EXPERT SYSTEMS AND COAL MINING

By
Van U. Nguyen and Ernest Y. Basfi
Department of Civil and Mining Engineering
University of Wollongong, NSW 2500

ABSTRACT: In this paper, impact of expert systems development is examined from the coal mining point of view. Some general concepts about expert systems are explained with a view to identifying possible beneficial applications of expert systems in coal mining.

It can be easily recognized that the practice of coal mining engineering involves a very large proportion of non-algorithmic and non-analytical procedures. In the investigation and design phase, a large amount of data and information have to be collected, which although can be processed by numerical and statistical methods, still require interpretation and subjective input of an expert. In coal winning processes, a wide variety of engineering operations and methods ranging from the selection, usage and maintenance of mining equipment to strata control and management of the mine workforce is involved. The operation and management of coal mining, despite recent advances in computing techniques still largely rely on input of experienced mine personnel like underground managers and shift foremen and in essence constitute a body of empiricism and good engineering judgement. This is perhaps most strongly supported by the fact that the First Class Certificate rather than a high degree in engineering or management from a university is recognized as the basic ticket for an engineer to enter the mine management ladder.

However, good mining engineers and experts are not always available and even if they are able to stay around for a very long time their judgements are not expected to be reliable or to get better all the time. Furthermore, with the advent of technology expert system is more likely to be developed in a narrower field (or domain) and joint contribution from many experts for the solution of a particular mining problem becomes most desirable.

The essence of application of expert systems in coal mining, and mining engineering in general, is thus to provide means to capture valuable knowledge of an expert or experts and to give consistently a better solution to a particular mining problem.

Referring to Figure 1 depicting the parallel development of computer science (and artificial intelligence) and coal mining practice in this country, it can be seen that coal mining practice can be grouped into 5 different generations like computer development. The first generation began with vacuum-tube computers at about the same time as the first longwall was installed at Aberdare, and the much publicized fifth generation characterized by expert systems is currently in closer steps with CAD-CAM applications in coal mining. The two previously unrelated developments tend to converge more rapidly as the generations evolve.

EXPERT SYSTEMS

The concept of expert systems emerged from researches in the field of Artificial Intelligence (AI) generated from enthusiastic attempts to render the computers capable of thinking and acting like human beings. The application branches of AI that can be easily identified include image-pattern recognition, speech generation and recognition, computer vision, robotics, and expert systems. Although the main objectives of AI are still far from realization, some practical benefits - though somewhat limited - have already been derived from these researches and today, an EXPERT SYSTEM can be defined...
<table>
<thead>
<tr>
<th>Hardware / Software</th>
<th>COAL Mining Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial Intelligence</td>
<td></td>
</tr>
<tr>
<td>1940 - 1947</td>
<td>Vacuum tubes relays COLossus, ENIAC</td>
</tr>
<tr>
<td></td>
<td>Logic of neural networks</td>
</tr>
<tr>
<td>1948 - 1955</td>
<td>Tubes, delay lines, drums IBM 701, 702, 650</td>
</tr>
<tr>
<td></td>
<td>Cybernetics Samuel's checkers player</td>
</tr>
<tr>
<td>1956 - 1963</td>
<td>Transistors &amp; Core stores IBM 704, 7090, 1401 UNIVAC 1103, PDP 1, 4, 4.5 FORTRAN, COBOL, ALGOL, BASIC Learning Machines LISP 1.5 Dartmouth AI conference</td>
</tr>
<tr>
<td>1964 - 1971</td>
<td>Large scale Inte. Circuit IBM 360, 370/168 6500 Data Base, Time sharing Interactive terminals Semantic nets, FUZZY sets Speech synthesis DENDRAL, UNIX</td>
</tr>
<tr>
<td>1972 - 1979</td>
<td>APPLE Microcomputers VLSI, Supercomputers Virtual memory IBM 370/168 Numerical methods in Rock mechanics PROLOG, KYCIN, Visicalc</td>
</tr>
<tr>
<td>1988 - 1993</td>
<td>Optical logic and storage Parallel processors AI in routine use Audio and visual sensors</td>
</tr>
</tbody>
</table>

Figure 1. Parallel developments in computer sciences and coal mining practice

The AusIMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1988

249.
as a computer program that can "extract" knowledge from human experts and then deduce the rules or the methodology that the human expert, consciously or not, is using to solve new or similar problems in the same field. In other words, an expert system is a special computer program, normally user-friendly, encoded with facts and knowledge about a very restricted domain, that can mimic a human expert in making intelligent decisions or providing practical solutions to a specific problem within that domain, through interaction with the knowledge base. Examples of expert systems include a program to prescribe antibiotics, an expert system to diagnose equipment failures, to classify patterns in images, to configure computer systems, etc.

Application of expert systems in coal mining is thus dependent on the central postulate which says that systems can achieve expert performance from rich diverse knowledge bases rather than clever algorithms. An expert system is therefore different from a conventional computer program in that it focuses more on exploiting symbolic manipulation, and attempts to "compute" a sequence of linguistic and logic strings representing the steps used by an expert in the solution of a problem.

A typical expert system comprises four main parts:

(i) The knowledge acquisition module
The knowledge acquisition module is a sub-program used to construct the knowledge base. The module processes information derived from extensive interviews with the expert to elicit verbalizations of rules and of highly detailed facts. There are currently many commercial expert system programs for general applications on the market, called expert system shells which have a knowledge acquisition module, an inference engine (see below), but are empty on the knowledge base.

(ii) The knowledge base
The knowledge base of an expert system contains the information used by the expert system in working out the solution of a problem. It is usually an extension of a conventional data base, and stores in addition relational information in the form of axioms and rules of inference.

One customary way of representing the knowledge of expertise in the data base is to use rules having the form

\[
\text{IF } \text{<condition>} \text{ THEN } \text{<action>}
\]

An expert system generally consists of a hundreds (and sometimes thousands) of those rules, in some way being acquired by the knowledge acquisition module and representing the expert's knowledge.

A block diagram of a typical expert system using facts and rules is shown in Figure 2.

![Figure 2. Expert system block diagram](image)

Other forms of knowledge representation, apart from a body of "IF...THEN" Rules, include:

* The use of symbolic languages like LISP and PROLOG to encode expert knowledge in the form of first-order predicate logic. In programming with LISP or PROLOG, the user tends to tell the program WHAT to compute rather than HOW to compute like procedural languages such as FORTRAN, Pascal and BASIC.

LISP was invented at MIT over 25 years ago, and in its coding a LISP program and the data used have the same form and can be treated somewhat interchangeably. This feature allows a LISP program to modify itself or other programs while it is being run. A version of LISP is used in the popular package AutoCAD (trademark of Autodesk Inc.) as macro language to customize a computer-aided drawing.

PROLOG was invented around 1970 at the University of Marseille in France. PROLOG is a major competitor of LISP and is preferred by the Japanese in the Fifth Generation Project. The basis of PROLOG is the notion of logic programming in which computation can be
viewed as controlled logical inferences. The following serves as a simple example on the use of PROLOG:

which (x + times(15 2 x)) = 30
which (x + times(15 x 30)) = 2

i.e. which will sort out the value of variable x regardless of the position of x in the statement.

* Network representation (Guillian, 1968). In a semantic network, facts are represented as entities which are interrelated forming a graph. As the network has explicit associations between entities (like circled events in a critical path network), the graph can be used for making direct inferences.

* Frame (Minsky, 1975). In the frame scheme, a complex data structure containing facts (slots) represented in a declarative form. Frame is possibly most suitable for geological classification systems.

(iii) The inference engine

The inference engine is another sub-program that scans the database and/or the knowledge base to extract rules applicable to the current problem in the course of searching for a solution. It is again a clever extension of the plain database retrieval system. The inference engine can answer questions in has not encountered before by inference from the facts and relational information contained in the knowledge base.

The spread of expert systems applications in the technological domain is at present very rapid, and expert systems applications include:

* Diagnosis
* Classification
* Prediction
* Teaching and learning
* Checklist
* Demonstration vehicle
* Interpretation
* Monitoring
* Planning and design
* Consultancy
* Refining expertise
* Modelling

Historical Expert Systems

MYCIN (e.g. Shortliffe et al., 1979) is perhaps the most historically well-known expert system. It was designed to diagnose infectious diseases, such as bacteremia and meningitis, which are normally complex and require urgent treatment. The important contribution of MYCIN to expert system methodology rests with its subjective CERTAINTY FACTORS used to combine different, sometimes conflicting evidence. Certainty factor is defined as a subjective assessment scale ranging from -1.0 (completely false) to 1.0 (absolutely true) assigned to various premises or evidence involved in the inerring process to provide the final conclusion with some degree of belief that the conclusion is true or correct. The rules of manipulating certainty factors are very similar to those of fuzzy sets (Nguyen, 1985) in that the conjunction (or linguistic AND) of several facts is represented by the MINIMUM of the relevant certainty factors, and the union (or linguistic OR) the MAXIMUM. For example, a MYCIN-like expert system for the prediction of an election result may have the following rules in its knowledge base:

Rule 101
IF x drives a Commodore
AND x reads the Australian
THEN x will vote Liberal

Rule 102
IF x dislikes the Australian card
OR x wants Australia not to recognize the new regime in Fiji
THEN x will vote Liberal

We assume a mining engineer in the State of Queensland:

(101a) drives a Commodore → certainty of 0.8
(101b) reads the Australian → certainty of 0.75

(the combined certainty factor is 0.75 being the Minimum (AND) of the two)

(102a) dislikes the Card → 0.40
(102b) wants to leave Fiji alone → 0.60

(the Maximum (OR) of the two is 0.60)

We can therefore say that the mining engineer will vote for Liberal with 0.75 certainty by Rule 101, and 0.60 by Rule 102. Suppose the foregoing observations are all the evidence we have had about the mining engineer's habit, the overall measure of belief combining evidence from both rules according to the MYCIN formula will be:

The AusIMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1988

291.
\[
MB[\text{LIE}_1\&\text{LIE}_2] = MB[\text{LIE}_1] + MB[\text{LIE}_2].(1 - MB[\text{LIE}_1])
\]
\[
= 0.75 + 0.6 \times (1 - 0.75) = 0.75 + 0.6 \times 0.25 = 0.90
\]
i.e. basing on the observed evidence, it can be inferred according to Rules 101 and 102 of the system, the engineer is a liberal voter with a measure of belief of 0.90.

It should also be noted that the inferencing architecture of MYCIN belongs to a group called action-driven or backward-chaining, that is the system starts from a goal (a hypothesis) and working backwards tries to prove through deductive inference that the goal is indeed true. This technique is in contrast with condition-driven or forward-chaining method as used in \text{META-DENDRAL} (Buchanan and Mitchell, 1979).

Other well-known expert systems include:
- \text{PROSPECTOR} (Duda et al., 1979) uses Bayesian statistics to combine different pieces of evidence in assisting with the analysis of information related to geological exploration. Funded by the U.S. Geological Survey and the National Science Foundation, \text{PROSPECTOR} was created specifically to provide geologists in the early stages of locating a site for ore-grade deposits. The data structure of \text{PROSPECTOR} is based on a semantic network, i.e. different from the \text{IF...THEN} structure.
- \text{SACON} (Bennett and Engelmore, 1979) is a system built with a MYCIN-like inference engine and advises engineers in the use of a large, general-purpose structural analysis program.
- \text{SFERIL} (Ishizuka et al., 1981) was coded by a team of Civil and Computer engineers from Purdue University. \text{SFERIL} departs from the MYCIN rule of inferring uncertain symbolic data and instead employs the Dempster-Shafer theory of evidence. \text{SFERIL} is used to assist the engineer in the assessment of damages of existing structures subjected to earthquake excitation.
- \text{WELDSELECTOR} is an expert system designed by the Colorado School of Mines (Wolfgren et al., 1987) to assist welding engineers in the selection of the proper material for welding. \text{WELDSELECTOR} was developed from an expert system shell (PERSONAL CONSULTANT) developed by Texas Instruments Inc.

\text{Potential Applications of Expert Systems in Coal Mining}

Potential applications of expert systems in coal mining have been identified to include the following:

(i) \text{Mine Monitoring System}

Computerized monitoring and control of equipment is becoming common in the coal mining industry. Parameters that can be monitored include those of power system, ventilation network, transportation and those required for equipment maintenance, as well as noxious gases such as methane and carbon monoxide in fire detection. Very experienced mine personnel are usually required to interpret the numerous data acquired by monitoring systems and to make appropriate decisions. In the absence of experienced mine personnel, an expert system may be incorporated into the mine monitoring system. Recent examples of this class of application include a methane control expert system known as \text{METHPRO} designed by the U.S. Bureau of Mines (King, 1986).

(ii) \text{Computer Aided Design and Planning}

Computation in strata control problems is a traditional area that requires the use of a computer. With expert systems it is envisaged that the front end of a computational design program will become more refined in providing expert advice on solution alternatives. For example, a roof support expert system can give sound advice on the choice of roof bolts or reinforcement based on information available on the roof conditions prior to design computation to determine the actual material and labour requirements of the chosen reinforcement system.

At the other end, output graphics can be complemented by another expert system that facilitates and speeds up the design and planning procedure. The merger of graphics and expert system methodology can also provide means for hazard zoning and complete risk assessment.

(iii) \text{Diagnosis}

Expert systems can offer a systematic procedure of diagnosing faults and
breakdowns of mining equipment or assessing potentially dangerous instability conditions or local damages. Suitable remedial measures can also be included in the expert systems.

(iv) Management

Management involves, among other things, the placement of key and suitable personnel in the jobs and the organization and supervision of work to achieve the desired goals most efficiently. In most stages and levels of management, particularly in project management, subjective estimation (of the suitability of a worker or the duration of a job) is normally required, and this is a suitable area that expert systems can provide meaningful assistance to the management.

Also within the ambit of management, the following tasks would be most suitable for the application of expert systems:

-Selection of suitable sites for hazardous mine waste disposal
-Training of mine personnel
-Checklist of engineering operations

(v) Fuzzy Control

Fuzzy control refers to the use of linguistic variables, such as "VERY HIGH" as in "The water level in the tailings dam is VERY HIGH", as a set of numerical grades ranging from 0-1 for input to electrically-operated controllers. Fuzzy logic can be used to develop heuristic (inexact) or rule-of-thumb controllers with the strategy based on the actual operating practice of experienced operators, such as those working in a coal washery.

(vi) Staffing advice

An expert system can help overcome staffing problems where difficulties have occurred or may occur in the future, since the mine specialist may be occupied in a different area or may be on a different project, or on leave.

CONCLUSION

In this paper, expert systems have been presented as timely, precise, and powerful tools to assist the engineers in modern and efficient coal mining. A large number of projects to build expert systems for coal mining and engineering in general is now under way all over the country. Concurrently, rapid advances are also made in the fields of computer sciences and Artificial Intelligence. The sixth generation of both the computer and coal mining will perhaps be most exciting as the two giant industries are converging on one path.

REFERENCES

Bennett, J.S., Engelsore, R.S. (1979) SACAN: A knowledge-based consultant for structural analysis. 6th Int. Joint Conf. on Artificial Intelligence (Tokyo). pp 47-49


The AusIMM Illawarra Branch, 21st Century Higher Production Coal Mining Systems—Their Implications, Wollongong, NSW, April 1988