Implications of Hypermedia for Cognition and Communication

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Since the dawn of civilization, few full-fledged media have emerged as vehicles for thought and interaction. The spoken word, the written word, still images, and full-motion images are the major representational methods that people have evolved to symbolize and communicate ideas. Enthusiasts for hypermedia (the associative, nonlinear interconnection of multimedia materials) are now claiming that a new medium has emerged. If this assertion is true, then a host of direct and indirect consequences for civilization will follow. Few technological innovations have greater potential to transform society than a new medium (e.g. the long-term effects of the invention of writing).

CLAIMS ABOUT HYPERMEDIA AS A MEDIUM

In the light of current knowledge, this article examines claims that hypermedia is a fundamentally innovative means of thinking and communicating. Alternative developmental directions for hypermedia research are depicted; also, some probable consequences for civilization of hypermedia's evolution and widespread dissemination are described. In addition, our discussion prefigures and frames the other articles in this special issue, since the specialized uses of hypermedia they discuss all illustrate different aspects of cognition and interaction.

All media except the spoken word have required a technological infrastructure; their advent in history coincided with the development of innovations capable of actualizing such a medium. Full-motion images, for example, were not widespread until a cluster of technological advances in the early part of this century empowered "motion pictures" (both photographic and animated). Hypermedia has not emerged until the present because powerful computers with relatively large memories are needed to create, store, and display large webs of nodes and links. The usage of computers has altered almost every aspect of society; will hypermedia be the next major impact, the first computer-centered medium?

Intuitive Reasons for Excitement about Hypermedia

Advocates of hypermedia pose several arguments for why this representational architecture is a major advance over other media:

- the associative, nonlinear nature of hypermedia mirrors the structure of human long-term memory, empowering both intelligence and coordination through intercommunication
- the capability of hypermedia to reveal and conceal the complexity of its content lessens the cognitive load on users of this medium, thereby enhancing their ability to assimilate and manipulate ideas
- the structure of hypermedia facilitates capturing and communicating knowledge, as opposed to mere data

• hypermedia's architecture enables distributed, coordinated interaction, a vital component of teamwork, organizational memory, and other "group mind" phenomena

The intuitive case for each of these arguments is presented below; the section following describes reasons for skepticism about these claims.

Hypermedia is Associative and Nonlinear: Human long-term memory is not similar to a computer database; remembering something does not involve doing a pattern-matching search through large numbers of records. Instead, the information a person assimilates is organized into an elaborate web of associations. For example, the term "apple" conjures up connotations of pies, orchards, Isaac Newton, the Beatles, the Garden of Eden, and a computer corporation—all interrelated through an correlational network. Our adeptness in quickly storing and retrieving large amounts of information seems to stem from this property of associativity (Caudill, Butler, 1990).

One of the most important subdisciplines in artificial intelligence is knowledge representation. This field centers on devising formalisms that allow a computer's logical mechanism to access and manipulate knowledge (a more complex entity than data, as will be discussed later). Some of the most useful representational architectures researchers in this area have developed—frame-based expert systems, object-oriented databases, semantic networks, and hypermedia—all share the property of associativity.

From a different intellectual perspective, biological researchers are studying neural networks (the physiological infrastructure underlying associative memory) to determine why organisms have such powerful abilities to recognize complex patterns and to learn. This work is generating insights about how simultaneous, distributed processes can be coordinated through intercommunication. From these studies of associative physiological networks, many applications are emerging in fields ranging from manufacturing to cognitive science. Research from these multiple perspectives suggests that associativity is fundamental to both to intelligence and to coordination via communication.

Hypermedia is much more associative than traditional media because of its nonlinearity. Spoken and written speech, still and full-motion images are all linear media: each conveys a sequential stream of data. Packets of information based on these media have a beginning, a middle, and an end; authors seek to find a single logical flow that expresses the totality of ideas they wish to communicate to their audience. Each concept is locationally associated only to those ideas preceding and following it in the linear stream.

In contrast, nodes in hypermedia can have an arbitrarily large number of direct associations (links) to other concepts. This flexibility is valuable in generating and communicating ideas. For example, divergent thinking (e.g. brainstorming) is difficult to capture when the ideas must be summarized convergently in quasi-linear form (i.e. a hierarchical outline). Mental models are have richer associations than can be represented by the "tree" of correlations a hierarchical structure can express; hypermedia provides a formalism that can depict this complexity.

As another illustration, recontextualization (seeing a phenomenon from a variety of perspectives) is a powerful approach to problem solving. Using this approach requires a medium capable of simultaneously representing multiple mental models (in the same way that a two-dimensional optical illusion can be interpreted as different solid objects, depending on the virtual orientation selected by the viewer). Hypermedia's flexibility as a representational formalism facilitates recontextualization; a web, for example, can be conceptualized via analysis (as a set of nodes) or synthesis (as a network of links). The combination of associativity and nonlinearity in hypermedia adds dimensions to thought and communication lacking in other media.

Using Hypermedia Lessens Users' Cognitive Load: Because hypermedia mirrors the representational architecture of long-term memory, assimilating and communicating thoughts in this format may require less internal preprocessing. The effort involved in translating to and from an associative intellectual structure is eliminated. For example, authors can develop writer's block even when they know everything they wish to express. Part of the problem may the challenge of mapping long-term memory's associative web of relationships into a linear stream. Hypermedia could serve as an external, virtual mirror for a person's memory: A writer could follow different trails through a web instantiating his knowledge until he found the best linear path to express the ideas in his document.

Beyond this, hypermedia seems a powerful approach for revealing and concealing complexity when analyzing a phenomenon. As an illustration, abstraction is an important cognitive strategy, but thinking abstractly involves rapidly shifting among different levels of specificity. Problem solving often requires moving from an overall perspective through increasing amounts of detail until an insight occurs and a subproblem less complex than the total situation is mastered. Then this understanding is generalized, as much as possible, to test its utility in comprehending other aspects of the problem.

Hypermedia can empower this type of intellectual process by providing ways to represent and navigate through complex levels of abstraction. Detail can be concealed until needed, then revealed by activating a link. A node, when viewed at a greater level of specificity, can reveal a subnetwork of nodes and links as its internal structure: webs embedded within webs. Attempts to create similar representations in the medium of paper generate a useless spaghetti of lines.

People using hypermedia report that this medium seamlessly interconnects its contents. Creating regularities in the menu structure of different tools on a computer is an important design strategy; users want the same commands to activate the "delete" function whether they are working with a word processor, a database, or a spreadsheet. In the same manner, consistency across the interface between the thinker and the subject of thought reduces cognitive load. The multiple representational formalisms hypermedia supports are all accessed in the same manner (activate a link). This ease of use stands in sharp contrast to a person juggling an atlas, a database of still images, an encyclopedia, a cassette tape, and a videoplayer to acquire information.

Hypermedia Facilitates Capturing and Communicating Knowledge:

Because of its associativity and low cognitive load, hypermedia is an attractive representational architecture for knowledge bases. "Data" can be defined as input gathered through the senses, and "information" as a pattern of input that signals an important change in the environment. In this schema, "knowledge" is integrated information that can be used to achieve a goal. To illustrate these definitions, learning that a new type of workplace tool exists would be data, realizing that it could add valuable functions to the one's occupational repertoire would be information, and mastering the tool would be knowledge.

Past generations of information systems have used advances in hardware and software to augment users' access to data, on the assumption that individual and institutional knowledge would thereby increase. After several decades of advances in data processing, however, even personal computers can deliver so much information that their users become overwhelmed: unable to decide which data is important or to interconnect new information with existing knowledge. Researchers in artificial intelligence believe that future information systems will use emerging increases in power not to create faster and larger databases, but instead to deliver "knowledge bases": contextually targeted, associationally interconnected data with embedded computational inferencing mechanisms (Brodie, Mylopoulos, 1986).

An interesting metaphor for knowledge processing is the concept of "cyberspace," a term that originated in a science fiction novel (Gibson, 1984). Cyberspace would be a real-time, online, multi-person virtual world in which, through ideas from scientific visualization, cognitive entities would take on tangible, sensory form to facilitate access and manipulation. This idea has captured the imagination of researchers in human factors, scientific visualization, gaming, computer-aided design, architecture, artificial intelligence, virtual realities, networking, computer-supported cooperative work, and hypermedia.

The design of cyberspace environments for depicting knowledge poses many research issues (Benedikt, 1991). These include the costs and benefits of reifying information, space-time axiomatics in artificial realities, magic versus logic as principles underlying user actions, the presentation of the self in a virtual context for group work, the meaning of travel and action when translated from a physical to a symbolic domain, coordinate systems for (un)real estate, the form and meaning (semiotics) of data objects, three-dimensional user interface design, visual languages, alternatives to a spatiotemporal metaphor for virtual reality, and the architecture of multi-dimensional data spaces. (An entertainment-oriented cyberspace would create a different set of challenges—its users could interact, go on shared adventures, get married or divorced, start businesses, found religions, wage war, hold elections, construct legal systems, tailor their virtual physical appearances, and assume alternative personal identities and interpersonal styles.)

Developers of cyberspaces are using hypermedia as their representational structure; no other medium can support the complex knowledge architectures required. Similarly, knowledge base research is focusing on associative formalisms, such as hypermedia, because interrelation seems central in transforming information to knowledge. (Later in this issue, Peper's and Jonassen's articles both discuss this issue in greater detail.) An illustration of the importance of associativity is the encyclopedia: civilization's attempt to encapsulate the total span of knowledge.

The chunks of data that are interrelated in an encyclopedia (a linear medium) are only those in the span of a single article; this segmented approach captures a small fraction of the total knowledge of the articles' authors. For example, to comprehend the role in history of the year 1842, one would have to scan every paragraph in the encyclopedia for events related to that period, then try to make sense of this jumble of data. A hypermedia-based encyclopedia, in contrast, could support webs of knowledge stretching across the full spectrum of articles: One could contrast an economist's perspective on the causes of the American Civil War with that of a slave or of an abolitionist. An associative encyclopedia can represent multiple mental models for interpreting the same data: alternative knowledge structures.

Hypermedia Enables Distributed, Coordinated Interaction:

Hypermedia may make knowledge easier to communicate as well as easier to represent. In the emerging field of computer-supported cooperative work (less formally known as "groupware"), many researchers are using hypermedia as the representational formalism for their projects—as discussed in Rada's article later in this issue. Applications in computer-supported cooperative work (CSCW) center on seven themes:

- building shared mental models
- aiding group design and decision making
- developing machine-based organizational memories

- coordinating complex, multi-person tasks
- enabling collaboration despite barriers of distance and time
- reducing Information overload in organizations
- enhancing psychosocial interaction in machine-mediated communication.

Hypermedia's capabilities to capture and communicate knowledge—coupled with its low cognitive load—make it an excellent representational medium for these CSCW applications.

For example, the correlational nature of hypermedia is valuable in building organizational memories. Complex, long-term projects necessitate institutional knowledge bases that transcend the involvement spans of individual personnel; otherwise, important information is lost when people leave, retire, shift to another project, or simply forget. Hypermedia-based associative memories can recall information even when queries are incomplete or garbled, can store data in a distributed fashion, can detect similarities between new inputs and and previously stored patterns, and do not degrade appreciably in performance if some of the memory's components are damaged. These characteristics are very useful for a distributed, shared organizational knowledge base.

Educators also are finding that hypermedia can aid in coordinating learning and communicating knowledge—as Beareano's and Haselkorn's articles later in this issue discuss. Dede (1990) describes how hypermedia-based applications from CSCW are changing the field of distance learning: The distributed, simultaneous processes underlying distance education can be orchestrated more effectively, and hypermedia's structure makes knowledge easier to transfer across barriers of distance and time.

Wenger (1987) has evolved a theory of knowledge communication, which he applies to artificial intelligence work on intelligent tutoring systems. Making knowledge communicable (the cognitive essence of instruction) requires many of the attributes hypermedia offers: easy translation into long-term memory, consistency across the interface between learner and subject matter, revealing and concealing complexity, support for multiple mental models, associativity. From the perspectives of both work and education, hypermedia seems a promising communications medium for distributed, coordinated interaction.

Potential Limits for Hypermedia

With all these potential advantages, enthusiasts argue, the world should become "hyperimmediated" as quickly as possible. However, skeptics argue hypermedia has several intrinsic problems that severely limit its effectiveness as a medium (Dede, et al., 1988). The major concerns currently being voiced about hypermedia are:

- people become disoriented when navigating through large hypermedia structures

- traversing a hypermedia network imposes considerable cognitive overhead on the user
- creating hypermedia structures involves a very large front-end investment of time and expertise
- "Tower of Babel" situations are likely in shared hypermedia systems

The intuitive case for each of these arguments is presented below; the next portion of this article summarizes the extent to which research supports these concerns.

Information that is organized in a complex manner poses a potential problem of user disorientation. In a linear medium, one can readily evaluate the extent to which a document's information has been traversed (how many pages read, how many left) and where a particular piece of data is located (chapter, section, paragraph). Large hyperdocuments may be more confusing. In a web of thousands--or millions--of nodes, how does one define a location in the network, establish a desired direction to move, or blaze a trail indicating those nodes already scanned? In a non-hierarchical structure, what type of coordinate system should be used to indicate where a piece of data has been stored? These problems of navigation and referencing are very challenging for networks with large numbers of nodes and links.

Even if a user familiar with a particular network experiences no disorientation, working in a hypermedia knowledge base entails some extra cognitive overhead. When entering material, an author must think carefully about how to link the information being added to the web which already exists. At each node they encounter, users must choose which link to follow from multiple alternatives and must keep track of their orientation in a complex multidimensional structure. The richness of a nonlinear representation carries a risk of potential intellectual indigestion, loss of goal directedness, and cognitive entropy. Unless a hypermedia system is designed carefully from a human factors perspective, increasing the size of the knowledge base may carry a cost of decreasing its usability.

The availability of multiple types of representations in a hypermedia system compounds this problem. Access to representational alternatives allows users to tailor input to their individual cognitive styles and enables authors to choose a format well suited to the material being entered. However, coping with multiple formats adds to cognitive overload, and little is known about which representational ecologies are functional for different task situations.

The large front-end investment in time and expertise required to author a large hypermedia structure is another type of potential limit. The challenges involved can be illustrated by considering the simple situation of adding a new node to an existing web. The number of links generated by adding an additional node to a network will vary depending on the type of knowledge being stored, the objectives of the documentation, and the sophistication of the user population.

Suppose that many vital, subtle interrelationships exist in the network's material. Although some new nodes will simply annotate single existing nodes, a substantial proportion of nodes that are added may require multiple links. In a million node web with 0.1% of the material interrelated, adding a single new node would require constructing one thousand. The difficulties of comprehending and maintaining such a web could exceed the benefits that a nonlinear medium provides.

One strategy for solving this problem is to aggregate subnetworks into composite nodes that chunk material on a higher level of abstraction: webs within webs. Such an approach is being explored in second generation hypermedia systems—but creating another dimension of hierarchy complicates the representational architecture and, unless implemented in a manner transparent to users, may increase disorientation and cognitive overload.

These potential limits are particularly acute in online, shared hypermedia systems. The user of a collegial electronic knowledge base may find that, since last entering the system, familiar paths have changed and new material has appeared. Links that seem intuitively obvious to the author adding them may be puzzling to others. Skeptics argue that "Tower of Babel" situations are likely with a large knowledge base in which multiple users can alter the fundamental medium of interaction.

Possible problems of disorientation, cognitive overhead, front-end investment, and collective communications dysfunctions reflect the intricacy of working with a knowledge base rather than a database. Knowledge is intrinsically complex, and transforming information to knowledge involves gaining a goal-directed, contextual understanding of the application domain. Utilizing an underlying representation based on hypermedia will require more sophisticated skills--a new type of "literacy"--from its users. Many are skeptical that the benefits of hypermedia will justify the costs of creating this hyper-literacy.

Contrasting these optimistic and pessimistic viewpoints on the utility of hypermedia illustrates that considerable disagreement exists about the value and significance of this innovation. The next section of the article presents alternative perspectives on the evolution of hypermedia, based on what researchers know at present about nonlinear media. This provides a partial basis for evaluating the relative merits of claims made by enthusiasts and skeptics.

ALTERNATIVE PERSPECTIVES ON HYPERMEDIA, COGNITION, AND COMMUNICATION

Much of the excitement surrounding hypermedia systems is based on their ability to meet the needs of various users. These include authors, designers, on-line readers and others utilizing the idea processing capabilities of such systems (Marshall, 1987). The central theme of currently available hypermedia applications is knowledge presentation. However, to fulfill its promise hypermedia must move beyond knowledge presentation to sophisticated knowledge representation and finally toward knowledge construction.

This section begins with a discussion of comparisons between human memory and hypermedia systems, with particular emphasis on the underlying importance of associational memory. Then, knowledge presentation, knowledge representation, and knowledge construction are addressed as alternative directions for hypermedia development. To illustrate the challenges and uncertainties involved in the latter, research issues in creating hypermedia-based knowledge construction tools are described, using the example of nonlinear environments for individualized learning.

Parallels Between Human Memory and Hypermedia

Much has been made of the similarities between hypermedia-based systems and current conceptions of human memory. These human memory models are based primarily on information processing theory. In this section, we will discuss strengths and weaknesses inherent in analogies between hypermedia and human memory.

Similarities

Current conceptions of learning are founded on principles of cognitive psychology. Learning can be defined as the reorganization of knowledge in semantic memory (Jonassen, 1988). The interconnections of knowledge in a structured associative network allow learners to combine ideas, extrapolate, and infer. These structural networks are composed of both the information presented and the relational links that interconnect them (Norman, et al., 1976).

Based on this description of semantic networks, "learning" can explicitly be described as building new knowledge nodes, then connecting them to existing knowledge and with each other (Norman, 1976). The more numerous the connections between the existing knowledge stored in memory and newly acquired knowledge, the better the additional information will be learned. Learning, therefore, becomes a function of connecting new material onto one's preexisting knowledge structure.

For example, when beginning to learn trigonometry, building a new, isolated knowledge structure will not in itself provide mastery of the material . The additional step of connecting these principles of trigonometry to already mastered knowledge structures in algebra and geometry is necessary. Those chunks of new material that link directly to previously mastered concepts will be the easiest to acquire. Effectiveness in learning is determined both by complete and correct acquisition of new knowledge nodes and by appropriate interconnections to previously existing webs of knowledge.

If we accept this definition of learning as an expansion of cognitive structure, then we need access to tools for assessing cognitive structure, tools for depicting and displaying knowledge structures, and ways of mapping new information onto learners' existing knowledge structures. Computer environments based on hypermedia are capable of doing this; in fact, much of the excitement surrounding hypermedia's potential centers on its use for such purposes.

From this description of learning, many commonalities can be seen in the terminology used by cognitive psychologists in describing the operation of human memory and by hypermedia developers in discussing their representational architecture: Nodes and links form the basic structure of each. In fact , current human memory models are strongly based on analogies to information technology, comparing storage and retrieval in human memory to similar mechanisms in computer architectures.

Hypermedia extends conventional database models of memory by allowing for more explicit relationships among information. The associativity of these relationships, a key aspect of human memory, is also central to hypermedia. Rumelhart (1977) discusses how the essential attribute of the human memory system is not the storage or retrieval of specific units of knowledge, but rather the organizational schemes by which knowledge is associatively related. Hypermedia provides a computerized technology to achieve similar organizational structures.

Another fundamental aspect of human memory is that, when new associations and therefore new organizational interconnections are developed, prior knowledge need not be completely recodified within the newly acquired structure. Hypermedia environments also provide such flexibility; new information and relationships can be easily integrated into previously stored information without having to recode its web structure.

In addition, human memory utilizes a variety of organizational schemes, not just one general scheme, to store and retrieve the variety of knowledge presented. Research has demonstrated that the human memory system stores and structures associational schemes that preserve the most important aspects of relationships without preserving every possible association (Bransford, Franks, 1971; Bransford, et al., 1972). Hypermedia systems offer the possibility of similar organizational schemes, allowing the the designer and the user to decide on relevant relationships between information, but not requiring that all possible relationships be specified.

Differences

Prior to the inception of the computer as the major metaphor for human memory models, the library was used as the prime analogy. However, both the computer—especially when used as a hypermedia device—and the library metaphor break down at certain points in their respective parallels with the human brain. For instance, Rumelhart (1977) indicates that, while other information storage systems (such as a library of books) archive complete units of information, the human brain appears to store fragmented bits of data. These must then somehow be processed via the retrieval system to form an integrated unit of information, allowing a complete answer to a specific query of the human knowledge base.

Thus, the retrieval of information from the human memory system can be broken down into two equally important processes: first, determining the diverse locations of fragments of the desired information; and second, reconstructing appropriate output from the incomplete data stored in different locations.

For example, if a person is asked to recall his childhood home, this information is not stored as one large node of knowledge in his memory system. Instead, bits and pieces of knowledge about this home are distributed in various locations throughout his cognitive structures. These memory stores do not share spatial proximity; however, when challenged with such a request, the mental retrieval system can search out these required fragments. Through this retrieval process, which is not well understood, a complete mental representation of the house (including the floor plan, the color of the walls, the type of floor covering, number of windows) can be reconstructed.

Current hypermedia systems differ from human memory in that they do not accommodate this second aspect; nodes hold complete units of information, and therefore no synthesis of information is required to provide an answer to a specific query. Hypermedia networks, like a library of books, store self-contained information "chunks" in each node. In fact, some developers now argue that hypermedia systems should have the capability to contain multiple "chunks" of information per node. Further, systems designers are debating whether nodes should be constructed as repositories of these units of informations or should be instantiated as the information itself without an explicit "container." The former representational architecture, while more powerful, would be far from the distributed storage characteristic of human memory.

A second crucial difference between hypermedia and human memory stems from an underlying problem in many current hypermedia systems: "content-free" links form the basis of associations. At present, most hypermedia systems support linkages indicating only that one unit of information is somehow related to another unit of information, without specifying the nature of this relationship and a rationale for its existence. This architectural constraint presents problems for both developers and users; an association that is intuitively obvious to one person may be very confusing to another.

In contrast, human memory supports a much stronger linking mechanism; links both establish a relationship and convey information about its associational nature. Attempts by hypermedia developers to develop links of similar power have been only partially successful. "Typed" links can labelled with descriptors such as "supports" or "refutes"; such a representational architecture might aid in depicting the knowledge structure underlying a debate. However, typing links introduces underlying complexities in the computational storage structure that can be difficult to manage, as well as creating rigidities in how new information can be added to the hypermedia system. Further, if enough information is attached to a link, it becomes equivalent to a node; this blurs the definitional concept of hypermedia: links interconnecting nodes.

Problems in representing the semantic relationship of nodes and links are especially evident in the placement of nodes in a large hyperspace. Due to our biological heritage of navigating visually in physical space, designers and users unconsciously tend to perceive the distance between nodes in hyperspace as directly related to the strength of their association (Locatis, et al., 1989). Yet this often not the case; in fact, such a physical metaphor severely limits the types of relationships that can be represented (Dede, 1989). No such reliance on distance is present in human memory. The strength of the relationships are conveyed by the value of the associational relationships rather than their physical proximity.

Hypermedia systems that allow for typed-link relationships may alleviate much of this problem; a designer can denote the strength of a relationship by the type of link used to connect two nodes of information, regardless of the distance between them in hyperspace. Still, overcoming an intuition that has been "wetwired" into the human brain by evolution adds to the cognitive load involved in using hypermedia. The challenge of how to associate content with links without violating the fundamental concept underlying hypermedia remains a major distinction between this representational architecture and human memory.

Depicting all the ways in which the analogy between hypermedia and human memory breaks down is not possible in the scope of this paper. In general, as with all metaphors, the parallel between associative memory and hypermedia is limited. Biological associative memories share common features (Caudill, Butler, 1990):

(1) the recall of information based on incomplete or garbled inputs,

(2) the storage of information in a distributed fashion,

(3) some degree of content addressability,

(4) resistance to degradation when parts of memory are lost, and

(5) the capability of generalizing new information structures.

Researchers in the fields of parallel distributed processing, knowledge bases, and neural networks are working to replicate these capabilities in the computer; but the challenges involved are substantial. While hypermedia does capture some aspects of these five features, it falls short in many respects.

Conclusion

The information processing models of human memory and hypermedia share attributes that seem relevant in assessing the potential impact of hypermedia, but multiple differences prevent the assertion that this new medium is a computerized information processing system completely replicating its human equivalent. Hypermedia proponents have based much of their theoretical claims on parallels between hypermedia and associative memory, but this analogy is limited. If a complete similarity to biological associative memories is critical to the power of hypermedia, then developers of the next generation of these systems should focus on reducing the differences between current capabilities and the greater power of human memory.

Knowledge Presentation, Knowledge Representation, and Knowledge Construction

Much of the discussion about the potential impact of hypermedia has centered on ways that such systems may become infused into our society. Current applications tend to focus on the presentation of information; a few wrestle with the challenges of representing information in an advanced storage and retrieval system. Some developers are proposing a next generation of hypermedia that will target the the construction of knowledge.

The power of hypermedia applications can be seen in three characteristics that relate directly to their uses as presentation tools, representation tools, and construction tools (Collier, 1987):

(1) Printed knowledge is inherently linear and often has arbitrary ordering forced on it by the print medium. Hypermedia systems eliminate such constraints in the presentation of information, allowing users to browse more freely through a data structure.

(2) Links enable semantically and logically related information to be tied together in conceptual webs. Using this representational architecture allows hypermedia systems to mirror some of the associational power of human memory.

(3) Linear information systems support only part of the potential web of interconnections. Authors choose which interconnections to present based on a hypothetical "typical" user. Since the prior knowledge, experiences, and

> learning style of all potential readers cannot be accommodated, many users may be unable to adequately transfer desired information into their cognitive structures; the appropriate semantic relationships may be missing. Hypermedia, on the other hand, holds the potential for users to access tools by which they can construct personalized transitions between the information to be accessed and their cognitive structure. This would truly individualize the information environment.

Hypermedia as a Presentation System

As a presentation system, the ability of hypermedia applications to exhibit information in a multimedia framework is emphasized. In fact, much of the excitement of lower end hypermedia systems, such as HyperCard™ and SuperCard™, tends to focus on their multimedia aspects rather than on the nonlinear attributes critical to any hypermedia application.

This emphasis on hypermedia as a presentation system is exemplified in Oren's (1987) discussion positing that the designers of hypermedia applications should focus on constructing the most useful pathway for users to proceed through the information in a particular data structure. His position is that hypermedia design should anticipate the needs of the learner and present information accordingly.

However, hypermedia applications optimized as vehicles for capturing, structuring, and presenting information will not necessarily be used to their fullest potential as knowledge representation systems. For this to occur, the representational process within hypermedia will need to become more formal.

To facilitate the movement of hypermedia systems from presentation systems toward representation systems, more attention must be placed on the underlying processes required for human knowledge representation. Presenting information on a computer screen is an inadequate pedagogical method to ensure that this material will be accurately and completely transferred to the knowledge base of the learner. Even multiple modes of presentation (a current theme of hypermedia proponents) do not assure adequate acquisition. As hypermedia systems move from knowledge presentation to knowledge representation, the issue of effecting knowledge transfer will be key.

Hypermedia as Knowledge Representation

As a representational architecture, much is made of the similarity of hypermedia to current models of long term memory. In fact, the definition of "representation" as the capacity to picture in the mind a mental image or idea leads one to such parallels. A common terminology also promotes such a relationship; as discussed earlier, nodes and links are the metaphor for both cognitive models of memory and semantic webs in hypermedia.

Nodes and links are also a common ground between artificial intelligence and linguistics researchers, but practitioners in these disciplines have been hesitant to claim that they are referring to the same entities. In fact, the field of cognitive science has evolved to reconcile the psychological, linguistic, and computer science conceptions of knowledge representation and to promote a more multidisciplinary approach to study in this important area.

While one of the often touted aspects of hypermedia is its ability to support the emergent properties of the representation process, researchers are beginning to realize that current hypermedia systems have failed to fully develop this capability. Specific inquiry into the fundamental aspects of nodes and links are needed if hypermedia is to become a sophisticated knowledge representation system.

For example, current systems differ in the way information is captured by the nodes in a hypermedia web. One difference is that, in systems such as Intermedia™, the information is stored as nodes; other systems, such as Thoth-II, separate the nodes and the information they contain. The benefit of this second type of system is that more complex connections between units of information are empowered, allowing an explicit conception of the knowledge representation to be conveyed from the designer to the user (Collier, 1987). Hypermedia applications also differ in the amount of information that may be placed in the nodes of this second type of system. One type, exemplified by Textnet, allows only one unit of information to be placed in a particular node. The principle behind the Thoth-II system, on the other hand, is to allow for multiple units of knowledge to be placed in any node.

An extension of such a system would promote levels of structure within a hypermedia environment. Information at one level of complexity could be combined and collapsed into a larger, composite node. For example, the HAKCS hypermedia system for physics instruction (Lidwell, et al., 1991) divides the physical domain into concepts— defined by domain experts— that are then further differentiated into specific units of information. As users demonstrate mastery of prespecified sub-domains, HAKCS collapses that micronetwork, instead presenting the sub-domain as a composite node.

For example, if the primary domain is wave dynamics, one sub-domain would be the Doppler effect. Once the user has demonstrated mastery of the micronetworks comprising the concept of the Doppler effect (by constructing appropriate associations between nodes), then those micronetworks would be collapsed into a composite node representing the Doppler Effect concept.. That node may then be associatively linked with other composite nodes, and so on, until the entire network has been constructed and collapsed into a primary domain node of wave dynamics.

As hypermedia systems move from mere presenters of information to more sophisticated knowledge representational vehicles, the use of linkages is also a critical issue. "In many representations, a key decision centers around the distribution of meaning—should links or cards carry the semantic burden?" (Mitchell, 1987, p.265). Ideally, the semantic weight of a hypermedia system needs to be equably distributed between its nodes and links, as neither entity is capable of conveying the full associational meaning in isolation.

While much of the semantic weight was placed on the nodes in early hypermedia networks, current implementations are moving more of this burden to links. The possibility of making "value" a link property would be beneficial in developing more complete knowledge representation systems in hypermedia. For example, simply stating that a node "apple" is associated with a node "fruit" does not convey as much information as stating "apple" is an example of "fruit." Such a representational structure would more readily parallel the organizational architecture of human memory. However, if link types are used for too many semantically orthogonal purposes, performing a representational task or interpreting the results of an analysis may become confusing.

One future direction of hypermedia is to develop systems that are capable of capturing knowledge representations via some type of concrete structure that could then be reapplied to other knowledge bases. Such systems would parallel human metacognition, in that they could incorporate capabilities for generalizable association that could be applied to novel information (Lenat et al, 1990). With the inclusion of artificial intelligence features, such systems could self-generate associational links between nodes, as well as assigning them appropriate link-types.

Hypermedia as Knowledge Construction

A key claim of hypermedia proponents is that these systems will be effective as a teaching medium: Users can access a large knowledge base and seek out information that meets their particular needs, in terms of both their prior knowledge and their preferred learning style. The development of systems to achieve these ends seems possible. However, simply providing an advanced presentation system, or even a more elaborate information storage and retrieval system that parallels the way that the human brain represents knowledge, does not guarantee that more effective or efficient learning will occur (Locatis, et al., 1989).

A more constructivist environment—where the user not only browses the information base, but also has the ability to build additional nodes and links—holds more promise to promote learning. One key to such environments is the level of interactivity promoted by the system. While an information presentation system that provides the user with a choice of direction does promote some level of user control, and therefore interactivity, this interchange between user and application is focused at a very basic level. In contrast, a knowledge construction system that also challenges the user to actively connect information to other nodes, to add additional information, and even to question and/or extend the relationships defined by the hypermedia designer provides a much higher level of interactivity. Many hypermedia systems support such an environment, yet little has been does to promote this obvious advantage.

Raskin (1987) laments that hypermedia has been heralded with mostly uncritical attention. While he does state that current implementations of hypermedia are worth pursuing, he strongly cautions that they may fail to realize the expectations currently promised. His criticisms focus mainly on technological and user-interface design limitations that seem addressable in the near term. However, this line of argument also leads to more daunting concerns in that current directions in hypermedia development may focus too heavily on the presentational features and storage/retrieval capabilities necessary for sophisticated representational systems. Instead, to achieve their full potential of hypermedia systems, developers should target empowering users to actively construct information via typed linkages. Developmental research in creating such constructive systems would be more strongly grounded in the psychological literature on learning and transfer than in the human factors and technological design community.

Such research needs to focus on critical issues of knowledge construction and knowledge transfer. The optimal degree of user control also needs to be addressed, as pure discovery environments do not promote efficient knowledge acquisition or transfer to other domains. The construction of hypermedia systems that support the development of metacognitive and problem-solving environments also merits considerable attention.

A key issue in the emergence of hypermedia is the ability of these systems to promote learning in an effective and efficient manner. The term HAI (hypermedia assisted instruction) has been proposed to describe the use of such systems (Heller, 1990). To extend hypermedia beyond the traditional uses of computers in instructional settings (drill and practice, tutorials, simulations), Heller believes that current hypermedia systems must be augmented. However, the issues that she addresses focus on presentation and interface concerns rather than on allowing the user to construct knowledge from within the hypermedia environment. To build effective hypermedia learning environments, the focus of such systems needs to include essential characteristics of effective learning environments as well as successful implementations of computer technologies.

Creating Hypermedia-based Individualized Learning Environments

The ability to individualize information access to accommodate the diversity of possible users has traditionally been a strength of instructional technology. As our society continues to evolve toward a diverse worldwide village, developing single-mode instruction designed for the needs of a "typical" learner is increasingly ineffective; no ethnic or cultural majority dominates the user population. Technologies that can individualize to the multiple, wide-ranging differences inherent in the global marketplace are needed.

Traditional computer-assisted instruction (CAI) is limited to presenting prespecified screens of material; these are tailored to individual learners only to the extent that the instructional developer could imagine and afford preprogrammed branching among alternative representations of content. Approaches more sophisticated than CAI to individualizing educational tools are necessary; proponents of hypermedia believe that their systems, if used for knowledge construction, could fill the need to tailor learning environments for the evolving demands of a global information society.

Hypermedia and Learning Styles

Research supports the claim that cultural influences have an effect on the cognitive learning styles exhibited by individuals (Ramirez, Price-Williams, 1974; Witkin, 1967). Learners' cultural background may effect differences in both their cognitive skills and intellectual performance. Children of different cultural and linguistic groups exhibit significant variations in both cognitive and sensory perceptions.

Cohen (1969) has identified two basic learning styles, analytic and relational. Those who learn in an analytic style view information as bounded, objective, and isolated (rather than intrinsic to some context). Those who exhibit a relational learning style instead see information as embedded on a larger environment and as inherently unbounded and subjective. Kirby (1979) indicates that, to address the cognitive learning styles of all students, information environments should be structured bicognitively. Otherwise, the many pupils who do not function effectively in the analytically structured environment typical of current educational practice will be poor achievers.

A crucial, and yet often neglected, aspect of effective information transfer is ascertaining and accommodating users' learning styles (Ausubel, 1968). Research suggests that learners who were taught by their preferred method achieved better, were more interested in the subject matter, liked the way the subject was taught, and wanted other instructional situations to be taught in a similar manner (Smith, Rezulli, 1984). Matching the presentation style of the information with the desired learning style of the pupil enhances cognitive outcomes and encourages students to become more involved in the learning process.

Hypermedia as a Flexible Instructional Environment

Hypermedia-based systems allow the user to redefine both the structure and content of the material to be learned. When compared to traditional forms of information presentation, this capability alters the constraints and opportunities for conveying information. The power of such a tool can be seen as both subtle and incremental; yet we need to harness this power to effectively and efficiently develop training programs that meet the requirements of the information age (Scacchi, 1988).

In traditional forms of instruction, learners most often are presented with information in a sequentially formatted environment. Hypermedia, on the other hand, allows the learner to determine the order of access for any information in the knowledge base (Jonassen, 1988). Learners need not be constrained by the initial structure imposed by either the database designer or the instructor. Since learners each have unique knowledge structures based on their experiences and abilities, the ways that they choose to access, interact, and interrelate information in the knowledge base will also vary. Hypermedia-based learning environments allow the knowledge base to accommodate the learner rather than the learner accommodating the knowledge base.

A major characteristic of hypermedia environments is that they enable users to link information together in multiple ways and to make these relationships explicit. Instructors and learners may create different pathways through the hypermedia knowledge base. Users can also annotate the knowledge base by creating notes, explanations, and analogies.

To realize maximum effectiveness from this type of environment, learners should be encouraged to explore information, to make associational links and relationships, and even to alter the knowledge base as a means of achieving greater understanding given their previous experiences and learning style. Hypermedia offers the potential to construct an environment that allows for these beneficial activities (Jonassen, 1986).

A major goal of hypermedia is to provide a learning environment that facilitates exploration. This type of learning environment provides immediate access to large collections of information. The most distinct aspect of hypermedia learning environments is their ability, in a node-link framework based upon semantic structures, to portray an accurate structural description of the knowledge base they are representing. Hypermedia offers advances from previously available technologies in that it is strongly connected with a cognitive conceptual framework, yet this framework does not limit or constrain its possible application.

Cognitive Load

A second potential benefit of hypermedia-based individualized learning environments is the possibility of decreasing the cognitive load associated with accessing information from within such an environment. Any information presentation/retrieval system has some load associated with its operation: Users must wrestle with issues of learnibility, efficiency, ease of remembering, and error frequency. The amount of time a user must devote to such operational issues directly increases the amounts of time and cognitive energy required to effectively interact with the information system. In turn, the efficiency of usage is adversely affected; systems that decrease cognitive load enable more effective utilization.

Nielsen (1990) addresses five usability parameters that are directly related to cognitive load. These include the ease with which the operation of the hypermedia system is learned, how efficiently the system can be used once the user has learned its effective operational structure, how easily the operation of the system is remembered from one interaction to the next, the number and cost of errors associated with system operation, and how pleasant the system is to use.

If hypermedia systems can optimize the usability parameters addressed above through knowledge construction features, this would decrease the cognitive load they require. However, compared with other methods of information access, cognitive load may still remain as one of the largest drawbacks of hypermedia environments.

The question of how much and at what level information should be presented to the user is often at the heart of such concerns. Issues of how many simultaneously displayed nodes should be allowed on any given screen and of how many links any one node of information should support are questions that need further investigation. To see how strongly these issues are tied to the theme of cognitive load, one of the prevailing sentiments in this area is that the number of nodes displayed and the the number of links allowed per node should be limited to seven: a direct connection to Miller's (1956) assessment of the limits of human working memory.

Novice/Expert Users of Hypermedia

Another key issue in the use of hypermedia as an individualized learning environment is the prior expertise and knowledge requirements of the intended user. While knowledge presentation systems may be very useful to those considered expert in the content area of a particular hypermedia, such presentation systems do not hold the key learning tools required by novices beginning to use a particular knowledge base.

Cognitive theorists view learning as the construction of mental models. Norman (1982) notes that such mental models are characteristically unique, incomplete, and lack essential information. Current implementations of hypermedia as individualized learning environments presume the existence of specific prerequisite knowledge and the ability of the learner to draw successfully from that knowledge. However, since these required mental models are inherently incomplete for novice learners, information presentation systems will not successfully accommodate their construction of correct and complete mental models in the desired domain.

While there is a continuum between novices and experts in a particular knowledge area, a bi-polar distinction between experts and non-experts is appropriate in interpreting the potential of hypermedia as a learning tool. Problems with cognitive overload, user disorientation, superficial browsing and disinterest often reported by users of hypermedia may well center on the issue of the level of experience of the user. Thus, while current hypermedia systems may well decrease the cognitive load of those users closer to the expert end of the continuum, they may well increase the load on users less familiar with the content of the knowledge base or the navigation of nonlinear structures.

Thus, while nonlinear media do provide a potential environment for the construction of individualized learning environments, current hypermedia systems do not fully actualize this potential. Several critical issues—including transfer of knowledge, cognitive learning style, cognitive load, and the construction of appropriate mental models—must be more fully investigated if hypermedia systems are to provide the type of individualized learning environment needed to meet the needs of 21st century society.

Summary: Two Directions for Hypermedia

This paper has addressed two possible future directions for hypermedia; both hold promise, yet need further investigation if hypermedia is to become more than just another "hyped" media (Locatis, et al., 1989).

The Next Generation Database?

While the focus of this paper centers on movement from the storage and retrieval capabilities of hypermedia to a more constructionist learning environment, hypermedia does possess representational attributes that may lead to a next generation of databases. Such systems would clearly be useful to any number of users. As we move headlong into the information age, an important attribute of workers will be their ability to access information; what information one currently possesses will be relatively unimportant compared to how quickly one can find and master desired information.

At present, work in hypermedia seems to focus on database-related directions; much of the current criticism of available systems rests on the inability of hypermedia users to access large volumes of knowledge in efficient ways. Organizational aspects of hypermedia are now a central development issue (Conklin, 1987; Halasz, 1987). Some system designers have moved toward a hierarchical linking structure, where movement among information nodes at any level of the hypermedia network is restricted to accessing only those nodes directly above or below that level in the designers' knowledge structure.

The contrast is to systems that support referential linking, where any two nodes can be linked together and traversed. Certainly this second type of system, while more difficult to create (especially if the designer is to construct all meaningful associations), meets more fully the central attribute of nonlinearity. Developing powerful access capabilities for referential hypermedia systems will be critical if a new generation of databases of information centered on nonlinearity is to become a reality.

Another issue that makes the possibility of hypermedia making a major contribution to database evolution seem likely is the requirement that emerging information systems be capable of representing information in more diverse ways than simple text. Hypermedia, with its multimedia capabilities, seems an ideal method for allowing retrieval of textual, graphic, auditory, animated, and image-based information.

Current proponents of database-oriented hypermedia development stress other benefits that nonlinearity offers in this area. These include the capabilities to mix both highly structured and loosely structured information, to allow for multiple representations of the same information, and to enable the extension of an information base in ways that may not conform to its original data structure (Marshall, 1987).

Knowledge Construction Sets?

First generation hypermedia systems, such as Notecards, gIBIS, and Intermedia™, required workstation level computer hardware. The recent introduction of weakly functional microcomputer-based hypermedia systems such as HyperCard™, Linkway™, and Guide™ have contributed to the hype surrounding hypermedia. These microcomputer-based systems have focused more on the presentation of materials rather than the knowledge construction applications that hypermedia could empower. Systems such as HyperCard™ are often referred to as "programming construction sets," in which a user with little computer programming experience can successfully produce a functional piece of software with minimal effort.

The promise of hypermedia, however, does not revolve around an easy way to produce software. Instead, proponents of hypermedia need to focus on developing knowledge construction sets: environments where information presentations can successfully and efficiently be transferred into knowledge by a diverse and ever changing population of learners.

Much of the theoretical framework for hypermedia promotes the development of such systems; yet little has been done to support this type of implementation. Future work in the area of hypermedia needs to address the the implications of cognitive science for hypermedia systems, issues of knowledge transfer from the hypermedia environment to the learner, and the incorporation of artificial intelligence features within nonlinear knowledge structures. If successful, such research will allow users of all experience levels, abilities, and learning styles to effectively and efficiently interact with sophisticated information environments.

If enthusiasts are even partially correct, hypermedia will have a considerable impact on civilization whether it evolves as a extension of databases or as a knowledge construction tool. Assuming that ways are found to surmount the more serious problems associated with developing and using hypermedia, what consequences may its widespread dissemination create?

SOME PROBABLE IMPACTS OF HYPERMEDIA

Describing in detail the potential implications of using hypermedia in various domains, such as education, is beyond the scope of this article. The broadest context for assessing the probable impacts of hypermedia is in its role as a medium for cognition and communication. Some general insights about likely effects of hypermedia usage can be drawn by analyzing how a nonlinear medium could extend the capabilities of our current, linear media.

The (Hyper)Medium and the Message

As Shirk's article later in this issue discusses, any medium shapes its message (and the sender and recipient of that message). For example, the imagination and involvement of a child are engaged in different ways when reading a fairy tale in a book than when watching a movie depicting that story. The general question of how the medium shapes the message is emerging as a central issue for information technology research (Dede, 1991).

For example, the primary goal of the discipline of telecommunications has been to improve the transmission capabilities of the various media while lowering their cost. Research has centered on technical issues underlying the electrical or optical transfer of information at a distance, irrespective of the content being conveyed. While the challenge of transferring signals reliably and cheaply is still an important theme, now the emphasis in studies of communications media is refocusing on how to extend a state of awareness and related intentions over a distance to others. The importance of this research for understanding the evolution of human thought and communication can be highlighted by describing two illustrative issues emerging in workplace and community settings.

In business, information technology is now seen as an effective method for improving worker productivity and for enhancing an organization's ability to respond quickly and flexibly to environmental changes. These gains are intrinsically accompanied by a decrease in face-to-face interaction and an increase in technology-mediated communication. Workers progressively have more and more colleagues with whom they exchange information, but their primary form of contact is through the telephone or electronic mail.

As a result, the psychosocial aspects of work are changing in complex ways that depend in part on the implementation strategy used to create the institution's information infrastructure. In general, people feel more productive, but less personally fulfilled by their work environment. The consequences of this shift for both workers and organizations are being studied, but our current understandings are very limited, and how the evolution of hypermedia might affect this situation is unclear.

The potentially troubling effects of using advances in technology such as hypermedia to mediate human experience are nowhere more clear than in today's community. The single greatest experiential input for many people is the pervasive sensory, informational, and normative environment created by television, radio, videogames, movies and videotapes. In this situation, people's knowledge and values can be constrained by the characteristics of these communications channels.

For example, concerns about "reality pollution" in the news media are mounting. Businesses produce and distribute self-serving, sometimes biased "docutainments" that the media broadcast to cheaply augment their programming. Images can now be doctored electronically to the point that their authenticity can no longer be determined. Political events are routinely followed by commentaries in which "spin control" experts attempt to skew viewers' perspectives on what they saw.

The cultural consequences of technology-mediated physical/social environments are mixed. On the one hand, people have a wider range of vicarious experience and more contact with specialized human resources than they could attain through direct interaction in their local region. On the other hand, to the extent that perceptions of family life come from situation comedies, of crime from police shows, and of sexuality from soap operas—and to the degree that physical exercise is confined to pressing the buttons on videogames—civilization is in serious trouble.

The technologies themselves do not dictate content that creates a "couch potato" mentality or implies all of life's problems can be solved in thirty minutes. As pervasive interpreters of reality, the media are influenced primarily by economic, political, and cultural forces. But, given that the medium does intrinsically shape the message, society must consider the extent to which communications technologies have generated passive, narcotic behavior for many of its members. Again, the factors that create this situation are largely not understood.

If hypermedia technology is used to mediate communicating a state of awareness and related intentions over a distance to others, how does the nonlinearity of this medium shape the sender, message, and recipient? A few ideas:

- Technology provides metaphors that influence how we conceptualize other aspects of reality (Postman, 1985). For example, we speak of "biological clocks" and "genetic codes." A nonlinear medium would empower analogies in which multiple, interacting causes create outcomes; in contrast, linear media convey a sense of sequential, simplistic causality. Hypermedia promotes metaphors that are systemic and wholistic, while linearity produces a more reductionistic, analytic orientation. Many of civilization's problems stem from a limited understanding of what "interconnectedness" means; thinking in webs would help to redress this weakness.
- Science and technology change our spatiotemporal orientation (Meyrowitz, 1985); we experience space and time differently in the Einsteinian world than our ancestors did when the Earth was seen as center of the universe and time as a universal constant. Through its nonlinear, multimedia capabilities, hypermedia provides a diffuse, complex spatiotemporal context; users must map arcane network geometries and assess the impact of multiple events occurring in parallel. A nonlinear artificial reality, such as cyberspace, could embody entirely new conceptions of space and time. In contrast, conventional linear media present a sequential, rigidly ordered spatiotemporal framework that no longer mirrors the complexity of civilization's dynamics.
- In Schrage (1990), Alan Kay analyzes the implications of new media through the question, "What does a medium ask you to become in order to use it?" Print requires a rational reader; television, a passive observer; the telephone, a conversationalist. Because nonlinearity adds another dimension of complexity to the content of messages, both senders and receivers have a more complicated set of responsibilities to fulfill. To interrelate chunks of message content, the sender of a hypermedia communication must select some subset of the total associational links possible for that material. While reading, listening, and viewing are passive in linear media, hypermedia demands continuous choice and navigation on the part of the message's recipient. If designed for knowledge construction, hypermedia blurs these roles of sender and recipient. In general, hypermedia promotes more metacognition (thinking about thinking) than linear media.
- The bandwidth of a medium determines the richness of the communication it can convey. For example, electronic mail is very limited because sending an

ambiguous message through text alone is more difficult than via face-to-face interaction, in which body posture, tone, and facial expression can each convey signals different than the verbal content. High-bandwidth media enable users to share understandings and experiences, to create meaning, and to build a shared context; low-bandwidth media constrain them to exchanging data. A nonlinear, multimedia communications channel has higher bandwidth than any current medium.

- Controlling a communications medium is a fundamental source of political and social power. Beyond this, media create new types of social structures (Innis, 1972). For example, large computers centralize power by limiting information access and dissemination to a few controlled channels; small-scale information technologies distribute power widely through a society. As discussed earlier, nonlinear media empower social processes that involve distributed, coordinated interaction. Through computer-supported cooperative work, the widespread use of hypermedia may lead both to further societal decentralization and to more complex institutional coordination structures.

The Sapir-Whorf hypothesis that language shapes thought and expresses a culture's underlying conceptual structure is widely accepted. For example, the syntax of the Japanese language requires that every utterance convey the relative social status of the speaker and the listener, reflecting the structural positioning central to this society. As the potential impacts listed above suggest, hypermedia promotes conceptualizing and expressing more complex ideas than linear media do, thereby creating the potential for a richer, more elaborate social structure.

CONCLUSION

The next generation of information technologies could potentiate history's first "knowledge medium": humanity's conscious mechanism to tailor its cognitive evolution (Stefik, 1986). For example, biologist Richard Dawkins (1976) suggests that ideas (he calls them "memes") are like genes. At any particular moment, an individual or organization has a certain cognitive ecology of ideas—a meme pool. As the external environment changes and new information is added, "survival of the fittest" alters the balance of different species (types of ideas) in the ecology—memetic drift. New ideas are memetic mutations; some survive and prosper, replacing old ideas—memetic displacement. A creative person or institution may deliberately manipulate this cognitive ecology—recombinant memes.

If this vision is accurate, over the next generation civilization may be profoundly shaped by two types of scientific advances: genetic and memetic manipulation. Hypermedia is a fundamental memetic mutation in the dominant strain of linear media. As with many mutations, its viability and ecological niche are uncertain. Problems of user disorientation, cognitive overhead, front-end investment, and collective communications dysfunctions could swamp the value of nonlinearity. However, if hypermedia's capabilities can be expanded toward those of human memory and if development focuses on knowledge representation and knowledge construction, this new medium could amplify our abilities to think and to communicate.

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