Abstract

Knowledge-based systems are widely used in many application areas, especially in health care and more recently in rehabilitation. The rehabilitation of cerebrovascular accident (CVA) victims can be a complex and demanding task. This research developed a Rehabilitation Expert System for Post-Stroke Patients (REPS) consisting of an assessment stage and a rehabilitation stage. The assessment is based on internationally validated assessment tools, and widely accepted methods of rehabilitation. Both stages are based on the expertise and knowledge of physical therapists at the FSA University Hospital. This prototype demonstrates the feasibility of knowledge-based systems in the field of physical therapy and post-stroke rehabilitation, in particular.

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1 Introduction

Knowledge-based systems have been developed in many domains. Clinical decision support systems and other knowledge-based systems are now a commonplace in health care. However, most of these systems are the fields of medicine and nursing. Physical therapy is rather an untouched area when it comes to knowledge-based systems. One of the most complex and demanding tasks in physical therapy is the assessment and rehabilitation of post-stroke patients. This project is focused on creating a prototype of a knowledge-based system containing domain knowledge in this area.

The prototype has been given the name Rehabilitation Expert System for Post-Stroke Patients or REPS for short. This report describes the development of the system, starting with some background information on the problem. A description of the work is then provided as well as a discussion on other systems related to REPS. Furthermore, the design of the system is explained and the implementation of that design is detailed. In section seven, the evaluation of the prototype is discussed, both the evaluation that has already been performed and the evaluation that should be performed in the future. Lastly there is a brief discussion on where this work might lead in a section on future work.

2 Work Motivation

Physical therapists at Fjórðungssjúkrahúsið á Akureyri (FSA), the regional hospital work with post-stroke patients on a daily basis. The repercussions of stroke are very subjective, and it can be very complex and demanding to assess and treat post-stroke patients. This section gives an introduction of the problem situation, explains what stroke is, how it is assessed and handled

2.1 Background Information

FSA is a university hospital and a regional hospital, established in 1873. It is situated on Eyrarlandsvegur, Akureyri. The hospital serves the town and the surrounding areas in North-Iceland. The hospital is an institution of knowledge that works a great deal with universities on instructions in health classes and resources in health science. It is the principal undergraduate nurse-training centre in the region and provides training for undergraduate medical students.

There are 650 people working at FSA on a daily basis. This evaluates to 490 full time jobs per year, including 50 doctors. Listed beds at FSA are 184 thereof 27 beds at Sel, which is joined to FSA, and 41 beds are at Kristnes, a rehabilitation ward operated just outside of Akureyri.

There are 13 active wards at FSA for inpatients staying overnight. In most of these wards there are also rooms for those patients who come and go the same day. There are 34 wards operated at FSA in total.

This system is done in cooperation with the physical therapy department at FSA. Currently there are 6 physical therapists working in the department. The physical therapists work mostly in rehabilitation. This involves helping people to get to the best possible physical condition they can be in after an operation or an illness. The most complex and demanding task they perform is the rehabilitation of patients that have had a cerebrovascular accident (CVA) or stroke.

The head of the department Lucienne ten Hoeve and her subordinate Sonja Middelink have both worked with post-stroke patients. They are the domain experts in this project.

2.2 Problem Description

The physical therapy department at Fjórðungssjúkrahúsið á Akureyri (FSA) handles many different types of patients. One of these types is patients that have had CVA.
CVA is the consequence of a sudden and permanent disturbance of blood flow to regions of the brain caused by vascular disease. The blood flow disturbance can be caused by a blockage in a cerebral artery from an embolism or because of a haemorrhage into the brain tissue. In both cases, the brain cells which are nurtured by the vessel suffer from a lack of oxygen and other nutrients. A part of the brain cells die and the activity of others is upset. Sometimes, the symptoms of stroke only appear for a short time. This is a temporary blood deprivation in the brain. Various diseases may cause CVA and the symptoms that appear are dependant on the location and size of the lesion (Nikulás Sigfússon et al, 2002).

2.2.1 Symptoms of CVA

A majority of the symptoms can be put into two categories, those symptoms that appear when the damage is on the right side of the brain and those that appear when the damage is on the left side. In the following subsections there is a recount of the most common symptoms that occur, according to Birna Baldursdóttir and Sonja Middelink (2003).

2.2.1.1 Symptoms of Lesion in the Left Hemisphere

The most common symptoms that occur when the lesion is located in the left hemisphere are paralysis on the right hand side, aphasia and an underestimation of ability.
Paralysis on the right hand side is characterized by an impaired stereognostic perception which is the ability to recognise objects by the sense of touch. A patient who is paralysed may also exhibit an impaired sense of posture and balance.
Aphasia is an impairment of language skills. A lesion in the posterior language area results in diminished comprehension of spoken language. However, perception remains normal. This is referred to as receptive aphasia.
A lesion in the anterior language area affects the functions of language production, so that patients have limited or no perception. This is called expressive aphasia.

All patients with aphasia have some type of abnormal language expression. Furthermore, patients may exhibit dysarthria, a speech disorder caused by a disruption in any of the inputs to the muscles of articulation. A patient with pure dysarthria can communicate normally using reading and writing.

In addition, patients with lesions in the left hemisphere may worry about physical inability and be depressed and/or defeated.

2.2.1.2 Symptoms of Lesion in the Right Hemisphere

The most common symptoms of patients having damage in the right hemisphere are paralysis on the left hand side, an impaired sense of spatial relations, impaired judgement and neglect.

Paralysis on the left hand side is, like paralysis on the right hand side, characterized by an impaired stereognostic perception. There may also be an impaired sense of posture and balance.

An impaired sense of spatial relations means that the patient has problems with judging distances, distinguishing forms and separating objects from a surrounding background. Moreover, the patient struggles with orientation in the environment, recognising objects, scenes and languages.

The patient may have a neglect of one side of the body. Patients with neglect may shave only one side of the face, use only one sleeve of the robe and fail to otherwise use one side of the body. These patients may neglect one half of the external environment as well, even in the absence of a visual field defect.

Finally, the patient may suffer from an impaired judgement which leads to an over- or underestimation of own ability.

2.2.1.3 Other Symptoms

Other symptoms that may appear with CVA patients are motor apraxia, ideational apraxia and visual field defects.

Motor apraxia is a motor disturbance which is characterized by clumsiness or involuntary grasp reflexes in the limbs contra-lateral to a cortical damage. Motor apraxia is closely associated with the language functions of the dominant hemisphere.

Ideational apraxia is a disturbance of complex motor planning, or a breakdown in the performance of a task than involves a series of related, but separate steps. The patient may perform each individual step of the task in isolation but cannot integrate the parts to complete the sequence. This is a complex disability that is usually seen in patients with lesions affecting both sides of the brain.

Visual field deficits may be seen in patients with or without associated visual neglect. Patients generally exhibit small saccadic eye movements as well as decreased speed and narrower scope of scanning.

2.2.2 Assessment and Rehabilitation

A doctor treating the CVA patient refers the patient to a physical therapist for rehabilitation. The physical therapist is given the status and medical history of the patient and the location in the brain where the damage occurred. When the patient is examined, two forms are used for assessing his/her condition. The first one, the CVA Status sheet has the name and social security number of the patient as well as the diagnosis and date of the examination. This form also has blanks for the assessment of the patient's mobility in his/her upper and lower limbs, for sitting balance and reflexes, and standing balance and reflexes, for walking, face and swallowing, and for neuropsychological function disorders (Appendix I). The CVA Status sheet is used in conjunction with the Modified Motor Assessment Scale (MMAS) for stroke patients.

These forms are used iteratively throughout the treatment of the patient. Each time the patient is visited an assessment is done on the MMAS shown in Appendix II. In this way the patient's progress can be monitored effectively (Carr et al., 1985).

In summary, assessing and rehabilitating a post-stroke patient is a complex task. Creating a knowledge-based system that captures the knowledge involved would therefore be beneficial. This would make the knowledge permanent, helping the department to maintain the knowledge and the experience that employees have gathered in their work. Such a system would make training easier since it would be built to guide the physical therapist though the process of assessing and rehabilitating a CVA patient.

Furthermore, this system would aid an experienced physical therapist in assessment and rehabilitation. This might prove useful, since the system is unemotional and consistent, while the physical therapist may be affected by the daily toil, tired, stressed or otherwise emotionally affected by the surrounding environment. In a wider context this knowledge-based system can be transferred between hospitals, where it may be expanded or modified, creating an even greater benefit for society.

3 Work Description

Creating a system that works well in a clinical environment is complicated. For such a project to be successful its objectives must be clearly stated and the functionality of the system must be evident before development of the system starts. The following section explains the project objectives and how the completed system will function.

3.1 Project Objectives

REPS is a knowledge-based system for the physical therapy department at FSA. In specific, the system is intended for the assessment and rehabilitation of CVA patients.

> The aim of this project is to create a system that guides a physical therapist through the assessment of patients that have suffered from CVA. Based on this assessment the system should also give the physical therapist advice on how to care for and rehabilitate the patient.

Developing such a system has various benefits. It makes the knowledge of the physical therapists in CVA rehabilitation permanent. Training of specialists in CVA rehabilitation becomes much easier and the knowledge can be distributed to other hospitals at a low cost. The system provides a means for a consistent and unemotional assessment of patients. Moreover, the system is in itself a documentation of the knowledge of CVA rehabilitation contained with in the physical therapy department at FSA.

3.2 System Functions

The expected users of REPS are trained physical therapists. The majority of the users will be accustomed to working with CVA patients. However, some of the users may have little or no experience in the field. They do not have any specific training in computer usage. The requirements of REPS are specified in Appendix III.

The functionality of the system is divided into consecutive stages. The first stage is assessment where the user inputs the necessary information about the patient. The second is the rehabilitation stage where the system outputs the advice on rehabilitation based on the assessment.

When REPS is first started a welcome screen is displayed. The user selects from two options, either to continue by pressing C and carriage return or to quit by pressing Q and carriage return. Figure 1 is a screenshot of the welcome screen.

```
***********************************************************************
*                            WELCOME TO REPS!                         *
*                                   -                                 *
*         Rehablitiation Expert System for Post-Stroke patients       *
*                      by Maria Osk Kristmundsdottir                  *
***********************************************************************

Press C to continue or Q to quit :o)
```

Figure 1 – The welcome screen

3.3 Assessment

The assessment is divided into seven phases. These phases correspond with the assessment tools used by physical therapists at FSA, i.e. the MMAS scales and the CVA status sheet. The phases are:

1. Upper limb movement
2. Lower limb movement
3. Movement in the bed
4. Sitting balance and reactions
5. Standing balance and reactions
6. Walking
7. Neuro-psychological function disorders

Each category consists of questions to be answered. The questions may be of two kinds, either a question on how the patient is rated on a MMAS scale or a general question on the patient's status. In the following discussion of the questions, we illustrate the operation of the system by providing answers for a specific patient.

The system displays MMAS questions by first displaying the scale under consideration. The original scales can be found in Appendix II. Figure 2 is a screen shot of the running system. It shows the category u*pper limb movement* and the first MMAS question in that category.

The top of Figure 2 is a header indicating to the user the category under consideration. Next, the full MMAS scale is shown, allowing the user to perform the relevant assessment on the patient. Finally, the user is asked how many points the patient receives on this scale. In this case, the patient receives 2 points. This means that the patient could perform the activity described in part 2 of the scale but was not able to perform the activity in part 3.

```
*******************************************
* Upper limbs                             *
*******************************************



MMAS scale: Arm
-----------------------------------------------------------------------
1 point:
The patient is lying on the back. The arm is pointing straight up,
but a little flex is allowed in the elbow. The patient gets help in
putting the arm in this position. The patient can hold the arm up
with or without support in the upper arm.
-----------------------------------------------------------------------
2 points:
The patient is lying on the back. The arm is in the same position
as in 1. The patient is able to put his hand on the forehead and
straighten the arm again. The shoulder should be protracted when
the arm is straight.
-----------------------------------------------------------------------
3 points:
The patient is sitting and holding the arm straight in 90° shoulder
flexio for 2 seconds. The patient does not lift the shoulders.
The patient receives help in getting into the position if necessary.
-----------------------------------------------------------------------
4 points:
The patient is sitting and lits the arm him/herself into a 90° shoulder
flexio. Holds the position for 10 seconds. Lowers the arm.
-----------------------------------------------------------------------
5 points:
The patient is sitting and holds both arms in 90° shoulder flexio.
Palms are up and eyes are closed. The postion is held for 10 seconds.
-----------------------------------------------------------------------
How many points does the patient get on this scale? (0-5) 2
```

Figure 2 – MMAS question on upper limb condition

The category *upper limb movement* has both MMAS scales and some general questions. Figure 3 shows the continuation of this category. After the MMAS questions, the user is first asked if the patient can actually move the arm. If the answer is "no" then the system does not ask about spasm and movement patterns in the arm. In this case the answer is "yes", so the system asks about spasm in the upper limbs. In Figure 3 the user has answered "no" to spasm in the upper limbs, so there are no more questions on spasm. The next question is on movement patterns. If the answer is "yes" to that question as in Figure 3, then a more specific question is asked about the movement patterns. Movement patterns can be of two types, either flexion or extension, in this case the patterns are flexion patterns, so the user enters "flexion". Regardless of whether or not the patient could move the arm, the two last questions are asked. These questions do not ask about the arm specifically, but rather about weight transference and defence mechanisms in the whole upper body.

```
How many points does the patient get on this scale? (0-5) 2
Can the patient move the arm?(Y N) Y
Is there spasm in the upper limbs?(Y N) N
Are there any abnormal movement patterns in the upper limbs?(Y N) Y
Are the patterns flexion or extension?(flexion extension) flexion
Is weight transferance normal?(Y N) Y
Are defence mechanisms in place in the upper limbs?(Y N) N
```

Figure 3 – Questions on upper limb condition

3.4 Rehabilitation

After going through all the different phases of assessment, the system gives advice on rehabilitation. The rehabilitation phase is based entirely on the information gathered about the patient in the assessment phase and requires no user input. In addition to giving recommendations on rehabilitation, the system can output a status report to a text file. This file can then be viewed, changed, and printed as the user desires.
At the end of the assessment stage, the system asks the user if he would like to have a status report. If the answer is yes all the information gathered in the assessment stage is printed to a report reflecting the patient's status.

```
*******************************************
* Rehabilitation                          *
*******************************************

Would you like a status report for this patient? (Y N)
N


WARNING!
Make sure that the patient is never unattended,
since he/she is at risk of falling or hurting himself/herself.
-----
Exercises in bed:
------------------------------------------------------------------------------
Clasp the patients hands, make him/her lift the hands up and to the side.
-----
Have the patients feet on the bed, the knees flexed and knees together. Have
the patient roll his knees from side to side.
-----
With the feet still on the bed and the knees flexed. Make the patient lift
his/her buttocks from the bed.
-----
With the feet still on the bed and the knees flexed. Make the patient spread
his/her knees to both sides.
-----
```

Figure 4 – Rehabilitation recommendations

Figure 4 shows a fraction of the advice that the system produces on-screen. Here a warning is displayed because the patient's defence mechanisms are not in place. The patient is therefore at risk, for example of falling, and not being able to defend himself. After displaying the warning, advice on appropriate exercises is given. In this case, the patient has scored less than 2 on the MMAS scale "Turning in bed". Therefore, the patient is prescribed some basic exercises that can be done in the bed.

4 Related work

Although knowledge-based systems have been used extensively by the health sector, there are very few systems that deal with stroke and even fewer in the field of physical therapy. This section examines systems that are related to REPS. Firstly, the section gives a short introduction to knowledge-based systems, what they are, how they are constructed, and where they are appropriate. Second is a discussion on knowledge-based systems in health care. This leads to a discussion of knowledge-based systems within the domain of CVA. The fourth subsection describes knowledge-based systems in physical therapy. This section concludes with an investigation of the robotic rehabilitation systems for CVA victims that are being developed at two universities in the USA.

4.1 Knowledge-based systems

A person is considered an expert if he/she possesses skills that allow utilization of past experiences and focus on the essence of a given problem. The expert has a high success rate in solving problems because he/she has obtained a set of powerful cause-and-effect relationships that are based on experience. The expert correctly gives a solution using this basic knowledge to identify the salient features of the problem and categorize it according to these characteristics (Gonzalez and Dankel, 2003).

Humans solve complex problems using abstract, symbolic approaches. These are not well suited for implementation in conventional programming languages. Although it is possible to model abstract information, considerable programming effort is required to convert the information to a format that is usable in procedural programming (Riley, 2002).

Research in the area of artificial intelligence (AI) has led to the development of techniques that allow the modelling of information at higher levels of abstraction. These techniques are languages or tools that support the programming of systems that closely resemble human logic in their implementation. These systems imitate human expertise in defined problem domains and are called expert systems, or knowledge-based systems. These terms are used interchangeably in this report (Riley, 2002).

There are many different definitions of a knowledge-based system. A simple definition of it is “a computerized system which draws upon the knowledge of experts in a field as a foundation for its database” (Pomerantz, 2003 p. 29).
The above definition is very general, and may be applied to many conventional computer systems. A more detailed definition is given by MacCallum and Turner, 2003:

> [A knowledge-based system is] a computing system capable of representing and reasoning about some knowledge rich domain, which usually requires a human expert, with a view toward solving problems and/or giving advice. Some knowledge-based systems are also required to explain the reasoning behind their decisions (p. 28).

Knowledge-based systems are fundamentally different from conventional software in three ways. (1) They separate the knowledge from how it is used. (2) They use highly specific domain knowledge. (3) The knowledge employed is heuristic rather than algorithmic in nature (Gonzalez and Dankel, 2003).
A knowledge-based system has the general structure as shown in Figure 5. The user interface is the mechanism by which the user and the expert system communicate. One level deeper is the knowledge acquisition facility and the optional explanation facility. The explanation facility explains the reasoning of the system to a user while the knowledge acquisition facility provides a way for the user to enter knowledge in the system. These components connect to the inference engine, which makes inferences by deciding which rules are satisfied. The inference engine also prioritises the satisfied rules and executes the rule with the highest priority. Furthermore, the agenda is a prioritised list of rules that are created by the inference engine, whose patterns are satisfied by facts in working memory. The working memory is the global database of facts that are used by the rules and the knowledge base contains the domain knowledge needed to solve problems coded in the form of rules (Giarratano and Riley, 1989).

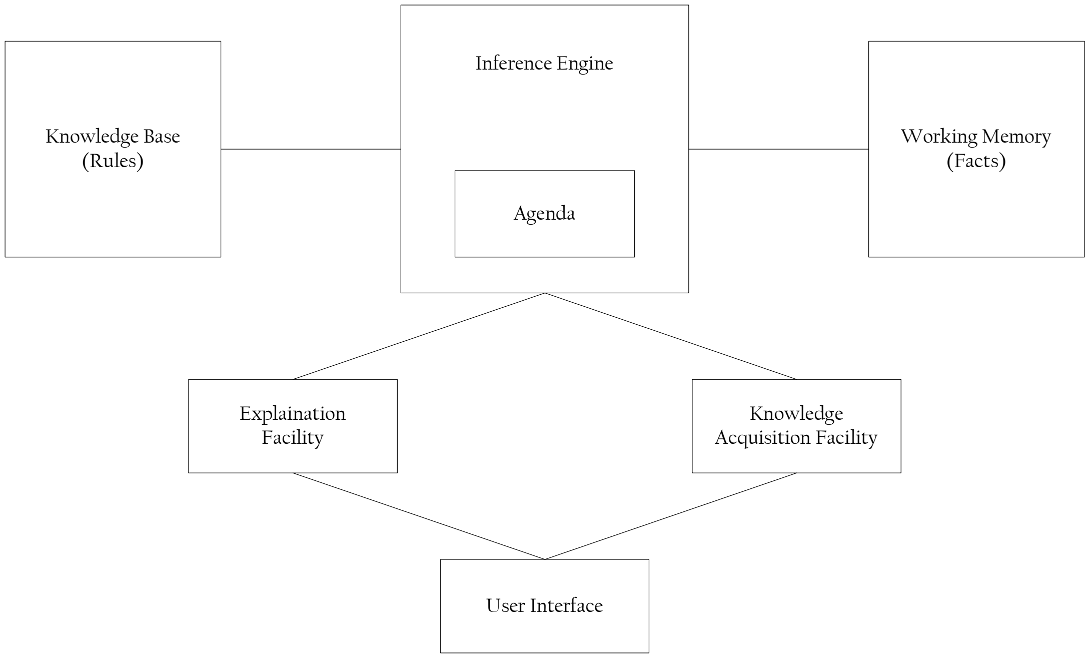

Figure 5 – The structure of a knowledge-based system (from Giarratano and Riley, 1989).

Knowledge- based systems have been applied to almost all fields of knowledge, both as research tools and as business and industrial applications. There are hundreds of expert systems that have been built and reported on in scientific journals, books, and conferences. This is probably only the tip of the iceberg since many companies and military organisations do not publish their results because of proprietary or secret knowledge contained within the systems. The domains in which these systems have been programmed include, for example: chemistry, electronics, medicine, engineering, geology, and computer systems (Giarratano and Riley, 1989).

4.2 KBS in Health Care

The two related disciplines, nursing and medicine have used knowledge-based systems to address similar problems in three different areas: treatment, diagnosis, and instruction. The following section looks at systems representative of these groups: Mycin for treatment, Internist for diagnosis, and Guidon for instruction.

4.2.1 Mycin

According to the Stanford Medical Informatics Website (2001), Mycin was developed at Stanford University in 1976. It is an expert system that diagnoses certain infectious diseases, prescribes antimicrobial therapy, and explains its reasoning in detail.

To properly diagnose bacterial infections cultures of the infecting organism have to be grown. This takes approximately 48 hours, which is too long for critical patients. Instead, doctors create guesses about the likely problems from the available data. These guesses result in a treatment where drugs prescribed that should deal with any possible problem.

The reason for developing Mycin was in part to explore how human experts make these rough guesses. However, Mycin was also an important practical tool since junior and non-specialised doctors could use it to prescribe a more effective treatment.

Mycin is a rule-based system that uses certainty factors. An example of one of its rules is given below:

IF the infection is primary-bacteria
  AND the site of the culture is one of the sterile sites
  AND the suggested portal of entry is the gastrointestinal tract
THEN there is suggestive evidence (0.7) that the infection is bacteroid

Mycin is written in LISP as a goal-directed system using a backward chaining reasoning strategy. Furthermore, Mycin uses various heuristics to control the search for a proof of a hypothesis. These heuristics were used to make the reasoning more efficient and to prevent too many unnecessary questions.

There are three main stages to the dialogue with Mycin. The first stage involves gathering initial data about the case to develop a broad diagnosis. In the second stage, more directed questions are asked to test a specific hypothesis. This section ends with a proposed diagnosis. The third stage asks questions to decide an appropriate treatment given the diagnosis and facts about the patient. This concludes with a treatment recommendation.

Although Mycin outperformed members of the Stanford medical school, it was never actually used in practice. This was not because of bad performance, but rather because of ethical and legal issues regarding the use of computers in medicine.

There were many developments from the Mycin project. NeoMycin was a later version of Mycin developed to remedy the fact that Mycin often mixed domain knowledge and problem solving knowledge. EMycin was the first expert system shell that resulted from taking all the domain knowledge from the system and leaving the inference engine. Other projects developed from Mycin include Teiresias, Centaur, VM, Guidon, Sacon, Oncocin, and Roget (Cawsey, 1994).

4.2.2 Internist

Developed in 1974 at the University of Pittsburgh, Internist was the first expert system to handle a wide range of internal medicine problems. Internist had over 4000 signs and symptoms, 1000 diseases, and nearly 100000 relationships between symptoms and treatment. Unfortunately, the user had to know how to phrase the patient's problem in the exact terms as the developers and this discouraged the users. Internist was later converted into a teaching tool in hypertext format, allowing the user to browse through the knowledge in Internist (Rada, 2004).

4.2.3 Guidon

Work on a tutorial system named Guidon started in 1977. The system was intended to make available to students the expertise contained in EMycin-based systems. The system engages the student in a dialogue that presents domain knowledge in an organised manner during a series of sessions. Guidon uses Mycin's domain knowledge and compares the learner's actions against those of Mycin, intervening if the learner's actions are not optimal or when the learner asks for help. The teaching strategy of Guidon is driven by approximately 200 tutorial rules, coded independently of Mycin's domain knowledge. The Guidon project explored several issues in intelligent computer-assisted instruction. These issues include structuring and planning a dialogue, generating teaching material, constructing and verifying a model of what the student knows, and explaining expert reasoning. Guidon had a very limited learner interaction and rather ineffective teaching strategies. However, the system played an important role in the development of AI techniques in intelligent computer based learning (Smith, 1998).

4.3 KBS and CVA

Only two medical expert systems were found that deal with CVA. Both these systems were developed in the late 1980's at the Neurological University clinic in Hamburg, Germany.

4.3.1 Toposcout

Toposcout is an expert system that finds the anatomic location and the corresponding vascular territory of a stroke, based on the clinical signs and symptoms. This system is able to detect typical stroke patterns. It has been tested for conformity with the final diagnosis of 129 patients in the Hamburg Stroke Data Bank. It was found to have a high level of agreement for hemispheric lesions (Caplan, Kunze, Spitzer and Thie, 1989).

4.3.2 Microstroke

Microstroke was designed to categorize and diagnose stroke types based on clinical information. The system's knowledge base includes information from large stroke registries. The system queries the physician for details of the patient's history, the onset of stroke, accompanying symptoms and pertinent neurological findings. It then sums the individual data items, puts in the relevant odds, and arrives at the probabilities of different stroke types for a given patient. Stroke type diagnoses by Microstroke, were correct in 72.8% of 250 cases in the Hamburg Stroke Data Bank (Caplan, Kunze, Spitzer, and Thie, 1989).

4.4 KBS in Physical Therapy

According to Myrna Donald (1999), there have been three knowledge-based systems within the domain of physical therapy. The first, the NIOSH Low Back Atlas prototype, assisted therapists in determining which of three treatment programs was appropriate judging from the symptoms a patient displayed. The focus of this project was primarily knowledge acquisition and obtaining consent for the heuristics used, in a group of physical therapy experts. The system is only a prototype and was never field tested.

Second is Elexsys, a computer assisted instruction (CAI) prototype that instructs physical therapy students and physical therapists in using interferential therapy. Rules of the system were derived from textbooks.

The third system is a prototype developed by Donald (1999). This prototype attempts to demonstrate the feasibility of knowledge based system application in the domain of physical therapy. The prototype acts as a clinical decision making aid in the management of post-poliomyelitis cases. The project is in progress, but results of preliminary verification of the prototype are encouraging.

4.5 Post-Stroke Rehabilitation Robots

The progress a stroke victim displays depends entirely on the amount of exercise received and stimulation of the stroke affected limb. This requires supervision of trained professionals who are unfortunately limited in availability. Having a robot to supervise, remind, and encourage patients would, therefore, speed up the recovery process.

Two universities in the USA have been doing research on robotics for rehabilitation of post-stroke patients. These are the Massachusetts Institute of Technology (MIT) and the University of Southern California (USC).

4.5.1 MIT-Manus

In 1997 the MIT-Manus research team first reported their findings on a robot that stimulates the disabled arm and wrist of post-stroke patients. A three-year clinical trial involving 56 patients was conducted at the Burke Rehabilitation Hospital in New York. The trial was concluded in March 1999 and showed a significant improvement of the patients' recovery. Work has started on another larger trial at the Spaulding Rehabilitation Hospital in Boston with a second generation of the robot.

Figure 6 shows a patient using the machine. The patient sits at a table placing their lower arm and wrist into a brace, which is attached to the arm of the robot. A therapist guides the patient through an exercise, which is recorded by the robot. The machine can then reproduce the exercise and direct the patient through it.

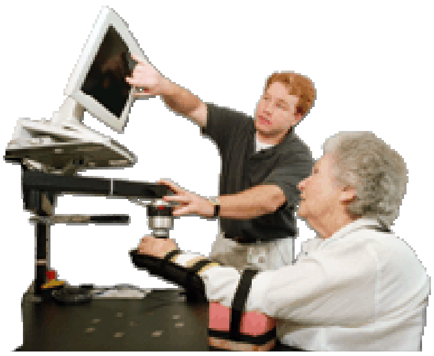

Figure 6 – MIT-Manus (from Thomson, 2000)

As the patient begins to recover and initiate movement the robot adjusts the amount of resistance it provides. All the exercises are visually guided and computer games are used for motivation and visual feedback (Thomson, 1999).

4.5.2 USC Interaction Lab

Jon Eriksson, a student at the University of Southern California, has started development of a robot similar to the MIT-Manus. The aim of his research is to investigate how to combine Rehabilitation Robotics and Human-Robot Interaction in an implementation of a hands-off mobile assistant therapy robot. The work started in November 2003 and is to be concluded in May 2004 when a prototype of the system will be completed. The prototype will be a mobile robot system that is able to supervise the rehabilitation process for a post stroke patient in a simple environment through the use of human robotic interaction methods. The system will monitor exercises and the use of the stroke-affected limb, as well as ensure that the patient is recovering by encouraging, reminding, and keeping track of the progress (Eriksson, 2003).

5 Design

The design of a knowledge-based system is entirely based on the domain knowledge it contains. Acquiring knowledge from the domain experts is therefore a part of the design process. The following section gives a description of the design of REPS and the reasoning behind the chosen design. First, knowledge acquisition is explained, providing reasoning behind the design decisions. The MMAS and the CVA Status sheet are explained in detail since they give the theoretical background. Finally, the knowledge-base structure is presented and discussed.

5.1 Knowledge Acquisition

Knowledge acquisition is usually the most time consuming aspect in the development of knowledge based systems. The domain knowledge in REPS was acquired by having weekly meetings with the domain experts, from January to April. The structure and content of the meetings varied, with the majority of the meetings prepared in advance, either by the domain experts or the developer. However, some of the meetings, especially in the beginning were unstructured, general discussions on the subject. The meetings then developed into question and answer sessions where the experts were asked about their experience and knowledge in the domain. A large amount of time went into reviewing and analysing the stroke assessment tools (see Appendix I and II). Moreover, some case files were investigated, both to check for patterns and to help the developer obtain a clear idea of the process involved in assessing and rehabilitating a post-stroke patient. As the developer became more familiar with the subject under investigation the dialogue continued by the experts quizzing the developer about the domain knowledge already acquired. Subsequently, the developer received demonstrations on the techniques involved in the assessment and the exercises prescribed.

One of the patients that the experts were working with allowed the developer to attend one of her rehabilitation sessions. This allowed for a more in-depth investigation of the rehabilitation techniques. This particular patient is hemiplegic and has an expressive aphasia. Becoming clinically acquainted to the assessment and rehabilitation process was important for the comprehensive understanding of the domain.

Additionally, knowledge was gained from a number of books on the subject of neurology, stroke, rehabilitation, and rehabilitation of stroke patients in particular. Davies, (1993) provides a detailed and complete guide to the treatment of hemiplegic patients. Her work is used extensively by the experts and was also used as a reference by the developer.

Early on in the knowledge acquisition it was clear that there were particular phases in the treatment of a post-stroke patient. These phases are incorporated into the assessment tools used in practice by the physical therapists. Gathering information about a patient's state is done iteratively through the rehabilitation process, and the treatment prescribed is largely based on that information. Therefore, a decision was made to structure REPS according to the assessment tools that are used in practice by the experts.

5.1.1 MMAS

The Motor Assessment Scale (MAS) was developed in the Cumberland College of Health Sciences, Australia. The first report on it was published in 1985. At that time it contained assessment of eight areas of motor function. Each area was scored on a scale from 0-6. Testing of MAS showed a high reliability with an average interrater correlation of 0.95 and an average test-retest correlation of 0.98 (Carr et al., 1985). Later studies also established the high validity and interrater reliability of the MAS (Poole and Whitney, 1988).

According to María Þorsteinsdóttir (2002), MAS has been used extensively in physical therapy since it was first developed. Its developers always intended that it would be further developed and tested. Physical therapists at the University Hospital in Uppsala, Sweden have been using the scale since 1991. There it was altered and improved, tested for reliability, and published with the title Modified Motor Assessment Scale Uppsala Akademiska Sjukhus (MMAS) in1999. This scale differs from the original in several aspects with the most obvious being that the scales now range from 0-5 and a scale called Tonus, rating muscle tension in the MAS, has been omitted.

In Iceland the MAS scale has been used since 1987 when it was first translated into Icelandic from Swedish. Physical therapists at FSA started using the MMAS in 2003.

Since the version used in Iceland is in Icelandic and the original in Swedish, the Icelandic version has been translated in to English. The areas within the MMAS are the following:

A. Turning in bed, from lying supine to side lying
B. From lying supine to sitting on the edge of the bed
C. Sitting
D. Standing up
E. Walking
F. Arm
G. Hand
H. Advanced hand movements

The scales for each of these areas can be found in Appendix II and the translation into English in Appendix IV.

5.1.2 CVA Status

The CVA Status sheet (Appendix I) is a form used to give a more personalised assessment than that of the standardised MMAS scales. The sheet has been in use for some time at FSA but no specific information about the origin of it has been found. The sheet is composed of a header and seven blanks, each of them representing an aspect that can be treated by the physical therapists. The header contains the name and social security number of the patient, the date, and initial diagnosis. The rest of the sheet is divided into the following categories that can be filled in with free form text:

- Upper limb movement
- Lower limb movement
- Sitting balance and reactions
- Standing balance and reactions
- Walking
- Face and swallowing
- Neuro-psychological function disorders

After careful analysis of the CVA Status sheet and how it was used, the experts and the developer found that there were patterns in the usage of this sheet. Therefore, the sheet could be standardised.

The *upper limb movement* category contains information about spasm in the upper limbs, abnormal movement patterns, weight transference, and defence mechanisms. Similarly, the *lower limb movement* category contains information on the spasm, abnormal movement patterns, and weight transference but unlike the previous category it also contains information about balance reactions when pushed back, forth, and to the sides. *Sitting balance and reactions* includes information about weight distribution in a sitting position, balance, as well as reactions when pushed back, forth, and to the sides. The *standing balance and reactions* category contains similar information about the patient as the previous category with the patient in a standing position. Additionally, information is gathered on the control a patient exhibits in the ankles, knees, and hips.

The categories *walking* and *face and swallowing* were omitted in this standardisation. *Walking* was considered too complex for standardised questions and the walking assessment performed in the MMAS was considered enough at this stage. *Face and swallowing* was omitted because analysis led to the conclusion that this was not used by the physical therapists since occupational therapists handle this aspect of the rehabilitation. The last category, *neuro-psychological function disorders*, cannot actually be treated by the physical therapists. However, it may affect rehabilitation and, therefore, must be included. The physical therapist checks for eight different disorders. These are receptive aphasia, expressive aphasia, dysarthria, ideational and motor apraxia, visual impairment, neglect, inattention, and impaired judgement.

After standardising the information that could be gathered in the CVA Status sheet, questions were formed to be able to gather that information from the user. There are two types of questions: both general questions and those more specific about the condition. Take, for example, spasm in an upper limb:

> Is there spasm in the upper limb?
>
> IF the answer is yes:
>
> > Is the spasm flexion or extension?
>
> IF the answer is no:
>
> > Ask the next question.

Furthermore, there are questions that need not be asked at all, given a certain condition. For example, the user should not be asked about spasm and movement patterns in a limb that cannot be moved. The questions that were formed can be found in Appendix V.

5.2 Knowledge-base structure

When usage of the MMAS and the CVA Status sheet was analysed it was clear that the CVA Status sheet is used to address some of the shortcomings of the MMAS. The MMAS is a standardised sheet that allows no room for personalised and detailed information about the patient. Therefore, a decision was made to combine the two assessment tools into one that would be implemented in REPS.

The categories of the CVA Status sheet were kept as a skeleton for the knowledge-base. However, the *face and swallowing* category was omitted. Additionally, a category called *movement in bed* was added.

The MMAS scales and the questions in the CVA Status sheet fall under these seven categories, resulting in a knowledge base structured as shown in the modified structure chart (MSC) in Figure 7.

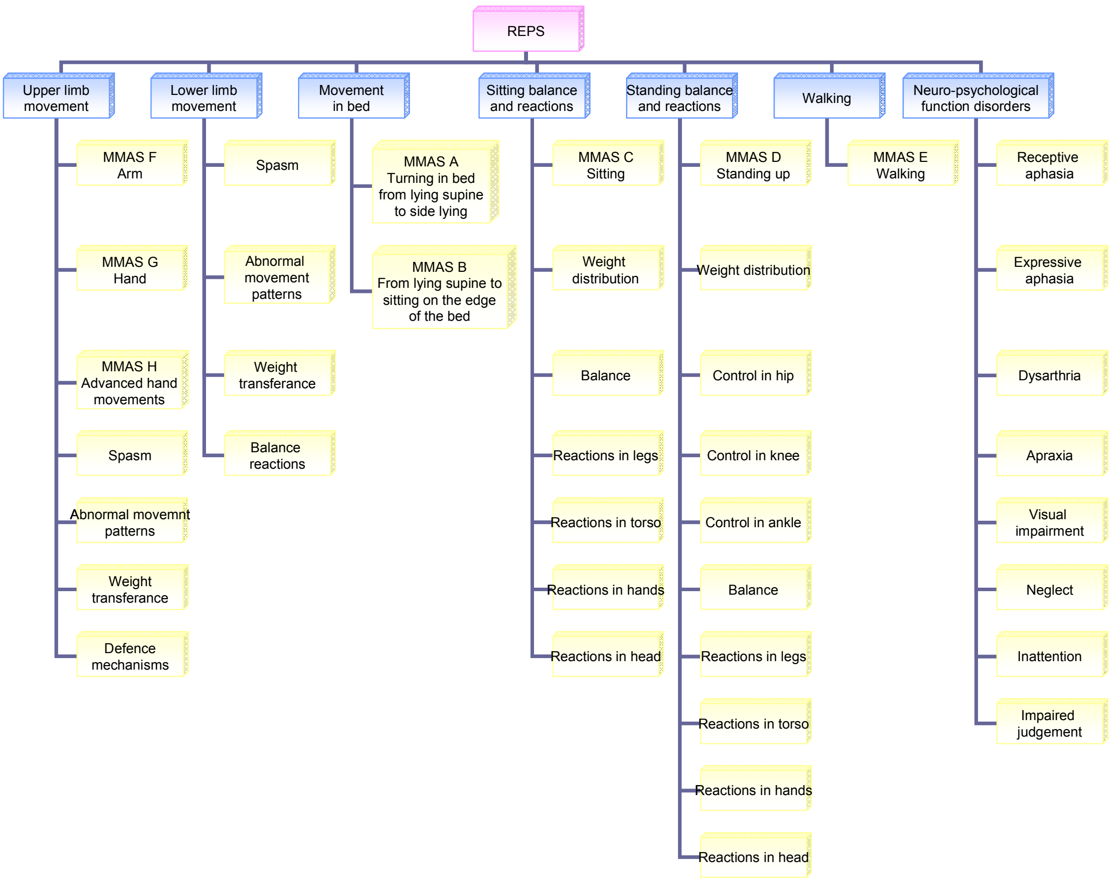

Figure 7 – A modified structure chart of the REPS knowledge base.

Both the assessment and the treatment stages are based on this structure. The assessment stage gathers information about each of these factors, and the rehabilitation advice is based on them.

6 Implementation

The implementation of the design described in the previous chapter is now discussed. This section starts by explaining the tool that is used and why this was chosen. Then the knowledge representation is explained in general and in greater detail.

6.1 Tool and platform

Knowledge acquisition involves both getting the knowledge from the experts and representing that knowledge in the relevant tool. There are currently two prominent expert systems shells freely available on the Internet; JESS and CLIPS. Both these tools were explored to find the best one for this project.

The C Language Integrated Production System (CLIPS) was originally developed at NASA's Johnson Space Centre in 1985. The shell has been developed further and version 6.2 was released in the spring of 2002. Originally, CLIPS was a rule based and forward chaining language. However, CLIPS now offers both procedural programming and object oriented programming within the shell. CLIPS is currently maintained independent of NASA, as public domain software. CLIPS has been tested on various operating systems including Windows 95/98/NT, MacOS X, and Unix. CLIPS can be ported to any system that has an ANSI compliant C or C++ compiler (Riley, 2002).

Java Expert System Shell (JESS) is written in Java. Ernest Friedman-Hill developed it at the Sandia National Laboratories in California as a part of an internal research project. The first version of the shell was written in 1995 and was originally a clone of the core of CLIPS. Version 6.1 is the most recent stable version of JESS. The JESS website states that most CLIPS scripts are valid in JESS and vice versa. The latest version of JESS is compatible with all versions of Java starting with Java 1.2 and may therefore be run on any machine that has a Java Development Kit (JDK) installed. Java is convenient for giving Java applets and applications a touch of knowledge-based system features (Friedman-Hill, 2004).

Both these system have gained support on the Internet. However, CLIPS seems to have a broader audience, probably because of its age. The difference in age also results in CLIPS being a more stable and complete development environment.

Moreover, CLIPS has a more extensive and coherent documentation than JESS. On the other hand, the author of JESS has been very responsive to feedback and has regularly put out new releases and bug fixes (Laerhoven, 1999).

In essence, the systems are very similar. However, for web-based applications JESS is a logical choice. REPS is not intended for the Internet, but it would benefit from the stable environment and more complete documentation of CLIPS. Therefore, CLIPS was chosen as the development tool for this project.

6.2 Knowledge-representation

A rule-based expert system consists of rules and facts. Rules are used to represent "rules of thumb" or heuristics, which specify a set of actions to perform under a certain situation. A rule has two portions: an *if* portion and a *then* portion. The *if* portion contains patterns of facts or data that must be matched for a rule to be executed. The *then* portion is a set of actions that are carried out when the pattern is matched (Riley, 2002).

In REPS, like other rule based expert systems, there are facts and rules. In general, there are two sets of facts. The first set of facts is the set of *initialisation facts* that are asserted when the program is first started and are used to drive the assessment process. The second set of facts is the *patient status facts* that are asserted in the assessment process and represent the current status of the patient that is being assessed. Each of the facts has its template that is defined at the beginning.

The rules can also be divided into two categories: the assessment rules and the rehabilitation rules. The assessment rules contain patterns that primarily match the initialisation facts, but sometimes the patient status facts as well. The rehabilitation rules are driven only by the patient status facts.

The rules are executed using the depth strategy. This means that newly activated rules are placed above all rules of the same salience.

6.2.1 Fact Templates

In CLIPS, ordered facts store information by position. To access information in an ordered fact, the developer must know which field in the fact contains the data of interest. In contrast, non-ordered facts, or deftemplate facts, provide a facility to abstract the structure of a fact by assigning names to each field within the fact. A construct, called deftemplate is used to create a template, which can then be used to access fields or slots of the fact by name. Using templates gives a certain standard of flexibility, since it ensures that any facts that comply with the templates can be run within the program.

The source code file “reps-templates.CLP” contains templates for all the facts asserted in REPS. There are seven different types of facts within CLIPS, each of these types is represented by a deftemplate construct.

The initial facts are asserted in two files, “reps-MMAS.CLP” and “reps-questions.CLP”. These files contain facts for the MMAS scales and the CVA Status questions, respectively.

6.2.1.1 phase

This phase template is used for facts storing details on the phases of assessment. The template has five slots. The slot “name” stores the name of the phase. The “MMAS” slot contains information about the MMAS scales in this phase, which can be left empty. The “question-no” is used to control the printout of the MMAS scale. The “questions” slot indicates if there are CVA Status questions in this phase. Finally, the slot “active” indicates if this phase is being processed or not.

6.2.1.2 phase-description

This phase-description template is used for facts that describe each of the phases. Its two slots contain the name of the phase and a description of the phase. This description of the phase is stored separately from the phase itself, since the description is used less frequently than the actual phase fact.

6.2.1.3 question

The deftemplate question is a template for CVA Status assessment questions. The template contains six slots. The slot “phase” indicates which phase of assessment the question belongs to (e.g., Walking or Sitting Balance and Reactions). The slot “no” indicates where in the order of questions this particular question should be positioned. The slot “condition” indicates what condition has to be true for this question to be asked. The default condition is “empty”, so if a question does not have a condition this does not have to be explicitly stated. The slot “question-string” contains the question itself. The slot “possible-answers” contains the answers that can be given to this question. The majority of the questions are yes or no questions, so the default is (Y N). The slot "factor" indicates which assessment factor is being asked about in this question. This slot is used for asserting the patient status facts from the question.

6.2.1.4 factor

The deftemplate factor is a template for assessment factors that eventually determine rehabilitation. The template contains four slots. The slot "phase" indicates which phase this factor belongs to (e.g., Walking). The slot "number" contains information about where in this phase the factor was asserted. The slot "factor" indicates the assessment factor that is being asserted and the "answer" indicates what answer has been given for this particular factor.

6.2.1.5 MMAS-question

This template is used for storing one statement within a MMAS scale. Five such statements compose one MMAS scale. The template contains three slots. The slot "scale" contains a symbol indicating to which scale this question refers. The "points" slot indicates how many points on the scale this statement gives. The slot "question" gives the statement to be printed.

6.2.1.6 MMAS-description

This template is for facts that describe MMAS scales. This is used at the beginning of each scale for explanation. This template has two slots: one giving the scale and one giving the description for that particular scale.

6.2.1.7 MMAS

This deftemplate, called MMAS, is used for storing results of MMAS assessment that determines treatment. It has two slots: "scale" and "points". The "scale" slot indicates the MMAS scale used, while "points" is a number from 0-5 indicating the patient's score on the scale.

6.2.2 Assessment Rules

The assessment rules are stored in a file called "reps-assessment.CLP". There are seven rules that control the assessment process. There is one fact to start the assessment, four rules for asking CVA Status questions, one for asking about MMAS scales, and one for switching between phases of assessment. These rules are driven by facts that represent the questions and scales needed in the assessment. The facts are stored in "reps-questions.CLP" and "reps-MMAS.CLP", respectively.

6.2.2.1 start

The start rule is the first rule that executes in the system. It gives a welcome screen and presents two choices to the user, either to continue or to quit the program. If the user chooses to continue then this rule starts the assessment by asking for the patient's name.

6.2.2.2 ask-question

This rule takes in the question with the lowest number that has an empty condition. Upon execution, it checks to see if the user input is correct and, if it is, asserts a fact describing the condition that was being questioned.

6.2.2.3 condition-true

This rule executes if there is a question that has a condition that is satisfied. It then asserts the question again with an empty condition.

6.2.2.4 condition-false

This rule is executed if there is a question having a condition that is not satisfied. Upon execution it deletes the question, so that it is not asked.

6.2.2.5 question-not-asked

This rule executes if there is a question with a condition that cannot be satisfied. This happens if the condition refers to a question that will not be asked. When this rule executes the question is deleted.

6.2.2.6 ask-MMAS

This rule is executed when there is a MMAS scale to display. It prints all the MMAS statement for the scale in order and asks for input. It then checks the user input for correctness. If the input is correct, then a MMAS fact is asserted with the points given by the user.

6.2.2.7 switch-phase

When each phase has finished all its MMAS scales and CVA Status questions then this rule is executed. It activates the next phase in order and prints out a header for that phase.

6.2.3 Rehabilitation Rules

There are two source code files that contain rehabilitation rules: "reps-report.CLP" and "reps-treatment.CLP". The files contain rules for the report and rules for the rehabilitation advice, respectively. Three rules control writing of the report, and ten rules give advice for treatment.

6.2.3.1 start-report

This rule executes when the user asks for a report. It prints the header of the report along with the patient's name into a file.

6.2.3.2 report-MMAS

This rule examines each of the MMAS facts representing the patient's condition. It prints the MMAS points along with a description of the patient's state according to that particular MMAS scale.

6.2.3.3 finished-report

This rule is executed when the report is finished and switches over to the rehabilitation advice.

6.2.3.4 switch-to-treatment

This rule is executed when there are no more questions left in the assessment stage. It starts the rehabilitation stage by asking the user if a report is required. If the user asks for a report then this rule switches over to the report stage. If not, it continues with the rehabilitation advice.

6.2.3.5 defence-mechanisms

This rule is executed if the assessment phase shows a lack of defence mechanisms. It warns the physical therapist of the danger of leaving the patient unattended.

6.2.3.6 MMAS-AB12

This rule is executed if the patient scores two points or less on the MMAS scales A and B. It then prescribes appropriate exercises.

6.2.3.7 MMAS-B3

This rule is executed if the patient scores 3 points on the MMAS scale B. It prescribes appropriate exercises.

6.2.3.8 MMAS-C123

This rule is executed if the patient scores 3 points or less on the MMAS scale C. It prescribes appropriate exercises.

6.2.3.9 MMAS-C45

This rule is executed if the patient scores 4 or 5 points on the MMAS scale C. It prescribes appropriate exercises.

6.2.3.10 MMAS-D12

This rule is executed if the patient receives two points or less on the MMAS scale D. It prescribes appropriate exercises.

6.2.3.11 MMAS-D34

This rule is executed if the patient receives three or four points on the MMAS scale D. It prescribes appropriate exercises.

6.2.3.12 MMAS-E1

This rule is executed if the patient receives one point on the MMAS scale E. It prescribes appropriate exercises.

6.2.3.13 MMAS-E234

This rule is executed if the patient scored two, three or four points on the MMAS scale E. It prescribes appropriate exercises.

7 Evaluation

Software evaluation can be divided into two parts: validation and verification. Gonzalez and Dankel (2003), have defined validation and verification of knowledge-based systems to be the following:

> Verification is the process of ensuring that the intelligent system(1) conforms to specifications, and (2) its knowledge base is consistent and complete within itself.
>
> Validation is the process of ensuring that the output of the intelligent system is equivalent to those of human experts when given the same inputs.

In essence, validation and verification are aimed at eliminating errors from the system. Knowledge-based sytems generally have three main sources of errors:

1. Inadequate or non-existent system specifications.
2. Semantic and syntactic errors introduced in the implementation.
3. Incorrect representation of the domain knowledge.

Knowledge-based systems should be exercised to locate and correct these errors. This chapter discusses the ways in which REPS has been and should be tested, based on the previous definition of validation and verification of knowledge-based systems.

7.1 Verification

The previous definition of verification of knowledge-based systems states that it should ensure that the system in question conforms to its specifications on one hand and that its knowledge base is consistent and complete on the other hand. This subsection examines these conditions.

7.1.1 Conformity with Specifications

REPS was checked for conformity to the Requirements Specification (Appendix III). It largely conforms to these specifications. However, the final version of REPS does not store patient information and monitor patient's progress as was originally intended. The main functions of the system, assessment and rehabilitation, are however implemented and meet the Requirements Specification.

To properly test the system for conformity with specifications, a third party should be involved, to ensure an objective evaluation. This has not yet been done for REPS.

7.1.2 Completeness and Consistency

REPS was tested for completeness and consistency by searching for eight different types of syntactic errors; redundant rules, conflicting rules, subsumed rules, circular rules, unnecessary IF conditions, dead-end rules, missing rules and unreachable rules (Gonzalez and Dankel, 2003). Initial testing of REPS found none of these error types.

7.2 Validation

Testing was done informally, to ensure that REPS produces the same output as an expert would when given the same inputs. At meetings with the experts, the system was exercised and viewed. Actual CVA cases were used as test cases to run the system. No major bugs where found and those that were found were fixed.

If REPS will be used in a clinically environment, it will have to be validated extensively. This should be done with field tests, where the system is tested in a clinical situation. This could also be done with subsystem evaluation, where each of the systems phases would be checked for correct output, given a specific input.

8 Future Work

The current version of REPS is considered a prototype for demonstrating the feasibility of developing a knowledge-based system for assessment and rehabilitation of post-stroke patients. Emphasis was placed on creating a complete and comprehensive assessment tool that could be used for future work. It is obvious that if the system will be put in use in a clinical environment it will need more effort. Hereafter are known problems with the current system as well as an overview of what is envisioned for REPS in the future.

8.1 Known Problems

REPS outputs a report on the assessment at the start of the rehabilitation stage. This report currently contains the MMAS assessment, but does not have the information on the CVA Status assessment. This feature should be implemented in the next version of REPS.

In the majority of cases, the rehabilitation advice given by REPS is based on the MMAS assessment scales. However, one rehabilitation rule is based on the CVA Status. This demonstrates the system's capability of having rehabilitation based on its CVA Status questions. Future versions of REPS should have a more complete and better articulated rehabilitation knowledge-base, based more extensively on the CVA Status assessment.

8.2 Future Developments

Hopefully, REPS will be used as a basis for more extensive knowledge-based systems in the domain rehabilitation of post-stroke patients. Future developments in that direction would for example be to store patient data and have the assessment time-stamped so that each patient's progress can be observed. This would provide a more effective tool for the physical therapists using the system.

A graphical user interface (GUI) would be the next development for the system. A GUI would give the system a more professional look, make the user experience more enjoyable as well as making REPS easier to use. Since the users of the system are not trained in computer usage, this would be a feasible extension.

In addition to this, REPS would be more easily used if it would be implemented on a personal digital assistant (PDA) or a handheld computer. Information on the patient would then be input into the PDA at the place of assessment but the data would be stored centrally. Eventually, the central database would become a valuable source of information for research in the domain.

Another vision would be that this type of expert system could be incorporated into one of the robots discussed in section 4.5. The robot would then both monitor the patient's progress and prescribe the correct treatment, with the aid of a physical therapist.

All these developments need to be carefully considered and the results must be tested extensively before the system is put in use. Systems that store patient information must also comply to a minimal requirements document for computer systems dealing with medical records, issued by the Ministry of Health and Social Security (2001).

9 Conclusion

An expert system intended for decision support in the assessment and rehabilitation of post-stroke patients was reported on here. Firstly, the problem situation was investigated as well as the causes and effects of stroke. Secondly, a description of the produced system was given along with a survey of related systems. Thirdly, the design of the system was detailed and reasons given for the design decisions. Fourthly, the implementation of that design was described as well as the evaluation of the system. Finally, visions of how the system might be expanded further were depicted.

After an extensive search on the web for similar systems to REPS, few were found. It seems as though physical therapy is a disadvantaged field when it comes to knowledge-based systems. With REPS the feasibility of knowledge-based systems in physical therapy has been demonstrated.

Furthermore, the work produced could be a basis for further work in this area. Hopefully, REPS will be expanded so that future versions will aid physical therapists through assessment and rehabilitation of post-stroke patients.

Glossary

AI – Artificial Intelligence

CLIPS – C Language Integrated Production System

CVA – Cerebrovascular Accident

FSA – Fjórðungssjúkrahúsið á Akureyri / FSA University Hospital

GUI – Graphical User Interface

JESS – Java Expert System Shell

MAS – Motor Assessment Scale

MIT – Massachusetts Institute of Technology

MMAS – Modified Motor Assessment scale

MSC – Modified Structure Chart

PDA – Personal digital Assistant

REPS – Rehabilitation Expert System for Post-Stroke Patients

USC – University of Southern California

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Appendix I – CVA Status

Appendix II – MMAS

Appendix III – Requirement Specification

Appendix IV – MMAS in English

Appendix V – CVA Status Questions

Appendix VI – User Manual

Appendix VII – Source Code