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MEDICAL EXPERT SYSTEMS FOR DEVELOPING COUNTRIES: AN APPLICATION IN PRIMARY HEALTH CARE

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1. Problem Overview

"Health for all by the year 2000" is one of the main goals the WHO set forth in its program. This effort would include to help underdeveloped countries to establish a sufficient standard of public health care. Currently, though, the cleft between health care in industrialized countries and underdeveloped countries seems to be increasing instead of decreasing. The majority of ailments people in developing countries are suffering from could in principle be effectively treated by simple treatment strategies. However, knowledge about treatment plans as well as resources are commonly scarce in countries where needed most urgently.

In comparison, problems of malnutrition and famine show obviously similar features. The world's economy could produce enough food to feed the world's population. The seemingly insurmountable problem is the question of transportation, and to date, there has been no solution worked out to effectively tackle this problem. Therefore, as one of the biggest scandals in the community of nations, the fact remains that in spite of producing enough food there are still hundreds of thousands of people starving to death.

As with food, the main problem in providing adequate health care is not a question of procuring knowledge but a question of the distribution of knowledge. For centuries, tutoring on a personal basis or transfer of knowledge in books were the two salient pillars of knowledge transfer. Personal tutoring correctly performed provides for an active transfer of knowledge as compared to books where written information is presented as a mere passive block of information waiting for the student to act on it.

With the advent of knowledge based systems, the computer seems to emerge as another viable way of transferring knowledge in a more active form prompting medical personnel for appropriate responses. Especially for developing countries, knowledge based decision support systems on rugged and portable personal computers independent of AC supply seem to offer a potential remedy to ease the problem of porting medical knowledge right to the location where it is needed most.

Primary medical care in developing countries is often provided by personnel with a very heterogeneous level of medical training, commonly called village health workers.

The main tasks of a village health worker include (1) to provide a diagnostic classification of a patient's disorder as an easy treatable and not life-threatening disease or as a potentially dangerous disease, (2) if appropriate, to deliver a treatment scheme compatible with his proficiency and therapeutic resources, and (3) to refer patients with potentially dangerous diseases to a professional nurse or doctor.

The availability of professional medical care has a direct bearing on the extent of a health worker's activities. If an information exchange with properly trained medical personnel is available, improvement in the quality of medical care provided by health workers is warranted. Problems of maintaining an adequate standard of primary medical care, therefore, include implementing policies to provide for an on-job training to improve efficiency and effectiveness and providing reference materials easy to consult in unclear cases.

The purpose of this project is (1) to establish a knowledge based decision support system for village health workers covering the most common diseases in developing countries, (2) to implement this knowledge based system on portable microcomputers, and (3) to include tutorial features as well as a reference structure in the design of the system to meet the demands of health workers on the job.

In the following we will present a description of the system specification and design, show the structure of knowledge representation and system implementation, and summarize the current status of the prototype and future directions.

2. System Design

Ample experience about principles of teaching medical care to health workers has been accumulated through the years (Werner, 1980; Werner and Bower, 1982; Abbat and McMahon, 1985). In the design of our system we strove to draw from that vast body of experience as much as possible to avoid common mistakes frequently encountered in intercultural exchange programs. For that purpose, the standard textbook "Where There is no Doctor" by Werner, 1980, served as the primary source of reference. In addition, medical knowledge was also extracted from the relevant literature (King et al., 1978; King et al., 1979; Manson, 1982; Upunda et al., 1983).

As a second source we used the experience gained by G. Porenta who, as a member of the Austrian Committee for Ethiopia, worked for two months in an ambulatory care center in the Tigre province of northern Ethiopia. Working together with village health workers of different educational levels, he experienced the need for a flexible source of information to cope with problems arising in primary medical care. Also health statistics showing the actual distribution of diseases within a three week period were used as a guideline for the selection of diseases in the design phase.

According to that statistics, a small group of diseases accounts for a large percentage of the disorders encountered. Accordingly, treatments of diarrhea, worm infestations, eye diseases, skin afflictions, and malaria made up approximately half of the daily work. Concentrating on a good quality of health care in these areas would significantly improve the overall performance.

The disease distribution presented pertains only to a specific situation which takes into consideration the geographical area (highland), political context (civil war), social environment (poverty, famine), infrastructure of health care (rural health centers closed, two town hospitals) and other factors. It is not possible to devise a detailed generic general purpose knowledge based system suited for village health workers in different countries. For proper function and acceptance, the system has to be tailored towards both the region where it is used and the people using it. Therefore, the system presented in this study is a specific instance applying to the northern part of Ethiopia, although general principles as outlined in the book by Werner, 1980, are included.

Designing the system, we identified five problem areas to be represented in the system (diarrhea, infestation with worms, eye diseases, skin diseases, common infectious diseases) and three different entry points into the system (diagnosis, therapy, drug prescription). These disease groups cover more than 70 per cent of the diseases encountered in this area.

If decision support for diagnosis is requested by the user, the system starts with a question-answer strategy to find an appropriate diagnosis, to suggest a treatment plan, and to give detailed advice about drug prescription if necessary. At this level we assume that the village health worker is familiar with the most common medical terms so that he can answer each question with "yes", "no" or "unknown".

The diagnostic strategy is structured around the five kernel areas of disease mentioned above. In a first step, the system tries to ascertain that the medical problem as presented by the patient is not dangerous and therefore falls within the range of competence of the village health worker. If none of the danger criteria is met, the system then goes on to ask questions about diseases ranked by their frequency of occurance in an ambulatory care center. If danger criteria can be ascertained, the system suggests to refer the patient to a doctor or a professional nurse.

After deciding on the main complaint, the village health worker is prompted to answer questions posed by the system. A choice to enter a set of symptoms in free order is not offered. With this strategy, we attempted to elucidate the diagnostic pathways of the system with a tutorial perspective. By following a predetermined sequence of questions a village health worker should get acquainted with a standardized way of efficiently taking the history and performing a very coarse physical examination.

In the present stage, questions are asked by displaying text on the screen using the terminology of Werner, 1980. Clearly, this is not the most appropriate form of a user-friendly interface. An icon-based dialogue using symbols instead of text with a pointing device for the user input might be more appropriate for a broader range of audience and might also feature language independence (Trappl and Horn, 1983). In developing our prototype, however, we concentrated on the proper representation of the knowledge and at this first attempt set aside the problem area of an adequate user interface.

At the second entry point, the system uses the diagnosis established in the first step to suggest an adequate treatment plan consisting of general advice and drug prescription if deemed necessary. It also provides the opportunity to start with a diagnosis independent of a pass through the diagnostic workup. While working on a treatment plan, questions about contraindications and, if yet unknown, about general patient data (e.g. age, weight) have to be answered. Finally, the treatment of choice is presented.

While determining an adequate treatment scheme, the system evaluates its knowledge about contraindications, side effects, treatments of choice, and price information pertaining to the drugs in its knowledge base. In the current implementation, the treatment scheme associated with the lowest cost for a complete course of treatment is selected from the set of equally effective schemes. Therefore, if the system is used for treatment selection on a regular basis, a significant cost reduction in drug expenditure will follow. User access to this module of the system is available independent of the diagnostic or therapeutic branch.

3. Implementation

A prototype of the system has been implemented on a portable personal computer (PC) by means of VIE-KET, the VIEnna Knowledge Engineering Tool (Pfahringer and Holzbaur, 1985). Similar to KEE (Kehler and Clemenson, 1983), and BABYLON (Primio and Brewka, 1984), VIE-KET is an hybrid knowledge engineering tool which offers subsystems to handle various knowledge representation schemes such as frames, rules, PROLOG, and LISP. In principle, the system could have been developed in a purely procedural language like Pascal, Basic, or Fortran. However, the developing environment associated with an hybrid knowledge engineering tool significantly improves and simplifies the developing process.

According to the specifications worked out during the design phase, the system consists of several modules assigned to deal with specific domains of knowledge. As the corresponding problem areas differ in their specific structure, the modules of the program differ in their implementation in VIE-KET.

3.1 Modules for Diagnoses

In the two problem areas "diarrhea" and "infestation with worms", expanded decision networks guide the health worker to the diagnosis. At each node, a node interpreter evaluates and weighs a set of symptoms represented as premises of a rule and branches according to the relation between a threshold value and the sum of weights. In the simplest case, the premises of the rule are classified into IS-PRESENT (IP) and MAYBE-PRESENT (MP) premises. Finding one IP premise or two MP premises will cause continuation on the YES branch of the decision node.

Within the system, the expanded decision networks are represented using a frame structure. A general frame NODE with slots IS-PRESENT, MAYBE-PRESENT, YES and NO is defined. Attached to each NODE frame is a method NEXT-NODE that determines which branch will be followed after evaluation of the premises. Networks then can be built incrementally by creating new instances of the general frame NODE. Advantages of choosing frames as representation tool include flexibility, a simple editing procedure, and graphic display routines for debugging purposes. During an actual consultation session, the tree is traversed by sending NEXT-NODE messages to the actual node, and updating the node accordingly until the proper form of diagnosis is reached.

For the diagnosis of diseases affecting the skin and the eyes, a rule-based approach is most adequate. Each symptom is associated with two certainty factors ranging from -1 to +1. The first factor characterizes the relation between a symptom and the disease currently in focus where +1 indicates a pathognomonic symptom and -1 indicates the exclusion of the disease if the symptom is present. The second factor gives an indication of the relation between the absence of a symptom and the disease.

In selecting the certainty factors, we opted to introduce a value restriction of 1, 0.7, 0.4, 0.2, and 0 for the positive and negative values respectively. Two physician then independently scored the symptoms in relation to the diseases. This scoring scheme was conducted according to the physician's personal believe and in most cases the certainty factors turned out to be identical between the two physicians. In diverging cases, discussions led to a consensus.

It should be pointed out that the certainty factors assigned to each symptom are not only depending on the relationship between a single symptom and the corresponding disease. The set of diseases as potential candidates for a diagnosis is decreasing as the diagnostic process proceeds. As diseases are sequentially worked on by the system, knowledge about which diseases have already been rejected by the system is available. In scoring the symptoms of diseases appearing late in the diagnostic pathway this narrowed solution space has a direct bearing on the importance and weight of certainty factors. So the rank order of diseases influences the associated certainty factors.

An algorithm similar to the formula in the MYCIN system is used to combine certainty factors for the different symptoms to arrive at a final score. If this score exceeds 0.8 the diagnosis of the disease presently evaluated is concluded and the diagnostic procedure stops.

During the diagnostic process, age and weight of the patient have to be provided. For all children under age 12 then a malnutrition module checks their nutritional status according to a simple algorithm (weight for age) commonly called "road to health" (Werner, 1980). As malnutrition poses a major threat to the well-being of infants in developing countries, the computed nutritional status of the child is pointed out to the health worker in units of percentage of normal. Appropriate actions are then expected from the health worker.

3.2 Modules for therapy

For the drug module, knowledge about usage and dosage of drugs is represented in a frame structure that can combine both declarative and procedural knowledge. Declarative knowledge about medication includes the period of time a drug should be given to reach an optimal effect, the contraindications that have to be checked before administering a certain drug, warnings about side effects, and additional advice related to drug usage. Procedural knowledge is applied to actually compute the required dosage for a specific patient. The algorithm then suggests the number of tablets or capsules that should be taken every day for a certain period of time according to the prescription stored in the knowledge base.

The frame hierarchy includes an inheritance mechanism that allows to conveniently represent different drug dosages for different diseases without creating two entirely different structures. For example, the frame "mebendazole" holds knowledge about this antihelminthic drug including default dosage, contraindications, side effects, and warnings. For the special case of infestation with threadworms, the default dosage however is not appropriate. Therefore, another instance of the frame "mebendazole" is created containing only the special dosage for this disease. The rest of the information is inherited from the original frame.

Depending on the availability of drugs, the system could arrive at several different drugs representing the treatment of choice. In this case price information is used to select the cheapest treatment scheme to be suggested to the health worker. The differences between two treatment plans can be clearly demonstrated in the treatment of ascariasis. Administering mebendazole is on the average 7.5 times more expensive than treating with piperazine.

Besides drug prescriptions, the system also suggests other therapeutic actions, if appropriate, such as bed rest, diet, or inhalations.

4. Discussion and Outlook

During the developmental phase, the ease of handling and the flexibility of an open system allowing access to the programming language proved to be important. Expert system shells usually abide by the paradigm of production rules and cannot easily support two certainty factors for one premise. In this case, a problem sometimes has to be adjusted to the developing tool whereas open systems allow to tailor the tool towards the problem. As a tradeoff, programming effort is increased when using open systems.

Providing knowledge transfer of simple medical knowledge is among the tasks of the present system. Without field tests, it is difficult to assess just how adequate the chosen structure serves this purpose. Clearly, several shortcomings deserve further discussion.

Proper usage of this system requires the user to be familiar with common medical terms. The system is not designed to interact with users who might need explanations of the medical terms encountered in the dialogues. A smart dictionary could be developed to accomplish this task.

The development of a language independent user interface relying on image based computer interaction would be an interesting and useful extension to this system. However, most of the currently available computer systems that are also truly portable do lack the technical specifications to allow for an implementation using high resolution graphics.

A question-answering strategy to guide through the diagnostic and therapeutical workup has been chosen to help in acquiring diagnostic and therapeutical skills. This rigid and structured approach still awaits evaluation. It could very well be that a flexible strategy with free entry of signs and symptoms and subsequent diagnostic and therapeutic workup turns out to be more effective.

Several other attempts have also been launched to provide decision support for health care in developing countries on various levels. A similar approach focusing on a microcomputer implementation has been taken in TROPICAID, a joint project between Medecins Sans Frontieres and the Universite Pitie Salpetriere, Paris, designed for use in the Tchad (Auvert et al., 1986). Field tests of that system are well under way and additional projects are in a planning phase. A preliminary evaluation provided evidence that a microcomputer based system can support the daily work of medical personnel in a useful way.

Implementing a knowledge based system on a personal computer naturally does impose restrictions on the design due to limited resources. To date, commercialy available tools for PC applications lack either sophistication or efficiency or even both. Maintenance of even a small knowledge base is by no means trivial, especially if more than one expert contributes to the knowledge. Usually, a choice between two alternative approaches has to be made: (1) allotting significant resources to the construction and maintenance of an efficient and fast knowledge-based system due to insufficient tools available on PCs (thus sacrificing the rapid prototyping paradigm) or (2) using available tools for prototyping thus forcing the user to spend considerable effort in time and attention while using the system (not an option with the intended audience of the present project).

For future projects, a reasonable tradeoff would include the development of the system on a dedicated workstation for rapid prototyping, and, upon completion, a transfer to the custom PC for the delivery of the final application using appropriate run-time versions. However, the software garden is as of yet only sparsely populated with suitable tools.

For the knowledge based system presented in this study, several aspects have to be worked out in more detail before eventually field tests might be considered. The main and yet unsolved problem is still the task to develop a user-friendly interface tailored towards the educational level of rural health workers. An icon-based approach seems to be promising but is obviously difficult to achieve. Also, before field tests can be undertaken, a disease profile has to be established to provide guidance in the adjustment of the knowledge base towards the specific situation.

Finally, the system presented in this study should serve as a starting point for discussions and considerations on how knowledge based systems might help to bridge the gap of quality of health care in develoing and industrialized countries.

5. Summary

A knowledge-based system has been designed and implemented to provide decision support for village health workers engaged in ambulatory health care in developing countries. Typical medical problems encountered by village health workers include diarrhea, infestation with worms, diseases affecting the eye and the skin, and several kinds of infectious diseases. Also assessment of malnutrition is among the tasks village health workers have to perform. The hybrid knowledge engineering tool VIE-KET has been used to construct a modular consultation system that provides entry points for diagnosis, therapy, and drug prescription. Medical knowledge is represented in the following ways: Expanded decision networks are used to represent the diagnostic processes for diarrhea and infestation with worms. The diagnostic procedures for diseases affecting the skin and the eyes are covered with a rule based approach using two certainty factors. Treatment schemes and procedural knowledge about drug prescription are represented in a frame structure. Design criteria and interesting implementation aspects have been discussed and the current status of the prototype and future directions has been summarized.

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