Future Generation Computer Systems 89 (2018) 137–147

Contents lists available at ScienceDirect

Future Generation Computer Systems

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

Semantic interoperability and pattern classification for a service-oriented architecture in pregnancy care

Mário W.L. Moreira [a,b], Joel J.P.C. Rodrigues [a,c,d,e,*], Arun K. Sangaiah [g], Jalal Al-Muhtadi [e,f], Valery Korotaev [h]

[a] Instituto de Telecomunicações, Universidade da Beira Interior, Covilhã, Portugal
[b] Instituto Federal de Educação, Ciência e Tecnologia do Ceará (IFCE), Aracati, Brazil
[c] National Institute of Telecommunications (Inatel), Santa Rita do Sapucaí, MG, Brazil
[d] University of Fortaleza (UNIFOR), Fortaleza, CE, Brazil
[e] College of Computer and Information Sciences (CCIS), King Saud University (KSU), Riyadh 12372, Saudi Arabia
[f] Center of Excellence in Information Assurance (CoEIA), King Saud University, Riyadh, 11653, Saudi Arabia
[g] School of Computing Science and Engineering, VIT University, Vellore, Tamil Nadu, India
[h] ITMO University, Saint Petersburg, Russia

HIGHLIGHTS

- A comparative analysis of standards used as pattern reference model for CDSSs.
- OpenEHR Performance and its compatibility keeping semantics interoperability of HISs.
- Archetypes to support the identification of high-risk situations in pregnancy.
- Proposed semantic model performance of a SOA for gestation related chronic diseases.

ARTICLE INFO

Article history:
Received 8 November 2017
Received in revised form 12 March 2018
Accepted 10 April 2018
Available online 28 June 2018

Keywords:
Semantic interoperability
Service-oriented architectures
Clinical decision support systems
Ontology
Electronic health systems
Hypertensive disorders in pregnancy

ABSTRACT

Semantic interoperability represents one of the main challenges in health information systems. The development of novel interoperability models should promote the integration of heterogeneous information in the acquisition and semantic analysis of complex data patterns, which are typically used in clinical information. The purpose of this study is to develop a knowledge-based decision support system that uses ontologies for integrating data related to hypertensive disorders in pregnancy. This model allows, when dealing with new cases, inferring from a knowledge base and predicting high-risk situations that could lead to serious problems during gestation in both pregnant women and fetuses. Results demonstrate that the use of ontologies to address semantically acquired patterns from different electronic health records has the potential to significantly influence a service-oriented architecture implementation for clinical decision support systems.

1. Introduction

The integration of distributed and heterogeneous health data has become an essential requirement for health institutions. This integration represents the challenge of reducing the high costs and increasing the quality of the services provided. The development of different database architectures has increased the necessity for data integration significantly. With the advent of the Web, novel proposals have been developed to solve complex interoperability issues [1]. The main challenges for interoperability among different knowledge sources must be resolved at both the technical and information levels. Thus, distributed data must not only be accessed but also integrated and processed by other systems. The restrictions that occur due to the heterogeneity of these data are mainly related to the heterogeneity among database management systems (DBMSs) and structural, syntactic, and semantic heterogeneity [2,3]. Recently, the use of ontologies has emerged as a potential solution to solve the complex problem of semantic data heterogeneity. The reason is that an ontology can provide a shared common understanding of an application field, in a consensual manner, with the meaning of the terms and their relationships

* Correspondence to: National Institute of Telecommunications (Inatel), Av. João de Camargo, 510 - Centro, 37540-000 Santa Rita do Sapucaí, MG, Brazil.
E-mail address: joeljr@ieee.org (J.J.P.C. Rodrigues).

https://doi.org/10.1016/j.future.2018.04.031
0167-739X/

to the modeled domain. That is, this methodology provides interoperability among health information systems (HISs) in such a fashion that users have no preoccupation regarding the data source or its storage method [4]. For heterogeneous data sources, the use of ontologies can make distributed processing understandable for a computer by describing entities and relationships among these data sources, as well as integrity rules for the domain. In this sense, an ontology can be used to define an overall system, serving as a fundamental basis for the data integration process.

The merging of clinical information is one of the most significant challenges in health informatics [5]. Once a patient receives additional or new care at a different healthcare institution in his lifetime, his information is distributed in different HISs, which typically execute on different hardware and software platforms. The difficulty of integrating heterogeneous databases for knowledge sharing does not only occur in healthcare systems [6]. This primary issue has been the subject of study for many years [7,8]. One of the most implemented techniques to address this problem is the development of ontologies to represent the knowledge domain [9]. An ontology is a description of concepts and relationships that can exist among these concepts in a given domain. For there to be knowledge sharing, there must be a standardized method to represent this knowledge. Novel patterns have been developed for this representation, making the possibility of semantic information sharing a reality [10,11].

Maternal mortality is an indicator of the status of women, their access to healthcare systems, and the adequacy of these systems to respond to their requirements [12]. The leading causes of maternal deaths are related to complications during and after pregnancy and childbirth. The principal complications are severe hemorrhage (27.1%), infections (10.7%), hypertension during pregnancy (14.0%), childbirth complications, and unsafe abortion (7.9%) [13]. High blood pressure accounts for 14% of the total number of deaths. To improve maternal health, according to the United Nations (UN) Millennium Development Goals (MDGs), difficulties that limit access to maternal health services must be identified and addressed at all levels of HISs [14]. In this context, efforts have been undertaken to provide health units with information and communication technologies (ICTs) that can contribute to improved access to information and adequate care. The development of intelligent solutions aimed at supporting health professionals in prenatal care is of fundamental importance to assist them in the search for better conditions for both pregnant women and fetuses [15]. The data generated during antenatal care constitute a significant information volume, being of fundamental importance for the identification of gestational risk factors. Thus, these data can provide an improved control throughout the gestation, contributing to the early diagnosis of possible complications. The development of methods for predicting risk situations through the use of knowledge-based decision support systems (DSSs) is essential to mitigate the difficulties inherent in gestational monitoring [16]. These models, when used with semantic integration, can cooperate to obtain excellent results in the prediction of risks related to pregnancy. This work presents the development of an intelligent system, based on ontologies, to predict pregnancy diagnosis risk levels. This model is integrated into a semantic platform supporting health professionals in prenatal care monitoring. The use of intelligent approaches to gestation monitoring allows that the data generated during the prenatal period can be processed automatically and, thus, can infer a pre-diagnosis autonomously, generating alerts for risk situations and providing valuable information for health professionals, anytime and anywhere. The contribution of this study to the literature is twofold. First, this work presents a knowledge-based model that links semantic interoperability to data analytics capabilities in real-time. Concerning other approaches, the proposed model offers a novel perspective to complement the data semantic acquisition, providing a comprehensive understanding of how data analytics in real-time can facilitate the decision-making process for the monitoring of chronic diseases. Secondly, the elements of a smart DSS are extracted from a real-world context and applied in different health care scenarios, providing new perspectives for healthcare practitioners. Thus, the main contributions of this paper are as follows:

- A comparative analysis of the leading standards used as information models and their compatibility in maintaining semantics in electronic health (e-health) environments;
- Development of archetypes based on the openEHR standard to recognize high-risk situations during pregnancy;
- Performance assessment of the proposed semantic model, which can serve as the basis for the development of a service-oriented architecture (SOA) for healthcare.

The remainder of this paper is organized as follows. Section 2 elaborates on the related work regarding this topic, focusing on semantic interoperability and its application in healthcare. Section 3 describes the use of ontology for pattern recognition in predicting hypertensive disorders in pregnancy. A performance evaluation, comparison of different methods, and analysis of the results of the proposed approach are presented in Section 4. Finally, Section 5 concludes the paper and suggests further works.

2. Related work

The increasing incorporation of informatics in health services has favored agility in the production, organization, and sharing of information. With the interoperability among HISs, information exchange among electronic health records (EHRs) has facilitated longitudinal patient monitoring, enabling improvements in their care, reducing errors and duplications, and minimizing the high costs of unnecessary diagnostic investigations [17]. The most important characteristic of EHRs is the sharing of information among systems. However, this requires the resolution of several problems related to functional interoperability [18], which represents the ability of systems to share information with each other. An archetype set involves complex tools for storing, indexing, and sharing information among HISs. Its vast diversity and scope represent one of its primary characteristics, for example, in epidemiological studies, the notification of diseases and reimbursement of health service providers [19,20].

The development of an EHR must consider health criteria because it contains complex information and the requirement of strict confidentiality. These records must also consider the recent reference models. Among the current models most used in the literature, the clinical document architecture (CDA) [21] and virtual medical record (vMR) [22], both developed by Health Level Seven, Inc. (HL7), and the model based on archetypes proposed by the openEHR foundation [23] are noteworthy.

2.1. HL7 CDA: an XML-based electronic pattern for clinical document exchange

The HL7 CDA is an extensible markup language (XML)-based standard that specifies the structure and semantics of clinical documents for information exchange. CDA aims to provide a model for clinical documents such as hospital discharge, clinical history, and transfers, advancing the healthcare industry closer to an EHR accepted by all. The use of XML by the HL7 reference information model (RIM) allows the use of clinical codes such as the systematized nomenclature of medicine — clinical terms (SNOMED CT) and the International Classification of Diseases, Tenth Revision (ICD-10) [24]. Thus, the CDA standard provides documents readable by both computers and users because of the ease of