Medical Imaging Markup Environment

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***Resumo* –Um novo mundo de capacidade de diagnostic digitais foi descoberto com os avanços da imagiologia médica. Estes avanços promoveram a comunicação e a cooperação entre várias entidades distintias de forma a criar protocolos e modelos que possam ser usados por toda a indústria, melhorando a qualidade do serviço oferecido aos pacientes. Apesar da crescente qualidade das imagens digitais, elas sozinhas não resolvem todos os problemas. É necessário que um clínico elabore um relatório contendo a sua opinião acerca de observações específicas encontradas nas imagens obtidas. Estes relatórios estruturados contêm maioritariamente anotações em texto livre, conceito que ainda não foi explorado. Assim, é crucial o desenvolvimento de um modelo de dados para os relatórios estruturados e anotações de imagens de modo a melhorar os serviços e tecnologias disponíveis em imagiologia médica.**

***Abstract* - A new world of digital diagnostic capabilities has been made possible with the recent advances in medical imaging technology. These advances promoted communication and cooperation between several distinct entities to create standards and models that can be used in the entire industry to improve the quality of the service offered to users. Despite the growing quality in digital images, they are not enough alone. That is, it is required that clinical reports, containing medical opinions about specific traits found in the obtained images, are analysed. These structured reports comprise mostly free text annotations that have not been explored yet. Therefore, the development of an environment for the management of structured reports and image annotations is a crucial step in the process of improving medical imaging technologies and services. In this paper, we present a prototype solution for such environment, based on ongoing research conducted by the caBIG AIM workgroup.**

I. INTRODUCTION

Nowadays, medical imaging is used daily in clinical procedures. Whether the clinician is dealing with a low-priority emergency or with a complex surgery, relying on images of the patient in hands, facilitates the clinician's job, improving the overall service quality. Throughout the years, medical imaging appeared in several distinct formats, from the older x-rays to the newer magnetic resonances. Though,whatever is the image capture method, there is a common denominator:radiology images provide a great added value to medical diagnosis, they are the source for vast amounts of clinical knowledge and their impact on medicine is remarkable.

Along with medical imaging evolution impact, one has to analyze information technology impact on the proliferation of the modern medical industry. Digital medical images are one of the greatest advances in recent years and have triggered the appearance of various information systems that modernized private and public hospital environments.

Newer digital images have an incredibly high resolution, only possible with advances in computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET) which have been steadily replacing x-ray technologies. Newer picture archiving and communication systems (PACS)[1] are more and more common in medical environments and have, propelled by private enterprise developments, gained significant relevance in patient treatment. These systems have a large set of features ranging from image storing[2] to image distribution, including integration with other environments like radiology [3] or nation-wide health information systems.

Digital radiology images offer valuable knowledge not onlythrough visual information, which fulfills the main purpose of creating the images, but also with metadata: how, when, where the image was acquired and what conditions the system had. Along with the images, textual reports are usually produced, containing the given medical diagnostic. Although they only contain text information, these reports are crucial to a deeper analysis of the image data as they are created by specialized clinicians. The textual information contained in these reports is, in its majority, free text. Free text has several major drawbacks derived from the fact that machines cannot understand it. This lack of autonomous understanding disables features like automatic spatial coordinate's discovery (inside an image) or associations among distinct reports or within a simple report. Summarily, it is difficult for both machines and humans to index, query or search free text annotated in images. This limits the added value that image data, image annotations and clinical reports can offer in future interpretations for clinical, research, and teaching purposes.An image annotation can be seen as a clinical report component that has to be digitally stored and made available to clinicians working in distinct operating environments.

Moreover, with the Internet gaining momentum as a development platform, we are assisting to a shift in the computational paradigm: moving from desktop applications to web applications. Therefore, it is crucial to prepare any novel web application for the future Internet: the semantic Web[4]. Combining next-generation web application requirements with the main objectives in supporting image annotations results in an extremely complex architecture.

To support this system, a comprehensive data model that supports a large number of distinct structured annotations is necessary.A data model that permits distinct instances in both data storage and data exchange, each with distinct purposes and features, is needed. The work presented in this article presents a prototype markup environment, complete with data model, architecture and viewing application. The rationale behind this research is to reinforce that the data model is the foundation for a solid distributed system architecture supporting the entire medical imaging and image annotations ecosystem.

This paper is composed of five sections. Next, we present the main features that must compose the data model, a state-of-the-art analysis regarding relevant work in this area and we propose a prototype data model. Section 3 describes the implementation architecture and its main features as well as a use case scenario. In section 4 there is a description of the created prototype application. Finally, in section 5 we present a discussion of the conducted research and some key topics for further developments in this area.

II.DATA MODEL

Health information systems (HIS) are a crucial intervenient in modern medicine[5]. As soon as a patient enters the emergency room or registers in the hospital a workflow is started with the main purpose of offering a digital service, with high quality, to hospital staff, clinicians and patients[6, 7]. Hospital information systems may be integrated (despite the inherent complexity) with regional or national health information systems for an easier integration of medical records and historic patient information[8].

Connected with these systems, there is, usually, a radiology information system (RIS) and a PACS. PACS rely mostly on the Digital Imaging and Comunication in Medicine (DICOM)[9]protocol while HIS are supported by Health Level Seven (HL7) [10]. Integration between these systems is a complex issue that has been addressed by many private and public research groups[11]. To support our system, we need to create a new framework. A new stack of features that will be added to the already cumbersome task of combining DICOM and HL7 data and services.

Creating a data model that can interact with both the protocols and support any kind of annotation is an utopia. A more restrained and achievable goal is to support a large set of structured annotations made by clinicians following a few strict rules.Summarily, our data model has to support the following features:

- storage of complex image annotations, composed by text and graphic elements;
- possibility to instance an image annotation in a simple structured report that could be exchanged between a multitude of systems;
- deep connection with the PACS system, enabling image exchanges between distinct software;
- support for patient data provided by the health or hospital information services;
- RIS integration along with PACS and HIS integration, thus promoting the creation of applications that can be used inside and the radiology department.

Research in this area has been mostly connected with DICOM improvements[12]. However, more recently the caBIG AIM group has published its efforts revealing a complex data model that is able to support the needed requirements[13]. This model is our main study object and will be adapted in our prototype system. The main purpose behind caBIG's work is to create a new industry standard for image annotation. The data storage issue is solved using a data model that can store structured annotations in a relatively simple fashion. The data model can also be simplified in a Extensible Markup Language (XML) file and exchanged between various platforms.XML is widely accepted in the medical industry, whether one is dealing with web applications and structured forms [14] or with the complex organization of the medical imaging workflow [15]. The integration of PACS, HIS and RIS is attained by including identifiers and foreign keys that can inequivocally identify external elements whether they are patients or DICOM images.

A. Data Storage Model

The annotation storage problem may lead to several distinct software solutions and implementations. An annotation is nothing more than a simple explanation or descriptive information, produced by a human or a machine, that is directly related to specific traits detected in an image or a collection of images. That is, an annotation describes, with a set of fixed parameters, the meaning of some relevant pixels inside an image.

Including annotations along with the images empowers the creation of a semantic layer on top of them, that enables the development of more autonomous software tools and the implementation of noveltext or data mining features. These new tools have a growing importance as they use concepts that will define the next generation of web applications.

caBIG'sproposed model can be organized in various logical groups: general information, ontology finding, image reference, markup and calculation. This model was chosen as the main case study especially because it is a state-of-the-art implementation and it is the one with more probability of becoming a *de facto* standard in image annotation.

The General Annotation group (Figure 1) describes the generic properties of a specific annotation or set of annotations that are part of a report.

The main class, Annotation, is an abstract class that derives in two kinds of annotations that can be Image Annotation and Annotation of Annotation, which are used to annotate images or other annotations respectively. Annotation can also be related to User and Equipment, which refer the annotation equipment. The Patient class can only be related with the Image Annotation entity.

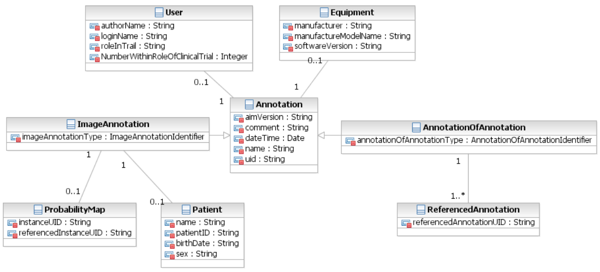

Figure 1 – General Annotation data model

The Calculation group (Figure 2) represents how calculations are stored in the data model. A calculation is a collection of results that are obtained automatically from the image annotations. For instance, if an annotation contains a circle, the calculation group will store features like area in square millimetres or maximum and minimum pixel values.

The Calculation Result is the main class that stores the type of the result, the number of dimensions and its units of measure. This class is crucial as it makes the model extremely generic, it can store distinct types of results: scalar, vector, histogram or array. In addition, it is also required that the calculation coordinates (class Coordinate) and also the final result (class Data) are stored.

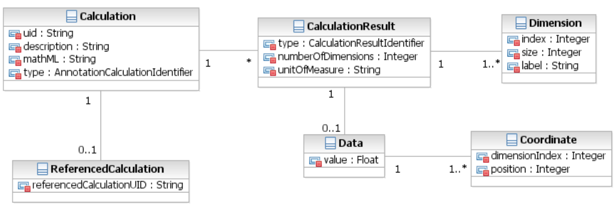

Figure 2 - Calcutation data model

Ontology defines a collection of related terms, a semantic thesauri that contains the terms that can be used to describe a certain feature belonging to a predefined scientific field. The Ontology group (Figure 3) describes the key classes used to classify the features belonging to an annotation.

In this particular scenario, the controlled terminologies derive from recognized ontologies: RadLex, SNOMED-CT or UMLS and are used to increase the semantic value of each set of annotations.

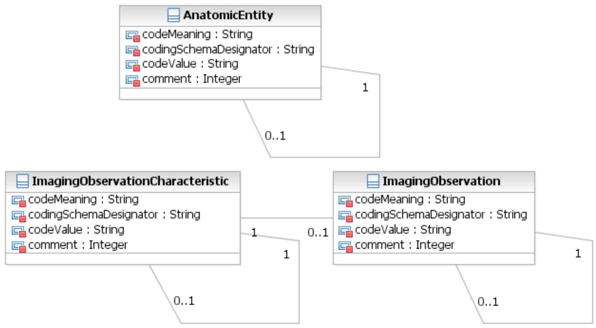

Figure 3 - Ontology data model

The Image group (Figure 4) is the core of the annotation markup. This group stores a set of identifiers that allow access to the DICOM image that the annotations refer to. The Image itself is not stored in the database; it is stored in an external PACS system and is only referenced in the data model.

Image Reference is the main image abstract class. Web Image Reference is an instance that only stores the URI to a specific image (PNG, JPEG...), not a DICOM file. DICOM Image Reference contains a subset of classes that are used to store the information required to access a particular DICOM study and the annotated images contained in the study.

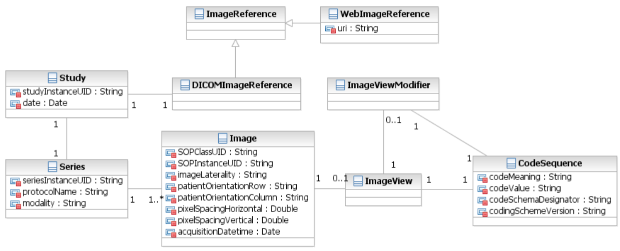

Figure 4 - Image data model

The Markup group (Figure 5) is used to store the image annotation elements: the textual and graphical representations. Text Annotation is used to label the image and store the reported annotation itself. Every annotation needs a graphical representation in the image. In this case one can have several basic shapes drawn in the image. In order to view these graphic annotations correctly, it also required that their coordinates are stored to allow a redrawing in the exact position when viewing the annotation.

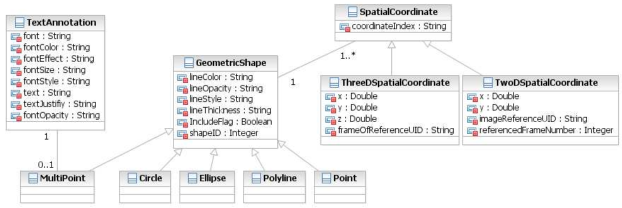

Figure 5 - Markup group data model

B. Data Exchange Model

The data exchange model is a simplified version of the data storage model, compressed in a XML file. This exchange format is important specially due to the ease of use of XML files and the facility of transporting XML files in the Internet. Using this data format, a simple XML file containing the minimum structured report required data could be exchanged between applications or even by mail between clinicians, thus improving communication and collaboration in the medical ecosystem.

The XML file is composed of two main groups: study information and image annotations. The study group is composed of information about the clinician, the patient and the used equipment. This group stores mostly identifiers that will be used by the applications that read the XML file.

```
<study id="T500278">
<info>
<user>
<authorName>the name</authorName>
<loginName>login</loginName>
<role>the role</role>
</user>
<patient id="1">
<name>anonymous</name>
<patientID>1</patientID>
<birthDate>1980-01-01</birthDate>
<sex>M</sex>
</patient>
<equipment>
<manufacturer>S</manufacturer><modelName>D</m
odelName>
<softwareVersion>3.0</softwareVersion>
</equipment>
</info>
```

As observable in the General Annotation data storage model, each annotation is composed of several elements. In the XML exchange file, each annotation contains information regarding the clinician, the technique used and optional commentaries. Additionally, it also stores the minimum information required to access the DICOM server and retrieve the annotated study. Next, there is a node list referring the concrete annotations, the clinician’s text and, if existing, the graphical shape marking the annotation in the digital image.

```
<annotations>
<annotation id="1">
<dateTime>02-01-06</dateTime>
<name>the anem</name>
<technique>technique</technique>
<comment>commentaries</comment>
<imageAnnotations>
<imageAnnotation id="11">
<imageReference>
<web>Dicom.aspx?uid=</web>
<dicomImageReference>
<dicomID>121111</dicomID>
<date>2006-06-01</date>
<seriesUID>1242342334</seriesUID>
<protocol>protocol</protocol>
<modality>modal</modality>
</dicomImageReference>
</imageReference>
<textAnnotation>free text</textAnnotation>
<geometricShapes>
<geometricShape id="1">
<type>c</type>
<spatialCoordinate>
<x>500</x>
<y>400</y>
</spatialCoordinate>
<diameter>47</diameter>
</geometricShape>
</geometricShapes>
```

The proposed data model is the main component of our prototype system. The data model is flexible: it can accommodate various distinct types of structured reports composed by heterogeneous annotations. The tradeoff between designing a generic model that is able to store any kind of annotation and designing a specific model for data exchange had to be made. Though we believe that the overall model fulfills the initial system requirements.

III. ARCHITECTURE

Starting from the same data model and fulfilling similar features, we can implement several distinct architectures. Common to any architecture we design, is the complexity in integration of the various components. Despite the advances in integrating HL7 and DICOM [11], it is still necessary to integrate RIS and our own data model in a single cross-environments architecure.Figure 6represents our prototyped architecture comprising only the essential components.In this scenario, we consider that each of the components offers access to available data through web services. This results in a small scale service oriented architecture (SOA) [16]. Considering that the elements

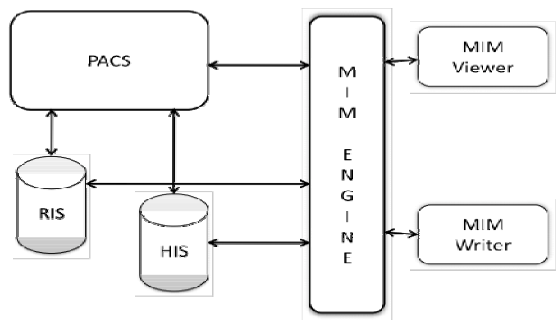

Figure 6 - Medical Imaging Markup Environment simplified

involved in this system act as services, results in a simplification of the information required in the data model. Therefore, another benefit is taken from using simple indentifiers in the data model.

A. System Components

The system is composed by six main components. This oversimplification does not include middleware components that are required in real world instances. Elements like firewalls, middleware conversion software or security providers (essential for providing authentication, authorization and accounting in health environments) are not mentioned as they would unnecessarily increase the complexity of our small prototype research.

The Medical Imaging Markup Engine (MIMEngine) is the core of the image annotation system. It is the component responsible for connecting all the intervenient in the system. This means that any message or data exchanged within the system passes through the MIMEngine. The MIMEngine is also responsible for controlling objects instanced in the proposed the data model. That is, accesses to the data storage database (store, retrieve or update) and data exchange files operations (read or write) are managed by the MIMEngine. The main abstraction is that the MIMEngine works as a proxy that the remaining components must contact for a proper execution of the operational workflow.

The PACS is a mesh of computers, mostly servers, connected with the main purpose of executing all tasks related to DICOM studies: storage, retrieval, distribution and presentation. In this particular case, it is required that the PACS system offers web access to DICOM objects (WADO) functionality. WADO permits that a particular series of a specifi study is accessed through HTTP. DICOM parameters are passed in the query string and the server will reply with the selected image.

The RIS is enclosed in the radiology section. This system is an organized framework that is used by medical radiology sections to collect, manipulate and distribute patient data and image references. RIS mostly store patient schedules and are directly connected with the image acquiring hardware. Thus, they are critical in the radiology workflow.

Besides the RIS there is often the HIS. The HIS scope is wider than the RIS. Although most of the HIS are directly related to hospitals, they can also be a part of a larger health information system, operating regionally or nationally. HIS store private patient data such as medical history, familiar relations and are optimized for security as they are often responsible for administrative and financial tasks.

In the architecture we have included two main client applications. They can be seen as application categories. Although diverse applications can be developed to interact with the system, they must be included in these two categories. Applications developed in both categories will connect directly with the MIMEngine to execute any operation.

Medical Imaging Markup Writers (MIMWriter) are heavy applications used to annotate images. Clinicians will use this kind of application to load DICOM images and to make their personal annotations. Features like voice or text recognition should be supported, in order to automate the process of generating a structured report from the clinician diagnosis. With MIMWriter, clinicians can add, view or modify structured reports at any stage. Considering the collection of features that MIMWriters can support, they will generally be desktop-based applications. This fact is not an imposition, but features like image editing or voice recognition require great hardware resources for proper execution.

Medical Imaging Markup Viewers (MIMViewer) are small applications with the main purpose of viewing annotated images. MIMViewers' features will be focused on simple and usable interfaces that can show complex annotations and structured reports to any user, whether it is a specialized clinician or a patient. The main purpose of MIMViewers is to offer annotated image access to various intervenient. That is, using MIMViewers, clinicians can share their reports with other clinicians that are geographically separated or provide report access to their patients. Therefore, MIMViewers should be cross-platform rich Internet applications, enabling real-time access to data at any time from any position in the globe.

B. Usage Scenario

For a better understanding of thementioned components involvment in a typical daily operation it is advisable that a real-world scenario is described. A execution workflow representing a traditional usage scenario is detailed next.

- A Patient arrives at the hospital and is registered in the HIS. In certain cases, private patientinformation is retrieved from a larger information system.
- After a preliminary analysis, the Patient is ordered a computerized tomography (CT). The required data is added to the RIS and the Patient is submitted to a CT scan.
- When the CT is finished, the obtained image is immediately stored in RIS and passed to the hospital PACS. When stored in the PACS, it is made available to other systems.
- Later, when Doctor A is examining the Patient, he accesses the CT scan with a MIMWriter. MIMWriter is a desktop-based application offering DICOM features that communicates with the MIMEngine to gather the Patient's study.
- Doctor A uses MIMWriter to make his diagnose and clinical report. At the same time,Doctor A

annotates the study with several noticeable traits found in the CT.

- When the job is finished, Doctor A saves the annotations and the structured report. MIMWriter will save the report in the MIMEngine database. No data from the PACS, RIS or HIS is changed.
- The Patient's CT shows some traits that do not corresponed to a easily-dectected disease. Doctor A has some doubts about the final diagnostic and contacts his colleague Doctor B, to obtain other opinion. This can be done using any kind of communication method.
- At the moment, Doctor B is at home. Due to this fact he has to access MIMViewer, a web application, and authenticate in the system to analyse the Patient's CT. MIMViewer will communicate with the MIMEngine to gather the required information: DICOM images, Patient information and clinic history showing it to Doctor B.
- Doctor B navigates in MIMViewer's interface analysing Doctor A report.
- Doctor B and Doctor A exchange information regarding the Patient's diagnostic which is then communicated to the Patient, resulting in an overall diagnose with improved quality.

This simple usage scenario highlights the relevance of the components included in the architecture as they play a key role in one or more steps of the detailed workflow.

IV. MEDICAL IMAGING MARKUP VIEWER

MIMViewer is the main client component that was prototyped in this work. The initial purpose for the development of this client was to exhibit the potentialities that this kind of platform can offer to general clinicians. The developed application is available online (alpha version) at http://bioinformatics.ua.pt/MIMViewer.

This simple application contains only a small subset of modules created to mimic the complete platform. These modules include a XML file containing the annotations, a Viewer and a DICOM component.

The annotations were taken from clinical reports made by clinician Miranda Rodrigues and are associated with the DICOM images provided in a distinct media format. The XML file containing the annotations intends to represent a structured report that includes multiple annotations,in adequacy to the previously defined scheme.

The DICOM module is a simple stub for a DICOM PACS server with WADO functionality. This component will receive the DICOM identifiers read from the annotations file and retrieve the image referenced in the annotation. The DICOM identifiers are passed in the HTTP query string allowing a generic access by the Viewer module as well as by any other application.

Although this represents a DICOM server, the DICOM images are not gathered in real-time: the DICOM module simply selects an image from a static group of images, which is more adequate to the study viewed on screen. This option was taken due to the fact that, during research, access to a real DICOM WADO service was not available.

The Viewer module is the main application component. It allows access to the list of available annotated studies and access to each study set of annotations. Figure 7shows an example of the Viewer in operation. On top there is the main application menu that provides access to the several available features. At the left there is the study list, the clinic list and room for any other list that can be accessed by the MIMEngine. In the middle there is the main workspace that is divided in three sections. The top section contains a simple annotation summary at the left and the annotation image at the right. At the bottom there is the complete annotation report with linkable elements that dynamically change the annotation image in real time. This image is obtained from the DICOM module and, if clicked, provides access to a full preview of the annotated image.

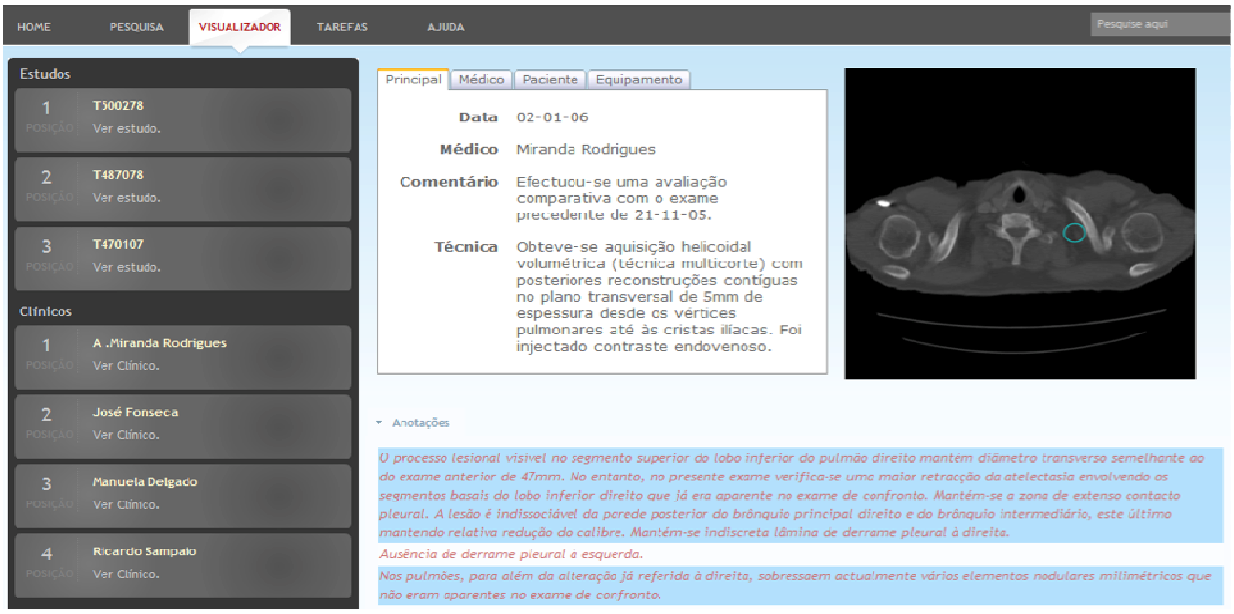

Figure 7 - Medical Imaging Markup Viewer prototype interface

V. DISCUSSION

The developments presented in this paperempower a deeper study in this area. Several research lines can be followed to improve know-how in the matter in hands and to foster the development of state-of-the-art medical imaging platforms.A primary research line should study the enhacement of the framework data model, implement it physically in a database and develop a data access layer to store, manipulate and retrieve the stored information. It is also important to improve the XML file format for annotation exchanges between heterogeneous systems. These exchanges can be made between several systems: import from portable format to database, export from database to portable format and exchange between distinct operating environments.Desiging and implementing MIMEngine, which is the platform core and must work as a proxy and integration element between the system components is required. Additionally, developing communication methods between the MIMEngine and the PACS, RIS and HIS platforms in order to allow direct reference to data and data exchanges between all the components in the environment is a needed complement. Further developments in MIMViewer should include new interface features that enhance visualization capabilities and ease the clinicians' tasks. Some of these novel features can be: annotation edition, dynamic annotation viewer, real-time annotation, data mining, text indexing and real-time access to heterogeneous data (patient, clinician, equipment, DICOM). The MIMWriter component should also be developed and tested by clinicians in their laboratories to assess the relevance and impact of such a tool in the lab operational workflow.

Image annotations represent a powerful added value to disease diagnostics based on medical imaging. Despite the quality of current computerized images, free text elements provided by clinicians will always be a valuable addition to the obtained medical data.Creating a standard data model for these textual elements is crucial to improve the quality of digital diagnosis and to empower the development of novel tools based on communication and collaboration between clinicians and supported by advanced data manipulation features and information exchanges.

In this paper we present a simple information model for image annotation and markup in health care based on caBIG AIM work. The prototyped also includes a simplified architecture and a prototype viewer application. We believe that our proposal highlights the major benefits that could be obtained by developing such complex environment. The ability to annotate images and to extract valuable information from the annotations is a vital step in the evolution of technological medical environments. Furthermore, a complete Medical Imaging Markup Environment will promote communication and cooperation between clinicians which will, ultimately, result in a better service provided to patients. With the web technologies constant evolution, it is of major importance that novel applications encompass features that can promote the future Internet. In this context, structuring text and adding semantic textual annotations to images will provide developers with a huge dataset of medical records that can be used to extract novel information from relations between medical terms or by browsing through large archives of medical information for a given disease.

In a long-term perspective, the studied AIM framework will empower multicenter clinical trials where data collection and analysis spans multiple investigators and institutions. In addition, caBIG's AIM has the main goal of becoming an industry standard through providing a foundation for standardized image annotation practice in the clinical and scientific research communities.

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