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Research Review: Application of Expert Systems in the Sciences

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Abstract: An expert system is a computer program which captures the knowledge of a human expert on a given problem, and uses this knowledge to solve problems in a fashion similar to the expert. The system can assist the expert during problem-solving, or act in the place of the expert in those situations where the expertise is lacking. Expert systems have been developed in such diverse areas as science, engineering, business, and medicine. In these areas, they have increased the quality, efficiency, and competitive leverage of the organizations employing the technology. During the 1980s, scientists and engineers have used this technology to search for oil, diagnose medical problems, and explore space. This paper provides an overview of this technology, highlights the major characteristics of expert systems, and reviews several systems developed for application in the area of science.

I. INTRODUCTION

Expert system technology has captured the interest of professionals in a number of fields in recent years. Systems have been developed in such diverse areas as science, engineering, business, and medicine. Almost every professional and computer society currently has a special interest group for expert systems technology. This widespread interest can be attributed to the ability of the expert system to aid various organizations in solving practical real-world problems. Organizations are looking toward these systems to aid them in increasing the quality, efficiency, and competitive leverage of their operations. This paper provides an overview of this technology, highlights the major characteristics of expert systems, and reviews several systems developed for application in the area of science. The paper also includes a short bibliography on expert systems for the interested reader to explore further.

Expert system definition

An expert system (ES) is a knowledge-based information system that uses its knowledge about a specific, complex application area to act as an expert consultant to end users. It is designed to utilize artificial intelligence to provide human like inferences about specific problems, and it must be able to explain how conclusions were formed. Using Artificial Intelligence technology, a computer system can make decisions like a human expert. Expert system is a branch of AI that makes extensive use of specialized knowledge to solve problems at the level of a human expert. An expert is a person who has expertise in a certain area. That is, the expert has knowledge or special skills that are not known or available to most people. An expert can solve problems that most people cannot solve or can solve them much more efficiently (but not as cheaply). When expert systems were first developed in the 1970s, they contained expert knowledge exclusively. However, the term expert system is often applied today to any system that uses expert system technology. This expert system technology may include special expert system languages, programs, and hardware designed to aid in the development and execution of expert systems.

Expert system structure

The structure and operation of an expert system are modeled after the human expert. Experts use their knowledge about a given domain coupled with specific information about the current problem to arrive at a solution. For example, a physician would possess knowledge about a variety of possible diseases and, coupled with specific information about a given patient, would be able to diagnose the patient's problem. Expert systems solve problems using a process which is very similar to the methods used by the human expert

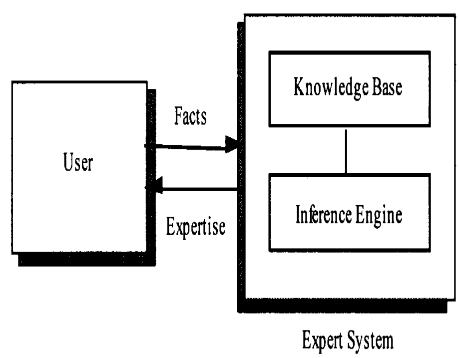

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Figure: Expert system structure.

Knowledge Base: The *knowledge base* contains specialized knowledge on a given subject that makes the human a true expert on the subject. This knowledge is obtained from the human expert and encoded in the knowledge base using one of several knowledge representation techniques. One of the most common techniques used today for representing the knowledge in an expert system is rules. A rule is an IF/THEN type structure which relates some known information contained in the IF part to other information. This information can then be concluded to be contained in the THEN part. For example,

RULE 1
IF Battery is dead
THEN Car will not start

RULE 2
IF Battery voltage is below 10 volts
THEN Battery is dead

These two rules capture knowledge which represents natural relationships for automobile diagnostics. The first rule relates the status of the battery to the status of the car. The second rule relates the state of the battery to its status. Using rules like these, one can form a complete knowledge base for diagnosing problems with an automobile. Representing knowledge in rules has two major advantages. First, each rule is a separate declarative statement about the problem, allowing one to add rules to the system as needed. Secondly, rules appear to match the way many experts formulate their knowledge about a problem in a natural "cause and effect" manner. Other knowledge representation techniques used are frames, semantic networks, and predicate calculus (Barr and Feigenbaum1981).

Working Memory

Specific information on a current problem is represented as case facts and entered in the expert system's *working memory.* The 'working memory contains both the facts entered by the user from questions asked by the expert system, and facts inferred by the system. The working memory could also acquire information from databases, spreadsheets, or sensors, and be used by the expert system to conclude additional information about the problem by using the general knowledge contained in the knowledge base.

Inference Engine

The analogy of human reasoning is performed in the expert system with the *inference engine.* The role of the inference engine is to work with the available information contained in the working memory and the general knowledge contained in the knowledge base to derive new information about the problem. This process is similar to the way a human reasons with available information to arrive at a conclusion.Two principle inference techniques are employed inthe design of an expert system.

The first technique relies upon first establishing a goal or hypothesis, and then attempting to prove it true. For example, a technician believes a particular fault exists, and then collects data to verify this hypothesis. This style of reasoning is known as *backward chaining.*

The second style of inference first collects information about the problem and then attempts to infer other information. For example, a control process engineer gathers data from sensors monitoring some process, and then uses this information to conclude the present status of the process. This style of reasoning is known *as forward chaining.*

Backward and forward chaining may be integrated to solve a given problem. For example, a physician may initially gather information about a patient and use this Information to form a hypothesis of the possible disease. This hypothesis would then be checked by gathering additional evidence to support the belief. Both techniques may also be challenged by a situation where the information is inexact or unknown. In this situation, the inference technique must have the ability of continuing its reasoning under the constraint of incomplete information. Inexact reasoning techniques for expert systems are discussed further in the reports that are cited. The inference engine, working either in the backward or forward chaining mode, will attempt to conclude new information about the problem from available information until some goal is reached or the problem is solved.

II. CONVENTIONAL PROGRAMS VERSUS EXPERT SYSTEMS

The most basic difference between the two is that conventional programs process data, while expert systems process knowledge. This basic difference influences both the nature of the processing technique used and the results obtained. The general differences between expert systems and conventional programs are characterized in Table

Table: *Expert system versus conventional programs.*

Conventional Programs	Expert Systems

Numeric Algorithmic Precise information Command interface Final solution given Optimal solution	Symbolic Heuristic Uncertain information Natural dialogue with explanations Recommendation with explanation Acceptable solution

Conventional programs process data which is usually in numeric form, while an expert system works with symbolic information. Data are isolated bits of information about a problem, whereas symbolic information represents statements or facts concerning the problem which can be used with general knowledge to infer new information. Conventional programs process data by means of algorithms, whereas an expert system will use heuristic reasoning techniques. An algorithm represents a finite set of well-defined steps to be performed. Heuristic reasoning works with the available information to draw conclusions about the problem, but does not follow a prescribed sequence of steps. A conventional program requires complete and precise information. An expert system can work with the available information whether it is incomplete or uncertain. In this sense, an expert system can provide some results even under the constraints of limited or uncertain information. A conventional program would be severely limited under such constraints. The interface of an expert system permits questions to be asked and answers given using a natural language style. This interface is more readily accepted by end-users than the command interface found with most conventional programs. Interaction with an expert system also follows more closely the conversation between one human obtaining advice from another human. During the conversation, explanations are provided by the expert to queries as to "why" a question is being asked, and "how" a given conclusion was reached. This point makes an expert system considerably unlike a conventional program, which simply provides a final answer. Conventional programs provide a final solution usually in the form of a result from a computation. The computation may have involved a complex series of tasks, but the user will only see the final result and not the intermediate steps that led to the final result. Expert systems provide a result in the form of a recommendation, with a justification in the form of a tracing of its reasoning.

Given the correct information, conventional programs will provide an exact solution to a problem. It is an "all or nothing" situation. Expert systems can make mistakes, just as a human expert might. This point appears to give the conventional program an advantage over the expert system. However, this appearance is only an illusion. Expert systems work on types of problems which are less structured than conventional programs, and the information available may not be sufficient to obtain an exact solution. However, the expert system will still be able to reach some reasonable conclusion, even if it is not optimal, whereas a conventional program will fail if not provided with all of the information it needs. This ability of an expert system to be able to make decisions in the absence of complete or certain information is the result of developments in the area of *inexact reasoning*.

III. TYPES OF EXPERT SYSTEMS

There are many different types of expert systems. The following list describes the various types.

Diagnosis. Diagnosis types of expert systems are used to recommend remedies to illnesses, trouble-shoot electronic or mechanical problems or as debugging tools.

Repair. Expert systems that define repair strategies are also very common. As well as diagnosing the problem they can suggest a plan for the repair of the item. The repair plan typically contains a scheduling structure and some control structure to validate the repair process. Such systems have been employed in the automotive repair field and similar areas.

Instruction. Instructional expert systems have been used for individualised training or instruction in a particular field. The system presents material in an order determined by its evaluation of the user's ability and current knowledge and monitor's the progress of the student, altering the sequence depending on this progress.

Interpretation. Interpretive expert systems have the ability to analyse data to determine its significance or usefulness. The knowledge base often contains models of real world situations which it compares to its data. These are often used in exploration for mineral, gas and oil deposits as well as in surveillance, image analysis and speech understanding.

Prediction. Predictive expert systems are used as a method to "guess" at the possible outcomes of observed situations, usually providing a probability factor. This is used often in weather forecasting.

Design and Planning. This allows experts to quickly develop solutions that save time. These systems do not replace experts but act as a tool by performing tasks such as costing, building design, material ordering and magazine design.

Monitoring and Control: In certain applications expert systems can be designed to monitor operations and control certain functions. These are particularly useful where speed of decision making is vitally important, for example in the nuclear energy industry, air traffic control and the stock market.

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Classification/Identification: These systems help to classify the goals in the system by the identification of various features (these can by physical or non-physical) For example various types of animals are classified according to attributes such as habitat, feeding information, colour, breeding information, relative size etc. These systems can be used by bird watchers, fishing enthusiasts, animal rescue shelters (to match animals to prospective owners) to name a few.

IV. WHY USE AN EXPERT SYSTEM?

When one compares an expert system with a human expert. From the comparison one can formulate several general reasons for employing an expert system such as:

Replacement of human expert
Assistant to human expert
Transfer of expertise to novice

Using an expert system to replace a human expert is done primarily to use the system when the expert is not available. For example, through time constraints, the human expert may not be available, while an expert system designed to control some manufacturing process would be available 24 hours a day. Another expert system, containing the expertise of a unique expert within a company, could be made available to company sites located in other geographic areas. If the expert should leave or retire from the company, the expertise captured in the expert system could serve as a replacement for the expert. Human experts may be scarce, hence expensive.

Expert systems, by contrast, may be inexpensive. Developing an expert system can be a costly venture, but the finished product would have low operating costs. The finished system can also be duplicated at low cost and distributed widely.

Table: Comparison between a human expert and an expert system

Factor	Human Expert	Expert System
Time availability	Workday	Always
Geographic	Local	Anywhere
availability	Yes	No
Perishable	No	Yes
Consistent results	High	Affordable
Cost Productivity	Variable	Consistent

One specialized application of an expert system which can be used to assist the expert is the ability of the expert system to learn about a specific problem. The most common learning method used in expert systems today is a technique known as induction. The induction technique works with information contained in a set of examples to induce a set of rules which capture the knowledge about the problem. This approach has particular value for those problems where the expert lacks the knowledge to form decisions, but has a history of data on the problem. The induction technique can uncover classifications in the data which can be used for guiding the decision process.

V. EXPERT SYSTEM APPLICATION AREAS

This section will review the application of expert systems in various areas of science. Several applications in each area will be highlighted and a number of references of expert system applications for each area will be given.

Agriculture: In the area of agriculture, expert systems have been applied to such problems as crop management, insect control, and productivity considerations for raising a given crop. Farmers and agents from the Department of Agriculture Research Services must make decisions concerning the effective and profitable production of various crops. Expertise for making these decisions exists, but the major problem is making this talent available to the large number of farmers.

PLANT (Boulanger 1983) predicts the damage to corn caused by the invasion of black cutworms. The system first obtains information on the current field situation, including such information as the concentration of weeds, soil condition, and corn variety being grown. This information, coupled with black worm simulation programs, is used to predict the expected level of damage from this pest.

CROPPRO (Durkin and Godine 1989) was developed to aid farmers in four major areas of crop production such as: crop management problems, pest control, financial considerations, and tutoring on various crop topics. The system is structured to be applicable for most crops by addressing common problem areas. Hypertext and interactive graphics are used extensively, which serve to enhance the system's interface and effectiveness. The Shiitake mushroom was chosen as a test case for this expert system.

Chemistry: The majority of expert systems developed in the area of chemistry have been applied in a laboratory environment. The major advantage of these systems is the assistance they provide to the laboratory technician throughout a given experiment. They can assist in the planning and monitoring of the experiment, and in interpreting test data.

One of the first expert systems was developed by Stanford University upon request by NASA. NASA was planning to send an unmanned spacecraft to Mars, and wanted a computer program developed which would implement chemical analysis of the Martian soil. NASA would provide information on the soil in the form of mass spectrograms; and, from this information, the program would have to determine its molecular structure. To develop this program, the Stanford team had to encode in the program the expertise of a chemist with specialized skills in this area. The resulting program from this effort became known as DENDRAL.

DENDRAL is capable of inferring the molecular structure of an unknown compound from the mass spectrogram data. SPEX (Iwasaki 1982) assists scientists in planning laboratory experiments in the area of molecular biology. The scientist defines and describes the various objects to be used in an experiment, such as the physical environment and the structure of the experiment. The system assists in developing a plan for achieving the goal of the experiment.

GA1 (Stefik 1978) determines possible DNA structures from restriction enzyme segmentation data. The system uses a model of enzyme digestion analysis of DNAstructures, coupled with knowledge of possible errors in laboratory test environments, to formulate its result.

DART (Bennett and Hollander 1981) diagnoses faults in the hardware of computer systems. The system incorporates knowledge of the structure and expected behavior of a system in order to find design flaws in new computer systems YES (Griesmer et al. 1984) assists computer operators in controlling the MVS operating system used in large mainframe IBM computers. This expert system monitors the operating system, interprets MVS messages, and makes recommendations to the console operator for system control. The major tasks of YES are: maintaining adequate queue space, handling network communications, scheduling batch jobs, responding to system errors, and responding to system hardware errors.

DIPMETER (Davis et al. 1981) determines the subsurface geological structure of a given site by interpreting dipmeter logs. The system uses knowledge about dipmeter data and basic geology to uncover features in the data that aid in the identification of geological structures. This capability is of particular importance in oil or mineral exploration.

Medicine

The most prolific application of expert systems to date has been in the area of medicine. A possible reason for the extensive application in this area is that most medical applications have been diagnostic in nature, an area where expert systems are very effective. The expert system can assist a physician in diagnosing medical problems of a patient or help in the interpretation of medical test results.

MYCIN was developed to capture the knowledge of an expert on infectious blood diseases (Shortliffe 1976). This expert system captured the expertise of individuals on blood diseases to provide accurate and quick diagnosis of the present disease and the proper therapeutic recommendation. The system could also work with unknown or uncertain information which might be all that is available in an emergency, life-threatening situation. MYCIN was valuable not only for its ability to diagnose infectious blood diseases, but for the contributions it made to our understanding of introducing an expert system into the workplace. Much of the current usage of rule-based expert systems is based on the work of MYCIN.

VI. SUMMARY

Expert systems technology is an emerging area of computer science which is finding applications in a number of diverse areas. Organizations are employing expert systems to capture the problem-solving skills of human experts to either assist the expert or use them in those situations where the expert is not available. This paper has provided a brief overview of this technology and has discussed its application in the area of science. Applications of expert systems in the sciences are expected to increase in the near future. The review of past systems developed in the various science disciplines should provide insight into the types of applications which can be expected.

VII. REFERENCES

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