A Multilevel-Model Driven Social Network for Healthcare Information Exchange

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ABSTRACT

The management of Big Data in healthcare is challenging due to of the evolutionary nature of healthcare information systems. Information quality issues are caused by top-down enforced data models not fitted to each point-of-care clinical requirements as well as an overall focus on reimbursement. Therefore, healthcare Big Data is a disjointed collection of semantically confused and incomplete data. This paper presents MedWeb, a multilevel model-driven, social network architecture implementation of the Multilevel Healthcare Information Modeling (MLHIM) specifications. MedWeb profiles are patient and provider-specific, semantically rich computational artifacts called Concept Constraint Definitions (CCDs). The set of XML instances produced and validated according to the MedWeb profiles produce Hyperdata, overcoming of the concept of Big Data. Hyperdata is defined as syntactically coherent and semantically interoperable data that can be exchanged between MedWeb applications and legacy systems without ambiguity. The process of creating, validating and querying MedWeb Hyperdata is presented.

Categories and Subject Descriptors

I.2.4 [**Computing Methodologies**]: Knowledge Representation Formalisms and Methods – *representation languages, semantic networks.*

General Terms

Management, Design, Standardization, Languages.

Keywords

Semantic interoperability; healthcare information exchange; Big Data.

1. INTRODUCTION

The health status of any population is the fundamental, common denominator to all other aspects of life. Without good health, a population will not thrive. Proper information management is key to good decision making at all levels of the healthcare system, from the point of care to the national policy making [1]. A given healthcare provider can have access to many sources of Big Data in healthcare and still not have access to meaningful clinical information. Having accurate, timely and semantically meaningful healthcare information is key to protecting the public in healthcare emergencies and in the day-to-day decision making in allocating scarce healthcare resources [2]. Therefore, it is important to ensure that the information related to each individual healthcare event is recorded at the moment and the place where the event happened, which is the most realistic representation of a given healthcare event. When the healthcare provider or the individual (the two most important components of the decision intelligence chain in healthcare) have control over the way this information is structured and how semantics is persisted, the realism of the knowledge representation is maximized [3].

The effectiveness of healthcare systems can be measured by their adequate response to the demographic and epidemiological profile of their target population. Over the last decades, these profiles have shown fast and complex changes due to globalization, as it can be seen during the occurrence of epidemics and pandemics, as well as in the daily overcrowding of emergency services [4]. The incorporation of Information Technology (IT) in healthcare has been proposed as a strategy to overcome the current situation, but there are obstacles for the accomplishment of this promise, which are derived from the significant complexities of health information in the dimensions of space, time and ontology.

In addition, in the typical healthcare provider spectrum, each provider has different information needs. Therefore, the applications or at least the views into applications need to be very specific in order to improve usability [5]. Large standardized systems are usually slow to change and adapt to the rapid rate of change dictated by the adoption of new emerging medical technologies [6]. The end result of the presence of such complexity in healthcare information systems is that they are usually not interoperable and have high maintenance costs. These issues have a significant impact on the low level of adoption of information technology by healthcare systems worldwide, in particular when compared to other sectors of the global economy [7].

The complex scenario of global health informatics has been studied over the last half of the 20th century and into the 21st century along with the explosion of information technology. Many different (and very costly) solutions have been proposed to the interoperability and maintenance problems of healthcare applications, with limited results [8]. In the past two decades, a different approach has been proposed for the development of healthcare information systems. This approach is generically defined as the Multilevel Model-Driven (MMD) approach and its main feature is the separation between the data persistence mechanisms and the knowledge modeling [9].

There are three MMD specifications available: the dual-model proposed by the openEHR Foundation [10], the ISO 13606 Standard [11], both of them adopting the object-oriented approach, and the Multilevel Healthcare Information Modeling (MLHIM) specifications [12], implemented in eXtensible Markup Language (XML) technologies. MedWeb is the implementation of the MLHIM specifications using many concepts of a social network application.

This paper presents the technical background for the implementation of MedWeb, including the definition of ‘hyperdata’, in dialectic relationship to the concept of Big Data, as well as the description of the technological solutions adopted in MedWeb for the process of generating, validating and querying hyperdata instances.

2. METHOD

MedWeb is a MLHIM-based meta-application, with a workflow structure set up as a social network, also providing the interface with independently developed MLHIM-based applications and other legacy systems. The MLHIM specifications are published (https://github.com/mlhim) as a suite of open source tools and documentation for the development of electronic health records and other types of healthcare applications, according to the MMD principles. The specifications are structured in two Models: the Reference Model and the Domain Model.

The abstract MLHIM Reference Model is composed of a set of classes (and their respective attributes) that allow the development of any type of healthcare application, from hospital-based electronic medical records to small purpose-specific applications that collect data on mobile devices. This was achieved by minimizing the number and the residual semantics of the Reference Model classes, when compared to the openEHR specifications. The remaining classes and semantics were regarded as necessary and sufficient to allow any modality of structured data persistence. Therefore, the MLHIM Reference Model approach is minimalistic, but not as abstract as a programming language [9].

In the MLHIM Reference Model implemented in XML Schema 1.1, each of the classes from the abstract Reference Model are expressed as a complexType definition, arranged as ‘xs:extension’. For each complexType there are also ‘element’ definitions. These elements are arranged into substitution groups in order to facilitate the concept of class inheritance defined in the abstract Reference Model.

The MLHIM Domain Models are defined by the Concept Constraint Definitions (CCDs), also implemented in XML Schema 1.1, being conceptually similar to the openEHR and ISO 13606 archetypes. Each CCD defines the combination and restriction of Pluggable complexTypes (PcTs) and their elements of the (generic and stable) MLHIM Reference Model implementation in XML Schema 1.1 that are necessary and sufficient to properly represent any given clinical concept. In general, CCDs are set to allow wide reuse, but there is no limitation for the number of CCDs allowed for a single concept in the MLHIM eco-system, since each CCD is identified by a Type 4 Universal Unique Identifier (UUID) [12]. This provides permanence to the concept definition for all time, thus creating a stable foundation for instance data established in the temporal, spatial and ontological contexts of the point of recording.

The MLHIM implementation uses XML Schema 1.1 in an innovative way. Modeling each PcT in a CCD by defining further restrictions on the Reference Model (RM) types as the xs:base in an xs:restriction. Giving the fact that the majority of medical concepts are multivariate, for the majority of CCDs, a n (n > 0) number of PcTs will be included. For instance, since it is likely to have a CCD with more than one PcT, each one of them will be nmed with a Type 4 UUID [12]. This allows the existence of multiple PcTs of the same RM complexType (e.g., ClusterType, DvAdapterType, DvStringType, DvCountType) in the same CCD without conflict. This approach also enables data query, since it creates a universally unique path statement to any specific MLHIM based data. This query approach holds true even when PcTs are reused in multiple CCDs.

Figure 1 shows the conceptual view of the sections of a CCD. Notice that the CCD is composed of two sections: the Metadata (white box) and the Definition (green oval). Primarily the definition is the structural component and the metadata is the ontological component of the concept. These are the overall separations between the two sections. Though it can be argued that the definition does carry some semantics as well as structural information about a concept; the metadata section is where the semantics for the entire CCD concept is defined and is therefore available for any healthcare application to discover about instance data. The blue circles represented XML Schema complexType definitions as restrictions of the MLHIM Reference Model complexTypes.

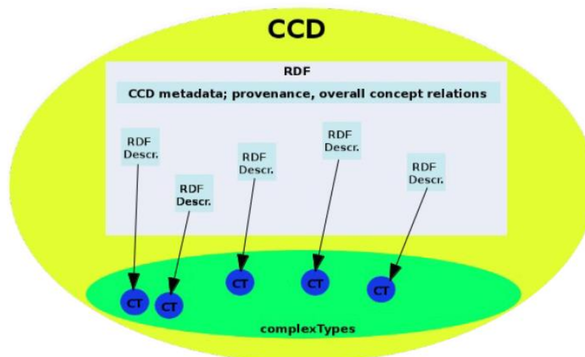

Figure 1. Structure of a MLHIM Concept Constraint Definition (CCD).

The light blue boxes represent Resource Description Framework (RDF) semantic links to definitions or descriptions of those complexTypes. RDF is a way to describe resources in a way that both humans and computers can interpret their meaning. RDF is a foundational component of the XML family for describing resources via URIs, specifically on the WWW. However, the concepts easily transfer to other environments and the technologies are well known. There are multiple syntaxes for presenting RDF. In MLHIM the RDF/XML syntax was adopted, to provide computability with the reference implementation.

The entire RDF section in a CCD is enclosed in an XML annotation by a starting, <rdf:RDF> and an ending </rdf:RDF> tag. This is the structural approach of all XML documents. A CCD is a special XML document called an XML Schema. An XML Schema defines the constraints to be placed on instance document of data contained in XML markup. Some examples of these constraints are: minimum or maximum value of a DvQuantityType, or string length of a DvStringType. It can also be a restriction on certain choices such as an enumerated list of strings of a DvStringType.

The CCD Metadata section describes the concept and provenance information for the CCD. It is located between the rdf:Description tags. It can be noticed that the tags all have two parts separated by a colon. The left side of the colon is referred to as a namespace. That can be thought of as the name of a vocabulary or a set of specifications. The right side is the element name.

It is also important to emphasize that every element name is unique within its namespace. This means that the same element name may be used in many different namespaces and still have different meanings.

In the CCD Metadata section there are tags that have a namespace 'dc:'. This is the Dublin Core namespace. The Dublin Core Metadata Initiative maintains an industry standard set of metadata definitions used across all industries. Therefore, any person or any application familiar with the DCMI standard will be capable of interpreting what is meant by the metadata entries in a CCD. Following and using industry standards is a foundation policy of MLHIM.

The two rdf:Description tags on the CCD display how the semantics of a PcT are improved. The rdf:about tag points to a PcT ID in the CCD, declaring 'what' is being described in this structure, and that description is 'about' this specific PcT. On the next line there is a rdfs:isDefinedBy tag, meaning that; in the RDF Schema namespace, there is an element that will be used to declare that this PcT is defined at this location or by this vocabulary and code. The rdf:resource tag is used to point to the resource for the definition. The description for this PcT is finally closed by the end tag. This structure appears consistently for all CCDs openly available at the Concept Constraint Definition Generator Library (www.ccdgen.com/ccdlib).

It is important to note that there can be several elements within a single rdf:Description tag set. This can alleviate the issues surrounding controlled vocabulary harmonization and mapping. By being performed at a single concept point, there is no doubt what is meant by the concept. In attempts at general mapping, it is often a matter of coarseness of the vocabularies as to whether or not the meanings actually correlate.

In MLHIM, the CCD knowledge modeler decides whether or not terms from different vocabularies represent what they intend to model. Thus, the MLHIM specifications help removing ambiguity in semantics. This is essential in healthcare, because it is not possible to achieve global consensus on all (or any) healthcare concept models [13]. In order to avoid semantic conflicts but at the same time that different medical cultures, schools and models are respected, the MLHIM eco-system allows for many different CCDs that model the same concept, even in slightly different ways.

Given the fact that MLHIM provides a common information framework against which any type of application can be built by independent developers, the type of syntactically coherent and semantically rich data generated by MLHIM-based applications can be regarded as 'hyperdata' [14]. The term 'hyperdata' is here proposed as an overcoming of the concept of Big Data, since the latter is based on conventional software and has created much more confusion and impossibilities than solid analytics in healthcare [15].

Big Data can be defined as a huge set of databases [16]. In healthcare, the level of complexity and heterogeneity of the distributed databases is such that querying the Big Data is not cost-effective and often inaccurate, since there are semantics missing and inconsistent structures across all of the databases included in any given Big Data set [17]. On the other hand, 'hyperdata' is a huge set consistently structured data, coming from any type of MMD-based healthcare applications.

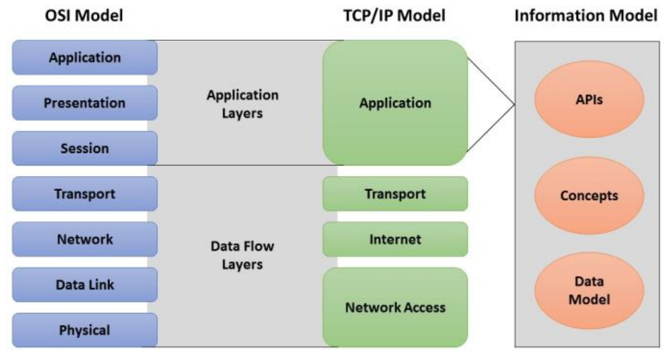

Figure 2. Analogy among the OSI, TCP/IP and Information Models.

For better clarification, Figure 2 displays the analogy among the OSI Model, the TCP/IP Model and the Information Model. It can be seen that the TCP/IP model aggregates the levels above the transport layer in one application level. On the other hand, the OSI model is more detailed on the communication layers. However, inside the application level there are the conceptual models that transforms the data into meaningful information. There are three components of the information model to take into consideration:

Data Model – The application data models, which is healthcare present extreme variability, Built upon ISO standardized datatypes, it allows machine processing and calculating.

Concepts – The conceptual models are needed in order to transform data into information. In human engineered domains these are typically well defined and semantics can be assumed even on a global basis, in many cases. In any of the sciences where evolution is involved in the engineering the approach goes from as simple, efficient and stable as possible (human engineered) to as complex and changing as necessary for survival. In the biosciences area, same or similar named concepts are actually interpreted differently and at varying levels of detail across different sub-domains and, often, in different cultures and even in different schools of training. Therefore these concepts must be well defined for the specific use intended and then be made available to every end-user of the data so that they can make the decision as to whether that data actually represents the information they need.

Application Programming Interfaces (APIs) – Consistent with any modern data exchange operation, there is a need for standardized APIs that can provide serializations, usually in JSON and XML formats.

The actual key to interoperability that is missing in todays' information system design is the ability to transfer the semantics of the concepts between applications. MedWeb has this capability through the use of the MLHIM technologies. This allows for machine based decision support and analysis vertically across individual records as well as horizontally across large datasets.

3. RESULTS

The MedWeb implementation is composed of the following structures: (1) the MLHIM Reference Model implementation in XML Schema 1.1; (2) the Patient and Provider profiles, modeled as CCDs; (3) a MarkLogic 7 database that provides data persistence and query built-in services.

The MarkLogic database stores data instances validated according to the correspondent CCD. The CCDs Schemas are valid according to the MLHIM Reference Model Schema, which is valid according to the W3C XML Schema 1.1 and XML Language specifications. Thus, as any other MLHIM-based application [9] MedWeb has a complete backward validation chain from data instance to the W3C specifications, provided by independent third-party tools such as the Xerxes and Saxon XML parser/validators. The proof of semantic interoperability achieved by the MLHIM specifications is demonstrated with simulated data automatically generated from a set of CCDs using oXygen and persisted into the an eXist database (https://github.com/mlhim/mlhim-emr) as a predecessor to MedWeb.

MedWeb applications that collect vital signs, using the Bluetooth® connected sensor on mobile devices, also capture contextual data, such as date and time, location, outside temperature. The data collected on these applications can be directly sent to MedWeb via a REST API, using a JavaScript Object Notation (JSON) representation instead of the XML. This is done to reduce the size of the message, which is feasible using ubiquitous XML technology, since it is a common development pattern to translate be-tween XML and JSON and back to XML, and there are open source tools readily available for this procedure. With the standard MedWeb REST API, it is possible to authenticate and authorize the user's connection, receive the JSON file, transform it to the XML representation, validate it against the CCD and return a status code that notifies the vital signs recording application that the data was received and added to the record.

Given the MMD level nature of the MLHIM specifications, the mobile application does not need to include the MLHIM Reference Model, the CCDs or XML data instances, producing valid JSON output directly instead. When the reference ranges or any other component of the information changes, or when the mobile device gets a new sensor array that also collects, for instance, humidity and air quality, the only requirement is to create a new CCD with the new syntax and semantics and generate a new format JSON file. When the MedWeb reports on these various data points across time it will know about the changes and report them all in their correct contexts. Fig. 3 shows the comparison of a portion of an XML instance with its transformation to the JSON equivalent.

Figure 3 displays the real configuration of MedWeb, operating with distributed XML databases in a cloud configuration. The MedWeb ecosystem is composed of Clients (patients, healthcare providers of all types, hospitals and clinics), which will access MedWeb via any of the front-end processes (a REST API, HTTP interface, SOAP XML message interface, authentication/authorization), also consisting of the external format to XML instance transformations. For instance, data in JSON format can be transformed back to the XML representation, validated against the CCD by the use of the MLHIM XML Instance Converter (MXIC) source code available at (https://github.com/mlhim/mxic) or any similar implementation. A status code is then returned to notify the application that the data was received and added to the record. Back-end processes have the primary functionality of data instance validation, as well as reporting, analysis and other preparation for presentation.

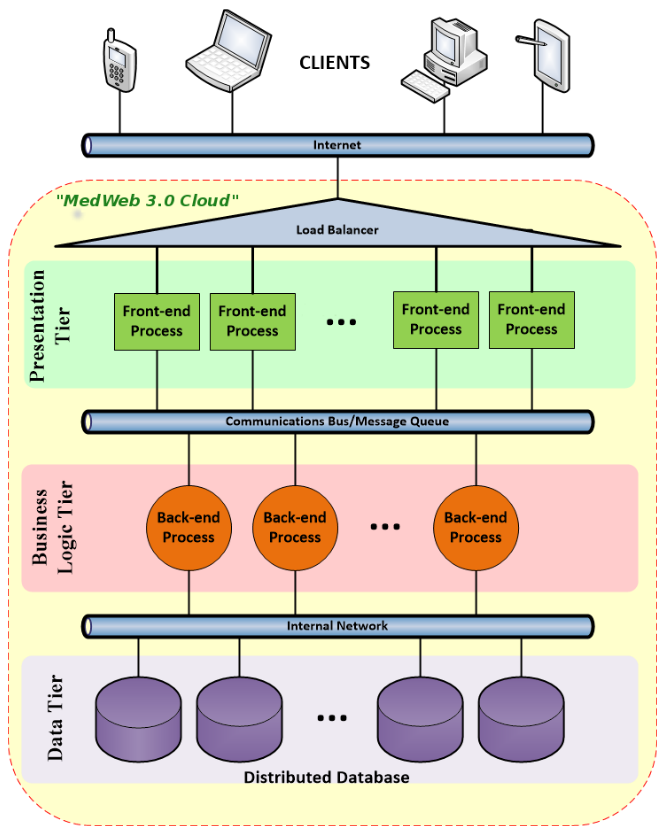

Figure 3. Schematic representation of the MedWeb ecosystem.

There are many user roles in this scenario and each role has *information to contribute* and *needs to be met*. These are not contrived for the purpose of MedWeb; those needs are currently expressed by the healthcare informatics community today. From this perspective, the actual role of MedWeb is to act as a barter mediator in this information exchange domain. Thus, it is relevant to define in an explicit way the roles, needs and contributions of each category of healthcare information user. Table 1 is a synthetic representation of such categories, associated to the correspondent solution proposed by MedWeb, in terms of technologies adopted for its implementation.

Table 2. Major categories of MedWeb users: roles, needs, contributions and solutions.

Role	Needs	Contributions	MedWeb Solution
Patients and Parents	Not to repeat form entry at every clinic To have each care giver know what the others are doing To have access to their own (or theirs child's) information	Can easily keep personal information up to date Can manage where all points of care are taking place	The patient is the center point of their information management
Healthcare Providers	To have access to their patients' data from any location To record the patient-related data according to their own expertise and clinical workflow	Can enter unbiased data about their patients Can improve scheduling and procedure management	The Domain Models underneath the professional profiles are MLHIM CCDs
Healthcare Institutions	To have opportune access to unbiased data collected at the point of care	Can create interfaces to the MedWeb for institutional use Can improve scheduling and procedure management	Access to anonimized data from REST APIs on MedWeb can be built for specific purposes
Researchers	To promote effective translational research based on biomedical research data coming from different sources	Can enter unbiased data about their research subjects Can make their anonimized data publicly available	MedWeb produces automatic UUIDs for each patient/research subject as well as maintains the data in an easy to anonymize infrastructure

4. DISCUSSION AND CONCLUSIONS

MMD is a solution for semantic interoperability of healthcare information systems, and it has been proven valid in software by independent researchers. The specifications adopted for the implementation of MedWeb present an industry standard, easily implementable, manageable way to develop semantically interoperable healthcare applications of any size.

Mobile health (mHealth) has been proposed as the solution of current healthcare IT shortcomings, which are (only apparently) related to the hardware support and the unfriendly user interface of Electronic Medical Records [18]. The current development of the mHealth technologies however, are showing that the same underlying problem is persisting, since the mHealth applications are unable to share data and their semantics are not transferrable from the original applications [19].

mHealth applications have the potential of giving the control of the information back to the patients, but it is essential to make this information shareable to the healthcare providers [20]. In order to achieve that goal, it is necessary to find a proper user interface that promotes sharing, and the social media architecture is fitted for that, since it has a wide acceptance by the general population [21]. Due to its features, the application of the social media approach to mHealth has been recently regarded as an important innovation with the potential to scale-up the compliance to mHealth [22] [23].

The current eHealth and mHealth scenario, where the challenge of achieving semantic interoperability among all the distributed applications recording data from patients following individual care pathways is the motivation for the development of MedWeb. For that to be accomplished, it was necessary to look at the standardized approaches to recording, storing and exchanging data and then improve the semantics of that data so that enough information is exchanged. Thus, the information receiver understands the same spatial, temporal and ontological concepts that were present at the moment the information was recorded.

While the information infrastructure of MedWeb, the MLHIM Reference Model, is a general-purpose model designed to be implementable in any programming language, the reference implementation adopted the constraints of the W3C XML specifications to insure the widest possible implementability, and XML Schema 1.1 was chosen to provide concrete evidence of functionality.

MedWeb can be regarded as the MLHIM-based application development framework for mHealth. At this point, there are development projects of purpose-specific applications for epidemics control and emergency case management that can also generate data extracts to be consumed by legacy systems, since it is possible to include data already persisted in conventional software to the MLHIM eco-system through MXIC and the MLHIM Application Platform & Learning Environment (https://github.com/mlhim/MAPLE). It is expected that those initiatives will expand the acceptance of the MMD principles by some new and innovative segment of the medical software industry, where conventional one-level 'data silos' [6] are still hegemonic.

It is expected that in the future, the best CCDs will be re-used and a large repository of publicly vetted CCDs would then emerge. However, MLHIM always allows the new models to be created as science changes, while the existing CCDs will be forever valid for any data instances created against them along with their specific RM version.

However, some issues are outside the control of the MedWeb eco-system. When knowledge modelers points to a controlled vocabulary or other resource as a semantic link for a CCD, they should choose the best quality resources available. Especially in the cases of controlled vocabularies (e.g., terminologies, ontologies, classifications), if the vocabulary is not well managed and versioned properly then the definition may disappear; or worse, be modified to change the meaning. If the vocabulary development organization does not provide version information and reuses codes with a different meaning this can cause semantic conflict. Thus, best practices for knowledge modeling of CCDs are always encouraged.

In the process of implementing MMD-based solutions for healthcare IT, healthcare professionals and computer scientists increase the dialogic interface between their domains. In consequence, the wider adoption of MMD will produce a new hybrid expert, and then healthcare knowledge modeling will emerge as a new area of expertise for the both scientific fields involved in the development of MedWeb applications.

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