Lehigh University
Lehigh Preserve

ATLSS Reports | Civil and Environmental Engineering

3-1-1987

Knowledge-Based Expert Systems in Civil Engineering at Lehigh University

Stuart S. Chen

John L. Wilson

George K. Mikroudis

Knowledge-Based Expert Systems in Civil Engineering at Lehigh University

by

Stuart S. Chen
John L. Wilson
George K. Mikroudis

ATLSS Report No. 87-01

LEHIGH UNIVERSITY

March 1987

ATLSS

An NSF Sponsored Engineering Research Center

Knowledge-Based Expert Systems in Civil Engineering at Lehigh University

by

Stuart S. Chen
John L. Wilson
George K. Mikroudis

Department of Civil Engineering
Lehigh University

Introduction

This paper presents an overview of knowledge-based systems (KBSs) that have been developed or are currently being developed in the Department of Civil Engineering at Lehigh University. After introducing the concept and rationale for KBSs in Civil Engineering, each system is briefly described. The distinctives of our approach are highlighted, and the paper concludes with some cautionary remarks and a brief description of anticipated future directions in the development of KBSs in Civil Engineering at Lehigh.

KBSs have recently emerged from research in Artificial Intelligence (AI), which may be said to be the science that tries to create intelligent behavior on computers [1]. An expert system (or knowledge-based system, or knowledge-based expert system) consists, conceptually, of two basic components:

- knowledge base
- inference mechanism

in addition to an interaction dialog handler of some kind. The user communicates with the system through this interface, as shown in Fig. 1. The knowledge base and inference mechanism correspond roughly to the data and algorithms, respectively, in a conventional computer program.

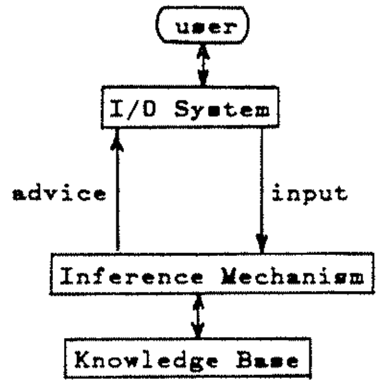

Figure 1 Basic Components of a KBS

The *knowledge base* fundamentally consists of data structures understood to have some meaning by virtue of a mapping from the data structures to some meaningful concepts of interest to the programmer or user. The knowledge base exerts a causal role in the behavior of a KBS, in contrast to, say, the inactive comment statements in a FORTRAN program.

Inferencing corresponds to what humans might call reasoning or drawing conclusions. In a KBS, inferencing simply means establishing the truth of some assertion that is implied but not explicitly present in the knowledge base. By chaining together individual inferences, aspects of expert reasoning can be mimicked and useful conclusions drawn. The *inference mechanism* is the control strategy by which the KBS navigates around among the various inferences that it might make.

Why We Are Developing Them

In an effort to build upon a well-established advocacy role with the practicing profession, the CAE Laboratory at Lehigh, in 1983, made a conscious choice to utilize AI technology in real-world problem solving. Civil Engineering is especially suitable for the use of knowledge-based systems due to the blend of often unformalized heuristics (rules of thumb) and fundamental principles frequently required to arrive at practical solutions. The conventional approaches offered by algorithmic systems alone, though extremely useful during the analysis explosion of the past two decades, offer little promise in extending computers to knowledge intensive problem-solving tasks. True decision support systems are needed which, among other characteristics, combine both procedural (how to do) and declarative (what to do) knowledge along with subjective and inexact knowledge. Several projects in the ATLSS Engineering Research Center continue to pursue the development of such systems.

The knowledge-based systems that are being or have been developed are focused on real-world, not toy, problems. They have been designed to provide a dialogue between the decision-maker and the machine-resident human expertise. In short, they are intended to: help expedite knowledge transfer to practicing professionals, assist in the utilization of current knowledge, and provide a medium for the extension of knowledge.

Knowledge-Based Systems Developed at Lehigh

Since the inception of the CAE Laboratory in the Civil Engineering Department at Lehigh, several new computer-based tools incorporating Artificial Intelligence technology and Computer Graphics have been implemented to bring appropriate expert knowledge to bear in a variety of domains. The productivity benefits resulting from the use of the systems are expected to be significant, not solely because more decisions can be made per unit of time, but rather that better, more rational decisions can be made by providing engineers access to an on-line "bank" of professional expertise. The KBSs that are currently under development or that have been completed are briefly described next.

ARCHQUAKE constitutes a primary module in an integrated system, being developed jointly between Lehigh and Cornell Universities, whose overall goal is to contribute to more rational and better earthquake-resistant design of buildings. The purpose of ARCHQUAKE is to aid architects and structural engineers in important design decisions regarding layout, proportions, structural systems and details which can affect the seismic safety of buildings. The basic concept of ARCHQUAKE is to communicate with an architect graphically by letting him lay out a building on a CAD workstation at different levels of detail or abstraction, and by evaluating at each level the design from a seismic point of view, pointing out problems and suggesting improvements. This system could therefore be both a working tool for the practicing architect and an educational tool for students. ARCHQUAKE is being developed with PROLOG [2] and GDS from McDonnell-Douglas Corporation.

The Bridge Fatigue Investigator [3] addresses a major infrastructure problem: the maintenance of America's immense inventory of existing bridges. The specific purpose of BFI is to assist a bridge engineer in the process of inspecting for fatigue damage in steel girder bridges and in evaluating such structures for their fatigue and fracture susceptibility. BFI draws on the interdisciplinary professional experience of experts in fatigue and fracture at Lehigh University as it guides the user through inspecting and evaluating this class of structure for fatigue damage. BFI is being developed with PROLOG, FORTRAN77 and GKS (Graphical Kernel System).

The Preliminary Fatigue Investigator (Pre-FI), a component of BFI, is intended to aid a bridge inspector in the location of fatigue cracks on steel girder highway bridges. This system will, to some extent, ameliorate the problem of an inspector failing to recognize the critical aspects of fatigue crack identification. It will increase the efficiency and credibility of the inspection process by concentrating the search for fatigue cracks in often overlooked areas where fatigue cracks are most likely to occur. It will also familiarize the inspector with several of the underlying considerations for fatigue crack location. The system utilizes PROLOG, FORTRAN77 and GKS.

CONNCEPT [4] is a functioning system for the conceptual design of beam-to-girder connections in steel two-girder bridges. This system represents a new approach to knowledge-based design aids, employing computer graphics for educational applications. This system is used by graduate and undergraduate students interested in learning more about the effects of altering design parameters on the integrity of connections. Computer graphics have been blended with the system to increase understanding through visualization. Figure 2 shows a display generated during a CONNCEPT session. The system utilizes PROLOG, FORTRAN77 and GKS.

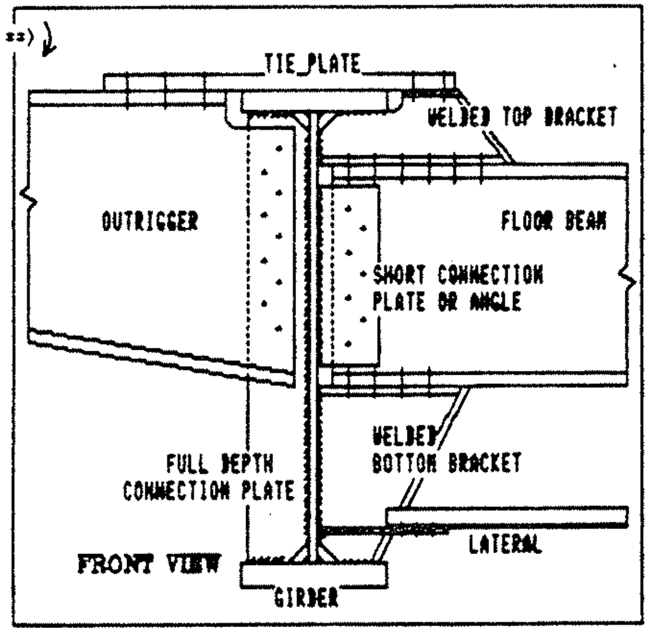

Figure 2 CONNCEPT Connection Display

COMPRESS [5] is a functioning system developed for Air Products and Chemicals, Inc., in Allentown, Pennsylvania. It is used to assist in the selection of compressors for chemical process plant design. This system demonstrates the advantages obtained by integrating PROLOG, FORTRAN77 and GKS on a personal computer.

The Designer-Fabricator Interpreter (DFI) is intended to provide designers and fabricators with the ability to collaborate effectively in evaluating designs and ranking appropriate fabrication decisions. Developed in tandem with Computer Science personnel, DFI will also be capable of accomodating design and fabrication modifications. The system will include both factual and procedural know-how of seasoned and experienced designers and fabricators. A distinctive characteristic of the system will be its ability to represent different perspectives on a common body of knowledge and to transform key features of one perspective into corresponding features of another viewpoint. DFI is being developed with PROLOG and FORTRAN77.

GEOTOX [6,7] provides surrogate consultation during preliminary and/or detailed hazardous waste site investigations. It provides a versatile framework for the interpretation, classification and diagnosis of environmental conditions at waste disposal sites. GEOTOX goes beyond a simple site ranking by allowing the user to express his confidence to the data, incorporate parameters in the assessment that he thinks are important, and modify the knowedge base according to site-specific conditions. This system introduces a new, unified approach that can effectively lead to more objective, detailed, and understandable assessments than those obtained from currently available methods. GEOTOX was developed using PROLOG, FORTRAN77 and GKS.

Figure 3 provides a glimpse of the internal structure of GEOTOX.

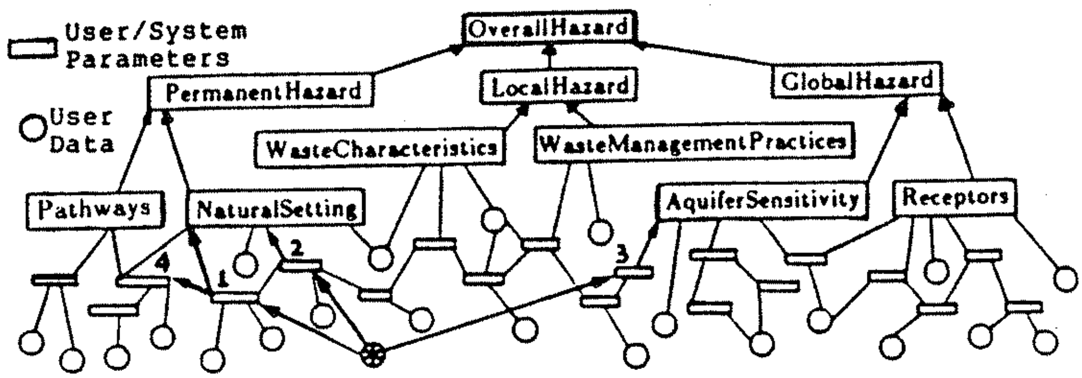

Figure 3 The GEOTOX Network (Partial)

As shown in the figure, the main problem of hazard assessment is analyzed into 3 components: the determination of hazard of "permanent" nature (related to the physical characteristics of the site), of "local" nature (related to the chemicals and waste characteristics), and of "global" nature (population or environments affected by the site). These component problems are further decomposed into other subproblems which can be addressed more or less separately and then combined together. The solution of these subproblems (pathways, natural setting, waste characteristics, waste management practices, aquifer sensitivity, receptors) is again composed of combined answers of other subproblems, including, e.g., the types of waste and the hydro-geological properties of the soil at the site.

In GEOTOX, certain subproblems can be answered directly from published information, field data, and observations. The associations between site data and parameters needed for a site evaluation are provided by the domain expert(s) and represented in GEOTOX by a network (part of which is shown in Fig. 3). This internal representation is further used to solve the problem, following a bottom-up search where simpler problems are addressed first (e.g., type of soil). Then the more complicated problems (e.g., site geology) are synthesized.

SEICO [8] offers advice about architectural configurations in seismic areas. The purpose of SEICO is to describe to a user the way in which a building's architectural configuration may affect its ability to withstand earthquakes and to provide information that will lead the architect toward good practice in seismic design. An educational aspect of the program is that it also provides examples of well-known cases of buildings damaged in earthquakes, thus illustrating the influence of architectural configuration on seismic performance. Computer graphics are used for visualization of the examples, questions, and answers of the system in order to improve understanding. This system utilizes the interface and inference mechanism of GEOTOX.

BINET [9] is intended to be a fully integrated knowledge-based Advanced Information Processing System. The result will be a monograph in a new medium supplemented by additional modules of supplier, code and specification information together with proprietary data bases. It will provide an additional tool to supplement books and go beyond them through a state-of-the-art technique that enables one to use the computer in his own reasoning process. The project will examine how we get information, how we manipulate it, and how we make it work for us. BINET is an ongoing project of the Corporate Sponsor Program of the High Rise Institute at Lehigh University.

Throughout the development of each of the above described systems, we have kept two considerations utmost in mind. The first concerns the suitability of the application area - from a professional need perspective as well as from an AI perspective. The second is the definition of user requirements that must be met by the software as an adjunct in the problem-solving process - what the software will be used for, who will use it, and what the users can learn from using the system. The preparation of a detailed usage document (e.g., [10]) proves to be a useful aid to defining these user requirements. Only by addressing these considerations can we assure the development of effective systems.

Distinctives of our Approach

Several distinctives have become evident in our development of these KBSs:

- the application focus
- undue restrictiveness of Expert System shells
- the use of the PROLOG symbolic programming language
- graphics
- KBS as assistant only

Our focus is on addressing real Civil Engineering applications, requiring real Civil Engineering knowledge often not found in textbooks. Although we are careful to define a fairly narrow scope for the problem areas addressed, they are not toy problems.

A second distinctive is that to date, our software development has consciously avoided the use of commercial expert system shells. Typical EMYCIN-like shells appear too shallow to support the kinds of representation and inferencing needs we have encountered. Shells presume a particular type of knowledge and reasoning and thus appear to be too restrictive. Rather than force-fit the application to fit the shell, we would rather attempt to develop the KBS to fit the application.

A third distinctive is that the PROLOG language [2] has played a substantial role in developing each of the systems described above. PROLOG provides the system developer facilities for quantification and pattern matching which are generally more powerful than production rule interpreters and semantic networks. It provides a relational database, which facilitates rule retrieval and the updating of the knowledge base. It provides certain functions of a shell (such as backward chaining inference) but also permits the construction of one's own knowledge representation and inference mechanism to suit the particular needs of the application. Our experiences suggest that PROLOG stands at the right level between a high-level KBS development environment [11] and a low-level programming language.

A fourth distinctive is the use of graphics. Historically, the development of interactive computer graphics has occurred separately from the development of AI and KBSs. It is clear, however, that graphics in KBS user interfaces is just as important as it is in more conventional software. Thus, graphics are a fundamental consideration in the design of our systems.

A fifth distinctive is that we view the KBS strictly as an assistant to the engineer. Although some AI researchers maintain that the goal of AI research is to create autonomous thinking machines [12], we strongly disagree.

Instead. our belief is that the proper role of a KBS, in engineering applications, is as an assistant only - as a surrogate consultant, not as an autonomous thinking machine.

Some Hurdles to Address

With the increasing popularity of this area of endeavor, some hurdles must be confronted. The following list, by no means complete, suggests some.

- over-selling of AI and KBSs
- difficulty of simple-looking problems
- unique dimensions of engineering problem solving
- skepticism of "traditional" faculty

The current coverage of AI in the popular press can mislead people to think that the major research problems have already been solved. This combined with exaggerated claims for some commercial products can leave the impression that the technology is neatly packaged and conveniently available for straightforward application to practical engineering problems. Such is not the case, of course, since there is still no comprehensive theory of knowledge representation: the effective mapping of real-world tasks to knowledge representation and inferencing schemes usually still must be done on a case by case basis.

A second hurdle regards the surprising difficulty of apparently simple problems. Even when problem scope is carefully limited, complications invariably arise as the knowledge engineering process makes explicit various aspects of the problem-solving knowledge involved and it is realized for perhaps the first time just how involved such knowledge can be.

A third hurdle involves the unique dimensions of engineering problem-solving that have typically not been sufficiently addressed in KBSs systems built by computer scientists. The practice of engineering involves a combination of engineering science and heuristic (rule-of-thumb) information. The science, or model-based, foundation enables the handling of novel situations and the generation of useful explanations, based on fundamental laws and theories, for the reasoning patterns employed. This model-based foundation must also account for the integral role of performing numerical calculations. The heuristic knowledge is often most useful for actually performing the reasoning. This <u>mix</u> of knowledge, and the representation thereof, is a critical issue in developing KBSs for engineering applications [13,14].

A fourth hurdle, the skepticism of "traditional" faculty, is no surprise to those who have been working in

CAE for years. A central question concerns the legitimacy of research involving the development of new computer tools. An additional hurdle is presented by faculty who are familiar with computers only as calculating machines. Providing faculty with hands-on experience using real KBSs is a necessary first step to help remove this skepticism.

Future Directions

The ongoing efforts in the CAE Laboratory have clearly demonstrated that AI should not be treated as an entity unto itself. If AI is to be used successfully it must be incorporated within sound data bases and rational knowledge bases. It must share significant characteristics of the human experts and reflect fundamental principles of software engineering. In the quest to build a genuine dialogue between the decision-maker and the decision aid, several topics related to innovative computing and "expert" systems are being investigated. These may be briefly classified as follows:

1. Utilization of empirical and heretofore unformalized knowledge coupled with the conventional algorithmic analyses.
2. Use of AI in the application of interdisciplinary knowledge.
3. Assistance in the integration of the information flow among processes.
4. Knowledge-Based systems as a dialogue expeditor in knowledge transfer.
5. Coupling of AI with other tools and techniques.

To achieve progress in these areas, several parallel efforts are taking place at Lehigh which include the following. First, development of computer graphics-supported knowledge bases wherein graphics does not represent just a pictorial display of data points but instead plays a more active role in conveying meaning during the inferencing process. Second, use of object oriented environments to accomodate flexible knowledge representation schemes and explanation facilities. Third, the right mix of memory and control aids for effective interfaces. Fourth, multi-level representation systems to accomodate varying levels of user skill as well as differences in human expert problem solving technique. Fifth, the use of workstations as delivery vehicles for these systems.

These research efforts, along with others in the CAE Lab and ATLSS Research Center, have as their common goal that of developing more principled domain models to support more robust man/machine interaction as well as improved problem-solving and teaching capabilities.

References

1. Dym, C. L., "Expert Systems: New Approaches to Computer-Aided Engineering", Engineering with Computers, Vol. 1, No. 1, 1985, pp. 9-25.

2. Clocksin, W. F., and Mellish, C. S., Programming in Prolog, Springer-Verlag, 2nd ed., 1984.

3. Chen, S. S., "A Knowledge-Based Surrogate Consultant System for Fatigue and Fracture Evaluation of Steel Bridges", Ph.D. Dissertation Proposal, Dept. of Civil Engineering, Lehigh University, 1986.

4. Seiler, K. W., "A Knowledge-Based System for the Design of Bridge Connections", M.S. Thesis, Dept. of Civil Engineering, Lehigh University, 1986.

5. Racine, J. P., "COMPRESS: A Knowledge-Based System for Compressor Selection", CAE Laboratory Technical Report, Dept. of Civil Engineering, Lehigh University, 1986.

6. Wilson, J. L., Mikroudis, G. K., and Fang, H. Y., "GEOTOX: A Knowledge-Based System for Hazardous Site Evaluation", Proceedings of the First International Conference on Applications of Artificial Intelligence in Engineering Problems, Southampton University, U. K., April 1986, pp. 661-672.

7. Mikroudis, G. K., "GEOTOX: A Knowledge-Based Surrogate Consultant for Evaluating Waste Disposal Sites", Ph.D. Dissertation, Lehigh University, Bethlehem, Pa., 1986.

8. Yu, W. T., and Mikroudis, G. K., "Development of SEICO, a Knowledge-Based Expert System for Building Configuration in Seismic Areas", in Fang, H. Y., ed., International Symposium on Environmental Geotechnology, Volume 2, Envo Publishing Co., Allentown, Pa., 1986.

9. Beedle, L. S., and Akiner, V. T., "A Knowledge System for the Tall Building Industry", Report 910.5, High Rise Institute, Lehigh University, December 1986.

10. Chen, S. S., and Wilson, J. L., "Proposed Usage of BFI (Bridge Fatigue Investigator)", Technical Report ATLSS 86-02, Center for Advanced Technology for Large Structural Systems (ATLSS), Lehigh University, October 1986.

11. Bobrow, D. G., "If Prolog is the Answer, What is the Question?", Proceedings of the International Conference on Fifth Generation Computer Systems, ICOT, 1984, pp. 138-145.

12. Stefik, M., "The Next Knowledge Medium", AI Magazine, Vol. 7, No. 1, 1986.

13. Chehayeb, F., and Connor, J., "GEPSE - A Computer Environment for Engineering Problem Solving", Technical Report R86-11, Intelligent Engineering Systems Laboratory, Dept. of Civil Engineering, Massachusetts Institute of Technology, December, 1985.

14. Dixon, J. R., "Beyond Graphics and Numerical Processing: the Computer in our Future", Proceedings of the Fourth National Conference on University Programs in Computer-Aided Engineering, Design and Manufacturing (UPCAEDM '86), Virginia Polytechnic Institute and State University, pp. 32-38.