33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

A semantically-aided approach for online annotation and retrieval of medical images

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***Abstract*—The need for annotating the continuously increasing volume of medical image data is recognized from medical experts for a variety of purposes, regardless if this is medical practice, research or education. The rich information content latent in medical images can be made explicit and formal with the use of well-defined ontologies. Evolution of the Semantic Web now offers a unique opportunity of a web-based, service-oriented approach. Remote access to FMA and ICD-10 reference ontologies provides the ontological annotation framework. The proposed system utilizes this infrastructure to provide a customizable and robust annotation procedure. It also provides an intelligent search mechanism indicating the advantages of semantic over keyword search. The common representation layer discussed facilitates interoperability between institutions and systems, while semantic content enables inference and knowledge integration.**

I. INTRODUCTION

ADVANCES in medical imaging have enormously increased the volume of digital images produced in clinical practice. At the same time, modern hospital information systems can only retrieve such images querying by attributes stored in the DICOM headers of the images such as patient name, age or gender. However, these attributes do not contain any information about the anatomy or disease associated with the image. Thus it has become challenging for clinicians to query for and retrieve anatomically, for example, relevant images, as this could help them deal with anatomically similar cases. Albeit there is such a huge volume of information, there is no efficient way to take advantage of it, due to lack of data annotation about anatomy or disease.

The solution seems to be located on Semantic Web technologies. The use of ontologies in data annotation and integration has gained wide acceptance. When data are annotated using terms from standardized ontologies, they are structured in a machine-computable way. Also they are more easily shared and integrated. Each annotation term is connected with others via several relations, creating a knowledge representation network. Following this technique an information system could be able to characterize medical images with semantic annotations of anatomy and disease, allowing users to perform semantic search for medical images.

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Various publications in recent years underline the importance of a semantic approach to the annotating task, which will allow ontology-based information retrieval (e.g. [1], [2]). Previous efforts on representing high-level annotations of medical images on an abstract level address the challenge of context-dependent image annotation requirements [3]. In [3] the annotation tool implemented emphasizes in supporting interoperability between the disparate systems where biomedical images are stored. A complete tool for semantic medical image annotation and retrieval, RadSem, was developed in Germany as part of THESEUS Program [4].

This paper aims to introduce an online approach that provides a semantic data representation layer for the medical image data allowing common understanding and interoperability in the medical imaging domain. The proposed approach aims to present the advantages of semantic over keyword search in retrieving of images annotated in a common vocabulary.

II. SEMANTIC WEB INTEGRATION

The semantic web is the most promising long-term solution to the problem of data and computational model integration at the level of meaning. The vision of the semantic web awaits local ontologies describing entities and relations relevant to specific application domains to be gradually linked together into worldwide knowledge networks. Many local “application” ontologies are being built, but it is difficult to link them together because of incompatibilities and lack of adherence to ontology standards. On the other hand “reference” ontologies have been proposed as a mechanism for providing the necessary ontological framework, in order to link ontologies. Reference ontologies describe parts of a generalized domain, in order to be reused. Therefore, reference ontologies are broad, deep and designed according to strict ontological principles, whereas application ontologies are narrow, shallow and designed according to the viewpoint of an end-user in a particular domain. However, the promise of reference ontologies will only be realized if ways can be found to utilize them in specific applications.

The continuous evolution of the Semantic Web now affords to incorporate into applications the ability to contact via standardized protocols a remote server hosting an ontology source, such as reference ontology. Having the ability to communicate with the remote server, it is possible to retrieve the whole ontology or just a specific part of interest [5]. The retrieval is materialized by performing

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queries on the ontology through the server. Such queries are expressed in a formal ontology query language (like SQL in the relational database world). The part, which the end-user is interesting in, can be characterized as a "view" of the reference ontology, extending the notion of "view" in relational database terminology [6]. The view can become end-user's application ontology or just a constitutional part of it [7]. Being greedy, there is also the ability to get several views from different reference ontologies, constructing a single view, which can be embed to the application ontology.

Taking advantage of this, a web application can encapsulate a dynamic and continuously extendable "Model". Mashing up this Service Oriented architecture style with the classic, widely accepted in web development, "MVC" style, the result is the hybrid architecture style presented in Fig. 1.

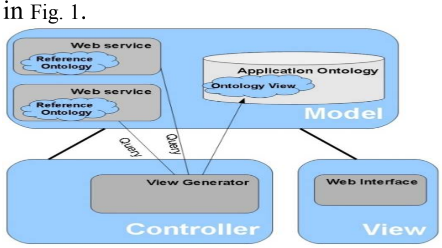

Fig. 1. Hybrid Architecture Style

III. Ontological Framework

A. Foundational Model of Anatomy (FMA)

The FMA is one of the most consistently structured reference ontologies in the biomedical domain. FMA thoroughly describes the anatomy of human body from macroscopic (organs) and microscopic point of view (sub-cellar entities). Currently, version 3.1 is available in OWL format (Ontology Web Language).

For the needs of this project, we are interesting in the hierarchy (subclasses mainly), and three essential relations: regional part, constitutional part, systematic part. These relations constitute the "semantic neighborhood" of each anatomical term.

FMA is accessible through two main web services. The first and primary one is located on a server of University of Washington, the institution where FMA was materialized, and it is a SOAP service. The query language is SPARQL (Query Language for RDF), and especially an extension of it named VSPARQL. The other server FMA is located on the server of NCBO Bioportal (http://bioportal.bioontology.org/), which comprises the most complete repository of biomedical ontologies. Bioportal offers several services, making the ontologies accessible.

B. International Classification of Diseases (ICD)

International Classification of Diseases is currently on the 10th revision (ICD-10). The ICD-10 is a coding of diseases and signs, symptoms, abnormal findings, complaints, social circumstances and external causes of injury or diseases, as classified by the World Health Organization (WHO).

However ICD-10 cannot be regarded as ontology, it is just a classification. This means that only hierarchy relations are applied to its terms. There are no other semantic relations between ICD-10 terms. Nonetheless, it is one of the most complete and widely accepted knowledge bases in the domain of diseases. ICD-10 is also available through NCBO Bioportal. Finally, it has to be mentioned that ICD-11 design will finally lead to an ICD ontology [9] and it will be conceptually enriched to include relations association with anatomical concepts.

C. SEMIA Ontology

Semia ontology is the application ontology and designed using the tool Protégé 4.1. The main classes, as presented in Fig. 2 are Image, ROI, SemanticAnnotation, AnatomyAnatotation, DiseaseAnnotation, Patient, and Annotator. There are, also, a number of other classes and many other relations. Additionally, information like the age of the patient is stored as Literals through DataProperties.

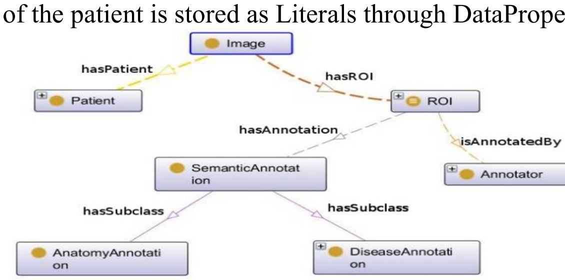

Fig. 2. SEMIA ontology

IV. Design and Implementation

Semantic Medical Image Annotation (SEMIA) is a web application developed as a case study of semantic technology using the hybrid architecture style, which was presented in Section II, in the domain of medical imaging.

SEMIA uses the FMA, as reference ontology for anatomy, and ICD-10, for diseases. FMA, as mentioned before, is accessible through a server of University of Washington (UWashington Server) and ICD-10 through NCBO Bioportal Server.

SEMIA's data is organized as RDF triples, a data model recommended by W3C for semantic data representation [8]. These triples constitute the application ontology, named Semia Ontology. The RDF repository used for hosting Semia Ontology is the open-source semantic repository Sesame, located on *Sesame Server*. ShiftOWLIM reasoner is used as inference mechanism and was embedded as a Storage and Inference Layer on Sesame. SEMIA is publicly available (http://kithira.biosim.ntua.gr/semia) and is hosted in *SEMIA Server*, which is located in National Technical University of Athens.

The SEMIA's deployment model is presented in Fig. 3.

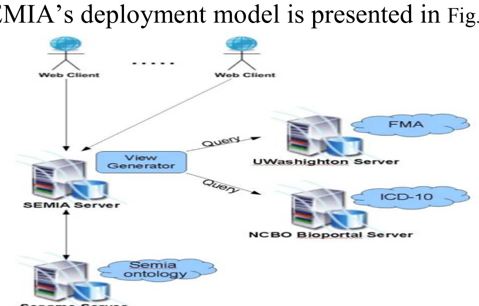

Fig. 3. SEMIA's ontology deployment

V. SEMIA

SEMIA offers two basic functionalities: semantic annotation of medical images and semantically-aided search and retrieval.

A. Annotation

The annotation of an image starts when the user uploads a DICOM image and consists of four steps. The steps are clearly presented in a wizard allowing the user to move forward and backward and review or change the inserted data.

In the first step, the image is displayed and the user selects the *Regions Of Interest* (ROI) on the image. Load and display of the image is performed by ImageJA, an applet for image processing. To confine these regions polygons with rectangular, ellipsoid and arbitrary shape are supported. Processing the image, by adjusting various filters to it, is also supported. In the second and third step, the user inserts the anatomical and disease terms, which better define the selected regions. To ease the task of finding the appropriate annotations we use auto-completing combo-boxes. While typing in a search term, concept names containing the term are shown in a drop down box and can be selected. The second step of the annotation procedure is shown in Fig. 4.

In the fourth step, an overview of the data inserted is presented. In case of an inconsistency, the user can move backwards in the wizard to correct it. Upon revising, the data is saved in the RDF repository.

Fig. 4. Annotation procedure. : Upon loading a DICOM image, *DICOM Header Tags* are automatically extracted and presented to the user, who is able to edit them. In every step, the user's actions are guided through a help desk, situated on the left of the image. Apart from the guidelines, online help contains components aiming to help the user, such as the *Body Region Visualization*, the A*natomical Term Cloud*, the *Disease Ontology Tree* and the terms' *External Links to* reference page in Bioportal. Each component appears in the appropriate step. A*natomical Term Cloud* and *Disease Ontology Tree* are used to present the "semantic neighborhood" of the selected term in order to make meaningful recommendations regarding the anatomical and disease annotations, respectively.

B. Search

The search frontend of the implemented application prompts the user to type the anatomical and disease terms of interest. Finding the appropriate term in the ontology is eased by the use of an auto-completed list, just like the ones described above.

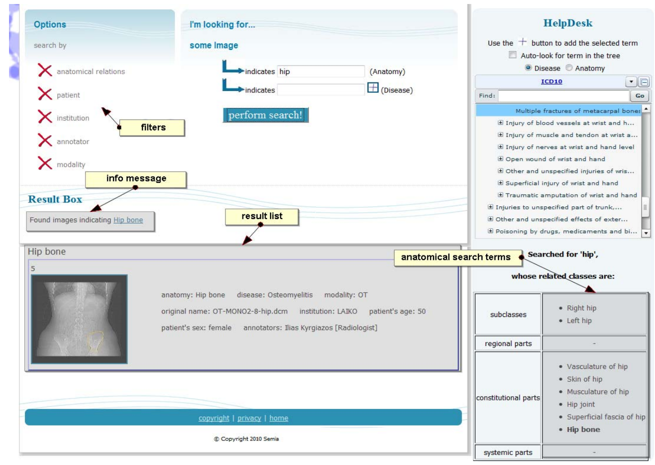

Fig. 5. Search frontend and search results for anatomical term "hip". The system offers various filters to narrow down the number of search results by specifying specific values of the images' metadata. Moreover, the user can explicitly determine which FMA relation will be included in the query expansion using the "anatomical relations" filter. Finally, an adjustable tree visualization of FMA and ICD ontologies is offered to facilitate the user's navigation through the ontology concepts.

When searching for an anatomical term, the system tracks down all the images that contain ROIs annotated with this term or any of the FMA concepts related to it via the *subclass_of*, *regional_part_of*, *constitutional_part_of* and *systemic_part_of* relations. Accordingly, when a disease term is part of the search criteria, the system retrieves all images with ROIs annotated with the specified concept or subclasses of this concept, according the ICD taxonomy. In this way, *query expansion and enhancement* is performed and semantically relevant data is retrieved.

Search results are appended to the results list, where a thumbnail together with the image details is presented for every image retrieved. If searched for an anatomical term, the image results are classified according to their anatomy class (Fig. 5). From the results list, the user can select the desired image, which is presented on image presentation page with its information. On this page a list of similar images, which contain the same anatomical and/or disease annotation, is also presented. Additionally, the user is able to extract the image's semantic information in RDF/XML format and the image itself in JPEG or DICOM format.

VI. Discussion

The main advantage of this project is the semantic meaning of annotations, allowing the user to perform semantic search and retrieval. Most information systems can search by strict attributes, as patient's age, but there is no ability to search by implicitly defined elements on the image pixels. As these elements are annotated with terms of ontologies in the system, images are linked via relations, according to their annotation terms. The result is the ability to retrieve images that are included in the semantic neighborhood of the user's search preferences. At this point, we have to underline the absence of correlation between anatomy and diseases in the world of biomedical reference ontologies. The existence of such unified reference ontology would let the addition of *possible diseases* feature, which is a list of diseases corresponding to each anatomical term.

Despite this broader and more intelligent search mechanism and the hybrid service-oriented architecture the system has an average overall query time of 0,5 sec. Whereas the query in the semia repository is extremely fast (around 50ms) due to the owlim reasoner [13], most of the time is spent when the REST services of Bioportal are used.

Another point of significance in this project is the use of reference ontologies. During the phase of design it was obvious that the mechanism of reference ontologies was a must for the project, in order to achieve high interoperability with other systems that use the same reference ontologies. The web accessibility to these ontologies helped to remain in the architectural frame of Service Oriented Architecture. Staying focused on this frame the system's repository is accessible and open to be used from other services. Also the system is designed to be integrated with other similar repositories and there is no restriction to extend or update. For example, a future updated version of the FMA can be integrated just by calling the updated web service. A possible future extention is the addition of the Radiological Lexicon (RadLex). RadLex provides the domain users with appropriate terms that allow them to describe additionally to the anatomic location the image quality, treatment, foreign body and other entities that can be found in a medical image.

Future work will be focused on combining semantic technologies and advanced data analysis methods to enhance computer-aided diagnosis (CAD) procedures. This integrated infrastructure will be based on advanced data analysis methods and semantic technologies in an attempt to (a) appropriately combine different clinical information and (b) facilitate easy access and review of data and metadata. State of the art image analysis methods can be used in the form of web services [10] to extract biomarkers with clinical value. Artificial intelligence methods could be used to classify the estimated biomarkers. Semantics can be used to model image context, image analysis results, as well as other information such as environmental data related with the disease. In addition to this, the computer-aided decision-making can be modeled with a Semantic Web Rule Language (SWRL) thus allowing the representation of the knowledge contained in clinical guidelines [11]. Also semantic technologies combined with computer-aided diagnosis (CAD) procedures can be used to create an ontological framework that links the high level entities of the medical images with the low level image characteristics. Such an ontological framework will be capable to solve the "Semantic Gap" problem [12]. This semantics-based CAD approach could offer safer, more cost-effective and personalized disease management to patients.

As a long-term plan, images annotated with ontological terms can be integrated with other data sources, like the Electronic Health Record, creating a uniform view of the patient's history and enabling Decision Support Systems to essentially enhance diagnosis and treatment process.

VII. CONCLUSION

The approach that is proposed in this paper sets the basis of the architecture that modern Health Informatics Systems can utilize. These systems can eventually help both the researchers to discover new or hidden knowledge and the medical professionals in their daily workflow. Not to be ignored, the analyzed system can be used in its current version for educational purposes. Creating an educational portal with a vast amount of annotated imaging data could boost the learning process of new radiologists. To sum up, while this work focuses on making semantic contents of medical images explicit, the approach discussed can be broadly applicable to a number of domains, where representation layer demands special attention.

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