DIGITAL CLINICAL GUIDELINES MODELLING

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KEYWORDS
Digital, Clinical, Guidelines, Modeling, CIG, CG, Medical Aid, Knowledge Representation

ABSTRACT

Healthcare environments are very demanding, because practitioners are required to consult many patients in a short period of time, increasing the levels of stress which usually harms the outcome of healthcare processes. The short time practitioners have with their patients does not facilitate informed decision making and checking all possibilities. A possible solution is the use of guideline-based applications, because they have the potential of being an effective means of both changing the process of healthcare and improving its outcomes. However, current Clinical Guidelines are available in text format as long documents, which render them difficult to consult and to integrate in clinical Decision Support Systems. With this paper we present a new model for guideline interpretation, in order to facilitate de development of guideline-based Decision Support Systems and to increase the availability of Clinical Guidelines at the moment of the clinical process. This model will also provide mechanisms to comply with cases where incomplete and uncertain information is present. The development and implementation of this model will be presented in the following pages.

INTRODUCTION

The health care sector is very demanding on health care professionals. They work several hours in stressful environments and make important decisions every second. It is only normal that sometimes psychological and physical fatigue may lead to a decline in healthcare quality. This leads to an increase of stress levels of the professionals and the management office, which is reflected in the quality of medical treatment, forming a vicious cycle. Although healthcare professionals are human beings, errors in their area of expertise are not well tolerated, since their errors can cost a human life. A study conducted in the Mayo Clinic (United States) (West et al. 2009) provides a useful insight of the levels of stress the physicians are submitted to, from the real registered errors and from the physician perspective. The number of hours and patient per hour that the physician attends and the levels of stress are strongly correlated. The typical spawn of such stress leads to factors as fatigue, burnout and depression.
Hence it is necessary to lessen their burden by providing them the means to make better informed decisions. Clinical Guidelines (CGs) and their computer implementation may hold the key to address this issue.

CGs are evidence-based statements that provide recommendations to patients and healthcare professionals about a medical procedure. These guidelines are good practice manuals that focus in the effectiveness, efficiency and transparency of medical practice (Woolf 2000).

Computer-based guideline systems may also give a solution to other current problems in hospitals and healthcare facilities. For instance the use of complementary means of diagnostic in situations where they are not really required is a great problem for hospital management, because it greatly increases the expenses. The recommendations of CGs assure that these means are only used when necessary and can also reduce the variability in medical practice, as well as the occurrence of medical errors. As a result the gap between ideal medical practice and actual medical practice, shown in recent research, will be reduced and healthcare quality will improve (Kawamoto et al. 2005)(Langley et al. 2009)(Sackett 1997).

CLINICAL GUIDELINES

During the last two decades, many countries started paying attention to the development of Clinical Guidelines (CG), recognizing their importance in the improvement of healthcare quality. CGs are documents based on scientific evidence and expert opinion, developed to assist practitioner and patient decisions about appropriate healthcare (Rosenfeld and Shiffman 2006).

Computer Science progressed greatly in the last years, expanding its reach to multiple areas, including medical science. The adoption of evidence-based procedures helped CGs to become a standard among medical personnel. Despite the fact that doctors have the specificities about the most common diseases memorized, CGs can still provide their contribution in difficult cases, where they can compensate for any knowledge gaps.
Although CGs are important sources of information, since they keep updated data about several symptoms, diseases and medical procedures, they are quite long documents with a high degree of complexity, which makes them inadequate for real life situations. This inadequacy is also caused by the speed at which information and guidance are required in a real life clinical situation. It is possible to address these issues through Computer Science, with computer representations of CGs, called Computer-Interpretable Guidelines (CIGs), the development of which started in the middle of the 1980's (Hommerson et al. 2004)(Hommerson et al. 2008).

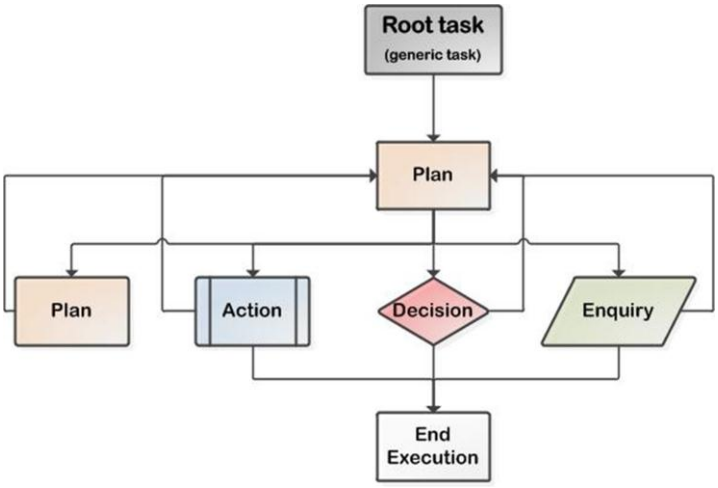


Figure 1: Schematic representation of the tasks of the formalism.

Studies conducted (Sánchez et. al. 2009) (Cannon et. al., 2000) demonstrated that with the adoption of current applications of CIG's have helped to minimize the clinical errors and provide a better overall efficiency of patients attendances, avoiding also hospital spending in unnecessary complementary exams.
This also affects positively the service provided to the user, by minimizing the time spent in the hospital and having a more precise diagnostic, scientifically justified.
However, nowadays hospitals are reluctant to use CIG based applications, because the available solutions show some functional issues, such as time of execution and the learning curve. These facts dissuade the use of the computerized solutions, where the medical environment of operation has time as a key factor.

RELATED WORKS

To implement guidelines within a computer-based clinical decision support system, guideline modeling is a critical issue. A good depiction model for guideline modeling will provide the user a good understanding of the clinical process, thus making it more transparent and consistent and less ambiguous and redundant. There are a number of existing formalisms for expressing CIGs, for instance Arden Syntax, Guideline Interchange Format (GLIF), Asbru and SAGE, among others.

The oldest depiction model is Arden Syntax (Kim et al. 2008). It was created in 1989 and its approach sees guidelines as independent modules, little pieces of knowledge for very specific situations that are easy to share and integrate in different Decision Support Systems (DSSs). Each independent module is called Medical Logic Module (MLM) and contains knowledge for a specific decision in his Knowledge Compartment. A MLM has two more compartments called Maintenance and Library. The current version of Arden Syntax is Arden Syntax 2.0 and it is now a standard of Health Level 7 (HL7).
In 1998, the group Intermed Collaboratory presented the GLIF (Peleg et al. 2000) depiction model, which focuses in modeling workflow, relying for this purpose on the Task Network Model (TNM). This depiction model consists of a set of steps that represent different moments in the clinical process. These steps are Decision steps, Patient State steps, Branch steps, Synchronization Steps or Action steps. For Decision steps it is used a subset of Arden Syntax logical expressions. GLIF also uses a subset of Asbru elaborated temporal language (Shahara et al. 1998) to represent temporal constraints. The current version of GLIF is GLIF3, which is available in XML format and has a medical data model based on the HL7 Reference Information Model (RIM).

The SAGE (Standards-Based Sharable Active Guideline Environment) (Ram et al. 2004) depiction model sees guidelines as Recommendation Sets built as graphs of Context Nodes, which can be Action Nodes, Decision Nodes and Routing Nodes. This approach is the product of a collaboration of six research groups, namely IDX Systems, University of Nebraska Medical Center, Intermountain Health Care, Apelon, Inc., Stanford Medical Informatics and the Mayo Clinic, and is an effort towards a sharable format of Clinical Guidelines.

The main goal of the present work is to combine general models of human task execution (present in the several available approaches) with formal decision making models and at the same time address the issue of incomplete information in decision making.

GUIDELINE MODELING

CGs are a good way of representing medical procedures, given their clear and concise nature. They compile all facts, terms and procedures about a given disease and make logical connections between them. CGs are subjected to a thorough review before being published are updated on a regular basis. The goal is to adapt textual CGs to a digital format, where they are represented according to a depiction model based on the best features of previous models. This depiction model represents guidelines as flowcharts to achieve a better communication with the user, making it easier to globally analyze the problem at hand. This flow-chart act will as a

blueprint that guides healthcare professionals through the clinical process. The automated execution of CG requires the development of an intelligent guideline engine, sensitive to the input of medical terms and symptoms. This guideline engine provides healthcare professionals a real-time suggestion system, maximizing the efficiency and the quality of healthcare.

The formalism proposed by this paper draws its inspiration from PROforma, one of the available depiction models for CGs. It presents an abstract view of decision making processes and task management during a clinical procedure. CGs are represented as oriented graphs where each node represents a task. Tasks are the basic unit of this model and every procedure in a clinical process is viewed as a task. The types of tasks presented in this approach are Decisions, Actions, Enquiries and Plans, which are inserted in a more general task called Root task, as in Figure 1. A CG is modeled as a Plan, which is a collection of tasks. The CG elements are the Root task, Plan, Action, Decision and Enquiry. The description of these elements is:

– **Root task** is a class of tasks that contains different Plans, according to their main orientation, namely diagnosis, treatment and clinical examinations, among others. The Root task has the following set of attributes: Name, Caption, Description and Goals.

– A **Plan** comprises a set of tasks that should be executed in order to achieve a certain goal. Besides Name, Caption, Description and Goals, a Plan has attributes like Trigger Conditions, Components, Scheduling Constraints and Abort Conditions. Trigger Conditions contain the events that trigger the execution of the Plan. When these Trigger conditions hold, the tasks that have their Name in the attribute Components start executing. The order by which these tasks are executed is defined in Scheduling Constraints. This attribute is also used to define which tasks are mutually exclusive and which tasks should be executed simultaneously. If there are events that imply canceling the guideline execution, they should be put in Abort conditions. Another important feature of Plans is that they can be nested inside another Plan.

– **Decisions** are tasks that involve a choice of any kind. For this purpose they contain different options as well as the rules that dictate which option to choose.

– **Actions** are medical procedures that can only take place outside the system and they are executed by an external agent. The specific attributes for Action tasks are Method, Confirmation and Special conditions. The Method is the detailed description of the means required to carry out the task. In Confirmation it is specified if the Action needs permission from the user to be performed or not. Special conditions are only used when the task at hand can only be executed under a set of conditions, which are textually specified in this attribute.

– **Enquiries** are tasks with the objective of acquiring information, through questions. They are entry points for data concerning the patient state. The specific attributes of this class of tasks are Enquiry name and Data Definition. In Enquiry Name we represent the name of the parameter to be obtained and in Data Definition we define how this parameter is input in the system.

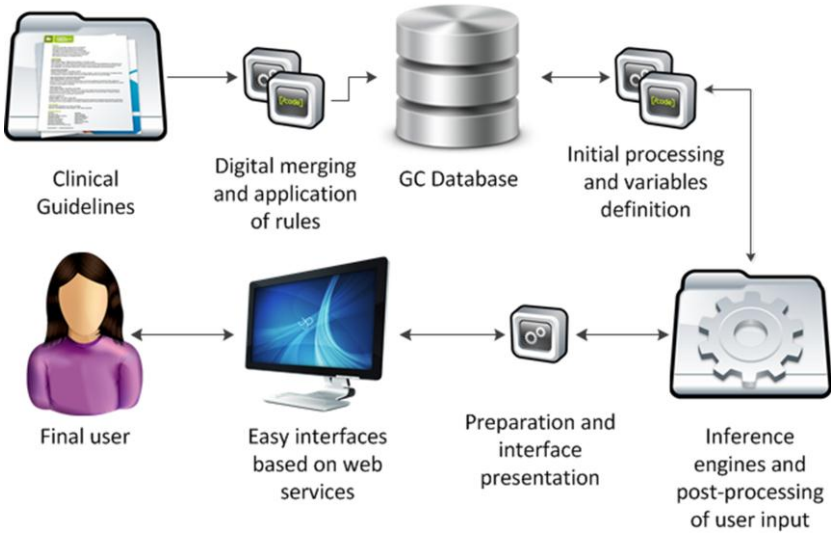


Figure 2: The architecture of the system.

ARCHITECTURE

This project works with several different programming paradigms, being heavily based on logic inference paradigms. The system relies mostly in four modules: Database Modulation, User Input Parsing and the Logic Inference Matcher (Figure 2). The final goal is the deployment of a system that was undergone through a process of modeling and simulation, the final product being a polished and fully functional suggestion system, having a very low-to-none rate of errors. This is a model on which a physician/nurse has to rely, and the medical condition of a patient is at the line, thus a thorough simulation process is demanded to test all the variables for possible problems.

The Database Modulation (DM) parses the guidelines introduced in the system and generates the associations

between the several elements that the guideline is composed of. It is also responsible to deliver the correct guideline when the model requires it. This is done by an initial interactive questionnaire that is presented in the form of a triage environment, and it serves as a first filter to select the appropriate guideline(s) to load, in order to follow on to the next step, the Logic Inference Matcher. The databases used are tagged textual data with medical knowledge that is a perfect transposition of the original guideline to the computer format. The resultant archives will constitute a well-defined guideline that is constituted by procedures, actions, questions, among other information. The knowledge resultant should be able to be machine and human readable, so it can be processed by computers and understood by man (Novais et al. 2010). To withstand time and different computer architectures where the model should run, JSON and XML were adopted (Nurseitov et al. 2009). These prototypes of data interchange files suit better than the standard databases, being lightweight and very portable, having the characteristic that an internal parser can easily read the content without any external tool or application, being also human-readable.

the values fluctuate given the perception of the patient towards the comprised symptom.
Having this in mind, we have adopted the Quality of Information methodology to relate the incomplete or inaccurate information with the formal information and produce answers with a confidence index associated to them (Gomes et al. 2010)(Costa et al. 2011).

The visual representation has the uttermost importance; the typical users are not much computer literate and being time and *time of response* a key component in a ER the interface should be as simple as possible, but, at the same time, provide all the options and inputs. The approach of this module development was towards the minimalism and follows a process of execution that emulates the human decision process. The emulation of the human process of logic elimination is, in our view, the best way to achieve the goal proposed. This process consists in having an array of possibilities, and by a process of elimination trough comparison and approximation leave only the possible items and processes. Translating to the visual form, it is a map of all the items, displaying the next item connected to the

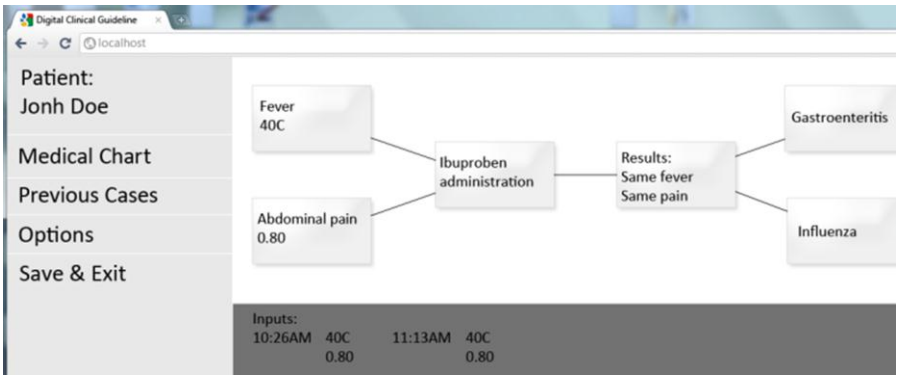


Figure 3: The interface of the system.

The Logic Inference Matcher (LIM) consists of a processing engine that has rules defined in a logic programming language. The LIM is highly dependent of what the user introduces in the interface, thus it depends on the User Input Parsing module. The data delivered by the User Input Parsing is processed and matched against the factual knowledge retrieved from the database and follows a hierarchy of processes that follows the tree of decisions that emulate the decision tree of the original guideline. The LIM is based in logic paradigms, embracing Java and Prolog as main constructing languages. The guideline interpreter is developed in Prolog language, to follow the conjuncture of the required logic and to better support the implementation of Extended Logic Programming. The link between the User Input Parsing and the guideline interpreter is done in Java, it supports the Prolog connection and the connection to the interfaces, adding the fact that nearly every computer can execute it (Wielemaker, Costa 2011).

Unlike temperature or blood pressure, some symptoms are difficult to measure and can only be described through subjective values, like pain. These measures are vague and

previous ones, providing an oriented graph, were the user can clearly see what was the path of the procedure and the selection that he has made.

The User Input Parsing (UIP) consists in a flowchart-like interface that has the ability of receiving various types user input and parses them in order to deliver them to the LIM (Figure 3). The interface of the system has three steps. The initial board, where the physician can see the user medical chart and general information, when he activates the Digital Clinical Guideline, a triage-like questionnaire form will be suggested for him/her to fill in, so the system can more easily select the appropriate guideline, or it can be done manually.

From there on the physician access a visual representation of the steps and actions taken, as also the data he input in the forms. This flowchart shows a time-frame of all the diagnostic processes that have been done so far and the future options that the physician has (Marcus et al. 2000) (Guyatt et al. 2000).

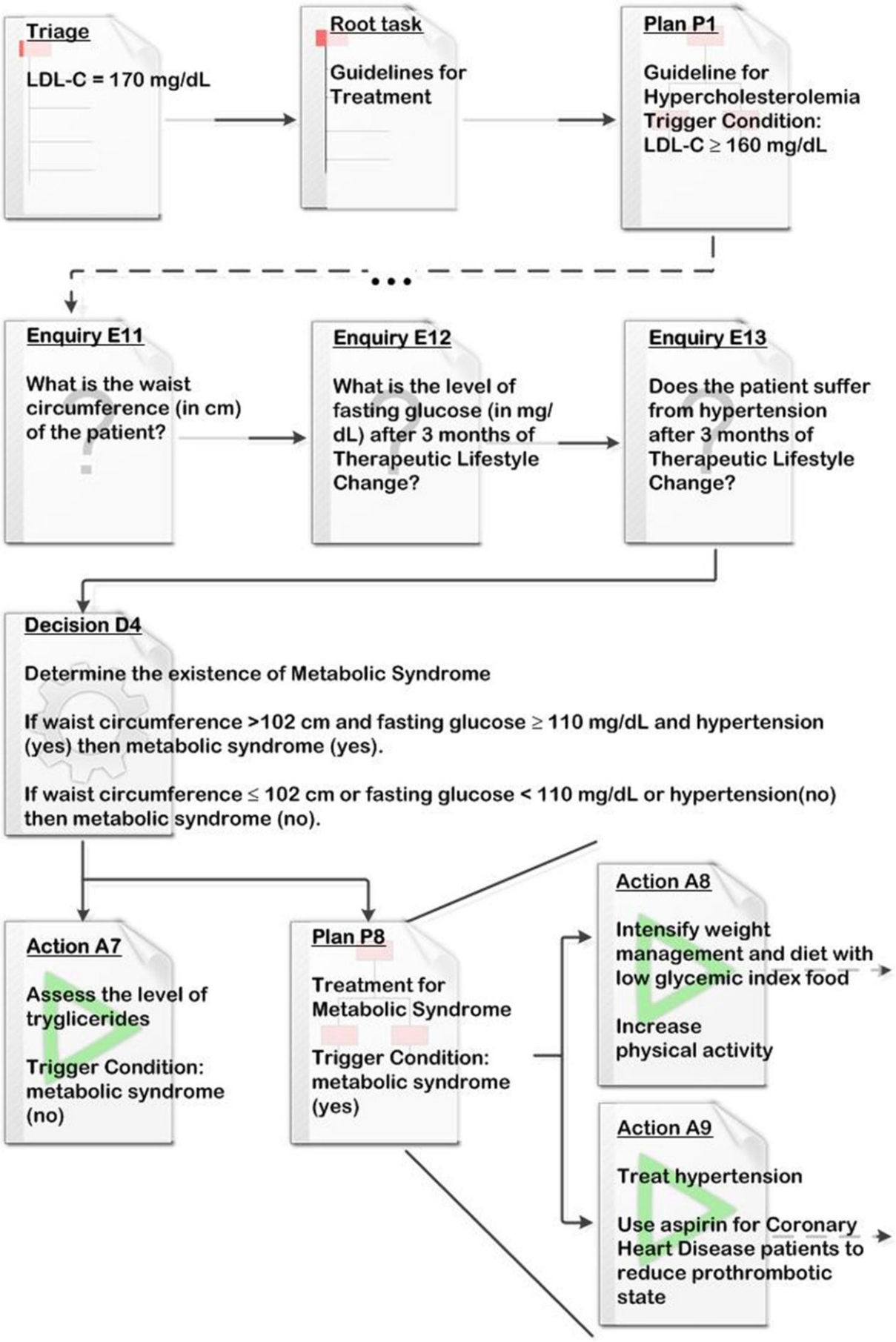


Figure 4: Representation of the detection of Metabolic Syndrome, a fragment from the ATPIII guideline for Hypercholesterolemia

KNOWLEDGE REPRESENTATION

Our model provides the means of dealing with incomplete information. The common problem is when a diagnosis is made and, because of insufficient data input or uncertain values, the output of the system has a weak confidence value or even provides no results. To deal with this situation an implementation of Quality of Information (Novais et al. 2010) was made to this project to provide a strong result and to manage the input provided by the user.

Knowledge representation is denoted by using Logic Programming, with a sense of strong negation. Extended Logic Programming (ELP) (Analide et al. 2006) uses classic negation as an explicit way of representing negative information, which is useful when the available information about a predicate p is incomplete and its absence does not necessarily mean its falsity. An Extended Logic Program is a finite collection of rules of the form:

$q \leftarrow p_1 \wedge p_m \wedge \text{not } p_m{+}1 \wedge \ldots \wedge \text{not } p_{m+n}$ (1)
$? \; p_1 \wedge p_m \wedge \text{not } p_{m+1} \wedge \ldots \wedge \text{not } p_{m+n}$ (2)

where ? is a domain atom that denotes falsity and p and q are literals. In ELP, default negation, not A (where A is a literal), represents an extension to literal A, while if it is classic negation, ¬ A and A are just simple literals.

ELP programs are associated with abducible sets, which represent hypotheses for possible solutions to queries. These abducible sets are represented as exceptions to the extension of the predicates and provide a way of dealing with incomplete information. Thus it is introduced a new way of classifying information, adding unknown as a viable classification, besides true and false.

This is very useful to cases where empirical data is collected from the patient. For instance, pain is, at least, a very relative value and is almost impossible to measure with accuracy a specific value; it depends from person to person and their tolerance to pain. The fact is that the confidence that this field implies is very weak, but in some cases the only method available to classify a symptom, so Quality of Information process works to supplant the missing values, so the guideline can continue to be executed with a strong value of confidence even if a required field has dubious values.

CASE STUDY

The system starts with a triage process that consists of a set of general questions whose objective is to make an initial assessment of the health of the patient. One of those questions is about the level of Low Density Lipoprotein Cholesterol (LDL-C) of the patient. The result from this triage process shows that the patient has elevated LDL-C (about 170 mg/dL). Then, the system searches the treatment Root task for a Plan that has this Trigger Conditions. If a Plan has this Trigger Condition, its execution is suggested to the user. The Plan P1 is the one considered most suitable and is specialized in the treatment of Hypercholesterolemia.

Hypercholesterolemia is a metabolic derangement characterized by the presence of high levels of cholesterol in the blood. Elevated cholesterol in the blood is due to abnormalities in the levels of lipoproteins, the carriers of cholesterol in the bloodstream. There are three major types of lipoproteins: Low Density Lipoprotein (LDL), High Density Lipoprotein (HDL) and Very Low Density Lipoprotein (VLDL). The detection of high cholesterol is done by measuring de levels of LDL Cholesterol (LDL-C), or bad cholesterol, in the bloodstream, since this is the lipoprotein responsible for the formation of atherosclerotic plaques. Atherosclerosis may cause Coronary Heart Disease (CHD), which is the leading cause of death in many developed countries, such as the United States (National Heart, Lung and Blood Institute 2001).

Figure 4 is a fragment from ATPIII Hypercholesterolemia guideline. The fragment refers to the detection of Metabolic Syndrome, a combination of metabolic disorders that when occurring together increase the risk of cardiovascular disease. This detection is done after the patient undergoes Therapy Lifestyle Change, which includes a low fat diet, weight management and physical activity, in order to reduce LDL-C levels (National Heart, Lung and Blood Institute 2001).

The detection of Metabolic Syndrome starts with three consecutive Enquiries: E11, E12 and E13. These Enquiries are data entry points in the execution of the guideline, for the metabolic disorders that feature Metabolic Syndrome. Enquiry E11 has the purpose of obtaining the value for the waist circumference of the patient, in order to detect if he suffers from obesity. Central adiposity is a key feature of the syndrome. The following Enquiry, E12, has the aim of discovering if the patient suffers from hypertension. The last Enquiry, E13, refers to the level of fasting glucose in the bloodstream.

The next task is Decision D4, where the objective is to determine if the patient suffers or not from Metabolic Syndrome, these being the two possible options. If the patient has a waist circumference superior to 102 cm, combined with a level of fasting glucose superior to 110 mg/dL and hypertension, then the patient has Metabolic Syndrome. In this case the workflow is redirected to Plan P8, the Treatment of Metabolic Syndrome, since it is the task that has a Trigger Condition that meets the conclusion of Decision D4. Plan P8 includes Actions A8 and A9 that should be executed simultaneously. Action A8 states that the patient must undergo weight management and diet, combined with increased physical activity. Action A9 states that hypertension must be treated and the patient should use aspirin to reduce prothrombotic state, when suffering from CHD. However, if the patient does not have one of the symptoms that are essential to the diagnosis of Metabolic Syndrome, he does not have this health condition and the workflow is redirected to Action A7 that recommends the assessment of the level of triglycerides.

CONCLUSION AND FUTURE WORK

There is a growing need in healthcare to offer support in decision making processes, because the knowledge used in it, namely in diagnosis situations, can often be incoherent, incomplete and subject to error which brings out the

necessity of modeling a set of tools that enable the manipulation of this knowledge. PLE can be a valuable asset in the solution of this issue. The Quality of Information methodology enables the achievement of a measure of how this information is reliable.

The work so far focused on the organizational aspects of a medical procedure and tried to model it in an intuitive way, through classes of tasks that humans use in their everyday activities, so that it would feel as natural as possible to practitioners. This approach was developed keeping in mind integration with a logic based decision model described above. Future work includes improving the issue of uncertain information and Quality of Information.

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