Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 58 (1989)

Rubrik: Session 1: Expert system technology

SESSION 1

Expert System Technology

Technologie des systèmes experts

Expertensystemtechnologie

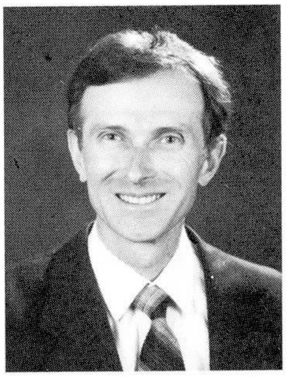
Leere Seite
Blank page
Page vide

Inductive Learning in Civil Engineering

Enseignement inductif en génie civil

Anwendungen induktiver Systeme im Bauwesen

Tomasz ARCISZEWSKI
Wayne State University
Detroit, MI, USA



Tomasz Arciszewski, born 1948, earned his Ph.D. from Warsaw Technical University. He has taught at this university and at the University of Nigeria. Since 1984 he has been Associate Professor of Civil Engineering at Wayne State University in Detroit. His area of interest is design methodology and applications of inductive learning in civil engineering.

SUMMARY
This paper discusses several potential civil engineering applications of inductive systems. An inductive system is a computer program using learning from examples to extract a system of decision rules. An inductive system can be used in knowledge acquisition for expert systems, and also for problem-solving, shallow modeling, learning about different domains, and in learning expert systems. All these potential applications are discussed and examples given. The examples were obtained using a class of experimental inductive systems based on the theory of rough sets.

RESUME
Cet article traite d'applications potentielles de systèmes inductifs en génie civil. Un système inductif est un programme d'ordinateur avec l'aide d'exemples, qui extrait un système de règles de décision. Il sert aussi comme un outil d'acquisition des connaissances pour les systèmes experts, et comme solution pour des problèmes de petits modèles, pour apprendre des domaines différents et pour enseigner les systèmes experts. Toutes les applications potentielles sont discutées, et des exemples sont présentés. Ces exemples sont obtenus pour des classes d'expériences de systèmes inductifs, basés sur la théorie des «rough sets».

ZUSAMMENFASSUNG
In diesem Beitrag werden mehrere potentielle Anwendungen induktiver Systeme in Bauwesen diskutiert. Ein induktives System ist ein Computer Programm, das von Beispielen lernt, um ein System von Entscheidungsregeln abzuleiten. Ein induktives System kann zur Wissensgewinnung für Expertensysteme, aber auch zur Lösung von Problemen, für oberflächliches Modellieren, zum Lernen in verschieden Wissensgebieten und für lernende Expertensysteme eingesetzt werden. Alle diese potentiellen Anwendungsgebiete werden mit Beispielen diskutiert, Diese Beispiele wurden mit einer Klasse von experimentellen induktiven Systemen erstellt, welche auf der «rough sets»-Theorie basieren.

1 INTRODUCTION

The civil engineering profession is in a period of intensive change, reflecting progress in various areas of science and technology. In particular, developments in computer science, especially in the area of artificial intelligence, are important for our profession. Knowledge-based systems and inductive systems are particularly useful for civil engineers. There is a large body of available civil engineering knowledge, accumulated over the centuries, which is difficult to use directly in the decision making process. This knowledge, however, can be used in decision-support computer tools, and can significantly improve the present practice of decision making in the design and management of civil engineering systems. The importance of this new area has been recognized by the American Society of Civil Engineers. In 1985 the ASCE Expert Systems Committee was established to stimulate and coordinate research and development related to expert systems technology in civil engineering [11]. This Committee also initiated the publication of a monograph series entitled "Expert Systems in Civil Engineering". The first volume [12] has already been published and others are in preparation [15]. The area of expert systems is considered in our profession to be one of the most promising, and there has been significant progress in this area, demonstrated by a number of recently published books and papers [1,2,10,13,16,18]. Expert systems have also become a part of civil engineering curricula at a number of U.S. research universities [8,15], and there is growing interest in the practical applications of expert systems.

This paper provides a brief review of potential applications of inductive systems in civil engineering, including examples of experimental applications developed at Wayne State University's Civil Engineering Department, Intelligent Computers Center. An inductive system is understood here as a computer program that uses learning from examples to extract a system of decision rules. From the civil engineering point of view, an inductive system can be considered as a black box, that is, as a new tool which can be used for different purposes. This new tool has significant advantages over human experts. Humans are very good at deduction, at using available general knowledge for dealing with individual problems. However, we have very limited inductive abilities. By induction, we mean the development of general knowledge from examples. Humans can handle only a very limited number of examples and attributes of a problem at the same time. Sillen [17] describes a human brain as a computer. He notes, that an average human can handle only seven attributes and seven examples at the time, while a computer can deal with a large numbers of both attributes and examples, limited only by the available working memory. This comparison clearly explains why computers are better than humans at learning from examples.

Inductive systems have already been used in space industry for the extraction of decision rules from examples to be used in an expert system [14], and for different industrial problem solving applications [17]. However, in civil engineering, applications of inductive systems still have mostly experimental character [3,5,6,19].

The approach to computer learning from examples must be different in civil engineering than in computer science. Computer scientists are interested only in the internal workings of an inductive system. As civil engineers, we want to know the potential applications of inductive systems, and we want to know how to use different inductive systems.

For these reasons, an engineering methodology of inductive learning has been developed at Wayne State University [4,7]. This methodology deals with the process of using inductive systems in knowledge acquisition, with applications for different civil engineering purposes. This work is intended to close the present gap between engineering and computer learning, and to stimulate engineering applications of inductive systems.

The engineering methodology of inductive learning is defined as a subarea of computer learning dealing with the process of inductive learning from the user's point of view. In the proposed methodology, the following three components have been distinguished: 1) inductive learning process, 2) selection of examples, 3) control criteria. Its initial outline is given, however, in [7]. This methodology was prepared for engineering applications, and should be useful for anyone interested in the practical use of inductive systems.

Our research indicates that an inductive system can be used for different civil engineering purposes. At least five possible applications of inductive systems in civil engineering have been distinguished:

1. Extraction of decision rules from examples for application in rule-driven expert systems.
2. Inductive problem solving.
3. Inductive shallow modeling.
4. Learning about a given domain through the process of gradually extracting decision rules from examples.
5. Learning expert systems for engineering applications, for example for conceptual design or for control.

These potential applications are discussed and examples of individual applications given, obtained using a class of experimental inductive systems based on the theory of rough sets and developed by Voytech Inc. of Regina, Canada.

2 EXTRACTION OF DECISION RULES FROM EXAMPLES

This application of inductive systems is the best known, and requires only a very few comments. It is well known that knowledge acquisition is a bottleneck in the development of many expert systems. Knowledge elicitation from domain experts is usually very time-consuming and requires the involvement of high-priced knowledge engineers. The process of knowledge elicitation is particularly difficult in all cases where decision rules are complex and are based on many attributes. In such cases traditional methods of knowledge acquisition are ineffective, and only very rarely are the expected results obtained on schedule and within budget.

The application of an inductive system changes this situation drastically. Very complex decision rules can be generated, involving a large number of attributes. Traditional development of such rules would be very difficult, if not impossible.

The developed methodology of inductive learning [7] can be used to guide engineers through the process of extracting decision rules from examples. This methodology is currently available, and inductive systems can be used as expert system building tools even today.

3 INDUCTIVE PROBLEM SOLVING

Inductive problem solving is defined as a process of extracting decision rules from examples to find one decision rule which is crucial to solving a problem. Its potential applications are much broader and more interesting than the simple extraction of decision rules from examples to be used in an expert system. Inductive problem solving can be considered also for immediate application, and should be particularly attractive to all civil engineers dealing with complex problems.

Very often, engineering problems cannot be solved, due to their complexity. A number of decision rules governing such a problem may be known, but there is still one rule missing. This missing rule, or as we call it, this "missing link," is crucial to the solution of the problem. The missing link cannot be found using traditional methods of analysis, because of the large number of examples, the large number of attributes, or both.

The limitations of human working memory have been mentioned in the Introduction. These limitations explain why human experts are very bad at dealing with such problems. The application of an inductive system can improve the situation immediately. All examples may be analyzed by an inductive system, and all decision rules, including our missing link, may be found immediately.

There are known engineering applications of inductive problem solving; Novacast of Sweden has a very impressive record here. For example, this company has used inductive systems for solving complex problems related to the production of margarine and the determination of its melting point. Another successful application was the determination of the factors causing cracks in welds in off-shore drilling platforms [17].

A simple problem from the area of quality control in the manufacturing of steel beams will illustrate the concept of inductive problem solving. The problem is described by several attributes, including the conclusion, which represents the quality of a steel beam. These attributes and their values are given in Table 1.

NO.	ATTRIBUTES	ATTRIBUTE VALUES		
		1	2	3
1	TYPE OF STIFFENER	STANDARD	EXPERI-MENTAL	
2	TYPES OF WELDS	FILLET	DOUBLE FILLET	GROOVE
3	WELDER'S EXPERIENCE	LOW	AVERAGE	HIGH
4	HUMIDITY	LOW	NORMAL	HIGH
5	TEMPERATURE	BELOW AVERAGE	AVERAGE	ABOVE AVERAGE
6	PRODUCT QUALITY	GOOD	BAD	

Table 1. Manufacturing of steel beams: attributes and their values

It was noticed that in some cases the quality of the beams was bad. Unfortunately, human experts could not find the reason. An inductive system was used to analyze all available 22 examples, based on 5 attributes, and given in Table 2.

The inductive system immediately extracted a rule, which provides the solution to the problem. This rule is given below:

When:
A1=2, stiffener is experimental,
A3=1, welder's experience is low,
A4=3, humidity is high,
A5=3, temperature is high,
then:
A6=2, the product is faulty.

This problem is relatively simple, but it shows the potential applications of inductive problem solving.

4 INDUCTIVE SHALLOW MODELING

Inductive shallow modeling is defined as a process of building a shallow model of an engineering system, physical or abstract, using an inductive tool.

Traditional or deep modeling is based on the assumption that we understand the behavior of an engineering system, and that we have its conceptual model. This conceptual model can then be used for building a formal mathematical model using available experimental results.

Very often, however, our understanding of the behavior of engineering systems is incomplete. In this case building formal mathematical models based on their predicted behavior is very subjective and simply incorrect.

Shallow modeling is based on the system's observed behavior. An understanding of the system is not required. Obviously, such modeling has significant advantages over traditional deep modeling. It is particularly useful in the modeling of very complex systems of unknown structure. Our initial experience in this area indicates that inductive shallow modeling may become very important, especially in engineering research. This experience and our initial methodological suggestions are presented in the paper [9].

To demonstrate the use of shallow modeling, the results of an inductive experiment conducted about two years ago [9] will be briefly described here.

Example No.	ATTRIBUTES					
	1	2	3	4	5	6
1	1	1	1	1	1	1
2	1	1	1	2	1	1
3	1	1	1	3	1	1
4	1	1	1	1	2	1
5	1	1	1	1	3	1
6	1	1	1	2	2	1
7	1	1	1	2	3	1
8	1	1	1	3	2	1
9	1	1	1	3	3	1
10	2	1	1	1	1	1
11	1	2	1	1	1	1
12	1	3	1	1	1	1
13	2	1	2	1	1	1
14	2	1	3	1	1	1
15	2	1	1	2	1	1
16	2	1	1	3	1	1
17	2	1	1	1	2	1
18	2	1	1	1	3	1
19	2	1	1	3	3	2
20	2	2	1	3	3	2
21	2	3	1	3	3	2
22	2	3	3	3	3	1

Table 2. Manufacturing of steel beams: examples

In the experiment, the results of only 15 tests of steel beams under bending were used. An inductive system was applied to confirm the existence of well-known relationships between different groups of variables.

In particular, we were looking for answers to the following questions:

1. Is the moment of inertia (V3) of our beams related to their depth (V1) and thickness (V2)?
2. Is the ultimate beam capacity (V6) related to its moment of inertia (V3)?
3. Is the ultimate capacity of the beam (V6) related to the measured strains (V7, V8) and calculated strains (V10)?

The modeling was conducted as a progressive learning process, and the results were recorded after each added example. These results are shown in (Fig.1).

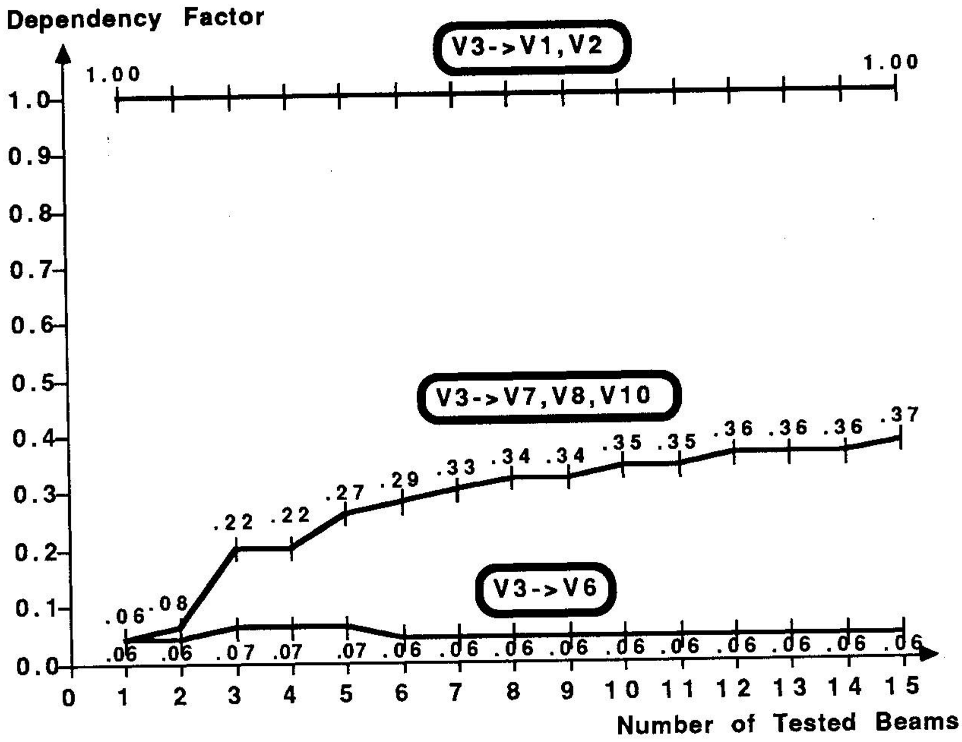


Fig. 1. Inductive shallow modeling: learning curves [9]

It can be easily seen that the answer to the first question is a very strong Yes.

In the theory of rough sets, the dependency factor measures the strength of the relationship between given variables and a group of variables. In this case the dependency factor equals unity, indicating a functional dependency.

The answer to the second question is more complex. There is a relationship between the moment of inertia and the ultimate capacity, but this relationship is not functional, and is relatively weak.

The results obtained for the third question indicate that the learning process has not been completed, but there is definitely at least a weak relationship.

Inductive shallow modeling is still in the experimental stage, but even now it could be useful for practical purposes, particularly in cases where traditional methods of deep modeling are not sufficient.

5 INDUCTIVE LEARNING ABOUT DOMAIN

Inductive learning about domain is defined as a systematic and monitored multi-stage learning process in which an inductive system is used as a learning tool. The objective of this process of learning is to improve the understanding of a given domain through the systematic development of a system of decision rules governing this domain.

Very often in civil engineering we have a large body of known examples. We spend months or even years on studies of a given domain, but because of its complexity we do not really understand it. We may identify several simple decision rules governing this domain, but we still need a more fundamental understanding. We simply need more fundamental decision rules governing our domain. This is a typical situation in the research and development of new engineering systems. We identify all known solutions and we want to understand all these solutions, which are our examples.

In this case we can use an inductive system as an engineering learning tool, a new tool which can be used by a human expert to learn about a complex domain. This new tool is used in a multistage learning process (Fig.2). At each stage of this process an inductive system is used to extract decision rules from a different collection of examples. The decision rules and parent examples are recorded. A human expert analyzes all examples and related decision rules, and tries to relate these decisions to examples and to improve his understanding of a given domain.

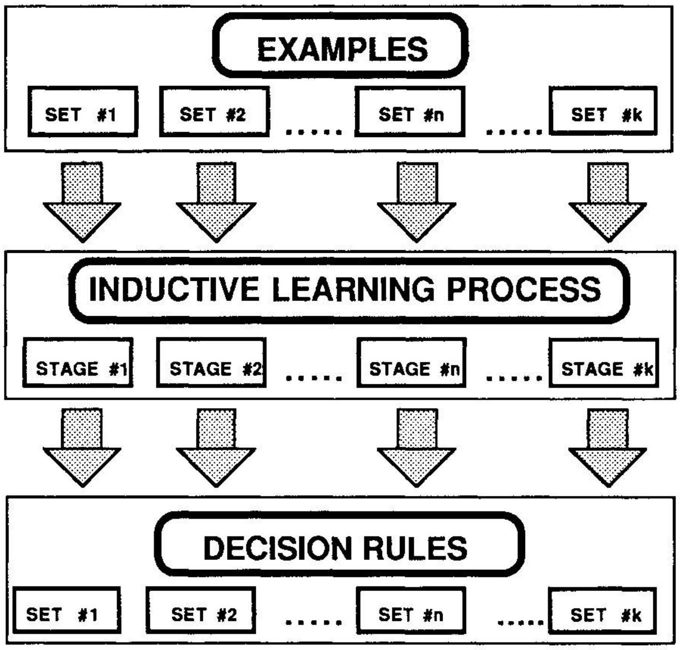


Fig. 2. Inductive learning about domain: a multistage process

This potential application still needs a lot of research and experiment, but it looks very promising.

6 LEARNING EXPERT SYSTEMS

A learning expert system is defined as an expert system with a learning component. Such a system has the ability to learn, (i.e.) to modify its decision rules to follow changing conditions. A learning expert system can be developed for the purposes of conceptual design, diagnosis, or control [3,5].

To explain the concept of a learning expert system, a system for conceptual parametric design will be briefly described here. [3] By "conceptual parametric design," we mean an early stage of the design process. In this stage, design needs and the available knowledge are analyzed and a number of concepts of a future civil engineering system are generated. In parametric design, a system under consideration is described by parameters and the design process is a sequence of operations on these parameters, including the identification of feasible values of these parameters and the determination of the optimal combination of parameters values. In conceptual design, the parameters considered are mostly qualitative in character, and a compatible combination of their values, when for all parameters one value is taken at a time, identifies a concept of a civil engineering system [3].

A learning expert system for conceptual design can be used for the production of concepts. These concepts can be selected from the generated combinations of values of qualitative parameters, using internally produced compatibility rules. In this case the system has to be used in two stages: learning and production. The objective of the first stage is to extract, from given examples, a system of decision rules governing a given domain represented by the examples. In the second, or production stage these decision rules are used for the evaluation of combinations of values and the selection of compatible combinations, which represent the concepts being sought. More details on learning expert systems for conceptual design and the results of structural experiments are given in [5].

In the case of conceptual design, the use of inductive learning has many advantages. It enables us to deal with a large body of examples, and also leads to the development of very complex decision rules, which otherwise would not be prepared because of their complexity and unusual character. A learning expert system for conceptual design has the ability to produce standard, well-known concepts, but there is also a possibility that it will produce innovative, patentable concepts. The present research on learning expert systems for conceptual design is still in its early stages, but its potential is enormous, and very interesting developments can be expected in the future.

7 CONCLUSIONS

Inductive learning in civil engineering is still in its early experimental stages. Available experience is very limited, but the initial results indicate that inductive systems may very soon become powerful tools in civil engineering, useful for different purposes, as proposed in this paper. It is difficult to predict, however, which civil engineering application of inductive systems will be the most important, or which will have the greatest practical impact. All potential applications of inductive systems are feasible even now, and should become of interest to both practitioners and researches.

ACKNOWLEDGEMENT

The author has a pleasure to acknowledge the financial support for his research from the Wayne State's Institute for Manufacturing Research.

REFERENCES

1. ADELI H., BALASUBRAMANYAM K.V., Expert Systems for Structural Design. Prentice Hall, Englewood Cliffs, 1988.
2. ADELI H., Expert Systems in Construction and Structural Engineering. Chapman and Hall, 1988.
3. ARCISZEWSKI T., ZIARKO W., Adaptive Expert System for Preliminary Engineering Design. Revue Internationale D.E. CFAO et D'Intographie, Vol. 2, No. 1, 1987.
4. ARCISZEWSKI T., MUSTAFA M., ZIARKO W., A Methodology of Design Knowledge Acquisition for Use in Learning Expert Systems. International Journal of Man-Machine Studies, No.27, 1987.
5. ARCISZEWSKI T., ZIARKO W., Adaptive Expert System for Preliminary Design of Wind Bracings, Second Century of Skyscrapers. Van Nostrand Publishing Company, 1988.
6. ARCISZEWSKI T., Inductive Learning in Engineering. Proceedings: USACERL/ASCE First Joint Conference on Expert Systems, June 29-30, 1988.
7. ARCISZEWSKI T., MUSTAFA M., Inductive Learning Process: The User's Perspective. Chapter 3, in the book Machine Learning, edited by R. Forsyth, Chapman and Hall, 1989.
8. ARCISZEWSKI T., Teaching Expert Systems Techniques at Wayne State University. Chapter 2, in the book Expert Systems Education in Civil Engineering, edited by M.L. Maher and S. Mohan, American Society of Civil Engineers, to appear.

9. HAJDO P., ARCISZEWSKI T., ZIARKO W., AKTAN H., Inductive Shallow Approach for Generation of Engineering Models. Proceedings of the Ninth European Meeting on Cybernetics and Systems Research, Vienna, Austria, April, 1988.

10. FENVES S., GARRETT J., Knowledge-Based Standards Processing, International Journal for AI in Engineering, Vol.1, No.1, 1986.

11. KOSTEM C.N., MAHER L.M., (Editors), Expert Systems in Civil Engineering, Proceedings of a Symposium sponsored by the Technical Council on Computer Practices of the American Society of Civil Engineers, Seattle, Washington, April 8-9, 1986, American Society of Civil Engineers.

12. MAHER M.L., Expert Systems for Civil Engineers: Technology and Application. American Society of Civil Engineers, 1987.

13. MAHER M.L., FENVES S.J., GARRETT J.H., Expert Systems for Structural Design, Expert Systems in Construction and Structural Engineering, Chapman and Hall, 1988.

14. MODESITT K.L., Space Shuttle Main Engine Anomaly Data and Inductive Knowledge-Based System: Automated Corporate Expertise, Proceedings of the Conference on Artificial Intelligence for Space Applications, Huntsville, 1987.

15. MOHAN S., MAHER M.L., (Editors), Expert Systems for Civil Engineering: Education, American Society of Civil Engineers, to appear

16. RYCHENER M.D., Expert Systems for Engineering Design. Academic Press, 1988.

17. SILLEN R.V., Building PC-hosted Expert Systems Using Induction Methods, Research Report, Novacast Expert Systems AB, 1987.

18. SRIRAM D., Knowledge-based Approaches for Structural Design. Computational Mechanics Publications, 1987.

19. TCHENG D.K., LAMBERT B.L., LU S.C-Y., Integrated Relation Learner, System for Optimization Inductive Bias, Proceedings of the Joint International Conference on Artificial Intelligence, Detroit, 1989.Lu from Illinois

Leere Seite
Blank page
Page vide

Architectural Design for Energy Savings and Thermal Comfort

Economies d'énergie et le confort thermique en architecture

Architektonischer Entwurf unter Einbezug der Energieeinsparung und der Behaglichkeit

L.F. PAU
Technical University of Denmark
Lyngby, Denmark

S. Skafte NIELSEN
Technical University of Denmark
Lyngby, Denmark

SUMMARY
This paper describes EKSPRO, a knowledge-based system integrating a 3-D CAD system, materials, heating, ventilation, lighting equipment, building code and occupational health regulations, as well as design guidelines user-defined by architects and engineers. It features an object oriented predicate logic knowledge representation, and interfaces to calculation packages (CAD, thermal balance, illumination, sun lighting).

RESUME
Cet article présente un système de traitement des bases de connaissance intégrant un module tridimensionnel de CAD, les matériaux, le chauffage, la ventilation, les équipements d'éclairage, les normes pour le bâtiment, les recommandations pour la santé des occupants ainsi que les régles de calcul définées par les architectes et les ingénieurs. Les principes sont une représentation logique de la connaissance orienté objet et des interfaces pour le calcul (CAD, équilibre thermique, éclairage et insolation).

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt EKSPRO, ein Expertensystem, welches ein 3D-CAD-System, Material, Heizung, Lüftung, Beleuchtung, Baunormen und Gesundheitsvorschriften wie auch durch den anwendenden Ingenieur oder Architekten definierte Richtlinien enthält. Es enthält eine objektorientierte Logikdarstellung sowie Interfaces zu den Berechnungsprogrammen (CAD, Wärmehaushalt, Beleuchtung, Sonneneinstrahlung).

1. INTRODUCTION

For project planning engineers, buildings, offices and houses, are complex dynamic objects in terms of their thermal, illumination, occupational and usage patterns. For architects, it is difficult to apprehend the consequences of alternative geometric layouts, of materials selection, of walls/window/door/vent placement, etc. . . , on thermal comfort, energy consumption (heating, cooling, ventilation), lighting and construction costs.

The consequence of this double dilemma is that most architectural designs tend to be quite traditional, based on the belief that past experience is the best reference, and/or that heating/cooling/ventilation engineering may compensate for unappropriate designs.

Furthermore, the thermal and lighting comforts depend on the usage of the construction, as well as of passive solar heating, weather and exposure. The concern for energy conservation is likely to re-emerge in the 1990's [16].

The goal is to select the layout, materials, as well as all equipments (types and locations), as to optimize jointly the thermal comfort and lighting comfort, while minimizing the total energy costs (investments, operations, maintenance), and possibly minimizing also total project costs.

This paper presents EKSPRO, a knowledge based system for architectural design in view of energy savings and thermal comfort. This system aims at fulfilling the goal stated above, while offering a fully interactive capability to both architects, project planning engineers, and equipment suppliers. EKSPRO is thus a CAAD (tool for Computer Aided Architectural Design, integrating 3-D CAD (Computer Aided Design) with knowledge bases (building code regulations, design/selection guidelines), data bases (material, windows, lighting), and calculation packages (thermal gra dient, scalar irradiation)).

EKSPRO was built by the Technical University of Denmark, for Cenergia A/S, also withDomus APS, Torben Wormslev M.A.A.cooperation.

2. SURVEY OF RELATED RESEARCH

On-going work in the CAAD area focuses on extensions of geometrical/spatial reasoning to CAD representations [1], [2], [3], [4], possibly with incorporation of generic design standards (structures, acoustics, lighting, etc.) [5], going all the way to the successive generation of designs from basic modules [6].

Other activities deal with intelligent user-interfaces to existing energy simulation, structural analysis, or other similar calculation packages, in order to assist the user in planning for a series of computation/analysis steps [7], [17], [18].

Finally, some projects concentrate on the design and configuration of the heating/ventilation/air conditioning systems for a given building layout, for tradeoffs between them [8], [19].

3. KNOWLEDGE AND DATA BASES IN EKSPRO

The data and rules used explicitly in EKSPRO are surveyed below. In the follow- ing Sections, this knowledge segmentation will correspond to knowledge worlds (KB-i), incorporating either declarative or procedural functions.

1. KB-1: Building code an occupational safety regulations:

KB-1 contains all legal, regulatory or standards constraints, originating in a diversity of official documents. Some sample rules are reproduced below in mnemonic form:

KB-1(1):	floor area $\geq 7\ m^2$/office
KB-1(2):	air volume/person $\geq 12\ m^3$ ($8\ m^3$ when ventilation is present)
KB-1(3):	ceiling height $\geq$ 2,5 m (or $\geq$ 2 m in average for inclined ceilings)
KB-1(4):	stationary work temperature $\in$ (18-25° C)
KB-1(5):	air cooling can be authorized, but only after sun screens, removal of heat/lighting sources, have been implemented.
KB-1(6):	escape window (height + width) $\geq$ 1,5 m, with height $\geq$ 0.6 m and width $\geq$ 0.5 m and lowest level above floor $\leq$ 1.2 m.
KB-1(7):	daylight factor $\geq$ 2%
KB-1(8):	electrical lighting factor $\geq$ 3%
KB-1(9):	air renewal rate $\geq 8\ m^3$/person/h.

2. KB-2: Architectural design and engineering knowledge

This knowledge is the hardest to acquire, but was structured into objects, object classes, attributes and attribute values, in order to comply with object oriented design principles. Table 1 gives the main objects and their properties, whereas Table 2 specifies how the attribute values are queried from data bases or calculated by application specific software modules. Price is an additional attribute for all materials.

Attached to these objects are a set of user-defined rules indicative of architectural, design or engineering practice for choices, preferences, or imperative conditions.

Example:-We give below some of the KB-2 rules, for one specific use, in terms of the selection of heating/cooling sources each represented by a specific class instance.

KB-2(1):	assert (radiators and cold air)
KB-2(2):	if: office building and area > $60\ m^2$, then: hot air and cold air.
KB-2(3):	if: office building and area < $40\ m^2$, then: mechanical ventilation and hot air
KB-2(4):	if: window area > $6\ m^2$ and window orientation = S, E, W, then: sun screens.
kb-2(5):	if window height $\geq$ 1.5 m, then: radiators.

4. KNOWLEDGE REPRESENTATION AND INFERENCE IN EKSPRO

EKSPRO involves the careful selection of a knowledge representation, of an inference procedure, of a user interface, and of interfaces to external data and procedures (Table 2).

4.1 Knowledge representation

EKSPRO is characterized by heterogeneous knowledge, as well as by a generate- and test paradigm, which lead quite naturally to a multiplayer object oriented knowledge representation. Three layers are selected: level-0 for regulations (KB-1), level-1 for evaluations (KB-2), and level-3 for calculations and data bases. Furthermore, as a PROLOG environment with viewpoints was selected [10], the representations at each level will be expressed via logical predicates operating on the objects defined in Table 1 and/or on their class instances and attributes.

Details of the EKSPRO knowledge representation are found in Table 3, with illustrations in Figures 1, 2, 3; see also [11], [12].

It should be noted that the CAD-package (CAD-1), uses a wire-frame input, but stores spatial data by facets, where each facet in turn has a list of labels which contain attribute values of that facet (coordinates, size, edge-facets, material of facet, k-value of facet).

4.2 Inference

EKSPRO is based on a generate and-test paradigm, where the architect or engineer select a configuration, which is first propagated through Level 1 to generate all possible/desired occurences, and then evaluated at Level 0 for compliance to building and occupational health safety regulations (see Figures 5, 6). The attribute values are queried or calculated at Level 2, when needed during the search at Level 1, and then transferred to the conceptual graph filters at Level 0. Typically an architect would generate in CAD-1 an architectural layout, configuration and possibly some materials. The engineer would select a configuration of heating/cooling/ lighting/ materials.

Consequently, EKSPRO inference procedures are reduced to the activation of PROLOG unification and backtracking, with account, however, for inheritance properties derived from the object oriented knowledge oriented design. In this way, EKSPRO aims at constraint satisfaction in a highly unstructured user environment.

Actually, it is the user dialogue with the EKSPRO system, which by itself characterizes the reasoning process taking place. This dialogue tends to be decomposed in tasks among the following (T1-T10), called upon in an almost random order by the users (see Table 4).

For the reasons above PROLOG based explanation facilities (why?, how?) are paramount for user acceptance during all tasks T1-T10 |12|.

4.3 User interface

EKSPRO belongs to the class of integrated multi-agent knowledge based systems, which allow the user to access specialized modules communicating amongst themselves while enforcing constraint satisfaction. The user must also be able to jump from one task to another (see Table 4).

The compromise solution selected in view of target environment constraints (see Section 5), is a menu based screen user interface, with DESQVIEW multi-windowing between major facilites (see Figure 4). The menu choices are currently by keyboard (digits or letters), because the end users did not yet want other devices (mouse, etc.), with the exception of their use for CAD drawing functions only. At this stage, EKSPRO offers no natural language facilities for CAD, although some research is carried out |20|.

At any time, one can bind some objects, class instances or attributes to fixed values, to exclude choices on the same (Task T-6); this is easily implemented in PROLOG by binding variables or freezing predicates |10|. The material choices, object graph, class instances, and attributes can be displayed as trees or graphs of any time.

At any time also, the MS-DOS, PROLOG og PASCAL editing facilities can be called upon to edit all parts of the EKSPRO knowledge bases.

4.4 Reporting facilities

Every search (Configuration-Query) will be concluded by a report listing all possible configurations (assignment of values (classes/attribute) to objects) along with characteristic values of ΔT and heat-loss for each of them. At the end the report contains a list of values preset by the user, and therefore not included in the search.

5. IMPLEMENTATION ENVIRONMENT

Although this implied a number of major technical restrictions, EKSPRO was developed on a VAXMATE PC/AT/MS-DOS to obey with end user requirements. The main argument was that such an environment (and its price) were the maximum architects and building engineers would accept (outside a few large consulting or projecting companies).

The languages used were Prologia PROLOG-II [10] (interpreter, and soon compiler), Microsoft PASCAL, Ecosoft SCRIBE Modeller. The interface module SPECALC was extended to extract spatial/geometric attribute values from the files generated by SCRIBE. Interface modules were programmed between PROLOG II and all PASCAL modules and data bases (see Table 2).

EGA colour graphics were used, and a two monitor system is considered to accomodate the DESQVIEW windows on two screens, essentially CAD drawings on one, and user selected screens on the other.

All text is written in Danish, which explains why no screen displays are presented in this paper.

6. CONCLUSIONS

EKSPRO represents both a concept and a tool for knowledge based CAAD for architectural design in view of energy savings and thermal comfort. The migration to more powerful and user friendly implementation environments is rather straightforward, thanks to the selected tools, knowledge representation and the knowledge acquired.

Functional enhancements would cover report generation, heating/ventilation equipment configuration rules, better price calculations (with price sensitivity and ranking capabilities), and the addition of filing utilities for building block modules. Better calculation modules may also be necessary (e.g. variations of indoor temperature, thermal simulation, electrical lighting).

Current satisfied users have also expressed desires to expand EKSPRO domains to encompass choices involving static structure calculations, building acoustics, building maintenance costs, and colour selection of walls.

REFERENCES

[1] ADELI H., Expert systems in construction and structural engineering, Chapmann & Hall, March 1988.

[2] SPECIAL ISSUE on knowledge engineering and expert systems, Architectural Science Review, (Australia), Vol. 28, No. 4, December 1985.

[3] COYNE R., Logic models of design, Pitman Publ. London, 1989.

[4] Proceedings EUROPIA '88, "The applications of AI to building, architecture and civil engineering", Chambre de Commerce et de l'Industrie, Paris, 28-29 November 1988.

[5] RASFORF W.J., WANG T.E., Generic design standards processing in an expert system, J. of Computing in Civil Engineering, Vol. 2, No. 1, 1988.

[6] JACKSON B., Development of knowledge based designing system, 1st National Conf. on Computer Applications, Lagos, 1985.

[7] CLARKE J.A., An intelligent approach to building energy simulation, ABACUS/ CAD/ Unit, Univ. Strathclyde, in: "Expert Systems for Construction and Engineering Services", London, 1986, 73-88.

[8] DOHENY J.G., MONAGHAN P.F., IDABES: An expert system for the preliminary stages of conceptual design of building energy systems, Artificial Intelligence in Engineering, Vol. 2, No. 2, 1987.

[9] MØRCK O., PAU L.F., EKSPRO manual, Industrial Technology Agency, Copenhagen, February 1989 (in Danish).

[10] GIANNESINI F. et al., PROLOG, Addison Wesley, 1986, ISBN = 0-201-12911-6.

[11] PAU L.F., NIELSEN S.S., Conceptual graphs as a visual language for knowledge acquisition in architectural expert systems, Special issue on Knowledge Acquisition, C. Westphal (Ed.), ACM SIGART Proc., Spring 1989.

[12] PAU L.F., NIELSEN S.S., Conceptual graphs as a visual language for knowledge acquisition in architectural expert systems, Alvey "Workshop on "Explanations"", Univ. Manchester, September 1988.

[13] BRODIE M.L., MYLOPOULOS J., SCHMIDT J.W. (Eds.), On conceptual modelling, Springer Verlag, N.Y., 1984.

[14] Scribe Modeller Manual, ECOTECH, Cedric Green, UK.

[15] Serilink Manual, Solar Energy Research Institute, Colorado, USA.

[16] The building that eats your heart out, The Economist, Februar 4th, 1989, p.85.

[17] Expert Systems: The strategic planning of construction projects, Quantity Surveyors Div., Royal Institution of Chartered Surveyors, London,. 1988.

[18] ADELI H., BALASUBRAMANYAM K.V., Expert systems for structural design, Addison-Wesley, 1988, ISBN = 13-295643-9.

[19] THEX (Expert system for thernal design of homes), CSTB Centre scientifique et technique du bâtiment, France.

[20] SAMAD T., A natural language interface for computer-aided design, Kluwer, Boston, 1986.

Object	Class	Attributes	Calculations or data base
Architectural shape	Esthetics Surface of windows Volume	Shape Surface Volume	CAD-1 CAD-2 CAD-2
Building utilization	Office School Apartment bldg Hospital	Persons/m2 Thermal emissions from electrical equipment Lighting level Day lighting Length Width Height	CAD-3 CAD-3 CAD-4 CAD-4 CAD-2 CAD-2 CAD-2
Fire safety	Direct escape routes Indirect escape routes	Window surface Door surface Height of window Smallest window dimension	CAD-2 CAD-2 CAD-2 CAD-2
Day light	Top light Window light Reflected light	Light intensity	CAD-4
Electrical light	Area lighting Spot lighting	Intrensity Power Thermal effect	CAD-5 CAD-5 CAD-5
External wall	Table of external wall materials and type	k-value Thermal accumulation Internal reflectance External reflectance Orientation Length Width Area	CAD-6 CAD-6 CAD-6 CAD-6 CAD-2 CAD-2 CAD-2 CAD-2
Internal wall	Table of internal wall materials and type	same as "external wall"	CAD-7 CAD-2
Floor	Table of floor materials and types	same as "external wall"	CAD-8 CAD-2
Ceiling	Table of ceiling materials and types	same as "external wall"	CAD-9 CAD-2

Table 1. Objects and properties: price is an additional attribute for all materials (Viemose and Spiele price catalog): the class instances are not given above, but correspond to specific instances, e.g. of materials etc., from the data bases.

Object	Class	Attributes	Calculations or data base
Windows	Table of window materials	k-value Thermal transmission Orientation Height Width Area Position in wall	CAD-10 CAD-10 CAD-2 CAD-2 CAD-2 CAD-2 CAD-2
Sun screens	Internal screens External screens	Sun screen factor Light screen factor Usage	CAD-11 CAD-11 CAD-4
Air infiltration	Air mass	Air flow	CAD-12
Mechanical ventilation	Air mass	Air flow	CAD-12
Heating/cooling	Radiators Cold air Hot air Ceiling irradiation Floor heating Radiators and hot air	Effect (W/m^2)	CAD-13
Thermal confort	Dimensioning heat loss	Heat loss (kW) Time constant (h)	CAD-14 CAD-14
	Dimensioning ventilation	Ventilation effect (kW)	CAD-14
	Dimensioning cooling	Cooling effect (kW)	CAD-14
	Energy demand	Heating effect (kW)	CAD-14
		Lighting thermal effect (kW)	CAD-14
Outside environment	Noise Lighting (direct) Lighting (diffuse) Lighting (reflected) Albedo Wind Air temperature	Light Radiance (W/m^2) Albedo Wind speed Air temperature	CAD-15 CAD-15 CAD-15 CAD-15

Table 1. Objects and properties: price is an additional attribute for all materials (Viemose and Spiele price catalog): the class instances are not given above, but correspond to specific instances, e.g. of materials etc., from the data bases.

Table 2: Data bases and calculation packages

Calculation on data base	Purpose	Implementation
CAD-1	3-D architectural CAD	SCRIBE Modeller system [14]
CAD-2	Calculation of geometrical attributes from CAD-1	PASCAL routines [9]
CAD-3	Building utilization data	Data base
CAD-4	Lighting calculation	SERILUX system [15]
CAD-5	Lighting source data	Data base
CAD-6	External wall data	-"-
CAD-7	Internal wall data	-"-
CAD-8	Flor material data	-"-
CAD-9	Ceiling material data	-"-
CAD-10	Window material data	-"-
CAD-11	Screen data	PASCAL routines [9]
CAD-12	Ventilation system data	User selected
CAD-13	Heating system data	PASCAL routines [9]
CAD-14	Thermal comfort	PASCAL routines [9]
CAD-15	Outside environment	TRY climatic data base and SUNCODE
CAD-16	Total price calculation	PROLOG routine cumulating the prices of all materials, using CAD-2 and CAD-17
CAD-17	Price list of all materials	Viemose and Spiele price catalog

Table 3 : EKSPRO knowledge representation

Level	Knowledge-base	Knowledge representation
0 (see Figure 1)	Building code and occupational safety regulations (KB-1) (see Section 3.1)	Conceptual graph of the objects in Table 1, with logic filters applicable to each arc, and text label attached to each arc [13]: <u>Generic predicates</u>. arc(obj–1, obj–2, filter (1,2), "text (1,2"). filter (1,2): – F(attributes (obj–1), attributes (obj–2)). where: – "text (1,2)" is the text of the building code applying to the relation between obj–1 and obj–2 – F is the predicate value of a function of the attribute values, as fixed by the codes (see KB-1) – arc is the arc predicate
1 (see Figures 2 and 3)	Architectual, design and engineering knowledge (KB-2) (see Section 3.2)	Predicate frames attached to objects from Table 1; the class instances are represented by logical t- uples [10]; the attributes apply to all class instances of the object; the attribute values are calculated as set-forth in Table 2; the class instances are instances of all classes in Table 2. <u>Generic predicate</u>: is-a (obj, class). t-uples <class, class-instance)(list)>. attribute (obj, attribute-list) where: – is-a, is the class definition predicate for the objects of Table 1 – class-instance, is the list of class instances – attribute-list, is the list of attributes in Table 1, calculated as indicated in Table 2
2	Data bases and calculation modules CAD-1-16 (see Table II)	Procedures (PASCAL or others), and data structures of Table II; this includes the geometrical facet representation of CAD package CAD-1

Table 4: User dialogue tasks as related to inference

T1	Check the design process completion by jumping between screens and verifying them
T2	Evaluate the choice of alternative materials, heating/cooling/ ventilation/lighting sources
T3	Comply with code-defined, or user-defined, dimensional constraints (room temperature, heat loss, . . .)
T4	Comply with qualitative, building code or practice relations, to identify ranges of class-instances or attribute values
T5	Update the CAD layout interactively
T6	Exclude some objects or classes from the design choices, by logical binds applying to them
T7	Calculate the ventilation, lighting and other conditions
T8	Search for window sizes and room depths
T9	Configure heating/cooling/ventilation system, in terms of modules and subsystems compatible with one another
T10	Select material price classes on the basis of total construction price (e.g. cheap and expensive design alternatives)

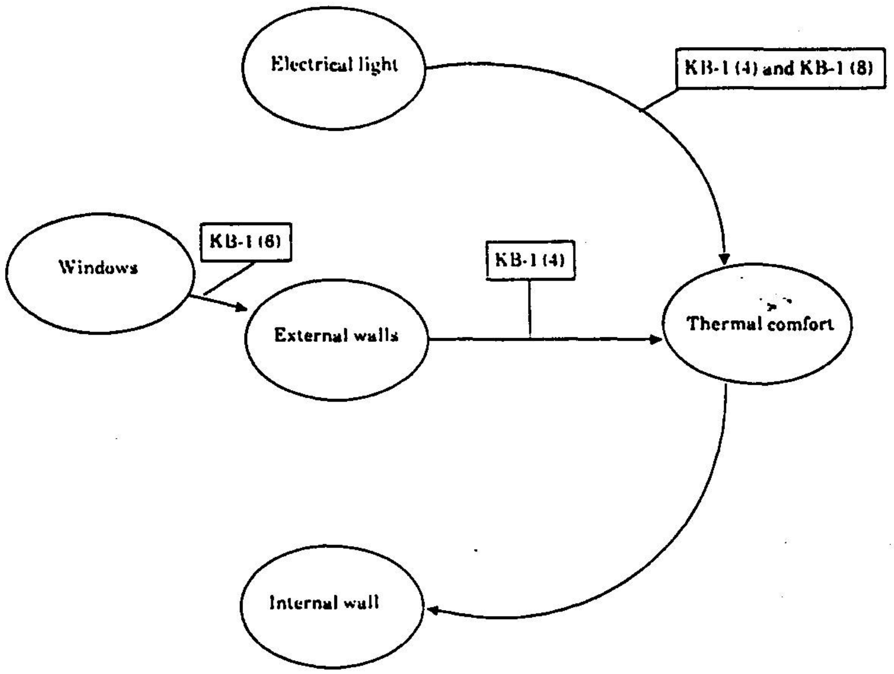


Fig. 1. Conceptual graph example (Level 0); this graph describes causal relations between objects, especially influences of one object on another, and displays building code regulations (KB-1) applicable to such relations. These KB-1 regulations appear as labels attached to each arc (see Table 3).

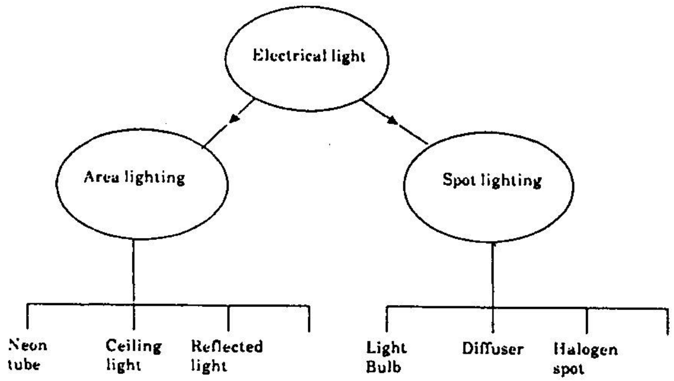


Fig. 2. Classes and object inheritance; the class-instances are the alternative types of occurence of the object.

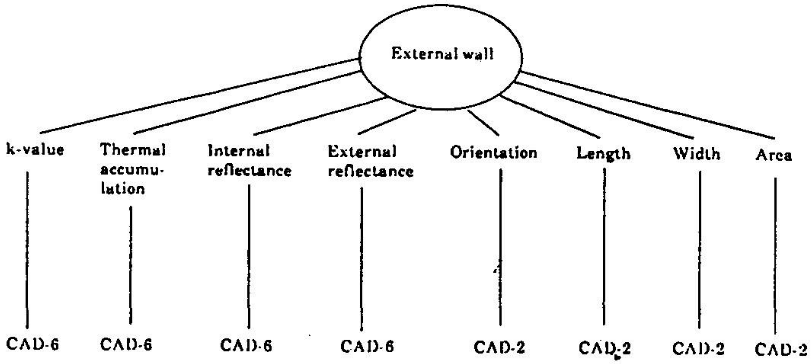


Fig. 3. Attribute-list t-uples.

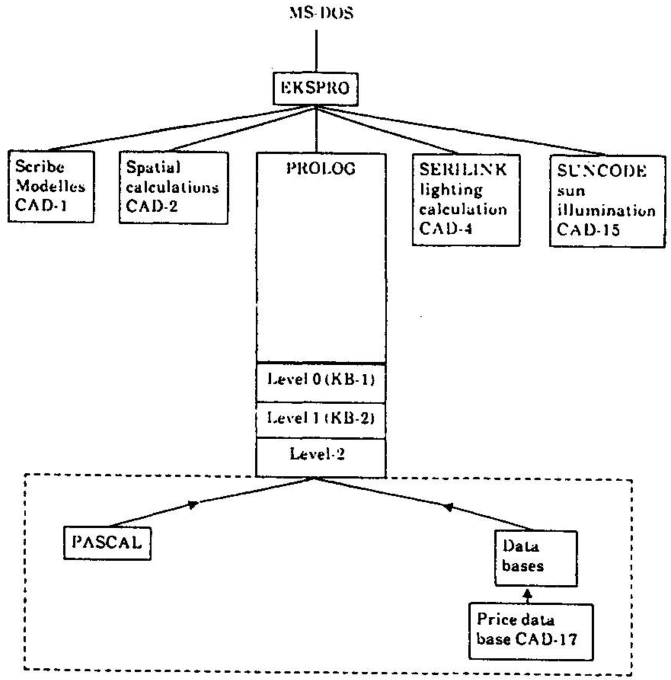


Fig. 4. User interface and major facilities available by multi-windowing.

Figure 5. **Semantic Levels**

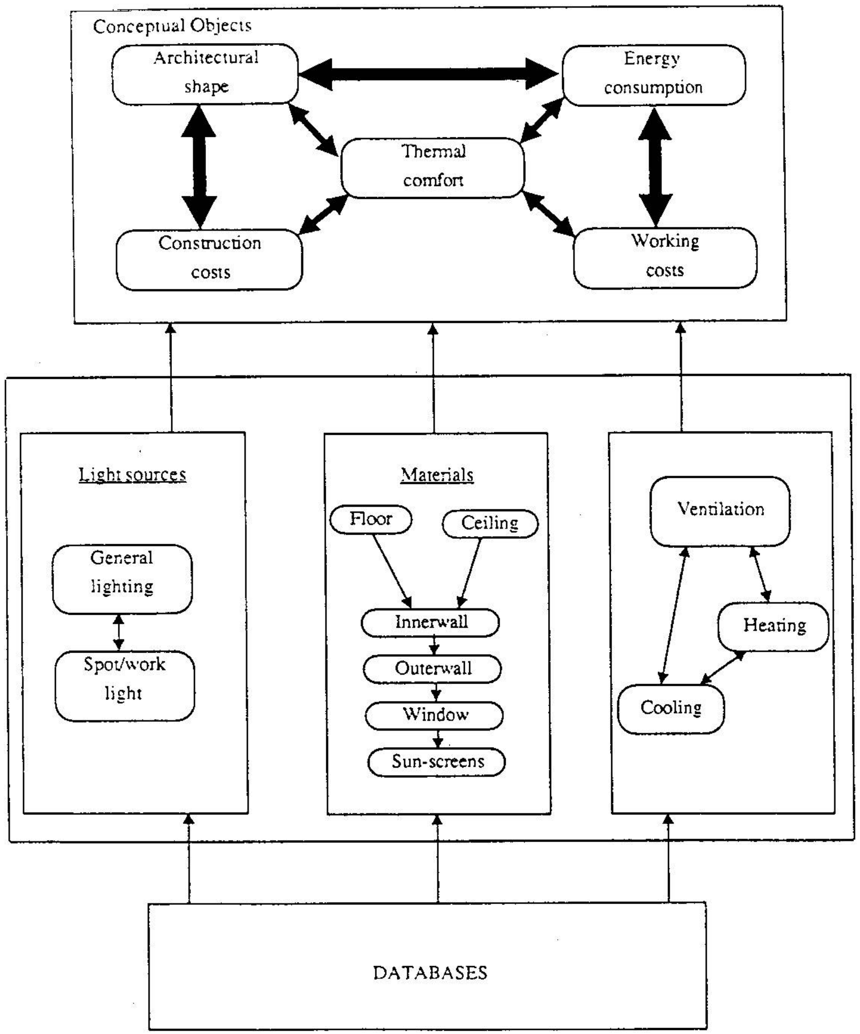
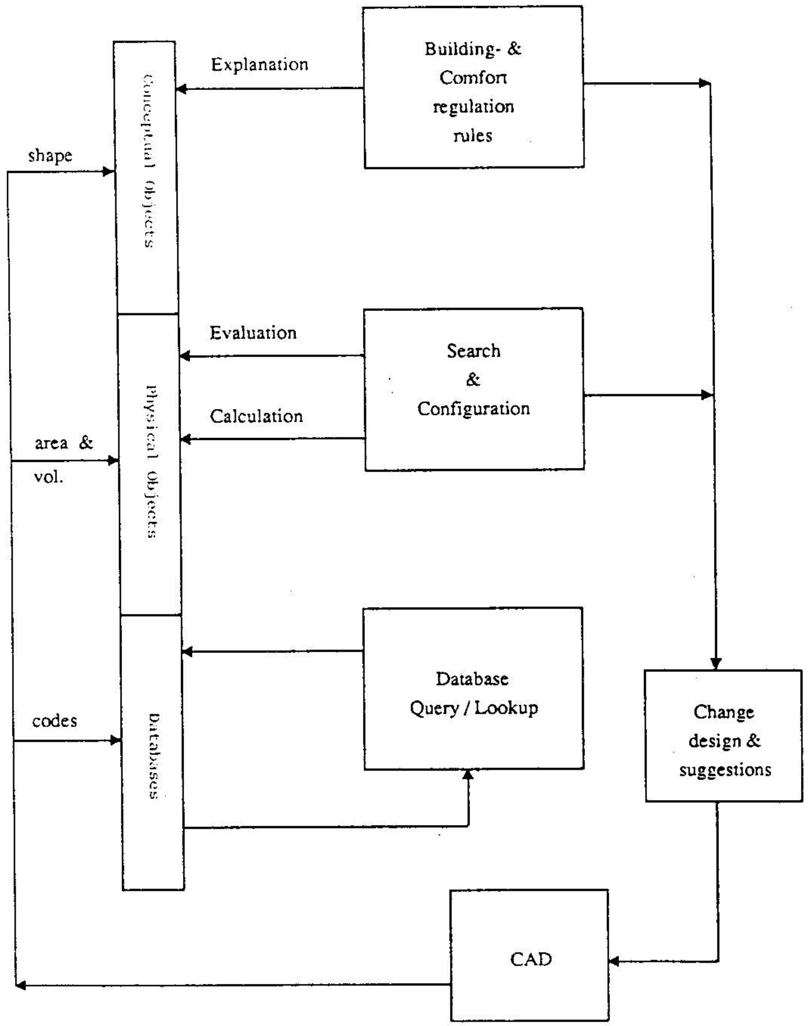


Figure 6. **Operational Levels**



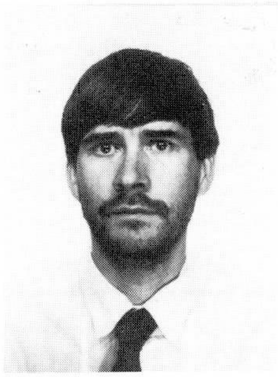
Leere Seite
Blank page
Page vide

Finding Patterns in Structural Failures by Machine Learning

Formulation de modèles de ruine des structures par apprentissage automatique

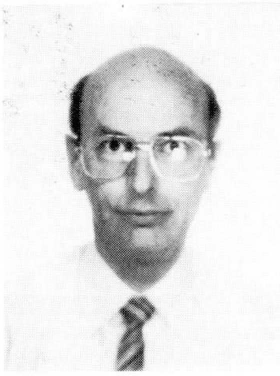
Erkenntnis von Mustern in Fehlleistungen durch «Machine Learning»

John STONE
Research Fellow
University of Bristol
Bristol, UK



John Stone is a Research Fellow in Civil Engineering at the University of Bristol. He is a Chartered Civil Engineer with ten years industrial experience in the design of engineering structures. His research interests include the application of artificial intelligence and machine learning to the problem of engineering safety.

David BLOCKLEY
Reader
University of Bristol
Bristol, UK



David Blockley is Reader in Civil Engineering at the University of Bristol. His research work has been concerned mainly with structural safety and reliability, with particular emphasis on the role of human error and the relationship with modern methods of risk and uncertainty analysis

SUMMARY
A new approach to the examination of significant features in structural failures is described. The method used is a development of the artificial intelligence (AI) technique of «machine learning» to extract sets of commonly occurring features from detailed reports of failures. By representing the information extracted hierarchically in the knowledge base of an expert system, advice can ben obtained on the proneness to failure of a current project. The method is illustrated by comparison with a previous analysis of features in the failure of twenty-three engineering structures. A support logic measure of uncertainty is associated with each set of connected features.

RESUME
Cet article décrit une nouvelle approche de l'examen des caractéristiques significatives de la ruine des structures. La méthode utilisée est un développement de la technique d'intelligence artificielle (IA) nommée apprentissage automatique; cette technique met en évidence des caractéristiques communes décrites dans des rapports détaillés de ruine de structures. En présentant l'information ressortie hiérarchiquement de la base de connaissance d'un système expert, on peut obtenir des conseils à propos de la susceptibilité à la ruine d'un projet en cours. La méthode est illustrée par une comparaison, réalisée au cours d'un analyse précédente, de la ruine de vingt trois structures de génie civil.

ZUSAMMENFASSUNG
Ein neuer Weg zur Überprüfung von bedeutenden Merkmalen in strukturellen Fehlleistungen wird beschrieben. Die verwendete Methode, ist eine Entwicklung der künstlichen Intelligenz-Technik des «machine learning», um Gruppen der häufgsten Merkmale aus detaillierten Meldungen von Feheleistungen zu extrahieren. Durch die Darstellung der hierarchisch extrahierten information in der Wissensbasis eines Expertsystems, kann Mitteilung bezüglich der Neigung zu Fehlleistungen im laufenden Projekt erhalten werden. Die Methode wird mit einer früheren Analyse von Merkmalen in Fehlleistungen an dreiundzwanzig Ingenieurbauwerken verglichen.

1. INTRODUCTION

It is clearly important to study past failures and learn from them. The aim of the project reported in this paper has been outlined by Blockley [1] as the production of "...a knowledge based computer system which might be an aid in the management of the safety of a project". The central issues are a) the search for patterns in data concerning case histories, b) the need to handle uncertainty in open world problems and c) the use of the concept of a hierarchically structured knowledge base. In this paper we will concentrate on a) and only briefly outline b)[2] and c)[3,4].

2. DISCRIMINATION AND CONNECTIVITY

The search for patterns in data is commonly undertaken by the use of a variety of different types of cluster analysis [5]. These methods employ a number of different heuristics to determine 'groupings' of elements of data.

The methods of *discrimination* and *connectivity* described in this paper were developed initially by Norris, Pilsworth and Baldwin [6], who wished to investigate the relationship between medical symptoms and diseases from a number of patient case histories. They formulated two new methods of examining tabular numerical data in an attempt to overcome some of the theoretical and practical problems associated with the use of traditional clustering techniques.

The two methods are to be seen as complimentary approaches to the examination of relationships between features of objects and their classification (e.g. "symptoms" and "diseases"), but will be described here separately before presenting an example of their use in Section 3.

2.1 Discrimination

Discrimination entails the search for a *single* feature of an object which, by its presence or absence, gives evidence for the belief that an object belongs to one class rather than to another. It is therefore a *serial* approach.

The presence of discriminating features is common in engineering. For example, the range of feasible structural materials for the construction of a bridge might include reinforced concrete, steel and masonry, and the one chosen in a particular situation will generally depend upon a combination of factors. However, a requirement that the bridge should be movable for the passage of shipping would discriminate strongly in favour of the use of steel irrespective of the other competing factors. Low maintenance cost, on the other hand, might discriminate in favour of reinforced concrete whilst the matching of an adjoining masonry bridge might discriminate in favour of the use of masonry.

The initial stage in the discrimination analysis is to produce an incidence matrix **I** for each outcome where I_{ij} denotes the degree to which feature *i* was present in example or case *j*. For example, consider Table 1. This represents invented incidence data for two outcomes **X** and **Y**, each of which have three example cases. The examples may have one or more of the five features **A** - **E**. Note that in this example, all the I_{ij} values are either 0 or 1, denoting the certain absence or presence respectively of that feature. In a more general case, a multi-valued representation in the range [0,1] may be assigned, to represent a degree of belief.

A frequency distribution matrix **F**, as shown in Table 2, is then calculated, where f_{ij} denotes the proportion of those features *i* in outcome *j*, summed over all the cases.

case j / feature i	outcome X 1	2	3	outcome Y 1	2	3
A	1	1	1	0	0	0
B	1	1	0	0	1	0
C	1	1	0	0	0	1
D	0	0	1	1	1	1
E	0	0	0	0	1	1

Table 1 Incidence matrices I

feature i	outcome X	outcome Y
A	1	0
B	$^2/_3$	$^1/_3$
C	$^2/_3$	$^1/_3$
D	$^1/_3$	1
E	0	$^2/_3$

Table 2 Frequency matrix F

feature i	outcome X	outcome Y
A	1	0
B	1	0
C	1	0
D	$^2/_3$	1
E	0	1

Table 3 Discrimination matrix P

From the frequency distribution matrix the positive discrimination matrix **P** and the negative discrimination matrix **N** are calculated, using the definitions:

$$p_{ij} = \sum_{\substack{k \in D \\ k \neq j}} \left\{ \chi_{ratio}(f_{ij}/f_{ik}) \right\} \Big/ (C_D - 1) \quad \text{and} \quad n_{ij} = \sum_{\substack{k \in D \\ k \neq j}} \left\{ \chi_{ratio}(f_{ik}/f_{ij}) \right\} \Big/ (C_D - 1)$$

where p_{ij}, $n_{ij} \in [0,1]$ and C_D denotes the cardinality of the outcome set (i.e. the number of outcomes). The suffix D is used to denote a set of indices corresponding to the outcome set. The discrimination value is an accumulated measure of the degree to which the frequency of one feature is greater than that of all the other features for a given outcome. "ratio" is defined as a fuzzy set with membership characteristic function $\chi_{ratio} : R^+ \rightarrow [0,1]$ mapping the positive real numbers (i.e. f_{ij}/f_{ik} and f_{ik}/f_{ij}) onto the interval [0,1]. An example of such a fuzzy set is shown in Figure 1.

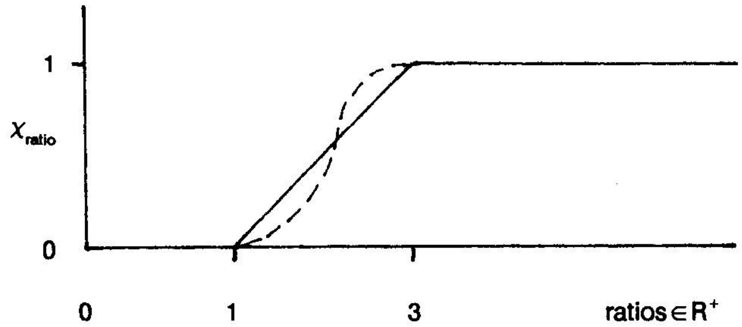


Fig. 1 Fuzzy set for discrimination analysis

Although the dashed line in Figure 1 represents a more general fuzzy set, the simplified solid line has been used for ease of computation. The resulting positive discrimination matrix for this example is given in Table 3. Note that if f_{ij} and f_{ik} are both equal to zero then 0/0 is defined as equal to 0. Norris et al.[6] give a heuristic 'explanation' of the positive and negative discrimination measures which, when translated into the current terminology, argues that p_{ij} represents the accumulated belief that feature *i* is more indicative of outcome *j* than it is any of the other outcome. This analysis therefore gives a method for assessing the significance of any single feature. The following section examines the importance of *groups* of features by using a *connectivity* analysis.

2.2 Connectivity

In contrast to the *serial* operation of the discrimination analysis, the connectivity algorithm adopts a *parallel* approach to the data. The method described here entails the search for *groups* of features which by their presence or absence give evidence for the belief that an object belongs to one class rather than to another. They are those features which have been found commonly to occur together and are associated with a given object classification. The algorithm is therefore a method for *pattern recognition*. Each outcome is considered in turn and a search is made for *groups* of features which commonly occur.

The connectivity analysis involves the calculation of both positive and negative connectivity matrices, with the negative analysis determining groups of features whose presence is indicative of the negation of a particular outcome. The starting point of the analysis is the incidence matrix **I** calculated during the discrimination phase. The positive connectivity analysis is applied to the incidence matrix directly whereas the negative connectivity analysis is applied to the *complement* of the incidence matrix.

If **a** and **b** are two feature vectors from an incidence matrix for a given outcome, then a connectivity measure, c_{ab} between **a** and **b** is defined as:

$$c_{ab} = \left\{ \sum_i (a_i \wedge b_i) \right\} \Big/ \left\{ \sum_i (a_i \vee b_i) \right\}$$

where $\vee$ and $\wedge$ denote maximum and minimum respectively and i ranges over the number of cases. The measure will be zero when **a**, **b** are disjoint and one when **a**, **b** are equivalent. Applying this algorithm to the incidence matrix in Table 1 for outcomes **X** and **Y** and the associated features, the positive connectivity matrices **C** of Tables 4 and 5 are obtained, with elements c_{ij} where i,j range over the feature names.

	feature A	B	C	D	E
A	1	2/3	2/3	1/3	0
B	2/3	1	1	0	0
C	2/3	1	1	0	0
D	1/3	0	0	1	0
E	0	0	0	0	1

Table 4 Positive connectivity matrix for outcome **X**

	feature A	B	C	D	E
A	1	0	0	0	0
B	0	1	0	1/3	1/2
C	0	0	1	1/3	1/2
D	0	1/3	1/3	1	2/3
E	0	1/2	1/2	2/3	1

Table 5 Positive connectivity matrix for outcome **Y**

	feature A	B	C	D	E
A	1	1	1	0	0
B	1	1	1	0	0
C	1	1	1	0	0
D	0	0	0	1	0
E	0	0	0	0	1

Table 6 Equivalence matrix from Table 4 for $\alpha = {}^2/_3$

Again in a more general case the incidence matrices will be multi-valued, with values in the range [0,1]. In this example, it can be seen that features **B** and **C** are the most strongly connected pair for outcome **X**, with $c_{BC} = c_{CB} = 1$, and **D** and **E** for outcome **Y** with $c_{DE} = c_{ED} = {}^2/_3$. This is intuitively to be expected from Table 1.

Having established a connectivity matrix **C** it is then possible to extract groups of connected features. This corresponds to finding paths in a graph [7]. A new relation can be derived by performing an α cut on the connectivity matrix. The new matrix contains values of 1 for those connectivities greater than or equal to α and zeros elsewhere. Warshall's algorithm [7] is then used to transform this symmetric matrix into a new connectivity matrix which can easily be partitioned. The partitions of the equivalence matrix now correspond to groups of features which are connected together at degree α. The value of α is set at various levels in the range [0,1] and the resulting connected groups of tail-vertices examined. The equivalence matrix from Table 4 for $\alpha = {}^2/_3$ is as shown in Table 6. Two tables are produced for each outcome based on the positive and negative connectivity analyses. Each table consists of sets of features corresponding to different values of the α cut in the range [0,1]. For example, the resulting table of connected groups of features from the positive connectivity matrix for outcome **X** in Table 4 is :-

$\alpha = 1$: **(B,C)** $\alpha = {}^2/_3$: **(A,B,C)** $\alpha = {}^1/_3$: **(A,B,C,D)** $\alpha = 0$: **(A,B,C,D,E)**

All the features form a single group at level $\alpha = 0$. At intermediate levels the features fall into separate groups, with the number of features in each group reducing as the connectivity level increases. Each higher level group may be thought of as being a representative set of features whose presence is evidence for the subsequent occurrence of the associated outcome (or evidence against it in the case of the negative table). In this example, the presence of group **(B,C)** is therefore strongly indicative of outcome **X**.

A pair of numbers in the range [0,1], known as a support pair [2], can be associated with a connected group at each connectivity level. These give lower and upper bounds on the evidential support for a proposition or event. The calculus is based upon an 'open world' representation of uncertainty in the sense that it is possible to represent propositions as true, false or unknown. The first number of the support pair, the necessary support, is given the value α from the connectivity analysis. The second number, the possible support, is always 1. Thus for outcome **X** a strong indicator is the group **(B,C)** with support pair (1,1). In support logic notation (a modified PROLOG rule) this is written **X** :- **(B,C)** : [1,1]. Other rules would be

X :- **(A,B,C)** : $[{}^2/_3,1]$ **X** :- **(A,B,C,D)** : $[{}^1/_3,1]$ **X** :- **(A,B,C,D,E)** : [0,1]

The computer program implementing the connectivity method allows the step levels at which the connected groups are determined (in the range $0 \leq \alpha \leq 1$) to be chosen by the user. This enables the structure of the groups at different connectivity levels to be examined as appropriate to the application. The values 0, ${}^1/_3$, ${}^2/_3$, 1 have been selected for this example since the small number of feature groupings are portrayed adequately. A more complex example in Section 3 illustrates a closer division at increments of 0·1.

3. FAILURE ANALYSIS BY SIMPLE SUMMATION

A detailed account of a simple analysis of structural failures has been given previously by Blockley [8]. This paper describes the application of the connectivity and discrimination analyses to Blockley's data, which were assessments of the relative truth (or dependability) and importance of a number of statements concerning well documented failures. The original investigation examined twenty four statements about twenty three failures, ranging from the Tay Bridge collapse of 1879 to the loss of the oil drilling barge Trans Ocean 3 in the North Sea in 1974. Typical statements were "the structure is not sensitive to random hazards", "the designers are adequately experienced in this type of work" and "the contractual arrangements are perfectly normal". The assessments, although made with engineering judgement and experience, were entirely subjective and personal, made with the benefit of hindsight, and a different investigator may have chosen quite different values. They do, however, represent a useful basis for analysis since they are a consistent set of interpretations carried out with a common method and purpose.

The assessments were made on the basis of five categories for both truth and importance. The level of confidence in the *truth* of a statement was graded between 1 (very high) and 5 (very low), and its *importance* between *A* (very low) and *E* (very high). Numerical values were assigned to each of the assessment ratings 1-5 and *A-E* on the following scale: 1 and *A* = 0·2, 2 and *B* = 0·4, 3 and *C* = 0·6, 4 and *D* = 0·8, 5 and *E* = 1·0. An overall 'combined rating' was calculated as the product of the two individual values and lying in the interval [0,1]. Thus a rating of 4 for truth and *C* for importance yields a combined figure of 0·48. The new combined assessments are therefore represented in the form of a fuzzy incidence matrix as described in Section 3.1. A simple analysis was made [8] by summing the combined ratings over all twenty three failures. Table 7 is a short extract form the results.

Order	Statement	Brief description	sum
1	5a	design error	15·48
2	6c	construction error	11·88
3	6e	contractor's staff	11·76
4	5d	designer's site staff	11·68
5	2b	R & D information	10·88

Table 7 Simple summation of accident statement parameters

These values have been interpreted elsewhere [8], but it is important to emphasise here that the sample of failures from which they were derived is not random and includes only failures important enough to merit individual reports of inquiry. The scores are not precise numerical quantities but only relative indications of the importance of the statements.

4. FAILURE ANALYSIS BY DISCRIMINATION AND CONNECTIVITY

The following example illustrates the application of the discrimination and connectivity methods to the analysis of the failure data given in Section 3. Note that all the cases selected refer to failures, so at one level there is therefore only one outcome to be considered. This means that a discrimination analysis cannot be performed, since it by definition determines an ability to discriminate *between* outcomes. However, it is apparent that the cases may also be classified by other means, such as mode of failure (e.g. fatigue, overstress etc.), structural form (e.g. bridge, oil-platform) or other criteria as desired. With more than one outcome, a discrimination analysis may be made. For example, if the cases are partitioned into 'bridges' and 'others' then the positive discrimination matrix shown in Table 8 is obtained.

statement	bridges	others	statement	bridges	others	statement	bridges	others
1a	0·00	0·23	4c	0·00	0·22	6a	0·39	0·00
1b	**1·00**	0·00	4d	0·13	0·00	6b	0·40	0·00
2a	0·00	0·18	4e	0·09	0·00	6c	0·00	0·11
2b	0·15	0·00	5a	0·00	0·04	6d	0·44	0·00
3a	0·04	0·00	5b	0·00	0·00	6e	0·14	0·00
3b	0·00	**1·00**	5c	0·83	0·00	7a	0·00	0·00
4a	0·02	0·00	5d	0·10	0·00	7b	0·54	0·00
4b	0·00	0·48	5e	0·36	0·00	8	0·00	0·36

Table 8 Positive discrimination values

The reader is referred to the original analysis [8] for the full list of the meaning of each of the statements 1a - 8. It is apparent that statement 1b (strength variability) discriminates strongly in favour of a bridge failure, and statement 3b (sensitivity to random hazards) in favour of 'other' failure. From the original data [8] it can be seen that the only occasions on which statement 1b was assessed as being of other than minimal significance both related to bridge failures (Tay and Quebec 2). It never appeared as a significant factor in any of the 'other' failures, and therefore discriminates in favour of bridge failures. A similar argument applies to statement 3b, which only occurred as a significant factor once, relating to an 'other' failure (Ronan Point).

From the discrimination analysis the frequency of occurrence of a feature for an outcome is obtained *relative to all the other possible outcomes*. Thus even a single occurrence can be significant if it occurs only for one outcome and never for any of the others, as seen above with statement 3b. A connectivity analysis carried out on the same data gives the following groups of positively connected statements:

$\alpha = 0 \cdot 5$	:	(5d, 6e)
$\alpha = 0 \cdot 4$	:	(5d, 6c, 6e)
$\alpha = 0 \cdot 3$	:	(5a, 5d, 6c, 6e)
$\alpha = 0 \cdot 2$	:	(2a, 2b, 5a, 5d, 6c, 6e)
$\alpha = 0 \cdot 1$	:	(1a, 2a, 2b, 4a, 4b, 4d, 4e, 5a, 5d, 5e, 6c, 6e, 7a, 7b, 8)

Note that no statements are connected more strongly than at a connectivity level of $0 \cdot 5$. This reflects the diverse nature of the practical problem, and is in contrast to the artificially chosen example of Section 3.2 where some features were connected at $\alpha = 1 \cdot 0$. It is interesting to compare the above connected groups with the results from the previous analysis shown in Table 7. The most strongly connected pair of statements from the connectivity analysis, 5d and 6e, occur as the fourth and third most frequent statements respectively in Table 7. Two connectivity intervals lower, at $\alpha = 0 \cdot 3$, all the top four of the previous results - 5a, 6c, 6e and 5d - are now found to be connected in one group.

The *meaning* of the connected groups may be considered as a new entity rather than in terms of the individual features. For example, the two most strongly connected statements (5d and 6e) each relate to a specific aspect of site control staff. "Site control staff" may therefore be thought of as a *higher level*, or more general, description encompassing both of the statements. Similarly, the second level group (5d, 6c and 6e) adds "construction error" to the top level group, and might therefore be thought of as "site procedure". Grouping together concepts in this fashion leads to the possibility of constructing a hierarchical knowledge base, consisting of progressively more general concepts at higher levels, and grounded in specific concepts relating to individual case histories at the bottom.

5. HIERARCHICAL KNOWLEDGE BASE

The analysis based upon connectivity, discrimination and the grouping together of related concepts can be extended [9] to develop a hierarchically structured knowledge base of case histories of failures. The case histories are 'captured' by the use of event sequence diagrams (ESDs) [10]. These diagrams show the temporal order and relationship of events leading up to a particular outcome. For example, Figure 2 shows a hierarchy of three ESD representations of the same 'story'. The lowest level (Level 1) is the most detailed, corresponding to specific detailed concepts from a case history. Level 2 is an intermediate representation, in which a number of the bottom level concepts have been 'merged' to form new, broader concepts as noted above. The most general representation, Level 3, is obtained by further merging of concepts by repeated application of the connectivity analysis.

The advantage of representing knowledge in a hierarchical form is realised when it is wished to query the knowledge base. The user is able to pursue a query about a concept to an appropriate level of detail.

Figure 3 is an outline of the structure of our proposed development of a knowledge-based system (KBS) to fulfil the objective stated in the Introduction. The upper section of the diagram, concerned with building the knowledge base, has been implemented in C on an IBM PC/AT. The lower section illustrates the proposed future development and use of the system. 'FRISP' is 'Fuzzy Relational Inference with SuPport logic' [11], a PROLOG program which allows a user to query a knowledge base and to receive information with the associated uncertainty expressed in the form of a support pair.The structure of the KBS includes two 'learning' loops. The first is in the upper, 'building' section, where knowledge from case histories is accumulated and merged into the hierarchical knowledge base. The second joins the 'building' and 'user' sections, and commences when the representation of the 'world' embodied in the knowledge base and the FRISP responses become unsatisfactory. This situation can only be remedied by the user providing the 'building' phase of the system with more case histories, which may result in the formation of new concepts in the knowledge base following a new connectivity analysis.

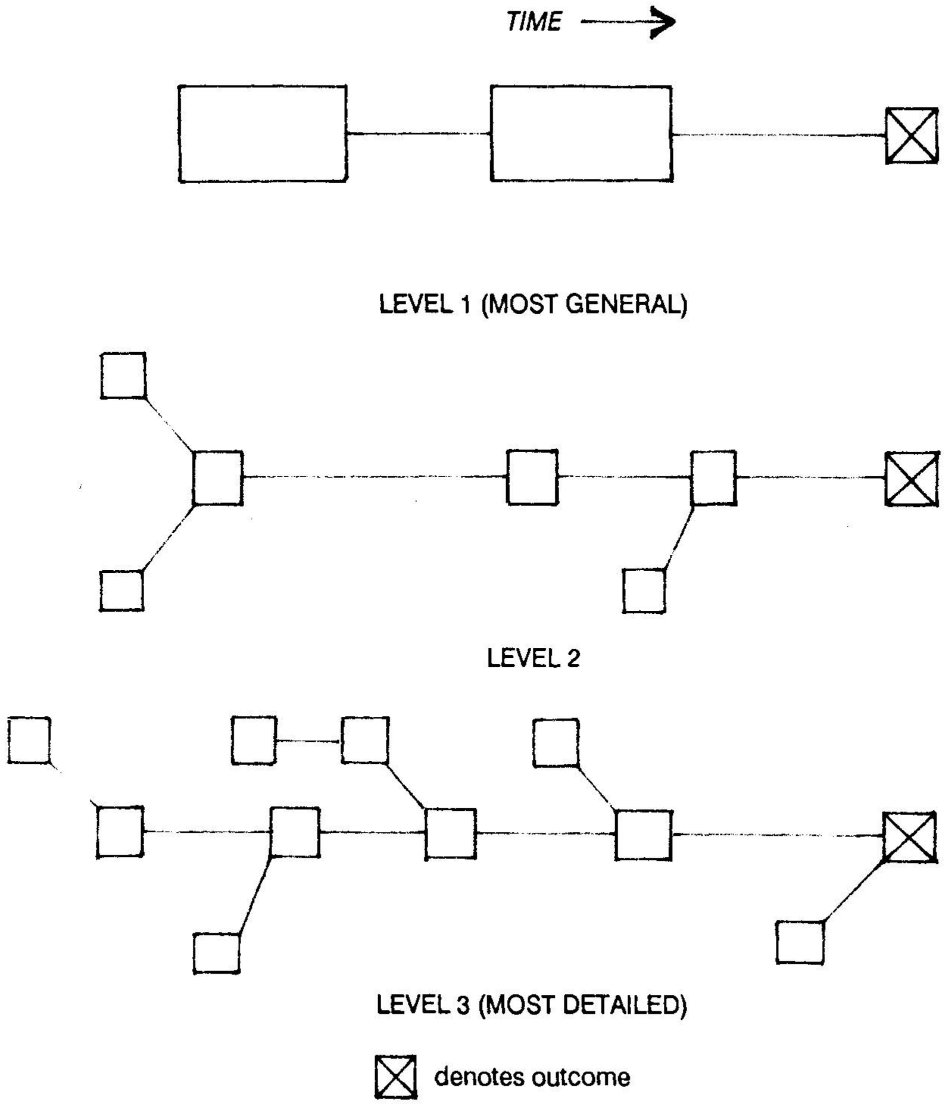


Figure 2 Hierarchy of Event Sequence Diagrams

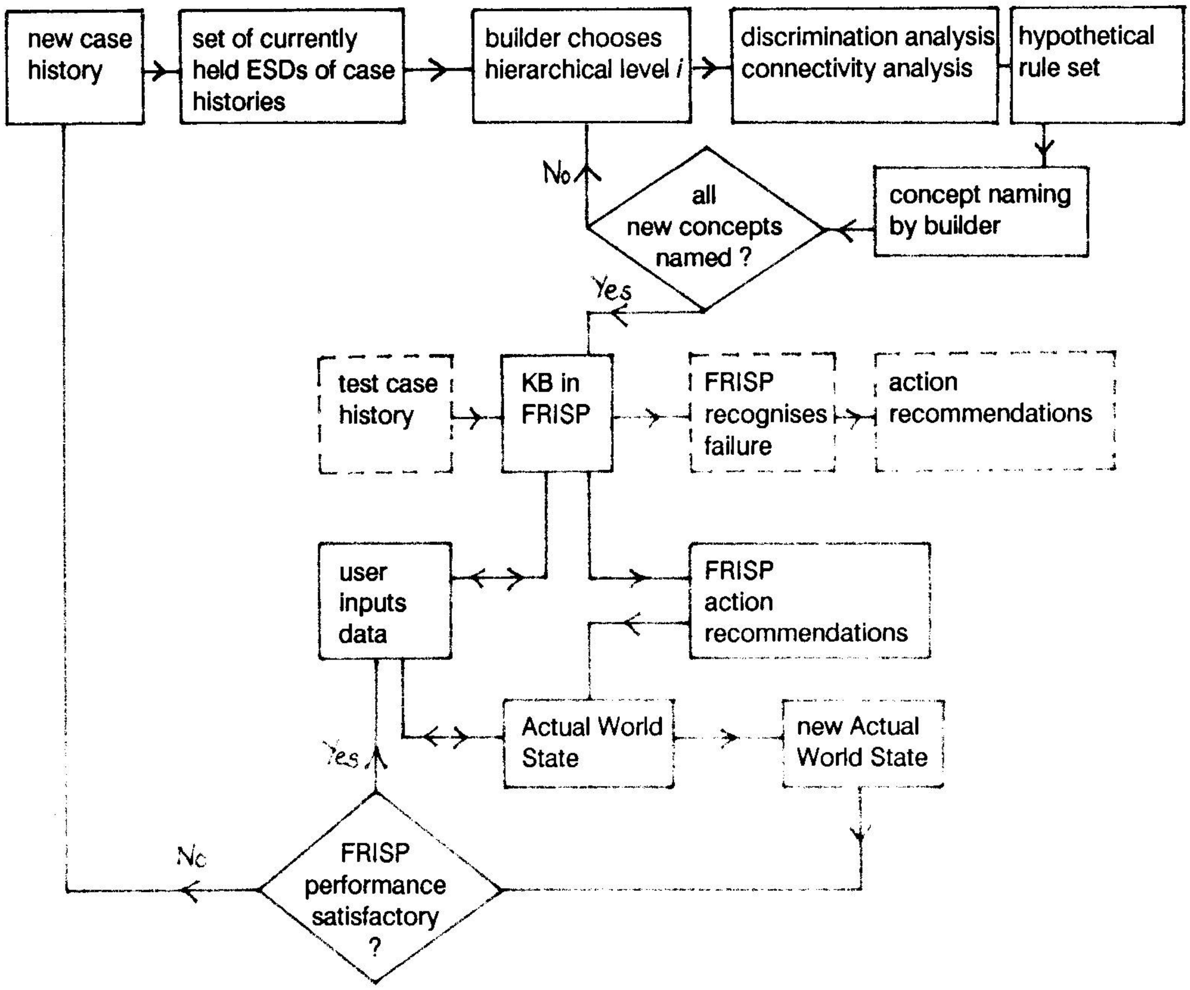


Figure 3 Outline of structural safety KBS

6. CONCLUSIONS

The application of a method of machine learning based upon the techniques of discrimination and connectivity to the assessment of structural safety has been described. The following points are significant :-

1) Many engineering failures contain common features. Attempts to learn from failures may therefore be based upon pattern recognition techniques.

2) The detection of common patterns of features may consider either single features (discrimination) or groups of features (connectivity).

3) The support logic calculus allows an appropriate 'open world' representation of uncertainty, in which propositions are either true, false or unknown.

4) The use of the connectivity analysis allows the meaning of groups of features to be merged in a hierarchical form suitable for inclusion in a structural safety knowledge base.

ACKNOWLEDGEMENTS

The work reported in this Paper was supported by a grant from the United Kingdom Science and Engineering Research Council.
The authors wish to thank Rosie Greenhill and Mrs V.M. Jenkins for their help with the translations.

REFERENCES

1. BLOCKLEY, D.I. An A.I. tool in structural safety control. In A.S. Nowak (Ed.), *Modelling human error in structural design and construction*. New York: A.S.C.E., 1986.

2. BALDWIN, J.F. Evidential support logic programming. *Fuzzy Sets and Systems*. **24**, 1987, pp 1-26.

3. STONE, J.R., BLOCKLEY, D.I. and PILSWORTH, B.W. Towards machine learning from case histories. *Civil Engineering Systems* (in press).

4. STONE, J.R. *Expert system learning from structural failures*. Ph.D. thesis, University of Bristol, 1989.

5. EVERITT, B. *Cluster analysis* (2nd ed.). London: Heinemann, 1980.

6. NORRIS, D., PILSWORTH, B.W. and BALDWIN, J.F. Medical diagnosis from patient records - a method using fuzzy discrimination and connectivity analyses. *Fuzzy Sets and Systems*, **23**, 1987, pp 73-87.

7. LEVY, L.S. *Discrete structures of computer science*. New York: John Wiley, 1980.

8. BLOCKLEY, D.I. *The nature of structural safety and design*. Chichester: Ellis Horwood, 1980.

9. STONE, J.R. and BLOCKLEY, D.I. Structural reliability through learning from case histories. *Proceedings of Fifth International Conference on Structural Safety and Reliability* (ICOSSAR '89), San Francisco, 7-11 August. A.S.C.E.

10. TURNER, B.A. *Man-made disasters*. London: Wykeham, 1978.

11. BLOCKLEY, D.I. and HENDERSON, J.R. Knowledge base for risk and cost benefit analysis of limestone mines in the West Midlands. *Proc. Instn. Civ. Engrs.*, Part 1, **84**, June, 1988, pp 539-564.

Do we really want Knowledge Based Systems in the Real World?

Application de systèmes à base de connaissance dans la pratique

Zur Anwendung von Expertensystemen in der Praxis

E. Geoffrey TRIMBLE
Prof. of Constr. Mgt.
Univ. of Technology
Loughborough, UK

Geoffrey Trimble practiced civil and structural engineering until 1960. Thereafter he has devoted his efforts to Construction Management and Knowledge Based Systems, firstly as a management consultant and, since 1967, as an academic.

SUMMARY
This paper draws attention to the important differences between academic and commercially based knowledge based systems. It provides advice to developers of knowledge based systems who wish to see their systems exploited in the real world.

RESUME
Cet article porte l'attention sur les différences importantes entre les systèmes à base de connaissance commerciaux et académiques. Il procure des conseils aux développeurs de systèmes à base de connaissance qui veulent voir leurs systèmes utilisés dans la pratique.

ZUSAMMENFASSUNG
Dieser Beitrag zeigt die wichtigen Unterschiede zwischen akademischen und kommerziellen Expertensystemen. Es werden Hinweise gegeben, wie Expertensysteme für die Anwendung in der Praxis aussehen und entwickelt werden sollten.

1. INTRODUCTION

Experience in developing ten KBS and reviewing seventy KBS has revealed an unfortunate gulf between the academic's approach to the development of systems and that of people who plan from the start to produce cost effective systems for use in the real world. What is often overlooked is that KBS in the real world are usually management systems which, either directly or indirectly, are intended to influence important decisions. Although people in the management world appreciate that systems must be designed around the intended users this simple fact often escapes academics who are developing KBS.

This paper therefore starts with a perspective on management systems. It continues with a review of KBS in construction with particular reference to project management. From these sections conclusions are drawn on the approaches to the development of KBS that are likely to prove useful in the real world.

2. MANAGEMENT SYSTEMS

In seeking to improve management procedures there are two alternative approaches.

- Identify and sharpen up one or more techniques and seek relevant applications
- Identify problems in the management procedures and attempt to solve them using common sense supported by available techniques

Once the alternatives have been set down in these stark terms most people, taking a broad perspective, would have no doubt that the second alternative is by far the better. Despite this there are many examples in industry and in management consulting of attempts to push selected techniques. In the 1960's and 70's strong efforts were made to sell the use of network analysis techniques (PERT CPM etc). These were motivated by commercial interests, particularly those of the computer industry which was trying to sell its hardware and software. (In those days the costs were such that hardware sales usually preceded software sales). The result was that network analysis became over-sold and many in the construction industry became dis-illusioned. It has taken a further ten years for the techniques to move into an appropriate niche and to be used effectively in appropriate circumstances.

During this period a study was undertaken at Loughborough University England (ref 1). This explored by statistical means, the factors that are associated with successful applications of network techniques. A follow-up study was made to explore the causal relationships that underlay the statistical associations. One of the interesting findings was that computer programs written by user companies were far more successful than commercial programs that had been well developed and strongly promoted. The detailed follow up revealed important managerial differences. In particular the circumstances which caused a user company to develop its own software were those in which management problems had been identified and tackled whereas the commercial software was usually found where a company had rather shallowly decided to apply the technique often under pressure from the computer salesman.

3. THE HISTORY OF KBS

The author was commissioned in late 1983 to study the potentials of KBS in construction management including project management (ref 2). Since then he has had a continuous involvement in this subject and has attempted to keep abreast of developments world-wide (ref 3).

It is clear that there are two main thrusts. One is an academic approach which attempts to harness the latest technology and push back frontiers of knowledge. A good example of this, despite its industrial funding is the PLANIT community club. This consisted of about ten companies whose financial contributions were matched by the British government's Alvey Directorate.

The software developed by this club is an Inter-active Planning Assistant. As this name implies its objective is to provide assistance to a project manager during the implementation of a project. A closely related development is Stanford's PLATFORM. Both were developed using a computer "tool-kit" called KEE. The kind of assistance these products will offer is to examine the productivity achieved so far in particular classes of activity, e.g. those that involve the placing of concrete, and to factor up or down the time estimates for future activities in the same class. They will also assess the phasing of activities in relation to expected weather conditions and make appropriate adjustments; and recommend that an alternative plan should be adopted by practising project managers. One can speculate on the reasons for this as follows.

- The managers do not consider that the effort in using these more complex systems is justified by the benefits
- Re-assessment of productivity will usually involve other factors than records of past performance
- The facility to change automatically to a new strategy requires that the alternative has been pre-planned but this is extra effort at the start of the project that most managers would consider unjustified

The other approach is much more pragmatic and is eptiomized by the work of Stone & Webster inc. of Boston Mass. Their approach is to take relatively simple problems such as the selection of suitable tests for newly recruited site welders and to produce uncomplicated systems that can be used by managers in the field. Their commercial literature lists also

- Centrifugal pump diagnostics
- Rotating equipment vibration diagnosis
- Weld defects diagnostics
- Welding procedure selection

It is significant that systems of this type are currently working not only on Stone & Webster's sites but are also available through remote terminals to their clients. It is significant also that they are all diagnostic or selection systems as these are the simplest to develop.

The systems developed by the author have revealed similar charcteristics. For example an early demonstration system was developed to select appropriate mechanical handling equipment on construction sites. When described to George Wimpey & Co (a large British contractor) it was judged to be impractical as it did not adequately reflect the diversity of shapes of buildings in the real world. This prompted the development of an entirely new approach which includes an inter-active graphics facility to enable users to explore the full implications of the geometry. A system commissioned by the (British) Building Research Establishment is designed to diagnose the cause of dampness in buildings. Its ultimate purpose is to reduce the work load of its Advisory Service. Having these laudably practical aims ensured that its development proceeded smoothly towards a product that can be used in the real world (ref 4).

So the general experience of management techniques is being repeated. On the one hand we have well sharpened techniques, with impecable credentials, that are not used while on the other we have pragmatic solutions that have been developed in response to a perceived need.

4. LESSONS FOR KBS

The author's experience with management systems and more recently with KBS leads to some clear conclusions. If we do really want to see expert systems working in the real world we must first address the management issues. Any executive who plans to authorize the development of a KBS should be quite clear about the objectives for the system. It is of course quite valid to have as an objective the demonstration of relevance of KBS technology within a particular domain. But the author knows of no demonstration system that has been directly exploited in the real world.

So the objective from the start must be to have a system that people are going to use in the real world. The authorizing executive must therefore address, in advance, such questions as "How will the system be used?" "Who will use it?" "Will prospective users understand the messages on the screen?" "Will the system solve problems more quickly and ensure that all relevant aspects are explored?" "Will the system be cost effective?".

Another important question is "Will people feel threatened by the system?". All management systems affect people's lives. Some people feel threatened by proposed changes and this is particularly the case with KBS. An effective KBS is capturing and exploiting someone's expertise. He may react favourably if he judges that it will relieve him of unwanted chores. On the other hand he may fear that he will become redundant when the system is in use. So the executive in charge must judge the extent and form of the threat and take whatever steps he can to alleviate the damage.

5. SUMMARY OF ADVICE

In summary, an executive planning a real world KBS should

- Know its basic objectives
- Know how it will be used and by whom
- Ensure that it will be understood by prospective users
- Assess and mitigate the possible threat generated by the system
- Assure himself in advance that the benefits from the system will justify its cost.

References

1. Arditi D. The behavioural and technical factors that affect the success of network analysis. (PhD thesis Loughborough University 1973).

2. Trimble E G et al. Expert systems in contract management. (Report for the Construction Engineering Research Laboratory 1985).

3. Trimble E G and Cooper C N. Knowledge acquisition for expert systems in construction. (Report for CERL 1988).

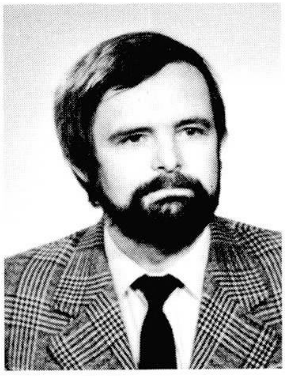
4. Allwood R J, Shaw M R, Smith J L, Trimble E G. Building dampness; diagnosing the causes. (Building Research and Practice. No 1 1988).

Graphical Expert Systems

Systèmes experts graphiques

Graphisches Expertensystem

Jan PETR
Assoc. Professor
Prague Technical University,
Prague, Czechoslovakia



Jan Petr, born 1944, received his civil engineering degree and PhD at the Prague Technical University. He worked as a designer, for several years he dealt with structure analysis by computers. Now he is involved in developing CAD systems at PTU.

SUMMARY
Graphical Expert Systems represent a new generation of computer graphics tools, a kind of Intelligent Knowledge - Based Systems. Goals and constraints of such a system are presented. So-called graphical knowledge is defined. A language for graphical knowledge representation is derived. The structure of the system GES being developed at Prague Technical University is described.

RESUME
Les systèmes experts graphiques (GES) représentent la nouvelle génération des outils infographiques. Les buts et les limites de ces systèmes sont présentés. La connaissance graphique et la langue pour sa représentation son définies. La structure d'un système expert graphiques développé à l'Université technique de Prague est décrite.

ZUSAMMENFASSUNG
Graphische Expertensysteme repräsentieren eine neue Generation der Werkzeuge für Computergraphik. Die Ziele und die Ausgangspunkte des Projekts eines solchen Systems sind in diesem Aufsatz abgeleitet. Das sogenannte graphische Wissen und seine Repräsentation wird definiert. Die Struktur und einzelne Bestandtelhate des graphischen Expertensystems GES, welches die Technische Universität Prag entwickelt, sind beschrieben.

1. INTRODUCTION

The paper presents some results of the efforts to develop a means capable of generating graphical information from object-oriented, not graphically expressed data. These data are the results (of a particular problem) achieved either through an artificial system or man. The goal is to make an object-independent programming system with the elements of artificial intelligence. System GES, a graphical expert system with inherent graphical knowledge, meets these requirements.

First some theoretical backgrounds of GES are presented: an analysis of graphical language, graphical knowledge definition neccessary for GES' knowledge base construction, and the language for graphical knowledge representation.

Second the GES' main components and structure are described.

2. CHARACTERISTICS OF GES

2.1 Purpose of GES

In many domains of civil engineering design the graphical form of information is used. We can say that the graphical language is one of the designer's natural languages. CAD systems respect this fact, too. Different types of computer software generate graphical outputs of these systems. Some of the software are special, problem-oriented, one purpose program moduls. Today's integrated systems for interactive computer graphics represent very sophisticated and effective tools of a designer. But even with such systems a designer must communicate in words of graphical language syntax, that means in words "how to draw"; usually it isn't possible to communicate with them in the language of the problem domain, that means in "semantic" terms "what to draw". The ambition of GES (or rather of its authors) is to understand "what" is to be drawn and to be able to draw it in a proper way, using "graphical" knowledge. Systems like GES are domain independent exept their knowledge base. The contents of the knowledge base assigns a concrete GES to a certain domain.
The main object of GES is to convert information expressed in non-graphic form (a description of a construction for example) into usual graphical form ("to draw" it). The "intelligence" of GES consists in "how to draw" it. Figure 1 shows the typical situations of GES applications.

2.2 Nature of GES

GES is designed as an expert system. To construct it knowledge of three branches is made use of:

- civil engineering designing; from this branch practical demands and constraints are drawn,
- classical computer graphics, from which graphical algorithms and programme moduls of geometric-graphic operations are borrowed,
- artificial intelligence, which gives data and procedures for knowledge processing; from this branch also the principles of expert systems are borrowed.

a) conversion of non-graphic data into graphic form in CAD complex

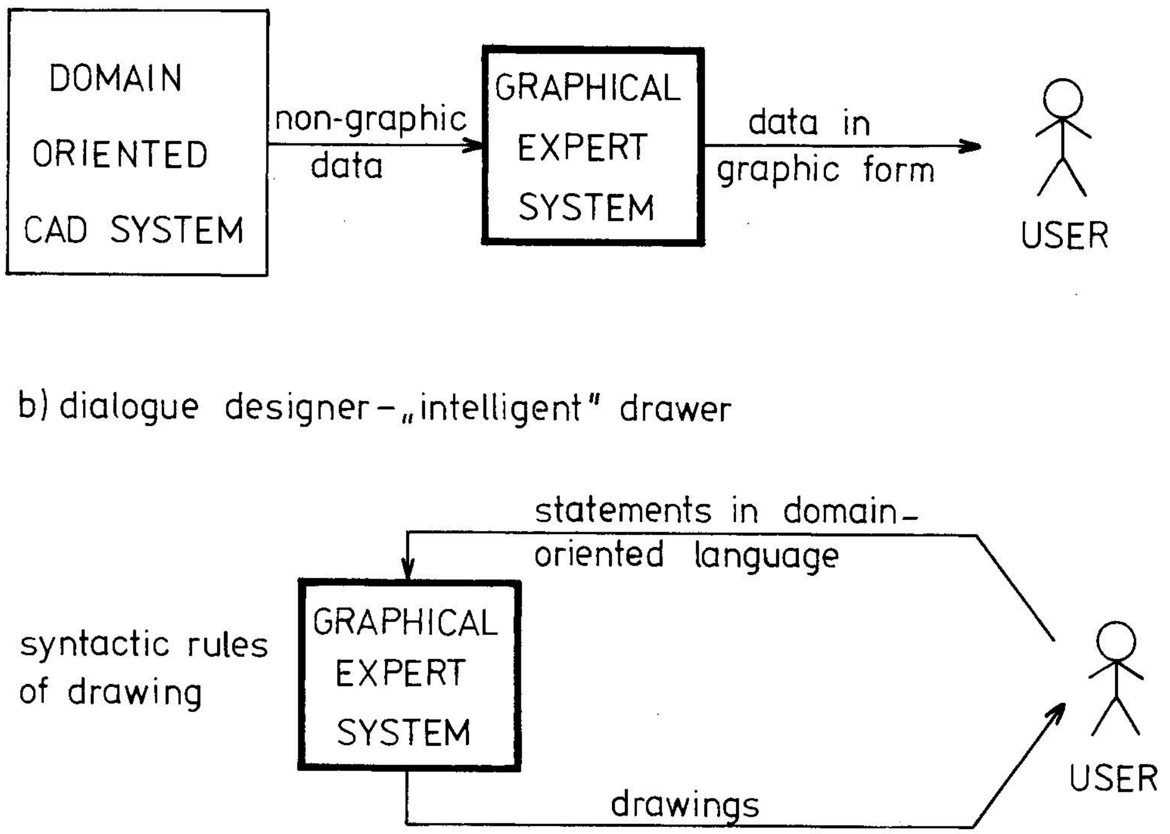


Fig.1 : Typical applications of GES

GES has typical attributes of classical expert systems. It uses the expert knowledge base (e. g. how to compose and construct particular drawings) and universal inference mechanism for knowledge base evaluation based on concrete input data.

What makes GES different from classical systems is that it works with graphical knowledge, depicting graphical entities and graphic-geometric relations between them. The GES inference mechanism is also based on specific graphic-geometric procedures.

To realize GES a host graphical system is used capable of handling graphical objects, e. g. keeping and drafting. Typical examples are AutoCAD, DOGS and others. GES presents superstructure over these systems.

GES is programmed for PC-AT computers equipped with graphical display.

3. GRAPHICAL KNOWLEDGE

3.1 Semantic entities in graphic information

Some parts of concepts, which reflect objects of real world in human mind, are connected with visual image. If these parts privail, then such concepts are conveyed by graphical language. From the semantic point of view these parts represent in the

commonly used graphical languages the following semantic entities:
- iconic characteristic,
- geometric characteristic,
- symbol of the object,
- scalar characteristic.

Let's call them **graphic entities**. Another kind of semantic parts are the **relations between graphical entities**:
- distance,
- rotation and
- superposition.

Iconic characteristic presents perceived or designed appearance of the object.

Geometric characteristic describes how the object is set up in space.

Symbol of the object is either an established figure or an instantaneous one depicting the kind of the object or identifying the object.

Scalar characteristic of the object is a visual image of the value or the course of values of a certain scalar variable typical of the object.

Relations depict manual distances and rotations of the objects.

Superposition describes the composition of graphical entities. By means of superposition the quality of the whole composed of several concepts is generated.

Graphical entities and relation between graphical entities are the **basic semantic entities** of graphical information.

3.2 Graphical Knowledge Definition

The use of computer in generating graphic information is of prime interest to us. From this point of view also the definition of graphical data and graphical knowledge is derived.

Graphical data are the elementary parts of graphical information. They represent values of the basic semantic entities. Let's formulate the following definition:

> **Item of graphical data** is a graphical figure or a graphical structure describing a part of real or potential world in values of the basic semantic entities.

Syntax of the item of graphical data is determined by the syntax of a graphical figure or a graphical structure. Its semantics is derived from the semantics of the graphical entity whose value it represents.

Graphic figure is an arranged composition of graphical primitives (abscissa, arc etc.). The arrangement of the composition must correspond to the iconic or symbolic depiction of reality. Graphical figure as an element of graphical language cannot be further divided. It is perceived as a whole.

Graphic structure is a composition of graphical figures. Between pairs of structure elements exist relations. The interrelations between all elements are determined by superposition. The graphical structure presents a complex visual information determined by the meaning of particular attributes and their

composition. All basic semantic entities are potential parts of the graphical structure.
Graphic knowledge means to know "how to draw pictures". To put it more correctly how to generate graphical structures from atomic graphical data. When used in GES it can be defined as follows:

> **Graphic knowledge** is the ability to generate pictures from elementary graphical data.
> By pictures we mean graphical structures carrying graphical information about the existing or designed state of some part of the real world.
> The nature of graphical knowledge is that of nomological data over data, which represent visual reflection of real world. Graphical knowledge is expressed by instances of basic semantic entities.
> Graphical knowledge is a metalanguage system (syntax) enabling us to handle graphical objects. It has the ability to generate graphical structures.

3.3 Graphic Knowledge Representation

In this paragraph the way of notation graphical knowledge in the GES knowledge base is described.

The **frames** used in classical expert systems were chosen as the main principle of graphical knowledge representation. They were, of course, modified for this purpose. The frames describe structures. They could be interconnected into higher structures. It satisfies our need to decompose complex structure of graphical information into particular graphical structures.

With help of one frame graphical knowledge about generating one graphical structure is denoted. Frames can form hierarchic sets expressing the knowledge of complex graphical structures composition.

Basic semantic entities are the semantic parts of frames. The frames are arranged in a way enabling inference mechanism based on methods and algorithms of computer constructive geometry to handle them.

Let's mention some construction parts of frames to denote graphical knowledge.

Graphic constant is a constant graphical structure related to co-ordinates.

<graphic constant>::=<identifier of graphic constant>

Graphic variable is a symbol, which can aquire various values - graphical constants.

<graphic variable>::=<identifier of graphic variable>

Typological graphical constant (TGC) stands for a typological element of a drawing. Various constants can be substituted for it. The choise of the constant depends on associative connections between graphical constants, which are part of knowledge base. For the arrangement of TGC set see Fig.2.

<typological graphical constant>::=<identifier of typological graphical constant>

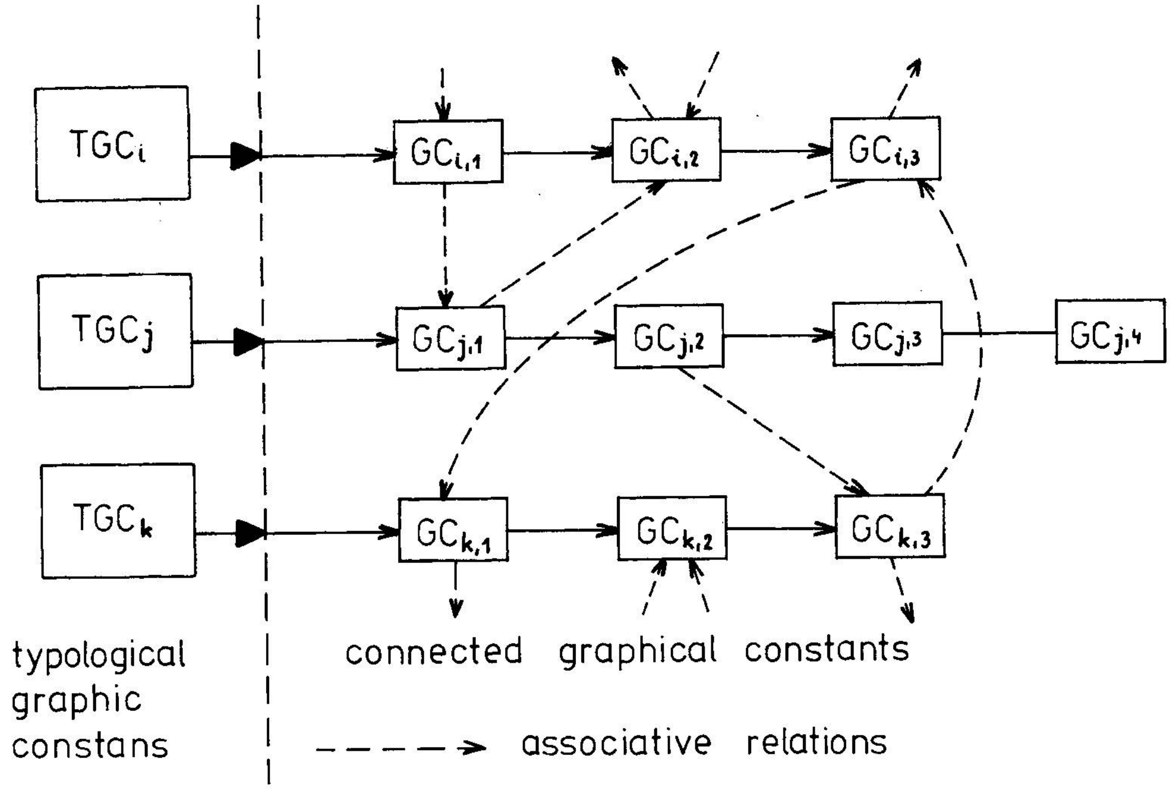


Fig.2 A set of typological graphic constants

Geometrical operations are traditional operations consisting in: moving, rotation and scaling.

<geometrical operation>::=<operator of geometrical operation>
(<argument of geom.operation>
(,<parameters of geom.operation>))
<operator of geom.operation>::=**MOVE|ROTA|SCAL**
<argument of geom.operation>::= <graphic constant>|
<graphic variable>

Logical operations evaluate expressions containing numeric parameters. Logical value is the result of this operation.

<logical operation>::=<numerical parameter><logical operator>
<numerical parameter>
<numerical parameter>::=<numer.constant>|<numer.variable>
<logical operator>::= <|>|≤|≥|=|≠

Superpositions. Composed graphical structures are constructed with help of superposition. Superpositions are based on principles of set operations with graphical objects. A graphical constant is the result of superposition. There are these kinds of superpositions:

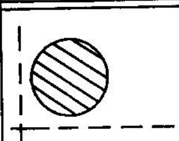
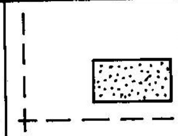
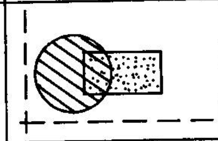
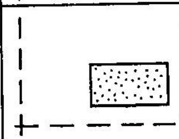
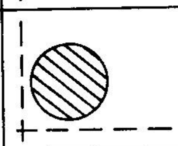
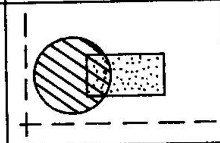
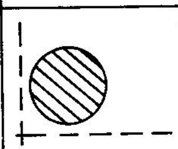
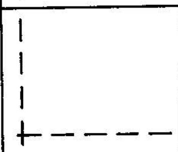
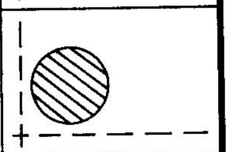
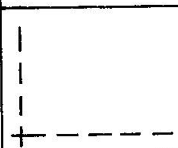
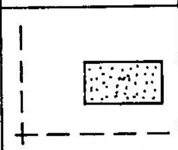
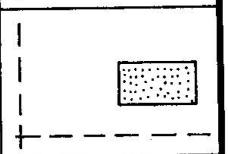
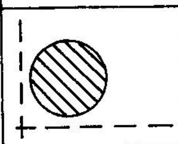
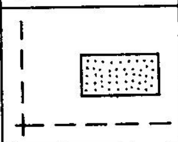
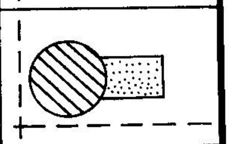
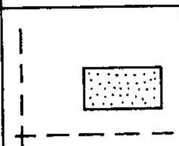
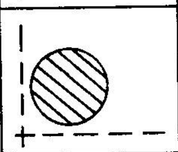
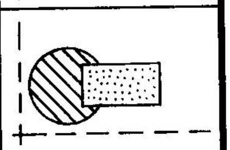
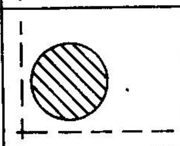
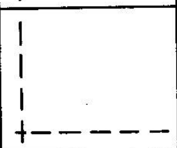
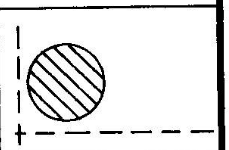
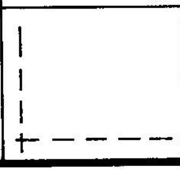
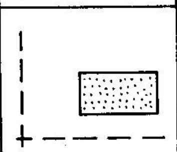
- union where the order of arguments is not relevant,
- union where the order of arguments is relevant,
- intersection where the order of arguments is not relevant,
- intersection where the order of arguments is relevant,

- substraction.

The meaning of particular types of superposition is defined in tables. To illustrate them we give Table 1.

<superposition>::=<operator of superposition>(<1st argument>,
<2nd argument>)
<operator of superposition>::= ∪|∪∪|∩|∩∩|-
<argument of superposition>::=<graphic constant>|
<graphic variable>

Table 1 : SUPERPOSITION - type „UNION"

superposition	symbol	1st argument	2nd argument	definition
order of arguments is not relevant	∪			
	∪			
	∪			
	∪			
order of arguments is relevant	∪∪			
	∪∪			
	∪∪			
	∪∪			

Input operations perform a graphic constant input or numeric constant input.

<input operation>::= **READ** <argument of input operation>
<argument of input operation>::=<graphic variable>|
<numerical variable>

Declarations, assigments and decision statements are constructed from the above mentioned (and other) components. Net of frames in hierarchic order, which is the basis of knowledge base, is composed of these frames.

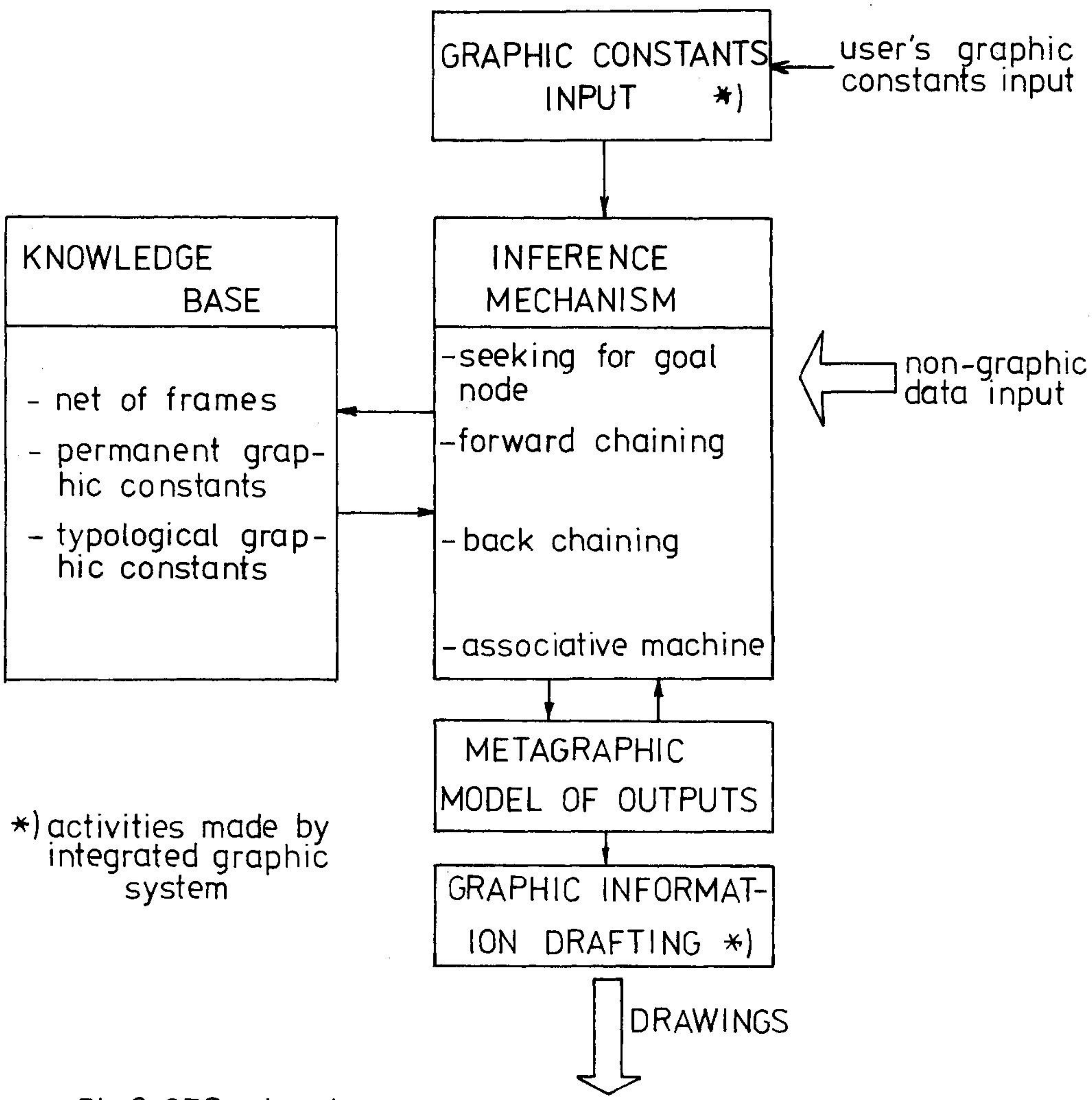


Fig.3 GES structure

4. GES STRUCTURE

The graphical expert system GES consists of these main parts:
- knowledge base,
- inference mechanism,
- graphic constants input,
- metagraphic model of outputs,
- graphic information drafting.

Their arrangement we can see at the Fig. 3.

4.1 Knowledge base

Knowledge base consists of three parts: a net of frames, a set of permanent graphical constants, a set of typological graphical constants.

Net of frames is a hierarchic system. It is a directed graph. Frames are represented by nodes, hierarchic relations between frames are represented by edges. The graph is an acyclic one. Any node can be a goal node in a given task. The goal node produces resulting graphical structure. The precedents of this goal generate the components of this structure.

The set of permanent graphical constants contains those constants introduced and made by an expert in the course of knowledge base making. They are called from frames as operation arguments. They present in advance prepared "characters" of graphical language to be generated.

The set of typological graphical constants contains groups of graphical constants. The elements of a drawing are picked from them by the inference mechanism. The arrangement of this set see Fig. 2.

4.2 Inference Mechanism

Inference mechanism reads input data, i.e. a description of reality in non-graphic form, and decodes them. It evaluates the knowledge base drawing from input data analysis. The result of the process is a metagraphical expression (written in a symbol language) of the drawing. We call it a metagraphical model of the drawing.

The inference mechanism performs these partial activities:
- input data reading,
- input data analysis; seeking goal node in the net of frames follows,
- forward chaining; during this operation the subgraph of goal node precedents is seeked. At the same time a record containing transformation parametres of each found frame is made. Also the associative machine seeking a suitable graphical constant may be activated during this process.
- back chaining proceeds from leaf nodes to the goal node. All operations required within the frames are carried out during this procedure. This way a metagraphic model of the drawing is created.

4.3 Graphic constants input and final drafting

In some cases the inference mechanism asks the user to supply a graphical constant. It is delivered by means of a graphical display or other input graphical device. The whole procedure is carried out by the host graphical system.

It is also this system that carries out last GES activity - final physical drawing of graphical information. It is based on the metagraphic model created by the inference mechanism.

5. CONCLUSION

For PC-AT category of computers a graphical expert system is being developed. It combines both the abilities of advanced graphical systems and the abilities of expert systems. Theoretical preparatory work on GES, mainly graphical knowledge definition and its language expression, have been finished. Also the algorithms of the inference mechanism have been derived.

At present programming of GES modules is carried out.

REFERENCES

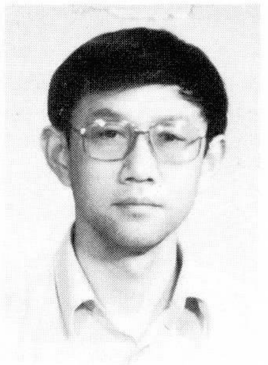
1. PETR J., ŠÍDA J., Communication in Graphic Language (in Czech). Research report P13-37-804. Prague Technical University, Prague 1988.

Decision Making System in Civil Engineering in China

Système d'aide à la décision en génie civil en Chine

Expertensysteme zur Entscheidungsfindung im chinesischen Bauwesen

Xila LIU
Professor
Tsinghua University,
Beijing, China



Xila Liu, born 1940, received his Ph. D. at Purdue University, West Lafayette, USA. He is a member of Board of Directors of China Civil Engineering Society, and also the deputy director of Research Institute of Structure Engineering at Tsinghua University.

SUMMARY
In the present paper, a significant Project «Intelligent Decision Support Systems in Civil Engineering», which is supported by the National Natural Science Foundation of China, is introduced. Several examples, such as some new reasoning methods and successful expert systems, are described briefly. Special attention is paid to the discussion on the task selection, the system applicability, and the system framework.

RESUME
Dans cet article, un important projet intitulé «Les systèmes du support de la décision intelligente dans les travaux publics» subventionné par le Fonds National chinois des Sciences Naturelles est présenté. Quelques exemples tels que nouvelles méthodes de raisonnement et systèmes experts sont décrits succinctement. On y relève spécialement la discussion du choix des tâches, aptitude du système à l'emploi et la structure du système.

ZUSAMMENFASSUNG
Ein bedeutendes Projekt «Das System der intelligenten Entscheidung für Bauingenieure», unterstützt von der Staatlichen Stiftung der Naturwissenschaften in China, wird in diser Abhandlung vorgestellt. Einige Beispiele, wie neue Schlussfolgerungsmethoden und erfolgreiche Expert-Systeme, sind kurz dargestellt. Besondere Beachtung findet die Diskussion der Aufgabenauswahl, der Systemanwendbarkeit und des Strukturaufbans.

1. INTRODUCTION

Computer, as an powerful calculational tool, has been developed for over 40 years. It seems that, in every 4 to 7 years, as a cycle, the calculation speed of computers increases to 10 times, and the volume and cost decrease to 10 times. This general trend is going on. There is no any industrial product which can compete with computer development. In this case, the civil engineering, as an very aged engineering domain, will certainly be changed by the great influence.

One of the significant changes in civil engineering is that the engineering theories are softenning, while the engineering experiences are hardening. In other words, as shown in Fig.1a, people are accustomed to input certain data and to pick up some certain output data through calculation procedure. Since a large amount of uncertainties of information or knowledge, such as ignorance, fuzziness, and randomness, exist, engineers have to input uncertain data and to receive some answers or conclusions by experience or inference, which is shown as Fig.1b. It is so-called "Theory softenning".On the other hand, a great deal of experience and knowledge of civil engineers in practice can be acquired, coded and stored in computer, which is called "Experience hardenning".

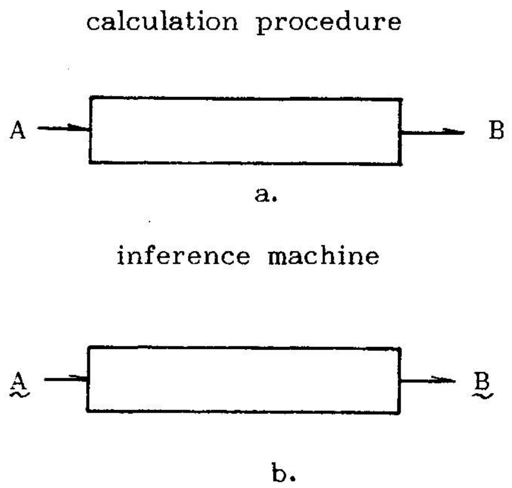


Fig.1

It is well-know that there are two major approaches in decision-making systems of civil engineering. One is to build a comprehensive mathematical model for the project. However, in most cases, this approach is not feasible because the available knowledge of the system is not sufficient, even though the computer develops quickly. Another approach is based or the experience of civil engineers. It is very often to solve an engineering problem without calculation or by engineer's intuition.

After the development of artificial intelligence, especially the development of knowledge Engineering, it is possible to develop some methodologies which imitate the actions of human experts in decision-making procedure. The intelligent decision-making system in civil engineering means that the two major approaches, which are mentioned above, are combined organically. This decision making system does not mean that the decision could be made entirely automatically. Human being must be involved during decision-making process. Strictly speaking, the intelligent decision making system in this paper is a knowledge-based decision support system, i.e., a generalized expert system.

In the first part of this paper, the development of intelligent decision making systems in civil engineering in China is reviewed. And them, several examples, such as some new reasoning method and successful expert system, are described. Some suggestion, which include very important philosophic thinking in knowledge engineering, is introduced in last part of this paper.

2. BRIEF HISTORY

Although the research works of knowledge-based systems or expert systems have been started in China over 20 years, the artificial intelligence technique has been used in civil engineering just for a couple of years. In the United states, the first knowledge-based expert system, SACON, was developed in 1978, which is later than Feigenbaum's DENDRAL, the first expert system in the world, for almost 10 years. Similarly, in China, the earliest knowledge-based systems in civil engineering were developed in 1985 to 1986, which are also later than those developed in other domains, such as the medical diagnostic domain. The reasons can be summed up as follows:

(1) during planning, design, construction, and maintenance, too many factor are in volved;
(2) very strong interactions exist among these factors;
(3) a great deal of uncertain information or knowledge have to be considered;
(4) in most cases, the civil engineering projects are tailor-made and often kept in service very long. It is difficult to do a statistical survey.

It should be noted that, since 1985, the artificial intelligence technique has been conspicuous in civil domain in China. A great many universities and research institutes are involved in the development of various intelligent decision making systems or expert systems. The enthusiasm is getting higher and higher. The increase rate is shown in Fig.2. According to the situation of

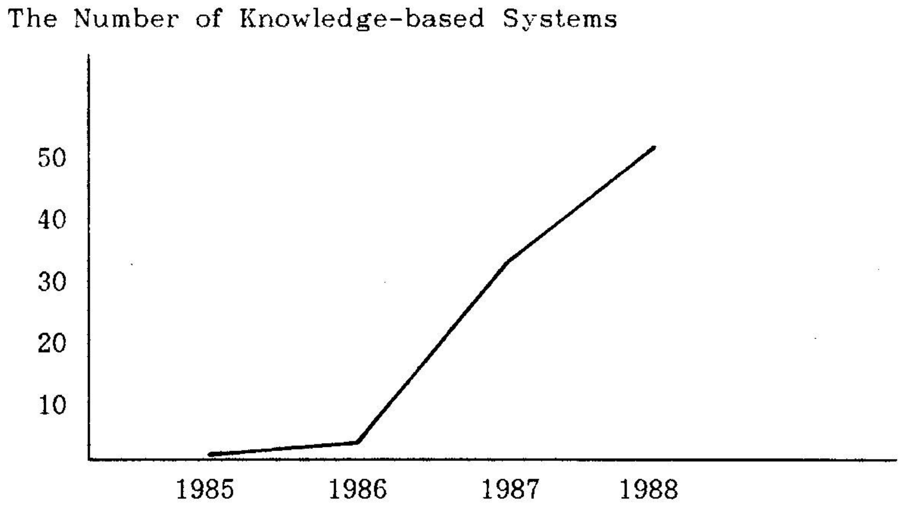


Fig.2

Chinese reconstruction, the incitement factors can be found as following points.

(1) There are tremendous number of civil engineering projects in China. Since the constraint of financial resources, the scientific decision-making is needed badly. It is well known that the decision-making process in civil

engineering is semi-structural or ill-structural. Many uncertainties have to be considered. Any decision mistakes may damage the society and may last very long.

(2) After the cultural revolution, almost one generation of experienced engineers has been last. China is really short of senior engineers in civil engineering. Many old engineers are going to be retired. In order to save their expertise, the knowledge acquisition and coding by knowledge engineers are really needed.

(3) Following the widespread of knowledge engineering and the marketing of various soft-wares or shells, it is possible build more systems. Especially, Chinese scholars have very strong background of the uncertain inference and mathematics.

(4) The National Natural Science Foundation of China can organize a very large group to work on such projects and gives sufficient financial support. Many professors and senior engineers joint together and work on the same project with low payment.

For example, there are more than 500 million square meters' industrial building existing in China, which contain almost 50 billion yuan facilities. Most of them are undergoing, to some extent, the deteriorates or damages. Some of them have been close to their intended usage lives. Their functions, or even safety, may be not satisfactory any more. According to the financial resources of China, the construction policy is that the maintenance and modification of the function of existing buildings are primary, the construction of new buildings is secondary. At first, it is urgently needed to assess the damage of existing buildings in order to make appropriate strengthening or maintenance plan. as mentioned previously, however, since the complexity and the uncertainty of existing buildings and the shortage of senior engineers in China, only a few experts are really qualified to make such assessments. In this background, knowledge-based expert system in the domain of damage assessment of existing buildings have made great progress in China.

Since 1985, the research works on following systems have begun : (1) A man-machine system on Seismic Damage Analysis developed in the Institute of Engineering Mechanics (IEM) of the State Seismological Bureau. (2) A expert system for Earthquake Intencity Evaluation (EIE) developed in Chinese Academy of Building Research. (3) Expert systems of Damage Assessment of Existing Reinforced Concrete Industrial Buildings (RAISE-1, ARCS-1) [2] [3] developed in Tsinghua University, Sichuan University, and the Sichuan Institute of building Research. In 1987, the expert system of Building Project Bidding Estimation (BPBE-1) [4] was built in Tsinghua University and has been market. Also in 1987, a big research project, "Intelligent Decision Support Systems in Civil Engineering", was organized by the National Natural Science Foundation of China (NSFC). The project is supported by NSFC and 7 Ministries or Bureaus, 25 universities and research institutes and almost 220 researchers, which include almost 90 professors or senior engineers, are involved. Ten aspects are included, such as

(1) Intelligent Decision Support Systems of Urban Planning;
(2) Seismic Risk Analysis and Protection;
(3) Railway Construction;
(4) Highway and Water Transportation Engineering Design;
(5) Environment Evaluation of Construction Projects;
(6) Preliminary Design of High-rise Buildings;
(7) Construction Management and Cost Prediction;

(8) Damage Assessment of Existing Buildings;
(9) Intelligent CAD and Simulation;
(10) Treatment of Uncertain Information in Civil Engineering;

In these 10 aspects, there are 31 subprojects included. It is expected that, after 5 years, a group of more complete knowledge-bases will be built in various domains of civil engineering. This is the first task in the significant project. and a number of applicable systems will be developed. Meanwhile, some new inference theories will be available. Besides, a large number of young knowledge engineers will be nurtured and educated in this project. In 1988, it is found that, among 31 subprojects, in most of them, a demonstration prototypes has already been developed. Some systems are going marketing. In this case, it should be mentioned that it really takes time to build an applicable, robust system. The strict practice check is entirely necessary.

3. UNCERTAINTIES IN CIVIL ENGINEERING

3.1 The Sources of the Uncertainties

Uncertainties of information or knowledge exist in three forms: ignorance, fuzziness, and randomness.

From information point of view, there are three sources of uncertainties. The first is the insufficiency of the primary information, which causes the ignorance. Sometimes, the information contradiction also belongs to the ignorance. The second is the simplification of problems. For example, the cracks in an existing structure may present themselves in any position and their shapes may relate to various causes. However, for convenience, experts often divide the cracks into finite types, such as flexual cracks, shear cracks, nodal cracks, ect.. Fuzziness arises when experts decide which type a certain crack belongs to. The third is the randomness, such as loads and structural resistance.

From knowledge point of view, however, the uncertainties have two sources. One is the fuzziness because of the complexity of the problem. For example, the reliability of an existing structure can be inferred from the safety, the function integrity, and the durability of the structure. Since the relations among them are rather complex, experts are unable to understand the relations completely. In other words, to conduct the inference, experts use fuzzy knowledge. The other source is the randomness due to the unreliability of the knowledge. For example, rule of "if the strength safety factor is enough, then the structure satisfies safety" is tenable in most conditions. However, if the rule is applied to damage assessment of a certain structure, it is not always correct.

3.2 Classification of Reasoning Methods

There are two kinds of events in the real world: two-valued events and continuous-valued events. The events such as the freeze of water are two-valued events because the truth value of the proposition of "the water freezes" can only be 1 or 0. The events such as the damage of a structure are continuous-valued events because the truth value, or the assessment value of the proposition of " the structure is damaged" may take any value in [0,1]. Problems involving only two-valued events are called two-valued problems, while problems involving continuous-valued events are called continuous- valued problems.

Primary information and inference knowledge may be certain or uncertain. Correspondingly, certainty and uncertainty reasoning methods will be developed.

At present, reasoning methods are divided into reasoning methods of two-valued problems and of continuous-valued problems, each of them being further divided into certain and uncertain reasoning methods (Table 1).

Table 1 Classification of Reasoning Methods

type of problem	reasoning characteristic	representation of uncertainty	reasoning method	example
two-valued	certain		classical syllogism	
	uncertain	certainty factors	certainty factor method	MYCIN
		probabilities	probability method	PROSPECTOR
continuous-valued	certain		decision-making table or combination function method	ARCS_1 [3]
			membership function method	RAISE_1 [2]
	uncertain	fuzzy measure	possibility method	
			belief function method	RAISE_2 [13]
		fuzzy subsets	plausible reasoning	
		truth restriction	truth function modification	

It seems that most of available reasoning methods used in mentioned systems are certain or uncertain reasoning methods of two-valued problems. Some attempts were made to establish uncertain reasoning methods of continuous-valued problems [5]. Many people in China prefer to introduce the fuzzy set concept. It should be noted that, up to now, the concept of degree of member ship, the cornerstone of fuzzy set theory, is not yet explicitly clear [6]. What is it's meaning in nature and how to determine it are crucial issues for applications. The fuzzy set theory does not satisfy the complementary law. What kind of influence it may induce during the inference process should be strictly checked.

3.3 The Combination Function Method

The following is a brief introduction of a new approach to model the inference process of expects, which is developed by Prof. Z.F.li, Sichuan University in 1987 [7].

In the practice of modelling the expert inference, a lot of knowledge possessed by human experts can be mathematically represented in the form of function as

$$Z = F(x_1, x_2, \ldots, x_n) \tag{1}$$

How to acquire and represent such a function F is an important issue in building knowledge-based systems. It is interesting to know whether or not the function F can be decomposed as follows

$$F(x_1, x_2, \ldots, x_n) = x_1 * x_2 * \ldots * x_n \tag{2}$$

where * is a binary operation satisfying some conditions, such as associativity, commutativity and so on. If Eq.(2) holds, the complex problem of acquiring and representing the function F of n variables could be reduced to a much simpler one, in which only the binary operations are needed.

On the other side, it is well known that the fuzzy set theory provides a natural frame for uncertainty management. Finding appropriate aggregative operations for fuzzy sets is an important issue not only in theory but also on its applications. Suppose that $A_1, A_2, \ldots, A_n$ are fuzzy subsets of a space X, A is an aggregate of $A_1, A_2, \ldots, A_n$, and x is a point of X. Mathematically, the membership of x in A, i.e. the z, is a function (may be multi-valued) of memberships $x_1, x_2, \ldots, x_n$ of x in $A_1, A_2, \ldots, A_n$, respectively. This function is called combination function. Up to now, almost all investigations on fuzzy set theoretic operations only deal with the binary operations. Thus, a problem arose natually: can all combination functions be represented as Eq.(2)?

Based on the measurement theory, Prof. Li proved that [7].

Let F: $[0,1]^n \rightarrow [0,1], n \geq 3$, be a function. Then F can be represented as

$$F(x_1, x_2, \ldots, x_n) = f^{-1}\left(\sum_{i=1}^{n} f_i(x_i)\right) \tag{3}$$

where f and f_i are continuous strictly increasing functions, satisfying $f_i(0) = 0$, and iff F is continuous, satisfying some conditions, such as the variable-independence condition with respect to (0,0,...,0).

In order to show how powerful the Eq.(3) is, the following example is given. Assume n=6, and each X_i and z has 7 admissible values. thus, if Eq.(1) is expressed by a decision-making table, then $7^6 = 117649$ groups of data are needed and there are 7 numbers in each group. However, if Eq.(3) is used, even in the tabular form, only (6+1)*7=49 groups of data are needed, there are only 2 numbers in each group. the number of data is reduction to 1/8403. When n increases, the reduction is more efficient. This method has been successfully used in an expert system ARCS_1 for damage assessment of reinforced concrete mill buildings [3].

4. SOME MARKETETABLE KNOWLEDGE-BASED SYSTEMS

4.1 BPBE_1: Building Project Bidding Estimation (Tsinghua University) [4]

BPBE_1 is a knowledge-based cost estimator for bidding on a new building project. It provides construction cost estimation by accessing a knowledge-base of construction expectise and cost databases. The four major modules of BPBE_1 are: (1) Chinese interpretation system; (2) inference machine; (3) a coat database of typical project with decision-making tables; and (4) knowledge-base of cost estimating expertise and bidding policy with a dynamic database. The cost database was derived from C-BASICA and C-DBAS III, and the system can be performed on Great Wall 0520 or IBM-PC.

The methodology can be briefly described as follows. For different type of buildings, a different vector of characteristic cost factors can be determined by expectise. According to the number of characteristic cost factors a multidimensional cost space is built. The loaction of many typical projects can be found in the cost space, which depend on the vector coordinates, i.e., the values of the characteristic cost factors. During making a bid for a new project, the vector coordinates should be determined first and the location of the new project in the cost space can be found. Then, the "distances" between the new project and the original typical projects can be calculated. The cost estimation of the new project can be obtained by the weighted integration. Of course, the weights and scores of related factors depend on the "distances". Obviously, this methodology is very similar to the bidder's thinking. In practice, comparing with the results from the bidding experts, the average accuracy is better than 97%.

4.2 RACODE_1: Reliability Assessment of Reinforced Concrete Mill Buildings (Tsinghua University) [8]

RACODE_1 is a knowledge-based decision support system based on "Specifications of Reliability Assessment of Metallurgical Industry Structures" [9]. A large number of experts and senior engineers spent almost 3 years for editing this specifications. Although the assessment details of each part in the metallurgical industrial structures are given respectively, it is found that, in practice, the synthetical decision is hardly made. In RACODE_1, the probability theory of fuzzy event and the cut set theory are used. According to some decision rules from experts, the final decision, how to treat the assessed existing building, can be clearly given.

The system is written in GCLISP and can be implemented on IBM-XT. The primary information can be input by a man_machine dialog system in chinese. The final output includes the damage level and the maintenance suggestions. After assessing $600000M^2$ industry buildings, the comparison between the system output and the expect assessment are very satisfying.

5. SOME COMMENTS

5.1 Task Selection

It is proved that careful selection of the task to be encapsulated in an expect system is essential for the success of the system development project. Several criteria for choosing projects and tasks have been enumerated and are summarized here.

(1) The technical market need must be considered first. the developed system must be capable of providing the technical or substantial benefit for the sponsor. Therefore, the task to be modelled in the system must be clearly defined. In some universities, many of the tasks chosen for knowledge-based systems are too large or even completely unbounded. The temptation does not come from the market need, but from professor's imagination. Of course, this is inevitable with any new attractive technology. From experts' point of view, however, the task itself should be fairly narrow and domain intensive [10].

(2) If the certainty algorithm has already been very mature in a certain domain, then it is not appropriate for knowledge-based system development. Sometimes, however, it seems necessary to add some knowledge base to a conventional program, such as knowledge-based CAD, to make it more flexible.

(3) If there is no enough expertise in the chosen domain, it is not appropriate for building the knowledge-based system either. According to the development level of artificial intelligence, the learning systems are very weak. It seems impossible to develop a knowledge-based system without sufficient knowledge.

5.2 System Applicability

It is found that, in our practice, to build a demonstration prototype is not so difficult, especially some shells can be available from the soft-ware market. For an applicable commercial prototype, however, much more time and money are really needed. Even some demonstration prototypes could never be developed to commercial types. The investigation shows that the failure reasons may be various, but some of them have been confirmed.

(1) The leader of research group in the front line is not real civil engineer, even there is no civil engineer working in the group. In the project "Intelligent Decision Support Systems in Civil Engineering", three kinds of people, i.e., the civil engineer, the knowledge engineer, and the software engineer must be included in one research group for each subproject. It is so-called "three in one". Usually, the knowledge engineer are very ambitions. They thought they could handle the knowledge in every domain. Couple years ago, many professors and researches spent lots of time to build a number of successful expert systems in China. But now, they are getting tired. they found the conceptualization and the formalization of knowledge is a "bottle neck", which is very difficult for unprofessional experts. Therefore, they prefer to build a generalized shell or to explore some new inference methods. In our project, the relationship between researchers is suggested as Fig.3.

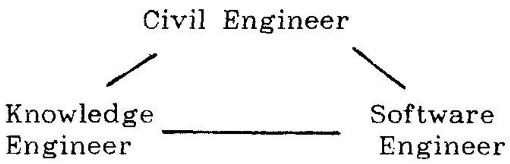


Fig.3

Furthermore, the civil engineer who is doing the knowledge-based subproject is encouraged to learn some general knowledge about knowledge engineering, meanwhile the knowledge engineer is suggested to know some basic concept about civil engineering.

(2) Building knowledge-base is an essential step, but it is often under-estimated in practice. Knowledge can compensate for lack of search. "A man's knowledge consists only of two parts, that which comes from direct experience and that which comes from indirect experience. Moreover, what is indirect experience for me probably is direct experience for other people. Consequently, considered as a whole, knowledge of any kind is inseparable from direct experience" [11]. It is impossible to build a knowledge-base without domain experts.

A knowledge-based system, in general, contains both perceptual knowledge, such as human expertise, and rational knowledge, such as textbook, code, or algorithms. But it should be emphasized here, the rational knowledge depends on the perceptual knowledge. "The rational is reliable precisely because it has its source in sense perceptions, otherwise like water without a source, a tree without roots, subjective, self-engendered and unreliable." "As to the sequence in the process of cognition, perceptual experience comes first,...". On the other side, however, the perceptual knowledge is "...merely one-sided and superficial, reflecting things incompletely and not reflecting their essence. Fully to reflect a thing in its totality, to reflect its essence, to reflect its inherent laws,..." "... it is necessary to make a leap from perceptual to rational knowledge"[11]. In general , a developed knowledge-based system should contain rational or deep knowledge as much as possible.

Any system to be used in commercial practice must be correct to every extent possible. In human knowledge, the process of coming into being, developing and passing away is infinite. Based on the dialectical-materialist theory, "Practice, knowledge, again practice, and again knowledge. This form repeats itself in endless cycles, and with each cycle the content of practice and knowledge rises to a higher level"[11]. Therefore, the name "commercial prototype" is preferable to the " commercial knowledge-based system".

(3) Lack of consideration for expected user. In the United States, people criticise that universities are notorious for they lack an appreciation of what are the real problems facting practising engineers. Somebody expects that 90% expect systems developed in this century will be garbage. In our project, the following points have to be considered: (1) the knowledge level of the intended user; (2) the computer level at which the system performs; (3) the foreign language level of the expected user. In China, microcomputerizing of programs and an interpretation system from english to chinese are needed.

5.3 Building Frameworks (Shells)

Building frameworks or shells are packages that aid in the rapid prototyping of application of knowledge-based systems. They usually provide one, or more, knowledge representation forms and inference mechanisms. Usually, they are domain-independent. When their use is appropriate, these tools can be used to speed up the implementation of new systems. The level of effort that must be applied to developing support structures is greatly reduced. Following the marketing of various shells, as mentioned previously, the knowledge-based systems in civil engineering are increasing rapidly. However, it should be pointed out that there are some limits and disadvantages existing, such as the size limitations, complaxity limitations, awkward representations, inadequate user interfaces, and slow system response times.

Using generalized shells or developing new particular systems directly, which one is the best way especially in the initial stage? From the dialectical theory, the general character is contained in every individual character. "Without individual character there can be no general character" [12]. The cognition process always moves from the particular to the general, and from the general to the particular; each cycle makes it more and more profound. Similarly,we have MYCIN first and then developed the non-domain EMYCIN, now EMYCIN has been used to develop several systems, such as PUFF and SACON. Therefore, it is not necessary to overestimate the domain-independent shell, also do not confine the designers in their own particular system only.

REFERENCES

[1] Liu Xihui and Wang Peizhuang, "Expert System For Earthquake Intensity Evaluation-EIE", Earthquake Engineering and Engineering Vibration, Vol.6, No3, 1986, PP.27-34

[2] Chen R.J., and Liu X.L, "An Expert System RAISE-1", Microcomputer

Knowledge-based expert System in Civil Eng., ASCE, 1988, PP.16-25

[3] Liu X.L., J.Y.,Cao, "The Research of an Expert System on Damage Assessment of R/C Mill Buildings" (Final Report), Sichuan Building Research, No. 4, 1988, PP.2-9 (in Chinese).

[4] Lu Qian, et. al "An Expert System of Building Project Bidding Estimation (BPBE-1)", Technical Report, CE-ESS-88-08, Tsinghua University, 1988 (in Chinese).

[5] Chen R.J., and X.L., Liu, "Modelling of Civil Engineering Knowledge in Damage Assessment of Reinforced Concrete Structures", Proceedings of IMACS 1988, Paris, Vol.3, PP.444-446.

[6] Li, Zhong-fu, 'Analysis of the Meaning of Degree of Membership" Fuzzy Systems and Mathematics, Vol.1, No.1, 1987, PP.1-6 (in Chinese).

[7] Li, Zhong-fu, "Decomposition of Function of Several Variables into Binary Operations", Proceedings of ISFK, Guangzhou, China, 1987, PP.684-689.

[8] Xia, C.C., and Xila, Liu, 'Code Related Expert system on Damage Assessment of R/C Mill Buildings", Computational Structural mechanics and Applications, No.2, 1989 (To appear in Chinese)

[9] The Metallurgical Industry Ministry of PRC, "Specifications of Reliability Assessment of Metallurgical Industry Structures YBJ-88", Beijing, 1988 (in Chinese).

[10] Liu, Xila, "Proposals to Developing Expert systems in Civil Engineering", Sichuan Building Research, Vol.2, 1988, PP.1-4.

[11] "On Practice", Selected Works of Mao Tse-tung, Foreign Languages Press, Peking 1975, Vol.1, PP.295-310.

[12] "On contradiction", Selected Works of Mao Tse-tung, Foreign Language Press, Peking 1975, Vol.1, PP.311-347.

[13] Chen, R.J., and X.L., Liu, "A Knowledge-based Expert System For Damage Assessment of Reinforenced Concrete Industry Buildings (RAISE-2)", Proceedings of IASSAR, San Francisco, 1989 (To appear).

Leere Seite
Blank page
Page vide

Uncertainty and Learning in Expert Systems

Incertitude et apprentisage dans les systèmes experts

Ungewissheit und Lernen in Expertensystemen

Enrique CASTILLO
Professor
Univ. of Cantabria
Santander, Spain

Elena ALVAREZ
Assistant Professor
Univ. of Cantabria
Santander, Spain

SUMMARY
The paper discusses some of the problems associated with conventional uncertainty propagation methods, as those based on independent probabilities, certainty factors, belief or possibility functions, and shows, by giving examples, the importance of associated errors. Then, alternative methods, based on log-linear, regression and casual networks or influence diagram models are discussed. Finally, their structural and parametric learning possibilities are analyzed.

RESUME
Le but de ce article est de montrer quelques problèmes associés aux méthodes conventionelles de propagation d'incertitude, tels que les dérivés des probabilités indépendantes, les coefficients de vraisemblance et les fonctions de possibilité. Nous montrons avec des exemples l'importance des erreurs associées à ces méthodes. Quelques méthodes alternatives, fondées sur des modèles logarithmiques linéaires, de regression et de réseaux ou diagrammes d'influence sont discutés. Finalement nous présentons leurs possibilités d'apprentissage paramétriques et structurales.

ZUSAMMENFASSUNG
Die vorliegende Arbeit behandelt einige Probleme, im Zusammenhang mit den konventionellen Fehlerfortplanzungsmethoden wie: unabhängige Wahrscheinlichkeiten, Gewissheitsfaktoren sowie Glaubens- oder Möglichkeitsfunktionen. Anhand von Beispielen wird die Bedeutung der aus den Ansatzhypothesen entstandenen Fehler gezeigt. Einige alternative Methoden, die auf Regressions — und linear-logarithmischen Modellen, sowie auf Kausalnetzen und Einflussdiagrammen beruhen, werden anschliessend vorgeschlagen. Zuletzt wird die Möglichkeit eines strukturellen und parametrischen Erlernens analysiert.

1.- INTRODUCTION

In classical logic any statement is either true or false; however, when working with uncertain implications, statements must be understood as possible rather than certain. Thus an uncertainty measure is necessary. The oldest measure of uncertainty and the most intuitive is probability. However, other measures are utilized in the field of expert systems, such as certainty factors, the measures of evidence theory and the possibility functions of fuzzy logic.

2.- UNCERTAINTY PROPAGATION

The main problem of coherence arises when propagation of uncertainty is involved. Some propagation formulas without an axiomatic basis have been proposed and accepted by the Artificial Intelligence community [3]. Many of the propagation formulas used are no better than the oft-criticized, independence assumption. When we deal with single evidence units, the calculation of uncertainty measures is straight forward, but what happens when we need to combine several single evidence units to get a mixed evidence?. In this section we shall analyze this question.

The problem of propagation of uncertainty in the case of probability can be reduced to the calculation of probabilities conditioned by all units of information [2]. In order to illustrate the problem we give the following example.

Example 1.- Let us assume that an engineer suspects the presence of problem E and that, based on some available data, he has arrived to a prior probability for E of 0.8. Because 0.8 is not high enough to make a decision (note that making a decision at this moment implies a probability 0.2 of error), he decides to obtain more information. Thus, he makes use of the following information, which is shown in figure 1a, where the shadowed area refers to hystorical cases with problem E and the white area to those without E, the symbols S_1, S_2 and S_3 refer to three symptoms related to E and the figures are frequencies (the knowledge base).

From figure 1a, the following information (prior probabilities and likelihoods) can be derived:

$P(E) = 0.80$	$P(\text{no } E) = 0.20$	$P(S_1 / E) = 0.70$	$P(S_1 / \text{no } E)=0.10$
$P(S_2/ E)=0.80$	$P(S_2/ \text{no } E)=0.20$	$P(S_3/ E)=0.60$	$P(S_3 / \text{no } E)=0.30$

This figure will allow us to illustrate the failures of the assumption of independence and to see how completely erroneous results can be obtained by using this assumption. It is important to indicate that the above information (prior probabilities and likelihoods) is not sufficient to completely define a probability. In other words, there are many different probability or frequency distributions having as prior probabilities and likelihoods the above values. In figure 1 we show two of them.

Let us assume that the engineer receives items of information in the following order: 1.-initial data, 2.-presence of S_1, 3.-presence of S_2 and 4.-absence of S_3. Table 1 gives the updated probabilities of E after the four steps indicated above for the two cases in figure 1. It is interesting to point out that for case (b), the real probability of $P(E/S_1, S_2$ and no $S_3)$ is zero, while that obtained from the independence assumption is 0.989. This suggests that care must be taken with the indiscriminated use of independence.

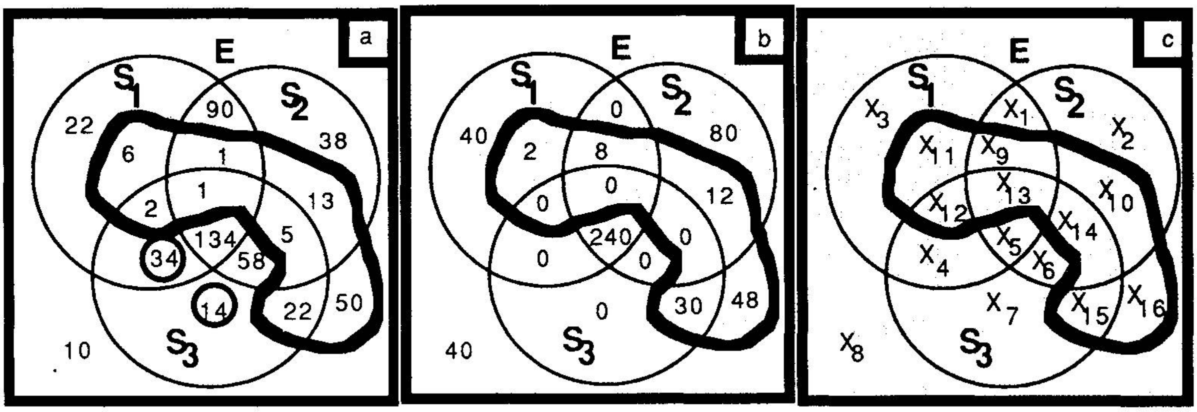


Figure 1.- Two different solutions with the same prior probabilities and likelihoods and notation

	P(E)	$P(E/S_1)$	$P(E/S_1,S_2)$	$P(E/S_1, S_2$, no $S_3)$	
				real	independence
case a	0.80	0.966	0.994	0.989	0.989
case b	0.80	0.966	0.968	0.000	0.989

Table 1.- Updating of probabilities

The existence of many probabilities with given prior probabilities and likelihoods, suggests the method of calculating lower and upper bounds of desired probabilities under these constraints. In this way, an interval $[P_{min}(A),P_{max}(A)]$, which measures ignorance and uncertainty, can be obtained. An example is now given.

Example 2.- Let us consider the case of example 1. If we call X_1 to X_{16} the frequencies shown in figure 1.c, fixing the values of prior probabilities and likelihoods, as in example 1, is equivalent to using the constraints:

$$
\begin{aligned}
&P(E) = 0.8 &&\leftrightarrow\; X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 = 400\\
&P(\text{no } E) = 0.2 &&\leftrightarrow\; X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} = 100\\
&P(S_1/E) = 0.7 &&\leftrightarrow\; 3X_1 - 7X_2 + 3X_3 + 3X_4 + 3X_5 - 7X_6 - 7X_7 - 7X_8 = 0\\
(1)\quad &P(S_1/\text{no } E) = 0.1 &&\leftrightarrow\; 9X_9 - X_{10} + 9X_{11} + 9X_{12} + 9X_{13} - X_{14} - X_{15} - X_{16} = 0\\
&P(S_2/E) = 0.8 &&\leftrightarrow\; 2X_1 + 2X_2 - 8X_3 - 8X_4 + 2X_5 + 2X_6 - 8X_7 - 8X_8 = 0\\
&P(S_2/\text{no } E) = 0.2 &&\leftrightarrow\; 8X_9 + 8X_{10} - 2X_{11} - 2X_{12} + 8X_{13} + 8X_{14} - 2X_{15} - 2X_{16} = 0\\
&P(S_3/E) = 0.6 &&\leftrightarrow\; -6X_1 - 6X_2 - 6X_3 + 4X_4 + 4X_5 + 4X_6 + 4X_7 - 6X_8 = 0\\
&P(S_3/\text{no } E) = 0.3 &&\leftrightarrow\; -3X_9 - 3X_{10} - 3X_{11} + 7X_{12} + 7X_{13} + 7X_{14} + 7X_{15} - 3X_{16} = 0
\end{aligned}
$$

The probability of any set, A, can be written as $P(A) = \sum_{i=1}^{16} a_i X_i$ where the coefficients a_i (i=1,2,...,16) are ones or zeros depending on whether or not the set associated with X_i belongs to the set A.

Determination of the interval $[P_{min}(A), P_{max}(A)]$ can be reduced to solving the following two linear programming problems:

$$\text{Minimize } \sum_{i=1}^{16} a_i X_i \text{ subject to (1) and Maximize } \sum_{i=1}^{16} a_i X_i \text{ subject to (1)}$$

If what we desire is an interval of conditional probabilities, the above problems are equivalent to the following two non-linear programming problems:

$$\text{Minimize } \sum_{i=1}^{16} a_i X_i \Big/ \sum_{i=1}^{16} b_i X_i \text{ and Maximize } \sum_{i=1}^{16} a_i X_i \Big/ \sum_{i=1}^{16} b_i X_i \text{ subject to (1)}$$

which are equivalent to sequences of linear problems:

$$\underset{\lambda}{\text{Min}} \left[\text{Min } \sum_{i=1}^{16} a_i X_i / \lambda \text{ subject to (1) and to } \sum_{i=1}^{16} b_i X_i = \lambda \right]$$

and

$$\underset{\lambda}{\text{Max}} \left[\text{Max } \sum_{i=1}^{16} a_i X_i / \lambda \text{ subject to (1) and to } \sum_{i=1}^{16} b_i X_i = \lambda \right]$$

where the coefficients b_i (i=1,2,...,16) are also zeros or ones.

The propagation of the belief and unbelief measures and of the certainty factors, CF, is usually carried out by means of the well known Dempster's formula. In order to illustrate some of the problems associated with this formula, Table 2 shows the exact values and those resulting from it.

	$CF(E ; S_1)$	$CF(E ; S_1, S_2)$	$CF(E ; S_1, S_2, \text{no } S_3)$	$CF(E ; S_1, S_2, \text{no } S_3)$ Propagation formulas
case a	0.873	0.970	0.945	0.989
case b	0.828	0.839	-1.000	0.972

Table 2.- Updating of certainty factors

Note the extremely large difference between the exact and the calculated certainty factor $CF(E ; S_1, S_2, \text{no } S_3)$ in case b. This result proves that the above propagation formula is not satisfactory in this case and should warn the user against its uncontrolled use.

Similar errors result from evidence theory or fuzzy logic if standard propagation formulas are used.

3.- STATISTICAL MODELS IN EXPERT SYSTEMS

Most of the problems mentioned above come from the fact that uncertainties of composed events cannot be derived from uncertainties of single events. Thus, a precise uncertainty propagation technique requires models to include frequencies of composed events as well as those of single events. In this section we describe log-linear, regression and causal network models. They are three of the most useful techniques to solve the above problems.

3.1.- Log-linear models

The most general log-linear model is of the form [1]:

$$\log m_{ijk..r} = u + u_1(i) + .. + u_s(r) + ... + u_{(s-1)s}(qr) + ... + u_{12..s}(ij...r)$$

where $m_{ijk...}$ denote the frequency of the class defined by the i-th problem, j-th level of the first symptom, k-th level of second symptom, and so on, parameters must satisfy some additional constraints and indexes vary from 1 to the number of levels for each symptom.

Example 3.- If the above model is fitted to data in figure 1.a we get the log-linear model

$$\log m_{ijkl} = u + u_1(i) + u_2(j) + u_4(l) + u_{12}(ij) + u_{13}(ik) + u_{14}(il)$$

$$u = 2.6429 \; ; \; u_1(1) = 0.938 \; ; \; u_2(1) = -0.337 \; ; \; u_4(1) = -0.110$$

$$u_{12}(1,1) = 0.761 \; ; \; u_{13}(1,1) = 0.693 \; ; \; u_{14}(1,1) = 0.313$$

S_1	S_2	S_3	case a E	case a no E	case b E	case b no E
YES	YES	YES	134(134.4)	1(0.6)	240 (239.7)	0 (0)
YES	YES	NO	90(89.6)	1(1.4)	0 (0.3)	8 (8)
YES	NO	YES	34(33.6)	2(2,4)	0 (0)	0 (0)
YES	NO	NO	22(22.4)	6(5.6)	40 (40)	2(2)
NO	YES	YES	58(57.6)	5(5.4)	0(0)	0 (0)
NO	YES	NO	38(38.4)	13(12.6)	80 (80)	12(12)
NO	NO	YES	14(14.4)	22(21.6)	0 (0)	30(30)
NO	NO	NO	10(9.6)	150(50.4)	40(40)	48(48)

Table 3.- Real values and predictions for frequencies in figure 1

Similarly, for data in figure 1.b, we get the model

$$\log m_{ijkl} = u + u_1(i) + u_3(k) + u_4(l) + u_{12}(ij) + u_{13}(ik) + u_{23}(jk) + u_{24}(jl) + u_{34}(kl) + u_{123}(ijk)$$

$$u = 4.004 \; ; \; u_1(1) = 0.188 \; ; \; u_3(1) = 0.117; \; u_4(1) = 1.534 \; ;$$

$$u_{12}(1,1) = -0.241 \; ; \; u_{13}(1,1) = -0.515; \; u_{23}(1,1) = -0.342 \; ;$$

$$u_{24}(1,1) = 1.137; \; u_{123}(1,1,1) = -1.035 \; ; \; u_{34}(1,1) = 0.633 \; ;$$

These models have 7 and 10 degrees of freedom, respectively, implying a saving of 9 and 6 parameters with respect to the general model.Table 3 shows the real values of frequencies and those given by the above models (in brackets).

3.2.- Regression models

The log-linear models in the previous section are useful for symptoms or variables of a discrete type, but not for continuous symptoms unless they are made discrete by subdivision into a finite number of intervals. With the aim of solving this problem, regression models are developed. The model to be described in this section is of logistic type [2]:

$$\log\left(\frac{p_i}{1-p_i}\right)=\sum_{j=1}^{r}\beta_j A_{ij}\ ;\ \beta_j\equiv u_{i_1 i_2\ldots i_s}(j_1 j_2\ldots j_s)\ ;\ 1\le j_k\le l_k\ ;\ A_{ij}=f_{i_1 i_2\ldots i_s}(x_1 x_2\ldots x_t)$$

where p_i is the probability of the disease conditioned by the given symptoms, l_j is the number of levels of the j-th discrete symptom and the functions $f(x_1,x_2,\ldots,x_t)$, which are given, can be constant, take on value one, if the term represents the influence of a group of discrete symptoms only, or be null. Analogously, the "u" parameters can degenerate to unity if the term reflects the influence of continuous symptoms alone.

If we have enough data of patients with their diseases and symptoms, the parameters of the regression model can be easily estimated by the maximum likelihood method ([2],[5]).

Example 4.- Assume that one engineer is interested in distinguishing the following 4 problems in a nuclear power plant based on the following 4 symptoms:

1.- Recirculation line large break	X_1=Reactor pressure (RP)
2.- Loss of vacuum condenser	X_2=Vessel water level (VWL)
3.- Loss of offside power	X_3=Drywell pressure (DP)
4.- Main steam line small break	X_4=Closed main steam valve (CMSV) (-1=no, 1=yes)

and that he has tha data shown in Table 4.

In order to make the distinction between those different problems he decides to fit 4 regression models (one for each problem) such that given the four symptoms indicated in Table 4, the probability of not having each problem can be calculated.

A very general logistic model is the following

$$\log\left(\frac{p_i}{1-p_i}\right)=u_0+u_1X_1+u_2X_2+u_3X_3+u_4X_4+u_5X_1X_2+u_6X_1X_3+u_7X_1X_4+u_8X_2X_3+$$
$$+u_9X_2X_4+u_{10}X_3X_4+u_{11}X_1X_2X_3+u_{12}X_1X_2X_4+u_{13}X_1X_3X_4+u_{14}X_2X_3X_4+u_{15}X_1X_2X_3X_4$$

where p_i is the probability of not having problem i-th and the u coefficients are constants to be estimated. From the data above, stepwise regression (a method for selecting which symptoms are and which are not relevant for the distinction) leads to the following models:

$$\log\left(\frac{p_1}{1-p_1}\right)=-0.21+10.776\ X_4\quad ;\quad \log\left(\frac{p_2}{1-p_2}\right)=472.86-6.472\ X_1$$

$$\log\left(\frac{p_3}{1-p_3}\right) = -4.436 + 0.378\,X_2 - 11.34\,X_4 \quad ; \quad \log\left(\frac{p_4}{1-p_4}\right) = 20.74 - 2.1\,X_2 X_3$$

DATA #	PROBLEM	RP	VWL	DP	CMSV	DATA #	PROBLEM	RP	VWL	DP	CMSV
1	1	69	10	0.2	-1	2	1	71	12	0.25	-1
3	1	70	6	0.26	-1	4	1	69	8	0.3	-1
5	1	68	5	0.18	-1	6	1	70	14	0.24	-1
7	1	72	16	0.17	-1	8	1	69	10	0.23	-1
9	1	71	12	0.25	-1	10	1	71	11	0.17	-1
11	2	75	74	0.07	1	12	2	74	75	0.08	1
13	2	77	76	0.08	1	14	2	76	76	0.07	1
15	2	76	75	0.06	1	16	2	77	77	0.07	1
17	2	77	74	0.08	1	18	2	75	74	0.08	1
19	2	76	76	0.07	1	20	2	76	73	0.06	1
21	3	70	15	0.20	1	22	3	71	16	0.17	1
23	3	72	12	0.30	1	24	3	70	17	0.19	1
25	3	69	11	0.25	1	26	3	70	15	0.21	1
27	3	70	15	0.26	1	28	3	70	14	0.20	1
29	3	70	16	0.21	1	30	3	69	13	0.18	1
31	4	68	75	0.20	1	32	4	69	73	0.21	1
33	4	72	76	0.26	1	34	4	70	75	0.19	1
35	4	70	77	0.30	1	36	4	70	74	0.20	1
37	4	69	73	0.25	1	38	4	69	75	0.18	1
39	4	71	74	0.21	1	40	4	71	76	0.21	1

Table 4.- Nuclear power plant data

The above models are surprisingly simple, but they differentiate very well the four problems (see Table 5 where the probabilities p_1, p_2, p_3 and p_4, have been calculated for the above models). The engineer is temptated to use more complicated models (at least with two non-constant terms) because he knows the symptoms associated with those problems (see Table 6) but they are not necessary to the above aim.

DATA #	p_1	p_2	p_3	p_4	DATA#	p_1	p_2	p_3	p_4
1 to 10	0.00	1.00	1.00	1.00	11 to 20	1.00	0.00	1.00	1.00
21to 30	1.00	1.00	0.00	1.00	31 to 40	1.00	1.000	1.00	0.00

Table 5.- Calculated values of p_1 to p_4 using logistic models

PROBLEM	SYMPTOMS
Recirculation line large break	high drywell pressure (≥ 0.14 Kg/cm^2) and low vessel water level (< 18 cm)
Loss of vacuum condenser	high reactor pressure (> 73.5 Kg/cm^2) and closed main steam valve
Loss of offside power	low vessel water level (< 18 cm), high drywell pressure (≥ 0.14 Kg/cm^2) and closed main steam valve
Main steam line small break	high drywell pressure (≥ 0.14 Kg/cm^2) and closed main steam valve

Table 6.- Symptoms associated with the above four problems

The knowledge base in the case of expert systems based on log-linear or regression models consists of their structures and associated parameters, and the inference engine consists of a program or procedure able to calculate conditional probabilities of problems given certain symptoms by means of the model. As information available is normally incomplete, it is necessary to add all the frequencies associated with the partial given information. Rough estimates can be obtained based on mean values.

3.3.- Causal network models

In this section we describe one modified version of the Lauritzen and Spiegelhalter [4] model, which is one of the methods based on causal networks. In order to illustrate the method, we shall analyze in detail the following pedagogical example.

Example 5.- Figure 2.a shows the security mechanism of a room which is composed of two subsystems. The first, C, consists of a video-camera which transmits the image to a computer for analysis. After the analysis, the computer decides whether or not to activate a relay which closes an electric circuit with a battery activating an alarm. The second, G, consists of a photoelectric cell, D, which closes another electric circuit with an alarm F activated by a battery E. Figure 2.b shows the rules associated with the alarm system. Note that the first system has been simplified to hardware plus software, and that rules are interpreted in a weak sense (conclusions are very likely but not sure).

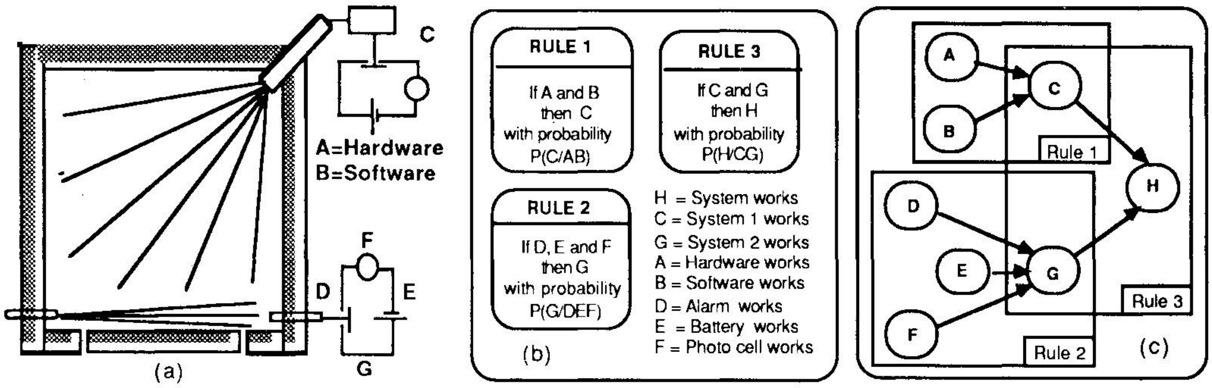


Figure 2.- Security system: rules and influence diagram

The idea of Lauritzen and Spiegelhalter consists of utilizing a probabilistic structure such that propagation of uncertainty can be carried out accurately, quickly and without the need for an excessive number of parameters. To this aim, they assume that the knowledge can be represented by means of an "influence diagram", which is a set V of nodes and a set of oriented edges between pairs of nodes (see figure 2.c). An oriented edge between nodes "A" and "B" can be represented by means of the notation $A \rightarrow B$ and then we say that the node "A" is a father of node "B" and that node "B" is a son of node "A".

A set of nodes **C** is said to be "complete" if there are edges between all pairs of nodes and we say that it is a "clique" if it is maximal, that is, it cannot be extended to another complete set. The set of all extremes of edges of a given node A is called the boundary of that node and is denoted by Bd(A). Numbering of nodes is called "perfect" if the set of nodes $Bd(i) \cap \{1,2,\ldots,i-1\}$ is complete.

The nodes of the graph represent the objects, which can take on a finite number of values. As starting data, "conditional probability tables" are given. These tables contain the probabilities of each node taking each of its possible values for any of the possible combinations of values for its parents. In addition they assume that if we know the values of parents, Π_A, of a node A whose value is currently unknown, then no other knowledge (except concerning descendants of A) will influence our opinion concerning the true value of A (Markov property), that is:

$$P(A / B, U) = P(A / B) \quad ; \quad \forall A, U \subset V - \Pi_A \ ; \ B \subset \Pi_A$$

This implies that the joint probability function of all nodes can be written as the product of conditional probabilities in the above tables.

Sometimes it is easier to use a representation of the joint probability distribution as the product of functions ("evidence potentials", which are denoted as ψ) defined on cliques (the set of cliques will be denoted as Δ). In this case the joint distribution does not need to be known exactly, but can be expressed as a proportional function, which can be normalized if needed. Thus, we have: $P(V) = \prod_{i=1}^{q} \psi(C_i) / Z$ where Z is a normalization constant.

Lauritzen and Spiegelhalter [4] utilize a third form of representing the joint probability of nodes by means of a "set chain" (of cliques) having the running intersection property, in that the nodes of one clique also contained in previous cliques are all members of one previous clique. This property facilitates the calculation of the joint probability functions on cliques. In fact, the above chain is such that:

$$P(V) = \prod_{i=1}^{q} P(R_i / S_i) \quad ; \quad S_i = C_i \cap (C_1 \cup C_2 \cup \ldots \cup C_{i-1}) \quad ; \quad R_i = C_i - S_i$$

Sets S_i and R_i are called clique separators and residuals, respectively.

From evidence potentials the marginal probability of a given set $U \subset V$ can be easily obtained (when doing this we say that we are marginalising over $\bar{U}$):

$$P(U) = \sum_{\bar{U}} P(U, \bar{U}) = \sum_{\bar{U}} Z^{-1} \prod_{A \in \Delta} \psi(A) = Z^{-1} \prod_{A \in \Delta_1} \psi(A) \sum_{\bar{U}} \prod_{A \in \Delta_2} \psi(A) = Z^{-1} \phi(B) \prod_{A \in \Delta_1} \psi(A)$$

where

$$\Delta_1 = \{A \in \Delta / A \cap U = \phi\} \text{ and } \Delta_2 = \Delta - \Delta_1 \ ; \ B = \bigcup_{A \in \Delta_2} A - U \ ; \ \phi(B) = \sum_{\bar{U}} \prod_{A \in \Delta_2} \psi(A)$$

Thus, if $\bar{U} = R_q$ then the initial evidence potentials transform to

$$(2) \qquad \bar{\psi}(A) = \begin{cases} \psi(A)\phi(B) & \text{if } A = C_{q-1} \\ 1 & \text{if } A = C_q \\ \psi(A) & \text{otherwise} \end{cases} \quad ; \quad \phi(B) = \sum_{R_q} \psi(C_q)$$

where A_1 is an element of Δ_1 such that $B \subset A_1$, and the normalization constant Z is unchanged in this operation.

In addition, for the last clique we can write:

$$(3)\ P(R_q / S_q) = P(R_q / C_1 C_2 \dots C_{q-1}) = P(V) / P(C_1 C_2 \dots C_{q-1}) = \psi(C_q) / \sum_{R_q} \psi(C_q)$$

Thus, progressive marginalization and expression (3) allow probabilities $P(R_i/S_i)$ $(i=1,2,\dots,q)$ to be obtained. In fact, $P(R_q/S_q)$ is directly obtained from (3). Then, we marginalise over R_q, using (2), and once again we use (3) to calculate $P(R_{q-1}/S_{q-1})$. Then, we marginalise over R_{q-1} and calculate $P(R_{q-2}/S_{q-2})$, and we repeat the same process until $P(R_1/S_1)$ is obtained.

If the value of node i is known and we want to know how the joint probability distribution P(V) is affected by that information, evidence potentials are modified in the following way:

$$\psi^*_{A^*}(.) = \begin{cases} 0 & \text{if value of node i is contrary to information} \\ \psi_{A^*}(.) & \text{otherwise} \end{cases} \quad ; \quad \psi^*_A(.) = \psi_A(.)$$

where A^* is the first clique containing node i and ψ^* are the new evidence potentials.

Initially, conditional probabilities are obtained from the human expert and/or the knowledge engineer or the data base and evidence potentials are obtained from them (see example 6).

Example 6.- As an illustration of the above method, we apply it to the case of example 1 (influence diagram in Figure 2.c and 3). The undirected edges (A,B), (D,E), (D,F), (E,F) and (C,G) have been included to take into account that sets {A,B,C}, {D,E,F,G} and {C,G,H} define the 3 rules for systems 1 and 2 to work, respectively.

If we assume that nodes can take values "true" or "false", we get the following conditional probability tables:

$$P(A,B)\ ,\ P(D,E,F)\ ,\ P(C/A,B)\ ,\ P(G/D,E,F) \text{ and } P(H/C,G)$$

Thus, the joint probability function of all nodes can be written

$$(4) \qquad P(V) = P(A,B,C,D,E,F,G,H) = P(A,B)P(C/A,B)P(D,E,F)P(G/D,E,F)P(H/C,G)$$

Due to the fact that the cliques are {(A,B,C), (D,E,F,G), and (C,G,H)}, the joint probability function of nodes as a function of evidence potentials becomes:

$$P(V) = P(A,B,C,D,E,F,G,H) = \psi(A,B,C)\,\psi(D,E,F,G)\,\psi(C,G,H)/Z \tag{5}$$

Initially, we can make (see (4))

$$\psi(A,B,C) = P(A,B)\,P(C/A,B),\ \psi(D,E,F,G) = P(D,E,F)\,P(G/D,E,F),$$
$$\psi(C,G,H) = P(H/C,G) \text{ and } Z=1$$

A perfect numbering of nodes is shown in figure 3. From it, the following set chain representation can be obtained (see Table 7):

$$P(V) = P(A,B,C,D,E,F,G,H) = P(A,B,C)\,P(G,H/C)\,P(D,E,F/G) \tag{6}$$

number i	clique C_i	residual R_i	separator S_i
1	ABC	ABC	F
2	CGH	GH	C
3	DEFG	DEF	G

Table 7.- Set chain decomposition

As an example, let us consider the conditional probability tables (we only give the conditional probabilities of the value "true", because those for "false" are their complements to one):

$P(a,b)=0.90$	$P(c/a,b)=0.96$	$P(d,e,f)=0.90$	$P(\bar{d},e,f)=0.02$
$P(a,\bar{b})=0.05$	$P(c/a,\bar{b})=0.04$	$P(d,e,\bar{f})=0.02$	$P(\bar{d},e,\bar{f})=0.01$
$P(\bar{a},b)=0.04$	$P(c/\bar{a},b)=0.02$	$P(d,\bar{e},f)=0.02$	$P(\bar{d},\bar{e},f)=0.01$
$P(\bar{a},\bar{b})=0.01$	$P(c/\bar{a},\bar{b})=0.01$	$P(d,\bar{e},\bar{f})=0.01$	$P(\bar{d},\bar{e},\bar{f})=0.01$

$P(h/c,g)=0.98$	$P(g/d,e,f)=0.98$	$P(g/\bar{d},e,f)=0.02$
$P(h/c,\bar{g})=0.03$	$P(g/d,e,\bar{f})=0.02$	$P(g/\bar{d},e,\bar{f})=0.01$
$P(h/\bar{c},g)=0.02$	$P(g/d,\bar{e},f)=0.02$	$P(g/\bar{d},\bar{e},f)=0.01$
$P(h/\bar{c},\bar{g})=0.01$	$P(g/d,\bar{e},\bar{f})=0.01$	$P(g/\bar{d},\bar{e},\bar{f})=0.01$

where "a" means A = true and "a" , A = false and we use analogous notation for the rest of the nodes.

This allows initial evidence potentials to be obtained as indicated, from which, using the process described after expression (3), terms in (6) can be obtained. Finally, marginal probabilities of cliques or nodes are calculated based on terms in (6). The first factor on the right hand side of (6) gives the marginal probability distribution of the clique {A,B,C}, from which, by marginalization (sum in the adequate set) we obtain the marginal of the nodes A, B and C. Multiplying P(C), which has already been obtained, by P(G,H/C) we obtain the marginal of the clique {G,H,C} and from it the marginal of G and H. Multiplying now P(G) by P(DEF/G) we get the joint probability of D,E, F and G, which allows the marginal probabilities of D, E and F to be obtained. In this way, the marginal probabilities of nodes shown in figure 3 have been obtained.If now we know that "C = true" (C="c") we get the new evidence potentials

$$\psi^*(A\,B\,c) = \psi(A\,B\,c)\ ;\ \psi^*(A\,B\,\bar{c}) = 0\ ;\ \psi^*(DEFG) = \psi(DEFG)\ ;\ \psi^*(CGH) = \psi(CGH)$$

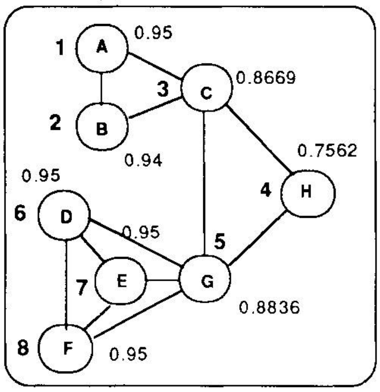


Figure 3.- Initial probabilities of nodes

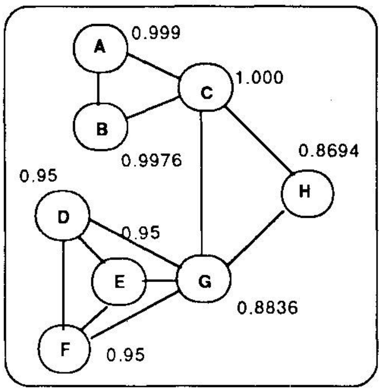


Figure 4.- Updated probabilities when C is true

By a similar process, the new marginal probabilities of nodes, shown in figure 4 have been obtained.

4.- LEARNING

In this section we analyse several techniques for making possible the learning process. We differentiate between parametric and structural learning. The parametric learning refers to the acquisition of parameters in the knowledge base. Whether we work with rules or probabilities, the uncertainty models depend on parameters, which must be known with precision in order to get a reliable expert system. Mechanisms for progressively estimating improved parameters are the basis for the parametric learning subsystem. In order to ilustrate the learning process for probability based models we give the following example.

Example 7.-Let us assume that we are in the case of example 1 and that the engineer knows of the presence of problem E with symptoms S_1, no S_2 and S_3. Then, the updating of parameters (frequencies), that is, parametric learning, consists of adding one unit to the frequency associated to that combination of symptoms, obtaining the value 35 (34+1) (see Figure 1.a). But, what happens if we only know symptoms no S_2 and S_3, but we ignore whether or not S_1 is present. In this situation we do not know if the problem is in the same case as the above 34 or in the case of the 14 problems without S_1 (see Figure 1.a). Thus, we do not know to which of the frequencies the one should be added. The Solomonic solution consists of distributing that unit proportionally to the previously existing frequencies. So value 34 modifies to 34+34/(34+14) and value 14 changes to 14+14/(34+14). In this way we get fractional values, instead of integers, but we update information without any loss of information. With this parametric learning procedure, we can start using the expert system with an imperfect knowledge base and progressively improve its quality with experience. In the case of the log-linear or regression models parametric learning involves a new estimation of parameters, with inclusion of the new data but without any modification of the model's structure. Any modification in the knowledge base structure leading to some improvement is known as structural learning. Among these, the most well-known variant is the inclusion of new symptoms (additional parameters). Some well known statistical techniques allow the selection, among a set of given parameters, of those which represent knowledge most adequately.

In order to test the adequacy of a probabilistic model relative to one of its extensions (more general models), it is sufficient to estimate, by the maximum likelihood method, parameters of both models and calculate the likelihood ratio. If M_1 and M_2 are two models with r_1 and r_2 parameters, respectively, M_2 being an extension of M_1, we calculate the ratio

$$V = \operatorname*{Max}_{M_2} \prod_{j=1}^{n} P(E_j \cap A_{1j} \cap A_{2j} \cap .. \cap A_{mj}) \;/\; \operatorname*{Max}_{M_1} \prod_{j=1}^{n} P(E_j \cap A_{1j} \cap A_{2j} \cap ... \cap A_{mj})$$

where n is the sample size (number of data items with known symptoms and associasted problems) and the maximization must be understood with respect to the set of parameters of models M_1 and M_2, respectively, and subject to their respective constraints. The significance level can be calculated by taking into account that the statistic -2logV converges in probability to a $\chi^2_2(r_2 - r_1)$.

Structural learning with log-linear or regression models consists of choosing the simplest model reproducing the real frequencies up to acceptable levels of error. Thus, terms to be included in the model must be selected. In order to make this selection we have two procedures:

(1) Start from the saturated model (with the maximum number of parameters) and proceed to eliminate terms until the quality of the model is substantially affected by their removal

(2) Start from a simple model and add new terms until a substantial improvement is no longer obtained.

For stepwise selection of log-linear and regression models several statistical packages can be used as BMDP, SPSS, SAS, etc. Log-linear and regression models in examples 3 and 4 were selected by this method using the BMDP package.

5.- REFERENCES

1. Bishop, Y. M. M., Fienberg, S. A. and Holland, P. W. (1975). Discrete multivariate analysis: Theory and Practice. Cambridge, Mass., The MIT Press.

2. Castillo, E. and Alvarez, E. (1989). Introducción a los sistemas expertos. Aprendizaje e incertidumbre. Editorial Paraninfo. Madrid.

3. Klahr, P. and Waterman, D. A. (1986). Expert system techniques, tools and applications. Addison Wesley Publishing Co.

4. Lauritzen, S.L. and Spiegelhalter, D.J. (1988). Local computations with probabilities on graphical structures and their application to expert systems. Journal of the Royal Statistical Society, Series B, 50, N0. 2, 157-224.

5. Luceño, A. (1988). Métodos de Estadística aplicada. Servicio de publicaciones. Universidad de Cantabria.

Leere Seite
Blank page
Page vide

Uncertainty Treatment in a Vulnerability-Assistant Expert-System

Traitement d'incertitudes dans les systèmes experts

Behandlung von Unsicherheiten in Expertensystemen

Fabio CASCIATI
Professor
University of Pavia
Pavia, Italy

Lucia FARAVELLI
Associate Professor
University of Pavia
Pavia, Italy

Fabio Casciati, received his civil engineering degree in 1972 at the University of Pavia, where he became professor of Structural Mechanics in 1980. Co-author of two books and author (or co-author) of more than 100 scientific papers, his main research interests are in reliability and risk assessment and stochastic dynamics.

Lucia Faravelli, received her mathematics degree in 1972 at the University of Pavia, where she became associate professor of Structural Safety in 1983. Author (or co-author) of two books and more than 80 scientific papers, her main research interests are in structural safety, seismic engineering and stochastic FEM.

SUMMARY
This paper illustrates the «Vulnerability Assistant» Expert System prepared for the study of existing masonry buildings in the framework of the GNDT (Italian National Group of Seismic Mitigation) activity. Its extension to reinforced concrete buildings and historical churches is also discussed. Finally the paper emphasized the inadequacy of the present commercial «shells» in dealing with uncertainty and shows how this can be obviated by building additional rules into the decisional process.

RESUME
Cet article concerne le système expert «Vulnerability Assistant» développé pour l'ètude de la vulnérabilité des bâtiments en briques, sous le patronage du GNDT (le Groupe National Italien pour la Prévention Sismique). L'extension à des bâtiments, en béton armé et aux églises classées monuments historiques est discutée. Les difficultés à étudier les aspects aléatoires du probleme sont examinées.

ZUSAMMENFASSUNG
Der Artikel beschreibt das Expertensystem «Vulnerability Assistant» zur Ermittlung der Erdbebengefährdung von Mauerwerkgebäuden der italienischen nationalen Gruppe für Erdbebenwesen (GNDT). Die Ausdehnung auf Stahlbetongebäude und historische Kirchen wird ebenfalls besprochen. Abschliessend werden die Mängel bestehender kommerzieller «Shells» zur Behandlung von Unsicherheiten erläutert und es wird gezeigt, wie diese durch den Einbau zusätzlicher Bedingungen in den Entscheidungsprozess behoben werden können.

1. INTRODUCTION

Existing structures come out to be the main object of safety evaluations during the Eighties. A valuable review of the early literature published on this topic in the United States can be found in Ref. [1]. Several investigations were also conducted in Europe, where, however, each single country focused attention on different kinds of buildings and, for them, established its own approach to the problem [2][3][4]. Old villages and monumental areas were and are the main object of the studies developed in Italy. Nuclear power plant facilities are deeply studied in Germany while North Sea Countries are investing many research resources in the analysis of offshore platforms. A synthetic review of problems and approaches is provided in the book quoted as Ref. [5]. This book, however, is mainly devoted to structural vulnerability assessment. By combining this aspect with site hazard and structural exposure the inherent risk can be evaluated.

As J.Yao state in the preface to his book [1], "much of the decision-making process has depended on each engineer's experience, intuition and judgement... To help understand how experts summarize and interpret results of measurements, inspection and analyses in reaching their decision concerning structural safety, the application of rule-inference methods" must be "reviewed and discussed". The strict connection with the Artificial Intelligence (AI) world became evident soon. Books as the one by Rich [6], among others, opended, to scientists operating outside Computer Sciences departments, the progresses in knowledge representation and in advanced problem - solving systems.

Several research groups of civil engineers became immediately active on this topic. The reader is referred to the special book edited by M.L.Maher [7] for a non specialistic introduction to the basic concepts of expert system theory and, mainly, for a systematization of their use in civil engineering. In particular expert system applications are categorized into five different fields:

- applications in Structural Engineering (reviewed by M.L.Maher in Ref. [7]);
- applications in Geothechnical Engineering (reviewed by T.J.Siller in Ref. [7]);
- applications in Construction (reviewed by R.E.Levitt in Ref. [7]);
- applications in Environmental Engineering (reviewed by L.A.Rossman and T.J.Siller in Ref. [7]);
- applications in Transportation Engineering (reviewed by S.G.Ritchie and R.A.Harris in Ref.[7]);

Of course, safety evaluations of existing structures belong to the first group, where at least five further classes can be distinguished;

- applications to materials (welding and weld defect advisors);
- applications in code checking
- applications to structural design
- applications to diagnosis
- applications to analysis problems, as the safety analysis of existing structures this paper is considering.

The experience of the authors is limited to problems of analysis and, in particular, of seismic risk analysis. They were in Stanford in the pioneering period, and started "to play" with expert systems shells as "DECIDING FACTOR" [8] or "INSIGHT" [9] in a context where the different aspects of ground motion, structural vulnerability and social impact of potential damage were simultaneously considered [10]. After that the Stanford's research group oriented itself to problems wider and wider by building the expert system IRAS

[11]. It includes not only earth science, seismology, geology and structural engineering, but also risk management, planning, insurance/ banking profession and facility management. By contrast, the authors concentrated their attention on the narrower field of seismic vulnerability [12][13][14]. The National Center for Earthquake Engineering Research (NCEER) is presently pursuing the same objective in the US [15][16].

2. A VULNERABILITY ASSISTANT FOR DATA COLLECTION

2.1. The masonry vulnerability form

Benedetti and Petrini [2] proposed, a method of classifying masonry buildings in Italian seismic areas, which makes use of a numerical value, called the "vulnerability index". It represents the seismic quality of each building and is obtained as a weighted sum of some numerical values expressing the seismic quality of structural and non-structural elements. The items with which numerical values must be associated were reduced to eleven as summarized in the form of figure 1 ("Level 2 Vulnerability Form"). The elements can be either of descriptive nature or of evaluative nature. The first group is formed by the "resistant system quality" (item 2 in figure 1), the morphological "configurations" (item 6 and 7 in figure 1), the structural typology (items 5 and 9 in figure 1) and the status descriptions (items 10 and 11 in figure 1). "Building quality" (item 1 in figure 1), "conventional resistance" (i.e. item 3 in figure 1: "the total shear strength" is estimated by the approximate formula at the top of the right column of figure 1), "building site" (item 4 in figure 1) and "interwall distance" (item 8 in figure 1) are the components of the second group.

Appropriate field investigations must be planned for evaluating all these elements. The operators must follow detailed rules and instructions [17] prepared in order to minimize the discrepancies among surveyors. For this purpose, the operator must provide answers to some questions which are regarded as "evaluation elements" (second column from right in figure 1). The answers are then combined to assign the item under discussion to a class. Class A indicates situations that are in agreement with the prescriptions of the Italian seismic code. Class D characterizes the unsafe configurations.
Each answer is accompanied by the degree of confidence on it. The operator can select among four different classes of quality of the information: E (high quality), M (average), B(low quality) and A (operator's guess).

Four lines of development, from this background, were identified in the context of GNDT (the Italian National Group of Seismic Mitigation):

1) to automatize the operations of data collection by building a software capable of running on portable ("lap-top") personal computers;

2) to extend the expertise and, hence, the AI approach to other classes of buildings;

3) to improve the way by which uncertainty is treated in the vulnerability assessment process;

4) to improve the vulnerability form by gathering together a greater quantity of elements and by exploiting the computational capabilities of portable personal computers. For instance, the data necessary for a parameter identification process can be collected. The values of the parameters are then evaluated and an analytical model is builts on them. The decision making process can eventually include the indications of the model [13].

G.N.D.T. - SCHEDA DI VULNERABILITÀ DI 2° LIVELLO (MURATURA)

Codice ISTAT Provincia [1] | Codice ISTAT Comune [3] | Scheda No. [6]

	PARAMETRI	Classi	Qual. inf.	ELEMENTI DI VALUTAZIONE
1	TIPO ED ORGANIZZAZIONE DEL SISTEMA RESISTENTE (S.R.)	11	22	33: Norm. nuove costruz. (cl. A) [1]; Norm. riparazioni (cl. A) [2]; Cord. e cat. tutti livelli (cl. B) [3]; Buoni amm. fra mur. (cl. C) [4]; Senza cord. cattivi amm. (cl. D) [5]
2	QUALITÀ DEL S.R.	12	23	34: (vedi manuale)
3	RESISTENZA CONVENZIONALE	13	24	35: Numero di piani N; 37: Area tot. cop. A_t (mq); 41: Area A_x (mq); 44: Area A_y (mq); 47: τ_k (t/mq); 50: Alt. media interp. h (m); 52: Peso spec. par. p_m (t/mc); 54: Carico perm. sol. p_s (t/mq)
4	POSIZIONE EDIFICIO E FONDAZIONI	14	25	56: Pend. perc. terr.; 58: Roccia fond. si [1] no [2]; Terr. sc. non sp. fond. si [3] no [4]; Terr. sc. sp. fond. si [5] no [6]; 59: Diff. max di quota Δh (m)
5	ORIZZONTAMENTI	15	26	62: Piani sfalsati si [1] no [2]; 63: Orizz. rig. e ben coll. [1]; Orizz. def. e ben coll. [2]; Orizz. rig. e mal coll. [3]; Orizz. def. e mal coll. [4]; 64: % or. rig. ben coll.
6	CONFIGURAZIONE PLANIMETRICA	16	27	66: Rapp. perc. β_1 = a/l; 70: Rapp. perc. β_2 = b/l
7	CONFIGURAZIONE IN ELEVAZIONE	17	28	74: % aumento (+) / riduz. (−) di massa; 77: Rapp. perc. T/H; 79: Perc. in sup. port.; 81: Piano terra port. si [1] no [2]
M8	D_{max} MURATURE	18	29	82: Rapp. massimo l/s
M9	COPERTURA	19	30	84: Cop. non sp. [Ø] poco sp [1] sp [2]; 85: Cord. in copert. si [1] no [2]; 86: Cat. in copert. si [1] no [2]; 87: Car. perm. cop. p_c (t/mq); 90: Lungh. app. cop. l_c (m); 93: Perim. cop. l (m)
10	EL. NON STRUTT.	20	31	(vedi manuale)
11	STATO DI FATTO	21	32	(vedi manuale)

SCHEMI - RICHIAMI (MURATURA)

Parametro 3. Resistenza convenzionale.

Tipologia struttura verticale — τ_k (t/mq)

Minimo fra A_x e A_y — A (mq)

Massimo fra A_x e A_y — B (mq)

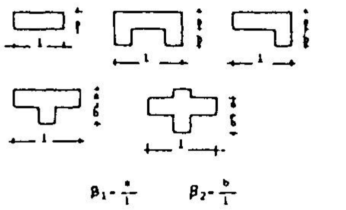
Coeff. a_o = A/At — Coeff. γ = B/A

$q = (A_x + A_y)\, h\, p_m / At + p_s$

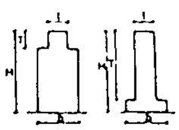
$$C = \frac{a_o \cdot \tau_k}{q \cdot N} \cdot \sqrt{1 + \frac{q \cdot N}{1.5 \cdot a_o \cdot \tau_k \cdot (1+\gamma)}}$$

$\alpha = C/0.4$

Parametro 6. Configurazione planimetrica.



Parametro 7. Configurazione in elevazione.



Parametro M9. Copertura.

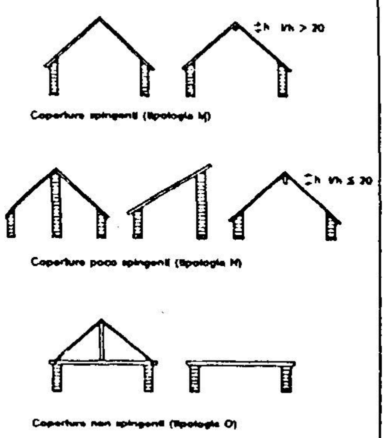


Figure 1

codice ISTAT Provincia 1[_ _] codice ISTAT Comune 3[_ _ _] scheda n° 6[_ _ _ _ _] n° schede P 11[_ _] n° schede V 13[_ _]

1	TIPO ED ORGANIZZAZIONE DEL SISTEMA RESISTENTE	ELEMENTI STRUTTURALI PRESENTI 15[ ] 16[_ _ _] 1) pareti e/o nuclei c.a. 2) telai in due direzioni 3) telai assenti o carenti in una direzione 4) telai assenti o carenti in due direzioni 5) presenza tamponature tipo A 6) presenza tamponature tipo B [indicare uno, al piu' tre elementi]	DISEGNI STRUTTURALI DISPONIBILI 19[ ] 20[si][no] REGIME L. 02/02/74 n° 64 21[ ] 22[si][no] GIUNTI STRUTTURALI NON SISMICI 23[ ] 24[si][no] PRESENZA PIANO FLESSIBILE 25[ ] 26[si][no] ANNO DI COSTRUZIONE 27[ ] 28[_ _ _ _]
2	TECNOLOGIA DEL SISTEMA RESISTENTE	SISTEMA RESISTENTE 32[ ] 33[_] 1) gettato in opera a travi e pilastri 2) gettato in opera a setti e/o casseforme tunnel	3) prefabbricato a pannelli portanti 4) prefabbricato a travi e pilastri
3	POSIZIONE EDIFICIO E FONDAZIONI	TIPO DI TERRENO 34[ ] 35[_] 1) roccia 2) compatto 3) sciolto PENDENZA PERCENTUALE TERRENO 36[ ] 37[_ _]	TIPO DI FONDAZIONI 39[ ] 40[_] 1) fondazioni profonde 2) plinti isolati 3) plinti collegati 4) travi rovesce 5) platea FONDAZIONI A QUOTE DIVERSE 41[ ] 42[si][no]

4 | ORIZZONTAMENTI — 5 | STRUTTURE VERTICALI

	43	44		48	49	51	53	56
24	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
23	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
22	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
21	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
20	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
19	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
18	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
17	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
16	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
15	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
14	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
13	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
12	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
11	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
10	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
9	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
8	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
7	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
6	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
5	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
4	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
3	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
2	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
1	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
0	[_]	[_ _ _ _]		[_]	[_ _]	[_ _]	[_ _ _]	[_]
L	+/-	Quota		P	L_I	L_s	H	V

7 | QUALITA' DI MATERIALI ED ESECUZIONE

QUALITA' 67[ ] 68[_]
1) buona
2) media
3) cattiva

8 | STATO DI FATTO

FONDAZIONI
presenza di cedimenti di fondaz. 69[ ] 70[si][no]
lesioni nelle strutture in c.a. del cantinato 71[ ] 72[si][no]

TAMPONATURE E TRAMEZZI
lesioni diagonali 73[ ] 74[si][no]
lesioni orizzontali 75[ ] 76[si][no]
lesioni verticali 77[ ] 78[si][no]
lesioni su tamponature aggetti 79[ ] 80[si][no]
distacco rivestimento per schiacciamento tramezzi 81[ ] 82[si][no]
malte degradate 83[ ] 84[si][no]

NODI TRAVE-PILASTRO
presenza segni di danneggiamento 85[ ] 86[si][no]

ORIZZONTAMENTI
sensibili frecce nei solai 87[ ] 88[si][no]
lesioni nei pavimenti 89[ ] 90[si][no]

STRUTTURE IN VISTA
rottura spigoli balconi 91[ ] 92[si][no]
rottura spigoli gronde 93[ ] 94[si][no]
rottura spigoli pilastri 95[ ] 96[si][no]
scollegamento parapetti 97[ ] 98[si][no]
fessurazione parapetti c.a. 99[ ] 100[si][no]
armatura travi in vista 101[ ] 102[si][no]

6 | COPERTURA

TIPO DI COPERTURA 57[ ] 58[_]
1) piana
2) portante a falde inclinate
3) non portante a falde inclinate

ALTEZZA MINIMA 59[ ] 60[_ _ _]
ALTEZZA MASSIMA 63[ ] 64[_ _ _]

Figure 2

Figure 1 - Form for the level - 2 vulnerability assessment of masonry buildings, from Ref. [2]. For sake of clearness, the eleven items can be summarized as follows:
1) builiding quality; 2) resistant system quality; 3) conventional resistance; 4) building site; 5) horizontal element features; 6) plan configuration; 7) vertical configuration; 8) interwall distance; 9) roof type; 10) nonstructural elements; 11) actual state (maintenance conditions).

Figure 2 - Main form for the level - 2 vulnerability assessment of reinforced concrete building, from Ref. [17]. For sake of clearness, the eight items on it can be summarized as follows:
1) building quality; 2) resistant system technology; 3) building site; 4) horizontal element features; 5) vertical configuration; 6) roof type; 7) material and construction quality; 8) actual state (maintenance conditions).

2.2. A "Vulnerability Assistant" expert system

The short presentation of Sub-Section 2.1 shows that the data collection cannot be automatized by algorithmic computer codes since they are unable to account for the descriptive (qualitative) elements. Non-algorithmic (linguistic) procedures (expert systems) are therefore required in order to implement a "Level 2 Vulnerability Assistant" software. On the other hand the presence of algorithmic steps (see the approximate formula of item 3 in figure 1) makes unsatisfactory the first generation of expert systems. They, in fact, were not able to alternate qualitative and quantitative steps (see [12] and [18] among others).
A particular shell of the second generation running also over (portable) personal computers is the INSIGHT 2+ [9]. It was used by Faravelli [19] for building her "Masonry Vulnerability Assistant" prototype of expert system.

A consultation can be described as follows:

- the operator is asked to select the item to be considered in the form of figure 1;
- the operator is then required to provide the evaluation elements specified in the second column of the form for the row (item) he selected. The process stops when the inference process reaches a conclusion (i.e. provides the class (A, B, C or D) to which the building under investigation belongs;
- some questions require an illustration is dispayed. This is obtained by the "explain" help facility, which can be activated for the following items: plan configuration, vertical configuration and roof type (see the third column in figure 1);
- to estabilish the conventional resistance means to collect the data listed at the top of the third column in figure 1. These data are then automatically combined in the formula there specified, whose result leads to the aimed classification;
- when all the items have been considered, the appropriate numerical values are associated with each of them, as well as the corresponding weights, and the numerical estimate of the vulnerability index is found.

The resulting number will represent that building in successive statistical studies, cost-benefit analyses of retrofitting and so on.

3. EXTENSION TO DIFFERENT TYPOLOGIES OF BUILDINGS

3.1 Reinforced concrete buildings

The expertise on reinforced concrete buildings led to propose the form of figure 2. It should be completed by two additional groups of sheets. The first set concerns the configuration plan and the second the vertical structures. The square brackets are reserved to a specification of the quality of the information (again by one of the four letters E, M, B, A).

There is one main difference between the forms in figure 1 and 2. The form of figure 1 aims to collect data in order to select an answer among 4 classes (A, B, C and D). The form of figure 2 only aims to collect data, the conclusion being delayed to a successive stage. The translation of this second form in a data-collection expert-system is therefore simplified since the inference part can be missed. However, the consultation becomes much more tedious, since all the questions must be answered. There are not branches for which the investigation is shortened as it occurs for the form of figure 1 when a conclusion (the assignement to a class) is reached.

Nevertheless, the expert system will have in this case, an additional task. The check of conflicts between answers, in fact, will give the analyser a complete confidence in the data he is collecting.

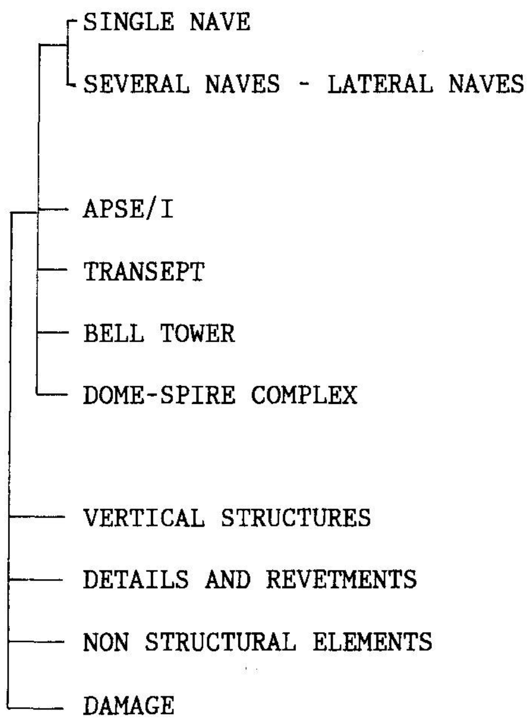


Figure 3 - The set of forms, and their links, to be filled for a "Vulnerability and Damage Assessment" of churches [21].

3.2. Churches

After the earthquakes of 1976 in Friuli and 1980 in Southern Italy, several resources were invested, in Italy, in the assessment of the vulnerability of the churches. The expertise was converted into a set of forms; rather than a single form, due to the non uniform and composite nature of this kind of buildings (see figure 3).

The main form requires elements of the map configuration, a defintion of the building site and a list of structural components which form the church (naves, apse, transept ...). Each of these components, then, is the object of a separate form. A graphical illustration is also required.
As for reinforced concrete buildings, the form aims to collect data rather than to assess church vulnerability. However, three main differences must be emphasized:

1) the answers are not all of Boolean nature (either 0 or 1) but often one has to identify the most appropriate among several classes proposed. For instance, the dome structure can be in wood (class 1), in steel (class 2) in masonry or stones (class 3) or other material (class 4): an expert system approach to such a form of data collection comes out to be very convenient;
2) the interaction between qualitative/quantitative descritptions and graphical illustrations leads to extend the capacities of the expert system to offer also drawing and sketching options;
3) the specification of the quality of information is missed in order to simplify a form already complex. The adoption of an expert system policy would obviate this inconvenience without additional efforts for the operator.

4. UNCERTAINTY TREATMENT

The expert system prototype which was presented in [19] provides the resulting classification (first column from the left in figure 1) for the item under investigation. It also gives the quality of the information (second column) which led to this classification. This quality is expressed by the resulting confidence measure. A number in the range (0,100) substitutes therefore the naive concept codified in [17] of four different degrees of confidence (E, M, B and A).

This "confidence measure" is a weak point of commercial shells, as INSIGHT2+ is. The reason is that the confidence calculations are driven directly by the inference engine. In other words the expert who builds the knowledge base is unable to interact with the uncertainty treatment. For instance, a conclusion is reached when the confidence on it is greater than a value fixed by the expert, but no mention is made on the likelihood of alternative events which can significantly influence the deductive process.

Unsatisfactory conclusions are prevented by building inside the knowledge base a logic treatment of uncertainty. This is made by additional rules which condition the inference engine process. The expert system prototype proposed in [19] should therefore be modified to provide, for each item, the probability of belonging to class A, B, C or D. Probability has not any frequentist meaning, but is only a degree of belief. At the end of the consultation, the probability mass function of the vulnerability index and some central measures can be computed.

In view of the extensions discussed in Section 3, there is not reason of combining the degrees of confidence the operator assigns to each answer. The forms relevant to reinforced concrete buildings and churches, in fact, are tools of data collection rather than deductive systems. However, since the expertise is still in evolution, the basic problem here is to select, among the possible uncertainty measures, the one which better represents the deductive chain of that field. A fascinating approach, for instance, interacts with the operator by using Bayesian concepts in the attempt of reaching, during the consultation, the best quality of information. Developments in this direction are presently in progress.

5. CONCLUSIONS

This paper illustrates the expert system prototype built in order to facilitate the seismic vulnerability of existing building according to Italian expertise. Unfortunately, the way of treating the uncertainty of commercial second generation shells is still elementary. This inconvenience can be obviated by building a more sophisticated scheme of uncertainty treatment by means of additional rules without shell modifications. However, this does not exclude that the production of an "ad hoc" shell, even elementary in its inference process, may result more efficient in view of the seismic prevention of existing buildings. This possibility should be carefully checked before the policy of dealing with uncertainty is selected among the ones compatible with the expert system shell in use.

ACKNOWLEDGEMENT

This paper is part of a reasearch funded by the National Group of Seismic Mitigation (GNDT) of the Italian Research Council (CNR). It is coordinated by prof. A. Corsanego, as chairman of the national research group on Vulnerability.

REFERENCES

1. YAO J.T.P., Safety and Reliability of Existing Structures, Pitman Publishing Ltd, 1985

2. BENEDETTI D., PETRINI V., Sulla Vulnerabilita' Sismica di Edifici in Muratura: Proposta di un Metodo di Valutazione. (In Italian), Industria Costruzioni, Vol. 18, 1984

3. KAFKA P., The Chernobyl Accident: a Challenge of PSA as the Tool for the Predicition of Event Scenarios Beyond the Design Basis and for Safety Improvements?, Trans. of 9th SMiRT (Int. Conf. on Structural Mechanics in Reactor Technology), 1987, Vol.M, 3-10

4. VROUWENVELDER A., JCSS Probabilistic Model Code. Assessment of Existing structures, Report BI-88-010, IBBC, TNO, Delft, 1988

5. CASCIATI F., FARAVELLI L., Fragility Analysis of Complex Structural Systems, Reseach Studies Press, 1989

6. RICH E., Artificial Intelligence, Mc Graw Hill, 1986

7. MAHER M.L. (Ed.), Expert Systems for Civil Engineers: Technology and Application, American Society of Civil Engineering, ASCE 1987

8. CAMPBELL A., FITZGERAL S., The Deciding Factor, User's Manual, Software Publishing Company, 1985

9. INSIGHT, Knowledge System, Level Five Research, Merbourne Beach, Florida, 1985

10. MIYASATO G., DONG W.M., LEVITT R.E., BOISSONADE A.C., SHAH H.C., Seismic Risk Analysis System, Proc. Symp. "Expert Systems in Civil Engineering", Seattle, 1986, 121-132

11. DONG W., WONG F., CHIANG W., KIM J.U., SHAH H.C., An Integrated System for Seismic Vulnerability and Risk for Engineering Facilities, in Nelson, J.K., (ed.) Computer Utilization in Structural Engineering ASCE, 1989, 408-417

12. CASCIATI, F., FARAVELLI, L., L'Impiego di Sistemi Esperti in Ingegneria Sismica. (In Italian), Proc. 3rd Conf. "L'Ingegneria Sismica in Italia", Roma, 1987, pp.199-210.

13. CASCIATI, F., FARAVELLI, L., Individuazione di Problemi di Meccanica dei Solidi Suscettibili di Inquadramento in Sistemi Esperti. (In Italian). Proc. 9th Nat. Conf. AIMETA, Bari, 1988, pp. 553-556.

14. CASCIATI, F., FARAVELLI, L., Seismic Vulnerability via Knowledge Based Expert Systems, in Brebbia C.A. (ed.) Structural Repair and Maintenance of Historical Buildings, Comutational Mechanics Publ., Southampton, 1989, 299-307

15. FENVES, S.J., IBARRA-ARRAYA, E., BIELAK, J., THEWALT, CH., A Knowledge Based System for Evaluating the Seismic Resistance of Existing Building, in Nelson J.K.(ed.), Computer Utilization in Structural Engineering, 1989, 428-437

16. SUBRAMANI, M., ZAGHW, A., CONLEY, C.H., A KBES for Seismic Design of Buildings, in Nelson J.K.(ed.) Computer Utilization in Structural Engineering, 1989, 342-351

17. GNDT - CNR. Istruzioni per la Compilazione della Scheda di Rilevamento Esposizione e Vulnerabilita' Sismica degli Edifici. (In Italian), September 1986

18. GAVARINI, C., PAGNONI, T., Amadeus. Un Sistema Esperto per la Valutazione d'Urgenza dell'Agibilita' degli Edifici dopo il Terremoto. (In Italian), Dept. of Structural Eng. and Geotech., Univ. "La Sapienza", Roma, 1988

19. FARAVELLI, L., Expert System for Fragility Assessment of Monumental Sites, Int. Symp. on Earthquake Countermeasures, Beijing, 1988, pp. 199-210

20. GAVARINI, C., SAMPAOLESI. L., Rilevamento della vulnerabilita' sismica degli edifici in cemento armato tramite schede (in Italian), unpublished CNR-GNDT document 1989

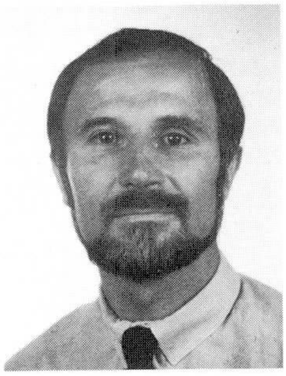
21. DOGLIONI, F., ANGELETTI, P., BELLINA, A., MORETTI, A., PETRINI, V., Istruzioni per la compilazione della scheda di rilevamento "Vulnerabilita' e Danno delle Chiese", unpublished CNR-GNDT document, 1989

Three Applications of BATI-SHELL, a Shell for Expert Systems Creation

Trois applications de BATI-SHELL, un shell pour la création de systémes experts

Drei Anwendungen von BATI-SHELL, einer Shell zum Aufbau von Expertensystemen

Jacques DUFAU
Civil Engineer, Doctor
University of Savoie
Chambéry - France



Jacques Dufau, born in 1947 received his civil engineering and doctor of sciences degrees at the INSA, Lyon. He is now responsibile for research on CAD systems for building in the Laboratoire Génie Civil el Habitat.

J.P. Mougin, Laboratoire Génie Civil et Habitat - University of Savoie
M. Tomasena, Laboratoire Intelligence Artificielle - University of Savoie
M. Vescovi - Laboratoire Intelligence Artificielle - University of Savoie

SUMMARY

BATI-SHELL is a tool which is particularly well suited to the realization of expert systems in the field of construction with a hierarchical structure of the base entities. It is a result of our experience in the realization of three expert-systems:

— CESSOL, whose objective is to contribute to the specification of soil investigations.
— ADOCC, which is able to analyze and describe the framework of current constructions.
— DESCARTES, connected with a CAD system, whose aim is to deduce the material characteristics for each kind of structure element in a building.

RESUME

BATI-SHELL est un outil bien adapté à la réalisation de systèmes experts dans le domaine de la construction avec structure d'entitès de base du type hiérarchique, il est le résultat de notre expérience dans l'élaboration de trois systèmes experts:

— CESSOL, dont l'objectif est de contribuer à la spécification de campagnes de reconnaissance de sol.
— ADOCC, qui est capable d'analyser de décrire la structure de construction.
— DESCARTES, couplé à un système de CAO, dont l'objet est la déduction des caractéristiques des matériaux constituant chaque sorte d'ouvrage dans un bâtiment.

ZUSAMMENFASSUNG

BATI-SHELL ist ein Werkzeug, das für die Verwirklichung von Expertensystemen im Bauwesen sehr geeignet ist. Es ist das Ergebnis unserer Erfahrungen bei der Realisierung von drei Expertensystemen. Ihre Datenbasen sind hierarchisch angeordnet:

— CESSOL, zur Festlegung der Baugrundwerte.
— ADOCC, um Gebäudestrukturen zu analysieren und zu beschreiben.
— DESCARTES, (mit einem CAD-System zusammenarbeitend) zur Bestimmung der Charakteristiken der Baumaterialien aller Gebäudeelemente.

1. INTRODUCTION

To develop various applications in building and construction field, we have created a shell dedicated to expert systems generation for computer aided design. Using our experience acquired during the development of the CESSOL and ADOCC expert systems, we can deduce that there is a class of problems leading to the same kind and the same structure of systems. This fact has been confirmed while we elaborated the third system (DESCARTES) presented in this paper.
After a short presentation of each expert system, through some explanations about the objectives, the structure of data, the nature of results and the reasoning process we will make a synthesis about the common characteristics of these expert systems and finally we will describe the composition of BATI-SHELL.

2. THE EXPERT SYSTEM CESSOL

2.1 Goals

CESSOL [1][2][3][4] is an expert system for the design of geotechnical site investigations for buildings.
A campaign of geotechnical site investigations is a set of tests made in a ground, in order to get all the information which is necessary to define the foundation conditions of a building on this ground.
CESSOL has to simulate the reasoning of an expert placed in two distinguished situations :
- the expert has to design a campaign of geotechnical site investigations to resolve a given problem : that is the case in a consultancy or in a geotechnical company for an engineer who has to propose a single campaign of geotechnical site investigations, the best one according to the problem to be studied and the characteristics of the company.
- the expert has to analyze a given campaign of geotechnical site investigations in order to know if it is suitable for the problem : that is the case for a consultant-engeneer working for an architect or a promoter, and who examines the answers at a bidding procedure in order to judge whether they can solve the given problem, and to choose the best one.
In this second situation, the expert must be able to consider all the possible solutions and not only one of them such as in the first situation.

2.2 Nature and structure of the data base

The campaign of geotechnical site investigations is defined from various data concerning:
- the building : information related to its purpose (dwelling, factory, offices, hospital, ...), its dimensions, its structure, etc.; this information can be known or unknown, more or less precisely ;
- the ground : it is characterized by its topography (size, slope) and its internal structure, such as the nature and the geometry of the layers, the existence of groundwater or cavities and the mechanical properties of the constituting elements.
This data constitutes a hierarchical data base that can be represented by subtrees. Each subtree is associated with a kind of main concept (building, soil ...)

2.3 Reasoning process

According to the expert's way of reasoning, the inference engine works according to the following sequence :

- data completion :
whose goal is to complete the data of the problem, from the answers given by the user;
- activation of the objectives :
a sub-set of suitable rules, applied to the data of the problem to be solved, define the objectives (bearing capacity, settlements, stability, ...) which have to be activated ; saying that an objective has been activated, means that the campaign of geotechnical site investigations has to procure all the necessary information for calculating and reasoning about the corresponding aspects of the problem;
- geotechnical investigation depths :
an algorithmic module is then needed to determine the investigation depth for each objective, that is to say the depth to which the necessary tests will be conducted in order to answer distinctly the questions of each objective;
- set of the necessary possible tests :
the following phase consists in elaborating the set of the necessary possible tests to answer the activated objectives. The inference engine then develops an AND/OR arborescence, by replacing each objective by successive sub-objectives, then by tests, objective by objective and layer by layer, for all the layers met on the depth of investigation of a given objective.

The result of this work is a set of tests which indicates, for each objective and for each layer concerned, the set of tests which allow this objective to be satisfied, these tests being linked by "AND" or "OR" whether they are simulateneously necessary or interchangeable.

3. THE EXPERT SYSTEM ADOCC

3.1 Goals

ADOCC [5] is an expert system for the analysis and the description of the frameworks of current constructions (wooden frames, roofing supports, building shell infrastructure, superstructure work and foundations).

The aim of the expert system ADOCC is to establish descriptive explanatory notes for centres of interest (frame, building shell, foundations). We are attempting to obtain a qualitative description of the works in such a way that they are consistant with the two others.
For each of the centres of interest the system will provide, as a definitive document, a qualitative description of the work split up into a certain number of elements (concrete, steel, shutterings, facing, mixings...) . The result provides us with an intermediate stage which is the production of a set of sheets describing the work, on the basis of which the description will be made.

3.2 Nature and structure of the data base

The starting data and the facts are of two sorts :
- the principal information describing the project (building, ground, site environment and appearance) the answers to the corresponding questions are not obligatory ; values by default can be taken : the range of possible answers is proposed to the user;
- the geometric data obtained from the basis of available graphic documents. They constitute the support from which certain representative values are extracted.

All those data are introduced into the system answering a single questionnaire. The questionnaire is organised in subtrees concerning the building, the ground , the site, the environment and the appearance.

3.3. Reasoning process

The way of reasoning of the expert is structured according to the principal technical functions of the building's elements. We can define three macro-functions which can be split up into a certain numbers of functions and sub-functions
The MACRO-FONCTIONS are : SEPARATION - SUPPORT - COVERING

ADOCC uses sets of rules allowing the structure of the building to be analysed and rules to put the descriptive into shape. At the end of the process ADOCC can give explanations about the reasonings carried out , as well as justification for the absence of certain solutions.

4. THE EXPERT SYSTEM DESCARTES

4.1 Goals

To realise technical and economic evaluations during the pre-project phase we have elaborated a CAD system named X2A [6].In this system , like in many other CAD systems, the definition of the project is elaborated in two stages :
- the definition of the "wireframe" , based on geometrical facets decomposition. A facet is a horizontal or vertical plan, whithout thickness. It separates the various volumes that constitute the building.
- the differenciated covering by addition of elements into a catalogue. This operation consists of associating a technological component with each facet.

This second phase interests us in order to bring facility and time saving to the designer. Three levels of action could be envisaged to do this:
- the use of graphic editors for facets generation and elements connection ;
- the definition and the utilisation of commands of the covering allowing the designer to add an element to a set of geometric facets identified by a function;
- the deduction of technical solutions on the basis of choices.

This third point about technical solutions deduction is the main objective of DESCARTES[7] .

4.2 Nature and structure of the data base

The initial facts on which the reasoning is based are of two types :
- the descriptive data of the builiding located in the Data Base of X2A ;
- the choices and the constraints of the designer. This information represents the technical orientations intended by the designer. It is independent of the geometrical data and results from a decision taken by the designer.

The results of reasoning are the components characteristics that must verify the designer choices.
The whole data is connected in a single tree that puts together the building characteristics, the different parts of building, the associate components and their characteristics.

4.3 Reasoning process

The first stage consists of defining for each type of domain to be covered the type or the types of material compatible with the domain in such a way that there is coherence between the different technical solutions in the building. A domain is a set of facets answering a same function : floorboards, supports, cell separators, ...).

The second stage consists of defining the characteristics of the materials to be implemented to assure the desired performances. These characteristics are represented by a set of values (nature of the material, minimum thickness, mass, thermal coefficients) for each layer of a same component (wall, floor), according to its localisation, the functions it has to assume and the constraints imposed by the designer. The set of characteristics is the result of the expert system DESCARTES.
From this data it is possible to find in a data base the material or materials that verify the deduced demands, and to set up the different layers of the corresponding component. Then we could elaborate the covering commands that can be automatically exploited by the CAD system X2A.

5 SYNTHESIS : COMMON CHARACTERISTICS OF THE THREE EXPERT SYSTEMS

Despite the different purposes and goals of the three expert systems we can consider that they constitute a kind of family identified by a set of common characteristics.

5.1 Hierarchical structure of data

Like in many problems we found in the construction field, it is easy to represent the data set by a tree

5.2 Questionnaire to define a particular problem

To define its problem, a user must fill in (even partially) the tree, answering a questionnaire. This questionnaire may be automatically elaborated from the hierarchical structure of data.

5.3 Rules for data completion

For each expert system it is necessary to write a set of rules whose aim is to complete the data tree, exploiting knowledge about the data base. We can notice that this step is typically the way of working for the expert system DESCARTES.

5.4 Dynamic construction of AND/OR trees

For the CESSOL and ADOCC expert systems, the problem solution could be represented by an AND/OR tree. In this expert systems we found a set of rules whose aim is to construct the solution from the data base.

5.5 Explanation

For the designer it is very interesting to have a tool that can allow the solutions to be verified. In particular if it gives the answer to the questions " why ?" and " why not ?".

6. BATI-SHELL [8]

6.1 The utilization context and results of BATI-shell

It is important to distinguish the user of the shell, whose knowledge is used to construct an expert system, and the user of the expert system himself. They are respectively called the "expert" and the "user" (Fig. 1).

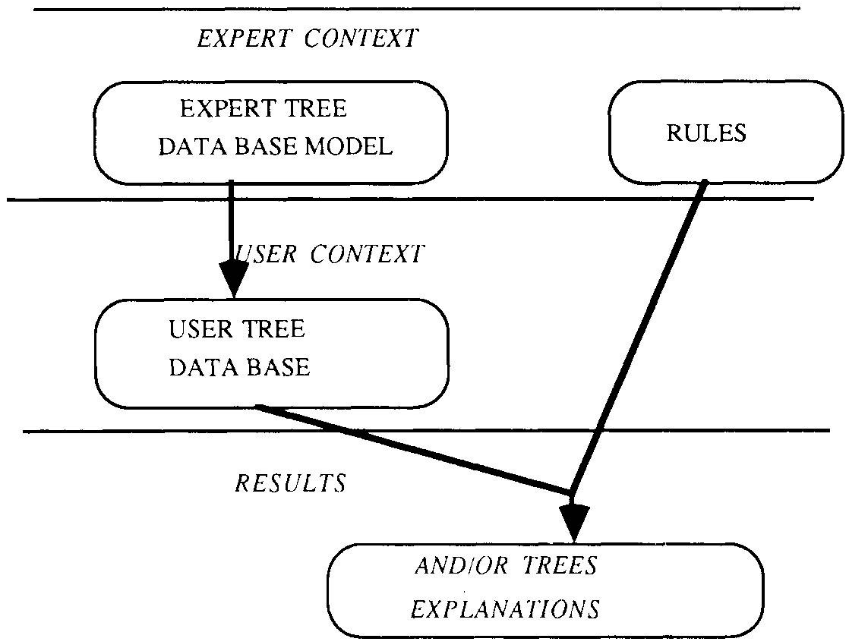


Fig. 1 The expert and user contexts

The expert has to provide the knowledge required for the construction of the expert system, that is to say a model for the data base and a set of rules.

Before defining the rules, the expert has to structure concepts that are necessary for describing the problems which belong to the same class. This structure becomes a model for the data base. The structure leads to a hierarchical relation between the concepts that is represented by a tree called the expert tree.

The system uses the information contained in the expert tree in order to construct a questionnaire that will be answered by the user. It is intended to acquire the data base of a particular problem. This data base is stored in a data structure called user tree.

We can distinguish in these trees, the terminal concepts (the leaves) and the non terminal concepts (the nodes).

The terminal concepts (in the user tree) are the only ones to which it is possible to associate values or sets of values. These values can be obtained from the user's answers to the questionnaire. In this case the expert has to define the concept as "to-be-asked" by the means of an attribute. Furthermore, the expert can define a condition under which the value will be asked to the user.

In addition to this, a sub-set of rules is intended to input or to modify the values of a terminal concept (see below). In this case the concept is "deductible". This possibility is very powerful because it is a means for eventual completion or modification of a partially defined data base.

The non terminal concepts represent more generic entities which can have many instances in the user tree. The rules' variables will refer to the non terminal concepts. For this reasons we will have variables which are typed ones.

Once the expert tree is defined, the expert can specify the rules. The rules will have to make reference to the concepts defined in the tree. The rules are divided in four sub-sets, each one intended to a particular objective.

The first sub-set is destinated to completing and to modifying the data base. For example this rule (in ADOCC)

If (Building destination) = (Level destination)
Then (Level framework) <-- (Building framework)

means that if the building's destination and the level's destination are the same then the value associated with the level's framework will get the value associated with the building's framework. Note that "Building" and "Level" represent variables that will refer to non terminal concepts in the user tree.

The other sub-sets of rules are dedicated to the construction of AND/OR trees which represent solutions (decompositions) of some problems (objectives).

The second one allows the problems to be selected that will have to be solved or studied by means of activation of objectives. For example (in CESSOL):

If (Excavation Stability) = wished
If (Lower Limit's Depth (layer n-1)) < Basement Height
If (Basement Height) > 6m
If (Lower Limit's Depth (layer n)) <= Lower Limit's Depth (layer f)
Then (Objective PASSIVE/ACTIVE Earth Pressure (layer n)) <- active
where layer n is the current layer and f the layer containing the fonudation.

The third sub-set of rules is used in order to construct the solution trees. The rules allow the problems to be split up into a set of sub-problems. The application of these rules leads to AND/OR trees.

Finally, the aim of the last sub-set is to cut off from the AND/OR trees the branches corresponding to inadequate or impossible solution aspects. A track of the application of these rules is stored in order to allow negative explanations to be produced. For example (in CESSOL) :

If (Ground nature) = gravel
Then (Static Penetrometer) <-- prohibited

Once the four sub-sets of rules have been applied, the system's interfaces give, for each problem all the possible solutions. They can also explain the behaviour of system, answering questions like "why ?" and "why not?".

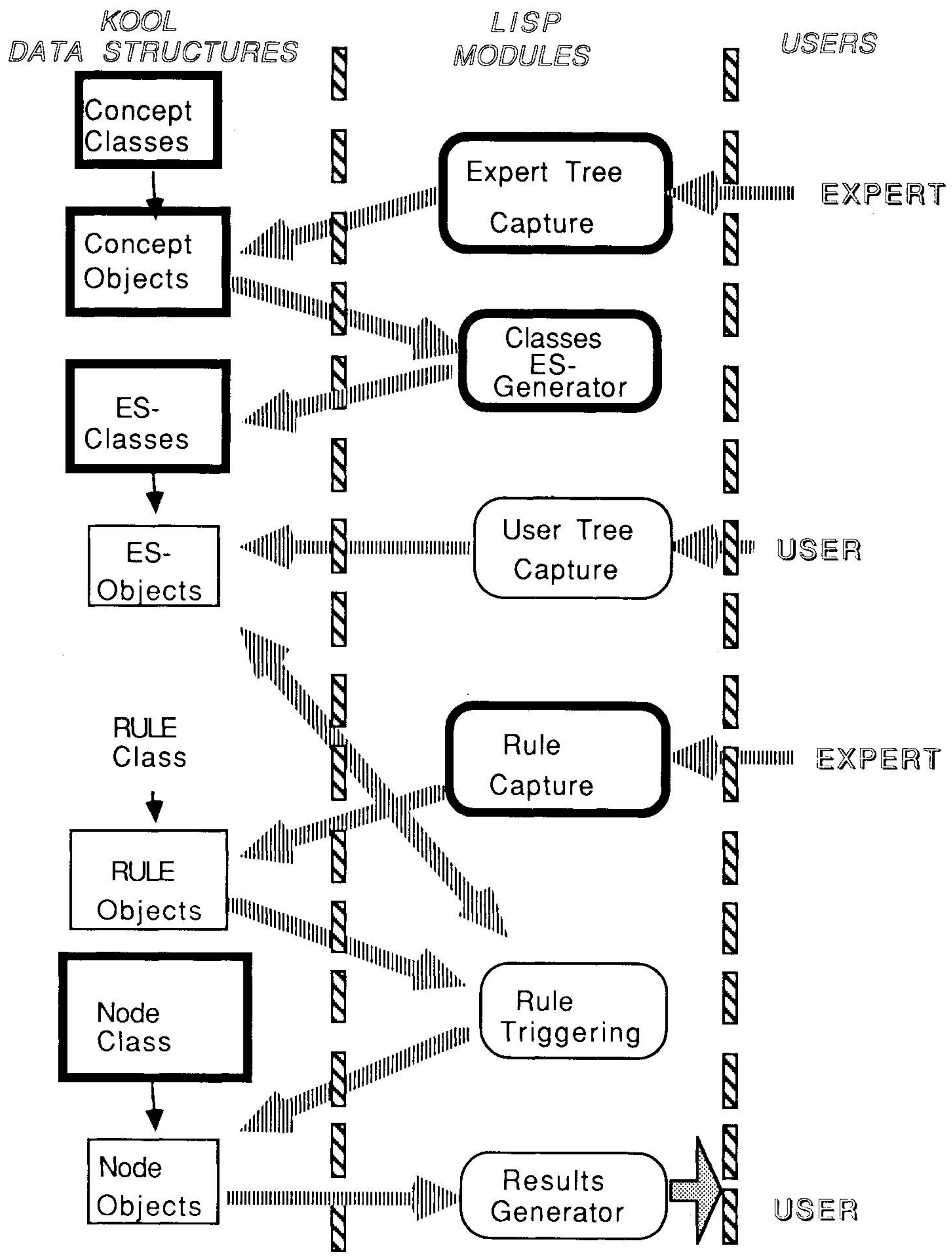


Fig. 2 Architecture of BATI-shell

6.2 Structure of the shell

BATI-shell is developed in KOOL, BULL company's development environment for expert systems construction. It consists on an object language and a inference engine of order one.

The shell contains a set of KOOL objects and LISP modules the function of wich is essentially to interface the users and the KOOL objects. The objects can exist initially or can be created dynamically during the system's working. The figure number 2 shows the relationship between the different KOOL data structures, the LISP modules and the users.

The concept classes define the classes initially know by the system. They represent the terminal and the non terminal concepts. The Expert Tree Capture and the ES-classes Generator modules allow classes to be created, that represent the current data base model. Using the ES-classes and the user's answers, the User Tree Capture module creates the ES-objects which represent the data base. The aim of the Rule Triggering module is to control the application of rules. The condition parts of the rules refer to ES-objects; at the opposite the action part refers to ES-objects (to complete the data base) or to Node Objects (to construct the AND/OR trees).

7 CONCLUSION

Using BATI-SHELL for the expert system DESCARTES development confirmed how it is easy to elaborate such systems in the field of construction when the analysis of the problem is well done. Effectively, the tutoring period needed by the experts of the domain (not specialized in computer sciences) to know how to use BATI-SHELL take only a few days. After this stage, the experts did not need the help of BATI-SHELL authors. They alone defined the base of facts model, constituted the different rules and obtained the first version of the expert system they expected.
At the present time, this shell seems to be a good way to generate a first version of expert systems. Despite the performances level of the result, mainly due to the environment of development (KOOL), that is not yet optimized.
In the field of construction it is current to find a hierarchical structure of data. However, for anyone who wants to elaborate a prototype of expert system, a shell like BATI-SHELL gives a friendly, easy way to obtain a quick answer.

REFERENCES

1. BOISSIER D., MANGIN J.C., MOUGIN J.P., An expert system for the specification of site investigation. PARK 83, London, September 1983.

2. LAURENT J.P., MOUGIN J.P., An application of expert system technics to geotechnics. Specification of site investigation for buildings. The CESSOL expert system. International Colloquium Computers in Earth Sciences, Nancy, April 1984

3. AYEL M. ,LAURENT J. P. , SOUTIF M. CESSOL, Un système expert pour définir des campagnes de reconnaissance géotechnique du sol. Congrès RF-IA de l'AFCET, Paris,1984, t. II, pp. 393-408.

4. AYEL M. ,LAURENT J. P. , MOUGIN J. P. ,MANGIN J. C. Original Explanation Abilities in the CESSOL Expert Systems Family. International Symposium on Knowledge Engineering, Madrid, Novembre 1985.

5. MOUGIN J. P. ,MANGIN J. C. ADOCC: an expert system to analyse and describe current building's frameworks. Séminaire Franco-Finlandais, Sophia-Antipolis, Octobre 1988.

6. X2A - Pour un système de C.A.O. en avant-projet sommaire de bâtiments. Rapport final de recherche . Marché n° 84.61.012.00.223.75.01 Direction de la Construction - MELATT Mars 1987

7. DUFAU J. ,MESSABHIA A. ,SILHADI K. Définition de la technologie de bâtiments dans un contexte de C.A.O. - Habillage par commandes et Système-Expert de déductions de solutions techniques. EuropIA, Paris,1988, pp. 261-272.

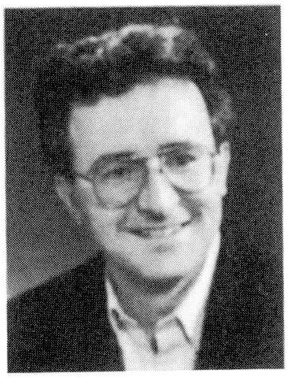
8. VESCOVI M., TOMASENA M., AYEL M.BATI-shell: un shell pour la génération de systèmes experts d'aide à la conception. EuropIA, Paris, 1988, pp. 161-178.

Development of an Advisory System for Site Managers

Développement d'un système conseil pour le chef du chantier

Entwicklung eines Beratersystemes für Baustellenleiter

Markus GEHRI
Dipl. Bau. - Ing. ETH/SIA
Swiss, Fed. Inst. of Technol.
Zürich, Switzerland



Markus Gehri, born 1953, received his civil engineering degree at ETH in Zürich. He worked for two years as assistant site manager in Munich and later for five years as site manager in Nigeria. Three years ago he came back to the ETH to do research work concerning ComputerAided Site Management.

SUMMARY
By use of modern computer methods we want the site management to become more attractive and efficient. The article describes the development work of an advisory system for site managers which shall fulfill different tasks emanating from a knowledge-based daily report. The aims and procedures will be explained. The intendent use of a meta-expert-system has lead to difficulties. The inadequacy of traditional shells for this task will be discussed and the necessity of developing a data model will be considered. An alternative attempt which is object-oriented will be presented.

RESUME
Notre but est de rendre la gestion d'un chantier plus attractive et plus efficace à l'aide des méthodes informatiques. L'article décrit le développement d'un système d'assistance pour la gestion d'un chantier par le chef de chantier. Ce sysème doit remplir des tâches différentes dont la base est le rapport journalier preparé à l'aide d'un système expert. Les buts et les procédés sont expliqués. L'introduction d'un méta-expert-système a été difficile. L'incapabilité de shells traditionels est traitée et la nécessité de créer un modèle de base de données est envisagée. Une variante de mise en application, orientée objet, est égalment présentée.

ZUSAMMENFASSUNG
Durch den Einsatz moderner EDV - Methoden soll die Baustellenführung attraktiver und effizienter gemacht werden. Der vorliegende Artikel beschreibt die Entwicklungsarbeiten an einem Unterstützungssystem für den Baustellenleiter, dasausgehend von einem wissensgesteuerfen Tagesrapport verschiedene Aufgaben erfullen soll. Es werden die Ziele und die Vorgehensweise erläutert. Die vorgesehene Einführung eines Meta-Expertensystems hat zu Schwierigkeiten geführt. Unzulänglichkeiten traditioneller Shells für diese Aufgabe werden besprochen und auf die Notwendigkeit der Erstellung eines Datenmodells wird eingegangen. Ein alternativer, objektorientierter Ansatz wird vorgestellt.

Preliminary Remark:

The following article describes a project at the Institute for Planning and Construction Management (Swiss Federal Institute of Technology Zurich) that is still in progress. At the time of writing this paper I am evaluating the software which is to be used. The essay describes therefore mainly the preliminary work and the experiences gained with expert systems and expert sytem shells.

1. WHAT WE WANT TO DO

1.1 Goals

The building sites are generally managed by one person only (site manager or foreman) whose status of knowledge can vary according to the size of a site. The most important task of these managers is to keep their sites running. This leads sometimes to a neglection of the administrative and economic aspects.

Our basic idea is to run all the building sites of one contracter as independent profit or cost centers. This implements, that the building site manager should be aided in the best possible way by all available means to fulfill his work in the shortest possible time and with a basic competence.

The following of the site manager's jobs should be supported:

- *To gain and keep the general overview by concentration, registration and clear presentation of the necessary information.*
- *Analysis and decision supporting by comparing and evaluating different alternatives of acting.*
- *The disposition will be improved due to high flexibility without loosing the link to planning and economical constraints.*
- *The controlling task shall be systematisized by building in minimal requirements which can be varied by the site manager according to his needs.*
- *The time to do creative and demanding work shall increase by taking over as much as possible of the routine (administrative) work by the computer.*

Additionally we try to improve the access to existing applications such as bidding and project planning programms by providing a common user interface. By incorporation of new solutions (e.g. graphic, expert systems or simulation packets) the building site computer should be able to become the central element of the construction process concerning organisation and administration.

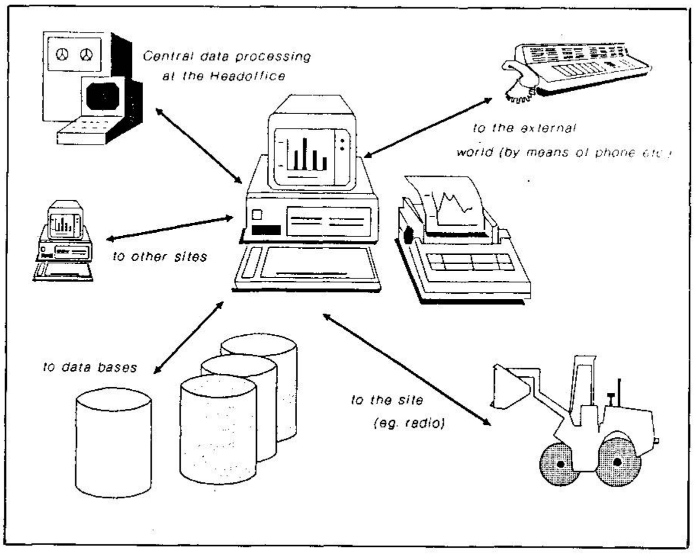


Fig.1 PC as central element

1.1 Analysis of the site manager's job

The tasks of the site manager are among the most varied (and most satisfying) that arise during a construction process. We examined the following aspects which we got from our own experience, from books or from discussions with other people:

- *Which tasks have to be settled by the site manager and how can these tasks be classified?*
- *What information is used at what time by those engaged in the building process, how accurate and in what manner has it to be?*
- *For which tasks and how far can we already offer computerised solutions?*

Detailed listings were made of the analysis of the site managers tasks and the flow of information. They cover a big part of all possible aspects. Hereby we found out that a splitting of the tasks into rhythme, importance and expenditure is useful. It is easy to find a measurement for the rhythme and the expenditure. The importance, however, is always in relation with urgence and needs (not to forget the site manager's personal affinity that makes him select one job out of a big heep of unfinished works).

The flow of information was split into necessary and useful information and into emitter and receiver of information.

Emanating from these investigations we consider a computer aid as being useful where:

- *data processing and/or calculations have to be done,*
- *the site manager has to write, to report or to draw a diagram,*
- *solutions have to be found and proved,*
- *plans and results must be analysed, compared and estimated.*

1.2 The basic idea

We ought to provide the site manager with a computerised assistant with advisory functions. (*This "domain assistant" will in the future eventually together with an "office assistant" and a "communication assistant" form the only interface between user and computer [1]*). This assistant serves him, in relation to his daily routine jobs as an multipurpose aid to manage his tasks.

We imagine the adviser to be a consultatively useable instrument which opens the way (based on knowledge) to how to deal with the most important problems of the site manager and which offers the necessary modules (as far as implemented) for their treatment. The adviser should help to supervise all incoming and outgoing information, the costs and to a certain point the technical problems of a site and it should indicate the manager arising problems as early as possible. Moreover the system should support the manager in time management and as far as necessary remind him the treatment and fulfilling of jobs.

It should be possible to connect some desired applications with the basic module in such a way that they can be called and treated with a standardized user interface. That means that the adviser himself calls external cooperators which can deal with calculating or data intensive tasks (*programs*) or which are able to advise him (*expertsystems*) if he likes to base his work on expert's experience.

In order that such an expert system will be attractive for the site manager, a strong stimulus for the daily use has to be created. One argument will be that the daily administration jobs can be done computer-aided to make them

-*faster / more efficient,*
-*more comprehensive / more systematical,*
-*qualitatively better.*

Furthermore all the information proceeded by the adviser will be of easier access in case of further use and treatment.

The function of the basic module is to direct the access with all other modules, perhaps to choose an appropriate data bank or knowledge domain and to maintain the dialogue with the user of the system. Therefore it can be called a meta-expert-system.

To provide the system with all the necessary information about the proceedings on the site, a regular (if possible daily) consultation should take place.

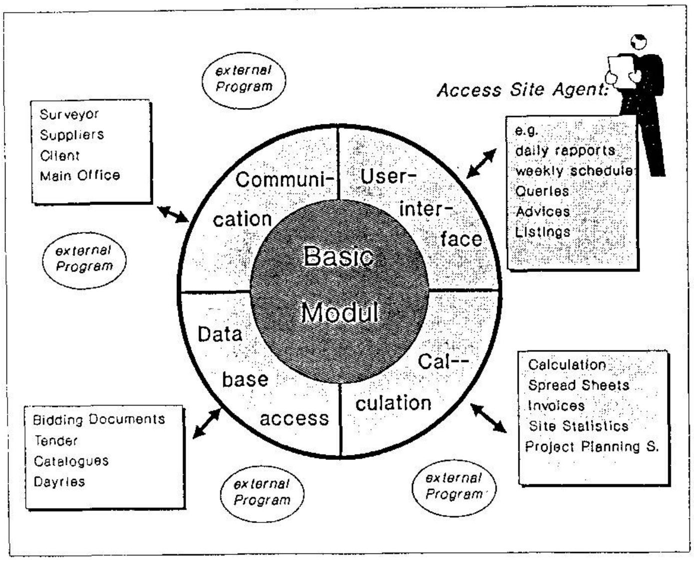


Fig. 2 The site manager's adviser

We imagine the following daily routine consultation in the sense of a "*management report*"

- *The goal of the "meeting" is to prepare a daily report for the own overhead business management or perhaps for the customer, too.*
- *In the course of the meeting the actual situation of the site is "discussed". The system has got a dynamic access to the "history" of the site and, if wished to the "history" of other sites of the firm (wich information refers to the "history" has to be decided later).*
- *The system asks all information from the site manager which is necessary to write down a day report. If possible the information is derivated from the "history" (e.g. "Is the weather as it was yesterday?").*
- *If a certain information is not at hand (e.g. the foreman's daily report) the system keeps it pending and asks for it in one of the following sessions. A subsequent input should be possible with a shortened procedure e.g. by a quantity surveyor.*
- *Additionally detailed working plans for the next 2 - 4 weeks should be produced in the sense of a "rolling planning".*
- *Because the system should have at hand the bid, the project plans as well as the actual capacity information and progress reports, it is possible to advice the site manager in his planning work.*
- *finally the system can present and file the results of a session in any desired way or form.*
- *It is possible that during a session check backs to other systems and persons can be arranged.*
- *After each session, a list with all the actually pending jobs of the site manager can be printed out.*

2. EXPERIENCES WITH ES

2.1 First Steps

At our Institute we developed (partly in cooperation with the University of Innsbruck) four expert-sytems, using the shell *XIplus*.

The first one concerned the conversion of a part of the SIA-Norm 118 *(consequences resulting from change orders caused by the client)*. In the whole we needed 70 rules, thereof 34 rules served the control of the lapse of the consultation. The system was equipped with help-functions and explanations, and during the following attempt to bring it into use among our students we experienced that the already tested system broke down at the moment when all the helps and explanations had been called (memory overflow).

Three further expertsystems were built up at the University of Innsbruck. They help with the preparation of building sites that means the planning of stationary equipment. The following topics were worked on:

- crane disposition, *the system was split into 16 modules with 158 rules, thereof 58 rules concerned the consultation control.*
- accommodation of the crew, *the system was split into 5 modules with 124 rules, thereof 12 rules concerned the consultation control.*
- Dimensioning of the concret mixing plant, *the system was split into 6 modules with 87 rules, thereof 19 rules concerned the consultation control.*

Three main points came up during this works:

- *The more narrow and specific the domain was the more interesting it became for the enduser. That was the result of the fact that special cases could be included and a real knowledge transfer was possible. Contradictionary we found out that the application became boring with a too narrow domain. Who is going to buy a shell just to find out if he should lodge his workers in a hotel, in mobil containers or in temporary barracks.*
- *The work involved to get a reasonable course of the consultation is sometimes enormous with rule-based shells. It became evident that it is of high importance to structure the rules and to know exactly the derivation mechanism of the interference machine.*
- *The subdivision of the applications into modules was necessary because the active memory of small machines (PC) is very restricted. The resulting difficulty consists in planning these modules as far as possible as homogenious domains because the data transfer between the modules is only possible in one direction and a backtracking over the module limits is not possible. Research efforts are made to push forward this modularity by means of a "blackboard" architecture [2], as to our knowledge no commercial shell supports these possibilities.*

Our experiences with these minor applications can be resumed as follows: the developing of an expert system, even of very small applications, needs analysis. It is important that the dialog control is thought over very carefully because everything that appears on the screen and the time when it appears can be directed only indirectly through the interference machine. This is contradictionary to the procedural (algorhythmic) approach.

One of our experience was also, that the whole backtracking mechanisme (WHY...?) which is considered a central element of expert systems, was only a good debugging-aid for the developer. Within these small systems it was rarely used by the enduser or only during the first run due to curiosity.

As a consequence from these experiences we looked for a "big" system to develop our advisory system for the building site manager. For further student works at the university of Innsbruck we are going to exchange the elderly XIplus against another PC-shell. We wish to get more functions and more capacity as well as a licence-free runtime module which can be tested by a running building site without beeing forced to buy additional copies of the shell.

For the development of the advisory system we got the shell TWAICE from Nixdorf running in UNIX and which is not (yet) available on a PC-platform.

2.2 The Shell TWAICE

TWAICE has, compared to other shells, some peculiarities which I like to mention hereunder:

- *The shell is based completely on PROLOG. In some way it can even be considered as a programgenerator to write PROLOG-programs. The advantage hereof is that the interference mechanisme is very fast and powerful (with even the possibility to ask WHY a fact was NOT concluded). PROLOG has, however, always some traps ready for the programmer.*
- *TWAICE is a rulebased shell wich is supported by an object-hierarchy. The rules refer to attributes of the objects which can adopt one or more values even with different probabilities, too. The objects (and the attributes) of TWAICE have got a predefined number of slots which can be filled with certain information (e.g. default values for an attribute or the indication whether it is permitted to ask for the value of an attribute or not) or which can be used to build up the rule base (e.g. EXIST: does the object exist?).*
- *The flow of a session can be controlled by an object hierarchy, rules needn't be written therefore. The inference mechanisme is described in figure no 3.*
- *Under some conditions predictated by the developer (e.g. rule-directed) TWAICE can create several instances of the objects that are defined in the kowledgebase (e.g. an engine has got 4 pistons). All of them get the same slot values and the same rulebase is used to evaluate their attribute values.*

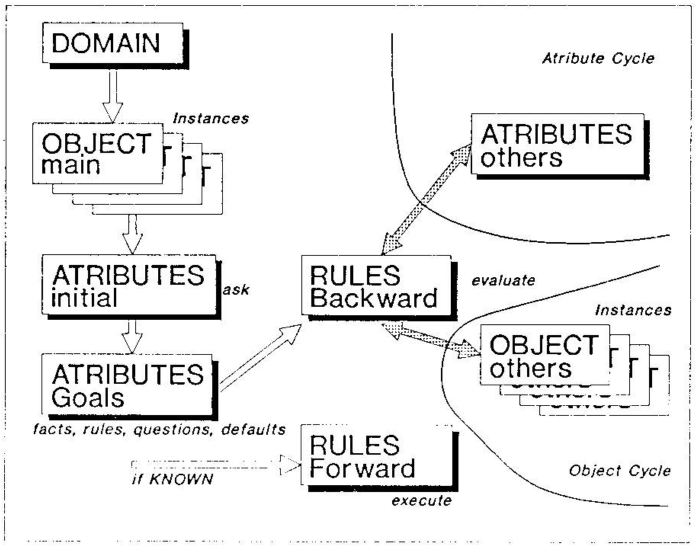


Fig.3 The Inference- Engine of TWAICE

- *TWAICE offers a lot of primitives (PROLOG- predicates), besides C-primitives can be called. The system therefore is very powerful but it requires for some knowledge at least what concerns PROLOG.*

2.3. Experiences with the Shell

First of all I transferred the XIplus-Model "SIA 118" and discovered that I needed less rules, but on the other hand the user interface was a lot more complex and difficult to program than I was used to from the PC. Everyone who is used to colours, graphics and mice to interact with his PC will have a lot of difficulties.

Another problem was the PROLOG specific treatment of arithmetic expressions or the syntax of procedures (which are necessary even for simple, non-automatic generated questions). These (beginner) problems are not described in the manuals, but a short training with PROLOG and the study of the examples were sufficient to help solving most problems.

But because some more PROLOG-specialities (e.g. the special treatment of the negation NOT) were integrated in TWAICE, the full function of the shell can only be used with some knowledge in PROLOG. PROLOG-Experts, however, prefer a direct implementation of their expert systems in the pure language.

Because the above mentioned possibility of instantations coincides very well with the concept of a meta expertsystem that is newly started every day, I pushed forward quickly into this field of the shell.

To test the capacity I made it run three models of different size in an endless loop until I got a range overflow or until the time to get an answer was too long. Figure 4 shows the results.

Looking backward, we can say that the number of facts limited the models, whereas a fact can be, for example, a generated object or a traced attribute. Even if it were possible to upgrade the system's hardware, it would not be possible with an information input of over 100 facts daily to treat a building site as instances of several individual days.

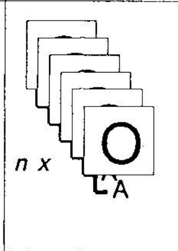
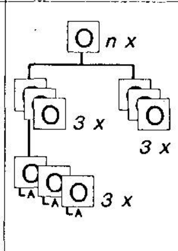
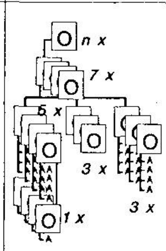
TWAICE Capacity Test			
	TEST 1	TEST 2	TEST 3
MODEL			
No generated	1445	116	6
Time for 1st	ca. 1s	19s	300s
Time for last	18s	2700s	unknown
Break by:	Overflow	time out	time out

Fig. 4 TWAICE Capacity test

A next trial would be to write the facts that are no longer used into a database and to read them in again when necessary. Although this system would be possible, we would resign many possibilities of the expertsystem attempt. The reading in into the expertsystem environment has to be selective according to predifined critirias.

Within our Institute, we dispose of some experience in handling PC database systems, but due to the fact that the shell is based on an UNIX environment, the database had to be based onto this platform as well. Therefore I decided to resign on further tests with the TWAICE solution.

The question was then, if we could continue with a declarative attempt for the basic system.

2.4 Declarative or procedural?

One of the advantage of expert systems is that the base of knowledge can be completely unstructured, what means that we talk of a declarative environment. Each knowlegde element has got access (through the interference mechanisme) to each other knowledge element at any time of the session. That implements a big workspace with reserves to store new information (in the case of TWAICE the new instances).

Opposite to this we get the procedural or algorhythmic approach. Here the system developer has to know exactly what has to be treated at what time and where, if necessary, the parameters can be called and stored.

The advantages of the declarative programming are most convincing where, by means of small programming elements, a high variety of results can be achieved.

A well known example is the PROLOG-predicate:

Member (element, list)

which can be used as a test procedure, access or generating procedure.

However, if an enduser works with an expert system the goal of the consultation is already defined at the beginning of the session, a lot of systems are explicitly capable to attend one goal only, e.g. to discover the fault of an engine or to find the ideal combination of machines for a special use.

For our construction manager's advisory system we decided to resign on shells as a master system and we try to master the data flow in a more traditional way. In the very future we shall try to come to a solution for this problem by means of an object-orientated attempt.

2.5 What is problematic with shells?

Shells are offered today in great variety, in all price categories (the expensive ones are called development environments) and in all comfort degrees. All together have one thing in common: the developer needn't worry about the inference process, he "only" should build up the knowledge base.

But all the same, the knowledge engineer has to think about the user interface and the content of the application, should his application ever come into use. Besides, he has to know his shell very well, LISP-based shells behave differently as PROLOG-based or C-based do.

The hundreds of expert systems which are often mentioned today, e.g. DuPont [3], are often small applications which are comparable with decision tables, they often cannot be maintained and they do not make special demands on in- and output.

On the other hand, the shells are ideal aids for novice or, referring to computer science, untrained developers (in our case the students) to get useful solutions with a relatively small expenditure. Seen from this side, they represent for the logic programming what spread sheets represent for calculating tasks and minor database applications: An aid that brings the computer capacity nearer to the enduser, but not a working instrument for the computer engineer to build up bigger applications.

3. FURTHER PROCEEDING

3.1 Object orientated approach

After having come to the conclusion that an expert systems approach, as well as any other software project, predicts a careful analysis and especially a modelling of the tasks and the data flow, I split the building site model into the following three models: cost model, resource model and administration model.

I like to continue with the definition of these models in an object-orientated environment as independent objects and to write down and test the therefore necessary procedures. At the moment of the redaction of this paper (May 1989), these jobs had just started (with SMALLTALK V), they are encouraging even though difficulties with the data bank capacity rise again, but they appear now in a familiar (PC) environment. I hope to be able to enter more deeply into the further proceeding of the job at the time of the congress.

3.2 Cost model

The cost model has to treat the material and the immaterial cashflow of the building site (figur 4). The essential requirement of each consideration of the building site as a cost and profit center is that the site manager is always clear about his cost and efficiancy.

The output is described in the tender and bidding documents and provided with costs in the calculation. Throughout a continuous consideration of the forthcoming costs, a relation can be established between the real output and the SHOULD-costs.

The derivation can be explained as a fault in the calculation, as a justified or unjustified falling-off in output compared with the assumptions or as a rise in price. (Herefore the use of an expert system would be nice).

This area of the construction-site management is rather well known, we worked on it for some time [4].

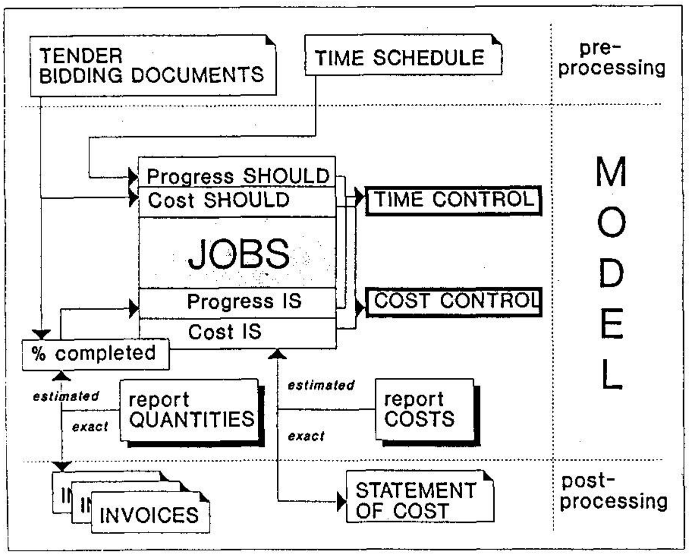


Fig. 5 The Cost Model

Difficulties rose only with the estimation of the actual progress and the therewith connected outstanding, additional expenditure as well as with the different presentation of the internal cost calculation and representation.

Therefore the definition of the *jobs*, as an integrated and finished output unit shall be integrated [5]. Jobs, macro-processes or, as a students called them once with an appropriate definition "building sites within the building site", have the properties that they are much more handy for any controlling approach as the traditionally used costruction labour keys (same job at different building parts) or pure physic block- or storey-splitting.

Jobs cannot only be used in the disposition but also in the weekly planning, the surveying and the estimating of the output.

3.3 Resource Model

The second important task which is the building site manager's duty is the disposition of the available machines and people to the jobs that have to be done on site. The bidding documents give us the points, but now, the spent hours and the real stand of output have to be considered in the weekly disposition. The model provided for looks as in figure 6.

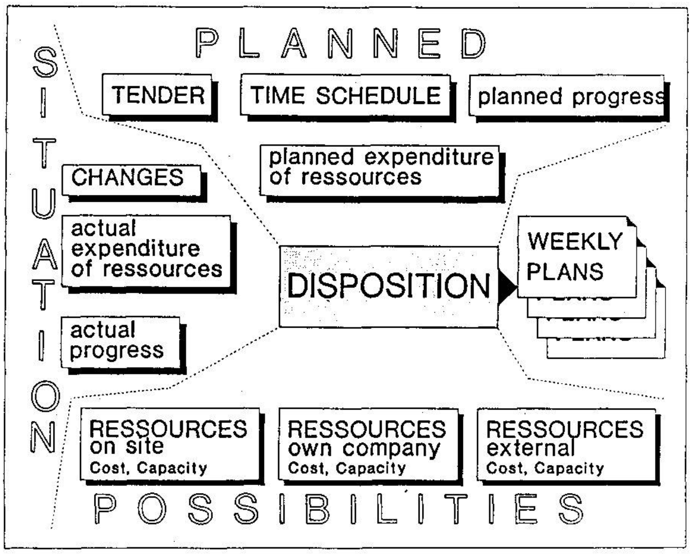


Fig. 6 The Resource Model

3.4 Administrator Model

With the administrator model we are going to spare the most of the site manager's time and therewith creat the biggest profit. We intend to concentrate all the outgoing information of the site in a central model and we shall read all the incoming information into this model whenever feasible. The working out of this model is postponed for the moment because it has to submit the two main models and because it is able to do so. (figure 7).

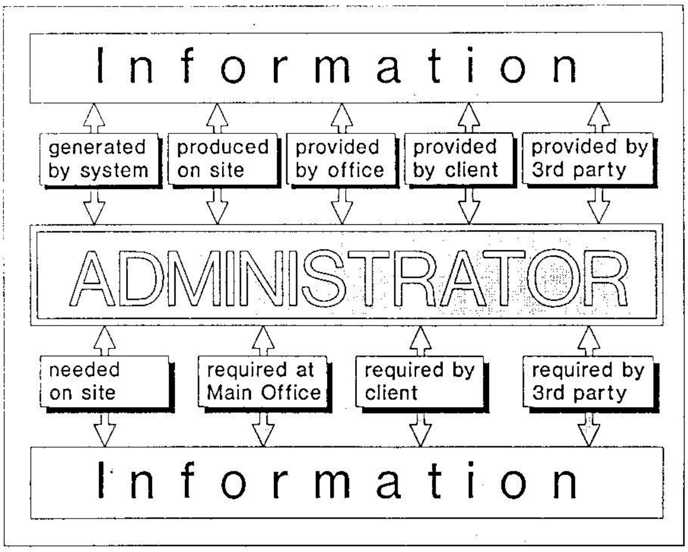


Fig. 7 The Administrator Model

REFERENCES

[1] GMD, Computer als Assistenten, Journal Führung und Organisation, June 1987

[2] HAYES-ROTH B., A Blackboard Architecture for Control, Artificial Intelligence, 26/1985

[3] various authors, Application Corner, PC AI, 1987-1989

[4] STRADAL O., Short Term Management on Building Sites, IABSE Journal, February 1981

[5] LESSMANN H., PC-Einsatz für die Baustellenkontrolle,IBETH Publikation, April 1987