HYPERMEDIA DESIGN

Brian R Gaines & Joan N Vickers

Knowledge Science Institute & Neuro-Motor Laboratory
University of Calgary, Alberta, Canada T2N 1N4

ABSTRACT

The essential, expected and desirable features of hypermedia systems are analyzed in order to give a basis for system specification, design and evaluation, and to avoid the trivialization of the term hypermedia through its loose application. Examples are given of knowledge-based hypermedium systems from our own developmental experience, and specific techniques for improving usability and orientability, and overcoming problems of mode-free operation, are described.

HYPERMEDIA SYSTEMS

Advances in technology have made hypermedia systems feasible and they are attracting widespread interest (Nelson 1980, Young 1986, Gassée 1987). However, the features of hypermedia systems are not well defined, and there are dangers that systems will not fulfil expectations and that the term will become over-used and lose its meaning. In particular, although the flexibility in presentation and access of hypermedia systems is often contrasted with the rigid sequentiality of books, there are very few examples of extensive material which is available in both book and hypermedia form. This paper is based on experience in designing, implementing and applying a series of books and a range of hypermedia systems for sports coaching, each based on overt and detailed expression of the knowledge structures underlying coaching for specific sports. The essential features of hypermedia systems are abstracted and related to developments in conventional media and information technology. Specific guidelines for hypermedia design are developed relating to the functionality and user interface, and illustrated through our own experience.

The Concept of a HyperMedium

The concept of a hypermedium is very open and systems are being developed for a diversity of applications, from simple hypertext systems such as Learning Tool (Kozma & Roekel 1986) and Guide (Owl 1986), through electronic books (Weyer 1982) and encyclopedias (Weyer & Borning 1985), through programmable hypergraphic systems such as NoteCards (Halasz, Moran & Trigg 1987) and its extensions (VanLehn 1985, Sharp & Gaines 1987), through complex, multi-media systems for literary studies (Yankelovich, Landow & Cody 1987) to knowledge-based, multi-media systems for expert system development (Neuron 1986), computer-integrated manufacturing (Gaines 1986a) and sports coaching (Vickers 1987, Vickers & Kingston 1987).

The hypermedium concept is significant in capturing the computer-supported, open-ended access to a diversity of media that offers many possibilities for creative thinking, problem solving and networking by individuals and dispersed groups. It provides a basis for the integration of the very wide variety of resources offered by information technology within a coherent but non-restrictive framework. Data-processing, simulation, information retrieval, text processing, presentation graphics, databases, knowledge bases, expert systems, knowledge acquisition, and so on, may all be regarded in a significant sense as particular aspects of hypermedia systems.

However, the essential openness and generality of hypermedia should not lead to vagueness in the concept or system design In our developments of knowledge-based hypermedia systems we have found it necessary to develop a vocabulary to describe and design various features of these systems, and have also been involved in extensive discussions of what are the essential features of hypermedia. Many general questions have also arisen such as: what essential role does information technology play in hypermedia; what differentiates hypermedia from conventional information technology; what differentiates hypermedia from conventional media?

At the root of the terms, hypermedium and hypermedia, is the notion of a medium that goes beyond existing, pre-1980s, standard media, that is of new and advanced forms of intermediate systems mediating between people and their experience of the world, including other people. Hypermedia are often defined in terms of the technologies involved, such as computers and videodiscs, but these are local to our era and

continually changing. Any definition must also take into account the intentions of the designers and users of such systems—to bring people into effective communication with sources of knowledge.

General Definition of Hypermedia

The following definition captures both the intentions and the technology: 'A hypermedia system is one that uses the most advanced technology practically available to facilitate those significant activities which result from increasing the effectiveness of interaction between people and materials relating to knowledge.' This is intended to be as timeless as possible; to subsume the wide variety of activities possible, such as problem-solving and creative thinking; and to leave open the question of what are materials relating to knowledge.

Once it would was meaningful to regard books as an innovative hypermedium, and later radio and television could have been similarly regarded. Computing systems, knowledge bases and videodiscs now exemplify the 'advanced technology' which can facilitate the 'significant activities' of education, training, decision-making, etc.

This definition still allows for various interpretations, and Figure 1 attempts to capture the key features of various concepts of hypermedia. Four major areas are involved: *human society*, particularly its knowledge processes; *instrumentation and control technology*, particularly transducers that capture audio-visual events in the world; *information technology*, particularly databases and information retrieval; and *media*, ranging from basic drawing materials through to videodiscs. The *strict hypermedia* definition sees hypermedia as integrating some components of information technology and modern graphic and videodisc media. The growing *hypermedia* concept is more general, seeing them as using information technology to extend all past media. The *generalized hypermedia* definition sees them as *knowledge support systems* (Gaines & Shaw 1987) that integrate existing human knowledge transfer processes with information technology, instrumentation and control technology, and the full range of media.

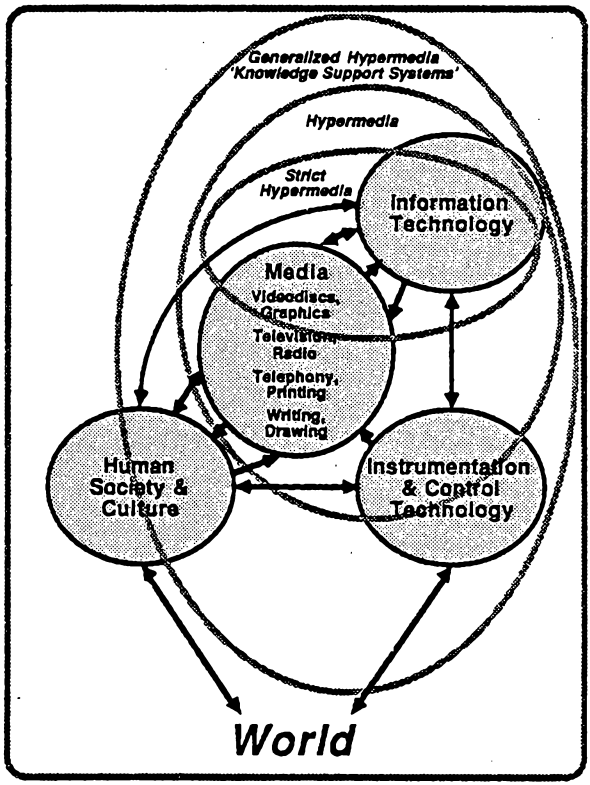

Fig.1 Features of various concepts of hypermedia

Technologies Within Hypermedia Systems

Generalized hypermedia systems can include conventional media as components and can also include non-mediated human activity and non-human activity. There are situations in interacting with a hypermedium system where it may be appropriate for the system to suggest to the users that they undertake activities quite apart from the system, possibly reporting back on the completion or consequences of the activity, for example, in sports coaching. There are also situations where it may be appropriate for the system itself to interact directly with the world rather than the user, for example, in process control.

There is a spectrum of components from those remote from the human-interactive and computer-comprehended aspects of hypermedia to the diversity of peripheral ways of transmitting knowledge which may have to be included in a hypermedia system to achieve its overall functionality:

non-human activity, e.g. process control, robotics, computer communication;
human activity not monitored by the computer, e.g. reading, walking
computer-monitored human activity, e.g. typing, gesture, speech
computer-controlled activity, e.g. videodisc display
computer-communicated activity, e.g. pre-stored speech, graphic and text display
computer-generated activity, e.g. computed speech, graphic and text display

Distinctions may also be made about computer-generated activity in terms of the sophistication of the underlying algorithms, for example, that it is formula-based or knowledge-based.

Terminology for Hypermedia Systems

Within hypermedia technology, some important distinctions may be made: between the hypermedium as a general carrier of information; a form of system using that hypermedium; a particular instance of such a system; and the the material that particular system carries. We use the terms: hypermedium shell, or *hypershell*, for a general system capable of carrying material in a particular hypermedium; hypermedium system, or *hypersystem*, for a particular instance of such a system loaded with material; and hypermedium base, or *hyperbase*, for the totality of material carried by a particular system. These neologisms are necessary to describe the structure and contents of hypermedia systems, and correspond to *expert system shell*, *data base*, *knowledge base*, and so on, linking with past referents. They remind us of the novelty and generality of the hypermedia concept which subsumes many aspects of previous media and information technology, but goes beyond them in essentially new features that cannot be subsumed by past concepts.

Two other important concepts in hypermedia are the linkage structure embedded in the material and the paths through the material generated by a user following parts of the linkage structure. We use the term *gateway* for a link within material to other material, and the term *perspective* for the viewpoint into the material that is built up through access to it. These have obvious spatial analogs and correspond to important features of hypermedia, that linkages are embedded in the material and that users build up new viewpoints to the material through their modes of access to it.

Relation to Knowledge Bases

The emphasis in the definitions above on access to knowledge raises the question of the relationship of hypermedia to knowledge bases (Brodie & Mylopoulos 1986). There is an interesting apposition between the two in that hypermedia research has focused on the anarchical nature of much knowledge in that it is unstructured and non-algorithmic, where knowledge base research has focused on the ordered nature of some knowledge in that it is well-structured and computer-processible. The term 'knowledge' has come to be used in a very narrow sense in the computing science literature, as 'those aspects of human knowledge that can be formally represented and processed.' This is a major restriction of the usual meaning of knowledge as 'acquaintance with ascertained truths facts or principles' (Oxford English Dictionary). The philosophical definition of knowledge as 'more than opinion, less than truth' (Runes 1972) captures the colloquial sense and is a useful concept for system development.

The problem is that much human knowledge is implicit in action and not formally represented and processed, possibly not formally representable and processable (Nisbett & Wilson 1977, Gaines 1986b, 1987b). Hypermedia go beyond knowledge bases in not requiring that the information system be able to represent and process the knowledge encoded in the media used. They subsume knowledge bases but extend knowledge representation to include any media whereby human knowledge can be transferred even if there is no means for analyzing that knowledge or its transfer. For example, a film of a skilled person performing a task which enables another person to perform that task better contains knowledge which can be accessed and transferred through a hypermedia system (Vickers & Kingston 1987).

HYPERMEDIA FUNCTIONALITY

As a technology hypermedia are defined by their *functionality*, the technical capabilities that they offer. It is useful to distinguish those aspects of functionality that are: *essential* in that systems without them would not be regarded as hypermedia; *expected* in that systems without them would be regarded as limited examples of hypermedia; and *desirable* in that systems with them would be regarded as good examples of hypermedia.

Essential Functionality

The essential features of hypermedia come from the intention of bringing people into effective communication with sources of knowledge through as direct as possible access to the hyperbase.

Integration: An essential feature of a hypermedium is that the medium itself carries gateways linking materials in the medium. Standard media require external indexes or directories to carry such linkage information. In books, footnotes, sidenotes, literature citations and explicit references may be used to approximate such gateways.

Freedom: An essential feature of a hypermedium is the freedom to browse through the material along paths which are not predetermined, or determined by the system in response to user answers to its questions. A hypermedium is as *mode-free* as possible within a particular context and across contexts. Note that this freedom may sometimes conflict with usability, but this should be overcome through guidance not restriction. A book gives complete freedom to browse.

Flexibility: An essential feature of a hypermedium is its flexibility in giving multiple perspectives upon the same data and in allowing new perspectives to be established which were not built in to the original hyperbase. Note that new perspectives will often be generated as the side-effect of action, by the user and by the system, such as search activity. There is an analogy to the way in which a traveller may come upon a significant but unexpected viewpoint by virtue of his attempt to get from one place to another rather than by specifically intending to find, or mentally create, that viewpoint as might a skilled artist. With books, perspectives are either inbuilt and fixed or have to be established using additional media such as pencil and paper. Multiple perspective building is common across books since many books contain, or are primarily, perspectives on other books.

Usability: An essential feature of a hypermedium is that the functionality provided is made as usable as possible. The functionality/usability distinction is a critical one in the human factors of computing (Shackel 1983). Ease of access to media has always been important—writing materials, books, phonographs, radio and television are extremely usable—and the incorporation of information technology should simplify access, not make it more complex.

Expected Functionality

The expected features of hypermedia are logical extensions of the intentions, and experience, of bringing people into effective communication with sources of knowledge.

Diversity: An expected feature of a hypermedium is its integration of diverse audio and visual media. Hypertext and hypergraphic systems without audio or videodisc capabilities can be examples of hypermedia, but many of the important design problems do not manifest until a diversity of media are considered. Books are often packaged with material on different media such as audio and video cassettes, particularly those concerned with training.

Extensibility: An expected feature of a hypermedium is its extensibility in allowing new material and new perspectives to be added to the hyperbase. Some components of current hypermedia systems, such as videodiscs, are not extensible at this stage of the technology. This is a significant limitation to their role in hypermedia and to the utility of particular hypermedium systems. A major design objective for a hypermedium system is to overcome this limitation, in the short term by providing remedial extensibility through the storage media of the computer, and in the long term by developing extensibility in components such as videodiscs. Some teaching books attempt extensibility by leaving blank pages for student notes, but books are generally not extensible.

Sociality: An expected feature of a hypermedium is its sociality in allowing multiple users to access and update a hyperbase. Nelson, in particular, has emphasized the communicative, social role of hypermedia (Nelson 1980). The designers have noted that, "One of the biggest limitations of NoteCards is the lack of support for collaborative work" (Halasz, Moran & Trigg 1987), and suggested extensions remedying this (Trigg, Suchman & Halasz 1986). Books allow for access sociality through widespread distribution of copies.

Spatiality: Existing hypermedia may be seen as making strong use of a spatial metaphor. Information is laid out in space and linkages are seen as paths accessed through gateways. This is so natural that it may not be seen as a metaphor, that is, knowledge in general has no intrinsic spatial representation, but we are so used to its presentation in books and through diagrams that we are conditioned to think of much knowledge in spatial terms. Other metaphors are possible and commonly used in our language: such as time, force, and

human aggression (Lakoff and Johnson 1980). It would be interesting to see how these could enter into hypermedia. Smith (1977) suggested in his design for Pygmalion that led to the Xerox Star (Smith, Irby, Kimball, Verplank, & Harslem 1983) and Apple Macintosh user interface designs that visual thinking was at the heart of creativity. A high proportion of the human population uses the spatial metaphor and visual thinking for problem solving. However, there are many other bases for creative thinking and these should be considered in the development of hypermedia. Books use spatial metaphors not only in diagrams but also in the typography of two-dimensional page layout. They also impose an often unwanted temporal metaphor in the serial progression of pages.

Desirable Functionality

The desirable features of hypermedia stem from the opportunities offered by hypermedia to subsume, and give effective end-user access to, many information technologies.

Programmability: A hypermedium shell provides an extraordinarily powerful end-user interface to a computing system, providing for intelligent help and presentation facilities to any depth required. To make use of this potential the shell must provide programming hooks into other programmed systems for dataprocessing, simulation, databases, and so on. A major limitation of simple hypergraphic systems is that they are not programmable in this way. NoteCards provides programming capabilities but only within the Lisp environment. Books lack programmability.

Orientability: One of the defects of current hypergraphic systems is that it is easy for the user to become disorientated, losing track of where he is in the hyperbase, along what path he has arrived there, and what further territory is open to exploration (Conklin 1986). Overview facilities need be provided to map the hyperbase and show the user's path through it. Indexes and flow-charts attempt to aid orientability in books, and, for large works such as encyclopedias, great efforts may be made to provide access aids, for example the *Propaedia* of Encyclopaedia Britannica.

Guidability: It has already been noted that the requirement for *freedom* may conflict with that for *usability*. A mode-free system that makes every possible choice available to a user may be difficult to use because it places an excessive decision-making burden on the user. The hypersystem should make provision for a range of different forms of guidance which do not restrict choice but indicate the basis of choice, the most likely choices, and the reasons for these. Some of this can be embedded within the material which provides a local context, but other guidance is essentially global and needs to link with the orientability functionality, for example, highlighted suggestions for further exploration on the overview map of the hyperbase. Again, attempts may be made to provide access guidance for books, but they are restricted by the need to have the entire range of possibilities visibly present.

Recreatability: To optimize their perspectives users may take advantage of the freedom to browse through the system looking for relevant data. However, it is possible that they will regard the finishing perspective as less desirable than some earlier one, and it is important that they can checkpoint a perspective at any time and recreate it easily. Page markers are a simple aid to recreatability with books.

Attributability: A hyperbase contains a diversity of information of various origins, dates, and reliability. It is desirable that a user be able to check the attribution of material. Technically, this can be just another gateway, but it requires proper management of accessions to the hyperbase. In many book applications proper attribution of sources is regarded as very important.

Communicability: It is never clear to either user or system wether material presented to a user has been understood. At times this can be very important, and it is desirable that explicit gateways are established to material which checks the understanding of other material. In educational applications, hypermerdia can provide an open-textured, rich, supportive environment corresponding to the modern *ecological* paradigm (Gaines 1987a). However, it is important to make provision for both system and student to ascertain the extent to which knowledge has been communicated. Pask (1976, 1980) in his *conversation theory* has discussed the significance and difficulty of establishing an "agreement over an understanding," and developed techniques very applicable to hypermedia. The explanation facilities of expert systems may be seen as an attempt to provide the rudiments of this type of communicability (Hughes 1986, Swartout 1986), but are currently restricted to output of more detailed computer reasoning rather than input and validation of the user's understanding. Educational books, in particular, attempt to provide exercises and commentaries that aid the students in checking their understanding.

Designing Hypermedia Shells

The list of functionality required, expected and desired in hypermedia systems may seem extensive but there is nothing within it that is not already available, or readily built, in commercially available computing systems. It is straightforward to design and implement systems with the functionality specified above if these design requirements are specified at the outset. A hypermedium shell is a logical extension of existing human-computer interaction shells on workstations, intelligent terminals and personal computers. All of the functionality specified is highly desirable to users of modern advanced computer systems where even simple personal computers may offer extremely complex facilities. Much of the functionality is already available through window/mouse graphic interfaces but not necessarily incorporated appropriately in applications.

The IRIS INTERMEDIA system at Brown University (Yankelovich 1986) is an outstanding example of the clean architecture and powerful extensible functionality that can be achieved using modern hardware and software technology, particularly an object-oriented design (Garrett & Smith 1986, Haan, Drucker & Yankelovich 1986, Meyrowitz 1986). The weaknesses of most existing hypergraphic systems stem largely from the operating environments in which they have been developed. Notecards lack of sociality, and its programmability only in Lisp, are due to limitations of the Xerox Lisp machine environment. The lack of a multi-tasking operating system on the Apple Macintosh has limited the programmability of products such as Guide and Learning Tools. Workstations with programmable window systems such as X-Windows integrated with multi-tasking operating systems having good inter-process communications such as Unix can readily provide most of the functionality specified. Recent developments such as the open architecture version of the object-orientated expert system shell, Nexpert (Rappaport 1986) make possible knowledge-based orientability, guidability, and communicability. The multiple screen capability of the Mac II makes it feasible to use a level IV interactive videodisc (Lambert & Sallis 1987) driving a fully-integrated display.

SOME HYPERMEDIA SHELLS AND SYSTEMS

Whereas many hypermedia systems are designed primarily for passive information retrieval from large multi-media hyperbases, we have also been concerned to integrate knowledge elicitation, expert systems and intelligent computer-assisted learning into hypermedia systems.

Knowledge Support System Zero

KSS0 (Knowledge Support System Zero) is a hypermedium shell designed to support the knowledge acquisition and transfer processes involved in the rapid prototyping of expert systems (Gaines 1987b). It operates on networked Macintosh computers and videodisc players, integrating a wide range of knowledge acquisition tools within a hypergraphic framework. In particular, the attribute elicitation techniques used by KSS0 to elicit the conceptual structures of experts are very natural ways of determining linkage structures for hypermedia. An attribute is one pole of a bipolar distinction applying to a class of objects and particular attributes provide natural links in a hyperbase, for example *refutes—supports* (Trigg 1983). The videodisc is used to illustrate entities, attributes and case histories in the domain. The knowledge elicitation and analysis modules within KSS0 have been incorporated in other hypermedia systems as tools to elicit user models, generate advice, and indicate appropriate individualized perspectives on the hyperbase.

InSport

InSport is a hypermedium system designed to aid those wishing to improve their involvement with sporting activities. It combines five sub-systems: a videodisc containing information on sports particularly relevant to a novice; an iconic interface to the videodisc representing spatially the knowledge structures underlying sporting activities; a personal knowledge elicitation system interviewing users on their perceived status in sports relative to various relations and role models; a cluster analysis mapping the user's relation to the role models; and a knowledge-based advisor highlighting a perspective within the iconic interface to suggest useful material for the user to review from the videodisc. Figure 2 shows a FOCUS cluster analysis (Shaw 1980) of entity-attribute relationships generated by KSS0 used in *InSport* to provide feedback and advice to the user. For example, Jane can see that she views herself and her brother as clustered with elite athletes, her father with average athletes, and her mother with novices. The uniform clustering of males and females shows that she is making no sexist distinctions. Her high estimates of her aerobic endurance and anaerobic power lead to training advice different from that if they had been low. If she had not understood these technical terms she could have asked for explanations through material on the videodisc. *InSport* operates on a Macintosh computer and videodisc player to generate a highly supportive environment for those desiring to participate fully in sporting activities but finding perceived, or actual, impediments to doing so.

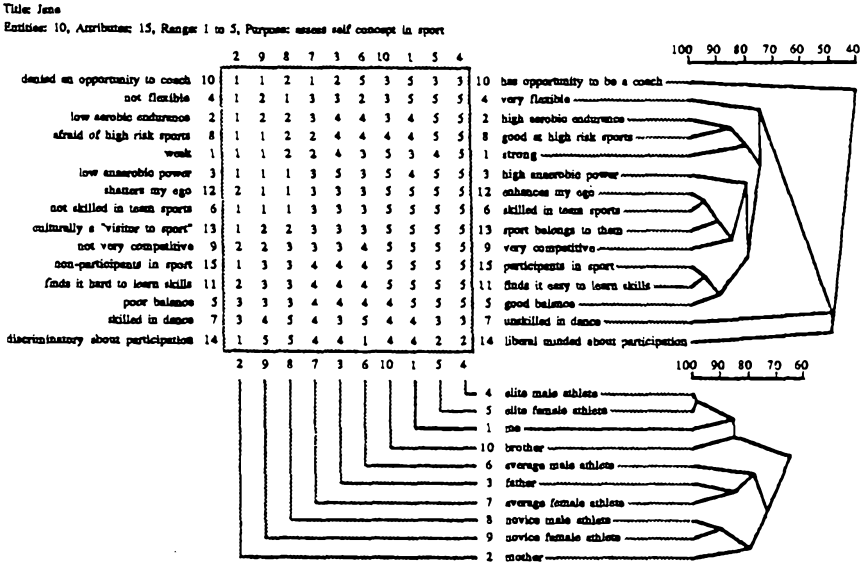

Fig.2 Cluster analysis used to give advice and feedback from KSS0 in *InSport*

Knowledge-Based Coach System

KBCS (Knowledge-Based Coach System) is a hypermedium system designed to aid coaches in the development of their skills and those of their players and teams. It subsumes the technology used in InSport but places greater demands on it because of the much greater range of detailed knowledge structures required in a professional context. It is based on research concerned with the modeling the cognitive processes of athletes through monitoring their eye movements when watching the performance of other athletes (Vickers 1986a, in press a). Previous to this the knowledge structures of master coaches and teachers were developed using other techniques (Vickers 1983), content analyses of sport specific technical and film sources, followed by the development of hierarchies in consultation with the expert coach or teacher. The development of knowledge structures leads to new teaching techniques based on structured knowledge acquisition. Structures have been developed for a wide range of individual sports, team sports, dance activities and outdoor pursuits, including archery, backpacking, badminton, basket ball, bowling, jazz dance, golf, gymnastics, ice hockey, racquet ball, softball, swimming tennis, and volleyball.

User Interface Problems

In all the systems developed a number of common problems have arisen with the user interface, particularly user disorientation and problems of lack of modality. A very open-ended, multi-functional, multi-media, multi-window, multi-activity system may seem very attractive in the functionality, flexibility and freedom it offers the user, but it can feel like attempting to drive a supersonic fighter with experience of domestic automobiles! The following sections describes our approaches to overcoming these problems, first, in the hyperbase, through the use of detailed knowledge structures as the basis of overall system design, and second in the hypershell, through the modular design adopted for the more complex systems.

HYPERMEDIA SHELL DESIGN

Usability and orientability requirements coupled with the problems of embedding gateways in videodisc material (we are currently using non-interactive level 3 systems under computer control without integrated graphics) have placed special emphasis on designing effective maps to the hyperbase. Figure 3 shows two approaches that we have found effective and mutually compatible in giving a user understanding of, and control over, access to hypergraphic and videodisc sub-systems, and the building of perspectives on both.

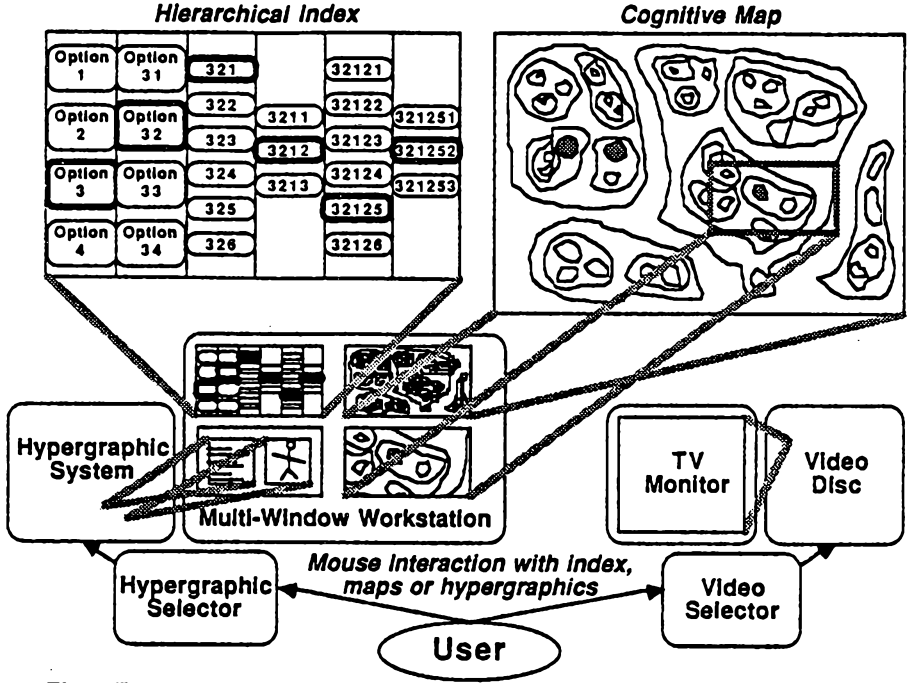

Fig.3 Hypermedia access through a hierarchical index and a cognitive map

In the *hierarchical index* each level is represented by a set of buttons in columns from left to right. Initially only the leftmost buttons are visible, corresponding to the four knowledge domains at the top of the hierarchy. Clicking on one of these buttons selects the relevant domain and makes visible a second set of buttons, specific to the first-level selection, for second-level selection. By successive clicks the user can descend to the lowest levels of the hierarchy and select a specific topic. Double clicking on any button gives access to the hypergraphic system or video disc as appropriate and causes content material to be displayed. The buttons in Figure 3 are numbered to show the selection sequence but normally have meaningful textual labels.

This hierarchical index gives rapid access to the hyperbase and has the advantage that a large amount of material can be accessed through a small window. It goes some way to orientability by showing the path taken through the hyperbase. However, it cannot show: the relation of the path to alternatives; which material is recommended for access; which material has already been accessed; and what relations exist between materials. The *cognitive map* is a second representation of the knowledge structure which gives these additional features at the expense of compactness. The map shown represents the hierarchical structure through enclosed knowledge islands which are again clickable and double-clickable for selection and hyperbase access. Multiple windows may be opened on the map and zoomed as required, usually one showing the overall map on a smale scale and others showing specific areas of interest in greater detail.

The map is marked to indicate material recommended for access and material already accessed. It can be used to display a variety of forms of auxiliary information through dynamic overlays, for example relations between one topic and other topics on the map. This allows for multiple hierarchies corresponding to different relations in the same hyperbase, for example, the declarative structure of a sport is shown as an *instance-of* hierarchy whereas the components of a tactic in terms of individual skills is a *part-of* hierarchy. Such maps can represent non-hierarchical and mixed relations equally well. The index and the map are mutually compatible systems which complement one another in operation and can be used together since

they mutually update one another, for example, the index provides a labeled access path when a low level topic is selected in the map.

CONCLUSIONS

Hypermedia may be seen as a very significant stage in the evolution of media in general, and in that of information technology as a medium for human knowledge in particular. The new possibilities for interactive communication with passive and active stores of knowledge provided by new generation computing systems create opportunities for further enhancement of human intelligent activity through new media. The hypermedia concept provides a basis for the integration of the very wide variety of resources offered by information technology within a coherent but non-restrictive framework. Data-processing, simulation, information retrieval, text processing, presentation graphics, databases, knowledge bases, expert systems, knowledge acquisition, and so on, may all be regarded in a significant sense as particular aspects of hypermedia systems.

This paper has analyzed the essential, expected and desirable features of hypermedia systems in order to give a basis for system specification, design and evaluation, and to attempt to avoid the trivialization of the term hypermedia through its loose application. Examples have been given of knowledge-based hypermedium systems from our own developmental experience, and specific techniques for improving usability and orientability, and overcoming problems of mode-free operation, have been described.

ACKNOWLEDGEMENTS

Financial assistance for this work has been made available by the Natural Sciences and Engineering Research Council of Canada, the Social Sciences and Humanities Research Council of Canada and Employment and Immigration Canada. We are grateful to our colleagues Eric Gullichsen for stimulating discussions relating to hypertext systems, Larry Katz for access to his research on interactive videodisc applications, Alain Rappaport for access to Neuron Data's developments of knowledge-based hypermedia, Kathleen Robertson for access to her notes on Jean-Louis Gassée's presentation and Mildred Shaw for access to her research on knowledge acquisition systems. The detailed knowledge structures for ice hockey and badminton have been developed in collaboration with George Kingston and David Brecht respectively. David Johnson jointly designed the hyperbase hierarchical index.

REFERENCES

Brodie, M.L. & Mylopoulos, J. (Eds) (1986). **On Knowledge Base Management Systems.** New York: Springer Verlag.

Conklin, J. (1986). A survey of hypertext. MCC Technical Report STP-356-86. Austin:Microelectronics & Computer Technology Corporation (October).

Gaines, B.R. (1986a). The design of expert systems for planning flexible manufacturing. **Proceedings of Japan-USA Symposium on Flexible Automation.** 761-768. Osaka (July).

Gaines, B.R. (1986b). Foundations of knowledge engineering. Bramer, M.A., Ed. **Research and Development in Expert Systems III.** pp.13-24. Cambridge: University Press.

Gaines, B.R. (1987a). From teaching machines to knowledge-based systems: changing paradigms for CAL. Norrie, D., Ed. **Learning in Future Education: Proceedings of International Conference on Computer Assisted Learning in Post-Secondary Education.** pp.17-26. University of Calgary.

Gaines, B.R. (1987b). Rapid prototyping for expert systems. Oliff, M., Ed. **Proceedings of International Conference on Expert Systems and the Leading Edge in Production Planning and Control.** pp.213-241. University of South Carolina.

Gaines, B.R. & Sharp, M. (1987) A knowledge acquisition extension to Notecards. **Proceedings of First European Workshop on Knowledge Acquisition for Knowledge-Based Systems.** UK: Department of Computer Science, Reading University (September).

Gaines, B.R. & Shaw, M.L.G. (1987). Knowledge support systems. **ACM MCC-University Research Symposium.** Austin, Texas: MCC. pp.47-66.

Garrett, L.N. & Smith, K.E. (1986). Building a timeline editor from prefab parts: the architecture of an object-oriented application. **Proceedings of OOPLA'86,** 1-16.

Gassée, J.L. (1987). Machine vs computer. **78th Conference of Special Libraries Association,** Anaheim, California (June).

Haan, B.J., Drucker, S.M. & Yankelovich, N. (1986). An object-oriented approach to developing consistent integrated applications. **IRIS Technical Report 86-3,** 1-11. Providence, Rhode Island: Brown University.

Halasz, F.G., Moran, T.P. & Trigg, R.H. (1987). Notecards in a nutshell. Carroll, J.M. & Tanner, P.P. (Eds), **Proceedings CHI+GI 1987**. New York: ACM. pp.45-52 (April).

Hughes, S. (1986). Question classification in rule-based systems. Bramer, M.A., Ed. **Research and Development in Expert Systems III**. pp.123-131. Cambridge: University Press.

Kozma, R.B. & Roekel, J.V. (1986). **Learning Tool Manual**. Ann Arbor, Michigan: Arborworks Inc.

Lakoff, G. & Johnson, M. (1980). **Metaphors We Live By**. Chicago: University of Chicago Press.

Lambert, S. & Sallis, J. (Eds) (1987). **CD-I and Interactive Videodisc Technology**. Indianapolis, Indiana: Howard Sams.

Meyrowitz, N. (1986). Intermedia: the architecture and construction of an object-oriented hypermedia system and applications framework. **Proceedings of OOPLA'86**, 1-23.

Nelson, T. (1980). Interactive systems and the design of virtuality. **Creative Computing, 6**(11), 56-62 (November).

Neuron (1986). **Reference Manuals for aiScreen and aiVision**. Palo Alto, California: Neuron Data.

Nisbett, R.E. & Wilson, T.D.. (1977). Telling more than we can know: verbal reports on mental processes. **Psychological Review 84**, 231-259.

Owl (1986). **Guide: Hypertext for the Macintosh**. Bellevue, Washington: OWL International Inc.

Pask, G. (1976). **Conversation Theory**. Amsterdam: Elsevier.

Pask, G. (1980). Developments in conversation theory—Part I. **International Journal of Man-Machine Studies**, 13(4), 357-411 (November).

Rappaport (1986). Task analysis in intelligent systems design. **WESTEX-86, IEEE 86CH2332-5**. 61-67. Anaheim (June).

Runes, D.D. (1972). **Dictionary of Philosophy**. London: Peter Owen.

Shackel, B. (1983). Usability: its meaning and evaluation in human-computer systems. **Tutorial 9 at CHI'83**. Boston: ACM SIGCHI.

Shaw, M.L.G. (1980). **On Becoming a Personal Scientist**. London: Academic Press.

Smith, D.C. (1977). **Pygmalion**. Basel: Birkhauser.

Smith, D.C., Irby, C., Kimball, R., Verplank, B. & Harslem, E. (1983). Designing the Star user interface. Degano, P. & Sandewall, E., Eds. **Integrated Interactive Computing Systems**. pp. 297-313. Amsterdam: North-Holland.

Swartout, W. R. (1986). Knowledge needed for expert system explanation. **Future Computing Systems**, 1(2), 99-114.

Trigg, R. (1983). A Network-based Approach to Text Handling for the Online Scientific Community. PhD Thesis, University of Maryland (University Microfilms 8429934).

Trigg, R., Suchman, L. & Halasz, F. (1986). Supporting collaboration in NoteCards. **Proceedings of Conference on Computer Supported Cooperative Work**. Austin, Texas: MCC (December).

VanLehn, K. (1985). Theory reform caused by an argumentation tool. **Xerox PARC Technical Report ISL-11**, 1-15. Palo Alto, California: Xerox Palo Alto Research Center (July).

Vickers, J. N. (1983). The role of expert knowledge structures in an instructional design model for physical education. **Journal of Teaching in Physical Education** 2(3) 17-32.

Vickers, J. N. (1986a). The resequencing task: determining expert-novice differences in the organization of a movement sequence. **Research Quarterly for Exercise and Sport** 57(3) 260-264.

Vickers, J.N. (1987). ActionMark: a software package designed to facilitate the acquisition of complex physical skills. Norrie, D., Ed. **Learning in Future Education: Proceedings of International Conference on Computer Assisted Learning in Post-Secondary Education**. pp.235-237. University of Calgary.

Vickers, J. N. (in press a). Knowledge structures of expert-novice gymnasts. **Journal of Human Movement Science**.

Vickers, J.N. & Kingston, G.E. (1987). Modelling the master coach: building an expert system for coaching. Norrie, D., Ed. **Learning in Future Education: Proceedings of International Conference on Computer Assisted Learning in Post-Secondary Education**. pp.207-212. University of Calgary.

Weyer, S. (1982). The design of a dynamic book for information search. **International Journal of man-Machine Studies** 17(1), 87-107 (July).

Weyer, S.A. & Borning, A.H (1985). A prototype electronic encyclopedia. **ACM Transactions on Office Information Systems** 3(1), 63-88 (January).

Yankelovich, N. (1986). Intermedia: a system for linking multimedia documents. **IRIS Technical Report 86-2**, 1-15. Providence, Rhode Island: Brown University.

Yankelovich, N., Landow, G.P. & Cody, D. (1987). Creating hypermedia materials for English literature students. **SIGCUE Outlook 20**, 1-11.

Young, J.S. (1986). Hypermedia. **MacWorld** 3(3), 116-121 (March).