Clinical Information Retrieval to Support Teaching and Research in Radiology

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Image and related information management in radiology mostly addresses the clinical task of patient management and practically always assumes adherence to the Digital Imaging and Communications in Medicine (DICOM) protocol. However, seamless image and related information retrieval for research and educational information systems is still hard to achieve mainly because it requires: (1) integration of the rather sophisticated DICOM-compliant radiology intranet with the open standards research and academic community; and (2) development of the necessary added-value services for clinical information processing and management that pertain to research and educational activities as opposed to the task of patient management. This paper presents a web services environment that allows complex search and dynamic information retrieval in conventional DICOM sources in order to support research and academic activities. The proposed solution is based on a web service which acts as a façade for conventional DICOM sources allowing DICOM image data and related information to be transformed into XML documents encapsulated in SOAP messages. At a second level, additional web services collaborate for the dynamic extraction and indexing of all data attributes represented in the DICOM information model, thus allowing for advanced complex searches in the DICOM information space. The purpose of this work is to create easily searchable clinical data repositories (with the ability to give compound structure to both queries and results) that can support research, teaching and data mining for administrative and clinical purposes.

Keywords

DICOM, radiology information systems, SOAP, web services, XML

1. Introduction

Like many other cognitive domains, medical research and education can be considered in terms of various levels of increasing complexity and importance: raw data (usually produced in the clinical setting), information (i.e. simple facts as produced by processing initial data), knowledge (i.e. information with a purpose), and understanding (i.e. conscious knowledge, achievement of explanation and grasp of reasonableness). Information technologies can be employed in diverse ways to support different levels of the educational and research process. Supporting the dissemination of information is the easiest and most straightforward achievement of information technology. It has been used extensively and successfully to give quick, easy and cheap access to medical information sources, such as books, textbooks, atlases, medical and biological databases, research journals, current research information systems, etc. Currently is underway the development of information processing and management tools that will help the instructor and the researcher with the overwhelming amount of information digitally available for network distribution.

However, there is another aspect of information when medical education and research is considered: processed data that arises from the clinical practice and routine medical procedures. This important pool of medical information nowadays is generated mostly in digital format and is managed and distributed with information systems and over computer networks (e.g. digital output of various diagnostic and interventional devices, the various components of the electronic healthcare record, clinical workflows, etc.). The current challenge is to bridge and technologically integrate the academic and research environment, where clinical information is consumed, with the healthcare enterprise where clinical data is generated and medical knowledge is put to use. Requirements for middleware that supports such information exchange and integration include the following:

- Flexibility. Teaching and research are dynamic activities with requirements that often change to achieve new goals. Information technology that supports such dynamic activities should also be able to change and adapt easily, and expand to cover new needs.
- Easiness to implement. The requirement that the software solution is flexible and expandable according to the varying needs of research and education, places the additional demand for easy implementation that does not require expensive infrastructure and long development times.
- Security. Dealing with medical information is sensitive. Data anonymization and integrity have to been guaranteed at all times, and security issues have to be addressed satisfactorily at various levels of a software implementation (preferably starting from the supporting technology itself).
- Adherence to open standards. In teaching and research, scientists from a variety of disciplines and backgrounds are involved, and disparate information systems and software tools often need to be used in concert. At the same time, software tools that support teaching and research are required to integrate with or even be embedded in the university or research institute infrastructure. Both requirements call for open standards and commonplace technologies.

This paper proposes a middleware approach based on commonplace, freely available Internet technologies for the integration of the healthcare domain with the research and academic environment that allows for the flexible, easy and on-demand development of additional software modules to support research and educational activities. The specific aim of this work is to provide a way to create easily searchable clinical data repositories (with the ability to give compound structure to both queries and results) that can support research, teaching and administrative tasks in the particular case of radiology.

2. Clinical Information Management in Radiology

Currently, image and related information management in radiology mostly addresses the clinical task of patient management. Towards this end, the Integrating the Healthcare Enterprise (IHE) initiative [1] proposes a framework for tight functional integration of radiology and related information systems using pre-set workflow (integration) profiles that are implemented by well-defined transactions based on existing standards, such as Digital Imaging and Communications in Medicine (DICOM) [2] and Health Level Seven (HL7) [3], as well as Internet technologies.

At present, as far as medical imaging is concerned, adherence to DICOM is practically always assumed, and efficient image distribution among different imaging modalities and information systems within the radiology department is realized via the DICOM protocol. The standard is continuously being enhanced to support new imaging and other diagnostic modalities, while it has recently been augmented with the DICOM Structured Reporting (SR) extension, a powerful and expressive mechanism for representing hierarchically structured clinical findings including links to the source diagnostic data, e.g. images, waveforms, etc. [4], thus extending the impact of the standard from the management of raw medical data to the more complex and broad tasks of diagnosis and patient management. However, seamless image distribution within the healthcare enterprise and especially to research and educational information systems is still hard to achieve, as software developers of such third-party applications have to go through the rather cumbersome task of adapting the DICOM communication model, implementing the DICOM protocol and keeping up with new changes in the standard.

During the past years, the Internet and related technologies have been widely introduced in the radiology department (and healthcare enterprise in general) to provide an easy and commonplace way of accessing clinical data and supporting various healthcare processes. In the case of medical imaging, respective work addresses both aspects of image management as supported by the DICOM standard, namely data representation and data communication.

In terms of medical image communication and distribution, nowadays most Picture Archiving and Communication Systems (PACS) manufacturers provide a web browser access to medical images, tightly coupled to their PACS implementation, e.g. [5,6]. Common to all approaches is the fact that DICOM images that originate from dedicated medical imaging repositories and archiving systems can be accessed by individual users via a commonly available web browser, without any need for special software or hardware. Although an easy and efficient solution for simple image distribution services to individual users, web browser access to DICOM images has some drawbacks: (1) initial DICOM data are usually transformed into a web compatible format, so that information is not entirely preserved (2) the web browser is a thin client, thus it cannot easily accommodate advanced functionality for processing, rendering, manipulation, and overall management of images and related information; and (3) access to DICOM images and related information is limited to human users, while other software applications cannot take advantage of this web-based communication. Software applications can independently access DICOM data through standard Internet technologies via the Web Access to DICOM Persistent Objects (WADO) supplement to DICOM standard [7]. WADO specifies a simple mechanism for accessing a DICOM persistent object (image, waveform, structured report, etc) from web pages or other software applications (e.g. an e-mail system), through the HTTP communication protocol. However, WADO does not support any other conventional DICOM services (e.g. find or store), and assumes that the unique identifiers required for retrieving an object from a DICOM archive are known by other means.

In terms of data representation, the widespread adoption of XML technologies [8] has made a notable step towards easier integration of clinical data in healthcare information systems. Transforming DICOM objects in XML format mainly aims to enhance exchange of medical image data across the healthcare enterprise [9,10], especially as other clinical information systems and relevant standardization bodies begin to adopt XML technologies. However, although XML addresses the problem of data integration, it does not support control integration among disparate information systems.

Recently, the XML/SOAP web services programming paradigm [11] has been a catalyst for achieving both data and control integration among applications through commonplace Internet technologies. Initially developed by a group of software companies and now handled by the World Wide Web Consortium (W3C), web services are loosely defined as self-contained, self-describing, modular applications that can be located and invoked over the Internet. Web services are based on open Internet standards: build on the HyperText Transfer Protocol (HTTP), they use XML for data presentation while messaging is described in an XML-based messaging protocol, SOAP (Simple Object Access Protocol). Web services describe themselves through a standardized Web Service Description Language (WSDL) document, and can be published to one or more Intranet or Internet repositories for potential users to locate through a standard Universal Description, Discovery and Integration (UDDI) registry. A whole suite of additional standards are currently being developed to formally address issues such as security, reliability, transactions, etc. Web services technology is a way for applications to expose software services using standard interoperability protocols, regardless of the platform on which they are implemented. Furthermore, third party applications that invoke web services do not need to know any of the web service implementation details; they only need to be able to send and receive XML/SOAP messages. Initially, it is expected that web services are mainly used as wrappers of existing applications serving to interconnect legacy systems without altering their code, as well as to decompose their usually complex functionality and offer it as separate, well-defined targeted services.

The web services paradigm has already gained broad industry support. It has recently been identified as an especially important technology for the future of healthcare delivery and administration [12,13], and the first implementations are currently emerging. For example, preliminary forms of XML services (though not XML/SOAP web services as described above) have been successfully used as a middleware solution for integrating disease specific information systems into a single clinical workstation [14] and for supporting a web-based virtual patient record architecture [15]. The emergent XML/SOAP web services technology has been employed to enable integration of biology sequence data banks over the web [16], as well as to support a core infrastructure of components and services for the management of data from diverse sources in cancer informatics [17]. Moreover, web services are expected to play a key role in integrating the healthcare enterprise as they are currently being adopted by relevant standardization bodies. For example, HL7 is promoting web services for message exchange [18], while IHE is already employing web services for the implementation of certain transactions of its integration profiles.

Web services have already been introduced in medical image management to create a façade for conventional DICOM image servers, and expose the principal DICOM services of query, retrieve, and store to any other software application over the Internet, using standard XML documents communicated via SOAP messages [19,20]. This paper builds on this previous work and presents a collaborating web services environment that allows complex search and dynamic information retrieval in conventional DICOM sources, while it can be easily augmented with other added-value services. The proposed approach combines the advantages of using XML for DICOM data representation with the benefits of employing open ubiquitous web technologies for messaging and communication. Thus, DICOM image data and related information can be discovered, retrieved, maintained and processed in third party non-DICOM applications, and through open, standard messaging.

3. Web Services for Clinical Information Retrieval in Radiology

In addition to the general requirements listed in the previous sections, any approach for clinical information retrieval and processing to support research and education in radiology has to satisfy two major needs: (1) provide a means to interface the rather sophisticated DICOM-compliant radiology intranet with the open standards research and academic community; and (2) provide necessary added-value services for clinical information processing and management that pertain to research and educational activities as opposed to the task of patient management.

To address these issues in a modular, extensible, and easy to implement way we propose a multilayer environment as shown in Figure 1. At a first level, simple web services act as wrappers to conventional DICOM image servers, and expose the principal DICOM services of query, retrieve, and store to any other software application or web service over the

Internet, using standard XML documents communicated via SOAP messages. Thus, DICOM image data and related information can be discovered, retrieved and maintained in a third party non-DICOM application in its fullness, and through open, standard messaging. At a second level, additional web services collaborate to provide added-value for research and academic purposes. The complex functionality addressed by this second layer of web services can then be exploited by any end-user application. Although this particular work addresses the specific case of radiology, the environment can be augmented by additional web services that act as wrappers to any legacy healthcare information system and expose their data and functionality for other web services that can support data and information processing for more complex research and academic tasks in the healthcare sector. This way, additional wrapper web services can be developed to expose basic functionality of any clinical and administrative information system, while a variety of added-value web services can be devised to combine available healthcare data in order to serve medical research and education.

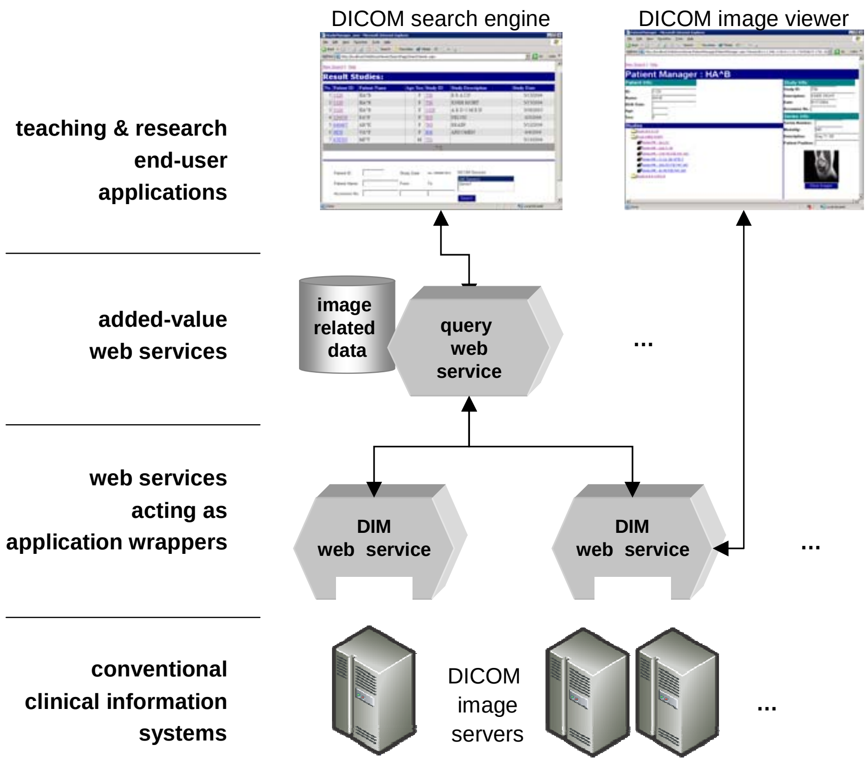

Figure 1 Web services environment for clinical information retrieval to support research and education.

In the case of radiology however, the façade for any conventional DICOM source (e.g. diagnostic imaging system, picture archiving and communication systems, stand-alone image databases, etc) is the DICOM Image Management (DIM) web service, which acts as a wrapper concealing the DICOM communication model and protocol specifics from the end application that requires access to the DICOM source. The DIM web service accepts queries from a client application about a DICOM server in SOAP/XML form, transforms them into the equivalent DICOM protocol services, communicates with the DICOM image server using the DICOM protocol, and transforms the results back into XML documents, encapsulated in SOAP messages. Any conventional DICOM source can use the proposed web service to expose the principal DICOM operations of query, retrieve, and store over the Internet, using XML documents communicated via SOAP messages. The web service can be invoked by any web-service enabled client application, regardless of its implementation specifics and the platform it runs on (this includes thin web-based clients, conventional software applications, as well as other web services).

Functional and information organization in the DIM web service is based on the DICOM information model. This model organizes information related to a medical image using a logical structure of information entities and their relationship. Basically, the standard specifies the entities involved in radiological operations, such as patients, visits, studies, images, reports, and other data objects. Each entity is characterized by a collection of attributes, which carry all information related to the particular entity. Every instance of study, series and data object in DICOM is assigned a unique number as an identifier (UID). The DIM web service assumes the DICOM information model and implements the basic functionalities supported by the DICOM protocol for searching a DICOM image server and retrieving images, structured reports and other data objects, as well as storing in a DICOM archive.

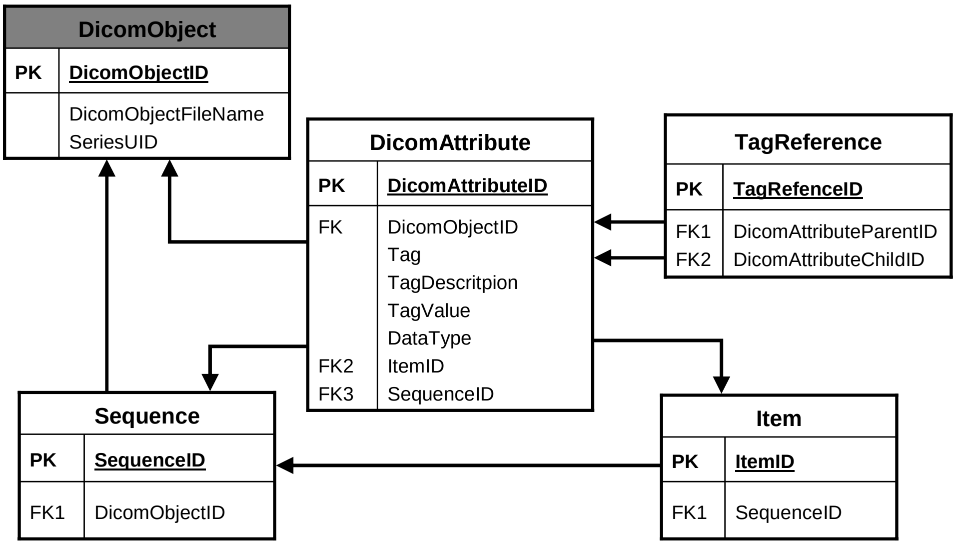

Figure 2: The model of the DICOM attribute database maintained by the DQM web service

At a second level, the DIM web service is engaged by collaborating web services that provide functionality specific to research and educational tasks. A representative example is the DICOM Query Management (DQM) web service, which supports complex search in medical image servers. In the DICOM information model, the collection of various attributes that characterize a study, a series or a data object carries in essence all image related information. These attributes are represented by a tag and its value and are grouped according to the information entity they describe. Since the primary scope of DICOM is medical image communication amongst different imaging modalities and radiology information systems in order to support the task of patient management, DICOM communication protocol is not built to be particularly friendly to research and academic demands. So, although the protocol supports basic search functionality, this is limited to exploit only certain attributes and of a specific information entity at a time. As a result it is not possible to formulate complex queries that combine any DICOM attribute from different levels of the information model. The DQM web services uses DICOM image related data (as retrieved by the DIM web service) to create a special database with indexed DICOM attributes. This database is then available for complex queries to any third party application via SOAP/XML communication. The attribute database maintained by the DQM web service is based on the dynamic model shown in Figure 2. It should be noted that the database model does not follow the DICOM patient-study-series relationship structure, but it is a fully dynamic model where no attribute based tables are used. Each DICOM attribute is represented by an object defined by its tag, tag value, data type, and related references.

Thus the model can be dynamically expanded to support vendor-reserved tags, new additions to the DICOM protocol (i.e. new attributes in newly defined objects), as well as additional user defined attributes (such as comments and task related flags).

In both web services, different access privileges are supported via a policy module which takes into account administrative information about the user (either client application or end-user of the client application) and the target DICOM server. Common to all methods exposed are certain input options that address security, privacy and management issues. In this respect, every method call requires inclusion of username (client application or end user specific) and password. Additionally, an optional list of target DICOM servers might be included. Finally, data anonymization can either be requested at method call, or be imposed by the web service itself following preset policies that take into account several factors such as the target DICOM server, the client application, the end user of the client application, etc.

A detailed technical description of the proposed web services can be retrieved from http://iris.med.duth.gr/, together with the corresponding WSDL documents that formally described the web service methods. Using these WSDL documents, software developers of third party applications can build the appropriate SOAP messages to invoke and consume the web services. It should be noted, that most current Integrated Development Environments (IDE) can generate automatically the required SOAP messages out of the WSDL document.

4. Implementation Issues

The web services described in this paper have been developed in C# using the MS .Net Framework 1.1 (Microsoft, Redmond, USA) and use the DICOM library DicomObjects 4.1 (Medical Connections, Reynoldston, UK). System requirements at runtime include the MS Internet Information Server >5.x, MS .Net Framework 1.1, and MS SQL Server 2000 Desktop Engine (Microsoft, Redmond, USA). Basic security is achieved through the Secure Sockets Layer encryption mechanism for data transmission, as provided by the Internet Information Server, and this is enhanced by user authorization processes. An asynchronous communication pattern is used to enhance the scalability and reliability of the web service environment and enable long running operations. This may prove especially valuable in cases of wireless connections (e.g. handhelds), allowing the client application to move seamlessly across various network cells (or on and off the network).

For demonstration purposes, a fellow software developer not acquainted with the DICOM standard was asked to build a web-based application for complex searches in DICOM repositories mainly to support physics and medical research in magnetic resonance imaging, solely by employing the proposed web services environment. Such an example complex search could be "get all pelvis MR images performed between July 2004 and September 2004 with the torso receiving coil and echo planar imaging pulse sequence" in order to check for possible image artefacts due to a malfunction of the specific receiving coil that was discovered retrospectively.

This demo application was developed using the open source content management system DotNetNuke 3.1 (Perpetual Motion Interactive Inc., Abbotsford, Canada), based on the ASP.NET platform (Microsoft, Redmond WA, USA) for the MS Internet Information Server >5.x (Microsoft, Redmond WA, USA) and uses the MS SQL Server 2000 Desktop Engine (Microsoft, Redmond, USA). The development process was reported to be simple and uncomplicated and a demo application prototype was completed in a few working days. The demo application is not itself DICOM aware. However, it employs the various methods of the DQM web service to search the DICOM attribute database and engages the DIM web service in order to retrieve related DICOM objects. Figure 3 displays two representative web pages showing the formulation and the results of a query for DICOM magnetic resonance images based on certain technical attributes described in the DICOM object information. The query is formulated as a logical series of attributes values. The attributes contained in the query are dynamically selected from a list of all available attributes for the DICOM MR object. The presentation of the results can also be dynamically formulated to contain only desired attributes.

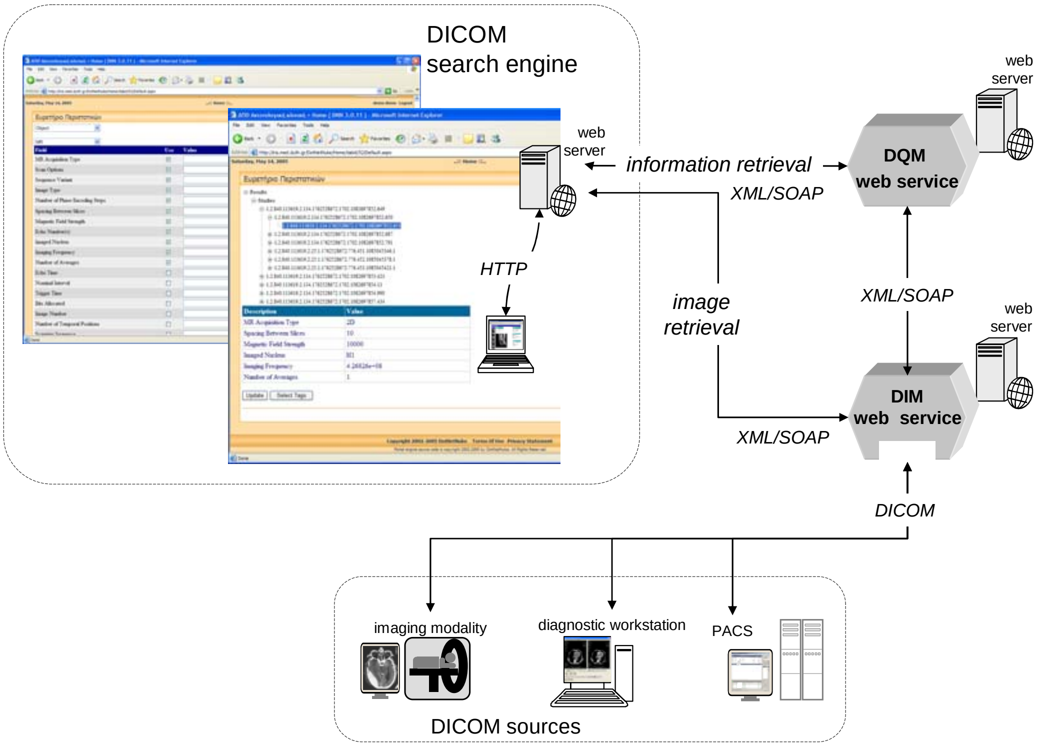

Figure 3 Example of a demo-application engaging the proposed web services environment to achieve web-based complex searches in DICOM databases.

5. Discussion

The proposed web services approach aims to achieve communication and integration of clinical information sources with other applications using Internet standards and commonplace Internet technologies The particular implementation presented in this paper refers to medical image information systems and its goal is twofold: (1) to extend the basic functionality of DICOM protocol (to support patient management in the radiology department) so that research and academic tasks can be performed equally well, and (2) to allow DICOM images and related data to be manipulated by third party applications that are not DICOM aware. Examples of such applications, that do not necessarily implement DICOM, could include Internet based medical e-learning environments, medical research information systems, medical expert systems and other healthcare information systems. The proposed environment can be augmented on demand with additional web services and end-user applications that use the DIM web service to access medical image data from various sources in order to perform more complex tasks, such as data mining and knowledge discovery for epidemiology, research, teaching, and administration purposes.

This work is part of our efforts to seamlessly integrate clinical data into a generic Internet based e-learning environment that will support undergraduate medical education in Democritus University of Thrace, Greece [21]. The project involves the use of open source technologies and off-the-shelve components to deploy an integrated e-learning environment, based on a conventional e-learning platform to support pre-clinical teaching, tightly integrated with teleconferencing technology for the real-time and/or on-demand transmission from an examination room or the operating theatre to the lecture room, to enhance clinical apprenticeship and provide extended real-world experience. At the core of the project is the effort to develop web service façades for legacy healthcare information systems, in order to extract and communicate educational information using common web standards (as opposed to standards proprietary to the medical environment). In this respect, the proposed web service environment is intended to be engaged in order to provide clinical data for a radiology teaching files authoring tool, as well as directly through the integrated e-learning environment for dynamic clinical data retrieval during the instructional process, e.g. to explain how a diagnostic imaging data set is manipulated and reviewed in order to reach diagnosis and construct the final report. The proposed environment acts a middleware to expose the DICOM-specific domain of radiology information systems into commonplace Internet technology, while providing added-value functionality pertaining to research and academic tasks as opposed to patient management. Thus, the developers of applications that support radiology research and education can solely concentrate on the task of data formulation and presentation according to the task at hand.

We strongly believe that this current implementation only scratches the surface of the potential capabilities web services might have for radiology and other healthcare information systems. Adopting an XML/SOAP web service oriented architecture for medical image management and distribution in healthcare intranets and even extranets may have many advantages when compared to traditional system integration and/or simple web-based application interfaces. These include the ability to give compound structure to queries and results, handle complex tasks that require coordination of a number of disparate applications, and implement store and forward techniques. Using a web service façade, traditional DICOM image servers can communicate seamlessly with general purpose research and academic tools (e.g. to create easily searchable clinical data repositories that can support research, teaching and data mining for administrative and clinical protocol planning, budget control, etc). Moreover, providing image data and related information in an XML format supports essentially the ongoing effort to create multimedia patient records and display them easily in various clinical workstations and devices with different display capabilities (from diagnostic workstations, to operating room displays and even handheld devices in wireless networks).

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Acronym Glossary

DICOM: Digital Imaging and Communications in Medicine protocol
HL7: Health Level Seven
HTTP: HyperText Transfer Protocol
IHE: Integrating the Healthcare Enterprise initiative
PACS: Picture Archiving and Communication System
SOAP: Simple Object Access Protocol
UDDI: Universal Description, Discovery and Integration registry
W3C: World Wide Web Consortium
WADO: Web Access to DICOM Persistent Objects supplement to DICOM standard
WSDL: Web Service Description Language
XML: eXtensible Mark-up Language