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Progress in extending DICOM to media interchange.

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ABSTRACT

The original ACR/NEMA standard, and the more recent DICOM 3.0 standard, address the issue of exchanging images over point-to-point interfaces or across a network. They did not envisage the exchange of images on media. Subsequently the DICOM standard was expanded to define an extensible mechanism for recording images and associated information on interchange media. Interoperability is achieved by defining application specific profiles that specify which medium, which recording format, and what kind of images may be recorded.

Keywords: ACR-NEMA, DICOM, media, image, interchange, archive

1. INTRODUCTION

Widespread adoption of the DICOM 3.0 standard[1] has greatly increased interoperability of acquisition devices, archives and workstations from different vendors. This interoperability is provided over a network connection using standard underlying protocols such as TCP/IP, with higher level protocols and encoding suitable for the storage of medical images and accompanying information as specified in the standard.

1.1 Role of media

In some circumstances where interchange of images is required, use of a network connection may not be appropriate. There may be no sufficiently reliable or cost-effective communications channel of sufficient bandwidth, such as when transnational or international transfer of large volumes of images is required, or where transfer of images from very remote areas is considered. Physical transport of media may be more cost-effective than use of a live connection. In addition, there may exist certain clinical contexts in which it is appropriate to create a record of a study on media for subsequent use at sites in an organization where network facilities are not available or are not sufficiently sophisticated, for instance at clinical meetings, in a healthcare provider's home or office, or in treatment areas. Research and teaching applications typically involve the exchange of large volumes of images off-line without urgency and within strict cost constraints, and the use of standardized interchange media in this application may provide significant benefit. The importance of standardization becomes especially apparent when conducting multicenter and international studies.

1.2 DICOM standard approach

In addition to an upper level network protocol, the DICOM standard defines a comprehensive object definition for most modalities and a set of encoding rules that are not dependent on the underlying transport mechanism. Recording of DICOM image datasets on media is therefore relatively

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straightforward. Extensions to the base standard are necessary to define what physical media are used and what logical filesystem is to be recorded on the media to organize DICOM datasets encapsulated in conventional files. Standard consumer industry media and filesystems were chosen to maximize interoperability across conventional platforms. Particular emphasis is placed on recordable Compact Disc (CD-R) and Magento-Optical Disk (MOD) as physical media. A DICOM Directory File organizes images recorded using the conventional filesystem into a clinically useful patient/study/series/image hierarchy.

1.3 Negotiation and conformance

One of the features of the DICOM protocol is the ability to negotiate capabilities, and in particular what kinds of images are supported (for example, modality specific image storage service classes), in what role, and with what encoding (Transfer Syntax), including options for uncompressed or compressed encoding. When DICOM datasets are recorded on media, the opportunity for negotiation is no longer present, and some indication must be present on the media as to what class and what encoding are used. The approach chosen was to prefix each dataset with a Meta-information Header that specifies this information.

Another consequence of the absence of live negotiation is the need to establish a conformance mechanism that will ensure media is interchangeable. With networked DICOM equipment, review of the supported service classes, roles and transfer syntaxes described in the mandatory DICOM Conformance Statement allows the equipment integrator to determine in what manner two devices should interoperate. The applications themselves negotiate when as association (connection) is established to determine the most appropriate manner in which image exchange will take place. To limit the number of options that a DICOM media application must support for a particular clinical context, so called Media Application Profiles are specified that restrict the choice of physical media, logical filesystem, transfer syntax, and supported image types and characteristics. A DICOM Conformance Statement for a media application will specify in the statement which profile will be supported, and in what role, as a creator, reader or updater.

1.4 Standard Media Application Profiles

Currently there are four categories of standard Media Application Profiles either in the standard, or in the process of being defined:

- Angiography on CD-R
    - Basic Cardiac Angiography
    - 1K Angiography
    - Dynamic Cardiac Review
- Ultrasound on CD-R and MOD
- General Purpose CD-R
- CT/MR on MOD

1.5 Media demonstrations

In order to promote the DICOM standard and increase awareness of its features in the user community, demonstrations have been organized at national and international meetings of major professional societies, such as the Radiological Society of North America (RSNA), the European Congress of Radiology (ECR), the American College of Cardiology (ACC), the European Society of Cardiology (ESC) and the Society of

Nuclear Medicine (SNM). This approach worked well with the DICOM image storage over networks and has been equally successful with the promotion of the new media standards.

2. DICOM MEDIA FORMAT

2.1 File encapsulation

A DICOM dataset consists of a message containing a stream of tagged attributes. In addition to an image pixel data attribute, there are other attributes that describe the type and form of the image pixel data, modality specific technique information, descriptive information, patient demographic information, and information system related information. It is the presence of this additional information that makes a DICOM dataset recorded on media suitable for clinical applications, as opposed to a more conventional, general graphics image file format. In some cases it is possible for the dataset to be recorded such that the image pixel data is accessible both as a DICOM File, and as a more conventional format, such as a Tag Image Format File (TIFF)[2].

The encoding of a DICOM data set is specified by a Transfer Syntax. The standard specifies several Transfer Syntaxes to satisfy requirements for baseline interconnectivity with uncompressed image pixel data, encoding of multibyte words in different byte orders (little or big endian), and facilities for lossless and lossy compression using the Joint Photographic Experts Group (JPEG) processes[3], as well as modality specific compression such as Run Length Encoding (RLE) for ultrasound images. These Transfer Syntaxes are fully defined in the standard and referred to by unique identifiers (UIDs) defined in accordance with ISO identifier registration mechanisms[4].

The contents of a DICOM image storage dataset, and in particular what modality specific attributes are present, are defined by the combination of an Information Object Definition (IOD) and a service class, in this case the Media Storage Service Class, which together are referred to as a Service-Object Pair (SOP) class. This SOP class is also identified by a UID.

A single instance of a modality specific SOP class is stored in a DICOM file, and will contain one single frame image or one multiframe (cine) image, depending on the IOD of the SOP class. The dataset will have prepended to it a File Meta-information Header that will specify, amongst other things, the UID of the Transfer Syntax and SOP Class of the following DICOM message. In order to allow the DICOM file to masquerade as another, conventional, file format, an initial 128 byte preamble is present whose contents are ignore by DICOM File-set Readers (FSRs), and may be used, for example, as a pointer to a TIFF Image File Directory (IFD) following the DICOM dataset. This layout is illustrated in Figure 2.1-1.

2.2 DICOM directory

The DICOM standard specifies that each file will contain a single instance of a stored single frame or multiframe (cine) image. The conventional filesystems recorded on the media provide no mechanism for the organization of the image files other than by file names of limited length in a conventional hierarchical directory structure. To support such conventional file structures, the naming convention is restricted to the least common denominator supported by all platforms.

The need to organize images to meet clinical needs is satisfied by the DICOM Directory File (DICOMDIR file), which is itself a DICOM file. It contains a conventionally structured DICOM message recorded in Explicit VR Little Endian Transfer Syntax. It specifies a patient, study, series and image hierarchy that references the individual image files, as illustrated in figure 2.2-1. The directory entries are organized as items of a sequence with byte offset pointers encoding a tree.

The presence of a DICOMDIR avoids the need to scan every file on the media to build a browsing mechanism to present to the user, and provides a central repository for updates.

An alternative approach would have been to store multiple images within a single file with an internal directory structure. Such an approach was considered but rejected. It is used in the Papyrus[5] format, which uses the DICOM File Meta-information Header and Transfer Syntaxes, but is incompatible with standard DICOM SOP Classes and Media Application Profiles.

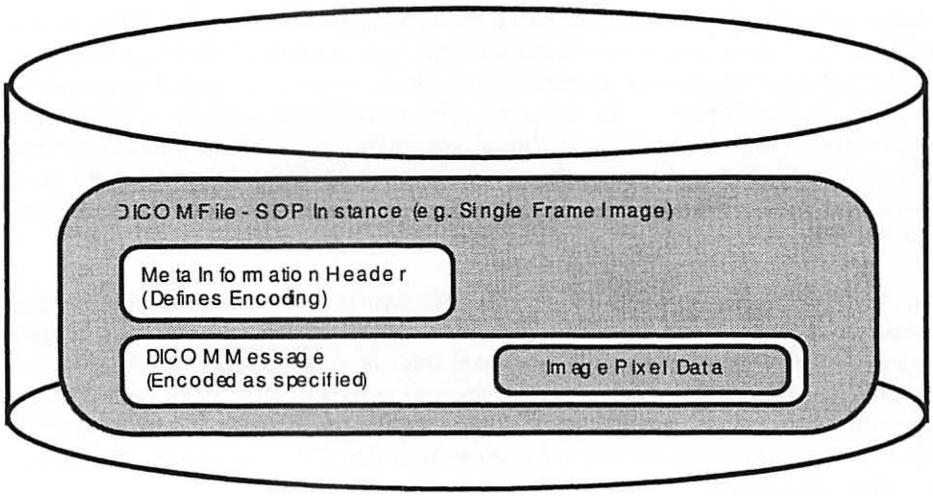

Figure 2.1-1 DICOM File encapsulation

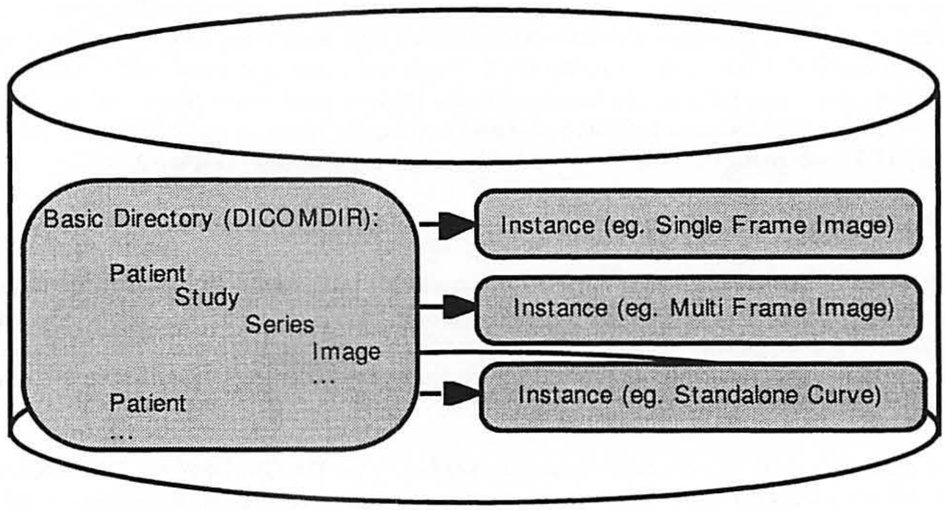

Figure 2.2-1 DICOMDIR File

3. MEDIA APPLICATION PROFILES

The key to interoperability of DICOM interchange media is the requirement for strict conformance to Media Application Profiles. These profiles define for a particular clinical context what is recorded on the media. Such a profile specifies:

- which SOP classes are supported (required or optional) for readers, creators and updaters,
- what Transfer Syntaxes are supported (required or optional) for each SOP class and role,
- what physical media and logical file system is used,
- what restrictions or additional requirements are placed on attributes in the DICOMDIR and objects.

The DICOM Conformance Statement for a device or application is required to reference such a profile, and in some cases elaborate on specific conformance issues. Note that the recording of DICOM messages in the encapsulated DICOM File Format with a File Meta-information Header is ***NOT*** by itself sufficient to claim conformance with the DICOM standard, as this would preclude interchange of media due to the plethora of possible permutations of media, filesystems, SOP classes and Transfer Syntaxes that would have to be supported by a File-set Reader.

Note also that it is the application or device creating, updating or reading the medium that claims conformance to an Application Profile, not the medium itself. Indeed a piece of media may have images recorded on it by creators conforming to multiple different profiles, and readers not recognizing an image SOP Class or Transfer Syntax are required to gracefully ignore such images.

3.1 Angiography profiles

The first profile to be defined was the Basic Cardiac Angiography profile. It defines the recording on CD-R using an ISO 9660 file system of 512 by 512 by 8 bit monochrome multi-frame cine cardiac angiography images using JPEG lossless compression with previous pixel prediction and Huffman encoding. The purpose of this profile is the replacement of the conventional 35mm cine film traditionally used for the recording and interchange of cardiac angiograms. This profile has been widely and successfully deployed and interchangeability between vendors has been demonstrated at professional meetings and in clinical sites. Considerable valuable experience in achieving interoperability has been gained using this initial profile, particularly in terms of the mechanics of CD-R writing, the encoding of JPEG images, and the handling of DICOM directory files and image files containing unexpected attributes.

The success of this effort has lead to the definition of a more general angiography profile for recording images with greater spatial resolution (1024 by 1024 pixels) and bit depth (10, 12 and 16 bit). This profile, though initially intended for cardiac work, is sufficiently flexible to be useful for general angiography images. The proposal for this profile is working its way through the DICOM standardization process.

CD readers have a relatively low transfer rate, despite the increasing speed of newer drives, and to achieve real time playback with this medium without first reading and buffering an entire multiframe image requires the use of lossy compression. Accordingly a third angiography profile for Dynamic Cardiac Review has been defined. The incorporation of this profile in the standard is awaiting the outcome of a large multicenter study on the effect of lossy compression at the proposed bit rates being organized by the ACC.

3.2 Ultrasound profiles

As part of the revised ultrasound IOD supplement, a class of application profiles for this modality was developed. These apply to both conventional diagnostic ultrasound as well as ultrasound for more specific contexts, such as echocardiography, where they may be used in conjunction with another profile, such as a cardiac angiography profile for instance.

The ultrasound community has a long history of the use of media for image interchange using earlier standards such as the Data Exchange File Format (DEFF)[6] standard based on TIFF. Accordingly, care was taken in the definition of the DICOM media extensions to ensure that some commonality and backward compatibility is possible. DICOM Files may be read as TIFF or DEFF images if the appropriate information is recorded in the Meta-information Header. The ultrasound profile class defines multiple media types including floppy disk, 90mm and 130mm ISO standard MOD, and ISO 9660 CD-R. In addition to Transfer Syntaxes used by other modalities, the RLE compression Transfer Syntax (equivalent to the TIFF PackBits encoding) is supported.

The ultrasound profiles have been incorporated into the DICOM standard.

3.3 General Purpose CD-R profile

Recognizing that some clinical contexts are undemanding in their image storage requirements, that the development of modality specific profiles is a time consuming procedure, and that the needs of image interchange for teaching and research require less strict conformance mechanisms, a general purpose profile was developed.

The media and file system chosen for this profile are CD-R and ISO 9660. These choices were made due to the low cost of the medium and the universal availability of readers for the medium and the filesystem. Though creators of the medium are non-trivial to design and build, the increasing availability of low cost off-the-shelf hardware and software in the consumer industry is clearly apparent.

The DICOM Files are recorded in an uncompressed Transfer Syntax, the Explicit VR Little Endian Transfer Syntax, in order to facilitate the ease of interchange. There is no pressing need for many modalities and applications to use compression to maximize storage density. This choice also allows conventional consumer image manipulation applications to read images from the media.

Though the profile allows any image storage SOP class to be recorded on the CD-R, applications are still required to state in their Conformance Statement which SOP Classes and which roles are supported. Just as with network DICOM applications, an integrator can compare Conformance Statements to determine the feasibility of interoperability.

The General Purpose CD-R profile has passed ballot and will be incorporated into the standard in its final form shortly. Demonstrations of this profile will be performed at ECR 1997 in Vienna, CAR 1997 in Berlin, and RSNA 1997 in Chicago.

3.4 CT/MR MOD profile

Currently under development is a profile to support the recording of CT, MR and related Secondary Capture (SC) images on 130mm MOD. Development of this profile is driven by demand for a high capacity storage medium for interchange purposes that contains losslessly compressed images recorded on reusable (read/write) media that is updateable on a frequent basis, without having to pre-queue and buffer an entire disk's worth of data. There is considerable experience with this form of media in the CT/MR community, and it is important to standardize its form in order to promote interoperability.

A draft for Public Comment of this profile, and an accompanying supplement defining the format of higher capacity 2.3GB 130mm MODs, is expected shortly.

4. CONCLUSIONS

The extension of the DICOM standard into the field of media interchange has been accomplished in a straightforward manner consistent with the existing network standard. A framework for definition of clinical context specific extensions has been established and proven to work in several fields, notably cardiac angiography and ultrasound. This framework maintains the strict conformance mechanism that is critical to the successful integration of medical imaging components in a heterogeneous environment.

Work is in progress to extend media profiles into other specific contexts as the need arises. In addition, a general purpose profile using a popular medium will provide a satisfactory solution for many applications, and in particular support the needs of teaching and research.

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