Disciplina: Bioengenharia.

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Background Check

- 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

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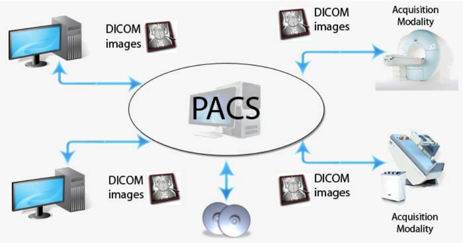
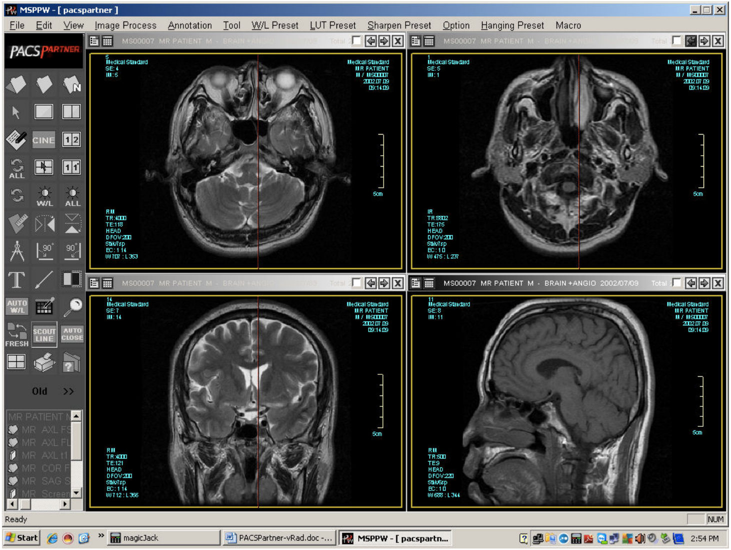
Image Processing	Image quality improvement
Machine Learning	Tissue types
Image Understanding	Semantic description & content understanding

where do radiologists interpret scans?

- Dedicated light source
- Darkened environment
- Limited distraction



PACS (example)



Medical Image Analysis

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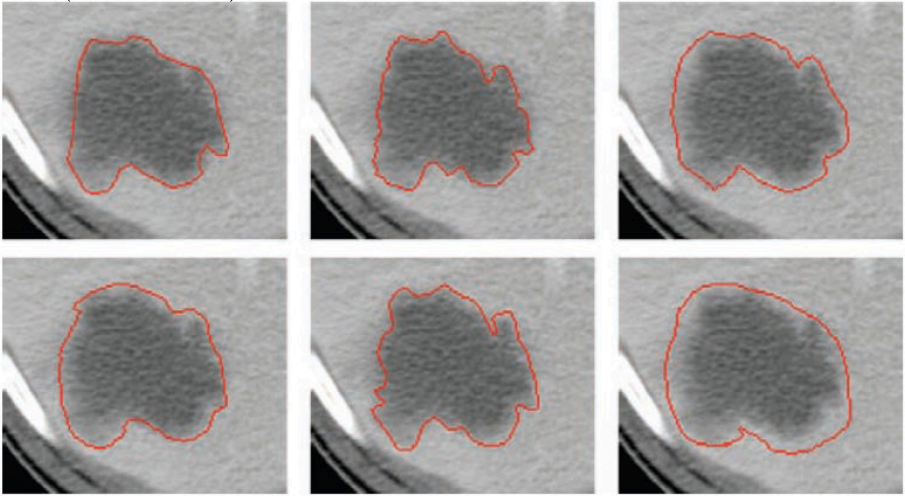
- Medical images are often **multidimensional (2D, 3D, 4D,nD)**, have a large dynamic range, are produced on different imaging modalities in the hospital, and make high demands upon the software for visualization and human–computer interaction.
  - A high resolution MR image of the brain, for instance, 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-Manual

- Often accepted as surrogate of the truth (if biopsy or real ground truth is not available)
- However, manual analysis is highly subjective because it relies on the observer's perception.
  - Intra and inter-observer agreements/variabilities
- It is highly tedious

Observer Variability – Example: Liver lesion

Intra- (one week interval)



Inter-

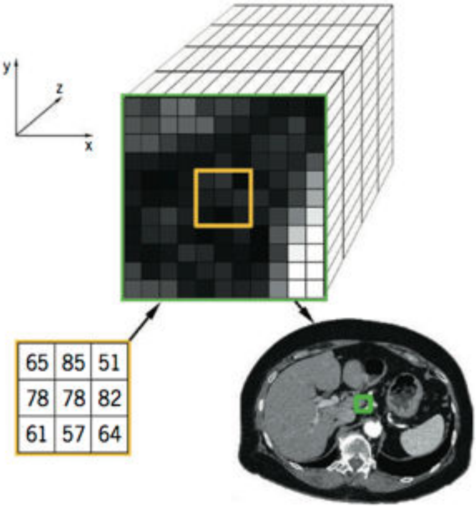
Medical Image Analysis-Automated

- Different strategies for image analysis exist. However, few of them are suited for medical applications.

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.

Digital Images

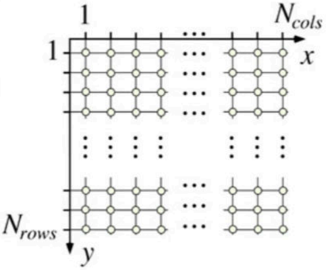


0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

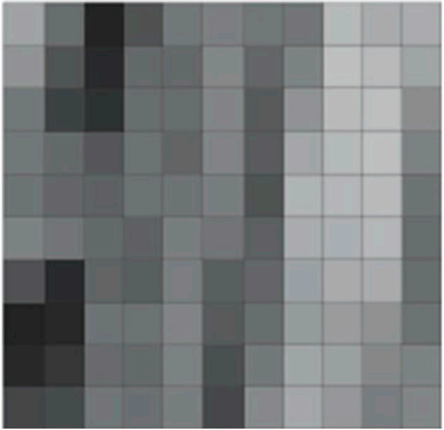
What computer sees!

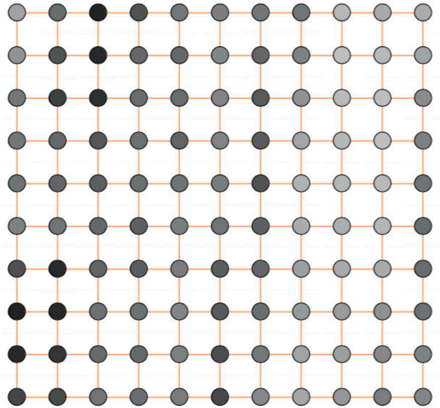
Digital Images

- Definition: A digital image is defined by *integrating* and *sampling* continuous (analog) data in a spatial domain [Klette, 2014].



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)

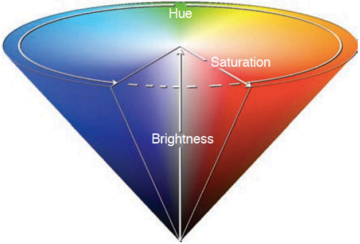
Ex. If 8 bit (a=8), image spans from 0 to 255

0 black

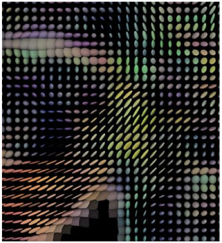
255 white

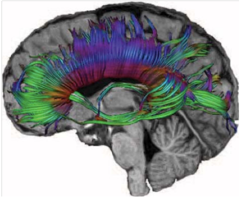
Ex. If 1 bit (a=1), it is binary image, 0 and 1 only.

Image Types-Color

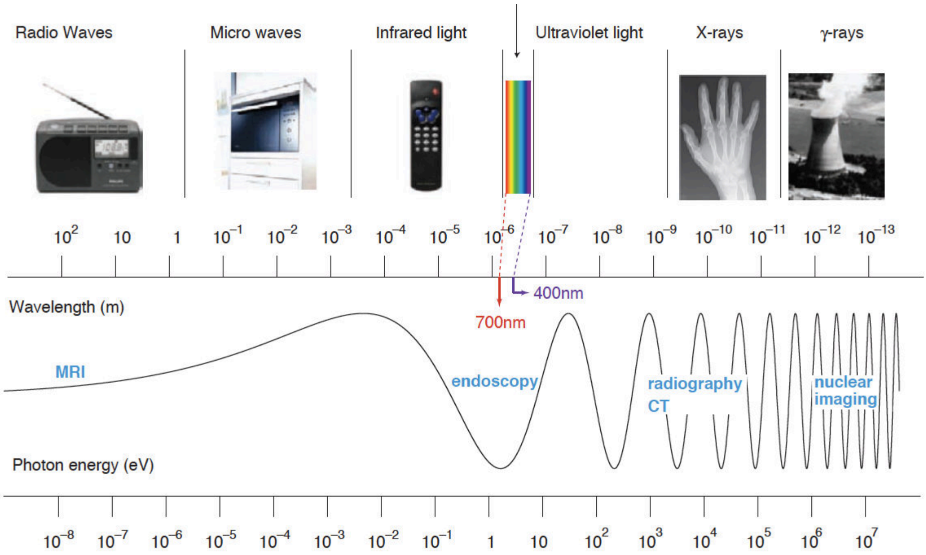


- Image has three channels (bands), each channel spans a-bit values.
- RGB, Hue-Saturation-Brightness





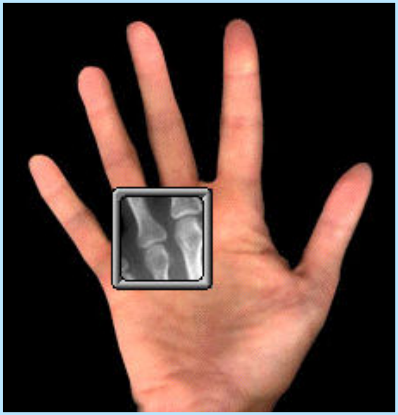
Brief Introduction to Imaging Modalities



ELECTROMAGNETIC SPECTRUM (P. Suetens)

X-Ray Imaging / Radiography

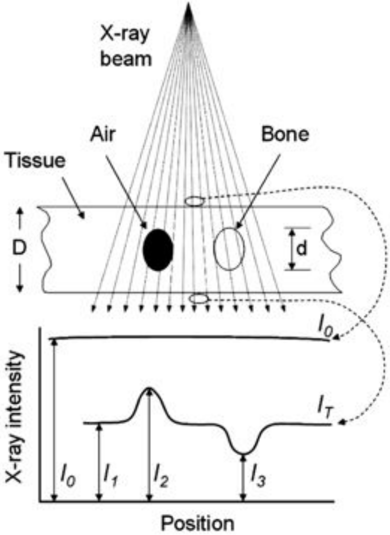
- The first published medical image was a radiograph of the hand of Wilhelm Conrad Roentgen's wife in 1895. *Nobel Prize in Physics 1901.*

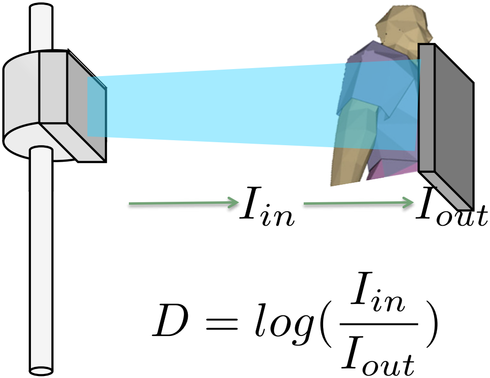


routine diagnostic radiography (2D images):

chest x-rays, fluoroscopy, mammography, motion tomography, angiography, …

X-Ray Imaging / Radiography

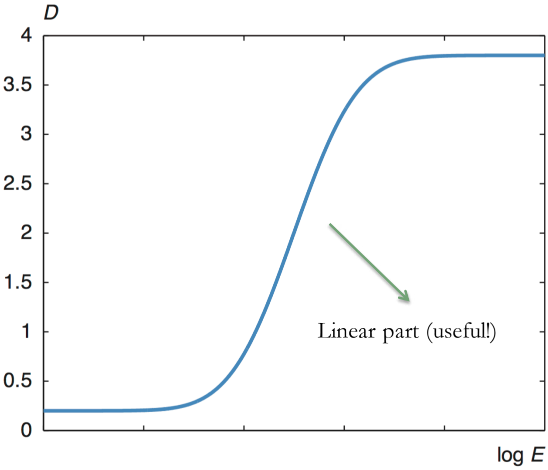




$$D = log(\frac{I_{in}}{I_{out}})$$

D=Optical density
E=exposure (Iin/Iout)
Iin=incoming light intensity
Iout=outgoing light intensity

X-Ray Imaging / Radiography-Sensitometric Curve



- Maximum slope of the curve is known as the gamma of the film.

- A larger slope implies a higher contrast at the cost of a smaller useful exposure range

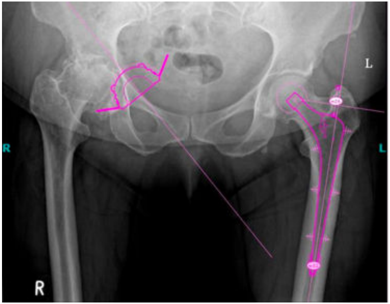
- In low and high density areas, contrast is low and little information available.

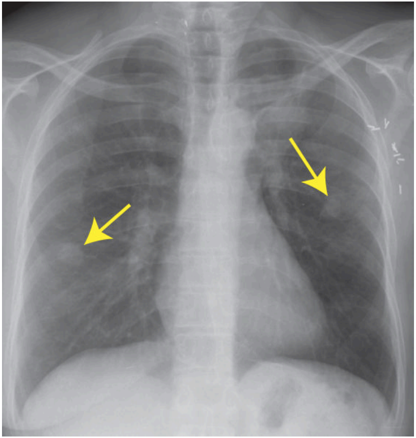
- In linear part, slope characterize Contrast of the film. Max slope is known as Gamma of the film.

Defn. Contrast: is the intensity difference in adjacent regions of the image.

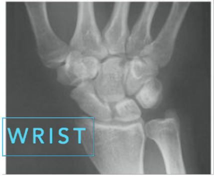
Basics Use of X-Rays

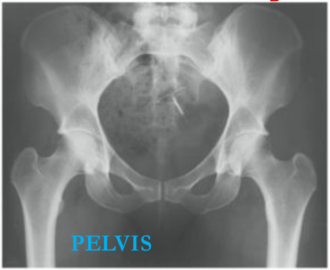
- Dental examinations
- Surgical markers prior to invasive procedures
- Mammography
- Orthopedic evaluations
- Chest examination (Tuberculosis)
- Age estimation (forensic, left hand)



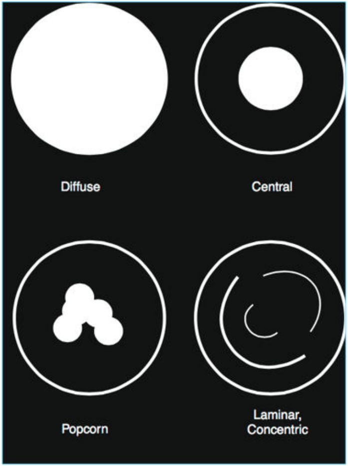


Clinical Examples – X-Rays

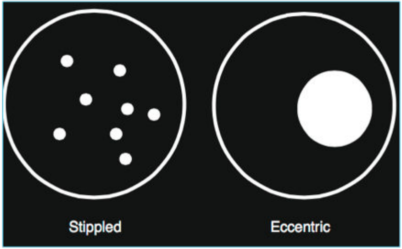




How Radiologists Search Abnormal Patterns in Chest X-Rays?



Patterns belonging to Potentially Benign Lesions



Patterns belonging to Potentially Malignant Lesions

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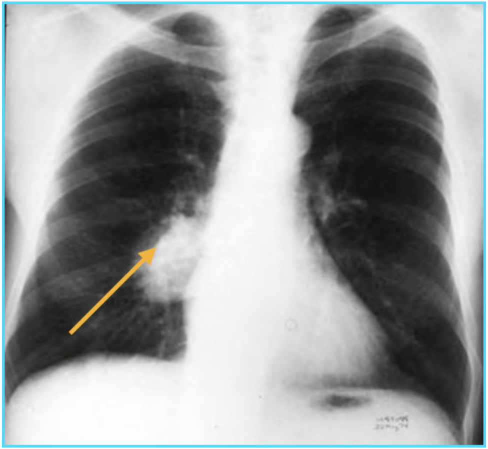

Radiologists often report the following

- 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

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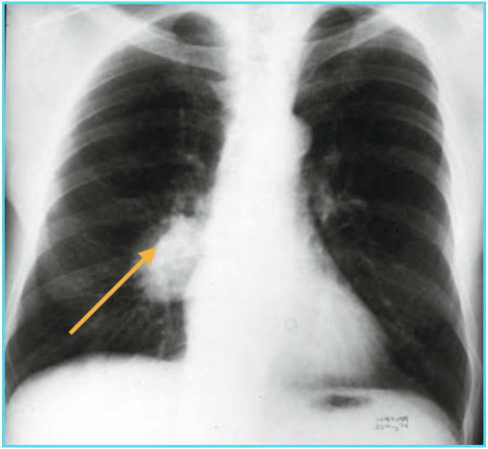

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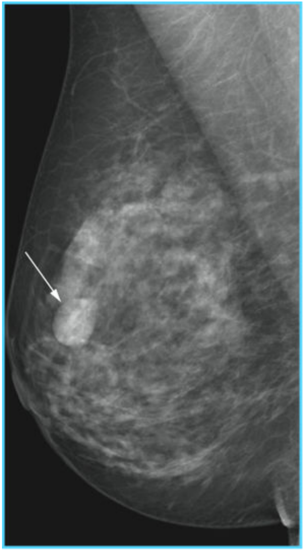
Computer algorithms can solve/simplify these problems for improved healthcare

Another Example for X-ray Imaging

Benign



Malignant

Ultrasound Imaging

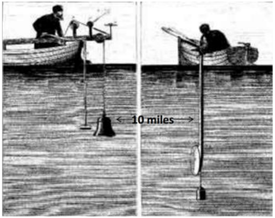
- US is defined as any sound wave above 20KHz

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.

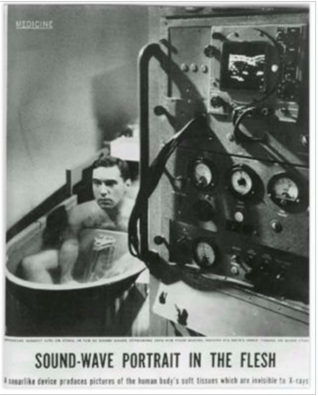


1880-Pierre&Jacques Curie

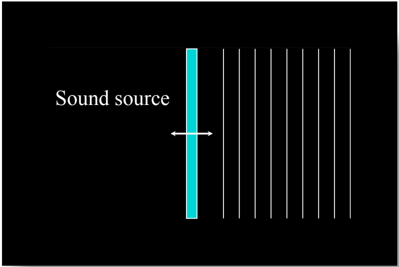
discover the Piezo-Electric Effect (ability of certain materials to generate an electric charge in response to applied mechanical stress.

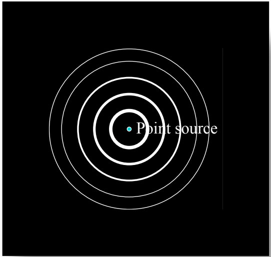
US Imaging Technology

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



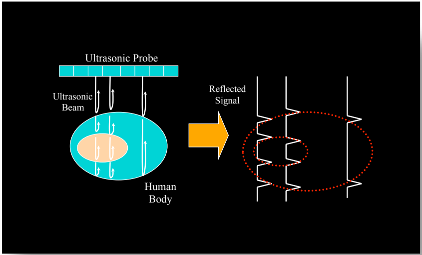
Principle of US Imaging





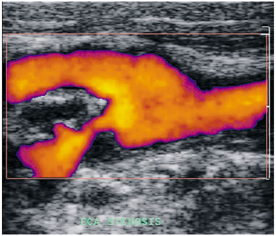
US equipment assumes that sound velocity is constant in the body.

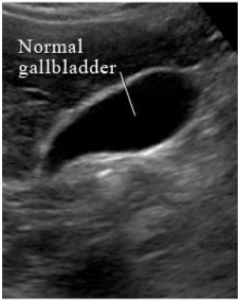
Body tissue	Acoustic impedance (10^6 Rayls)
Air	0.0004
Lung	0.18
Fat	1.34
Liver	1.65
Blood	1.65
Kidney	1.63
Muscle	1.71
Bone	7.8



Features of US Imaging

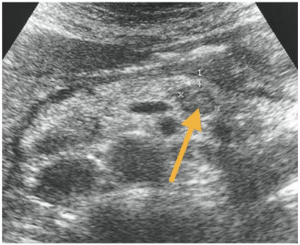
- Resolution:
  - direction of pulse propagation, pulse width 1-2mm
  - direction of scanning: beam width 2-3mm
  - low resolution and low SNR in deep region
- Ability of imaging soft tissue
- imaging in real time
- Doppler image
- Artefacts

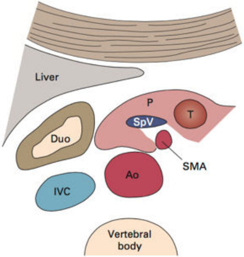




Color flow mapping shows simultaneous amplitude (US) and velocity information (doppler)

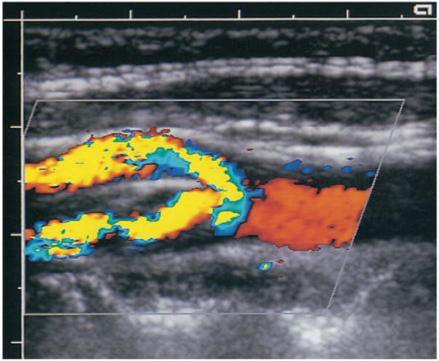
Clinical Use of US Imaging

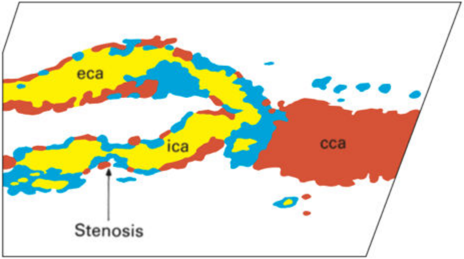




Clinical Use of US Imaging

Renal Artery Blood Flow

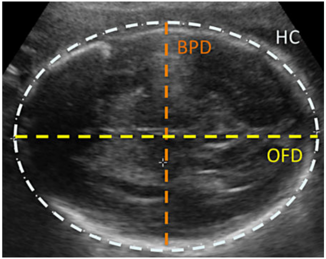


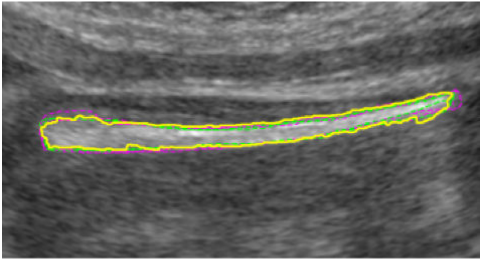


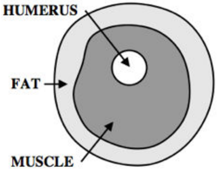
manual measurements?
can computer help calculating all blood flow and identify automatically the abnormal regions? (See Next Lecture, afternoon)

stenosis is seen
eca: external carotid artery
cca: common carotid artery
ica: internal carotid artery

Clinical Use of US Imaging





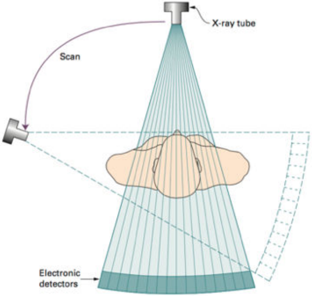


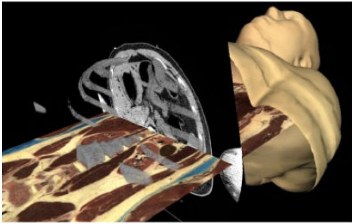
(a) Arm Composition

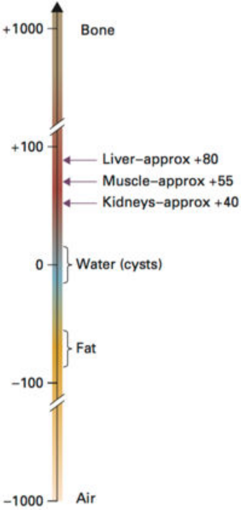
(b) Original Image

Bone, fat, and physical length
Measurements –unborn babies
(Image Credit: S. Rueda, Oxford Univ.)

Computed Tomography (CT)



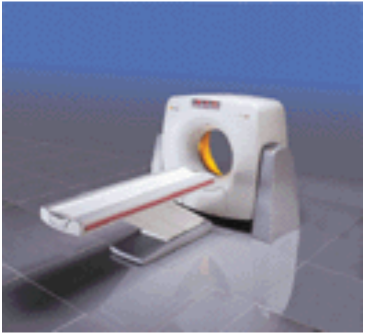




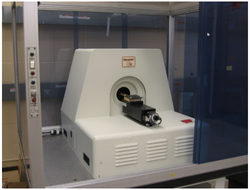
Tomo: slice/level (Greek)
Graphe: draw

CT Imaging (continue)

C-arm



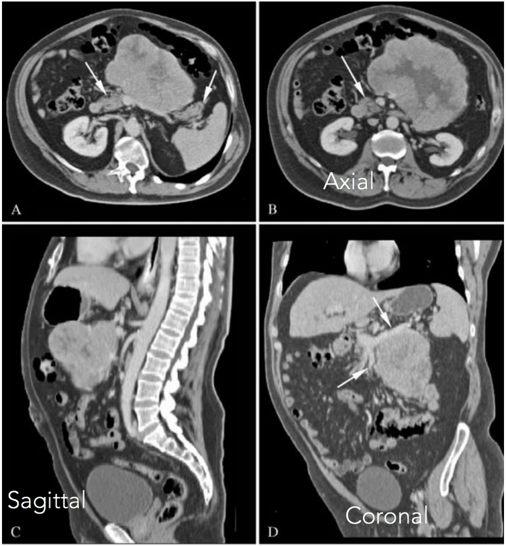
CT

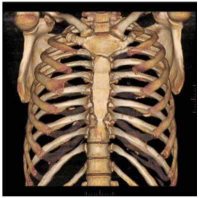


Micro-CT

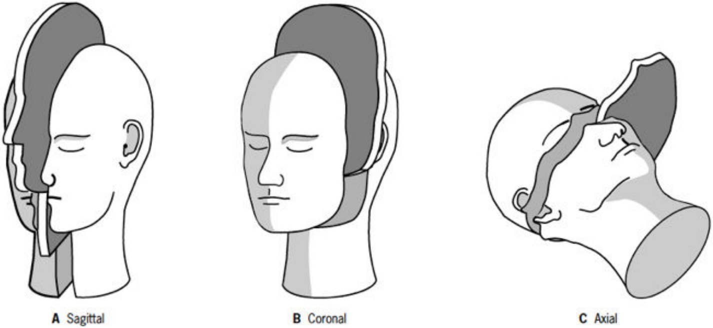
~CAT Scan (computerized Axial tomography)

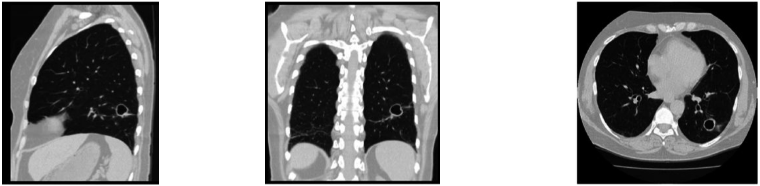
3D Nature of CT



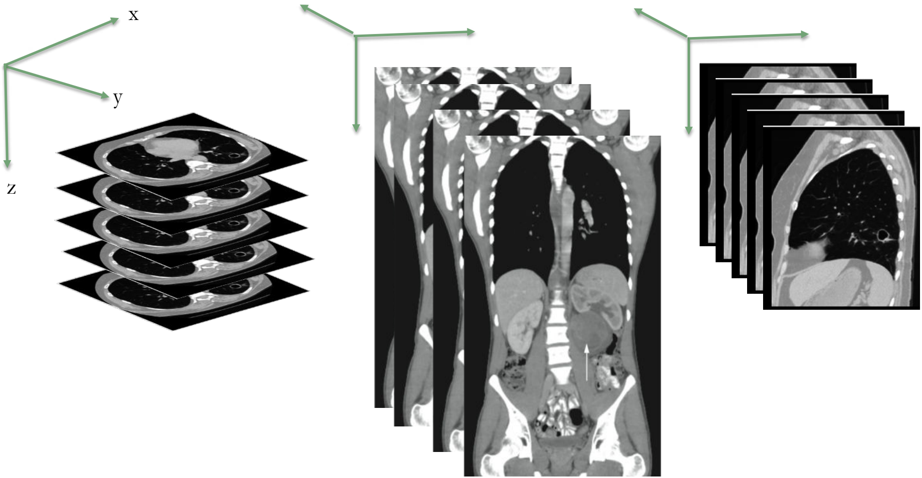


Remark: 3D View Terminology





3D Images



I: Image

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

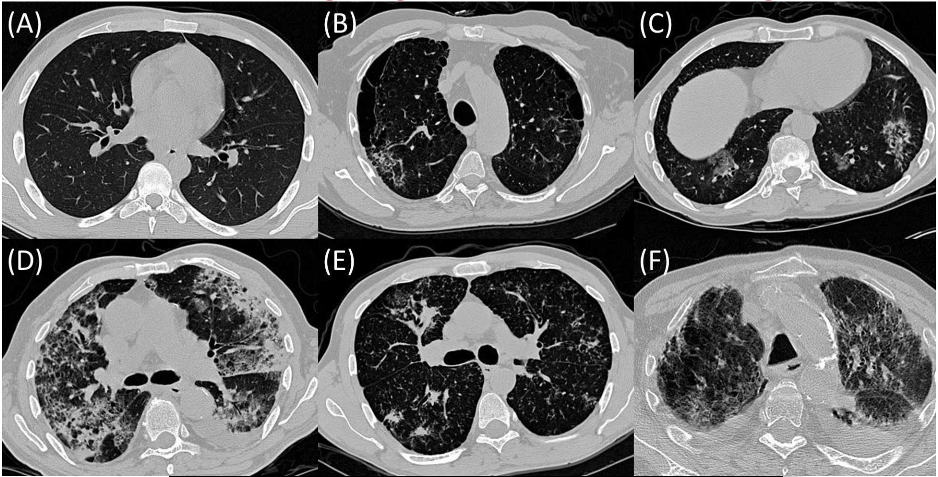
Clinical Use of CT Imaging

- 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: Tumor

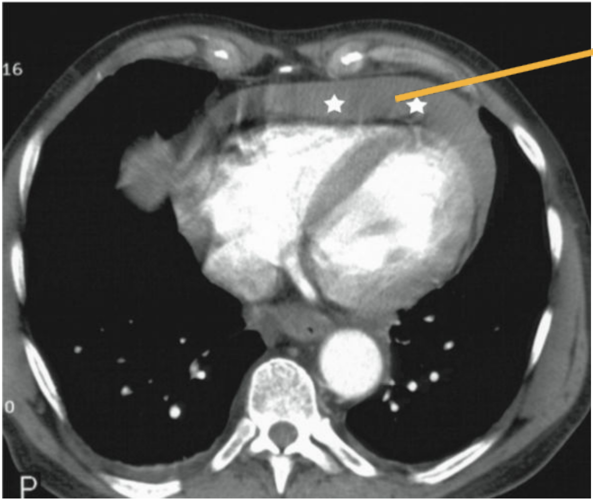
2D manual measurement of tumor size (short and long axis of tumor)

CT Imaging Example: Lung



(A) Normal (B) Emphysema (C) Ground Glass Opacity
(D) Fibrosis (E) Micronodules (F) Consolidation

CT Imaging Example: Cardiac



Fluid

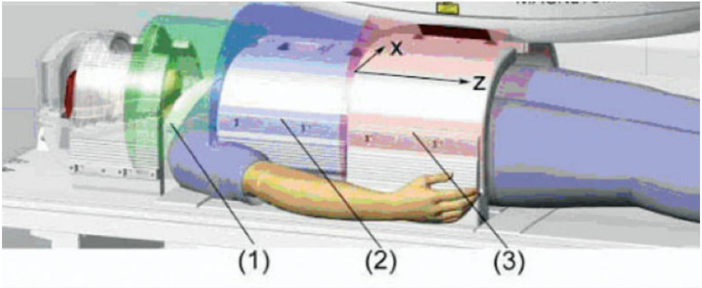
how to calculate the amount of fluid?

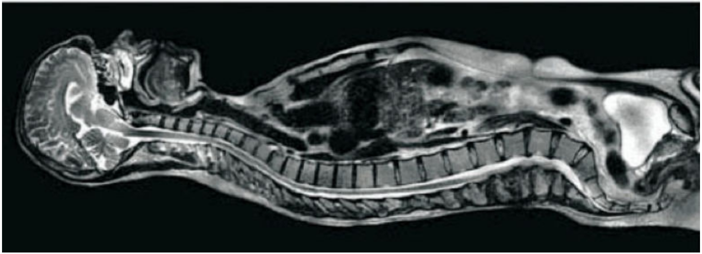
Magnetic Resonance Imaging (MRI)

- 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.

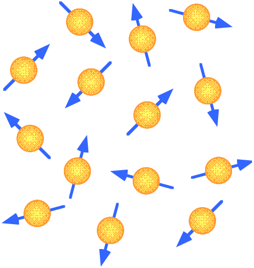
- CT is more widely used than MRI.
- MRI does not have ionizing-radiation.
- MRI has excellent soft tissue contrast, while CT is preferred for lung and bone imaging.
- CT is fast (few seconds), while MRI is slow (sparse MRI ~5-10 mins, abdomen or brain may take 30-40 mins).

MRI Basics

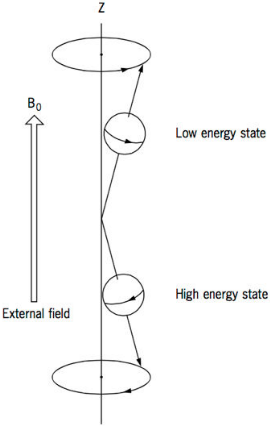


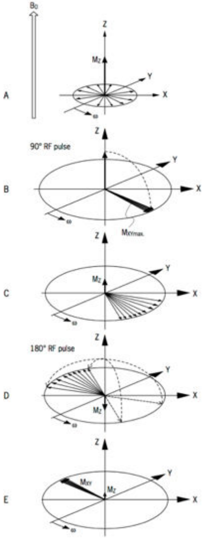


MRI Basics

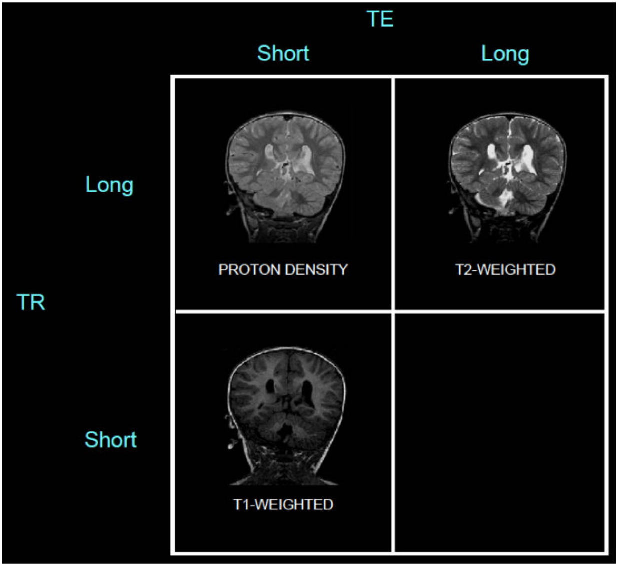


No magnetization

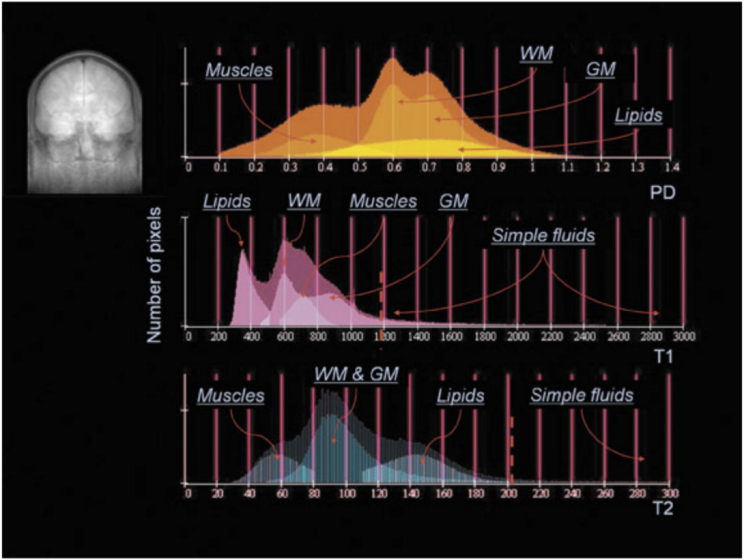




Types of MRI

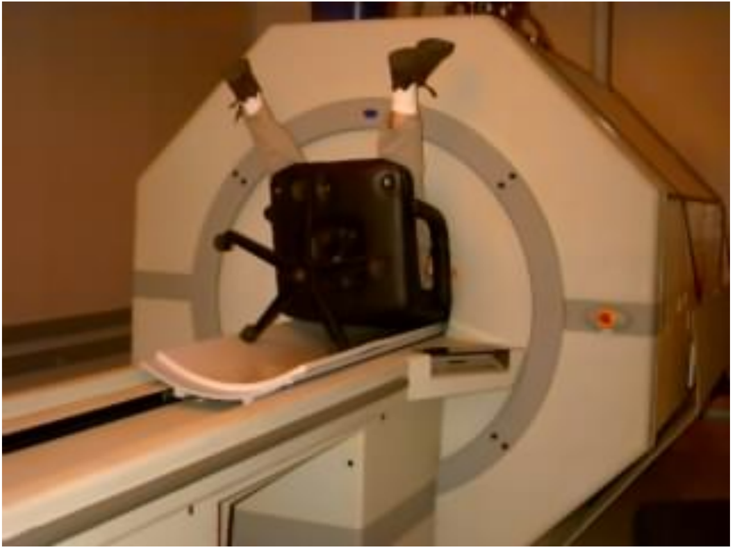

TE
Short
Long
TR
Long
Short
PROTON DENSITY
T2-WEIGHTED
T1-WEIGHTED

Brain MRI

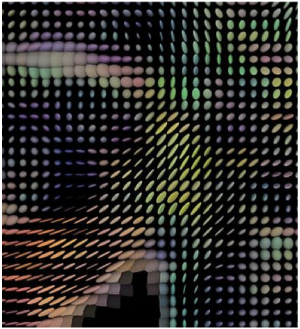


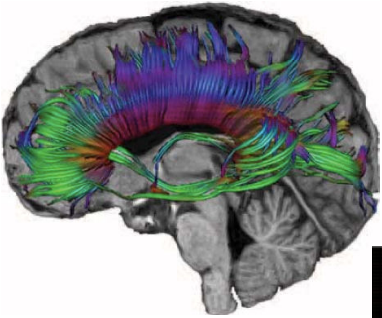
Muscles
WM
GM
Lipids
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4
PD
Lipids
WM
Muscles
GM
Simple fluids
Number of pixels
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000
T1
WM & GM
Muscles
Lipids
Simple fluids
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
T2

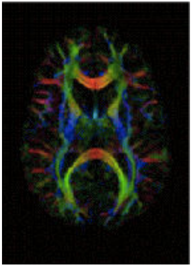
Safety in MRI



Diffusion Tensor Imaging

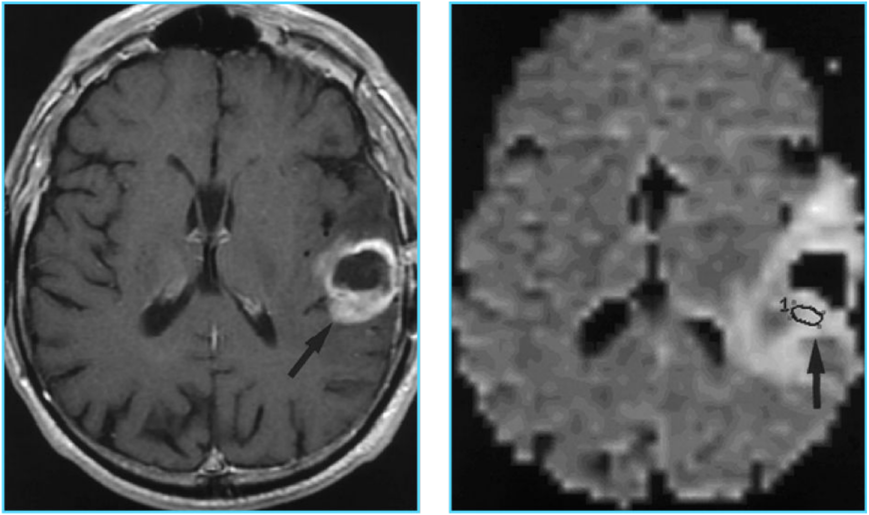






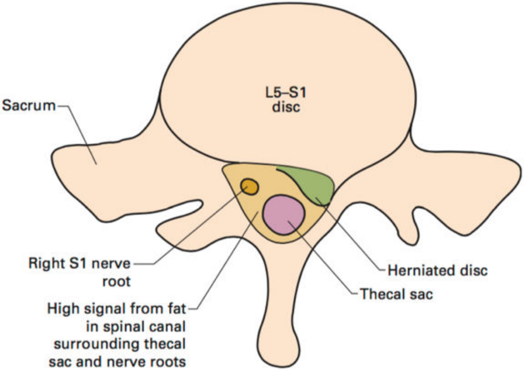
- measures random Brownian motion of water molecules.
- useful for tumor characterization (densely cellular tissues exhibit lower diffusion).

Diffusion Weighted Imaging (DWI)



Glioblastoma Tumor

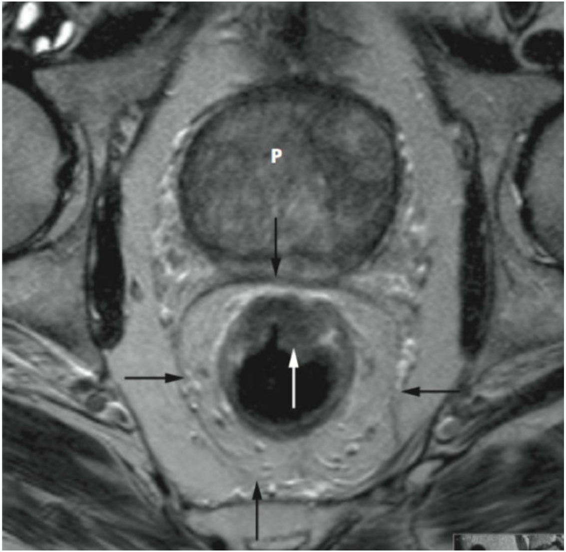
Clinical Use: Example



Clinical Use: Example

Myocardial Infarction Detection

Clinical Use: Example



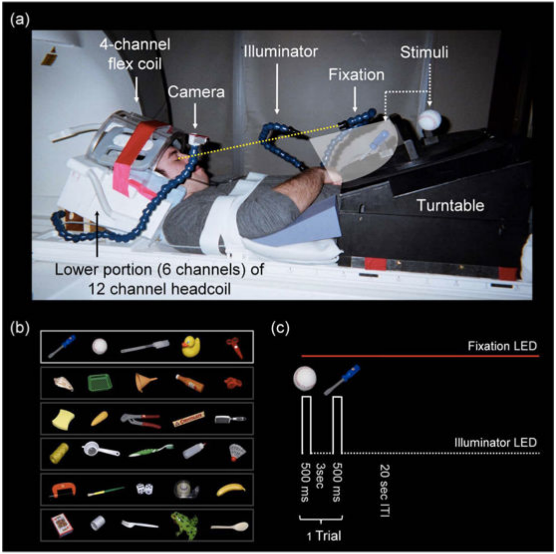
rectal tumor

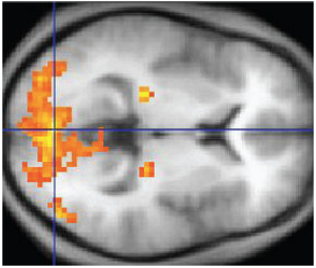
Functional MRI (fMRI)

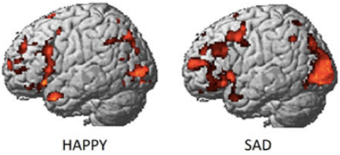
- measures brain activity through oxygen concentration in the blood flow.
- relies on the fact that cerebral blood flow and neuronal activation are coupled.
- when area of the brain is active (in use), blood flow to that area also increases.

- which part/location of the brain is activated when reading?
- which part/location of the brain is activated when listening music?
- which part/location of the brain is activated when searching puzzle?

fMRI Settings



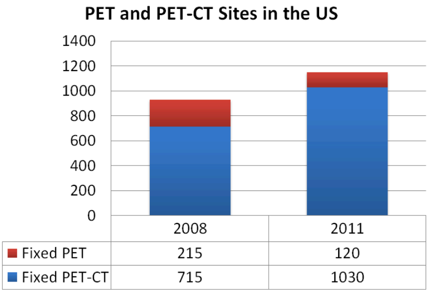




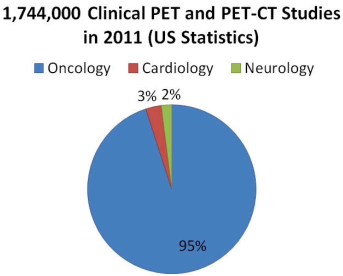
Active Regions

Nuclear Medicine Imaging – PET/SPECT

- Scint: Scintigraphy, two-dimensional images
- PET: Positron Emission Tomography
- SPECT: Single Photon Emission Tomography

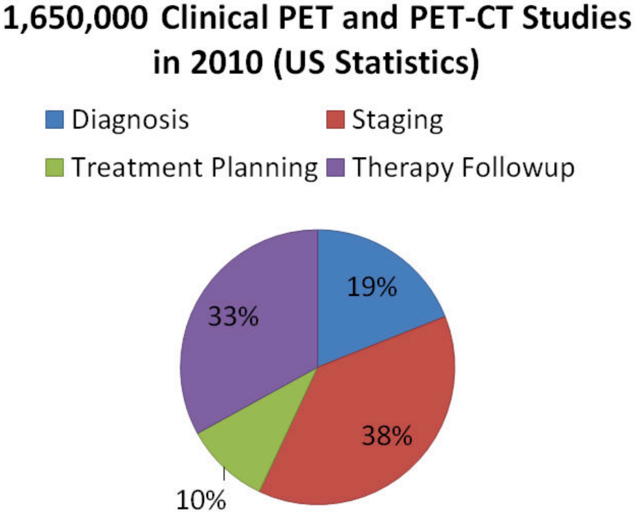


(a)



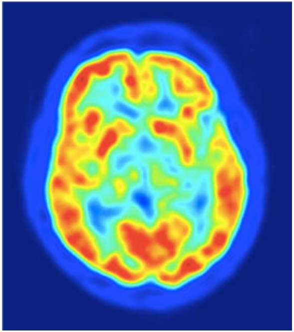
(b)

Nuclear Medicine Imaging – PET/SPECT



Basics of PET Imaging

- uses short-lived positron emitting isotopes (produced by collimators)
- two gamma rays are produced from the annihilation of each positron and can be detected by specialized gamma cameras
- resulting image show the distribution of isotopes
- an agent is used to bind into isotopes (glucose, …)



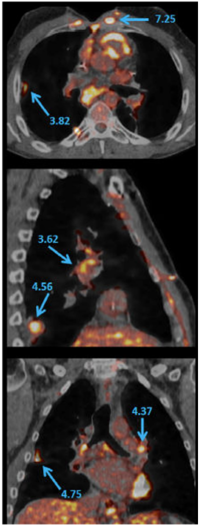
Late 1950s, David L. Kuhl
concept of emission and transmission

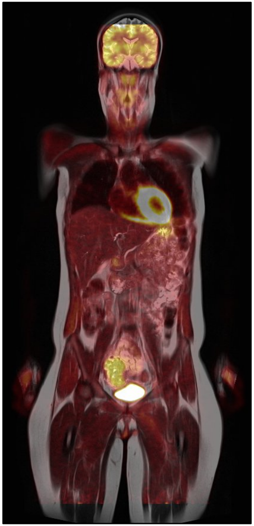
molecular activity is measured.

PET/CT and MRI/PET (Hybrid Imaging)

PET/CT

-choice of modality for oncological applications(yet)





MRI/PET

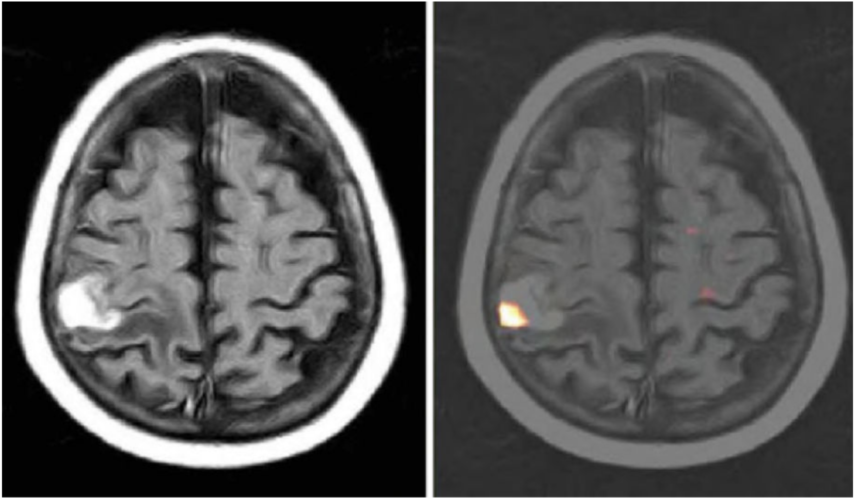
-superior soft tissue contrast resolution

-minimized radiation

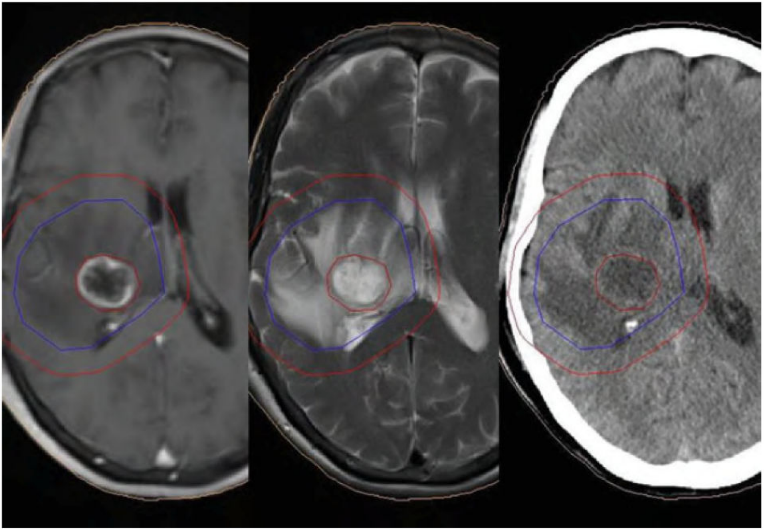
What to Measure in PET?

- SUV (standardized uptake value: voxel-wise or region-wise) (SUVpeak, SUVmax, SUVlbm)
- Metabolic lesion/tumor volume (MTV)
- Shape information of (functional) lesion (spiculated vs focal)
- Texture information of lesion (heterogeneous vs homogeneous)
- Number and distribution of the lesions (focal, multi-focal)

Clinical Use of PET: Example



Clinical Use of PET: Example



Serial and Simultaneous MRI/PET

Past

Now!

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