DICOM Media Interchange Standards for Cardiology: Initial Interoperability Demonstration

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The first multi-vendor demonstration of digital exchange of cardiac image data was held in conjunction with the annual scientific sessions of the American College of Cardiology (ACC) in March, 1995. This was the culmination of several years of effort by the ACC to help extend the DICOM standard to be suitable for cardiac images exchanged on removeable media. The software was designed to help system implementors with little or no DICOM experience quickly acquire this technology. File content can be specified and manipulated in human-readable form, and converted as needed to its binary equivalent. Images were selected from those submitted from a varierty of sources, and a recordable CD (CD-R) created with 30 echocardiograms and 30 angiograms). A prototype display program was created that reads the DICOM directory ("DICOMDIR"), allows user interaction, and decompresses the image files. This paper describes the ACC's interoperability demonstration with 29 vendors, the CD-R of images that was used, and the software used by the participants .

INTRODUCTION

There continues to be a proliferation of digital technologies within the cardiac catheterization lab, as well as with other cardiac imaging modalities (such as echocardiography, nuclear, etc.). Despite continued efforts to move from cine film to all-digital approaches, there has to date not been adequate means for exchanging images between institutions in digital formats. Whatever limitations exist for cine film, it remains a universal medium, and one that can be viewed anywhere in the world. Until similar capabilities exist for digital studies, the goal of the filmless cardiac catheterization lab cannot be realized.

In 1992, the American College of Cardiology (ACC) recognized this problem and began to help establish standards for digital storage of cardiac studies. This paper briefly describes those efforts, along with the first major demonstration of image exchange capabilities, a demonstration that was termed Digital Interchange Standards for Cardiology (DISC'95).

STANDARDS EFFORTS

The National Electrical Manufacturers' Association (NEMA) and the American College of Radiology (ACR) began work in 1982 on developing a standard for the digital exchange of medical images. The resulting ACR/NEMA standard was first released in 1985, and subsequently revised in 1988. In the most recent release, the standard has been renamed to "Digital Imaging and Communications in Medicine" (DICOM). This standard extends the earlier ACR/NEMA work in several ways, using industry standard networking protocols, specifying mechanisms for image storage on removable media, adding additional imaging modalities, and including information about services to be performed on the data. As the major image standard for medicine, DICOM is therefore a key component to be addressed within the broader concept of the Computerized Patient Record.

The ACC has been working with NEMA and ACR to help refine standards for the digital storage and interchange of *cardiac* images. The initial effort was for x-ray angiography, with a parallel effort coordinated through the American Society of Echocardiography for cardiac ultrasound. A strong emphasis of this effort has been standards for exchanging images on removable media. Many DICOM networking implementations exist, and these capabilities have previously been featured at inter-operability demonstrations. The work presented in this paper focuses on the creation of DICOM *files* for storing cardiac image data, and on the collection of these files for exchanging data without the need for network connections.

DICOM CONCEPTS

While the specifications in the DICOM standard as published are very complete[1], little has been written in the way of general introductions to the concepts behind the standards.[2] Furthermore, DICOM networking discussions do not help to understand the concepts underlying the formation of DICOM files. This section briefly introduces some of the concepts of DICOM files containing cardiac images.

The smallest piece of information handled by DICOM is called an *attribute*, and is specified as the combination of an attribute *tag* and its associated

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value. The *tag* is specified as a pair of 16-bit integers, one representing the attribute's *group*, and one representing the *element* number within the group. There are 24 data types defined for the data values, referred to as *Value Representations* (VR's), with strict definitions of how each data type is represented and stored.

Table 1 shows some sample attributes. VR's shown include Unique Identifier (UI), Date (DA), Short Text (ST), Person Name (PN), and Integer String (IS).

Table 1. Typical DICOM Attributes

(group,element)	VR	Description
(0002,0010)	UI	Transfer Syntax
(0008,0020)	DA	Study Date
(0008,0070)	ST	Manufacturer
(0008,0090)	PN	Referring MD
(0018,1063)	IS	Frame Time

DICOM defines an information model that is object-oriented, based around a collection of information referred to as an *information object*. An Information Object Definition (IOD) specifies the lists of attributes that are used to describe a given object (such as an x-ray angiographic image, an ultrasound image, etc.). Attributes are grouped into modules for convenience, and each IOD can therefore be described as a collection of selected modules.

X-Ray Angiography

The X-ray Angiographic Image Object Definition was created using existing DICOM structures and tools. The Basic Cardiac X-ray Angiographic Application Profile describes the exchange of digital cardiovascular x-ray data. Images are represented by a 512 X 512 pixel matrix with 8 bits of gray scale resolution[3] (further definitions that allow larger images with greater pixel depths are still being refined, and were not part of this demonstration). This resolution was chosen as typical for current digital systems[4], and sufficient to provide diagnostic-quality images[5].

Lossless data compression is used to increase the effective storage capacity of the disk and the image retrieval rate. This reduces storage requirements for an image, but allows the original image to be accurately recovered by decompression, and does not restrict subsequent digital image processing. Lossy compression was not felt to be acceptable as a standard for x-ray angiography, as the clinical utility of a suitable compression schemes and acceptable compression ratios have not been thoroughly characterized.

The JPEG (Joint Photographic Experts Group) first order differential pulse code modulation with Huffman encoding was chosen as the technique for lossless data compression[6]. This process was selected because of the existence of hardware and software that could handle the calculations, and because the DICOM Standard already contained a syntax for encapsulating JPEG-encoded image data.

Cardiac Ultrasound

Unlike X-Ray Angiography that currently only defines one type of image, the ultrasound part of the DICOM standard allows for several different formats[7]. For the sake of simplicity, only a few of these formats were selected for the initial demonstration (none use compression). These include `MONOCHROME2` (monochrome images, 8-bit), `PALETTE COLOR` (8-bit "indexed color" with corresponding color lookup tables), and `RGB` (24-bit pixels, with red, green, and blue triplets for each pixel).

There are several other features of ultrasound IOD's that are distinctly different from angiographic IOD's. There are distinct formats used for single-frame and multi-frame images (examples of each were used in the demonstration). All `PALETTE COLOR` images (and all color icons) use large color lookup tables (16 bits for each color's entry for each pixel value, rather than a more typical 8 bits per entry).

Removable Media

While the DICOM standard initially focused on network communications, there are provisions for specifying the storage of information in files, and for combining files with a medical directory (called "DICOMDIR"). A DICOM file is simply the information from the corresponding IOD, combined with "file meta information" (a short set of descriptors that provide information about the content of the file). The DICOMDIR file provides a collection of information about the contents of each file in a file set, allowing navigation and queries of the file contents. Previous demonstrations of DICOM capabilities did not exercise these facilities of the standard.

Early on in the standards process, it was recognized that it was not going to be possible to arrive at a single device or storage medium that would be implemented by all vendors as their sole archive strategy. Instead, it was decided to encourage each vendor to pursue their own unique solution to the digital archiving problem, while providing a standardized way for exchanging images[8]. The exchange problem needed to avoid reliance on dedicated network solutions, as this did not fit the current paradigm of image exchange as it is practiced with cine film. In other words, a means of exchanging information with removable media was needed.

Selection of the exchange medium was a challenging task, and a large variety of digital storage technologies were considered. After lengthy discussion and debate, the recordable 5.25 inch optical compact disk (CD-R) was selected. The storage format on the CD-R is based on international standards, among them ISO 9660. The medium is physically similar to the CD-ROM used in popular multimedia applications. Several critical features of this technology are particularly noteworthy:

- CD-R is a mature, highly standardized technology offering particularly economical data storage. It is used widely in industry (such as multimedia).
- CD technology is expected to continue to improve in coming years, resulting in increased storage capacity and faster data transfer rates.
- The CD-R is a "write once" non-erasable medium, physically robust, unaffected by electromagnetic fields, relatively insensitive to dust and scratching, and is virtually error free.
- The storage capacity of 680 megabytes permits recording of 4,800 frames per disk (512X512), when 2:1 compression is used. This should be sufficient for 99% of all cardiovascular examinations (this figure is based on analysis of 1,200 catheterization studies from 44 institutions).

While CD-R technology lacks sufficient speed to enable direct viewing of angiograms at 30 frames per second, this is not a great disadvantage for a medium intended for exchange, not necessarily for viewing. If this technology were used for direct viewing, current CD-ROM readers could provide replay at about one fourth real time (assuming a 6X reader at 900 Kbytes per second, and 2:1 lossless compression).

SOFTWARE DESIGN

In designing the software to support this demonstration, it was necessary to account for varying levels of sophistication of the participants. Many of the vendors that wished to show their support of the standard had little or no in-house expertise or experience with DICOM. They needed help understanding the components of a DICOM file, and the contents of a DICOMDIR file. The resulting system design for the creation and display of the DICOM data takes this into account.

A Strategy Using ASCII Source Files

A simple utility (`build`) is used to translate ASCII "source" files containing DICOM attributes into the corresponding DICOM files. In a sense, this is roughly analogous to the process of converting a program written in human-readable form into its corresponding binary representation. It is *not* intended for the `build` program to have a significant understanding of IOD's, or even of DICOM protocols. This knowledge is encapsulated in the source files. No checking is done, for example, to see if a Type 1 field has been omitted. It is the responsibility of the author of the source file to assure the completeness of the data that is presented to the `build` utility.

There are two very strong advantages of this approach: simplicity and self-documentation. The simplicity of the approach should be obvious. The complexity of the `build` program is minimized, and a simple linear translation of ASCII to DICOM is accomplished. The self-documentation aspect refers to the fact that the source file very completely describes (in human-readable form) the contents of the corresponding DICOM file. Even a casual reader will immediately see what has been included in each file.

A simple syntax was developed for specifying the information in the source files, resembling that which would be used in a symbolic assembler. The features of this syntax and its associated `build` utility that translate it include:

- Locations in the source file can be labeled, allowing for symbolic referencing for offsets and length calculations.
- Free use of comments to document the content.
- Intelligent generation of offset tables for pixel data (an entry in the table for each frame of a multi-frame sequence).
- Automatic inclusion of the Value Representation (VR) in each attribute specification of the compiled DICOM file.
- Adjustment of byte-ordering (for "Big-Endian" or "Little-Endian" machines), based on the values specified in the source file.

A matching `parse` program was created to reverse the actions of the `build` program, allowing contents of DICOM files to be examined. This program was also used to edit DICOM files submitted by vendors, as the output of the `parse` program is a source file that can be edited and used directly as input to the `build` program.

Generating DICOM Files

Multiple hospitals, equipment manufacturers, and research institutions submitted images for consideration for inclusion in the demonstration. These images were screened by members of the ACC, and forwarded in digital format to the Brown University Institute for Medical Computing for conversion to DICOM format. Many of the ultrasound files had already been converted to DICOM format by the manufacturers, but their content was edited to conform to the selected model of showing images from a single patient (some images also had to be edited to remove vendor or patient identification).

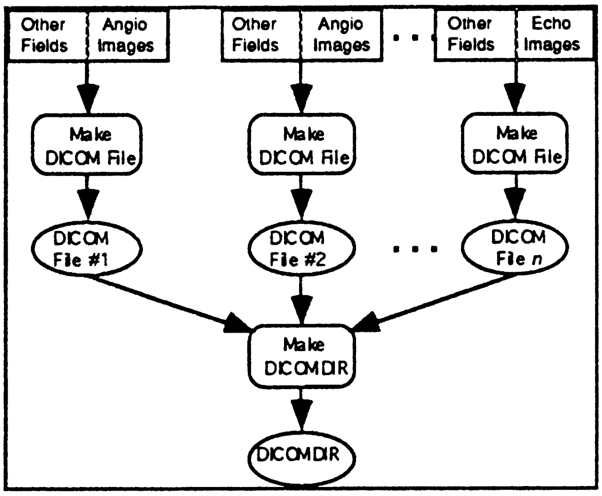

Figure 1: The steps used to create DICOM files

The general procedure used to process x-ray angiographic data is shown in Figure 1. The raw image pixels were stripped out of the submitted digital angiograms, then compressed. The utility that performed the lossless JPEG compression also created an offset table, showing the location of each frame of the multi-frame sequence within the compressed data stream. The offset table, compressed pixels, and additional attributes (in the source file) were then processed by the `build` utility to produce the final DICOM file. The offset table was modified in the process to account for the delimiters that had to be added to conform to DICOM specifications for compressed pixel encoding. The raw pixels were also used to create an icon image for each sequence, using 4:1 averaging to produce the icon (128 X 128).

The DICOM Directory: DICOMDIR

A collection of DICOM files (known as a "File Set") must have a directory file associated with it on removeable media. This file, called the "DICOMDIR", provides information about four levels of objects: patients, studies, series, and images. The information contained within DICOMDIR is formatted as a multiply-linked list that implements a directory tree. There is an initial pointer to the first directory record (the first patient).

This file is itself a DICOM file, and follows the same formats and requirements as other DICOM files (such as having meta information at its head that describes the contents of the file). This means that it can be built using the same approach as was used for other DICOM files, namely, creating its specification in a source file, then using the `build` utility to convert it to its binary equivalent. This approach was particularly helpful for DICOMDIR, as the cross-linkages that are required could be easily examined in the source file, helping those who were new to DICOM understand the construction of the DICOMDIR.

The Demo Program

A prototype image display program was created and provided to the 29 participants of the demonstration. It was intended to be used as the starting point for programs to display images from the CD-R. The main purpose of the program is to show how to read information from within a DICOM file, and how to interact with the DICOMDIR file.

This program is designed to "flatten" the directory hierarchy into a simple linked list. Each record in this list uniquely describes all of the directory information that has been provided about a given image file (remember that the DICOMDIR contains many fields of descriptive information at various levels.

All of the programs were developed under DOS 6.2 using the Borland C compiler, version 4.0. Every effort was made to restrict the code to standard ANSI C, with no operating system, Posix, or other language or system dependencies. Extensive use of type casting, together with strict error and syntax checking helped to minimize warnings on other systems (but did not always totally eliminate compiler warnings). Each program can sense whether it is running on a Little-Endian (Intel-like) or Big-Endian (Motorola-like), and handles the data files accordingly (it was *not* necessary to modify the source code or any `#define` statements for it to compile on the different Endian systems). The programs were tested and run successfully under Unix on a Sun workstation (SunOS 4.1.3 on a Sparc 10), and under Macintosh System 7.1 with CodeWarrior 4.5 (with ANSI C library).

DISC'95 DEMONSTRATION

The first multi-vendor demonstration of the exchange of cardiac image data among vendors was held in conjunction with the annual scientific sessions of the ACC in New Orleans in March, 1995. The demonstration, known as "DISC'95" (Digital Interchange Standards for Cardiology), showed how a CD-R can be used for exchanging images on a single patient between institutions.

The software to support the demonstration was written by the Brown University Institute for Medical Computing, and was supplied to participating vendors to assist with their preparation for the demonstration. The software has now been placed in the public domain, with copyright maintained by the Brown University Institute for Medical Computing and the American College of Cardiology. This process is intended to mirror that used by the Radiological Society of North America (RSNA) and Washington University's Mallinckrodt Institute of Radiology in the software to support the InfoRad demonstrations of DICOM networking.

For the demonstration, there was a large-scale "pressing" of 5,000 CD-ROM's of the file set so that adequate numbers of the discs were available for meeting attendees, vendors, and ACC officials. The differences between a CD-R and a CD-ROM are technical with regards to their method of recording, do not effect the reading of the discs.

Of the 29 vendors who signed up for the demonstration, two made no plans to exhibit anything at the ACC meetings (presumably joining the effort to have early access to the software and images). Of the remaining 27 vendors, one joined the process only three weeks before the meeting, and did not have a computer at their booth showing DISC'95 images. All of the remaining 26 vendors had computers showing images from the CD-ROM. There were 16 systems shown using Pentium-based PC's (13 using Windows, 3 using DOS), 2 systems using an Apple PowerMac, 6 Unix-based systems (4 on Sun workstations, and 2 on an HP workstation), and 2 systems on proprietary platforms. All showed the ability to interact with the contents of the DICOMDIR, and to display appropriate images (some x-ray vendors did not display color ultrasound images).

SUMMARY

Several years of work extending the DICOM standard for cardiac imaging has culminated in a large multi-vendor demonstration of cardiac image exchange. Software was provided to all participating vendors, and even those with little previous DICOM experience were able to show their support of the standard and their ability to read and display the images provided by the American College of Cardiology. This software has now been placed in the public domain, further encouraging the dissemination and implementation of the standards. Plans are already underway for "DISC'96" to be held in Orlando at the 1996 annual meeting of the American College of Cardiology. This will be a demonstration of both reading and writing CD-R's, and will feature biplane angiography, larger image formats, pixels deeper than 8 bits, and will add nuclear cardiology and hemodynamic data.

References

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