SEMPATH: Semantic Adaptive and Personalized Clinical Pathways

Dimitrios Alexandrou, Fotis Xenikoudakis, Gregoris Mentzas

Information Management Unit,
Electrical and Computer Engineering, National Technical University of Athens,
Athens, Greece
dalexan@mail.ntua.gr, fxeni@image.ece.ntua.gr, gmentzas@mail.ntua.gr

Abstract - As scientific achievements in the area of Healthcare have increased during the last decade, inevitably there has been an increase of treatment quality. One of the challenges to be confronted is the personalization of treatment. The personalization requires the continuous reconfiguration of the treatment schemes since the clinical status of each patient and circumstances inside a healthcare organization constantly change. In this paper we present a prototype that provides an IT solution concerning the real-time adaptation of healthcare processes. The software comprises a healthcare process execution engine assisted by a semantic info-structure for reconfiguring the pathways. The semantic info-structure utilizes an ontology enclosing the required knowledge and a semantic rule-set. During the execution of clinical pathways, the system reasons over the rules, the knowledge and information, and reconfigures the next steps of the treatment. The results of the rule-set execution may generate knowledge objects to be inserted in the ontology.

Keywords: adaptive clinical pathways; semantics; semantic rule-set; adaptive treatment; personalized treatment; pathway dynamic reconfiguration;

I. INTRODUCTION

The treatment quality consists one of the main research and business challenges of the modern healthcare organizations. The utilization of standardized clinical protocols in many diseases is their major means of succeeding their objective. Each clinical protocol comprises detailed medical plans for diagnosis, therapy scheme and follow-up. Additionally, it contains all the required scientific information in order to confront any undesired deviations, which occur during the treatment execution and require prompt and effective reconfigurations of the treatment of a patient, thus increasing the flexibility of the treatment process. Clinical Pathways constitute a valuable tool to achieve the above-mentioned objectives.

Clinical pathways constitute the means for the implementation of medical guidelines in a specific healthcare environment and decrease undesired variations of medical practice [5]. In contradiction with medical guidelines, clinical pathways contain multidisciplinary resources and materials, like personnel, education level, medical equipment availability and other operational and administrative information. Medical guidelines require the consensus between medical doctors. However, clinical pathways require a consensus between multidisciplinary groups of hospital personnel taking actions during the treatment execution. Clinical pathways constitute treatment process patterns which aim to increase both the healthcare process quality and utilization of resources. Consequently, a clinical pathway may deviate from a clinical guideline due to administrative reasons, and a treatment scheme may deviate from the clinical pathway due to patient’s symptoms during its execution.

In order to effectively support the execution of treatment schemes based on clinical pathways and to relieve the medical personnel a software system is required so as to handle the healthcare business processes efficiently [8]. Such a system would be responsible for the constant monitoring of the execution and the current status of the applied clinical pathway, automatically recognize any exceptional events and provide decision support services in order to handle the exceptions / deviations [9], [10], [19] in an efficient and effective way. Moreover, the software system should be capable of dynamically adapting the treatment process so as to control the appropriate reconfigurations.

In this paper we propose an approach that includes a workflow management engine combined with a rule base in order to handle the abovementioned requirements. The workflow environment handles the execution of treatment schemes and the incorporation of user types, data and peripheral applications. Additionally, the implemented software prototype supports the dynamic adaptation of clinical pathways in order to handle the flexibility of treatment schemes [7], [13]. The rule base is responsible for the handling of the required streams of knowledge enclosed in the
clinical pathways and is utilized for the detection of exceptional events and their confrontation.

In this paper we present our software prototype, SEMPATH, which follows this approach and has all the required functionality to support adaptive clinical pathways. SEMPATH performs a rule-based exception detection with semantic rules [17] and dynamic clinical pathway adaptation during the execution time of each pathway.

The rest of the paper is organized as follows. Section 2 refers to our motivations and related work performed in the area of our interest. Section 3 overviews the SEMPATH technical architecture which is implemented accompanied with a system walkthrough. Finally, section 4 concludes the paper combined with our thoughts for future work.

II. MOTIVATIONS AND RELATED WORK

At this section we present the motivations, the related work and our contribution in the area of the adaptive clinical pathways. The motivations presented led to the research stream of adaptive clinical pathways. Moreover, a significant amount of work has been realized towards the direction of the optimal handling of the exceptions occurring during the execution of treatment schemes of a patient. Finally, our research in the area and the development of SEMPATH prototype tries to contribute in specific and focused issues.

A. Motivations

The trends in healthcare business processes and their establishment and utilization in the healthcare routine are up to now quite mature. Nevertheless, there are several open issues / challenges that further motivate our effort [16]:

- **Clinical Pathways Adaptability:** The traditional clinical pathways are normally static and lack of dynamicty. Moreover, they are standard procedures applicable to a patient taxonomy not addressing the case of each patient. Moreover, they do not take under consideration the most current medical, operational, and financial knowledge [6].

- **Maintenance:** The implementation of Clinical Pathways is based on medical guidelines and additional types of knowledge. The maintenance of the healthcare business process suffers from the continuous update, since both the medical guidelines and the circumstances inside a healthcare organization change constantly.

- **Medical Guidelines Formalization:** The formalization of medical guidelines is being performed in a specific and per case manner. Their formalization is required since their parameters will be able to be processed by an IT infrastructure that supports their execution.

- **Clinical Pathways Modeling:** The modeling of Clinical Pathways lacks a formal structure. Different approaches exist in the area of modeling. Their interoperation could be of major importance since the Clinical Pathway exchange between healthcare organizations could facilitate the execution of the treatment schemes utilized.

- **Real-time information capturing:** Information capturing consists one of the major factors for success of the treatment scheme executed for each patient. The lack of real-time information feed to the clinical pathway creates a major need, since the information collected could lead to major reconfigurations of the executed Clinical Pathway.

- **Real-time knowledge recycling:** The knowledge recycling during the execution of a Clinical Pathway constitutes one of the major challenges for the area. The knowledge feedback would be valuable since the knowledge update is able to redefine the Clinical Pathway and the model of the exception rules.

B. Related Work

As [12] states, “healthcare processes require interdisciplinary cooperation and coordination”. Towards this direction, he divides the processes inside a healthcare organization into two categories: the organizational processes and the medical treatment processes. The organizational processes are of equal importance to the medical treatment ones, since they heavily affect their execution and effectiveness. Moreover, the medical treatment processes are influenced by the medical knowledge and the patient information. So, he introduces the need for WfMS (Workflow Management System) inside a healthcare organization so as to handle the intra-organizational processes. Moreover, the addition of the appropriate web-services could lead to the inter-organizational healthcare processes. The abovementioned concerns led to the implementation of ADEPT system [15] which focuses on the healthcare processes execution. The ADEPT system enables the execution, monitoring and management of the healthcare process running inside a healthcare organization. Moreover, it offers the functionality of dynamic changes in the predefined healthcare processes on execution time. The development of the specific system lasted for some years and provided valuable information and experience from its pilot and productive periods [11], [4].

Additionally, [6], [2], [3] introduces the term of adaptive clinical pathways and presents the research
work performed inside Agfa Healthcare. He stresses out that Adaptive Clinical Workflows are based on a) Medical, b) Practice, c) Clinical and d) Operational Knowledge. Agfa constitutes one of the active members of W3C Semantic Web Health Care and Life Sciences Interest Group [20] which encloses the “Adaptive Healthcare Protocols and Pathways Task Force” which aims at the utilization of semantic web technologies in order to enhance the adaptable clinical protocols and pathways.

[1] introduce another IT platform that enables the adaptability of clinical pathways based on a semantic framework. CAREPLAN system [1] tries to combine heterogeneous healthcare knowledge sources with the available patient information. The system reasons over the knowledge and adapts standard pathways towards personalized healthcare plans, utilizing the technology of web-services for the composition of the integrated pathways.

C. Our Contribution

Our approach led to the creation of the SEMPATH software system which enables the adaptation of clinical pathways in order to serve the personalization of the treatment plans for each patient. Our contribution concerning the state-of-the-art in the specific domain could be summarized in the following axes:

- **Real-time adaptation of clinical pathways:** SEMPATH approach is based on continuous reasoning over the current knowledge so as to adapt each step of the clinical pathway under execution.
- **SWRL Rule Base:** SEMPATH encloses a rule-set created by utilizing SWRL [17] language in order to integrate the rule-base with the ontology. The rule-base is able to create new facts and update the ontology accordingly, thus creating new knowledge as each pathway evolves. This feedback constantly updates the knowledge stored in the ontology and leads to better results concerning the adaptation of the pathway.
- **Establishment of a repository of clinical actions:** SEMPATH contains an indicative set of actions and clinical steps, semantically annotated, which are further utilized by implemented the info-structure for the formation of Clinical Pathways.

III. SEMPATH Prototype

The following sections present the technical architecture of the software system prototype that executes the clinical pathways and performs the required dynamic adaptation. Furthermore, a system walkthrough is provided accompanied by an indicative system screenshot.

A. Technical Architecture

The technical architecture of the implemented prototype is presented in Figure 1. The Adaptive Clinical Pathway Prototype technical architecture comprises three (3) major components. These three major components are described in full detail in the following sections:

- **a. Semantic Info-structure:** The core of Semantic Info-structure component is the Clinical Pathway Ontology. As depicted in the following diagram, the ontology is implemented in OWL [14] format. The ontology encloses the abovementioned streams of knowledge to be utilized for (1) the creation of rules, (2) the modeling of Clinical Pathways and (3) the recycling of knowledge through the dynamic production of facts by the rule engine. Moreover, it is utilized for the patient instantiation and storage during the treatment (Clinical Pathway execution).

The Protégé API has been utilized concerning the implementation and maintenance of the specific ontology. Additionally, the SWRL a Protégé Plug-in [18] is used as the designer of the semantic rules so as to ensure the smooth integration between the Ontology and SWRL rules. Consequently, each rule created by the specific plug-in is consistent in semantic terms, since the semantics required originate directly from the ontology.

- **b. Rule Execution Environment:** This component handles the maintenance of the semantic rules as well as the Rule Engine implemented. The SWRL rules implemented with the Protégé Plug-in are stored as a SWRL repository. Once the system is triggered, the appropriate rules are selected. The SWRL rules are initially converted into JESS rules in order to be executed by the rule engine. Once the semantic rules are executed, the result of the rule engine is produced in XML format.

The specific XML file is a custom structure which is utilized by the prototype so as to proceed to the adaptation of the clinical pathway.

Moreover, once the rule set is executed, despite the production of the XML result, a feedback message is generated which contains new facts and conclusions that update accordingly the knowledge stored inside the ontology.
c. Clinical Pathway Execution Environment: Finally, the last technical component of the prototype architecture is the Execution Environment. The core of the specific component is the workflow execution engine which in our case is JBP\textsuperscript{M} workflow environment. The interface between the workflow engine and the rest of the components is the Clinical Pathway Manager. Firstly, the specific component triggers the system once an exception occurs during the execution of the pathway. The message produced is forwarded to the Rule Engine in order to run the complete rule-set for the pathway and produce the result for the adaptation. Moreover, the Clinical Pathway Manager interoperates with the Result Analyzer which is responsible for the processing of the result structure.

The developed SEMPATH Prototype Software can be found here: http://www.imu.iccs.gr/index.php?option=com_content &task=view&id=206&Itemid=90

B. SEMPATH Walkthrough

One of the main end-user interfaces of the implemented SEMPATH prototype is depicted in Figure 2. As presented, the screen is divided into two main areas. The upper area, where the Clinical Pathway execution is presented in graphical terms for each patient, and the lower one where the clinical and treatment status is presented for currently treated patients.

The software implemented support the simultaneous execution of several clinical pathways, since each one comprises a discrete process with specific parameters and is instantiated separately.

In the lower section, in Figure 2, there are three (3) concurrent patients under treatment. Each patient is modeled by four (4) main categories of information:

- **States:** the specific information set contains the clinical states that the patient passes through his/her treatment scheme execution.
- **Pending Steps:** the specific parameter set holds the sequence of pending clinical pathway steps that need to be executed until the system needs to reason over the new clinical status of the patient. The specific part of the Clinical Pathway that can be executed without the decision of the implemented info-structure comprises a Clinical Pathway step.
- **Finished Steps:** the specific elements holds the complete list of the already executed steps, accompanied with their detailed date of execution, their results, and the corresponding instance of the patient’s clinical status.
Diagnosis List: each patient is accompanied by a list of possible diagnoses as the execution of Clinical Pathway evolves and more medical information is gathered by the SEMPATH info-structure.

The upper part of the interface presents the executed Clinical Pathway for the same set of patients. As presented, all the patients have been finally cured by the execution of the proper and personalized Clinical Pathway for each case. The execution of a Clinical Pathway in the above-presented cases encountered a set of exceptions that required “adaptation” and personalized handling in order to avoid the appeared deviation and return to the desired clinical status and further proceed with the treatment scheme execution.

IV. CONCLUSIONS AND FUTURE WORK

SEMPATH prototype software comprises a set of multidisciplinary technologies aiming at providing personalized healthcare treatment. The execution of the healthcare business processes is performed by utilizing a workflow infrastructure as the backbone of the system. The adaptation of Clinical Pathways is performed by the establishment of a semantic info-structure the core of which is the SEMPATH Ontology. SEMPATH Ontology is further utilized for the creation of a rule-set of SWRL rules. The integration of the SWRL rules with an expert system leads to the reasoning over the knowledge stored in SEMPATH architecture. The continuous reasoning provides feedback to the system through the production of new facts of knowledge which is stored inside SEMPATH Ontology. Thus, the execution of Clinical
Pathways for each patient is totally personalized and based on his/her clinical status and reaction to the treatment scheme offered to him/her.

Our intentions for further work can be presented in a four-fold structure:

- **Semantics Infrastructure**: our main aim concerning the evolution of SEMPATH semantics infrastructure is to proceed with the ontology enhancement. The enhancement will focus on organizational issues modeling and medical knowledge representation. Furthermore, our intention is to integrate existing medical ontologies.

- **Pathway Modeling**: in the field of pathway modeling we plan to concentrate on simultaneous execution activities management and on providing different views of the pathway for each type of user. Moreover, our intention is to add semantic information in activities that will establish a priority weight model in order to perform more intelligent resource and activity management.

- **SWRL Rules graphical notation scheme and graphical editor**: the main task of maintenance of SEMPATH infrastructure is the rule production over SWRL. Since it will be implemented as a Protégé plug-in.

- **System evaluation and usability**: since the SEMPATH prototype is finalized and functional, we intend to perform real-life stress tests concerning its performance inside a healthcare organization. A real-life test will provide valuable results concerning the usability of the system, the performance and further enhancement of the implemented ontology and the further enhancement of the semantic rule-set.

V. ACKNOWLEDGEMENTS

This work has been partially funded by the European Commission with an ICT contract RIDE Project.

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