertext space stable? How do coauthors communicate and coordinate their work?

### 4.1. FORMATION OF FISHEYE VIEWS

Fisheye views in user interfaces aim to provide a balanced display of local detail and global context (Furnas, 1986; Fairchild *et al.*, 1988; Noik, 1993; Rivlin, Botafogo & Shneiderman, 1994). Generalized fisheye views were formalized in Furnas (1986) by a *degree of interest* (DOI) function. The value of the DOI function at a point $x$ in a given structure G estimates whether the point $x$ is interesting enough to be displayed with respect to the current focal point *focus* of the user. A formal definition of DOI function is based on the *a priori importance* (API) associated with each point in the structure G and a metric of distance between any two points in the structure. The following formula represents the framework (Furnas, 1986):

$$\mathrm{DOI}(x, \mathrm{focus}) = \mathrm{API}(x) - \mathrm{DISTANCE}(x, \mathrm{focus})$$

Different fisheye views can be generated from this formula by instantiating specific API schemes and defining one's own concept of distance. In general, within the same distance, points with higher API have a higher degree of interest to the user; with the same API, points nearer to the focal point should be highlighted in the display.

The MUCH system displays a hierarchical view to the underlying document in the outline window. A set of operations is associated with the hierarchical structure to form a semantic model of users' interaction. The distance between two items in the hierarchy is defined as the length of the shortest path connecting the two items in the structure. The API associated with each item in the hierarchical outline is consistent with the logical structure. Items nearer to the root of the tree are assigned higher API. This definition is the same as that in Furnas (1986):

$$\mathrm{DOI}(x, \mathrm{focus}) = -\mathrm{distance}(x, \mathrm{root}) - \mathrm{distance}(x, \mathrm{focus})$$

Figure 3 shows an example of the fisheye view effect. The MUCH system provides a pair of operations called unfolding and folding operations. The circled nodes in Figure 3 depict subtrees that are folded up to their roots. One can use unfolding operations on a circled node in effect to move the focal point to the root item of the subtree and therefore increase the DOI of the nearby items.

### 4.2. EXTENSION OF FISHEYE VIEWS

The MUCH system uses an extended fisheye view browser to facilitate collaborative writing. The API component in the DOI function is extended along two additional dimensions with respect to the content and the evolution of a document being collaboratively written.

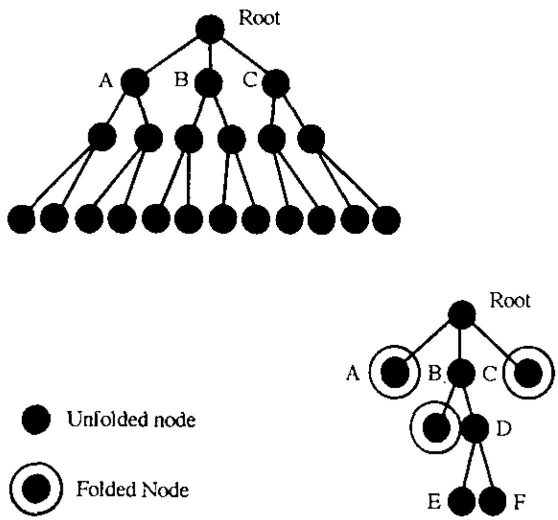


FIGURE 3. The fisheye view of a hierarchy in the MUCH system. The upper tree is generated by the traversal program of the MUCH system from the underlying semantic network. Nodes A, B and C have identical *a priori* importance as they are the same distance from the root node of the tree. The tree in the lower right corner is a fisheye view of the upper tree with the current focal point at the node F. Subtrees rooted at nodes A and C are folded to display only the high-level structure.

The occurrence of a word throughout a document has been recognized as an important indicator of the content (Egan, Remde, Gomez, Landauer, Eberhardt & Lochbaum, 1989). The extended fisheye view browser in the MUCH system overlays two layers of API schemes. The first layer is the API defined by the position of an item relative to the root of a hierarchical structure. The second layer is the API associated with the occurrence of a word of concern in the item. A formal definition of this additional dimension of the API is given as follows:

$$\mathrm{DOI}(x, \mathrm{focus}, \mathrm{word}) = \mathrm{occurrence}(x, \mathrm{word}) - \mathrm{distance}(x, \mathrm{focus})$$

The occurrence of a word in the node which is represented by the outline item $x$ is aligned with the first layer of the fisheye view browser. The display of the occurrence of a word in a tree structure is partitioned according to the display of the structure. Given a word $w$ and a tree structure $T$ which has the root $r$ and subtrees $T_1, T_2, \ldots, T_n$, the function $F$ for the display of the occurrence of the word $w$ in a fisheye view is defined as follows:

$$F(T, w) = F(r, w) + \sum_{i=1}^{n} F(T_i, w)$$

Let $U$ denote the unfolding operation and $D$ the display function in a fisheye view. $U$ is defined by the following equation:

$$U(T, w) = D(r, w) + \sum_{i=1}^{n} U(T_i, w), \quad \text{for any word } w.$$

The operational semantics of a two-dimensional fisheye view browser with word frequencies and the organizational structure of a hypertext document can be defined as a function $V$:

$$V(T, w) = V(r, w) + \sum_{i=1}^{n} V(T_i, w)$$

$$V(T, w) = (U(T, w), F(T, w))$$

$$V(T_i, w) = (U(T_i, w), F(T_i, w)), \quad \text{for} \quad i = 1\text{–}n.$$

An experiment was conducted based on an implementation of the fisheye view browser following this model, and will be reported in the following sections in detail.

In addition to the word frequency dimension of a fisheye view browser, the MUCH system maintains information on the number of times a particular node has been read by users other than the creator of the node. This information is known as the *credits of selection* in the MUCH system. The credits of selection indicates the degree of interest from the point of view of a group of users and it can be used to modify the DOI function by taking reading activity into account:

$$\text{DOI}(x, \text{focus}) = \text{API}(x) - \text{distance}(x, \text{focus}) + \text{credit}(x).$$

Fisheye view browsers can be extended to visualize the degree of interest related to the evolution of a document. Artifacts being actively modified can be highlighted in the display. In a cooperative hypertext system, hypertext entities such as nodes and links can be versioned to allow users to work in parallel. A configuration of versioned entities is a collection of the entities that must be developed with great consistency. A configuration highlights a substructure of the overall organization of artifacts of special interest to the collaborators. Incorporating the significance into the component of API is one way to extend the range of visualization to provide cues which would be useful for organizing one's actions. A document node may be related to a number of different documents being written. A node may belong to a number of configurations, if several users have been working on it. An additional component of the API at a node can be defined as the number of configurations it belongs to within a particular time interval:

$$\text{DOI}(x, \text{focus}) = \text{Config}(x) - \text{distance}(x, \text{focus}) + \text{credit}(x).$$

Consider an example: the point $x$ is the root of a subtree $T$, which has lower level subtrees $T_1, T_2, \ldots, T_n$. Three configurations $C_1$, $C_2$, and $C_3$ are related to $T$. If $C_1 \cap C_2 = C_1 \cap C_3 = \{\ \}$, and $C_2 \cap C_3 = C$, then

$$\text{Config}(x \mid T) = \text{Config}(x \mid T \cap C_1) + \text{Config}(x \mid T \cap C_3) + 2\,\text{Config}(x \mid T \cap C).$$

The display of the extended fisheye view browser must reflect the API definitions along multiple dimensions. A 3-dimensional graphical presentation with the temporal dimension rendered by simulation could provide an appropriate solution to the visualization. Visualizing a structure along multidimensional degrees of interest at the same time differs from employing a different API for each alternative view of the structure. For instance, Rivlin *et al.* (1994) also noted several options to choose from in defining the API. One option was using a metric system they developed for structure analysis. Another option proposed was to use the user behaviour, the number of times a node was visited, which is similar to the credits of selection in the MUCH system. However, the interrelationships among different API options were not fully investigated in their article.

The motivation and orientation of using word frequencies in the user interface are related to but different from the approach taken by the researchers of SuperBook (Remde, Gomez & Landauer, 1987; Egan *et al.*, 1989). SuperBook is designed for accessing static documents, and its major concern is the improvement of retrieval efficiencies for each individual user, whereas the approach described here is to integrate word frequencies into a fisheye view visualization of an evolving hypertext that is being collaboratively authored. This dynamic approach provides additional information not only on the organizational structure and content but also on the underlying authoring and coordinating processes.

An experiment was conducted in order to investigate the impact of the fisheye view browser with additional word frequency information on users' interactions with a hypertext document. The experiment also aimed to investigate the interaction between the browser and the evolution of a hypertext document in the MUCH system. The evolution of a collaboratively authored document is expected to result in more cognitive load for users, in order to keep their understanding of the status of the work up to date. According to the theory of cognitive dissonance, one of the conditions which may cause people to seek information and initiate communication with others is when one is exposed to new information which may not easily fit into one's existing knowledge structure. The experiment only considered information-seeking tasks, and the conditions of initiating communication and the structure of the subsequent interactions are addressed by other research, such as discourse analysis, and are beyond the scope of the experiment.

## 5. Method

The experiment used a $2 \times 2$ factorial design with between- and within-subject variables. The two factors were: (1) INDEX and (2) DYNAMIC. Both were two-level variables. INDEX was the between-subject variable and DYNAMIC was the within-subject variable. INDEX(0) was the condition in which the fisheye view browser was provided only for node headings, whereas in the condition of INDEX(1), the fisheye view browser was provided with the word frequency displayed against node headings for a word chosen by users. DYNAMIC(0) was the static condition in which users interacted with a static electronic version of a book on the UNIX operating system, whereas in the condition of DYNAMIC(1), users interacted with a dynamic version of the book. The dynamic version of the book was obtained by re-organizing the structure of and renaming some node headings in the static version. The experiment consisted of two sessions, corresponding to the conditions of DYNAMIC, and the DYNAMIC(0) session was followed by the DYNAMIC(1) session with an interval of at least a few hours to reduce the possible carryover effect. Data were collected into computer log files for each subject, including the name of an operation invoked by the subject, the time stamp of the invocation, the name of the current node, and the name of the item selected in the outline window.

The subjects observed in the experiment were 12 graduate student volunteers in computer science. Most subjects had working knowledge of the UNIX system and had experience of using the MUCH system with the browser only on node headings. None of them had read the book in either printed or electronic version. Subjects were assigned to two groups which corresponded to the two conditions of INDEX. Subjects in each group participated in two sessions with different DYNAMIC conditions. In each session, subjects were asked to find answers to four questions on the UNIX operating system by locating a node for each question where they thought the answer was to be found. There was a difference in the instructions given to the subjects in the two different DYNAMIC sessions. For DYNAMIC(0) sessions, subjects were told that the document was a read-only version. In fact, the evolutionary history of the document such as the time stamps and modification information associated with each node was hidden from users by initializing such information to a default value. For DYNAMIC(1) sessions, the evolutionary information was restored and made available to users; subjects were asked to answer the identical set of questions but they were told that the structure and content of the document has been changed since the static sessions.

There were four questions to be answered in each session. For each question, subjects were asked to identify the location of each node where they thought the answers were to be found. For instance, the first question asked about the usage of "`grep`" in the UNIX system. The term `grep` appeared 26 times throughout the book and appeared once in a node heading. In other questions, it was not obvious which single keyword should be used in forming a query to either filter the node headings in the outline window or display frequencies of the keyword.

The experiment tested hypotheses concerning the effects of the word frequency-based fisheye view browser and the effects of dealing with an evolving hypertext document. Users' interactions with the hypertext document in this study were measured collectively by a vector of four dependent variables: (1) *node*—the rate of multiple selections to a previously visited node; (2) *outline*—the number of outline views generated; (3) *unfold*—the number of unfolding operations used; and (4) *keyword*—the number of keyword searches used. These four dependent variables correspond to information needed at each level of information seeking as interacting with the collaborative hypertext system.

Hypotheses are stated in the null form on the comparisons of the vector $\boldsymbol{v} = \langle node, outline, unfold, keyword \rangle$ as follows:

H1: There will be no difference between the group with and the group without the work frequency browser on the vector of four variables.

H2: There will be no difference between static and dynamic sessions on the vector of four variables.

H3: There will be no difference on the vector of four variables between static sessions for the group using the word frequency browser and dynamic sessions for the group without using the word frequency browser.

The study intended to find out whether the extended fisheye view browser will reduce the number of node selections and the number of unfolding operations used. If the browser can help users to cope with increasing cognitive complexity associated with an evolving collaborative hypertext, the numbers of these operations should decrease.

First, users' patterns of interacting with the MUCH system were investigated. Operations used were grouped into three categories: navigation, search, and inspection. The percentage of each of these categorical operations used was expected to be different for both between- and within-subject variables.

Multivariate Analysis of Variance (MANOVA) was used for the hypothesis tests with respect to the between–within mixed design. When the results of multivariate tests were significant, corresponding univariate $F$-statistics were further considered to determine which variables contribute to the overall differences. Correlation coefficients were also calculated for observed variables.

## 6. Results

The experiment consisted of two sessions of interaction with the MUCH system. For each session, operations performed by the subjects were collected by computer log files. For most subjects, interactions with the MUCH system during the first 4–5 min were not particularly related to the questions. Experimental data were collected for each subject from the point that the subsequent transactions indicated that the subject was ready to seek information in order to answer the questions. Users' interactions with the MUCH system were examined for any patterns in terms of the usage of operations in the categories of browsing, searching, and inspecting. The browsing category included operations such as unfolding an outline item, generating a filtered outline, and folding an outline item. Operations in the search category included looking-up an index term from a word-list window and generating outlines for headings containing a particular keyword. Operations for inspection were the node selection operation and the INFO function associated with the current visited node. Table 1 shows the results of the examination of interaction patterns.

The use of navigational and inspecting operations indicated different patterns of interacting with the MUCH system between the group with the work frequency browser and the group without the word frequency browser. For the group without the word frequency browser, the percentage of navigational operations used was increased and the percentage of inspecting operations was decreased as the stability of the document was reduced. For the group with the word frequency browser, the percentage of navigational operations used was decreased and the percentage of

TABLE 1

*Percentage use of each categorical operation. The table is organized so that the factor DYNAMIC is nested within the factor INDEX. Major differences are in the changing of proportions of navigating and inspecting operations*

| | Without word frequencies | | With word frequencies | |
|---|---|---|---|---|
| | Static | Dynamic | Static | Dynamic |
| Navigating | 67% | 72% | 64% | 50% |
| Inspecting | 23% | 19% | 18% | 35% |
| Searching | 10% | 9% | 18% | 16% |

inspecting operations was increased as the stability of the structure and content of the document was reduced.

The number of unique nodes selected (UNIQ) by each subject was boxplotted by four conditions. The word frequency browser vs. the browser with node headings only on the variable UNIQ is expected to lead to a lower UNIQ in dealing with both static and dynamic documents. It is also hypothesized that dealing with a dynamic version of the document will increase the value of the UNIQ. In essence, the central hypothesis is to test whether there is an interaction between the word frequency and the stability of the document being used. The experimental data indicated that the group without the word frequency browser dealing with a dynamic document had the highest mean of unique nodes selected; the group with the word frequency browser dealing with a static document had the lowest mean. However, the differences were not statistically significant.

MANOVA was used in order to take into account the interrelationships among recorded operations and to fit the experimental design. Two groups of multivariate tests for significance were conducted. In the first group, the set of variables were analysed based on the total number of times an operation was used, whereas in the second group, the analysis was conducted for the number of operations used on each unique node.

In the first multivariate test for significance, the dependent variables included the number of selections on a node which was previously selected, the total number of outline generation operations used, the total number of unfolding operations used, and the total number of keywords and index terms used. The first variable was measured as the square root of the ratio of the node selections in total to the selections on unique nodes. The variables were normally distributed and had equal variance. The between variable was coded as INDEX and the within variable was DYNAMIC. Statistical significance for the tests was chosen at the level of $p = 0.05$.

Significant interaction was found between INDEX and DYNAMIC ($F(4, 7) = 6.333$, $p = 0.018$). The results indicate that the vector variable of the four dependent variables which were interrelated to each other as a whole was significantly different in at least two pairs of conditions: using the word frequency browser on a static document, and using a plain node heading browser on a dynamic document. The multivariate test also found the main effect of INDEX to be statistically significant ($F(4, 7) = 4.565$, $p = 0.040$). However, the within-subject variable DYNAMIC was not found to be statistically significant ($F(4, 7) = 1.804$, $p = 0.233$). Table 2 summarizes the results of the multivariate test by MANOVA.

When multivariate results are significant, univariate statistics may help determine which variables contribute to the overall differences. The univariate $F$-statistics are shown in Table 3. The suffix "1" indicates the static condition and the suffix "2" indicates the dynamic condition. These $F$-tests all had $df = (1, 10)$. The only variable on which INDEX had a significant main effect was NODE1. For each unique node selected by a subject in a session with the MUCH system, NODE1 measured the degree to which, on average, the same node was repeatedly selected throughout the session in the static condition of DYNAMIC. The normality of the variable was tested to be satisfied. For users interacting with a static version of the document, users with the word frequency browser visited significantly fewer times to a previously visited node than users without the word frequency browser ($F(1, 10) =$

TABLE 2
*Multivariate tests of significance with (4, 7) df. Interaction between the two factors was significant. The factor INDEX also had a significant main effect. The results of Hotelling's test were reported only*

| Factor | $F(4, 7)$ | Significance of $F$ |
|---|---|---|
| INDEX | 4.565 | 0.040* |
| DYNAMIC | 1.804 | 0.233 |
| INDEX × DYNAMIC | 6.333 | 0.018* |

* Significant at the $p < 0.05$ level.

6.204, $p = 0.032$). The effects of INDEX were not found to be statistically significant with other variables. Therefore, NODE1 is the variable that contributes the most to the overall differences in the multivariate tests.

Table 4 gives the means and standard deviations of variables Node1 and Node2. In both static and dynamic sessions, users with the word frequency browser tended to have a lower rate of multiple selections of a node than users without the word frequency browser. Standard deviations in dynamic sessions were larger than that in static sessions. For the group with the word frequency browser, the mean of the rate of multiple selections of a node in dynamic sessions was higher than those in static sessions. For the group without the word frequency browser, the mean in static sessions was higher than that in dynamic sessions.

The second multivariate test for significance was conducted on a similar set of dependent variables, except that variables that measured the total number of operations

TABLE 3
*Univariate F-tests with (1, 10) df by factor INDEX. Variables measured with a static hypertext have a suffix "1" and variables measured with a dynamic hypertext have a suffix "2"*

| Variable | $F(1, 10)$ | Significance of $F$ |
|---|---|---|
| Node1 | 6.204 | 0.032* |
| Outline1 | 4.388 | 0.063 |
| Unfold1 | 1.697 | 0.222 |
| Keyword1 | 0.255 | 0.625 |
| Node2 | 2.341 | 0.157 |
| Outline2 | 1.258 | 0.288 |
| Unfold2 | 1.450 | 0.256 |
| Keyword2 | 0.040 | 0.846 |

* Significant at the $p < 0.05$ level.

TABLE 4
*Mean and S.D. of the rate of multiple selections of a node*

| | Mean | S.D. | Significance of $F(1, 10)$ |
|---|---|---|---|
| Node1 | | | |
| Without browser | 1.1720 | 0.0285 | |
| With browser | 1.0423 | 0.0209 | 0.032* |
| Node2 | | | |
| Without browser | 1.1085 | 0.0414 | |
| With browser | 1.0658 | 0.0323 | 0.157 |

* Significant at the $p < 0.05$ level.

used were replaced by variables that measured the number of unique operations used. A significant main effect of INDEX was found ($F(4, 7) = 4.782$, $p = 0.035$). However, the main effect of DYNAMIC and the interaction between INDEX and DYNAMIC were not found to be statistically significant ($F(4, 7) = 0.821$, $p = 0.551$, and $F(4, 7) = 3.316$, $p = 0.080$, respectively). Table 5 shows the statistics of the univariate $F$-tests on these dependent variables.

Finally, the analysis of the data revealed some significant correlational relationships among observed variables. The total number of regenerating outline operations used was found to be negatively correlated with INDEX ($r = -0.5043$, $p = 0.012$). The major use of this operation was to filter the view to the document by searching for a chosen keyword in node headings only. The correlation coefficient between INDEX and the ratio of the number of node selection operations used in total (TOTAL) to that of node selection operations used on unique nodes (UNIQ) was found to be statistically significant ($r = -0.4977$, $p = 0.013$).

In the following sections, the interpretation of these results will be discussed in relation to corresponding hypotheses and the formulation of fisheye view browsers.

TABLE 5
*Univariate F-tests with* (1, 10) *df. The variable which contributes the most to the overall differences in multivariate tests is NODE*1

| Variable | $F(1, 10)$ | Significance of $F$ |
|---|---|---|
| Node1 | 6.204 | 0.032* |
| Outline1 | 4.388 | 0.063 |
| Unfold1 | 0.707 | 0.420 |
| Keyword1 | 0.002 | 0.969 |
| Node2 | 0.496 | 0.497 |
| Outline2 | 1.537 | 0.243 |
| Unfold2 | 0.330 | 0.578 |
| Keyword2 | 2.438 | 0.150 |

* Significant at the $p < 0.05$ level.

Conclusions of the study are based on the results of the experiment and their implications with respect to other empirical findings in the literature related to collaborative writing.

## 7. Discussion

The results of the multivariate tests for significance indicate an overall interaction between the fisheye view browser and the evolution of a document. The tests also found a significant main effect of the fisheye view browser. However, there was no significant main effect of the document changes. The significance of the interaction between the fisheye view browser and a changing document suggests the complexity of interacting with an evolving document tended to be increased by the absence of the word frequency information on the fisheye view browser. The interaction also suggested that the additional word frequency information provided by the fisheye view browser can make the task of interacting with a static document easier.

Hypotheses 1, 2 and 3 were null hypotheses on a vector of four interrelated dependent variables. The alpha level was chosen at $p = 0.05$. The null hypothesis on the interaction between the two factors (H3) was rejected by multivariate tests ($p = 0.018$). The null hypothesis on the main effect of the word frequency browser (H1) was also rejected ($p = 0.040$). However, the null hypothesis on the main effect of document evolution was not rejected ($p = 0.233$).

Univariate $F$-statistics revealed that the overall differences were related to the fact that users without the word frequency browser had a higher rate of multiple selections of a node than users with the browser. The analysis of interaction patterns of users also found that users without the word frequency browser did more browsing and less inspecting in a dynamic session that they did in a static session. In contrast, users with the browser did less browsing but more inspecting in dynamic sessions than corresponding measures in static sessions. The reasons for the differences in patterns need to be further researched. The rates of multiple selections of a node were becoming closer for the groups with or without the browser in the dynamic condition. This fact was consistent with the corresponding interaction patterns. Users without the browser used less inspecting operations in a dynamic session than they did in a static one. There was also a slightly decreased rate of multiple selections for the group without the browser.

There could be a number of reasons to explain the interaction between the word frequency browser and document evolution. The word frequency browser could be helping users to locate a desired substructure quickly. Two-dimensional descriptive information on a node was easier to identify than one-dimensional information. Furthermore, the word frequency sometimes provided a finer means of specifying a target node without actually inspecting the content of the node.

One should be cautious in drawing generalized conclusions based on the results of an experiment. Comparing with research findings in other experimental studies on collaborative writing produces a meaningful context for understanding the implications of the results of the study. Egan *et al.* (1989) investigated the impact of a full-text index in SuperBook. The structure and content of the document in SuperBook was static. SuperBook users performed worst on questions with neither node heading cues nor cues in text. Users had to rely on their understanding of the structure of the target domain and this kind of task was not particularly supported by SuperBook. In the study reported here, users without the word frequency browser took more steps to locate desired information than were taken by users with the browser. On the other hand, as indicated in some empirical findings in the literature on interacting with hypertext, users' cognitive models of a domain may become closer to the model represented by an associative network of hypertext as they interact with the hypertext (Leidig, 1992; Yusof, 1992; Jonassen, 1993). Longitudinal field studies are needed for further understanding of users' interactions with hypertext.

The empirical results from the study provide a useful basis for understanding interaction with a collaborative hypertext and for designing specific facilities to help some aspects of collaborative writing with hypertext. Little empirical work is found in the present literature concerning collaborative hypertext systems. Lessons learned from conducting this study can be used to refine experimental designs for other collaborative hypertext systems. For instance, subjects in this study had certain familiarity with the subject domain of the document, namely the UNIX operating system. What would be the results if the document were chosen from an unfamiliar domain to the subjects? The structural and content changes from the static to the dynamic version could be larger. Would the main effect of the document evolution start to emerge with a larger number of nodes and links in the document, and greater degree of changing? These questions are difficult to answer adequately within a single experiment. The results of the study and their relationships with research findings in other studies have direct implications to the design and refinement of the user interface of a collaborative hypertext system.

## 8. Conclusions

The formation of generalized fisheye views in Furnas (1986) provides a framework to the visualization of organizational structures in user interface design. It has been noted that a particular fisheye view can be derived from the framework by instantiating a specific "*a priori* importance". The MUCH system aims to support collaborative writing with hypertext and maintains several kinds of evolutionary information which could be useful for coordination and collaboration. A multi-dimensional extension of the fisheye view framework is formalized in order to organize and visualize information for collaborative writing activities.

A word frequency-based extension to the existing fisheye view browser was implemented in the MUCH system. This extension was developed in order to facilitate users' comprehension of the underlying hypertext at different levels with respect to tasks being performed. The effects of the fisheye view browser with word frequencies were investigated by an experiment. The experiment was designed to test the utility of incorporating word frequencies into the fisheye view browser. The results of the experiment indicated a significant interaction between the fisheye view browser and the magnitude of the evolution of the document. The experiment also found a significant main effect of the fisheye view browser on a vector of several interrelated dependent variables. The differences with the evolutionary magnitude were not statistically significant.

The word frequency-based fisheye view browser facilitates information seeking and processing aspects of collaborative writing. The theory of cognitive dissonance is relevant to the study in that cognitive dissonance is an essential element in the process of collaborative writing and it is in fact a motivating factor which may lead to insightful understanding of the collaboration and the task domain. According to the theory, information seeking is one of several possible actions to be taken to rationalize the relationship between the dissonant issues and one's existing knowledge structure. The extended fisheye view browser is designed to help users with local details and the overall structure of the knowledge in this context. The additional word frequency dimension of the fisheye view browser provides dynamic views with respect to the logical structure of a document.

The design and results of the experimental design were discussed with respect to other empirical studies related to collaborative writing. The relationship between the theory of cognitive dissonance and the formation of generalized fisheye views will be investigated in future work in the context of collaborative writing. The relationship between generalized fisheye views and similarity-based inferencing networks may also lead to insights on the design of cooperative hypertext systems.

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