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DICOM OVERVIEW

The paper introduces preliminary results of our research on DICOM – JPEG 2000 coupling: DICOM standard. DICOM standard defines method for transferring digital images of various formats and associated data between devices manufactured by various vendors. PACS (Picture Archiving and Communication System) inside a hospital that can interface with other informational subsystems is based on this standard. DICOM standard is applicable to a network and/or to an off-line media environment. These features of DICOM standard manage communication between PACS in different hospitals. That means that if patient is transferred to another hospital his new physician can access patient's medical records over the network. They also manage online accession to medical records from physician's home. The standard supports operations that are based on other computer protocols (TCP/IP, ISO 9660, etc). Digital image and associated data are coupled in a single DICOM file. Image pixels are encapsulated inside this file. Format of image can be native DICOM format and/or some other lossless or lossy standard (jpeg, jpeg 2000, etc). At the end, development of PACS system of Hospital for chest-diseases which is based on DICOM standard is discussedi.

1. Introduction.

ICOM (Digital Imaging and Communication in Medicine) is a standard for the communication of the medical images and associated data. In reality the standard is far more complex than said in that simple statement. It is structured as a multi-part document according to ISO/IEC Directives, 1989 Part 3: Drafting and Presentation of International Standards. The last draft of DICOM v3.0 standard consists of 18 documents. They are referenced as PS 3.x where PS 3 refers to whole DICOM Standard and x refers appropriate part (document). Each of the documents describes one level of standard.

As it is said in the DICOM PS 3.1, the DICOM Standard facilitates interoperability of medical imaging equipment by specifying:

- a set of protocols for network communications,
- the syntax and semantics of commands and associated information that can be exchanged using these protocols,
- a set of media storage services for media communication, as well as a file format and a medical directory structure,
- the information which must be supplied with an implementation for which conformance to the standard is claimed.

This paper will describe short history of DICOM Standard, compare it to other medical standards and describe basic features and its capabilities. At the end, development of PACS system of Hospital for chest-diseases which is based on DICOM standard is discussed.

2. Historical Background.

Increasing use of digital diagnostic imaging modalities (like computed tomography, etc.) in the late 1970s and in the early 1980s and increasing use of computers in clinical applications showed need for a method for storage and transmission of medical images. In the 1983 ACR (American College of Radiology) and NEMA (National Electrical Manufacturers Association) formed a joint committee. Their task was to find or develop an interface between imaging equipment and what ever the user wanted to connect. Because none of the existing standards was satisfactory, they created new standard **[**13**]**.

The ACR-NEMA Standards Version 1.0 was published in 1985. This standard specified a hardware interface, a minimum set of software commands, and a consistent set of data formats.

The first version of standard had errors, and it was quickly replaced with ACR-NEMA Standards Version 2.0 in 1988. This version kept nearly the same hardware specification as Version 1.0, but it added new data elements and fixed number of errors and inconsistencies.

Drawback of both versions of ACR-NEMA Standards was non-existence of interface between imaging devices and network. The existing standard defined only point-to-point connection **[**13**]**. In 1990 began the work on new version of the Standard. The first public demonstration was in 1992 at RSNA. The new standard was productized in 1995 and it was named ACR-NEMA DICOM (also called DICOM 3.0). This standard is much larger then previous two, supports many more features and the basic design of standard was changed. It also expended beyond Radiology. From then standard had many revisions and supplements **[**16**]**.

DICOM is not the only standard for communication of medical related messages. In the domain of medical imaging DICOM Standard has "unparalleled, international, success" **[**6**]**.

In 1997 Europe standardization organization CEN TC251 developed MEDICOM Standard for imaging in medicine [4]. This standard referenced DICOM and it represented harmonization between existing imaging standards in healthcare industry and DICOM. Today CEN TC251 is actively involved in development of DICOM Standard [1].

In Japan existed IS&C (Image Save and Carry) Standard. The standard defines medical image format and their exchange through various mediums. Today the IS&C committee is actively involved in development of DICOM Standard, primarily on part PS 3.12 [1]. More information about IS&C Standard can be found on IS&C web-site [5], but unfortunately it is only in Japanese.

One of the most prominent standards in the field of medical related messages is HL7 (Health Level 7) [2]. This standard defines the format for messages that contain different types of healthcare information (patient registration, billings, orders and results of laboratory tests, imaging studies, notes, pharmacy orders and inventory/supply orders). HL7 is seventh layer protocol and that means that it specifies only the application level (7^{th} level) of OSI model. It defines format and meaning of a message, but not how the communication between applications is realized. In its fundamentals, HL7 does not specify exchange of medical images but it can incorporate image and its associated data in HL7 message. The problem is that HL7 messages are strictly ASCII and image pixels are coded binary, so encapsulating image information inside of HL7 message means creating very large messages.

Communication between bedside devices and hospitals information system is define through MIB (Medical Information Bus) standard [3]. The sets of standards that define MIB standard are known as IEEE P1703 family of standards. MIB is a 7 layer standard and it defines all levels of OSI communication. Its main purpose is to establish plug and play environment for bedside sub-network. For successful communication of bedside sub-network and rest of the HIS (Healthcare Information System), interface must be provided.

The described standards, along with DICOM, are the major standards in the field of medical related message communication [11, 6]. These standards complement each other in process of creating a complete HIS.

3. DICOM Properties.

This part of the paper describes some properties (from many) of DICOM Standard: set of network communication protocols for medical image exchange, storage and retrieving, image format and the format of object instances. The other properties of DICOM Standard are of non-less importance but they are not of interest for our research.

3.1 Information and Operation Modeling

DICOM Standard is object-oriented. The communication between DICOM aware applications, called AE-s (Application Entity), is modeled through SOP (Service Object Pair) class.
SOP class is formed of two parts:

- IOD (Information Object Definition) – informational part of the SOP and represents abstraction of real-world entities.
- SC (Service Class) specification – definition of roles both partners play in communication and set of operations allowed on IOD.

IOD contains group of attributes called IE (Information Entity). Each attribute describes single peace of information. IOD can represent abstraction of one real-world entity (normalized IOD) that contains only one IE, or it can represent abstraction of more real-world entities (composite IOD) that contains more IE.

There are two roles that SC defines:

- SCU (Service Class User) – client role in communication.
- SCP (Service Class Provider) – server role in communication.

DICOM defines set of operations (commands) used in communication between two AE, called DIMSE (DICOM Message Service Elements). There are two groups of operations:

- DIMSE-C (Composite) – operations applicable only to a Composite IOD
- DIMSE-N (Normalized) – operations applicable only to a Normalized IOD.

SC specification defines which of the DIMSE commands are applicable on specific IOD.

Before communication between AE-s takes place they have to agree upon SOP class they are going to use in communication. Elected SOP class defines the set of attributes and operations that can be used.

After agreement which SOP class is going to be used, AE-s have to divide roles they are going to play (SCU/SCP role) and to agree upon the transfer syntax used. Transfer syntax defines the way data set is going to be encoded: how attributes are encoded, byte ordering (little or big endian), the compression format in case of encapsulation (compression).

After all that has been agreed, the communication can take place. The communication between specific AE-s is done through specific SOP class Instance.

3.2. Networking

DICOM network or PACS consists of different sections: for image acquisition, for image and data storage, physicians work station, image processing, image printing, etc. PACS does not have to contain all this sections and/or they can be combined in one section. One DICOM network is showing on Figure 1.

Medical images can be acquired through analog or digital devices. These devices can be connected directly into DICOM network. In the first case, there must be some analog-to-digital conversion interface provided.
Devices used for acquiring medical images must be DICOM aware; they must have ability to communicate in DICOM fashion. This way vendor independence is achieved.

In some countries, like in our, digital medical images are not regulated by low. PACS systems here represent only a way to help and speed up physician work, but old fashion medical X-ray films are still must. In this environments a way for converting X-ray films in digital medical images and their introduction in to PACS system must be provided, Figure 1.

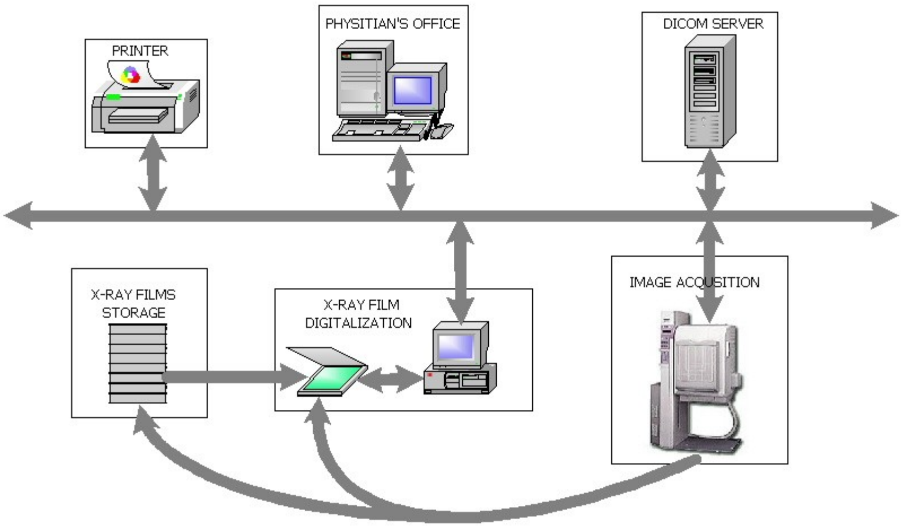

Figure 1. A PACS system architecture

During image acquisition associated data must be defined. One way is to manually enter all the data. This way is liable to errors. The standard defines MWL (Modality Work List) SOP class that creates particular work list. A work list is the structure to present information related to a particular set of tasks. This way, it is enough to select patient to be examined together with the imaging procedure request, and all the rest of the data are going to be automatically generated, minimizing the error possibility. The MWL attends list of finished and unfinished tasks. Work list is defined by authorized person (usually physician or other member of medical stuff).

Associated data and image are combined in one DICOM object and this object is sent to DICOM storage unit. Usually, this is called DICOM server. This server can also represent interface to rest of the world by Internet.

PACS system increase productivity, quality and security of medical image flow through hospital. Physician can issue new request for imaging procedure, he can view image from last imaging procedure, all images from one sequence of images or all the images related to the patient, he can create hard-copy of image (printing), and he can attach notes and comments on image. All this can be done from his office. Patient is not forced to carry his images with him when visiting a physician.

DICOM network is built upon a network protocol defined by the standard. In its present state, standard defines full 7 layer protocol stack. DICOM allows support of numerous OSI protocols stacks, but in most cases DICOM networks are realized using the TCP/IP protocol stack. The application, presentation and session layer functionalities of TCP/IP as required for DICOM [1] (PS 3.8) are combined in one layer called the DUL (DICOM Upper Layer), Figure 2.

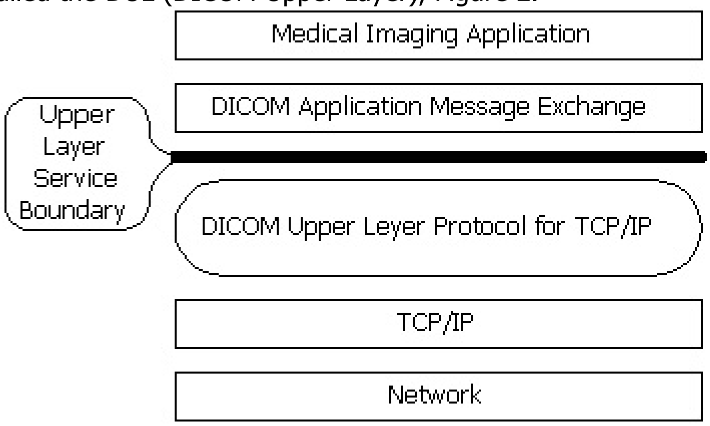

Figure 2. DICOM Network Protocol Architecture

Combining DICOM with TCP/IP allowed connection and combination of DICOM networks and public networks.

3.3. Storage and Retrieving

One hard issue in PACS system is object instances storage. Standard does not impose solution for this. A common solution, used in most cases, is to build a DICOM AE in charge for storage based upon some DBMS (Database Management System). This AE is often called DICOM server. It transforms information from DICOM object into appropriate database records and vice versa depending on the request from other AE.

AE communicates with DICOM server through different kinds of SC. Every transfer of object instances in DICOM is called storage. Basic SC-s for image storage are Storage SC and Storage Commitment SC. SOP classes of the Storage SC and Storage Commitment SC are implemented using the DIMSE-C service:

– C-STORE – defines the process for storage request, transmission and acknowledge of storage. The SCU requests from SCP to store object instance.

When Storage Commitment SC is used, SCP explicitly takes responsibility for the safekeeping of received data. It means that SCP will keep object instance for some amount of time.

Retrieving of DICOM images and associated data is done through Query/Retrieve SC. This SC facilitates the simple management of composite object instances. The types of queries which are allowed are not complex. It provides the ability to retrieve and transfer a well identified set of composite object instances.
SOP classes of the Query/Retrieve SC are implemented using the DIMSE-C services:

– C-FIND – implements operation for finding all SOP instances that have the same attributes as the ones SCU defined in C-FIND request
– C-MOVE – implements operation of moving image SOP instance from one storage AE to another. SCU must supply unique identifier of SOP instance that is going to be moved. The SCP of C-MOVE is invoking storage sub-operation with another AE.
– C-GET – implements the retrieve operation. SCU must supply unique identifier of SOP instance that is going to be retrieved. The SCP of C-GET operation is invoking storage sub-operation with the same AE using the same communication channel.

Query/Retrieve of image object instances could be combined with JPEG 2000 retrieving which enables finding images by their JPEG 2000 attributes too, and enables selection of image quality and resolution.

Another way of implementing storage and retrieving of object instances is using DICOM Media Storage SC. This SC facilitates the simple transfer of images and associated information between DICOM AE-s by means of Storage Media (the storage of Medical Imaging information on removable media). PC file system, floppy-disc, CD-R disc, DVD-RAM disc and other can be used as removable media for DICOM object instances storage. DICOM AE that uses Media Storage SC can take role of FSC (File-set Creator), FSR (File-set Reader) or FSU (File-set Updater). SOP Classes of the Media Storage Service Class (either option) are implemented using the Media Storage operations:

– M-WRITE – writing of object instance in to DICOM file.
– M-READ – reading of object instance to DICOM file.
– M-DELETE – deletion of object instance from file, or deletion of complete file.
– M-INQUIRE FILE-SET – checking the structure of DICOM FILE-SET.
– M-INQUIRE FILE – checking the structure of DICOM FILE.

To have the features of reading to and writing from removable media, DICOM AE must be conformant with appropriate standards (media formats). Examples of standards are: for 1.44 MB floppy diskette must be used ANSI X3.171 format, for 120 mm CD-R Medium must be used ISO 9660 Standard, for 120 mm DVD-RAM must be used UDF 1.5 Standard, and so on.

Described approaches are compatible. Use of both implementations for storage of DICOM object instances enables PACS system to fulfill different kinds of communication and achieve greater flexibility and security. Removable media storage represents not only a way for communication between AE, but it also represents a way for creating back-ups of stored data. These back-ups are easy to re-integrate in to the system because they contain DICOM object instances.

Use of removable media storage means that patients can get all or some of their medical images and associated data on a CD-R.

3.4. Image Formats

Image inside DICOM object instance is described with Image IE. An image is defined by its image plane, pixel data characteristics, gray scale and/or color mapping characteristics, overlay planes and modality specific characteristics (acquisition parameters and image creation information). The pixel data within an Image IE may be represented as a single frame of pixels or as multiple frames of pixel data. Image IE can contain additional parts if their information is directly associated with the image:

- Overlay – some bit-map format, graphics or text used to indicate items like region of interest, reference marks, annotations, etc.
- Lookup Table – extra information on every pixel that describes necessary transformation of pixel value.
- Curve – graphical data that represents series of connected pixels used to specify multi-dimensional graphs, region of interest, etc.

Pixel data incorporated inside the object instance may be sent in two formats:

- Native Format – represents raw pixels in their uncompressed form
- Encapsulated Format defined outside the DICOM standard.

When pixel data is sent in Encapsulated Format, they are encoded according to the encoding process defined by appropriate compression standard and agreed transfer syntax. DICOM supports the use of:

- Run Length Encoding Compression,
- JPEG, JPEG-LS and JPEG 2000 Image Compression,
- MPEG2 MP@ML Image Compression.

DICOM support for this formats is described in PS 3.12. Use of these image compressions formats leads to smaller object instances and smaller messages transmitted during DICOM communication which reduces network bandwidth requirements. It also lightens the process of conversion from DICOM object instance to popular image format (for example: some non-DICOM medical image browser) **[**1**]**.

JPEG 2000 is the latest image compression standard added to DICOM Encapsulated Format. DICOM encapsulates only ISO/IS 15444-1 Standard (JPEG 2000 Part 1). Use of JPEG 2000 enables:

– use of compressed files that 30 percent to 50 percent smaller then traditional JPEG files,
– progressive decoding and viewing (an image can be displayed already after 10 percents of the file has been received),
– higher quality compression for parts of the image that are signed as region of interest,
– extracting and viewing of smaller versions of the same image **[**15**]**.

The last feature of JPEG 2000 compression format enables viewing of images on PC or palmtop computer, and even on mobile phone. This is the base of for future research at our Institute.

MPEG2 MP@ML is option of IS0/IEC MPEG2 Video Standard for the video compression of generic coding of moving pictures and associated audio information. This feature of DICOM Standard enables AE-s to exchange continual medical data (like ultrasound, video files of medical procedures, physician's voice print, etc) **[**1**]**.

Lossy compression formats may lead to loss of important medical data. The context where the usage of lossy compression of medical images is clinically acceptable is beyond the scope of the DICOM Standard **[**1**]**. The policies associated with the selection of appropriate compression parameters for lossy compression of particular image format is also beyond the scope of the standard.

4. Conclusion

The paper is part of DICOM-JPEG 2000 coupling research made for project: *E-roentgen of Special hospital for lung disease "Dr. Vasa Savic, Zrenjanin"* No 6233B, financed by government of Republic of Serbia. The purpose of this project is to develop PACS system for hospital were radiology is one of the basic activities.

DICOM Standard was recognized as the best solution for problem of medical imaging because it defines encapsulation of medical image and associated data, communication protocols for their exchange and JPEG 2000 support. It is the one of the most used standards in the field of medical imaging **[**6, 9, 10, 14**]** and it is supported from the most prominent vendors of medical equipment **[**1, 6, 7, 9, 14**]**. Two types of images (both supported by DICOM) are recognized as the primary types of medical images for future PACS system:

– X-ray images – used for acquisition of new images from digital X-ray devices.
– scanned digital images – used for digitalized X-ray films, new and old (made before the development of PACS systems). Old X-ray films will be digitalized for purpose of healthcare researches and disease history tracking.

The PACS will have DICOM server in charge of DICOM object instance storage built upon a DBMS. All the rest parts of the system (radiology laboratory, physician office, etc) will address the server for storage/retrieval of the object instances.

The system will contain NET server that will represent the gateway to the rest of the world (primary Internet). It will present medical images and associated data to authorized DICOM aware and non-aware applications.

Filmless radiology lightens the work of physicians enabling them to see all of the medical images associated with particular patient or type of disease not making them to carry hard copy images. DICOM in the other way enables filmless radiology to be the vendor independent, and enables worldwide flow of medical images and associated data.

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