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Emergent Knowledge Maps

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Introduction

There are now many practical examples of knowledge management based on the use of concept mapping tools to produce either informal knowledge maps representing the association of ideas (Gaines and Shaw, 1995) or formal knowledge maps operationalizing logical concepts and rules (Gaines, 1994). The visual presentation of knowledge is a powerful means to promote mutual understanding in groups and organizations, and associated hypermedia linking supports knowledge level indexing of complex collections of organizational materials.

However, the manual production of maps relies on the relevant knowledge being explicitly available to those producing the maps or, at least, sufficiently accessible that it readily emerges through the process of map-making. With increasing emphasis of the role of *tacit knowledge* in organizational knowledge management, it is interesting to investigate processes for the creation of knowledge maps that do not rely on access to explicit knowledge.

We have been experimenting with processes that generate knowledge maps from sources where the relevant knowledge is not explicit and which facilitate its emergence so that tacit knowledge becomes visible through the map. This article describes some studies in an industrial context of tools generating emergent knowledge maps from project documents and from the elicitation of mental models.

Deriving knowledge maps from mission statements

The studies reported were undertaken under the auspices of the GNOSIS research program, one of six test cases under the international Intelligent Manufacturing Systems (IMS) research program (Gaines and Norrie, 1995). The program involved over one hundred participants from thirty one organizations in fourteen countries, with the objective of developing a *post mass production manufacturing paradigm*. The conceptual framework for the program originated in Japan and attracted worldwide interest from research groups who brought to it their own ideas and interpretations making overall coordination a major problem in knowledge management. All the IMS projects report to an independent international review body, and the communication of the project objectives and progress to outsiders has also been problematic.

Figure 1 shows the *mission statement* of the GNOSIS project laid out as a knowledge map. This concise statement of the project objectives formed the introduction to the legal agreement signed by all participants, and much effort went into its formulation. The map shown was produced manually in our KMap tool by portraying the text of the mission statement as a set of concepts connected by relations. Context boxes were then added for the five technical work packages that constituted the major projects addressing the objectives in the mission statement: TW1, knowledge systematization;

TW2, product configuration management systems; TW3, configurable production systems; TW4, soft machinery; and TW5, post mass production paradigm.

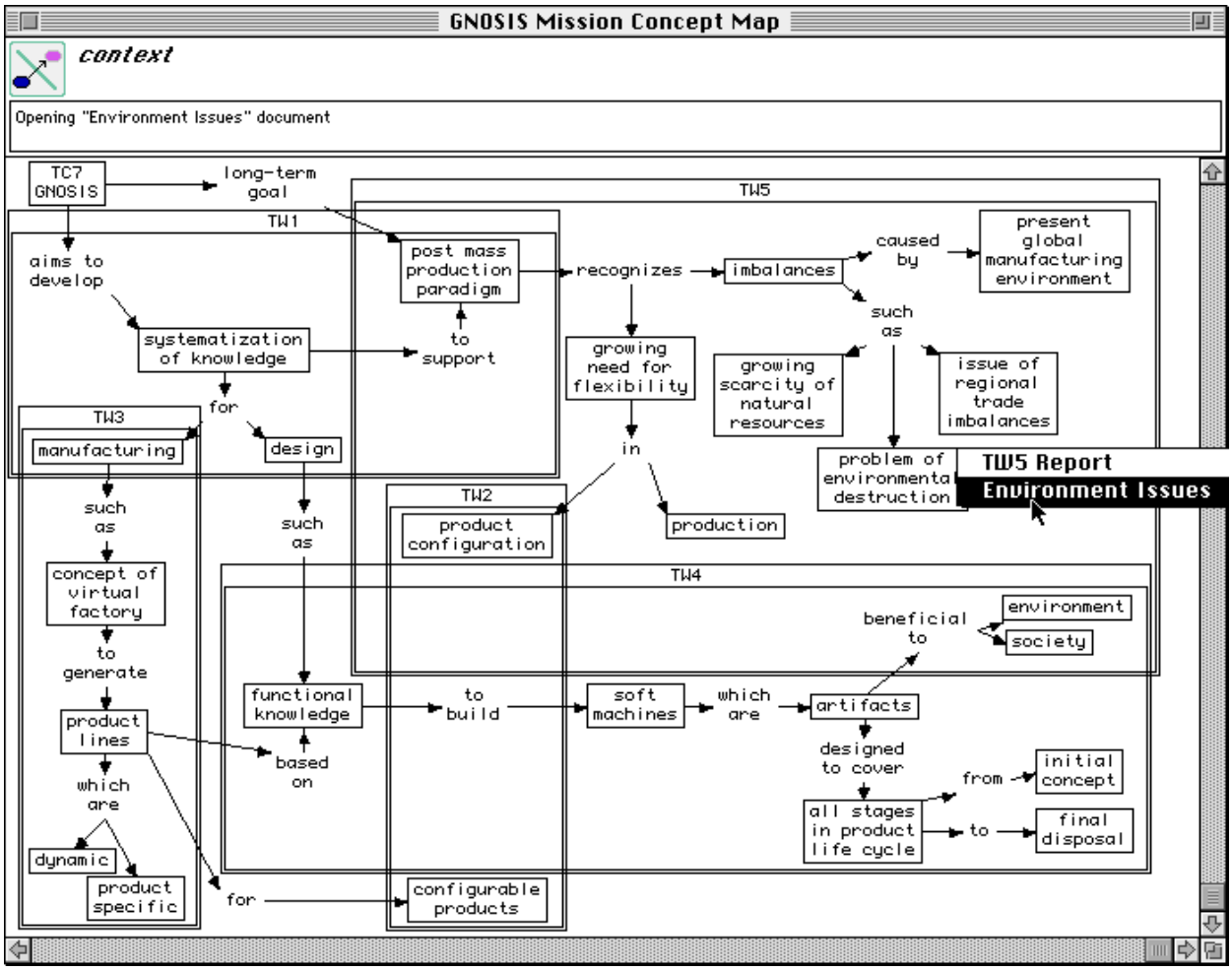

Figure 1 Concept map of GNOSIS mission statement

What emerges from this representation of the mission statement as a knowledge map is the relationship of the sub-projects to the mission and to one another. In addition, the hypertext linkage capabilities of KMap, locally and through the web, allow this top level knowledge map to be used to access the GNOSIS repository of project reports on CD-ROM or through the web.

3 Generating knowledge maps from documents

It was simple to generate the knowledge map of Figure 1 from the mission statement. In other projects we have also reversed the process and generated a mission statement from a knowledge map of top level concepts and relationships. This led to interest in generating knowledge maps from project documents that were far less terse and explicit than a mission statement, such as position papers and project specifications. A document might seem the archetype of explicit knowledge. However, anyone who has read a dense technical article will be aware of the difficulties posed to the reader of

teasing out the underlying knowledge from the text. The skills to write effective text books, procedure manuals and mission statements are rare, and the effort required to communicate knowledge explicitly in such forms is high. The majority of documents are helpful and evocative attempts to convey knowledge from author to reader which often leave much that is not effectively communicated.

Research in library and information science has investigated a range of tools to summarize information in textual form (Endres-Niggemeyer, 1998), and major practical applications have been demonstrated in areas such as modeling knowledge in patent databases (Callon, Law and Rip, 1986). We have developed a text analysis tool, Texan, that treats a document as a set of entities which are sentences whose features are the words they contain. Rules are derived using an empirical induction tool, Induct (Gaines, 1989), in which the premise is that if a specific word occurs in a sentence then the conclusion is that another specific word will occur. A graph is generated that shows the links from premise words to conclusion words derived in this way. The graph is automatically laid out and plotted as a knowledge map. The layout algorithm minimizes line crossings so that highly connected words are placed close together as clusters in the map. The graph is exported to our knowledge mapping tool, KMap, and subject matter experts are asked to annotate the clusters that have emerged by enclosing them in labeled context boxes.

Figure 2 shows a knowledge map for the GNOSIS project objectives produced in this way. The document analyzed was *The Technical Concept of IMS* (Tomiyama, 1992) that played a major role in the design of the research program. The Texan output had one major connected component linked to some minor ones relating to topics such as intellectual property rights that were discussed but did not play a major role in the program. The annotator noted that the major component itself consisted of three loosely connected sub-components, and added the context boxes shown to distinguish and name these parts. One interesting feature of these parts is that they correspond to only three of the five technical work packages of the final research program shown in Figure 1. The missing work packages are TW2, concerned with product configuration management systems and TW3, concerned with configurable production systems. These were added to the GNOSIS research program during its formation through amalgamation of interests with other potential proponents of IMS test cases. These packages link technically to the knowledge systematization activities on the lower left of Figure 1 but are neutral to the major issues of the IMS program on the right.

Again the hypertext linkage mechanism in KMap allows the terms in the knowledge map of Figure 2 to be linked to their occurrences in underlying document, and the clusters to be linked to the GNOSIS project repositories.

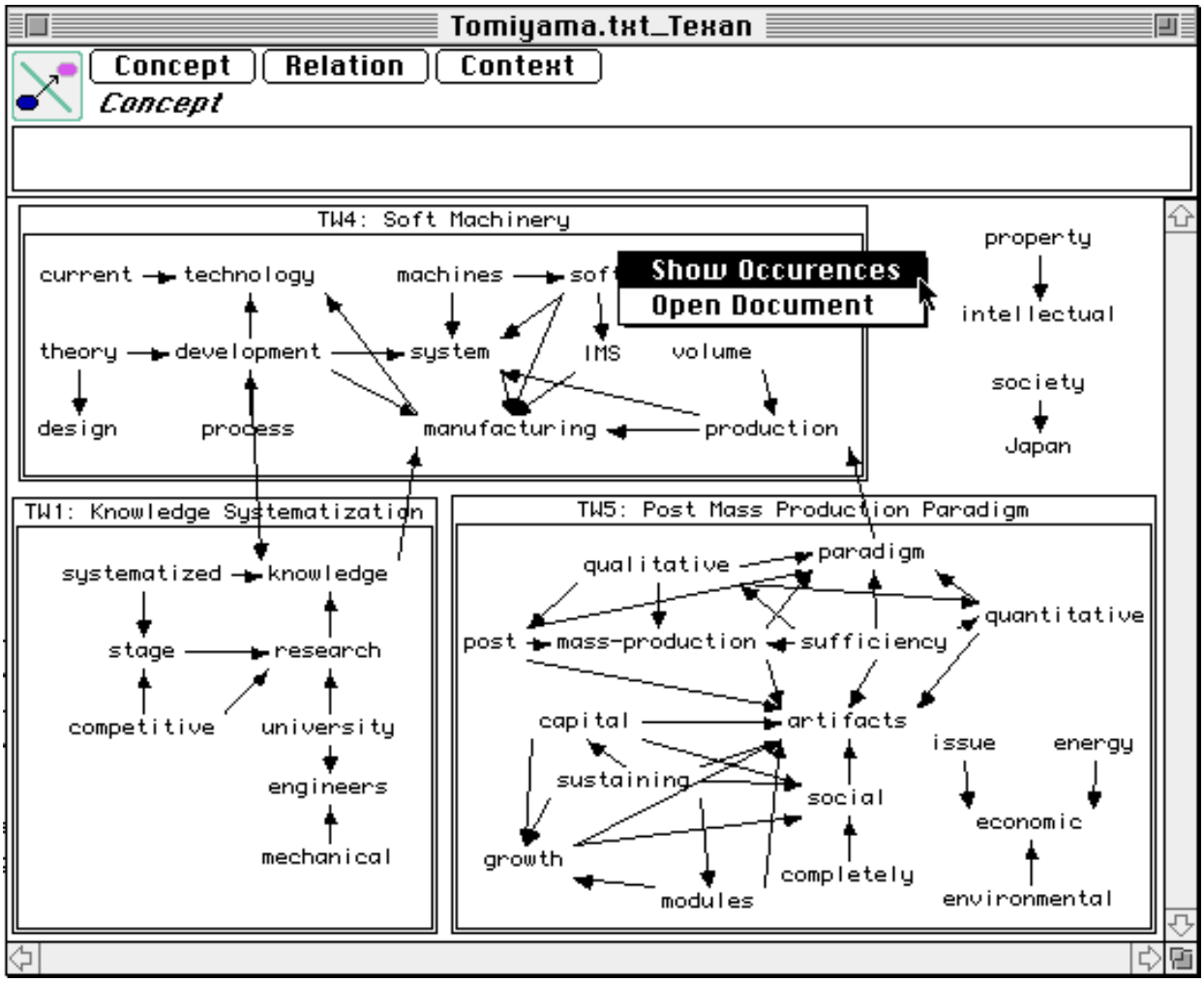

Figure 2 Analysis of paper describing objectives of IMS program

4 Generating knowledge maps through the elicitation of mental models

Sometimes it is difficult to express knowledge in textual form. It may be truly tacit in that it is inherent in the way a person describes the world but the basis for that description is not readily expressed. Repertory grids are used in knowledge elicitation when a person finds it easier to provide exemplary cases rather than express knowledge directly (Gaines and Shaw, 1993). The technique elicits the significant distinctions between cases all the time feeding back matches between cases to elicit new distinctions, and matches between distinctions to elicit new cases. We have used repertory grid techniques to elicit mental models and analyzed these with techniques that generate knowledge maps exhibiting the way in which a person construes the world.

For the GNOSIS program we elicited a grid from one of the program coordinators starting with six major GNOSIS projects as initial elements. The ensuing repertory grid elicitation process resulted in the addition of another 10 elements, including human operators and organizational structures that provided contrasts to some aspects of the

technological projects. Ten distinctions were elicited that provided detailed insights into the relationships between the projects and the overall program.

Figure 3 shows a knowledge map generated from a principal components analysis of the grid using our WebGrid tool (Gaines and Shaw, 1997). The analysis treats the distinctions made as axes in 10-D space, with the elements plotted in that space, and rotates the space to find a 2-D cross-section that accounts for as much of the variance as possible. It can be seen that the right hand side of the map contains all the GNOSIS projects and is characterized by the distinctions: *IMS research target*, *reconfigurable* and *machine intelligence*. The upper right quadrant contains the self-reconfiguring systems, the so-called *soft machines*, and the lower right quadrant contains systems designed for ease of human reconfiguration.

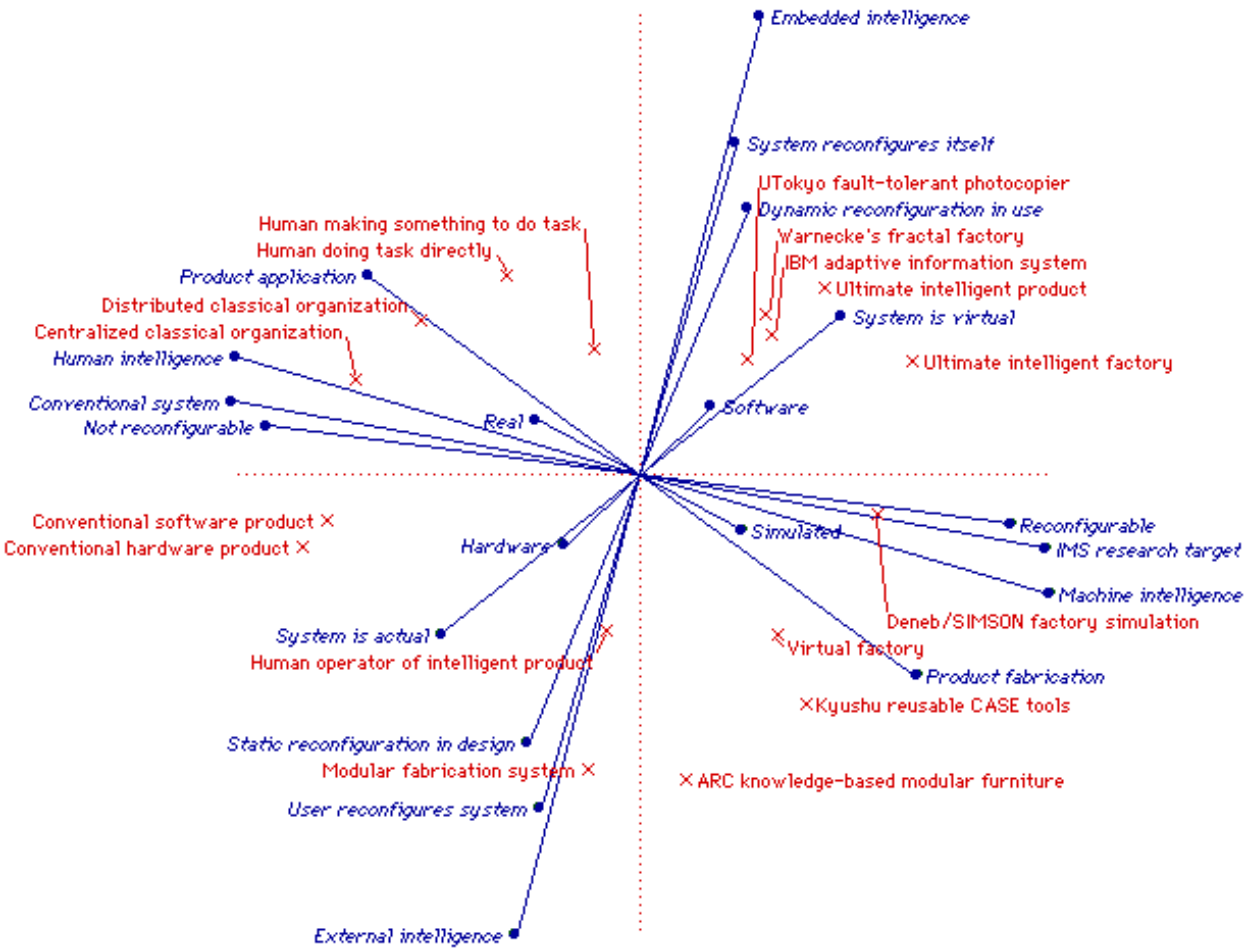

Figure 3 Knowledge map generated from elicitation of mental model

The distinctions elicited were presented on viewfoils to the review body to explain the roles of the GNOSIS projects and the relations between them relevant to issues of soft machinery. The map itself is active with hypertext links to the annotations provided by the coordinator when it was elicited. These included HTML links to the relevant project document archives so that, again, the map could be used to access the GNOSIS knowledge base.

5 Conclusions

Various techniques are available that may be used to develop knowledge maps through the analysis of knowledge sources such as text or repertory grids. They enable knowledge that may be tacit in its original form to emerge in explicit form in an interactive map that links back to the knowledge sources and related data.

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