

NCC 9-16

# DESIGNING A TRAINING TOOL FOR IMAGING MENTAL MODELS

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Cooperative Agreement NCC 9-16  
Research Activity No. ET.8  
June, 1990

N91-21776

Unclas  
0330306

G3/63

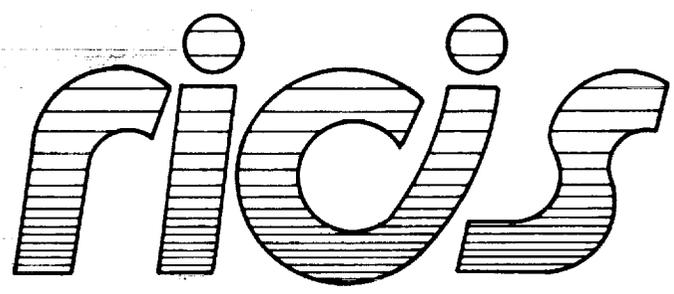
CSCL 09B

(NASA-CR-187891) DESIGNING A TRAINING TOOL  
FOR IMAGING MENTAL MODELS Final Technical  
Report, Feb. 1989 - May 1990 (Houston  
Univ.) 87 p

Co-Sponsors:

INTELLIGENT SYSTEMS BRANCH  
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Final Technical Report for Period February, 1989 - May, 1990

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This report has been reviewed and is approved for publication.

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# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1. AGENCY USE ONLY (Leave blank)</b>		<b>2. REPORT DATE</b> November 1990	<b>3. REPORT TYPE AND DATES COVERED</b> Final Report - February 1989 - May 1990	
<b>4. TITLE AND SUBTITLE</b> Designing a Training Tool for Imaging Mental Models			<b>5. FUNDING NUMBERS</b> C - NCC9-16 PE - 62205F PR - 1121 TA - 09 WU - 57	
<b>6. AUTHOR(S)</b> Christopher J. Dede Geetha Jayaram				
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Director, Advanced Knowledge Transfer Project University of Houston, Clear Lake 2700 Bay Area Boulevard Houston, Texas 77058-1098			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)</b> AFHRL/IDI Brooks AFB, TX 78235-5601			<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b> AFHRL-CR-90-80	
<b>11. SUPPLEMENTARY NOTES</b>				
<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.			<b>12b. DISTRIBUTION CODE</b>	
<b>13. ABSTRACT (Maximum 200 words)</b> The training process can be conceptualized as the student acquiring an evolutionary sequence of classification-problem-solving mental models. For example a physician learns (1) classification systems for patient symptoms, diagnostic procedures, diseases, and therapeutic interventions and (2) interrelationships among these classifications (e.g., how to use diagnostic procedures to collect data about a patient's symptoms in order to identify the disease so that therapeutic measures can be taken. This project developed functional specifications for a computer-based tool, Mental Link, that allows the evaluative imaging of such mental models. The fundamental design approach underlying this representational medium is traversal of virtual cognitive space. Typically intangible cognitive entities and links among them are visible as a three-dimensional web that represents a knowledge structure. The tool has a high degree of flexibility and customizability to allow extension to other types of uses, such as a front-end to an intelligent tutoring system, knowledge base, hypermedia system, or semantic network.				
<b>14. SUBJECT TERMS</b> artificial intelligence hypermedia hypertext			<b>15. NUMBER OF PAGES</b> 84	
			<b>16. PRICE CODE</b>	
<b>17. SECURITY CLASSIFICATION OF REPORT</b> Unclassified	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> Unclassified	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> Unclassified	<b>20. LIMITATION OF ABSTRACT</b> UL	

## SUMMARY

The training process can be conceptualized as the student acquiring an evolutionary sequence of mental models. The type of mental model that underlies almost all training is classification problem solving. As an example, training to be a physician involves learning 1) the classification systems for patient symptoms, diagnostic procedures, diseases, and therapeutic interventions and 2) how these entities are interrelated. Then, in practice, a physician uses diagnostic procedures to collect data about a patient's symptoms in order to identify the disease so that appropriate therapeutic measures can be taken.

Training is seldom depicted in this manner because educators do not have an adequate method for representing mental models. Typically, the core of training is portrayed by presenting outlines of subject headings or lists of goals and behavioral objectives. Unfortunately, these methods of summarizing focus primarily on individual, isolated pieces of the curriculum; they do not capture the nonlinear web of interrelationships among integrated, hierarchically nested concepts and skills. In the absence of a representational system for these complex knowledge structures, curriculum designers, instructors, and learners are frequently left groping for some way to present the "big picture" underlying training.

This project developed functional specifications for a computer-based tool, Mental Link, that allows the evaluative imaging of classification-problem-solving mental models. The fundamental design approach underlying this representational medium is traversal of virtual cognitive space. Typically intangible cognitive entities and links among them are visible as a three-dimensional web that represents a knowledge structure. The user can navigate through this virtual environment and also can transcend the metaphor of physical space by shifting among alternate contexts (e.g. informational, relational, diagnostic) that provide different perspectives on a particular cognitive entity. In addition, special capabilities to minimize complexity (i.e. guided tours, filters, hypertext, visualization features) are available.

Through embedded inference across the semantic networks in a mental model, Mental Link provides both a medium for communication and an empowering environment for individual and group work. Authoring functionalities are designed to make creating or extending a model simple, as the application generates virtual semantic structures with minimal input. The tool has a high degree of flexibility and customizability to allow extension to other types of uses, such as a front-end for an intelligent tutoring system, knowledge base, hypermedia system, or semantic network. This representational architecture for mental models different and more powerful than any medium now being used to conceptualize and evaluate the training process.

## PREFACE

The research reported herein was conducted in support of the Intelligent Systems Branch research agenda in the Training Systems Division of the Air Force Human Resources Laboratory (AFHRL) at Brooks AFB, Texas. This work was co-sponsored by the Space Station Training Office, Missions Operations Directorate, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration (NASA-JSC) at Houston, Texas.

Dr. Chris Dede, the Principal Investigator of the project, is a Full Professor and Director of the Advanced Knowledge Transfer Project at the Clear Lake campus of the University of Houston (UH-CL). His research specialties are artificial intelligence, instructional computing, strategic planning, and technology forecasting and assessment. Ms. Geetha Jayaram was the Technical Documentation Specialist for this project and collaborated in many aspects of the functional design. Ms. Jayaram holds a master's degree in education from India. She has developed training courseware for large corporations such as AT&T.

This research (Activity No. ET.8) was co-sponsored by the National Aeronautics and Space Administration under Cooperative Agreement NCC 9-16 between the Lyndon B. Johnson Space Center and UH-CL. The Research Institute for Computing and Information Systems (RICIS) at UH-CL provided the funding umbrella under which this project was coordinated. The mission of RICIS is to conduct, sponsor, and disseminate research on computing and information systems among researchers and users from UH-CL, NASA-JSC, the aerospace and computing industries, and other research organizations. Its Director, Dr. A. Glen Houston, can provide additional information about RICIS activities.

The authors wish to express their thanks to several individuals who were instrumental in advancing the work of this project. At AFHRL, Lt. Colonel Hugh Burns, Major James Parlett, and Captain Mike Slaven were particularly supportive in their service as Air Force Technical Monitors. At the Johnson Space Center, Barbara Pearson and Frank Hughes were very helpful as NASA Technical Monitors.

The views and conclusions contained in this report are those of the authors and should not be interpreted as representative of the official policies, either express or implied, of NASA, the U.S. Air Force, or the United States Government.

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# DESIGNING A TRAINING TOOL FOR IMAGING MENTAL MODELS

## I. INTRODUCTION

### Mental Models In Training

Training centers on communicating a standardized package of knowledge and skills from an expert source to a learner. This process can be conceptualized as the student acquiring an evolutionary sequence of predetermined mental models of the subject domain. For the purposes of this study, a "mental model" is defined as an internal representation of a real world phenomenon. This imagery can be processed by the mind to provide predictive and explanatory power. For example, many adults have a mental model of fluid flow that allows them to accurately predict when a liquid will flow, stand still, or spread into a thin sheet on a surface (Stevens & Gentner, 1983).

The type of mental model that underlies almost all training is classification problem solving (Clancey, 1984). Real world phenomena can be classified as entities in category systems nested hierarchically; for example, a cold is a type of viral infection, which is one kind of disease. A physician's mental model for classification problem solving includes categories for symptoms (such as fever), diagnostic techniques (oral thermometers), diseases (influenza), and therapies (bed rest).

In addition, the doctor has mastered a web of causal interrelationships among the entities in these category systems. As an illustration, weakness and inflammation are both symptoms likely in a bacterial infection, which can be diagnosed by cultures and treated by antibiotics. Training a student to acquire this type of mental model involves communicating both the classification systems for a subject domain and the network of causal relationships among the entities in those categories.

When the learner has constructed this type of mental model, he can solve a problem through mapping its phenomena into classification systems linked by webs of relationships. In contrast, even if a student has memorized all the concepts and skills in a training sequence, without such an integrative synthesis this data is a meaningless jumble. Students who pass the tests on individual components of a training sequence, but later can't function in real-world situations, often lack a classification-problem-solving mental model.

### Representing the Essence of Training

Training is seldom depicted in this manner because educators do not have an adequate method for representing mental models. When instructional designers, teachers, and students want to step back from the details of a curriculum to reflect on its overall purpose and scope, they need a way to summarize the heart of the training process. Describing the essence of training

involves abstracting the most important themes that the learner is mastering from the mass of detailed instructional communications in the complete curriculum.

Imagine being in darkness, slowly examining the total surface of a wall-sized painting with a tiny light that illuminates one square inch at a time. From this fragmentary data, visualizing the overall scene the painting portrays is extremely difficult. Without a powerful method for abstracting and summarizing the detailed content of training, educators are comparably handicapped—aphasic—in describing a training process.

Typically, the core of training is portrayed by presenting outlines of subject headings or lists of goals and behavioral objectives. Unfortunately, these methods of summarizing focus primarily on individual, isolated pieces of the curriculum; they do not capture the nonlinear web of interrelationships among these integrated, hierarchically nested concepts and skills. Conceptualizing the training process as the communication of mental models requires synthesizing and depicting knowledge structures greater than the sum of their parts.

In the absence of a representational system for these knowledge structures, curriculum designers, instructors, and learners are frequently left groping for some way to present the "big picture" underlying training. Visualize an architect attempting to construct a building without being able to use blueprints, or a geographer trying to describe a region without utilizing maps. Imagine, as George Orwell portrayed in 1984, trying to discuss democracy in a culture without a word for the concept of freedom.

In particular, course developers have difficulty preparing materials that emphasize interrelationships as well as data and that cover the subject matter consistently and completely. Teachers have limited means for assessing the learning style a pupil is using to master content and for communicating with other instructors about how to weave together their disparate fields into a seamless web of knowledge. Learners often cannot visualize how the concepts and skills they have acquired are interrelated and seldom reflect on how they can best integrate new information into their existing knowledge. In all these situations, the only representational media available are very abstract and general descriptions (such as a subject outline or a list of goals); no current medium presents a detailed, interrelated overview.

Discussing mental models is as fundamental to training as asking "what if" questions is to planning. A decade ago, the spreadsheet provided a medium for simulating financial alternatives, and business management strategies became much more effective. A similar software program is needed to empower the next generation of advances in training.

## Imaging Mental Models

While adequate for presenting lists or outlines, sequential media such as text or speech are unsatisfactory when describing a mental model. Diagramming the interrelationships of multiple curricular components typically produces an indigestible tangle of visual spaghetti. Since causal links among entities across hierarchies produce very complex networked structures, a nonlinear medium with support for visualization techniques, navigation in virtual space, and imaging from multiple perspectives is required to represent mental models.

This project has developed functional specifications for a computer-based tool, Mental Link, that images classification-problem-solving mental models. Hypermedia—a knowledge representation emerging from advances in information technology, artificial intelligence, and cognitive science—is used as the nonlinear representational architecture. Strategies from the field of scientific visualization have been applied to allow the presentation of complicated information without overwhelming the viewer. To empower intelligent responses from the tool, artificial intelligence capabilities, such as inferencing over the network structure, have been incorporated into the design.

Describing a dynamic visualization tool by using words is very difficult; seeing a simulated version of the application in action gives a much better sense of its capabilities. Accordingly, coupled to this Final Report are additional products of this project: several software files and two videotapes. The software files, when executed, simulate many of Mental Link's functionalities, so the user can experience a guided tour through the interface (described in the Appendix) and most features of this proposed application. (However, these prototypes are unable to replicate the actual capabilities of the tool; they are merely demonstrations and contain no code that could be used in building Mental Link. They present an image of what could be rather than documenting actual construction of the tool.)

Much of the guided tour these software files provide is also presented on the longer of the two videotapes ("Functional Design for a Tool That Images Mental Models"); this allows viewers without access to a computer to see a simulation of Mental Link's major capabilities. The shorter videotape ("Imaging Mental Models") contains both an abbreviated version of this tour and a discussion by the Principal Investigator of the reasons such a tool would be useful in training settings.

Section II of this report describes the fundamental precepts and rationale underlying the design of this application and delineates the major capabilities incorporated in the tool. In Section III, potential applications of Mental Link to USAF and NASA training settings are described; many of these uses also would generalize to any training environment. Section IV presents the issues for further research that this study raises, and Section V summarizes the conclusions from the project. The Appendix contains written instructions for

using the software files to present a guided tour through the functional specifications.

## II. DESIGN OF THE TOOL

The fundamental design approach underlying this mental modeling tool is traversal of virtual cognitive space. Typically intangible cognitive entities and links among them are visible as a three-dimensional web that represents a knowledge structure. The user can navigate through this virtual environment and also can transcend the metaphor of physical space by shifting among alternate contexts (e.g. informational, relational, diagnostic) that provide different perspectives on a particular cognitive entity. In addition, special capabilities to minimize complexity (i.e. guided tours, filters, hypertext, visualization features) are available.

Through embedded inference across the semantic networks in a mental model, Mental Link provides both a medium for communication and an empowering environment for individual and group work. Authoring functionalities are designed to make creating or extending a model simple, as the application generates virtual semantic structures with minimal input. The tool has a high degree of flexibility and customizability to allow extension to other types of uses, such as a front-end for an intelligent tutoring system, knowledge base, hypermedia system, or semantic network.

Below are summarized the design assumptions and principles underlying this prototype for a mental modeling tool. Many of these could generalize to any application involving traversal of virtual cognitive space.

### Cognition Enhancers

The investigators have designed an intelligent tool to amplify human thinking skills rather than a smart machine to direct the activities of instructional designers, trainers, and learners. The concept underlying a cognition enhancer is that of using the complementary cognitive strengths of a person and an information technology in partnership (Dede, 1989a). For example, computers have large short-term memories (megabytes of RAM), while human beings are limited to an immediate storage capacity of less than ten chunks of information. Computers can also execute complex "algorithms" (precise recipes for solving one class of problem) more rapidly than people. For tasks involving manipulation of successive symbolic results (e.g. involved mathematical calculations), these two cognitive attributes give a computer an advantage over a human being. In general, computers are becoming superior at all forms of standardized problem solving.

However, people store information long-term in webs of associationally related textual, temporal, and visual imagery. For example, in a human memory the word "apple" conjures up themes that are religious (the Garden of Eden),

computational (the Macintosh computer), botanic (trees), aesthetic (the Beatles' record company), scientific (Isaac Newton), and gustatory (pies). At present, computers are much more limited in how their information can be interrelated, as anyone who uses a database knows. These cognitive attributes of human beings give them an advantage over computers at applying peripheral real world knowledge to ill-structured problems (such as diagnosing the source of a student's motivational difficulties). In general, people are much better than computers at problem recognition, learning, metacognition (thinking about thinking), and non-standardized problem solving.

Because of current limitations of computers, cognitive science, and artificial intelligence, developing devices capable of independent instruction is difficult. While intelligent machine-based tutors and coaches can be very useful, they are narrow in their expertise and expensive to build. Cognition enhancers designed to combine the intellectual strengths of humans and computers are evolving more rapidly and can be applied to a wider range of educational settings. Therefore, this prototype mental modeling application has been designed to complement human cognition in in conceptualizing and representing the complex knowledge structures underlying training.

In particular, Mental Link would support search, query, and inference over the entire knowledge base embedded in the network, including the descriptive information stored for each node and link in the structure. The tool could aid an author in maintaining the completeness and consistency of the knowledge network, as well as in creating concept maps that provide multiple perspectives on semantic structures. Further, embedded inference over the network allows customizing and tailoring the tool to specific purposes, such as making judgements about learning style based on an evolutionary sequence of mental models. Such intelligent aids are vital for preventing users from being overwhelmed by the scale, detail, and complexity inherent in the classification-problem-solving models that Mental Link images.

### Classification Problem Solving

This mental modeling tool is based on the concept that training can be formally represented as mastery of a classification-problem-solving strategy for the domain being learned. Clancey (1984) describes how many types of well-structured problem solving can be understood as classification. The inference structure characteristic of these problem solving activities systematically relates data about a real-world situation to a pre-enumerated set of solutions through abstraction, heuristic association, and refinement. For example, a physician uses diagnostic procedures to collect data about a patient's condition with the goal of identifying the cause of the problem. Then, appropriate therapeutic measures are taken. For routine medical problems, training involves learning 1) the classification systems for patient symptoms, diagnostic procedures, diseases, and therapeutic interventions and 2) how these entities are interrelated.

Most training involves learning such a method of identifying and solving typical real-world problems. In these instructional situations, the mental model that the student is to master can be represented as interlinked sets of classification systems. Such a formalism is a useful way of depicting the complexity inherent in the domain, as this representational architecture captures the core of what the pupil is to master—concepts and interrelationships—without bogging down in descriptive detail (Dede, 1989b).

Of course, category systems are not absolute, Platonic entities; instead, they reflect the perspective of the observer. In training situations, however, the epistemological uncertainty of these entities is not important. The curriculum defines a mental model of the domain to be communicated, and the teaching/learning process is one of transferring a semantic structure rather than stimulating creative thought about alternative ways of representing that knowledge.

Greeno (1983) discusses the general issue of how the ontology of a domain (its entities, attributes, relations) influences the learning of mental models. This type of analysis could be facilitated by the availability of evaluative imaging systems, such as Mental Link, to represent conceptual structures. Classification problem solving seems the best approach for conceptualizing the the mental models intrinsic in the sophisticated performance situations characteristic of military and aerospace settings.

### **Hypermedia as a Representation for Semantic Networks**

The representational architecture selected for the mental modeler is a semantic network instantiated in a hypermedia system. A fundamental aspect of any information system is its underlying knowledge representation. Symbols "re-present" reality, and the properties of any form of communication are shaped by the attributes of its symbolic substrate. For example, sometimes "a picture is worth a thousand words" because the characteristics of an image are better suited to the needs of that particular knowledge transfer situation (Dede, Sullivan, & Scace, 1988).

This tool required a representational architecture that satisfied several constraints. First, its knowledge structure needed to mirror the associational webs underlying human long-term memory. Second, the formalism chosen had to be capable of representing a classification-problem-solving perspective on mental models. Third, the architecture needed to support an embedded inference engine to provide intelligent functionalities for users. Finally, the representational system had to facilitate revealing and concealing the complexity intrinsic in interrelated hierarchical structures.

A hypermedia system for depicting semantic networks best satisfied all these constraints. A semantic network is a representational architecture that provides a semi-structured mechanism for displaying associative

interconnections (Woods, 1985). These interconnections are determined by the relational meanings of the chunks of knowledge being linked.

Hypermedia is a nonlinear format that provides a facile interface for presenting and manipulating semantic network structures (Conklin, 1987). In hypermedia, nodes of information are connected by links. A node might contain text, data files, graphics, images, code, animation, or some mixture of these. Nodes can be arbitrarily large or small, but generally embody the equivalent of a few sentences to several pages of information; they can have multiple embedded links to other nodes. Since knowledge is implicitly stored in the structure of interconnections among nodes—as well as the nodes themselves—intelligent retrieval from hypermedia can be more powerful than in standard text-based systems (Carlson, 1989).

Links are associative paths between nodes; they can be as simple as a connection between an origin and a destination or can have a variety of properties. Links allow the creation of a conceptual web with complex interdependencies among nodes. This provides a framework for nonlinear representations of knowledge, as well as creating the potential of embedded inference across the network of interconnections (Halasz, 1988).

Such an architecture can represent the internested hierarchies typical of the classification-problem-solving perspective on training. In addition, hypermedia allows the user substantial control over the complexity and depth of the material being presented. Through activating a browsing capability, the user can access a global view of the hypermedia network; this simplifies traversing a complex cognitive map. Also, by activating or suppressing the contents of nodes, users can selectively access detailed data while retaining an overall perspective on the entire knowledge structure (Halasz & Conklin, 1989).

Researchers in cognitive learning (Jonassen, 1989), instructional design (Russell, Moran, & Jordan, 1987), and educational applications of semantic networks (Denenberg, 1988) are finding hypermedia useful as a representational formalism. External to the training community, a hypermedia system has been developed that supports representing a mental model as a network of associations among the elements of a strategic plan (Carlson & Ram, 1990). The design of Mental Link extends these approaches by creating a nonlinear, semantic architecture for the three-dimensional virtual cognitive space the tool uses as its visual interface.

### Visualization of Virtual Cognitive Space

This mental modeling tool immerses the user in a three-dimensional virtual environment in which cognitive entities and their interrelationships are presented as images. The power of visual representations lies in the human mind's ability to extract patterns when viewing a complicated image (Tufte, 1983). Scientific visualization transforms the symbolic into the geometric, making normally intangible entities visible and enabling profound and

unexpected insights (McCormick, DeFanti, & Brown, 1987). In particular, visualization technologies are useful in situations where the amount of data is large, communication among co-workers is vital to task performance, and interacting with the data to shape its presentation can aid in interpretation.

An emerging concept in visualization, cyberspace, seems well suited to the types of evaluative imaging requisite for depicting mental models. The term "cyberspace" originated in a novel by a science fiction writer (Gibson, 1984) and refers to a multi-dimensional virtual environment in which all of civilization's data—stored as sensory entities—could be accessed and manipulated. This idea has since 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.

Researchers exploring aerospace applications are on the forefront of cyberspace work. The U.S. Air Force has been developing virtual environments as one component of the heads-up cockpit. The most widely accepted interface for artificial realities—gesture technology coupled with a head-mounted display—was initiated by NASA and is now being used to study interactive data visualization in cyberspace contexts (Fisher, Wenzel, Coler, & McGreevy, 1988).

The design of cyberspace environments for data visualization poses many research issues (Benedikt, 1990). 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, alternative spatiotemporal metaphors from physical reality, and the architecture of multi-dimensional data spaces.

The investigators selected a manageable subset of these research issues as the focus of this project. Evaluative imaging in a cyberspace environment seems naturally suited to coalescing the complex data typical of a sophisticated training process. A three-dimensional virtual space with icons, shadings, and colors is used to depict clustered, nested hierarchies and their interrelationships. Users can traverse and act on these cognitive structures through Mental Link's capabilities for semantic navigation.

### Semantic Navigation

A major challenge for this mental modeling tool, as for any cyberspace application, is management of the computer-human interface. Complex configurations of multi-dimensional data must be converted to a spatiotemporal analog that allows users to transfer their usual strategies for navigation and action from physical contexts to cognitive space. User disorientation has been a particularly difficult problem in cyberspace work to date, because a nonlinear

medium offers fewer clues to relative position and orientation than sequential forms of communication (McAleese, 1989). While hypermedia representations offer some leverage by allowing user control over image complexity, large-scale semantic networks can present a cluttered and confusing appearance if viewed in full detail.

However, preliminary work in manipulating the visual presentation of large node/link structures indicates that interface functionalities can provide substantial aid in reducing the complexity of the image. For example, the SemNet tool developed at the Microelectronics and Computer Technology Corporation illustrates how controlled manipulations of associative webs can be used to reveal and conceal complexity by focusing on particular types of categories and relationships (Fairchild, Poltrock, & Furnas, 1988). This research is now generalizing into a theory of semantic navigation—based on multiple views of information and hierarchical object structures—that seems likely to reduce disorientation problems (Fairchild & Wexelblat, 1989).

In addition, the hypermedia community has been developing a variety of alternative strategies for facilitating user traversal through conceptual maps. Nielsen (1990) has constructed a system that uses two navigational dimensions, each with a different animation technique, to aid in orientation. The NoteCards group at Xerox's Palo Alto Research Center has been studying how visual cues embedded in the contents of hypertext nodes can create a guided tour through a complex web of information (Marshall & Irish, 1989). Brown University's Intermedia project has synthesized a variety of navigation approaches into a web-view capability for browsing (Utting & Yankelovitch, 1989).

The design of Mental Link incorporates and extends many of these design strategies. By viewing hypermedia-based visual representations from varied perspectives and at different levels of granularity, the user can focus attention only on those aspects relevant to the current instructional issue. The multiple hierarchical structures characteristic of classification problem solving are mapped into spatial analogues whose physical characteristics aid orientation and navigation. While the imaging of three-dimensional views of the entire cognitive space still presents many challenges in reducing complexity, the semantic navigation strategies in this mental modeling tool offer simple functionalities that empower sophisticated traversal and action.

### Summary

Cognition enhancers, classification problem solving, hypermedia representations of semantic networks, visualization of virtual cognitive space, and semantic navigation are the fundamental design principles underlying Mental Link. Combined, they provide a representational architecture for mental models different and more powerful than any medium now being used to conceptualize and evaluate the training process. These design strategies also

suggest the foundations of a general theory for traversal of virtual cognitive space.

### **III. APPLICATIONS OF MENTAL LINK TO USAF/NASA SETTINGS**

#### **The Scope of Aerospace Training**

As Fletcher (1988) discusses, Department of Defense (DoD) training in the United States is a substantial enterprise:

The 1987 Military Manpower Training Report (MMTR) reported that, on an average day in Fiscal Year 1988, about 210,000 active duty personnel and 45,000 National Guardsmen and Reservists will undergo formal training. This training load has increased by about 13% in the 1980-88 period. The cost of this effort will exceed \$18.4 billion in FY 88; and it will require the support of about 192,000 military and civilian personnel to provide instruction, administration, and student supervision. However, the MMTR underestimates the magnitude of the military training enterprise. It only concerns instruction conducted in formal courses by organizations whose primary mission is education or training. It excludes all job-site training, factory and unit training for new systems, organized team training for the performance of specific military missions, and all field exercises... The expenditures reported by the MMTR may underestimate the resources required by the full military training enterprise by as much as an order of magnitude.

In 1988, the Air Training Command alone provided instruction for almost 400,000 students on an operating budget of \$2.9 billion. Trainers carry a heavy and rising teaching load, and limited time and resources are available to provide them with mastery of their domain content and pedagogy. This poses a growing challenge to maintaining the current high quality of instruction.

Fletcher lists reasons why the problems faced by military trainers can be expected to increase in the future. These include:

- The supply of people available for military service is decreasing. The proportion of male citizens who are eligible (not in college; not disqualified for mental, moral, or physical reasons; and age 18-21) that the Services must recruit may grow from 50% today to 77% by 1995 (Binkin, 1986).
- The number of military systems is increasing (from 500 material systems at the end of World War I to 4000 today).
- The technological complexity of military systems is growing (from 525 pages of technical documentation in 1939 for the J-F Goose "Catalina Flying Boat" to about 1,000,000 pages for the B-1 bomber).

- Costs to conduct training have risen in both absolute and relative terms.
- Modern warfare doctrine calls for more widely dispersed, autonomous units, requiring an increased capacity to deliver training to dispersed and isolated job-sites.

Many of these problems can be ameliorated by sophisticated technology-based technical training systems.

NASA faces similar challenges in the scale, cost, and complexity of its instructional functions. The Space Station program has increased the number of personnel to be trained, the amount of knowledge to be mastered is very large (estimated core technical documentation for the Station is expected to grow by 2 terabytes per year), and the skills to be communicated are highly sophisticated. Both the military and the aerospace communities, therefore, have much to gain from instructional advances that improve the efficiency and effectiveness of technical training.

As this report has discussed, cognition enhancers based on artificial intelligence and scientific visualization offer a target of opportunity for substantially increasing the productivity and cost-effectiveness of training. This project developed the design for a mental modeling tool that could exemplify transfer of leading edge technology from these research areas into real-world settings. Because Mental Link has a broad range of potential uses, it provides a framework for broadly disseminating a synthesis of advances in knowledge representation into the Air Force and NASA technical training communities. Due to the generalizable utility of semantic network representations, this tool would be useful in conventional computer-assisted instruction (CAI) as well as advanced intelligent tutoring system (ITS) development environments, both inside and outside the DoD and aerospace training communities.

### Technology in Aerospace Training

To prepare personnel for their duties, technical training at Air Force and NASA sites is delivered primarily by human teachers, written materials, CAI lessons, and complex simulation experiences. Technology-based instructional delivery systems can be very attractive as a major component of training because 1) the material is partially individualized to the background and experience of each student, thus increasing the efficiency of instruction, and 2) the cost of preparing large numbers of learners by this method is substantially less than that of human teaching.

However, attempts to utilize traditional CAI and simulation approaches in complex training situations have been mixed in their results. In response, both DoD and the aerospace community have been pioneers in applying cognitive science and artificial intelligence advances to instructional systems. The Intelligent Systems Branch of AFHRL and the Space Station Training Office at

NASA-JSC are leaders in this area. The design of this tool is part of a larger research agenda centered on technology transfer of advanced research in cognitive learning theory, instructional design, knowledge representation, and ITS to real world settings. In particular, Mental Link advances the FY 89 Air Training Command Research Objective of applying artificial intelligence approaches to training development and delivery,

Advanced technology is important for improving human performance because all types of sophisticated technical training face a common challenge: preparing adults for complex work roles requires communicating a large body of descriptive and procedural knowledge. Some of this information is general and of enduring usefulness (e.g. theories in orbital mechanics for aeronautical engineers, strategic principles for battlefield commanders); other data are very specific and of transitory value (procedures tailored for one particular shuttle mission or combat encounter). Typically, students acquire this knowledge via instructional formats (briefings, printed materials, simple CAI lessons) in which a preset series of concepts is presented, followed by questions to increase assimilation.

The emphasis in these learning situations is on providing the foundation of concepts by which students can comprehend the sophisticated problem solving procedures they must master. Without this fundamental understanding, the skills personnel acquire are merely memorized. Each individual problem has its own solution "incantation" to be learned, and every variation in the situation requires mastering an idiosyncratic response. When skills are "magical," teaching problem solving via anticipation/reaction becomes very complicated and detailed, and giving people the capability to resolve unusual situations via reasoning is impossible. Thus, the instructional goal underlying training is not whether the student can regurgitate information, but how the concepts learned provide a context—a mental model—in which procedural skills are better understood (Dede, 1987).

Artificial intelligence and cognitive science researchers believe that the learning, recall, execution, and adaptation of complex procedures are enhanced by conveying multiple levels of meaning. Four dimensions on which a process can be understood are: 1) the theoretical basis by which it works, 2) the tasks and goals it accomplishes, 3) the strengths and limits of its user, and 4) its larger context of related procedures. These types of meaning are better communicated in an individualized, interactive format—such as an ITS could provide—than through a standardized approach (lecture, text, preprogrammed CAI lesson). The strength of a mental modeling tool is that it can improve both CAI and ITS by providing a sophisticated representation through which instructional designers, trainers, and learners can place all four of these dimensions in a richly detailed, integrated cognitive context.

## Mental Models in Aerospace Training

This project is predicated on the assumption that training can be conceptualized as the student acquiring an evolutionary sequence of predetermined mental models of the subject domain. Many learning theories and instructional design strategies that underlie current aerospace training support this view. However, the absence of a representational medium such as Mental Link precludes trainers, at present, from synthesizing this isolated use of semantic networks and hypermedia into an integrated strategy for developing mental models.

For example, Jonassen (1986) describes a range of ways in which hypermedia can present information to learners. "Chunk" hypermedia provides choices to the user about what to view next, "collateral" hypermedia presents multiple perspectives on an issue (through annotations and parallel presentations), and "stretch" hypermedia offers learners control of the depth to which material is presented (by tailoring grain size). In aerospace training, authoring systems and hypermedia tools are frequently used to implement similar approaches to instruction.

Another cognitive principle of learning that supports semantic networks in knowledge transfer is schema theory (Norman, Gentner, & Stevens, 1976). Schema theory represents subject knowledge as associations among ideas (nodes). These interlinked nodes are clustered into hierarchies that form a complex structure of related plans to cover various contingencies. When a task performance situation arises, scripts for action are retrieved from this network of interacting schema. In learning situations, material is most easily incorporated if it can be mapped into existing schema through adding links—a pedagogical strategy instinctively followed in many military training settings.

Web teaching (Reigeluth & Stein, 1983) is a third instructional theory that utilizes semantic network knowledge representations. In this approach, teaching begins with a coarse network of information that outlines the topics to be discussed. Increasingly detailed levels of associational substructure are subsequently communicated. Models of the student's knowledge can be compared with a semantic network of the complete material, and the instructor can then present information which fills in gaps in nodes or links. Generative learning (Wittrock, 1978) also supports the use of associational webs in technical training situations. This theory argues that learners activate prior knowledge structures in assimilating material; new information only has meaning to the extent that prior ideas can be found to explain it. In this approach, often used in technical training, semantic networks provide a representational structure for understanding and responding to students' active construction of knowledge.

In brief, conceptualizing the training process as developing mental models supports and enriches current instructional approaches in aerospace settings. Constructing a representational medium such as Mental Link would fill a current gap by providing instructional designers, teachers, and learners with

an intelligent tool for constructing, delivering, assimilating, and evaluating complex procedural knowledge.

All these different cognitive approaches provide a theoretical framework for using hypermedia representations and semantic networks in representing the content of technical training. In a partial instantiation of these ideas, Russell, Moran & Jordan (1987) constructed a prototype computer-aided design system for instructional development. The Instructional Design Environment (IDE) articulates design and development procedures through hypermedia representations. The process of creating educational material is separated into distinct stages, each of which requires different types of knowledge structure manipulations. Tools and semantic networks tailored to each stage are accessed in sequence to guide the designer from overall objectives to detailed models of instruction.

For example, IDE captures the rationale for design decisions so that later changes need not require "reinventing the wheel" to determine why a particular pedagogical strategy was chosen. Rationales are represented as associational webs that link specific development strategies with fundamental instructional principles and goals. This type of group decision support is an important component of computer-supported cooperative work.

Mental Link extends the approaches underlying IDE by focusing on a related, more general issue. Implementing a method for evaluatively imaging virtual cognitive space would provide a representational context in which specific applications such as IDE could be instantiated. Also, the visualization and semantic navigation strategies designed for this mental modeling tool are potentially valuable additions to the interface of IDE-like programs. Beyond this, Mental Link is a general and customizable medium useful for trainers and learners as well as instructional developers.

In brief, a wide range of theorists, researchers, and practitioners in cognitive learning and instructional design are using semantic network structures to relate the material to be taught, the student's prior understanding of the subject, and the pedagogical strategies to be used. Mental Link could provide a computational medium by which these different approaches would be actualized, contrasted, and evaluated in military and aerospace technical training. The diversity of theoretical perspectives that lead to the same representational architecture indicate the solid foundation on which this technology transfer work is based.

### **Summary**

The evolving scale and complexity of technical training necessitate new paradigms for increasing the effectiveness of the instructional process. Advanced technologies that build on emerging ideas in artificial intelligence and cognitive science offer the potential for substantial improvement beyond current uses of conventional computer-assisted instruction. Conceptualizing

training as the development of mental models is a promising method for synthesizing and extending today's leading edge training practices.

Mental Link is flexible enough as a representational medium to enhance many current military and aerospace training initiatives. For example, the Intelligent Systems Branch of AFHRL is developing an ITS for orbital mechanics that uses a rule-based expert system to manipulate a semantic network of the subject domain (Augusteijn, Fosha, & Kolbe, 1989). In a second AFHRL project centered on frame-based representations—the major alternative knowledge structure to rules—a group at the University of Texas has been studying ways to generate explanations in an ITS (Porter, Acker, Lester, & Souther, 1989). This mental modeling tool can provide a sophisticated representation of both types of knowledge structures for these and similar training systems. In addition, Mental Link would empower the exploration of many research issues currently unstudied for lack of suitable representational and evaluative tools.

#### **IV. ISSUES FOR FURTHER RESEARCH**

A computational tool for imaging virtual cognitive space is such a fundamental technology that it could generate a large number of research initiatives. To keep this assessment manageable, this section focuses on 1) short-range issues connected with the construction of Mental Link and 2) a spectrum of research themes that could be explored with a mental modeling tool.

##### **Research Issues in Mental Link's Construction**

When designing the functional specifications for an application, as in this project, the investigators are constrained by the capabilities of the prototyping software available. In this case, no commercial programs existed for building a working, primitive version of Mental Link. This mental modeling tool is unique in combining and extending the functionalities of an inference engine, hypermedia system, and graphical rendering application.

Accordingly, the operation of Mental Link could only be simulated, not emulated. Further, user prototyping was beyond the scope and resources of this study. As a result, the interface constructed for this tool could not be tested by instructional designers, trainers, and students to determine the appropriateness of the design choices made. Because the human factors strategies underlying this interface are familiar and well-tested (Brown, 1988), even people unfamiliar with computers will likely master the tool's functionalities easily and intuitively. However, controlled research users' interactions with the tool's interface would be an important aspect of Mental Link's development process.

A task analysis is also a research initiative that would aid in construction of this tool. Studying what instructional designers, trainers, and students currently do to determine how a mental modeling tool might aid their work would be part of such a study. However, this would be like studying accountants

before the development of the spreadsheet—the availability of a powerful application changes the nature of the task and the skills of its performer. Therefore, such a task analysis would also need to go beyond standard methodology to assess the new roles that Mental Link would empower for its potential users. This knowledge would be vital in determining which of the possible functionalities of the tool will be most useful in real-world settings and how powerful a hardware architecture will be needed for acceptable performance.

In addition, identifying "proof of concept" demonstrations that provide leverage for dissemination would be an important consideration in the tool's construction. Mental Link is flexible and customizable enough to allow many potential uses. An assessment could be conducted to select training situations in which such a tool could substantially increase productivity and effectiveness. Versions of Mental Link optimized to these sets of tasks could then be developed and disseminated. This targeted group of demonstrations would enhance the interest of other groups facing similar challenges in acquiring such a mental modeling application.

Overall, the major research work underlying this training tool has been already been completed by this project. The theoretical and technological foundations of this software application are solidly established, and the functional design specifications are complete. None of these additional studies would be resource or time intensive, and all would enhance the capabilities of Mental Link by providing feedback from the military and aerospace training community on its design, role, and utility.

### **Illustrative Themes Empowered by a Mental Modeling Tool**

An application that empowers traversal of virtual cognitive space opens up a spectrum of research initiatives on teaching, learning, and instructional design. Young adults are the typical population receiving military and aerospace training, so this is the set of pupils on which studies of instructional effectiveness should focus. In the past few years, new paradigms have emerged on how young adults learn and what constitutes optimal pedagogy for these students (Pintrich, 1990). Many of the research directions that these paradigms suggest are constrained by the inability of current representational media to capture the complexity of the mental processes underlying teaching and learning. The list of research themes later in this section is necessarily incomplete, but illustrates the types of enquiries that a mental modeling tool could facilitate.

The core issue that underlies any mental modeling research is, "for a particular subject, through what typical evolutionary sequences of mental models do pupils' knowledge and skills progress?" This concept of research on genetic graphs comes from Piaget; he used "genetic" in the sense of source and growth and thought of himself as a genetic epistemologist studying the origin and development of knowledge. A modal path representing the natural

progression of an average learner can be postulated (diSessa, 1982), and the temporal links which connect these clusters of problem solving approaches may be thought of as evolutionary relationships. One set of strategies may suggest another via generalization/specialization, analogy, deviation/correction, or simplification/refinement (Goldstein, 1982). These types of studies build a bridge between content-based and learner-based paradigms for instruction, combining the developmental and cognitive attributes of the student with the intrinsic characteristics of the knowledge domain.

A related, basic research question is, "what measures of semantic complexity might instructional designers, trainers, and learners usefully analyze through visual representations?" Two measures that reflect aspects of a mental model's complexity are:

- the hierarchical structure of categorizations: how many categories of attributes the model distinguishes among, how many distinctions are possible within each category, and how these categories are nested
- the number and type of interconnections: how many interrelationships exist both among elements within each categorization and among the classification systems the model incorporates

A crude quantitative measure expressing two mental models' relative degree of complexity could be obtained by comparing their numbers of entities, types, and interconnections. A more qualitative approach would add a consideration of the hierarchical structure of categories. For example, systems with many degrees of distinction in a single category might be difficult to learn because of the limits of human short-term memory.

As they gain expertise in a domain, human beings seem to have automatic organizing mechanisms which control the complexity of these semantic structures. For example, Chase and Simon (1973) discuss the visual "chunking" that chess masters develop as a discrimination net to recognize typical patterns arising in games. This parallels the grouping into composite nodes discussed earlier as a method of managing complexity in imaging semantic networks.

Visual representations that capture the degree and types of complexity in these elaborate semantic networks could be very useful in developing and delivering training. For example, the core of ITS development is the incorporation of dynamic models of the task, student, and teaching discourse. The designer must simultaneously consider three semantic networks: the complexity structure of the subject domain, the dynamic mental model of the student, and the ephemeral set of associational links formed between these two during the process of learning. Providing imaging methods for revealing and concealing the complexity of these interacting models could significantly aid the ITS development process.

From these two foundational issues of evolution and complexity, research themes for which a mental modeling tool would be seminal include:

- How is the procedural knowledge in a mental model different in its characteristics from the domain knowledge (Holland, Holyoak, Nisbett, & Thagard, 1986)?
- How do particular sociocultural environments influence situated learning (Brown, Collins, & Duguid, 1989) and the development of students' belief representations (Pea, 1988)?
- How do a pupil's neurological development (Basseches, 1986) and psychosocial development (Kitchener, 1986) and personal history (Cantor & Kihlstrom, 1987) and motivational state (Pintrich, 1988) and cognitive style (Claxton & Murrell, 1987) influence the evolution of his mental model?
- What does the evolution of a learner's mental model indicate about his ultimate intellectual potential (Sternberg, 1988)?
- How do sophisticated mental representations build beyond declarative and procedural knowledge to ultimately affect intentionality and self-concept (Johnson-Laird, 1983)?
- How does the availability of a mental modeling tool empower students to develop their cognitive skills in synthesis and in metacognition (Corno, 1986)?
- How does the availability of a mental modeling tool facilitate trainers 1) assessing the learning style a pupil is using to master content and 2) communicating with other instructors about how to weave together their disparate fields into a seamless web of knowledge?
- How does the availability of a mental modeling tool enhance the ability of instructional designers to prepare materials that emphasize interrelationships as well as data and that cover the subject matter consistently and completely?

As this illustrative list suggests, the range of potential research topics with significant potential to improve the effectiveness of the training process is very large.

### **Developing a Metric of Conceptual Distance**

A longer range, fundamental research issue suggested by the concept of traversing virtual cognitive space is that of establishing some metric of conceptual distance. The more related two elements in the semantic network are, the closer they would be located to each other in the virtual three-

dimensional space. One aspect of such a relative metric would be to base the length of each link on the total number of links connecting the two nodes it spans. More complex methods available for determining node proximities from the relationships among nodes include centroid and annealing heuristics and multidimensional scaling (Fairchild, Poltrock, & Furnass, 1988).

These approaches involve wrestling with complicated issues about what constitutes "relatedness." For example, any metric distance function must be based on three axioms:

- minimality: the distance from point a to point b must be greater or equal to the distance from point a to itself, which must be equal to zero
- symmetry: the distance from point a to point b must be equal to the distance from point b to point a
- the triangle inequality: the distance from point a to point b plus the distance from point b to point c must be greater than or equal to the distance from point a to point c

Tversky (1977) discusses how similes such as "my love is as deep as the ocean" violate these axioms.

Such difficulties may be partially overcome by improved theories of analogy. For example, Gentner (1983) describes how relations between objects—rather than attributes of objects—can form the basis of structure-mapping to express a semantic comparison. This type of analogical relationship, readily expressible in a semantic network formalism, is a form of similarity typical of conceptual distance issues in training situations.

As an alternate means of imaging a metric of conceptual distance for mental models, three dimensions related to the content of a semantic network could be mapped onto spatial x, y, and z coordinates. For example, nodes representing different animals could be plotted on dimensions of size, predacity, and domesticity. The attributes along which the coordinate axes were scaled could be varied depending on the purpose for which that particular aspect of the network was being viewed.

At times, a network instantiating the training material itself may be depicted, rather than a mental model expressing its semantic classification structure. In this situation, the observer's purpose becomes a central determinant of conceptual distance, since many possible relationships can be posited between the extended sets of information present in any two nodes. Frisse and Cousin's work (1989) illustrates the sophisticated metrics that are needed to establish conceptual distance under these conditions; given a specific query, their research utilizes inverted indices and term-weighting schemes to quantify the utility of viewing any particular node.

One established computational architecture for implementing conceptual distance as an attribute of these semantic representations would be belief networks: directed acyclic graphs in which links represent direct dependencies

between nodes and the strengths of these dependencies are quantified by conditional probabilities (Pearl, 1986). Such a formalism would be very useful in expressing how conceptual distance changes as the learner progresses from novice to expert. The perceived relatedness of two nodes would increase as their content was mastered, shrinking the conceptual distance between them.

A belief network could quantify this change through conditional probabilities; the three-dimensional image could depict such a shift by portraying the link as curved rather than straight (similar to a gravity-well representation in the space-time continuum). Animating this type of representation would highlight the progression of learning through the mental model. Also, when the learner was using such a representational system, this computational architecture would allow strategies to aid in belief revision, such as dependency-directed backtracking (de Kleer, 1986).

By building on the analogy to real-world spatial relationships, metrics for conceptual distance would increase the expressive power of visual representations of complexity. Qualitative measures that might become more feasible include:

- judgements about the difficulty a student would have in adding a new concept to his existing mental model
- assessments of the degree of belief an individual has in an aspect of his mental model
- measurements of the cognitive overhead involved in interacting with a cluster of new ideas
- identification of potential conceptual bottlenecks in a subject matter

In summary, a metric of conceptual distance would be a very difficult capability to add to a tool for imaging mental models (or any representation of virtual cognitive space). However, the power that such a functionality would create—allowing a translation of users' understanding of spatial distance to symbolic domains—justifies attacking this challenging problem.

## V. CONCLUSIONS AND RECOMMENDATIONS

This project has developed functional specifications for a computer-based tool, Mental Link, that images classification-problem-solving mental models. Hypermedia—a knowledge representation emerging from advances in information technology, artificial intelligence, and cognitive science—is used as the nonlinear representational architecture. Strategies from the field of scientific visualization have been applied to allow the presentation of complicated information without overwhelming the viewer. To empower intelligent responses from the tool, artificial intelligence capabilities, such as inferencing over the network structure, have been incorporated into the design.

Cognition enhancers, classification problem solving, hypermedia representations of semantic networks, visualization of virtual cognitive space,

and semantic navigation are the fundamental design principles underlying Mental Link. Combined, they provide a representational architecture for mental models different and more powerful than any medium now being used to conceptualize and evaluate the training process. These design strategies also suggest the foundations of a general theory for traversal of virtual cognitive space.

The evolving scale and complexity of technical training necessitate new paradigms for increasing the effectiveness of the instructional process. Conceptualizing training as the development of mental models is a promising method for synthesizing and extending today's leading edge training practices. Mental Link is flexible enough as a representational medium to enhance many current military and aerospace training initiatives. In addition, this imaging tool for virtual cognitive space would empower the exploration of many research issues currently unstudied for lack of suitable representational and evaluative tools.

Given the functional specifications generated by this project, the next stage of development would be to commit resources for building Mental Link. Conducting user interface prototyping, initiating a task analysis, and selecting "proof of concept" demonstrations to enhance dissemination are supplementary research activities that would enhance the tool's ultimate capabilities for improving military and aerospace training.

## REFERENCES

- Augusteijn, M.F., Fosha, C., & Kolbe, R.W. (1989). Intelligent training system for orbital mechanics (AFHRL-TR-88-47). Brooks AFB, TX: AFHRL.
- Basseches, M. (1986). Dialectical thinking and young adult cognitive development. In R.A. Mines & K.S. Kitchener (Eds.), Adult cognitive development: Methods and models. New York: Praeger.
- Benedikt, M. (1990). Introduction. In Collected abstracts from the first conference on cyberspace. Austin, TX: School of Architecture, University of Texas.
- Binkin, M. (1986). Military technology and defense manpower. Washington, DC: Brookings Institute.
- Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher 18 (1), 32-42.
- Brown, C.M. (1988). Human-computer interface design guidelines. Norwood, NJ: Ablex.
- Cantor, N., & Kihlstron, J. (1987). Personality and social intelligence. Englewood Cliffs, NJ: Prentice-Hall.
- Carlson, D.A., & Ram, S. (1990). HyperIntelligence: The next frontier. Communications of the ACM 33 (3), 311-321.
- Carlson, P.A. (1989). Hypertext and intelligent interfaces for text retrieval. In E. Barrett (Ed.), The society of text: Hypertext, hypermedia, and the social construction of knowledge. Cambridge, MA: MIT Press.
- Chase, W.G., & Simon, H.A. (1973). The mind's eye in chess. Visual information processing. New York: Academic Press.
- Clancey, W. (1984, August). Classification problem solving. In Proceedings of the American Association of Artificial Intelligence. Los Altos, CA: Morgan Kaufmann.
- Claxton, C.S., & Murrell, P.H. (1987). Learning styles: Implications for improving educational practices. Washington, DC: Association for the Improvement of Higher Education.
- Conklin, J. (1987). Hypertext: An introduction and survey. Computer 20 (9), 17-41.
- Corno, L. (1986). The metacognitive control components of self-regulated learning. Educational Psychologist 18, 88-108.

- Dede, C. (1989a). Technological trends shaping the future of teacher education. In Future societal trends: Implications for teacher education in the twenty-first century, pp. 9-32. Madison, Wisconsin: University of Wisconsin System.
- Dede, C. (1989b, October) The evaluative imaging of mental models: Visual representations of complexity. Proceedings of the American Institute of Aeronautics and Astronautics computers in aerospace VII conference, 433-438. Washington, DC: AIAA.
- Dede, C., Sullivan, T., & Scace, J. (1988). Factors Shaping the Evolution of Electronic Documentation Systems. Houston, TX: Research Institute for Computing and Information Systems, University of Houston-Clear Lake.
- Dede, C. (1987). Artificial intelligence applications to high technology training. Educational Communications and Technology Journal 35 (3), 163-181.
- de Kleer, J. (1986). Dependency-directed backtracking. Encyclopedia of Artificial Intelligence. New York: Wiley.
- Denenberg, S.E. (1988). Semantic network designs for courseware. In D.H. Jonassen (Ed.), Instructional designs for microcomputer courseware. Hillsdale, NJ: Lawrence Erlbaum Associates.
- diSessa, A.A. (1982). Unlearning aristotelian physics: A study of knowledge-based learning. Cognitive Science 6, 37-75.
- Fairchild, K.F., & Wexelblat, A. (1989). Navigation through cyberspace (MCC Technical Report Number STP-161-89). Austin, TX: Microelectronics and Computer Technology Corporation.
- Fairchild, K.F., Poltrock, S.E., & Furnas, G.W. (1988). SemNet: Three-dimensional graphic representations of large knowledge bases. In R. Guindon (Ed.), Cognitive science and its applications for human-computer interaction. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Fisher, S.S., Wenzel, E.M., Coler, C., & McGreevy, M.W. (1988, October). Virtual interface environment workstations. In Proceedings of the annual meeting of the Human Factors Society. New York: ACM.
- Fletcher, J. D. (1988). Intelligent training systems in the military. In G. W. Hopple & S. J. Andriole (Eds.), Defense applications of artificial intelligence: Progress and prospects. Lexington, MA: D.C. Heath & Co.
- Frisse, M.E., & Cousins, S.B. (1989, November). Information retrieval from hypertext: Update on the dynamic medical handbook project. In Proceedings of Hypertext '89. New York: ACM.
- Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. Cognitive Science 7, 155-170.

- Gibson, W. (1984). Neuromancer. New York: Ace.
- Goldstein, I.P. (1982). The genetic graph: A representation of the evolution of procedural knowledge. In D. Sleeman & J.S. Brown (Eds.), Intelligent tutoring systems. New York: Academic Press.
- Greeno, J.G. (1983). Conceptual entities. In D. Gentner & A.A. Stevens, Mental Models. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Halasz, F., & Conklin, J. (1989, May). Issues in the design and application of hypermedia systems (workshop manual from the Association for Computing Machinery Computer-Human Interaction conference). New York: ACM.
- Halasz, F.G. (1988). Reflections on Notecards: Seven issues for the next generation of hypermedia systems. Communications of the ACM 31 (7), 836-855.
- Holland, J.H., Holyoak, K.J., Nisbett, R.E., & Thagard, P.R. (1986). Induction: Processes of inference, learning, and discovery. Cambridge, MA: MIT Press.
- Johnson-Laird, P.N. (1983). Mental Models. Cambridge, MA: Harvard University Press.
- Jonassen, D.H. (1989). Hypertext/Hypermedia. Englewood Cliffs, NJ: Educational Technology Publications.
- Jonassen, D.H. (1986). Hypertext principles for text and courseware design. Educational Psychologist 21 (4), 269-292.
- Kitchener, K.S. (1986). The reflective judgement model: Characteristics, evidence, and measurement. In R.A. Mines & K.S. Kitchener (Eds.), Adult cognitive development: Methods and models. New York: Praeger.
- Marshall, C.C., & Irish, P.M. (1989, November). Guided tours and on-line presentations: How authors make hypertext intelligible for readers. In Proceedings of Hypertext '89. New York: ACM.
- McAleese, R. (1989). Navigation and browsing in hypertext. In R. McAleese (Ed.), Hypertext: Theory into practice. Norwood, NJ: Ablex.
- McCormick, B.H., DeFanti, T.A., and Brown, M.D. (1987). Visualization in scientific computing. Computer Graphics 21 (6), 1-14.
- Nielsen, J. (1990). The art of navigating through hypertext. Communications of the ACM 33 (3), 298-310.

- Norman, D.A., Gentner, S., & Stevens, A.L. (1976). Comments on learning schemata and memory representation. In D. Klahr (Ed.), Cognition and Instruction. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Pea, R.D. (1988). Putting knowledge to use. In R.S. Nickerson & P.P. Zohdriates (Eds.), Technology in education: Looking toward 2020. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Pearl, J. (1986). Fusion, propagation, and structuring in belief networks. Artificial Intelligence 29 (3), 241-288.
- Pintrich, P.R. (1990). Implications of psychological research on student learning and college teaching for teacher education. In R. Houston (Ed.), Handbook of research on teacher education. New York: Macmillan.
- Pintrich, P.R. (1988). A process-oriented view of student motivation and cognition. In J. Stark & L. Mets (Eds.), Improving teaching and learning through research: New directions for institutional research (Vol 57). San Francisco: Jossey-Bass
- Porter, B.W., Acker, L.H., Lester, J.C., & Souther, A. (1989, April). Generating explanations in an intelligent tutor designed to teach fundamental knowledge. In Proceedings of the 2nd intelligent tutoring systems research forum. Brooks AFB, TX: Intelligent Systems Branch, AFHRL.
- Reigeluth, C.M., & Stein, F.S. (1983). The elaboration theory of instruction. In C.M. Reigeluth (Ed.), Instructional design theories and models: An overview of their current status. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Russell, D.M., Moran, T.P., & Jordan, D.S. (1987). The instructional design environment. In J. Psocka, L.D. Massey, & S.A. Mutter (Eds.), Intelligent tutoring systems: Lessons learned. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sternberg, R.J. (1988). The triarchic mind: A new theory of human intelligence. New York: Viking Penguin.
- Stevens, A.A., & Gentner, D. (1983). Introduction. In D. Gentner & A.A. Stevens (Eds.), Mental models. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Tufte, E.R. (1983). The visual display of quantitative information. Cheshire, CT: Graphics Press.
- Tversky, A. (1977). Features of similarity. Psychological Review 84, 327-352.
- Utting, K., & Yankelovitch, N. (1989). Context and orientation in hypermedia networks. ACM Transactions on Information Systems 7 (1), 58-84.

Wittrock, M.C. (1978). The cognitive movement in instruction. Educational Psychologist 13, 15-29.

Woods, W.A. (1985). What's in a link?: Foundations for semantic networks. In R.J. Brachman & H.J. Levesque (Eds.), Readings in knowledge representation. Los Altos, CA: Morgan Kaufmann.

## **APPENDIX: GUIDED TOUR THROUGH THE FUNCTIONAL SPECIFICATIONS**

This Appendix to the report presents detailed instructions for using the prototyping software files developed in this project to simulate the capabilities of Mental Link. Even if this software is not available to the reader, the descriptions and figures below give an overview of the functionalities and interface for this mental modeling application. In addition, the longer of the two videotapes produced by this study ("Functional Design for a Tool That Images Mental Models") gives a visual depiction of most material in this Appendix. The shorter video ("Imaging Mental Models") adds a description of the rationale underlying the development of this prototype and suggests possible uses for Mental Link if it were to be constructed, while presenting a more abbreviated version of the functional specifications.

To focus attention on the attributes of the tool rather than the content of the mental model being imaged, the sample model used in this simulation of the tool's operation was chosen to be both simple and familiar. The prototype below illustrates traversal through parts of a mental model of basic medical knowledge, the sort that most adults have learned through their own experience. This model is incomplete and is not intended to represent an actual training curriculum, nor did the authors go to great lengths to ensure its accuracy (beyond general verisimilitude). Accordingly, the reader's focus should be on the capabilities of the tool rather than on the attributes of the model being imaged.

### **Overview of Objectives**

On completion of this tour, the reader will be able to accomplish the following objectives:

1. Distinguish between local and global views of the model, Mental Link.
2. Define categories, entities, and intra- and inter-category links.
3. Move among the different hierarchical levels of the model using mouse-commands or the "Shift," "Move" and "Jump" pull-down menus.
4. Toggle between informational and relational modes of displaying entities.
5. Access entity descriptors and link descriptors by pop-up definitions.
6. Perform several types of diagnostic matching among entities and among clusters of the same category and across categories.
7. Author and display related entities in sizes proportional to a selected criterion.

8. Author and display entity clusters in an X-Y plane, where the X and Y axes define an independent and a dependent variable, respectively.
9. Author a navigational tour through the web structure; after creating a tour, access any point of the tour through a tour map.
10. Create new categories, entities, links and clusters.
11. Modify or remove existing categories, tours, entities and links.
12. By invoking the "History" function in global view, identify the previously traversed entities and links during this use of the model.
13. Reduce the visual complexity of the global view by applying previously created filters; create such filters.
14. Create and display entity clusters in several colors in global view, with each color having a legend about some distinguishing attribute.

### **Before Beginning the Guided Tour**

Since this prototype model is a simulation only, without any working codes that generates the actual functionalities of the application, following the directions for activating for each feature on the tour is important. For example, beginning the tour in the middle may cause some portions of the scripts not to function as described in the instructions. Although the place in the model from which each demonstration begins may seem arbitrary, the tour is scripted to perform properly only if commands are used in the proper sequence.

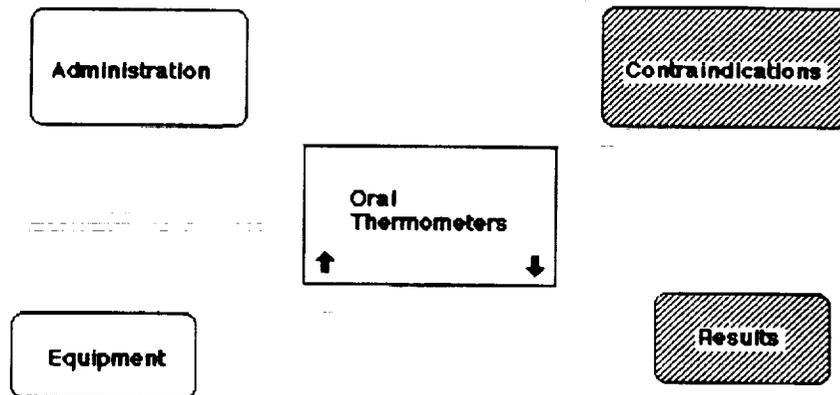
This demonstration requires a Macintosh II™ with at least 4MB of memory, System 6.0.5 (the data fields in the model may not display properly on earlier versions of the Macintosh system software), a 640X480 color monitor set for 256 colors on the palette (the program will not display legibly in black-and-white), and the SuperCard™ application. Portions of the simulation can be run on a Macintosh with only 2MB, but the three-dimensional color screens require the additional memory. The tour must be run under the Macintosh Finder, not the MultiFinder. To initiate the tour, open the "Mental Link" SuperCard file developed by this project; the other files in the "SC Pouch" folder are used by SuperCard to run the "Mental Link" simulation.

New terms and concepts are defined as they are used. The tour does assume a basic familiarity with the Macintosh interface of mouse commands and pull-down menus; please consult the Macintosh manual if additional information is needed. (Although the tour has been created to work on a Macintosh computer, Mental Link has been designed to be hardware-independent, using interface features standard on many brands of computers.)

## Functional Specifications for Mental Link

### Global and Local Views of Mental Models

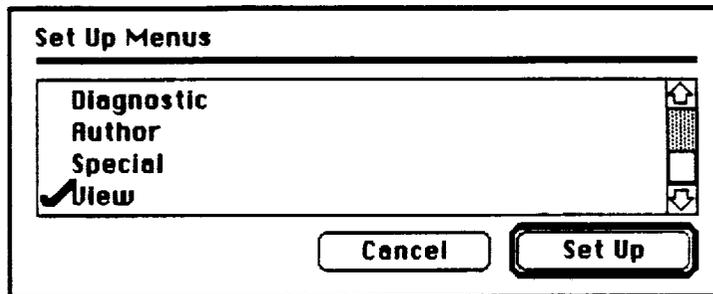
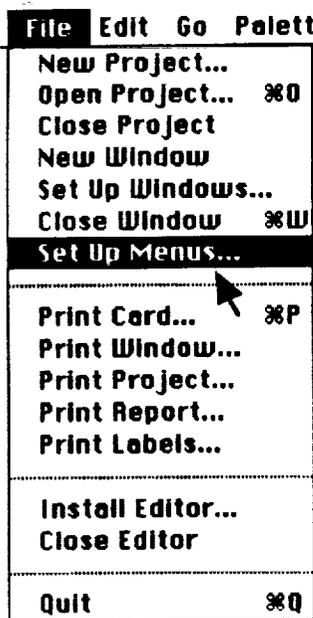
The program opens to the screen image shown in Figure A-1:



**Figure A-1. Initial Screen Image**

Under the "File" pull-down menu, activate the menu item "Set up Menus" (See Figure A-2). On the list of menu items from which to choose, click on "View" to place a check mark next to it, then click the "Set Up" button. Now pull-down the "View" menu and activate "Global Browse" (see Figure A-3).

The image shown on the screen will now be that in Figure A-4: this is the sample mental model in "global" view. The model used to illustrate the functional specifications for this tool consists of a medical classification system having many categories (i.e. Symptoms, Diagnostic Methods, Diseases, Therapies). "Symptoms" and "Diseases" are conceptual categories because they represent descriptive information about real-world phenomena (e.g. a fever). In contrast, "Diagnostic Methods" and "Therapies" are procedural categories; they provide information about processes by which people interact with phenomena (e.g. using an oral thermometer). As discussed later, typically conceptual and procedural categories would present information in different formats to reflect distinctions in the types of entities they contain.



**Figure A-2. Setting Up Menus**



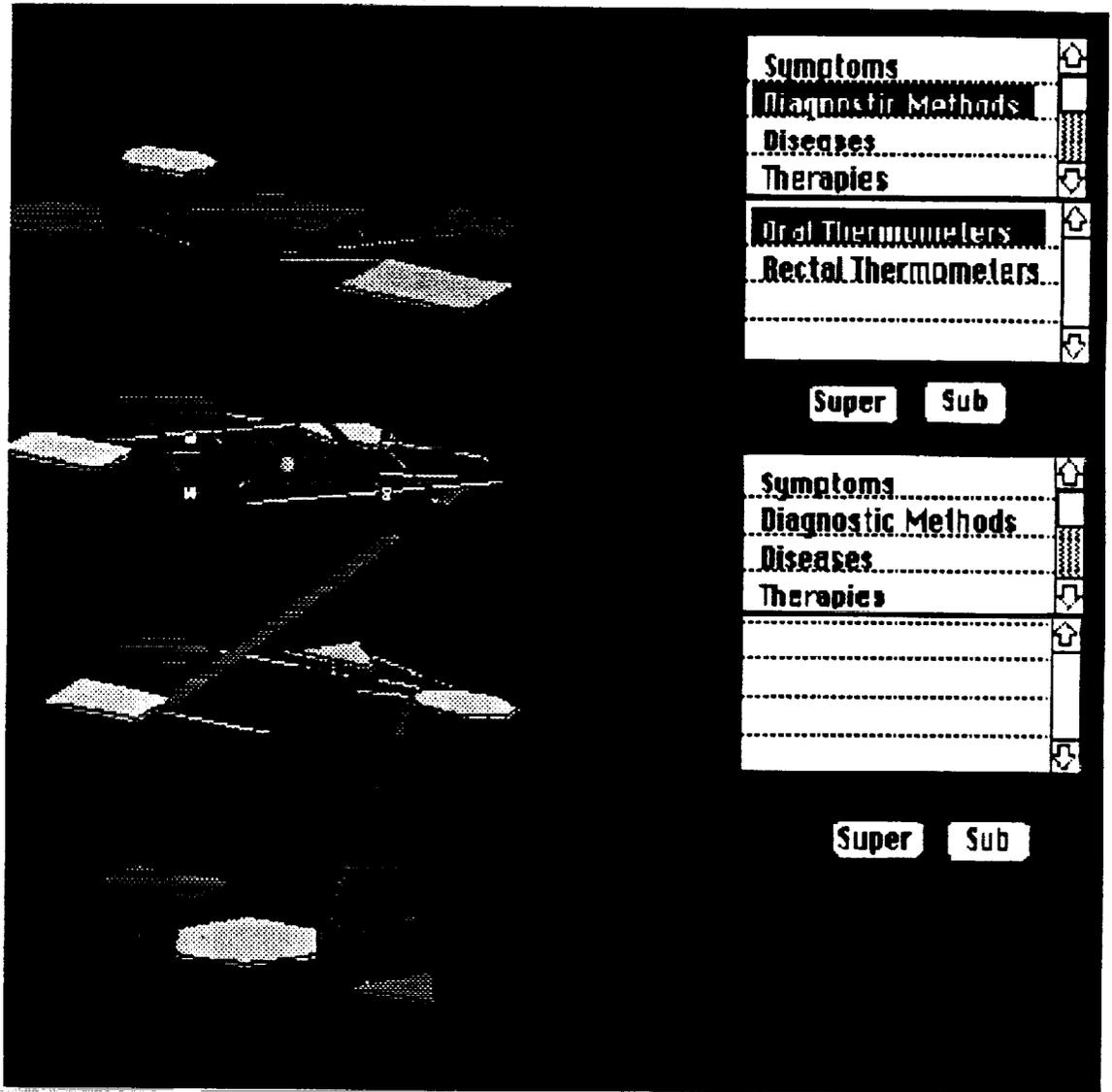
**Figure A-3. "Global Browse" from "View" Menu**

Each category is presented in a separate three-dimensional (3-D) plane parallel to the other categories' planes in the model. Within each category, entities are represented by geometric symbols. Links (represented by lines) can connect entities in the same category or across categories. In this global view of the sample mental model, the category planes from top to bottom image symptoms, diagnostic methods, diseases and therapies.

In global view, a column of scroll boxes is visible to the right of the 3-D image. The scroll box at the very top is for selecting the category to be displayed in the "local" (two-dimensional, detailed) view. Below this scroll box is a second scroll box for selecting the entity in that category system to be at the center of focus. The third and fourth scroll boxes perform similar functions in selecting another category and entity. This provides a way of highlighting any link that exists between the two entities selected using these sets of scroll boxes.

One can access different hierarchical levels of an entity by the "Super" and "Sub" buttons below the entity scroll box. For example, the entity "Oral Thermometers" in the "Diagnostic Methods" category system would have "Thermometers" as its superlevel, while "Analog Oral Thermometer" and "Digital

Oral Thermometer" would be its sublevels. In Figure A-4, the entity "Oral Thermometer" has been selected, and therefore the corresponding symbol is highlighted on the 3-D view. (To minimize visual clutter in this prototype, the super- and sub-levels of each entity are not imaged in the global view.)



**Figure A-4. Global View of the Medical Mental Model**

In the actual working model, one could double-click on a highlighted symbol to move to the local view with that entity at the center of focus; this could not be implemented using the prototyping software. Instead, the local view of "oral thermometer" can be accessed by an alternate method: selecting the menu item "Local Browse" from the "View" pull-down menu (Figure A-5).

## Informational Mode

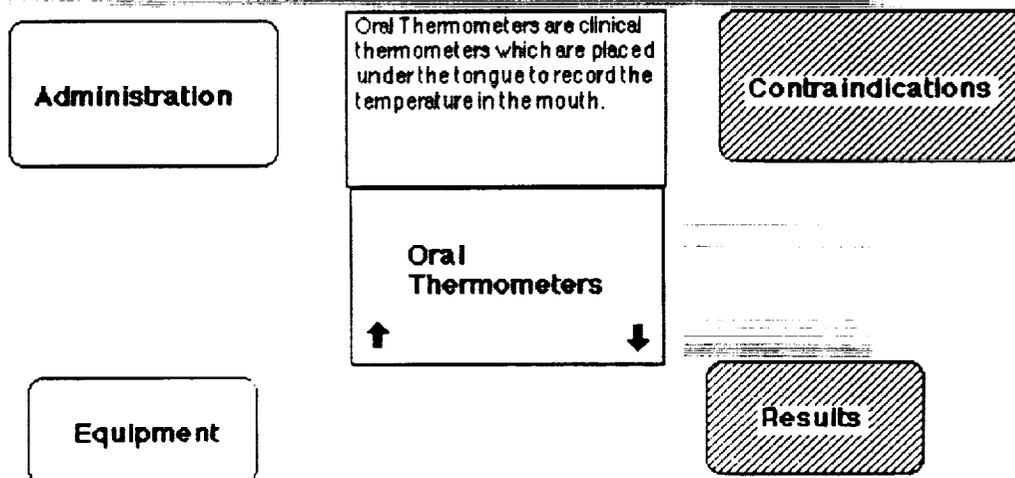
Activating this function brings up the screen of information that initially



**Fig A-5. "Local Browse" from "View" Menu**

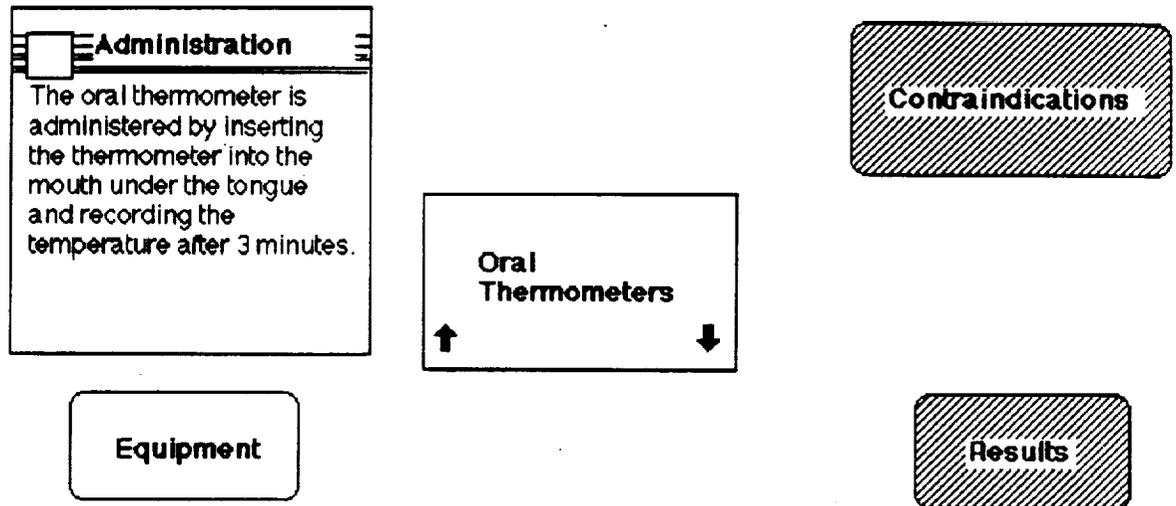
appeared when the tour began (Figure A-1). Clicking on the box labelled "Oral Thermometer" pops-up a detailed definition of this entity (Figure A-6). Clicking anywhere in the definition box puts it away again.

The "Oral Thermometer" entity is surrounded by rounded rectangles labelled "Equipment," "Administration," "Contraindications," and "Results." In local view, these types of symbols surrounding a entity can be used to access in-depth information about aspects of that entity; they are differentiated from entities by their rounded shape and their shading. This type of image (an entity surrounded by related informational symbols) is known as "informational" mode. Because of the nature of their entities, procedural category systems are typically represented in informational mode—as opposed to "relational" mode, the other type of local view (to be described later).



**Figure A-6. Pop Up Definition**

Clicking on "Administration" brings up instructions for using the thermometer (Figure A-7). Clicking on the "close box" at the top left corner of these instructions puts them away again. Clicking on "Equipment" brings up a diagram of a thermometer; this illustrates that the contents of these informational nodes could be text, graphics, animations, sound, images, video. In other words, the tool has full hypermedia capabilities.



**Figure A-7. Pop-Up Information**

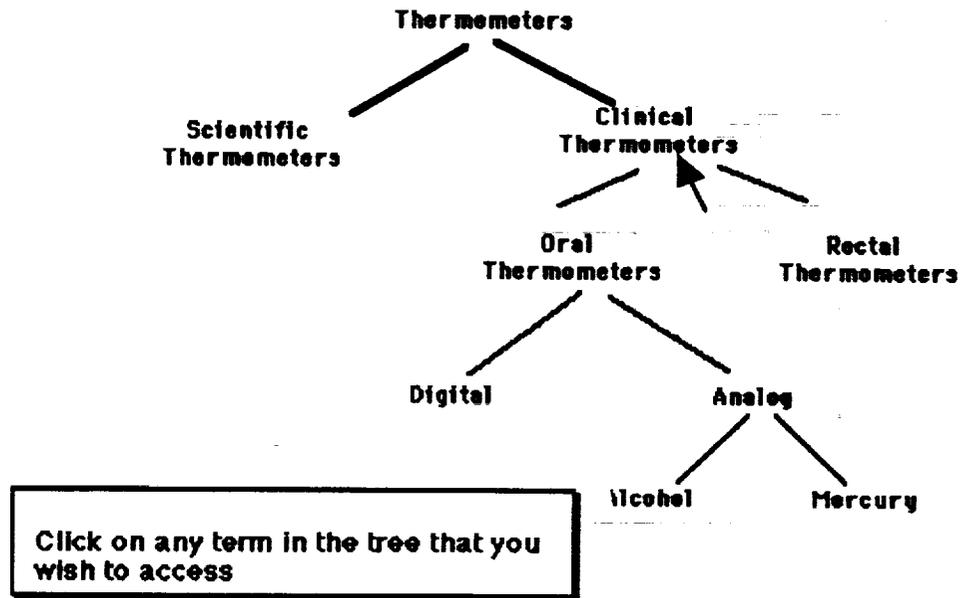
### **Shift-Navigation**

Mental Link empowers three types of semantic navigation. Shift-navigation is used for moving up and down the hierarchical levels of a particular entity. Move-navigation alters the center of focus among entities in the same category system. Jump-navigation can change the center of focus to an entity in a different category system. Enabling three dimensions of navigation helps to reduce user disorientation when traversing virtual cognitive space. Each of these types of navigation will be demonstrated in turn, beginning with shift-navigation.

Clicking on the "up-arrow" symbol on the "Oral Thermometer" entity brings up a tree showing the hierarchical classification of thermometers (Figure A-8). By clicking on the word "clinical" in the tree, the local view shifts one level up in the hierarchy. Now "Clinical Thermometer" is the center of focus, surrounded by its informational symbols. Clicking on the "down-arrow" symbol on the "Clinical Thermometer" entity brings up another tree which shows this entity's sub-levels in the hierarchy. Clicking on "Oral Thermometer" returns to the local view screen with the "Oral Thermometer" entity as the center of focus.

Through similar use of the up- and down-arrow symbols, the local view can be shifted to a sub-level, "Analog Thermometers," and back again.

### THERMOMETER TREE



**Figure A-8. "Thermometer" Tree**

This navigation up and down a classification hierarchy can also be accomplished with pull-down menu commands. Please go back to the "File" menu and choose the item "Set Up Menus" again (as shown in Figure A-2). This time, deselect the "View" menu and instead choose the "Shift" menu by selecting it and clicking on the "Set Up" button. Pulling-down the "Shift" menu now reveals two items: "Super-Level" and "Sub-Level" (Figure A-9). Selecting these items brings up the same hierarchical trees as the up- and down-arrows activated.

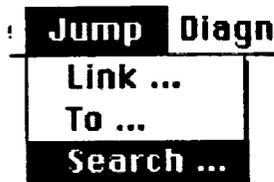


**Figure A-9. "Shift" Menu**

## **Relational Mode**

As discussed earlier, relational mode is an alternate type of local view to informational mode. So far, this demonstration has focused on a procedural category, "Diagnostic Methods," whose entities would typically be shown in informational mode. Since relational mode is most useful in conceptual categories, such as "Symptoms," changing the center of focus to an entity in that category system is necessary. Just as shifting provides a way of navigating up and down the hierarchical levels of a category system, jumping is a method of traversing from one category system to another.

Once again, choose "Set Up Menus" from the "File" Menu (Figure A-2). This time, deselect the "Shift" menu and instead activate the "Move," "Jump," and "Special" menus. From the "Jump" pull-down menu, activate "Jump Search" (Figure A-10).



**Figure A-10. "Jump Search" from "Jump" Menu**

The dialog box in Figure A-11 appears on the screen. "Jump Search" is one of three methods of jump-navigation (the other two, "Jump Link" and "Jump To," will be described later). "Jump Search" allows the user to access any entity in the mental model as the center of focus in local view; typically, this feature would be used to shift the center of focus between entities in different category systems. Using the name-of-entity field in the dialog box, the user can name the entity directly and jump to it. Or, if unsure of the entity's name, the user can specify the category system to be searched in the name-of-category field and then can enter terms describing attributes of the entity in the descriptive-terms field. Mental Link performs a search through its database records on entities, their informational descriptions, and their link rationales. Based on the results of this search, a list of entities that provide a match for these descriptive terms is made available.

To enter information in one of the fields for data entry, the cursor must first be placed in that field. Please position the cursor on the line "Name of Entity" and click; the cursor changes to an I-beam, indicating that the field is ready to receive information. Type the term "Moderate Fever" (without quotes), then—without pressing the "Return" or "Enter" keys on the keyboard—click on the "Search" button.

**ENTITY SEARCH IN OTHER CATEGORY SYSTEMS**

To perform search, please provide at least one of the information items listed below:

Name of Entity \_\_\_\_\_

Name of Category \_\_\_\_\_

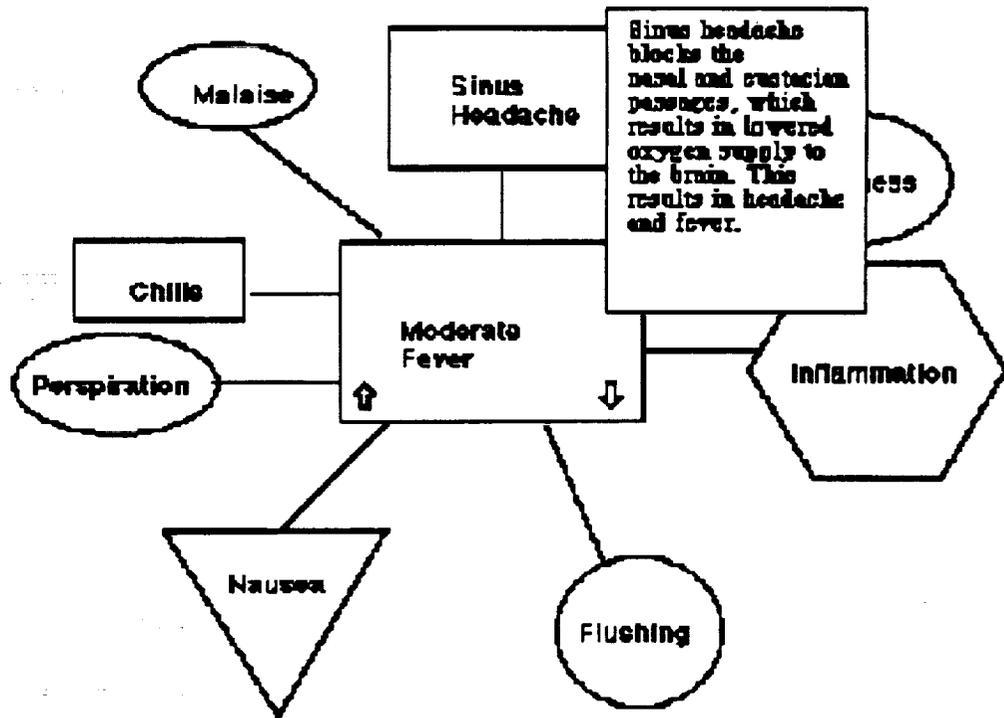
Descriptive terms \_\_\_\_\_

**Figure A-11. "Jump Search" Dialog Box**

The screen now displays the entity "Moderate Fever," which is in the "Symptoms" category system, surrounded by other conceptual entities in the same category (Figure A-12). This display is in relational mode (the typical default mode for conceptual category systems). The entities surrounding "Moderate Fever" are not the informational symbols that earlier were depicted around "Oral Thermometers," but instead are conceptual entities representing other symptoms.

The lines between these entities are links showing some causal or correlational relationship. Clicking on the line connecting "Moderate Fever" to "Sinus Headache" brings up a box explaining the relationship between these two entities; these boxes are called "link rationales." As with the informational nodes shown earlier for "Oral Thermometer," these boxes can be made to disappear again by clicking anywhere within them. Similarly, clicking on the "Moderate Fever" entity (in the lower right quadrant of its icon) brings up a box with a brief definition.

Thus, a brief description of an entity can be accessed in relational mode. The user can access more detailed information by activating the appropriate selection on the "Special" pull-down menu (Figure A-13) to toggle to informational mode for this entity. (If this selection is "greyed out" on the pull-down menu, activate the alternate mode—in this case, "Relational"—to make it accessible.) The screen display in Figure A-14 is now visible, paralleling the earlier informational mode display discussed for the "Oral Thermometers" entity.



**Figure A-12. "Moderate Fever" in Relational Mode**

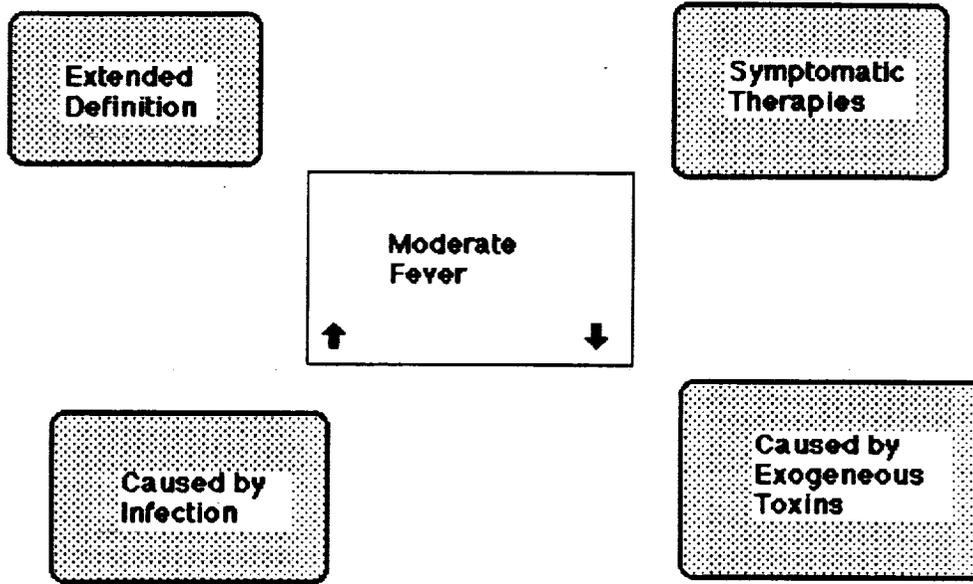


**Figure A-13. Changing to Informational Mode**

### **Shape and Meaning.**

Please use the "Special" pull-down menu again to return to relational mode (Figure A-12). Another important aspect of the relational screen display is that entities are represented by geometric symbols having different shapes. These shapes indicate relative position in the levels of classification hierarchy described earlier in the discussion on shift-navigation. For example, the entity "Inflammation" is at the highest level of its hierarchical tree—having sublevels, but not superlevels—so it is displayed as a hexagon. The triangle surrounding

"Nausea" indicates that it is at the lowest level in its tree—having superlevels, but not sublevels. Rectangles indicate entities that have both superlevels and sublevels (are somewhere in the middle of their hierarchies). Circles and ovals depict flat entities without hierarchical levels. Thus, shape has meaning; even in a glance, users can learn much about the interrelationships among a complex web of entities at different levels in interrelated hierarchies.



**Figure A-14. "Moderate Fever" In Informational Mode**

### **Move-Navigation**

Move-navigation provides a method of changing the center of focus to a different entity in the same category system. Please put away any open descriptor boxes by clicking on them. Now activate the "Move To" selection on the "Move" pull-down menu (Figure A-15).

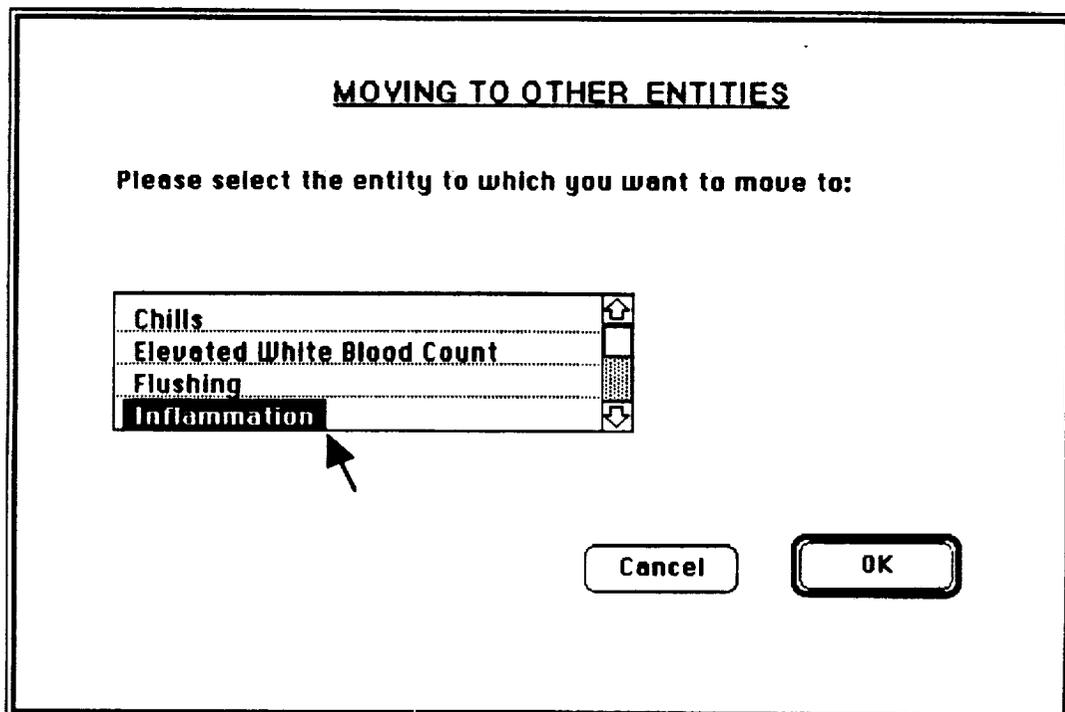


**Figure A-15. "Move To" from "Move" Menu**

The screen will show the dialog box in Figure A-16. The scroll box at the center contains a list of all the entities in the category "Symptoms." By clicking on "Inflammation" to highlight it, then clicking on the "OK" button, this entity becomes the new center of focus.

The "Move Search" menu item is similar to the "Jump Search" feature discussed earlier (Figure A-11), except here the focus is limited to entities in the same category. Please use "Move Search" now to change the center of focus back to the "Moderate Fever" entity (remember not to press the "Return" key after entering the entity's name in the name-of-entity field).

In Mental Link, local moves from the current center of focus to another entity in the group surrounding it can be accomplished by mouse commands (shift-clicking) as well as pull-down menus. To illustrate this feature, hold down the shift key while clicking on the "Inflammation" entity. In the tree structure that appears, click on "Inflammation." To get back to "Moderate Fever" as the center of focus, shift-click on the "Fever" entity that is linked to "Inflammation," then click on the term "Moderate Fever" in the tree that appears.



**Figure A-16. "Move To" Dialog**

### **Jump-Navigation**

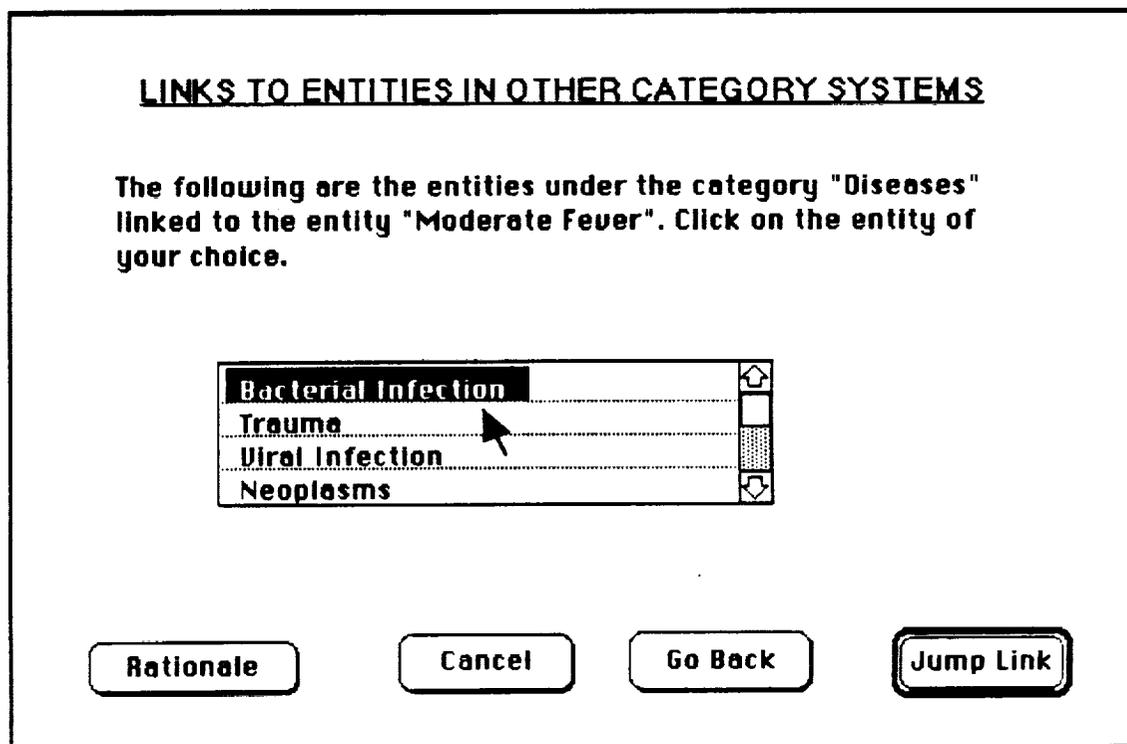
As discussed earlier for the "Jump Search" feature (Figure A-11), jump-navigation provides a means for changing the center of focus to any entity in the mental model, regardless of its category system.

The "Jump Link" menu item changes the center of focus to an entity linked to the current center of focus, but located in some other category system. Activating "Jump Link" on the "Jump" pull-down menu brings up a dialog box that allows the user to select the category system to which to jump. Please

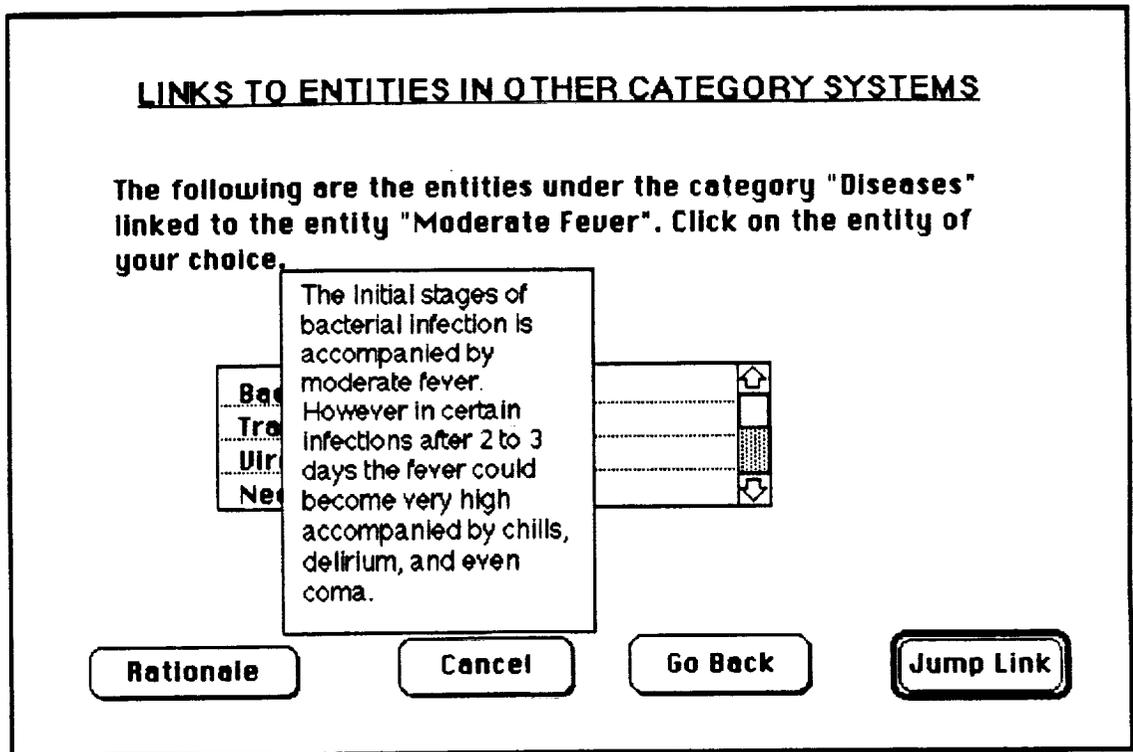
highlight the "Diseases" category in the scroll box, then click on the "OK" button. Another scroll box now appears (Figure A-17) showing all the disease entities linked to the current center of focus, "Moderate Fever." Highlighting "Bacterial Infection" and clicking on the "Rationale" button brings up a descriptive dialog box (Figure A-18) explaining the reason why "Moderate Fever" is linked to "Bacterial Infection." This parallels the rationales for links between entities in the same category system. Now put away the rationale box by clicking on it. Clicking on the "Jump Link" button completes traversal across the link and places "Bacterial Infection" in the "Diseases" category at the center of focus.

As with the other forms of semantic navigation (moving and shifting), jumping can also be accomplished through mouse commands rather than pull-down menus. Please move back to the "Moderate Fever" entity by using the "Jump Search" menu (Figure A-11). Now click on "Moderate Fever" while holding down the "option" key. The same "Jump Link" dialog box appears; click the "Cancel" button to avoid using it.

When the user knows to which entity in another category system he wishes to jump, the "Jump To" feature provides a rapid method of traversal. Please activate the "Jump To" selection on the "Jump" pull-down menu. A dialog box appears with a scroll list of all categories in the system. Highlight the category "Diseases" and then click on the "OK" button. This opens up a "Diseases" tree (Figure A-19) showing the hierarchical relationships of entities in this category system. Clicking on the term "Genetic" in this tree brings up a screen with the "Genetic Diseases" entity as the center of focus.



**Figure A-17. "Jump Link" Dialog**



**Figure A-18. "Jump Link" Rationale**

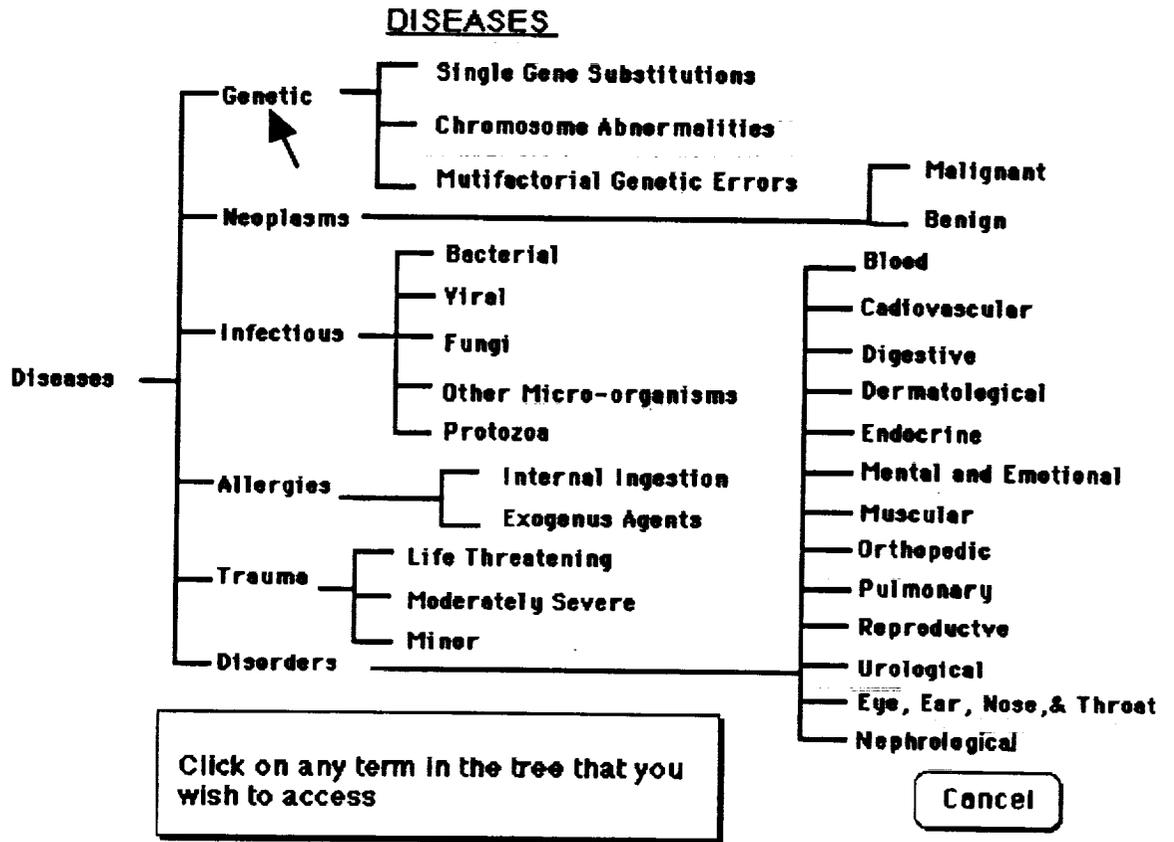
This completes the survey of methods for semantic navigation through the cognitive networks in the mental model. Next, other ways that this tool can image complex relationships will be demonstrated.

### **Diagnostic Clustering**

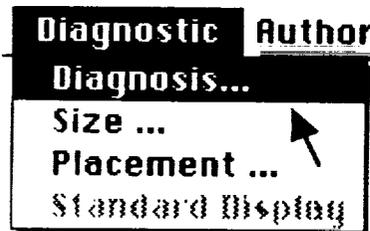
The "Diagnostic" pull-down menu has three selections available: "Diagnosis," "Size," and "Placement." The "Diagnosis" function is used to access different types of diagnostic matching of entities or entity clusters across category systems. The "Size" feature displays related entities in sizes proportional to some given criterion. The "Placement" feature images entities in a virtual X-Y plane, with the X-axis representing an independent variable and the Y-axis a dependent variable. Each of these capabilities will be discussed in turn.

**Diagnosis.** Please use the "Set Up Menus" feature to activate the "Diagnostic" pull-down menu (through the process described in Figure A-2). Make the "Infection" entity the center of focus by using the "Move Search" feature, as described on page 39. Activate the "Diagnosis" selection from the "Diagnostic" pull-down menu (Figure A-20). The dialog box shown in Figure A-

21 appears; this allows selection among the various kinds of diagnostic matching that can be performed.



**Figure A-19. "Diseases" Tree**



**Figure A-20. "Diagnosis" from "Diagnostic" Menu**

The first selection gives information about all entities and categories to which the current center of focus is linked. The second selection displays a screen much like the relational mode in local view, except here the links displayed are from the entity at the center of focus to entities in other category systems (rather than in the same category system, as demonstrated earlier). The third selection can be used to provide a similar inter-category perspective for any entity in the mental model, not just the entity currently the center of focus. The fourth selection allows the user to specify a set of entities in the same

category and to determine if all these are linked to any one entity in another category—this provides a means for identifying a disease from a group of symptoms. The fifth selection compares two sets of entities to provide information about similarities and dissimilarities.

These are all methods of accessing more complex relational information than can be gained by viewing the cognitive structures demonstrated thus far. Each of these five diagnostic capabilities will be now be demonstrated.

**MATCHING ENTITIES IN DIFFERENT CATEGORIES SYSTEMS**

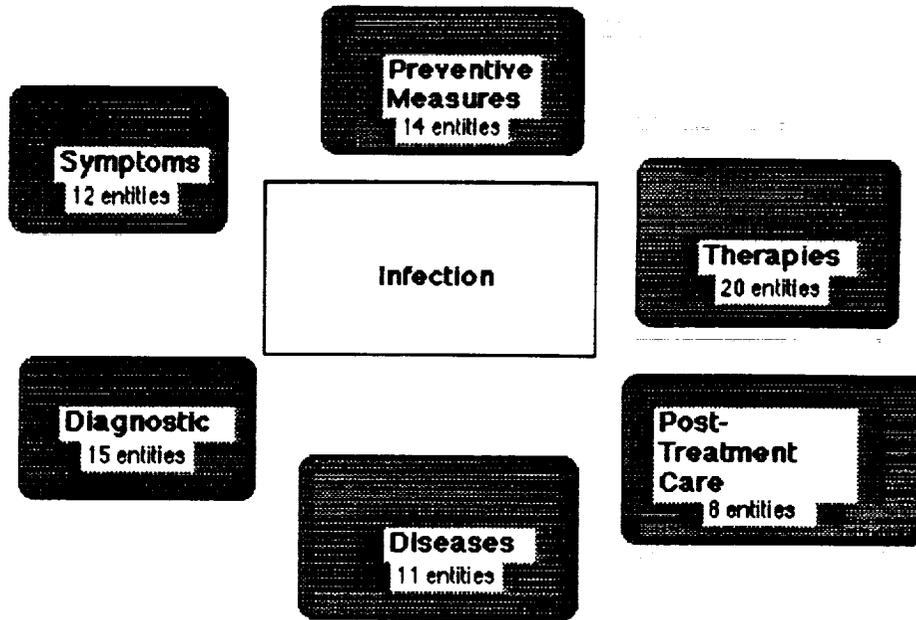
Please specify the type of diagnostic entity matching you wish to perform by clicking on the appropriate button among the following choices:

- Display all linked categories
- Match the current focus to entities in another category
- Match any entity with entities in other categories
- Match entity clusters to a category
- Match entity clusters in two categories

**Figure A-21. "Diagnosis" Dialog**

Please click on the first "radio button" in the "Diagnosis" dialog box to activate this selection, then click on the "OK" button. The display in Figure A-22 appears; it shows, for the current center of focus, the number of linked entities in each category. For example, twelve entities in the "Symptoms" category are linked to "Infection."

Please activate "Diagnosis" again from the "Diagnostic" pull-down menu; this time, select the second radio-button and click on the "OK" button. Highlight "Symptoms" in the scroll box that appears and click "OK." The screen presents a relational view (Figure A-23) depicting links to the twelve symptoms associated with "Infection." As with all relational views shown by the tool, Mental Link automatically creates this virtual image rather than the structure having to be programmed by the author.

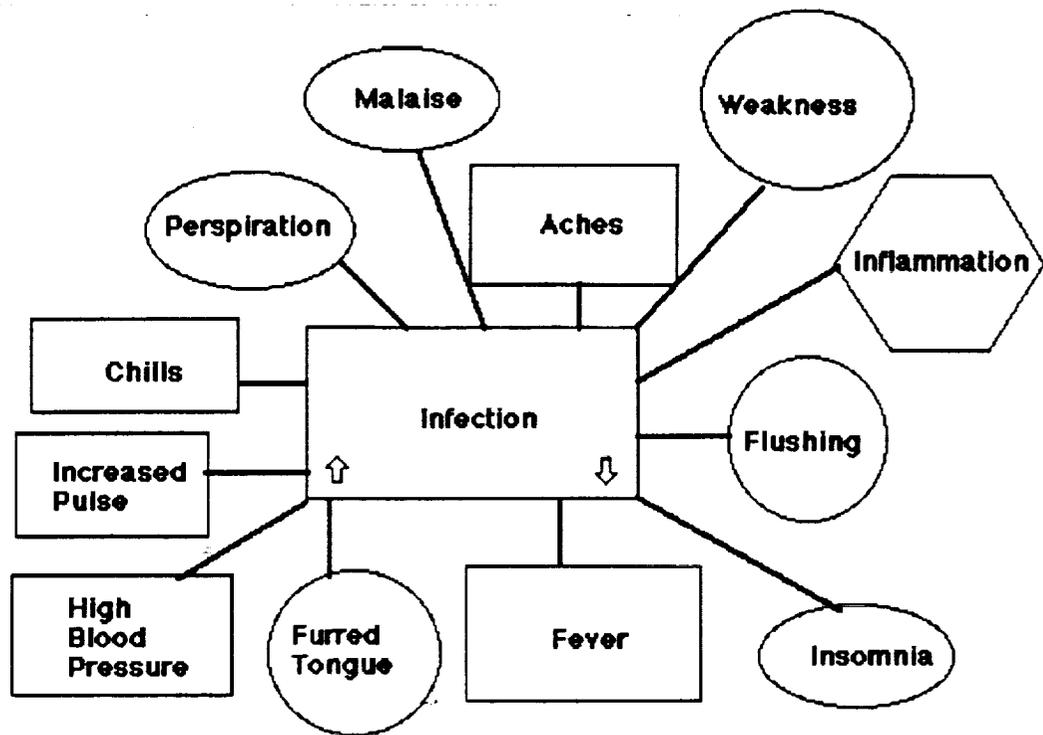


**Figure A-22. Numbers of Linked Entities**

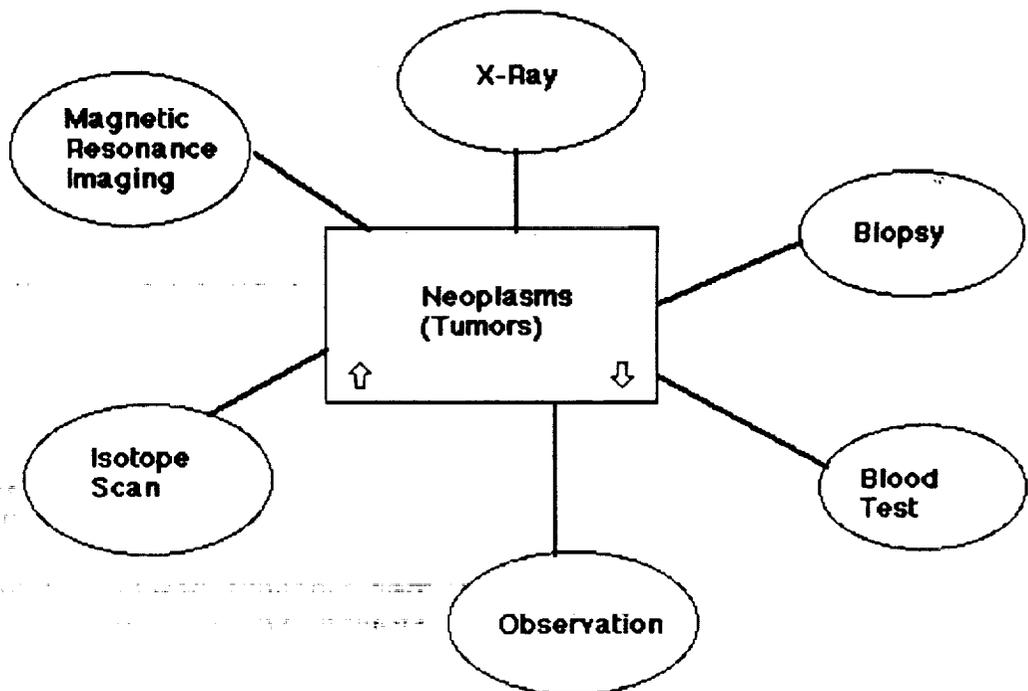
The third item on the Diagnostic dialog box provides this same functionality for any entity. Please activate "Diagnosis" again from the "Diagnostic" pull-down menu, selecting the third radio-button and clicking on the "OK" button. This brings up a scroll box of categories; highlight "Diseases" and click "OK"; then highlight "Neoplasms" in the next scroll box and click "OK." Another scroll box appears to select the category with which you wish to match "Neoplasms"; highlight "Diagnostic Methods" and click "OK." Now "Neoplasms" and its related diagnostic methods are imaged on the screen (Figure A-24).

In the fourth type of diagnostic clustering, a set of entities in the same category is selected to determine if all these are linked to any one entity in another category (an opposite functionality to that of the second type of clustering). Please activate "Diagnosis" again from the "Diagnostic" pull-down menu; this time, select the fourth radio-button and click on "OK." A scroll box of categories appears; highlight "Symptoms" and click "OK." The screen now shows the dialog box in Figure A-25. On the left-hand side is a scroll box for selecting categories with the default selection, "Symptoms," highlighted. On the right-hand side is another scroll box listing all the entities in the "Symptoms" category. Highlight "Congestion" and click on the "Add" button; notice that this term now appears in the selected-entities field on the lower left.

Similarly, please select and add—one at a time—the entities "Cough," "Sinus," and "Fever." Imagine that 12 such entities have been selected and added (the prototyping software is limited to demonstrating four choices). Now click the "OK" button. A scroll box appears for selecting the category to which you want to match this symptoms cluster. Highlight "Diseases" and click "OK."

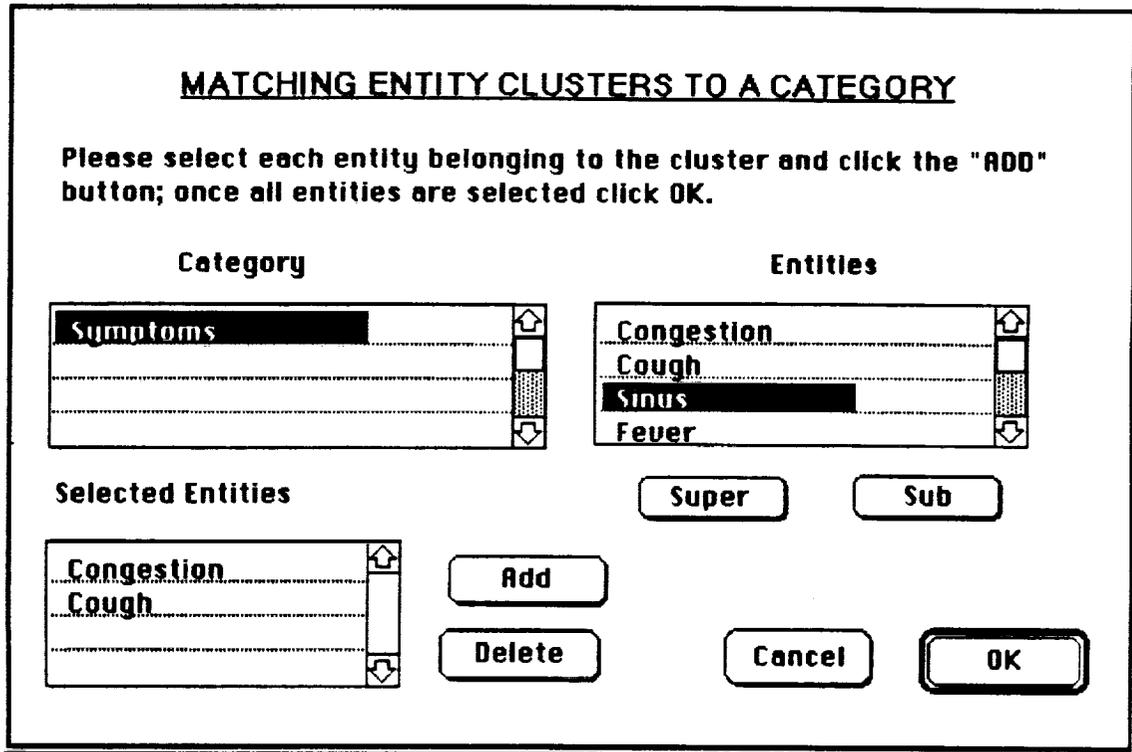


**Figure A-23. Symptoms Linked to "Infection"**



**Figure A-24. Diagnostic Methods Linked to "Neoplasms"**

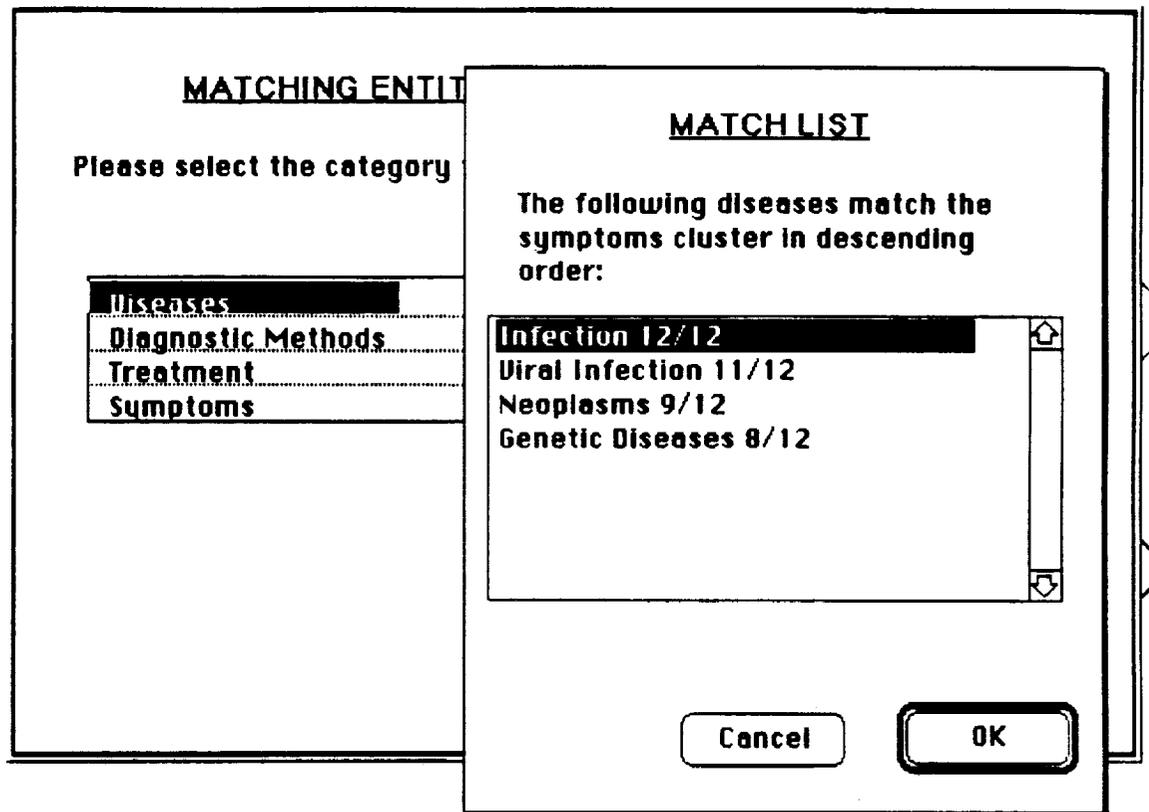
A message box now is shown (Figure A-26) listing in descending order the closest matches between single disease entities and this set of symptoms. "Infection" tops the list, with links to all 12 symptoms in this diagnostic cluster. Highlight "Infection" and click "OK"; this brings up a screen in relational mode with "Infection" as the center of focus surrounded by linked symptoms.



**Figure A-25. Selecting a Symptoms Cluster**

The fifth type of diagnostic matching compares two sets of entities to provide information about similarities and dissimilarities. Please again activate "Diagnosis" from the "Diagnostic" pull-down menu, selecting the fifth radio-button and clicking on the "OK" button. A dialog box appears for choosing the two categories you want to match. Highlight "Diseases" in the left scroll box and "Diagnostic Methods" in the right one, then click "Match."

A second dialog box now displays the two categories selected with "Super" and "Sub" buttons below each scroll box; this allows traversing the hierarchical levels for each entity in that category. Highlight "Diseases" in the left scroll box and click on the "Sub" button below it; this brings up the different top-level entities in the hierarchical tree for the "Diseases" category. Highlight "Infection" and click on "Sub" again; then highlight "Bacterial Infection," the specific entity to be used in this demonstration. Now click on the "Add" button; note that "Bacterial Infection" appears in the list below the left scroll box, while the left scroll box defaults to its topmost level ("Diseases") again. Please follow a similar procedure to select "Malignant Neoplasms" and add it to the list.



**Figure A-26. Matching A Symptoms Cluster to Disease Entities**

In the right scroll box, highlight "Diagnostic Methods" and click on the "Add" button (Figure A-27). This category appears in the second list below the right-hand scroll box and will be compared to the two specific disease entities already selected. Clicking on the "Match" button brings up a screen image showing a Venn diagram similar to Figure A-28.

Each circle in the diagram encloses a set of diagnostic methods for a particular disease entity. The methods both entities have in common are displayed within the intersecting area of both circles. Clicking on a diagnostic method, "Observation," that lies within the area of intersection brings up a box describing the similarities and contrasts in observation for neoplasms and bacterial infection. Clicking on the box puts it away again. Clicking on an entity outside the area of intersection, "MRI" (Magnetic Resonance Imaging), describes that procedure as it relates to the disease entity in whose circle it is located.

**MATCHING ENTITY CLUSTERS IN TWO CATEGORIES**

Please select one or more entities from each category to be matched. You can access the super and sub-levels of each selection by clicking the appropriate buttons under each list.

**Diseases**

↑
↓

Super

Sub

**Diagnostic Methods**

↑
↓

Super

Sub

**Bacterial Infection**

**Neoplasm-Malignant**

↑
↓

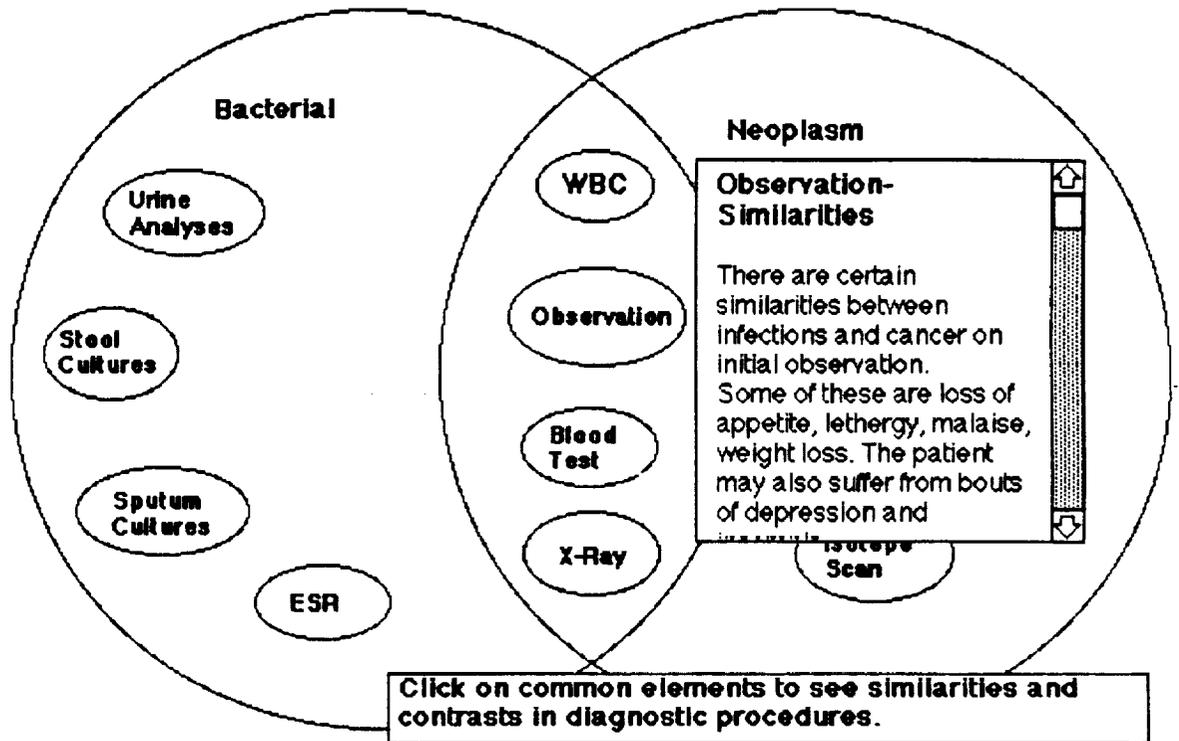
↑
↓

Add

Cancel

Match

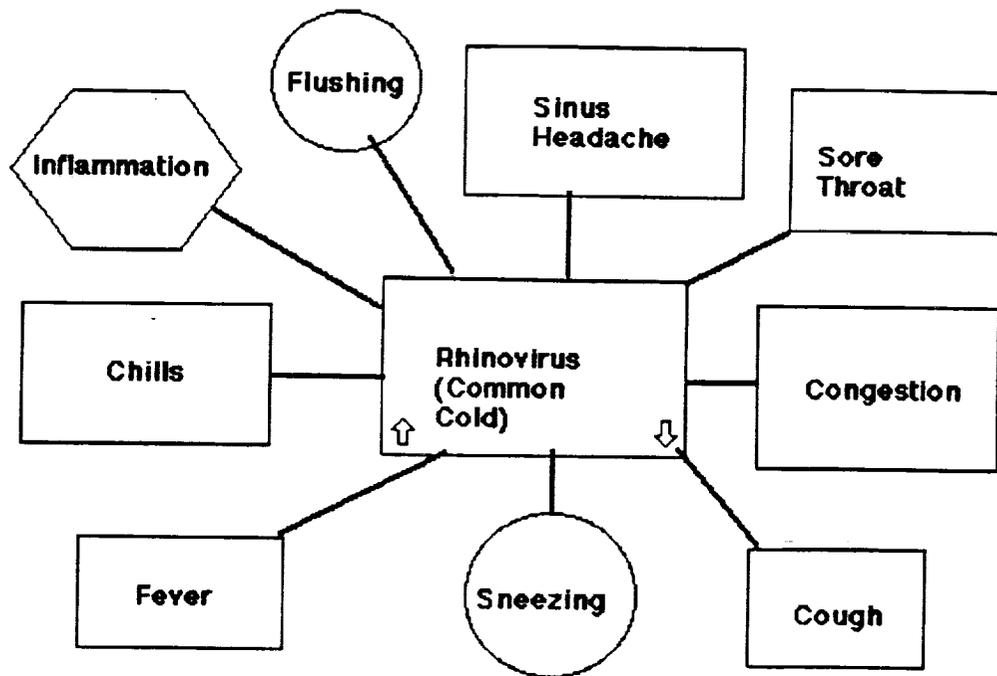
**Figure A-27. Diagnostic Matching of Two Entity Clusters**



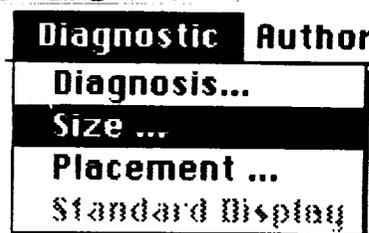
**Figure A-28. Venn Diagram Comparing Diagnostic Methods**

**Clustering by Size.** Now that the features under the "Diagnosis" function on the "Diagnostic" pull-down menu have been demonstrated, the "Size" feature on this menu will be described. This function displays related entities in sizes proportional to some given criterion. The information about these relative proportions is stored in a previously authored file; creating this file will be discussed later in the tour.

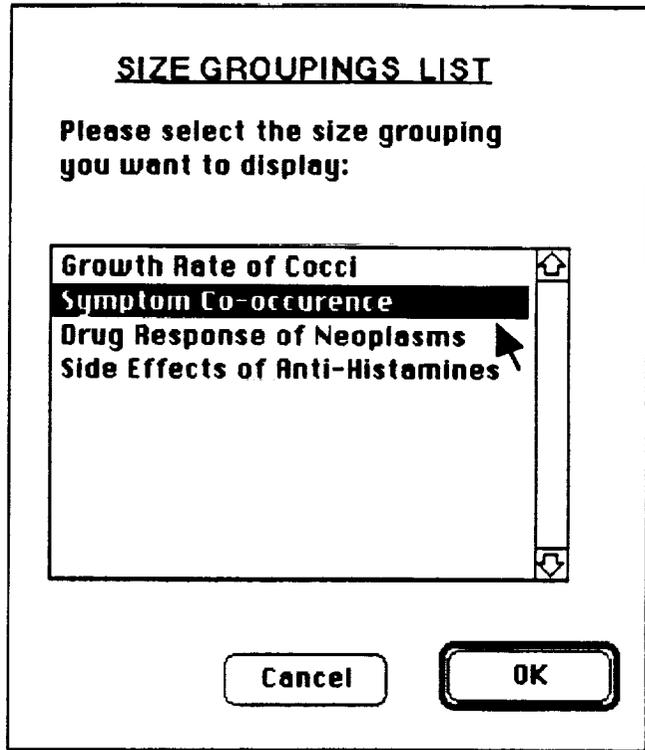
To illustrate viewing an entity grouping based on size, the center of focus must be the "Rhino Virus" entity in the "Disease" category (Figure A-29). Please use the "Jump Search" dialog box (described in Figure A-11) to bring up this view of the mental model. Then, activate the function "Size" on the "Diagnostic" pull-down menu (Figure A-30). A message box is displayed listing all previously authored size groupings (Figure A-31). Highlight "Symptom Co-occurrence" on this list and click "OK."



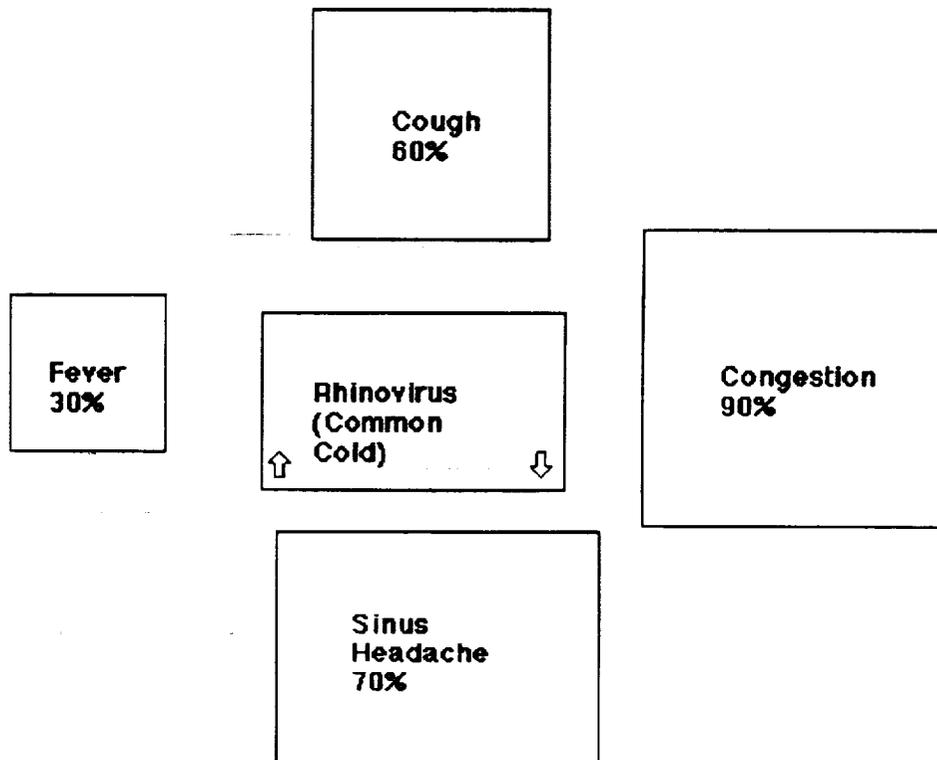
**Figure A-29. Relational View of "Rhinovirus"**



**Figure A-30. "Size" from "Diagnostic" Menu**



**Figure A-31. Size Grouping List**



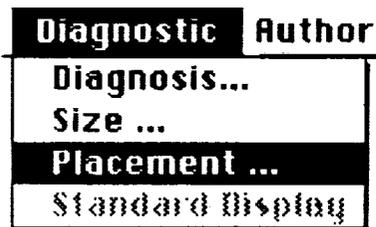
**Figure A-32. Size Grouping by Symptoms Co-occurrence**

The screen display now shows "Rhinovirus" surrounded by four symptomatic entities: "Congestion," "Cough," "Sinus Headache," and "Fever." As the numbers displayed with each symptom and the relative areas of the geometric icons suggest, congestion co-occurs with a rhinovirus infection ninety percent of the time; sinus headache, seventy percent; and so on. To go back to the default relational display, please activate "Standard Display" on the "Diagnostic" pull-down menu (Figure A-33).



**Figure A-33. "Standard Display" from "Diagnostic" Menu**

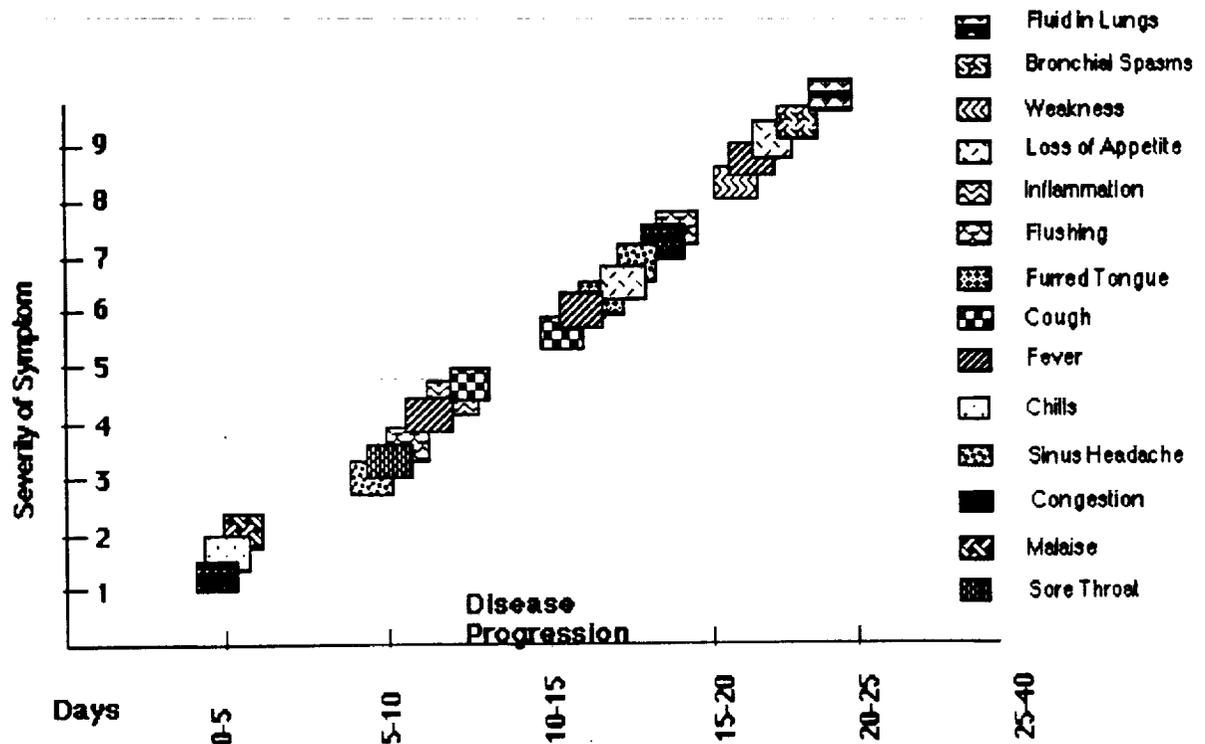
**Clustering by Placement.** The remaining function on the "Diagnostic" pull-down menu, "Placement," images entities in a virtual X-Y plane, with the X-axis representing an independent variable and the Y-Axis a dependent variable. These placement groupings have been previously authored; creating such files will be discussed later in this tour. To begin the demonstration of this function, activate the "Placement" feature on the "Diagnostic" pull-down menu (Figure A-34).



**Figure A-34. "Placement" from "Diagnostic" Menu**

To allow choosing the placement grouping to be imaged, a dialog box similar to that for the "Size" feature is displayed. Highlighting "Symptom Severity" and clicking "OK" brings up the placement grouping shown in Figure A-35.

On the right is a legend for all the symptoms of the "Rhinovirus" disease entity. On the X-axis, the progression of these symptoms is depicted; on the Y-axis, the severity of the symptoms is indicated on a scale of 1 to 10 ( the lower the number, the milder the symptom).



**Figure A-35. Placement Grouping**

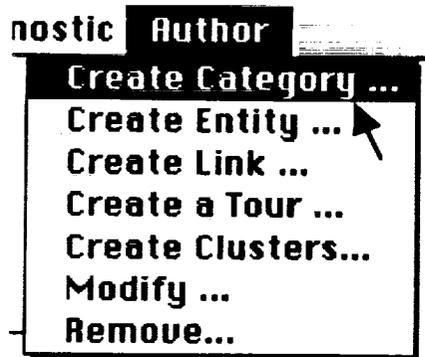
This completes the demonstration of methods on the "Diagnostic" menu that enable displaying complex relational information. Again, please go back to the default relational display by activating "Standard Display" on the "Diagnostic" pull-down menu (Figure A-33). The next stop on the tour is to describe the various functionalities the tool provides for authoring mental models.

### **Authoring Functions**

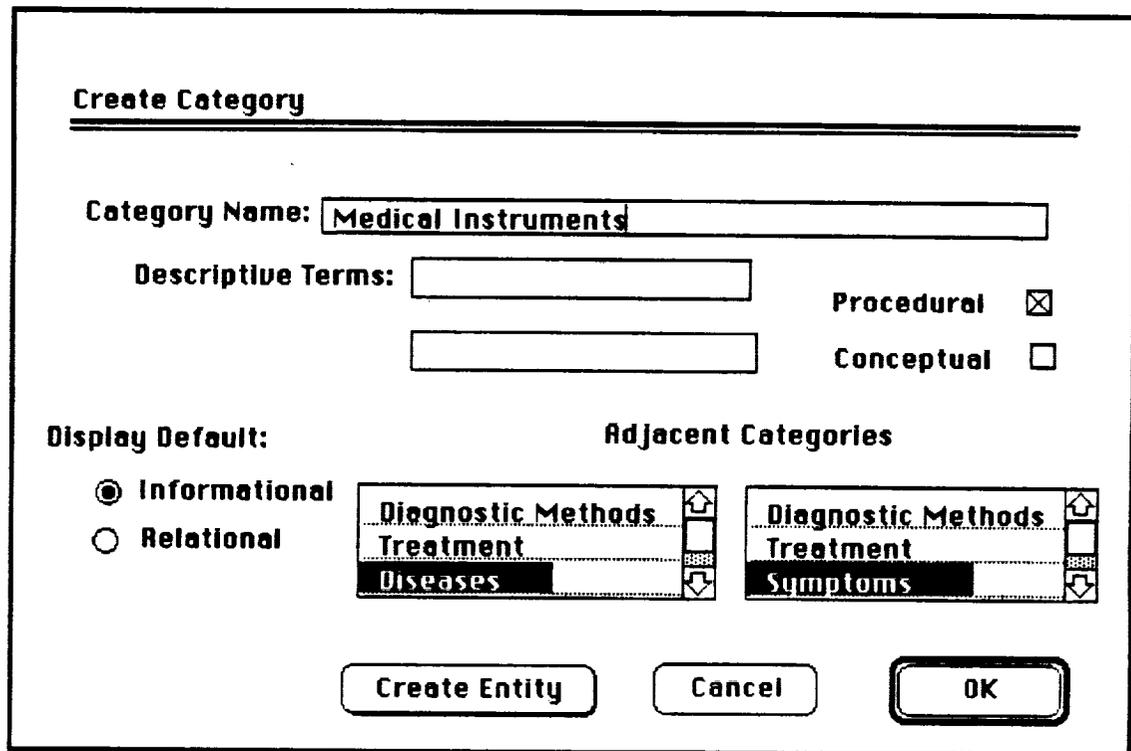
The "Author" menu can be used to create new categories, entities, entity groupings, links, trees, and tours, as well as to modify existing aspects of the mental model. Please activate "Set Up Menus" again from the "File" menu (Figure A-2) and deselect the "Diagnostic" menu. In its place, please select the "Author" menu, then click "OK."

**Creating a Category.** Activating "Create Category" from the "Author" pull-down menu (Figure A-36) brings up the dialog box shown in Figure A-37. Type "Medical Equipment" in the category-name field; this is a procedural category, so check the procedural box on the right-hand side. Select the information-mode radio button for default display; this would be typical for a procedural category. The relative position that this new category will occupy in the 3-D global view must also be determined. Click on "Diseases" in one of the

two scroll boxes under the "Adjacent Categories" heading, then on "Symptoms" in the second. Now, clicking the "OK" button adds a new category system to the mental model, as shown by the position of "Medical Equipment" at the top of a tree. No entities have yet been created, so the rest of this screen is blank.



**Figure A-36. "Create Category" from "Author" Menu**



**Figure A-37. "Create Category" Dialog**

**Creating an Entity.** Next, a new entity, "High Blood Pressure," will be created in the "Symptoms" category. First, go back to the "Moderate Fever" relational view by using the "Jump Search" feature (as described in Figure A-

11). This returns the user's position in the model to the "Symptoms" category, to which the new entity will belong. Activate "Create Entity" on the "Author" pull-down menu. The dialog box shown in Figure A-38 appears.

Enter "High Blood Pressure" in the entity-name field and "HBP" in the description field. Highlight "Symptoms" in the Super Level scroll box, then click on the "Sub" button below it. Next, highlight "Symptoms" in the Sub Level scroll box (to the right of the Super Level scroll box), then click on the "Sub" button below it. Highlight "Blood Pressure" and click on the "Sub" button again, to bring up "Chronic" and "Acute" as the two sub-levels of the new entity being created.

**Create Entity**

Entity Name: High Blood Pressure

Descriptive Terms: HBP

Category: Symptoms

Super Level: Aches, Blood Pressure, Chills, Cough

Sub Level: Acute, Chronic

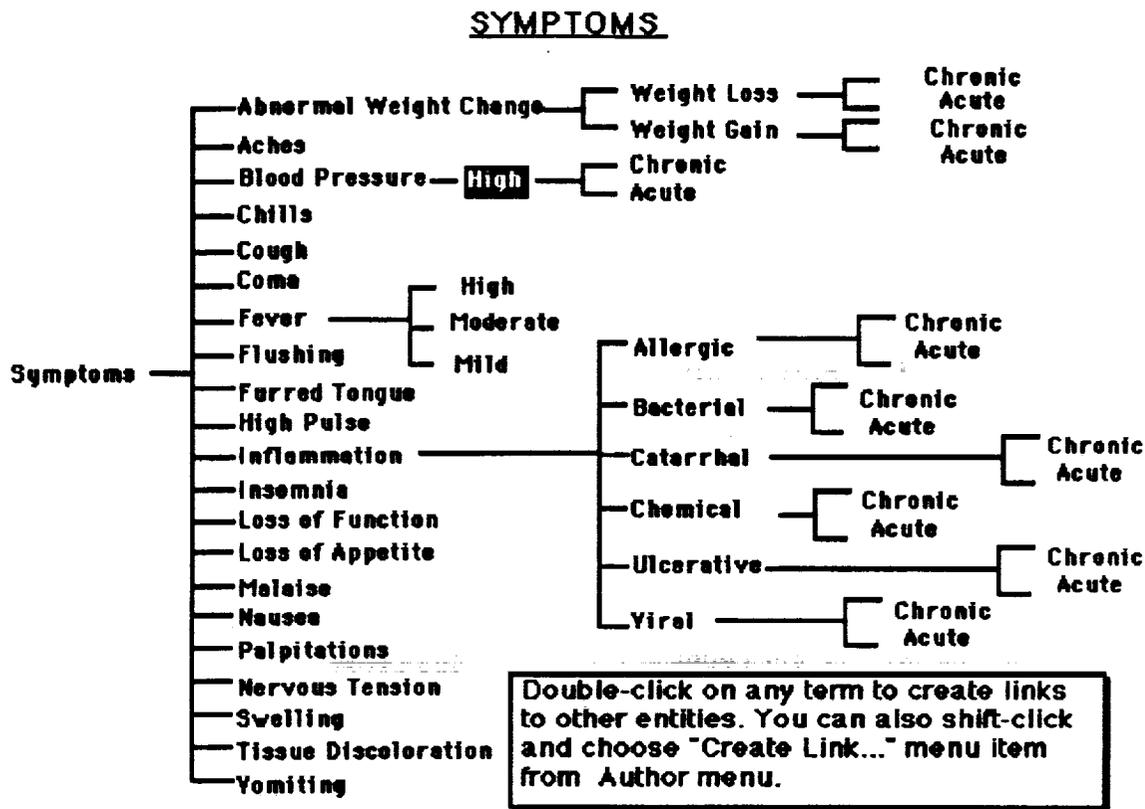
Buttons: Super, Sub, Super, Sub, Create Link, Cancel, OK

**Figure A-38. "Create Entity" Dialog**

Now highlight "Blood Pressure" in the Super Level scroll box and "Acute" and "Chronic" in the Sub Level scroll box, then click "OK." The screen shows the hierarchy of entities in the "Symptoms" category (Figure A-39), with the new entity displayed in inverse.

**Creating a Link.** Links to this new entity can be created directly from this screen, rather than having to access the "Create Link" function on the "Author" pull-down menu. Please double-click on the highlighted word "High"; this brings up a dialog box for creating links (Figure A-40). Because this creation sequence was initiated from a highlighted entity, the source-entity field already has "High Blood Pressure" entered. To create a link to another entity in this same category, select the intra-category-link radio button. This

automatically highlights the category "Symptoms" in the top scroll box on the right-hand side.



**Figure A-39. Symptoms Tree with "High Blood Pressure" Added**

From this point, any entity in that category could be selected in the lower scroll box, and a link constructed. Instead, to illustrate a feature that provides intelligent aid for authors, click on the "Related Entities" button. Mental Link now scans its database for entity and link descriptors that mention "blood pressure" and prepares a list—now on the screen—of entities that are possible candidates for links. Highlight "Moderate Fever" in this list. The entity-descriptor field automatically provides information on the entity that mentioned blood pressure; the link-descriptor field functions in a similar manner for rationale information. Now click on "Link." This returns to the "Create Link" dialog box and highlights the link name as MF-HBP.

Please enter the following text in the rationale-for-link field: "In some infections, fever is accompanied by an increase in blood pressure and pulse rate. This is due to the production of certain chemicals that aid white blood cells in combatting the disease." Finally, click on the create-reverse-link box, and then click "OK."

**Create Link**

---

Source Entity: **High Blood Pressure**

Intra-Category Link
 Destination:
Category

Inter-Category Link
 Treatment
Post Treatment Care
Symptoms

Link Name: **MF-HBP**

Rationale for Link

In most infections the fever is accompanied by increase in blood pressure and pulse rate. This is due to

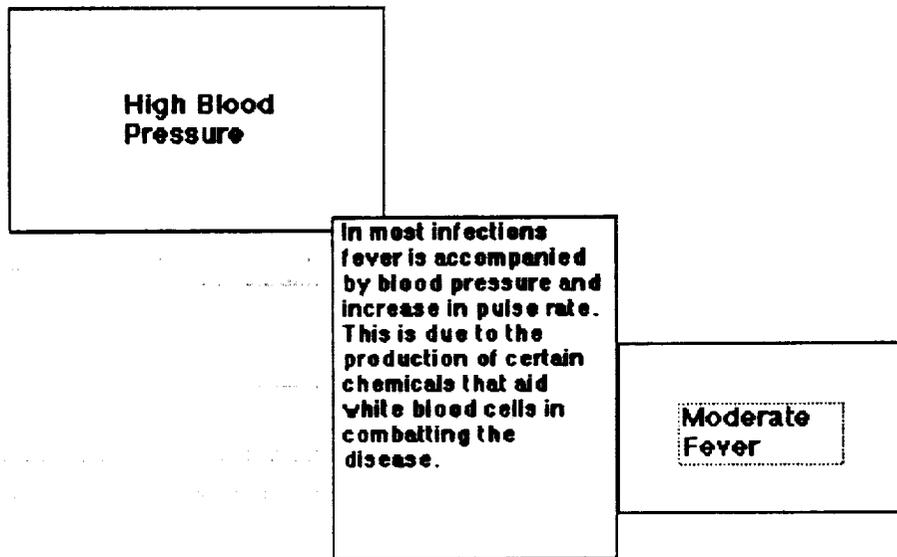
Entity

High Fever  
**Moderate Fever**  
 Low Fever

Create Reverse Link
 Related Entities
Cancel
OK

**Figure A-40. "Create Link" Dialog**

The screen shows the new entity, "High Blood Pressure," as the center of focus with a newly created link to "Moderate Fever." Clicking on the link brings up the link rationale just entered (Figure A-41).



**Figure A-41. High Blood Pressure-Moderate Fever Link**

**Creating and Taking a Tour.** As an aid to traversing through the complex structures that Mental Link images, an author might wish to create a tour that users could follow. To prepare for a demonstration of this feature, please go back to "Moderate Fever" as the center of focus by using the "Move Search" function (page 39); this will be the starting point of the tour. Activate "Create Tour" on the "Author" pull-down menu; this brings up the dialog box shown in Figure A-42.

**Create a Tour**

Tour Name:

Tour Description:

The tour begins from the current focus. If you would like a different category and entity as your starting point please choose from the menu below:

Category	Entity
<input type="checkbox"/> Post Treatment Care <input checked="" type="checkbox"/> Symptoms	<input type="checkbox"/> High Fever <input checked="" type="checkbox"/> Moderate Fever
	<input type="button" value="Super"/> <input type="button" value="Sub"/>
	<input type="button" value="Cancel"/> <input type="button" value="OK"/>

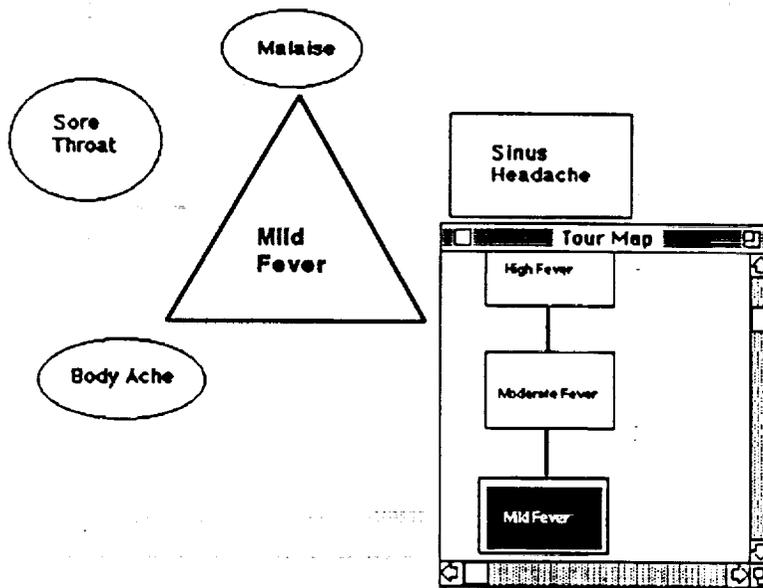
**Figure A-42. "Create Tour" Dialog**

Notice that the appropriate descriptors in the category and entity scroll boxes are already highlighted. Enter the name "Explore" in the tour-name field and click "OK." Now, a new window has been added in the lower right-hand corner of the relational view for "Moderate Fever." This window is the tour map. As the author traverses from one entity to another, the tour map automatically records all the entities visited.

As an aid in user orientation, navigation from one entity to another in the same category is represented by a solid line in the tour map, while inter-category travel is depicted by a dotted line. Click twice on the up-arrow in the "Moderate Fever" entity. From the tree displayed on the screen, click on the term "High Fever." Now click twice on the down-arrow on the "High Fever" entity and use the tree to move back to "Moderate Fever." Click twice on the down-arrow on "Moderate Fever" and use the tree to move to "Mild Fever." Notice that, with each move, another entity is added to the tour map (Figure A-43). Please use

"Jump Search" feature (Figure A-11) to move across categories to an entity labelled "Infection 2." Then click twice on the "Bacterial Infection" entity to move to it. To stop recording the tour, activate the "End Tour" function on the "Special" pull-down menu. Respond "Yes" to the question about saving the tour.

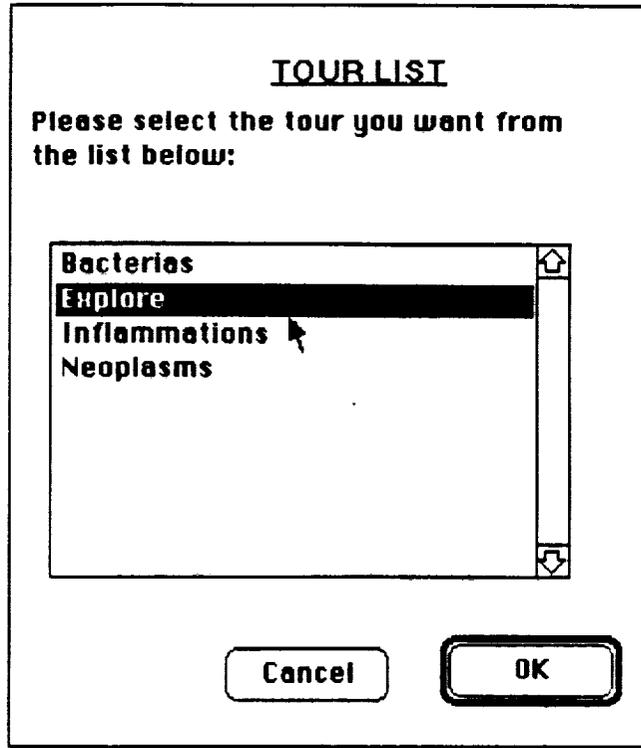
Now the tour just created can be traversed. From the "Special" pull-down menu, activate the "Begin Tour" feature. Highlight "Explore" in the scroll box that appears on the screen (Figure A-44), then click "OK."



**Figure A-43. Recording the Tour "Explore"**

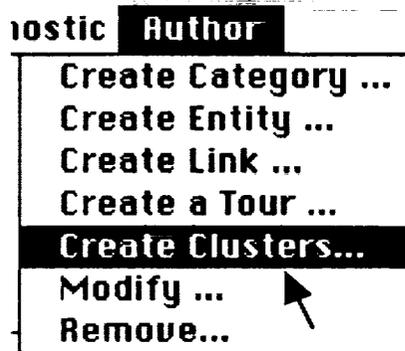
The tour map is used to control movement. On the map, click on the link from "Moderate Fever" to "High Fever"; the image automatically alters to this new perspective. Scroll through the tour map to find the dotted link, then click on it; the image changes to show "Infection" in the "Diseases" category system. Conclude by activating "End Tour" from the "Special" pull-down menu, then clicking on "Save."

In Mental Link, the functionalities for authoring and taking tours would be considerably more elaborate than can be demonstrated in prototyping software. For example, users could take the tour as a "movie" in which digitized voice and automatic movement provided explanations of the changing images. The types of navigational features that the Tour feature could incorporate are further described in Section III of this report.

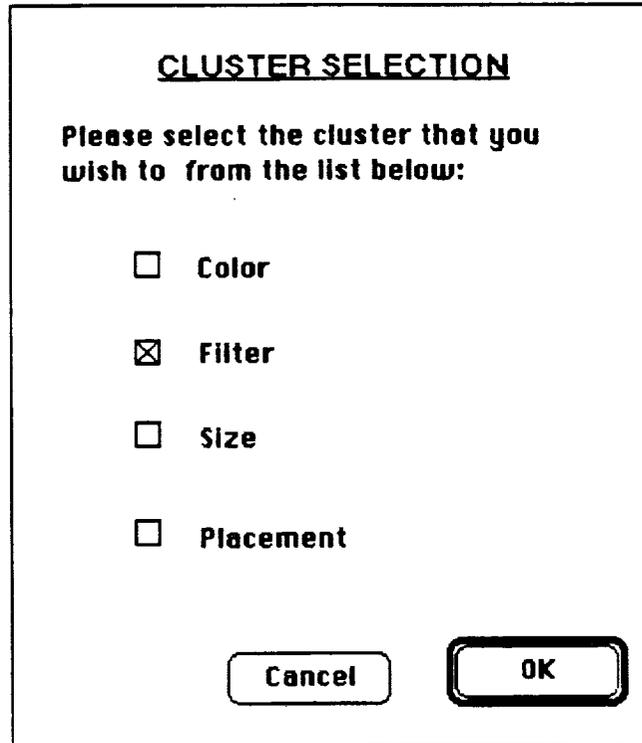


**Figure A-44. Tour List**

**Creating Color, Filter, Size, and Placement Clusters.** The next function to be demonstrated from the "Author" menu is "Create Clusters." Four types of entity clusters can be customized using this capability: color groupings, filter groupings, size groupings and placement groupings. To begin, please use the "Move Search" feature (Page 39) to bring up the "Rhino Virus" relational view. Then activate "Create Clusters" on the "Author" pull-down menu (Figure A-45). This brings up a dialog box to choose among the four possible features for clustering (Figure A-46); place a check in the "color" box and click "OK."



**Figure A-45. "Create Clusters" from "Author" Menu**



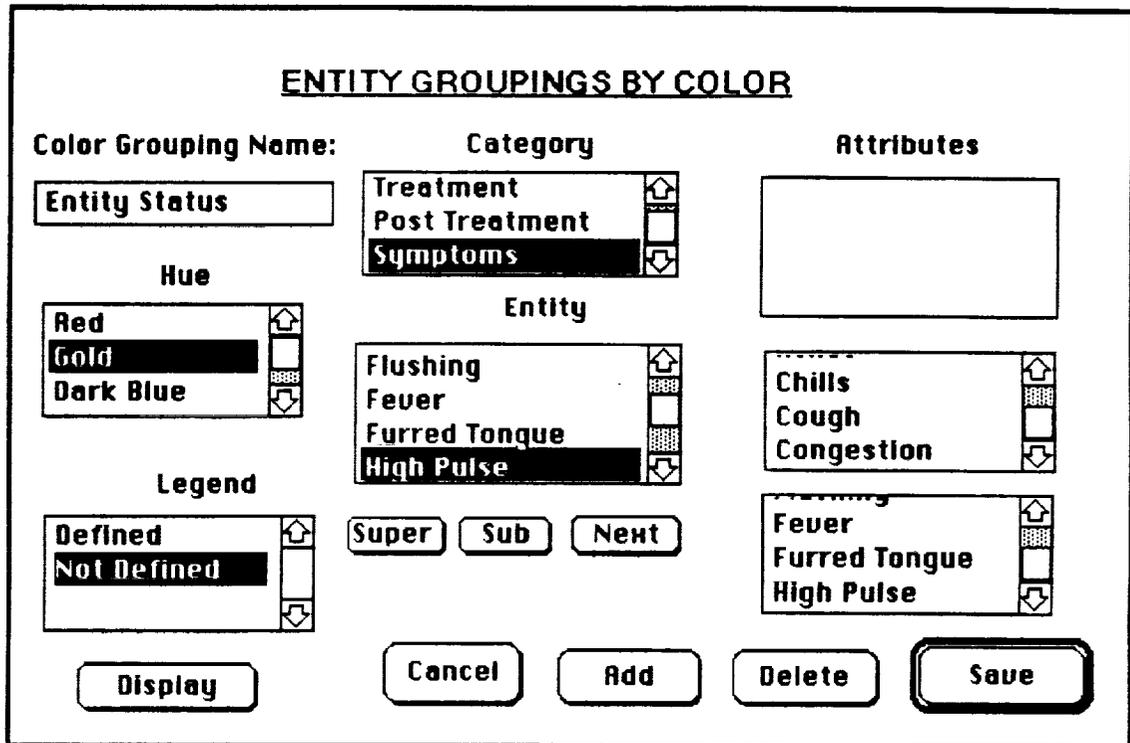
**Figure A-46. "Cluster Selection" Dialog**

The screen now shows a dialog box similar to Figure A-47. To create just two clusters based on color (1) entities completely defined and 2) entities not completely defined, enter "Entity Status" in the color-grouping-name field. Now type the term "Defined" in the legend box, press the "Return" key, and enter the term "Not Defined." Highlight "Defined" (by dragging the cursor over it), then click on "red" in the hue scroll box. To add four entities ("Aches," "Chills," "Cough," and "Congestion") to the "Defined" cluster, first highlight "Symptoms" on the category scroll box. Then highlight these entities one-by-one in the entity scroll box, clicking on the "Add" button each time. Each item is added to the scroll box on the right of the screen.

To build the second cluster, click on the "Next" button. Highlight the term "Not Defined" in the legend box, and click on "gold" in the hue scroll box. Now add "Flushing," "Fever," "Furred Tongue," and "High Pulse" as previously done with the first set of entities. Finally, click the "Save" button, and answer "Yes" to save the two clusters. To see this grouping, please use the "Set Up Menus" feature to activate the "View" pull-down menu, then activate "Choose Color" from the "View" pull-down menu. Select "Entity Status" from the list of color clusters that appears and click "OK." The screen shows a global view of the mental model with the color clusters just created (Figure A-49).

Just as with the color grouping, we can create a filter grouping to view only a restricted set of elements from a complex mental model. Please click on the "Reset" button on the global view image to move back to local view. Go to "Rhino Virus" using the "Jump Search" feature. Again, activate "Create Clusters"

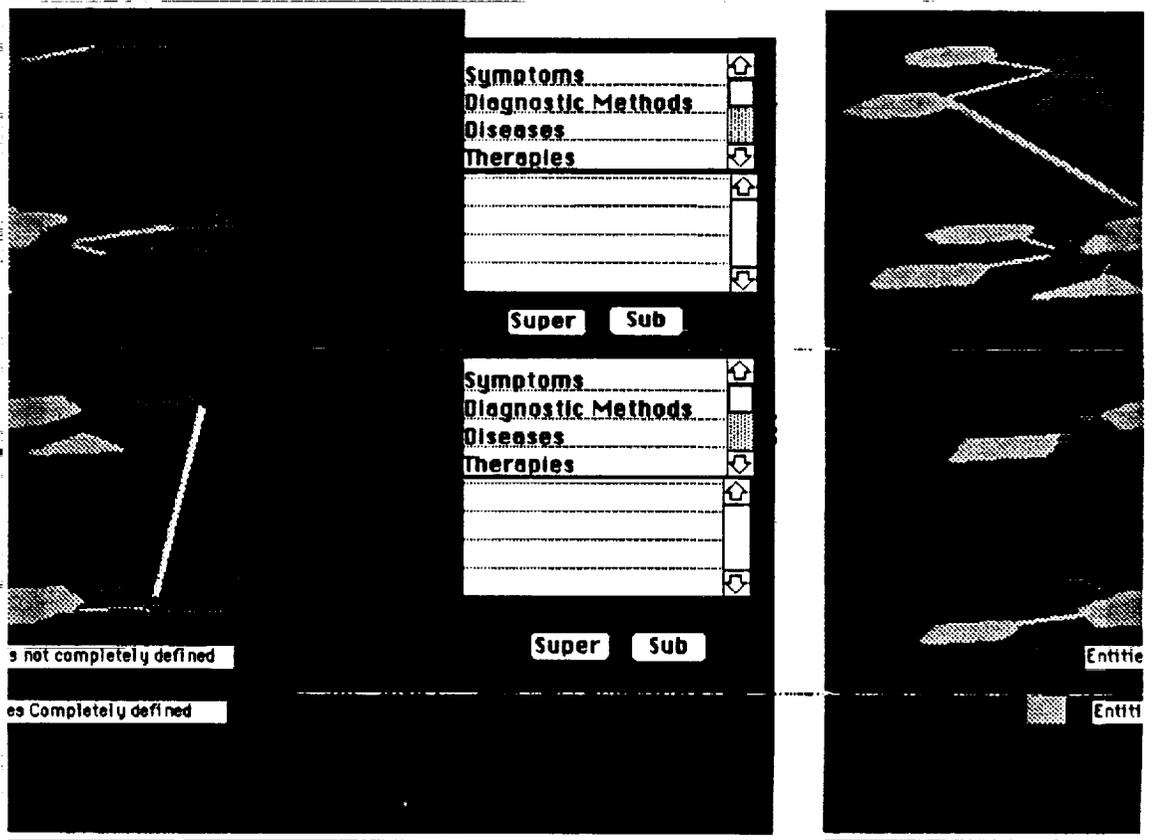
on the "Author" pull-down menu, but this time check the box for filter grouping and click "OK." A dialog box will appear (Figure A-50). Enter the term "Rhino Virus" in the field for filter name. Use the "Tab" key to move to the field for legend, then enter "Entities Linked to Rhino Virus." Now highlight "Symptoms" in the category scroll box; then add "Aches," "Chills," "Cough," and "Congestion" one at a time (as done for creating a color grouping). Please click the "Save" button to store this grouping.



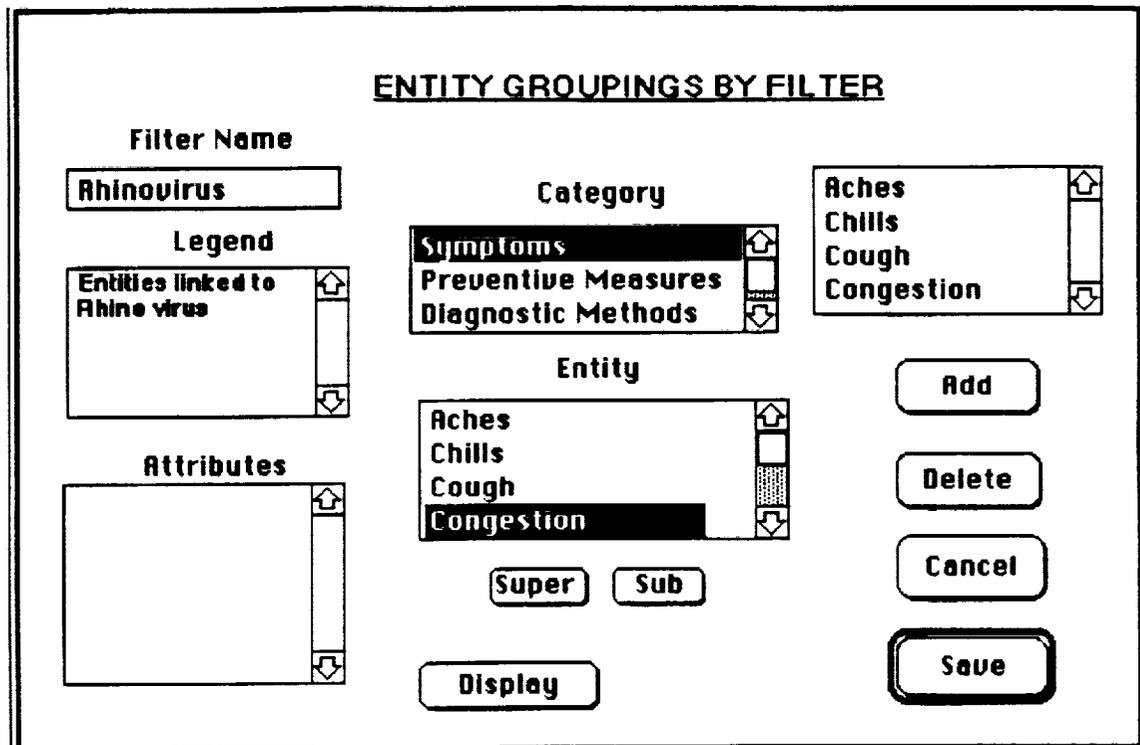
**Figure A-47. Creating an Entity Color Grouping**



**Figure A-48. "Color" from "View" Menu**



**Figure A-49. Viewing the Color Cluster "Entity Status"**



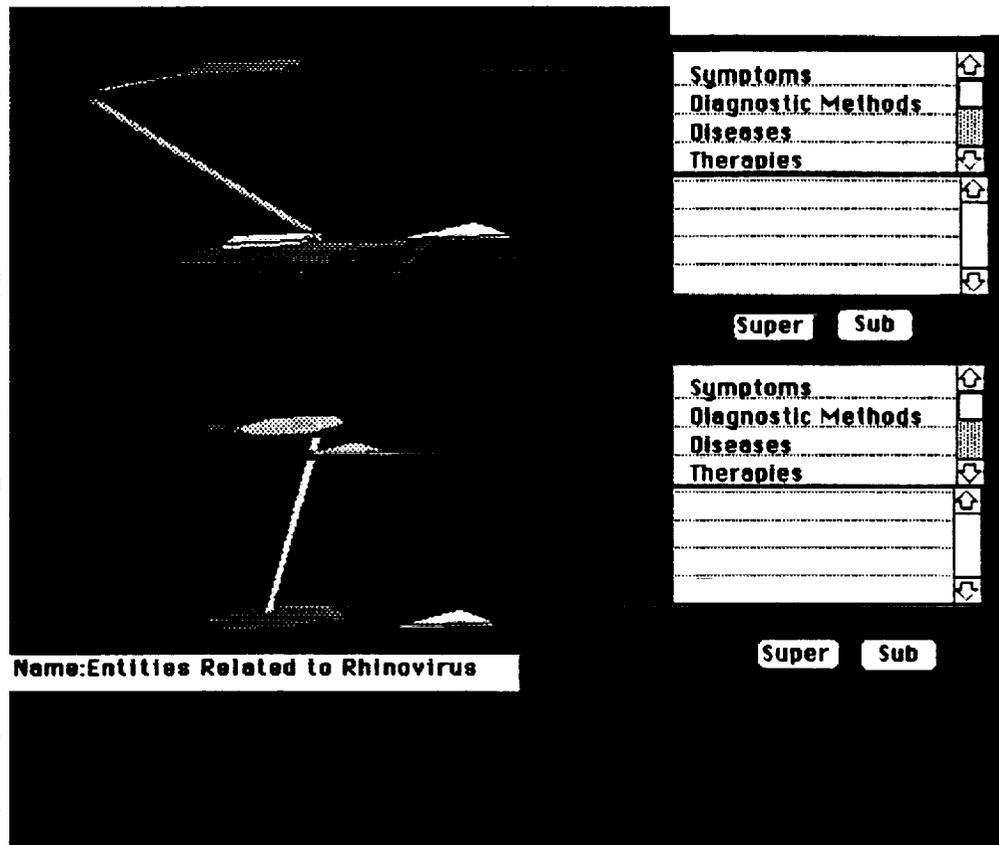
**Figure A-50. Creating an Entity Filter Grouping**



**Figure A-51. "Filter" from "Special" Menu**

To image a global view of the mental model with this filter imposed, activate the "Filter" feature on the "Special" pull-down menu (Figure A-51). Click on the filter name "Rhino Virus," then click "OK." The screen will display an

image similar to that in Figure A-52. Viewing through such filters reduces the visual complexity of the model as an aid in understanding specific features.



**Figure A-52. Viewing the Filter Cluster "Rhinovirus"**

Please click the "Reset" button on the global view image to go back to local view. Previously, the feature of displaying entities via a size grouping was demonstrated (Figure A-32). To demonstrate how to create such a size cluster, use the "Jump Search" feature to return to the "Rhino Virus" entity. Again activate "Create Clusters" from the "Author" pull-down menu. This time, check the box for size grouping and click "OK." A dialog box similar to the one in Figure A-53 will appear. Enter the term "Co-occurrence" in the size-grouping-name field; then highlight "co-occurrence" in the comparison-criterion scroll box. Highlight "Congestion" in the associated-entities scroll box, then enter "90%" in the display-percentage field. After clicking on the "Add" button, this entity and percentage will appear in the entities-in-group box. In a similar manner, please add "Cough" (60%), "Sinus" (70%), and "Fever" (30%); then click the "Save" button. This size cluster can now be viewed by activating the "Size" feature on the "Diagnostic" pull-down menu (as shown earlier in the tour).

**ENTITY GROUPINGS BY SIZE**

**Size Grouping Name**

**Comparison Criterion**

**Current Focus**

**Associated Entities**

**Display Percentage**

**Entities in Group**

**Figure A-53. "Size Grouping" Dialog**

Previously, the feature of displaying entities via a placement grouping also was discussed (Figure A-35). To create this placement cluster, please use the "Jump Search" feature to return to the "Rhino Virus" entity, and again activate "Create Clusters" from the "Author" pull-down menu. Check the box for placement grouping and click "OK." A dialog box similar to Figure A-54 will appear; the center-of-focus field already contains the current entity, "Rhino Virus."

Enter "Symptom Severity" in the placement-name field. Highlight "Symptoms" in the category scroll box; this brings up all the symptomatic entities linked to "Rhino Virus" in the associated-entities scroll box. Highlight "Bronchial Spasms," then highlight "Small Squares" in the display-icon scroll box. Highlight "Dark Blue" to assign this color to "Bronchial Spasms," then click on the "Add" button. "Bronchial Spasms" will now appear in the grouping-list scroll box. Other entities can be assigned shapes and colors in the same manner.

Now, click on the "Next" button; this brings up the dialog box in Figure A-55. Enter "Disease Progression" in the X-Label field and "Severity of Symptom" in the Y-Label field. Now, enter numerical values for the X-Axis minima and maxima as shown in Figure A-55. Then, click on the "Plot" button; the X-Y grid ready for plotting is displayed as in Figure A-56.

### ENTITY GROUPINGS BY PLACEMENT

Placement displays entity clusters in a H-Y plane, with the H-axis representing one variable and the Y-axis another variable. Select each entity, assign color and display icon and add to the grouping list.

<p><b>Center of Focus:</b>  <input type="text" value="Rhinovirus"/></p>	<p><b>Associated Categories</b>  <input type="text" value="Treatment"/>  <input type="text" value="Symptoms"/></p>	<p><b>Placement Name:</b>  <input type="text" value="Symptom Severity"/></p>
<p><b>Color</b>  <input type="text" value="Dark Blue"/>  <input type="text" value="Parrot Green"/>  <input type="text" value="Cobalt"/></p>	<p><b>Associated Entities</b>  <input type="text" value="Bronchial Spasms"/>  <input type="text" value="Cough"/>  <input type="text" value="Chills"/>  <input type="text" value="Congestion"/></p>	<p><b>Grouping List</b>  <input type="text" value="Bronchial Spasms"/>  <input type="text" value="Cough"/>  <input type="text" value="Chills"/></p>
<p><b>Display Icon</b>  <input type="text" value="Bullets (•)"/>  <input type="text" value="Asterisk(*)"/>  <input type="text" value="Squares (□)"/></p>	<p><input type="button" value="Super"/>   <input type="button" value="Sub"/></p>	
	<p><input type="button" value="Add"/>   <input type="button" value="Delete"/></p>	<p><input type="button" value="Cancel"/>   <input type="button" value="Next"/></p>

**Figure A-54. "Placement Grouping" Dialog**

### Calibrating X-Y Axes

**Definig H-Axis:**

Minimum

Maximum

H-Label

**Definig Y-Axis:**

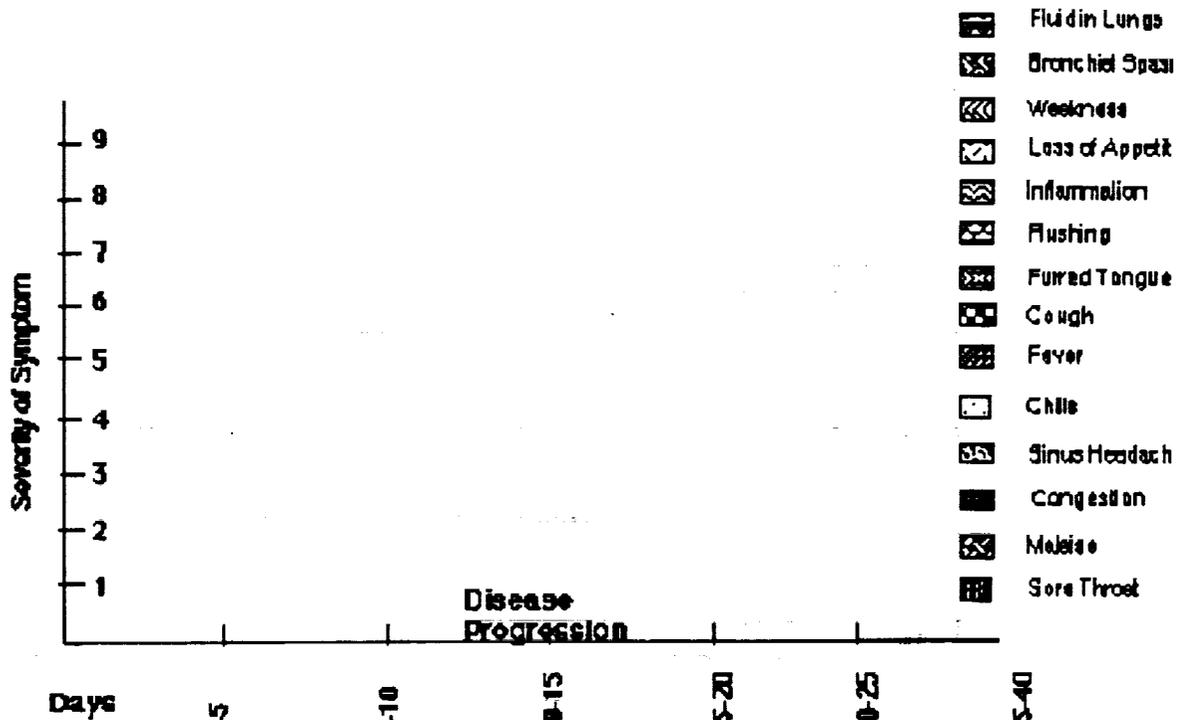
Minimum

Maximum

Y-Label

**Figure A-55. Deflning X-Y Axes**



**Figure A-56. X-Y Plotting Grid**

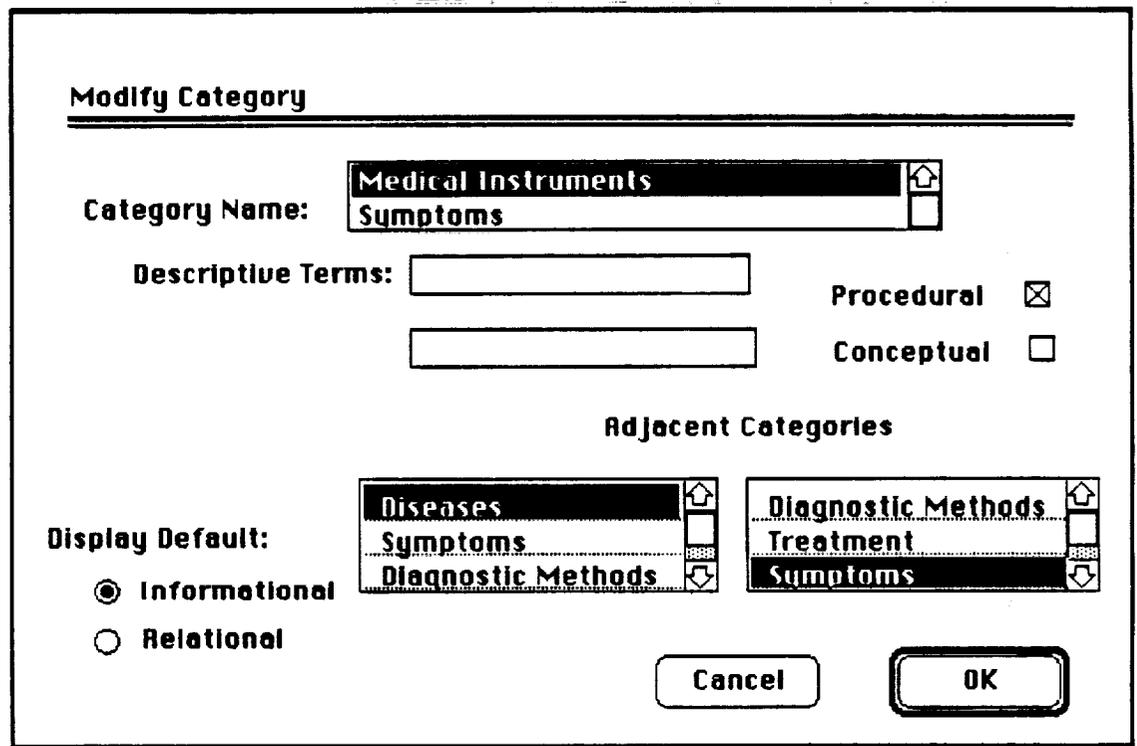
Each icon has a legend to indicate the entity it symbolizes. Activate the "Pointer Tool" from the "Palette" pull-down menu; the cursor will change to an arrow. Now, click on each icon in turn and drag it to a location on the plotting grid. Through such a method, an author could easily create a placement cluster.

Since the final grouping is already stored, please return each icon to its original position to the right of the grid. Now activate "Browse Tool" from the "Palette" pull-down menu to return the cursor to its usual state.

**Modifying Aspects of Mental Models.** Please activate the "Modify" feature on the "Author" pull-down menu (Figure A-57); this is used to alter the attributes of existing categories, entities, links and tours. Select "A Category" in the dialog box that appears, then click "OK." The screen will now show the dialog box in Figure A-58. Highlight "Medical Instruments" in the category-name scroll box. Immediately, the present settings for this category are displayed. This is a procedural category in the informational mode with diseases and symptoms as adjacent categories in the 3-D global view. Any of these attributes can be altered.



**Figure A-57. "Modify Entity" from "Author" Menu**



**Figure A-58. "Modify Category" Dialog**

To change the adjacent categories to "Diagnostic Methods" and "Treatment," highlight these two terms in the left and right scroll boxes, respectively, and click "OK." This will bring up another dialog box summarizing changes; click on "Save." This prototype version does not have the capability of displaying the final product of this modification; at the next screen, click on "Quit."

The "Modify Entity" feature is used to alter an entity's name, attributes, descriptors, or position in its category's hierarchical structure. To change the

position of "High Blood Pressure" in the "Symptoms" tree structure, please first use the "Jump Search" function (Figure A-11) to go to "High Blood Pressure." Activate the "Modify" feature on the "Author" pull-down menu; select "An Entity" in the dialog box that appears, then click "OK."

On the screen is now a dialog box similar to Figure A-59, with the entity-name and descriptive-terms fields already completed. In the "Super Level" scroll box, highlight "Blood Pressure," then click on the "Sub" button below the scroll box. Now highlight "High BP" and "Low BP," then click on the "Sub" button again.

Currently, "Chronic" and "Acute" are at a lower level of the hierarchy than "High Blood Pressure"; moving them to a higher level will demonstrate how the "Modify Entity" feature can alter the hierarchical networks in the model. Highlight "Chronic" and "Acute" in the "Super Level" scroll box; then highlight "None" in the "Sub Level" scroll box. Now click "OK." The modified "Symptoms" tree is now shown (Figure A-60). To complete the demonstration, please double-click on "High" to go back to "High Blood Pressure" as the center of focus.

**Modify Entity**

Entity Name **High Blood Pressure**

Descriptive Terms **High BP**

Category **Symptoms**

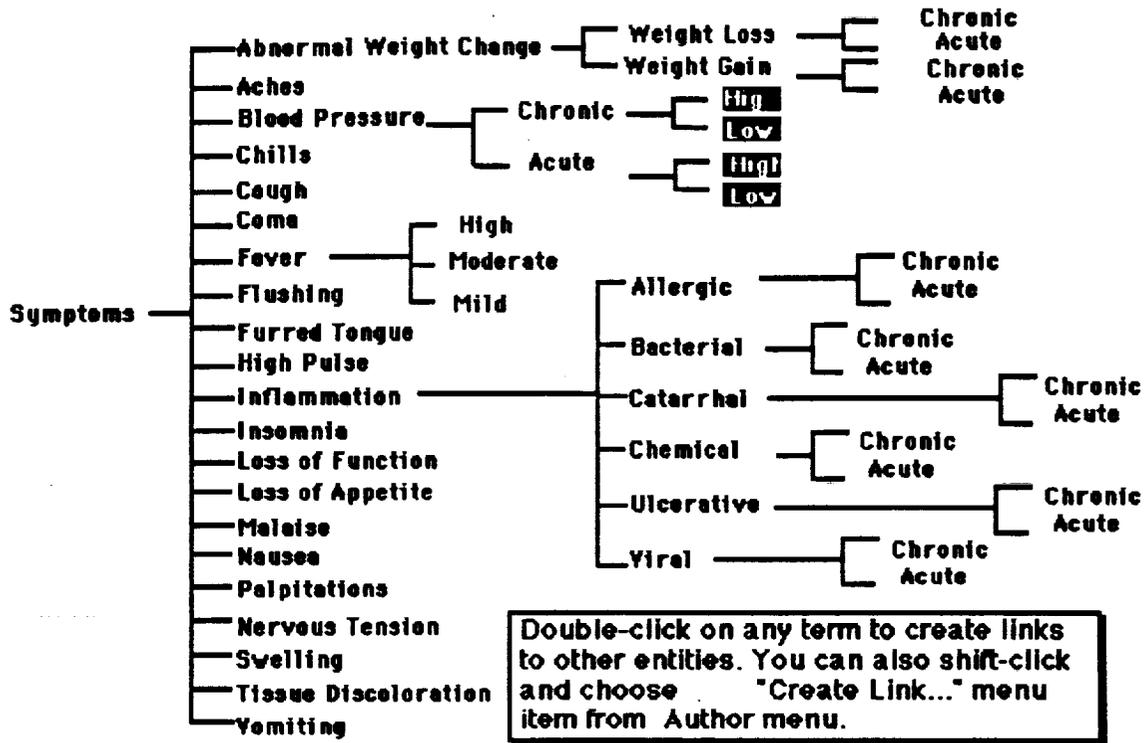
Super Level: **Acute**, **Chronic**

Sub Level: **None**

Buttons: Super, Sub (under Super Level); Super, Sub (under Sub Level); Create Link, Cancel, OK

**Figure A-59. "Modify Entity" Dialog**

## SYMPTOMS

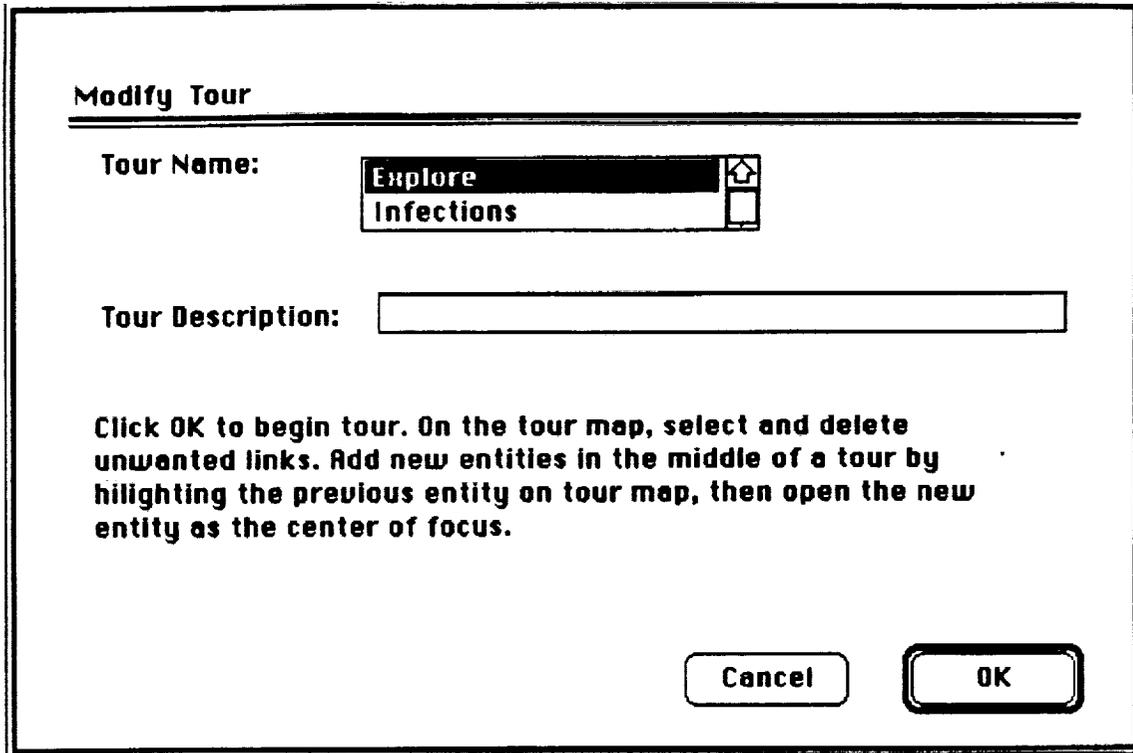


**Figure A-60. Modified "Symptoms" Tree**

The "Modify Link" feature is used to alter the name, attributes, source and destination, or descriptors of a link. To change the link descriptor between "High Blood Pressure" and "Moderate Fever," activate the "Pointer Tool" from the "Palette" pull-down menu, then select the appropriate link by clicking on it with the cursor arrow. Now, activate "Browse Tool" from the "Palette" pull-down menu to return the cursor to its usual state.

Please activate the "Modify" feature on the "Author" pull-down menu. Select "A Link" in the dialog box that appears, then click "OK." In the dialog box now on the screen, click in the link-rationale box, delete the current text (by dragging the cursor over the text to highlight it, then hitting the "Delete" key), and enter new text as follows: "The immune response system of the body generates additional white blood cells to combat the disease. This process also produces certain proteins that increase body temperature and blood pressure." Click "OK." At the local view, click on the link to verify that its rationale has altered to the new version.

Previously created tours can be changed or extended using the "Modify Tour" feature. Activate the "Modify" feature on the "Author" pull-down menu; select "A Tour" in the dialog box that appears, then click "OK." The next dialog box presents a scroll box of possible tours to be modified (Figure A-61); highlight "Explore," then click "OK."



**Figure A-61. "Modify Tour" Dialog**

The screen now shows the beginning of this tour. By activating the "Pointer Tool" from the "Palette" pull-down menu, links and entities can be deleted from the tour map (please do not do this). In Mental Link, new entities could also be added to the tour; this capability is not possible in the prototype. When modifications were finished, activating "End Tour" from the "Special" pull-down menu would initiate saving the changes.

**Removing Aspects of Mental Models.** The "Remove" function is used to delete categories, entities, links, and tours from the mental model. Activate "Remove" on the "Author" pull-down menu, then select "A Category" from the dialog box that appears. The dialog box now on the screen is similar to Figure A-62. Highlight "Medical Instruments" in the scroll box; the category-name field automatically accepts this entry. After clicking the "Remove" button, answer "Yes" to the cautionary dialog verifying this deletion process. Mental Link would then image a global view of the mental model to indicate that the category had been removed; the prototype is not capable of this feature, please click "Quit" on the screen that appears.

**Remove Category**

---

Please select the category to be removed:

Category Name:

Descriptive Terms:

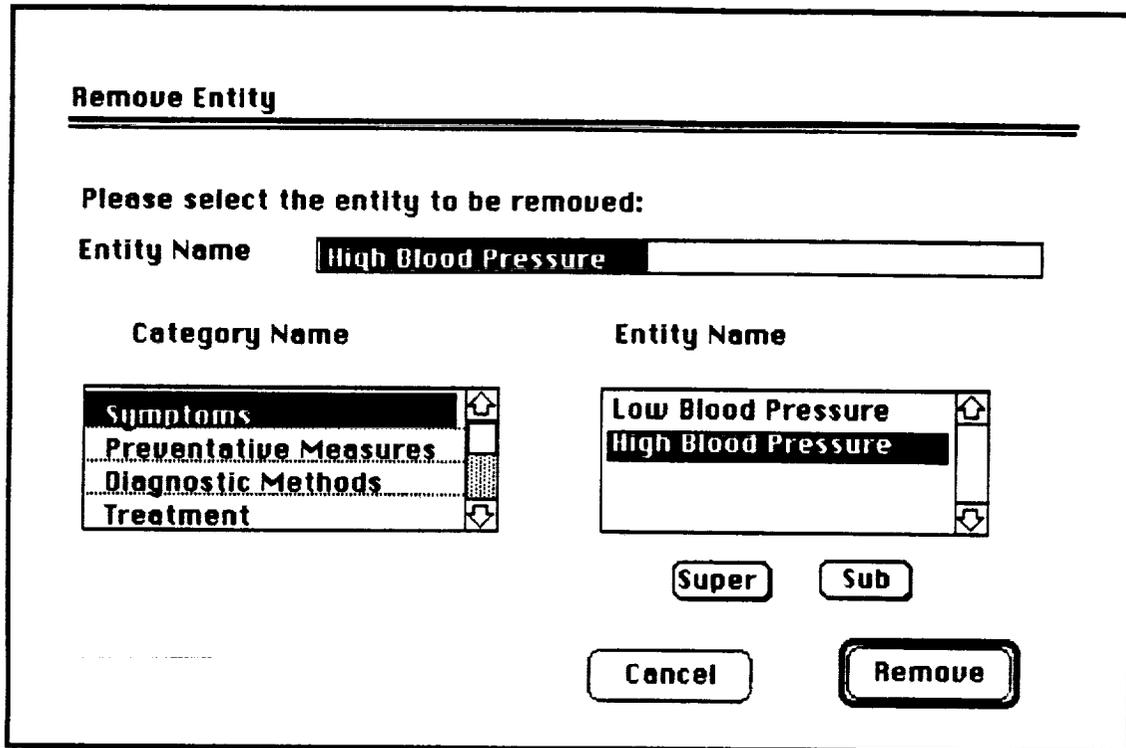
Medical Instruments	<input checked="" type="checkbox"/>
Diagnostic Methods	<input type="checkbox"/>
Treatment	<input type="checkbox"/>
Post Treatment Care	<input type="checkbox"/>

Procedural

Conceptual

**Figure A-62. "Remove Category" Dialog**

To remove the entity "High Blood Pressure," first make it the center of focus using the "Move Search" feature (Page 39). Activate "Remove" on the "Author" pull-down menu, then select "An Entity" from the dialog box that appears. As shown in the next dialog box (Figure A-63), the entity at the center of focus is automatically highlighted. (If desired, the category-name and entity-name scroll boxes could be used to identify an alternate entity for removal.) Clicking on "Remove" brings up a "Symptoms" tree showing a black area where "High Blood Pressure" previously existed.



**Figure A-63. "Remove Entity" Dialog**

To initiate removing the link from "Perspiration" to "Moderate Fever," go to "Moderate Fever" by double-clicking on this entity in the "Symptoms" tree. Now, activate the "Pointer Tool" from the "Palette" pull-down menu, then select the appropriate link by clicking on it with the cursor arrow. Now, activate "Browse Tool" from the "Palette" pull-down menu to return the cursor to its usual state.

Please activate "Remove" on the "Author" pull-down menu, then select "A Link" from the dialog box that appears. As shown in the next dialog box (Figure A-64), the selected link's name is automatically highlighted. Clicking the "Remove" button brings up "Moderate Fever" as the center of focus, with the entity "Perspiration" no longer visible. This entity has not been deleted, but is no longer linked to "Moderate Fever."

**Remove Link**

---

Link Name:

Source Entity:

Destination Entity:

Category	Entity
<input type="text" value="Symptoms"/>	<input type="text" value="Mild Fever"/>
<input type="text" value="Preventive Measures"/>	<input type="text" value="Moderate Fever"/>
<input type="text" value="Diagnostic Methods"/>	<input type="text" value="High Fever"/>

Intra-Category Link              
 Inter-Category Link           

**Figure A-64. "Remove Link" Dialog**

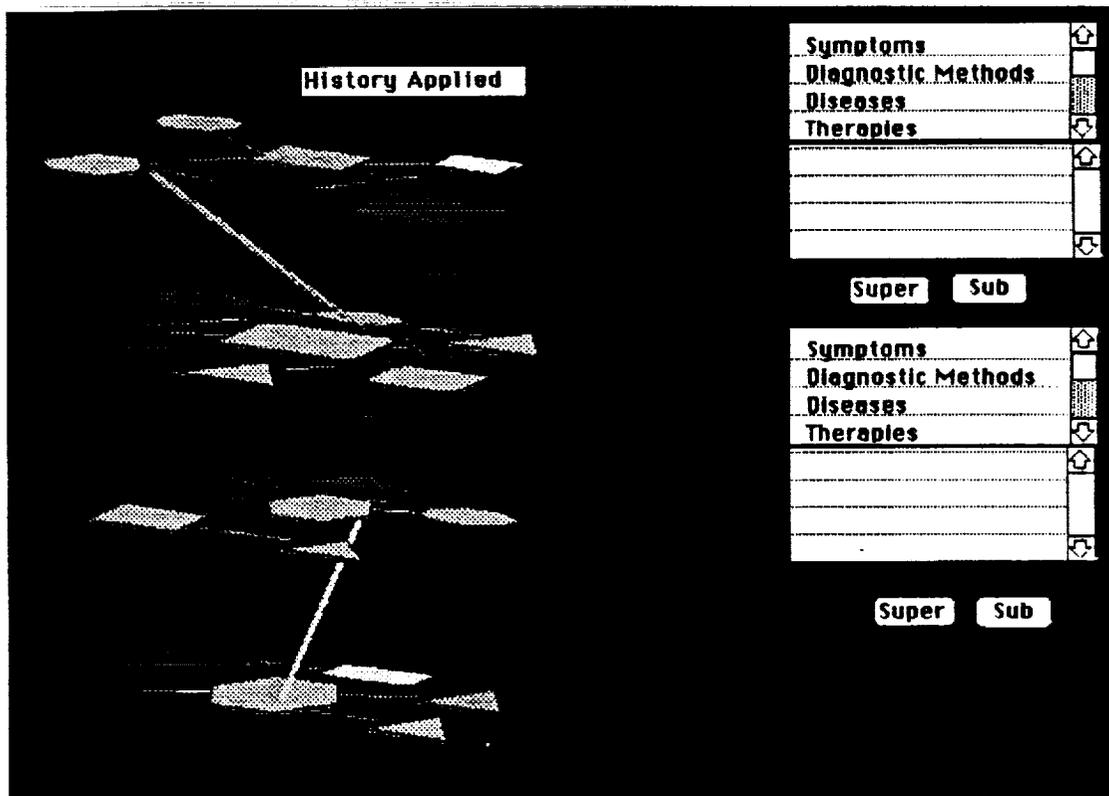
Removing a tour from the mental model is a similar process to those already described. Activate "Remove" on the "Author" pull-down menu, then select "A Tour" from the dialog box that appears. In the next dialog box, highlight a name of a tour in the scroll box, then click "Remove."

### **The History Function**

The final feature to be demonstrated, "History," presents a global view of the model in which all entities and links visited since during this use of Mental Link are highlighted. Activating "History" on the "Special" pull-down menu (Figure A-65) brings up the image depicted in Figure A-66. This aids the user in keeping track of which portions of the cognitive structure have been viewed. In the working tool, more elaborate versions of the "History" feature would allow storing personal histories encompassing more than one session of usage.



**Figure A-65. "History" from "Special" Menu**



**Figure A-66. Viewing the "History" Cluster**

### In Closing

On this tour, the reader familiar with human factors may have noticed occasional inconsistencies in the prototype's user interface. These are not accidental, but instead illustrate variations in how Mental Link could interact with users. Since the purpose of this project was functional design rather than final specification, a range of interface modalities was shown. As discussed

later, user prototyping would provide useful feedback in choosing from among these alternate design approaches.

This guided tour has simulated many of the features of Mental Link. However, other functions of this tool could not be demonstrated due to the inadequacies of prototyping software. Also, aspects of the prototype interface were often more cumbersome than Mental Link would be; this was again due to the limits of mimicking a sophisticated application. Hopefully, despite these flaws, this tour has conveyed a sense of how a tool that images virtual cognitive space could aid in representing and evaluating complex mental models.

