PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON MEDICAL EXPERT SYSTEMS AND SOCIAL-ECONOMIC OPPORTUNITIES FOR THEIR IMPLEMENTATION IN DEVELOPING COUNTRIES (25–27 November 1985, IIASA, Laxenburg).

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Foreword

This international workshop was the result of a UNESCO, VNIISI, and IBI initiative, the objective being to start activity in the application of Informatics for much needed improvements to the health care systems in developing countries. One of the most promising ways is the use of expert systems. The proposed small international workshop was immediately inundated with several other objectives:

- to assess the present state of Medical Expert Systems now easily usable in the developing countries,
- to identify the specific problems connected with the use of these systems in those countries,
- to identify the promising areas for further activity and research in this domain.

Several of the papers presented dealt with the description of expert systems (Dr. Auvert, *et al.*, Dr. Gelovani, *et al*, Dr. Mařík, Drs. Popper, Stefanelli* and Goldberger*). Hand-held computers, PC-types, and main-frames, based on Expert Systems, were also presented (Professor Trappl, K.-P. Adlassnig *et al.**)

The second objective was covered both by Dr. Capaldo and Ms. Benlamara, and also by Dr. Auvert *et al.* They elaborated on the specifics of using expert systems in developing countries. The paper by Dr. Najim is an illustrative application case-study. Its importance is, in fact, that this system is not only applied in developing countries, but it is also developed there. In such cases the route from laboratory to terrain should be the shortest possible.

The third objective was much discussed during the workshop, and touched upon in responses received later. From the suggestions received two directions seem to have emerged as worth focussing on – i) Expert Systems for Diagnosis and Therapy; ii) Expert Systems for training medical and paramedical personnel. To focus on these topics it was proposed to hold a meeting in the future.

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*Here are references to papers and systems presented but published elsewhere:

P. Cristiani, S. Quaglini, and M. Stefanelli: *The Anemia Project* Artificial Intelligence in Medicine, (North-Holland) 1985

K.-P. Adlassnig, G. Kolarz, and W. Scheithauer: *Present State of the Medical Expert System CADIAG-2.* Methods of Information in Medicine, (F.K. Schattauer Verlag) 1985.

H. Goldberger: *The Medit-Media System: Tschad.*

International Workshop on Medical Expert Systems and Social Economic Opportunities for their Implementation in Developing Countries

Opening Address

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I am both honored and pleased to address you today, on this occasion representing the Intergovernmental Bureau for Informatics, an international organization specializing in informatics.

Allow me first of all to convey to you, on behalf of Professor Bernasconi, Director General of the Organization, his best wishes for success in your work, and to confirm the importance that he attaches to it. In effect, this meeting is, in many ways, exemplary for IBI:

- exemplary in terms of cooperation between international, governmental and national bodies, and scientific institutions;
- exemplary in terms of the methodology selected that proposes a purposeful approach to informatics, and considers the concepts of fundamental needs.

I would, therefore, like to express here our gratitude to those people who, through their work, have made this meeting possible, and in particular to the officials of the International Institute for Applied Systems Analysis, UNESCO, and to the All-Union Research Institute of Systems Studies.

It is a great pleasure today to meet representatives of the USSR. While we at IBI are in close contact with UNESCO and IIASA, with regard to our normal activities, our contact with the USSR is only just beginning. We do hope that this contact will strengthen in the both our interests.

I am also pleased that this event, towards which IBI has contributed, is taking place, and I believe that this cooperation, which is already a reality, will continue in the future.

My opening comments will deal with three points:

a brief description of IBI and its activities,

reflections concerning, in particular, informatics and its development, in order to put the meeting into its proper perspective, and, finally, some brief and general considerations on informatics when applied to medicine, and the use of expert systems in aiding a doctors' decision making process.

The Intergovernmental Bureau for Informatics was created in the 1950s following the recommendations of the United Nations Economic and Social Council and at the initiative of UNESCO. It has operated in its current form since 1973.

It has 40 member States, the majority of which are developing countries. Let me provide some figures: the budget for the current biennium amounts to 30 million dollars; it has seven regional centers or ad hoc structures: CREI (Spain), CREALC (Mexico), the Regional Centers in Dakar, Abu Dhabi and Lagos, IBIDI (Italy), and the Industrial Informatics Institute (Spain).

The fields of intervention are grouped around such main issues as: policy-related action, and project implementation.

The policy-related action features the fostering of national policies through SPIN, a governmental conference held jointly by UNESCO and IBI in Spain in 1978.

Since then action towards regional policies has been developed through meetings in Mexico City, Yamoussoukro, Tunis and Cali. The activities relating to Transborder Data Flows should also be mentioned, as an example of action on informatics' stakes under international debate. The projects are organized in terms of cooperative actions, technology transfer actions, and the application of new technologies adapted to specific contexts.

The projects underway in Togo, Tunisia, Mexico, Colombia, the Ivory Coast or Nicaragua, to quote some examples, demonstrate the importance of these achievements. As far as training is concerned, during the last biennium, more than 400 students and technicians benefited directly from IBI programs and IBI support in the form of fellowships.

I will now address the second point, and present some considerations on informatics and its development, taking as a basis the study, supported by the European Community and IBI, and carried out by Futuribles.

Informatics in the developing countries is not a recent event. In most of these countries, the first computer was installed at the beginning of the 1960s. With rare exceptions, informatics was based on the offer of equipment designed and produced by industrialized countries. Informatics in developing countries accounts for less than 6% of the world total, and within this percentage, its distribution varies greatly from one developing country to another.

Informatics systems, which were mainly introduced as administrative management tools, are still essentially dedicated to this type of activity. The development of data collection and processing systems as an aid to economic decision-making is a rarity. Few applications have been made in other fields even though they are considered to be priority areas – agriculture, health, education ... . The architecture of the informatics systems used has always been and still is, highly centralized. This involves complex organizational methods, calling for a technological environment (electricity, air conditioning, highly skilled personnel) that needs professional skills and takes a long time to create.

The public and semi-public sectors are the largest users of informatics systems organized around large centers, almost all of which are installed in the large metropolises. The prospects for the coming years are likely to be encouraging, for a number of reasons, including:

- the existence of more and better trained manpower in virtually every country;
- the change in available material as a result of new technological possibilities;
- the new attitudes towards mastering technologies that is emerging, and the political awareness of what is at stake in the area of information technologies.

The first point deserves to be emphasized, even though there are not enough technicians to meet the needs, and the educational effort still has to be continued and stepped up, there is now a significant potential pool of skills and expertise in the developing countries.

The second aspect relates to the transformation of hardware, and particularly, to microinformatics and communications. This represent a development that augurs very favorably for applications in the developing countries.

How can informatics help us to meet the fundamental needs? We must take into account that, up to now, informatics does not feed, cure, or educate us. Therefore, in view of the fundamental needs, a considerable intellectual investment must be undertaken in order to identify the necessary measures for meeting those needs, then the information systems, and its potential contribution, and, finally, evaluation of the introduction of informatics.

I now come to the third part of my address: informatics applied to medicine and, in particular, the use of expert systems in doctors' decision-making processes. A doctor has to solve complex decision-making problems in his everyday work at all levels of specialization. He diagnoses and prescribes treatment as the result of a gradual process based on his knowledge, using the information he obtains about the patient, and the instrumental data available, or specially requested. In addition to the strictly clinical problems, other decision-making processes exist in medicine that are more of an organizational nature (such as the ways of providing treatment) or have to do with biological engineering (as in the case of sophisticated aids for the handicapped).

The Impact of Informatics

Since the beginning, informatics has turned its attention to these problems both to help process statistics or analyze mathematical models, and also to serve as a useful tool for managing administrative data. The impact of computers on the most important areas of medicine, however, has not been as widespread or far-reaching as initially expected. They have not been widely used for medical decision-making, and when the computer is used for routine work it is mainly for administrative management, or laboratory and hospital management, or as a processor for highly complex equipment.

In other words, even though the computer has demonstrated its utility in *medical research* (mainly as a sophisticated computing tool), as far as *day-to-day clinical applications* are concerned, it has not managed to get beyond the stage of presenting numerical data, sometimes previously processed, and managing files with no part to play in the actual decision-making process.

The Growing Problems of the Medical Profession

Medicine today has to cope with an increasing number of structural problems:

- the chaos due to the information explosion, both because of the proliferation of paperwork, and the production of new knowledge is too great, in terms of quantity and speed, for the individual doctor to handle – the result is that doctors have to concentrate on increasingly more restricted fields in order to cope with the increasing depth of each specialization;
- the uneven distribution of health care personnel, nationally and internationally;
- the increased demand for health care, for increasingly higher standards of medical care for an increasing number of individuals, and the spiraling costs.

In other words, there is an increased need to have access to areas of more or less specialized medical knowledge (structured and consolidated knowledge in textbooks and the latest advances of research) as and when needed for decision-making, and to be able to make efficient use of it.

Many advantages derive from the dissemination of decision-making tools into medical practice:

1. a systematic, complete approach, making it possible to promptly incorporate knowledge from a variety of sources;
2. the possibility of making reference to similar cases, and of weakening the influence of similar, but non-identical cases;
3. a more appropriate choice of tests and therapies, with a more accurate appraisal of timing, advisability and costs in terms of benefits and risks.

On this basis, how can an expert system help the doctor?

Definition of an Expert System

An expert system is a tool that can help professionals (in this instance, doctors and health service managers) in activities that require the judgment and experience of a specialist. Its work is similar to that of a human expert, imitating the decision-making process, because it is able to explicitly manage a huge organized corpus of knowledge on a given subject.

The expert system establishes a dialogue with the user and draws conclusions on a given case, using a previously memorized "knowledge base", and interactively reaches an opinion on the case itself and/or provides suggestions for dealing with it. The system also provides explanations on *how* it has reached certain "convictions" and *why* it has concerned itself with particular items of information.

Broadly speaking, this system can carry out three kinds of functions:

a) it can *replace an expert, enabling a user or a machine to make* decisions independently: dangerous or repetitive tasks or when an expert is momentarily unavailable (in emergencies), or when there is a structural shortage of experts, or to create and manage cases used as examples for teaching purposes;

b) it can *help* an expert to deal with problems that frequently arise in his work and are particularly difficult to handle: generating and testing hypotheses, assessing risks and predicting the outcome of decisions, routine analysis of very complex systems, or helping to carry out an analytical study of its own knowledge of its own field of application;

c) it can act as a user-friendly *interface* with computer-based subsystems, replacing cooperation with experts specializing in other sectors: interrogating data bases, using statistics packages (selecting appropriate tests, interpreting data), managing equipment, analyzing econometric or biological models.

The expert systems can be used in clinical practice at several levels on a "specialized scale" of the following type:

1. high level specialists in a restricted field;
2. specialists over a broad field;
3. general practitioners;
4. nurses (no nurses may be available, or the personnel at this level may be used to filter patients before being examined by the doctor, as for example in the developing countries);
5. citizens.

Here are a few of the problems linked to the use of expert systems in medicine.

Expert systems can have an impact in the developing countries where the problems of decision-making in medicine or public health is a general one, involving both the health care and the social sectors:

- decisions relating to health care planning with a shortage of resources;
- diagnostic and/or therapeutic decisions with inadequate and an insufficient number of medical technicians;
- the obvious educational spinoffs on decision-making aids in regions where the problems of education and training are most strongly felt;
- the frequent need for these decision-making aid tools to be able to draw on data banks, when they are most often in isolated areas and outside any information system.

It should be noted that this field is a perfect example of the possibilities for cooperation between developed and developing countries. Although software can be designed in the developed countries, the applications have to be adapted locally to meet the specific local needs, and this must involve local technicians.

Furthermore, experts from the developed countries are likely to learn a great deal from the experiences gained in these fields with regard to software and technology ("bush micros", teleinformatics networks, etc.).

That is the challenge awaiting us.

And that is the whole point of our work – to explore the fields of expert systems to find out the needs, the information and communication functions, and the knowledge requirements in order to identify their role.

Tropicaid: A Medical Expert System Running on a Hand Held Computer and Usable by Rural Health Workers of Developing Countries

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1. Introduction

In many developing countries, much of the population still lives in rural areas where health care services are rather limited. Dispensaries, where they exist, often have few beds, materials sufficient only for the most minor surgery and less than one hundred medications. Staff, generally, have had no more than than six months to two years of training, which is not helped by distance from more competent practitioners, and the lack of continuing education. While, as emphasized at the Alma-Ata Conference (1) in 1978, the existence of competent medical personnel is an indispensable condition to the amelioration of the level of health of a country, qualified doctors are reluctant to remain where there are no resources. There are difficulties in training para-medical personnel (bush medics,"barefoot" doctors) and, once trained, people tend to seek more remunerative positions.

The principal objective of our work is to offer to rural health workers a tool to increase their effectiveness, and also to provide a teaching aid. Among the many possibilities, we have tried to create something that provides immediate help without needing major changes in their working conditions. Since the 1970s, most of the organizations, such as WHO, recommend guidelines, lists of signs to be validated, to lead to a diagnosis. These guidelines, designed for paramedics working without assistance from a doctor, are used for sorting the patients in a mass medicine context. They are, however, heterogeneous concerning presentation or content and their efficiency remains limited. Portable computers for paramedical personnel have already been proposed to augment their diagnostic and therapeutic skills and to provide reinforcement (2). So, with the humanitarian organization "Médecins Sans Frontières" (MSF), we define the specifications of such a system.

2. Hardware

The system should have the following qualities: autonomy, to be operational in dispensaries without direct current, and robustness, to be able to combat heat and dust; ergonomy, to be used by untrained people, and a large memory to deal with big software.

The material used is an HHC (Blaise) intended for biomedical applications (3). The device is made autonomous by running on batteries that are rechargeable (via a solar panel). The prototype measures 29x20x5 cm and weighs 1.5 kg. The waterproof and shock resistant keyboard has 51 alphanumeric and 5 function keys. The liquid crystal display can show 8 lines of 40 large size characters. On the inside, in addition to the NI-Cad batteries, there are two circuit boards which include: 1) an 8-bit Z80-compatible CMOS microprocessor (NSC800), 2) CMOS RAM memories totaling 128 K bytes, 3) NMOS EPROM memories (up to 500 K bytes) containing the programs and data that are activated by VMOS only when they are to be read by the processor. Information may be updated by simple replacement of the EPROM modules. The overall energy consumption of the prototype fully running is 60 mA and it will run continuously for 20 hours without recharge. Data in the RAM are saved up to seven weeks on a standby current (turned on but not running).

3. Operating System

The operating system is the Softech P-System. Its major advantages are the ease of developing large application packages, its portability and (because of the dynamic code segment swapping) the fact that extremely large programs can be implemented. These programs once implemented can be ported to a large number of different microcomputer systems without being recompiled. It is used with Pascal-UCSD, a high-level language for structured programming, dynamic data structures, and recursive procedures. The application software was developed on a Victor S1 then transferred to the prototype's storage by an EPROM programmer.

4. Application Software

A system of aid to the medical practice, intended for use by paramedical personnel, in developing countries should cover the following four areas:

1) knowledge and use of medications,
2) treatment of a given disease,
3) diagnostic decision,
4) collection of epidemiological data.

Moreover, it should be easy enough to be used by people with no informatics training. We present now the solutions provided by the first system called Tropicaid 1.

4.1. Information on Drugs

We created a data base of 64 drugs used by MSF in health centers and appearing among those classed to be "essential" by the World Health Organization (WHO) (4). For each drug, information was recorded according to WHO and MSF recommendations, and include the following: brand name, international non-proprietary name, indications, contra-indications, side effects and how to control them, interactions and how to manage them, signs of toxicity, overdose or reaction and the way to treat it, recommendations for use, posology including dose, duration of administration and how to administer (the posology depends on indication, patient's characteristics and drug form), pharmacological class and properties, follow-up measures, forms and prices.

This information, except numeric values, is coded into thesauri. Thus, a drug record contains only references to the previous dictionaries. After packing, the size of a drug record is less than 100 bytes.

The data base may be consulted using successive selection grids that allow the user to choose at first the drug (which is classed by pharmacological class) and then the various characteristics. The average access time to a drug record is about ten seconds starting from the main menu.

4.2. Information on Treatments

A therapeutic data base concerning 200 diseases among the most severe and the most frequently occurring in developing countries include, for each disease, the following information: a) clinical description and therapy management, b) therapeutics: it lists the drug(s) in order of preference and with the posology as above. This field includes rules that allow the user to select an appropriate treatment for each possible set of the following parameters: clinical appearance, patient type, epidemiological situation and type of treatment; c) general remarks.

All of this information is codified, using thesauri, except for the clinical description and the remarks, both of which appear as text, limited to the size of two screens (2x8x40 = 640 characters).

The interrogation software also uses successive selection grids. For each treatment, the selection of a drug allows access, not only to the posology according to the treatment, but also the whole set of information about the drug. This module also encompasses the previous one. To study a treatment takes about 35 to 45 seconds.

4.3. Decision-aid

The "diagnostic decision-aid" module of the first system uses symptom-oriented flow charts derived from the diagnostic pathways of B.J. Essex (5) by which one can obtain possible diagnoses through successive questions and answers. These charts are programmed to avoid repetition of a question. A chosen chart will not be left before it has been completely examined. However, while examining a path, it is possible to jump to another one before returning to the preceding one. This can be done in a recursive way.

The pathways are represented as a set of nodes. Each node contains the code number of the question to ask and, for each possible answer, the code number of the next node or the code of a diagnosis. One group of answers is of a "yes", "no", or "don't know" type; another group consists of a choice of one answer from a list appearing on the screen. For certain questions, the "Help" key allows the display of an explanatory text. The complete network includes 464 nodes with 412 different questions and 72 explanatory messages and 210 diagnosis.

Once arriving at a diagnosis, the user may either continue the interrogation, or access its specific therapy as described in the previous module. It takes, generally, about 30 seconds to obtain a diagnosis if it is not too complicated.

4.4. Data Collection

This module allows for storage, in a non volatile memory, for each patient, up to a maximum of 2000 patients, with the following characteristics: age group, sex, month of consultation, geographical origin, symptoms, diagnosis and medical action. It is possible to define for each of these items the number of possibilities (up to 14) and their labels (up to 17 characters). The recording of a patient's data takes about 20 seconds. A statistical program may give numbers according to selected criteria. A sort among 2000 patients is about 15 seconds long.

5. Software Organization

Programs and files are stored in ROM. The whole program, which represents 48 K bytes of code for the first version, is divided into segments. During operation, only index files and needed segments are present in the active memory (which has a capacity of 64 K bytes for P-system).

All the data files are packed: each item of data is stocked in the number of bits strictly necessary to code the information. We used direct access files with variable length records. The address for each record is stored in an index, which is also a direct access file. The whole set of data and index files occupies 164 K bytes in this first system. The use of a data transfer function such as "blockread" allows a quick access to the data. By using indexed files, response time is independent of the quantity of data.

The user-machine interface relies mostly on selection grids in order to shorten the response time in training and use (6). Furthermore, there are three function keys: START, NEXT, and HELP. The START key allows the user at any time to restart the program. The NEXT key leads to the next step in the application of software.

6. Field Trial

A first trial of this prototype (6) took place in Chad, in Spring 1984. The approximately 50 doctors (MSF and Chadian) and paramedical workers who tried it found the device to be easy to use, fast, and very useful. One Chadian paramedic managed to use it successfully during a consultation after only a 30 minute prior initiation.

It is apparent that the systematic use of selection menus (7) with only three function keys is responsible for this ease of learning. The dominant impression of the users is the feeling of conversing with a system that "knows" a lot of information. In fact, some doctors indicated they would gladly use the system regularly in their daily work.

This trial also demonstrated the physical resistance of the device despite numerous trips into the field (around 100 km of rough road, heat and dust). In addition, recharging the batteries via a solar panel proved entirely satisfactory (7).

7. Discussion

The Chad trial was intended to gauge acceptability. It lead to several remarks, first concerning TROPICAID 1, in particular, which will be seen now and then in the light of the general concept of a portable decision aid for health workers in developing countries and will be outlined in the conclusions.

7.1. Data bases

The data bases concerning medications and treatments in our system appeared to be satisfactory, from the point of view of both information and interrogation. Needed modifications were minor: possibility of assessing a medication directly by its common international name, and the inclusion of information on the follow-up of treatments.

7.2. Decision-aid

However, the diagnostic module had problems linked to the method of knowledge representation.

7.2.1. The path of a graph that is evolved, according to the given clinical situation, is of a rigid structure and can not take into account, for instance, seasonal or geographic variability in the frequency of a disease, . Nor can it be adapted to avoid unhelpful areas of interrogation, such as those beyond the user's level of training, or material means, to answer.

7.2.2. Since it is separate from the treatment module, the diagnosis graph may lead to one or more diagnoses whose treatments are beyond the possibilities of the user. We feel, however, that the diagnostic process should be closely linked to the treatment possibilities.

7.2.3. The graph diagnosis method does not correspond to the medical diagnosis process in which hypotheses are formulated based on a few signs, using further examination to reject or reinforce a hypothesis before deciding on the "best" treatment. That is, one that will be simple, effective, and low cost, relative to one or more diagnoses that may be more or less "certain".

7.2.4. This graph method offers no "explanation" for the diagnoses it derives. Each decision point appears to be independent from the others. The lack of any physio-pathological underlying model makes justification impossible. Thus, it deprives the user of a potential learning situation.

7.2.5. Thus, lastly, an explicit method of representation is not compact; it would require an enormous amount of memory to consider all the possible sequences of situations.

7.2.6. On the other hand, the simplification of the domain studied yields a diagnosis after only a few questions and this rapidity is an important factor in user acceptability. The collection module may prove extremely valuable. Gathering data directly at the clinical level is a good way of keeping track of disease incidence. The use of a simple system provides for the recording of medical information and its immediate verification, as well as the means of analysis and transmission of such data.

8. Tropicaid 2

8.1. Improvements Since Tropicaid 1

The field trial involved several modifications, mainly in order to make the system more powerful in diagnosis decision, and more adaptable to the local conditions of use.

8.1.1. The pharmacological data base is extended to 160 essential drugs. This sample might cover any possible situation in different dispensaries where drugs not available can be "masked" into the program. These drugs can be accessed by their international denomination.

8.1.2. The therapeutic data base concerns about 500 diseases likely to be usually encountered in all developing countries. The information for each of those is stored into records including: as before, 1) a clinical description; 2) the rules by which to determine the specific treatment (drug(s) and/or other treatment) as a function of the following conditions: type of patient, clinical form of the disease, epidemiological context and causal agent; and newly, 3) a priority index for the treatment; 4) a reference to a more generalized treatment; 5) the symptoms for which the treatment is effective.

8.1.3. The diagnostic data base concerns the same diseases as the therapeutic data base, that are now represented by a "frame" (8) made up of two fields.

A selection field includes a set of rules of evocation concerning 350 basic symptoms likely to be recognized by the majority of health workers having received a basic medical training; these signs, which are sufficient to activate a diagnosis, may also, separately or in association, lend a weight of evocation ("weak, "strong"), to the diagnosis under consideration.

A diagnosis field contains rules of two types: obligatory and optional. Non verification of an obligatory rule leads to the elimination of that diagnosis. These rules, separately or in association, participate in the attribution of a degree of certainty for each diagnosis ("certain", "very probable", "probable"). The premises of these diagnosis rules rest either on some 2000 clinical or para-clinical signs or on other diagnoses. Certain of these symptoms, such as intense pain, are classed "to be treated", and such a patient should, at least, receive symptomatic relief.

8.1.4. For each sign considered in the preceding bases, there is a corresponding question. Explanatory messages are provided for difficult questions. Each question belongs to a category so as to avoid questions beyond the capacity of the user's knowledge or material circumstances. A set of conditional rules links all the signs into a network that assures the consistency of the interrogation.

8.1.5. In order to adapt TROPICAID 2 to the environment in which it is to be used, the different knowledge bases take into account several parameters: 1) the level of knowledge of the user; 2) the diagnostic tools available; 3) the therapeutic means available; 4) the epidemiological situation of the diseases. These parameters may be interactively defined by the user and remain in a non volatile RAM, thus making one system usable in widely diverse situations.

8.2. Operation

8.2.1. TROPICAID 2 may still be used as a series of data bases that may be consulted using successive menus of selection. TROPICAID 2 uses the rules of the therapeutic data base to select the best treatment, and those of the pharmacological data base to determine the best posology. In the diagnostic data base, the rules allow the realization of a system for the collection of epidemiological data in which the diagnoses may be checked before entry.

8.2.2. In developing countries, especially, rather than make an accurate diagnosis leading to a specific treatment, the problem remains of choosing the optimal therapy in the face of more or less probable diagnostic hypotheses and limited means of healing. We propose a three step solution to this problem:

The first step consists of registering the principal symptoms cited by the patient using successive selection grids concerning the 350 elementary signs.

The second step begins with the selection of suspected diseases, based on the signs noted down, using the rules of evocation in the first part of the diagnostic data base. The diagnoses thus selected are ordered relative to an index calculated for each, in terms of the frequency of the disease, its priority rating, the concordance with clinical presentation, the weight of suspicion, and the degree of certitude. Then, the choice of the most pertinent question calls into play the diagnosis rules of the top classed diseases. Anamnestic signs are asked before clinical examination signs and both of them before lab signs. The answers obtained update the findings base and permit, using the obligatory and optional rules, the elimination of some diagnoses and the imputation to others of a degree of certitude. It permits also, as the system then goes back to step 2, the addition of some new diagnoses in the first phase of step 2, if certain signs are premises of the rules of evocation. This cycle continues until the verification of a stop criterion which may depend on the number of questions posed, signs classed as "to be treated", and the number of "priority" diseases not having been verified.

The last step consists of choosing a therapy based on the diagnoses retained that are now classed according to their frequency, degree of certitude, degree of priority and therapeutic possibilities. For diagnoses that are "certain", the program proposes their specific treatment, while for those that are "highly probable", the specific treatment is recommended, unless it falls within a group of several "highly probable", for which there is a generalized treatment, in which case the latter is selected. For those diagnoses that are only "probable", only the generalized treatments are suggested, and the second only if the first does not "cover" all the signs classed "to be treated" complained of by the patient.

9. Conclusions

During the development of this advanced version, we were invited by the Ivory Coast Ministry of Health to present our work. This led us to consider and prepare two trials: as a teaching and reinforcement tool for doctors and nurses in the school of medicine, and as a decision-aid system for nurses in dispensaries. It will also be used by Public Health teams for data collection among dispensaries.

Indeed, from a general standpoint, a computer aid for paramedics could serve three major functions. Certainly, it serves as an aid to decision and for the consultation of its data bases in real time with the patient, but this requires a speed and an ease of use that must be reconciled with the quality of the response given. The time constraint is partly removed for the second function, training and continuing education, intended not only for the local paramedics, but also possibly, for foreign professionals whose field experience is limited. This teaching aim appears to be the most realistic use at the moment. Lastly, the collection and manipulation of local medical data is of great interest to public health. Epidemiological surveillance would benefit from better quality data as provided by direct recording and verification without intermediaries or delay and which may be transferred without deformation (and even faster via a modem) to a larger computer at a centralized site. There it would also be possible to monitor the activities at a number of local dispensaries, and in addition coordinate the distribution of resources (such as the stock of medications).

Such a system could certainly be operational on a desk-top computer (TROPICAID will function, by the way, on an IBM-PC) although all this capacity in a dedicated, ready-to-use HHC is even more interesting, particularly as an aid to decision-making. In addition, HHCs have shown themselves to be particularly well adapted to the conditions of use in developing countries because of their ruggedness, internal mass storage, and energy autonomy, to say nothing of the fact that they cost about half as much as a desk-top model (currently around $1000-$1500 instead of $2000-$3000).

The use of systems like TROPICAID faces some constraints. At the present time it would appear difficult to create a decision aid system to encompass all medicine, at least as it is practiced in the West. Aside from INTERNIST (9), medical expert systems are confined to highly specialized fields and are of limited size: glaucoma, antibiotic therapy (10). Although INTERNIST covers 600 diseases, it requires a mainframe computer and takes one hour to interrogate. However, to consider all the pathology likely to be encountered at an outpost dispensary in a developing country is not unrealistic, since it represents only a rather small sub group of all known medicines, especially considering the inability to perform the more demanding sorts of diagnosis, and the unavailability of a larger number of treatments, thus preventing an "explosion" of information due to a greater refinement of the possibilities.

Nevertheless, the current data bases already represent the work of six men during a year. Another problem is to associate developing countries' doctors into the elaboration and the updating of these bases. Of course, a decision aid system is of little use if the user has not had the training necessary to register sufficiently the signs and symptoms and to understand the systems replies, as well as needing a certain amount of willingness to learn and appreciate what the system can offer. These, being human qualities, technology can do little to change directly. Lastly, such systems remain relatively costly, about 10% of an annual dispensary budget, but maintenance is minimal, and they could contribute to a better all round functioning of a dispensary.

We are convinced of the future of portable systems in this domain. While their cost is tending to fall, it will surely remain more expensive than paper, but will permit a wide distribution of systems such as the one we describe. Their performance continues to improve while their size is decreasing. The widespread use of large numbers of such devices will permit a certain "standardization" of practical education, and thus, of the conduct of medicine throughout a country or beyond. One can only hope that such an improvement to the organization of health care will lead to positive consequences in the public health as well as the general development of a developing country.

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Medicine and Expert Systems: The Responsibility in Question

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It is an undeniable fact, well known by every country, whatever the political or economic system in force, that evolution is leading towards societies where information will be the prevailing concept and informatics, in its widest sense, the privileged technology. It is also a known fact that this movement must be well prepared to allay any harmful consequences that may result. In other words, everyone should develop their own form of informatics and not submit to that of others. This is true for countries, enterprises, and individuals, since informatics, through the various types of microcomputers and software, is becoming a widely consumed product.

For countries and large enterprises, this change is based on three fundamental axes:

- competitiveness in key areas of information technology: microelectronics, telecommunications, informatics;
- command of the use and adaptation of new technologies for manpower training, and the production of goods and services;
- The capacity to develop structures and methods which best suit the technological environment and challenges that this complexity presents.

To simplify this, one could say that in order to establish these fundamental axes, three conditions must exist simultaneously: i) a clearly stated political desire; ii) human resources, with intellectual and technical experience; iii) sufficient financial resources.

In two countries – the United States and Japan – all of these conditions exist, which explains their amazing development, and their role in commerce, in new technologies, and in the application of innovations.

For another twenty or so industrialized countries, some of these conditions exist, but slow progress is made, in comparison with the leaders. Regrouping, which is taking place both in the West and in the East, to form regional projects, will no doubt lead to swifter progress, perhaps even certain competitiveness, and definitely greater security.

What is the situation in the developing countries? In most, only political desire exists, which in many cases, has already taken shape, and informatics has, thus to some extent, developed, particularly in management, and sometimes in the administration sector, and within certain areas of industry. It would be difficult to have done better considering the lack of financial and human resources.

The educational and services sectors – essential to development – have barely been touched by informatics, whereas these are, in fact, the areas that would benefit most from the new technologies. Virtually everything is dependent on education and health, prerequisites for all forms of development, whether economic, industrial, cultural, or whatever. The tragic underdevelopment suffered by many countries, despite the richness of their earth and subsoil, is due to the fact that they have been deprived, or cast aside, for so long. Can this process be reversed by these new technologies, including informatics and its applications? Let us be cautious and say why not?

Informatics is not the universal panacea. The computer does not train, educate, or look after people. It is man who is in charge. However, informatics can facilitate the acquisition of knowledge and the sharing of know-how and expertise.

This brings us to Expert Systems and their applications, in particular in the field of medicine. Let us not spend time over problems of definition. Can intelligence be artificial, and can the machine think? Let us just say that in the relationship between Man and the Machine, the expert system is the link. Born of man's competence, it increases the performance of the machine through the results that can be obtained.

Leaving aside all the commercial aspects surrounding it, an expert system is a marvelous result of mankind's cooperation for the benefit of others facing problems that they cannot resolve in their current environment. Since its conception, the expert system combines pluri-disciplinary competence – a result of years of experience, observation, and practice. Paradoxically, industrialized countries, possessing in quantity and quality the necessary medical personnel, could more easily do without, for example, applied medical expert systems. Although consulting the expert system to corroborate a diagnosis that has been made, or a therapy prescribed – and this has often been proved – provides the doctor with complementary, and often useful, information (contra indications, side effects).

In developing countries, where there is a patent lack of doctors, particularly specialists, the situation would be quite different. This, aggravated by an ever-growing population, and poor medical facilities, results in a medical service which has to cope with very many patients, and yet is severely lacking in all the essentials. Turning to expert systems for help in diagnosing, automatic processing of electrocardiograms (ECG), automatic consultation of available medical stocks and their dosage, will provide effective help to doctors.

These systems could, likewise, be used to train medical students and paramedical personnel, or to help doctors ask patients relevant questions.

The lack of an adequate medical infrastructure is also a characteristic of developing countries.

Away from his base, the doctor can only resort to his knowledge and memory for diagnosis, based on clinical symptoms and the few elements that he can easily ascertain (temperature, blood pressure, heart beat). Portable, easy-to-use microcomputers and expert systems could improve what is termed "bush medicine".

With these few examples, it is obvious just how useful expert systems could be, especially in times or situations of crisis. Should they, however, be used without caution? What measures are envisaged against fraud or mishandling?

As it is a question of human lives, the problem of responsibility arises. Normally the doctor is responsible for his diagnosis, and thus assumes responsibility for his errors. However, what would happen if the error were in the system itself? Can expert systems be marketed without being subject to controls, in the same way that different software systems have invaded the market? The user should be notified of the scientists responsible for the expert system? Can the risk of encouraging self-diagnosis and the administration of drugs be taken? Perhaps expert systems should be considered as medical products and pass the various visa controls, and also be subject to marketing regulations, as is the case for drugs. On the other hand, therapeutics implies a choice of drugs; if the nomenclature used refers to commercial brands of drugs, would expert systems not risk promoting certain products?

These are just a few aspects that should incite reflection and caution. Far from condemning the use of medical expert systems, it is necessary to define more clearly regulations for their use and to be more aware of their potential and limits. It would be a serious error, particularly for developing countries, to think that training could be affected more quickly by using expert systems and informatics. However, medical students could receive a better training, when provided with systems into which years of experience, and a wealth of knowledge, are concentrated. In the meantime, while awaiting something better, we can use them to guard against difficult situations. In the hands of experts, these systems can be of the greatest value, in the hands of the profane, caution is imperative. Expert systems should be considered, not as solutions, but as an additional asset to provide a more effective and reliable medical service. In any event, the doctor will always be present and his presence, in itself, provides security, in the same way that the school teacher is there to transmit scientific messages through informatics, and emotional support through himself.

We have not, fortunately, waited for expert systems and informatics to provide a good medical service, and possessing and knowing how to use them does not necessarily make a good doctor.

Expert systems are certainly useful. However, it is not the miracle solution, but an excellent complementary tool that should be responsibly used, with complete lucidity, and when necessary, taking into account the context and circumstances. Thus, they will encourage man's creativity, and not act as a substitute for him.

Automatic Schistosome Eggs Detection and Counting

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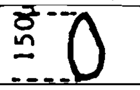
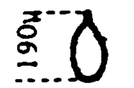
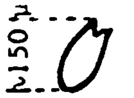
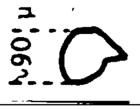
Schistosomiasis is a parasitic infection prevalent in many developing countries in Africa, the Orient, Central America, Spain, Portugal, Turkey, and the Balkans. The direct mortality is low, but the parasitic multiplicity and transmission are very fast and constitute a heavy burden on the populations health and on the medical services.

There are four types of schistosome infections. The following synoptic table summarizes their egg shapes, their specific targets, and their geographical localization.

Type	Target	Eggs	Geographical localization
Schistosome haematobium	people		Africa, Middle East, Madagascar, Turkey
Schistosome intercalatum	people		Equatorial Africa, RCA Congo, Gabon, Angola, Cameroon
Schistosome mansoni	people animals		Africa, Madagascar, Central America
Schistosome Japonicum	people animals		Far East

About 200 million persons are actually affected, and about 600 million others are exposed to this disease. To combat this parasite, the medical services work has, until now, consisted of taking urine samples from effected people and counting the schistosome eggs under the microscope. The number obtained by unit area determines the gravity of the infection. As the personnel is subject to tiredness, such a slow procedure will introduce counting errors.

In recognition of this the World Health Organization (WHO) has launched a vast program of research to control the transmission speed of this disease, and to evaluate the clinical treatments. The first part of this program consists of the automatic recognition of schistosome eggs, and counting techniques design. The second part, which is the ultimate goal, is to set up autonomous equipment as an automated schistosome egg recognition and counting system.

Such a system, under technological constraints, must be rugged, lightweight, and inexpensive equipment, for large scale screening by minimally trained personnel. This realization may be based on digital image analysis and pattern recognition techniques. Hence, three different methods have been studied on the basis of haematobium eggs obtained from WHO in the form of microscopic preparations. These techniques are summarized as follows:

1. Edge Tracking Technique

With this technique, the contour image (high-pass filtered image) is scanned line by line until reaching a point whose gray-level value is greater than a contour start threshold (CST) value. When this point is found, a local maxima is searched for in its neighborhood. This local maxima will be the starting location of the contour. Successive connected points, in the direction pointed out by the local maxima, plus or minus forty-five degrees, are tested against a contour continuation threshold (CCT). The largest pixel gray-level is retained and stored in a contour buffer. If a pixel is found to be less than CCT, the search is terminated in this direction and will begin in the other possible direction from the starting location. When the search is terminated in the second direction the two contour pieces constitute a segment whose length is tested against *a priori* given length threshold L. Segments of length less than L are considered as false positives and are rejected.

The success of this technique depends on the choice of the three threshold values. In this work, one can note that the first two (CST, CCT) may be selected automatically, using the picture informations, while the third one (L) will be chosen by experience, and a knowledge of the eggs average perimeter.

2. Template Matching Technique

In this case, the original image is high-pass filtered, and the resulting one is scanned with a ring shaped mask whose inner and outer radius are chosen to be equal to the egg's short and long axis, respectively. For each position of the ring, the pixel values are accumulated in the center, and when an egg is fully intercepted the resulting value is a local maxim. After this scanning, the resulting image is analyzed for local maxima search and counting.

We have shown problems related to non-uniform illumination and the overlapping of eggs that occur in this technique. Furthermore, there are two crucial parameters relative to the adaptive thresholding in the counting part. These two threshold values will be chosen by experience.

3. Shrinking and Expansion Techniques

Shrinking and expansion are two neighborhood transformations developed for absorption images where strains have caused the objects to be stained and non-uniform.

By these transformations, small debris is removed from the background in order to end up with a picture in which objects and background are of unequal, but approximately the same, gray-levels. The shrinking operation causes the objects to be smaller, and expansion causes them to be larger.

This technique is applied as follows:

- the gray-level image is first binarized using a threshold,
- the resulting binary picture is processed by a series of shrinking and expanding operations,
- the image obtained is then subjected to the logical exclusive OR operator that permits the contour extraction from which the eggs total number is determined.

It was shown that this technique is a function of two parameters – i) the threshold value permitting a "good" binarization of the gray-level image, ii) the number of shrinking and expanding operations necessary to end up with a cleaned picture.

It was shown that the image obtained with this technique differs from one image to another. It is difficult to determine a global series that works well for all pictures. To solve these two problems the following ideas are proposed:

- The threshold value should be automatically selected using the enthropic threshold approach. The value is taken to be the highest threshold given by this technique.
- The number of shrinking and expanding operations is determined as an average number obtained from an individual series of operations for each image. This average series of operations is taken to be that giving a minimum global counting error on a relatively large number of eggs. It is evident that a certain compromise must be made between the exact number of eggs and the series of shrinking and expanding operations used.

4. Conclusions

These three methods of image processing and pattern recognition have been compared on the basis of haematobium egg detection and counting. The edge tracking technique may be retained as the "best" one when taking into account only the counting error. The tests will continue and the study will deal with computational time and memory problems, as well as the detailed analysis of mansoni pictures. Furthermore, the second part of the project will concentrate on the automated schistosome egg detection and counting system by autonomous equipment.

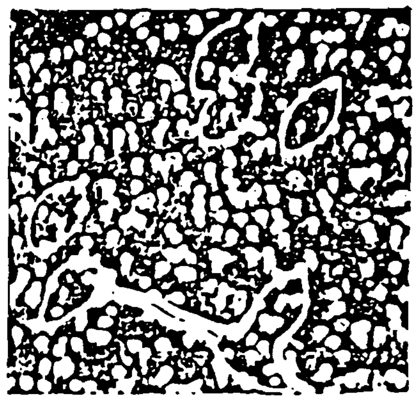
Image Number	Number of Eggs Counted	Real Number of Eggs
1	6	5
2	3	2
3	5	5
4	2	1
5	12	11
6	8	6
7	9	7
8	6	8
9	4	7
10	8	8
11	8	6
12	5	7
13	7	9
14	3	7
Total	86	89

Results are those obtained by the contour method in the case where the length of the contour retained is $L = 75$ points. The error in counting is 3%.

9

10

11



12

13

14

Images acquises par transparence (suite)

Les résultats détaillés de comptage sont donnés par le tableaux ci-après.

System for Producing Expert Intelligent Systems – SPEIS

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Introduction

Recent years were a remarkable time for Artificial Intelligence (AI). Considerable progress was made in the development and broad application of AI methods to problems of practical significance. An important achievement in this field was expert knowledge-based systems, so named because they model knowledge, possessed and exercised by an expert, or group of experts, into a narrow confined domain. Expert systems of today are used for consultations (diagnoses, recommendations) in various application areas such as medicine (1, 2), chemistry (3), geology (4), and some others. The purpose of each system discussed here is to assist a person, who is not a skilled expert in a particular field, to make correct decisions.

Expert systems are developed in a branch of Artificial Intelligence known as "knowledge-engineering". A computer is used to manipulate symbols instead of numbers, and to perform symbolic inference. In other words, it follows qualitative lines of reasoning leading to the solution of problems that are stated symbolically. This feature gives rather rich opportunities to researchers. It makes it possible to model many crucial processes such as ecological and social development, human decision making, etc., that can not be modeled properly by numerical methods, but must be represented by the logical processing of qualitative non-numerical information.

There are two main units in an expert system – a knowledge base containing domain-specific knowledge supplied by an expert, and an inference mechanism, often called a control structure.

In a broad sense the domain-specific knowledge involves two components. The first comprises the laws and facts of the domain chosen, i.e., widely accepted knowledge. The second reflects heuristic knowledge, i.e., some kind of information that represents long-term practice, experience, and the intuition of an expert.

The inference mechanism consists of a number of procedures that work with the knowledge base, and relevant initial data to solve a problem of interest.

An expert system can be considered as an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution (5).

The process of building an expert system can be described as a multi-step procedure involving the following four stages:

a) eliciting the needed knowledge from the expert;

b) transforming the knowledge to the computer consistent form;
c) testing the system and revealing its faults;
d) discussing the faults with the expert and correcting the system in order to adequately simulate the expert's decision process.

These stages overlap, and are heavily interdependent. It may take several years of hard work by experts, computer scientists, and researchers, to produce a knowledge-based system.

This procedure is closely connected with the three central problems of AI: knowledge representation, knowledge utilization, and knowledge acquisition.

Knowledge representation is defined by a formal scheme, and knowledge utilization is characterized by the architecture of the inference mechanism. These issues are very important. However, of paramount importance is the acquisition of knowledge as the performance of the expert system depends strongly on the completeness of the knowledge base.

Last but not least, is the problem that exists when building an expert system – the issue of explanation. Augmentation or modification of the knowledge base is facilitated by the ability of the system to show to the expert that the information is stored, and how it can be used. This ability speeds up the process of verification and debugging the system. Moreover, it makes the process possible. On the other hand, the system's ability for explanation increases the users confidence in the system and promotes an active application of the expert system in practice.

One basic feature of all expert systems is that each system is strongly oriented to a special class of problems. It means that many months of hard work by the systems developers may result in only a single working program. It is obvious that in order to facilitate the process of constructing an expert system, and reducing time consumption, some general tools are needed.

It is not surprising that with the growing number of expert systems now available some common ideas and program techniques are beginning to emerge. EMYCIN (6), EXPERT (7), AGE (8), are examples of software packages that help engineers to construct expert systems.

SPEIS – a computer-based system, described in this paper, belongs to a class of domain-independent systems and is intended for the computer-aided construction of problem-oriented expert systems.

The SPEIS System. The Experts Problem-Solving Model

SPEIS (System for Producing Expert Intelligent Systems) was developed along the current context of knowledge engineering. It is designed to construct some class of knowledge-based systems.

Before discussing the structure of SPEIS it is worth mentioning that we have chosen and implemented into a computer the following model of the experts decision-making process. An expert solving a problem on the basis of some initial information generates hypotheses that reflect relevant concepts. They may be diseases, events, structures, etc., that are dependent on the application domain. The validity of the hypothesis generated is verified by gathering additional data that would either confirm or reject this hypothesis and give birth to a new hypothesis. These concepts form a hierarchical structure similar to the classification scheme where the most general concepts are placed at the top, and the most specific at the bottom. The expert's knowledge is distributed through this hierarchy. At the beginning of the decision-making process the expert activates hypotheses of higher levels, and if they are confirmed, he tries to analyze more specific concepts. The hypotheses generation is carried out in such a way that if the information gathered allows invoking a more specific hypothesis it happens immediately, without fully checking the activated general hypothesis.

The proposed model is a rough approximation of the real mechanism the expert uses while solving the problem. Our practice shows that the model seems quite natural to the experts, and is willingly accepted by them.

The Knowledge Representation Scheme and Elements of the Inference Mechanism

The expert's problem-solving model, suggested above, is based on a consequent generation of hypotheses and their validation. The formal scheme chosen for knowledge representation uses frames to describe the concepts and production rules attached to the appropriate frames to characterize the concrete details of the concepts and govern the hypotheses generation.

An individual production rule has the form:

IF condition THEN conclusion

that shows a small portion (chunk) of the experts decision process. The condition is composed of conjunctions or disjunctions of premises that either refer to initial data or to the conclusions of other rules using such data. Thus the conclusion of one rule may be used as a premise in other rules. As a result such chains of rules represent rather complex decision processes.

A frame is a protypical description of a concept. Each frame is a structure with a name and a number of slots that are filled by various properties, logical and semantic relations, associated sets of production rules and attached procedures.

The SPEIS frames at all hierarchical levels have a unified form that is represented in Figure 1.

The frame structure

Name of a slot
NAME-OF-A-FRAME
ANCESTOR
DESCENDANTS
PARAMETERS

CONDITION
TRANSITIONS
CONNECTIONS
AXIOMS
CONCLUSION

Figure 1.

Let us consider the role of each slot.

Slot NAME-OF-FRAME contains a unique name that denotes a concept. A frame that should be activated is referred to by its frame.

Slot ANCESTOR and DESCENDANTS describe the hierarchical structure of the concept. The frames with names written in slot DESCENDANTS inherit properties of the concept stored in slot ANCESTOR.

Slot PARAMETERS stores all of the parameters that characterize the concept described by the frame. The values of the parameters are assigned either as input data or derived from production rules. A parameter of the first group is called simple, and of the second, derived. A simple parameter is represented as a pair (NAME-OF-PARAMETER VALUE-OF-PARAMETER), while a derived parameter – as a production rule:

((IF (AND (NAME-OF-PARAMETER-1 VALUE-OF-PARAMETER-1)
(NAME-OF-PARAMETER-1 VALUE-OF-PARAMETER-1)
(THEN (NAME-OF-DERIVED PARAMETER VALUE-OF-PARAMETER))),

where atom AND stands for conjunction.

It is worth mentioning that the information in slot PARAMETERS also determine a protocol for requesting input data in the course of a systems run.

Slot CONDITION holds a production rule that serves as a clue for the activation of the frame.

Slot TRANSITIONS show all the possible logical links that connect the frame with other frames in the hierarchy, with the exception of the frames indicated in the ANCESTOR and DESCENDANTS slots. A link is defined by a production rule and, if the left hand side of the rule is valid, the frame written in the right hand side is activated.

On the contrary slot CONNECTIONS lists the name of frames that may excite this frame. So it is the second way to activate a hypothesis.

Slot AXIOMS contains irrefutable statements that are valid in the domain selected. This information is mainly used at the explanation step.

Slot CONCLUSION holds the set of production rules, each of which gives us a final result, depending on the data provided during the systems run. As soon as any rule of this set fires the decision process is over.

It should be noted that the content of some slots may be empty.

The inference mechanism separated from the knowledge base does not depend on the domain semantics, but is based on the syntactic structures of the representation scheme. It uses semantics by interpreting some data structures, for example, the information of the TRANSITIONS slot, as commands to change the direction of problem solving. The inference mechanism is realized as a hypotheses-driven procedure with the forward (left hand side) scan of the production rules.

The Explanation Block

There are several explanation capabilities in SPEIS that can be used to understand or verify some aspects of the system's performance. The capabilities may be divided into two groups.

The first group is intended to explain the dynamics of the decision process. More precisely, after a system's run, the expert may get a list of all the hypotheses that have been generated in the run. He may also receive information as to why any of the hypotheses activated were rejected, or how the final result was arrived at.

This information is accumulated during the run in special working frames that the system automatically compiles. The structure of a working frame is shown in Figure 2.

Structure of a working frame

SLOT NAME	slot contents
NAME-OF-FRAME	an atom
ACTIVATED-BY	a name of a frame
ACTIVATE	a list of frame names
ACTIVATION	NIL NOT (NIL)
STATUS	CLOSED OPEN
TRANSITIONS	a list of production rules
RESULT	a list of production rules

Figure 2.

Slot ACTIVATED-BY holds the name of the frame that generated the hypothesis.

Slot ACTIVATED stores names of all the hypotheses that have been generated by the hypothesis. Recall that slot TRANSITIONS (see Figure 1) enables activating transitions from one frame to several frames.

Slot ACTIVATION registers the way in which the hypothesis has been activated. There are two ways to do this: the execution of a production rule in the TRANSITIONS slot, and the validation of the rule in the CONDITION slot.

Slot STATUS characterizes the current state of the frame.

Slot TRANSITIONS contains the current state of the frame.

Slot TRANSITIONS contains a list of production rules that have caused the activation of the hypotheses shown in the ACTIVATED slot.

Slot RESULT stores the result of the decision process.

The second group of explanation capabilities is oriented to demonstrate how segments of knowledge in the knowledge-base can be used. The expert may ask the system the following three questions. How is it possible to activate the frame? How is the hypothesis rejected? How should the hypothesis be accepted as a final result?

To answer these questions the information in the CONDITION, TRANSITION, AXIOMS, and CONCLUSION slots is used.

Knowledge Acquisition

As SPEIS was designed to help knowledge engineers construct expert systems, the knowledge acquisition block is a key component of the SPEIS architecture. The block represents the tools for computer-aided design and for modification of the knowledge base to be created.

The acquisition block contains a base of meta-knowledge in which formal schemes of knowledge representation and models of specific domain notions are stored. The schemes provide a framework for expert–SPEIS conversation with the system responsible for making the knowledge structures added to comply with the adopted syntax and semantics. Special procedures also verify that a new portion of knowledge is correctly defined and does not contradict the information accumulated in the knowledge base.

The meta-knowledge base is domain independent and relies on the semantic net of the structures chosen for representation. The capability given to SPEIS to examine and manipulate its knowledge base provides rather rich possibilities for the expert while constructing a domain-oriented system. He may i) define a new frame, ii) declare a new parameter, iii) enter a new rule or a parameter into a slot of a frame, iv) modify a rule or a parameter.

Consider, for example, the dialogue between the expert and SPEIS when they are "both" creating a new production rule in the TRANSITIONS slot of a frame named F. Note that the expert's answers, end with a special symbol Z (see below).

SPEIS	We are constructing a new transition rule.
SPEIS	Let us begin with the condition of the rule.
SPEIS	Term?
	AND Z
SPEIS	Enter the parameters and their values.
SPEIS	Parameter?
	NUMBER-OF-SIDES Z
SPEIS	Value?
	FOUR Z
SPEIS	Parameter?
	SIDES Z
SPEIS	Value?
	EQUAL Z
SPEIS	Parameter?
	It is all Z
SPEIS	The left part of the rule is constructed.
SPEIS	IF (AND (NUMBER-OF-SIDES FOUR) (SIDES EQUAL))
SPEIS	Is it correct?
	Yes Z
SPEIS	Enter the name of the frame.
	SQUARE Z
SPEIS	The rule is created.
SPEIS	((IF (AND (NUMBER-OF-SIDES FOUR) (SIDES FOUR)))
	(THEN (SQUARE)))
SPEIS	Is the expression correct?
	Yes Z

After receiving the experts agreement on the created version, SPEIS inserts the rule into the TRANSITIONS slot of frame F. SPEIS automatically adds atom F to the list of names in the CONNECTIONS slot of frame SQUARE.

The other possibilities of SPEIS to modify the knowledge bases are implemented in analogues ways.

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Expert Systems in Services of Computer Assisted Medical Diagnostics

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1. Introduction

Several decades of computer applications to a wide variety of problem domains is indisputable proof that computers are not only very efficient problem solving instruments, but are indeed, inevitable for handling various classes of problems. The problems in the domain of medicine are no exceptions.

Whenever a medical problem can be stated in terms of numerical expressions, its algorithmic, i.e., deterministic, solution, in most cases, is within reach. Therefore the possibility of employing a computer for its solution can, and should be, considered. The same is valid for problems of a non numerical nature, if the problem can be stated in terms of symbolic expressions for which algorithmic processing methods are available. However, the majority of real life problems do not meet the conditions for their algorithmization, i.e., solving them is not based on well defined procedures. This is especially true in medicine.

The human capability to successfully solve non algorithmic problems is a manifestation of cognitive abilities, and also a manifestation of intelligence. Human intelligence is a subject of study in several scientific disciplines. One is artificial intelligence (AI). Its aim is to attempt to (i) understand the nature of intelligence, and (ii) produce new classes of intelligent machines through programming computers to perform tasks that require reasoning and perception. The goal of AI, as a whole, is to produce machines that act intelligently. By the term "act intelligently" it is understood that the computer has the capability to cover a broad range of activities corresponding to the human ability to reason. The ultimate target is to provide methods for developing programs that enable computers to mimic, or even out-perform, in some respects, the human cognitive problem solving abilities.

As a result of efforts in AI, many programming techniques have been developed for computerized cognitive problem solving. Among the most successful practical products, based on those results, are the knowledgeable systems. These are rather complex program systems equipped with symbolic data structures representing knowledge. These knowledgeable systems are becoming of more practical use and belong to a class of expert systems.

The invention of expert systems (ES) is a challenge for computer applications to problem areas in which computer utilization had not been expected. The capabilities of these systems are increasing unceasingly and rapidly. Thus, the continued improvement of their cognitive competence gives grounds for the realistic forecasting of their dominant role in the majority of computer applications (14). This should be especially true in the domain of medicine as most diagnostic problems, treatment decisions, health care management, etc., are of a cognitive (non algorithmic) nature.

2. The Cognitive Nature of Medical Diagnostics

Among the most motivating problem domains participating in the origin of expert systems and stimulating their development is the domain of medicine. This is reflected by the fact that a great amount of existing ESs is devoted to medical, and particularly, diagnostic, problem solving.

By the late 1960s, in the field of medical informatics, it became more and more obvious that the contemporary mathematical, probabilistic, and symbolic data processing methods in the services of medical diagnostics, proper therapy selection, and patient management in general, were not adequate. Recognition of the cognitive nature of the related problems, and a search for new principles to be employed in corresponding solving processes, brought the principles and methods of artificial intelligence to the focus of attention. An increased interest in diagnostic ES can be attributed to this fact. As a result, important changes in the computer assisted diagnostic paradigm evolved – computerized diagnostics is associated with computerized cognitive problem solving.

We have attempted to discuss, in some detail, the principles of the new paradigm in (9). The following is an abbreviated presentation of the basic ideas discussed in that paper.

When medical diagnostics is identified with cognitive problem solving then it is necessary to specify its initial and end state, and also, the transformation processes between these two states.

The initial state can be understood as a kind of (mostly) stereotyped story, usually only partially worked out, that is to be completed and summarized, i.e., understood. The "story" is given by a (partial) clinical image of the patient's health state, i.e., by a structuralizable set of manifestations (findings), and also by related information concerning his health and life conditions. The problem is then the interpretation of this "story", i.e., recognizing the disease in the patient. In other words, the problem is to answer the question having one of the following forms: By what disease can the patient's findings be explained?" or "Is a supposed disease provable by the observed findings?"

The clinical image – as a structuralizable collection of significant findings in the patient – results from the patient's complaints, evaluation, observation, examination, and inquiries, and also, sometimes, by the evaluation of his previous or current treatment. It is obvious that at the beginning of the diagnostic problem solving only a partial clinical image is usually available. This image must then gradually be completed, under the existing constraints, in the course of the problem solving.

The end state is the interpretation (summarization) of the clinical image. As various, seemingly contradictory, interpretations may have been made concerning the meaning of the disease and, therefore, of the diagnosis (2, 3), naming the disease in the patient need not be a sufficient diagnostic end result. Besides a diagnosis or diagnoses, the diagnostic end result ought to connotate the knowledge of the causal factors of the disease, its character regarding type, severity, and stage, as well as an estimation of the amount and the kind of damage the patient has received. Therefore, it is claimed, the diagnostic end result should, whenever possible, take the form of a brief descriptive statement – a sort of clinical assessment. This corresponds to the "story" summarization. It should consist of, among others, a description of the pathological process or processes (one frequently predisposes to another) and where they are acting, a description of the structural changes, (lesions) and functional disturbances (dysfunctions) that have led to the findings observed (by what means and under what circumstances) in a patient.

If the described notion really corresponds to the practical needs in medical diagnostics then it should be clear that the previous paradigm of computer assisted diagnostics (based mostly on probabilistic approaches and blind algorithms) can not meet the requirements of the cognitive nature of medical diagnostics. The term "diagnose", meaning "mediated knowing", suggests itself a conception in which diagnostic problem solving is to be based on domain specific medical knowledge and methods of their goal-oriented efficient utilization. In this respect the expert system approach provides a promising knowledgeable means for satisfying the required features of cognitive diagnostic problem solving, and the expected form of its end result.

The ESs strive, from various aspects, to mimic the cognitive nature of a physician's knowledgeable diagnostic activities. They are based on principles that reflect the generalized systematic component of the physician's competent information processing performance. In as far as it is possible to describe (articulate) such a performance, it is also possible to incorporate the corresponding cognitive problem solving methods into expert systems. This is based on a powerful inference mechanism modeling well human ability to reason effectively, and on general, and yet flexible, knowledge representation data structures that permit the rich diversity of medical knowledge, and types of its fundamental criteria to be embodied in those systems. ESs makes it possible to represent schemes of diagnostic categories general, and species and it also makes it possible to imitate many of the reasoning processes in a physician's mind, moving up and down across those schemes when evaluating and interpreting a patient's clinical image. These are the underlying principles on which ESs perform the transformation of initial facts onto the end result, i.e., search for plausible identification of the patient's health state.

Expert Systems

Expert systems are, in principle, systems of cooperating programs whose performance is based on non procedural data structures that represent human knowledge and skills. The ESs are (4) specified as follows:

> An ES is regarded as the embodiment, within a computer, of a knowledge-based component, from an expert skill, in such a form that the system can offer intelligent advice or take an intelligent decision about a processing function. A desirable additional characteristic, that many would consider fundamental, is the capability of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the enquirer.

This specification offers a very condensed notion. Without going into detailed specifications of those systems, we extend the above specifications by listing some of their notable characteristics (cf. 4, 8):

1). Expert systems perform difficult tasks at expert levels of performance.

2). They emphasize domain-specific problem solving strategies over more general methods, i.e., they are limited to a specific domain of expertize (also due to a limited range of embodied knowledge).

3). They can reason (infer) with uncertain and incomplete data and knowledge.

4). They can explain their train of reasoning in a comprehensible way.

5). The active reasoning processes (performed by programs) and the passive (non procedural) data structures representing knowledge (the knowledge base) are in ESs clearly separated, i.e., the knowledge is not hard-coded into programs.

6). The ES's capabilities are designed to grow incrementally, i.e., the system allows a gradual enhancement of its active processes and, most important, a step-wise extension and refinement of attachable knowledge bases.

7). The knowledge base is most frequently designed as a system of rules having the form

IF a condition is satisfied THEN a conclusion should be drawn

or

IF a situation occurred THEN an action can be taken.

Such rules correspond to diverse assertions having validity in the given problem domain. In more advanced representation systems other sorts of knowledge (e.g., generalization-specialization hierarchies, contextual dependencies, object descriptions, decision utility functions, technological procedures, norms, tabularized facts, etc.) are represented also. Different representation formalisms correspond to different knowledge types. Frame systems seem to be the most promising general representation formalism.

8). Expert systems performance, besides being based on symbolically represented knowledge, are also based on describing problems at multiple levels of abstraction, allocation of problem solving resources, control of cooperative processes, and on integration of diverse sources of knowledge in inference (all of these depend primarily on the capacity to manipulate symbolically the problem descriptions and to apply relevant pieces of knowledge selectively).

9). The ESs solve problems that generally fall into at least to one of the following categories: interpretation, prediction, diagnostics, debugging, design, planning, monitoring, repair (therapy), instruction, and control.

10). As an output ESs deliver not numbers, figures, or tables, but sound advice.

Each ES consists of two basic parts, the inference mechanism (IM) and the knowledge base (KB). The IM takes care of various reasoning processes, and the KB embodies the expert knowledge. Besides those two basic ES components the following two are also integral parts of those systems: the explanation module – taking care of the explanation and justification of the reasoning processes, as well as of the attained results – and the communication module – taking care of the user-system interactions.

An ES, when not delivered as a turnkey system, is also provided with supporting modules for KB design, maintenance, and consistency control. These modules are rather complex systems of programs serving for knowledge acquisition and knowledge base tuning by its designer.

The above list of ES components is not necessarily an exhaustive one. There are several advanced and sophisticated ESs comprising some additional procedural and non-procedural components that support more enhanced system performance. For example, the inference mechanism control module supporting optimal inference strategies, agenda (a control data structure) that by its content reflects the course of problem solving, and thus enables focusing the system's attention to the currently most promising sub-goals, the end result generating module that serves for integrating partial results into an easy to understand whole, the external data access module enabling the ES to be interfaced with external data sources (e.g. with external cooperating data processing systems), etc.

4. Expert Systems in Medicine

Several hundred medical, and especially, diagnostic ESs have already been developed. They cover a very broad range of problem domains from nearly all clinical disciplines. Some of them are rather narrowly oriented (e.g. SERUM-DIAGNOSTIC-PROGRAM) and others strive to be very complex (e.g. CADUCEUS aiming to cover diagnostics in all of internal medicine). Most of these ESs are either under development or in a phase of experimental verification. Not too many systems have reached the stage of routine daily use (we shall return to this later).

Scientists from the US did the pioneering work in the development and application of these systems. They have produced most of the well-known ones. ATTENDING, CASNET, CENTAUR, EXPERT, INTERNIST, MYCIN, ONCOCIN, PUFF, VM, and many more. Some of these systems have significantly marked and influenced developments in this area.

The challenge of ES medical applications did not, however, remain limited to the US. Scientists from Canada, Japan, and many European countries also made significant contributions in this area. To illustrate this, let us mention just a few of the European projects: CADIAG and ESDAT from Austria, CODEX and FEL-EXPERT from Czechoslovakia, SUPER and TROPICAID from France, HERMAN and IDEA from Holland, PERINATOLOGY-ES from Hungary, ANEMIA from Italy, and MODIS from the USSR.

Professionals from the medical informatics communities (in spite of some objections) are becoming more and more aware of the ES position in computer assisted diagnostics. Nowadays, theses systems seem to be the most promising alternatives, because of the following considerations (cf.4):

- Whenever human experts are in great demand and in short supply, an expert system (a computer consultant) can help amplify and disseminate the needed expertise.
- ESs can capture the practical experimental knowledge that is hard to pin down and is rarely, if ever, found in textbooks.
- Seeking a second opinion for complex or hard to treat problems is becoming increasingly important, especially in medicine where specialization has grown.
- Summarizing the expertise of the best specialists within computer models (of medical knowledge and efficient patterns of use) can provide some very good advise for its users, and put the latest results of medical

research at their fingertips.

- Even very proficient physicians can be exposed to many conflicting demands allowing the possibility of being distracted and more vulnerable to errors than a computer based expert system.
- The ESs may serve as a very useful interactive intelligent problem solving and advisory system that augments the capabilities of the user as the systematic component of expert problem solving is becoming superior.

It is important to realize that, generally, a running ES does not have any special hardware requirements. Actually, any computer allowing interactive user-system communication will do, from a personal computer (even hand held battery powered, e.g. Husky) to mainframes. Naturally, the hardware may have a lot of influence – terminals predetermine the comfort and friendliness of communication, disk and core memory capacity, the extent of the knowledge base and the systems response time.

After promoting the role of ESs in medicine, one can certainly wonder why not too many of them are in real routine use. Before giving an answer it is important to note that the computer assisted diagnostic systems based on other principles, namely, Bayesian approaches, in spite of having a longer evolutionary history, are seldom found in routine use (especially when a decision should be made for a particular individual).

Several reasons may be listed to clarify the limited number of ESs in real medical use (cf.4). Let us divide them into two groups. In the first we mention those mostly having reasons in theory:

- The ESs are still only in the early phase of their evolution.
- Computer capabilities in sensory recognition are still far from matching that of humans.
- Lack of understanding, representing, and utilization of common sense knowledge.
- Lack of possibilities to represent and interpret the time and space relations.
- No generally accepted and sound methods for approximative reasoning have, as yet, been invented.
- Lack of methodology for knowledge acquisition and knowledge base design.
- Lack of knowledge engineers (professionals for KB design) properly skilled in medical (generally any) application domain.
- More natural and easy user-system interaction is needed.

The second group of reasons are to be assigned mostly to problems related specifically to the domain of medicine and people beyond KB design and ES applications:

- There are serious gaps in attitudes among cognitive scientists, scientists in informatics, medical researchers, and practicing physicians.
- Lack of methodology for articulation of medical knowledge and skills.

- One knowledge source for KB design is usually not sufficient and the cooperation of several medical experts is hard to organize.
- Lack of motivation in medical experts for KB design (more recognition is gained by writing a book), there are even significant barriers in articulating ones own skills.
- In order to develop a routinely usable ES the system and the attachable KBs should undergo extensive testing in various settings with corresponding refinements, this is hard to organize.
- Flexible ES adaptation is needed to comply with the various requirements of differently skilled users. This, as a rule, leads to significantly higher requirements in KB design.
- In ES developments and KB design it should be clarified when and to whom the system is addressed.

It is not our intent to dissuade anybody from ESs – just the opposite. Keeping in mind the previously listed supporting considerations we do not see any better alternative in computer assisted cognitive problem solving than ESs embodying the AI methods. Among others, the experiences and results attained by our CODEX expert system we consider to be very plausible for our conviction. However, it would not be realistic to neglect several serious problems. Presently, applications of AI methods in medicine would not fully meet the expectations.

5. The CODEX Expert System

CODEX (computerized diagnostic expert) was developed primarily for medical diagnostics. Its capabilities, however, are not limited to this purpose only.

We do not aim to present a full description of this system now, instead a list of some of its main characteristics follows:

- CODEX is, in principle, an expert system shell, i.e., an "empty" system to which various knowledge bases may be attached; the system is provided with program tools for KB design, maintenance, and consistency control.
- The inference mechanism, besides deductive reasoning, performs several other activities – inductive reasoning, i.e., the selection of hypotheses for (deductive) evaluation and ordering the urgency of their evaluation of the hierarchical (generalization-specialization) dependencies; considering contextual dependencies; approximative inference based on qualitative (non-numerical) endorsements; use of pre-specified numerical calculations when needed.
- The user-system communication via a display is friendly and well structuralized, the screen is, software-wise, divided into two parts. The upper one is used to inform the user about the course of inference (information about the current goal, current sub-goal, and the last evaluated object is displayed), or for automatic display of navigating information that helps the user to understand what it is he is expected to do. The lower part of the screen is used for actual communication, i.e., for displaying questions, answers, error and recommendation messages.
- The user may actively influence the systems performance by using a command language. He may ask for several kinds of explanations, make the system return to a previous inference step requiring a specified change, change or modify his original system performance parameters, etc.

- The system's explanation facilities, besides being able to give answers to questions such as WHY and HOW, facilitates, on demand, obtaining information regarding the current problem solving status, and may also have displayed specified parts of the KB.
- CODEX has facilities to archive the facts and inferred results and reuse them under new conditions. For a new run it requires confirmation of all previously entered information that can change over time.
- CODEX is equipped with a module that enables it to access data provided by external data sources (e.g. by an independently run process or by various kinds of files).
- For the end result generation there is a component that enables it to summarize, from various aspects, all intermediate results so that the user obtains the inferred results in a well organized form without any redundancies.

These characteristics of the system's performance are closely related to the CODEX knowledge base architecture:

- Knowledge is represented in framelike data structures. The frames are composed of five parts – specification, evaluation, association, message, and result-oriented components.
- In the specification part, significant information characterizing the represented object and its attributes, (properties) are stored.
- The evaluation part is the core of the frame. It enables it to specify the objects that are on the next higher generalization level to a given one (its super concept), and contains a well structuralized set of criteria for the inference. The criteria enables it to determine, in the following sequence, whether the represented object can at all be evaluated, categorically rejected or confirmed. The next ordered sequence of criteria are evaluated only if none of the previous ones led to frame evaluation, serves for qualitative endorsement (approximative evaluation) of the represented object. The following sequence of criteria, being evaluated only if the represented object has been confirmed, at least with some pre-specified plausibility, serve for object attributes determination.
- The association part contains criteria that allows making associations (inductive reasoning) to other represented objects that, under given conditions, are also worth evaluation. To each associated frame a weighting factor can be assigned to determine the urgency (priority) of its evaluation.
- In the frame message part several kinds of messages can be stored. They serve as user navigators for the proper use of the system, notification of inconsistency in inference occurrances, or simply for displaying medical recommendations. The display of any message can be conditioned by a criterion.
- In the result generation part there are sentence part phrases that are combined to form a natural language sentence expressing the result of the frame evaluation.
- Each criterion used in any frame part is to be understood as an ordered set of production rules that have the same consequent (the THEN-part). The antecedents (the IF-parts) of those rules represent various alternatives for concluding the consequent. Only one alternative is to be TRUE-

evaluated to assign TRUE-value to the consequent.

This is a short-hand characterization of the CODEX expert system. Some more detailed partial system descriptions can be found in other publications (1,5,6,7,10,11,12). A comprehensive description of the whole system has been published as a technical report in our institute (13).

6. The CODEX Results and Experiences

CODEX is written in the Standard MUMPS programming language. The system runs on the Digital PDP-11 family of computers under the DSM-11 operating system and on the Czechoslovakian made TESLA SM family of computers under the DIAMS-2 operating system. (The compatible computers from the SMEP family made in the USSR, Bulgaria, and Romania may also be used). The minimal hardware requirements for the CODEX system are as follows: 64 KB of core memory (the CODEX requires only 8 KB, this enables using the system concurrently in multi-programming regimes), a disc unit (its capacity determines the size of a knowledge base and their number on one disc pack), a CRT terminal (for each user), and any kind of printer (including a tele-typewriter).

The system, as an expert system shell, has already been released in its third version. It is used at five different health care institutions in our country. The next enhanced version will be released in early 1986. This version, among others, enables CODEX interaction with a clinical information system environment. It is also possible to archive each problem solving procedure, thus creating a time sequence of solutions (considered as intermediate ones). Then the next activation of the same problem to be solved again enables referring to previous information and to evaluating some of the changes in a system being diagnosed or treated. Further CODEX developments, besides being oriented to various enhancements in its cognitive problem solving capabilities, is oriented to its redesign for a new programming environment, namely the C-language under RSX-11 and DOS-RV operating systems. Other operating systems (e.g., UNIX) are also considered.

The CODEX functional capabilities, its multi-level inference control mechanism, approximative inference, explanation and communication capabilities, knowledge representation in hierarchical frame structures, the inner organization of those structures, etc., together with the overall system performance allow for its successful comparison to other well known expert systems.

For the CODEX shell several knowledge bases have been developed, or are under development. We list some of the problem areas in KBs development in which members of the institute participated:

1). Diagnosing clinically and on X-ray manifesting lung diseases (specific and non-specific inflammations, benign and malign lung tumors, embolies, secondary pneumopathies, fibroses and colagenoses, chronical obstructive lung diseases) the KB is quite extended. It contains more than 1200 frames with, in the order of tens of thousands, rules embedded in them.

2). Neurology diagnostics (syndromes of cerebellum: floculonodular syndrome-vermal, axial disequilibrium, "paleocerebral", neo-cerebral and frontal paleo-cerebral syndromes; localized lesions of peripheral nerves and entrapment neuropsthies in extremities; epileptic seizures classification).

3). The PSYCHO knowledge base is already in use in a real clinical setting and it covers all endogenous psychiatric distortions. The KB has been designed according to the DSM-3 classification system diagnostic criteria.

4). Evaluation of blood gas tests and acid-base equilibrium in arterialized capillary blood (interpretation of pH, pCO_2, act. HCO_3, pO_2, blood oxygen saturation, iron and minerals concentration: serum buffer bases, anion gap residual anions, and differential diagnostics of metabolic acidoses); this knowledge base, foreseen as a possible component of others, is interesting from the knowledge engineering point of view as it combines algorithmic computations with methods of cognitive problem solving.

Some developments from the KBs (e.g., PSYCHO and LLPN, for neurology) reached a stage that allowed for their practical routine use. During the testing period very satisfactory results were obtained. No incorrect solutions were inferred, up to 95% agreement with the results was reached by independent specialists invited as referees. This, of course, gives good grounds for optimistic expectations of CODEX applicability, particularly with well designed ESs.

7. Conclusions

In this paper we have attempted to advocate the use of ESs in the services of computer assisted medical diagnostics and patient management in general. To claim that the ES approach is currently the best approach, or being more moderate, a very reasonable and valuable alternative approach, we remain realistic in expectation of the rapid spread of expert systems that will meet the end-users needs. The development of non-trivial ESs and mainly all non-trivial knowledge bases, acceptable in real settings, is neither an easy nor a straightforward task. Not surprising! To feed a sufficient amount of properly structuralized knowledge into a KB to enable its efficient use, under differing conditions, for non-trivial problems, must be a complex task requiring a lot of effort. The pre-condition is not only to have a deep understanding of the domain knowledge, but also to understand the available methods of AI and their efficient use. This naturally puts a high demand on well prepared manpower and resources. Only when this is available may one expect the acceleration of ESs development.

Finally, we repeat – whenever human experts are in great demand and in short supply an expert system can help amplify and disseminate the needed expertise. We stress can help as *a computer consultant*. For expert systems to help, two conditions (among many others) must be satisfied: specialists must be available to design proper systems; and, qualified end-users should profit from their use.

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The FEL-EXPERT and MIFELEX Empty Expert Systems and Their Applications

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1. FEL-EXPERT Expert System

1.1. Basic Features

FEL-EXPERT, an empty rule-based expert system, has the following characteristics:

- *Domain independence:* The application area can be changed by replacing the knowledge base, with no modification to the empty FEL-EXPERT system required.
- *Machine independence:* FEL-EXPERT is written in standard Pascal programming language. It is conservative of memory, permitting its use on a personal computer.
- *Diagnostic character:* FEL-EXPERT is a suitable tool for solving diagnostic tasks. A finite set of goal hypotheses is considered, and evaluated and re-evaluated during the consultation run.
- *Ability of uncertainty handling:* The uncertainty of both the knowledge and the data is considered and accepted. A built-in model for handling the uncertainty is based on ideas previously used by PROSPECTOR (1).
- *Explaining capabilities:* A wide spectrum of explaining abilities (including the answering of "What" and "Why" questions) makes possible very detailed, user friendly, explanations of the decision making process and also of the actual model state of the case in hand.

1.2. The FEL-EXPERT Architecture

The FEL-EXPERT architecture is – in principle – shown in Figure 1. The user's data (the data from the data base) are provided in a sequential manner, in the form of a dialogue between the expert system and the user. Making use of both knowledge base (general rules, given by the expert) and the users particular information the actual model becomes tailored for the case in hand and the resulting conclusion is formed. The explanatory system serves for the user's better understanding of the reasoning process.

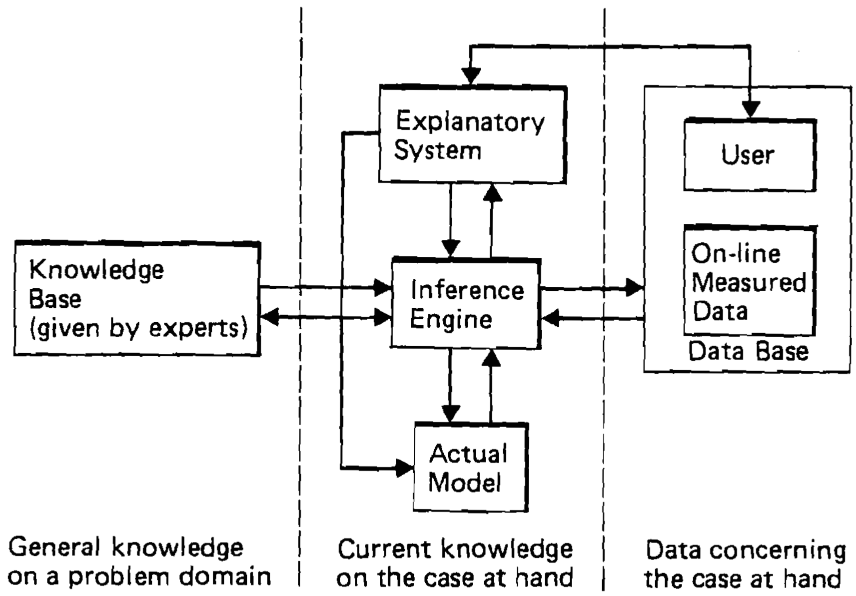

Figure 1

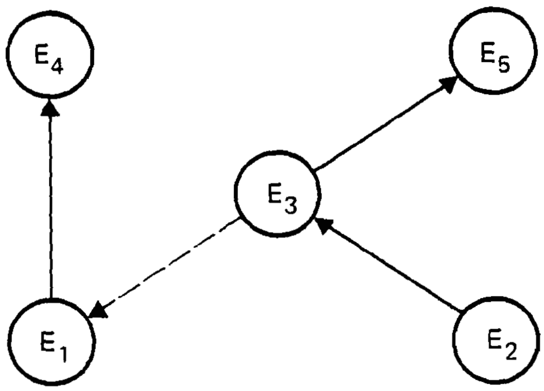

Figure 2

1.3. Knowledge Representation

Basically, three types of knowledge representation in the knowledge base are used: production rules, logical functions, and context rules.

A. *The production rules* have the following form:

IF < evidence E > THEN < hypothesis H > WITH < probability P_1>
ELSE < hypothesis H> WITH < probability P_2>,

where < evidence E> and < hypothesis H> are assertions, < probability P_1>,< probability P_2> are subjective uncertainty measures (not probabilities in an exact mathematical meaning!), called – similarly as in (1) – the sufficiency and necessity measures respectively. Their values are given by the expert. The model for uncertainty handling requires assigning prior probability to each assertion. This value is also given by the expert.

Hypothesis H can serve as evidence for the other production rule, assertion E could be a hypothesis with respect to quite another production rule and so on. In this way the knowledge base represented only by the production rules may be graphically expressed as an oriented graph, usually called *the inference net*, each assertion is represented as a node of the graph, and each production rule as an oriented arc.

The nodes with no outcoming arcs are called the top hypotheses, the nodes with no incoming arcs are called the leafs. The nodes that are neither the leafs nor the top hypotheses are marked as inner ones. The aim of this particular consultation is to prove all the goal hypotheses (the goal hypotheses are the top ones, and sometimes, the selected inner ones, too) or at least some of them.

The assertion (node) can be either askable or unaskable. It is an unaskable one if it is either nonsense to ask for it, (the user never knows the answer), or if it was answered by the user during the course of the current consultation. The remaining nodes are askable. Of course, the goal hypotheses are always unaskable ones, all the leafs are askable at the beginning of the consultation run.

B. *The logical function* makes the expression of composed assertions possible. Three types of logical functions are considered in the FEL-EXPERT system: AND, OR, NOT.

C. *The context rules* are used in cases where, before one assertion can be investigated, the complete checking of the other one is necessary, see Figure 2, the context rule is expressed by a dashed line. The assertion E_3 is a context of E_1, that means that before investigating E_1 the assertion E_3 has to be proved in a sufficient way (the context must be satisfied). In the opposite case the E_1 is excluded from the investigation. To each context rule two numbers α 1, α 2 are assigned by the expert; they represent the range in which the probability (validity of the context) has to lie.

The context rules are, as a matter of fact, meta-rules that ensure the common sense ordering of questions. These rules are very often used to dynamically remove that part of the knowledge base which is not relevant to the case at hand.

The knowledge representation language is simple, and allows for construction and change in the knowledge bases, without any knowledge of programming languages. The syntax of the knowledge representation language is described in the manual (2).

1.4. Control Strategy.

The control strategy can be described briefly in the following way:

1) There is one investigated hypothesis at each step of a consultation. This hypothesis is either, a) chosen by the system but it's investigation has not been completed until now (starting the consultation the goal hypothesis with the highest prior probability is chosen to be completely investigated; later the goal hypothesis with the highest actual probability is always chosen to be completely investigated and so on), or, b) chosen by the user but it's investigation has not been finished until now.

2) The following two control strategy modes are permanently alternated during the course of the consultation:

a) During *a question-selection mode* the backward chaining strategy in the inference net is used: starting from the investigated goal hypothesis, the suitable node (the question for the user) is chosen, a special *heuristic scoring function* is recursively utilized at each step of the backward chaining process to select the proper rule.

b) During *a model-updating mode* the information obtained from the user (from the data base) is propagated along all oriented paths leading from the node being answered to all the top hypotheses: the probabilities of the assertions (nodes) on these paths are recomputed, both the sufficiency and necessity measures art taken into account. The pseudo-Bayesian formulae used by recomputing the probabilities along the arcs in the inference net are combined with the fuzzy logic formulae by logical connectives (2). The model-updating mode strategy ensures that top/goal hypotheses are evaluated in parallel.

3) The automatic run of a consultation can be interrupted by the user by means of an $-instruction (the $-instructions are described below).

4) The consultation is finished, a) when there are no questions to be answered (all the relevant questions have been exhausted), or b) at the user's request.

1.5. Actual Model

The actual model is composed of a set of all posterior node probabilities. Starting the consultation it consists of the set of the prior probabilities. With any users particular information the node probabilities change to posterior ones and thus the actual model becomes – step by step – tailored for the case in hand.

1.6. Communication Module

The communication module ensures:

a) the *question putting* and the users *answer understanding*. The users uncertainty is expressed by a number within the interval <-5; 5>:
"+5" means "I am sure that the assertion holds",
"-5" means "I am sure that the assertion does not hold",
"0" means "I do not know",
"+2" means "I am not completely sure that the assertion holds",
"+4" means "I am almost sure that the assertion holds", and so on.

b) the creation of ***the protocol of the consultation*** (as a separate computer file).

c) ***the $-instruction execution.*** Some of the $-instructions serve as explaining/inspection facilities (explanatory system), the remaining ones are used to make the user's influence on the consultation run possible. Let us show the (standard version of) $-instruction list:

$C Complete information regarding the given node (assertion) is displayed. The node is specified by an assertion text fragment or by the node name.

$D Investigation of the current goal is terminated.

$E Explanation of the actual model is provided (a particular assertion being chosen by the user, the evidence supporting (excluding) this assertion is displayed).

$F The system is forced to investigate a new goal specified by the user.

$G The goal currently being investigated is displayed.

$H The list of the $-instructions is displayed to help the user.

$I Inspection of the knowledge base/actual model is made possible.

$M Probability interval of investigation is modified.

$P Results are printed out and the system is reinitiated.

$S Results are printed and the consultation is over.

$T The current line of reasoning is traced.

$V Volunteered information can be entered. (The information at the user's disposal can be put in the system momentarily; waiting for the system's question is not necessary).

The communication subsystem has a highly modular structure. At a customers request further supporting facilities can be added. For instance, a WHAT-IF module for hypothetical situation modeling, and also a module for the automatic creation of a patient's data list (filling in of prespecified forms in medical applications) were developed with respect to the particular request.

1.7. Versions of FEL-EXPERT

Version FEL-EXPERT 1.5: This is the basic version completed in 1983 and showing all of the features described above. A slightly modified version, with the communication module in English, were distributed as the system MEXEXP 1.0 (3).

Version FEL-EXPERT 1.7: was derived from version 1.5 by adding a blackboard control structure to make the evocations and use of different knowledge bases in the course of the consultation possible. The blackboard rules are – as a matter of fact – WHEN rules (4) having the form:

WHEN < logical combination of elementary conditions >
THEN GOAL: = < Mode name >,

where an elementary condition is expressed as

$$P(U_i) \gtrless t_i \ ,$$

where $P(U_i)$ is the actual posterior probability of the node U_i,

t_i is a threshold (within the interval < 0; 1 >).

As mentioned earlier, FEL-EXPERT is primarily a goal driven, backward chaining system. In addition to goal-driven inferencing, the blackboard structure allows data-driven, forward-chaining reasoning through the use of WHEN rules. These rules act as demons that come alive when certain events occur (that is, when actual posterior probabilities acquire values within a specified range). This is why the blackboard structure may be applied conveniently, even in the case of a single knowledge base such as a meta-level reasoning tool. Just as Laffey *et al.* in (4), we have also proved that the WHEN rules, when added to the standard IF-THEN production rules, bring a higher expert systems efficiency. Moreover, through the use of the WHEN rules, FEL-EXPERT allows the knowledge engineer to explicitly state the expert's reasoning process in a more natural way.

Version FEL-EXPERT 2.5: enables – in comparison with version 1.5 from which it was derived – a simple representation and processing of quantitative information. The nodes, representing assertions that require numerical value/values as the users answer, are called quantitative nodes. The rules having a quantitative node as evidence are called quantitative rules. Two types of the quantitative nodes are involved in knowledge representation language:

a) The *S-node* is associated with the user's answer in the form of an exact numerical value (for example: the question "What is the patient's temperature?" may be answered by a single numerical value, "38").

b) The *Q-node* is associated with the user's answer in the form of one or several disjunct intervals, and the users uncertainty degree, assigned to each of these intervals (for example: the same question mentioned above may be replied in the following way: "37, 8-38, 2", with the uncertainty degree "+4", "38, 5-39, 3", with the degree "-5").

The representation of the quantitative nodes have been solved in such a way that all possible numerical values have been split into disjunct intervals. The quantitative rules consist, in fact, of a "bundle" of elementary rules with different sufficiency and necessity measures (one elementary rule corresponds to one interval in the node specification).

Version FEL-EXPERT 2.6: derived from version 2.5, makes use of a modified question-selection strategy. The scoring function used in FEL-EXPERT 1.5, 2.5 is computed, the uncertainty measures and the node probabilities being combined. In FEL-EXPERT 2.6 a new scoring function has been implemented (5). This takes into account, not only the measures and the probabilities mentioned above, but also the cost of the user's answer. The new scoring function enables us to combine properly two different influences: a) the actual model parameters, b) the cost of the answers; these costs are constants given by the expert and stored in the knowledge base. The highest values of the new scoring function are reached for such nodes (assertations), the investigation of which is likely to have a significant influence upon the top hypotheses at a comparatively low cost (similarly as in (6)).

1.8. Implementations.

FEL-EXPERT is written in Pascal and can be run on the PDP 11, SM3/SM4a, and similar machines under RT11, RSX11, FOBOS and DOS; on HP-1000-like machines under DOS and RTE. It (written in Turbo-Pascal language) can also be used on the IBM-PC compatible machines. The communication module versions in

Czech, English, Russian, and Spanish are available.

The FEL-EXPERT system is conservative of memory, the empty system occupies about 12 kwords of core, the "medium-size" knowledge base needs about 10-20 kwords (for instance: The MYOPAT knowledge base, described below, occupies 11.5 kwords of core). The "size" of a knowledge base is – in principle – not restricted, a segmentation can be used if needed.

1.9. Supporting aids.

To make the knowledge base constructing much more comfortable, a user-friendly knowledge base editor, now in an advanced stage of development, will soon be available for the knowledge engineer. Moreover, the program for a computer-aided knowledge base constructing, based on Quinlan's inductive algorithm (7), was developed and tested (8). This program makes use of the learning set of cases (the user's uncertainty is excluded) to offer the knowledge base structure.

2. MIFELEX Expert System

MIFELEX is an empty expert system written in Basic language (2). From the theoretical point of view, it makes use of the same knowledge representation as FEL-EXPERT 1.5, the restrictions of the Basic languages are, of course, respected. Therefore, it is necessary to have the knowledge representation language with a quite different syntax. Also the machine representation is not so effective (recursive procedures and dynamical fields are not allowed in Basic). A special program TBM executes an automatic conversion of the knowledge base, described in the FEL-EXPERT representation language, to a form that is acceptable by MIFELEX. MIFELEX can be operated on microcomputers with a Basic interpreter (Sinclair ZX, HP-85). It is, of course, much slower than FEL-EXPERT, the menu of $-instructions is restricted, but the decision results achieved are identical.

The MIFELEX-PC version (9) for microcomputers equipped with a Basic translator is approximately as fast as FEL-EXPERT. The knowledge base constructing process is supported by a screen editor, EXPEDIT, checking the correctness of the knowledge base from the syntactical and partly semantical points of view. EXPEDIT displays the inference net in a graphical form and offers the constructor's/user's "zooming" inside both the inference net and the actual model structure.

The MIFELEX expert system was developed primarily for educational purposes. The simple Basic language makes it possible for students to perform effectively their "private" changes in the control strategy, and to study the overall behavior of the system. The MIFELEX system enables a practical exploration of high-quality knowledge bases (developed by means of FEL-EXPERT) on low-cost simple microcomputers in an industrial environment.

3. Applications

The empty FEL-EXPERT expert system is a flexible and effective tool enabling the build-up of problem-oriented expert systems for solving different problems in a wide spectrum of application areas. We find that good technical people can become knowledge engineers for FEL-EXPERT in a couple of weeks, and quite expert in the knowledge base constructing in a couple of months. Especially, when the knowledge engineer sees, not only the knowledge representation language, but examples of how this language has been applied, a good technical person can catch on rather quickly. By marking use of FEL-EXPERT it is possible for a non-technical person, with no experience in programming, to become an expert in domain-oriented knowledge engineering.

A lot of knowledge bases for FEL-EXPERT have been prepared and used in various hospitals, factories, and research institutes, in Czechoslovakia and abroad. Over 20 of them were developed at the Czech Technical University of Prague. We have had several reasons to develop them: to test the FEL-EXPERT versions by solving real practical tasks, to gather experience from knowledge engineering activity, and to prepare examples for the education of knowledge-engineering groups – FEL-EXPERT users.

Most of the applications have been aimed at the medical diagnosis area, some at the fields of technical diagnosis, geological prospecting, and production planning. Let us briefly describe some of the knowledge bases; a small overview is presented in Table 1. (The knowledge base structure, the third column in the table, is expressed in the form – number of nodes/rules/context rules/top nodes/goals/ inference net depth).

Table 1

Knowledge Base Name	FEL-EXPERT Version	Structure	State of Exploration
MYOPAT	2.5	97/153/24/3/3/6	in use
POLYD	1.5	134/234/28/21/21/3	in use
FRA(X)	2.5	27/33/1/1/1/3	in experimental testing
METABOL-AC	2.6	25/41/6/2/2/4	in use
TUMOR	1.5	218/391/89/50/50/6	in experimental use
PSYCH	2.5	43/72/7/2/5/8	in experimental use
GTIS	1.5	42/59/22/2/2/5	in use
MOTOR	1.5	514/605/63/167/154/6	in experimental testing
TDN	1.5	16/24/6/4/4/4	in experimental testing
FERPLAN	2.5	35/126/14/7/7/3	in experimental use

3.1. Medical Applications

3.1.1. Genetic Counseling

For differential diagnosis of the most commonly occurring progressive muscular dystrophies, (Duchenne and Becker types, and limb girdle dystrophy), a knowledge base MYOPAT was developed. The data processed by the knowledge base consists of pedigree information, results of laboratory tests, and of clinical findings. The knowledge base MYOPAT was tested in a group of 113 patients: there was full concordance of the expert system conclusions, and the decisions of a panel of experts, in 112 cases (10). The expert system has been used as a regular supporting tool for geneticists since 1984.

Another knowledge base POLYD, for the differential diagnosis of 21 syndromes with a symptom of polydactyly, was developed and has been used in genetic practice.

A knowledge base FRA(X) was prepared for the screening of the "fragile-X syndrome" patients among mentally-retarded boys. It contains only one goal hypothesis, ("Suspectivity on the fragile-X syndrome"), and makes use of simple clinical findings. (The more demanding chromosomal examination can only be performed by the suspected boys).

The FEL-EXPERT version 2.6 has been successfully tested on a real problem of the diagnosis of the metabolic genetic diseases, (a knowledge base METABOL-AC), with a remarkable economical effect.

The knowledge bases MYOPAT, POLYD, and FRA(X) were prepared in cooperation with the Department of Genetics, Faculty of Pediatrics, and Charles University of Prague; the base METABOL-AC, with the III Internal Clinics, Faculty of Medicine, Charles University.

3.1.2. Per-Operation Diagnosis of Brain Tumors

A knowledge base TUMOR, for the pre-operation diagnosis of cerebral tumors was prepared, in collaboration with the Central Military Hospital, and the Institute of Molecular Genetics of the Czechoslovak Academy of Sciences. The knowledge base was corroborated on a testing set of seventy cases of tumors where the diagnosis was correctly established in more than 90% of the test cases. The explanatory capacity of the expert system makes it possible to use it also for studying purposes; therefore, its use for better undergraduate and postgraduate teaching is foreseen.

3.1.3. Recognition of Long-Termed Psychophysiological States

A knowledge base, PSYCH, serves for the classification of long-termed psychophysiological states. The parameter of the preprocessed EEG-signals, (the original EEG-signal is filtered by $\alpha, \beta, \delta, \mu$-activity band-pass filters, integrated and statistically tested), as well as the results of several mental tests are used as the data base. 97% correct decisions were obtained in the course of experiments. These experiments were prepared in cooperation with the Research Institute of Psychiatry, Prague.

3.2. Non-Medical Applications

3.2.1. Geological Prospecting

A comparatively small, but very effective knowledge base, GTIS, for Sb-ore discovery, has been prepared, in collaboration with Naftoprojekt Poprad. This knowledge base concentrates the knowledge of three experts. The results of the expert system have been recognized as being better than those obtained by the experts.

3.2.2. Technical Diagnosis

A complex set of 13 knowledge bases, MOTOR, for the technical diagnosis of oil-engines has been developed, in cooperation with the CKD company. The diagnosis of all engine subsystems is covered by this knowledge base set. Another knowledge base, TDN, has been developed for diagnosing faults in radar hardware; it can be deployed, by means of MIFELEX, onto a built-in-radar microcomputer.

3.2.3. Production Planning

A knowledge base FERPLAN was developed for the FEROX company, that produces large-size boilers. It enables the estimation of final product parameters and demands on necessary production facilities, with respect to the customers' demands on the product performance. It seems to be an effective labor saving tool in the area of production planning.

The experiences gathered during the FEL-EXPERT development are used in constructing an original problem-oriented knowledge-based system TEPRO (11) for computer-aided production planning in a flexible workshop. This system ensures the transformation of the product definition data, (geometry, material to be used etc.), into process definition data, i.e. the instructions for manufacturing the product as a sequence of production steps. The TEPRO system has been run daily, for more than two years, by the Tesla Kolín company.

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