A SEMANTICALLY ENHANCED ENVIRONMENT FOR SCP-ECG RECORDS

A. Kokkinaki, I. Chouvarda and N. Maglaveras

Lab of Medical Informatics/The Medical School, Aristotle University, Thessaloniki, Greece

nicmag@med.auth.gr

Abstract: Health care standards like SCP-ECG (Standard Communication Protocol for Computer Assisted Electrocardiography) aim at enhancing interoperability of digital electrocardiography. However, the complexity of information included in such a file makes difficult the wide adoption of SCP-ECG as the default standard in the field. The proposed work consisting of two complementary parts, a structured definition of the semantics of SCP-ECG and an ontology-based repository of SCP-ECG files, aims at facilitating the access to information regarding SCP-ECG's structure and content. It constitutes a flexible and scalable solution for SCP-ECG information handling, by the adoption of ontology-based computing, towards integration of heterogeneous medical information.

Introduction

Modern medical information infrastructure consists of many heterogeneous systems with diverse mechanisms to manage the underlying data. Patient information might be spread in the systems of different hospitals in different file formats. TeIemedicine involves the integration of information, telecommunications, human-machine and healthcare technologies. One of the aspects of telecardiology, known as tele-electrocardiography, deploys electrocardiography (ECG) machines to transmit ECGs over networks. Tele-electrocardiography diagnosis and ECG interpretation is simple, reliable and cost-effective. As different parts of this tele-electrocardiography system work on different computing environments, software interoperability is a major issue.

The development and use of health care standards like SCP-ECG (Standard Communication Protocol for Computer Assisted Electrocardiography) was specifically geared to provide a common interchange format and a messaging procedure for ECG cart to host communication and retrieval of SCP-ECG records from the host. SCP-ECG tends to become the default protocol for the formatting of ECGs, thus contributing to the interoperability of digital electrocardiography [1]. Since its inception, SCP-ECG has evolved resulting in various versions. Although a lot of work was put into its development, it has not yet been adopted as widely as its creators would like. The binary format that is not human readable, the degrees of freedom in its implementation that lead to misinterpretations are some of the reasons why SCP-ECG has not yet become the default standard in digital electrocardiography [2].

Demographic patient data, diagnosis, ECG device data, ECG biosignal data and annotations, drugs and patient measurements are stored in an SCP-ECG file. The maintenance of such records and the extraction of information becomes a difficult procedure, considering the nature of binary files that should be kept in an organized file system named by descriptive filenames. As routine tasks of the clinical practice include procedures like creating, updating and querying patient files, it seems that such a system will result in difficulties rather than benefits for the clinician. Additionally if the clinician tries to keep the EHR updated then additional effort is required in order for the data to be consistent.

Moving a step beyond, in the domain of education and research, where quick and accurate access to scientific data is a necessity, ECG signals are difficult to be searched, and when obtained they are poorly described. As IT technology moves towards semantic web, the need for structuring diverse data, becomes obvious.

According to our approach, SCP-ECG applications need not be "stand alone" but should be integrated into an electronic patient record system. On the other hand, such integration brings up many difficulties deriving from the different nature of the systems and common data they share.

This paper proposes a flexible and scalable solution for SCP-ECG information handling, by the adoption of ontology-based computing. The implementation of a structured definition of the semantics of SCP-ECG allows the user to post queries pertaining the content of the protocol, while an ontology based repository of SCP-ECG files allows the user to query the content of the files.

Materials and Methods

The proposed work aims at providing semantically enhanced tools for accessing information related to SCP-ECG files, in the sense of :

- the file structure itself, since it is a rather complicated file format, and therefore explicit and user friendly presentation of this structure would make the medical and medical informatics community more familiar with such a solution, and
- the medical information included in this type of data files, therefore facilitating access to the information included in such binary files, or combination with other types of information towards integration of medical information.

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The SCP-ECG structure: SCP-ECG standard, as defined by the TC251 committee, specifies that information is to be structured in data sections, as shown in Table 1 [3]. Besides the actual time-series, various types of information regarding the patient and the medical procedure is included, either as mandatory or optional. Therefore, the need to access and query all the information available, as well as to integrate it with other sources of medical information rises.

Table 1: SCP-ECG structure

Type	Description
M	2 bytes - checksum - CRC - CCITT over the entire record (excluding this word)
M	4 bytes - (unsigned) size of the entire ECG record (in bytes)
M	(Section 0): pointers to data areas in the record
M	(Section 1): header information - patient data/ECG acquisition data
O	(Section 2): Huffman tables used in encoding of ecg data (if used)
O	(Section 3): ECG lead definition
O	(Section 4): QRS locations (if reference beats are encoded)
O	(Section 5): encoded reference beat data if reference beats are stored
O	(Section 6): "residual signal" after reference beat subtraction if reference beats are stored, otherwise encoded rhythm data
O	(Section 7): global measurements
O	(Section 8): textual diagnosis from the "interpretive" device
O	(Section 9) : manufacturer specific diagnostic and overreading data from the “interpretive” device
O	(Section 10): lead measurement results
O	(Section 11) : universal statement codes resulting from the interpretation

Ontologies for semantic representation: Ontologies are crucial for maintaining the coherence of a large collection of complex concepts and their relationships. Formally specified knowledge can thus be shared and reusable, and inferences based on the represented knowledge are facilitated. Among various examples of existing ontologies in the medical informatics field, the following are worth menioning:

- GLIF. Referring to the medical knowledge, as coded in guidelines, an effort has been paid towards a specification for structured representation of guidelines, named GLIF [4]. An example of GLIF has been already implemented for hypertension, and can be a basis for medical knowledge representation, especially in relation with hypertension treatment.
- OpenEHR. In order to share the knowledge between the different and heterogeneous medical information systems, within the framework of a federated information system, OpenEHR ontologies [5] can contribute to interoperable electronic health records.

The proposed approach for semantically enhanced SCP-ECG tools: The proposed work consists of two complementary parts:

- a structured definition of the semantics of SCP-ECG, corresponding to a definitional ontology and
- an ontology-based repository of SCP-ECG files, by use of template-based ontology.

The semantics definition is used for the precise analysis and evaluation of the standard itself and as a reference model for the development of generic SCP-based software. Any changes in the versions and vocabularies of the standard can be easily incorporated into the model, keeping it valid, updated and consistent. A friendly user interface allows the user to query the various parts that compromise an SCP-ECG record. Queries like “*which fields of sectionX are mandatory*?” or “*what is the data type of a certain part of a section*” can save valuable time from time-consuming browsing, while functioning as an educational tool of the protocol.

The ontology-based repository of SCP-ECG files is an application that reads such records and registers their parts in the appropriate slots of the ontology.

Since an SCP-ECG file contains information concerning patient diagnosis, and demographics, medication and the biosignal itself, the most important functionality of the application, is that SCP records are structured to a meaningful content, creating an environment where physicians can carry out sophisticated queries regarding various kinds of ECGs, based on patient diagnosis or/ and demographics, drugs, medical history, or even based on the type of recordings and the characteristics of fiducial points.

The ultimate goal is to perform ontology merging and cross-validation with an EHR (Electronic Health Record) ontology, thus enabling the automatic update of patient records, paving towards the consistency of the overall patient medical information. Since SCP and EHR ontology merging will be performed, the clinician can perform more complex queries like “*find all female patients with QT longer than a threshold (SCP record) whose diagnosis was ischemic heart disease (EHR or SCP record)* ”.

Implementation issues: The ontologies are written in OWL language, which is the most recent development in standard ontology languages [6]. Protégé including Protégé OWL Plugin was used as ontology editor, and. Racer as Description Logic Reasoner, to check the consistency of the ontology and automatically compute the ontology class hierarchy [7]. The implementation of the graphical user interface was performed with Protégé OWL API, which is an open source Java library for the Web Ontology Language and RDFs. Finally the software tool that was chosen for the project’s development and deployment was Eclipse 3.1 using compiler Java[tm] 2 Platform.

The SCP-ECG viewer encompassed in the above mentioned application was developed as an entry to the openECG programming competition on February 2003.

The results along with the source code of the application are published in OpenECG's web site. SCP-ECG viewer is Java based application developed with open source tools. It offers two main functionalities: SCP-ECG viewing and writing. Specifically, the application can read SCP files and visually display their content (both alphanumeric and signal parts), as well as update it. Furthermore, a raw ECG file can be read and converted to the SCP format.

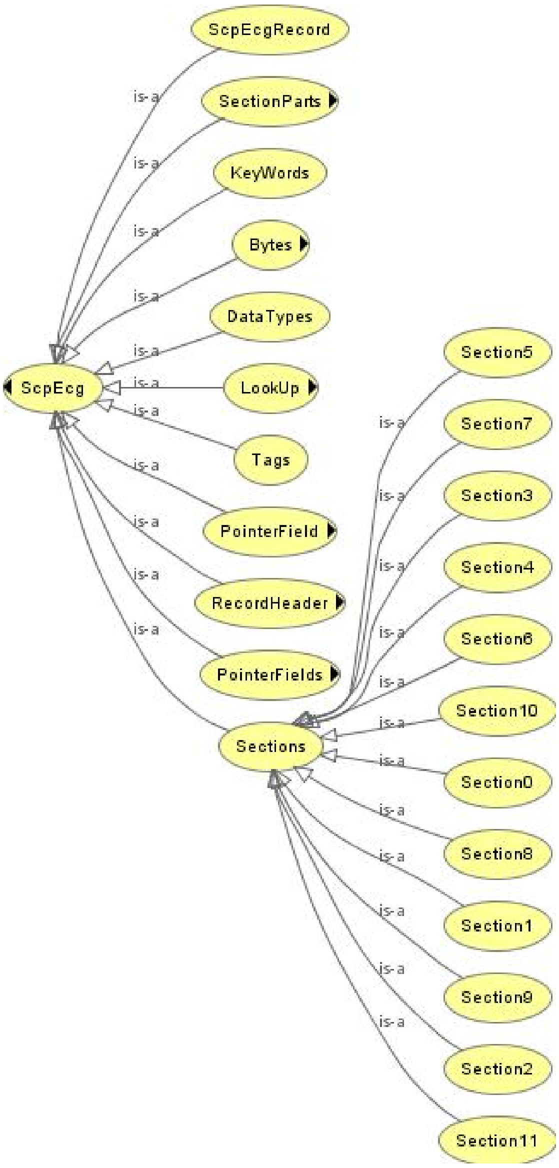

Figure 1: Partial view of SCP-ECG ontology

Results

Our approach considers the use of two different ontologies both implemented in OWL. The first ontology describes the semantics (definition) of the protocol, while the second one describes the semantics that need to be used to create instances of SCP-ECG files by the extraction of their content.

The protocol's structure was used as basis to define the SCP-ECG ontology. We defined a number of basic classes that constitute the class ScpEcgRecord,. RecordHeader, SectionParts and SectionDataPart, are some of the basic classes described in the ontology. Because SCP files consist of a record header and record data part, which in turn consist of RecordHeaderParts and SectionDataParts respectively, objectProperties were used to relate the different parts of the protocol while datatype properties were used for the descriptive knowledge that was added in the form of instances. Another example of our ontology classes, is LookUp class, which defines coded data that are represented as look up tables inside the protocol's document
After defining the ontology, we used Racer (reasoner) to check its consistency and compute its class hierarchy.

The reason that we preferred to keep names like "Section1" or "Tags" was to maintain the naming provided in the protocol's document which is the first study resource in order to familiarize with SCP.

A partial view of SCP ontology is shown in figure 1.

The user can add classes, properties or instances directly into the ontology, by using Protégé ontology editor. A user friendly graphical interface of the ontology allows the user to post queries concerning technical details of the protocol.

The user chooses the class and the property he is interested in, and poses questions like "*which tags of Section1 are mandatory, what are the allowed values of byte1 of tag 15, or which byte of which section holds diagnosis data*". A set of instances is returned to the user who can have a more detailed view of each one of them.

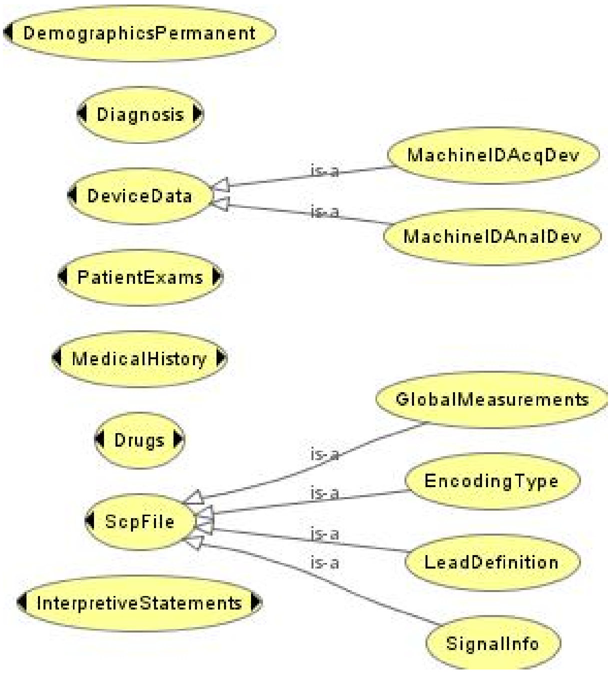

Figure 2: Partial view of SCP-ECG File ontology

The second part of our system consists of an ontology describing "template knowledge" of SCP files (see figure 2). The main class of the ontology is ScpFile, which is related to all other classes by the inverse property hasParts. ScpFile class is used to create instances that act as proxies of SCP-ECG files All other classes contain the inverse property isPartOfFile which automatically relates them to the file they belong to. **PatientDemographics** contains information of general interest concerning the person from whom the recording is obtained, such as demographic data (e.g. **patientID**, last**Name**, etc.) contact information (e.g. **Address**, etc.) and permanent characteristics of the individual (e.g age, height sex and race). **Diagnosis** class contains the physician's diagnosis of the patient, while class **InterpretiveStatements** contains a text version of the latest diagnostic interpretation of the ECG. Class **DeviceData** is subclassed to **MachineAcqDevice** and **MachineAnalDevice** classes which contain data related to the device that acquired and analyzed the ECG respectively. **Drugs** class contains patient's medication , MedicalHistory concerns patient's medical history, and PatientExams class consists of attributes like Systolic and Diastolic blood pressure.

The application was tested for the functionalities of reading and writing. The test procedure for reading an SCP file was implemented using SCP files certified by OpenECG and comparing them to the result produced by two other SCP viewers. The test procedure for writing an SCP file, either by updating an existing one or by converting an ECG file to SCP format, was implemented by using raw ECG files provided by OpenECG Consortium. The SCP file that was produced by our Writer was opened and displayed by the above mentioned viewers.

When a SCP file is opened by SCP-ECG viewer it visually displays its content (both alphanumeric and signal parts). The user can edit the information presented update the file and finally save it. In order to add the file to the ontology, button «Add to ontology» is pressed. An instance named by the name of the file is automatically created under ScpFile Class, capturing information related to the file. A capture of SCP-ECG Viewer/Writer is shown in Figure 3.

An instance named by class name + file name is created for every class of the ontology (that is present in the file) and populates its attributes with values.

Figure 3: Partial view of SCP-ECG viewer

After a number of SCP files have been added to the ontology, the user can manipulate the structure of data to search for ECGs related to values contained in SCP files. The user first selects the class that contains data he is interested in. After the selection, a set of attributes that belong to the class is presented. By choosing an attribute and a value related to his search and then press the button "find", a set of instances is returned to the user. An example query could be "*Show all SCP files of patients over 60 years old, with diagnosis atrial fibrillation*".

Discussion

Electrocardiogram (ECG) data have been traditionally generated by multiple software applications on various platforms. Furthermore local data storage and distribution uses different formats and structures. These data modelling and distribution tasks should consist of flexible and inexpensive tools to enhance pattern recognition and visualisation capabilities of humans and machines. There is an increased need to promote the development of standards in order to support a seamless exchange and migration of ECG data as well as the native integration into Electronic Patient Records (EPR) and medical guidelines. Such models should be platform-independent, flexible and open to the scientific community. In the case of ECG data interpretation, an important pre-requisite is a comprehensive data description independent of the number of channels, instrumentation platform and type of experiments. Additionally, an ECG record should include annotations relating to the acquisition protocols, patient information and analysis results.

An interesting effort is being made by openXDF which is an open standard for the digital storage of time-series physiological signals and annotations. The primary focus is on electroencephalography and polysomnography. OpenXDF is based on XML. Separating the descriptive data from the binary waveform data also allows multiple waveform files to be linked together under one OpenXDF header file. XML files are human readable by design, but this feature is not always desirable for security reasons [8].

Another interesting effort is the use of "ecgML: Tools and Technologies for Multimedia ECG Presentation" Based on advantages of XML technologies, ecgML has the ability to present a system-, application- and format-independent solution for representation and exchange of ECG data. Moreover, a distinct separation of content and presentation (among other components such as links and semantic) exhibits a remarkable advantage over existing systems where information is merged and intertwined with its representation format [9].

Our system provides an environment of structured SCP-ECG file representations, and can be used as a repository of ECG files where the user can pose queries based on the alpanumeric information they contain. On the other hand the implementation of the SCP-ECG ontology provides an explicit representation of the semantic and lexical connections that exist between information carried in the fields of SCP-ECG files. The ontology can be used as an educational tool, and can be

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further utilised by agents to facilitate data interoperability between the various systems.

Our future intention is to provide an integrated platform, where the different formats of ECG recordings will be converted to SCP-ECG files and further enrich our repository. Our ultimate goal is to enable the seamless integration of SCP-ECG files into Electronic Patient Records, where each patient's record will be connected with the corresponding SCP files.

Another future intention is to convert the standalone application to a protégé custom tab plugin in order to have direct access to the ontologies

Conclusions

The collection and integration of all medical information, distributed in different files, encoded in different formats, originating from different systems, is a hard and time-consuming procedure.

The proposed work, following the widely adopted ontology–based computing, is believed to contribute towards promoting the consistent use of SCP-ECG standard. Furthermore it constitutes a step towards the integration of medical information, by enabling a reusable representation of SCP-ECG based information.

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