Chapter 3

IMAGE STORAGE AND TRANSFER

Concepts Introduced in this Chapter

› Information systems: the role of HIS, RIS, and PACS;

› Basic concepts of HL7;

› Introduction to the DICOM standard: information objects and services, establishing DICOM connectivity, the DICOM file format;

› Technical properties of medical images;

› Medical workstations.

- Archival and transfer of images is governed by two standards **HL7 and DICOM.**
- The goal of presentation is to enable the reader to understand way images are stored and distributed in a hospital.
- It should further enable the reader to access images if some analysis method shall be applied to it and to decide how to implement such an analysis method in a clinical environment.

Introduction

- Medical images differ from other images in several aspects:

1) Medical images **receive their semantics only within the context** in which they were created. Context information includes for instance demographic information about the person who was imaged, technical details about the image acquisition system, or the reason for the examination. Context information about medical images is much more extensive than for other images, where information about the size and quantization may suffice. For reasons of data integrity and data security, context needs to be firmly associated with the image.

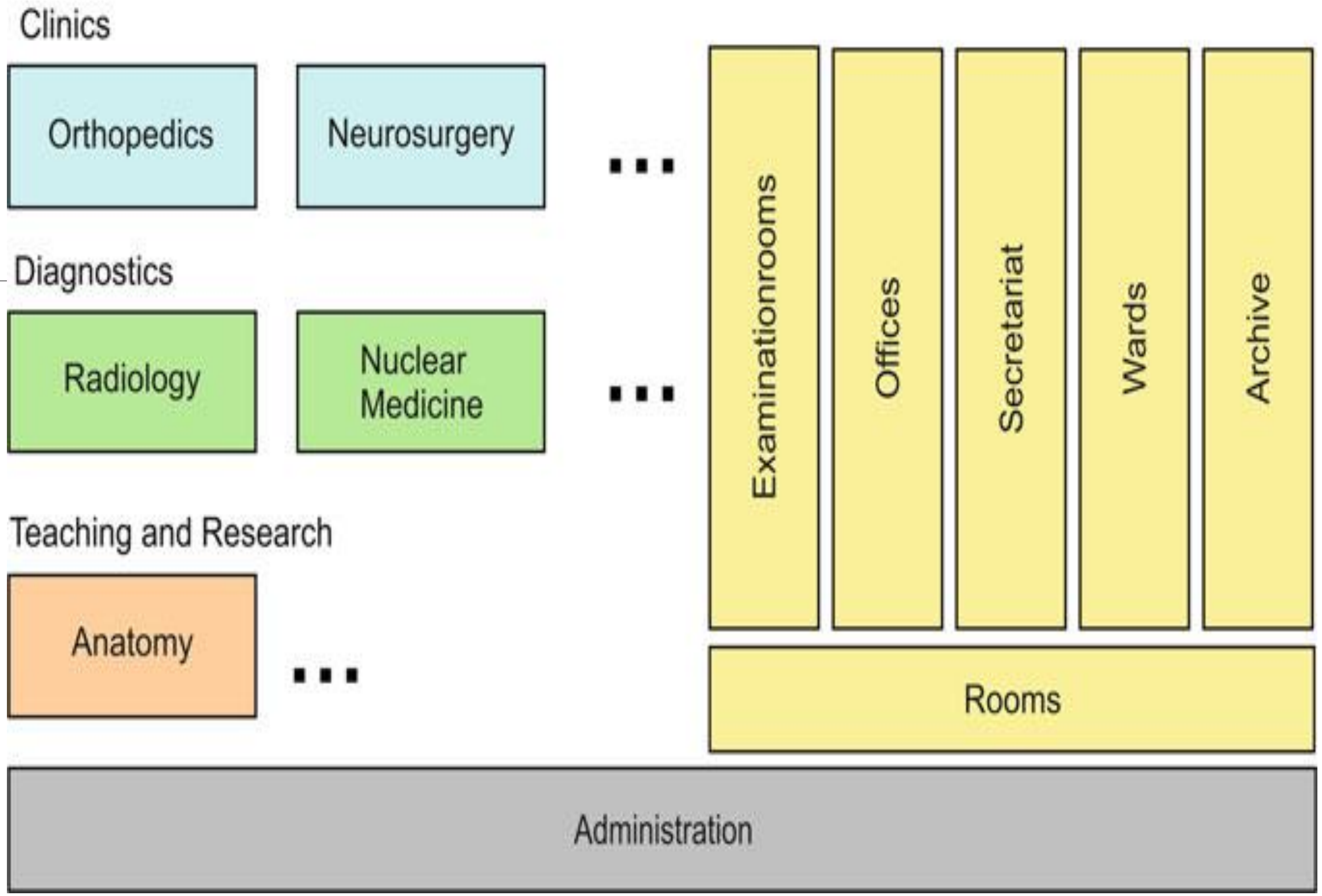
2) A second important difference is that **medical images are mappings of measurements of very different origins** into a pictorial representation. Storing meta-information describing the different parameters related to some image acquisition system efficiently leads to image formats that are different from conventional formats such as JPEG or PNG.

3) A third aspect which differentiates medical images from other pictures is that **the use of medical images is highly constrained and regulated**. Medical images contain sensitive personal information of which misuse must be prevented.

<u>If a user intends to apply computer-based analysis techniques on a medical image, he should be aware of these points</u>

Information Systems in a Hospital

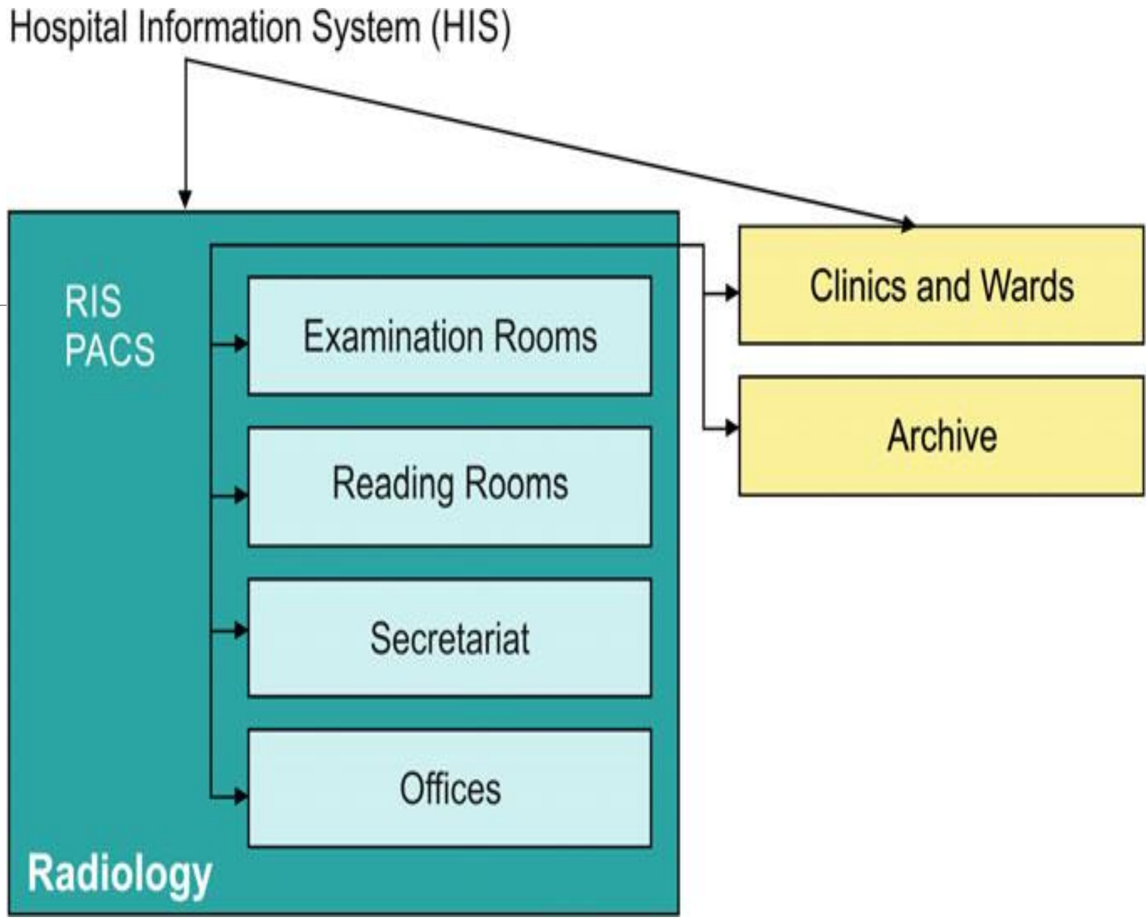
- Image information has to be accessible at various places , which is necessary including:
- • for administrating the patient’s stay such as patient demographics and billing information;
- • for performing the examination to which the images belong such as patient demographics, anamnesis, and reports;
- • for interpreting the images such as patient demographics, reports, imaging device information, and the images themselves.



Schematic view of functions and locations in a hospital that deal with images or information related to images

HIS and RIS

- The information is kept in different information systems in the departments of the hospital.
- Patient administration data is kept in the **hospital information system (HIS).** The HIS maps the internal structure of a hospital (its departments, clinics, and its access points for getting administrative information) into a database representation and governs access to this information.
- Data about radiological examinations is kept in a different system which is called **radiology information system (RIS)**, which is independent subsystems within the hospital is the complexity of the information structure and information flow.
- Radiology information systems are built to manage information about services that are connected with a radiological examination.
- RIS and HIS are similar in that they mainly cover administrative aspects of the patient's stay.



PACS

- In 1980s, introduction of another image information system, called **picture archiving and communication system (PACS)**.
- **RIS and PACS are the two information systems** that a computer scientist is most likely to encounter when images in a hospital need to be accessed.
- The RIS contains information about the specific examination and associated previous examinations. RIS governs access authorization and basic image manipulations such as retrieving or anonymizing images. The task may also be part of the PACS.
- separation between RIS and PACS is much less obvious than that between HIS and RIS.
- In the future, **PACS and RIS will probably fuse into a single departmental information system**

HL7 & DICOM

- Two different communication standards evolved: the HL7 messaging standard and DICOM.
- **HL7 was developed for standardizing communication between clinical information systems, whereas DICOM was specifically targeted at standardizing communication of images**.
- The former plays a role when connecting HIS, RIS, and PACS, and the latter mainly standardizes image communications between components of a PACS.
- HL7 is a standard developing organization which is accredited by the American National Standards Institute (ANSI). It is devoted to developing standards for communication in the healthcare business.
- The name HL7 stands for **Health Level 7**, and it refers to the application layer (the 7th layer) of the OSI (open systems interconnect) reference model.
- HL7 is not a complete specification of such a protocol (such as DICOM), but describes syntax and semantics of messages on this layer.
- An **HL7-conform system** typically means that HL7-conform messages are created by an interface by which a system (archive, workstation, etc.) communicates with other systems.

HL7 Basics

- HL7 messages are based on the **HL7 reference information model (RIM),** which is the main contribution of the HL7 organization. They succeeded in **mapping most of the clinical information entities onto one big, generic, relational model.**
- Within the **RIM, six different stereotypes are specified,** four of which refer to the nodes and two of which refer to the relations between nodes of the RIM:
- • entity, • act, • role, • participation, • role relationship, and • act relationship.

HL7 messages in versions 2.x are sequences of ASCII characters delimited by carriage return symbols

HL 7 Basics…

- The new HL7 version 3 standard replaced the outdated way of structuring the data. **XML tags are used** to tag information units, but the basic structure of the syntax remains the same.
- The semantic of an HL7 message is determined by the **fi and mandatory identifying component.**
- The current standard defines more than 100 different segments.
- In order to let a message adhere to the standard, the standardization committee allowed **user-defined "Z" messages**.
- It is a potential source of incompatibility between two HL7-conform systems, as it for instance allows a vendor to hide non-mandatory information in a "Z" message.
- Other reasons of incompatibility are the use of different versions of the standard and various violations against the standard that are difficult to detect, such as missing fields.


```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
 <message>
   &lt;segment name="msh" &gt;
    <field name="field_separator" len="1" >|</field>
    <field name="encoding_characters" len="4" >^~\&amp;</field>
    <field name="sending_application" len="180" >SENDAPP</field>
    <field name="sending_facility" len="180" >SENDFAC</field>
    <field name="receiving_application" len="180" >007</field>
    <field name="receiving_facility" len="180" >007</field>
    <field name="date_time_of_message" len="26" >20060121214O</field>
    <field name="security" len="40" ></field>
    <field name="message_type" len="7" >ORU^R02</field>
    <field name="message_control_id" len="20" >HL7777</field>
    <field name="processing_id" len="3" >P</field>
    <field name="version_id" len="8" >2.3</field>
    <field name="sequence_number" len="15" >3434</field>
    <field name="continuation_pointer" len="180" ></field>
    <field name="accept_acknowledgement_type" len="2" ></field>
    <field name="application_acknowledgement_type" len="2" ></field>
    <field name="country_code" len="2" ></field>
    <field name="character_set" len="6" ></field>
    <field name="principal_language_of_message" len="60" ></field>
    &lt;/segment&gt;
 &lt;segment name="pid" &gt;<field name="set_id" len="4" >1</field>
```

The DICOM (Digital Image communication in medicine) Standard

need to preserve semantically relevant information, which includes the following:

- **Patient information:** name and demographic information, identification in other information system in the hospital, etc.
- **Examination information:** referring clinic and/or physician, examination type, etc.
- **Technical information:** Many image acquisition systems require careful parameter selection controlling the acquisition process. A description of an X-ray CT, for instance, would include wavelength and amplitude of radiation, number and spacing of slices, spatial resolution within slices, reconstruction method, and reconstruction kernel.
  - **(Auxiliary) reporting information:** Measurements and annotations being created during reporting, etc.
- The **image** or image sequence.

With number and variety of digital imaging systems increasing, there was a growing need to manage images digitally.

DICOM contd…

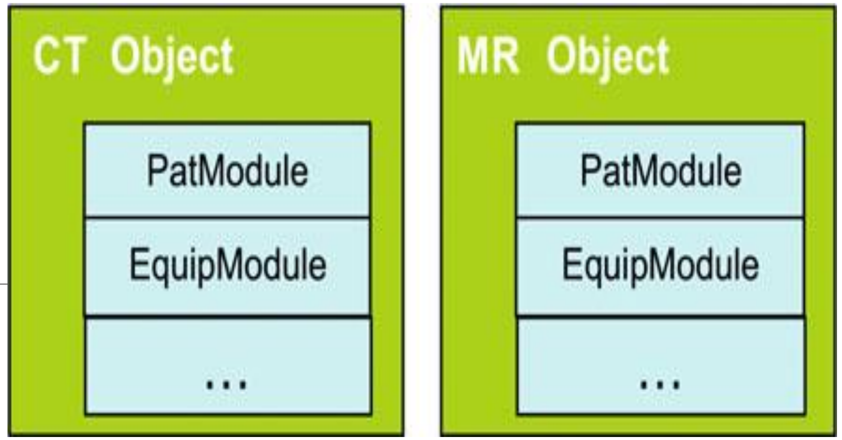
- This motivated the development of the DICOM 3.0 standard (and its predecessors ACR-NEMA 1.0 and 2.0).
- DICOM stands for **digital image communication in medicine** and is a full-fledged specification of the application layer of the OSI model. For communication of medical images, it replaces other file communication protocols such as FTP.
- The DICOM standard and its two predecessors evolved from a joint effort of the American College of Radiology (ACR, http://www.acr.org) and the National Electrical Manufacturer's Association.
- Initially, DICOM was adopted only reluctantly by the industry. On the other hand, DICOM-conform machinery greatly simplifies connectivity between imaging components and the hospital information system.
- Today, it will be difficult to sell a major imaging device that does not conform to the standard.
- DICOM is an interface standard similar to HL7. Internal communication is still vendor-specific. DICOM is designed to standardize communication between components such as imaging systems, printers, archives, and workstations.

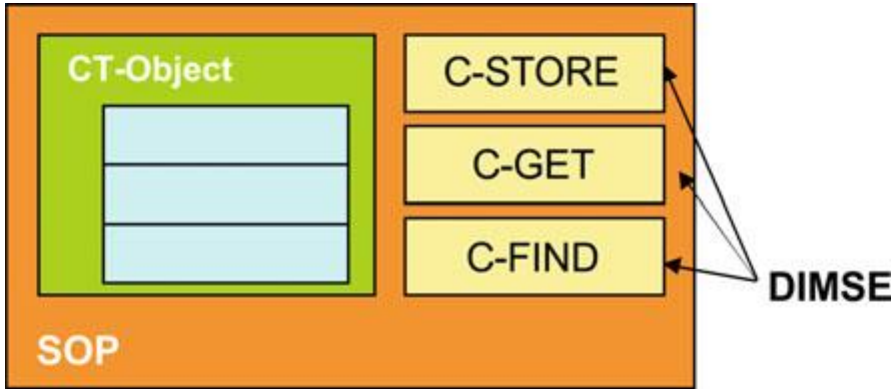
DICOM Details

- DICOM specifies a protocol for communicating objects between devices. **Two different types of objects, composite and normalized**, may be exchanged.
- An image is a typical composite object since it consists of several different entities, such as various text entities (e.g., the patient name), numerical entities (e.g., the number of pixels), and the image itself.
- **Normalized objects**, on the other hand, consist only of a single entity, such as a report. For each of the two types, the standard defines a number of services associated with it.
- Services for composite objects : Four services, C-STORE, C-FIND, C-GET, and C-MOVE, are designed to exchange images.
- Normalized services apply to single real-world entity. Four general services: such as N-CREATE, N_DELETE, N_SET, and N_GET, as well as the two specialized services such as N_ACTION and N_EVENT_NOTIFY were defined.
- Service classes describe services that may be rendered to representations of information entities.
- Classes of information entities in the DICOM world are templates that are called **information object description (IOD)**
- An instance of an IOD is an information object. Information objects are uniquely identified by unique identifier (UID), for each organization as per ISO std.

Information Object Description (IOD)

- For a given IOD, several composite or normalized services may be useful.
- A service is defined as DICOM message service element (DIMSE), invokes an operation or notification across the network. A DIMSE service group is a collection of DIMSEs applicable to an IOD .
- An information object description and the set of services operating on it are called a **service object pair (SOP) class.**
- An SOP class using composite services is called a composite SOP class, and an SOP class using normalized services is called a normalized SOP class.
- DICOM classes are static, which means that information entities (the data structures) and services (i.e., the methods) are provided as a template.
- Communication follows the **client–server paradigm.**
- In the DICOM world, the **server is called the service class provider (SCP)** and a client is called the service class user (SCU).

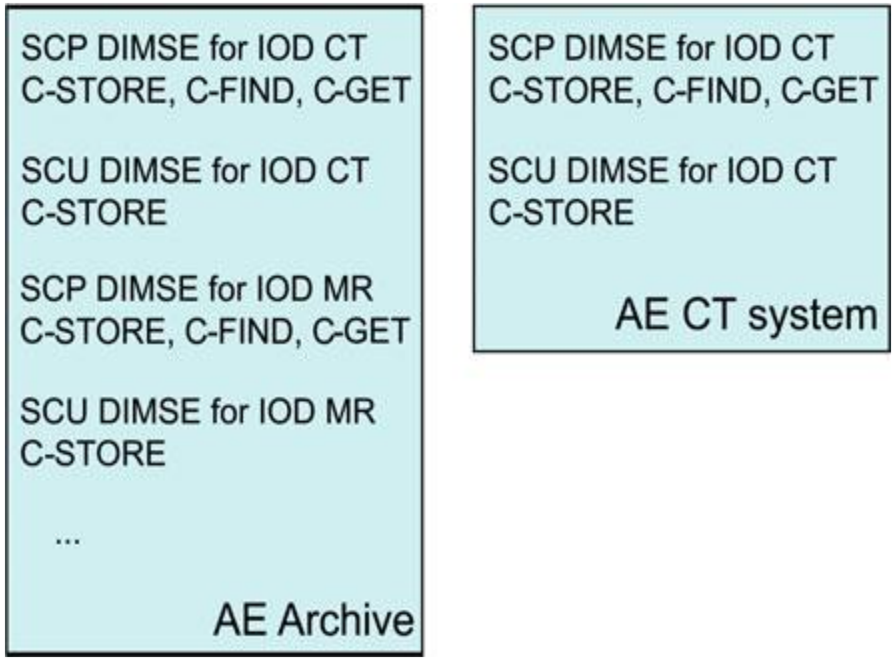




A service–object pair combines an IOD with services that are offered for this object. The services are called DICOM message service elements (DIMSE)

Application Entities (AE)

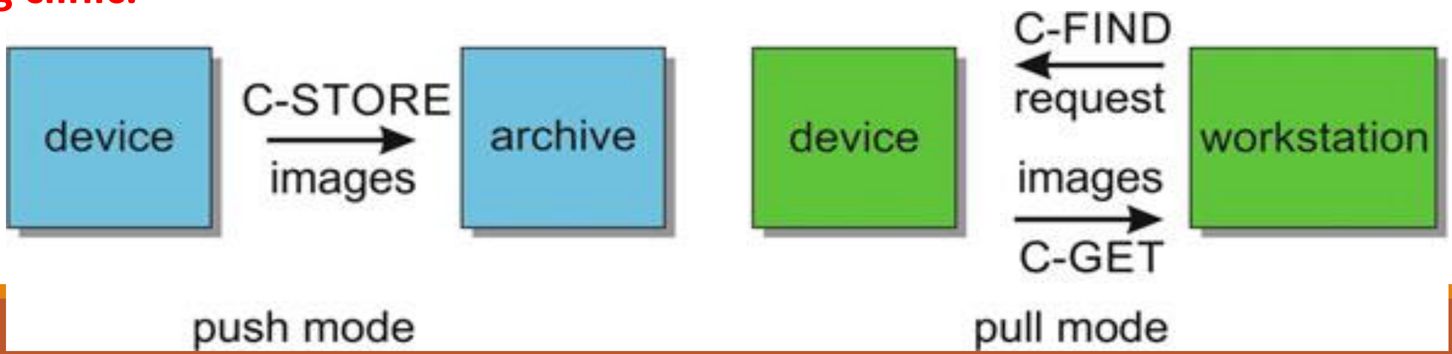
- **A communication session between two components, which are called application entities (AE),** is initiated by establishing a DICOM association.
- Basic understanding is established to what information objects are to be exchanged and what services are to be invoked. If communication is established such that full interoperability is ensured, components may exchange messages via DIMSEs.
- **DICOM service classes support five different general application areas for communication** as follows:
- • network image management,
- • network image interpretation management,
- • network print management,
- • imaging procedure management, and
- • off-line storage media management.



Different application entities (AE) offer different services

Application Entities (AE) contd…

- Of these five, the first application area is most relevant for accessing images in a hospital environment.
- Network image management involves sending images between two devices.
- Two different kinds of communication are supported: **In push mode**, images are sent from one device to another device.
- This basic service would be appropriate, e.g., for sending images from a scanner to an archive.
- DICOM does not specify the timing behavior of the sending device, which means that the scanner could send images whenever system is ready to do so. The receiver acts as listener, to accept information at any time during which a DICOM association is established.
- Pushing images may also be appropriate for communication to a workstation. This could be the case if the workstation serves as a reporting station where all images should be present. It could also be **intended for sending images to a departmental workstation of a referring clinic.**



Application Entities (AE) contd…

- The pull mode may be used for information exchange. It allows querying the sender first about its images. Selected images may then be pulled by the receiver.
- The pull mode consists of two phases: First, the requesting component sends a query to the sending component. The prospective sender matches the keys of the query with images in its database and returns the number of information objects that match the keys together with their UIDs. The receiver then selects images from this list that he or she wishes to receive and requests them from the archive. Finally, these images are sent to the workstation.
- The transfer of information is similar to that using other file transfer protocols FTP, however, with one important difference:
- **Establishment of communication includes a common understanding between sender and receiver about basic properties of the kind of information exchanged such as keys to request in a pull service**. Hence, sender and receiver know how to interpret such relevant information before a data transfer takes place. This enables organization and presentation of data according to such criteria.
- Instead of listing data by file names which, in case of the DICOM images, are their UIDs and difficult to interpret anyway, images can be presented in a more meaningful fashion. The result of a query may be structured by listing image data by patient name, patient ID, and study ID. Such organization by clinically relevant categories substantially enhances the use of transferred information.

network management services

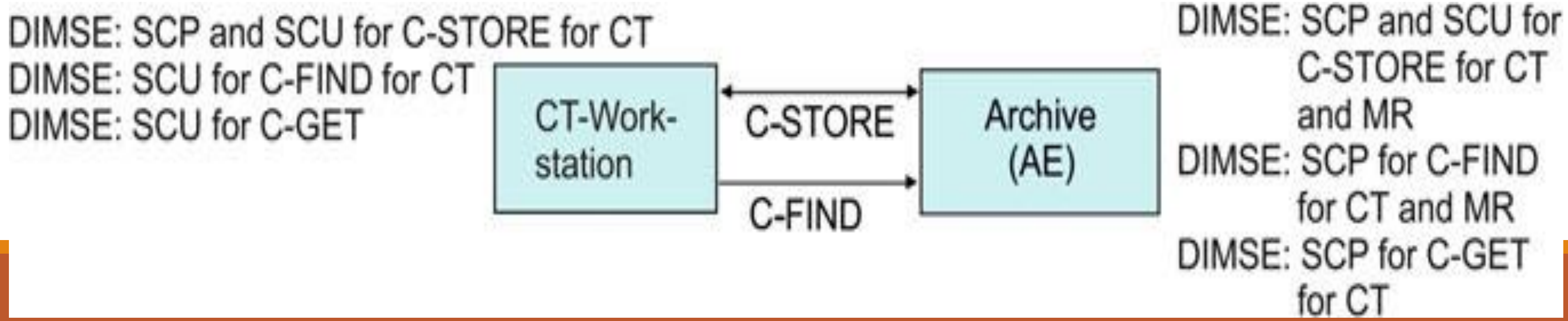
- DICOM network management services are specified in the service, query/retrieve, and storage commitment service classes. They are defined for composite objects only.
- The **storage service class** specifies the **C-STORE** service for pushing data to a client.
- **The query/retrieve service class** specifies **C-MOVE, C-FIND, and C-GET** services. With C-FIND, the sender is queried using a number of keys sent to him. With C-MOVE, a third party may invoke transferring images between two locations. A workstation, e.g., may query a scanner using the C-FIND service and then initiate a move of images from the scanner to an archive. C-GET is a service to retrieve images from a sending device.
- For every information object, service classes have to be separately defined and supported.
- The **storage commitment service** class specifies the quality of storage provided by a device.
- Long-term storage devices such as long-term image archives commit to store an image permanently, while short-term storage devices such as a departmental image archive commit to a specified amount of time.

Establishing DICOM Connectivity

- Somebody who has to access images from a DICOM-conform image acquisition device, a DICOM archive or a DICOM workstation, needs to know just to which part of the standard this device conforms.
- For this purpose, every piece of equipment that is said to conform to the DICOM standard has to provide a DICOM conformance statement.
- **A DICOM conformance statement consists of four parts: problem statement, application entity specifications, communication profiles, and specialization.**
- In the problem statement, the vendor states the purpose of communication for his piece of Equipment. The major part of the conformance statement is the application entity specification. An application entity is a software module of the equipment implementing a specific application on the equipment. The communication profile then describes how services are communicated.
- The conformance statement will list and specify necessary details such as supported media access protocols (FDDI, Ethernet, etc.) or supported physical media (fiber, coaxial cable, etc.).
- The specialization part of the conformance statement relates to extensions and vendor-specific specializations.

Establishing DICOM Connectivity

- It should be possible to decide whether two pieces of DICOM-conform equipment can communicate based on the information in the conformance statements.
- If a CT system is SCP for C-STORE of CT information objects and some workstation is an SCU for the same service and information objects and if the two components communicate using the TCP/IP protocol and are connected by an Ethernet connection, then the scanner should be able to send images to the workstation.
- However, **Communication may still be impossible or limited because of the several reasons as follows:**
- • Conformance has not been thoroughly tested and fails to establish in the specific environment.
- • Information which is optional in the information object may be expected but is not present.
- • Optional information may be present in specialized fields. • Claimed conformance is erroneous.



Establishing DICOM…

- It should be possible to decide whether two application entities are able to exchange information by comparing the desired service for the exchange with services offered by the Aes.
- Client and server software for various DICOM services may be found at the DICOM website of OFFIS (DICOM Test Kit DCMTK, http://dicom.offis.de) or at the Mallinckrodt Institute of Radiology (DICOM Test Node DTN, http://milan.wustl.edu/DICOM/).
- These two testing modules have been used for several years as vendor-free installations for various demonstration projects and are the base for many of the open source implementations of DICOM viewers.

The DICOM File Format

- Since the file format has to support the storage of many different types of information objects, it has to be highly variable. On the other hand, necessary effort for reading a file should be minimal. **The two goals have been achieved by choosing a tagged format.**
- Each tag relates to some data element (e.g., the patient name) of an information object. Its description can be found in a data dictionary.
- The name of the DICOM file is its UID. Its content consists of a header of fixed length followed by a sequence of tagged data elements. The header contains the following:
- • a 128 byte preamble, which is meant to support specific DICOM implementations. If it is not used, it should be filled with zeroes.
- • a 4-byte identification by the ASCII codes of the letters “D”, “I”, “C”, and “M”. Again, this information is not tagged.
- • a mandatory set of data elements containing meta-information about the file. Each of the data elements has to follow the tagged file format described below.

The DICOM File Format

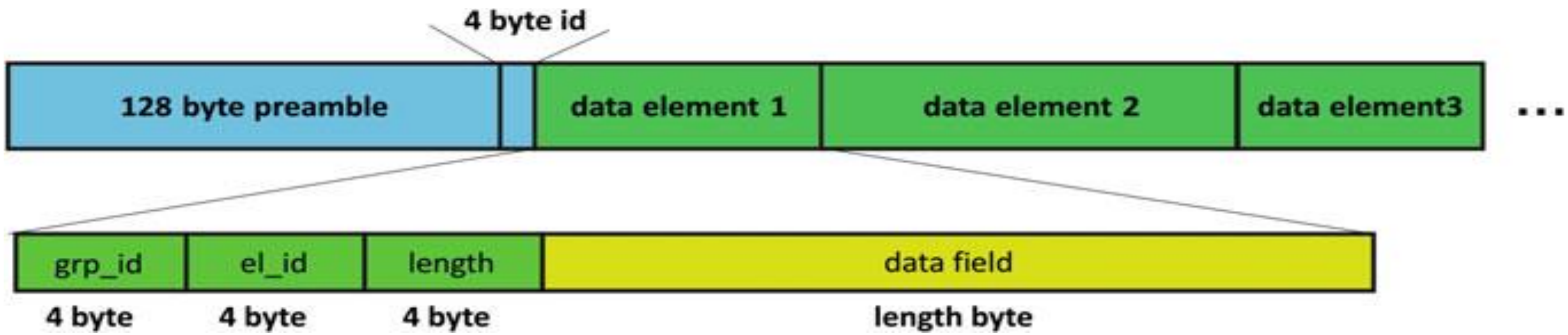


Fig. 3.12 Structure of the DICOM file format. The preamble and the id are for DICOM-specific information only and do not contain any meta-information about the images. All the meta-information and the image itself are data elements

File Format…

- A data element consists of three parts: The tag, the length of the data element specified by the tag, and the information itself.
- The tag consists of a 4-byte group number and a 4-byte element number. The length of the tag is a 4-byte element following the tag and indicates the number of bytes reserved for the following information in the data field.
- Data elements are characterized by their value representation (e.g., DS—decimal string, IS—integer string, and ST—short text), the maximum length of the data field, the set of acceptable symbols, the set of symbols that are explicitly not allowed, and the value multiplicity (a scalar has a multiplicity of “1”, and a 3d coordinate vector has the multiplicity of “3”).
- Three different types of data elements exist:
- • Type-1 data is mandatory and has to be filled with content,
- • Type-2 data is mandatory but the data field may be empty, and
- • Type-3 data is optional.

File Format…

- The data type may also be tagged by the letter C, such as 1C and 2C, which indicates a conditional type classification; e.g., it is type-1 only if specified conditions are fulfilled.
- An information object must contain all mandatory data elements as specified in the standard for this type of object. The standard may also list a number of optional data elements.
- The information object may be encapsulated according to the meta-information in order to provide possibilities for encrypting and/or compressing the data.
- If it is neither encrypted nor compressed, it consists of a sequence of tagged data elements similar to the ones in the meta-information.
- Tags are listed by their group and element number in the data dictionary. The data dictionary is part of the DICOM standard and can be found on NEMA's Web site. It also describes how data is represented (bytes may be interpreted as ASCII code or as various types of integers).

File Format...

- Odd group numbers are reserved for allowing vendor-specific adaptations or specializations. Hence, tags with odd group numbers will not appear in the data dictionary. These groups are also called shadow groups.
- Sometimes, shadow groups are used to represent non-mandatory data elements, which is an efficient way to hide this information.
- Data elements of which the tag definition is missing may be skipped by a DICOM reader, since the length of information of a data element is part of the representation. This helps dealing with unknown shadow groups, and it enables reading data without a data dictionary.

DICOM Reader

simple DICOM reader:

- For the latter, tag interpretation of only the most vital information for reading the data is hard-coded into the reader program. This is a solution of some software products that read the DICOM file format. The advantage is its simplicity although it is clearly insufficient for a DICOM reader within a PACS.

```
while not eof do begin
        int t_group = read_tag_group (file)
        int t_element = read_tag_element (file)
        int length = read_length (file)
        Interpret_Data (t_group, t_element, length, file)
endwhile

Interpret_Data()
        if t_group is even and exist(t_group, t_element) then
              interpret according to data dictionary
        else
              skip length bytes
```

Tagged file format makes interpretation simple. Even if some data elements are unknown, others can be read, since unknown elements are simply skipped

Technical Properties of Medical Images

- Medical images differ from ordinary images taken by a camera in several aspects because they are visualized measurement values .This has consequences on the technical properties of these images.
- With technical properties, we mean attributes that result from the image acquisition technique and that are independent from the semantics of an image.
- Medical images may come with two, three, or four dimensions. 2d images may be slices of the human body such as an ultrasound image or a single CT slice. They may also be projections of a 3d scene such as an X-ray image or a scintigram. 3d images are volumes of the human body, such as a 3d sequence from computed tomography, or time sequences of 2d images. 4d images are 3d volumes acquired over time.
- The DICOM file format in which images are stored often treats 2d images as an information unit even if they are part of a 3d or 4d sequence.
- A 3d data set is then treated as a sequence, and a 4d data set is treated as a study of several sequences.

Technical Properties…

- Images may be differentiated into projection and slice images. In projection images, image attributes are integrated along rays and projected on a single pixel. The type of projection is important, if measurements in such images shall be made.
- Images may be acquired at several signal bands. If done so, these bands are stored separately. Two different bands may even be stored as separate studies. Interpretation is only possible if the image file information about the semantic of each image with respect to the signal can be retrieved.
- Image sizes given in the DICOM tags relate to the number of pixels per column or row. The true physical size of a pixel or voxel (in mm or cm) is a mandatory data element which can be found if the tag identification is known.
- Pixel values of medical images are quantized. The quantization often differs from digital photographs.
- The user should be aware that there is no guarantee that different vendor represent values in the same fashion. This is especially true if the file format for data exchange is non-standard.
- Hounsfield units, e.g., may be represented on a scale from −1000 to 3000 or—shifted—as unsigned integers on a scale from 0 to 4000.

Technical Properties…

- Transferring digital image files between systems may involve changing between big-endian and little-endian notation of the two bytes.
- This refers to whether the first or the last byte is the most significant byte in a 2-byte word.
- It should be no problem if communication is standardized, but needs to be considered otherwise.
- It is easily recognized when looking at the images. Endianness may also be different for the bit order in a byte.

MR image with correct endianness (scaled from its original range 0–4000 to 0–255) and the same image with byte endianity reversed

Displays and Workstations

- Replacing analog data transfer and display by a PACS has advantages:
- Most notably, digital data can be easily copied and transferred to any location reachable on the network. Transfer may also be extended to long distances in short time (teleradiology).
- Replacing the analog archive by a digital archive also makes localizing images easier. It has been reported that accessibility increased from 70 to 98% after switching from analog to digital archives.
- Another advantage is that image enhancement techniques such as magnification or contrast enhancement may support image interpretation.
- There are no legal standards for the display of digital radiography, but the American College of Radiology (ACR) has developed some recommendations.
- The ACR distinguishes between images used for diagnosis (interpretation) and those used for other purposes (clinical review, teaching, etc.).
- According to ACR, the image quality should be sufficient to satisfy the needs of the clinical circumstances if images are meant for display use only.

Displays and Workstations

- Their recommendations for display and display software are as follows:
- • The luminance of grayscale monitor should be greater than or equal to 50 foot-lamberts.
- • Controlled lighting should enable eliminating reflections in the monitor.
- • The ambient light level should be as low as feasible.
- • A capability for selection of image sequences should be provided.
- • The software should be capable of associating the patient with the study and demographic characterizations with the images.
- The rendering software for images should:
- • be capable of window and level adjustment,
- • be capable of pan and zoom (magnification) function,

- be capable of rotating or flipping the images, provided that correct labeling of patient orientation is preserved,
- • be capable of calculating and displaying accurate linear measurements and pixel values,
- • be capable of displaying prior image compression ratio, processing or cropping, and
- • have available the matrix size, the bit depth, and the total number of images acquired in the study.

Requirements for display consoles which are not used for interpretation are less stringent. This relates for instance to workstations that are used for computer-assisted procedures. There are two places where such work can take place:

- • Workstations as part of the image acquisition system, and
- • Independent workstations in the hospital network.

Most vendors sell workstations and workstation software for post-processing image data. These workstations are a part of the imaging system and as such may communicate with image acquisition devices in some non-standard fashion.

They are generally not open, i.e., they are neither adaptable nor extendable.

Software groups

Software being delivered with such a workstation falls in six different groups:

• **Image display:** retrieval and display of images, setting window and level of the mapping between image values and rendered intensities, and printing of images.

• **Image enhancement:** magnification, contrast enhancement, and noise filtering.

• **Image annotation.**

• **Image analysis:** measurements of distances and angles, volume estimation or volume measurements, and simple segmentation techniques.

• **3d imaging:** slice view in cine mode, maximum intensity projection, and surface and volume rendering.

• Specialized interpretation or support to a specific planning task (e.g., surgical and radio-therapeutical).

DICOM Viewer

- Images may also be accessed from other workstations connected to the network. DICOM client software such as contained in the DICOM Test Kit is needed that pulls images from the archive, the imaging device, or some other workstation.
- A more comfortable solution is a DICOM viewer which is able to query other modalities and display the results in some organized fashion. The functionality of a DICOM viewer should consist of the following:
- an implementation of a query to the database of a DICOM sender (C-FIND),
- • an implementation of the C-GET in order to retrieve images,
- • an interface for displaying the result of a query and for selecting queried images to be fetched,
- • a rendering module to display retrieved images, and
- • a storage module that stores retrieved images on the local machine.

The DICOM viewer may be used for selecting images for further processing .The viewer may contain further routines that support interpretation or computer-based analysis.

Compression of Medical Images

- DICOM supports data compression.
- Images may be compressed lossless or lossy. Lossless compression such as entropy encoding or run-length encoding typically results in compression rates of 1:2–1:3. Lossy compression achieves much higher compression rates in the range of 1:10–1:30.
- Regarding medical images, lossy compression is a difficult issue.
- Compression is part of the DICOM standard. Among others, the JPEG and JPEG2000 standards have been adopted by the DICOM standardization committee.
- Not all DICOM viewers, however, can read compressed DICOM images.