Knowledge-Based Systems 22 (2009) 545–551

Contents lists available at ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

Executing medical guidelines on the web: Towards next generation healthcare

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ARTICLE INFO

Article history:
Available online 9 January 2009

Keywords:
Electronic health records
Medical guidelines
Semantic web services
Reasoning on the web
Ontologies

ABSTRACT

There is still a lack of full integration between current Electronic Health Records (EHRs) and medical guidelines that encapsulate evidence-based medicine. Thus, general practitioners (GPs) and specialised physicians still have to read document-based medical guidelines and decide among various options for managing common non-life-threatening conditions where the selection of the most appropriate therapeutic option for each individual patient can be a difficult task. This paper presents a simulation framework and computational test-bed, called V.A.F. Framework, for supporting *simulations of clinical situations* that boosted the integration between Health Level Seven (HL7) and Semantic Web technologies (OWL, SWRL, and OWL-S) to achieve content layer interoperability between online clinical cases and medical guidelines, and therefore, it proves that higher integration between EHRs and evidence-based medicine can be accomplished which could lead to a next generation of healthcare systems that provide more support to physicians and increase patients' safety.

1. Introduction

The trends in healthcare informatics are changing with the impact of the information technology revolution. Building the infrastructures enabling the sharing of the Electronic Health Records (EHRs) of a patient is currently the first priority of the national e-Health roadmaps of many countries. In the UK, NHS Connecting for Health [20] is creating an NHS Care Records Service to improve the sharing of patients' records across the NHS with their consent.

Despite the large volume of research into clinical decision making in general, and referral decisions in particular, there is still a lack of full integration between current EHRs and evidence-based medicine, and therefore, general practitioners (GPs) and specialised physicians still have to read document-based medical guidelines and decide between various options for managing common non-life-threatening conditions and where the selection of the most appropriate therapeutic option for each individual patient can be a difficult task. To illustrate this: EMIS [4] is a primary care clinical system in the UK that considers each clinical problem of the patient independently and where most of the help provided is by means of document-based medical guidelines that are accessible by *Mentor on the web* [17].

Due to the success of Internet and the Web, a substantial amount of clinical data is now publicly available on-line such as: (a) medical guidelines developed by recognised organisations like NICE [21], European Glaucoma Society [5], American Academy of Ophthalmology [1]; and (b) clinical cases from reputed healthcare centres that represent both outpatient and inpatient encounters and that can appear grouped together as in [6]. This clinical data is usually in a non-standardised form of clinical language that makes it difficult to gain greater understanding of patient care and the progression of diseases.

This paper presents a simulation framework and computational test-bed, called V.A.F. Framework, for supporting simulations of clinical situations that boosted the integration between Health Level Seven (HL7) [8] and Semantic Web technologies (OWL [22], SWRL [29], and OWL-S [23]) to achieve content layer interoperability between online clinical cases and medical guidelines, and therefore, it proves that higher integration between EHRs and evidence-based medicine can be accomplished which could lead to a next generation of healthcare systems that provide more support to physicians and increase patients' safety.

The paper is organised as follows: Section 2 presents HL7 Clinical Document Architecture and how an online clinical case can be re-written to add more markup, although the clinical content remains unchanged. Section 3 shows how relevant fragments of medical guidelines can be modelled as SWRL rules and provides

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doi:10.1016/j.knosys.2008.10.003

details about how a knowledge-intensive task can be exposed as a modelling procedure that involves the control and data flow of OWL-S process models. Section 4 outlines the validation of the proposal that is performed by focusing on ophthalmology. Concluding remarks are in Section 5.

2. HL7 clinical document architecture

HL7 Version 3 is a *lingua franca* used by healthcare computers to talk to other computers. The name HL7 comes from 'Healthcare' and the top level (Level 7) of the Open Systems Interconnection (OSI) model, which carries the meaning of information exchanged between computer applications.

HL7 Clinical Document Architecture (CDA) [3] is a HL7 standard organised into three levels. The clinical content of a document remains constant at all levels where each level interactively adds more markup to the clinical document. CDA documents are encoded in Extensible Markup Language (XML), and they derive their machine processable meaning from the HL7 *Reference Information Model* (RIM) [7] and use the HL7 Version 3 [9] data types. The RIM and the V3 data types provide a powerful mechanism for enabling CDA's incorporation of concepts from standard coding systems such as *Systematized Nomenclature of Medicine, Clinical Terms* (SNOMED CT) [27], which is a comprehensive clinical reference terminology; and *Logical Observation Identifiers, Names, and Codes* (LOINC) [14], which provides universal names and codes for laboratory and clinical observations.

CDA, Release Two (CDA R2), became an ANSI-approved HL7 standard in May 2005 [26]. A CDA document has two parts: the CDA Header and the CDA Body (see Fig. 1). *Level One* CDA focuses on the content of narrative documents and offers interoperability only for human-readable content. *Level Two* CDA benefits from RIM Act classes and makes possible to constrain both structure and content of a document by means of a template, and therefore, it increases interoperability. *Level Three* CDA provides a completely structured document where the semantics of each information entity is specified by a unique code and thereby enables machine processing. The approach presented combines biomedical background knowledge with Natural Language Processing (NLP) and Machine Learning (ML) techniques to semi-automatically code clinical information according to *Level Three* CDA, although the details of the semi-automatic codification are out of the scope of this paper.

Fig. 1 can be interpreted as a simplified overview of the Clinical Document Architecture (CDA) Release 2 which emphasises the connection from a document section to RIM Act classes.

The Ground Rounds section of the *Digital Journal of Ophthalmology* [6], a publicly available online journal, was selected as it groups together clinical cases from reputed healthcare centres that represent both outpatient and inpatient encounters. Each case included up to seven sections: history, physical examination, labora-

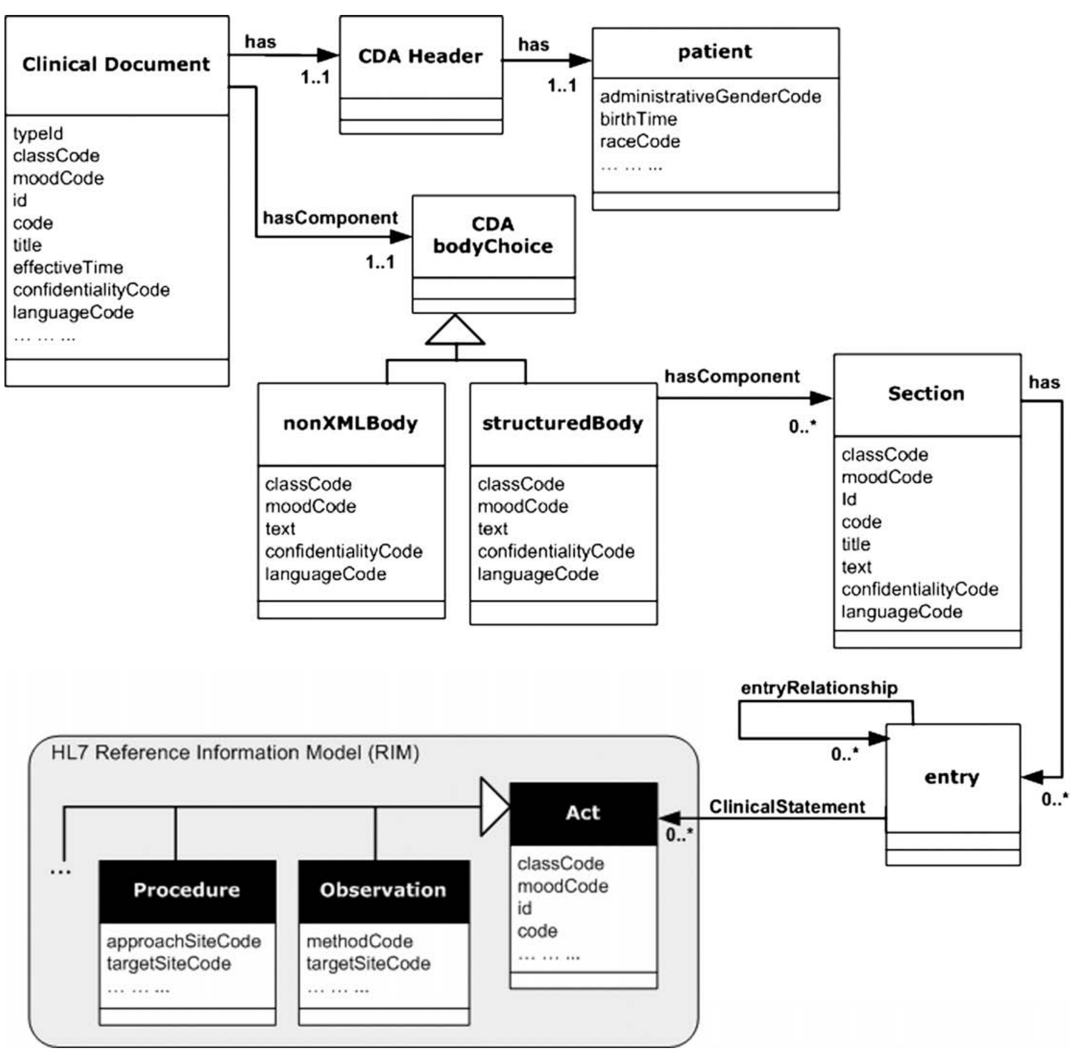

Fig. 1. Simplified overview of the CDA Release Two.

tory test results, radiology results, pathological examination, differential diagnosis, and final diagnosis. It should be noted that although the clinical cases are based on actual patient data, no identification information is present, in other words, the anonymity is guaranteed.

The research study presented here pays special attention to the history section of the online clinical cases from [6] as the history section is suitable to be confronted with medical guidelines related to patient referral, and the current study pursues to expose the advantages of a higher level of integration among clinical cases and medical guidelines.

Recently, HL7 has released several HL7 templates. HL7 templates are constrained on a balloted model, such as the CDA R2 model. The fundamental goal is to provide a mechanism to define best practices, which can be expressed in a standard format. In May 2007, it appeared an implementation guide levels 1, 2 and 3 for *History and Physical* documents [10] which describes constrains on the CDA Header and Body elements.

According to [10] a History and Physical document has required and optional sections. The sections required are: Reason for Visit/Chief Complaint; History of Present Illness; Past Medical History; Medications; Allergies; Social History; Family History; Review of Systems; Physical Examination; Diagnostic Findings; and Assessment and Plan. The optional sections are: Past Surgical History; Immunizations; and Problems.

The history section of an online clinical case from [6] (see Fig. 2) has been semi-automatically coded according to *Level Three* CDA and HL7 *History and Physical* template [10] to obtain a structured document where the semantics of each information entity is specified by a unique code, and therefore, it enables machine processing. Among the clinical information that appears in Fig. 2, the words in bold were identified as belonging to the required section *Reason for Visit/Chief Complaint* and after the semi-automatic codification performed, the result obtained appears in Fig. 3.

Based on the semi-formal model that appears in Fig. 1, which can be interpreted as a simplified overview of the CDA Release 2 that emphasises the connection from a document section to RIM Act classes, it is possible to obtain a Semantic Web Ontology in OWL [22]. In [16] it was exposed the advantages of adopting the OWL's XML presentation syntax [24] to enable Web services that exchange XML documents, but where a XML document contains OWL ontology fragments and/or SWRL rule fragments that are useful to be passed between the services and that may be needed by other components in the same workflow. The same approach is followed here, and therefore, it is possible to map the clinical content from Fig. 3 to the clinical content from Fig. 4. The main advantage of allowing the co-existence of the two formats, i.e. XML-based HL7 CDA *Level Three* and the OWL's XML presentation syntax, is to have the clinical content expressed in an ANSI-approved HL7 standard for healthcare, and at the same time, to follow the standardisation efforts for the Semantic Web that as proved in [16] it allows the integration of ontologies and rules. Thus, the V.A.F. Framework presented here promotes re-usability of functionality; follows a service-oriented approach; and outlines the use of OWL's XML presentation syntax to obtain Web services that provide reasoning support and easily deal with facts and rules.

One fundamental advantage of the use of controlled terminologies, such as SNOMED CT, is that some of them have been already translated to other languages, and therefore, it facilitates enormously to obtain extra-functionality such as automatic translation to other languages. Fig. 5 shows the summary report generated by the V.A.F. Framework, when the language activated is Spanish, based on the clinical content of Fig. 2.

A 44 year-old man **presents with double vision**. The diplopia began 2 months ago and has not changed since that time. It is binocular, vertical, and the same at both distance and near. He denies pain. His past medical history is only significant for gastroesophageal reflux disease for which he is taking Omeprazole. His past surgical history is notable for an appendectomy at age 20. Family history and social history are non contributory.

Fig. 2. History section of an online clinical case from [6].

```
<component><section>
<code code="10154-3" codeSystem="2.16.840.1.113883.6.1"
codeSystemName="LOINC"/>
<title>Chief complaint</title>
<text>The patient presents with double vision.</text>
<entry><observation classCode="OBS" moodCode="EVN">
<code code="24982008" codeSystem="2.16.840.1.113883.6.96"
codeSystemName="SNOMED CT" displayName="diplopia"/>
</observation></entry>
</section></component>
```

Fig. 3. *Level Three* CDA – Example of *Chief Complaint*.

```
<owlx:Individual><owlx:type owlx:name="Chief_complaint">
<owlx:DataPropertyValue owlx:property="LOINC_code">
<owlx:DataValue owlx:datatype="&xsd;string">10154-3
</owlx:DataValue></owlx:DataPropertyValue>
<owlx:DataPropertyValue owlx:property="Text">
<owlx:DataValue owlx:datatype="&xsd;string">The patient presents
with double vision.</owlx:DataValue></owlx:DataPropertyValue>
<owlx:ObjectPropertyValue owlx:property="has_Observation">
<owlx:Individual><owlx:type owlx:name="double_vision">
<owlx:DataPropertyValue owlx:property="SNOMED-CT_code">
<owlx:DataValue owlx:datatype="&xsd;string">24982008
</owlx:DataValue></owlx:DataPropertyValue>
<owlx:DataPropertyValue owlx:property="Presence">
<owlx:DataValue owlx:datatype="&xsd;string">yes</owlx:DataValue>
</owlx:DataPropertyValue></owlx:Individual>
</owlx:ObjectPropertyValue><owlx:Individual>
```

Fig. 4. Example of OWL's XML presentation syntax for *Chief Complaint*.

3. Executing clinical practice guidelines on the web

To execute *clinical practice guidelines* (also known as *medical guidelines*) in a computer supported way, the medical knowledge embedded in medical guidelines that can be in plain textual form, in tables, or represented in flow charts, has to be formalised. Since the 1990s many researchers have proposed frameworks for modelling medical guidelines and protocols in a computer-interpretable and computer-executable format. Thus, a variety of guideline representation languages have emerged, including PRODIGY [11], PROforma [12], EON [15], and CLIF [18]. Nowadays, the various guideline representation languages and related frameworks also need to address compatibility with healthcare information systems that aim to be interoperable on nation-wide and even international levels.

From the point of view of Knowledge Engineering, computer-based decision support in healthcare implies knowledge-intensive tasks. Due to the importance to check progress and alter the development direction if necessary, tests and revisions cannot be postponed to the final stages of knowledge-model construction. This paper presents a simulation framework and computational test-bed, called V.A.F. Framework, for supporting experiments (*simulations of clinical situations*) that explore the viability of achieving content layer interoperability between online clinical cases and medical guidelines. On the one hand, a computational test-bed is needed for conducting experiments to investigate how to obtain a successful integration between HL7 templates and Semantic Web technologies (OWL, SWRL, and OWL-S) that brings the

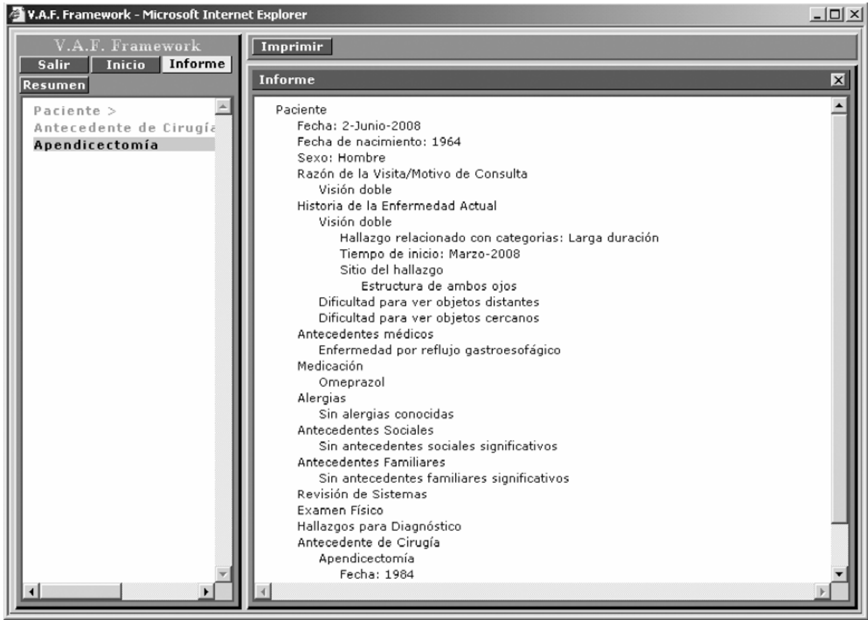

Fig. 5. V.A.F. Framework (language activated: Spanish) – Example of summary report.

fundamental support to foster automatic reasoning of knowledge-intensive tasks within medical guidelines. On the other hand, a simulation framework that allows *simulations of clinical situations* has the benefit of shortening the required number of physical prototype setups. Thus, the V.A.F. Framework emerges as a bilingual test-bed simulation framework that is one of the outcomes of fruitful ongoing collaboration between academics and clinicians based in the UK and Spain.

The V.A.F. Framework allows interoperability with the ontology-design and knowledge acquisition tool Protégé [25]. The V.A.F. Framework uses: (a) OWL [22] to formally defined concepts, relationships, properties and axioms of the domain knowledge; (b) SWRL [29] to represent the rule knowledge; and (c) OWL-S [23] to formally capture the task knowledge.

The main scientific contribution of the research study presented here is twofold: (1) practical applicability of HL7 templates and provision of fundamental support to perform experiments that imply a mixture of different terminologies to facilitate the standardisation of clinical cases publicly available online, and (2) to make easy the *virtual* transformation of document-based medical guidelines into Web-based executable medical guidelines compatible with EHRs (HL7 CDA). The evaluations performed highlight the capability of the V.A.F. Framework to conduct content layer interoperability experiments concerning higher integration between EHRs (HL7 CDA) and evidence-based medicine, where several medical guidelines can be activated at the same time.

3.1. Rule knowledge within medical guidelines

In common with many other rule languages, SWRL [29] rules are written as antecedent–consequent pairs, where the antecedent is called the *body* and the consequent is called the *head*. The *head* and *body* consist of a conjunction of one or more atoms.

The following text belongs to an online referral medical guideline [19]:

Acute Diplopia: Painful → IMMEDIATE; Painless → URGENT; Longstanding Diplopia → ROUTINE

Fig. 6 shows one of the three SWRL rules that have been modelled by interpreting the plain text fragment that appears above from the medical guideline [19], and that has been loaded into the SWRL editor of Protégé [25].

3.2. Knowledge-intensive tasks within medical guidelines

A Web service is a set of related functionalities that can be programmatically accessed through the Web [2]. The V.A.F. Framework is built on the foundations that computer-executable medical guidelines need a common underlying functionality that

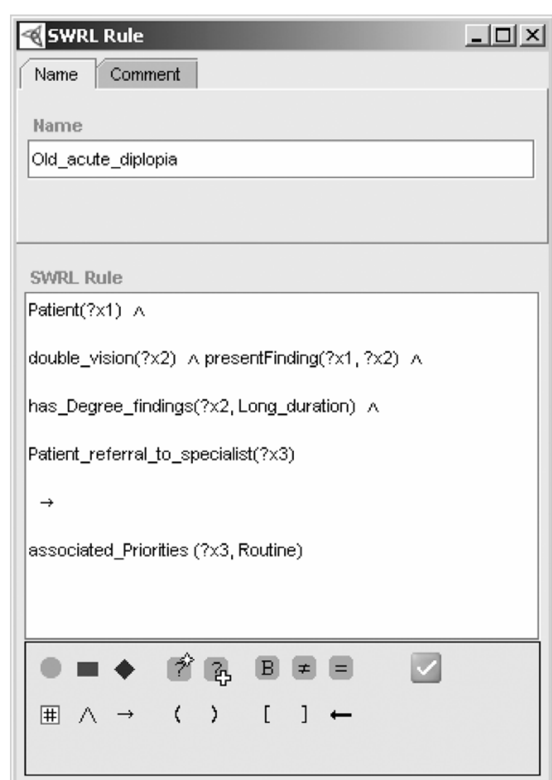

Fig. 6. Snapshot of the SWRL editor of Protégé: example of rule in SWRL.

could be addressed by allowing compositions of Web services into added-value Web services. The current research study follows [16], and thereby, it outlines the use of the OWL's XML presentation syntax to obtain Web services that provide reasoning support and easily deal with facts and rules.

The current research study uses OWL-S [23] to formally capture the knowledge-intensive tasks within medical guidelines. A service in OWL-S is described by means of three elements [23]: (1) the *Service Profile* describes what the service does; (2) the *Service Process Model* describes how to use the service; and (3) the *Services Grounding* specifies the details of how to access/invoke a service. The current approach pays special attention to the *Service Process Model* because it includes information about inputs, outputs, preconditions, and results and describes the execution of a Web service in detail by specifying the flow of data and control between the particular methods of a Web service. The execution graph of a *Service Process Model* can be composed using different types of processes (e.g. AtomicProcess and CompositeProcess) and control constructs.

The human body has symmetries and this fact is reflected in medical terminologies where 'right', 'left', 'unilateral', 'bilateral', etc., are terms that typically belong to the (multi)term combinations used to define medical concepts. To illustrate this: the following list shows two SNOMED CT concepts for several main classes, where each concept has its concept id, and fully specified name.

Clinical Finding: 162051008 Right iliac fossa pain; 162052001 Left iliac fossa pain

Table 1
SNOMED CT version released in January 2008.

SNOMED CT main classes – Number of concepts	SNOMED CT concepts containing the terms 'right'; 'left'; 'unilateral'; 'bilateral'; or 'O/E'
Clinical Finding – Number: 35425	Number: 741 (2.1%)
Body Structure – Number: 26722	Number: 1662 (6.2%)
Procedure – Number: 57731	Number: 742 (1.3%)
Observable Entity – Number: 8033	Number: 174 (2.1%)

Body Structure: 118757005 Vein of left lung; 118756001 Vein of right lung
Procedure: 426420006 X-ray of left ankle; 426721006 X-ray of right ankle
Observable Entity: 386708005 Visual acuity – left eye; 386709002 Visual acuity – right eye

In CDA R2, a typical *observation* (specialisation of the *Act class*, see Fig. 1) may have a targetSiteCode (see Fig. 1) which typically takes values from the subtypes of the SNOMED CT concept '*body structure*'. The SNOMED CT concept '*Finding site*' can be used to specify (locate) the part of the body affected, for example: '*Injury of cornea*' (has) '*finding site*' '*Corneal structure*'. By forcing the use of targetSiteCode, the amount of SNOMED CT concepts can be substantially reduced as the replication of medical concepts to take into account the body symmetries can be easily avoid. To illustrate this: '*visual acuity*' (has) '*finding site*' '*right eye structure*' or '*left eye structure*'.

Table 1 takes into account the total number of SNOMED CT concepts under several main classes (left column) of the SNOMED CT version released in January 2008, versus the number of SNOMED CT concepts under each of these main classes that use the terms '*right*'; '*left*'; '*unilateral*'; '*bilateral*'; or '*O/E*' as part of the (multi)term combinations used to define medical concepts (right column). Table 1 exemplifies the current replication of medical concepts in SNOMED CT to take into account the body symmetries. This replication could be stronger depending on the clinical speciality, for example, in ophthalmology the phenomenon is magnified. To illustrate this: there are 146 SNOMED CT concepts related to '*visual acuity*', 4 of them contain the term '*binocular*', 54 of them contain the term '*right*' or '*R-*', and another 54 contain the term '*left*' or '*L-*'.

In ophthalmology several clinical contexts, such as *Red Eye* [28], can be distinguished. Each clinical context typically involves a set of symptoms that are elicited in the *History of Present Illness* (required section of the CDA body of a *History and Physical* document, see Section 2) and has associated a set of possible diagnoses. OWL-S can be used to expose the combination of required activities

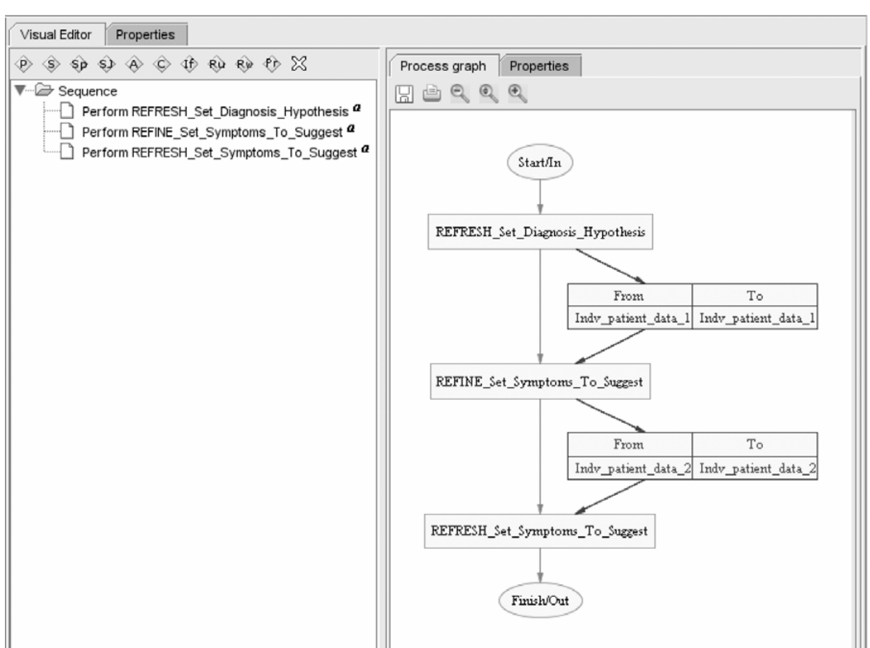

Fig. 7. Snapshot of Protégé OWL-S editor: control and data flow of an OWL-S process model.

involved in the diagnosis task, as a modelling procedure that involves the control and data flow of OWL-S process models. Fig. 7 shows the control flow and data flow of a composite process, which is constructed from three atomic subprocesses, and that supports the relevant activities after eliciting a new symptom in the *History of Present Illness*.

4. Experimental validation

The acceptability of the V.A.F. Framework has been initially assessed by means of evaluation sessions with a small number of physicians related to primary care and clinical specialities, where the simulations of clinical situations performed have focused on ophthalmology. Two types of medical guidelines have been used: (1) referral medical guidelines (e.g. [19]) that are intended for GPs; and (2) medical guidelines for specialists (e.g. related to the clinical context *Red Eye* [28]). During those sessions, the Think-Aloud-Protocol [13] was frequently used to gain insights about the efficacy of the V.A.F. Framework.

The SWRL rule from Fig. 6 can be activated by the clinical content that appears in Fig. 2. Fig. 8 shows the V.A.F. Framework when the SWRL rule from Fig. 6 is activated. Typically, the button *Reasoning Engine* (Fig. 8 on the left) appears to indicate the clinical expert that a suggestion/recommendation is available based on existing clinical information. When the button *Reasoning Engine* is pressed, the V.A.F. Framework shows the trace of the reasoning process (in this case the *Rule activated* and its consequent) in another Web browser.

Fig. 9 captures the trace of the reasoning process generated by the V.A.F. Framework after selecting the first symptom of the *History of Present Illness* of an online clinical case from [6], where its history section starts as follows:

The patient is a 38 year-old male originally from Finland who presented to our eye clinic with a red painful right eye and photophobia for 5 days.

The traces of reasoning processes are particularly useful to verify if the medical knowledge modelled captures appropriately what should be done, as well as to make the automatic reasoning performed transparent to physicians. It should be noted that the V.A.F. Framework takes into account the '*finding site*' (see Subsection 3.2), and thereby, the trace of the reasoning process that is shown in Fig. 9 reflects that the composite process that appears in Fig. 7 is executed twice: once for the '*right eye structure*' (***RE*** for short) and once for the '*left eye structure*' (***LE*** for short).

Highlighted benefits of the V.A.F. Framework that appear repeatedly in the evaluation sessions performed are: (1) it is possi-

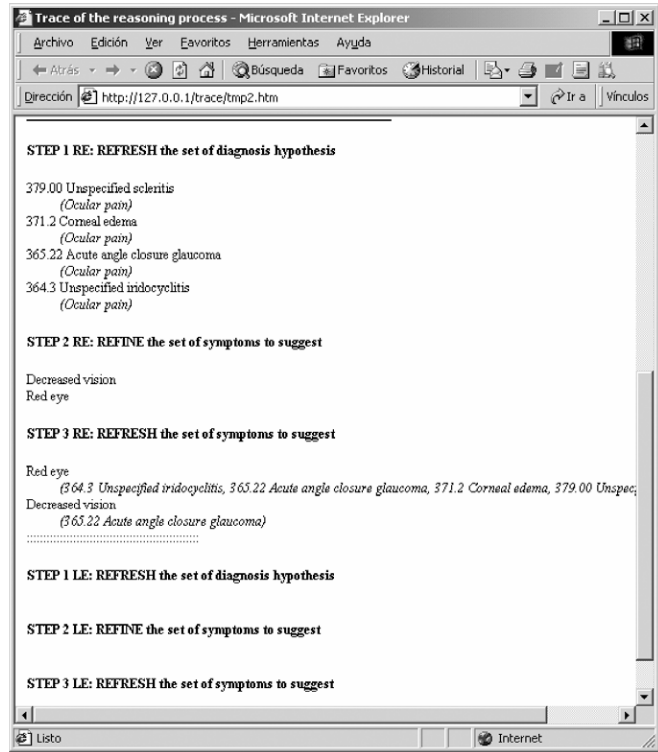

Fig. 9. V.A.F. Framework – Executing medical guidelines *for specialists* on the Web.

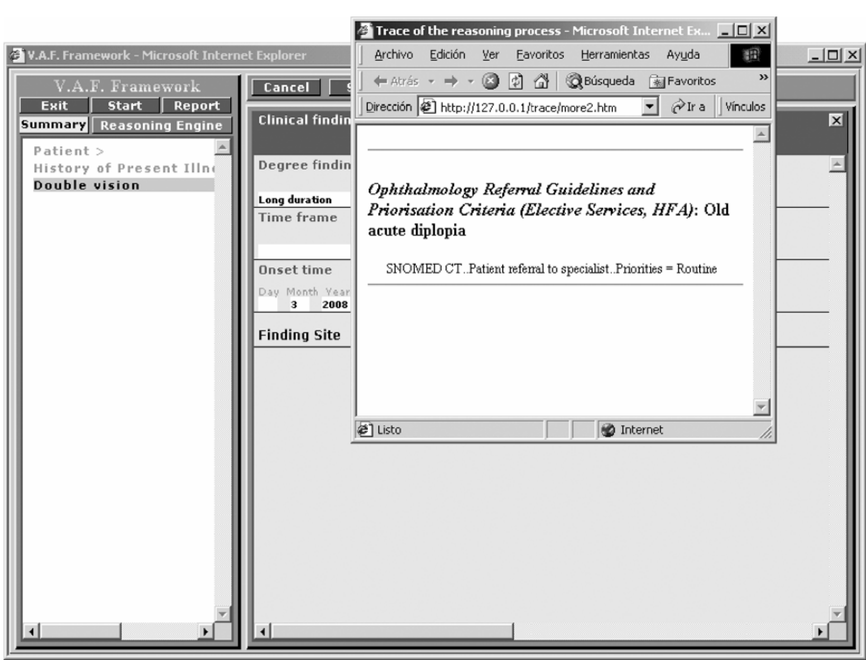

Fig. 8. V.A.F. Framework – Executing *referral* medical guidelines on the Web.

ble to evaluate quickly the knowledge modelled; (2) easy to use, i.e. the physicians can participate actively in the modelling process and further validations, and they are not mere spectators; and (3) modifications and updates can be applied without limitation.

5. Concluding remarks

Exchanging medical documents over healthcare networks is becoming a reality, although, there is still a lack of health information systems for patient care where prominent EHRs standards (such as HL7 CDA) and a wide-spectrum of computer-interpretable medical guidelines (including the ones related to common non-life-threatening conditions) are fully integrated.

This paper presents a bilingual V.A.F. Framework that (1) outlines the use of the OWL's XML presentation syntax to obtain Web services that provide reasoning support and easily deal with facts and rules, and to map the clinical content expressed in XML-based HL7 CDA *Level Three*; (2) proves the viability of having a simulation framework and computational test-bed for supporting experiments (*simulations of clinical situations*) that foster the achievement of higher integration between EHRs and evidence-based medicine; and (3) is promising in the light of the feed-back obtained from physicians (end-users) who are kept unaware of the use of Semantic Web technologies and HL7 templates.

Acknowledgements

The development and deployment of the V.A.F. Framework presented here was inspired by Maria Victoria Alvariño Figuerola and Evaristo Casteleiro López.

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