Biomedical Image Analysis and Understanding

Institute Elective

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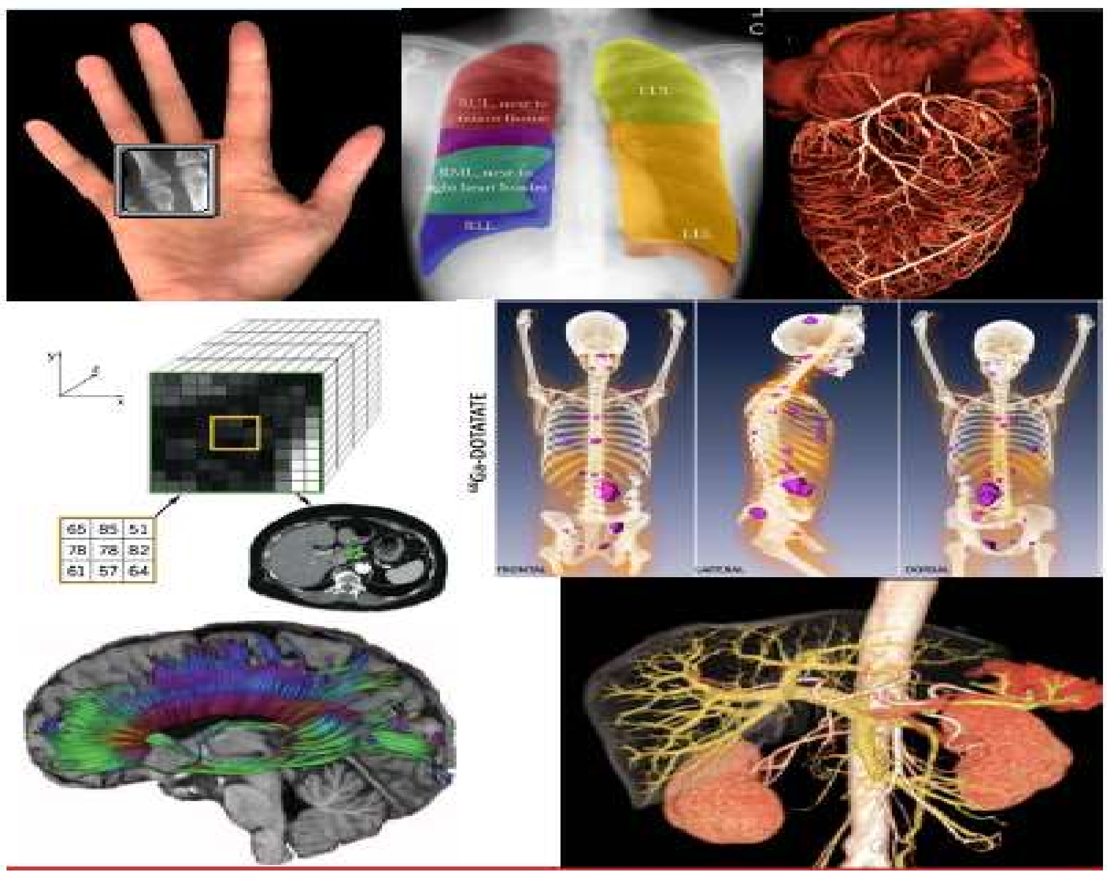
Unit – I: Introduction to Biomedical Image Processing

Content:

- Digital Image Processing System
- Medical Image modalities
- Image Algebra, Image transform (FT, DCT, DWT, HOUGH, KL)
- Image Enhancement in spatial and frequency domain
- Image Restoration
- Medical applications of Imaging
- Frontiers of Image processing in Medicine



65 85 51
78 78 82
61 57 64
^{68}Ga-DOTATATE

Biomedical Imaging and Understanding

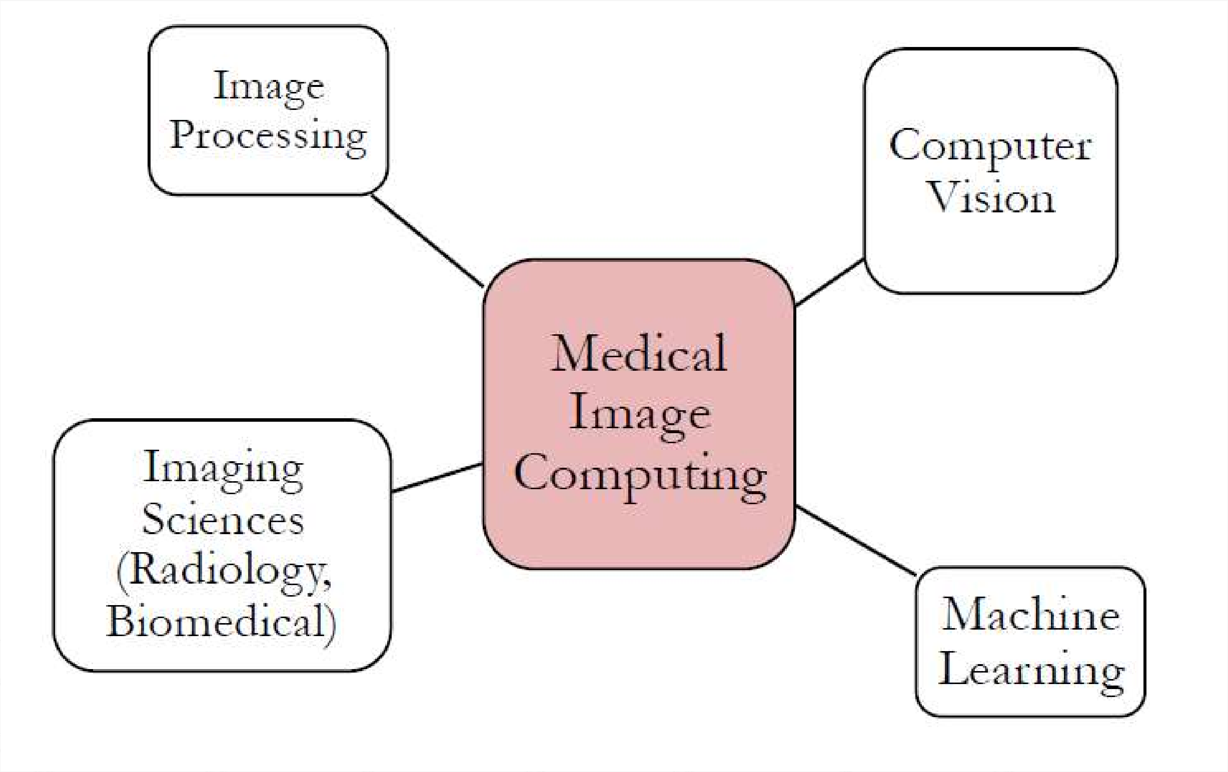
Medical Image Computing :

Biomedical imaging and its analysis are fundamental to

(1) understanding,

(2) visualizing, and

(3) quantifying information.



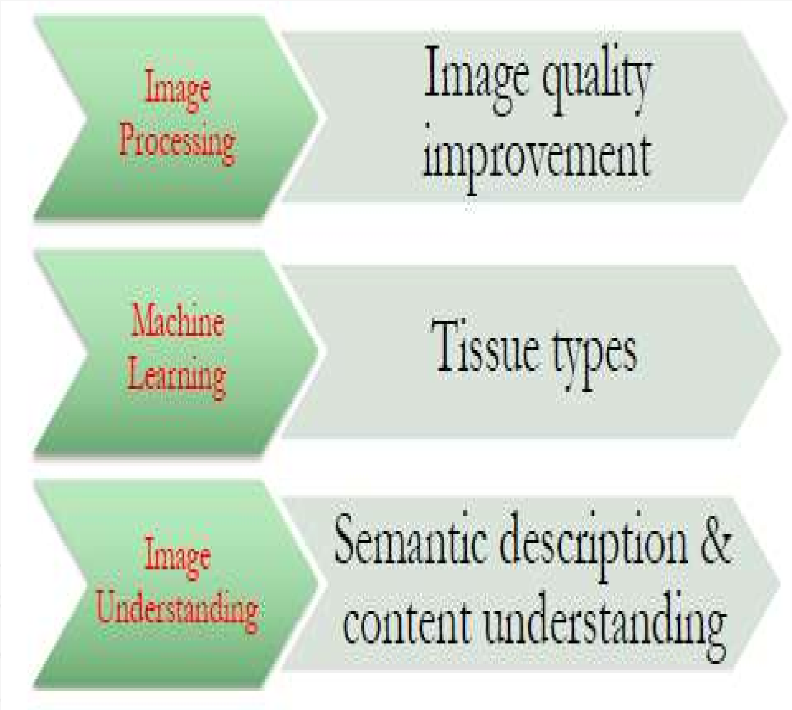
Biomedical Images – Modalities

- (Bio)medical images are different from other pictures
– They depict distributions of various physical features measured from the human body (or animal).
- Analysis of biomedical images is guided by very specific expectations
– Automatic detection of tumors, characterizing their types,
– Measurement of normal/abnormal structures,
– Visualization of anatomy, surgery guidance, therapy planning,
– Exploring relationship between clinical, genomic, and imaging based markers

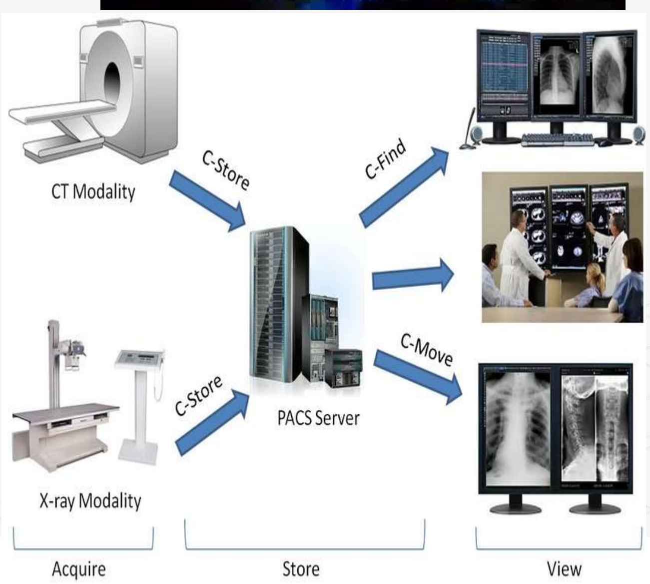
- X-ray
- Ultrasound
- **Computed Tomography (CT)**
- **Magnetic Resonance Imaging (MRI)**
- Positron Emission Tomography (PET)
- Diffusion Weighted Imaging (DWI)
- Diffusion Tensor Imaging (DTI)
- Magnetic Particle Imaging (MPI)
- Optical Coherence Tomography (OCT)

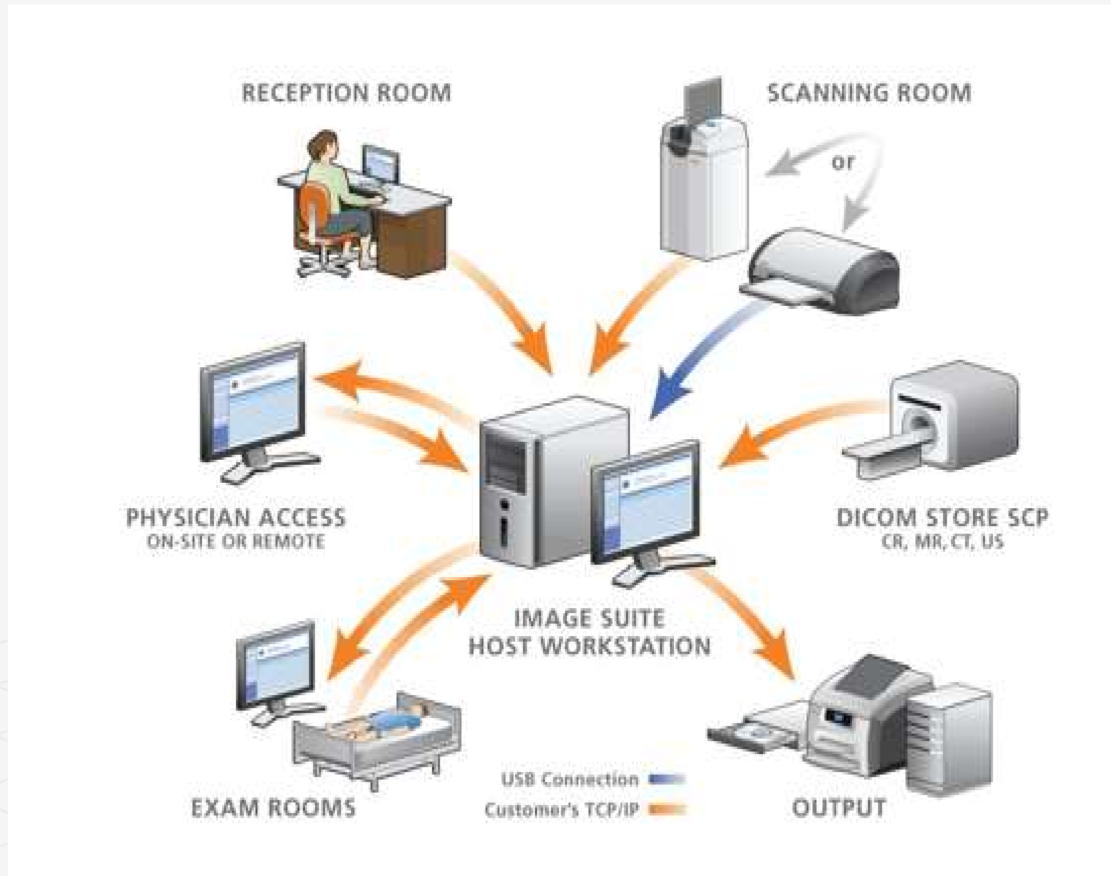
Medical Imaging

- The most direct way to see inside the human (or animal) body is cut it open (i.e., surgery)
- We can see inside the human body in ways that are less invasive or (completely non-invasive)
- We can even see metabolic/functional/molecular activities which are not visible to naked eye



Picture archiving and communication system (PACS) is a modality of imaging technology which helps in image transmission from the site of image acquisition to multiple physically-disparate locations





where do radiologists interpret scans?

- Dedicated light source
- Darkened environment
- Limited distraction

Medical Image Analysis

- Because of the rapid technical advances in medical imaging technology and the introduction of new clinical applications, medical image analysis has become a highly active research field.
- Improvements in image quality, changing clinical requirements, advances in computer hardware, and algorithmic progress in medical image processing all have a direct impact on the state of the art in medical image analysis.
- Medical images are often **multidimensional (2D, 3D, 4D,nD)**, have a large dynamic range, are produced on different imaging modalities in the hospital, and make high demands upon the software for visualization and human–computer interaction.

  – A high resolution MR image of the brain, for instance, may consist of more than 200 slices of 512 x 512 pixels each, i.e., more than 50 million voxels in total. (100MB)

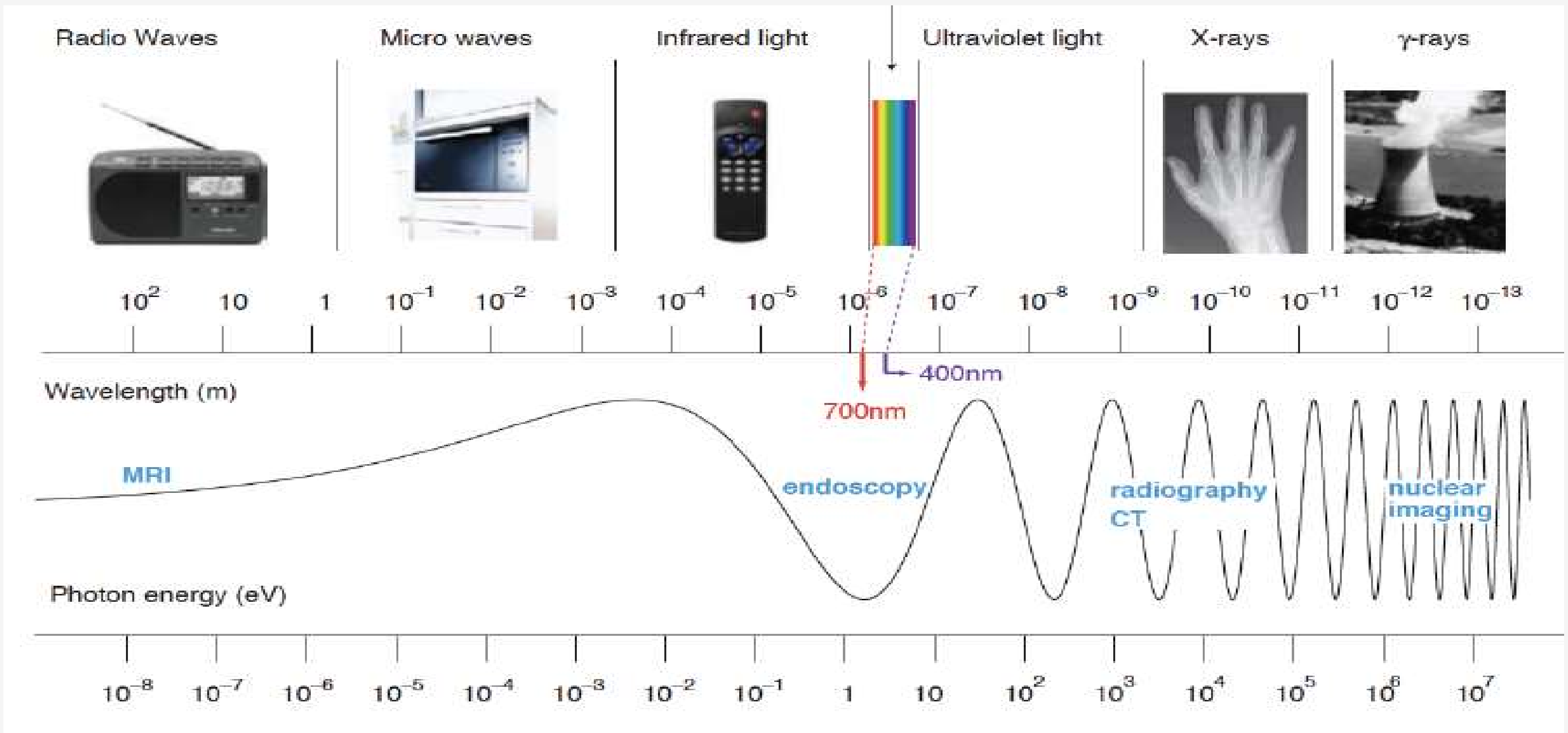
  – In clinical studies that involve the analysis of time sequences or multiple scans of many subjects, the amount of data to be processed can easily exceed 10 GB.

  – While 8 bits or 1 byte per pixel is usually sufficient in digital photography, most medical images need 12 bits per pixel (represented by 2 bytes in the computer memory).

Medical Image Analysis-Automated

- Different strategies for image analysis exist. However, few of them are suited for medical applications.
- The reason is that both the medical image data and the model or prototype (i.e., the a priori description of the features to be analyzed), are typically quite complex.

ELECTROMAGNETIC SPECTRUM

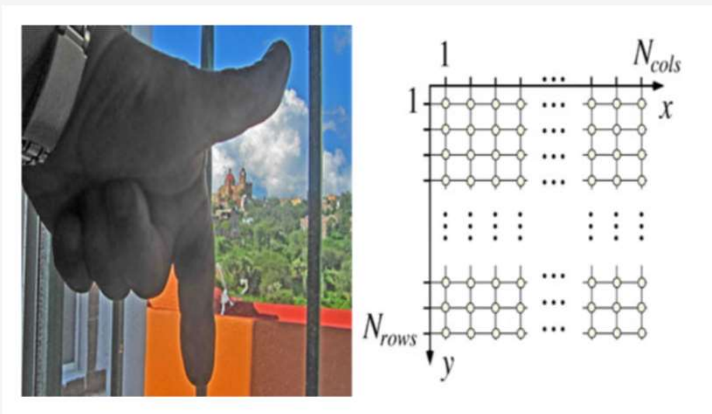


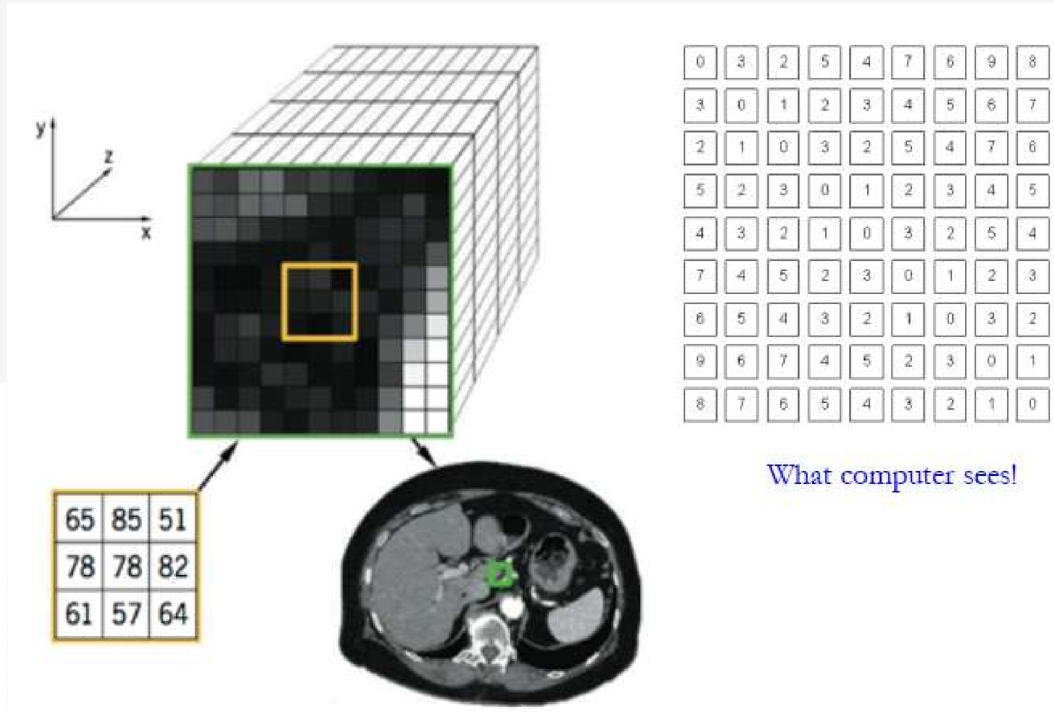
Examples of Fields that Use DIP

- Gamma-Ray Imaging
- X-Ray Imaging
- Imaging in the Ultraviolet Band
- Imaging in the Visible and Infrared Bands
- Imaging in the Microwave Band
- Imaging in the Radio Band
- Example in Which Other Modalities Are Used

Digital Images

Definition: A digital image is defined by *integrating* and *sampling* continuous (analog) data in a spatial domain





Picture Elements (Pixels), Volume Elements (Voxels)

PIXELS are ATOMIC ELEMENTS of an image.

In late 1960s, terminology 'pixel' was introduced by a group of scientist at JPL in California!

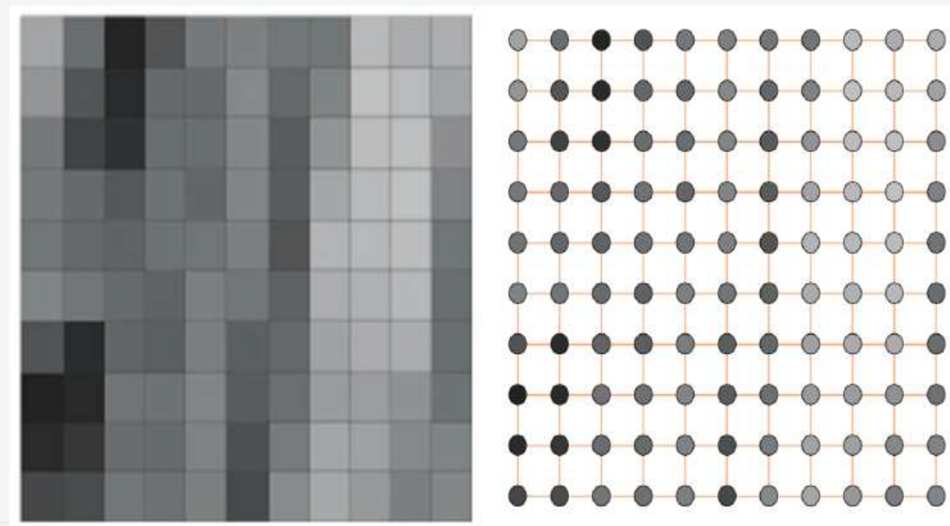


Image Types

- A scalar image has integer values

$$u \in \{0, 1, ..., 2^a - 1\}$$

a: level (bit)

Ex. If 8 bit (a=8), image spans from 0 to 255

0 black

255 white

Ex. If 1 bit (a=1), it is binary image, 0 and 1 only.

Digital Image

Mainly Classified into 3 types

- Binary Image
- Gray level Image
- Color Image

0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	1	0	0	0
0	0	0	0	1	0	0	0	1	0	0	0	0
0	0	0	1	1	1	1	1	1	1	0	0	0
0	0	1	1	0	1	1	1	0	1	1	0	0
0	1	1	1	1	1	1	1	1	1	1	1	0
0	1	0	1	1	1	1	1	1	1	0	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0
0	0	0	0	1	1	0	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

Binary Image

162	161	159	161	162	160	158	156	156	161
162	161	159	161	162	160	158	156	156	161
163	158	159	159	160	158	155	155	156	158
159	157	159	156	159	159	154	152	155	153
155	157	156	156	158	157	156	155	154	156
156	157	155	151	157	156	155	156	156	154
157	156	156	156	156	156	154	156	155	155
158	157	155	155	156	155	155	155	155	155
156	155	156	153	156	155	156	155	154	156
155	155	157	154	157	155	157	158	158	158

The pixels in the top left corner (10*10)

gray image

64	63	75	95	157	99
120	135	55	75	116	67
99	132	60	54	100	75
64	150	113	50	81	138
110	130	162	60	76	109
97	82	179	81	74	113

150	57	43	94	140	97
125	97	35	72	86	52
74	118	41	46	106	58
79	144	98	51	89	127
84	132	132	46	83	84
84	80	166	53	77	97

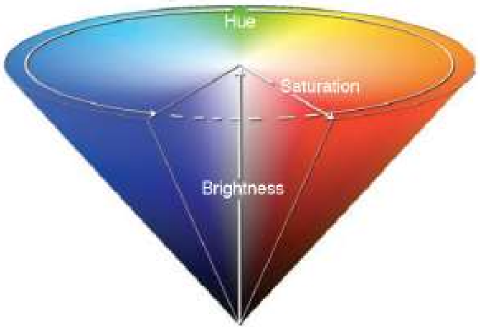
Pixels in RGB components

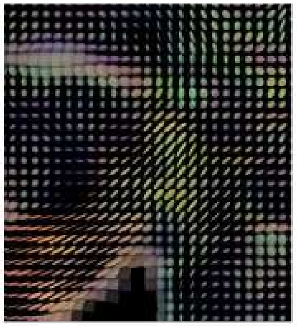
Left top (6*6)

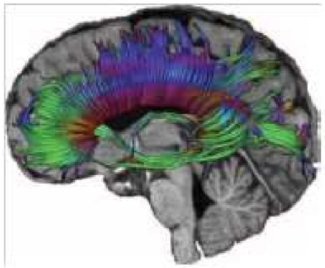
Color image

71	31	10	46	73	33
62	33	23	24	46	34
31	46	36	29	51	30
48	57	35	28	54	36
39	46	52	42	40	48
29	39	69	46	42	43

Image Types-Color







- Image has three channels (bands), each channel spans a-bit values.
- RGB, Hue-Saturation-Brightness

What Is Digital Image Processing

Three layers of DIP

- **Low-level processing:** inputs and outputs are images;
- **Mid -level processing:** inputs are images and outputs are attributes
- **High -level processing:** "making sense" , performing cognitive functions

Digitizing	Restoration	Image database
Store	Reconstruction	Classification
Transmission	Segmentation	Recognition
Display	Object detecting	Image model
Enhancement	Feature extracting	Image marching
Transform	Object measurement	Image understanding
Coding		

DIP relationship between with other areas

Computer Graphics

Pattern recognition

Computer vision

They are based most same theories such as:

AI(Artificial Intelligent)

NN(Neural Network)

GA(Genetic Algorithm)

FL(Fuzzy Lagical)

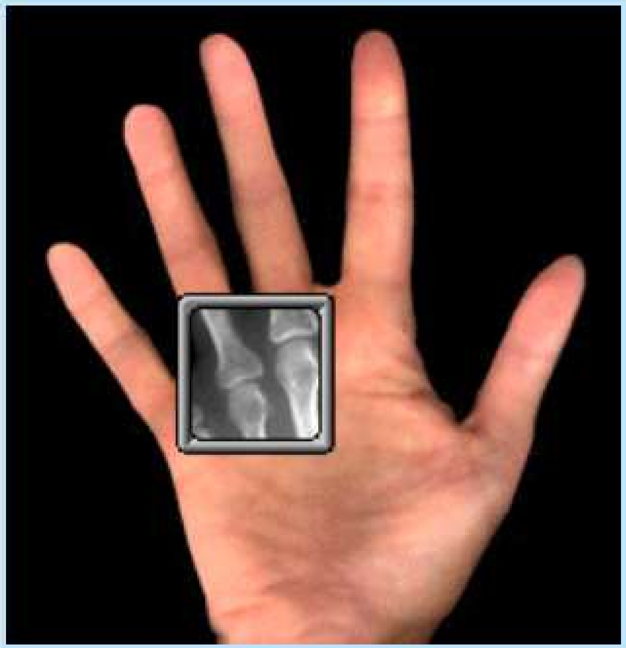
Fundamental Step in DIP

Research directions:

- Image Compression
- Wavelet Transform
- Digital Watermarking
- Image Reconstruction
- Indexing By Image Content
- Image Recognition
- Image Understanding

X-Ray Imaging / Radiography

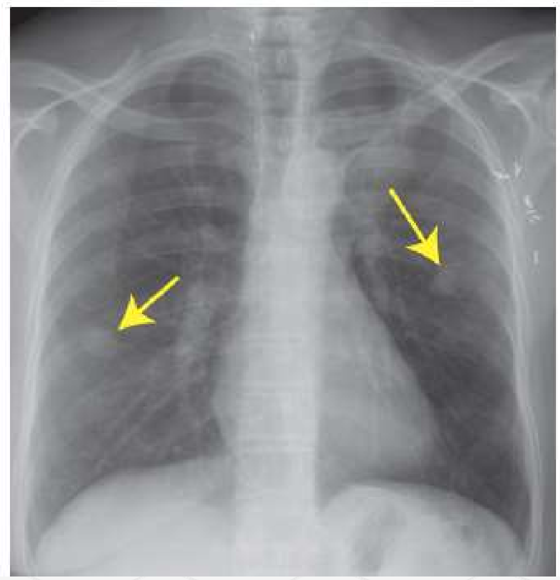
- The first published medical image was a radiograph of the hand of Wilhelm Conrad Roentgen's wife in 1895. *Nobel Prize in Physics 1901.*

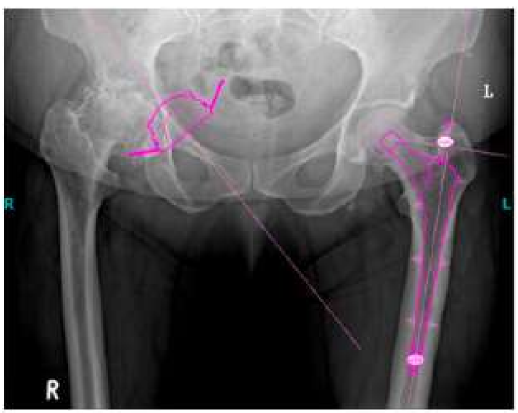


<u>routine diagnostic radiography (2D images):</u>
chest x-rays, fluoroscopy, mammography, motion tomography, angiography, …

Basics Use of X-Rays

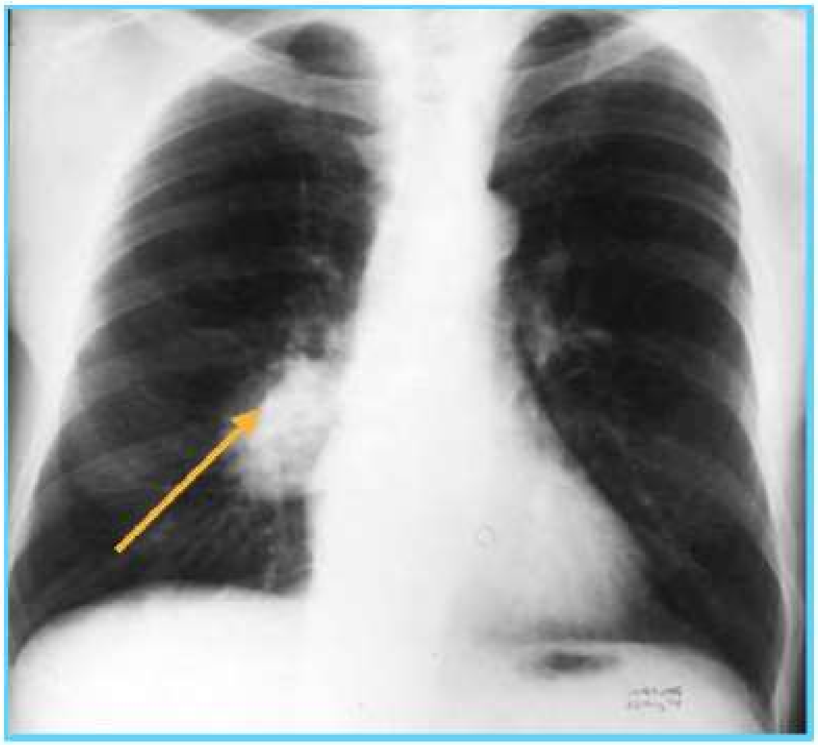
- Dental examinations
- Surgical markers prior to invasive procedures
- Mammography
- Orthopedic evaluations
- Chest examination (Tuberculosis)
- Age estimation (forensic, left hand)





Clinical Examples – X-Rays

How Radiologists Search Abnormal Patterns in Chest X-Rays?



Radiologists often report the following

- Size, dimension, volume
- Pattern description,
- Location,
- Interaction with Nearby structures,
- Intensity distribution
- Shape
- …

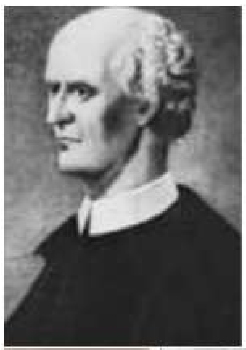
Difficulties

- Noise
- vessels can be seen as small nodules
- radiologists may miss the pattern
- patterns may not be diagnostic
- CT often required for better diagnosis
- size estimation is done manually in 2D
- Shadowing
- total lung capacity computation

Computer algorithms can solve/simplify these problems for improved healthcare

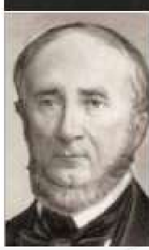
Ultrasound Imaging

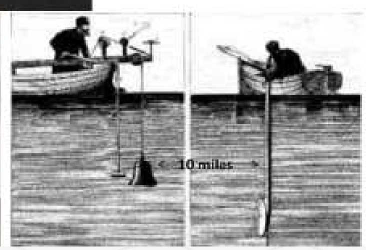
- US is defined as any sound wave above 20KHz



1794-Lazzaro Spallanzani - Physiologist
First to study US physics by deducing bats used to US to navigate by echolocation

1826-Jean Daniel Colladon - Physicist
Uses church bell (early transducer) under water to calculate speed of sound through water prove sound traveled faster through water than air.





1880-Pierre&Jacques Curie
discover the Piezo-Electric Effect (ability of certain materials to generate an electric charge in response to applied mechanical

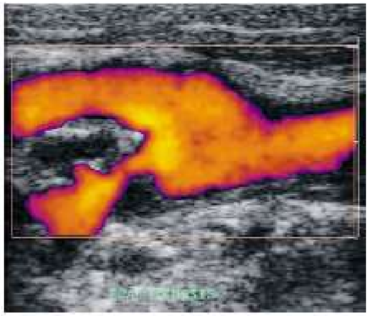
Principle of US Imaging

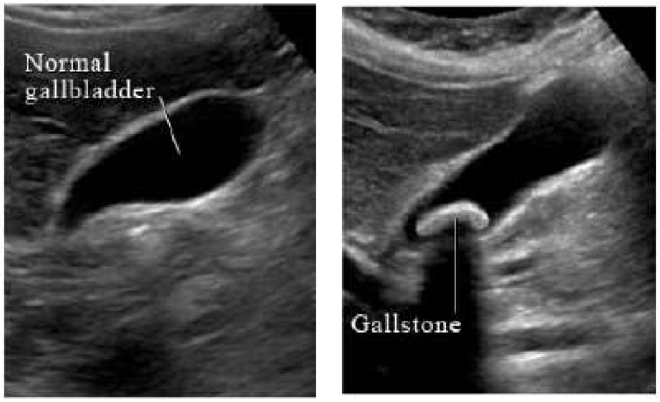
US Imaging Technology

1942-Karl Dussik - Neurologist
First physician to use US for medical diagnosis
1948-George Ludwig - MD
First described the use of US to diagnose gallstones
1958-Ian Donald
Pioneers in OB-GYN

Features of US Imaging

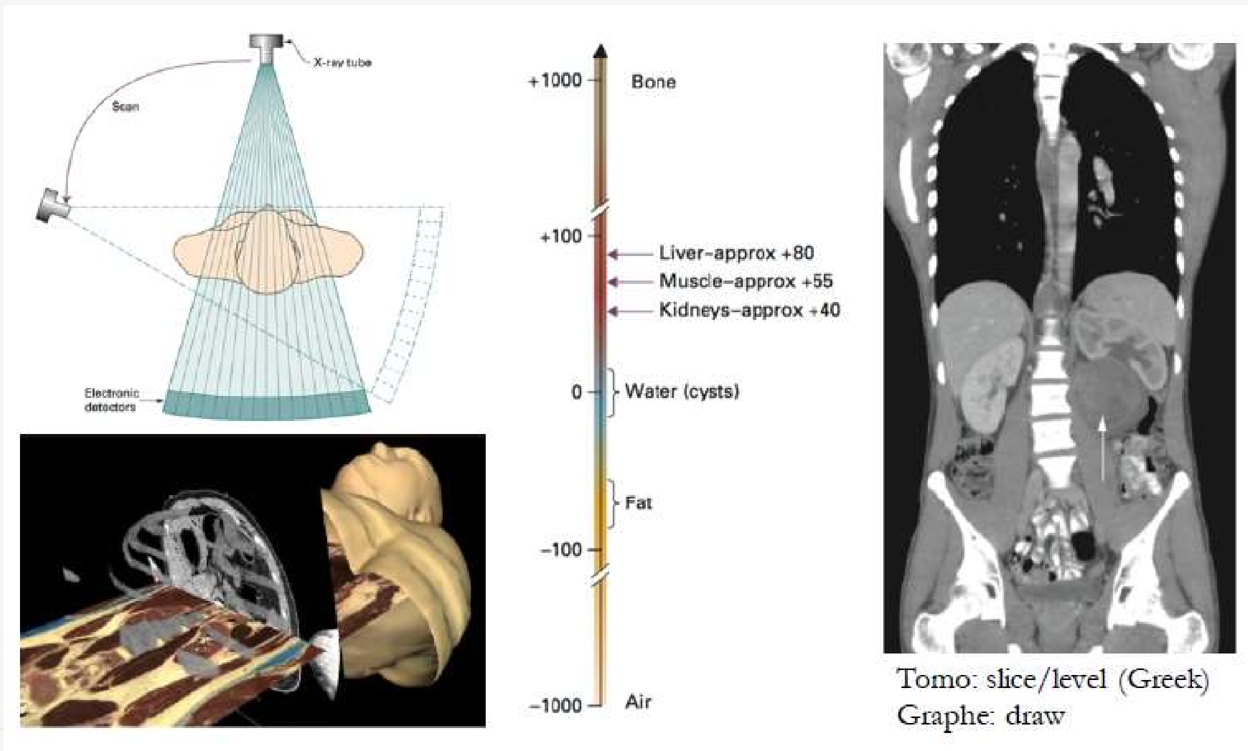
- Resolution:
  - direction of pulse propagation, pulse width 1-2mm
  - direction of scanning: beam width 2-3mm
  - low resolution and low SNR in deep region
- Ability of imaging soft tissue
- imaging in real time
- Doppler image
- Artefacts





Color flow mapping shows simultaneous amplitude (US) and velocity information (doppler)

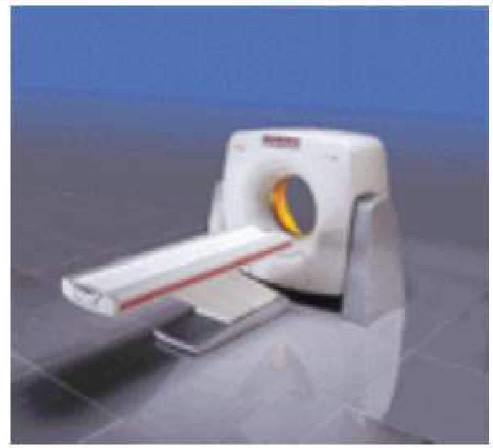
Computed Tomography (CT)



Tomo: slice/level (Greek)
Graphe: draw

CT Imaging (continue)

C-arm

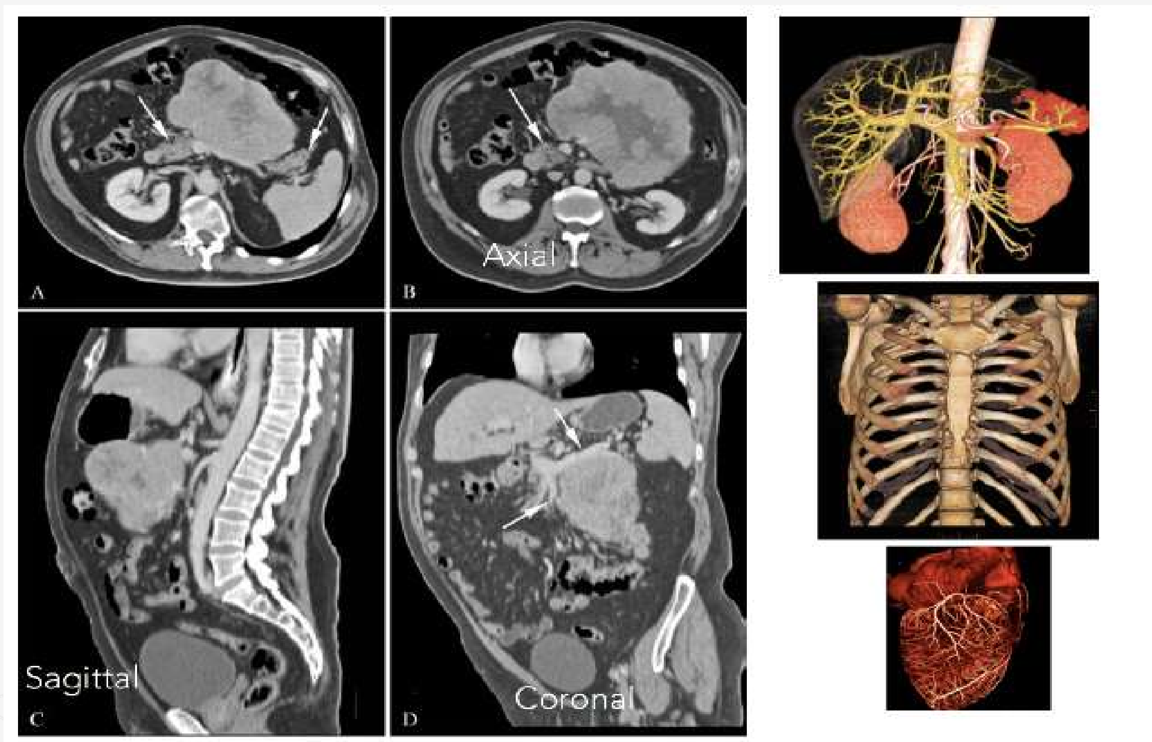


CT

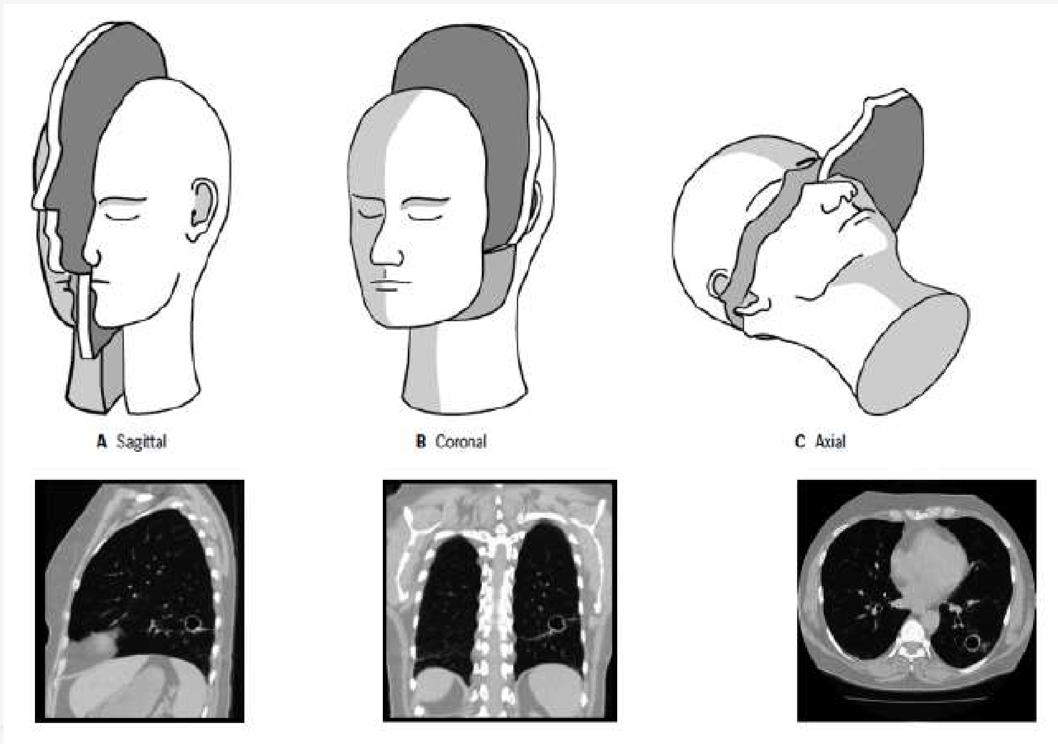
Micro-CT

~CAT Scan (computerized Axial tomography)

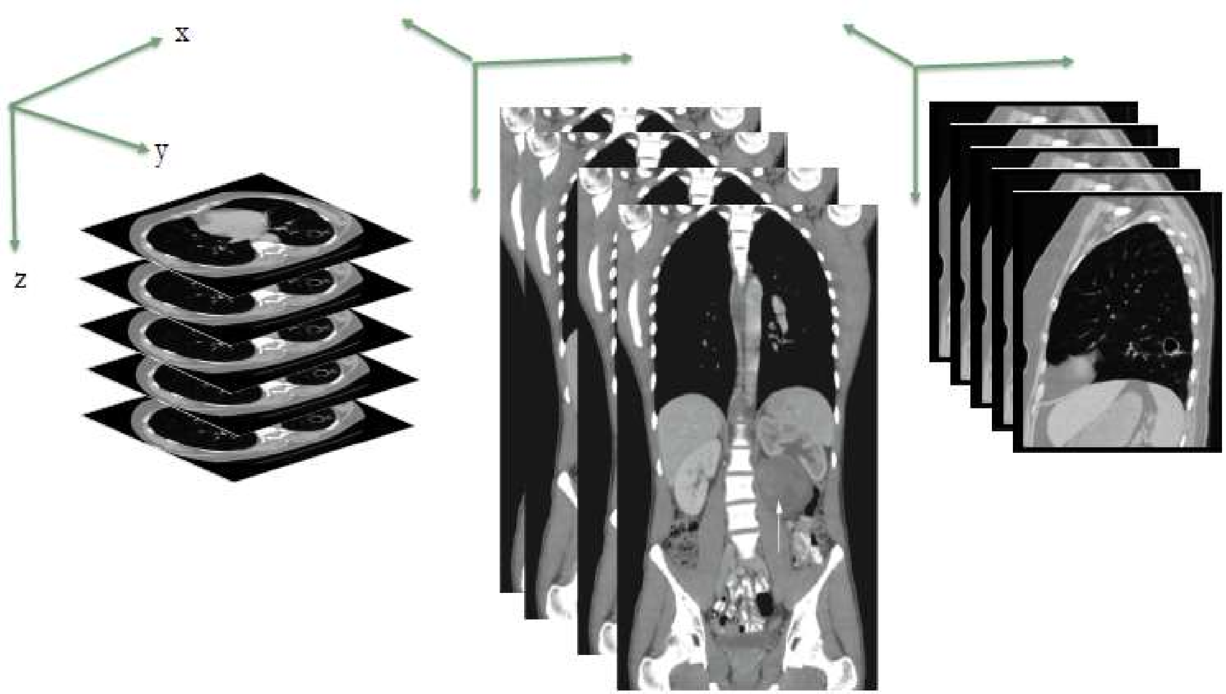
3D Nature of CT



3D View Terminology



3D Images

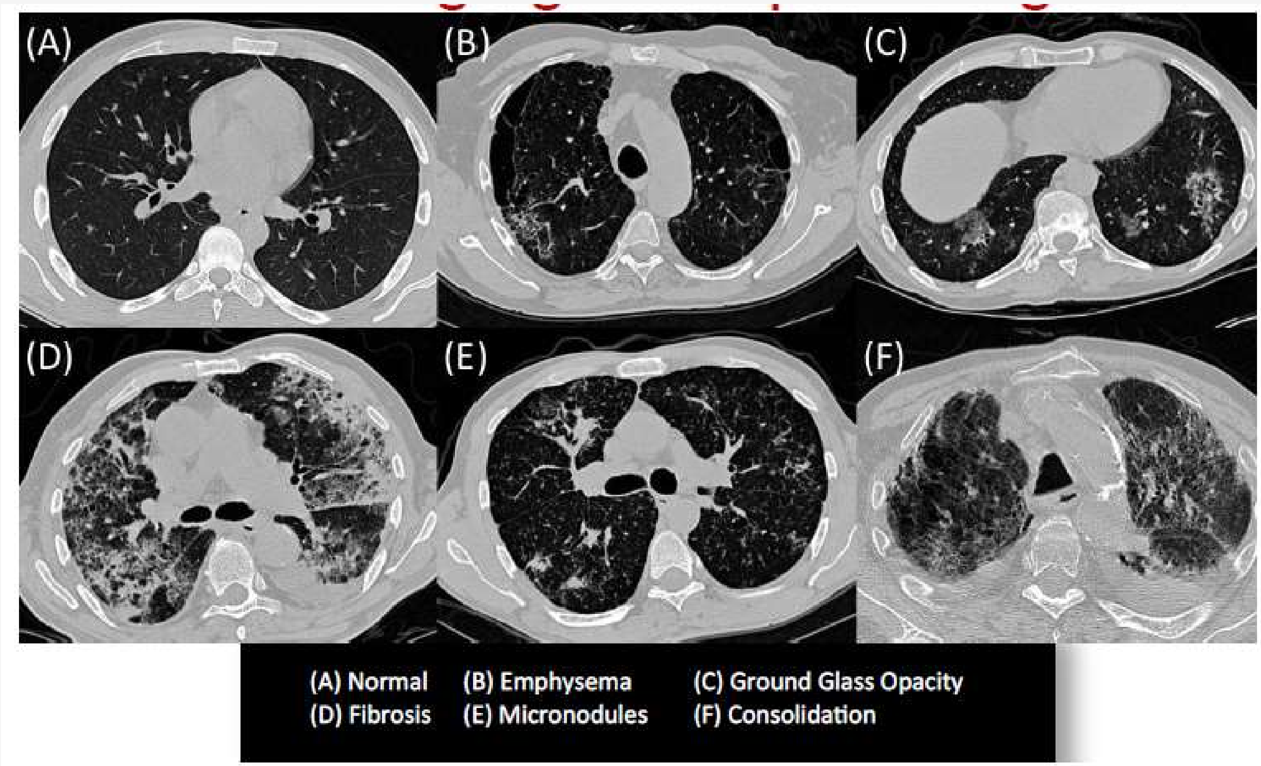


I: Image
I(x,y,z) denotes intensity value at pixel location x,y,z

Clinical Use of CT Imaging

- Standard imaging technique in many organs, particularly gold standard for lung imaging
- Fast
- Radiation exposure
- Often used in surgery rooms
- Show anatomy and pathology
- Intensity values are (more-or-less) fixed, read as HU (Hounsfield Unit)

CT Imaging Example: Lung

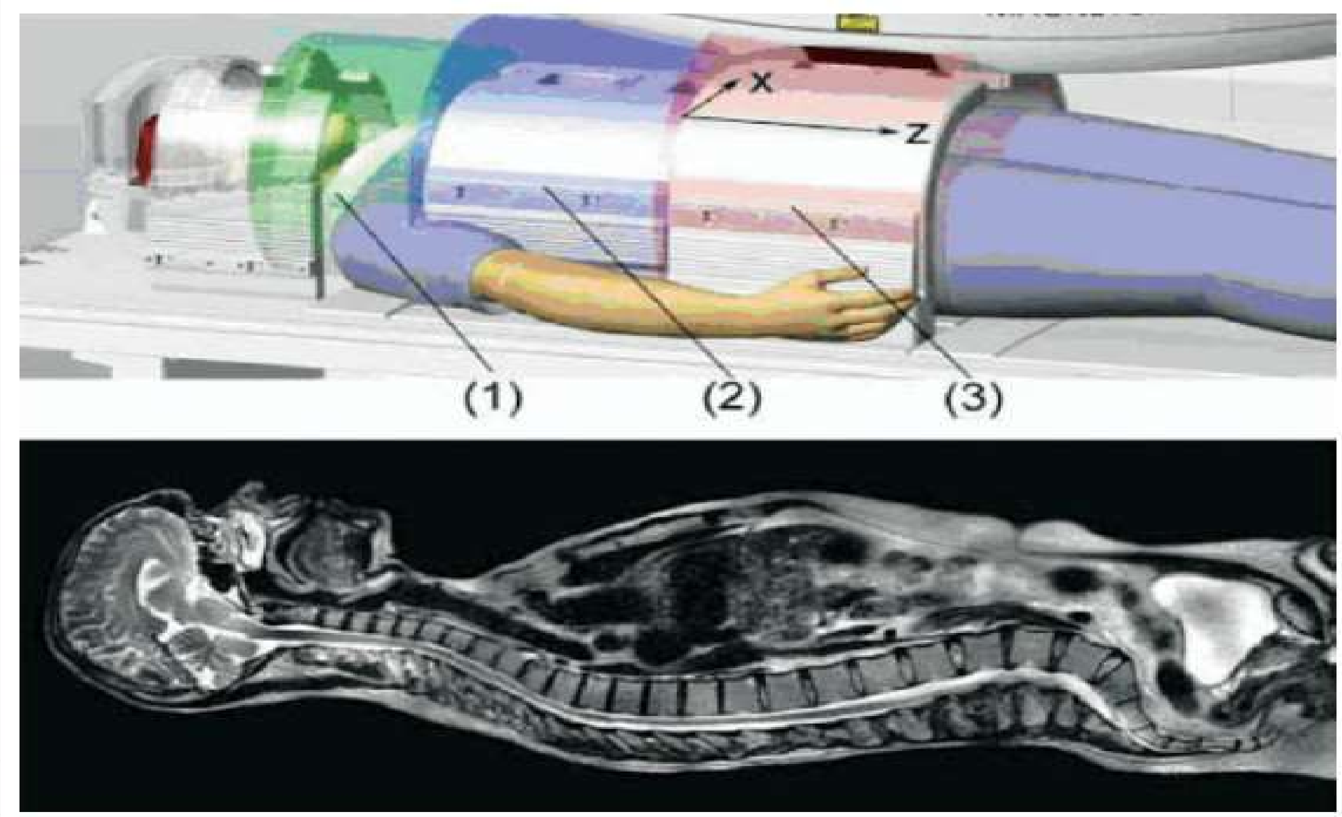


Magnetic Resonance Imaging (MRI)

- 1882-Nichola Tesla
- Discovered rotating magnetic field
- 1971-Paul Lauterbur NOBEL PRIZE
- First invented MRI
- Late 1970-Sir Peter Mansfield (Nottingham) NOBEL PRIZE
- Developed mathematical techniques to create clearer images and also in minutes rather than hours as Lauterbur did.

- CT is more widely used than MRI.
- MRI does not have ionizing-radiation.
- MRI has excellent soft tissue contrast, while CT is preferred for lung and bone imaging.
- CT is fast (few seconds), while MRI is slow (sparse MRI ~5-10 mins, abdomen or brain may take 30-40 mins).

MRI Basics



Shallow Comparison of Imaging Methods

	Chest	Abdomen	Head/Neck	Cardiovascular	Skeletal/muscular
CT	gold standard	Need contrast for excellency, widely used	Good for trauma	Gold standard	Gold standard
US	no use except heart or P.Effusion	Problems with gas	Poor	Poor	Elastography
Nuclear	Extensive use in heart and therapy in lung	CT or MRI is merged	PET	Perfusion	bone marrow
MRI	growing cardiac applications	Increased role of MRI	Gold standard	Will replace ct in near future	Excellent

Fundamentals of Image and Vision

General Introduction and Classification

Human Eye and Brightness Vision

Color Vision

Photometry and Imaging Model

Imaging Transformation

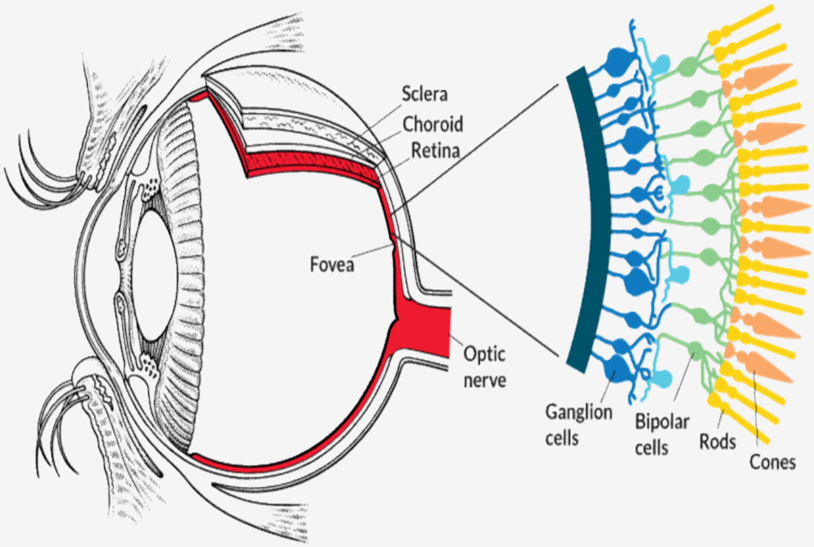
Sampling and Quantization

Relationships between Pixels

Arithmetic and logic Operations

- **Fundament of Vision** :eye and it's perception, color model
- **Fundament of Imaging**: imaging model, projection transformation, sampling and quantization
- **Fundament of image**: relationship between pixels, arithmetic and logic operations, coordinate transformation.

Human Eye and Brightness Vision



Comparison of Cones and Rods

	cones	rods
number	6~7 million	75~175 million
Sensitivity	color	shape
vision	Photopic (Bright-light)	Scotopic(dim-light)

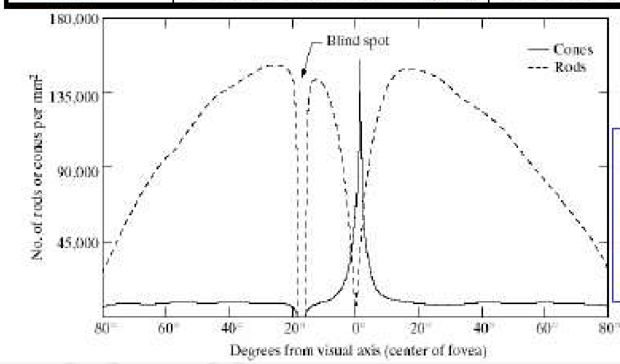


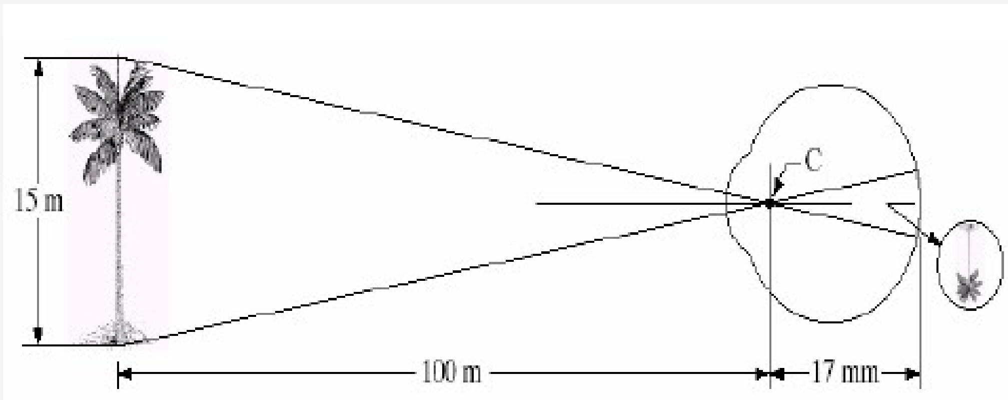
FIGURE 2.2 Distribution of rods and cones in the retina.

Fovea area: 1.5mm*1.5mm

Density of cones: 15000/mm^2

Cones in fovea: 337 000

Human Eye and Brightness Vision



If h is the height of that object in the retinal image,

$$\frac{15}{100} = \frac{h}{17} \Rightarrow h = 2.55mm$$

Sampling and Quantization

Image Fundaments: Image data presentation

We often use a more traditional matrix notation to denote a digital image and its elements.

$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & & a_{1,N-1} \\ \vdots & \vdots & & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

- Clearly, $a_{ij} = f(i, j)$

Image Fundaments: Image data presentation

two dimensional array	A[M][N]
Image size	M*N
Pixel at point (i,j)	A[i][j]

Image Fundaments: Image Types

Binary Image   Gray Image   Color Image

Type	Bits/pixel	color levers
Binary image	1	2
Gray Image	8	256
Color image	24	16777216
Multispectral Image	8*n	

Image Fundaments: Image statistic parameters

Max value: $ma\_value = \max(A(i,j))$

Min value: $mi\_value = \min(A(i,j))$

Mean value: $$me\_value = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} A(i,j)$$

Variance: $$\sigma^2 = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (A(i,j) - me\_value)^2$$

Where: $i = 0,1,\dots M-1$ $\quad j = 0,1,\dots N-1$

Spatial resolution

The number G of discrete gray levels and the size of image are typically integer power of 2. The range of values spanned by the gray levels is called the dynamic range of an image

$$G = 2^k \qquad M = 2^m \qquad N = 2^n$$

The number b of bits required to store a digital image is :

$$b = M \times N \times k$$

When $M=N$:

$$b = N^2 k$$

8 bits 4 bits 2 bits 1 bit

Relationship between Pixels

Neighborhood of a pixel

A pixel p at coordinates (x,y) has four horizontal and vertical neighbors whose coordinates are given by This set of pixels,called the 4-neighbors of p,is denoted by $N_4(p)$

0	$(x, y-1)$	0
$(x-1, y)$	(x, y)	$(x+1, y)$
0	$(x, y+1)$	0

The four *diagonal* neighbors of p have coordinates. and are denoted by $N_D(p)$

$(x-1, y-1)$	0	$(x+1, y-1)$
0	(x, y)	0
$(x-1, y+1)$	0	$(x+1, y+1)$

$N_D(p)$ together with $N_4(p)$,are called the *8-neighbors* of p,denoted by $N_8(p)$

Connectivity

To establish if two pixels are connected,it must be determined if they are neighbors and if their gray levels satisfy a specified criterion of similarity. If V is defined as the set of gray levels, then

- *4-adjacency*: two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$
- *8-adjacency* : two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$
- *m-adjacency* : two pixels p and q with values from V are 4-adjacent if
  (i)q is in $N_4(p)$,or
  (ii) q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.

Distance Measures: definitions

For pixels p,q and z ,with coordinates (x,y),(s,t),and(u,v),respectively, D is a *distance function or metric* if

(a) $D(p,q) \geq 0 \quad (D(p,q)=0, if \;\; p=q)$

(b) $D(p,q) = D(q,p), and$

(c) $D(p,z) \leq D(p,q) + D(q,z)$

Distance Measures: definitions

- The Euclidean distance is

$$D_e(p,q) = [(x-s)^2 + (y-t)^2]^{\frac{1}{2}}$$

- And the city-block and chessboard distances are:

$$D_4(p,q) = |x-s| + |y-t|$$

$$D_8(p,q) = \max(|x-s|, |y-t|)$$

- The D_m distance is defined as the shortest m-path between the points.

Arithmetic and Logic Operation

Arithmetic operations between two pixels *p* and *q* include:

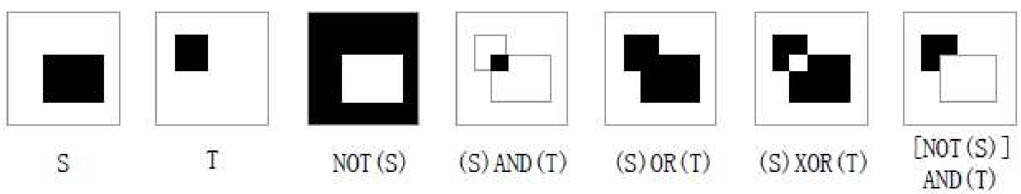
Addition: $p+q$

Subtraction: $p-q$

Multiplication: $p*q$

Division: p/q

AND OR NOT



Point operation and Local operation:

$$A(x,y) \longrightarrow B(x,y)$$

Point Operation: $B(x,y) = f(A(x,y))$

Local Operation: $B(x,y) = f(A(x \pm s, y \pm t))$

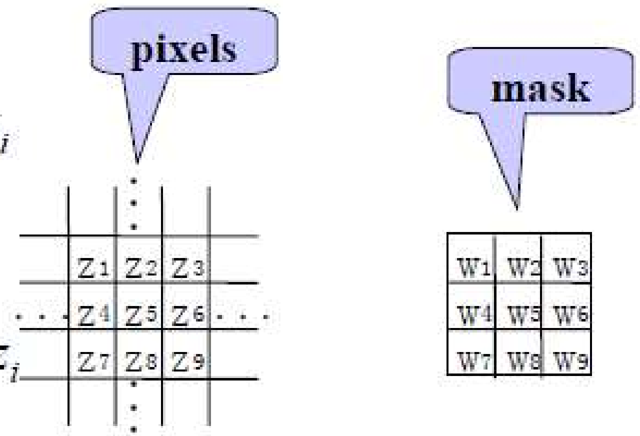
Windows: $s = 0,1,\ldots S-1 \quad t = 0,1,\ldots T-1$

Usually, *S=T=1,3,5,7…*

Local operation:

$$z = \frac{1}{9}(z_1 + z_2 + \cdots + z_9) = \frac{1}{9}\sum_{i=1}^{9} z_i$$

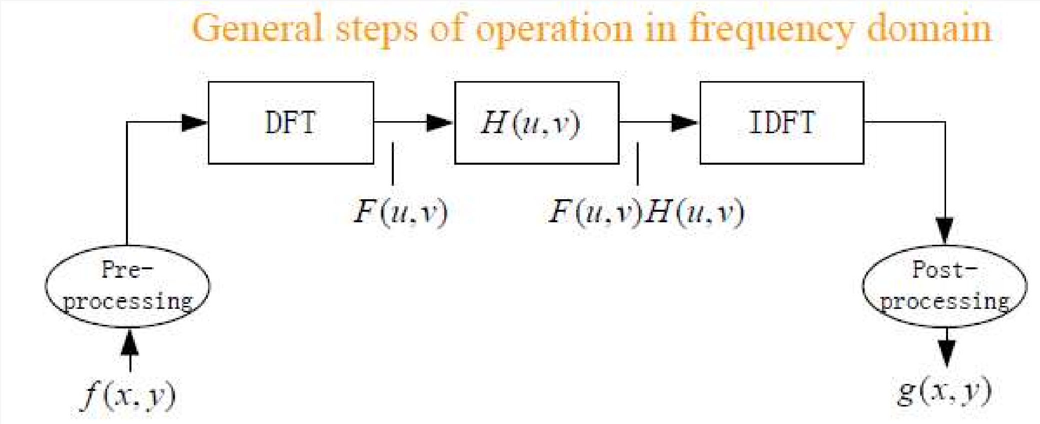
$$z = w_1 z_1 + w_2 z_2 + w_n z_n = \sum_{i=1}^{9} w_i z_i$$



(a) (b)

Image Transforms

- image transforms are the bases of image processing and analysis
- image transforms are used in image enhancement, restoration, reconstruction, encoding and description



General Introduction and Classification

- image transforms
  - separable transforms
    - DFT and its properties
    - others
      - DCT
      - Hadamard Transform
      - Walsh Transform
      - Slant Transform
      - Haar Transform
  - statistical transforms: Hotelling transform

Discrete Cosine Transform (DCT):

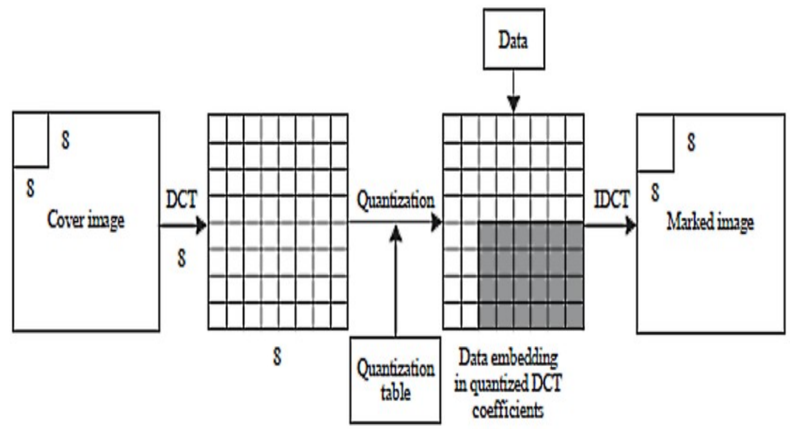
- The forward equation, for image A, is

$$b(u,v)=\frac{2}{N}C(u)C(v)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}a(x,y)\cos\left(\frac{\pi u(2x+1)}{2N}\right)\cos\left(\frac{\pi v(2y+1)}{2N}\right)$$

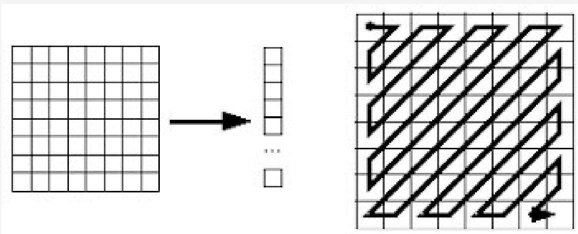
- The inverse equation, for image B, is

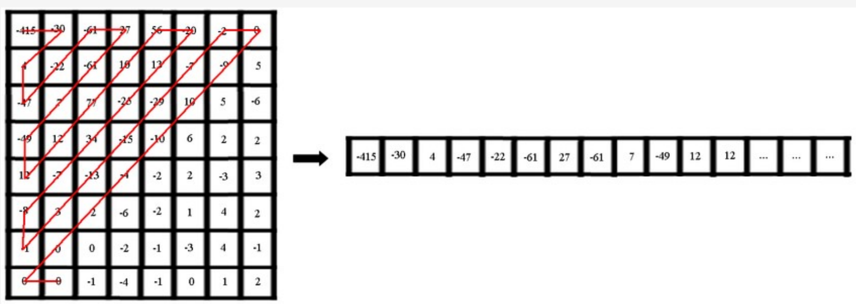
$$a(x,y)=\frac{2}{N}\sum_{u=0}^{N-1}\sum_{v=0}^{N-1}C(u)C(v)b(u,v)\cos\left(\frac{\pi u(2x+1)}{2N}\right)\cos\left(\frac{\pi v(2y+1)}{2N}\right)$$

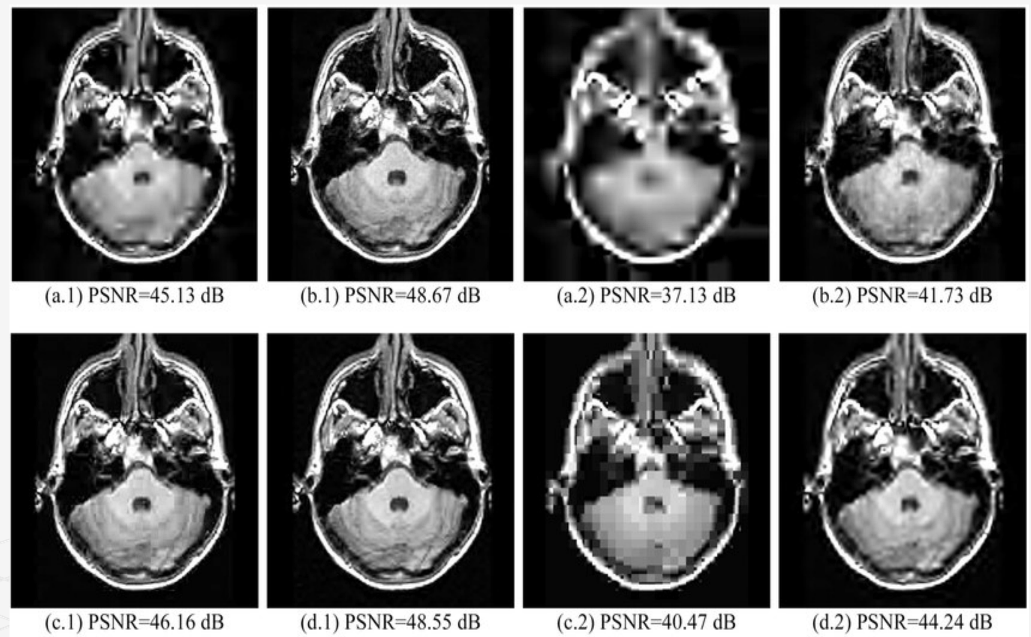
•Here $C(u)=\begin{cases}\frac{1}{\sqrt{2}} & if\ u=0\\ 1 & otherwise\end{cases}$



MRI compression using DCT Transform



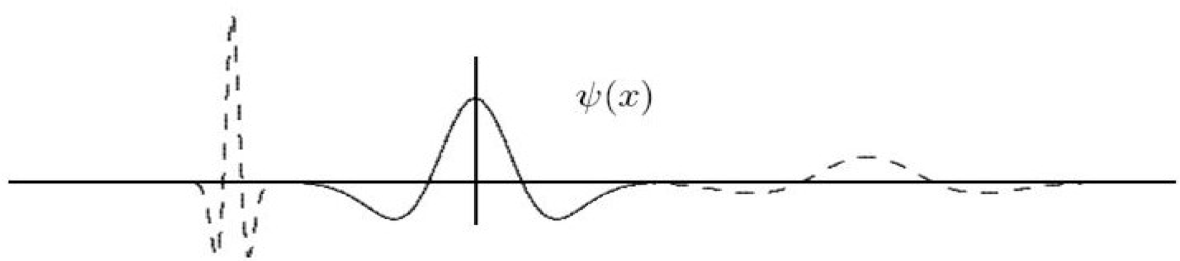




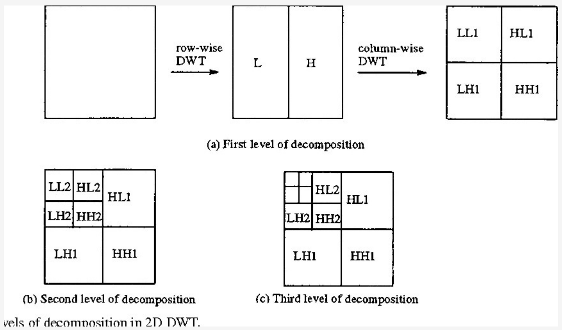
Discrete Wave Transform (DCT):

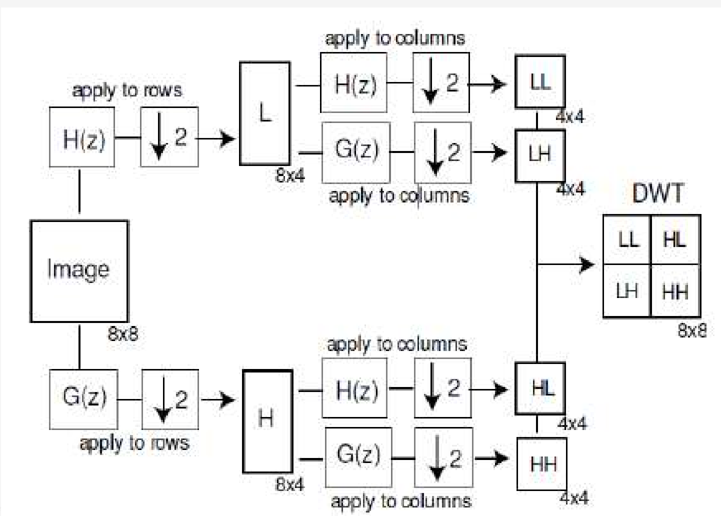
- wavelet $$\psi_{a,b}(t) = \frac{1}{\sqrt{b}}\psi(\frac{t-a}{b})$$

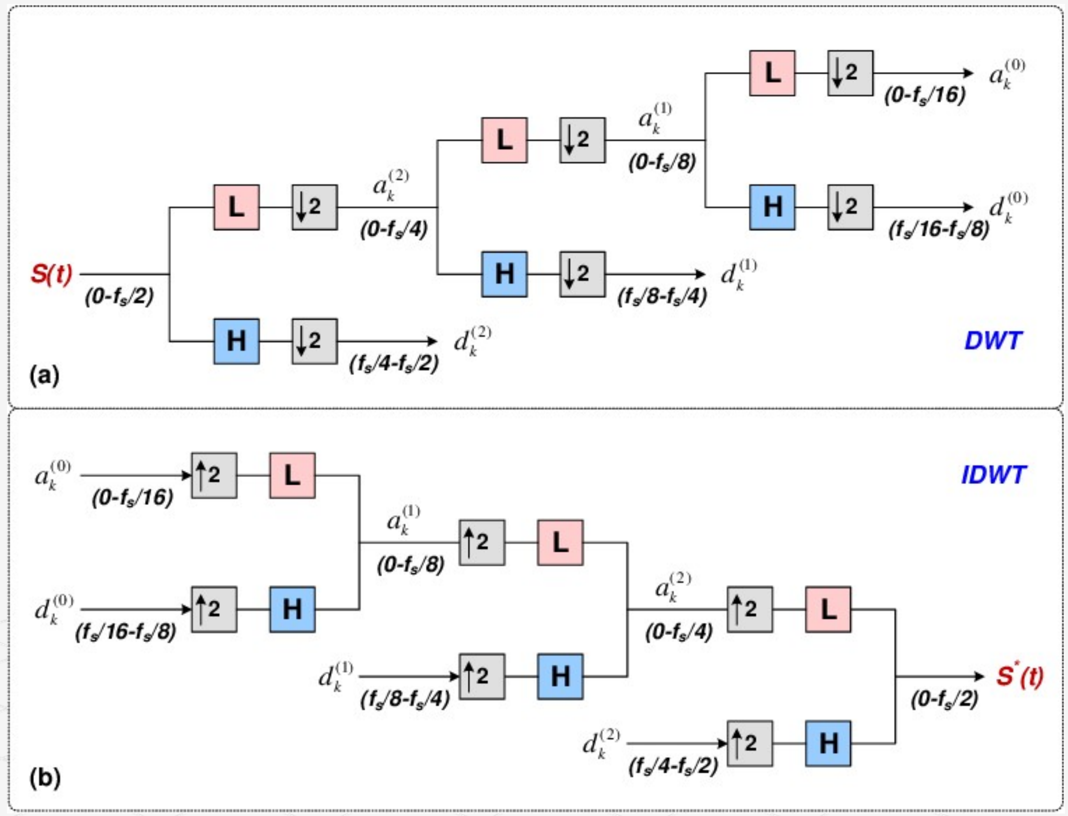
- decomposition $$W(a,b) = K\int_{-\infty}^{+\infty}\psi^*(\frac{x-b}{a})f(x)dx$$



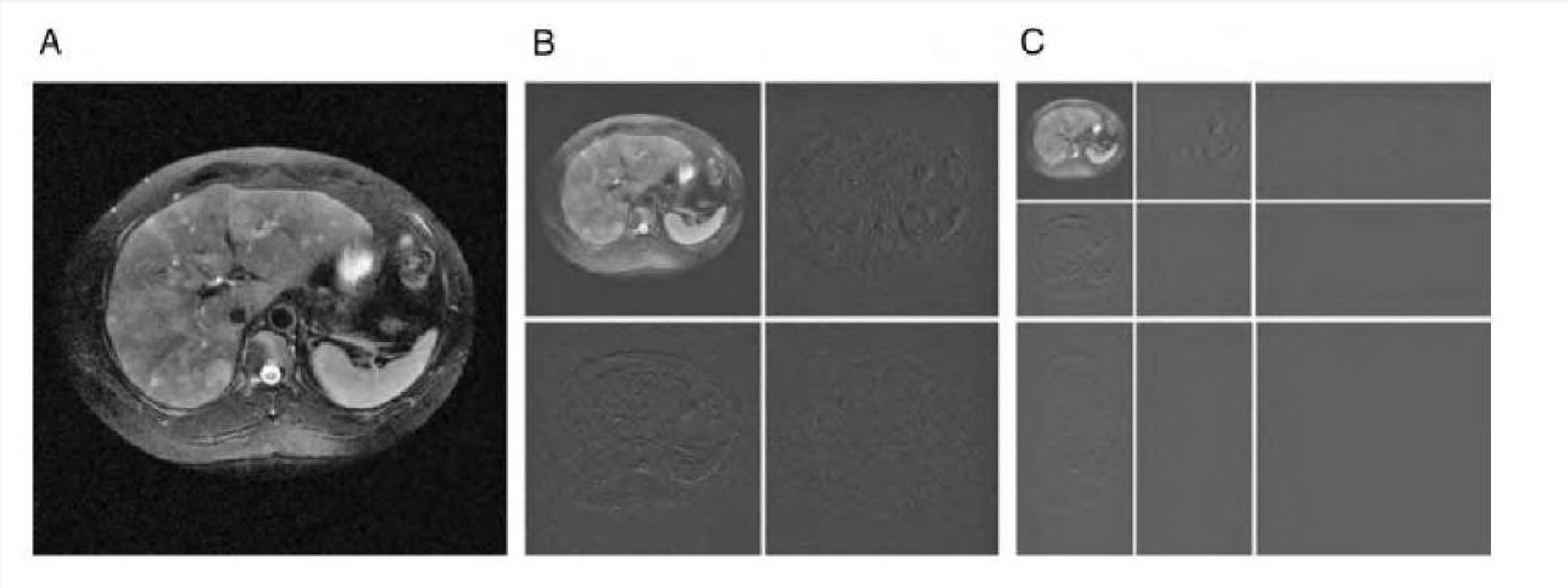
Discrete Wavelet Transform Decomposition



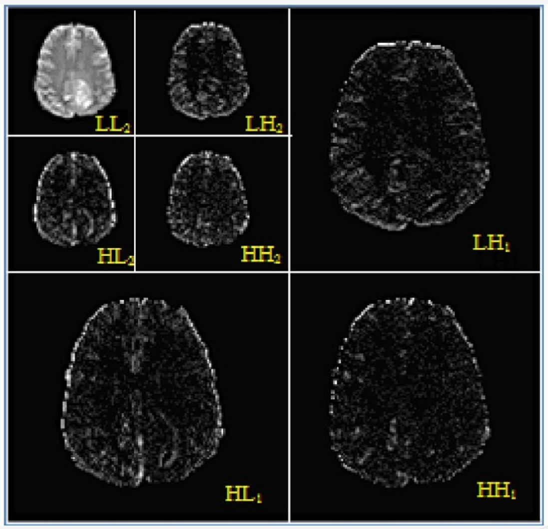


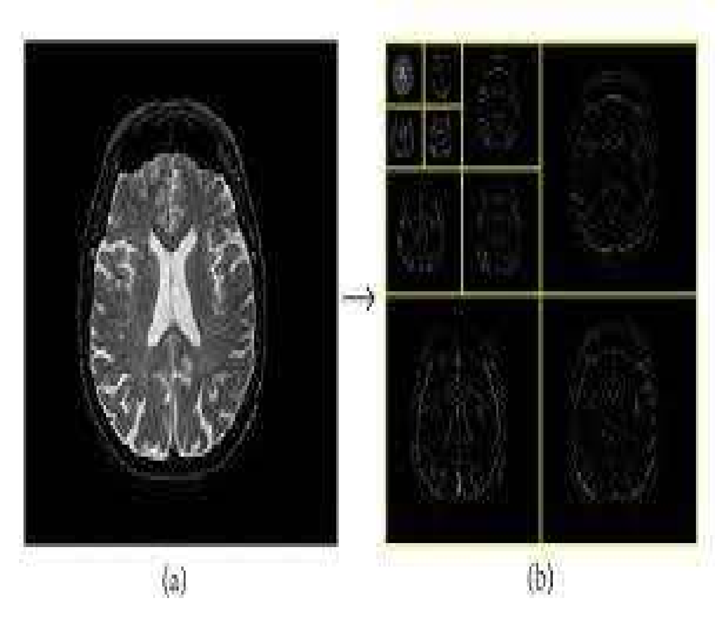


DWT Decomposition

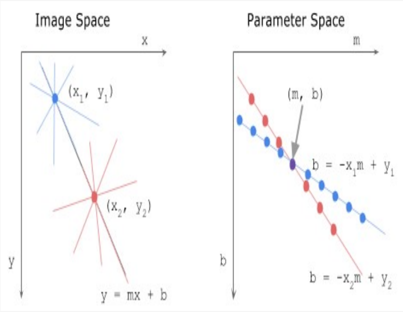


Example of the pyramidal decomposition of an image.





Hough Transform



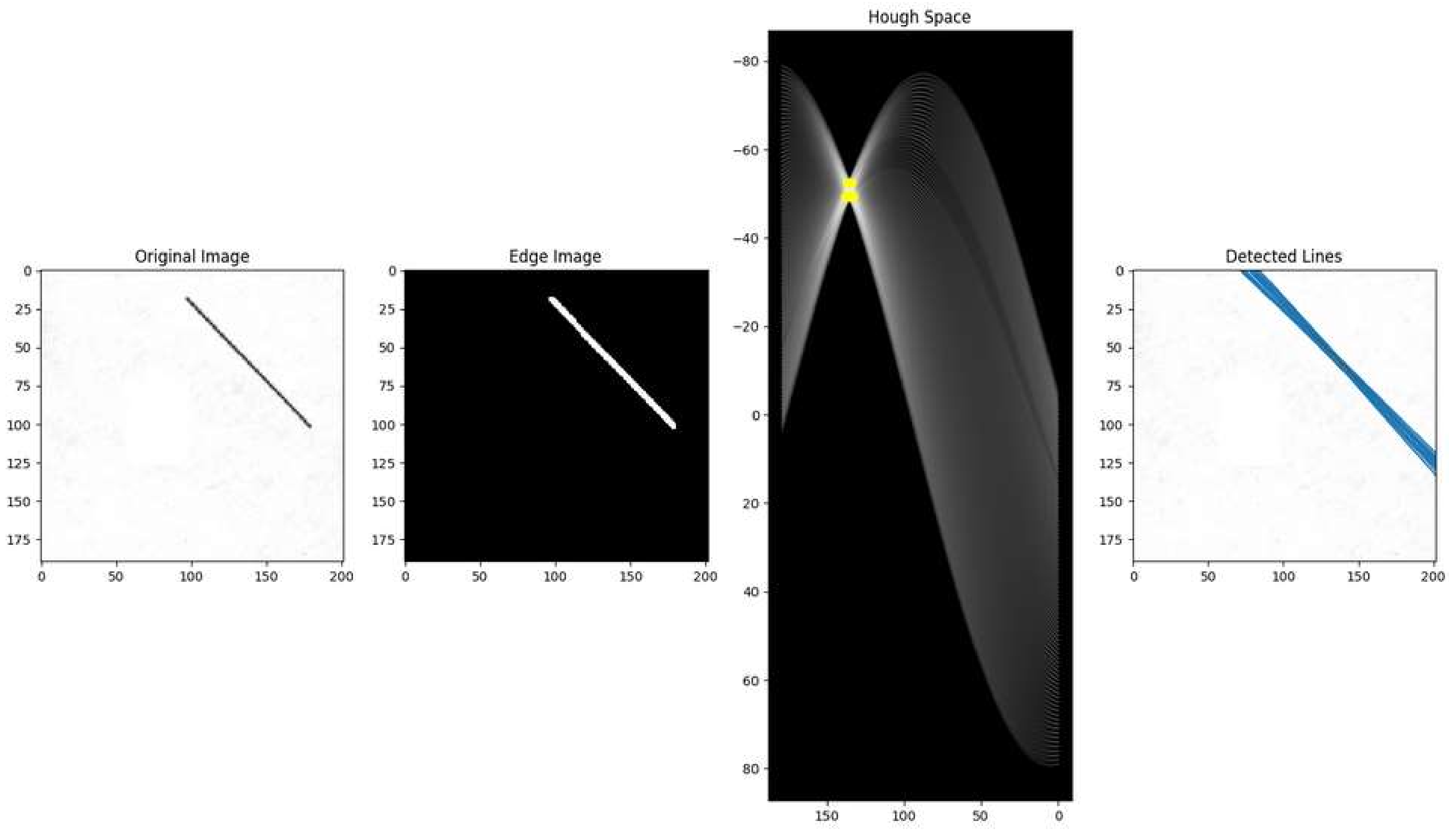


Image Enhancement

Enhancement by Spatial Transforming(contrast enhancement)

Enhancement by Spatial Filtering (image smoothing)

Enhancement by Frequency Filtering (image sharpening)

Color Enhancement

contrast enhancement:	linear transform non-linear transform, histogram equalization histogram matching local enhancement
image smoothing:	averaging mask, order-statistics filter lowpass filter.
image sharpening:	derivatives, highpass filter
color image enhancement:	pseudo color processing, full color processing

Image Super Resolution and Image Fusion:

Single Frame and Multiframe Super Resolution

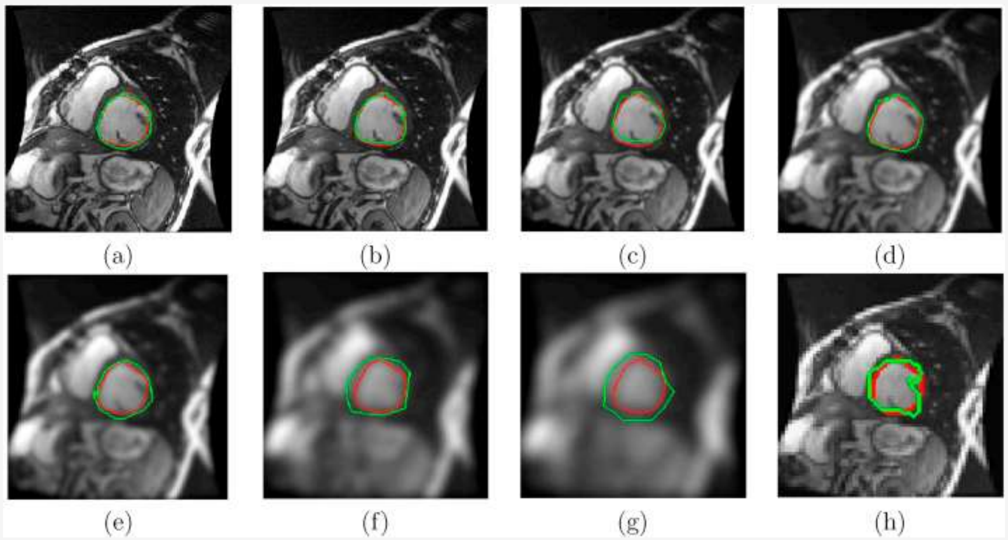

(a) (b) (c) (d) (e) (f) (g) (h)

Image Restoration

"compensate for" or "undo" defects which degrade an image.

Introduction

Diagonalization

Unconstrained Restoration(inverse filtering)

Constrained Restoration(wiener filtering)

Estimating the Degradation Function

Geometric Distortion Correction

image inpaiting

Degrade Causes

(1) atmospheric turbulence

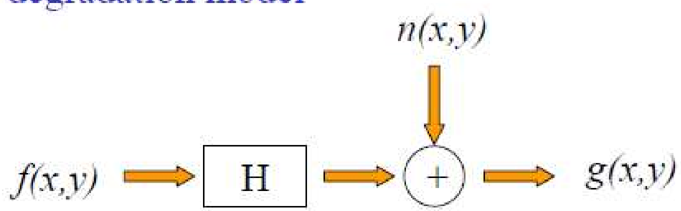
(2) sampling, quantization

(3) motion blur

(4) camera misfocus

(5) noise

degradation model



Assume it is a linear, position- invariant system, We can model a blurred image by

$$g(x,y) = f(x,y) * h(x,y) + n(x,y)$$

Where $h(x,y)$ is called as Point Spread Function (PSF)

Methods

Unconstrained Restoration: inverse filtering

Constrained Restoration: wiener filtering

Medical image processing encompasses **the use and exploration of 3D image datasets of the human body**, obtained most commonly from a Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) scanner to diagnose pathologies or guide medical interventions such as surgical planning, or for research purposes.

Thank You..

Question and Answer ?