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Research Issues Involving Hypertext in Decision Support Systems

Robert P. Minch
Boise State University

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Robert P. Minch

Computer Systems and Decision Sciences
College of Business
Boise State University

ABSTRACT

The term hypertext describes a computerized system which allows the user to browse through a network of nodes, each of which is commonly a collection of text but which may be quantitative models or other entities. A review of DSS research and applications frameworks in the literature reveals several areas where further research may be valuable in identifying the usefulness and appropriate role of hypertext in DSS. These issues involve user characteristics, decision and problem characteristics, situational and organizational factors, and technological factors. Some areas which appear to be worthy of further investigation include hypertext's support of the human brain's hemispheric specialization, its isomorphism with generalized problem solving paradigms such as the state-space approach, and extensions of the basic model whereby nodes become executable decision models. In addition, hypertext may be self-applied by DSS researchers as a vehicle to simulate and study various user interface techniques and as a process tracing laboratory.

INTRODUCTION

Computer software based on the "hypertext" paradigm has recently gained popularity and has come to be promoted in some quarters as a potential information retrieval and applications interface standard. Although the concepts involved are over 40 years old [7], widespread implementation on microcomputers [1], [27] is now largely responsible for a tremendous current surge of interest in the area. Paralleling the marketplace success of hypertext is an increasing number of primarily application-oriented research papers appearing in the computer-related literature.

Although little of the hypertext research to date has addressed DSS specifically, it seems inevitable that both conceptual and application papers will be forthcoming in significant numbers. If past experience with technology-related DSS work is an accurate predictor, we may experience a period of eclectic and disjointed efforts. This paper will examine areas of Decision Support System (DSS) research where hypertext and hypertext-like technology appear to

be appropriate and potentially fruitful areas of research, in hopes of beginning to define a broad perspective of the issues.

The remainder of the paper is divided into three main sections: (1) Definition and Discussion of Hypertext; (2) Relevant DSS Research Frameworks; and (3) DSS Hypertext Research Issues. A final Summary and Conclusions section completes the paper.

Definition and Discussion of Hypertext

In a remarkable display of prescience before the advent of stored-program computers (1945), Vannevar Bush proposed a device called the Memex, whose operation can be gleaned from the following example [7], page 107:

The owner of the memex, let us say, is interested in the origin and properties of the bow and arrow. Specifically he is studying why the short Turkish bow was apparently superior to the English long bow in the skirmishes of the Crusades. He has dozens of possibly pertinent books and articles in his memex. First he runs through an encyclopedia, finds an interesting but sketchy article, leaves it projected. Next, in a history, he finds another pertinent item, and ties the two together. Thus he goes, building a trail of many items. Occasionally, he inserts a comment of his own, either linking it into the main trail or joining it by a side trail to a particular item. When it becomes evident that the elastic properties of available materials had a great deal to do with the bow, he branches off on a side trail which takes him through textbooks on elasticity and tables of physical constants. He inserts a page of longhand analysis of his own. Thus he builds a trail of his interest through the maze of materials available to him.

Later Englebart [10] proposed a computerized system incorporating some of the Memex concepts, emphasizing the augmentation and amplification of the user's native intelligence. Finally Nelson

[26] would popularize the term hypertext to denote a computerized implementation of linked literary material that, in principle, could be virtually universal in scope.

Today the most basic and common form of hypertext consists of a computer-implemented network of screen windows associated with database objects. Links between the objects appear as selectable tokens or "buttons" to the computer user, and correspond to pointers in the database. Links are usually selected through the use of a pointing device such as a mouse or a touchscreen. The operationalization of machine-supported links allowing traversal of a non-linear network of nodes (usually containing text) is central to the hypertext paradigm. The concept may also be described as a system of imbedded menus (as opposed to explicit menus) that allow a user to select items in context within a current window for further investigation or manipulation [18]. An introduction and survey of hypertext can be found in [8] (and, in more detail, in [9]).

Figure 1 shows how part of a hypertext database may appear to the user on a computer screen. It is difficult to appreciate the qualitative aspects of hypertext as a user interface without experiencing the phenomenon firsthand, however this example may help to motivate the discussion. A computerized implementation of individual income tax preparation via hypertext may incorporate a "home" node corresponding to a display of the 1040 form shown graphically on the screen. Each line of the form then provides a link to other screens providing helpful information, while areas for entry of numbers may link to ancillary schedules which return data to the 1040 form. Many such links between a large number of forms are provided for selection by pointing to the desired item and clicking on it with a mouse input device. The user may read information, fill in data, and navigate at will through the network until the task of completing all relevant tax forms is accomplished (this particular example is presently commercially available on microcomputers).

A hypertext database may be browsed in at least four distinct ways: (1) spontaneously and iteratively by choosing any desired link from the present node, (2) in a directed manner by following a pre-defined path through the network, (3) in search mode by invoking a mechanism to locate a node having some desired characteristics; and (4) in quasi-direct access mode by viewing a graphical "browser" which displays a visual representation of all or part of the network and allows the user to select a node to visit. Specific implementations may customize or restrict the browsing mechanisms for particular users or tasks.

Existing hypertext systems have been used in four general ways [9]: (1) as macro literary systems supporting on-line collaborative writing; (2) as problem exploration tools such as outliners; (3) as browsing systems, e.g., for access to public information or encyclopedias; and (4) as general experimental vehicles most often related to

textual applications. While all areas have potential DSS applicability, use as problem exploration tools appears very promising for DSS. As discussed in a later section, hypertext may also provide a convenient experimental vehicle for certain empirical and laboratory research studies in DSS.

While the nodes in most existing hypertext systems correspond to collections of text, in principle these nodes may be generalized to include quantitative models and other decision making tools. For example, the Xerox NoteCards system [14] includes a large number of specialized node types such as video, animation, graphics, and actions. Perhaps the most significant of these are the action nodes, which, when activated, initiate the execution of procedural code. Thus the user may select from a network of programs to run in addition to text which may be read. Other extensions to hypertext include hypermedia systems--those involving a variety of presentation media and modes such as videodisc and audio output [37] (for those interested in hypermedia applications in academia, a survey appears in [4]). For simplicity we will use the term hypertext to include extensions such as non-text nodes and media as well.

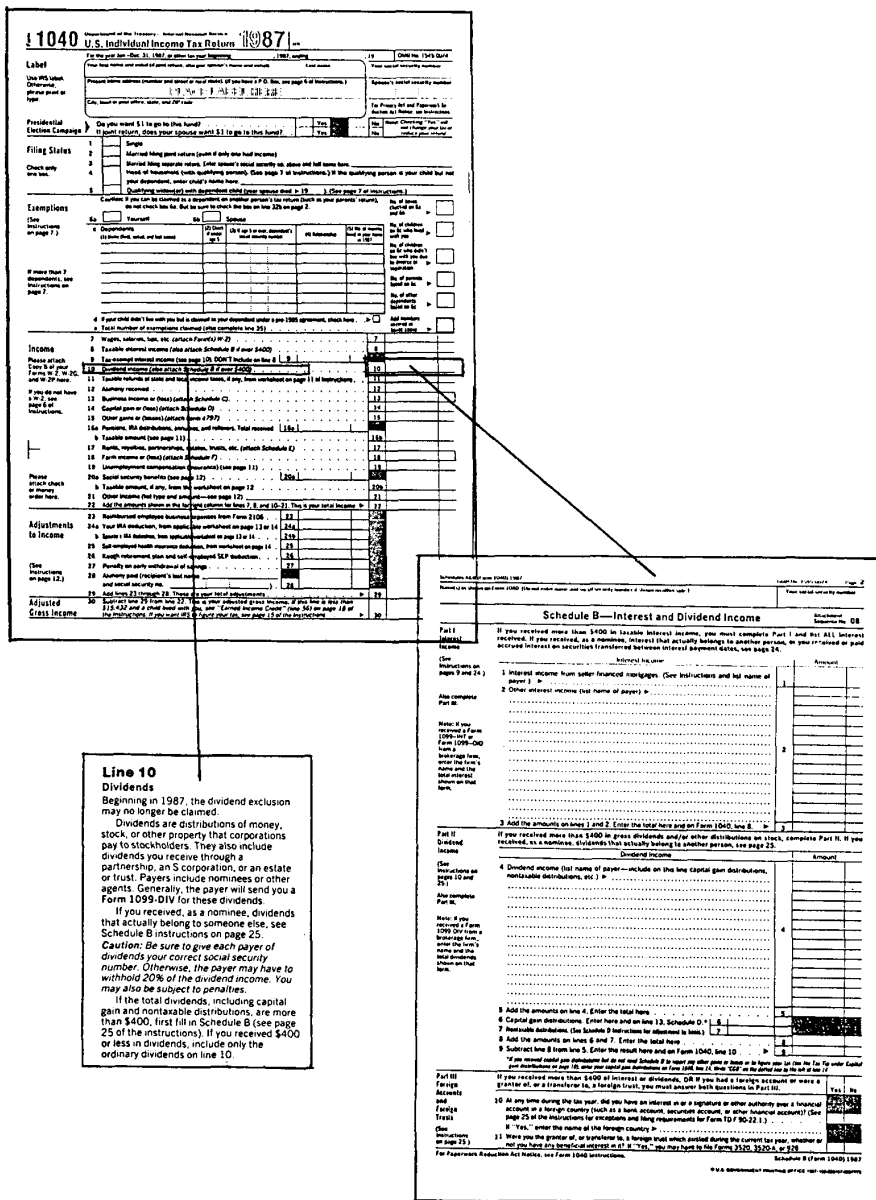
Relevant DSS Research Frameworks

While many researchers have proposed frameworks to guide DSS research and practice, the most important aspects of the majority can be addressed by reviewing a small sample in the following paragraphs. From these we will distill a selected few critical issues for further investigation in relation to hypertext.

Frameworks for information systems (including DSS) include those by Mason and Mitroff [23] and Gorry and Scott Morton [Gorr71]. Mason and Mitroff suggest that an information system serves an individual with a certain cognitive style faced with a particular decision in some organizational setting. Gorry and Scott Morton classify information systems along two dimensions of decision structuredness and level of management activity (operational control, management control, or strategic planning).

Frameworks specifically addressing DSS include those by Keen and Scott Morton [19], Sprague and Carlson [32], Bonczek, Holsapple and Whinston [3], and Zmud [39]. Keen and Scott Morton define a DSS as assisting managers in decision processes with semistructured tasks, supporting but not replacing managerial judgment, and improving decision making effectiveness rather than efficiency. Sprague and Carlson emphasize a "characteristics" approach to understanding DSS: an aim at less well structured problems faced by upper-level managers, use of models as well as data retrieval functions, interactive use by "noncomputer" people, and emphasis on flexibility and adaptability to the decision maker. These same authors delineate three technology levels (specific DSS, DSS generator, and DSS tool), five personnel roles (manager/user, intermediary,

Figure 1: An Example Hypertext Display



builder, technical supporter, and toolsmith), and propose the process-independent ROMC (representations, operations, memory aids, and control mechanisms) list of desirable DSS capabilities. Bonczek, Holsapple, and Whinston emphasize three technological components: the

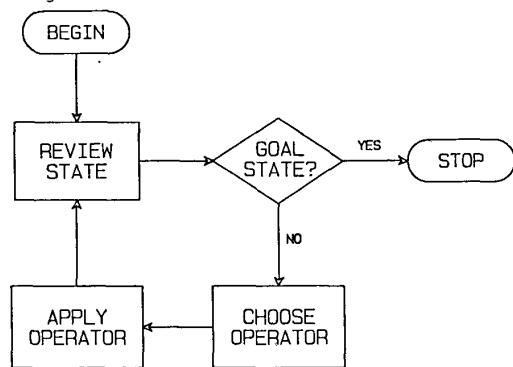
language, knowledge, and problem processing systems as well as note formalizations of purposive systems such as the state-space and problem reduction approaches to decision support. Zmud summarizes the goals of a DSS as including the following: it must capture and reflect the way decision makers think; support multiple decision processes and multiple decision styles;

be easy and convenient to use and not require extensive training; help decision makers to structure situations and must help them in the initial stages of resolution; allow the decision maker to adapt the system as he or she gains experience in DSS capabilities; and be user-friendly.

Frameworks addressing the cognitive and decision-making characteristics of humans are particularly important to DSS. Several of these paradigms are due to Simon [30], [31]. The most common decision-making model associated with Simon consists of three phases: intelligence, including problem and data definition; design, including generation of feasible alternatives; and choice, the selection and implementation of the best alternative (review, a fourth phase sometimes included, consists of reviewing past choices). A negative consequence of this framework is that it appears most appropriate when the decision-making process is sequential and linear--that is, each step is performed in a pre-determined order. It is also a normative or prescriptive model describing how decisions should be made, which may not necessarily describe how they are made in practice. Behavioral decision theorists note the presence of a variety of descriptive problem solving strategies [11] which may not be supported well by this framework.

Simon also proposed the generalized means-ends problem solving paradigm [31] which has been widely adopted in the artificial intelligence community and is sometimes referred to as the state-space approach [36]. In this problem-solving metaphor operators are selected to successively move from an initial state through intermediate states toward a goal state (see Figure 2). It is a non-linear, network approach because it is analogous to moving node-by-node through a network of nodes connected by operators from the initial node to the goal node. Many paths from the initial to the goal node may be present. The appropriateness of this paradigm

Figure 2: State-Space Problem Solving Model



for DSS has been noted [3] and it has been proposed for use in DSS for complex problem domains such as multicriteria decision making [25]. Some acknowledgement of descriptive and empirical decision making realities is provided by allowing for satisficing or bounded rationality [30].

We may summarize discussion of DSS frameworks in preparation for examining the role of Hypertext in DSS by noting the presence of four main areas addressed by the various frameworks:

1. Individual factors, including:
 - users' personality and cognitive style
 - users' level of computer competence
2. Decision and problem characteristics, including:
 - paradigms supported
 - level of structuredness supported
 - stages of decision making addressed
3. Situational and organizational factors, including:
 - task characteristics
 - management level
4. Technological factors, including:
 - characteristics of data, models, and user interface
 - level of technology, e.g. tool, specific DSS, etc.

DSS Hypertext Research Issues

A suitable framework incorporating hypertext into DSS must address the four categories above. We will discuss these in turn below, following that with a discussion of potential end-user application areas and self-application areas for DSS researchers. The reader will note that the areas examined are similar to those proposed in a previously published framework for investigating the human/computer interface [5], with the primary difference being the expanded treatment of technological factors.

Individual factors

Various individual differences based on cognitive style, personality traits, etc., have been proposed as being important issues in information systems [38]. For instance, the human brain's hemispheric specialization has been investigated in the context of DSS [28], [29]. This particular model characterizes the left hemisphere as analytical, sequential, and linguistically oriented while the right hemisphere is said to be heuristic or intuitive, simultaneous, and oriented toward visual images. One might reasonably posit that the hypertext metaphor, with its non-linear, graphical nature would appeal to individuals with a right

hemisphere orientation. The cognitive style factors of field independence-dependence, thinking mode, and cognitive complexity have been identified as receiving the most attention in information systems research [38], yet a recent survey of hypertext applications [9] does not report any work formally testing these factors. This area of research involving cognitive and personality styles may be important to assessing the impact of hypertext on DSS.

An interesting issue related to cognitive style considerations, however, is the controversy involving the very importance of cognitive style factors in DSS. Some DSS researchers have concluded that these factors are not relatively important, and that perhaps we should devote our efforts not to measuring user cognitive style and subsequently designing a system specifically to support that style, but rather to design systems with sufficient flexibility and generality to support a variety of user individual differences [17]. Hypertext systems may be configured to support either individual or broad classes of decision styles in a number of ways. For instance, pre-defined paths may be established for analytic/sequential use, while more generalized browsing may be provided for heuristic/simultaneous users. Thus additional research topics will involve the appropriate provision and use of various cognitive style-supporting mechanisms for different classes of users and indeed, further investigation of the hypothesis that general flexibility is superior to systems tailored to a particular style. Perhaps we may yet lend positive or negative support to the proposition that "... it is likely that hardware and software advances will outpace and largely negate the value of cognitive style research." [22].

Users' levels of computer competence are often addressed in advocating DSS that are usable by nonprogramming managers [32]. At the same time, many of the recently introduced hypertext-like systems such as Apple's HyperCard [1], [13] have as a primary objective ease of use by relatively naive users. Areas of research should include questions related to whether hypertext-based systems are in fact easier to use for unsophisticated users than alternative systems and whether ease of use comes at the cost of some other desirable system attributes.

Decision and Problem Characteristics

The non-linear, network-based hypertext approach is by nature quite generalized and can be customized to support several decision making paradigms. For instance, its structure may be "flattened" and constrained to simulate a relatively sequential and linear model such as the intelligence-design-choice approach. In such a case a pre-defined, acyclic path through the network allows the user to consider each stage in turn. More flexible decision making approaches such as the state-space model are much more isomorphic with hypertext-like systems, however, as described below.

Consistent with the state-space problem solving approach, hypertext-based DSS are able to facilitate all four activities (ignoring the "begin" and "stop" activities) shown in Figure 2. Review of the current state is supported by allowing the user to browse through output from previously applied operators, observe the values of important variables, and generally explore the existing state of the problem solving process. The decision regarding whether the goal state has been reached (or approached to an acceptable degree) is assisted by providing the decision maker with a convenient means for accessing and comparing current and desired variable values. The choice and application of operators is supported by displaying the available operators to the user (perhaps through a graphical depiction). These operators may be a subset of the larger set which have been identified as appropriate for this stage of the problem. At first the user may select potential operators for further investigation, in which case the system might explain their operation and perhaps make suggestions as to their appropriate use. When the user has selected a particular operator to use, it may then be invoked directly. In relatively well structured problem domains, certain "paths" through the network may be pre-defined to assist the user as well. Further research into the parallels of hypertext and paradigms such as the state-space approach is called for.

The information retrieval, free-text search, and problem exploration capabilities of hypertext clearly aim to support early stages of decision making such as the intelligence phase. Furthermore, they are intended to be useful in less structured problems such as those traditionally suggested for DSS. A hypertext user interface for a DSS provides a number of important mechanisms for judgmental flexibility which have been called for by researchers [12] but rarely implemented. These include process independence (input order independence) and model judgmental flexibility (user freedom to choose from and evaluate a variety of decision models). Hypertext-based systems give the user a feeling of control over the decision making process, and relieve certain cognitive limitations such as limited short-term memory as well. This is due to the ease of navigating through the network of available tools according to the user's needs and desires, including the ability to return to previously visited stages in the process. Questions regarding the appropriateness of hypertext in supporting various stages of decision making, levels of structuredness, and other decision making-oriented issues should be tested formally.

Situational and Organizational Factors

It will not be possible to do justice to the many relevant task characteristic, management level, organizational environment, and other situational and organizational factors in this short paper. Tasks often employed in empirical DSS research involve locating information, analyzing alternative decision models [35], and playing

management simulation games [5]. Structuredness of tasks and decision making are often intermingled, with some asserting that task structurability, rather than structure, is the characteristic of interest [2]. Some tasks, such as information retrieval from literary databases, appear well suited to hypertext. Empirical research will be necessary to identify the suitability of various tasks.

Management level and its relationship to decision support systems has also been much discussed, particularly in early DSS work. Most often it was proscribed that DSS should be used at higher levels of management, however more recent work indicates that several levels may benefit [32]. Certainly the proponents of hypertext believe it to be highly usable by those whose interest lies in solving problems, not gaining expertise with computers--presumably characteristic of many upper-level managers. The use of pointing devices rather than keyboards as primary input devices may reduce the reluctance of some managers to user computers directly, as well. Field studies may be appropriate to determine the acceptability of the hypertext approach at higher levels of management.

In addition to individual use, hypertext-based DSS may be part of information sharing systems and group decision support systems. This is already the objective of some systems such as the Information Lens [21]. Tasks which may benefit from a hypertext group DSS might include idea generation and member-to-member communications.

Technological Factors

Hypertext extensions for database querying going beyond text retrieval are possible in a number of areas. For instance, Spatial Data Management Systems [16] uses a graphical interface where users may view cartographic information and select geographic regions for more detailed study. The system supports a hierarchy of map detail as well as retrievals based on conventional selection criteria but displayed graphically (e.g. display the states meeting certain population criteria on a map).

Experimental results using the TIES system [18] with a database describing the Student Union of the University of Maryland have compared embedded menus in a hypertext system with conventional explicit menus. Test results from a timed period of use followed by an examination covering database contents indicated the embedded menus promoted better understanding while the users viewed fewer screens. Users expressed a preference for the embedded menus as well. More research is appropriate to compare the hypertext approach with a variety of existing query facilities in a number of application areas.

A related and potentially fruitful area of user interface investigation would involve implicit menus in addition to explicit and imbedded menus. An implicit menu may be defined as one which is not specifically enumerated in advance but is constructed in real time during system use. For

instance, when viewing a map, users may want to select any area for further study while it may be impractical to establish all possible selections in advance. In this case the appropriate response may be determined by accepting geographical coordinates chosen by the user and invoking a generalized algorithm with these coordinates as input. Similarly, text-based systems might avoid explicitly defining links for common key words by using automated knowledge-based techniques to create a dynamic, automated concordance.

The user interface is a very important component of DSS, serving as both an action and a presentation language [22]. These two functions are very closely linked in hypertext as elementary actions (such as selecting a link) are directly followed by an associated presentation (e.g., display of a text node). A few hypertext systems have now been in use long enough to gain insight into their value as user interfaces (although some were not originally labeled as hypertext systems). The study of one such system, ZOG [24], has resulted in design prescriptions which are very much consistent with hypertext goals, including: a single, flexible tool environment; direct manipulation of data; low learning overhead; and a safe, exploratory environment. Previous user interface studies examining user performance with command, menu, and iconic interfaces have found significant differences between interface modes [34]. More research is needed to confirm or reject the value of the hypertext mode of interface. Appropriate dependent variables may be quality of information recall or decisions, time taken to retrieve information or make decisions, amount of data accessed or number of alternatives considered, and user confidence in decisions made.

Issues related to the use of models in a DSS using hypertext include how such models might be constructed, linked, and invoked within the integrated environment. Some models might cause data retrieval or initiate other models--perhaps affecting the user's view of the problem or dynamically restructuring the underlying network. Methods will need to be devised to integrate the consequences of model execution into the interactive problem exploration and solving process. Graph-based methods for model management have been proposed [20], which may be appropriate in the hypertext environment.

All levels of DSS technology, from low-level tools to specific DSS for end users, may benefit from hypertext. For example, the Tektronix Neptune CASE (computer-aided software engineering) system [6] functions as a DSS for its users, who are members of systems analysis and design teams (toolsmiths). At the same time it can be used to create object systems for end users (specific DSS) which also employ hypertext. The Neptune system incorporates specifications, documentation, source code, object code, and several other node types into an integrated programming environment. Initially, primary DSS hypertext research efforts will

likely focus on systems for non-programming end users because of the user-friendly interface.

End-user Application Areas

Many successful hypertext DSS applications will no doubt be characterized by their suitability for structuring problems along the lines of a decision making paradigm compatible with the non-linear network structure of hypertext. One particularly promising area of investigation might be multiple criteria decision making, which has previously been cast in a state-space problem solving framework [25]. This problem is often characterized by fuzzy and changing objectives and decision criteria, requiring a very flexible and interactive approach for suitable computerized assistance.

Another paradigm amenable to hypertext is the problem reduction approach to decision support [3]. This approach recursively reduces a problem into more easily solved subproblems until all problems have been reduced to primitive subproblems which are solvable. Often it is desirable to allow the user to iterate among a number of subproblems while exploring the problem and searching for the best strategy to solve the larger problem. The ability to maintain a number of active subproblems and facilitate switching between them is consistent with the hypertext approach.

Self-Application Areas for DSS Researchers

The hypertext approach may contribute to future research in DSS in the several ways. Use of hypertext allows the study of user performance as it relates to type of user interface by simulating a variety of interfaces. In addition to studying distinct interface techniques such as command, menu, and iconic interfaces [34], hypertext may be used to manipulate some design variables over a virtually continuous range, e.g. from minimally directed to strongly directed control of user tool selection.

The establishment of a generalized hypertext DSS interface provides a process tracing laboratory for studying computer-assisted decision making. Process tracing is used to gain insight into the cognitive and decision making processes employed by DSS users [33], for which data has often been manually collected. An automated version of process tracking is facilitated by hypertext interfaces which are easily able to record the exact sequence of user inputs to the system.

Finally, a large number of technical issues related to the conceptualization and implementation of hypertext-based DSS can be expected to arise. A few areas expected to be important in relation to hypertext are listed below:

- the role of graph and network-related algorithms such as shortest path, minimal spanning tree, etc.

- the relationship to other network formalisms commonly used in information systems such as associative or semantic networks, data flow diagrams, petri nets, activity networks, etc.

- appropriate data models for the logical and physical organization of hypertext databases

- appropriate algorithms for rapid network browsing and traversal

- usefulness of visual formalisms such as higraphs [15] in representing complex hypertext systems with multiple hierarchies and composite nodes

- various programming models such as object-oriented programming

- integration of knowledge-based and expert systems capabilities

These and many other technical questions are yet to be resolved.

SUMMARY AND CONCLUSIONS

Whether one considers hypertext to be a revolutionary concept or merely the rediscovery of established user interface techniques, it appears to be capturing considerable attention in the marketplace and information system literature. There are many areas involving user, problem, organizational, and technological factors which may be addressed by additional research specifically aimed at clarifying the role of hypertext in DSS. We have identified some of these areas which appear to be promising and have begun a discussion which we hope will evolve into a broader perspective on the appropriate integration of hypertext and DSS.

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