The Role of Digital Imaging and Communications in Medicine in an Evolving Healthcare Computing Environment: The Model is The Message

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The decision to use Digital Imaging and Communications in Medicine (DICOM), Health Level 7 (HL7), a common object broker such as the Common Object Request Brokering Architecture (CORBA) or ActiveX (Microsoft Corp, Redmond, WA) or any other protocol for the transfer of DICOM data depends on the requirements of a particular implementation. The selection of protocol is independent of the information model. Our goal as message standards developers is to design a data interchange infrastructure that will faithfully convey the computer-based patient record and make it available to authorized health care providers when and where it is needed for patient care. DICOM accurately and expressively represents the clinically significant properties of images and the semantics of image-related information. The DICOM data model is small and well-defined. The model can be expressed in Standard Generalized Markup Language (SGML) or Object Management Group Interface Definition Language or other common syntax—and can be implemented using any reliable communications protocol. Therefore our opinion is that the DICOM semantic data model should serve as the basis for a logically equivalent set of specifications in HL7, CORBA, ActiveX, and SGML for the interchange of biomedical images and image-related information.

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KEY WORDS: DICOM, American College of Radiology-National Electrical Manufacturers Association (ACR-NEMA), HL7, Special Interest Group for Object Brokering Technology (SIGOBT), Image Management Special Interest Group (IMSIG), Object Request Brokering (ORB), Object Management Group (OMG), CORBA, Interface Definition Language (IDL), Microsoft Healthcare Users Group (MS-HUG), ActiveX, SGML, Information Model, Representation Syntax, Communication Protocols, Information System-Imaging System (ISIS), biomedical images.

THE DIGITAL IMAGING and Communications in Medicine (DICOM) standard is the de facto international standard for interchange of biomedical images and image-related information.^{1,2} The DICOM protocol is the industry stan-

dard for network transfer of images in North America, Europe, and Japan. DICOM is endorsed by many leading professional specialty organizations for use in medicine, dentistry, and veterinary practice. There is a large and growing implemented base of DICOM-conformant equipment. Commercial DICOM software tool kits and public domain implementations of DICOM interfaces are readily available.

When the predecessor of DICOM—the American College of Radiology-National Electrical Manufacturers Association (ACR-NEMA) standard—was created, there was no commercially viable alternative protocol for the exchange and representation of biomedical images and image-related information. However, several alternatives are emerging such as the Health Level 7 (HL7), Object Request Brokering (ORB) technology, and the Standard Generalized Markup Language (SGML). This article will explore these options.

HL7 is an American National Standards Institute (ANSI) sanctioned medical information exchange standard that has historically addressed the exchange of inpatient data.³ As HL7 matures, the use has expanded to exchange interenterprise data between healthcare providers and subsystems such as laboratory measurement devices. These sub-

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systems were previously seen as small niche areas of information. There are immense commercial and practical advantages to using a single information standard to encompass all these granularities of information. In this context, HL7 based systems are keenly interested in exchanging information with DICOM based systems. Indeed, HL7 software developers are investigating the delivery of DICOM data through HL7 messages.

Progress in internetworking has lead to the emergence of standard frameworks for distributed computing platforms. At the time DICOM and HL7 were created, the problems of transporting information and achieving connectivity among stand-alone systems were not fully understood. Currently, these problems are considered solved, and the focus has shifted towards achieving interoperability among healthcare applications. These applications will operate in heterogeneous environments and will scale with the growth of the institution boundaries.

ORB technologies promise to provide the software infrastructure that deliver plug-and-play capabilities and address the growth needs for healthcare enterprises. Among the leading object brokering technologies are ActiveX⁴ (previously called OLE) from Microsoft Corporation (Redmond, WA) and Common Object Request Brokering Architecture (CORBA)⁵ from Object Management Group. Businesses which have built end-user applications around ORBs will expect the same standards of interoperability and ease of interconnection when they create healthcare applications.

Finally, the success of the Hypertext Markup Language (HTML) in representing Web documents in a platform independent manner has given renewed life to HTML's umbrella standard, the Standard Generalized Markup Language (SGML).⁶ SGML is used to create information rich, reusable documents in many technical domains, such as aircraft maintenance records. Several efforts are underway in America and Europe to represent the electronic patient record as a set of structured SGML documents. It is only natural for SGML based systems to represent the information carried by the DICOM and HL7 messaging standards within their framework of structured documents.

In our view, the success of these messaging and information standards and platforms within their original domains of application is leading to pressure for the standards to interoperate. Users would like to transport DICOM information content using

HL7, CORBA, or ActiveX. They want to represent DICOM information objects as SGML structured documents. The question is: Can this be done? What will be left of DICOM if they do? Or, bluntly, can DICOM survive in a multiprotocol world?

CURRENT STANDARDS

Before we can answer these questions, we need to provide a common analysis of the contending standards. Standards define an information model, provide a representation syntax, and define the mechanism by which we transfer these representations between systems. For each standard, we ask:

1. Does it provide a specific data model of the information content? Does the standard define the objects of interest in its area of application? For example, does it define objects such as Image, Patient, or Report? We will see that several standards provide the ability to define objects, but they do not define any specific objects.
2. Does the standard provide a way for representing instances of these data objects? What kind of data, such as numeric, string or pixel data, is represented directly? How do we describe the data for a specific instance of a computed tomography (CT) study, including patient demographics and image pixel values?
3. Does the standard provide a way to communicate information between systems? Does it define the rules on how to find a communication partner, and to establish communication with them? Or is the standard silent on these issues, letting the user use whatever techniques that are most appropriate?

DICOM

DICOM is a message standard for the communication of medical images and associated data. The standard provides a common information model, definition of messages, and protocols for communication.

DICOM provides an explicit and detailed model of how real world entities involved in radiology operations are described and how they are related. Entities such as Patient, Image, and Report (to name a few) are defined, and the relationships among these entities are specified. Figure 1 shows a subset of the entity-relationship (E-R) diagram of the information model covered by DICOM.

DICOM calls the objects based on its model

Fig 1. The Entity-Relationship Diagram of the DICOM Information Model.

information objects, and the models and tables of attributes that define them *information object definitions* (IODs). The definition of an image IOD is presented in Fig 2.

Coupled with the definition of the information objects, DICOM defines application services. These services offer a DICOM application the ability to transfer images and image related data (or more specifically IODs) between itself and other DICOM conformant applications. The combination of an information object and such services is called a service-object pair (SOP). These services support two contexts of interaction, a push mode and pull mode. The basic service is push mode, in which one device simply sends information to another, using

the STORE command of the Storage Service. Pull mode is a more elaborate two-stage process that allows the user first to query a remote device using the FIND command of the Query Service, and then to retrieve the selected IODs using the MOVE command of the Retrieve Service.

A DICOM message consists of a command and an instance of an information object. The message is constructed of attributes having values, with each attribute identified by a tag, as depicted in Fig 3. An attribute is a unit of data (eg, patient name). A tag is a 4-byte number identifying an attribute (eg, 0010 0010H for patient name).

In a DICOM environment the application layer uses four different methods to transfer data. The

Fig 2. Example of a DICOM Image IOD.

network protocols are modeled as a series of layers, often referred to as stacks, as depicted in Fig 4. The following is a list of these methods:

1. The ACR-NEMA Version 2.0 stack that defines a point-to-point connection.
2. The Transmission Control Protocol/Internet Protocol (TCP/IP).
3. The International Standards Organization-Open Systems Interconnection (ISO-OSI).
4. Off-line storage on removable media for manual transport.

The basic design philosophy was that a given biomedical image application (that is outside the scope of the standard) could communicate over any of the stacks to another device that used the same

stack. With adherence to the DICOM standard, it would be possible to switch the communication stacks without having to rewrite the applications.

The first versions of the ACR-NEMA standard defined a 50-pin hardware interface for point-to-point connections. There are few applications, particularly connecting to older equipment, that use this interface. For this reason, this older protocol is becoming extinct. The ISO-OSI has the same fate as the point-to-point protocol as most commercially available implementations use the TCP/IP stack. DICOM off-line storage enables users to manually exchange DICOM files on removable media. A DICOM file can include not only images but also related information that distinguishes one

Fig 3. Structure of a DICOM Message.

Fig 4. The DICOM Communication Protocol.

image from another (eg, pertinent details of the performed procedure, interpretation text, or the format setting for printing).

HL7

The HL7 information model mainly addresses the inpatient issues of Admission Discharge and Transfer (ADT), Orders, and Observations. With each release, HL7 extends its scope. Version 2.3 adds support for clinical trials, medical records, patient care planning, scheduling, and referral.

HL7 encodes data into a human readable character stream. HL7 messages are variable patterns of segments, each segment containing a predefined sequence of fields. The emphasis in HL7 has not been in formalizing many of the lower level details of how to establish connections between systems. It casually assumes the use of TCP/IP or any reliable transport to carry the data from system to system. The "Seven" of HL7 refers to the application layer, level 7, of the OSI protocol stack. HL7 views the communication layers as merely transporting an HL7 formatted payload.

HL7 is developing its Version 3.0, which will be based on an entirely new object-oriented, model-based design.⁷ It will explicitly accommodate a number of transport and data representation mecha-

nisms, including an ASCII character based one, and the use of CORBA and ActiveX.

The HL7 Standard Committee released Version 2.3 in May 1997.³ This version specifies a data type for *opaque encapsulation* of binary objects and a reference pointer mechanism to denote them. Many HL7 systems, rather than migrating immediately to an object broker architecture, will begin to use gateways to encapsulate DICOM messages into HL7 syntax binary objects. HL7 will then carry these DICOM payloads throughout the HL7 sphere of influence. However, the structured information and pixel data within the payloads will not be available to normal HL7 applications. Only applications with knowledge of DICOM data representation will be able to extract the data.

Meanwhile, progress is underway to integrate DICOM and HL7 at the information model level. HL7 has formed an Image Management Special Interest Group (IMSIG) to map the DICOM model to Versions 2.x of the HL7 Standard. In this approach, DICOM studies will be represented as native HL7 observation reports. The IMSIG has submitted the DICOM Information Model to HL7 for consideration as the imaging component of the HL7 Version 3.0 Reference Model. In agreement with the IMSIG, we suggest that HL7 carefully

consider adopting the DICOM information model of the imaging domain—including the DICOM extensions for structured reporting^{8,9} of image-related observations that are not currently supported by the HL7 Version #2.x. These include the ISO unique identifier schema, and the standard support for DICOM object-instance references. There will be a common area between the DICOM and HL7 information models that will be harmonized. However, DICOM will maintain its distinct information model around images and image related data.

CORBA

The OMG was formed in 1992 as an international consortium of over 600 companies involved in development of computing systems and software. The mission of the group is to define nonproprietary (platform, programming language, and network protocol independent) consensus standards for distributed object management. The suite of standards produced by OMG is known as CORBA. CORBA standards will allow system developers to address the growth of their software over heterogeneous computing platforms. It specifies common services and facilities that will ease the development process, such as directory services, time services, and security services. The key to CORBA is the Interface Definition Language (IDL). IDL is used to describe the interface to an application or to the objects within an application in a programming language independent manner. CORBA does not itself define any particular data objects. Objects themselves are defined by specific vertical domain task forces.

CORBAMED⁴ is a vertical domain task force of the OMG that uses CORBA technologies for interoperability throughout the global healthcare community. It will issue Request For Proposals (RFPs) to standardize the IDL interface to healthcare objects. The Biomedical Imaging Working Group of CORBAMED has acknowledged DICOM as the prevailing message standard for biomedical imaging. In order to ensure compatibility between message-based and object-broker mediated systems, CORBAMED will specify that CORBA-conformant imaging applications conform to the DICOM information model.

The HL7 Special Interest Group on Object Brokering Technology (SIGOBT) has defined a framework for representing HL7 messages, seg-

ments, and fields as CORBA IDL and Microsoft ActiveX representation. The SIGOBT framework does not alter or contribute to the HL7 information model. It defines how to use the HL7 information model in conjunction with the component interface representations and transmission machinery.

ActiveX

ActiveX is a Microsoft standard competing with CORBA to provide a software platform that will allow software components to collaborate. Historically, ActiveX was called Object Linking and Embedding (OLE) facilitating the integration of multiple applications and multimedia data types at the desktop level. ActiveX is the new version that extends the original OLE features over the network to support distributed components. The Microsoft Healthcare Users Group (MS-HUG) was launched from the podium of the 1995 Healthcare Information and Management Systems Society (HIMSS) annual conference by Bill Gates, who opened the conference as the keynote speaker. He recognized that MS-HUG would be a clear declaration of Microsoft's commitment to the healthcare industry. This group encourages the interaction among its members in the direction and application of Microsoft's ActiveX technology. Like CORBA, ActiveX also does not define any particular information content. It provides the ability to define objects, then concentrates on support for object sharing and interaction.

The MS-HUG has been very active in the HL7 SIGOBT, providing technical and marketing support for the ActiveX efforts. Developers find significant value from the general-purpose ActiveX objects being offered commercially. Commercial objects that deliver functionality required by an application can significantly reduce development time. Healthcare specific objects are beginning to appear.

So far most efforts to use ActiveX have focused on using the HL7 information model. As with CORBA, as described in the previous section, the SIGOBT mapping approach does not utilize the full expressiveness of ActiveX to define objects. The mapping simply defines how to represent HL7 message objects as ActiveX objects. The next logical step for both component technologies is to define the mechanism for representing objects drawn from the DICOM information model.

Standard Generalized Markup Language

The SGML is a well established international standard. SGML is a metalanguage that defines the rules for creating a document grammar; it does not specify document structures or tag semantics. Furthermore, SGML does not address the transport of documents among applications. SGML grew from the publishing community's need for a system to represent text in machine readable form that was portable across any application or platform and that would be stable over time. SGML has a large user base in many industries. Its use in the healthcare industry is growing rapidly.¹⁰ In 1996 an organization was formed to standardize the use of SGML in healthcare applications. This group has since become a formal component of HL7 as the HL7 SGML Special Interest Group. There are currently four primary areas where SGML has been applied in healthcare: medical publishing, new drug submissions, clinical practice guidelines, and patient health records. The HL7 SGML initiative is developing the architecture to enable message transport applications and is assuring compliance with the HL7 reference information model.

DICOM requires many features of a markup syntax that can be readily expressed by SGML. The recent announcement of a DICOM conformant plug-in for Netscape will enable radiology reports and images to be readily viewable from a web client. HTML is a limited application of SGML syntax. A new SGML initiative, eXtensible Markup Language (XML), will be supported directly by Microsoft's Internet Explorer so that XML/SGML documents will be web-ready.

Work should continue on the harmonization of data models. We suggest that SGML syntax could serve as the normalized representation of DICOM and HL7 information structures—eliminating the need for pair wise translations between them.

Summary of Current Standards

We have examined each standard in terms of its definition of an information model, data representation, and transfer mechanism. Table 1 shows the coverage of each standard. Both DICOM and HL7 define an information model for their domains of interest. CORBA and ActiveX do not define any particular information content. They provide the ability to represent the information objects and a mechanism to transfer them. Finally, SGML pro-

Table 1. Summary of Features

Standard	Information Model	Representation Syntax	Transfer Mechanism
DICOM	✓	✓	✓
HL7	✓	✓	✓
CORBA		✓	✓
ActiveX		✓	✓
SGML		✓	

vides a syntax that can be used by all other standards.

OUR MODEL OF INTEROPERABILITY AMONG STANDARDS

In this section, we describe how standards can interoperate. Given that a standard defines a set of objects, gives a specific way of representing objects on the computer, and defines conventions for exchanging objects, how can different standards interoperate? There are three primary techniques:

1. Tunneling/Encapsulation: Treat data from one standard as a payload, and carry it, without interpretation, via the carrier standard. For example, we could take a file in DICOM file format, encode it as a single large HL7 encapsulated data type value, and use HL7 to carry it between systems. A DICOM parser is required to extract the information from the encapsulated data type.
2. Re-Expression/Mapping: Take the data elements of one standard and represent them using the rules and style of the outer standard. Re-expression refers to the representation of data elements from one standard in another while preserving the original semantics. For example, a DICOM IOD and its tag-value pairs could be expressed as an SGML entity, with SGML tags for each tag from DICOM. Because there are no existing SGML tags for such purpose, new ones need to be created and the semantics of DICOM will be preserved. Mapping occurs where there are semantic differences or ambiguities between corresponding data elements in the two standards. DICOM Data elements need to be mapped to HL7 data elements since the semantics are different for some data elements.
3. Harmonization: Make the data model of one standard be a subset or extension of the data model of the other standard. When standards share information models, information can be

Fig 5. The Evolution of the DICOM Communication Protocol Model.

represented and communicated without loss of fidelity using either standard.

The traditional DICOM approach, as illustrated in Fig 4, is to encode the DICOM information model using a DICOM representation syntax and transported through a variety of communication stacks. The evolution of DICOM would mean that the information model can be encoded in a variety of representation syntaxes and transported over a variety of transport mechanisms, as illustrated in Fig 5. In a CORBA environment, DICOM objects are defined using IDL and are transported using the Internet Interoperability Protocol (IIOP). When CORBA is used to tunnel DICOM objects, the IDL interface defines an uninterpreted opaque string object to carry DICOM IOD's encoded in the DICOM file format. When the IDL is used to explicitly represent DICOM IOD's, the specification will contain IDL level interfaces such as Patient or Image to represent the corresponding DICOM IODs. DICOM information will be naturally accessible as IDL attribute values. ActiveX provides similar mechanisms to CORBA in its ability to tunnel and re-express DICOM IODs. SGML provides another representation syntax that can be used to express DICOM information objects. These objects may be transported using the HTTP protocol. As previously stated, HL7 can be used to tunnel DICOM entities. Additionally, DICOM elements can be mapped to HL7 elements,

which are encoded and transported as HL7 messages. The HL7 IMSIG is working on this mapping.

We suggest a "first hop principle" to describe the domain of the DICOM protocol, as it exists now. We suggest that the DICOM protocol should remain the primary protocol for the first hop from the backplane of image acquisition equipment or image interpretation workstations to image management systems. Image management systems should deliver images to other destinations by whatever protocol is most effective. This recommendation is based on our opinion that the most enduring and valuable aspect of the DICOM Standard is not the protocol itself, but the semantic data model (information model) that underlies it. Because the DICOM information model was carefully crafted to serve the needs of the Radiology community (Fig 6), we suggest that it be adopted as the convergence data model for image-related specifications of any data interchange standard for transactions in the biomedical imaging domain. This recommendation considers backward compatibility with the installed base of DICOM interfaces and enables orderly expansion of vendor product lines to include additional protocols.

CONCLUSION

More work is needed to harmonize the prevailing perspectives of the interaction model for Informa-

Fig 6. The Evolution of DICOM in Clinical Environments.

tion Systems and Imaging Systems. We suggest that CORBAMED, DICOM, and HL7 develop a unified interaction model for the Information System-Imaging System (ISIS) interface (Bidgood WD Jr, unpublished manuscript). In our opinion, the interaction model notation of the HL7 Message Development Framework would be a suitable normalized representation for this purpose. Controlled terminology is another area in which continued cooperation is needed. We suggest that HL7 harmo-

nize the design of its proposed controlled terminology resource with the SNOMED DICOM Microglossary¹¹—and that both the HL7 and DICOM controlled terminology resources be compatible with the proposed “Terminology Resource for Message Standards.” Finally, we suggest that the DICOM, HL7, and CORBAMED Standards should include specific references to jointly-developed convergence specifications, to facilitate interoperability across protocols.

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