Groupware Concept Mapping Techniques

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Abstract: Concept maps have been used in education, policy studies and the philosophy of science to provide a visual representation of knowledge structures and argument forms. They provide a complementary alternative to natural language as a means of communicating knowledge. In many disciplines various forms of concept map are already used as formal knowledge representation systems, for example: semantic networks in artificial intelligence, bond graphs in mechanical and electrical engineering, Petri nets in communications, and category graphs in mathematics. This paper describes the design and application of a groupware concept mapping tool designed to support the knowledge processes of geographically dispersed communities.

Introduction

Concept maps are used to structure argument forms and express relationships between ideas [10]. In education, Nowak and Gowin [23] have promoted the use of concept maps to investigate a student's understanding of a topic, and there are many different forms that have been applied in this field [18]. In management, Axelrod [3] proposed *cognitive maps* as a means of representing the conceptual structures underlying decision making, and these have been used empirically to analyze organizational decision making [5] social systems [4] and the policies of political leaders [15]. In artificial intelligence, Quillian [25] developed a form of concept maps that came to be termed *semantic networks* and used extensively for formal knowledge representation.

In knowledge acquisition, concept maps are used to elicit knowledge from experts, for example the Wright-Patterson studies of the pilot's associate [20]. In linguistics, Graesser and Clark [14] have developed an analysis of argument forms in text in terms of structured concept maps with eight node types and four relation types. In the history of science, Thadgard [29] and Nersessian [22] have used the dynamics of concept maps to model processes of conceptual change in scientific revolutions. In the philosophy of science, Toulmin [30] developed a theory of scientific argument based on typed concept maps that provides a model of the rhetoric of Western thought [12].

This article reports on the development of a number of concept mapping tools designed for stand-alone and group use, and on their integration with multimedia documentation systems.

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DOC 94-10/94 Banff, Alberta, Canada
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The Structure of Concept Maps

Figure 1 shows a typical concept map from an educational domain in which a student has been asked to show the way in which they think about water [23]. The map has two types of nodes, *concepts* shown by ovals, and *instances* shown by rectangles. These are linked by arrows labeled with relations such as *needed by*, *made of*, *changes*, and so on. The conceptual structure developed encompasses some of the physics and biological roles of water. The student has developed the map within broad guidelines as to what are concepts and instances, and that they are to be linked by labeled directed arrows denoting relations.

Figure 2 shows a concept map developed using Toulmin's [30] methodology for the analysis of argument forms applied to the derivation that Harry, born in Bermuda, is a British citizen. The methodology prescribes various types of component that may be expected in argument forms such as *backing*, *warrant*, and so on, and these are indicated by textual labels rather than differing shapes.

Figure 3 shows a concept map representing a knowledge structure for part of an expert system [7]. Nodes that are: ovals represent *concepts*; ovals with short horizontal lines, *primitive concepts*; rectangles, *individuals*; rounded corner rectangles, *constraints*. Unboxed text represents *roles* (relations or attributes). The structure shown has a formal interpretation as a semantic network in a visual language for knowledge representation [6].

Figure 4 shows a concept map representing a knowledge structure, a conceptual graph [28] for the assertion that "Tom believes that Mary wants to marry a sailor." This concept map is another form of semantic network having a formal interpretation in terms of deductive logic.

The general form of a concept map is a sorted, directed graph of nodes, each of which has a type, and some of which are linked by arrows. This abstract structure encompasses all three of the examples given so far, plus many other forms of concept map such as PERT charts [21], Petri nets [26], bond graphs [17], and category-theoretic diagrammatic proofs [19].

As well as having specified types of node, concept maps may also have specified syntactic constraints relating to the possibility of arrows between the types of node. For example, a common constraint is that illustrated in the concept map of Figure 1, that the graph should be *bipartite* with concepts and instances forming one part and relations another. The syntactic constraint is then that arrows can only be drawn between nodes of different parts. Bipartite graphs are often conceptualized as the relation nodes being labels on arrows going between the other nodes.

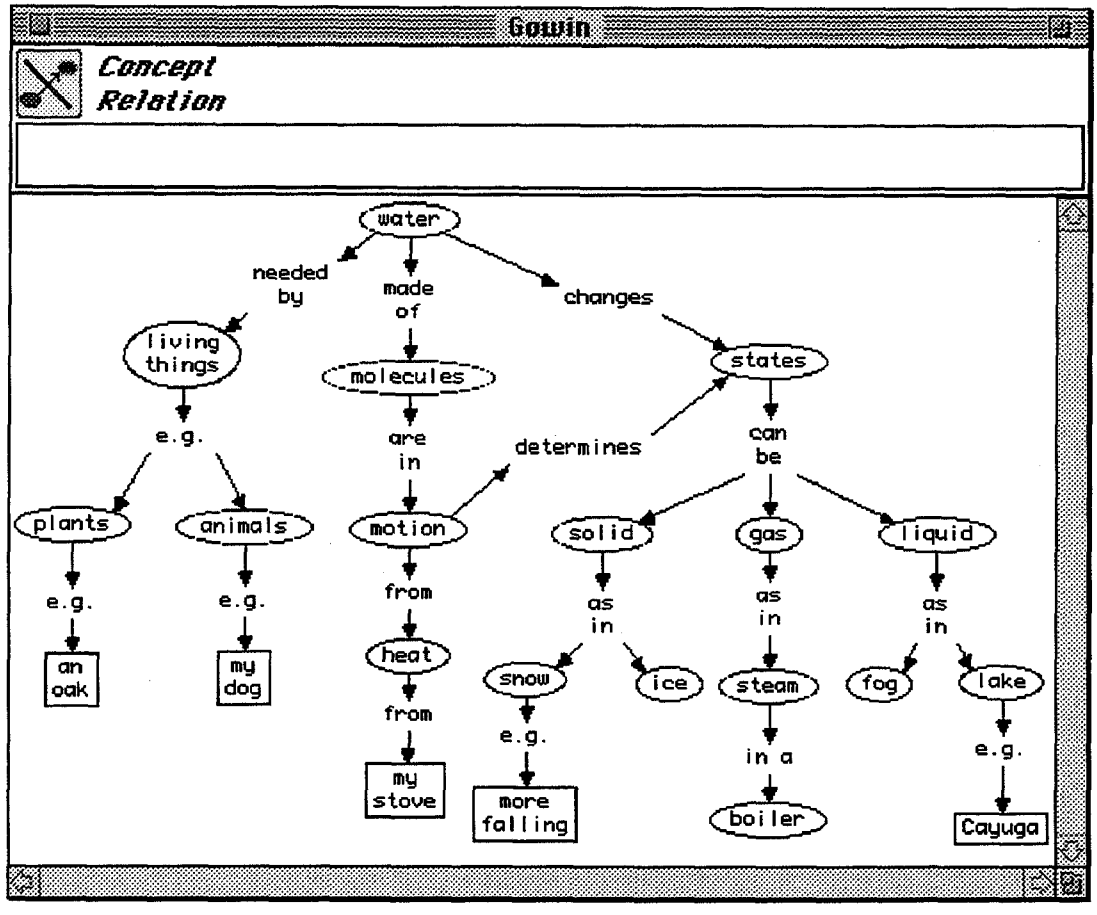

Figure 1 Concept map of student's knowledge [23]

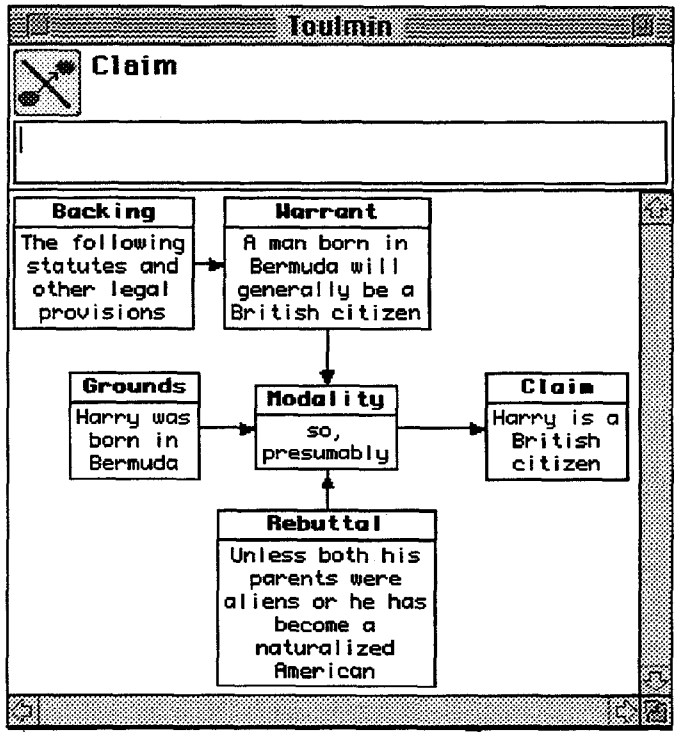

Figure 2 Concept map of argument form [30]

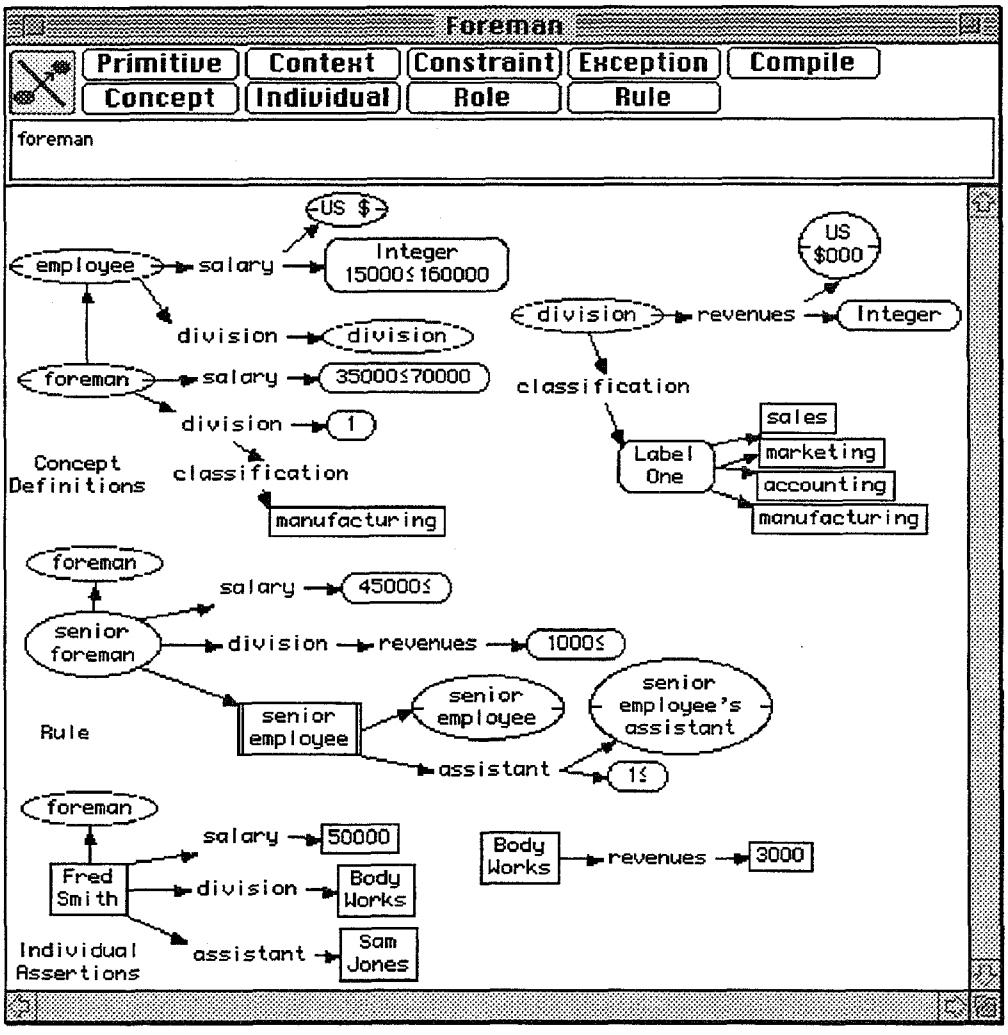

Figure 3 Semantic network of knowledge structure [7]

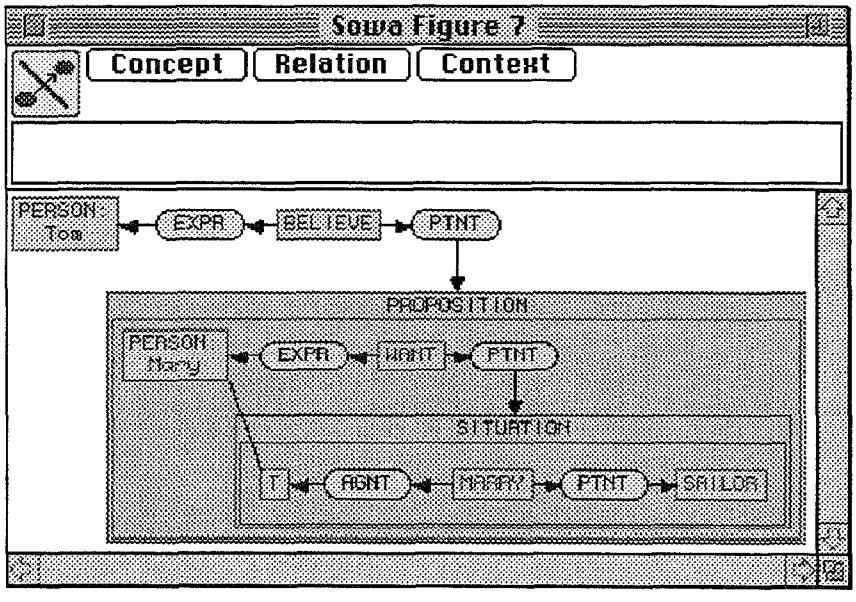

Figure 4 Conceptual graph of knowledge structure [28]

The constraints upon argument forms as shown in Figure 2 are more severe since the methodology requires arguments to be analyzed according to the structure of nodes and links shown. The semantic network of Figure 3 has some constraints such as arrows from concepts to individuals being meaningless, and cycles not being allowed. The conceptual graph of Figure 4 is essentially bipartite with respect to concepts and relations, but introduces contextual enclosures such as proposition and situation, and coreference lines such as that from Mary, which go beyond a simple directed graph. They can be interpreted graph-theoretically as sub-graph and equality operations respectively.

A General Concept Mapping Tool

The four concept maps shown above are all screen dumps from a general concept mapping tool called KMap which provides a grapher for nodes and arcs that can be programmed by the user to support different forms of concept map. User interaction with KMap takes place through the creation of statements in the visual language, and through interaction with existing statements through popup menus whose content is specific to node type. The actual action initiated is context-sensitive: to the node selected for the popup, to nodes linked to it, and to other nodes preselected by clicking on them in the graph. This allows both simple and complex activities to be initiated by natural and comprehensible user actions.

KMap is itself programmable through the Apple high-level object event protocol [2], and can be driven by any of the scripting languages in Apple's open scripting architecture such as AppleScript [13], Frontier [31] and TCL [24]. It can also run scripts triggered by user interaction. The combination of these two capabilities enables KMap to be integrated with other applications, and user interaction with graphical structures in the visual language to be used to control any activity supported on the host computer or network. The development of a specific system involves writing scripts to provide the required functionality by drawing upon existing applications.

Figure 5 shows a user interacting with a concept map of multimedia materials concerned with the field identification of North American birds. The map itself gives an overview of the topic and an index to available material. As the user mouses over a node a popup menu symbol appears. Clicking on this displays a menu that can be used to access the material, display text, play a sound, run a movie, and so on. The menu is generated from an underlying script, and user actions are reported to the script. The material accessed can be retrieved using either standard facilities for sound and movie playing within the application, or through commands which initiate another application and appropriate dataset.

The actions on the popup menu can include the opening of other concept maps so that is possible to index a large body of material through layers of connected maps. It can also include opening files in other applications which may themselves make calls back to the concept mapping tool. Hence complex heterogeneous systems may be developed if needed for particular applications.

Figure 6 shows the generation of the visual language being used in Figure 5. The system designer generates nodes of different types appropriate to the domain of materials to be accessed. The visual features of each type can be designed to be distinctive and attractive. The script can associate simple retrieval activities for each type dependent on the data stored with each node, or, since it has full access to the concept map, can take context-sensitive actions as appropriate.

Groupware Concept Mapping

In a multi-user environment, concept maps can provide user interfaces to shared resources supporting a range of group processes such as brain-storming, collaborative planning and joint development of knowledge structures. Table 1 shows a standard analysis of modes of interaction in computer-supported cooperative work (CSCW) systems [16]. To support the normal activities of target user groups, a multi-user concept mapping tool should ideally support all four synchronicity/locality quadrants in the table. That is, users should be able to use the software together in an electronic meeting room in a face-to-face meeting to jointly construct a rough concept map of their task. After the meeting, any of the users should be able to use the same software to access the same concept maps generated by the group from her computer at her desk as though it was single-user software (asynchronous remote interaction). If a second user starts using the same maps, she should be able to seamlessly (and harmlessly) enter into the environment in a synchronous remote interactive mode (possibly supplemented with an audio link).

	Same Place	**Different Place**
Same Time	face-to-face meetings	synchronous remote interaction
Different Time	asynchronous interaction	asynchronous remote interaction

Table 1 Interaction modes of CSCW systems

Any application must project to the user some model of how data is organized and how it is accessed and navigated. There is a familiar model that applies well to concept mapping: hypertext and hypermedia. While there exists no universally accepted definition of hypertext, Akscyn provides a good description [1]:

- Information is "chunked" into small units, variously called *notecards, frames, notes,* etc. Units may contain textual information. In *hypermedia* systems, units also contain other forms of information such as video graphics, bit mapped images, sound and animation.
- Units of information are displayed one per window (systems vary in the number, size and arrangement of windows permitted).
- Units of information are interconnected by *links*. Users *navigate* in a hypermedia database by selecting links in order to travel from unit to unit.
- By creating, editing, and linking units, users build up information structures for various purposes (e.g. authoring documents, developing on-line help systems).
- In *shared* hypermedia systems, multiple users may simultaneously access the hypermedia database. Shared systems may be implemented as *distributed* systems, in which portions of the database are distributed across multiple workstations and file servers on a network.

Concept maps form arbitrary networks of *concepts* and *links*; hypermedia forms arbitrary networks of *nodes* and *hyperlinks*. The match is quite natural whether one looks at it from the vantage point of hypermedia or from concept mapping: Many hypermedia systems provide views or maps of the hyperspace, and these views strongly resemble concept maps (although they do not usually convey the obvious meaning that concept maps do). On the other hand, from the perspective of concept mapping, one often uses a single concept (node) in a map which itself needs to be elaborated as a concept map; the elaboration can accomplished by hyperlinking between the parent concept and the "internal" elaborated concept map. Furthermore, concepts can be annotated by hyperlink references to other (non-concept map) documents.

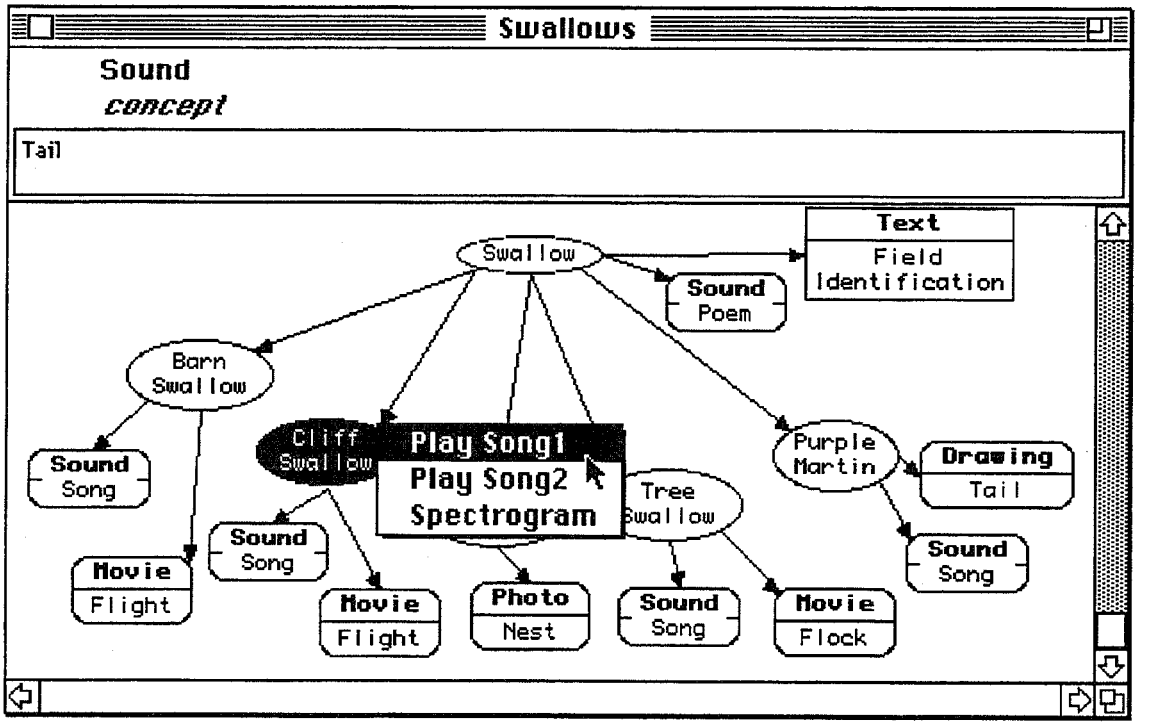

Figure 5 Concept map accessing multimedia materials

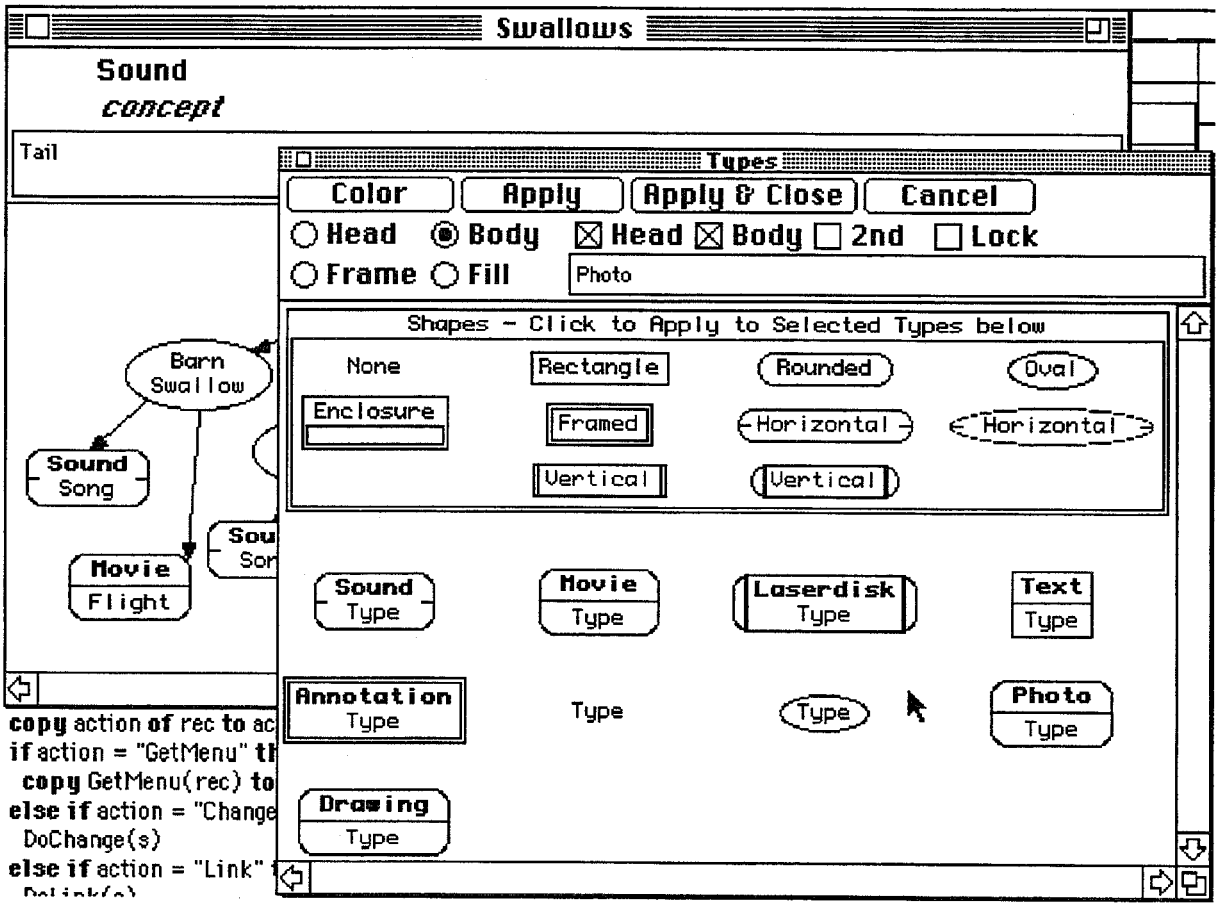

Figure 6 Entering concept map types to define a visual language

Mediator: Distributed Manufacturing Support

Mediator [8] is an open architecture information and knowledge management system designed to provide a flexible technology to support the management of complex manufacturing environments. A heterogeneous environment is assumed in which the sub-systems are geographically dispersed and involve different application packages, not necessarily designed to work together, multiple platforms, protocols and forms of user interface. The function of Mediator is to provide a knowledge support system for the managers and system operators involved in running a virtual factory. It is designed to facilitate communication, compliance with constraints including physical restrictions and legal obligations, and to generally represent knowledge *about* any activity or sub-system relevant to the manufacturing process.

The Mediator design and prototype is one outcome of the *knowledge systematization* technical work package of test case 7, GNOSIS, of the international Intelligent Manufacturing Systems (IMS) pre-competitive research program. GNOSIS involves over 100 participants in 31 industry and university organizations in 14 countries, with the objective of developing a *post mass production manufacturing paradigm* involving *reconfigurable artifacts*. The knowledge systematization work stream has been concerned with the modeling and management of information and knowledge flows throughout the complete product life cycle from initial needs through design, engineering, production, to reuse and recycling. A study using knowledge acquisition and representation tools to define and analyze major policy and technical issues in GNOSIS itself is reported in one accompanying paper [11], and the use of Mediator to index a CD-ROM in another [27].

Figure 6 shows the architecture of Mediator. A server agent at a site manages a knowledge base consisting of a heterogeneous set of files from different applications. Concept maps are used to represent the files and relations between them. Files may be opened from the maps, automatically using the appropriate applications. Since the maps and hypermedia documents of Mediator are also files, the system can be used to support large-scale linked knowledge structures. Client agents at remote sites connect to server agents across the network and allow files to be accessed remotely in the same way as they are locally. A write token for each file is passed around the network allowing collaborative development of knowledge structures. The data structures for the visual languages are very compact allowing real-time updates with network data rates as low as 1 Kbyte/sec.

In research coordination the top-level knowledge structures are concerned with the mission. They link to structures concerned with technical projects and, since the visual language tools support Petrinets, knowledge bases, and so on, much of the detailed technical material can be captured in Mediator. At the lowest level files represented in Mediator may be opened using unrelated applications, automatically selected by file type.

The initial implementation of Mediator was done completely in KMap using AppleScript to program both the information retrieval and groupware protocols. Hence, all of the Mediator knowledge structures may also be embedded through KWrite [9] in active, printable documents, so that reports, manuals, and so on, are readily generated. The concept map links support world wide web URL's, so that Mediator is able to interoperate seamlessly with tools such as NCSA Mosaic.

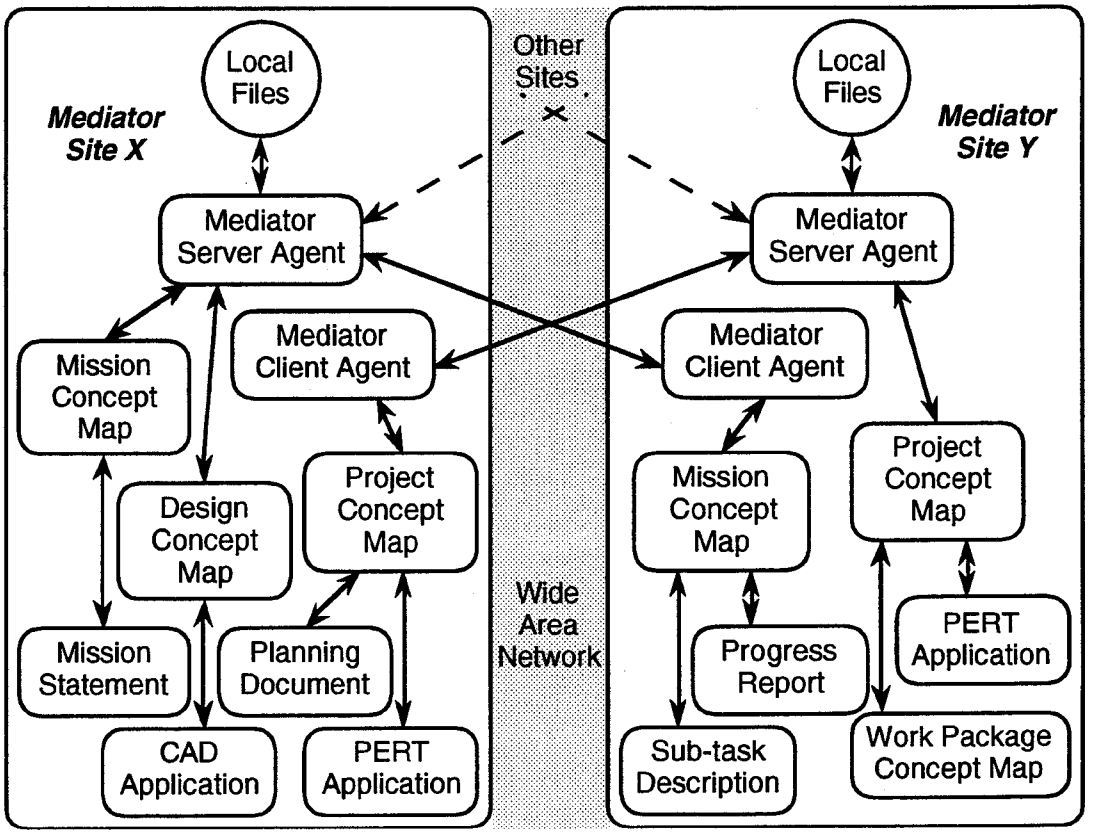

Figure 5 Mediator knowledge-based coordinator

Accord: Groupware Hypermedia System

Mediator takes advantage of the synergy between concept maps and hypermedia: it can act as a viewer through which an author can organize subject material stored in diverse formats. SMART Accord is a project which takes the concept map/hypermedia synergy a step further. Accord allows one to draw concept maps using an editor similar to Mediator's, but every node and link drawn in the map is also represented in an underlying hyperspace which is potentially shared with other users and other concept maps. Figure 6 illustrates the concept. The hyperspace contains "abstract" hypernodes which have hyperlinks between them. In this case, the nodes represent states in a simple communication protocol. The links between them all represent state transitions. Surrounding the hyperspace are several concept maps as they would appear to a user reading or editing them. Each concept map shows some subset of the nodes and links in the hyperspace. The concept map window labeled "The Complete Protocol" contains a view of the entire hyperspace.

Although the Figure 6 shows similar graphical layouts between the concept maps, no such constraint is enforced by the system: users may drag nodes and link labels to achieve any layout they wish; the arcs always remain anchored to their terminating objects.

Whenever a user draws a new node in a concept map, a corresponding hypernode is always created in the hyperspace; likewise, whenever a user draws a new link between to nodes in a concept map, a corresponding hyperlink is created between the corresponding hypernodes in the hyperspace. Nodes and links may be removed from the view with or without removing them from the hyperspace. Most operations on the concept maps, such as renaming nodes and links, have corresponding effects in the hyperspace.

One advantage of storing all the information in the hyperspace is that one can easily *expand* nodes in a concept map to reveal its neighbors in the hyperspace. An expansion operation on a concept map node looks up each of the hyperlinks that are anchored (either to or from) the corresponding hypernode. For each link, the other anchor node is either found in the current concept map or is drawn as a new concept map node, and the labeled link is drawn between the two anchor nodes. Users may request expansions to proceed recursively to any depth. For example, looking back to Figure 6, a user looking at the "Simple Send" view could perform a two-level expand of either node to have the system draw in all the information in the hyperspace (although the layout may not be optimal).

The expansion operation has been observed to be used successfully by groups engaged in brainstorming activities. Users each have their own copy of Accord on their own workstation, which is connected to a network where a shared Accord hypermedia database resides. Each user works in his or her own concept map, however, a central concept node is chosen as a "hub" which all users open as a node their own concept map. Each user then generates ideas and links them to the central hub node. Users may perform an expansion of the central hub node to draw the work of the other participants into their own map. In this way they may build upon one another's ideas, integrate several related threads, or express relationships between the threads. Although no formal studies have yet been performed, the result appears to be a far more organized, polished, and complete consensus than is usually achieved by other brainstorming techniques. This may be due to this technique integrating both the brainstorming and organization/selection stages of many group decision support systems.

Like Mediator, Accord uses the nodes in concept maps as a navigational tool. In both Mediator and Accord, one can merely double-click on a node to hyperlink to an associated document. In Mediator the link may be to any arbitrary document handled by an appropriate application. In Accord, the document is always the Accord hypernode which is represented by the concept map node. This may contain another concept map. Indeed, this answers the question of where Accord concept maps are stored—they are always stored as the contents of hypernodes in the hyperspace. A hyperspace contains nodes which contain views of the hyperspace itself. It might be pointed out at this time that the information in Figure 6 is a bit rarefied: assuming all of Figure 6's views reside in the same hyperspace, the hyperspace is a bit bigger than advertised, for it must also contain one node for each view:

Some data has been collected on how users make use of the tool. Users have been from a variety of backgrounds. Most were technically oriented people such as engineers and computer support personnel, but users also included managers and people from the marketing, personnel departments, and education. The situations observed include:

- individuals working on a concept mapping task strictly for private use;
- individuals using the tool to produce concept maps to be used as overhead projections to a group;
- groups using a single projected-screen Accord workstation with an individual acting as "scribe";
- small groups working concurrently on individual workstations in a lab;
- small groups working asynchronously via a file server.

While almost all users had some computer experience, the experience ranged from novice to expert. All the groups seemed be able to use the tool effectively. But there were problems. For example, early sessions in the "scribe" situation showed difficulty: Verbal interaction in face-to-face meetings was too fast for the scribe to track in the interface. A "hotkey" command was added that allows one to type concept names rapidly to a series of cascading glyphs without removing the hands from the keyboard. This seems to be effective in allowing the scribe to capture ideas quickly so the group can later organize and relate them to the rest of the map. There are several other interface elements that have been added or are under consideration for speedier map creation.

None of the users interviewed expressed any difficulty understanding the use of concept maps, even though none of them had any previous experience with their use (although some had experience with paper-and-pencil flow diagrams). This supports much of the literature's contention that concept maps have *prima facie* validity. As one user put it, "I appreciate the structure and operation as being closer to the real thought process." Another user compared concept mapping with 'spider webs' (no doubt, the childhood educators' term for concept maps) that his child had been taught in school—"It's easy if you grasp the 'spider web' concept." Not only did the users find concept maps easy to use, some commented that they found others' use of concept maps valuable. One manager who participated in a three-way same time, same place Accord session commented, "I was able to achieve my objective and get the supposed owner of an idea to develop and identify his thoughts in a semi-formal way."

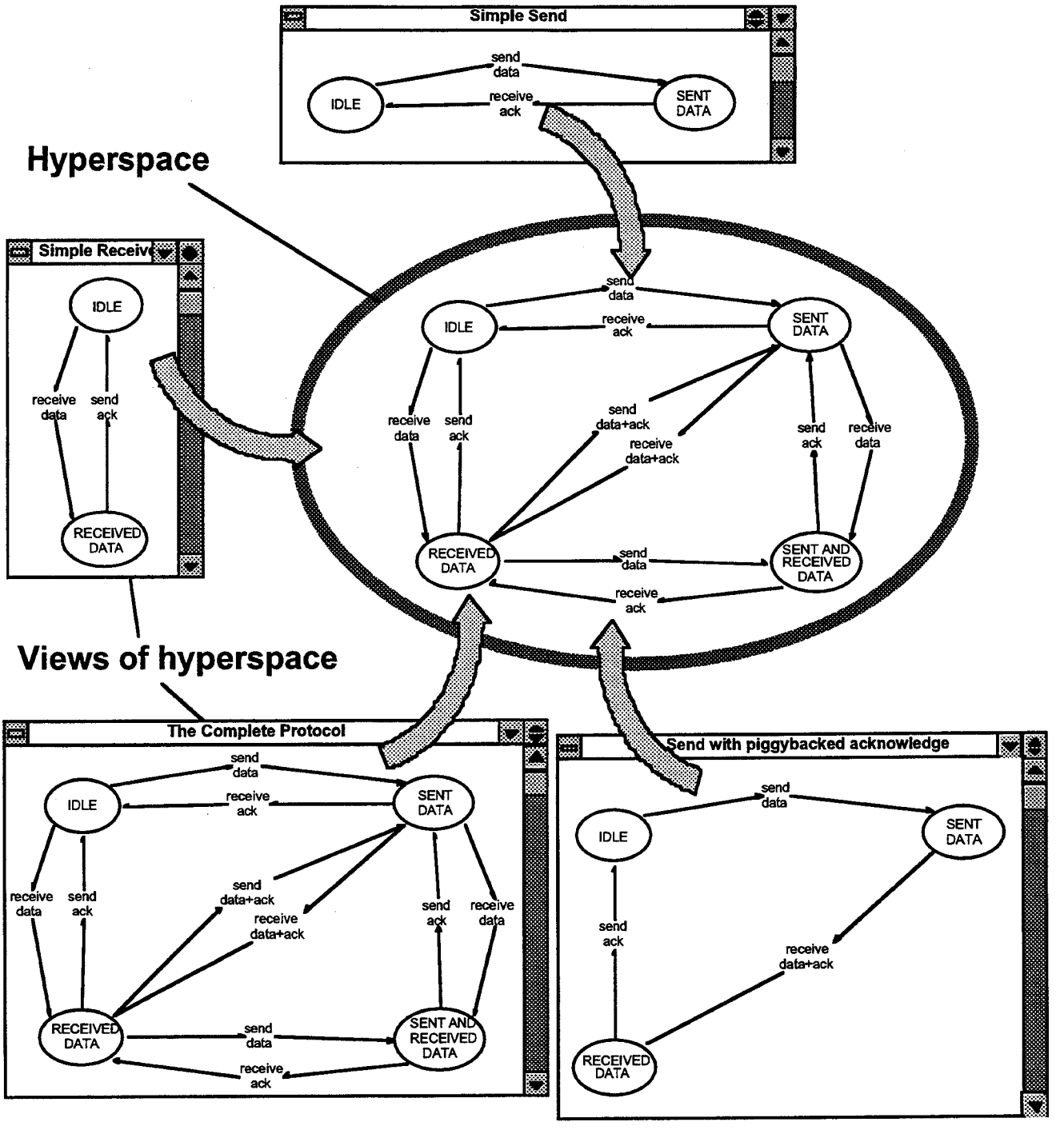

Figure 6 A hyperspace (large thick oval) containing several nodes and links represents a state transition diagram of a simple communication protocol. Four concepts are shown which contain subviews of the hyperspace

The groups working concurrently on individual workstations, not surprisingly, expressed a need for more coordination. The system did not automatically update them on changes made by other group members; they had to keep verifying and expanding their maps themselves to get this information. Most of this problem will be overcome when finer grained locks and multiple writers become available. An example of this kind of concurrent work is given in Figure 7, which is one of the maps produced in a single ninety-minute session by a group of three people who had never previously used the tool.

Although concept maps are excellent for describing complex concepts, they are not the only way and not always the most appropriate. Accord allows concept maps to be annotated with other objects such as text boxes and embedded documents. Accord hypernodes may sometimes contain no concept maps at all but only such annotation. Annotations may stand on their own, or they be may be visually linked to any other objects on the display, including nodes, link labels, and other annotations. Figure 8 illustrates two annotations, an embedded document (a bar graph) and an editable text box which is linked to a concept map node.

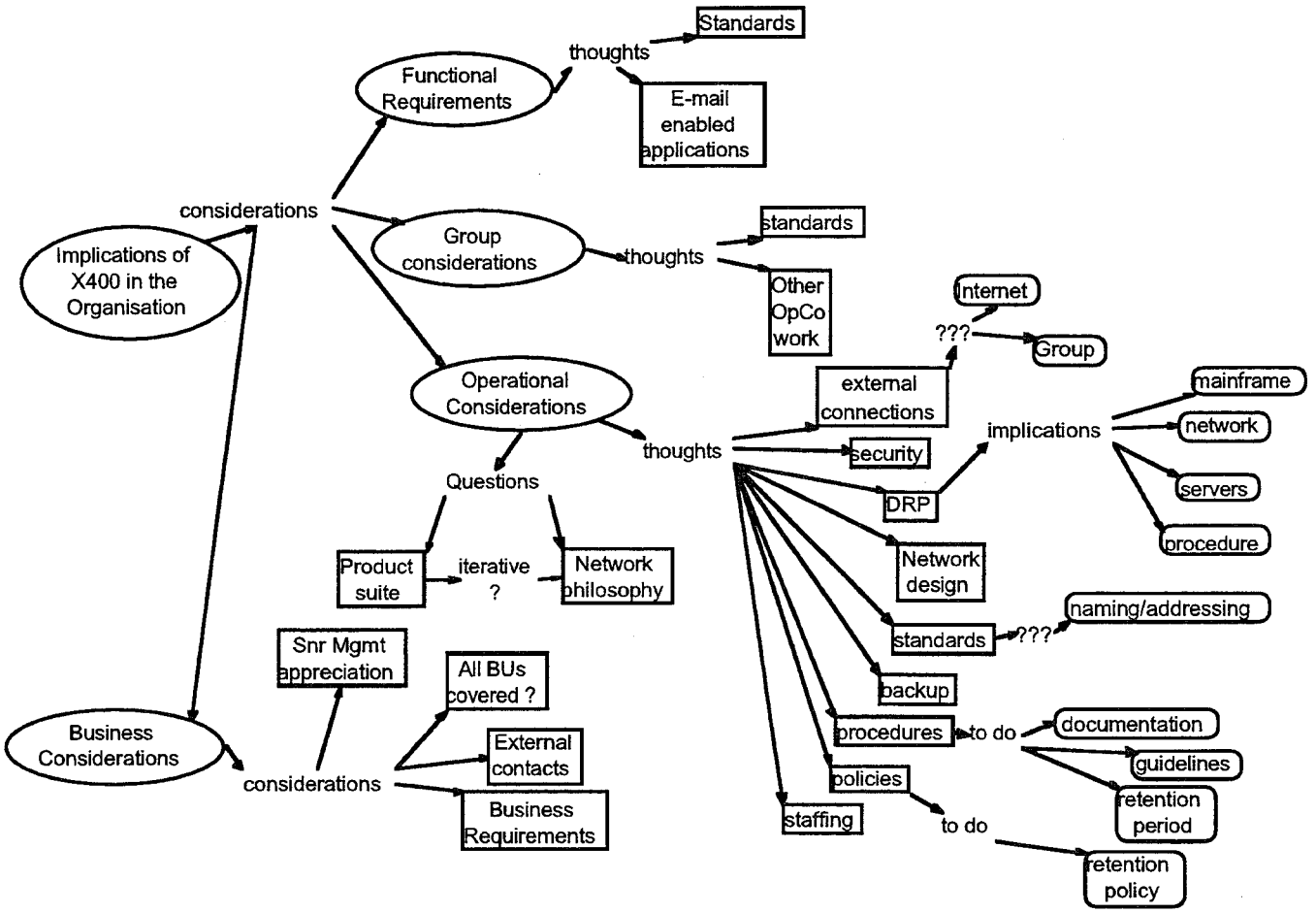

Figure 7 A concept map developed in Accord by a three member grouping working concurrently in a face-to-face situation

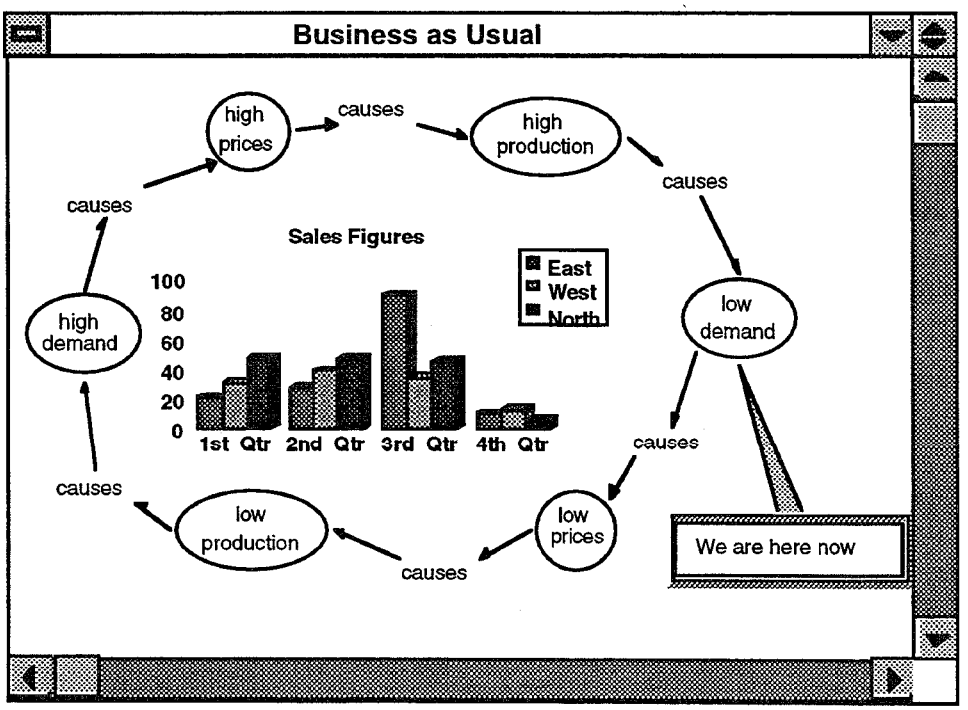

Figure 8 An Accord concept map with an embedded document annotation and an editable text box annotation.

Conclusions

Concept maps have been used in many disciplines and applications to provide a visual representation of knowledge structures and argument forms. They provide an alternative to natural language as a means of communicating knowledge. With the current state of the art in personal computer graphic workstations it is possible to develop generic concept mapping tools that may be programmed to emulate the different visual languages used in different disciplines, semantic networks, Petri nets, PERT diagrams, and so on. With the current state of the art in networking it is possible to offer such concept mapping tools in a groupware environment allowing them to be used to coordinate the knowledge processes of geographically dispersed communities.

This article has provided an overview of concept mapping techniques and applications, illustrated their basic structure and usage through KMap, and illustrated groupware implementations and applications through Mediator and Accord. It is suggested that concept maps provide an important methodology that is readily supported by tools in an electronic documentation system. They may be expected to play a significant role in computer-based systems supporting knowledge processes through network, CD-ROM and paper publication.

Acknowledgments

Financial assistance for this work has been made available by the Natural Sciences and Engineering Research Council of Canada. SMART Accord will be commercially available from SMART Technologies of Calgary, Alberta, Canada.

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