ADAPTIVE CLINICAL PATHWAYS WITH SEMANTIC WEB RULES

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Abstract: The increase of treatment quality offered by the healthcare organizations is one of the main challenges of the modern health informatics. The personalization of treatment presupposes the real-time adaptation of treatment schemes since the clinical status of the patient and circumstances inside a healthcare organization constantly change. In this paper we present SEMPATH prototype which aims at providing a solution concerning the real-time adaptation of healthcare business processes. The prototype consists of a healthcare process execution engine assisted by a semantic framework for the adaptation. The semantic framework consists of an ontology enclosing the required knowledge based on which a semantic rule set was created. During the execution time of the clinical pathways, the system reasons over the rules, the knowledge and information collected, and provides decisions and recommendations for the next steps of the treatment. Moreover, the results of the rule-set execution may produce new knowledge objects which are inserted in the ontology.

1 INTRODUCTION

One of the main challenges of modern healthcare organizations is to increase the treatment quality. In order to achieve their goal, they need to utilize standardized clinical protocols used in many domains of medicine. Such a protocol contains detailed medical plans for diagnosis, therapy scheme and follow-up. Moreover, it encloses the information required so as to deal with exceptional situations, which occur during the treatment execution time and require quick and appropriate modifications of the treatment of a patient, thus increasing the flexibility of the treatment processes. One valuable tool to achieve the above-mentioned objectives is "Clinical Pathways".

Clinical pathways can be utilized for the implementation of medical guidelines in a specific healthcare environment and decrease undesired variability of medical practice (Campbell et al., 1998). In contradiction with the medical guidelines, clinical pathways enclose multidisciplinary valuable resources like personnel, education level, medical equipment availability and other operational and administrative information. Medical guidelines require the consensus between medical experts. On the other hand, 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 the 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 support the execution of treatment schemes based on clinical pathywas and to relief the medical personnel, a software system is required which will handle the healthcare business processes in an efficient manner (Greiner et al., 2004). Such a system would be responsible for the observation of the execution and the current status of the apllied clinical pathways, offer the characteristic of automatic recognition of exceptional events and provide decision support services in order to handle the exceptions in an efficient and effective way. Moreover, the software system should be capable to dynamically adapt the treatment process so as to control the appropriate modifications.

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In this paper we propose an approach which includes a workflow management system 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 specific software system needs to support the dynamic adaptation of clinical pathways in order to handle the flexibility of treatment schemes (Dadam et al., 2000), (Miksch et al., 2001). 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 (SWRL) and dynamic clinical pathway adaptation during the execution time of each pathway.

The rest of the paper is organised as follows. Section 2 refers to our motivations and related work performed in the area of our interest. Section 3 overviews the proposed Semantic Approach the SEMPATH follows, while Section 4 outlines the SEMPATH conceptual framework and technical architecture which is being implemented. In section 5 we present our experimental scenario and the SEMPATH walkthrough. Finally, section 6 concludes the paper combined with our thoughts for future work.

2 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.

2.1 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 (Song et al., 2006):

- **Clinical Pathways Adaptability:** The traditional clinical pathways are normally static and lack of dynamicity. 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 (Colaert, 2007).
- **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 Modelling:** The modelling of Clinical Pathways lacks a formal structure. Different approaches exist in the area of modelling. 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.

2.2 Related Work – State of the Art

As (Lenz et al., 2006) 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 (Reichert et al., 2003) 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 (Lenz et al., 2007), (Blaser et al., 2007).

Additionally, (Colaert, D., 2007) 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 (W3C) 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.

(Abidi and Chen, 2006) introduce another IT platform that enables the adaptivity of clinical pathways based on a semantic framework. CAREPLAN system (Abidi and Chen, 2006) 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.

2.3 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 (SWRL) 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 meta-model for each clinical pathway:** in our approach, we define a meta-model for each clinical pathway to be executed. The meta-model encloses atomic and complex sub-pathways which are fed to the process execution engine. The integration of discrete parts and connections results to the establishment of the meta-model of the pathway to be executed.

3 THE SEMPATH APPROACH

The SEMPATH approach followed during the implementation of the software prototype includes the design and creation of the Adaptive Clinical Pathway Ontology. The created ontology is utilized for the implementation of the semantic web rules. The implemented rules are inserted into the JESS System to comprise the rule-base in order to be executed and extract the appropriate facts that influence the adaptation of the clinical pathways.

3.1 Adaptive Clinical Pathway Ontology

The Adaptive Clinical Pathway Ontology constitutes the main infostructure of the semantic layer of the implemented architecture. The core of the ontology is based on the ACPP Ontology (ACPP Ontology) that is implemented by ACPP Task Force (ACPP Task Force).

The core of the ontology was further extended and broadened both in subdomains and existing concepts and instances. The specific ontology is divided into four (4) main knowledge streams.

The main stream refers to the representation of the medical knowledge. It contains the semantics utilized for the description and structure of the medical part of the clinical pathway. The specific concepts describe the medical domain knowledge that semantically enhances each clinical pathway.

Moreover, the second stream of the ontology comprises the operational knowledge structure. It contains the concepts utilized for the description of the operational issues that arise during the execution of the clinical pathway and may affect its evolvement. Each healthcare organization encloses specific procedures and resources which are combined in order to offer its services. Consequently, the operational knowledge is one of the main elements of a clinical pathway since it affects its execution and success.

Additionally, the third knowledge stream refers to the concepts and terms that define the financial issues that affect the execution of a clinical pathway. The utilization of a clinical pathway aims at the optimization of the financial resources required for the treatment path of a patient. Each healthcare organization aims at both the reduction of its costs and the increment of the quality of healthcare services provided. Consequently, the financial part of the ontology models the financial resources and rules utilized during the execution of each clinical pathway.

Finally, the fourth knowledge stream refers to the modelling of the clinical pathway itself. It contains the concepts and terms that describe the building blocks of the clinical pathway. It is utilized by the software prototype for the design of the treatment workflow.

SEMPATH Ontology is available online at: http://www.imu.iccs.gr/index.php?option=com_content&task=view&id=206&Itemid=90/sempath_onto.zip.

3.2 SWRL Rules Modelling

The rules implemented for our prototype refer to the execution of a clinical pathway, and more specifically to the exception handling procedure. The exception management procedure constitutes one of the every-day routine of healthcare professionals (Kobayashi et al, 2005), (Tucker et al, 2002). As (Han et al., 2006) states, "a*n exception, constitutes an abnormal behaviour from the normal workflow*". The handling of exceptions occurring during the execution of a clinical pathway encloses three major issues: a) exception management representation, b) implementation and execution of exception management and c) exception analysis.

Concerning SEMPATH prototype, the rules for exception management are designed in SWRL format. SWRL enables the integration of the modelled rules with the Clinical Pathway Ontology. The interaction between rules and ontology leads to new knowledge. An indicative set of implemented rules for the SEMPATH prototype is presented below:

Rule-1:

TriageAdmission(?t) ∧
DiagnosedNeurologicalDeficit(?s) ∧
hasTask(?a, ?t) ∧
hasPatient(?a, ?p) ∧
hasPatientState(?p, ?s) ∧
EvaluationForThrombolysisEligibility(?t2)
→ hasNextTask(?a, ?t2)

Rule-1 describes the following situation: if the patient is admitted in the healthcare organization and there is a diagnosis of Neurological Deficit, then the patient has to be evaluated for Thrombolysis eligibility.

Rule-2:

EvaluationForThrombolysisEligibility(?t) ∧
ThrombolysisCandidate(?s) ∧
hasTask(?a, ?t) ∧
hasPatient(?a, ?p) ∧
hasPatientState(?p, ?s) ∧
ConfirmationOfAcuteStroke(?t2)
→ hasNextTask(?a, ?t2)

Rule-2 describes the following situation: if the Evaluation for Thrombolysis Eligibility is confirmed and the patient is Thrombolysis Candidate, then the next examination has to confirm or not the Acute Stroke episode.

Rule-3:

EvaluationForThrombolysisEligibility(?t) ∧

AcuteCVA(?s) ∧
hasTask(?a, ?t) ∧
hasPatient(?a, ?p) ∧
hasPatientState(?p, ?s) ∧
EmergentHeadCT(?t2) ∧
CBC-PT-PTT_stat(?t3)
→ hasNextTask(?a, ?t2) ∧
hasNextTask(?a, ?t3)

Rule-3 describes the following situation: if the Evaluation for Thrombolysis Eligibility is confirmed and the patient's state is Acute CVA, then the patient has to be forwarded to the CT department for Emergent CT and for CBC-PT-PTT examination.

The above-mentioned and explained SWRL rules are indicative elements from rule-base which is utilized by the SEMPATH infostructure. As seen above, the rules contain classes from the ontology, both in the antecedent and the consequent parts of the rules. Any new facts deriving from the rules execution are being added in the ontology as new knowledge objects for future utilization.

3.3 Adaptation Methodology

SEMPATH adaptation methodology is based on a meta-model clinical pathway establishment. Each clinical pathway to be executed is a meta-model of a set of atomic and complex sub-processes. The atomic processes are executable parts of the healthcare business process forwarded to the execution engine. The complex processes are sub-workflows which contain atomic processes and a set of decisions. The atomic and the complex processes are interconnected in the meta-model level. Their connections are based on SWRL rules. Once an atomic or complex process is executed, the rule-base is triggered. The knowledge existing inside the ontology, the current clinical status of the patient and the rule-set are interoperating in order to select the next executable part of the clinical pathway. Thus, the adaptation occurs during each step of the pathway execution.

During each cycle of execution, the triggering of the rule-base may result to new knowledge creation that will be utilized in next steps during the execution. This fact ensures the constant update of medical, organizational and operational knowledge stored inside the ontology and consequently to the rule-base.

4 SEMPATH PROTOTYPE

The following sections present the conceptual framework and technical architecture of the software system prototype that executes the clinical pathways and performs the required dynamic adaptation.

4.1 Conceptual Framework

As depicted in Figure 1, the conceptual framework of the SEMPATH system comprises three (3) distinct architectural layers. The upper layer of the architecture is called "Semantic Layer" since it encloses the required semantic infrastructure.

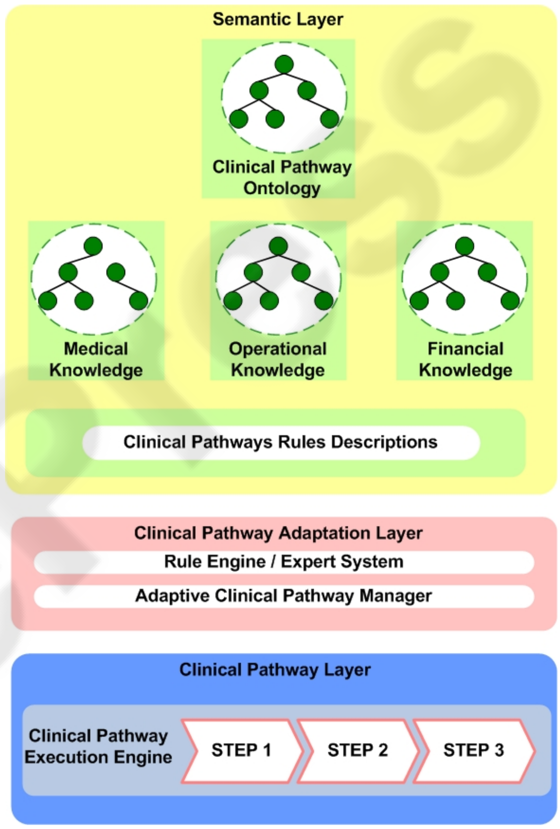

Figure 1: Conceptual Framework.

The core of Semantic Layer is the Adaptive Clinical Pathway Ontology which encloses the appropriate knowledge streams required for the modeling of the clinical pathways, in terms of structure and content. Moreover, the specific layer encloses the semantic modeling of the rules that handle the exceptions inside the clinical pathway during its execution. These rules are the cornerstone of the dynamic adaptation performed in the clinical pathways.

The second layer constitutes the “Clinical Pathway Adaptation Layer”. The specific layer encloses the components required for the adaptation of the clinical pathway. The rule engine is responsible for the execution of the semantic rules concerning the exception handling of the pathway. Once the result is produced the “Adaptive Clinical Pathway” manager is the software module that updates accordingly the structure of the pathway.

Finally, the last layer of our conceptual framework is the “Clinical Pathway Layer”. It contains the workflow – part of the clinical pathway. The execution of the clinical pathway happens inside a workflow engine since is constitutes a healthcare business process (Lenz, 2006). A clinical pathway repository contains a set of available clinical pathways so as to select the most appropriate for each patient.

4.2 Technical Architecture

The technical architecture of the implemented prototype is presented in Figure 2. 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 Infostructure: The core of Semantic Infostructure component is the Clinical Pathway Ontology. As depicted in the following diagram, the ontology is implemented in OWL (OWL) format. The ontology encloses the abovementioned streams of knowledge to be utilized for (1) the creation of rules, (2) the modelling of Clinical Pathways and (3) the recycling of knowledge through the dynamic production of facts by the rule engine.

The Protégé API has been utilized concerning the implementation and maintenance of the specific ontology. Moreover, the SWRL designer of the semantic rules is a Protégé Plugin (SWRLTab) which enhances the integration between the Ontology and SWRL rules. Consequently, each rule created by the specific plugin is consistent in semantic terms, since the semantics required come 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 Plugin are stored as a SWRL repository. Once the system is triggered, the appropriate rule set is 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.

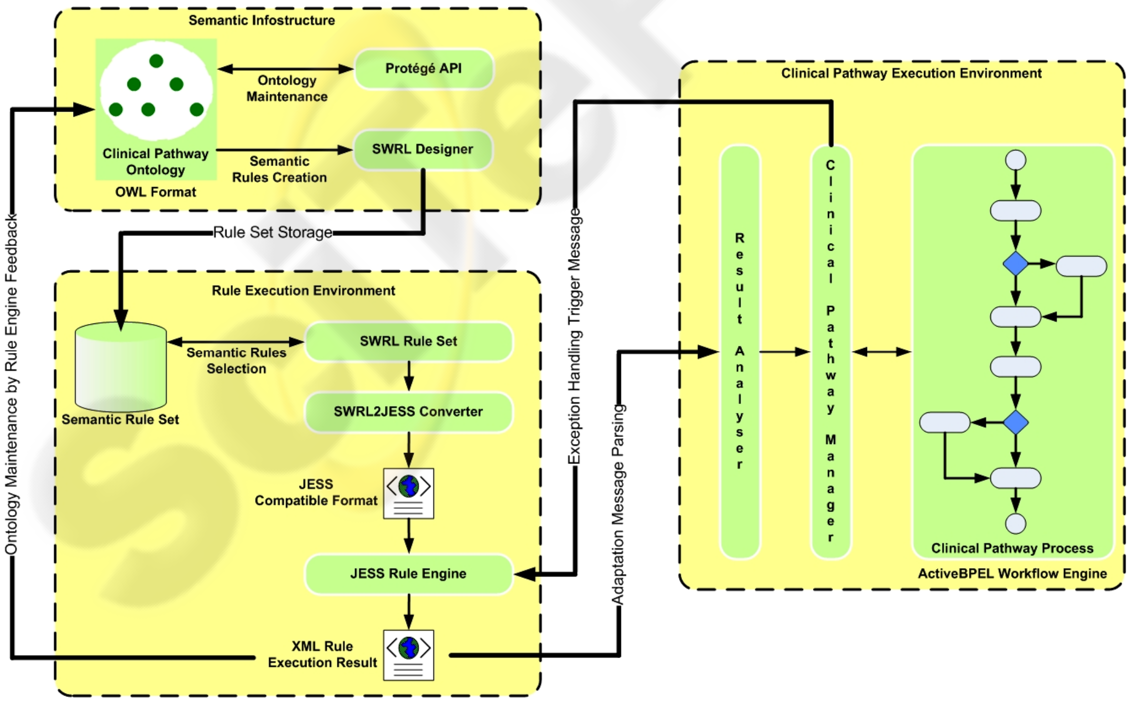

Figure 2: Technical Architecture.

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 ActiveBPEL 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 Analyser which is responsible for the processing of the result structure.

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

4.3 Experimental Scenario

According to the real-life scenario, a patient confronts a health problem and decides to be admitted to a healthcare organization for treatment. Once the admission is performed, an initial set of medical examinations is decided to be performed. The result set of the initial examinations provides valuable information for the clinical status of the patient which leads to the decision concerning the selection of the appropriate clinical pathway to be executed. The execution of the treatment scheme produces exceptions which are handled on real-time basis by the implemented software prototype.

More specifically, once the patient is admitted to the healthcare organization, its IT infrastructure should become aware of the data accompanying the specific patient. So, an initial data entry for the medical record dataset is performed. This procedure is performed either manually or automatically if the patient's medical record is received from another healthcare organization.

Once the clinical status of the patient is set, SEMPATH proposes an initial set of examinations to be performed. Afterwards, the result set of the test is inserted into the medical record of the patient. The system proposes an appropriate clinical pathway according to the diagnosis. So, the execution of the treatment scheme begins, under the constant inspection of SEMPATH prototype. Once an exception occurs, SEMPATH receives the exception information, executes the required rule-set and proposes the next "step" of the treatment scheme. The "step" derives from the following two categories:

- **Atomic process:** a single step procedure, executable by the process execution engine.
- **Complex process:** a multiple step procedure. It is a set of atomic processes without decision making. A complex process may contain parallel execution paths leading to a unified result.

The above-mentioned procedure is repeated during the execution of the treatment scheme of the patient. This way, the personalization of treatment for each patient is highly ensured, increasing the possibilities for the most suitable treatment.

After the implementation of the SEMPATH prototype, we are now in close cooperation with a University Hospital (LAIKO Hospital). We have modelled five (5) clinical pathways, defined the corresponding rules and we are in the process of real-life scenario execution.

5 CONCLUSIONS & FUTURE WORK

The existing practices and work performed in the area of clinical pathways has led to significant results. Nevertheless, clinical pathways are static procedures based on medical guidelines and organizational and operational knowledge. The current trend focuses on the adaptation of these static structures in case of exception occurrence.

The introduction of semantic technology provides further opportunities for clinical pathway adaptation. Semantics enable the representation of all required types of knowledge by the utilization of the corresponding ontologies. A significant amount of work has been done in the area of ontology creation. The developed ontologies cover several streams of medical knowledge.

However, this knowledge has to be combined with rules in order to handle the pathway exceptions. In this paper we presented SEMPATH prototype, a software platform based on semantics. SEMPATH introduces the creation of semantic rules in SWRL format which provide the basis for the rule-engine that handles the pathway exceptions. SWRL rules were created by the utilization of the SEMPATH ontology. The execution of the semantic rules provides new knowledge objects that can be added to the existing ontology. Consequently, the knowledge enclosed in SEMPATH prototype is constantly updated and maintained by its routine operation.

Our intensions for further work can be presented in a three-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 modelling and medical knowledge representation. Furthermore, our intention is to integrate existing medical ontologies so as to enrich our ontology model.
- **Pathway Modelling:** in the field of pathway modelling 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.
- **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.

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