Design Considerations for Hypermedia Systems

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Hypermedia systems based on personal microcomputers coupled to videodiscs and CD-ROMs offer new opportunities for managing large volumes of information, including text, drawings, photographs, and sound. However, the technical possibilities should not blind us to the design problems of constructing large information systems, and, in particular, making them accessible to human users. This paper analyzes 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 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.

INTRODUCTION—HYPERMEDIA SYSTEMS

The concepts behind hypermedia can be traced back at least to Vannevar Bush's article in 1945 entitled "As We May Think," calling for a major post-war effort in mechanizing the scientific literature and support associative linking:

> The human mind . . . operates by association. Man cannot hope fully to duplicate this mental process artificially, but he certainly ought to be able to learn from it. One cannot hope to equal the speed and flexibility with which the mind follows an associative trail, but it should be possible to beat the mind decisively in regard to the permanence and clarity of the items resurrected from storage. (Bush, 1945)

The technology in Bush's time was not equal to the task, and it was not until 1963 that Bush's vision was regenerated by Douglas Engelbart in a paper on "A Conceptual Framework for the Augmentation of Man's Intellect," in which he

suggests a new stage of evolution characterized by "automated external symbol manipulation" supported by computer technology:

> In this stage, the symbols with which the human presents the concept he is manipulating can be arranged before his eyes, moved, stored, recalled, operated upon according to extremely complex rules—all in response to a minimum amount of information supplied by the human. (Engelbart, 1963)

Ted Nelson is generally credited with coining the terms "hypertext" and "hypermedia" for the richly associative information storage and retrieval systems consistent with Bush's and Engelbart's visions. His *Xanadu* hypertext system design provides for a massive corpus of documents worldwide to be linked associatively in an information network supporting scientific and literary creativity and the associated critical commentary, refereeing, and royalty arrangements:

> The *document,* our fundamental unit, may have windows to any other documents. The evolving corpus is continually expandable without fundamental change. New links and windows may continually add new access pathways to old material. (Nelson, 1980)

Hypermedia extend the concept of richly linked textual material to all forms of material that may be digitally encoded for storage and retrieval through computer-based systems, including images and sound. Figure 1 shows a typical hypermedia configuration, and Figure 1 in the companion paper in this journal (Vickers & Gaines, 1988) shows a photograph of such a system in action. The various subsystems are:

- Hardware System

- microcomputer with at least 1 MB of memory
- graphic display screen with a fairly high resolution for computer text and graphics
- television display screen for videodisc and CD-ROM pictorial output, possibly with the capability to superimpose computer text and graphics
- speakers or headphones for videodisc, CD-ROM, and videodisc audio output
- keyboard for text input
- mouse, and possibly touchscreens on the displays, for pointing and graphic input

- Information System

- magnetic disc for variable data in the hyperbase, text, graphics, and associative links

Figure 1. The Components of a System Supporting Hypermedia

- videodisc for fixed data including movie and still pictures, sound, text, and graphics
- CD-ROM for fixed data including movie and still pictures, sound, text, and graphics

- Software System

- hyperbase index providing an annotated list of everything on the storage media
- hyperbase map providing pictorial access to everything on the storage media
- hyperbase linkage using the index, map, and link structures to navigate the stored material
- perspective generation helping the user to combine material to build new accesses to the stored material
- video selection indexing and control software for the image data stored
- audio selection indexing and control software for the sound data stored

- Communications System

- networks, local and remote, allowing access to other information systems

The videodisc classically held pictorial information and the compact disc read-only memory audio information. However, both are now capable of carrying any digitally encoded data (Lambert & Ropiequet, 1986; Lambert & Sallis, 1987), so that they are becoming increasingly interchangeable in hypermedia applications. The software shown is minimal, and applications that go beyond information storage and retrieval, such as computer-assisted learning and expert systems, require extensive additional modules.

In the 1980s, advances in technology have made hypermedia systems feasible, and they are attracting widespread interest for a variety of applications (Young, 1986; Gassée, 1987). However, the essential features of hypermedia systems are not well defined; there are danger that systems will not fulfil expectations and that the term will become over-used and lose its meaning. A combination of microcomputer, videodisc, CD-ROM, and graphic and aural input–output devices, as shown in Figure 1, may provide an adequate technical foundation for hypermedia system development, but it does not in itself constitute an effective hypermedium system. Most of the problems now lie in the software for information storage, manipulation, and retrieval, particularly in the human–computer interface since the most frequent criticism of hypermedia implementations is that they are too complex and that users get lost among the information and facilities (Conklin, 1986).

The massive success of Bill Atkinson's implementation of HyperCard on the Macintosh (Apple, 1987) is an indication that effective software for hypermedia systems can be developed. It has enabled a new constituency of computer system developers to emerge, able to produce high-quality information systems with

little training or experience in programming. The hypermedia concept is significant in capturing the computer-supported, open-ended access to a diversity of media that offers so many attractive 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 acquisitions, and so on may all be regarded in a significant sense as particular aspects of hypermedia systems.

The concept of hypermedia is very open-ended; a range of systems is 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; Gaines & Sharp, 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). 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?

This paper abstracts, discusses, and illustrates the essential features of hypermedia systems, relating them to developments in conventional media and information technology. It develops specific guidelines for hypermedia design relating to the functionality and user interface, and illustrates these through our own experience.

DEFINITION AND ROLE OF HYPERMEDIA

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 that 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. At one time it would have been meaningful to regard a book as a highly innovative hypermedium system, and at later times radio and television could have been similarly regarded. In our era, computing systems, knowledge bases, and videodiscs exemplify the "advanced technology" that can facilitate the "significant activities" of education, training, decision making, problem solving, and so on.

This definition still allows for various interpretations, and Figure 2 attempts to capture the key features of various concepts of hypermedia. Four major conceptual areas are involved: human society and culture, 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. There is no conflict between these interpretations—they differ only in their strictness and are usually differentiated by context.

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 in which 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 in which 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-

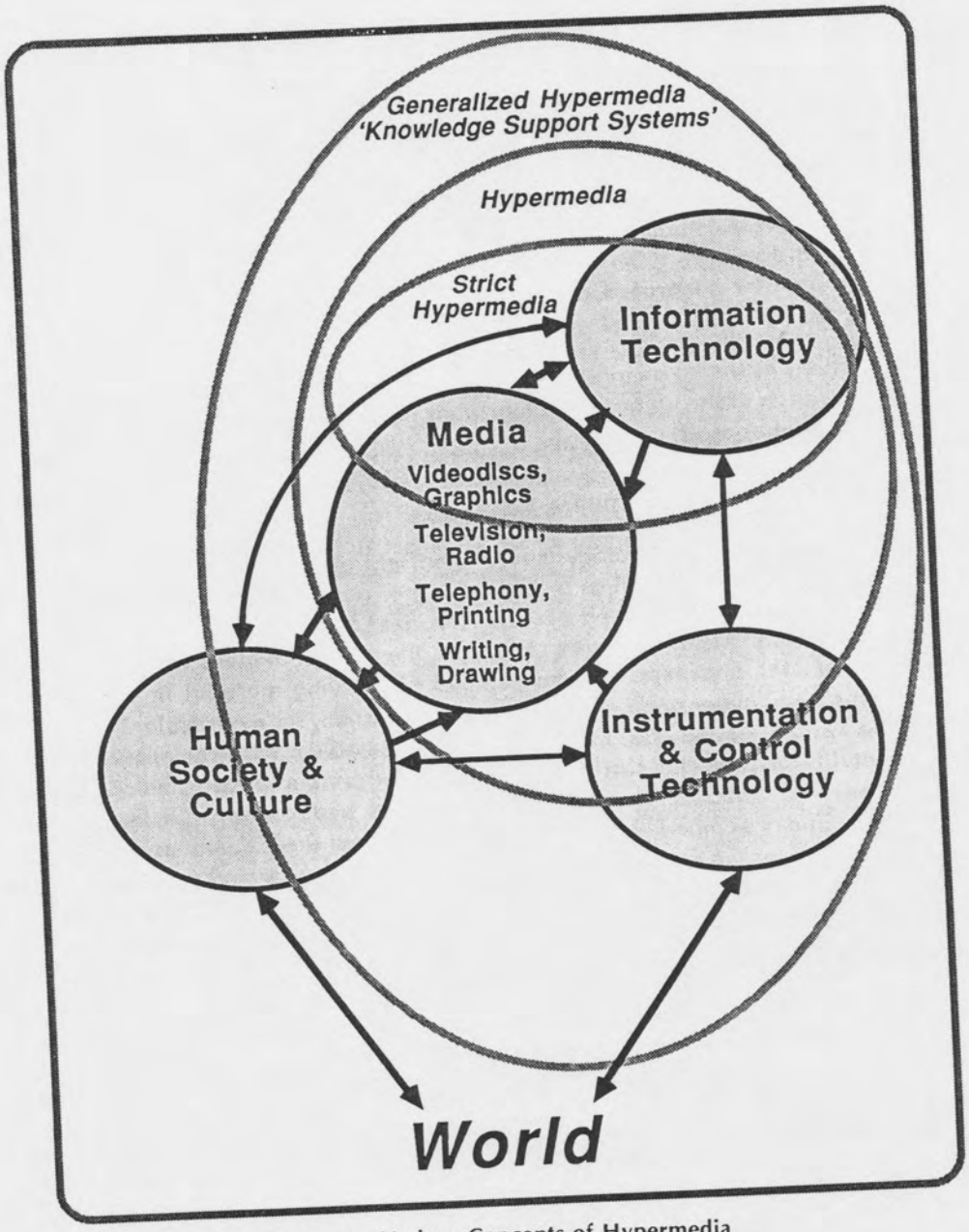

Figure 2. Various Concepts of Hypermedia

interactive and computer-comprehended central aspects of hypermedia to the diversity of peripheral ways of transmitting knowledge that 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 are worth making: 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 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 precisely the structure and contents of hypermedia systems, and are coined on a model of *expert system shell, database, knowledge base,* and so on, so as to link with past referents. They remind us of the novelty and generality of the hypermedia concept that 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, while 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 processible (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 that enables another person to perform that task better contains knowledge that 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 particularly good examples of hypermedia. Figure 3 gives a synopsis of the definitions and terminology above, together with various aspects of hypermedia functionality.

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,

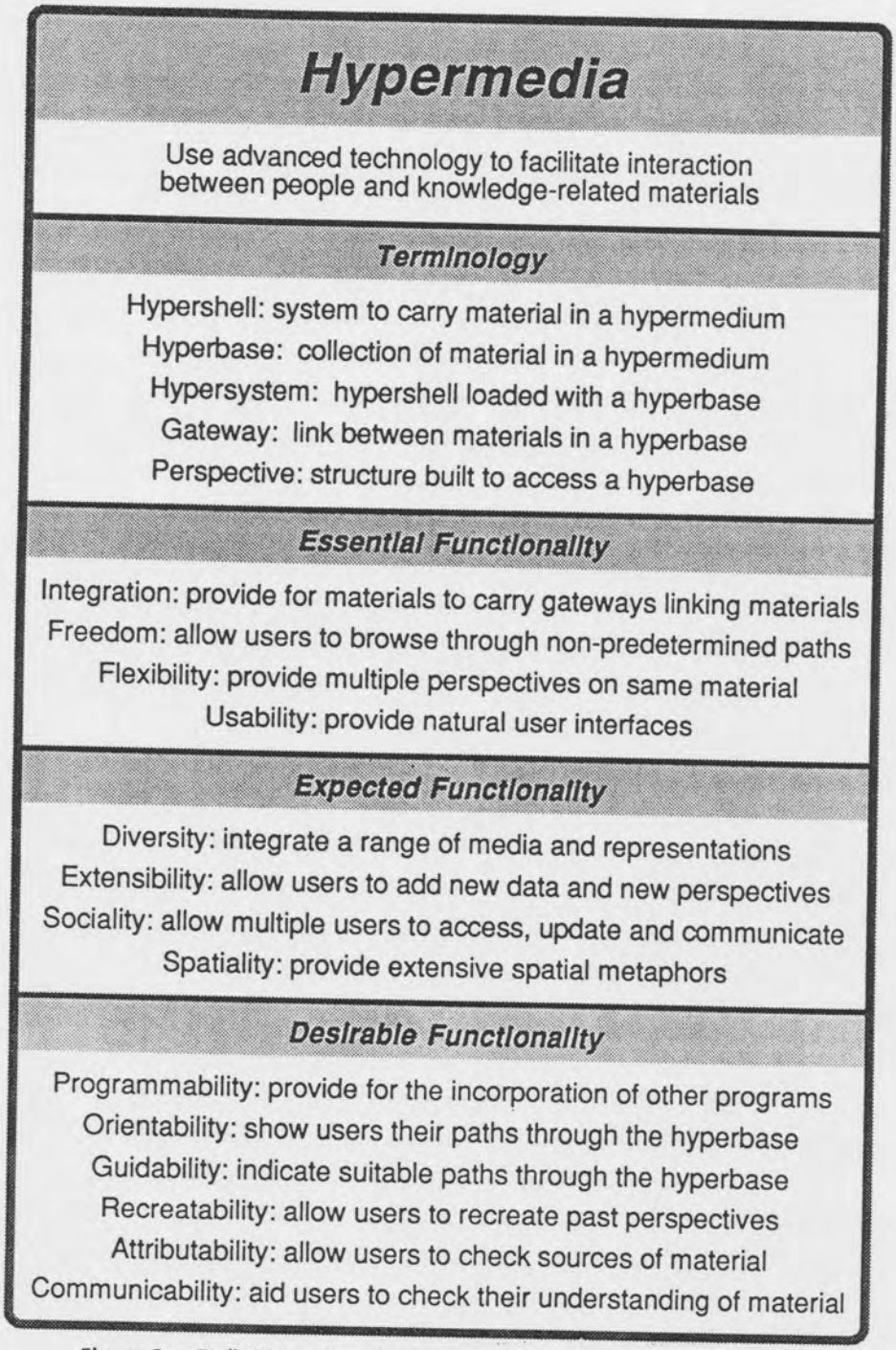

Figure 3. Definitions, Terminology, and Functionality of Hypermedia

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 that 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 through 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 that were not built into 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 the 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 either are 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 & 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 data

processing, 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 disoriented, losing track of where he or she is in the hyperbase, along what path he or she has arrived there, and what further territory is open to exploration (Conklin, 1986). It is desirable that some form of overview facilities be provided to map the hyperbase and show the user's path through it. Indexes and flowcharts 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 that 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 that 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 at 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 whether 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 that checks the understanding of other material. In educational applications, hypermedia 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 has 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 commmunicability (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 in which even simple personal computers may offer extremely complex facilities. Much of the functionality is already available through window/mouse graphic interfaces, but is not necessarily incorporated appropriately in applications.

The 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 multitasking 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), on the MicroVax and Mac II 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 proesses 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).

Figure 4 shows entities being rated on elicited attributes in an interaction with KSS0 in the InSport system. The videodisc is used to illustrate entities, attributes, and case histories in the domain under discussion. 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 subsystems: a videodisc containing information on sports particularly relevant to a novice; an iconic interface to the videodisc spatially representing 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 knowlege-based advisor highlighting a perspective within the iconic interface to suggest useful material for the user to review from the videodisc.

Figure 5 shows a FOCUS (Shaw, 1980) cluster analysis of entity-attribute relationships generated by KSS0 and 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. Once within that material, she can use the hypermedia gateways to browse at will.

InSport operates on a Macintosh computer and videodisc player to generate a highly supportive environment for those desiring to participate fully in sporting

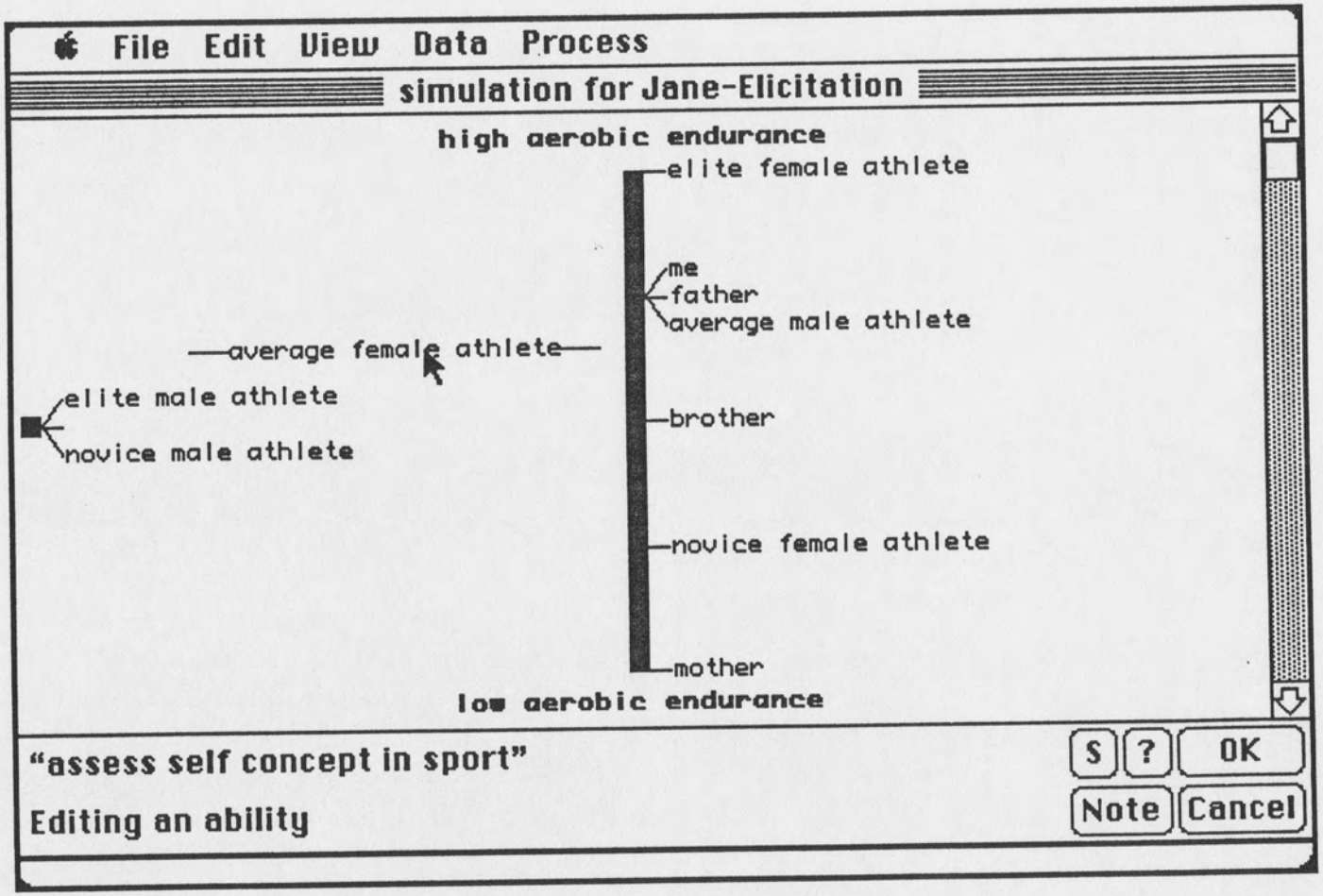

Figure 4. Ratings Etities on Attributes in KSS0

activities but finding perceived, or actual, impediments to doing so. It illustrates how the user interface to hypermedia systems can combine user modeling and conceptually meaningful graphics bypassing a conventional index.

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 modeling the cognitive processes of athletes through monitoring their eye movements when watching the performance of other athletes (Vickers, 1986a, in press). Previous to this the knowledge structures of master coaches and teachers were developed using other techniques (Vickers, 1983)—namely, 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 then 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, basketball, bowling, jazz dance, golf, gymnastics, ice hockey, racquetball, softball, swimming, tennis, and volleyball.

KBCS is described in more detail in a companion paper in this journal (Vickers & Gaines, 1988).

Technology Management System

We have a number of related hypermedia developments, including TMS (Technology Management System, Figure 6), to aid the design and management of flexible manufacturing systems, incorporating a videodisc catalog of robots and machine tools, an expert system advisor, machine grouping optimization, and animated simulation (Gaines, 1986a). Figure 7 shows how each specialist area of manufacturing knowledge is represented as a *knowledge island* that has within it the datasets and procedures specific to that knowledge. Data from external sources trigger processing within an island that eventually results in processed data being passed from one island to another. This in turn triggers further data processing in the other knowledge island, which eventually propagates to other islands. Some islands have external connections that pass conclusions, recommendations for action, out to the external world. Islands are distinguished by the relative homogeneity of the data and processing within them. Connections between them represent data that are relevant to more than one island, but probably relevant in very different ways.

The structure is fully recursive in that islands generally have sub-islands within them and group naturally into areas. This graphic structure is not only

Figure 4. Ratings Etities on Attributes in KSS0

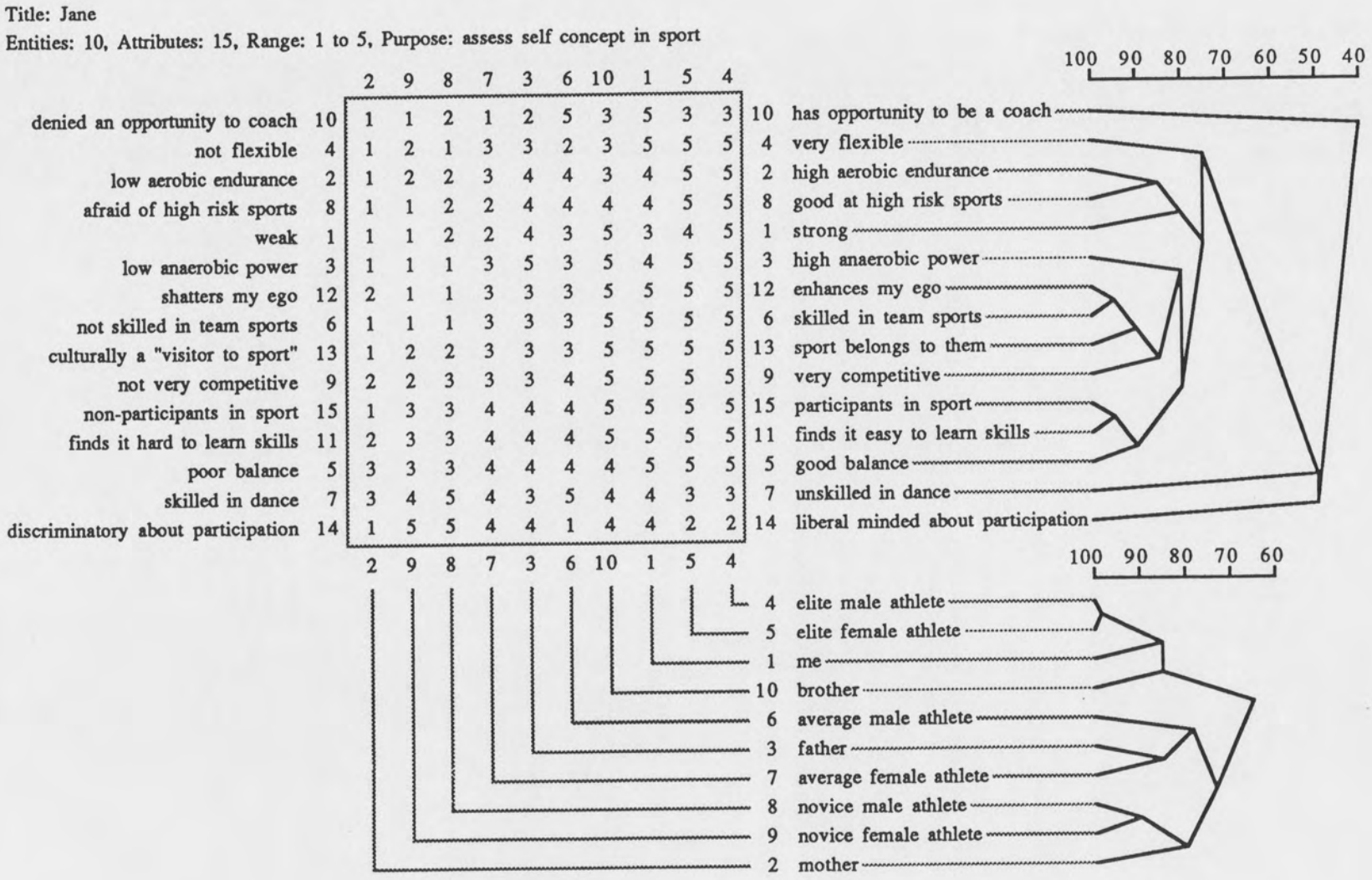

Figure 5. Cluster Analysis Used to Give Advise and Feedback from KSS0 in InSport

Figure 5. Cluster Analysis Used to Give Advise and Feedback from KSSO in InSport

Figure 6. A Technology Management System for the Design of Flexible Manufacturing Systems

used to drive the expert system but also to provide a cognitive map of the hypermedia system's activities to the user.

USER INTERFACES IN HYPERMEDIA SHELL DESIGN

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 only of domestic automobiles! The following describes some of our approaches to overcoming these problems.

Usability and orientability requirements coupled with the problems of embedding gateways in videodisc material have placed special emphasis on designing effective maps to the hyperbase. Figure 8 shows two approaches that we have found effective and mutually compatible in giving a user understanding of, and control over, access to our hypergraphic and videodisc subsystems, and the building of perspectives on both.

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 videodisc as appropriate, and causes content material to be displayed. The buttons in Figure 8 are numbered to show the selection sequence, but normally have meaningful textual labels.

This hiearchical 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 that gives these additional features at the expense of compactness. The map shown represents the hierarchical structure through enclosed knowledge islands that 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 small 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

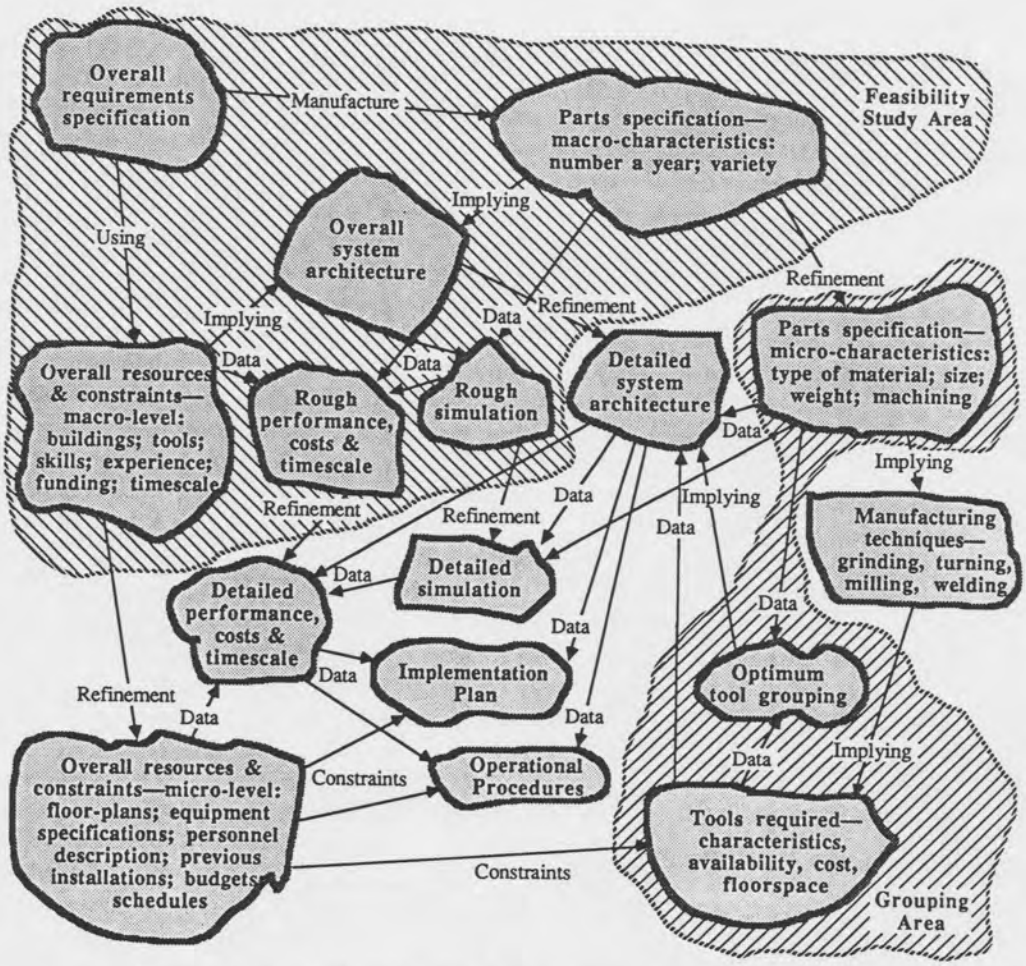

Figure 7. Knowledge Islands for Integrated Manufacturing Systems

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 are a *part-of* hierarchy. Such maps can represent non-hierarchical and mixed relations equally well. The index and the map are mutually compatible systems that 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.

The problems that counterbalance the advantages of a freely accessible, nearly modeless system have also been major design considerations. We have introduced the concept of a *recommendation for access* as a way of highlighting appropriate paths and perspectives for the user without forcing the user to follow them. The recommendations may come from a wide range of sources, but it is usually convenient to think of them as generated by an expert system acting in an advisory role based on a user model. For example, in InSport we use the knowledge elicitation process of KSS0 shown in Figure 4 to generate a simple user model, feed it back directly as generated hypergraphics as shown in Figure 5, and use the model to recommend access to the hyperbase through highlighting a cognitive map as shown in Figure 8. Figure 9 shows how these activities interact to give individualized advice generation as a front-end to a generalized hyperbase access through a cognitive map. Thus, although the underlying structure of hypertext and hypermedia systems is one of linkages between items of information, the user interface should reflect the users' cognitive models of the information, not the underlying technical system. The examples outlined in this paper, the detailed example in the companion paper (Vickers & Gaines, 1988), and other systems, such as the Intermedia system at Brown University (Yankelovich, 1986), illustrate a variety of ways in which users can access hypermedia without becoming lost in a maze of computational linkages.

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

Figure 8. Hypermedia Access through a Hierarchical Index and a Cognitive Map

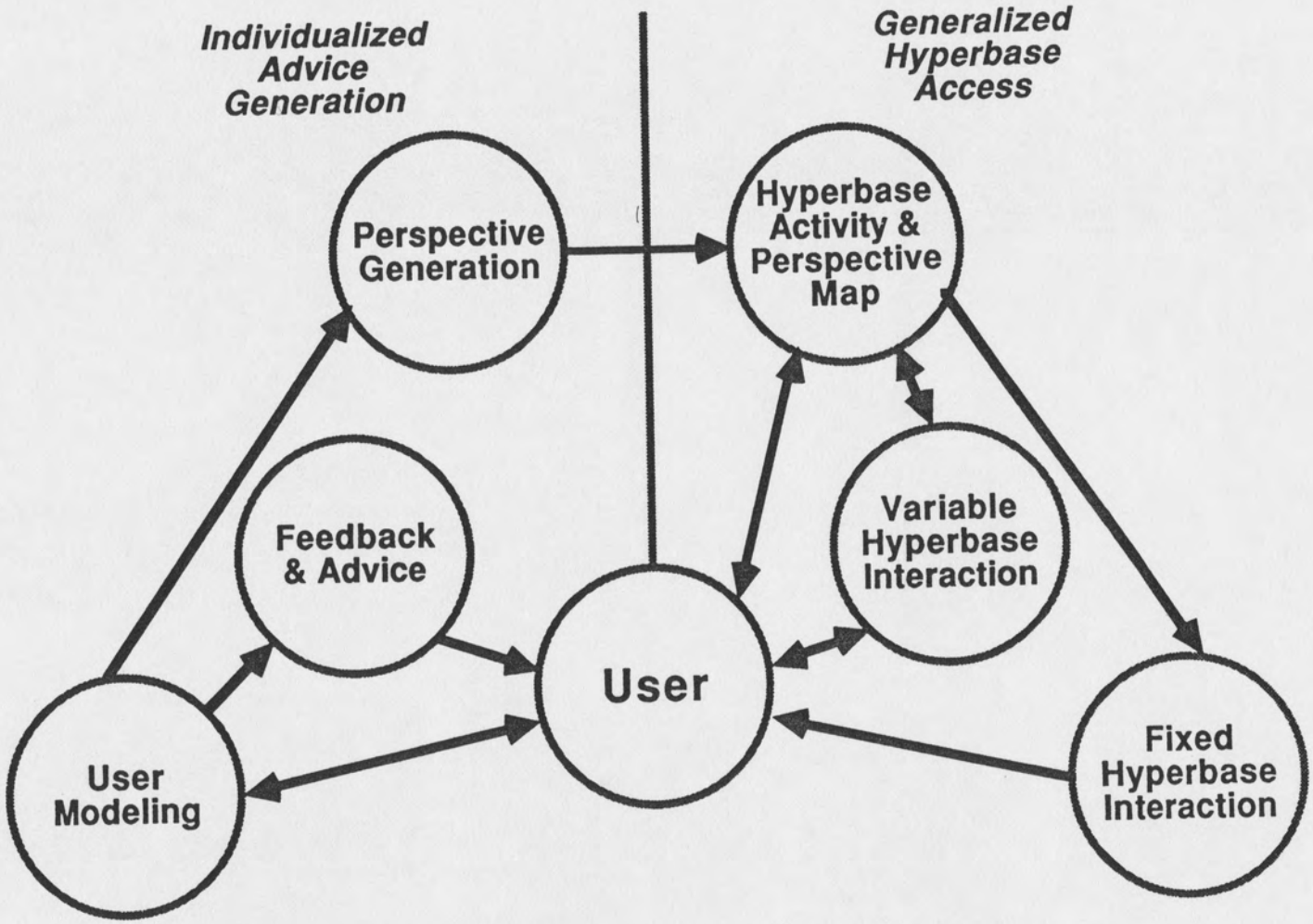

Figure 9. Combining Various Techniques to Aid User Access to Hypermedia Systems

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.

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Figure 9. Combining Various Techniques to Aid User Access to Hypermedia Systems

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