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Building a Semantic Model to Enhance the User's Perceived Functionality of the EHR

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Abstract. In order to facilitate and increase the usability of Electronic Health Records (EHRs) for healthcare professional's daily work, we have designed a system that enables functional and flexible EHR access, based on the execution of clinical workflows and the composition of Semantic Web Services (SWS). The backbone of this system is based on an ontology. In this paper we present the strategy that we have followed for its design, and an overview of the resulting model. The designed ontology enables to model patient-centred clinical EHR workflows, the involved sequence of tasks and its associated functionality and managed clinical data. This semantic model constitutes also the main pillar for enabling dynamic service selection in our system.

Keywords. Ontology, Electronic Health Records, Workflow, Diabetes Mellitus, Semantic Web Services

1. Introduction

Interoperable digitalized clinical information, provided by means of Electronic Health Records (EHR), is a success factor for high healthcare quality. Advances in this research field and support of institutions such as Integrating the Healthcare Enterprise (IHE[2]) have enabled the development of mechanisms that contribute to solve major challenges such as sharing clinical information between institutions with maximum syntactic, semantic and process interoperability. Besides these efforts, additional research is needed to address other challenges like the functionality perceived by the end users like physicians. Functions as intelligent data filtering to avoid information overload when accessing medical documents and the integration of the IT-related functions within a clinical workflow are necessary [1,2]. In order to address this challenge the OntoHealth[3] project provides with a service-orientated approach based on semantic technologies to access a standard-based EHR. The resulted system should support clinicians in their everyday work through the composition and execution of user defined clinical workflows.

The core of the OntoHealth architecture is based on a modular ontology. This ontology formalizes the description of workflows with related tasks, each described as a set of functions, clinical data and non-functional properties desired by the physician. It

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enables the description of the desired goals regarding the interaction with medical data within a clinical workflow. The ontology is also used for the description of Semantic Web Services (SWS), which are integrated in the OntoHealth architecture and define the related units for processing the workflow according to the user defined tasks. Suitable services can also be used to access the EHR. In this manner, our model facilitates service discovery, the selection of the best viable eHealth service and its composition. Although a number of existing works have already modelled workflows in the clinical domain [3,4], to the best of our knowledge there is no approach so far that offers an ontology to represent generic clinical workflows, targeted towards the interaction with standards-based EHRs through SWS. Our goal in this paper is to present the methodological strategy we followed to design the ontology, provide an overview of the integrated semantic models and the reasoning for the selected classes and integration of vocabularies. Although the components of our system are generic, we have studied and thus refined our architecture for the purpose of diabetes mellitus.

2. Methods

Based on well-known steps for the engineering process of ontologies [5], our approach contains the following stages and activities: (Stage 1) Specification: We defined the purpose of our model and conducted a systematic literature review, observations in the clinical setting, and interviews with domain experts to acquire the required workflow and domain knowledge. (Stage 2) Conceptualization: Conceptual design of the workflows. Vocabularies were derived and the integration of already developed models was conducted. (Stage 3) Formalization and Implementation of the ontology using an ontology representation language. (Stage 4) Evaluation: Assessment of the adequacy of the developed ontology for modelling the identified clinical workflows and the refinement of the ontology.

The initial literature review conducted within Stage 1 resulted in a preliminary model for diabetes related workflows [6]. Afterward, we conducted observations of physician-patient consultations to assess EHR tasks, executed within routine diabetes care [7]. Finally, interviews with diabetes experts were performed to validate and enrich the obtained results [2]. The resulting semantic model enables to formally describe clinical processes which integrates the required functions and information needs. In addition, non-functional requirements (e.g. quality or price) can be defined to further specify the service selection. The goal within the second step was to provide with the generic conceptualization of the workflows and the activities to be integrated. Our strategy was to integrate existing models and facilitate the alignment of our model with standards used in the domain to enhance its interoperability and extensibility for additional diseases and/or modelling requirements.

3. Results

Our model differentiates two major concepts: *workflow template* and *workflow routine*. A workflow template represents an initial guideline for a user defined EHR-workflow. It describes a generic process which includes a sequence of tasks that usually are followed by the doctor. The tasks define restrictions in terms of functionalities that can be selected and data that can be processed. The output of one task can act as the input for the following task. The user can create new workflow templates on demand. Examples of such workflow templates are: (1) new diabetes consultation (*instanceTA*), (2) follow-up routine diabetes consultation (*instanceTB*), and (3) research workflow (*instanceTC*). When the user selects a certain workflow template for a particular patient case, a related workflow routine is created from the template, describing the selected tasks as a set of goals. Hence, the workflow routine models the particular selection of tasks as goals describing the needed functionalities and data for a given patient-case. For example, if the physician wants to execute a new diabetes consultation for a patient with identification "PID_11244", the workflow template, *instanceTA,* will be used to configure a new workflow routine, *instanceRP12442*, where each task from the template is represented as a goal in the routine. For the task "obtain patient overview", a goal "obtain HbA1c values for the patient measured within the last 24 months" can be configured. This goal is related to the functionality "*retrieve data*" and the data element "HbA1c". Additional conditions like "last 24 months" add more flexibility to the goal design. The goals configured within the routine will be fulfilled by means of adequate SWS.

The following standards and vocabularies were chosen for the development of the semantic models:

IHE XDW (*IHE Cross-Enterprise Document Sharing) profile* [8]. As the IHE XDW profile is also dealing with the executions of workflows for EHR data management, our strategy was to use the XDW workflow document to inspire the organization of our model and derive properties and classes from it. Note that the concept of a workflow defined in this profile differs from the workflow definition in OntoHealth: While in the XDW profile, a workflow is referring to the collection of tasks that are associated to a complete treatment path of a patient (past results and future planned actions), we limit our definition of workflow to EHR related tasks that the physician conducts for one particular situation.

BPMN 2.0. For the observations in the clinical routine it was decided to use the Business Process Model and Notation 2.0 (BPMN) to model the observed workflows as it is an established standard for modelling business processes. From BPMN 2.0, we extracted the requirements and the structure of such workflows and abstracted generic templates for different clinical situations, e.g. follow up routine examination. These templates gather general activities conducted by the physician for different situations and correspond to the named *workflow templates* in our model. We decided to include BPMN 2.0 as an ontology in order to add the flexibility of semantic technologies in the process models. In order to re-use existing vocabularies, it was decided to include a subset of the BPMN 2.0 ontology [9] for this purpose.

MSM (Minimal Service Model) [10,11]. Each of the goals within a *workflow routine* is executed using the most suitable SWS available in terms of functional and non-functional requirements. The decisions are made based on matching-descriptions regarding the SWS and the instances describing the goals. To facilitate the matching process and make it more efficient, the same descriptions are used to model both, the goals and the services. We decided to use the MSM model and extend it as needed. The MSM provides with a lightweight model approach that enables to describe both REST and WSDL (Web Service Definition Language) services. It provides a simple solution covering the demands of the services to be included in our system. Also, this model uses other popular vocabularies to benefit from already defined formalism.

WSMO (Web Service Modeling Ontology) [12]. The OntoHealth user is allowed to set priorities in terms of non-functional requirements for the selection of the services for a particular task. To model these, we have used classes and relations already available as part of WSMO non-functional properties ontologies. These ontologies provide with a set of non-functional properties for the description of general SWS. For our model, we selected the relevant classes and properties and extended the model to cover requirements directly related with the interaction of the EHR.

Table 1. Description of the sub-models of the WISE-DM ontology

Ontology	Description
WISE-CORE	Describes basic information about the workflow templates, workflow routines, patients and clinical personnel. It was inspired from IHE XDW profile (generic model).
WISE-SWS	Describes the goals and services. This ontology contains classes from the MSM plus additional new classes to model data elements (generic model).
WISE-BPMN	Describes the tools to model a business process. In fact, this ontology contains a subset of classes from the BPMN 2.0 ontology(generic model).
WISE-NFP	Describes non-functional requirements e.g. "financial" or "quality requirements". This ontology is based on the WSMO non-functional properties ontologies (generic model).
WISE-DM-FN	Contains a taxonomy of functionalities that might be necessary for a diabetes consultation (diabetes specific model).
WISE-DM-DE	Contains classes to describe different data elements that represent the user's information needs. A data element is a meta-concept for medical content. These elements, e.g. "HbA1c" can be managed by the services (diabetes specific model).

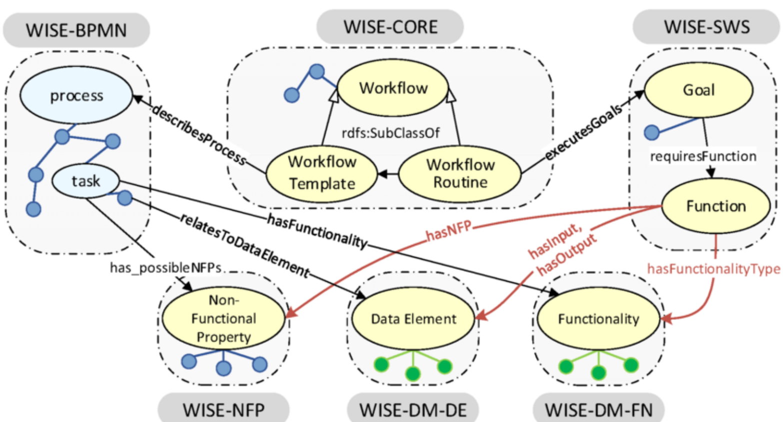

Figure 1. Overview of main classes and relations of the OntoHealth ontology.

The ontology has been named as "WISE-DM: standards-based ontology for clinical workflow-based e-health services for diabetes mellitus", which groups six sub-ontologies (Table 1). Figure 1 shows the main classes and the relation between them. As shown, a workflow template contains a BPMN process which is depicted as a graph of flow elements like tasks and sub-workflows. The tasks within this process indicate restrictions in terms of functionalities, data elements and non-functional properties. A workflow routine executes a set of goals. Each of these goals will be associated to a particular functionality (e.g. "data analysis") and will be executed over specific data elements (e.g. "blood pressure"). Restrictions for a specific goal can be defined in terms of non-functional requirements. Thus it is possible to model simple tasks such as "retrieve blood pressure data" as well as more complex tasks modeled as sub-workflows like "retrieve blood pressure data for the last 24 months and calculate the risk for a cardiovascular disease using a highly trustable service by other users".

4. Discussion and Conclusions

The goal of the WISE-DM ontology is to model patient-centered EHR workflows executed within the context of diabetes care at physician-patient contacts. For this, the ontology enables to describe functionalities within each task, particular data elements and non-functional restrictions for the service selection. For deriving required vocabularies we conducted different types of activites (literature review, observations and interviews). Each activity revealed different types of information which were combined and used for modelling the required ontology. Then, in order to leverage already developed ontologies and standards available we revised existing models used for similar purposes and adapted to our case. Aligning the ontology model with medical standards and established vocabularies facilitates the proposed architecture in different manners: One the one hand, we benefited from modelling community efforts and on the other hand we facilitated the extensibility and further integration of our semantic model. For example, the integration with the BPMN ontology enhances the flexibility of the ontology as the inclusion of new classes is straight forward if required. Indeed, the BPMN language has been already proposed by other authors to model Clinical Pathways [3]. For the evaluation of our model we have defined a set of complete workflows based on real-observations and variety of tasks with different levels of complexity.

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