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# Hypermedia Knowledge Management for Intelligent Organizations

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## Abstract

Using a simple model consisting of individual knowledge bases, organization knowledge bases, organization actions, and environment responses, hypermedia is investigated as a technology for knowledge management in intelligent organizations. Cognitive mapping, issue-based information systems, and generalized hypertext methods are reviewed before proposing desirable features of hypermedia organization knowledge management. These desirable features include a variety of typed hypertext nodes and links, process memory, learning support, and both automated and user-directed manipulation of knowledge bases. Interactions of the knowledge bases with organization actions and environmental responses are also discussed.

## Introduction

Increasing internal complexity and external competition are compelling organizations to adopt survival strategies analogous to high-level biological systems. These strategies support intelligent behavior through the accumulation and management of knowledge and through the abilities of learning and adaptation to changing conditions. We have consistently seen a corresponding evolution of information system technology from low-level data processing to high-level knowledge and model management, and from isolated small-scale systems to organization-wide, large-scale systems.

To achieve any semblance of true intelligence, organizations will have to rely on new information processing and decision/action supporting technologies. This paper will revolve around one such new technology known as hypermedia. After identifying selected relevant concepts of knowledge management in intelligent organizations in the next section of this paper, the third section will introduce fundamental features and uses of hypermedia. The fourth section will then review three organizational knowledge representation methods: cognitive mapping, issue-based information systems, and generalized hypertext, followed by proposals concerning advantages to be gained by using hypermedia extensions in knowledge management and facilitating interfaces to organizational actions and environmental responses. A conclusions section completes the paper by summarizing recommendations involving hypermedia.

## Intelligent Organizations And Knowledge Management

Organizations must have at least the following basic attributes and capabilities to be termed intelligent: (1) goal-directed behavior; (2) the ability to gather, maintain, and access an organizational knowledge base; (3) the ability to choose and execute actions; and (4) the ability to evaluate the results of actions. Most other characteristics of intelligent organizations cited (c.f. [7], [10]) are closely related to these basic elements. For instance, memory implies a historical record of actions, results, and knowledge base states while learning implies the process of evaluating the results of actions to update the knowledge base and action choosing/executing mechanism.

We will use a simplified model of intelligent organization behavior which focuses on certain elements and processes related to knowledge management, shown in Figure 1. In this model individual user's knowledge bases supply knowledge to an organizational knowledge base, which in turn also supplies knowledge to each individual knowledge base. The organizational knowledge base is used in selecting organizational actions which, when executed, evoke an environmental response. Completing the feedback loop, environmental responses are detected and incorporated into individual knowledge bases. Due to the simplicity of the model and its focus on knowledge management, many other possible elements and relationships are omitted. These include non-environmental (e.g., internal) inputs to knowledge bases, non-knowledge related organizational action stimuli, etc. The model parsimony is intended to foster concise analysis while allowing for further refinement when desired.

Discussion of organizational knowledge management in section four of the paper will concentrate on the structure and contents of individual and organizational knowledge bases as supported by hypermedia. Relationships numbered one through four in Figure 1 will also be discussed in the context of hypermedia, and are introduced now in general terms to further explain the model shown. Relationship one (environment responses affecting individual knowledge bases) primarily relates to the organization's ability to scan its environment and resolve uncertainty (absence of information) [8] by absorbing information from its environment. Relationship two (individual knowledge bases affecting the organization knowledge base) includes the combining of individual cognitive maps, hypotheses, world views, etc. into their integrated organizational



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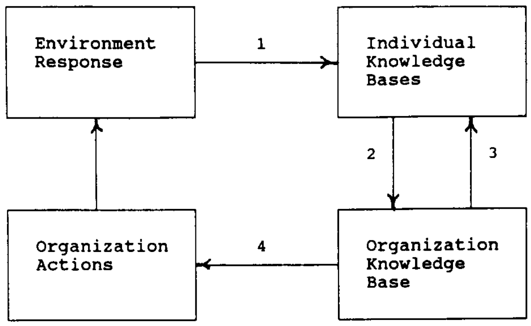


Figure 1
Intelligent Organization Model

counterparts. Functions supported must include communication and equivocality reduction (resolution of ambiguities and conflicting interpretations) [8]. Relationship three (the organization knowledge base affecting individual knowledge bases) indicates communication in the opposite direction as relationship two, but is more concerned with transferring internal organizational data, models, assumptions, priorities, and goals to be used in updating personal cognitive models. Finally relationship four (the organization knowledge base affecting organization actions) assumes at least semi-rational decision making in which knowledge plays an important role in choosing appropriate actions. Section three below defines and discusses hypermedia in preparation for addressing its role in knowledge management for intelligent organizations.

## Hypermedia

Hypermedia is an emerging technology which uses information and knowledge management techniques appropriate for organization-wide use in intelligent organizations. It may be used to facilitate several important functions of the intelligent organizations' knowledge management domain, including: (1) a learning function helping to acquire, structure, and integrate organizational knowledge, (2) a memory function helping to access and manage organizational knowledge, and (3) a communications function helping to share knowledge at the organizational level. In this section we briefly define hypermedia and discuss common current applications.

Hypermedia systems are computer-implemented networks of nodes (database or media objects) and links (arcs used to traverse between nodes). Although various media including audio and video are included under the general term hypermedia, the most common medium currently employed is text, hence the more specific term hypertext is used to describe these systems. As shown in Figure 2, in hypertext systems the database objects are collections of text which are displayed to the user as screen windows. Links between the objects appear to the user as selectable tokens (also called buttons or link icons), forming anchors in source and destination nodes and corresponding to pointers in the database. Links are activated by selecting a link icon 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 is central to the hypertext paradigm. Hypertext appears to the user as a system of imbedded menus (as opposed to explicit menus) that allows selection of items in context within a current window for further investigation or manipulation [13].

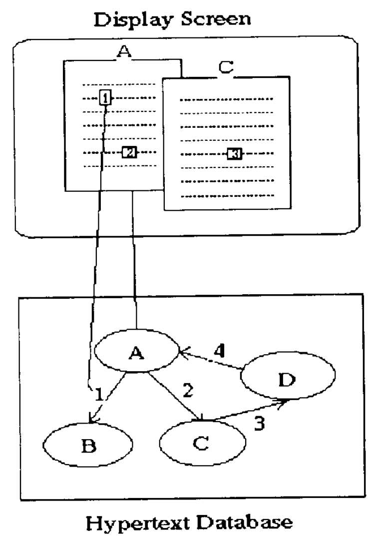


Figure 2
Hypertext as Displayed and Stored

The most prevalent use of hypermedia technology currently is to facilitate browsing of (exploration and information retrieval from) textual databases. 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 characteristic; 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. In addition to browsing of textual databases existing hypertext systems commonly have been used in three additional ways [5]: (1) as macro literary systems supporting on-line collaborative writing; (2) as problem exploration tools such as outliners; and (3) as general experimental vehicles most often related to textual applications.

Readers seeking background information on hypermedia will find the following sources valuable. An introduction and survey of hypertext can be found in [5] (and, in more detail, in [4]). A survey of hypermedia applications in academia appears in [2]. Hypertext and hypermedia bibliographies include [11], [18}, and [25]. A comparison of ten hypertext systems which examines their general, node, link, authoring, and browsing characteristics is reported in [22]. Applications and research areas involving hypertext in decision support systems are discussed in [20] and [21].

## Hypermedia Knowledge Management and Intelligent Organizations

Intelligent organizations require organization-wide knowledge bases to perform functions such as memory and learning. Rather than merely containing the traditionally maintained historical data and records, these knowledge bases contain shared experiences, world views, evolutionary chronologies, preference and objective functions, and considerable other knowledge with varying degrees of structure and formality. The management of such knowledge bases implies effective and efficient means for collecting, storing, manipulating, and retrieving relevant knowledge to enhance the organization's intelligent behavior.

The fundamental property that imbues hypermedia with organizational knowledge management capabilities is its representation of knowledge as a network of linked nodes. Critically important in this regard is the fact that nodes may be typed, with the type recorded among the set of attributes for each node. The possible node types include a wide variety of knowledge representations and entities such as free-text (prose), structured data (e.g., database records), rules and other formal knowledge representations, mathematical models, algorithms, user-defined concepts, qualitative or quantitative variables, and multi-media representations.

Similarly, links may be typed. The most powerful link types portray semantically significant relationships between nodes such as cause/effect; dialectical, issue-based, or argumentative analysis; and formal logical/mathematical associations. The structure of a hypertext network, including the number, type, and configuration of nodes and links, is itself a base of useful knowledge.

In the next section we will first review three approaches to organizational knowledge management which have been applied in separate contexts, two of which currently employ hypertext. We will identify selected features of each which may be enhanced and combined, with additional capabilities, to produce powerful organizational knowledge management capabilities through hypermedia. The following section will then propose a hypermedia organizational knowledge base structure which will be discussed in terms of desirable node, link, and other characteristics.

### Organizational Knowledge Bases

Table 1 presents a coarse comparison of three knowledge management systems: cognitive mapping, issue-based systems, and generalized hypertext; by selected system attributes. These will be discussed below. Due to limited documentation and the possibility of differing interpretations of the available documentation, this table should be used as an approximate guide for the particular representative systems only--the references indicated should be consulted for further information.

Cognitive mapping A very promising approach for structuring and representing one form of organizational knowledge is through cognitive maps [1], [16]. Cognitive maps are networks of concepts (nodes) and signed, directed relationships (arcs) between concepts indicating hypothesized causal relationships. Thus a negatively signed arc from the concept "clouds" to the concept "sunshine" indicates the belief than an increase in clouds causes a decrease in sunshine. A number of manual and computer-assistant methods for combining individual cognitive maps into collective maps are discussed in [16].

The cognitive map paradigm is an interesting and useful formalism, and one which provides an excellent starting place to investigate further enhancement and modifications which might be possible by incorporating hypertext technology. Some of the current limitations of collective cognitive maps in organizational knowledge bases seem to be: (1) node types are limited to particular entities called concepts, which in practice are often manifested primarily with quantifiable variables; (2) link types tend to be limited to cause/effect relationships, commonly binary (direct or inverse) relationships, sometimes modified by weights or fuzzy variables; (3) only the present artifacts of relationships (e.g. concepts and relationships in the latest version of the cognitive map) are preserved, not the evolutionary process involved in identifying concepts and relationships; (4) the representation and manipulation systems tend to be separate and isolated from other organizational knowledge sources, including less formal sources such as text documents; (5) communication between individuals is not facilitated in general ways; and (6) usually only rudimentary user interface facilities are provided which do not allow users desirable functions such as direct manipulation, exploratory browsing, generalized model querying, and sensitivity analysis.

Issue-based hypertext systems Issue-based hypertext systems are designed to facilitate and record the processes involved when groups of people discuss and deliberate planning, design, and policy issues. The concept of issues as information system objects (Issue-Based Information Systems, or IBIS) pre-dates recent hypertext work [15], but many of the principles have now been implemented using hypertext in the gIBIS system [6].

Nodes in the IBIS paradigm contain free-form prose, and can be of three types: issues to be discussed, positions proposed to deal with an issue, and arguments which support or object to a position. Nodes are connected by semantically significant link types such as an argument supporting a position, one issue generalizing another issue, etc. The gIBIS system enhances the basic IBIS features with additional node and link types,

| SYSTEM ATTRIBUTE | COGNITIVE MAPPING (as reported in [Lee89]) | ISSUE-BASED SYSTEMS (as reported in [Conk88]) | GENERALIZED HYPERTEXT (as reported in [Bhar88]) |
|---|---|---|---|
| Nodes | "Concepts": usually variables | Free-text: issues, positions, arguments | Generalized, similarly treated model/data entities |
| Links | Cause/effect: none, direct, or inverse; can be weighted or fuzzy | Verbal argument analogs: supports, generalizes, etc. | Generalized, semantic relationships |
| Process memory | No | Yes | No |
| Learning support | Yes | Incidental to use | Incidental to use |
| External interfaces | Internal data & models only | Text-oriented | Yes |
| Individual KB to group KB combining | Semi-automated | Manual | No |
| Group communication | External to system | Automatic, implicit, passive | No |
| Automated network manipulation | Yes | No | Yes |
| User direct manipulation | Some, non-hypertext | Hypertext | Hypertext |

Table 1
Comparison of Three Knowledge Management Systems

including external nodes containing non-IBIS materials such as source code.

Current limitations of the IBIS/gIBIS approach for use in organizational knowledge bases seem to include: (1) node contents are primarily manipulatable only as free-text prose (not as variables, for example); and (2) link types relate primarily to counterparts in verbal arguments rather than more formal logical or mathematical relationships. As an implemented, extensible system, however, gIBIS and similar tools hold significant promise for enhancing and studying issue-based paradigms, including questions relating to usage of direct-manipulation user interfaces. Among several observations made from experience using the gIBIS system which are significant to intelligent organizations is the unfortunate propensity of the system to support divergent and segmenting problem solving tasks better than converging processes and problem resolution. Thus they seem to be better for generating alternatives than choosing the best alternative, for example.

Generalized hypertext An important research effort integrating model management and hypertext in a symbolic programming environment is reported in [3]. In this approach the hypertext data/model base is organized as an attributed acyclic graph of definitional dependencies. Nodes are generalized entities in which data and models are treated similarly and symbolically, as are Prolog terms. Links are generalized and semantically significant relationships, as are Prolog predicates. One of two systems described in [3] is Max, a Prolog-based model management system using a hypertext interface implemented on a Macintosh microcomputer. The system exhibits an extraordinary repertoire of functionality and usability features due largely to the choice of a symbolic programming language and an integrated hypertext user interface as implementation vehicles, respectively. Among its functions are generalized query facilities for node and link contents and structure, automatic generation of links, explanation of generated values (i.e., what models and data were used to compute the values) and a flexible drill down facility allowing the user to view varying levels of detail in the model base.

The generalized hypertext approach as described above has a great deal of technical merit and promise for organizational knowledge bases. As reported to date, however [3], it does not adequately provide several of the facilities necessary for group/organizational use, including: (1) communications methods for informal person-to-person discussion and debate; and (2) methods for combining and integrating individual knowledge bases into an organizational knowledge base, including equivocality reduction. Perhaps many of the features necessary to address these behavioral and organizational needs may be realized through further exploitation and extension of basic system capabilities.

### Proposals for hypermedia organization knowledge bases

Nodes in a network of organizational knowledge should be allowed to contain knowledge in a variety of forms and media. These may include text, database records, logical/mathematical models, pictorial and graphical representations, sound, etc. Some manipulation methods may not be appropriate for all types, but this is insufficient reason not to make provision for a rich universe of types. To do otherwise would be to preempt the possibility for truly flexible and adaptable intelligent organizations and instead restrict organizational memory to particular objects and organizations which are conveniently managed. Hypermedia, by its inherent nature, allows a wide variety of information media to be incorporated in an integrated system. Furthermore, the use of typed nodes not only does not limit the possible operations which may be performed on the nodes, but the type attributes themselves contain information which may be valuable (e.g., nodes may be identified and manipulated appropriately depending on both contents and type). For instance, by defining a node to be of type "cognitive map concept" we have lost no cognitive map manipulation ability while at the same time not restricting ourselves to this node type alone.

Links in a network of organizational knowledge should be allowed to represent a variety of relationships between the nodes they connect. For example one node may cause, support, define, refute, restate, give an example of, pictorially represent, justify, or summarize another node (to name only a few possible relationships). Indeed, some proposed link types such as the cognitive map causality relationship itself may prove blunt in comparison to more semantically rich combinations of relationships such as "is a necessary condition of," "is a sufficient condition of," "temporally precedes," etc. Ideally we would want the ability to represent many types of relationships (several of which may simultaneously affect a given node), including not only what is hypothesized, but also how, when, why, where, etc.

Organizational knowledge bases should record not only the current state of knowledge but also the goals, constraints, and processes which lead to that state. This can be termed process knowledge or process memory. Without process memory an organization will not learn to replicate successes and avoid failures in the future. Without process memory an organization cannot re-analyze a problem when an input assumption changes, because it has only a single static solution--not the means for generating new solutions. While collective cognitive mapping procedures may be able to recall individual map inputs and aggregation algorithms, we also want the ability (as issue-based systems provide) to maintain a chronology of discussions, negotiations, and evolutionary steps which might typically underlie the aggregation. Process tracing is a research technique which has been used to gain this insight into the cognitive and decision making processes employed by DSS users [24]. An automated version of process tracing is facilitated by hypertext interfaces which are easily able to record the exact sequence of user inputs to the system. As an example, this could be used to record the number, type and order of nodes and links employed by the user during a particular task, facilitating process memory by making both identification and chronicling of the user's underlying problem solving strategies possible.

Learning support must also be provided for intelligent organizations. While perhaps less directly related to knowledge management than process memory, learning does manifest itself through changes in the organizational knowledge base. For instance, the alteration or replacement of a hypermedia node might indicate that a new fact or concept has been learned, replacing an older version. Similarly, changes in links between nodes represent learned relationships. The degree of automation in supporting learning may range from simple facilitating roles such as in issue-based hypertext systems to artificial intelligence techniques which may actually induce new relationships from the existing knowledge base.

Organization-wide knowledge management virtually requires a significant degree of automated knowledge manipulation. This is desirable and present in algorithms which semi-automatically combine cognitive maps [16], and in hypertext systems which automatically create links [3]. Another appropriate application of automated knowledge manipulation may be to perform housekeeping functions on the knowledge base itself. For instance, in some cases it is possible to at least detect (if not eliminate) inconsistent relationships or information that is no longer relevant. If typed nodes and links are used in hypermedia, algorithms and procedures may be applied against the network which properly interpret and manipulate appropriate subsets of that network depending on node and link types present.

Organization knowledge management benefits from direct-manipulation, graphical user interfaces, such as hypermedia systems provide, in several ways. First, the graphical representation of the network serves as an overview and memory device for the user, showing all or some desired part of the network including selected nodes and arcs. Second, the user may control the level of model scope and detail displayed. For instance, one could drill down, i.e., uncover more detail, about a particular arc or node simply by selecting that object. This additional detail may range from a simple attribute (such as the estimated strength of the relationship) to a complete sub-network which determines the value of a variable in question. Finally, the interface serves as a direct manipulation and simulation language for the underlying model, allowing the user to rapidly conduct sensitivity analysis and re-structure or re-parameterize the model.

### Interfaces Between Intelligent Organization Elements

This section briefly elaborates on the four numbered interfaces between intelligent organization elements shown in Figure 1.

Environmental responses to knowledge bases (interface 1) Organizational knowledge bases need to be integrated with (or at least dynamically interface with) internal and external sources of data and information. Internal interfaces are necessary to maintain consistency, accuracy, and integrity of knowledge, preventing situations where a database change invalidates knowledge base contents without warning. Internal interfaces also furnish the means to explicitly identify relationships between the knowledge base and data sources (the number and type of links present being information also). Hypermedia systems have been developed with very large databases such as on-line encyclopedias, and with extensive interfaces to other internal databases. External interfaces are perhaps more interesting as they allow the organizational knowledge base to benefit from environmental scanning and external stimuli. One method suggested to accomplish this in hypermedia has been the use of daemons or rule-based agents [18]. These agents can be used to actively and continuously monitor the environment in search of conditions signalling significant changes or availability of important information. Since external information sources do not typically abide by any pre-defined internal knowledge base structures, it is advantageous to be capable of managing a variety of forms and media (as in hypermedia).

Individual and organizational knowledge base interfaces (interfaces 2 and 3) Combining individual knowledge bases into organization knowledge bases often requires communication among members. Communication in hypermedia can be described as an integral and passive capability. Rather than actively sending a message to a particular receiver, the hypermedia user simply submits his/her contributions for integration into the existing knowledge base. If desired, contributions may be identified by author merely by including author ID as an attribute of the node or link submitted. This is similar to a broadcast mode of communication, but the message is not lost to receivers not currently listening--rather they will have access to it anytime in the future. Furthermore, messages are semi-structured by the organization of the hypermedia network and may be later retrieved according to desired link type, contributor, etc. This communication is also related to and supports the process of equivocality reduction (resolution of conflicting interpretations and ambiguities).

An important criteria for good strategic planning techniques is that they should expose the assumptions underlying a proposed plan so that management can reconsider them [19]. Issue-based techniques used in hypertext systems such as gIBIS [6] support this technique explicitly, as do generalized query capabilities of hypertext systems which allow the user to conduct structure searches answering questions such as "what arguments exist in support of proposition X?". Again this may be helpful in reducing equivocality by encouraging deliberation about premises and the adoption of common assumptions.

Organization knowledge-to-action interfaces (interface 4) Organization action implies group and organizational decision making. Recently there has been growing interest in systems supporting group processes variously referred to as collaboration, cooperative work, information sharing, and group decision making [14], [9], [23]. This is already the objective of some existing hypertext systems such as the Information Lens [18] and gIBIS [6]. Group applications emphasize the communication-facilitating abilities of multi-user systems as well as the individual problem processing capabilities. Furthermore they must help to manage not only the mechanics of concurrent multi-user access but also complex social interactions among users [12]. Tasks which may benefit from a hypermedia group DSS which facilitates decision making and action include equivocality reduction, member-to-member communications, deliberation, and voting/issue resolution. Collaboration systems also use more informal techniques such as manipulation of verbal models, outlines, and graphical images. Hypermedia techniques which support structured participation, consensus formation, and group decision making would be valuable for organizational decision making and action.

## Conclusions

The cognitive mapping, issue-based information systems, and generalized hypertext paradigms we have reviewed each offer valuable contributions to knowledge management for intelligent organizations. In selecting useful features from each and combining them with hypermedia technology, we can recommend powerful strategies for organizational knowledge management.

The proposed systems maintain knowledge in several forms through typed nodes and links, with user and task-specific manipulation of the hypermedia database related to type and content of nodes as well as type of links. They interface with their environment through the use of intelligent agents which monitor external events. They facilitate process memory and learning by maintaining chronological records of dynamic internal processes in addition to static event artifacts. They aid in several forms of group intra-organizational communication, collaboration and coordination. Finally, they provide both automated and direct user manipulation of knowledge in various modes and levels of detail dependent on the needs of the users. These facilities will enhance the intelligence of organizations using them.

## REFERENCES

[1] Axelrod, R. M. (ed.) The Structure of Decision. Princeton, NJ: Princeton University Press, 1976.

[2] Beck, J. and Spicer, D. Hypermedia in academia. Academic Computing, (February 1988), 22-50.

[3] Bhargava, H.; Bieber, M.; and Kimbrough, S. Oona, Max, and the WYWWYWI principle: Generalized hypertext and model management in a symbolic programming environment. Proceedings of the Ninth International Conference on Information Systems, Minneapolis, (December 1988), 179-191.

[4] Conklin, F. A Survey of Hypertext. Microelectronics and Computer Technology Corporation, MCC Technical Report Number STP-356-86, 1987.

[5] Conklin, J. Hypertext: An introduction and survey. IEEE Computer, (September 1987), 17-41.

[6] Conklin, J. and Begeman, M. gIBIS: A Tool For All Reasons. Microelectronics and Computer Technology Corporation, MCC Technical Report STP-252-88, July 1988.

[7] Daft, R. and Weick, K. Toward a model or organizations as interpretation systems. Academy of Management Review 9, 2 (1984), 284-295.

[8] Daft, R. and Lengel, R. Organizational information requirements, media richness and structural design. Management Science 32, 5 (May 1986), 554-571.

[9] DeSanctis, G. and Gallupe, R. A foundation for the study of group decision support systems. Management Science, 33, 5 (May 1987), 589-609.

[10] Fiol, C. and Lyles, M. Organizational learning. Academy of Management Review 10, 4 (1985), 803-813.

[11] Franklin, C. An annotated hypertext bibliography. Online, 12, 2 (March 1988), 42-46.

[12] Halasz, F. Reflections on NoteCards: Seven issues for the next generation of hypermedia systems. Communications of the ACM, 31, 7 (July 1988), 836-852.

[13] Koved, L. and Shneiderman, B. Embedded menus: Selecting items in context. Communications of the ACM, 29, 4 (April 1986), 312-318.

[14] Kraemer, K. and King, J. Computer-based systems for cooperative work and group decision making. ACM Computing Surveys, 20, 2 (June 1988), 115-146.

[15] Kunz, W. and Rittel, H. Issues as elements of information systems. Technical Report S-78-2, Institut fur Gundlagen der Planung i.A., Universitat Stuttgart, Keplerstrasse 11, 7000 Stuttgart 1, West Germany.

[16] Lee, S. and Courtney, J. Organizational learning systems. Proceedings of the Twenty-Second Annual Hawaii International Conference on System Sciences, Vol. III, Kona, Hawaii, (January 1989), 492-503.

[17] Leggett, J., Kacmar, C., and Schnase, J. Working Bibliography of Hypertext. Department of Computer Science Technical Report No. TAMU 89-005, Texas A&M University, College Station, TX, March 1989.

[18] Malone, T.; Grant, K. R.; Turbak, F. A.; Brobst, S. A.; and Cohen, M. D. Intelligent information sharing systems. Communications of the ACM, 30, 5 (May 1987), 390-402.

[19] Mason, R. A dialectical approach to strategic planning. Management Science, 15, 8 (April 1969), B-403 - B-414.

[20] Minch, R. P. Research issues involving hypertext in decision support systems. Proceedings of the Twenty-Second Annual Hawaii International Conference on Systems Sciences, Kona, Hawaii, January 1989.

[21] Minch, R. P. Application and research areas for hypertext in DSS. Journal of Management Information Systems, Winter 1989 (forthcoming).

[22] Schnase, J.; Leggett, J.; Kacmar, C.; and Boyle, C. A Comparison of Hypertext Systems. Hypertext Research Lab, Technical Report TAMU 88-017, Texas A&M University, September 1988.

[23] Stefik, M.; Foster, G.; Bobrow, D. G.; Kahn, K.; Lanning, S.; and Suchman, L. Beyond the chalkboard: Computer support for collaboration and problem solving in meetings. Communications of the ACM, 30, 1 (January 1987), 32-47.

[24] Todd P. and Benbasat, I. Process tracing methods in decision support systems: Exploring the black box. MIS Quarterly, (December 1987), 493-512.

[25] Yankelovich, N. Hypermedia bibliography, Unpublished report, Brown University, Providence, RI, Institute for Research in Information and Scholarship, 1987.