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ON THE DEVELOPMENT OF AN EXPERT SYSTEM FOR WHEELCHAIR SELECTION

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ABSTRACT

The prescription of wheelchairs for the Multiple Sclerosis (MS) patients involves the examination of a number of complicated factors including ambulation status, length of diagnosis, funding sources, to name a few. Consequently, only a few experts exist in this area. To aid medical therapists with the wheelchair selection decision, a prototype medical expert system (ES) was developed. This paper describes and discusses the steps of designing and developing the system, the experiences of the authors, and the lessons learned from working on this project. Wheelchair_Advisor, programmed in CLIPS, serves as a diagnosis, classification, prescription, and training tool in the MS field. Interviews, insurance letters, forms, and prototyping were used to gain knowledge regarding the wheelchair selection problem. Among the lessons learned are that evolutionary prototyping is superior to the conventional system development life-cycle (SDLC), the wheelchair selection is a good candidate for ES applications, and that ES can be applied to other similar medical subdomains.

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INTRODUCTION

The medical field was one of the first testing grounds for Expert System (ES) technology; the now classic expert system, MYCIN, has often been cited as one of the great breakthroughs in Expert Systems. MYCIN, however, is only one of a large number of expert system applications introduced over the last two decades in the medical field alone [Waterman, 1986]. Other examples include NURSExpert [Bobis and Bachand, 1992], CENTAUR, DIAGNOSER, MEDI and GUIDON [Waterman, 1986], MEDICS [Bois et al., 1989], and DiagFH [Lin and Tang, 1991] to mention only a few. However, no expert system, to our knowledge, has been developed for the wheelchair selection problem. In this paper, we report on a new application of ES in the medical field; the paper discusses the experiences of the authors with a prototype system developed, using CLIPS, to delineate a wheelchair selection for multiple sclerosis (MS) patients. Our work, therefore, contributes to the existing applications of medical expert/support systems by expanding the domain of applications to the wheelchair selection problem and demonstrating the utility of CLIPS on this problem domain. We will demonstrate that the complexity of the wheelchair selection decision makes it a prime target for an expert system application.

To prescribe a wheelchair for a patient with MS involves more than knowing the patient's disease condition and available choices of potential wheelchairs. A complex web of factors has to be untangled to reach an appropriate choice of a wheelchair. The decision is complicated by such factors as physical body measurements, age and life style, degree of neuralgic impairment, and environmental factors.

MOTIVATIONS FOR COMPUTER-AIDED WHEELCHAIR SELECTION

The motivations for using computer-aided wheelchair selection support fall into two categories: those from the therapist's standpoint and those from the patients' standpoint.

From the Therapist's Standpoint:

The use of computer-aided selection of wheelchairs benefits the therapist in several ways. The prescription of wheelchairs for the MS population is complicated by diverse presentations and symptom fluctuations as well as many other factors. The selection of a well-suited wheelchair is a function of the following variables.

1. **Ambulation status**: In general, a patient is classified as able to walk or not able to walk. In multiple sclerosis, some ability to walk may be limited to short distances or specific terrains. This factors into the type of wheelchair they will need.
2. **Environments to be traversed**: This variable includes both indoor and outdoor locations. The existence of ramps in the patient's residence and the size of the bathroom are among the environmental factors relevant to the choice of an appropriate wheelchair. The frequency of need in each environment helps determine the priority.
3. **Distances to be traversed**: Under this factor, both the indoor and outdoor activities are considered. Self-propelling for short distances may be feasible for some individuals who stay primarily at home, so a manual wheelchair may be appropriate, although disability level may be high. More active users may require a power wheelchair to travel long distances in the community.
4. **Transport of the wheelchair:** Consideration must be made for the wheelchair to disassemble into parts so as to fit in a car or to be sized to fit on public lift-equipped busses.
5. **Caregiver characteristics**: If a caregiver exists for the patient in question, the characteristics of the caregiver(s) are considered in the wheelchair selection. The age, number of caregivers, tolerance for equipment, their health, and the degree of support for the patient are some of the factors to be evaluated when selecting a wheelchair for the patient.
6. **User characteristics**: This variable includes both physical and cognitive dimensions. For the physical, body measurements of the patient are essential to the selection processes, along with qualities of posture, balance, and abnormal muscle tone. Wheelchairs come in made-to-order frame sizes and appropriate sizing is essential. Physical abilities are also evaluated: voluntary movements of the extremities and head are noted. Areas requiring support for best posture and function are documented. As for the cognitive dimension, physical and occupational therapists have to consider the extent to which the patient can safely use the devices. Some other issues to be examined by the therapists are the ability to learn the electronic system of power wheelchair, to respond quickly in dangerous situations and the ability to report discomfort or problems with fit of the wheelchair.
7. **Length of diagnosis—history of disease course**: This composite variable aids in determining if the MS symptoms of the individual are stable. If they seem stable, a less-modular wheelchair can be appropriate. A progressive disease course would require many modular options for future needs; as the MS symptoms change, it would be possible to modify the wheelchair to fit the needs of the patients.
8. **Currently owned wheelchairs**: Therapists need to consider this item early in their analysis. The current wheelchair may or may not meet some of the needs of the patient. One possibility is that the current wheelchair can be modified to meet the patient's needs. Another possibility is that the wheelchair needs to be replaced because it is inappropriate for current needs, beyond repair or desired modifications can not be performed.
9. **Funding sources of past and potential wheelchairs**: This factor is considered at the end of the process but it is a crucial one. Most patients are restricted in terms of the number of wheelchairs that they can purchase over time under their insurance coverage. Typically, a therapist examines and evaluates the factors that determine the needs of the patient to narrow down the choices of the available wheelchairs. Once the options are reduced, the therapist uses the funding source variable to choose among the options. The funding sources can include Medicaid, Medicare, private insurance (e.g., third party), private purchase, or charity (e.g., MS Society Equipment Loan Program). Each one of these sources has its own rules regarding the wheelchair selection problem. For example, some policies restrict the purchase of a new wheelchair to one every five years. Some will not cover a manual wheelchair if an electric wheelchair was previously

obtained. Hence, such restrictions need to be factored in when considering the selection of an appropriate wheelchair.
10. Current wheelchairs on the market: There are over 500 models, each offering sporting multiple options of sizing, weight, frame styles, footrests, armrests, cushions, and supports. A current database of technical information would greatly aid in wheelchair selection.

Note that the degree of importance placed on each one of the foregoing factors is not fixed. There is a complex interaction between variables for each patient under consideration. It can be seen from the above illustration that selecting an appropriate wheelchair would be difficult to solve algorithmically. Hence, an expert system is a good candidate for this kind of problem. It was observed by the expert involved in this pilot project that the process of selecting the wheelchair involves both forward and backward reasoning. A therapist starts with the factors that are considered to be important to the patient in question and then narrows down the options available to the patient. This process involves forward reasoning and it is estimated to be eighty percent (80%) of the overall analysis performed by the therapist. The rest of the reasoning, twenty percent (20%), is devoted to backward chaining where the therapist starts with a specific set of wheelchairs and sees if they meet the needs of the patient as well as the requirements of the funding source.

A computer-aided support system can play a significant role in helping the therapist cope with the factors mentioned above. It can guide the therapist in making the best decision about what wheelchair and features need to be prescribed, based on comparison to other successful cases. It can aid the therapist by insuring thorough evaluation. Also, it can help the therapist keep abreast of new products on the market. Such a system insures quality in the wheelchair selection process. An inappropriately prescribed wheelchair usurps coverage and prevents re-prescription of a more appropriate chair. In addition, the standardized reporting format could also be used to conduct more objective studies on wheelchair prescription.

Such a system also has value as a training tool for both novice therapists and therapy students. A tutorial in which real-life or simulated applications are demonstrated can be used for teaching and training. Furthermore, innovations in the wheelchair industry change frequently. The use of computer-based support can overcome this problem. A database of currently available wheelchairs kept and updated on a regular basis, is needed in the field of rehabilitation technology. Finally, the documentation of valuable expertise as reflected by real-life applications will be easier using a computer based system. In this context, an expert therapist is a scarce resource. Hence, years of experience involving the prescription of numerous wheelchairs can be stored in the system and used later as a reference by therapists who practice in more general areas.

From the Patient's Standpoint:

Of all patients with Multiple Sclerosis (MS), about 40 percent will lose the ability to ambulate [Poser, 1978]. Thus, wheeled mobility stands out as a primary need in this population. Because of the nature of the wheelchair selection problem, it is not unusual for the medical therapist/specialist to prescribe a seemingly appropriate wheelchair for a particular patient only to have the patient reject the wheelchair. The importance of the selection of an appropriate wheelchair for a particular patient cannot be overstated. From the MS patient's standpoint, the selection of a suitable wheelchair is critical for the following reasons:

1. Insurance: Because of funding restrictions, the patient might be restricted to a wheelchair for a minimum number of years before being eligible for another wheelchair. The MS patient wants to be sure the right chair is prescribed.
2. Cost: The prescription of an appropriate wheelchair should take the cost factor into consideration, especially if the patient is to bear that cost, for patients' resources vary. Also cost consideration is important due to funding restrictions imposed by insurers or Medicaid/Medicare programs. The costs of a wheelchair can range from several hundred to several thousands of dollars.

3. Mobility and comfort: The selection of an inappropriate wheelchair will limit already diminished mobility and deny the individual MS patient the potential for increased functional independence from an otherwise suitable wheelchair.
4. Health: An inappropriate wheelchair not only may inhibit mobility and cause discomfort, but it may worsen the patient's condition, e.g., postured deformities, pressure sores, etc.
5. Image and psychological factors: A suitably selected wheelchair might enhance the patient's personal image, and thus contribute to more community/social involvement. For example, a young MS patient might desire a sporty wheelchair to remain active and socially involved.

Because of the foregoing reasons, it is desirable to have a computer-aided wheelchair selection support system that will hopefully maximize the benefits in the selected wheelchair.

Rationale For Using An Expert System

As was discussed earlier, the selection of the wheelchair for the MS population involves the examination of presentations and symptom fluctuations. Because of the complexity of these factors, only a few therapists are available with a body of expertise to tackle the wheelchair selection decision. A computer-aided system, however, would capitalize on this expertise and make it more widely available. Hence a knowledge-based system seems appropriate, more specifically, a knowledge-based expert system. The next section discusses medical expert systems in general and develops a taxonomy for them. We then show where our prototype system fits relative to this taxonomy.

TAXONOMIC FRAMEWORK FOR MEDICAL EXPERT SYSTEMS

The wide range of intelligent (knowledge-based) medical systems today can be broadly classified using the taxonomy shown in Figure 1. This taxonomy is based on three broad dimensions: technology, domain, and application type.

A. Technology

Technology is further divided into: 1) hardware platform (e.g. PC-based, workstation-based, etc.), 2) AI method (solution), and 3) programming tools. A medical knowledge-based system can thus be classified on whether it is PC-based, mainframe-based, etc. It can also be classified on whether it is an expert system solution [Cagnoni and Livi, 1989], a neural network (ANN) [Kuhn et al., 1991], a natural language system, interactive hypermedia [Hammel, 1992], a paper-based [Ward and Reed, 1993], etc. Programming tools include AI programming languages and shells. Examples include OPS5, Lisp, Prolog, and CLIPS [Stylianou and Madey, 1992].

B. Domain

Knowledge-based systems have been applied in a variety of medical subdomains [Prasad et. al., 1989; Cagnoni and Livi, 1989; Waterman, 1989; Bobis and Bachand, 1992a; Bobis and Bachand, 1992b; Bois et al., 1989; Lin and Tang, 1991]. Example subdomains include: heart diseases, blood analysis, asthma, artificial limbs, childhood diseases, and this project on multiple sclerosis (MS). It is difficult, however, to neatly classify medical computer-aided systems on the basis of medical subdomains since many of these systems have overlapping domains.

C. Application Type

The application type dimension describes the function of the knowledge-based system for which it is developed. These applications types include diagnosis [Lin and Tang, 1991], classification [Waterman 1986], prescription/selection [Stylianou and Madey, 1992], tutoring/training [Prasad et al., 1989], data analysis and interpretation, prognosis, and knowledge/technology transfer. Many knowledge-based systems are built to support more than one of these functions.

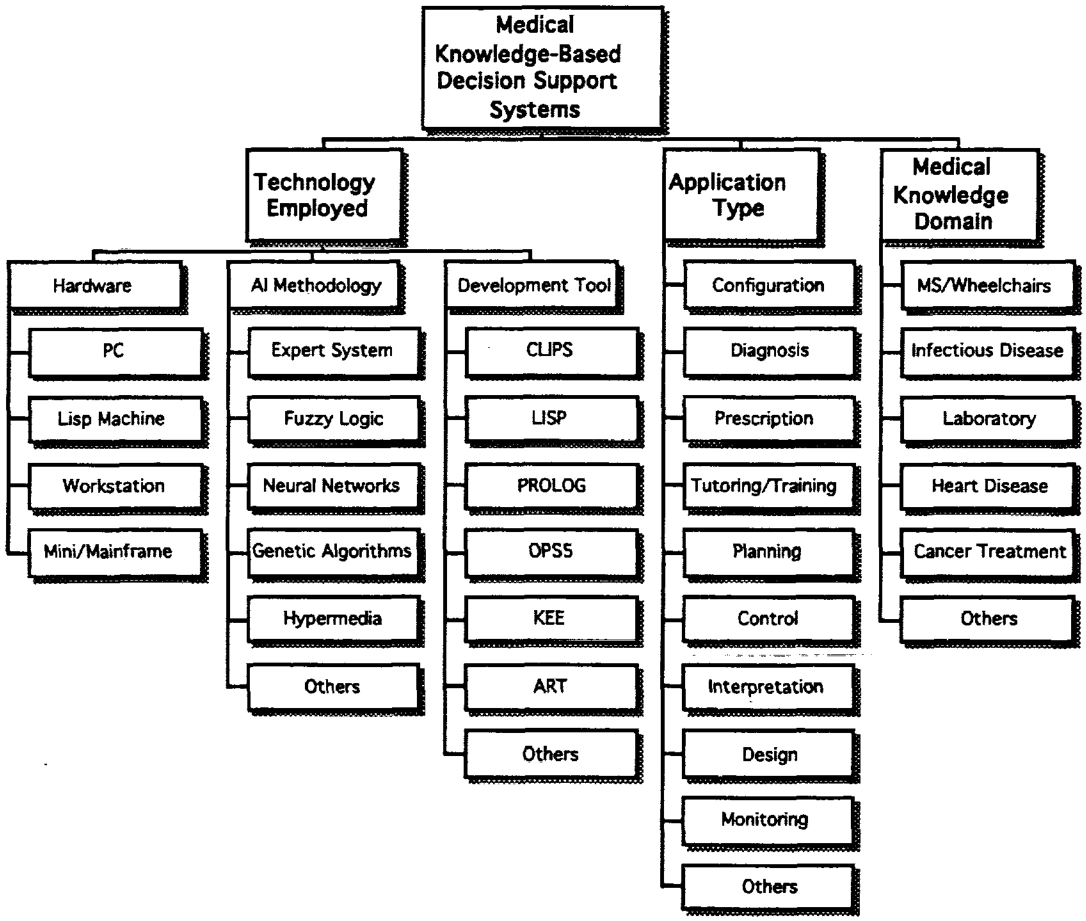

Figure 1: A Taxonomic Framework for Knowledge-Based Decision Support Systems

Review of Medical Expert Systems

Our emphasis in this paper is on medical *expert systems*, which is a subset of the computer-aided support systems in the technology dimension mentioned above. Some of the well known medical expert systems include the following [Waterman, 1986, pp.272-288]:

1. CENTAUR: The domain of this expert system is lung diseases, developed in the INTERLISP programming tool by the Stanford University. Operational functions include diagnostic interpretation of pulmonary function tests.
2. DIAGNOSER: Deals with heart diseases, develop in LISP by the University of Minnesota.
3. GUIDON: The medical domain include bacterial infections. It is developed in INTERLISP by the Stanford University.
4. MDX: Deals with liver problems, developed in LISP by the Ohio State University.
5. MED1: Deals with chest pain, developed in INTERLISP at the University of Kaiserlautern.
6. MYCIN: Best known of all medical expert systems, MYCIN's medical subdomains include bacteremia, meningitis, and Cystis infections. It was developed at Stanford University and the main operational functions include diagnosis of the causes of infections, treatment, and education.
7. NEUREX: Concerned with the nervous system, NEUREX was developed in LISP at the University of Maryland. Its functions include diagnosis and classification of the diseases of the nervous system.

8. CARAD: This expert system handles radiology; it was developed at the Free University of Brussels. Its main functions is the interpretation and classification of X-ray photographs [Bois et.al., 1989].

Our Wheelchair_Advisor stands apart from these expert systems listed above by its unique domain of wheelchair prescription for MS patients and our choice of the programming tool. This project involved the use of a PC and the expert system shell CLIPS [NASA, 1991; Giarratano and Riley, 1994; Wygant, 1989; Gonzalez and Dankel, 1993]. The functions/objectives of the Wheelchair_Advisor included diagnosis, classification, prescription, and training. Figure 2 maps these characteristics into a classification scheme to show where our prototype expert system fits relative to current computer-aided medical systems. As Figure 2 indicates, and to our best knowledge, no other expert system application has been developed in the domain of wheelchairs for MS patients.

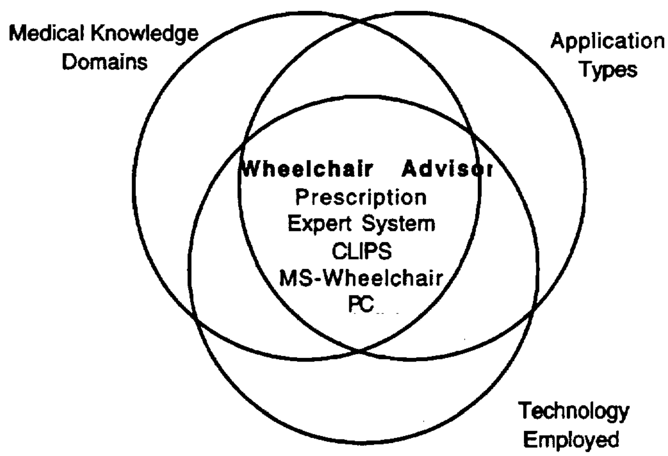

Figure 2: Classification Framework for Medical Decision Support Systems

THE WHEELCHAIR EXPERT SYSTEM PROJECT

A. The Environment

The Cleveland Clinic Foundation's Mellen Center for Multiple Sclerosis Treatment and Research was initiated in 1985 with a grant from the Mellen Foundation. The Mellen Center, the largest and most comprehensive full-time MS center in the country, is an interdisciplinary outpatient rehabilitation facility providing direct patient care, education, and basic and clinical research into the causes and management of MS. In 1993, the Mellen Center had 14,000 patient visits for its services of neurology, nursing, occupational therapy, physical therapy, psychology, and social work. Approximately 350 new patients are seen each year.

B. The Knowledge Engineering Process

The knowledge engineering process has often been described as the "knowledge engineering bottleneck" due to the difficulty and complexity of this process. To deal with the complexity of the knowledge engineering process, three basic methodologies were used to elicit knowledge from the expert: interviews, insurance documents, forms, and prototyping.

1. Interviews

Multiple interviews were conducted with the expert by three knowledge engineers (KE) all of whom, including the expert, are the authors of this paper. A typical session lasted from 3 to 5 hours.

2. Insurance Letters/Other Forms

The insurance and other prescription forms supplied the knowledge engineers with the missing links in the pieces of knowledge gained from the interviews. These forms embodied actual cases describing patient symptoms, condition, cognitive/psychological state, and the recommended wheelchair. Because of the difficulties of obtaining sufficient knowledge using interviews only, as pointed out above, the knowledge obtained from these documents was invaluable inasmuch as it complemented the expertise derived directly from the expert.

3. Prototyping

The interviews went side by side with an actual prototype developed to foster better communication between the expert and the KE's. This helped offset some of the limitations of the interviewing process. Each subsequent version of the prototype provided a chance for the expert to "endorse" the KE's interpretation of the knowledge supplied in the previous interview. At times the expert would clarify a previous answer and supply a new one; thus it became clear that the prototype helped correct errors in communication and misinterpretations.

C. The System-Building Process

The project was conducted in an interactive fashion and rapid prototyping was used to develop the system. Figure 3 shows the block diagram of the prototype system. First, the patient's needs and constraints are considered. This data can be provided on line or by using an input text file in which the data about a particular patient is stored. To accomplish this task a number of rules of the type IF/THEN are implemented. The result of this examination, which is a template of facts about the patient in question, is then used by the search module which in turns uses this information while searching the wheelchair database to find the appropriate wheelchair(s). Note that the optimizer module consists also of IF/THEN rules. As for the wheelchair database, it contains a list of wheelchairs with different features. An explanation facility where the reasoning of the system is explained to the user can be added to the system. Finally, there is a solution set module where the recommendations of the ES are included. In the next subsection, a description of CLIPS, an expert system language, is presented. Then, sample screens and dialogue are shown.

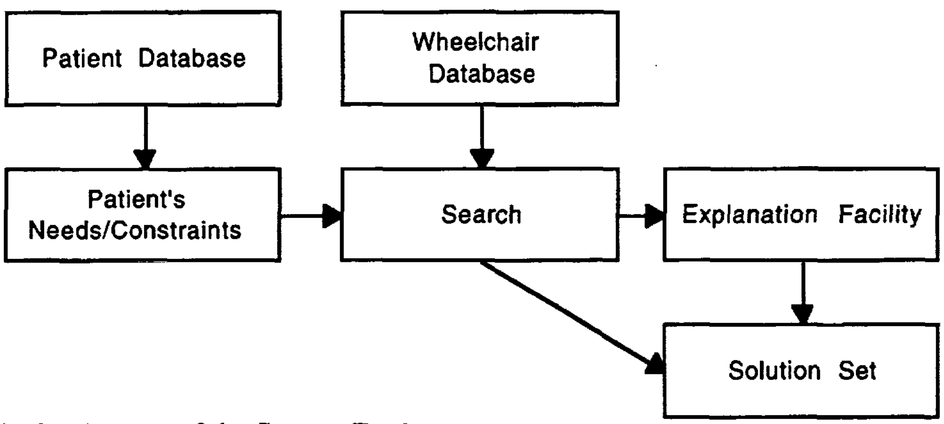

Figure 3: Block Diagram of the System Design

CLIPS

CLIPS (short for C Language Integrated Production System), developed at NASA/Johnson Space Center, has recently shown increasing usage [NASA, 1991; Giarratano and Riley, 1994; Gonzalez and Dankel, 1993; Martin & Taylor, 1992]. CLIPS is a forward-chaining rule-based language that resembles OPS5 and ART, other widely known rule-based development environments. Figure 4 shows the basic components of CLIPS, which are essential for an ES. Following this figure is a brief description of each component.

1. User Interface: The mechanism by which the user and the expert system communicate.

2. Fact-list: A global memory for data. For example, the primary symptom of an MS patient can be represented in CLIPS syntax as in Figure 5. For clarity, the reserved key words of CLIPS are printed in bold letters.

3. Knowledge-base: Contains all the rules used by the expert system. For instance, consider the following partial rule that is used by the system to list all the primary symptoms of an MS patient:

> **IF** user has a primary symptom of cerebellar ataxia
> **THEN** the primary symptom is cerebellar ataxia

In the CLIPS syntax, this rule and the associated dialogue can be written as shown in Figure 6.

4. Inference engine: Makes inferences by deciding which rules are satisfied by facts, prioritizes the satisfied rules, and executes the rule with the highest priority.

5. Agenda: A prioritized list created by the inference engine of instances of rules whose patterns are satisfied by facts in the fact list. The following shows the contents of the agenda at some stage:

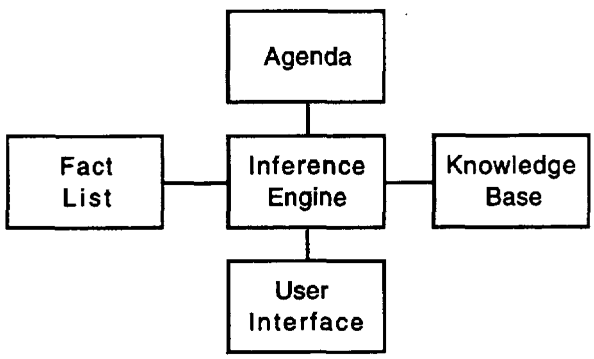

Figure 4: CLIPS Basic Components. Adapted from [Giarratano and Riley, 1994].

```
English:
  The primary symptom of the patient is cerebellar ataxia.

CLIPS:
  (deffacts user-data
      (ms symptoms primary cerebellar ataxia)
  )
```

Figure 5: CLIPS Syntax for storing facts

n Figure 7, three instantiated rules are placed on the agenda. Each entry in the agenda is divided into three parts: Priority of the rule instance, name of the rule, and the fact-identifiers. For the first entry in the agenda, for example:

- 2 refers to the priority.
- ms-symptom-primary is the name of the rule.
- f-5 is the fact-identifier of the fact that matches the pattern of the rule. Such facts are stored as in Figure 5.

```
(defrule ms-symptoms-primary
     ?phase <- (phase ms symptom)
=>
     (retract ?phase)
     (printout t crlf "What is the primary symptom of the MS
                             patient? ")
     (bind ?answer (readline))
     (if (not (stringp ?answer))
     then (printout t crlf "Please check again!" crlf)
     (assert (phase ms symptom))
     (if (stringp ?answer)
     then (bind $?sym (str-explode ?answer))
     (assert (ms symptoms primary $?sym secondary))))
```

Figure 6: CLIPS Syntax for rules

```
Agenda
    2 ms-symptoms-primary:          f-5
    1 ms-symptoms-secondary:        f-6
    0 ms-symptoms-secondary-more    f-7,f-8
```

Figure 7: CLIPS Agenda

Sample Screens And Dialogue

The above rule, the ms-symptoms-primary rule, can be used to show a scenario of a dialogue between the end user (e.g., a physical therapist) and the expert system as follows:

```
WHAT IS THE PRIMARY SYMPTOM OF THE MS PATIENT?
cerebellar ataxia
WHAT IS THE SECONDARY SYMPTOM OF THE MS PATIENT?
weakness
```

Figure 8: A Sample screen of a dialogue in a session

Based on the new information provided by the end user, the data about the patient will be updated. Accordingly, the fact-list will include a new fact which shows the name of the primary symptom of this patient. The resulting fact is presented in Figure 5. Another impact of this new information will be to update the agenda to include the next rule to be fired, the ms-secondary-symptom rule in this case. This is possible because a new fact, f-5, which was entered by the user as an answer to an on-screen question, now satisfies this rule.

LESSONS LEARNED

There are many lessons to be learned from this project. First: the evolutionary prototyping in designing expert systems is proven to be superior to conventional system development life-cycle. Figure 9 shows the steps involved in designing a system under the traditional method.

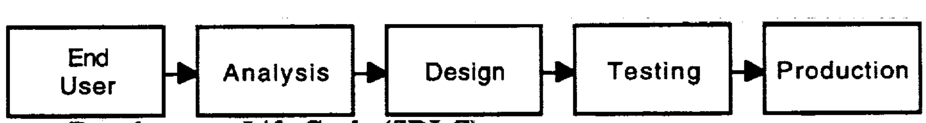

Figure 9: System Development Life Cycle (SDLC)

On the other hand, prototyping presents a more efficient way to design a system. Under this method, the end user will be aware of the costs/benefits and, most importantly, will be a part of the development team. In essence, the system will be modified a number of times until the desired system is obtained. Figure 10 shows the steps involved in this method.

Figure 10 : Evolutionary Prototyping

Second: the expert system developed in this project has shown the wheelchair selection problem to be a good candidate for ES applications. This project has also shown that there are major benefits for both the medical practitioners and the MS patients to be derived from such an application. Third, it is evident from this project that other similar medical subdomains might be good candidates for the application of the ES technology. Our project serves to expand the medical applications domain. Fourth, CLIPS was found to flexible, powerful, and intuitive development environment for this application.

CONCLUSIONS

The authors of this paper were involved in a project concerned with the actual development of a wheelchair selection expert system. A prototype expert system (Wheelchair_Advisor) was developed, using CLIPS, to prescribe wheelchairs for Multiple Sclerosis (MS) patients. This paper reports the process, the experiences of the authors, the advantages of evolutionary prototyping for expert system development, and the possibilities for new medical subdomains as candidates for expert system applications.

Our findings show that there are major advantages for using an expert system tool to aid in the analysis and selection of a wheelchair for an MS patient. Such an expert system can also be used as a training and educational tool in the medical industry.

REFERENCES

Bobis, Kenneth G. and Bachand, Phyllis M., "URSExpert: An Integrated Expert System Environment for the Bedside Nurse," in proceedings of **IEEE International Conference on Systems, Man and Cybernetics**, Chicago, 1992, pp. 1063-1068.

_________ "Care Plan Builder: An Expert System for the Bedside Nurse," in proceedings of **IEEE International Conference on Systems, Man and Cybernetics,** Chicago, 1992, pp. 1069-1074.

Bois, Ph. DU, Brans, J.P., Cantraine, F., and Mareschal, B., "MEDICS: An expert system for computer-aided diagnosis using the PROMETHEE multicriteria methods," **European Journal of Operations Research**, Vol. 39, 1989, pp. 284-292.

Cagnoni S. and Livi R., "A Knowledge-based System for Time-Qualified Diagnosis and Treatment of Hypertension," in Computer-Based Medical Systems: Proceedings of the **Second Annual IEEE Symposium**, June 26-27, 1989, Minneapolis, Minnesota. pp. 121-123.

Fieschi, M., **Artificial Intelligence in Medicine**, Chapman and Hall, London, 1990.

Giarratano, Joseph and Riley, Gary, **Expert Systems: Principles and Programming**, PWS-Kent Publishing Company, Boston, 1994.

Gonzalez, Avelino J. and Dankel, Douglas D., **The Engineering of Knowledge-Based Systems: Theory and Practice**, Prentice-Hall, Englewood Cliffs, NJ, 1993.

Hammel, Joy M., "Final Report of the AOTA/Apple Grantees," Veterans Administration, Palo Alto, CA, March 1992.

K. Kuhn, D. Roesner, T. Zammler, W. Swobodnik, P. Janowitz, J. G. Wechsler, C. Heinlein, M. Reichert, W. Doster, and H. Ditshuneit., "A Neural Network Expert System to Support Decisions in Diagnostic Imaging," in **Proceedings of IEEE 4th Symposium on Computer-Based Medical Systems,** May 12-14, 1991, Los Angeles, pp. 244-250.

Lin, W. and Tang, J.-X., "DiagFH: An Expert System for Diagnosis of Fulminant Hepatitis," in **Proceedings of IEEE 4th Symposium on Computer-Based Medical Systems**, May 12-14, 1991, Los Angeles, pp. 330-337.

Martin, Linda and Taylor, Wendy. **A Booklet of CLIPS Applications**, NASA, Johnson Space Center, Houston, TX, 1992.

Mouradian, William H., "Knowledge Acquisition in a Medical Domain," **AI Expert**, July 1990, 34-38.

NASA, Lyndon B. Johnson Space Center, **CLIPS Basic Programming Guide**, 1991., Houston, TX.

Prasad, B. , Wood H., Greer, J. and McCalla G., "A Knowledge-based System for Tutoring Bronchial Asthma Diagnosis," in **Computer-Based Medical Systems: Proceedings of the Second Annual IEEE Symposium**, June 26-27, 1989, Minneapolis, Minnesota. pp. 40-45.

Stylianou, Anthony C. and Madey, Gregory R., "An Expert System For Employee Benefits Selection: A Case Study," **Journal of Management Systems**, Vol. 4, No. 2, 1992, pp. 41-59.

Ward, Diane and Reed, Stephanie, "PowerSelect: A Prototype for Power Mobility Selection—Based Upon Human Function," in **Proceedings of the Ninth International Seating Symposium,** February 25-27, 1993, Memphis, TN, pp. 307-310.

Waterman, Donald A. **A Guide to Expert Systems**, Addison-Wesley Publishing Company, 1986.

Wygant, Robert M., "Clips—A Powerful Development and Delivery Expert System Tool" **Computers in Engineering**, Vol. 17, Nos. 1-4, 1989, pp. 546-549.