Chapter 16: Digital Imaging


Diagnostic Radiology Physics: A Handbook for Teachers and Students

Objective:
To familiarize the student with terminology and practical issues associated with digital imaging.

Slide set prepared by E. Berry (Leeds, UK and The Open University in London)
### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.1.</td>
<td>Introduction</td>
</tr>
<tr>
<td>16.2.</td>
<td>Image Encoding and Display</td>
</tr>
<tr>
<td>16.3.</td>
<td>Digital Image Management</td>
</tr>
<tr>
<td>16.4.</td>
<td>Networking</td>
</tr>
<tr>
<td>16.5.</td>
<td>Image Compression</td>
</tr>
</tbody>
</table>
16.1 INTRODUCTION
Introduction

- The original means of recording X-ray images was a photographic plate.
- Today, all medical imaging modalities provide for digital acquisition, though globally, the use of radiographic film is still widespread.
- Many modalities are fundamentally digital, in that they require image reconstruction from quantified digital signals, such as computed tomography and magnetic resonance imaging.
16.2 IMAGE ENCODING AND DISPLAY

16.2.1 CHARACTERISTICS OF DIGITAL DATA
16.2 Image Encoding and Display

16.2.1 Characteristics of Digital Data

- Pixels and Voxels
- Photometric representation and dynamic range (channels, bits and pixel depth)
- Image data vs. image meta-data

16.2.2 Display of digital images

- Window and Level
- Display consistency (Perceptual Linearization, etc.)
16.2 IMAGE ENCODING AND DISPLAY

16.2.1 Characteristics of Digital Data

Pixels and Frames

- Individual digital images typically consist of a two-dimensional rectangular array of regularly sampled pixel elements or pixels.

- When multiple images are grouped together for some purpose, such as to provide multiple samples through time or space:
  - each image may be referred to as a frame.
  - the entire set of frames may be referred to as a multi-frame image.
16.2 IMAGE ENCODING AND DISPLAY
16.2.1 Characteristics of Digital Data

Pixels and pixel spacing

- Pixels are typically square
  - the two physical dimensions in space that they represent are equally sampled along the horizontal and vertical axes

- These dimensions are usually expressed as the pixel spacing
  - i.e. the distance between the centres of each pixel

- The meaning of the pixel spacing depends on the type of acquisition
Pixel spacing and acquisition type

- For cross-sectional modalities such as CT and MR, the pixel spacing within the patient is known at the time of image reconstruction.

- In projection radiography with a diverging X-Ray beam, the pixel spacing is dependent on the position along the beam and subject to geometric magnification:
  - it can only be defined at a known reference point, typically the central ray at front face of the detector.

- For photographic and scanned images, a reference of known size within the image can be used for calibration.
Voxels

- When an image or frame consists of a cross-sectional slice through the body, then an additional dimension exists, normal to the plane of the slice.
- A pixel is then referred to as a volume element, or voxel.
- Voxels in a single slice typically:
  - are all of the same thickness.
  - have the same spacing to the previous and next slice.
- Slice thickness and spacing are not necessarily the same:
  - slices may be acquired with a gap between them.
  - slices may overlap.
Photometric representation

- In consumer applications, images from digital cameras and for the web are (in their decompressed state) usually
  - 8 bits per channel
  - encoded with three channels of red, green and blue (true color) information

- Medical imaging applications often
  - involve a single channel of information representing a single physical quantity, such as X-Ray density
  - are visualised as greyscale images without colour
    - encoded such that the lower numeric values are displayed as either dark or light
Pseudo-color for medical images

- If color is applied to such single channel images, it is an artificial pseudo-colour palette.
- Intention is to make subtle differences in intensity more visually apparent.
- Three ways to apply pseudo-colour:
  - Colour may be applied to the grayscale single component image in the display application.
  - The colour palette that is to be applied may be included in the images.
  - The greyscale image may be transformed into a colour representation.
Bit depths other than 8 bit

- Medical images
  - may contain signal intensities sampled with a dynamic range that exceeds the 256 values that may be encoded in an 8 bit channel
  - may contain signed data with negative values (e.g. Hounsfield Units (HU) in CT may be negative)

- Typically 10, 12 or 16 bits in depth

- Data that is between 9 and 16 bits in dynamic range is usually
  - encoded in a single 16 bit (two byte) word, uncompressed
  - the remaining unused high bits are left empty, or used for other purposes, such as graphic overlays
Image data vs. image meta-data

- Encoded pixel values (pixel data) are distinct from the information that describes the characteristics of the pixel data – meta-data (data about data)

- Recipient needs meta-data to interpret the pixel data

- The meta-data may be
  - stored in a separate file from the pixel data, or
  - stored in a “header” preceding the pixel data (more common)
    - fixed length binary format
    - variable length binary name-value pairs
    - some sort of structured text format, such as XML
Image meta-data

- the dimension of the pixel data array (rows and columns and number of frames)
- the number of channels (samples) per pixel
- the physical spacing of the pixels
- the number of bits used to store each sample
- the number of bits within each stored word that contain significant bits and where within the word they are positioned
- the photometric interpretation of each pixel (whether it is grayscale or color, zero is black, etc.)
16.2 IMAGE ENCODING AND DISPLAY

16.2.2 DISPLAY OF DIGITAL IMAGES
Image Encoding and Display

16.2.1 Characteristics of Digital Data
- Pixels and Voxels
- Photometric representation and dynamic range (channels, bits and pixel depth)
- Image data vs. image meta-data

16.2.2 Display of digital images
- Window and Level
- Display consistency (Perceptual Linearization, etc.)
Pre-processing of images for display

- Acquired medical images typically differ in size and dynamic range from those of the devices on which they are to be displayed.

- Processing is needed in order to convert the images into the matrix of values that is sent to the display device:
  - Single point operations applied repeatedly for each pixel, such as conversion of pixel intensity.
  - Multi-point operations, such as re-sampling and interpolating all or part of the image to fit the display.
  - Spatial operations such as rotation, flipping, zooming and panning.
  - Descriptive annotations derived from the meta-data are also typically applied to the image during display.
The display may need to be adjusted because
- the number of sample values within an image exceeds the number of discrete displayable intensities available
- the human visual system of the observer is not able to discern small differences in displayed signal intensity (luminance)
- only a subset of the sample values is of interest for a particular diagnostic task

The adjustment involves the user selecting a window of signal intensities for display specified by a pair of centre (the level) and width values

The selected range of input values are then linearly mapped to the full dynamic range of the display device.
Window and Level in CT

- The acquired and encoded values typically
  - span a range of 4096 values
  - unevenly distributed over the range of densities corresponding to air, fat, soft tissues, iodinated contrast media and bone

- The user selects a window of signal intensities for display
  - when viewing soft tissue a narrow range of intensities centred around water density is selected
  - when viewing bone, a wider range of intensities needs to be displayed, with the subtle variations in soft tissue density sacrificed

- Preset pairs of window values and interactive adjustment are both routinely provided
Window and Level in projection radiography

- A linear mapping as used for CT may result in clipping to white or black at the upper and lower limits of the window.

- To produce a more satisfactory “roll off” of intensity in the light and dark regions:
  - apply a non-linear function, such as a sigmoid function
  - may be encoded in the meta-data as parameters of a defined function
  - or given as a lookup table (LUT) that encodes the mapping of each input to each output value
  - result comparable to the behaviour of X-Ray film (Hurter and Driffield (HD) characteristic curve)
Human visual system (HVS)

- Display devices translate digital driving levels (DDLs) into light intensity (luminance)
- Luminance is perceived by the human visual system (HVS) in combination with a contribution from any ambient lighting
- HVS is non-linear in its response to luminance
  - the minimum change in luminance that is detectable is not the same at different absolute luminance levels
- The net effect is that the same displayed image will be perceived differently with different levels of luminance (displayed and ambient)
Just Noticeable Difference (JND)

- The change in luminance required at any particular luminance level to be perceptible can be measured or predicted.
- The change is referred to as a Just Noticeable Difference (JND).
Perceptual linearization

- Applied to compensate for non-linear response
- Arranging that each change in DDL results in a luminance change that has the same perceptual impact
  - i.e. same number of JNDs
- Use the Barten model of the HVS to provide a calibration function for displays
  - as described in the DICOM Grayscale Display Function Standard (GSDF)
DICOM Greyscale Display Function Standard (GSDF) (1 of 2)

- Net effects of GSDF calibration
- Consistency
  - all images will appear to be of similar contrast on displayed devices of different luminance ranges
- Quality
  - the most effective use of the available luminance range will be used
DICOM Greyscale Display Function Standard (GSDF) (2 of 2)

- Calibration should be performed using lookup tables of sufficient bit depth in the display hardware
  - to avoid sacrificing JNDs through quantization
- The same maximum luminance be used on all devices within a site
  - for greater perceived consistency of appearance
- Regular re-calibration is also required to account for
  - degrading back light intensity or other display technology factors
  - changes in ambient lighting conditions if not dynamically accounted for by the display hardware
16.3 DIGITAL IMAGE MANAGEMENT

16.3
16.3 DIGITAL IMAGE MANAGEMENT

16.3.1 PICTURE ARCHIVING AND COMMUNICATIONS SYSTEMS
Digital Image Management

- 16.3.1 Picture Archiving and Communications Systems
- 16.3.2 DICOM (Digital Imaging and Communications in Medicine)
- 16.3.3 RIS/HIS Interfacing, HL-7 (Health Level 7)
- 16.3.4 Integrating the Healthcare Enterprise
Picture Archiving and Communications Systems

- Overview
- Scope
- Functions, Components and Workflow
  - Ordering and scheduling
  - Acquisition
  - Quality Control
  - Analysis and Post-processing
  - Display and Reporting
  - Management
  - Archival, Retention and Business Continuity
  - Distribution
16.3 DIGITAL IMAGE MANAGEMENT
16.3.1 Picture Archiving and Communications Systems

Overview

- A film image, of which there is only one original
  - is physically located in one place and requires manual handling, storage and transportation

- A digital image, which may be replicated as many times as necessary with full fidelity, requires
  - a means of distribution, electronic archival, electronic display

- Individual devices can be constructed to perform each of these tasks
  - grouping such devices together to form a system that manages these tasks produces a Picture Archiving and Communications System (PACS)
16.3 DIGITAL IMAGE MANAGEMENT
16.3.1 Picture Archiving and Communications Systems

Scope

mini-PACS

- A small system that addresses the needs of one department
- Perhaps involving a single modality
- A modest number of workstations for a limited number of specialized users

Enterprise PACS

Cross-Enterprise PACS
Scope – Enterprise PACS

- A system that serves an entire enterprise, such as a hospital or a large outpatient (ambulatory) facility

- A PACS is responsible for
  - acquisition, archival and distribution
  - and also management of the workflow and integration with other departmental or enterprise-wide information systems
    - such as the Radiology Information System (RIS), Cardiology Information System (CIS), Laboratory Information System (LIS) or Hospital Information System (HIS)

- Two kinds of user
  - local users, accessing information from within the organization
  - remote users accessing information from off-site
Scope – Cross-Enterprise PACS

- Patients are often investigated and treated at multiple locations
  - images and related information need to be interchanged between different sites and organizations

- This process of cross-enterprise interchange may involve the use of physical recording media or electronic networks
  - individual systems and entire PACS may be federated (grouped together and accessible in a single view) to provide for such interchange
  - data may be pushed over point-to-point connections, or stored (centralised) in regional archives that provide for broader access
PACS and medical records

- PACS may be linked to
  - Electronic Medical Record (EMR) systems that provide access to a broader range of information about a patient in one facility
  - a longitudinal Patient Health Record (PHR) system that provides for information to span facilities
Ordering and Scheduling (1 of 2)

- Digital images may be acquired
  - in response to a request or order (scheduled)
  - in the course of investigation or treatment of the patient by a clinician (unscheduled)

- Information may come from Admission, Discharge and Transfer (ADT) systems
  - demographic information about the patient
    - including their identity and characteristics
    - other information about their condition
  - information about the identity of those placing the orders
Ordering and Scheduling (2 of 2)

- **Orders** may be placed in a Computerized Physician Order Entry (CPOE) system or other form of Order Placer, such as a HIS.
- **Scheduling** may occur in a separate Order Filler and Department System Scheduling (DSS/OFS) system, such as a RIS.
- An electronic source of identity, ordering and scheduling information, and the integration of disparate sources of information:
  - reduces need for re-entry of data leading to operator error.
  - images may be associated with information in other systems.
Acquisition – data and meta-data

- A digital acquisition modality is responsible for
  - the acquisition of the raw data from which to reconstruct an image suitable for display to a human observer
  - associating that image with the order and demographic metadata

- The human operator of the device may provide this information through
  - direct data entry at the modality console (which is error prone)
  - by scanning previously printed bar-code information
  - by selection from a predefined schedule on a worklist or other electronic source of demographic information

- The modality includes this metadata in the image “header”
Acquisition – local transmission

The modality then transmits the images and related information to another device on the local network such as:

- a quality control or interpretation workstation
- an analysis system
- an image manager or archive
- a digital film printer
Acquisition – local activities

- Typically a modality will send the images once to a single pre-configured location which will then:
  - take responsibility for interpretation, archival and distribution
  - purge any local copies after a pre-determined interval

- Alternatively, some modalities provide for local archival, such as on removable media like CD or Magneto-Optical Disk (MOD), of:
  - the reconstructed image data
  - the raw data
  - or both
Acquisition – local activities for other modalities

- Older modalities that produce digital images, but pre-date the widespread use of standard means of network communication, may require an acquisition gateway or converter “box” of some type to perform these functions.

- Similarly, non-medical devices used to capture images from other sources may require such a gateway to convert the consumer format images (like JPEG or TIFF) to a standard medical format containing the additional metadata for transmission.
  
  - for example a digital camera or digital video recorder attached to an endoscope or a microscope
Acquisition – local activities for other devices

- Correct interpretation of the current examination may need other information
- Digitizers may be used to capture physical material
  - images from previous examinations - radiographic film or printed images
  - paper documents - request forms, operators’ notes and worksheets
- Digital images and reports previously recorded on interchange media such as CD can be imported
- These devices are integrated in a similar manner to any other acquisition device
  - may need specialised workflow e.g. to reconcile the identifiers on externally provided material with local record numbers
Acquisition – film digitisers

- Digitisers for scanning radiographic film, or laser printed medical film, differ significantly from consumer systems
  - the mechanism of scanning is transmissive, rather than reflective
  - the range of optical density of the film is dense
  - the requirements for spatial and contrast resolution are demanding
  - specialised physical handling of the film transport is required

- Both CCD and laser devices are available that provide for
  - at least a spatial resolution of 2.5 lp/mm, a contrast resolution of 10 bits and a maximum optical density of 4.0
  - mechanisms of calibration are provided that allow for predictable values of optical density or a standard perceptually linear space
Quality Control – After acquisition

- Quality control (QC) by a human operator is usually required to confirm:
  - positioning, technique, absence of motion or other artefact
  - correct labelling and identification

- Mechanism for QC
  - a display device may be present at the modality console itself
  - a separate QC workstation may be provided to which the images have been automatically routed
  - the images may be available from a central location via an ordinary PACS workstation but sequestered from general availability until QC has been completed
Quality Control – Choice of mechanism

Choice dictated by

- the type of modality
- local optimization of workflow
  - a direct digital X-ray system may have an integrated display,
  - a Computed Radiography cassette reader may require a separate workstation

Separation of acquisition and QC responsibility to different operators may improve efficiency

Whatever workstation is used for QC it should have a display adequate for the purpose, in terms of size, functionality, calibration and viewing environment
Image Analysis – Computer Assisted Detection/Diagnosis

- Some types of digital images are amenable to automated image processing and analysis to provide for Computer Assisted Detection (CAD) and Computer Assisted Diagnosis (CADx).

- Cancer detection on X-ray mammography is the primary application for CAD.

- CAD is also applied for cancer detection to dynamic contrast enhanced MRI, chest X-rays and chest CT, as well as CT virtual colonoscopy.
Image Analysis – Other types of post-processing

- Other types of post-processing may be appropriate for some applications and modalities a human operator may
  - create additional reconstructions of the acquired image data, for example, 3D reconstruction
  - perform quantitative measurements on the images, prior to transmission to the physician for interpretation

- A typical example would be quantitative analysis of coronary arteries on CT angiograms
  - requires segmentation of the vessels, presentation in specialized 3D software, and semi-automated quantification of stenosis
16.3 DIGITAL IMAGE MANAGEMENT
16.3.1 Picture Archiving and Communications Systems

Image Analysis

- May be performed as
  - a separate workflow step
  - by the physician themselves during reporting

- Choice depends on the
  - preferred workflow
  - specialisation and expertise of staff
  - reimbursement pattern
  - capabilities of the PACS
Image Analysis – digital images and data

- CAD and other post-processing devices
  - receive digital images from the modality, either directly or via the PACS
    - the images required for processing may be different from those required for presentation to a human observer
    - a modality may be required to send raw data to the CAD system rather than processed images
  - produce additional information to be used during human interpretation of the examination
Image Analysis – output

- The output of any post-processing step may be:
  - derived and annotated images
  - structured information that can be rendered and analysed by a user’s workstation

- The CAD or analysis workstation transmits this information to the PACS for the subsequent workflow steps
Display and reporting

- The end product of a radiological examination includes not only the images, but also the report by the radiologist.
- Digital images need to be displayed to the radiologist and interpreted by them (soft-copy reading).
- An appropriate image display needs to be able to provide:
  - a worklist of unreported studies to interpret
    - this is more efficient but requires greater integration with the information systems
  - or a list of all available studies for the user to choose from, preferably with their reported state.
16.3 DIGITAL IMAGE MANAGEMENT
16.3.1 Picture Archiving and Communications Systems

Image display for reporting – general

- Images need to be made available in a timely manner, including those from relevant prior examinations
  - may be obtained on demand or pre-fetched, depending on the architecture and performance of the system

- When a study is selected
  - the full available screen real-estate should be automatically populated with images in the most efficient manner for interpretation according to the user’s preferences
  - apply hanging (default display) protocols that
    - recognize the type and content of current and prior images
    - layout the images for comparison accordingly, flipping and rotating into the correct orientation as necessary
Image display for reporting – modality specific – 2D

The display software needs to support adequate display of the different image types from the different modalities being supported, including support for:

- projection (e.g. X-ray) and cross-sectional (e.g. CT, MR) images
- true colour (e.g. ultrasound) and pseudo-colour (e.g. NM) images
- multi-frame and cine images (e.g. cardiac ultrasound and angiography)
Image display for reporting – modality specific – 3D

- Support for 3D multi-planar reconstruction (MPR) and maximum intensity projection (MIP) and volume rendering (VR) is expected for
  - CT and MR
  - especially for musculoskeletal and angiographic interpretation
  - tumour size measurement

- Interpretation of hybrid PET-CT examinations requires
  - MPR support and
  - display of fused images (pseudo-coloured PET superimposed on CT)
Basic image review features

- Visual navigation of the available series of images through the use of thumbnails or a hierarchical browser
- Side-by-side comparison of at least two sets of images, whether they be series from the same study, or different studies, with synchronized scrolling, panning and zooming in the case of cross-sectional modalities
- Annotation of laterality, orientation as well as spatial localization of cross-sectional images for anatomic reference,
- Annotation of demographics, management and basic technique information to provide for safe identification and usage
- Simple measurements of linear distance and angle as used for change detection and treatment planning
PACS and reporting requirements

- Reporting styles vary
  - some radiologists use conventional dictation (recorded digital audio)
  - some use speech recognition
  - others fill in pre-defined structured report templates on the screen

- Integration of reporting technology with image display and other information systems for optimal user efficiency and workflow remains challenging
No system is perfect and human error is possible at each stage of the process

- images may be inadvertently assigned to the wrong patient or order
- the wrong study may be performed
- images may be of poor quality and need repeating, which may require rescheduling and recall of the patient
- the wrong side may be inadvertently recorded in the image header or pixel data.
Management – error correction (2 of 2)

- Systems must therefore provide a management function that allows
  - corrections to be made by authorized personnel
  - a record of these corrections (audit trail) to be reliably maintained

- These corrections may involve changes to various databases that need to be promulgated to everywhere the images may be used
Management – purging and export

- The ability to purge selected studies may be desirable, both manually and in a rule-based automated manner
  - over time, the PACS archive will fill with images that may no longer need to be immediately available
  - when statutory retention periods expire
  - prior exams for reporting rapidly decrease in usefulness over time

- Export capabilities, both over the network to remote facilities and via standard interchange media are required
  - patients frequently need to be referred elsewhere for further treatment; their records must be available to accompany them
Archiving

- Images must be stored, both in the short term for immediate use
  - for use as relevant priors for subsequent examinations
  - for referral for subsequent treatment
  - for statutory retention purposes
- Many types of storage technology have been used for PACS archives
16.3 DIGITAL IMAGE MANAGEMENT
16.3.1 Picture Archiving and Communications Systems

Types of storage technology (1 of 2)

- Hierarchical Storage Management (HSM) systems
  - attempt to provide fast access to current images and slower access to older images
  - by pre-fetching from slower storage (tapes or optical disks) in anticipation of demand

- “All spinning” media
Types of storage technology (2 of 2)

- Hierarchical Storage Management (HSM) systems
- The use of so-called “all spinning” media is now routine
  - driven by the plummeting cost of high capacity hard drives
  - all images are available on-line on hard drives with the same level of service
  - relevant recent technologies include
    - Redundant Arrays of Inexpensive Disks (RAID), Network Attached Storage (NAS), Storage Area Networks (SAN), Fixed Content Storage
  - a variant on the HSM concept is to use hard drives of differing performance to minimize cost for less frequently accessed content
Total Cost of Ownership (TCO)

- Today, the cost of archival may not be dominated by the cost of the drives, but rather the Total Cost of Ownership (TCO)
- This is the infrastructure required to support them, including the cost of power and cooling, and network bandwidth for off-site replication
High Availability (HA)

- Access to images has become mission critical, so inaccessibility of the PACS is unacceptable, either for scheduled (maintenance) or unscheduled (failure) reasons.
- This requirement drives the need for **High Availability (HA)** in the entire system design, but particularly with respect to recent examinations for current inpatients.
- Satisfying HA requirements may require the use of an off-site replica of the archive maintained to a near real-time consistent state with the local primary archive, and a means of redirecting requests for images in the event of failure.
Backup

- A separate requirement from HA is the need for backup in the event of significant local data loss.
- Since images are now stored exclusively electronically, the loss of the only copy results in total loss.
  - not acceptable either for clinical care nor to meet statutory retention requirements.
- Backups must be performed and backups must be stored off-site, in a sufficiently distant and robust facility to protect them.
- HA and backup requirements can be satisfied with a single solution, but the needs are distinct.
Disaster Recovery or Business Continuity plan

- Defines the design and procedures associated with HA and backup solutions
- Analyses failure scenarios
- Provides predefined procedures to follow for likely contingencies

Plans must
- include estimates of the time to recover
- be regularly tested
Alternative models for archiving

- The prospect of using regional and national in addition to or in place of local archives is being considered
  - provide an opportunity to provide access across enterprises and to community physicians
  - could potentially be re-used for backup purposes or the primary archive

- Commercial services also offer off-site storage, not just for HA and backup, but as the primary archive
Information to be archived

- What type of information needs to be archived for patient care and medico-legal purposes is dictated by:
  - local regulations
  - site policies
  - standard of care
  - risk management
  - cost

- Not only the radiological report but also the digital images themselves may form a critical component of the medical record.
Image data to be archived

- When images are acquired in multiple forms policy will dictate whether these are retained or not
  - for example thin CT slices intended for post-processing and thicker reconstructions intended for distribution and viewing

- Retention of raw data for CT and MR is not typical

- It may be of benefit to the patient
  - to retain images for processing for screening mammography CAD
  - to retain CAD results, to improve accuracy at the next round of screening
Distribution of images

- Though some referring providers are satisfied with the report alone, many require the images
  - to make their own clinical and diagnostic decisions
  - for surgical or other treatment planning
  - for patient education
  - for teaching
Distribution and confidentiality

- Digital images have an advantage over film in
  - subject to the appropriate authorization and access controls they can be made available at multiple locations simultaneously
    - via a secure network or via interchange media
    - both inside and outside a facility,
- If necessary for teaching or research purposes, the digital images may be de-identified to protect the patient’s confidentiality
16.3 DIGITAL IMAGE MANAGEMENT
16.3.1 Picture Archiving and Communications Systems

Distribution and image quality

Many PACS systems provide
- for local and remote network access by authorized users other than the primary interpreting radiologists
- often utilizing a web browser component or a software application that has significantly constrained functionality
- or with images of limited quality, and on displays that may not be calibrated or of medical grade

For many sophisticated users this may be unsatisfactory
- a complete set of diagnostic quality images must be made available, preferably routinely, but certainly on request
- if necessary, the providers of clinical care must be able to import the images into their own systems
Distribution to different users

- Different users require different functions to be available in their image display software.
- An assumption is often made that only rudimentary image manipulation tools are required.
  - Counter-examples include the dedicated software needed for orthopaedic prosthesis template application, neurosurgical robotic surgery planning, and radiotherapy planning.
- Patient access is often neglected.
Patient access

- Though the authorization and access control issues of providing external network access to patients are non-trivial, institutions deploying EMR systems are increasingly providing patient portals.

- More commonly though, a set of images on interchange media is routinely be provided to all patients:
  - either immediately after examination or
  - after the final report is issued.
16.3 DIGITAL IMAGE MANAGEMENT

16.3.2 DICOM (DIGITAL IMAGING AND COMMUNICATIONS IN MEDICINE)
Digital Image Management

- 16.3.1 Picture Archiving and Communications Systems
- 16.3.2 DICOM (Digital Imaging and Communications in Medicine)
- 16.3.3 RIS/HIS Interfacing, HL-7 (Health Level 7)
- 16.3.4 Integrating the Healthcare Enterprise
DICOM (Digital Imaging and Communications in Medicine)

- Background
- Composite Information Model and Information Objects
- Attributes, Data Elements, Encoding and Transfer Syntaxes
- Service Classes, SOP Classes, Associations and Conformance Statements
- Interchange Media and Archival Storage
- Composite Instances other than Images
- Service Classes other than Storage
DICOM - Background

- The earliest digital medical imaging devices were both proprietary in nature and provided output in the form of printed film
  - users had no expectation that digital images would be extracted from such devices
  - nor that they could be exchanged between devices or software from different manufacturers

- As use-cases were developed for transferring, storing and remotely displaying images electronically, manufacturers initially provided proprietary solutions that were not interoperable
DICOM – Background

- One could, for example, equip an entire hospital with X-ray, CT and MR acquisition devices as well as a PACS and review workstations, but
  - only if everything was purchased from one vendor, or
  - if custom interfaces were developed for each acquisition device

- This approach was neither scalable nor affordable

- The need to develop open standards to promote interoperability between equipment from different manufacturers quickly became apparent
The first open standard effort for medical imaging was the ACR-NEMA standard published in 1985. Jointly sponsored by the American College of Radiology (ACR), representing the users, and the National Electrical Manufacturers Association (NEMA), representing the producers.

Mechanism for encoding the pixel data of the images themselves, together with information about the images in the form of a list of data elements.

A set of commands and a means of exchanging this data over a point-to-point connection between two devices using a 50-pin parallel interface.
ACR-NEMA standard revised to DICOM

- Until 1993 there was little adoption of the ACR-NEMA standard
- In 1993, an extensively revised version of the standard was produced, renamed Digital Imaging and Communications in Medicine (DICOM)
- A key feature of DICOM that distinguished it from its predecessor was the use of evolving computer networks and Internet technology and protocols
DICOM today

- The use of DICOM is ubiquitous
- No manufacturer would be able to market a device that did not conform to the standard
- The standard is not static, but rather evolves through extension with additional features, as new imaging and communication technology is developed
DICOM beyond radiology

- Though initially targeted towards radiology applications, today the DICOM standard is not so restricted in scope.
- Includes support for many other medical specialties such as cardiology, dentistry, endoscopy, dermatology, and pathology.
- DICOM has also been extended beyond the scope of medicine to include non-destructive testing of aircraft parts (DICONDE) as well as baggage screening and other security applications (DICOS).
Information Object Definitions (IODs)

- A primary purpose of DICOM is the interchange of images and their accompanying information.
- The standard describes Information Object Definitions (IODs):
  - specific to a type of image produced by a particular modality
  - shares a common structure
- There is an IOD for CT, and another IOD for Ultrasound:
  - share common information about the patient and the management of the study
  - but include different information about the acquisition technique, spatial and temporal relationships, and encoding of the pixel data.
16.3 DIGITAL IMAGE MANAGEMENT

16.3.2 DICOM (Digital Imaging and Communications in Medicine)

Modules

- DICOM describes this information in **Modules** that are either general or modality specific.
- The **Patient Module** includes the patient’s name, their birth date and their identifier:
  - i.e., characteristics of the patient that are fixed
- The **General Study Module** includes additional information required to manage the study:
  - date and time that the study was started
  - identifiers of the request and the study itself
  - descriptors of the type of procedure
16.3 DIGITAL IMAGE MANAGEMENT
16.3.2 DICOM (Digital Imaging and Communications in Medicine)

Modules associated with several modalities

- CT images will contain additional modules that are
  - applicable to all forms of cross-sectional imaging, or
  - may be specific to CT

- CT, MR and PET images all share the concept of an image as a slice in a well-defined three-dimensional space
  - the Frame of Reference Module defines the patient-relative coordinate system shared by a set of slices acquired in the same procedure
  - the Image Plane Module defines the position and orientation of an individual slice

- Ultrasound images do not contain these modules
  - traditionally acquired with a free-hand transducer
  - do not have a Cartesian geometry
16.3 DIGITAL IMAGE MANAGEMENT
16.3.2 DICOM (Digital Imaging and Communications in Medicine)

Modules associated with specific modalities

- Since CT images are acquired using an X-ray beam, the CT images contain specific attributes that describe the characteristics of that beam and its production, including the kV, tube current, exposure time, filtration.

- Ultrasound images on the other hand include information about the type of transducer used, the transducer frequency and so on.

- Accordingly, there are CT Image and Ultrasound Image Modules defined to record this modality-specific information.
16.3 DIGITAL IMAGE MANAGEMENT
16.3.2 DICOM (Digital Imaging and Communications in Medicine)

Modules associated with images in a procedure

- Modules also describe information that is shared between multiple images during the same procedure
- This commonality defined in DICOM Information Model
- Describes entities, such as
  - Patients
  - Studies
  - Equipment
  - Series
  - Images
  - and the relationships between them
Entities

- All images that are acquired as part of the same procedure will contain exactly the same information about the Patient and Study.
- If the procedure is performed on the same device, then the information about the Equipment will be identical in all such images.
- Multiple images may be grouped into the same Series if they have something in common, such as if they were acquired in a single run of the CT gantry.
Composite instances

- When images are encoded, all of this common information is replicated into each instance
  - every image contains a full set of information
  - for this reason they are referred to as Composite instances
  - as opposed to Normalized instances in which the information about each entity would be managed and transmitted separately

- The intent is that a single image may be separated from other images or the system on which it is produced or stored, yet still contain a full set of information necessary to identify and interpret it
16.3 DIGITAL IMAGE MANAGEMENT
16.3.2 DICOM (Digital Imaging and Communications in Medicine)

Attributes

- Modules are defined as a list of attributes, each of which encodes a specific piece of information such as a name or a numeric value.
- For transmission and storage, these attributes are encoded as data elements in a single binary dataset.
  - Each data element in the standard is assigned a unique 32-bit numeric tag, usually described as a pair of 16 bit hexadecimal group and element numbers.
    - The Patient’s Name attribute is assigned a data element tag of (0010,0010).
    - A textual description of the name of each data element is not included in the encoding.
    - The format is not “self-describing” and the recipient needs to have prior knowledge of what each element means.
Value Representation (VR)

- Each data element is of a pre-defined type, or Value Representation (VR)
- The standard defines a variety of such types
  - binary types for signed and unsigned integers of 16 and 32 bit lengths
  - IEEE floating point binary types of 32 and 64 bit length
  - specific string types, such as those for names, integers and decimal values, dates and times, and codes
  - general string types for free text descriptions
Value Representation (VR) and Value Length

- The VR may either be
  - encoded explicitly, or
  - implied and looked up in a dictionary by the recipient

- The Value Length (VL) of each data element is always explicitly encoded

- Value lengths are always even, and where necessary strings are padded to even length
Pixel data

- The **Pixel Data** itself is encoded as just another data element, (7FE0,0010)
  - a very large element with some specific encoding rules
- Hence a DICOM dataset does not consist of a fixed length “header” that may be skipped to reach the pixel data
- The pixel data are not necessarily at the end of the dataset
- Full parsing of the successive data elements, including recursion into any variable length sequences, is necessary to reliably recover the pixel data
Transfer Syntax

- The Transfer Syntax defines the actual encoding.
- The Transfer Syntax is also used to distinguish images whose entire dataset or pixel data may be compressed.
- In addition to the standard Transfer Syntaxes defined by DICOM, a manufacturer may define their own private Transfer Syntaxes, which can be used as long as both the sender and recipient agree to support them.
Storage Service / Service-Object Pair (SOP) Class

- Once an instance of an image information object has been assembled and encoded in a particular Transfer Syntax, it is transmitted on the network using one of the many network services that DICOM defines, the Storage Service Class.

- Not all devices support all types of images from different modalities.
  - so DICOM defines the combination of a Service Class and an IOD as a Service-Object Pair (SOP) Class.
  - the combination of the Storage Service Class and the CT Image IOD is the CT Image Storage SOP Class.
Service-Object Pair (SOP) Classes

- The purpose of defining SOP Classes is to allow the sender and receiver to negotiate their mutual capabilities when establishing a connection on the network, what DICOM refers to as an Association.

- This negotiation mechanism allows:
  - the sender to offer, for example, CT and MR images each in uncompressed or compressed form,
  - the receiver to accept either those which it supports, or prefers,
  - the sender to then select among the accepted choices which to use.
A sender may have images to send of more than one SOP Class, say CT and Ultrasound.

Yet the receiver, say a 3D workstation, may not support Ultrasound images, and would then reject the corresponding SOP Class.

In general, such limitations are known before hand, at purchase and installation time, and are determined by comparing DICOM Conformance Statements.
DICOM Conformance Statements (2 of 2)

- Each manufacturer is required by the standard to document their product’s capabilities in a conformance statement
  - amongst other things, these statements contain a tabulation of which SOP Classes and Transfer Syntaxes are supported
- A simple statement by a vendor that a device is “DICOM compliant” is NOT sufficient to describe interoperability
- A specific review of every pair of devices’ conformance statements by an educated purchaser with a critical eye is required to assure compatibility
Application Entities (AEs)

- The devices at either end of the association are referred to as Application Entities (AEs).
- This term is used since there is no requirement that there be a one to one correspondence between physical devices or software applications and AEs.
Interchange Media

- In addition to providing for transfer of DICOM instances on a network, the standard also includes rules for the use of Interchange Media:
  - such recordable CDs, DVDs, MODs and USB devices
  - sufficiently robust to allow the information to be preserved for transfer from one physical location to another by mail or courier

- DICOM has chosen conventional consumer-format media and file systems whenever possible to:
  - maximize reuse of affordable technology
  - assure that they readable with ordinary operating systems on ordinary computers - no need for special hardware or software
File format for interchange media and archival storage

- A short **Meta Information Header** is required, preceding the encoded DICOM dataset, the header provides
  - a recognition string (magic number) by which DICOM files can be distinguished from other files
  - a description of the Transfer Syntax actually used to encode the data set that follows

- All DICOM media must contain, in the root directory, a **DICOMDIR** file
  - encodes a summary of the content of the media
  - lists every patient, study, series and instance present, together with a summary of the characteristics of each of those entities

- An application can read this file and quickly summarize the contents in a browser for the user, without having to read every file on the media
Composite Instances for non-image data (1 of 2)

- The initial focus of DICOM was the interchange of images themselves.
- There are other types of bulk data that can be handled in a similar manner to images, such as:
  - time-based waveforms (e.g. ECGs)
  - spectroscopic data (e.g. MR spectroscopy)
  - documents of various types (e.g. PDFs)
  - even the raw data that is acquired prior to image reconstruction
Composite Instances for non-image data (2 of 2)

- These different types of data need description in a similar manner to the information model for images
  - hence can share the Composite Information Model that is used for images
- Each can be described as a composite IOD with the addition of the appropriate modules, attributes, data elements and encoding mechanisms
- The same storage service class can be used for transfer of these objects on the network
- They can be encoded on interchange media in the same manner as images
Composite Instances for information

- Other types of information may be acquired that do not consist of bulk data that needs to be described, but can adequately be described as a set of individual attributes.

- A Radiotherapy (RT) Plan can be described in such a manner:
  - as distinct from an RT Image (portal image) or an RT Dose map which are encoded as images.

- There is an entire family of RT-related objects to support both external beam and brachytherapy.
DICOM Structured Report (SR) (1 of 2)

- The need to encode data in an extensible structured form is common to many use-cases, including:
  - the recording of quantitative and categorical data from acquisition devices (such as obstetric or cardiac ultrasound measurement)
  - Computer Assisted Detection (CAD) of abnormalities on images such as mammograms
  - the encoding of human-generated reports

- This is the province of the **DICOM Structured Report (SR)** family of objects
  - use nested recursive sequence attributes to encode an extensible tree of categorical, coded, numeric and free text information
  - using templates defined for specific applications
DICOM Structured Report (SR) (2 of 2)

- A distinguishing feature of the DICOM SR, as compared to other structured document formats, is a mechanism for making reference both
  - to DICOM images (and waveforms) in their entirety
  - to specific coordinates referencing locations in space (or time)

- These are used, for example, to illustrate findings or to define the locations at which measurements were made

- DICOM SR objects are also used to encode
  - Radiation Dose Structured Reports (RDSR)
  - lists of relevant images for some purpose (Key Image Notes (KIN) or Key Object Selection (KOS) documents)
Presentation State

- Medical images when displayed are often manipulated by the user to
  - zoom or pan to a specific location
  - adjusted in contrast and brightness (window width and center)
  - annotate with text or graphics

- These manipulations can be captured as a Presentation State
  - such states can be stored as composite instances for retrieval and application to the same images at a later time
Presentation State and DICOM Structured Report

- References to images in SR instances may also contain an accompanying reference to a presentation state
  - for example to capture the appearance of the display of a particular region when a measurement was made

- The SR and presentation state instances are exchanged using the normal storage service class and interchange media profiles
  - like the non-image bulk data composite instances
Service Classes to support storage activity

- The major use of DICOM network services is to transfer (store) images and other composite instances from one AE to another.

- Many other service classes are defined, some of these exist primarily to support storage activity:
  - The Storage Commitment service, allows the sender of a set of instances to ask the receiver if it will take responsibility for the persistence of the stored objects - used by an acquisition modality prior to deleting its local copies of images.
  - The Query/Retrieve service class allows a remote device to be queried for patients, studies, series and instances using identifiers and other matching attributes, and an item be selected for retrieval.
Service Classes for non-storage activity

- Other service classes are defined for use-cases that are not directly related to storage
  - the **Worklist Management** service class provides demographic and request and scheduling information via a **Modality Worklist (MWL)**
  - the responses obtained, **Scheduled Procedure Steps**, provide the modality with the necessary information to
    - choose the correct patient
    - perform the work of image acquisition
    - populate the attributes in the resulting images

- When image acquisition is complete
  - feedback is provided to the management system in a **Modality Performed Procedure Step**
16.3 DIGITAL IMAGE MANAGEMENT

16.3.3 RIS/HIS INTERFACING, HL-7 (HEALTH LEVEL 7)
Digital Image Management

- 16.3.1 Picture Archiving and Communications Systems
- 16.3.2 DICOM (Digital Imaging and Communications in Medicine)
- 16.3.3 RIS/HIS Interfacing, HL-7 (Health Level 7)
- 16.3.4 Integrating the Healthcare Enterprise
Background

- Just as DICOM is ubiquitous and unchallenged as the single standard for interchange of medical images, other information systems in a healthcare enterprise depend upon the HL-7 standard for communication.

- The first version dates back to 1987, but varieties of the Version 2.x are the most common in use today, particularly since version 2.3 (1997).

- An almost completely different and much more complex standard, HL-7 Version 3 has been defined, but has yet to supplant the dominance of the Version 2.x in the field.
Clinical Document Architecture (CDA)

- HL-7 defines a Clinical Document Architecture (CDA)
  - a means of encoding and managing structured documents with consistent metadata

- CDA documents
  - may be exchanged using Version 2.x or 3.x or other mechanisms
  - persist independently of the communication mechanism
  - can be exchanged and stored using DICOM services
HL-7 and other standards

- The HL-7 organization has also grown to absorb, embrace or define several other standards
- This includes the Clinical Context Object Workgroup (CCOW)
  - defines a means of loosely coupling different desktop applications to share the same context
  - for example to enable recognizing that the patient being viewed has changed
Version 2.x

- Unlike DICOM, HL7 Version 2.x messages are encoded as text messages, rather than as binary
  - the format and meaning of messages are defined in detail, as are the circumstances under which they will be sent (trigger events)

- Most commonly, HL7 devices communicate over a network
  - using TCP/IP and the Minimal Lower Level Protocol (MLLP)

- Third-party “interface engines” can be used to centralize the messages produced by individual sources, transform them and propagate them to other devices that need the information
Composition of HL7 messages – segments

- HL7 messages are composed of "segments" separated by carriage returns
  - the first segment is always the MSH or message header segment
    - assigns an ID to the message
    - specifies the separator (delimiter) characters used
    - specifies the "trigger event" that stimulated the message to be sent
  - subsequent segments carry the payload of a message
- Many segments are common to several different types of message
Composition of HL7 messages – fields

- HL7 segments are composed of “fields” that have a “data type” associated with them.
- There are no explicitly conveyed tags to identify a field in a segment, and no explicit data type conveyed.
- The meaning of a field is conveyed by its position in a segment alone.
HL7 messages relevant to imaging

- The scope of HL-7 Version 2.x message types and trigger events is broad; only a few are relevant to imaging applications.
- Of specific interest are those related to the management of patient identification, which includes:
  - the ADT (Admission, Discharge and Transfer) messages
  - those related to Order Entry (OE) such as the ORM general order message
- Both are commonly used to construct the set of information required to respond as a DICOM Modality Worklist query provider.
16.3 DIGITAL IMAGE MANAGEMENT

16.3.4 INTEGRATING THE HEALTHCARE ENTERPRISE
Digital Image Management

- 16.3.1 Picture Archiving and Communications Systems
- 16.3.2 DICOM (Digital Imaging and Communications in Medicine)
- 16.3.3 RIS/HIS Interfacing, HL-7 (Health Level 7)
- 16.3.4 Integrating the Healthcare Enterprise
The need for Integrating the Healthcare Enterprise (IHE)

- The DICOM and HL-7 standards define rules for very specific services or messages, but neither defines an overall architecture for building a complete system to support an entire enterprise.

- Significant gains in interoperability were achieved using both standards, and large and complex systems were built without dependence on proprietary interfaces.

- However, further progress towards producing turn-key devices that could “plug and play” required definition of specific use-cases and specific architectures to support them.
RSNA and IHE

- The Radiological Society of North America (RSNA), an organization that had been instrumental in the promotion and adoption of DICOM, began in 1997 to convene key stakeholders to establish momentum and direction.

- In 1998 RSNA allied with the Healthcare Information and Management Systems Society (HIMSS) to initiate the Integrating the Healthcare Enterprise (IHE) effort.

- The premise was that an annual cycle of release of technical specifications, testing of implementations at “connectathons”, and public demonstrations would quickly demonstrate value to product marketers and customers.
The first connectathon

- Year One focused on one problem
  - scheduling radiology workflow from patient registration through ordering, scheduling, to image acquisition, transfer, archival and distribution

- This problem involved
  - two standards (DICOM and HL-7)
  - multiple types of device manufacturers (HIS, RIS and PACS)

- Resulted in
  - 24 vendors demonstrating 47 systems at the first connectathon
  - a public demonstration at the RSNA annual meeting in 1999
The growth of IHE

- Initially conceived as a three to five year project – as of 2009 the project is ongoing in its eleventh year
- IHE is now a global organization spanning multiple domains well beyond radiology
Profiles, Actors and Transactions

- The IHE approach is to identify a set of use-cases that require a common infrastructure.
- Then to define an Integration Profile composed of Actors and Transactions sufficient to support those use-cases.
- The resulting profile may not be the only way to solve the problem, but it is designed to be sufficient as well as consistent with:
  - other integration profiles
  - where possible, the installed base of equipment in the field.
Actors

- For each profile a family of **Actors** is defined
  - abstract devices that in the real world serve different purposes
  - often, but not necessarily, provided by different manufacturers

- For example, that part of an HIS or RIS that performs the scheduling function is
  - referred to as a Department System Scheduler/Order Filler (DSS/OF) actor
  - distinct from the actor that performs the ordering function, the Order Placer actor

- In reality, these may be grouped together in a single implementation
Actors from PACS

- Similarly the management and archival functions of a PACS are grouped
  - as the Image Manager/Image Archive (IM/IA) actor
  - distinct from the image display functions of a PACS workstation, the Image Display (ID) actor

- The various actors are common between various profiles where appropriate
IHE and existing standards

- The behaviour of an actor
  - is not defined generically
  - is specified in the context of transactions between actors in the context of a profile

- IHE profiles do not define new standards to implement transactions
  - if possible uses existing messaging standards such as DICOM or HL-7
  - if necessary specializing or constraining particular HL-7 messages or DICOM SOP Classes to achieve the objective
Example of IHE and existing standards

- In Scheduled Workflow (SWF) profile
  - HL-7 messages are specified for patient registration and order entry
  - the protocol to be used, the version of HL-7 and the content of certain segments and fields, are explicitly defined
  - since other transactions in the same profile use DICOM SOP Classes, such as the provision of Modality Worklist, the mapping from the HL-7 messages, segments and fields to the DICOM query return attributes is defined, providing a deterministic bridge between two similar, but not identical, standards
  - the degree of specificity in the definition of the profiles serves to eliminate uncertainty on the part of implementers and purchasers
IHE Integration Statements

- The profiles are in general an all or none proposition.

- Instead of having to match the specific capabilities in DICOM Conformance Statements of two different devices, the purchaser can compare the IHE Integration Statements of two devices.

- Two devices supporting the same profile should interoperate, without the need to evaluate the specifics of the DICOM Modality Worklist implementation, e.g.
  - a CT scanner claiming to be an Acquisition Modality (AM) actor supporting the IHE SWF profile and
  - a RIS claiming to be a DSS/OF actor for the same profile.
IHE and interchange media

- The IHE Portable Data for Imaging (PDI) profile
  - requires the use of the DICOM standards for media
  - but selects and limits the choices provided to those in common use, specifically to the use of uncompressed images on CD

- Subsequent extensions to the PDI profile
  - adopt more DICOM features
  - allow for the use of DVD and USB media
  - allow selective use of compression
  - allow encryption for privacy protection

- Encrypted media are required in IHE PDI to provide accompanying on-media decryption software
Another type of integration profile addresses the behaviour of single actors in terms of the features available to the user.

The **Image Display (ID)** actor, which describes the functions expected in a workstation or viewer, is included in several profiles that specify detailed application-specific behaviour:

- The Mammography Image (MAMMO) profile
- Basic Image Review (BIR) profile
Mammography Image (MAMMO) profile

- Describes a list of detailed requirements that a display must implement, such as
  - achieving the proper orientation
  - comparable size of current and prior images
  - justification to the chest wall
  - consistency of greyscale contrast (window) settings
  - completeness of annotations and the display of CAD marks

- Requires that specific DICOM attributes be used to implement specific behaviour
  - rather than leaving this discretion to the implementer

- Burdens the Acquisition Modality with requirements to populate these attributes
Greyscale Standard Display Function (GSDF)

- In order to facilitate consistency of perceived contrast of displayed images
- Profiles require the display to implement and conform to the DICOM Greyscale Standard Display Function (GSDF)
  - the MAMMO profile
  - the Consistent Presentation of Images (CPI) profile
Basic Image Review (BIR) profile

- Enumerates the minimal features that a clinical review user requires
  - down to the level of detail that will provide a similar user experience regardless of manufacturer
  - going so far as to define standardized icons and minimum performance requirements

- The goal of this profile is to improve the consistency of viewers included on PDI media (Portable Data for Imaging)

- It is not limited to that application
Radiation Exposure Monitoring (REM) profile

- Describes
  - the production of Radiation Dose Structured Reports (RDSRs)
  - their transfer to the PACS
  - use for local monitoring
  - de-identification
  - submission to dose index reference level registries
Cross-Enterprise Document Sharing (XDS) (1 of 2)

- Development of a new family of profiles, was driven by
  - the spread of electronic records
  - the need for interoperability between enterprises

- The first of these profiles was XDS for imaging (XDS-I)
  - provides for a central Document Registry actor that keeps track of metadata about documents (including images)
  - these documents now reside in multiple Document Repositories
  - though they were originally intended to be collocated with the sites that originated the documents, perhaps implemented as a gateway to the local PACS
Cross-Enterprise Document Sharing (XDS) (2 of 2)

- The sequence of operations is
  - query the registry
  - identify the documents required
  - retrieve them from the appropriate repository

- For imaging, the document retrieved is a manifest encoded as a DICOM SR

- An additional level of retrieval is then used to return the images themselves
Cross-Enterprise Document Sharing – evolution

- Mechanisms to address additional complexities encountered with loosely coupled, externally accessible systems
  - security
  - privacy and access control
  - incorporation of centralized (regional or national) rather than local repositories
  - support for distributed consistency after local corrections and updates
Conventional technology

- Medical image networking applications are all
  - based on conventional underlying wired, optical and wireless network technology
  - using standard Internet protocols such as TCP/IP for communication

- Applications use ordinary network
  - hardware (such as routers, switches, cables)
  - software (such as firewalls, network protocol stacks in operating systems and network management utilities)

- Local area networks (LANs) within a single site as well as wide area networks (WANs)
Quality of Service

- Though image data transfers are very large
  - switched high speed Ethernet is used for this routinely in LANs
  - networks are often shared with other lower volume traffic

- Quality of Service (QoS) concerns can be addressed with virtual local area networks (VLANs)
  - through configuration rather than physically separate networks
Privacy and performance

- Privacy concerns must be addressed when sites are connected using public facilities such as the Internet
  - conventional encryption hardware or software to establish either Virtual Private Networks (VPNs)
  - session based secure connections (using Transport Layer Security (TLS) as used for electronic commerce)

- Greater latency on high speed wide area networks
  - results in delayed acknowledgement and can impact performance

- Address specifically in the choice of protocol, configuration of the protocol stack, application, or through the use of additional devices such as WAN accelerators
Mobile devices

- The increasing use of mobile computing devices allows for additional channels of distribution of full or partial sets of image data, particularly if forms of compression can be selected that are appropriate to the task.
16.5 IMAGE COMPRESSION
16.5 IMAGE COMPRESSION

16.5

- 16.5.1 Purpose
- 16.5.2 Transformation and coding
- 16.5.3 Lossless compression
- 16.5.4 Lossy compression
- 16.5.5 Standard and Common Compression Schemes
- 16.5.6 Compression in DICOM
16.5 IMAGE COMPRESSION

16.5.1 PURPOSE
16.5 IMAGE COMPRESSION

16.5

- 16.5.1 Purpose
- 16.5.2 Transformation and coding
- 16.5.3 Lossless compression
- 16.5.4 Lossy compression
- 16.5.5 Standard and Common Compression Schemes
- 16.5.6 Compression in DICOM
The need for image compression

- Digital images, when stored or transmitted in uncompressed form, occupy an amount of space proportional to the matrix size of the image
  - each pixel occupies a fixed number of bytes

- Images typically contain a significant amount of redundant information that can be represented more compactly
  - e.g. there is often a large amount of black space around the “important” parts of the image

- Reducing the amount of space occupied by an image is a priority
  - cost of storage and bandwidth are significant
  - sometimes there is insufficient time to transmit a large set of images over a slow connection to meet the clinical need
16.5 IMAGE COMPRESSION

16.5.2 TRANSFORMATION AND CODING
16.5 IMAGE COMPRESSION

16.5.1 Purpose
16.5.2 Transformation and coding
16.5.3 Lossless compression
16.5.4 Lossy compression
16.5.5 Standard and Common Compression Schemes
16.5.6 Compression in DICOM
Transformation and coding

- Compression schemes typically consist of a series of steps that
  - first transform the original data into an alternate representation that exposes redundancy
  - then encode the information in a more compact form

- Variable length encoding, e.g. Huffman encoding
- Dictionary coding
- Arithmetic coding
- Run length encoding
Huffman Encoding

- When compressing a series of symbols
  - such as plain text represented as successive characters, one byte per character
- The data may be directly encoded using a mechanism that substitutes
  - a short encoding for more frequently occurring characters
    - the letter “e” might be encoded with a single bit
  - a long encoding for less frequently occurring characters
    - the letter “z” might be encoded with a large number of bits
- This is referred to as “variable length” coding, by comparison with the one byte per character “fixed length” coding
- One very common approach to encoding data this way is Huffman encoding
Dictionary Encoding

- When compressing the series of symbols
- More complex analysis of the plain text might consist of:
  - storing sequences of characters in a dictionary
  - computing their frequency
  - representing entire sequences with single variable length symbols
- This approach is referred to as “dictionary” coding
Arithmetic and Run Length encoding

- Another approach is to encode the entire message as a very long binary fraction
  - given an accurate model of the frequencies of each symbol, this can produce near-optimal output for a given set of symbols and probabilities

- A special case that is often considered separately is that of the same symbol occurring multiple times
  - it may be encoded as the symbol and the number of occurrences, rather than repeating the symbol
  - referred to as “run length” encoding
Additional redundancy in images

- These approaches are equally applicable to encoding images.
- However, they do not account for the additional redundancy that is present in two (or more) dimensions in an image.
- Transformation steps may be used prior to coding to expose such redundancy in an image.
Transformation steps prior to encoding images (1 of 2)

- Where successive pixels differ little from their predecessors most of the time, encoding the difference between the current and previous pixel may result in a
  - more compact value to code
  - more compact frequency distribution

- For some types of image, more regional “context” can be considered
  - the difference between the pixel above as well as the pixel to the left may be included in the difference signal
  - yet more complex models that consider the rate of change in the local region can be constructed
Transformation steps prior to encoding images (2 of 2)

- Redundancy in multiple colour channels
  - colour images are typically encoded uncompressed as red, green and blue channels
  - and all three channels carry the same luminance information

- To expose this redundancy, transform the colour space into
  - a luminance channel
  - a pair of chrominance channels

- Transformation from the spatial to the frequency or wavelet domain may also allow for a more compact representation
16.5 IMAGE COMPRESSION

16.5.3 LOSSLESS COMPRESSION
16.5 IMAGE COMPRESSION

16.5

- 16.5.1 Purpose
- 16.5.2 Transformation and coding
- 16.5.3 Lossless compression
- 16.5.4 Lossy compression
- 16.5.5 Standard and Common Compression Schemes
- 16.5.6 Compression in DICOM
Lossless compression

- Some forms of compression allow complete and exact recovery of the original data from the compressed data.
- These are referred to as “lossless” or “reversible” compression schemes.
- Schemes used in consumer applications to compress text documents, for example, would be unacceptable if characters changed when decompressed, regardless of how infrequently this occurred.
- Likewise, medical imaging applications may require perfect reproduction of the input, and hence lossless compression is widely used.
Approaches to lossless compression

- Lossless compression schemes for images may utilise transformation steps as described previously.

- The transformation must be implemented in a mathematically reversible form.
  - Difference transformations must have sufficient depth to preserve the maximum possible difference value and its direction (sign) with full fidelity.
    - This requires one more bit to encode than the original values.
  - Frequency domain or colour space transformations require the use of equations and implementations that use fixed, not floating point, arithmetic of sufficient precision.
Lossless compression in practice (1 of 2)

- Lossless compression of medical images produces compression ratios (relative to the original number of bytes occupied by an unpacked image)
  - that depend on the modality and type of image
  - range from approximately 2.5:1 to 5:1

- Typically, medical images
  - contain a significant amount of noise, texture and other high frequency content
  - even background air or collimated regions contain noise
  - this interferes with the ability to achieve higher lossless compression ratios
Lossless compression in practice (2 of 2)

- Despite the low compression ratios achievable, cost and transmission time savings of this order are often sufficient to satisfy the use case.

- Lossless compression of 512 by 512 by 8 bit cardiac angiograms using a relatively simple scheme is commonly used to fit an entire such examination on a single CD.
16.5 IMAGE COMPRESSION

16.5.4 LOSSY COMPRESSION
16.5 IMAGE COMPRESSION

16.5.1 Purpose
16.5.2 Transformation and coding
16.5.3 Lossless compression
16.5.4 Lossy compression
16.5.5 Standard and Common Compression Schemes
16.5.6 Compression in DICOM
Lossy compression

- Lossy or irreversible compression occurs when the decompressed result is not identical to the original, yet the amount and type of loss is acceptable for some purpose.

- For example, lossy compression is:
  - routinely applied to color photographic images obtained from consumer digital cameras
  - widely used in consumer Internet web browser pages
Approaches to lossy compression (1 of 2)

- The process involved is similar to that used for lossless compression, with transformation and encoding steps.
- Since a finite amount and type of loss is permitted, neither of these steps is required to be entirely reversible.
- A certain amount of loss may be involved in transformations in:
  - colour space, frequency domain, wavelet domain
- The use of continuous functions with finite precision can expose more redundancy.
Approaches to lossy compression (2 of 2)

- Additional, deliberate steps may be applied to discard specific types of information
  - higher frequency coefficients may be represented with fewer bits of precision than more important lower frequency coefficients
  - this can be controlled in a “quantization” step applied after transformation and before coding
  - in some compression schemes quantization is the step at which the quality of the result is explicitly controlled
Lossy compression in practice

- Lossy compression results in artifacts becoming visible in the reconstructed image
- For images that are compressed as an entire frame, these artifacts may involve
  - subtle smoothing of the entire image
  - alterations in perceived texture of complex regions
  - the introduction of distinct small structures that were not present in the original
Examples of lossy compression artifacts

- In the case of wavelet transformation
  - reflections of the wavelet basis functions may appear

- In the case of truncated high frequency coefficients
  - ringing may appear around sharp edges, such as text

- For schemes that involve splitting the image into small tiles before compression
  - block artifacts may appear where the boundaries of such tiles become distinctly visible
Visually lossless vs. diagnostically lossless

- Despite these artifacts, lossy compressed images may be sufficient for many clinical purposes.
- Two levels of compression may be defined for medical imaging, “visually lossless” and “diagnostically lossless”.

Visually lossless compression
- type and level of compression at which a human observer is unable to visually distinguish the original from the reconstructed image, even though mathematical loss has occurred.

Diagnostically lossless compression
- images are sufficient for primary interpretation.
Visually lossless compression

- Human observer is unable to visually distinguish the original from the reconstructed image, even though mathematical loss has occurred.
- This can be determined by relatively simple experiments.
- It is known to vary considerably depending on
  - the modality
  - body part of the image
Diagnostically lossless compression

- Whether visually lossless images, or images compressed more or perhaps less, are sufficient for primary interpretation, i.e. are diagnostically lossless, depends on the diagnostic task.

- A chest X-ray for the purpose of locating the tip of a catheter could undergo extreme degradation and still be sufficient.

- Yet detection of the pneumothorax caused by the insertion of that catheter might require an image with much less compression.
Observer-performance studies

- To establish the appropriate levels of compression for each such modality, body part and diagnostic task may require powerful observer-performance studies.

- Must have sufficient statistical power to detect that any lack of difference found is due to a genuine absence of a clinically significant difference caused by compression.
  - Avoid studies that simply have too few subjects to detect any significant difference.

- Such studies are expensive and few in number, but
  - There are emerging guidelines from professional societies on the matter of appropriate use of lossy compression.
To compress or not to compress?

- If one is going to compress for archival or subsequent distribution
  - a confounding factor is whether or not to perform lossy compression
    before or after primary interpretation

- As long as there is the potential for a misdiagnosis
  - some advocate that optimum patient care requires interpretation of
    uncompressed images
  - indeed the US FDA requires this by regulation for digital mammography

- Lawyers argue, however, that exactly what was interpreted should be archived

- The most conservative strategy is to avoid lossy compression, regardless of the attractiveness of the potential infrastructure cost-savings
16.5 IMAGE COMPRESSION

16.5.5 STANDARD AND COMMON COMPRESSION SCHEMES
16.5 IMAGE COMPRESSION

16.5

- 16.5.1 Purpose
- 16.5.2 Transformation and coding
- 16.5.3 Lossless compression
- 16.5.4 Lossy compression
- 16.5.5 Standard and Common Compression Schemes
- 16.5.6 Compression in DICOM
Standard and Common Compression Schemes

- The International Standards Organization (ISO) and International Electrotechnical Commission (IETC) joint technical committee has established subcommittees responsible for
  - still image standards
    - resulting in the Joint Photographic Experts Group (JPEG) family of standards
  - video compression standards
    - resulting in the Moving Picture Experts Group (MPEG) family of standards
**JPEG schemes**

- The widely used 8 bit greyscale or colour lossy Discrete Cosine Transform (DCT) JPEG format
  - used in consumer digital camera and web applications
  - only a subset of a large number of schemes defined in several standards

- Additional JPEG schemes are used for other types of medical images, including:
  - 12 bit DCT, applicable to greyscale images of greater bit depth
  - 16 bit lossless compression with difference and Huffman coding
  - JPEG 2000, with wavelet transformation and arithmetic coding, in both lossless and lossy variants
JPEG schemes for multiple frames

- For medical images that involve multiple frames that contain redundancy between frames
  - cine images acquired over time
  - successive 3D cross-sections
- Each frame may be encoded separately using JPEG or JPEG 2000
- Or other schemes, such as multi-component or 3D JPEG 2000 or MPEG may be applied
Other file formats

- There are several other common proprietary or de facto standard file formats with inherent compression schemes
  - widely used on the web and for other professional applications
  - GIF and PNG and TIFF

- Rarely used for medical imaging due to
  - bit depth constraints
  - lack of sufficient compression support

- File formats with compression schemes commonly used for text and data files, e.g. ZIP, may be applied to images
  - generally not as effective as methods that take advantage of the image structure
16.5 IMAGE COMPRESSION

16.5.6 COMPRESSION IN DICOM
16.5 IMAGE COMPRESSION

16.5

- 16.5.1 Purpose
- 16.5.2 Transformation and coding
- 16.5.3 Lossless compression
- 16.5.4 Lossy compression
- 16.5.5 Standard and Common Compression Schemes
- 16.5.6 Compression in DICOM
Compression in DICOM

- DICOM makes use almost exclusively of ISO-IETC standard compression schemes
- Defines Transfer Syntaxes for each of the appropriate JPEG and MPEG lossless and lossy schemes
- This approach allows devices communicating on the network to negotiate the most appropriate compression scheme to use depending on the circumstance
Association negotiation

- Allows the sender to propose combinations of the
  - type of image (SOP Class)
  - the type of compression (Transfer Syntax)
- Allows the receiver to accept or reject each combination depending on its capabilities
- For lossless compressed images
  - there is a fall back mechanism to allow the default, uncompressed, transfer syntax to be used, in case the recipient does not support any proposed compression scheme
- For lossy compressed images
  - fall back mechanism is not required, the principle being that the sender may not have access to original uncompressed image
New compression schemes

- As technology evolves and new compression schemes are standardized, DICOM adds them as new Transfer Syntaxes
  - potentially making them available for any type of image, since the Transfer Syntax is independent of the SOP Class
- DICOM is a technology standard, and does not address the appropriate use of any particular compression scheme for any particular purpose
- The inclusion of a scheme in DICOM is not an endorsement of such a scheme
16. BIBLIOGRAPHY


16. BIBLIOGRAPHY

- HEALTH LEVEL 7, www.HL7.org