EXPERT SYSTEMS IN MEDICINE: ACADEMIC ILLUSION OR REAL POWER?

K. S. METAXIOTIS, National Technical University of Athens  
Email: Kmetax@epu.ntua.gr

J. E. SAMOUILIDIS, National Technical University of Athens  
Email: contact@epu.ntua.gr

ABSTRACT

From the very earliest moments in the modern history of the computer, scientists have dreamed of creating advanced systems which would simulate the process of human meditation and reasoning. Of all the modern technological quests, this research to create artificially intelligent computer systems has been one of the most ambitious and fascinating. Although attempts had been made more than 30 years ago to develop and apply such systems to the medical sciences, the field languished for decades.

In this framework, this paper aims to share thoughts and predictions on the important role of expert systems in Medicine and address their future as well as the trends that are foreseen in this area.

INTRODUCTION

In the past decade there has been a virtual explosion of interest in the field known as expert systems (or, alternatively, as knowledge-based systems). Appearing from seemingly out of nowhere, expert systems have quickly evolved from an academic notion into a proven and highly marketable product. Expert systems provide powerful and flexible means for obtaining solutions to a variety of problems that often can not be dealt with by other, more orthodox methods.

Nowadays their use is being proliferated to many sectors of our social life, while their applications have proven to be critical in the process of decision support and decision making. In particular, one of the most successful areas in which expert systems are applied is in the clinical laboratory. Medical expert systems have evolved to provide physicians with both structured questions and
structured responses within medical domains of specialized knowledge or experience.

The purpose of this paper is to analyze the role that expert systems (ES) will play in healthcare over the next decade. It aims to identify the key clinical areas that will require computerized decision support, and to examine the way in which ES technology may prove to be the key enabling technology.

EXPERT SYSTEMS: AN OVERVIEW

Introduction

An expert system (ES) is a computer system containing a well-organized body of knowledge which emulates expert problem solving skills in a bounded domain of expertise. The system is able to achieve expert levels of problem solving performance, which would normally be achieved by a skilled human when confronted with significant problems in the domain (BCS, Expert Systems Specialist Group). Expert systems have arisen as a development within the more general discipline of Artificial Intelligence (AI), which has been an area of academic research for thirty years.

Expert systems are characterized mainly by:

- symbolic logic rather than just numerical calculations
- data-driven procedures
- an explicit knowledge base which is understandable to an expert in that area of knowledge, and
- ability to explain its conclusions with concepts that are meaningful to the user.

Their Structure

In general, an ES consists of the following basic elements:

- The Knowledge base, which is the very heart of any ES and contains a representation of the human knowledge / experience (rules, semantic networks, frames, predicate logic).
- The Inference engine, which is employed during a consultation session. During consultation, it examines the status of the knowledge base, handles the content of the knowledge base and determines the order in which inferences are made.
- The Working memory, which contain all the results of the inference process during (and at the conclusion of) the consultation session.
- The Input / Output interface, which enables the user to supply facts and data, and enables the system to ask questions or supply advice and explanation.

The following Figure 1 illustrates a typical representation of an expert system.

![Figure 1. Representation of an expert system](image-url)
Improving IS Service Quality

The Journal of Information Technology Theory and Application (JITTA), 2:1, 2000. 21

Their Importance

While expert systems are sometimes misused and misapplied, one can not and should not dismiss them as either unimportant or a passing fad. They can be very useful in two different ways:

- Decision Support:
  - To remind an experienced decision maker of options or issues to consider. This is the most common use in medicine.

- Decision Making:
  - To allow an unqualified person to make a decision that is beyond his/her level of training experience. This is the most common use in many industrial systems.

While expert systems have considerable room for improvement, it should be stressed that they are not just academic notions. Rather, expert systems have already been developed and are being sold in various areas as follows:

- Diagnosis & treatment of various diseases
- Financial planning
- Stock market advisors
- Scheduling and control of the automated factory
- Determination of the chemical properties of unknown compounds

Their Advantages

Expert systems have some significant advantages in comparison with the traditional computer systems. These advantages are described in Table 1.

Uncertainty in Expert Systems

The real world is characterized by uncertainty and fuzziness, expert systems encounter these variables from various sources. Actually there are two primary sources of uncertainty:

- Uncertainty with regard to the validity of the knowledge base content (rules, frames, etc.)
- Uncertainty with regard to the validity of a user response

Concerning the first category, considering the heuristic rule given by “if a dog barks, then it will not bite,” an expert may not be able to state that the rule is always true. On the other hand, the second source of uncertainty is associated with the responses of the user of the expert system. Considering the question of a medical diagnostic expert system, “Does the patient have severe headaches?,“ the patient may not be able to answer strictly with “yes” or “no”.

In order to handle all these types of uncertainty and fuzziness, expert systems can use various methods:

- Bayesian Probability
- Fuzzy Logic
- Belief Networks
- EXSYS Approach

Table 1: Advantages of Expert Systems

<table>
<thead>
<tr>
<th>Availability</th>
<th>Consistency</th>
<th>Comprehensiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts are not born. They are to be trained and then practiced. It generally takes over five years for someone to acquire expertise in a particular area. In contrast to the human, an expert system has all the expertise inside, it never gets tired and or dies. The included knowledge is often more readily available to trainee experts or users.</td>
<td>Even the best experts can make mistakes or may forget an important point. Once an expert system is programmed to ask for and use certain inputs, it is not prone to forgetfulness. If a line of reasoning is acceptable, it will remain so in different consultations.</td>
<td>An expert can only draw upon his knowledge and experience. In some domain an expert system could encapsulate the knowledge of more than one expert and consequently offer several offers.</td>
</tr>
</tbody>
</table>

The Journal of Information Technology Theory and Application (JITTA), 2:1, 2000. 21
EXPERT SYSTEMS IN MEDICINE

Introduction

According to Clancey & Shortliffe (1984), “Medical artificial intelligence is primarily concerned with the construction of AI programs that perform diagnosis and make therapy recommendations. Unlike medical applications based on other programming methods, such as purely statistical and probabilistic methods, medical AI programs are based on symbolic models of disease entities and their relationship to patient factors and clinical manifestations.”

Much has changed since then, today this definition would be considered narrow in scope and vision. Today, the importance of diagnosis as a task requiring computer support in routine clinical situations receives equal emphasis with other clinical tasks.

Their Role in Clinical Care

The clinical care of a particular patient often proceeds in distinct phases, such as diagnosis before therapy, or prevention of disease before onset of disease, or rehabilitation of the patient after therapy. The analysis of queuing and renewal within human systems has permitted the identification of both decision elements and potential decisions in at least 10 distinct phases of clinical care, as follows.

Table 2 : Ten distinct phases of clinical care

<table>
<thead>
<tr>
<th>Phase of Care</th>
<th>Predicted Disease</th>
<th>Risk Factors Present</th>
<th>Disease Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction of Disease</td>
<td>Risk Factors</td>
<td>Present</td>
<td>Disease Diagnosis</td>
</tr>
<tr>
<td>Prevention of Disease</td>
<td>Motivation of</td>
<td>Patient</td>
<td>Preventive Measures</td>
</tr>
<tr>
<td>Diagnosis of Disease</td>
<td>Diagnostic</td>
<td>Findings</td>
<td>Disease Diagnosis</td>
</tr>
<tr>
<td>Staging of Disease</td>
<td>Factors Present</td>
<td>Disease Stage</td>
<td></td>
</tr>
<tr>
<td>Therapy of Patient</td>
<td>Pathologic States</td>
<td>Present</td>
<td>Therapy Selected</td>
</tr>
<tr>
<td>Rehabilitation of Patient</td>
<td>Residual Defects</td>
<td>Present</td>
<td>Schedule Selected</td>
</tr>
<tr>
<td>Health Status of the Patient</td>
<td>Specific Load</td>
<td>Tolerances</td>
<td>Specific Capacities</td>
</tr>
<tr>
<td>Counseling of the Patient</td>
<td>Specific Patient</td>
<td>Concerns</td>
<td>Specific Advice</td>
</tr>
<tr>
<td>Advocacy for the Patient</td>
<td>Specific Dangers</td>
<td>to Patient</td>
<td>Specific Defenses</td>
</tr>
</tbody>
</table>

From the above Table it becomes obvious that diagnosis is only one of many problems in clinical medicine. Today, medical expert systems are mainly applied to the following types of clinical tasks:

Generating alerts and reminders.

In real-time situations, an expert system attached to a monitor warns of changes in a patient’s condition. Otherwise, it scans laboratory test results and sends reminders or warnings.

Diagnostic assistance.

When a patient’s case is complex (or rare) or the person making the diagnosis is inexperienced, an expert system helps by giving likely diagnoses based on patient’s data.

Therapy critiquing and planning.

Expert systems are used to look for inconsistencies and omissions in an existing treatment plan, or to formulate a treatment based upon a patient’s specific condition and accepted treatment guidelines.

Education.

Expert systems are used to train and practice clinicians and students on various medical tasks.

Obstacles & Benefits

Despite the increasing use of expert systems in medicine, it should be stressed that the development of such systems for medical applications has to surpass some basic obstacles, such as:

- Medical tasks are difficult because of differences between individual patients and the uncertainty of the available clinical data.
- The range of acceptable errors is very small because of ethical concerns and malpractice risks.
- Funding for capital expenses is in short supply.

On the other hand, factors that favor increasing dissemination of expert system technology are:

- Cost effectiveness
• Improved quality of patient care.

**Famous Medical Expert Systems**

In the first decade of Artificial Intelligence in Medicine, most research systems were developed to assist clinicians in the process of diagnosis, typically with the intention that it would be used during a clinical encounter with a patient. Most of them were not developed further than the research laboratory. Others, however, have continued to be developed and have been transformed in part into educational systems.

**MYCIN.** It is, at this time, probably the most widely known of all medical expert systems thus far developed [Shortliffe, 1976]. And this is despite the fact that it has never been put into actual practice. It was developed at Stanford University solely as a research effort to provide assistance to physicians in the diagnosis and treatment of meningitis and bacteremia infections.

**PUFF.** It was developed in 1979, using the EMYCIN shell. Its purpose is to interpret measurements related to respiratory tests and to identify pulmonary disorders. PUFF is said to now be used on a routine basis.

**INTERNIST.** It was developed in the 1970s at the University of Pittsburgh. Its goal is to perform a diagnosis of the majority of diseases associated with the field of internal medicine. It is supposed to consider all the possible combinations of diseases that might be present in the patient.

**Iliad.** It has been under development for several years, primarily for diagnosis in internal medicine. Now it covers about 1500 diagnoses in this domain based on several thousand findings. Its current use is as a teaching tool for medical students.

**DXplain.** It was developed at the Massachusetts General Hospital (1987) and is used to assist in the process of diagnosis, taking a set of clinical findings including vital signs, symptoms, and laboratory data. Then it produces a ranked list of diagnoses. DXplain is in routine use at a number of hospitals and medical schools, mostly for clinical education purposes, but it is also available for clinical consultation.

**HELP.** It is a knowledge-based hospital information system, which began operation in 1980. It provides clinicians with alerts and reminders, data interpretation and patient diagnosis facilities, patient management suggestions and clinical protocols. HELP is currently operational within 6 major hospitals in Utah and at several sites in USA.

**DoseChecker.** It was developed at Barnes Hospital in Missouri in order to assist the staff pharmacists with monitoring drug orders for a set of drugs which must be carefully dosed for patients with possible renal impairment. It has been used in production since September 1994.

**QMR.** It assists physicians in the diagnosis of an illness based upon the patient's symptoms, examination findings and laboratory tests. It is currently in use at the University of Pittsburgh.

**PEIRS.** It is a Pathology Expert Interpretative Reporting System, which interpreted (during its period of operation until 1994) about 80-100 reports a day with a diagnostic accuracy of about 95%.

**Apache III.** It was designed to predict an individual's risk of dying in the hospital. It compares each individual's medical profile against 18,000 cases in its memory before reaching a prognosis that is (on average) 95% accurate. There are 16 hospitals in USA where APACHE III is in use.

**MDDB.** It was designed in order to assist physicians with the diagnosis of dysmorphic syndromes. Up to now the system has been used on about 3,000 patients and all knowledge about these patients has been integrated into the knowledge base. Today it is in routine use.

**Hepaxpert I, II.** It has been developed in order to interpret tests for Hepatitis A and B and has been in routine at the Hepatitis Lab of University of Vienna Medical School since September 1989.

**Jeremiah.** It was designed to provide dentists with orthodontic treatment plans for cases suitable for treatment by general dental practitioners with knowledge of removable orthodontic techniques. The program became available commercially in 1992.
Tools for Construction of Medical Expert Systems

Medical expert systems can be constructed generally through the use of one of two types of tools, namely AI languages and expert system shells (or generally speaking tool-kits).

By far the most common of the AI languages used in the development of medical expert system are LISP and PROLOG. Using these languages, the system designer has a great deal of freedom in his choice of knowledge representation techniques and control strategies. However, use of these languages requires a high degree of expertise and skill.

On the other hand, expert system shells (or tool-kits) attempt to combine the flexibility of AI languages with cost-effectiveness to provide more general development facilities.

The following Table presents, indicatively, some of the most popular expert system shells (commercial software packages) used in the construction of medical expert systems.

Table 3: Most popular expert system shells

<table>
<thead>
<tr>
<th>Commercial Expert System Shells</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXPERT</td>
<td>Rule-and-object-based development tool, integrated forward and backward chaining, automatic goal generation, non-monotonic reasoning.</td>
</tr>
<tr>
<td>OBJECT</td>
<td></td>
</tr>
<tr>
<td>EXSYS</td>
<td>Supports backward and forward chaining, linear programming, fuzzy logic, neural networks and has an SQL interface.</td>
</tr>
<tr>
<td>XpertRule</td>
<td>Represents knowledge as decision trees and set of pattern rules, supports fuzzy logic and genetic algorithm optimization.</td>
</tr>
<tr>
<td>GURU</td>
<td>Development environment and RDBMS which supports mixed chaining, multi-value variables, fuzzy reasoning.</td>
</tr>
<tr>
<td>FLEX</td>
<td>Hybrid expert system toolkit which supports frames and rules, mixed chaining, logic programming, multiple inheritance.</td>
</tr>
<tr>
<td>ACQUIRE</td>
<td>Knowledge represented as objects, production rules and decision tables, handles uncertainty by qualitative, non-numerical procedures.</td>
</tr>
<tr>
<td>ReSolver</td>
<td>Combines decision trees and individual rules, supports multiple confidence modes, report generator, mixed chaining, very graphical interface.</td>
</tr>
</tbody>
</table>

CONCLUSIONS / RECOMMENDATIONS

Today, the limited amount of medical expert systems research is being performed mostly by medical practitioners or academics. Because medical expert systems represent real power and not just academic notion (obviously nor academic illusion), we should court the stable accession of expert system technology to healthcare in general. We should seek to support common clinical problems, which comprise the great bulk of clinical duties, rather than the more complex and rare ones, which may intuitively appeal to academic interests.

We should focus on supporting the patient management process in its entirety, rather than focusing specifically on the sub-task of diagnosis. We should focus on supporting patient management throughout primary, secondary and tertiary care institutions, not just in the traditional large hospital setting. Further, applications should be developed for a broad spectrum of clinical users from nurses and physicians to dietitians, pharmacists, and others.

The role of medical expert systems in clinical care is very clear. Based on the recommendations made above, this paper could specify application areas, which are suitable for immediate implementation or further development and exploitation. These clinical application areas include:

- Laboratory systems - Clinical laboratories have proven to be a fertile domain for the use of expert systems.
- Drug advisory systems - There is a clear opportunity to design expert systems which will assist clinicians with the prescription of medications and selection of the most cost-effective treatments.
- Signal interpretation - The development of interpretive alarms for real-time clinical signals in areas like the intensive care unit will offer some assistance with the task of clinical vigilance.
- Quality assurance - There will be a need to check that the different types of knowledge-based systems (which appear in clinical settings) remain up to date.
• Education - The need to continually educate both patients and clinical professionals offers significant opportunities for automated assistance. Indeed, education for most clinicians is an ongoing process. Expert systems should be built with this type of support in mind.

REFERENCES

AUTHORS

Dr. K. Metaxiotis is an electrical & computer engineer and researcher in the Department of Electrical and Computer Engineering of NTUA. He has wide experience in MIS Administration, Database design and development, Expert System design, object-oriented knowledge modelling, inference mechanisms, Strategic Development of MIS, Artificial Intelligence, Analogue / Digital System design, Electrical Circuits Analysis. In addition, he has deep knowledge of Monitoring & Evaluation of projects, Project Management. Since 1996 he has participated in many EC projects as an Information Technology expert.

Prof. J. E. Samouilidis is a professor in the Department of Electrical and Computer Engineering of National Technical University of Athens (NTUA) and Deputy Head of EPU (Energy Policy Unit). He has over 30 years of experience in energy policy analysis, national and regional energy planning, energy and environmental modelling, energy management, decision support and monitoring systems. He has held top government positions having served as chief advisor to many Ministers and has a complete grasp of EC projects. He has worked as Project Director and as Senior Consultant in numerous projects funded by EC since 1985.