SUPPORTING THE CREATIVITY CYCLE THROUGH VISUAL LANGUAGES

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Abstract: The application of visual language tools for knowledge acquisition and modeling to the support of student's creative processes has been investigated. Such tools have potential application to both phases of the creativity cycle, the transition from loose divergent thinking to focused convergent thinking, and the converse transition whereby received knowledge is deconstructed through detecting anomalies and making overt the underlying tacit presuppositions. This paper outlines this model of creative dynamics, gives an overview of past applications of visual languages, such as concept maps, in a range of disciplines, and illustrates their use by graduate research students developing their research frameworks.

1. Introduction

This paper presents a progress report on ongoing research on using knowledge acquisition and modeling tools to support creative processes (Shaw and Gaines, 1982). At the AAAI Workshop on Creativity in 1991 we presented some early studies of graduate students on a Cognitive Science course using repertory grid tools to develop their research ideas (Shaw and Gaines, 1992). We also gave these students access to another knowledge modeling tool recently developed at that time which provided graphic support of a visual language for KL-ONE-style knowledge representation systems (Gaines, 1991). The students exported their repertory grids and derived rules to this tool, and were also able to use it for direct knowledge entry. One student in particular developed elaborate knowledge structures for his PhD research in this tool and commented that he found it more effective in developing his research ideas than a conventional text outliner—it was a visual *idea outliner*. We became interested in investigating this type of tool as a support for creative thinking, and realized that the students' using it had not adopted the KL-ONE semantics. They had used the shapes and connections to create *concept maps* that were expressive and useful to them in thinking, but had no formal semantics (or, at least, did not have those originally intended).

Concept maps, as used in education (Novak and Gowin, 1984), have already been used as knowledge acquisition tools (McNeese, Zaff, Peio, Snyder, Duncan and McFarren, 1990). and are generated by *Cognosys*, a text analysis tool developed for knowledge modeling (Woodward, 1990). In the knowledge modeling research, we were concerned with refining the maps into well-defined formal knowledge structures. In the creativity research, we became interested in supporting concept maps in general and developed a tool, KMap, that allows the visual syntax of most common forms of concept map to be emulated.

This paper summarizes the many different forms of concept map used in different disciplines, gives an overview of how we see them supporting creative processes, and reports some empirical studies of students on a recent Cognitive Science course using KMap to develop their ideas.

2. Knowledge Modeling in the Creativity Cycle

Barron, who has authored a number of major encyclopedia articles on creativity, has described what he sees as the current consensus of the nature of creativity:

"1. Creativity is an ability to respond *adaptively* to the needs for new approaches and new products. It is essentially the ability to bring something new into existence purposefully, though the process may have unconscious, or subliminally conscious, as well as fully conscious components. Novel adaptation is seen to be in the service of increased flexibility and increased power to grow and/or to survive.

2. The "something new" is usually a *product* resulting from a *process* initiated by a *person*. There are three modes in which creativity may easily be studied: as product, as process, as person.

3. The defining properties of these new products, processes, and persons, are their originality, their aptness, their validity, their adequacy in meeting a need, and a rather subtle additional property that may be called, simply, *fitness*—esthetic fitness, ecological fitness, optimum form, being "right" as well as original at the moment. The emphasis is on whatever is fresh, novel, unusual, ingenious, clever, and apt.

4. Such creative products are quite various, of course: a novel solution to a problem in mathematics; an invention; the discovery of a new chemical process; the composition of a piece of music, or a poem, or a painting; the forming of a new philosophical or religious system; an innovation in law; a fresh way of thinking about social problems; a breakthrough in ways of treating or preventing a disease; the devising of new ways of controlling the minds of

others; the invention of mighty new armaments, both of offense and defense; new ways of taxing the citizens of a country by its government; or simply a change in manners for multitudes of people in a specific period of time." (Barron, 1988)

There is *prima facie* validity of knowledge modeling tools to support these creative processes from the literature on scientific development, change and revolution. For example, Torretti, in analyzing the development of modern physics, considers the dynamics of conceptual schema to be the basic framework within which all other activities can be located. In particular, he analyzes in detail the essential limits to conceptual innovation that provide continuity in scientific development, noting that:

"C1. Some concepts are immune to change, and they provide a stable reference to decisive facts.

C2. The new concepts are arrived at through internal criticism of the old, by virtue of which the facts purportedly referred to by the earlier mode of thought are effectively dissolved.

C3. Reference to facts does not depend on the concepts by which they are grasped." (Torretti, 1990)

Tools that provide means to make these relations between concepts more overt and operational should have a role in the creative process of conceptual transformation.

Barron, Torretti, and many others, describe the phenomena of creativity, but what are its underlying psychological processes? One of the first psychologists to consider the relationship between the convergent and divergent knowledge processes of creativity within a cognitive framework was George Kelly whose *personal construct theory* presents a person as exploring his or her environment, collecting data about the world and constructing a personal reality from which to view it (Kelly, 1955). Personal construct theory has been the basis of many knowledge acquisition and modeling methodologies. The theory encompasses both the extensional, case-based methodology of tools based on the repertory grid, and the intensional, concept-based methodology of tools supporting term-subsumption knowledge representation systems (Gaines and Shaw, 1993).

Kelly analyzes the dynamics of change in a person's construct system in terms of a *creativity cycle* in which convergent and divergent thinking alternate. A system of personal constructs is not fixed, but may vary from one occasion to another:

"There are typical shifts in the sequence of construction which people employ in order to meet everyday situations....The Creativity Cycle has to do with the way in which a person develops new ideas." (Kelly, 1955, pp.514-515)

Kelly sees convergence/divergence as a sequence of loosening and tightening of constructions. A person who uses only tight construing may be very productive but cannot be original. On the other hand, loose construing is characterized by a person's "preposterous thinking" (p. 529) which is unformulated and often preverbal. The structured alternation of these processes is what we perceive as the creativity underlying intelligent behavior.

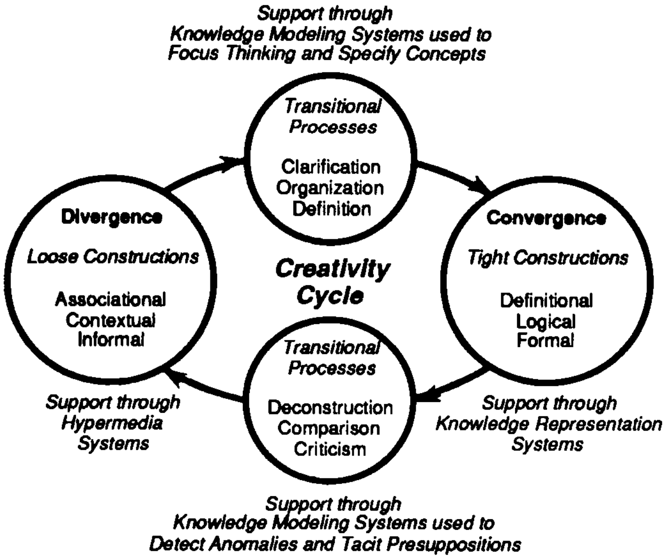

Figure 1 Creativity cycle and its support

Figure 1 illustrates the nature of the creativity cycle and the types of process involved in it, together with the roles that we have designed the associated computer-based tools to play in supporting these processes. Note that we see that phase of the cycle that is divergent and deconstructive as equal in importance to that which is convergent and constructive. It is as important to be able to deconstruct a well-established base of received knowledge through critical processes that can start a new creativity cycle, as it is to be able to clarify and formalize ideas into theories. Becoming aware of anomalies and tacit preconceptions is a stimulus to the creation of new approaches, experiments, interpretations and theories. This is not only important to experienced researchers but also to new graduate students where the weight of received wisdom is often the most significant burden impeding their establishing their own research directions and identities.

Creativity is part of a cyclic process. Each phase of the cycle is different in nature and requires its own support. At one time one may be clarifying and substantiating one's preconceptions, at another attempting to identify and demolish them. Different tools and techniques may be appropriate to different parts of the cycle, and the same tools may be used in very different ways dependent on whether the objective is a transition from divergence to convergence, or the converse.

3. Visualization in the Creativity Cycle

It is no coincidence that the words image and imagination have the same roots. It has been known from early times that visual imagery plays a significant role in the creative processes of many people. Hadamard's studies in the 1940s showed the significant role of imagery in creative thinking, and many case studies of genius recount vivid images as the precursors to significant new ideas (Hadamard, 1945). This has led to a specialist literature on the role of imagery in creative thought processes, such as Arnheim's *Visual Thinking* (Arnheim, 1969) and Miller's *Imagery in Scientific Thought* (Miller, 1984).

The availability of low-cost, high-performance graphic workstations and personal computers has made it possible to support visual thinking processes in a variety of ways across a wide range of disciplines, and again has led to a major literature on *visualization* such as the annual IEEE meetings with this theme (Kaufman, 1990; Nielson and Rosenblum, 1991). There is also a large and growing literature on the use of computer-based tools to support visual languages with formal semantics for the specification of a wide variety of structures (Glinert, 1990).

The studies reported here are concerned with the applicability of visual languages developed in artificial intelligence research to the support of creative processes. Semantic networks began as qualitative models of human memory processes (Quillian, 1968) and have been refined over this period to become highly formal visual languages representing knowledge structures based on sound and complete denotational or intensional semantics (Gaines, 1991). Examples include *SNePs* (Shapiro, 1979), *Conceptual Graphs* (Sowa, 1984), and various visual languages for *KL-ONE* (Brachman and Schmolze, 1985). More pragmatic examples include the graphic user interfaces for knowledge entry, editing and visualization in commercial tools such as KEE, ART and NEXPERT. Nosek and Roth have shown that users comprehend visual language representations of knowledge structures better than they do textual representations (Nosek and Roth, 1990).

Such developments in artificial intelligence are paralleled in other disciplines by the development of visual languages for 'concept maps', 'cognitive maps' and argument forms that are visually remarkably similar to those cited above, but do not have the formal semantics. In education, Ausubel's theories of the role of conceptual structures in learning (Ausubel and Robinson, 1969) led Novak to develop a system of concept maps (Novak, 1977) that has been widely applied in the evaluation of students' learning in the school system (Novak and Gowin, 1984). There is now a wide variety of different forms of concept map that have been applied in education (Lambiotte, Dansereau, Cross and Reynolds, 1989). They have also been used as tools to support the interviewing process in knowledge acquisition from experts, for example in the Wright-Patterson development of the pilot's associate (McNeese et al., 1990). In management, Axelrod proposed cognitive maps as a means of representing the conceptual structures underlying decision making (Axelrod, 1976), and these have been used empirically to analyze organizational decision making (Eden, Jones and Sims, 1979), social systems (Banathy, 1991) and the policies of political leaders (Hart, 1977). In linguistics, Graesser and Clark have developed an analysis of argument forms in text in terms of structured concept maps with eight node types and four link types (Graesser and Clark, 1985), and Woodward has developed tools to extract such maps from text (Woodward, 1990). In the philosophy of science, Toulmin developed a theory of scientific argument based on typed concept maps (Toulmin, 1958) that is regarded as one of the major themes of the rhetoric of western thought (Golden, Berquist and Coleman, 1976). In the history of science, the dynamics of concept maps have been used to represent the processes of conceptual change in scientific revolutions (Nersessian, 1989; Thadgard, 1992).

Hypertext systems that display overviews of nodes and links provide a natural tool for the computer support of concept map development (Smolensky, Bell, Fox, King and Lewis, 1987), and specific tools to do so have been developed (Streitz, Hannemann and Thüring, 1989; Bernstein, 1992). Frames, semantic networks and hypertext structures have been compared (Travers, 1989), and Jonassen has shown how the elicitation of semantic networks may be used to structure hypertext (Jonassen, 1990). A variety of techniques and computer-based tools have also been developed for the analysis of concept maps. When they represent the strict semantics of a visual language for knowledge representation, it is appropriate to use deductive inference engines to draw logical conclusions from the maps (Sowa, 1991). Leishman's computation of analogical relations as constrained partial correspondences may also be used with such knowledge structures (Leishman, 1989). Many cognitive maps represent influences and causal relations and may be treated as visual languages specifying qualitative simulations which may then be analyzed using constraint-based reasoning, or logics of uncertain reasoning (Kosko, 1986; Zhang, Chen and King, 1992). Even general concept maps can be analyzed in terms of their structure of their link relations (Cropper, Eden and Ackermann, 1990).

4 Some Experiments with KMap

KMap is a generalized visual language tool that provides a user interface and data structures for creating, editing, analyzing and exporting typed graphs with directed and undirected links. The user interface allows KMap to be tailored to particular requirements by specifying the node types required, and associating with visual interface characteristics such as shape, color and text attributes. KMap recognizes a variety of user interface items, such as menus and buttons, that need not be specified in advance, and this enables its interface to be tailored by specifying different interface resources rather than modifying code. The specified types and interface then allow graphs to be generated using these node types together with lines and arrows as links. Links may be labeled using specified link label node types.

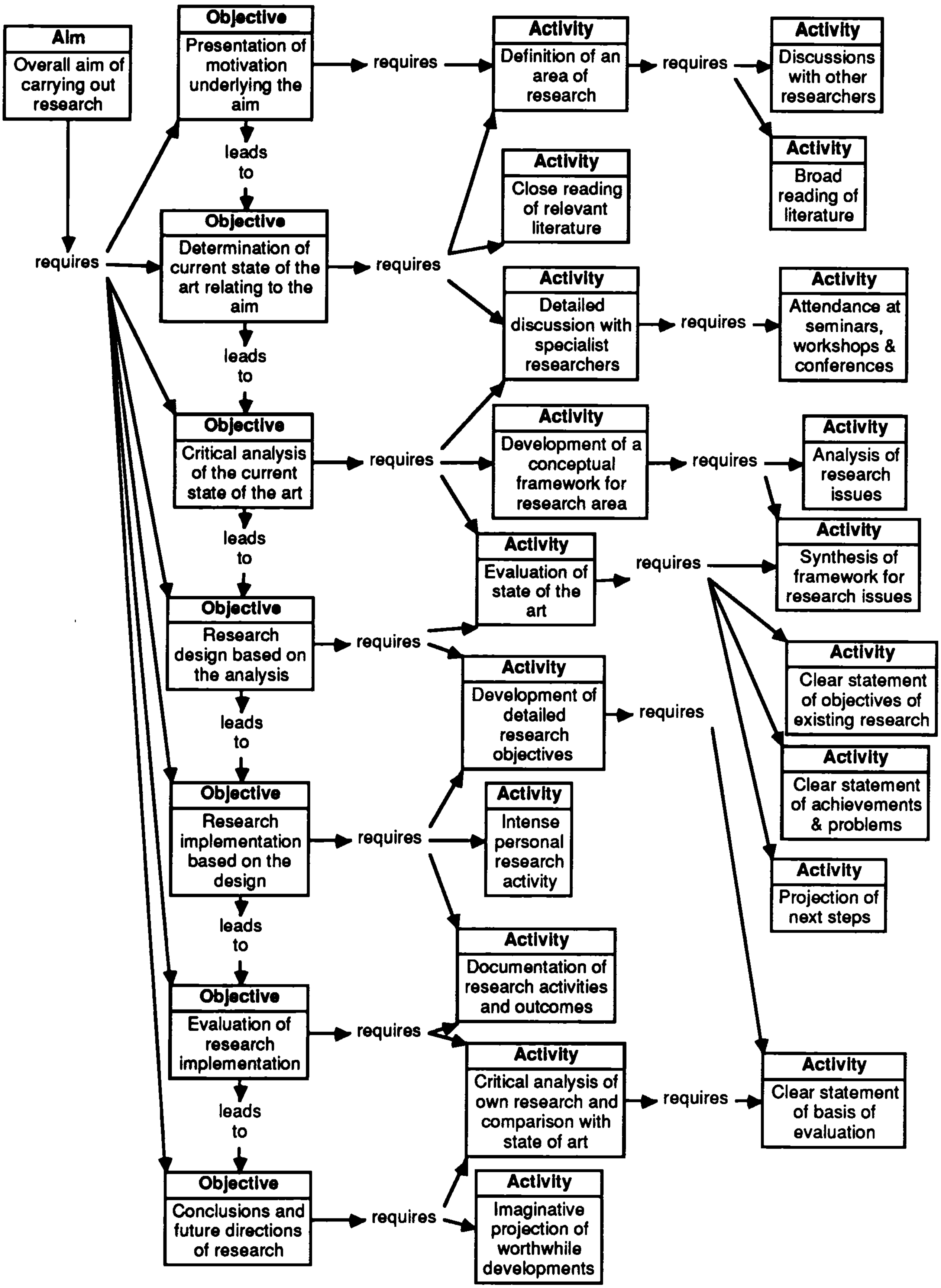

Figure 2 Concept map on carrying out graduate research

KMap itself supports all the interactive graphical capabilities for editing, printing and so on. It supports an inter-application communication protocol enabling other programs to make use of the graphs, and to interact with the users through the graphs. Hence it may be used as a front end to many other systems such as conceptual graph and KL-ONE deductive systems, qualitative simulation systems, and Petrinet and category-theoretic proof systems.

KMap may also be used more informally to specify concept mapping environments, and to develop concept maps within them. It is this type of use that we have explored with graduate students on a cognitive science course. The objective was not only to see how the availability of such tools affected their research activities, but also to see what use they made of the open-ended concept map environment development tools. This contrasts with other applications in education where the form of concept maps is specified in advance.

Figure 2 shows an example concept map on writing a thesis which we developed and supplied to incoming graduate students. Three node types have been defined, *Aim*, *Objective* and *Activity*, together with two link types, *requires* and *leads to*. A rectangular shape has been used to identify nodes, and an unboxed shape to identify links. The type name of a node is shown at the top—this is an optional interface feature.

In the Fall of 1992, we repeated the previously reported experiment (Shaw and Gaines, 1992) in which students in a cognitive science course used knowledge acquisition and modeling tools to investigate their own research ideas. Eight students again used repertory grids and visual languages individually and in conjunction with supervisors and other researchers. This time the visual language editing tool was KMap and we did not impose any semantics on the concept maps. Examples of Toulmin's and Gowin's concept maps were discussed and made available, but the tool was otherwise presented as an open-ended grapher with links to HyperCard so that nodes could be annotated. A HyperCard stack supporting such annotation was provided so that the students did not have to program an appropriate protocol.

KMap was fully utilized by all the students, both individually and in conjunction with others discussing, amending, or developing alternatives to, the primary concept maps developed. The students all developed their own systems of node types and styles, taking little note of the examples provided. The node types introduced seem to be very domain specific, legitimately so, and this is itself a lesson for future design. One limitation of previous concept maps is that even when node typing is supported, it is not dynamic and there is no explicit relation between types. The open ended student use suggests that node types should be treated as a full type lattice. This does not appear to be an artifact of the computing background of the students, since the types used are more those suggested by common sense than data structure theory, but the conclusion should be tested with users with other backgrounds.

Figure 3 shows a typical example of a large concept map produced by a student involved in groupware development. The students used two page monitors, and some of the maps produced were large, requiring several pages of printout when put into their reports. Figure 4 shows the right hand side of the same map so that the content may be examined.

This student had used rounded corner box to indicate fairly concrete exemplars. The cluster of exemplars of hypertext on the right of Figure 4 forms a natural set of elements for repertory grid elicitation, and the concept maps proved a very natural way of dividing up an overall domain into coherent sub-domains that could be studied in more detail.

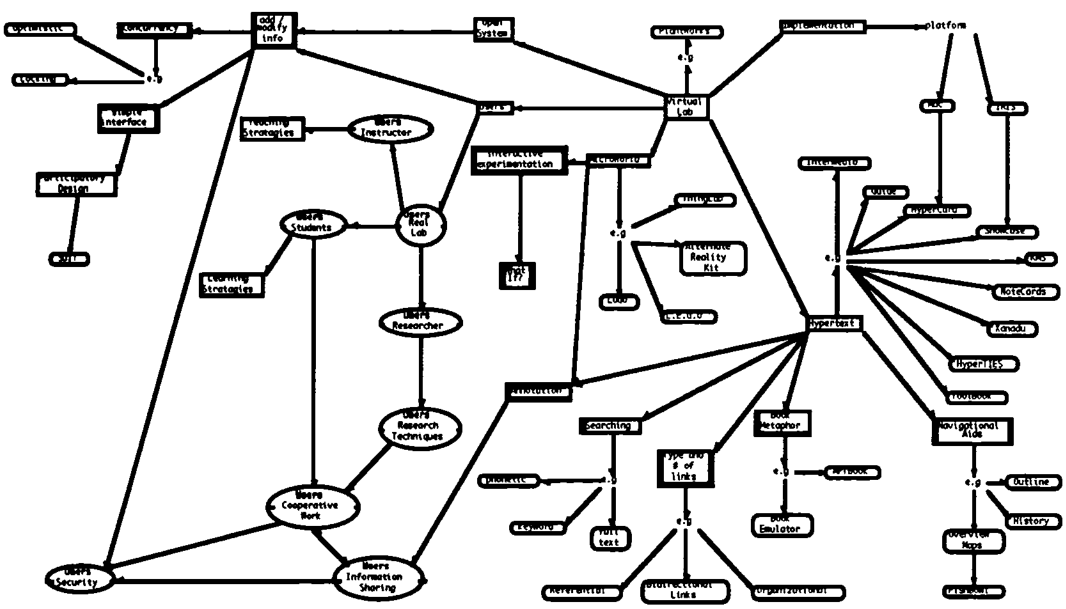

Figure 3 Overall structure of a concept map on issues relating to collaborative hypertext development

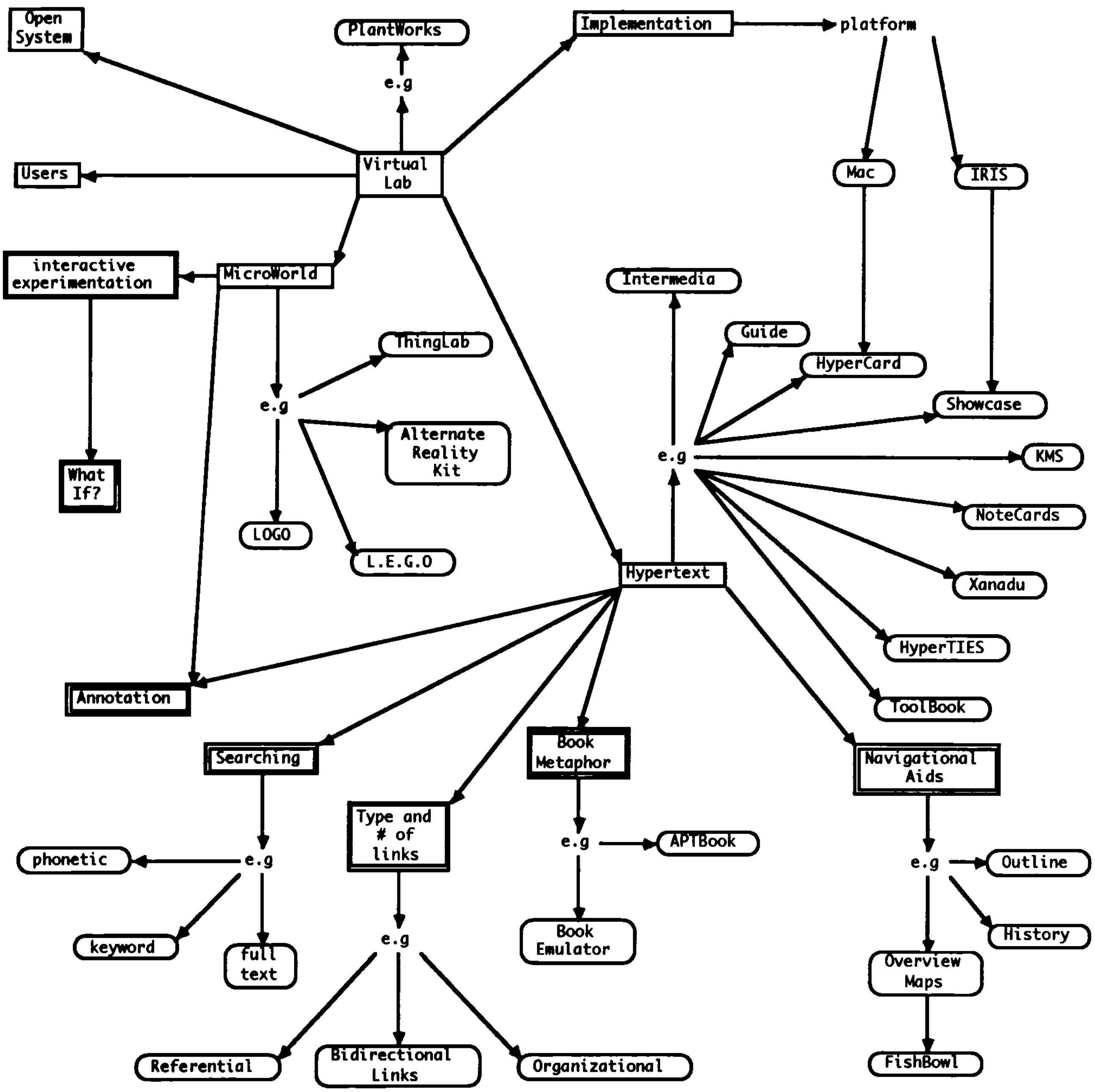

Figure 4 Right hand side of concept map on issues relating to collaborative hypertext development

Figure 5 shows an alternative approach adopted by another student in expressing his ideas about the legal protection of computer software. He developed four separate maps, the top level one shown as an overall view of the issues in the domain, and three linked ones about patents, copyrights and trade secrets. This student is developing a knowledge-based system to model software protection issues, and saw the concept maps as a natural first stage in knowledge elicitation. From one perspective, a knowledge-based system developer is not a typical user and this type of approach may have no general validity. However, this type of application raises the intriguing question as to whether all researchers might not eventually become interested in making their research results operational as knowledge-based systems.

Multimedia digital publication supports 'active documents' containing not only text and pictures but also operational models for visualization, animation, simulation, deduction, experimentation and alternative analyses. This will lead to major changes in scholarly publication in the next decade (Gaines, 1992, 1993). We are already seeing parallel publication of books and journal articles as passive print on paper to satisfy existing publication outlets, and as active electronic documents on CD-ROM to support improved scientific communication (Claerbout and Dellinger, 1991; Gaines and Shaw, 1992). From this perspective, one can see the tools that we are providing to students as the forerunners of electronic publication tools providing a more expressive medium for the dissemination of knowledge.

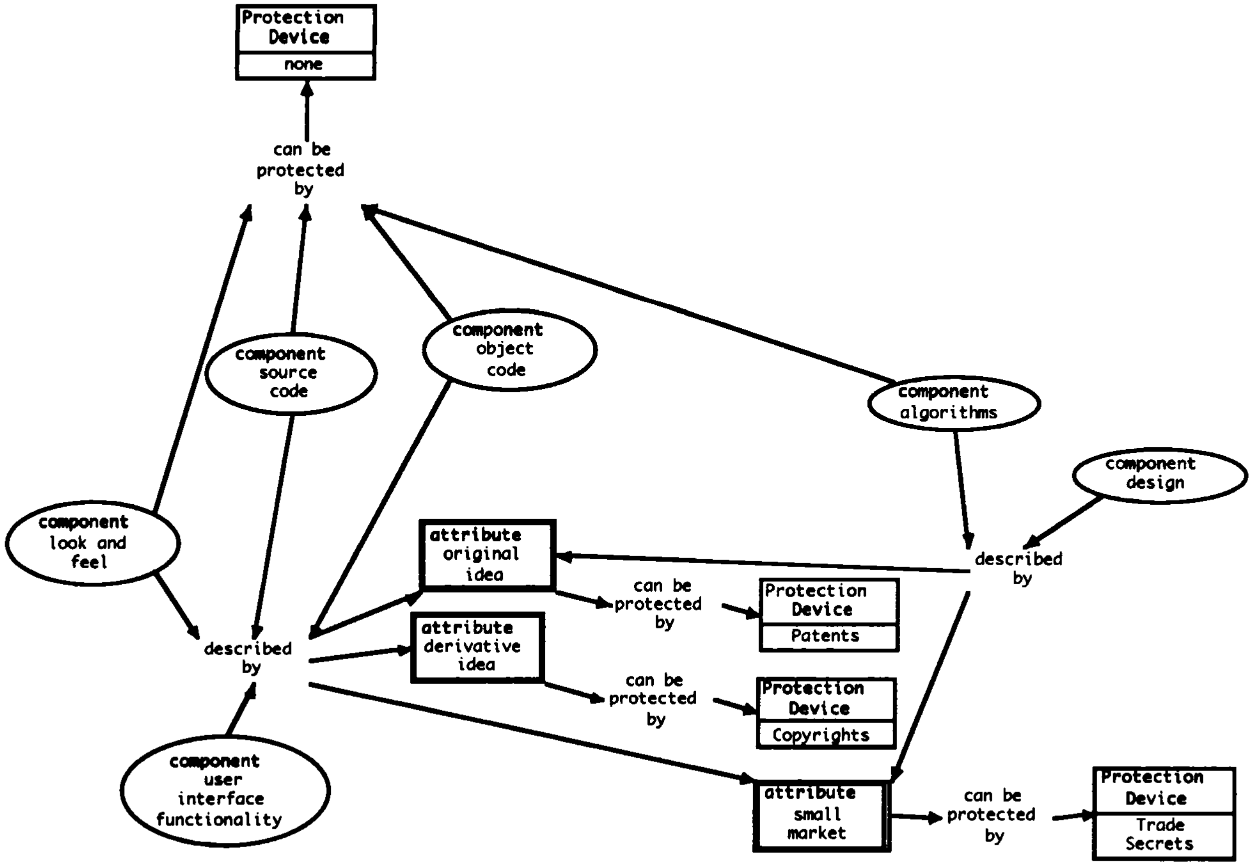

Figure 5 Top level concept map on the protection of computer software

5. Conclusions

This paper has provided a progress report on a research activity concerned with the use of knowledge acquisition and modeling tools to support creative processes in scholarly research. It would be inappropriate to attempt to draw significant conclusions from the informal studies reported. We do not know whether our students' creative processes are being affected by the tools used. Moreover, we do not know how to measure this in a meaningful way. We have to rely on the *prima facie* validity of the approach and on subjective evaluation. This is not particularly satisfactory from a research perspective, and it would be useful to develop and test more specific hypotheses related to theories of creativity such as those of Kelly (1955) and Kim (1991).

Meanwhile, to tools builders, the support of scholarly research processes offers a very interesting application of knowledge acquisition and modeling tools. Once scholarly publications are made available through interactive electronic media it will become possible to actively support the creative processes of those *reading* them. That is, what we now see as specialist tools for knowledge acquisition and modeling, when embedded in interactive documents, will become part of the routine publication process. This application of artificial intelligence research to the general processes of knowledge dissemination is very attractive.

Acknowledgments

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