Digital Image Processing

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Course Overview

- Many kinds of medical imaging systems
  - X-ray, CT, MRI, Ultrasound, PET, SPECT, Endoscopy
  - Microscopy, IR
- Digital image processing techniques are widely used for analysis and visualization in the medical imaging area.
- This class offers
  - Fundamentals of digital images
  - Basic techniques of digital image processing
  - Significant laboratory work
- Finally, this class will be focusing on image segmentation as an advanced topic.
- Students will be required to make one paper presentation and do a programming project to explore a method.

Goals

- Understand the fundamentals of digital image processing
- Learn how to implement image processing techniques
- Research advanced image processing algorithms by studying special topics

- Finally, you will be skillful of medical image processing techniques and able to develop image processing algorithms for your research.

Prerequisites

- Digital Signal Processing
- Programming (Matlab or C++)

Textbooks

- Digital Image Processing (**3rd** ed.) by R. C. Gonzalez and R. E. Woods, Prentice Hall, 2008
- Handbook of Medical Imaging - Processing and Analysis by I. N. Bankman
- The Image Processing Handbook (2nd ed.) by J. C. Russ
- Some literature (Papers, Internet,...)

Useful Web Sites

- http://rsb.info.nih.gov/ij/
  - NIH ImageJ
  - Basic and simple image utility
- http://www.itk.org/
  - The National Library of Medicine
  - Insight Segmentation and Registration Toolkit (**ITK**)
- http://mipav.cit.nih.gov/
  - The **MIPAV** (Medical Image Processing, Analysis, and Visualization) application

Contents

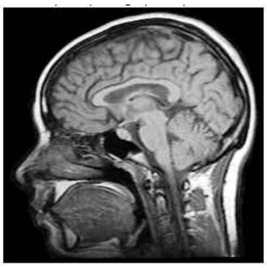
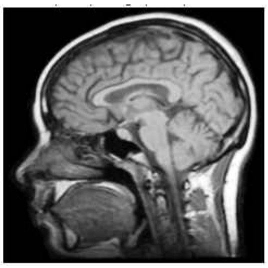
0. Course Overview
1. Introduction to medical images
   - Medical imaging systems
   - Digital image processing
2. Digital Image Fundamentals
   - Image sampling and quantization
   - Some basic relationships between pixels

Image Enhancement : Improving the appearance of a image
*(Human **subjective** preference)*

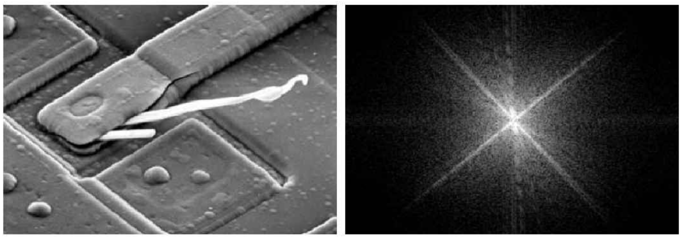
3. Intensity Transformations and Spatial Filtering
   - Intensity transformation functions
   - Histogram processing
   - Spatial filtering (smoothing and sharpening)
4. Filtering in the Frequency Domain
   - Fourier transform
   - Frequency domain
   - Filtering

Enhancement

Which is the best?


Fourier Transform and Frequency Domain



a b

FIGURE 4.29 (a) SEM image of a damaged integrated circuit. (b) Fourier spectrum of (a). (Original image courtesy of Dr. J. M. Hudak, Brockhouse Institute for Materials Research, McMaster University, Hamilton, Ontario, Canada.)

Contents – cont'd

6. Image Restoration
   Improving ***objectively*** *the appearance of a image*
   - Noise models
   - Noise reduction
   - Image reconstruction from projection
7. Morphological Image Processing
   Extracting image components that are useful in the representation and description of shape
   - Erosion and dilation
   - Opening and closing
   - Morphological algorithms
8. Image Segmentation
   Partitioning an image into its constituent parts
   - Point, line and edge detection
   - Thresholding
   - Region-based segmentation
   - Segmentation using morphological watersheds
9. Special Topic – Active Contour for Segmentation
   - Snake algorithm
   - Level set algorithm
10. Paper Review and Term Project

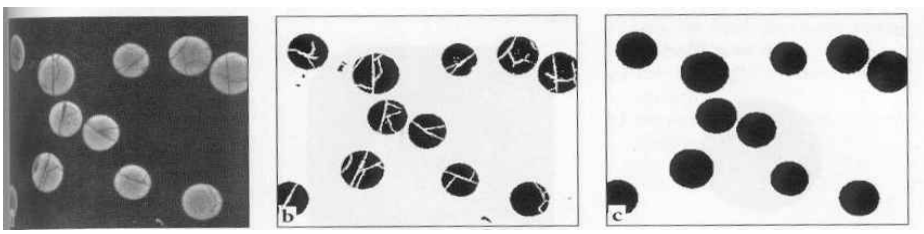
Restoration

Motion blurred
+ Noise

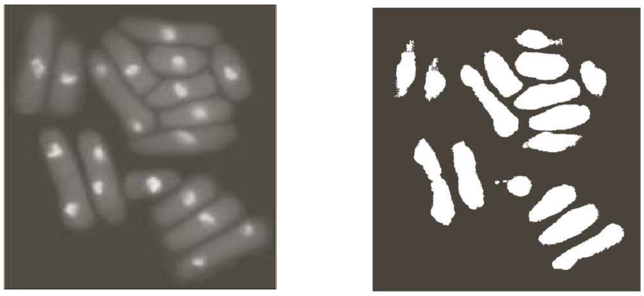
Inverse filtering

Wiener filtering

Morphological Processing



Segmentation



I. Introduction

- Digital and analog images
- Medical imaging systems
  - X-ray (Digital radiography)
  - CT
  - MRI
  - PET
  - SPECT
  - Ultrasound
  - Endoscopy, Microscopy
  - PACS

Digital Images (Basic Terms)

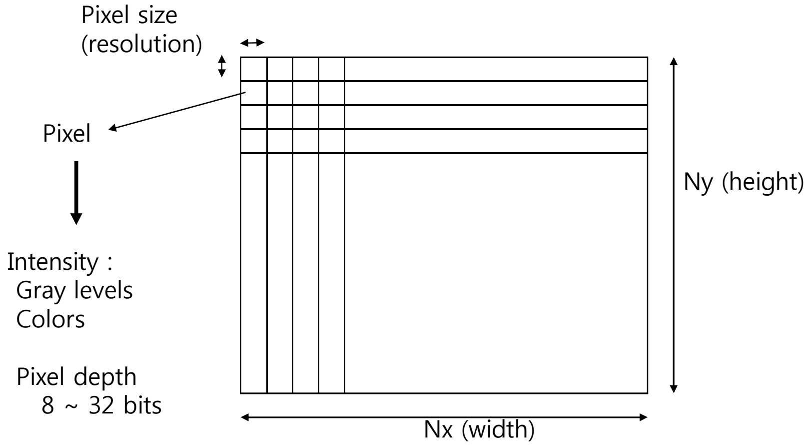


Image Size : Nx x Ny , Field of View (FOV) : Nx, Ny x Pixel Size

Ex) VGA : 640 x 480, SVGA : 1024 x 768, XVGA : 1280 x 1024

Why Digital in Medical Images?

- Most medical images are acquired in digital.
  - Obtained by digital computation (reconstruction) of sampled raw data
    : CT, MRI, PET, SPECT, Ultrasound
  - Analog : conventional x-ray, endoscopy, …
- Additional information by analysis
  - Enhancement for human recognition
  - 3D visualization
  - Extracting hidden physical parameters
    - fMRI, Doppler Ultrasound, Perfusion images,…
    - DEXA, Bone parameters
    - Cancer detection (CAD)
- Archiving, copy, communication, …
  - PACS (Picture archiving and communication system)

Features of Medical Images

- Digital
- Pixel depth : 8 ~ 16 bits, Gray scale
- Image size : 64 x 64 ~ 4096 x 4096
- 2D, 3D, 4D
- Simple display → Enhancement
  → 3D visualization
  → Computer aided diagnosis
- A huge amount of data and complicated reconstruction algorithm require high-performance computers.

Digital Image Processing for Medical Images

- Acquisition
- Reconstruction
- Processing
  - Enhancement
  - Restoration
  - Segmentation
  - Registration
  - Classification and analysis
  - 3D visualization
  - Compression

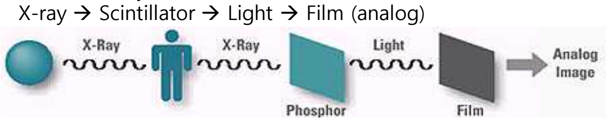
What to know about digital images

- Meaning of pixel values (physical quantity)
- Pixel depth
- Image size
- Spatial resolution
- Reconstruction method

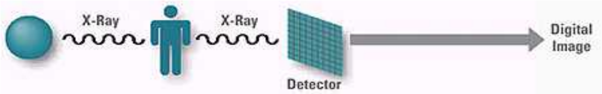
- Brief principle of imaging modalities

X-ray / Digital Radiography

- Intensity : X-ray attenuation
  - $f(x, y)= I_0\exp(-\int\mu(x,y,z)dz)$
    $\mu(x,y,z)$: attenuation cofficient
  - Projection image similar to a shadow
- Conventional x-ray
  - X-ray → Scintillator → Light → Film (analog)



  - Film → Scanner → Digital (not enough)
- Digital Radiography
  - Digital acquisition (Spatial sampling by use of a 2D array sensor)
  - Image Size : 1024 x 1024 ~ 4096 x 4096
  - Pixel Size : ~ 100 microns
  - Pixel Depth : 12 ~ 14 bits

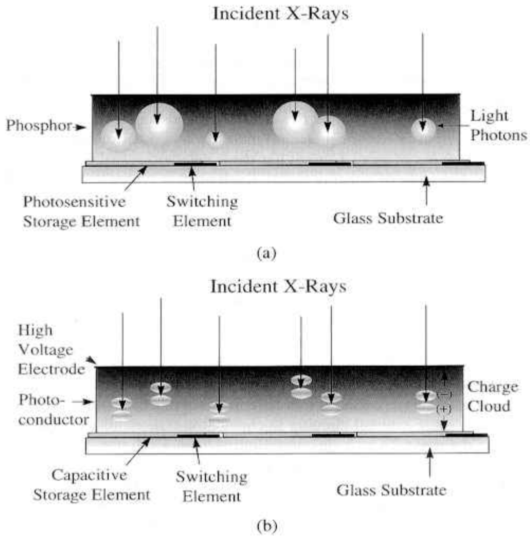


- Fluoroscopy, Angiography, Mammography

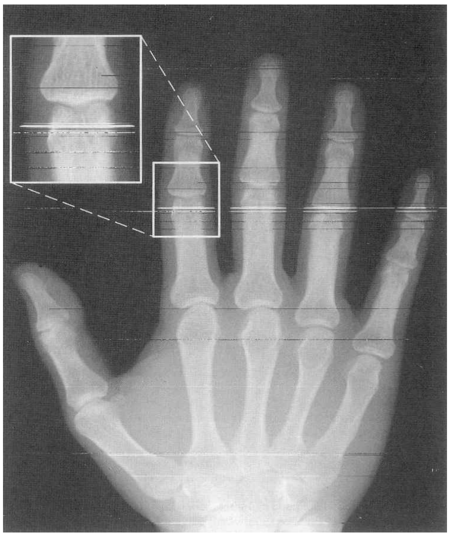
print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895

Flat Panel Detectors for DR

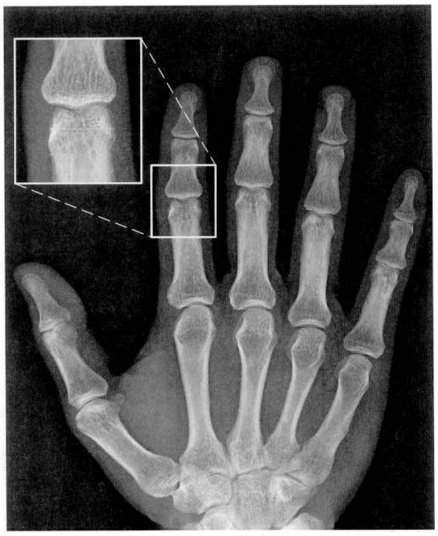
Indirect (w. scintillator) and Direct (wo. scintillator)



DR Images and Digital Processing



→



Defective pixels (indirect)

Gain/offset correction, Median filter, Image enhancement

CT (Computed Tomography)

- Tomographic image (cross section)
- Intensity : X-ray attenuation coefficients $\mu(x,y,z)$

  cf) x-ray imaging $f(x, y)= I_0 \exp(-\int \mu(x,y,z)dz)$

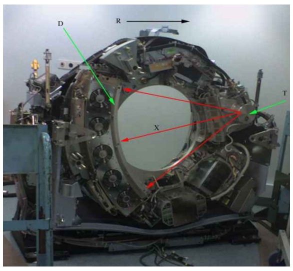
  Hounsfield Unit [HU] =

  $(\mu-\mu_{water})*1000/(\mu_{water}-\mu_{air})$

  water: 0, air: -1000,

  fat: -120, muscle: 40, bone: 400 or more

- Image Reconstruction
  - 360˚ x-ray projection → 2D tomographic image
  - Filtered back-projection
- 512 x 512 (Pixel size : ~0.5 mm)
- Pixel Depth : 12 bits
- Spiral scan → 3D tomographic images
- 3D volume image processing



Back-projection

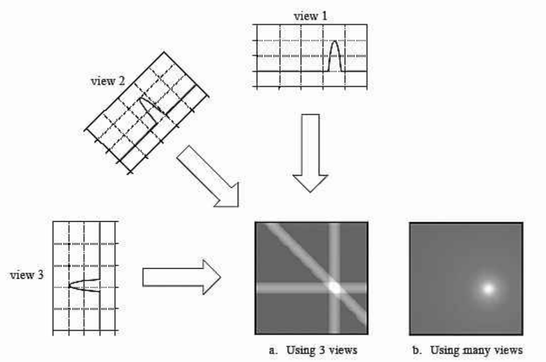
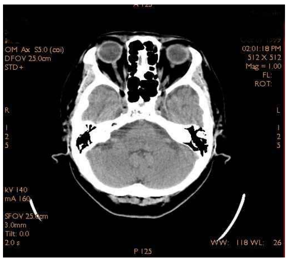
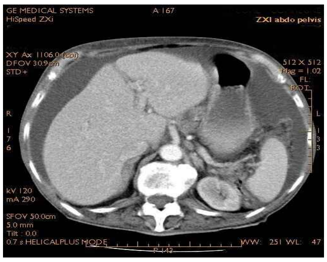
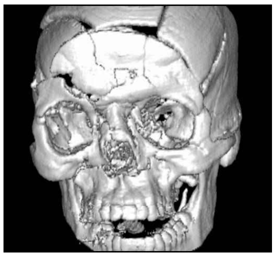


FIGURE 25-16
Backprojection. Backprojection reconstructs an image by taking each view and *smearing* it along the path it was originally acquired. The resulting image is a blurry version of the correct image.

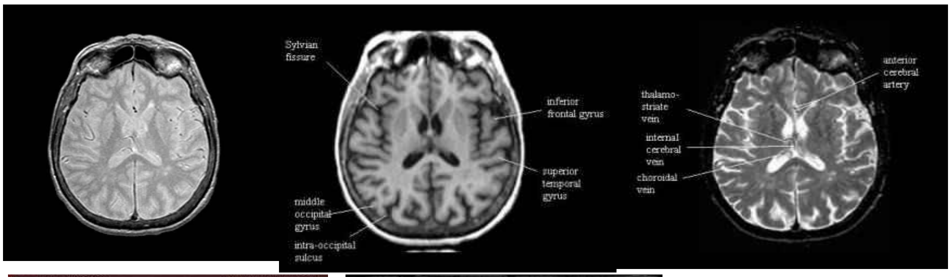
Typical CT Images

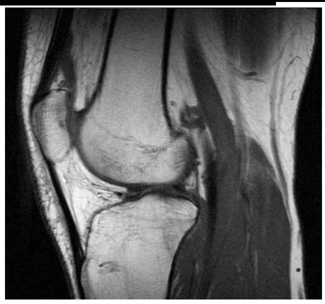




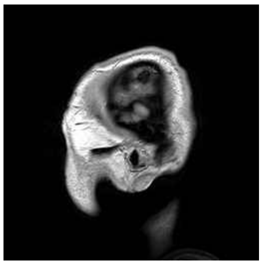
MRI (Magnetic Resonance Imaging)

- NMR phenomenon in the huge magnetic field
- Intensity ~ Proton (hydrogen) density, T1, T2 relaxation times
- A variety of imaging methods give different images.
  - Extraction of many physical parameters
  - Image processing
- Reconstruction : Fourier transform
- 256 x 256, 512 x 512 (Pixel size: 0.5 ~ 1 mm)
- Pixel Depth : 14 ~ 16 bits


Typical MR Images

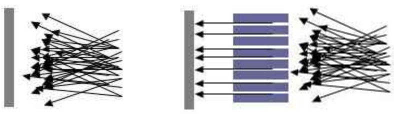






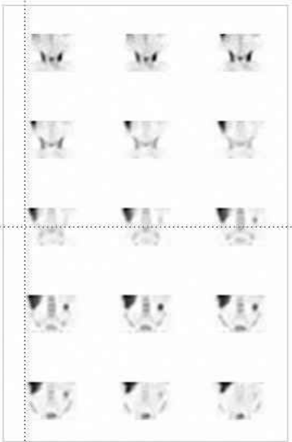
SPECT (Single Photon Emission CT) / Gamma Camera

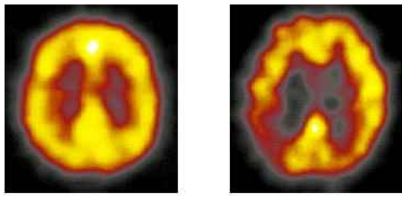
- Radionuclide: ^{99m}Tc, ^{123}I,… → gamma ray
- Intensity : distribution of radionuclides
- Rotating a gamma camera
  → projection data
  → tomographic reconstruction
  (filtered backprojection, EM algorithm)
- 64 x 64, 128 x 128 (pixel size : 3~ 6 mm)
- Collimator + NaI(Tl) + PMT
- Low sensitivity, low resolution



collimator filters a stream of rays so that only those traveling parallel to a s pecified direction are allowed through

SPECT Images

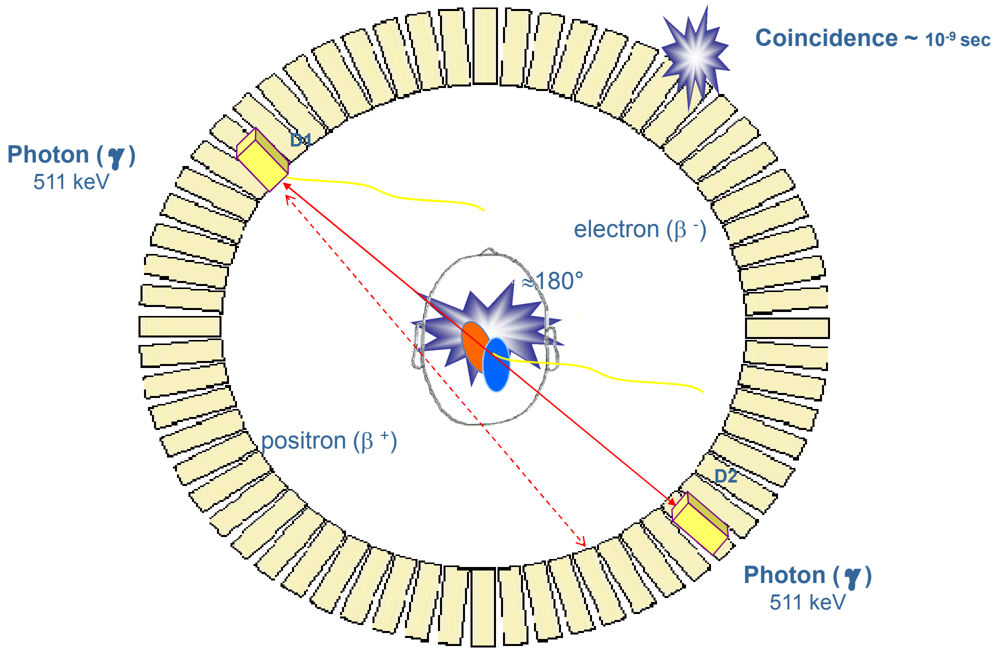




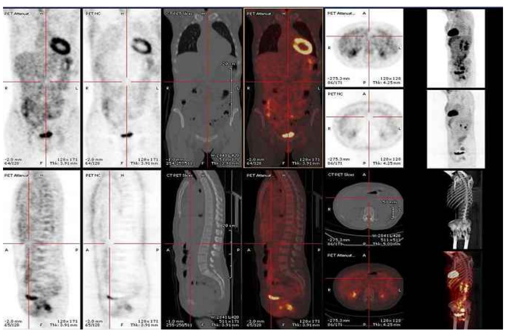
PET (Positron Emission Tomography)

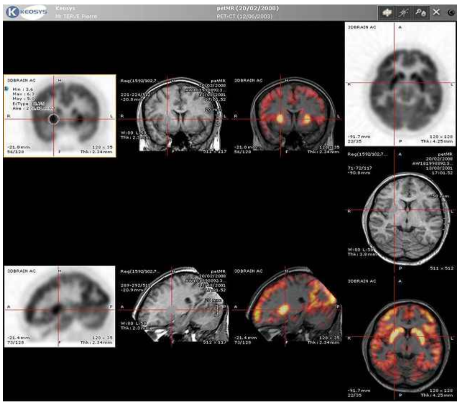
- Radioactive tracer isotope ^{11}C, ^{13}N, ^{15}O, ^{18}F
  → Positron → a pair of annihilation (gamma) photons moving in opposite directions (coincidence)
- Short half-life → cyclotron
- Physiologically important elements
- Functional study
- Intensity : distribution of isotopes
- 128 x 128 (pixel size : 2~ 3 mm)
- Inherent collimator → higher sensitivity, higher spatial resolution
- Combined with CT

Positron Annihilation

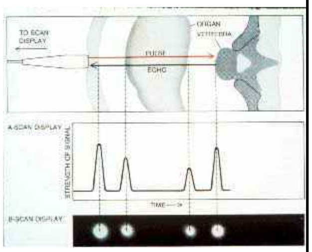


PET Images

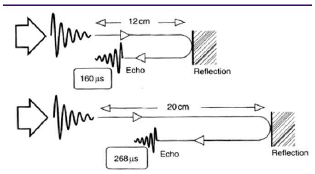




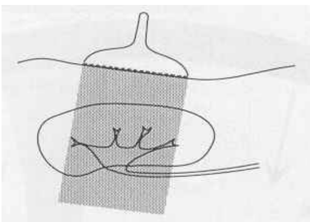
Ultrasound Imaging (Sonography)

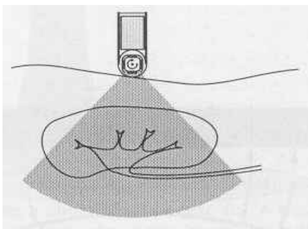


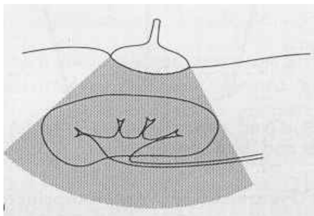
- Ultrasound (2~18MHz) reflection
- Frequency → spatial resolution and imaging depth
  (wavelength) (attenuation)
- Non-hazardous, low cost, real-time
- Intensity : Echo signal (Reflected ultrasound)
- Imaging : B-mode
  - A-mode: the simplest type of ultrasound. A single transducer scans a line through the body with the echoes plotted on screen as a function of depth.
  - B-mode: A linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen.
  - M-mode: M stands for motion. A rapid sequence of B-mode scans
- Scan conversion
- Poor quality
- 128 x 128 (Pixel Size >1 mm), 8 bits
- Color Doppler
- 3D scan and visualization



Scan Format (Scan Conversion)





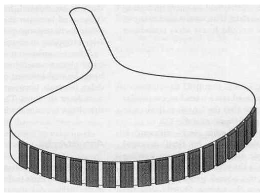


Linear array

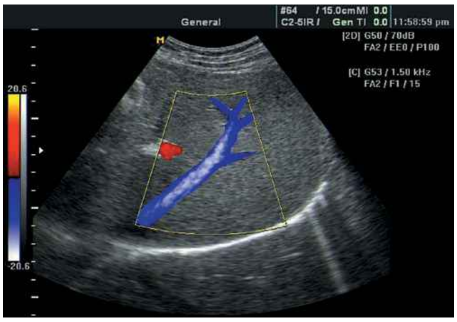
Sector

(Cardiac, intercostal)

Curvilinear



Ultrasound Images



PACS (Picture Archiving and Communication System)

Past

- Analog
- Manual

e.g) Film

Future

- Digital
- Automatic
- Networking
- Database

e.g) PACS

Film vs PAGS

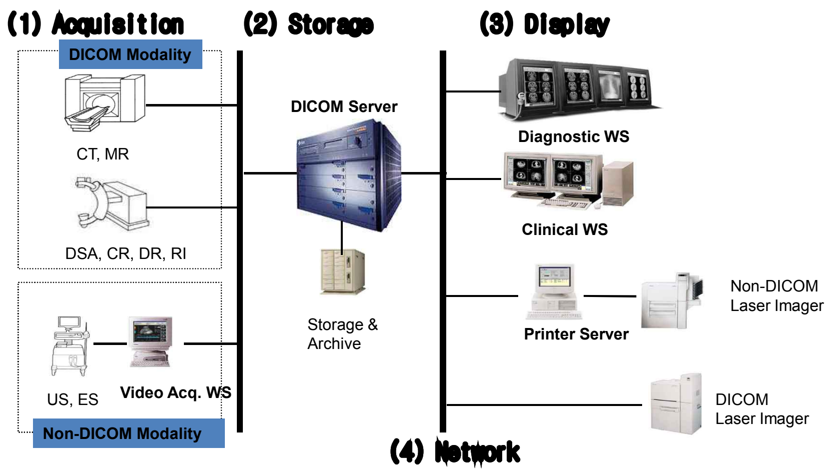
Film System

- Single hardcopy
- Analog
- Manual
- Film loss
- Film storage problem

PACS

- Multiple softcopies
- Digital (image database)
- Automatic & electronic
- No film loss
- Simultaneous & immediate viewing
- Initial cost of PACS equipment
- Maintenance benefits (visible & invisible benefits)

PACS System and DICOM



Funny History

The world 1st photograph.
Sold for $900,000 at a Sotheby auction

The world 1st digital camera.
Developed by Kodak in 1976.
100 x 100 pixels, Black and white.
3x optical zoom lens
23 seconds to record a single image onto cassette tape
4 kg weight