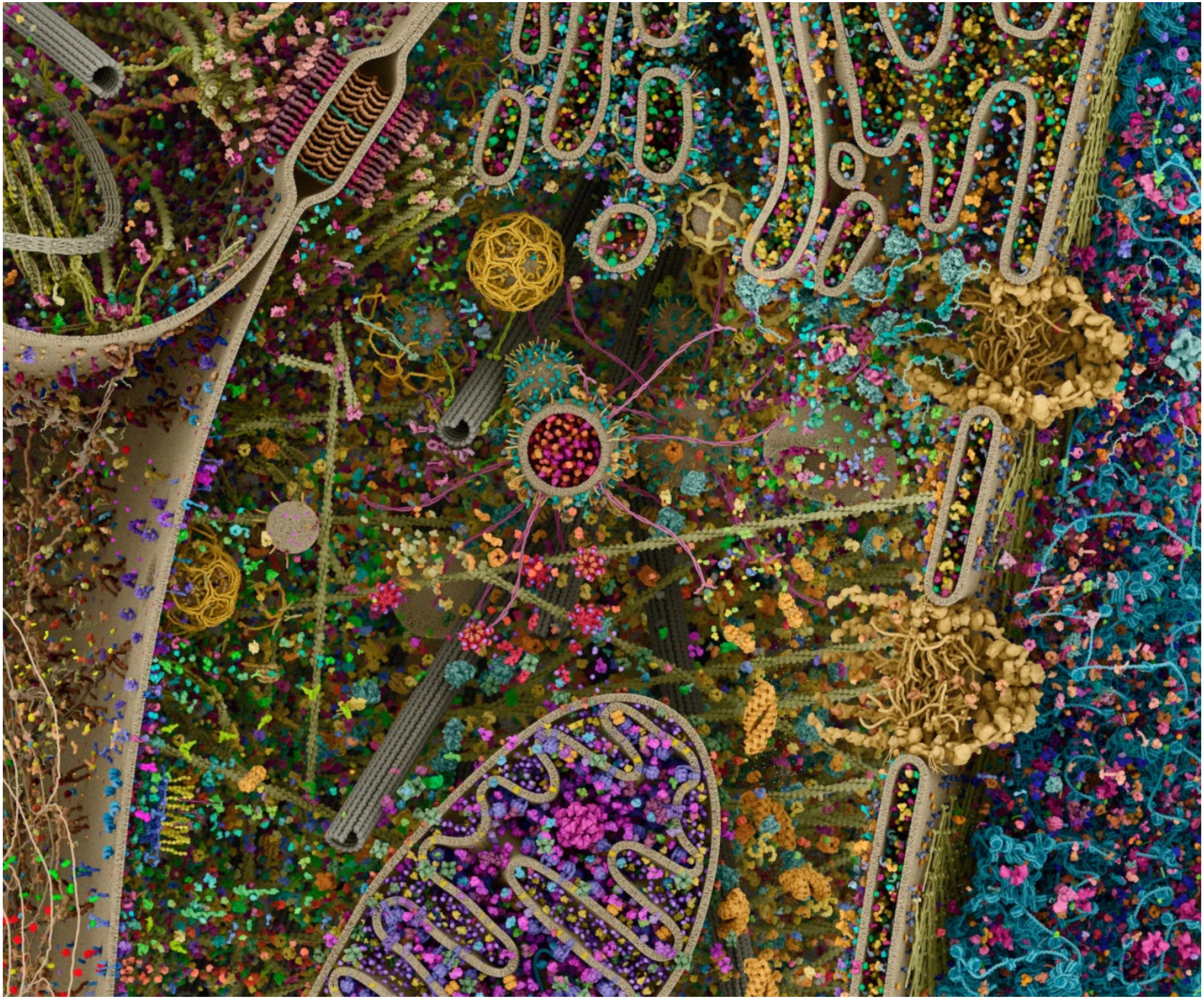
Medical Image Computing
Lecture 2



DICOM (the mostly used)

Digital Imaging and Communications in Medicine standard

- Since its first publication in 1993, DICOM has revolutionized the practice of radiology, allowing the replacement of X-ray film with a fully digital workflow.

- It is the international standard for medical images and related information (ISO 12052)

- Defines the formats for medical images that can be exchanged with the data and quality necessary for clinical use.

- It is implemented in almost every radiology, cardiology imaging, and radiotherapy device (X-ray, CT, MRI, ultrasound, etc.), and increasingly in devices in other medical domains such as ophthalmology and dentistry.

Free Software to use

- ImageJ (and/or FIJI)
- ITK-Snap
- SimpleITK
- MITK
- FreeSurfer
- SLICER
- OsiriX
- An extensive list of software: www.idoimaging.com

Digital Image and Medical Image Modalities

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

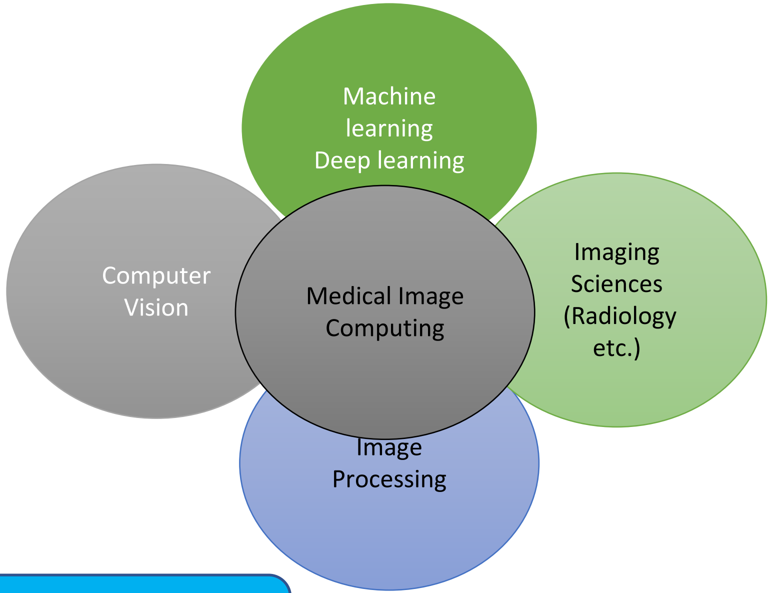


Image Quality Improvement

Tissue/cells etc Classification

Semantic description/understanding

Medical Imaging Analysis

- 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,…), 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 MRI 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 pixels 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 Imaging Analysis- Automated

- 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

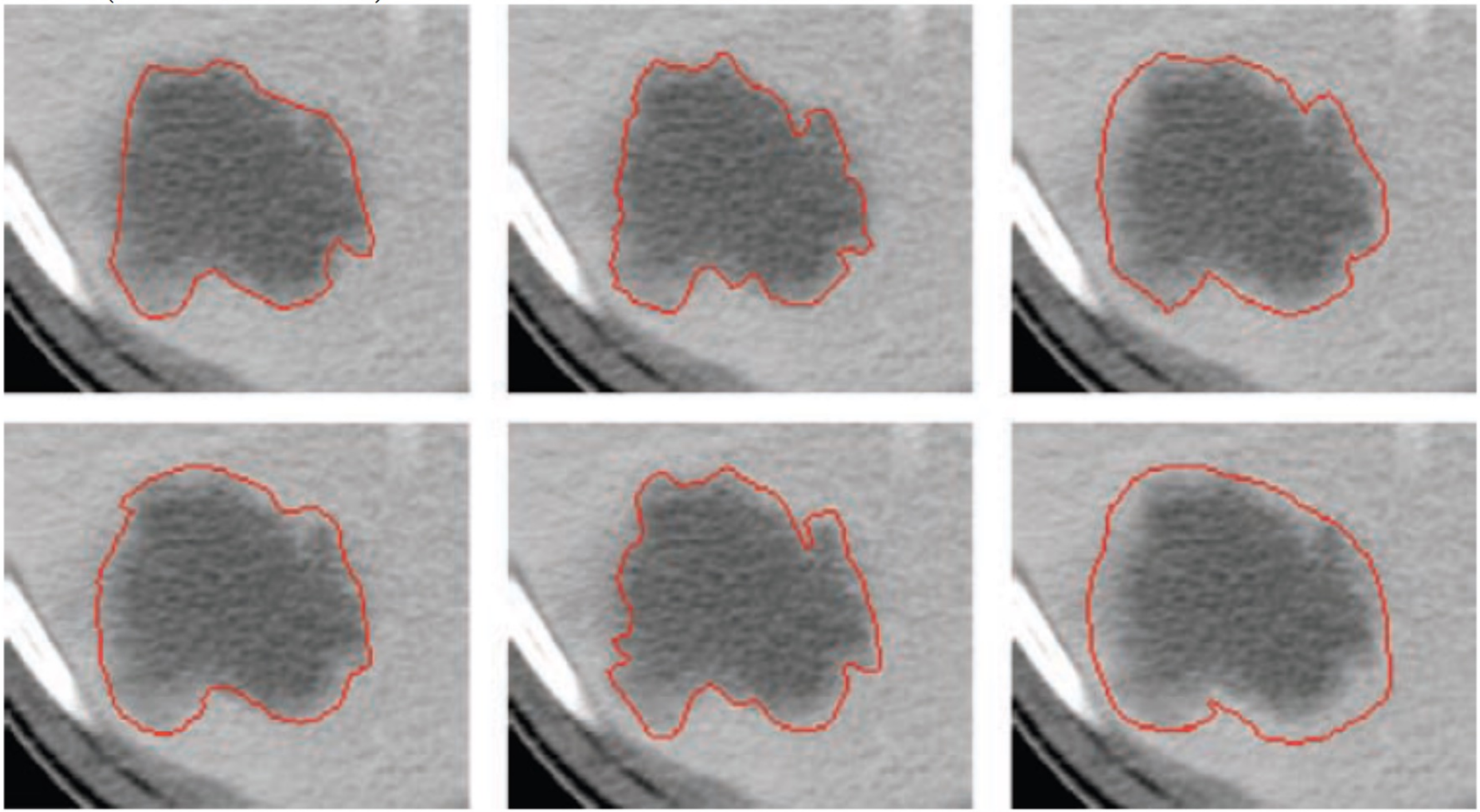
Medical Imaging Analysis- Manual

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

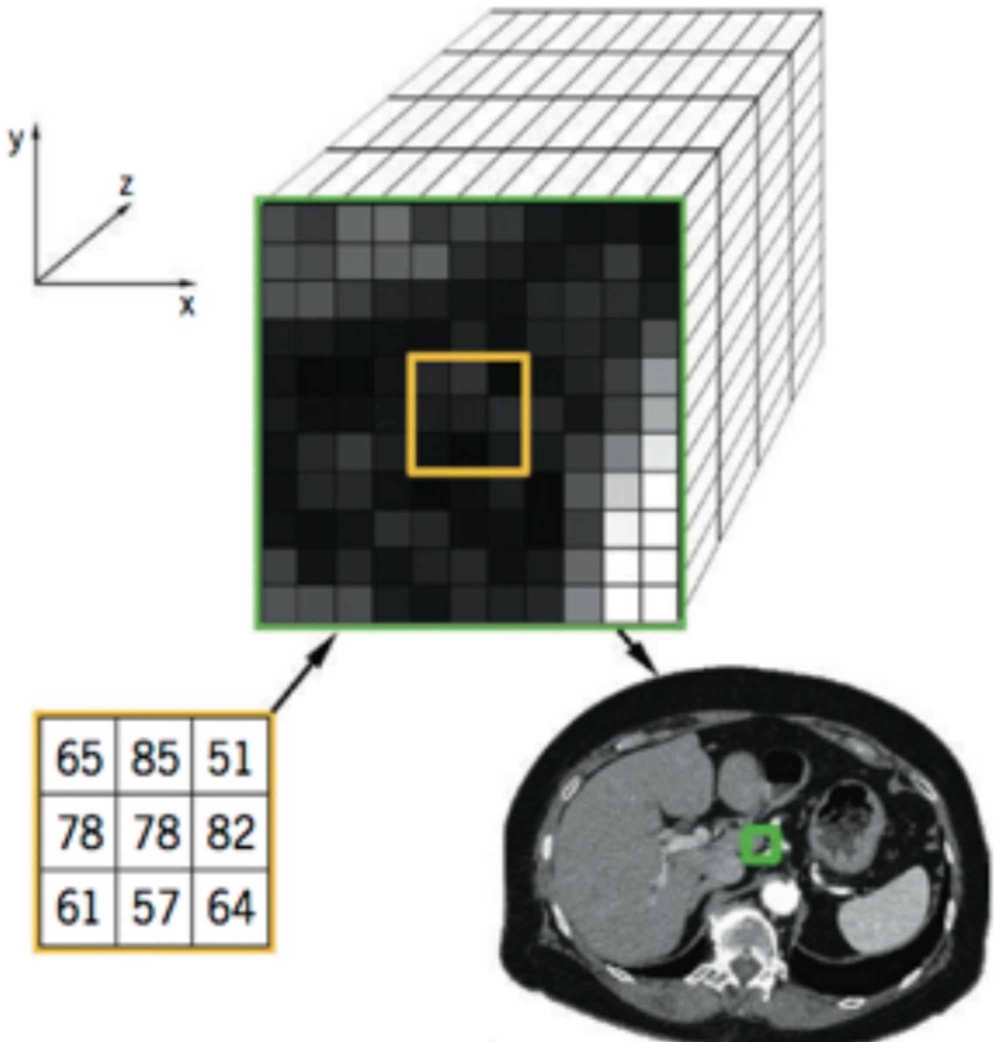
- The reason is that both the medical image data and the model or prototype (i.e., the a priori description of the features to be analyzed), are typically quite complex.

Observer Variability – Example: Liver lesion

Intra- (one week interval)



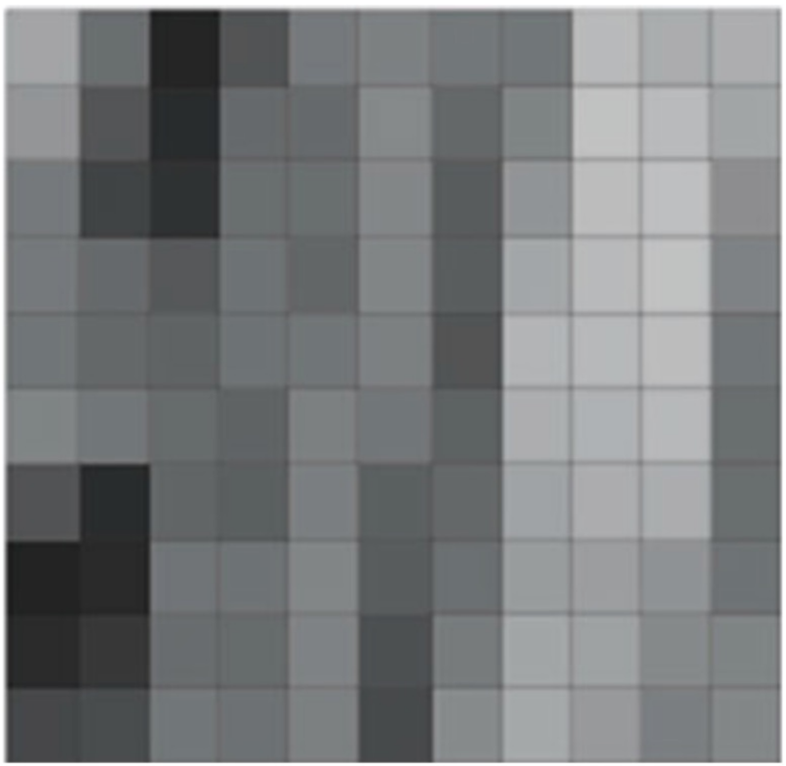
Digital Images

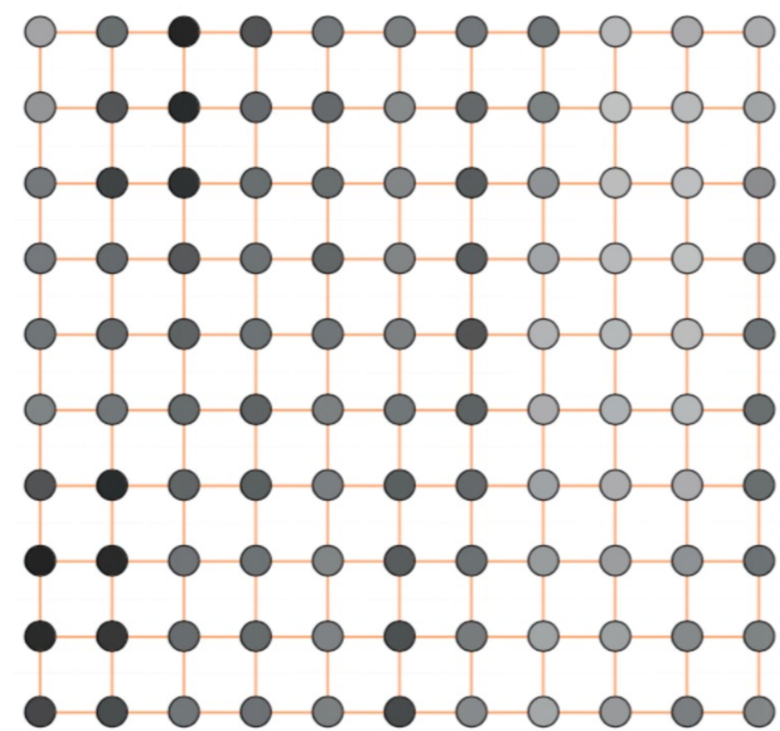


0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

What computer sees!

Picture Elements (Pixels), Volume Elements (Voxels)





Digital Images

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

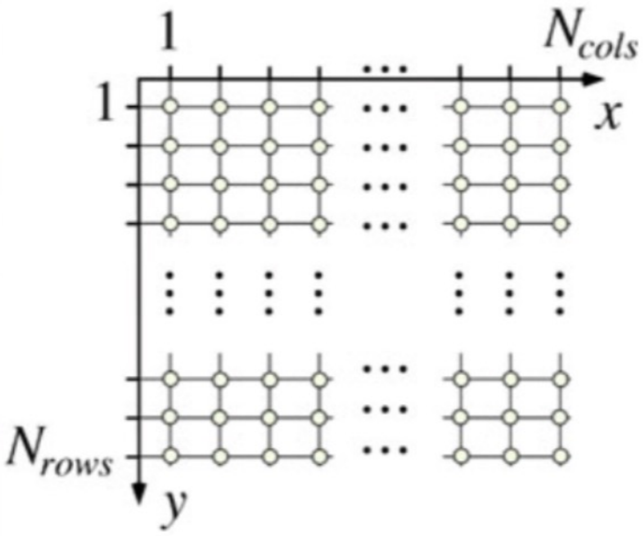


Image Types

Gray Scale Image

- A scalar image has integer values
- Ex. If 8 bit (a=8), image spans from 0 (black) to 255 (white)
- Ex. If 1 bit (a=1), it is binary image, 0 and 1 only.

Color Image

- Image has three channels (bands), each channel spans 8-bit value
- RGB

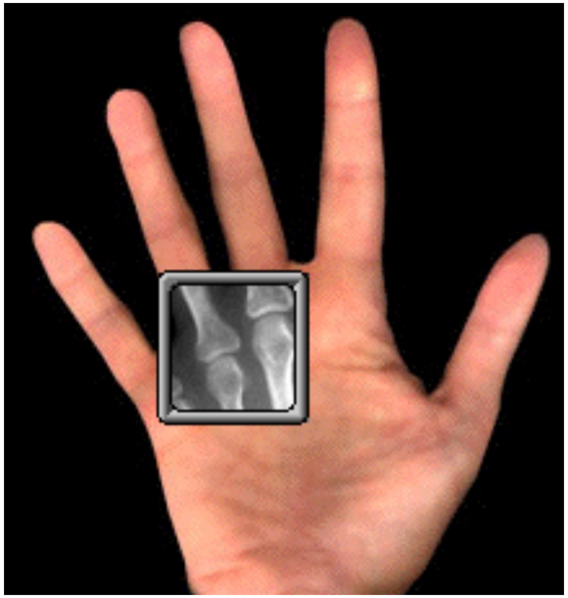
Introduction to Imaging Modalities

Medical image

- Medical imaging began with the discovery of X-Rays by Wilhelm Conrad Röntgen in 1895 and his work showing that these rays could be used to peer inside the body and visualize bony structures.

- From this Nobel Prize winning discovery to the modern day, there are now many means by which the internal structures of the body can be assessed without the need for cutting it open

- Röntgen discovered a new type of radiation in 1895 that would be subsequently named after him, but he always preferred the term X-rays – from the mathematical designation for something unknown – as no one understood what these remarkable rays actually were.



Radiographic Imaging

- Radiography is the art and science of using radiation to provide images of the tissues, organs, bones, and vessels that comprise the human body.

- Applications of radiography include medical radiography ("diagnostic" and "therapeutic" (treatment)) and industrial radiography. Similar techniques are used in airport security ("body scanners").

- To create an image in conventional radiography, a beam of X-rays is produced by an X-ray generator and is projected toward the object. A certain amount of the X-rays or other radiation is absorbed by the object, dependent on the object's density and structural composition. The X-rays that pass through the object are captured behind the object by a detector (either photographic film or a digital detector).

Radiographic Imaging

- In the human body, bones block x-rays very well, while skin and muscle block them less. Parts of the body that contain air, like lungs, block x-rays even less. The amount of blocking, or *attenuation*, of the x-ray beam is related to density. Generally, the more dense an object, the better it blocks the x-ray beam.

- When an X-ray beam passes through a person, we can collect the energy on the other side to see what body parts blocked the beam. Just like the first visible light cameras used film to capture an image, the first x-ray cameras did, too.

- When the X-ray beam hit the film, it changed the color of the film, and that allowed the x-ray to be turned into a picture that could be seen with the eye.

Radiographic Imaging

It can be broadly classified into two categories

- Projection Radiography

- Computed Tomography

Radiographic Imaging

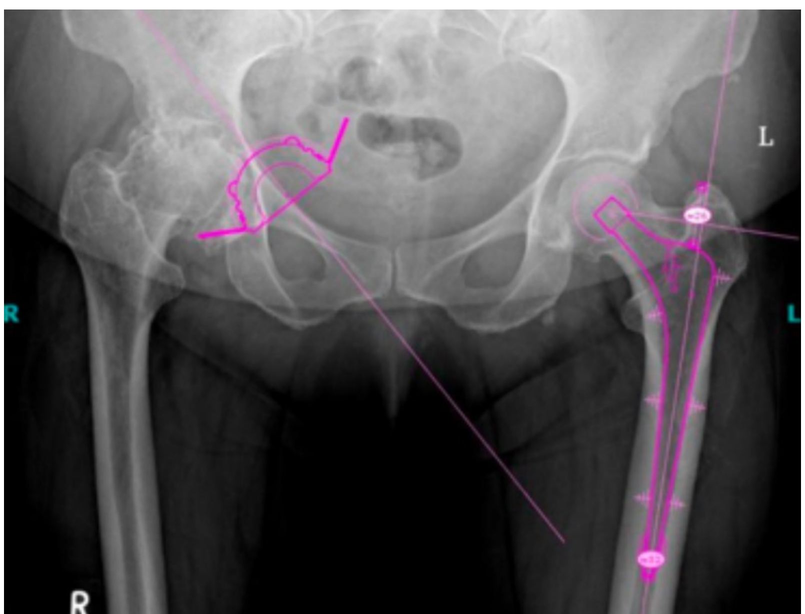
Projection Radiography:

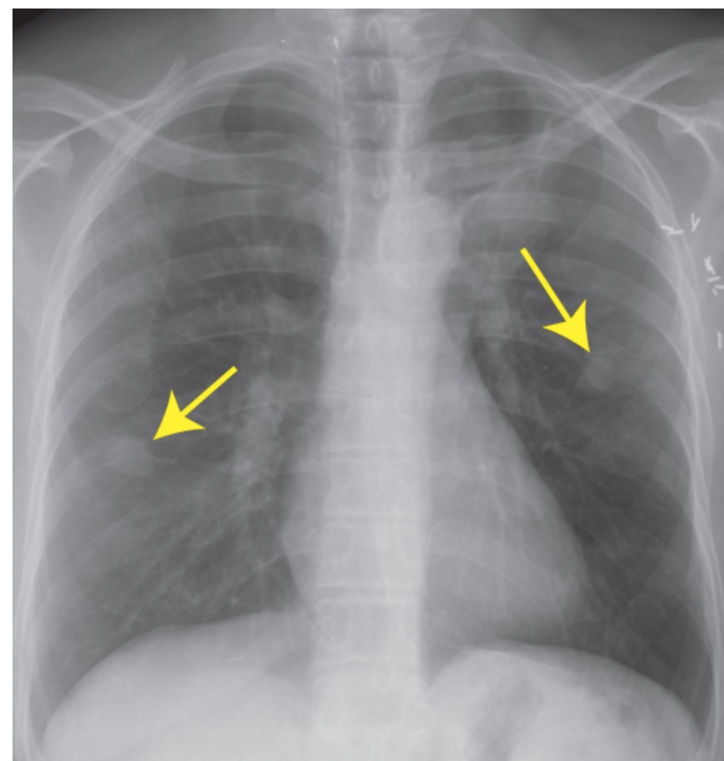
- Projection of a 3D object or signal onto a 2D image
- The generation of flat <u>two dimensional</u> images by this technique is called <u>projectional radiography</u>.

- Routine Diagnostic Radiography (x-rays, fluoroscopy etc.)
- Digital Radiography
- Angiography
- Neuroradiology
- Mobile X-ray systems
- Mammography

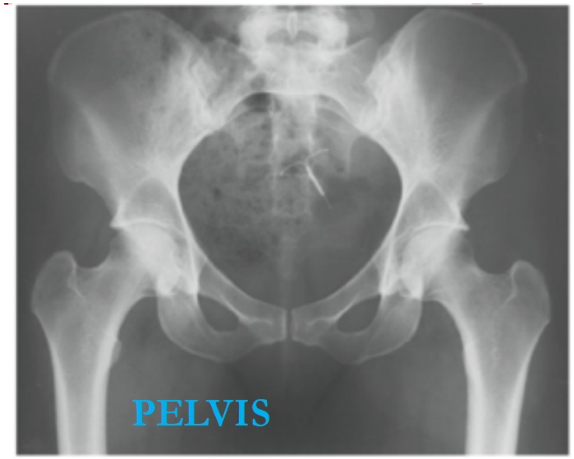
Basics Use of X-Rays

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



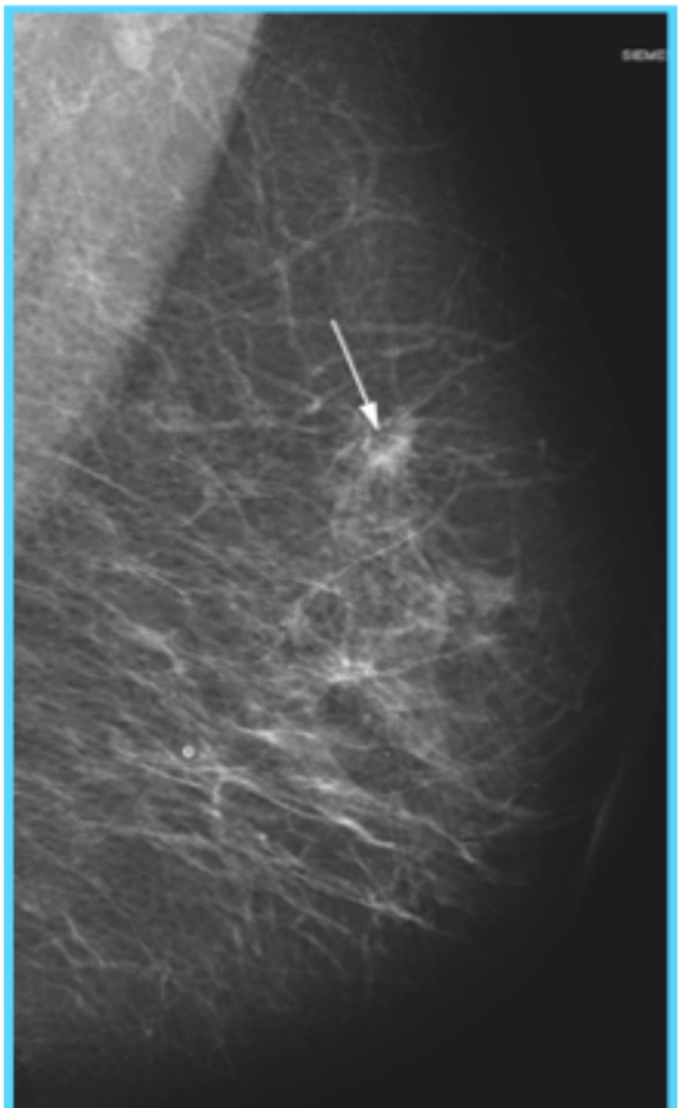


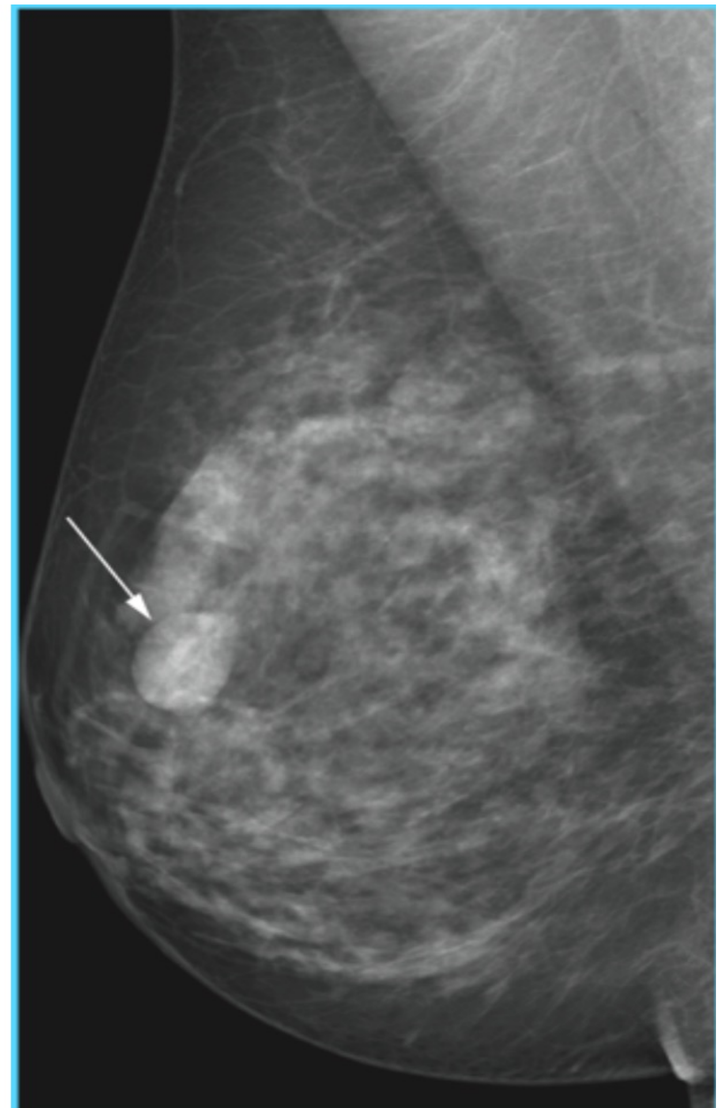
Clinical Examples- X-rays



Clinical Examples- X-rays

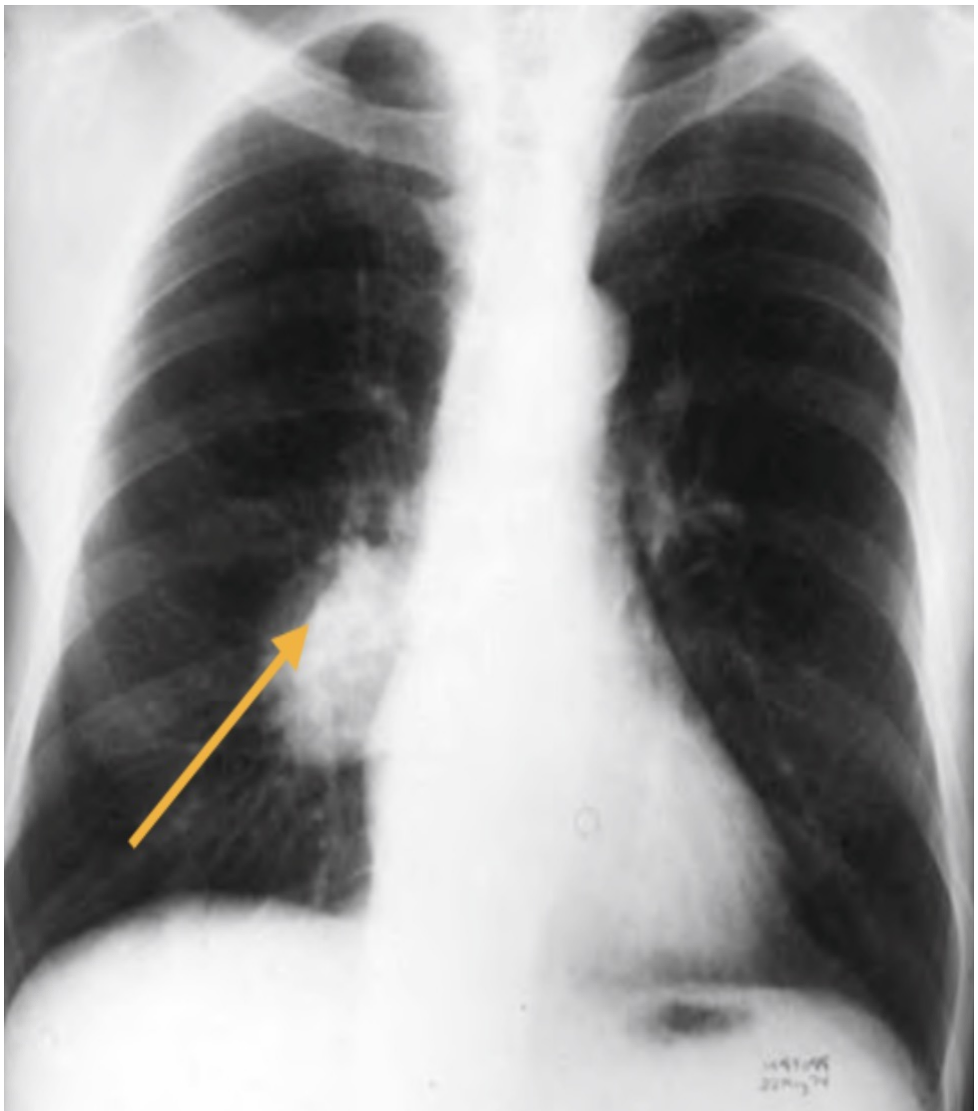
Benign





Malignant

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

Radiographic Imaging

Computed Tomography:

- Provides "slice-wise" 3D information.

- In computed tomography (CT scanning) an X-ray source and its associated detectors rotate around the subject which itself moves through the conical X-ray beam produced. Any given point within the subject is crossed from many directions by many different beams at different times. Information regarding attenuation of these beams is collated and subjected to computation to generate two dimensional images in three planes (axial, coronal, and sagittal) which can be further processed to produce a three dimensional image.

Ultrasound Imaging

- It uses electrical-to-acoustical transducers to generate repetitive bursts of high-frequency sound.
- These pulses travel into the soft tissue of the body and reflect back to the transducer.
- The time-of-return of these pulses and intensity of these pulses is used to infer location and strength of the reflector.

How Ultrasound Works

Ultrasound Imaging

- Non-invasive
- Safe (under regulations)
- Real-time
- Reflection mode (similar to RADAR)
- Blood flow imaging
- Access
- Portable
- Body type dependent

Not Good

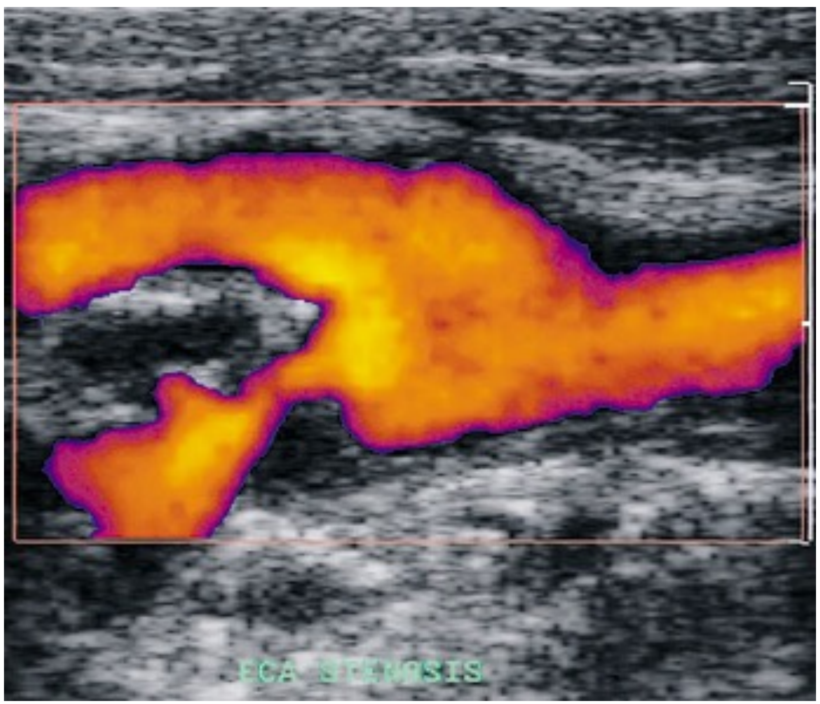
Ultrasound waves are disrupted by air or gas. Therefore, ultrasound is not an ideal imaging technique for the air-filled organs.

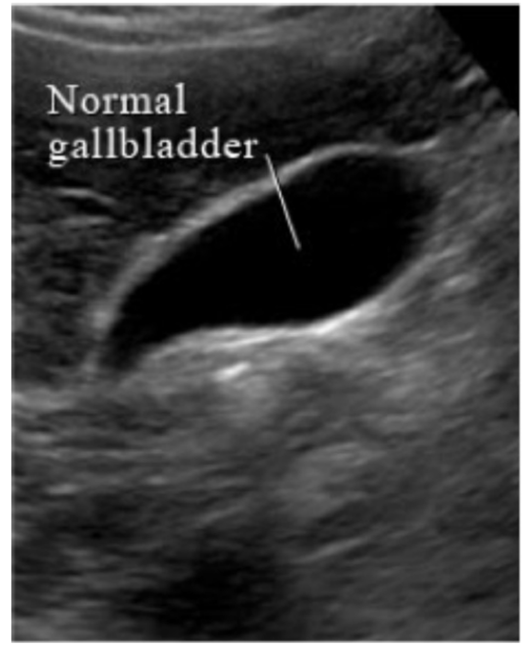
Ultrasound is not as useful for **imaging air-filled lungs**, but it may be used to detect fluid around or within the lungs.

Disadvantages of ultrasonography include the fact this imaging modality is operator and patient dependent

Clinical Use of US Imaging

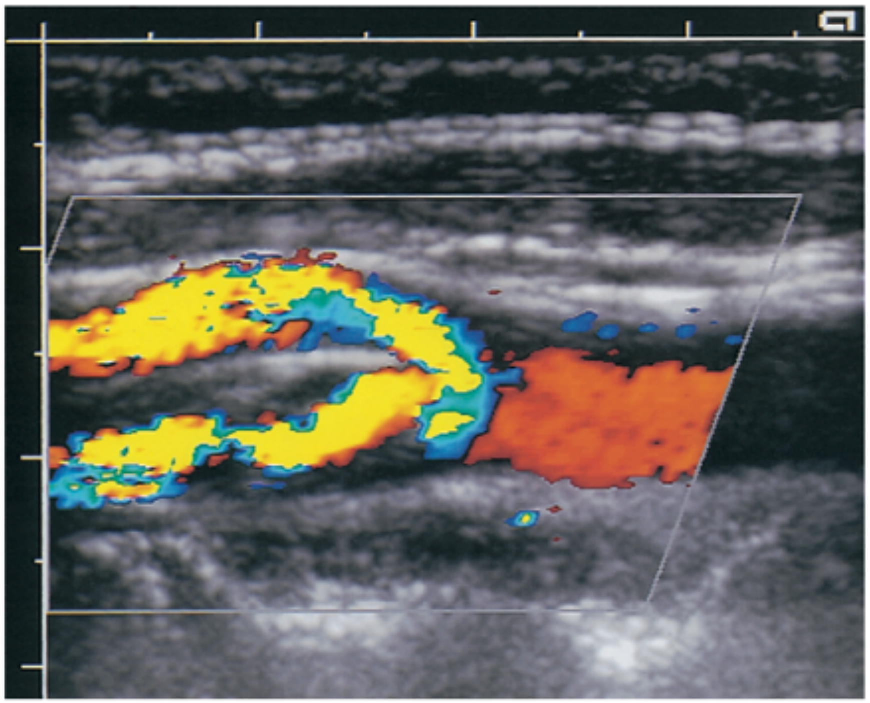
Ultrasound Imaging

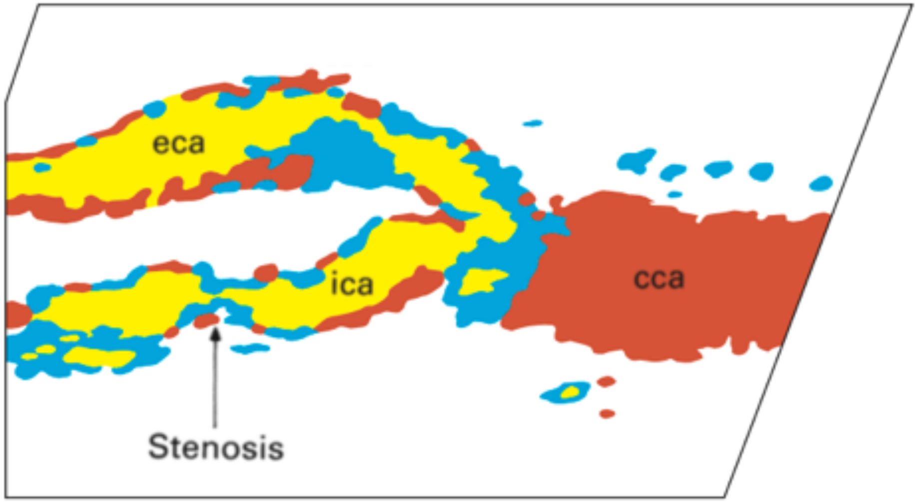




Colour flow mapping shows simultaneous amplitude (US) and velocity information (doppler)

Clinical Use of US Imaging

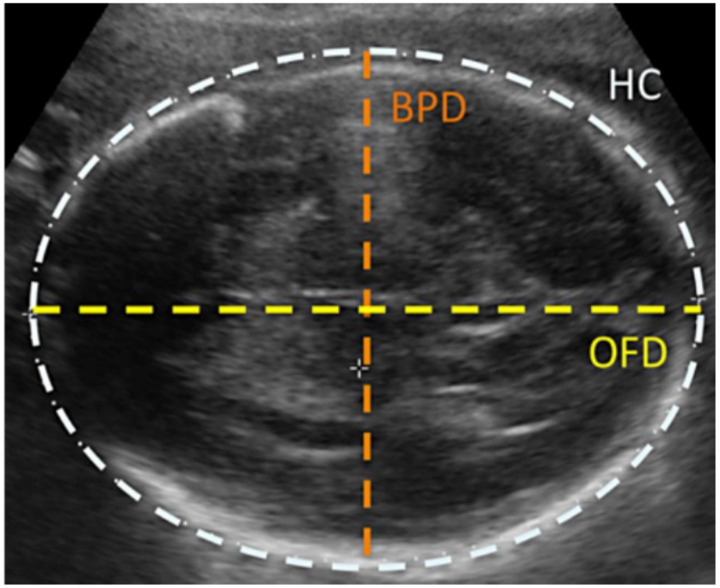


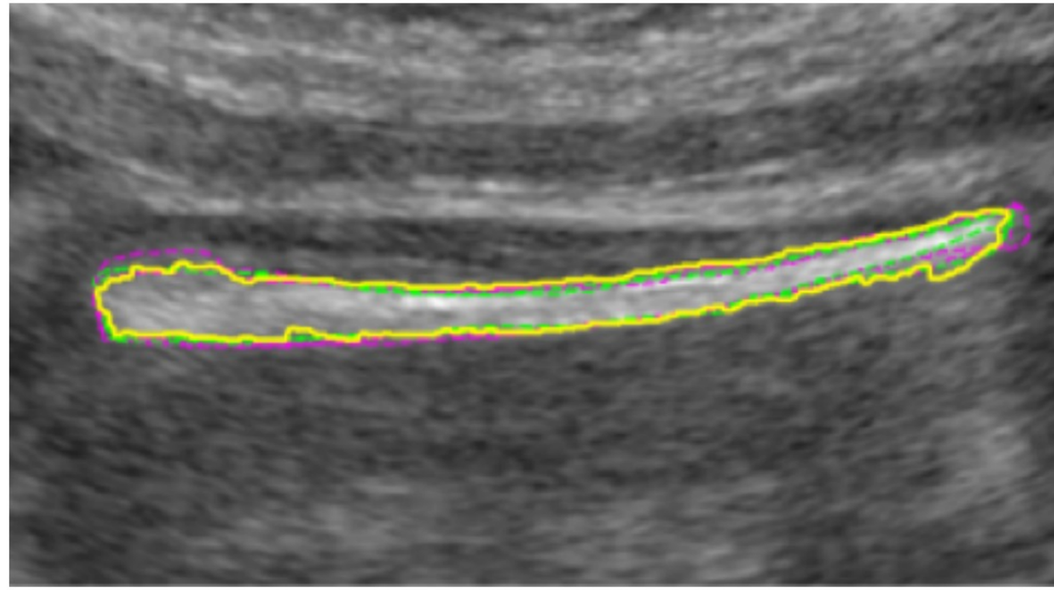


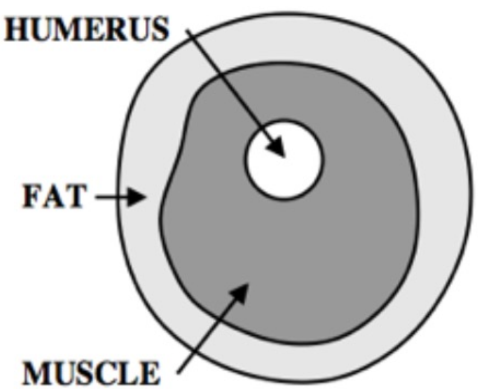
manual measurements?
can computer help calculating
all blood flow and identify
automatically the abnormal regions?

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

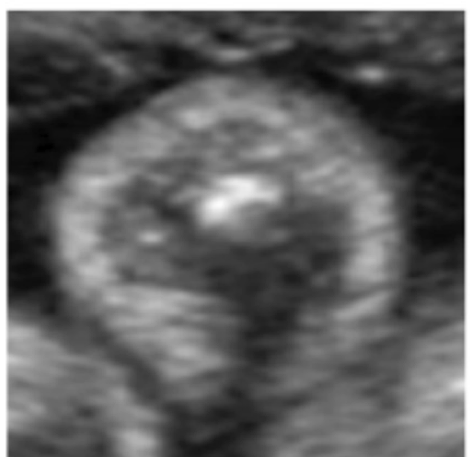
Clinical Use of US Imaging







(a) Arm Composition



(b) Original Image

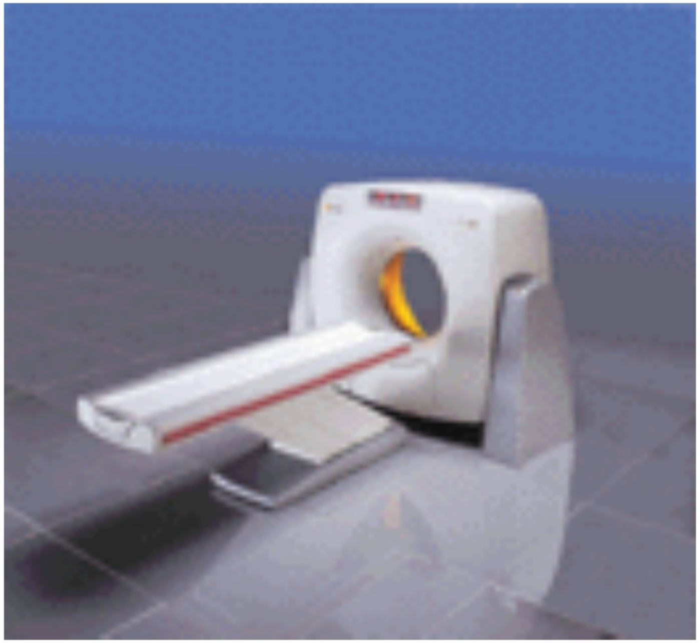
Bone, fat, and physical length
Measurements –unborn babies
(Image Credit: S. Rueda, Oxford Univ.)

Computed Tomography (CT)

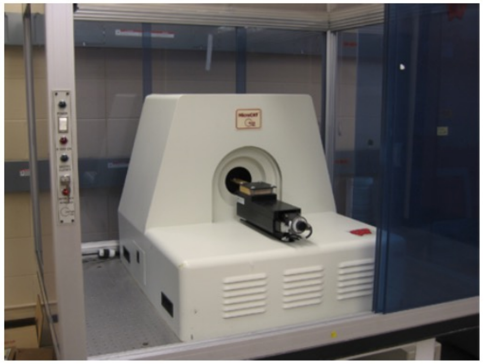
Tomo: slice/level (Greek)
Graphe: draw

CT Imaging (continue)

C-arm



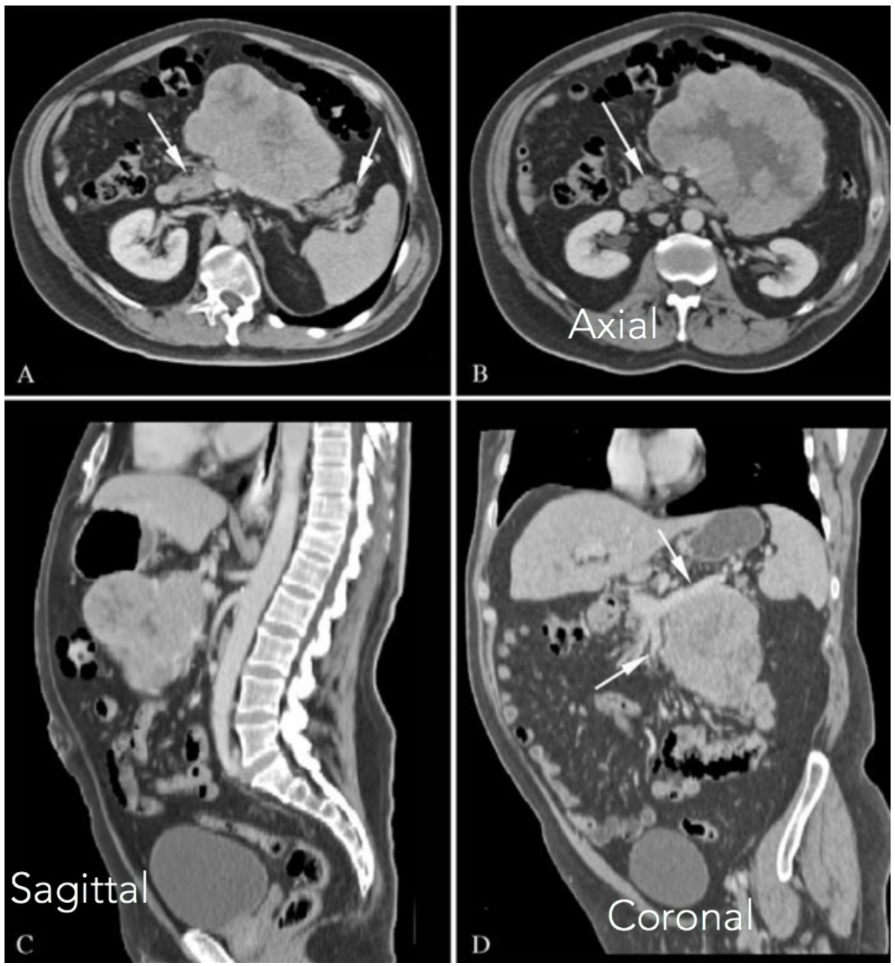
CT

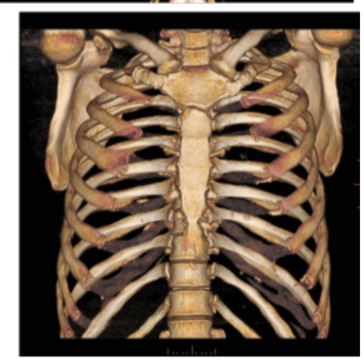


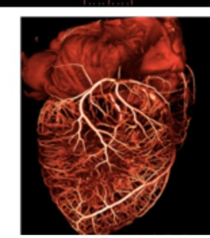
Micro-CT

~CAT Scan (computerized Axial tomography)

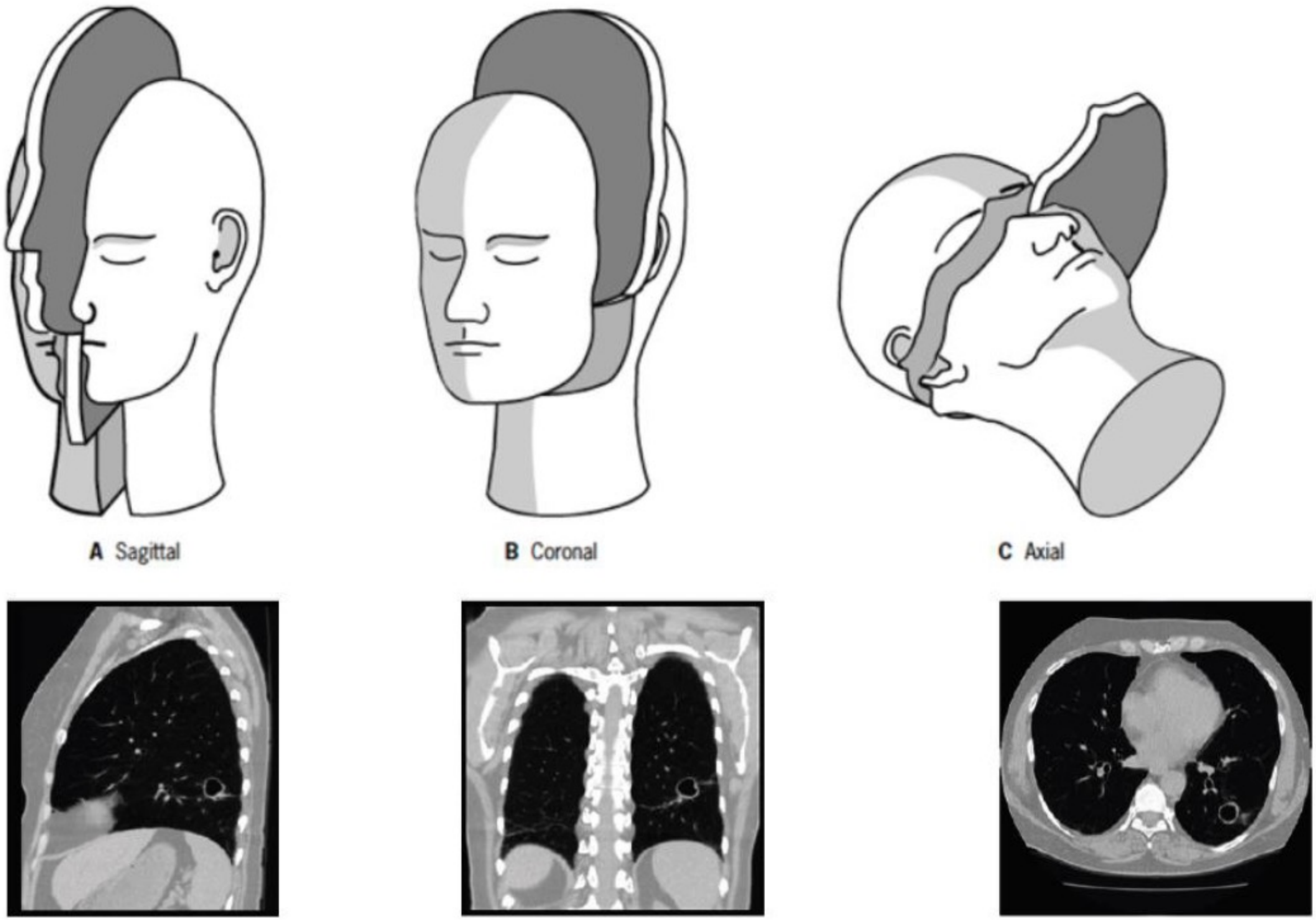
3D Nature of CT

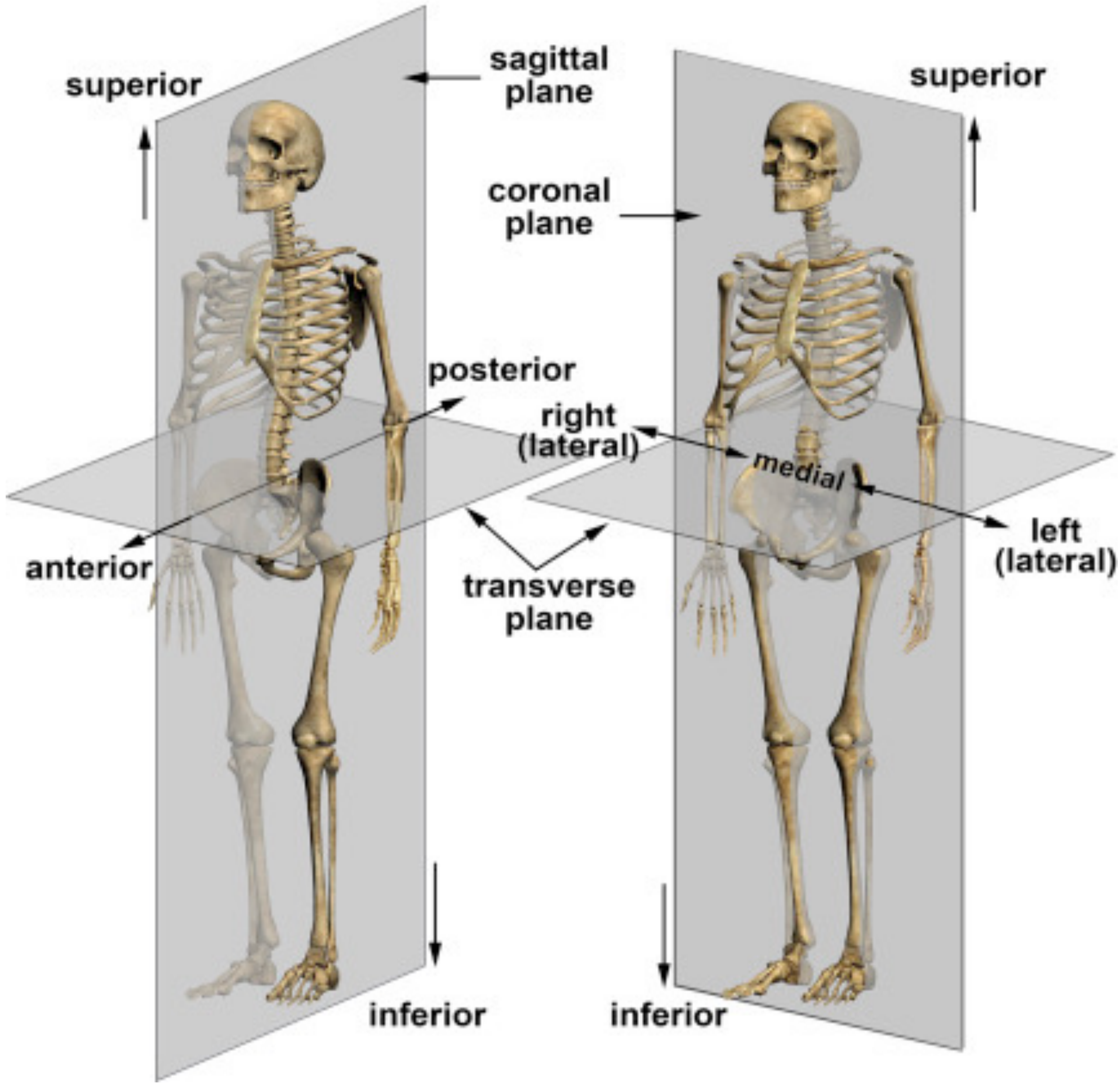






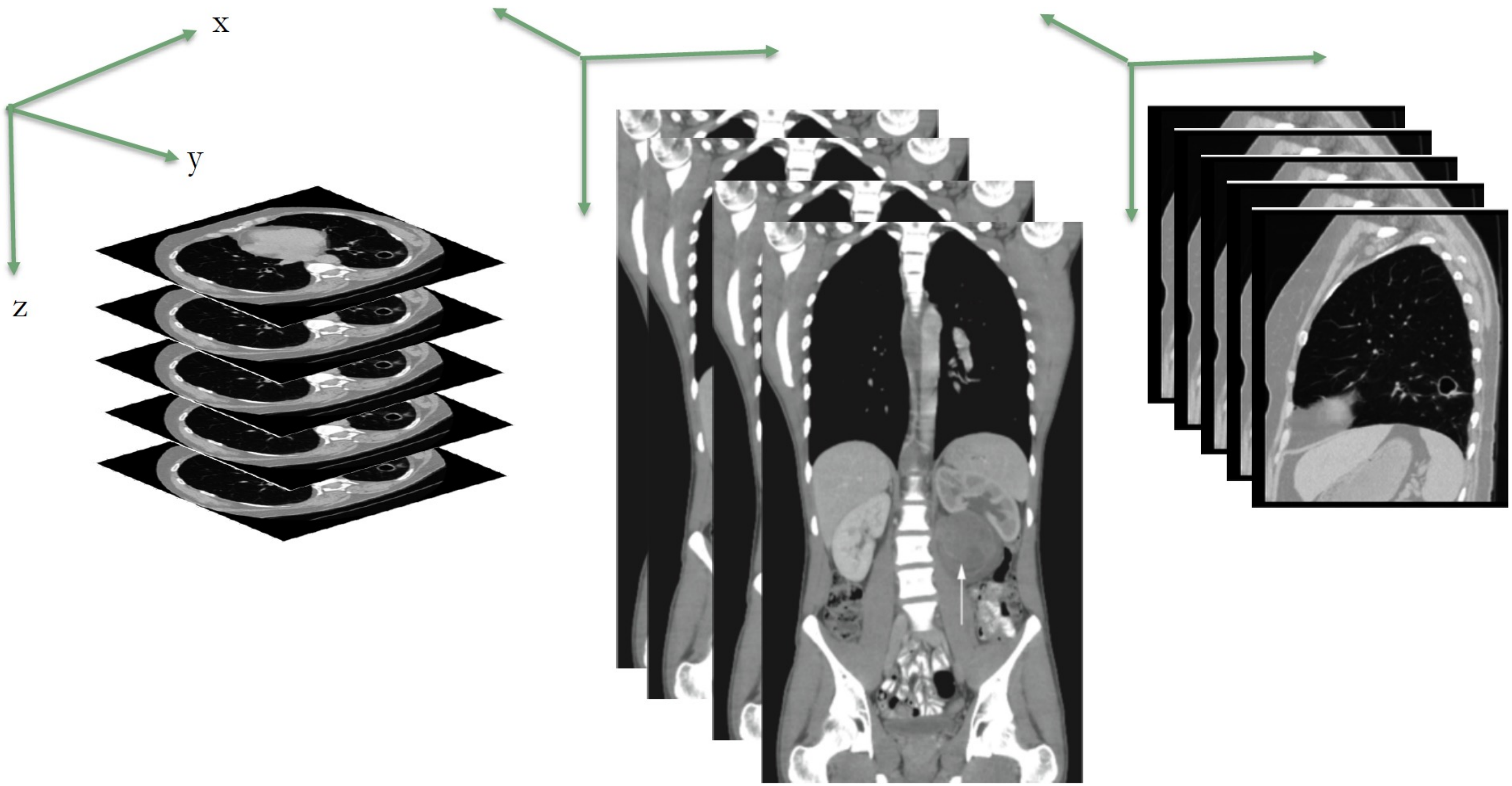
Remark: 3D View Terminology





sagittal plane
superior
coronal plane
superior
posterior
right (lateral)
medial
left (lateral)
anterior
transverse plane
inferior
inferior

3D Images



I: Image

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

Note also that whatever you see on the left is right part of the body!

Clinical Use of CT Imaging

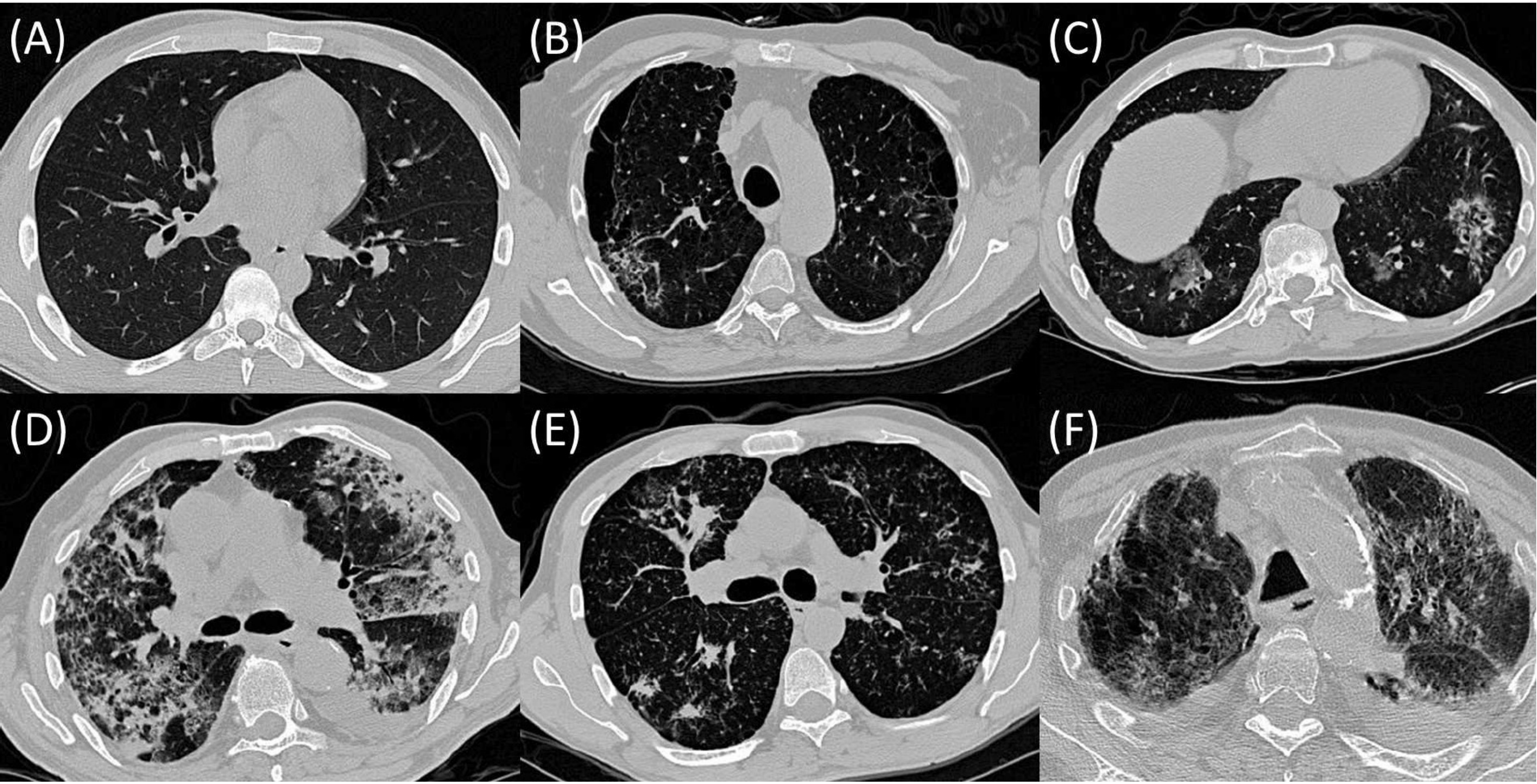
- Standard imaging technique in many organs, particularly gold standard for lung imaging
- Fast
- Radiation exposure
- Often used in surgery rooms
- Show anatomy and pathology
- Intensity values are (more-or-less) fixed, read as HU (Hounsfield Unit)

Anatomy is the branch of biology concerned with the study of the structure of organisms and their parts

Patholoyg medical specialties that diagnose disease, mostly through analysis of tissue, cell, and body fluid samples

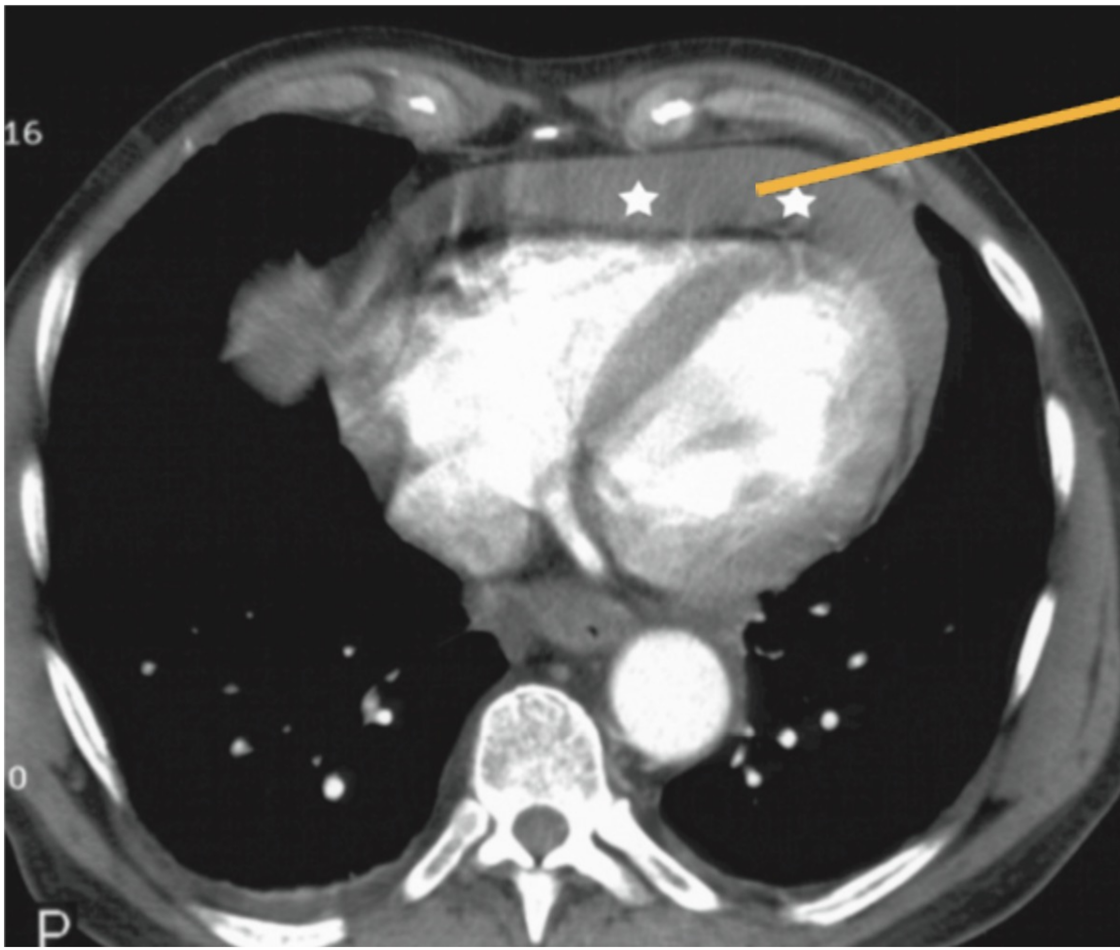
CT Imaging Example: Tumor

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?

MRI (Magnetic Resonance Imaging)

- Doctors order CT scans or MRI scans to help diagnose a wide range of medical conditions.

- Both types of scan have similar uses, but they produce images in different ways. A CT scan uses X-rays, whereas an MRI scan uses strong magnetic fields and radio waves.

- CT scans are more common and less expensive, but MRI scans produce more detailed images.

- CT scans are good to capture bone related details and MRI is good to capture soft tissues details

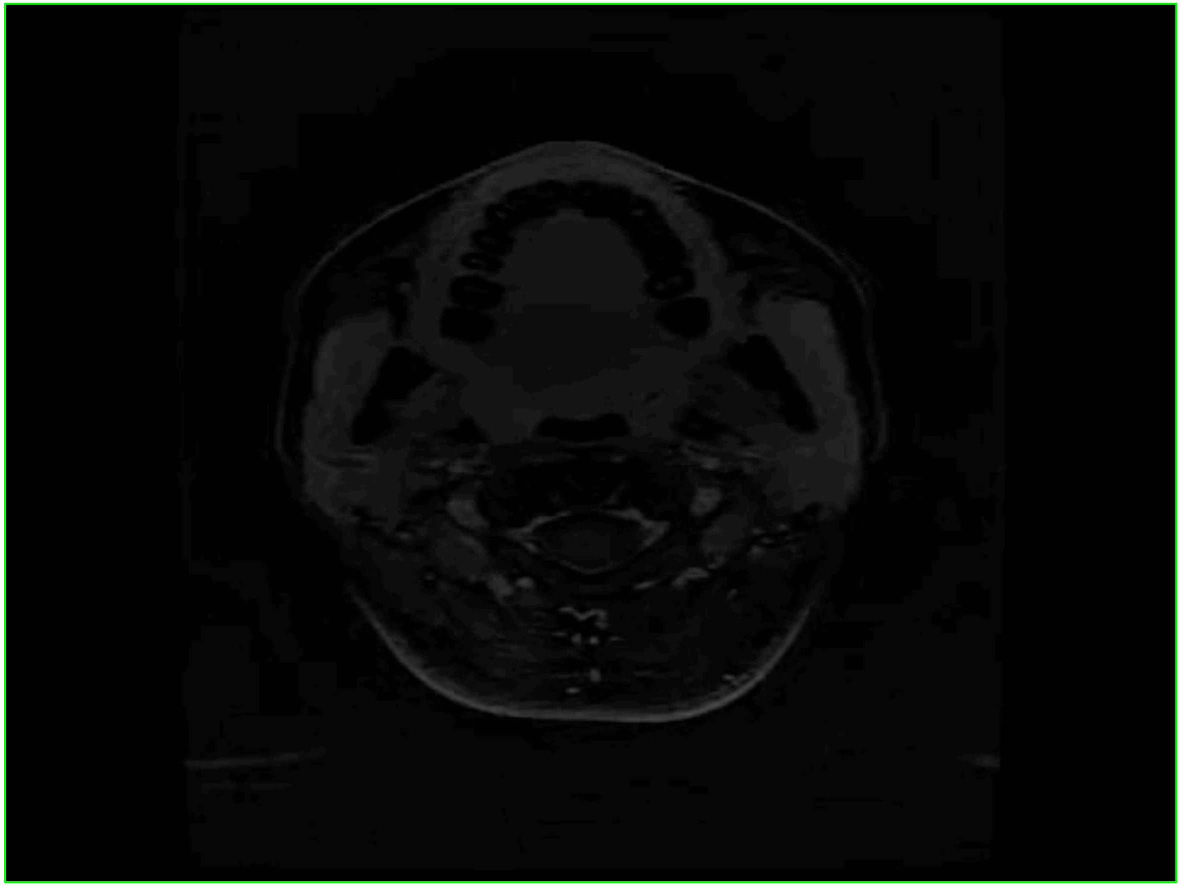
- CT scans use ionizing radiation, which has the potential to affect biological tissues. The risk of developing cancer from exposure to radiation is generally small.

- CT scans and X-ways may not be safe during pregnancy, so doctors might recommend MRI scans or ultrasound scans instead. However, they may still avoid using MRI scans, especially during the first trimester, as a precaution.

MRI (Magnetic Resonance Imaging)

- 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 (**M**agnetic **R**esonance **I**maging)



Functional MRI (fMRI)

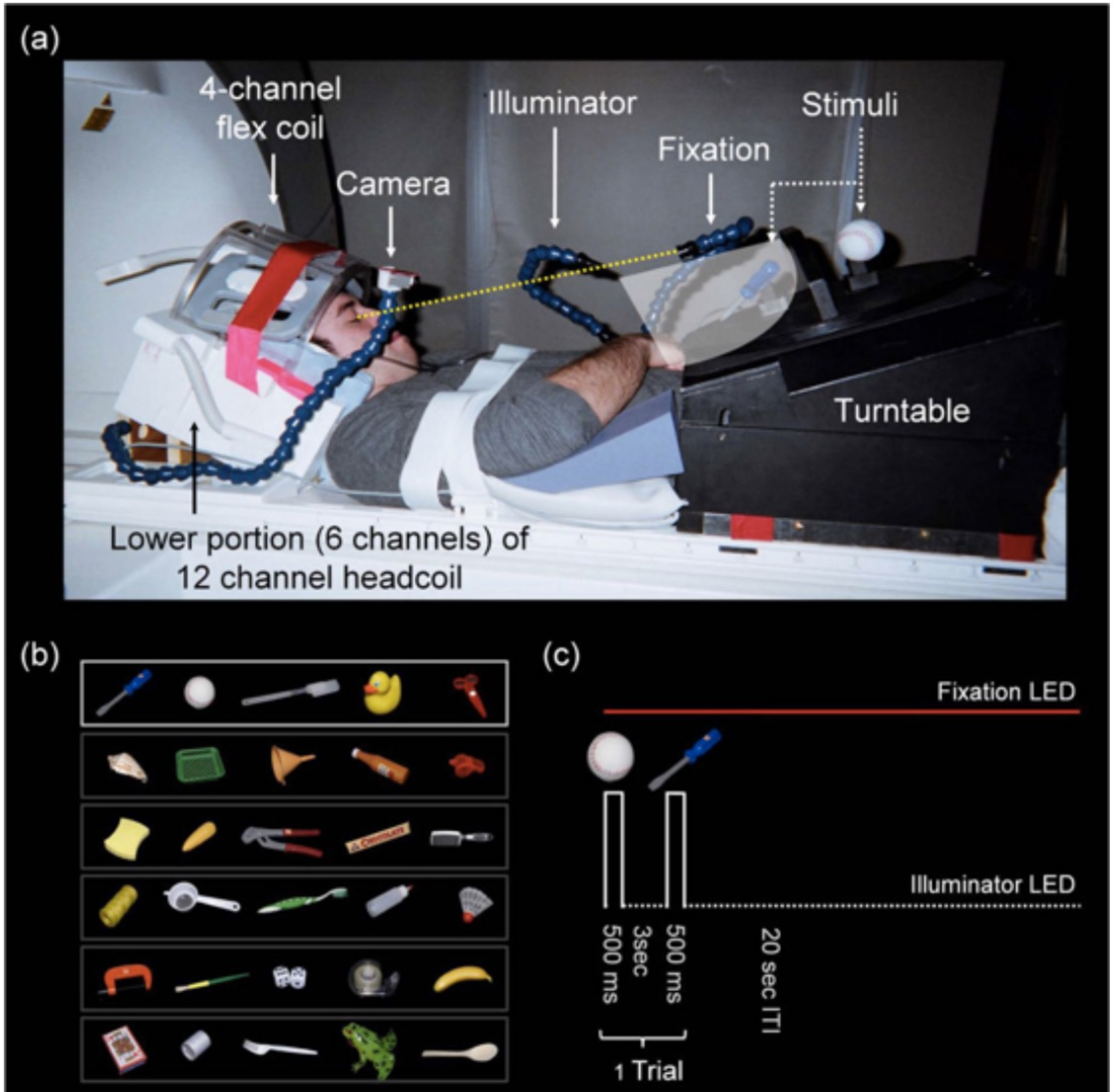
- Measures brain activity through oxygen concentration in the blood flow.

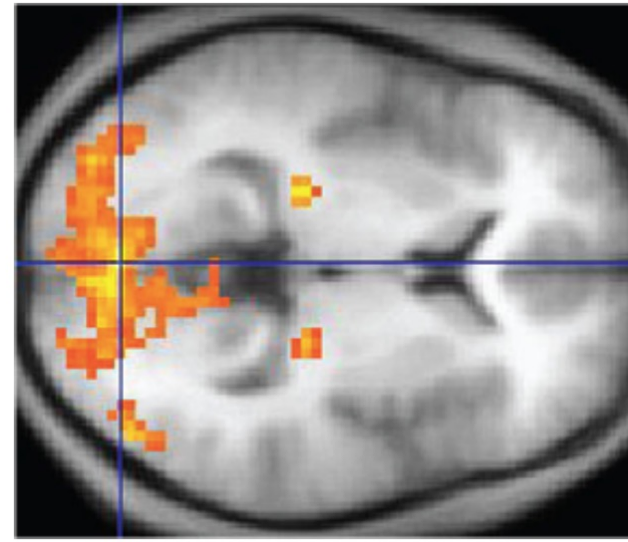
- Relies on the fact that cerebral blood flow and neuronal activation are coupled.

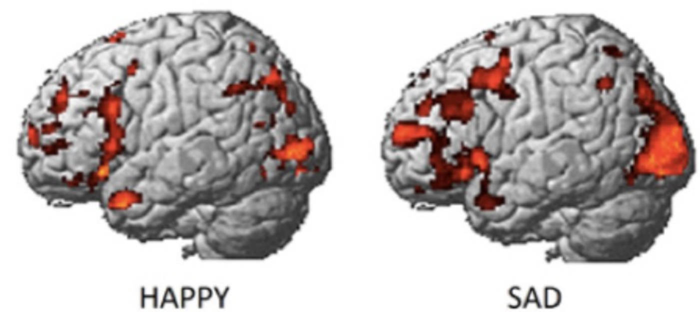
- When area of the brain is active (in use), blood flow to that area also increases.

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

Functional MRI (fMRI)

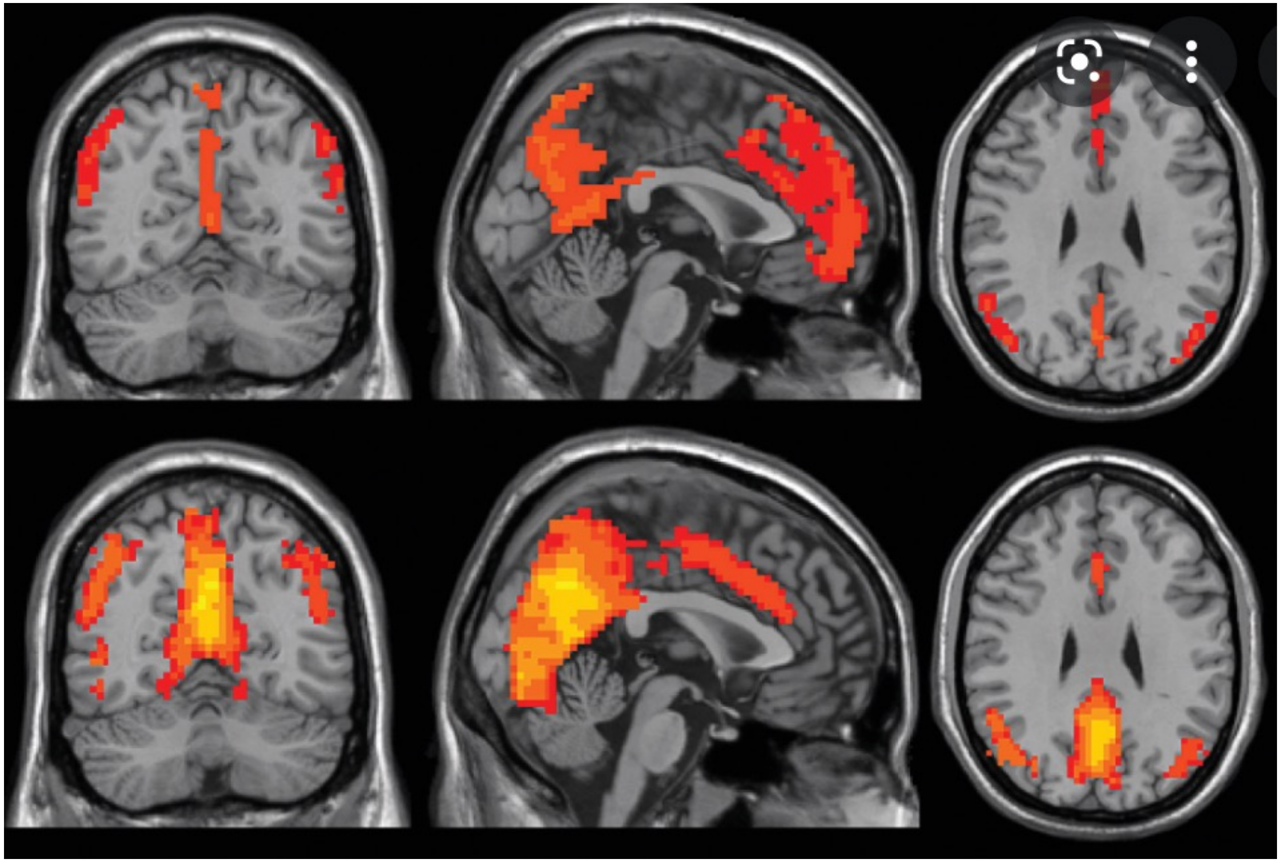


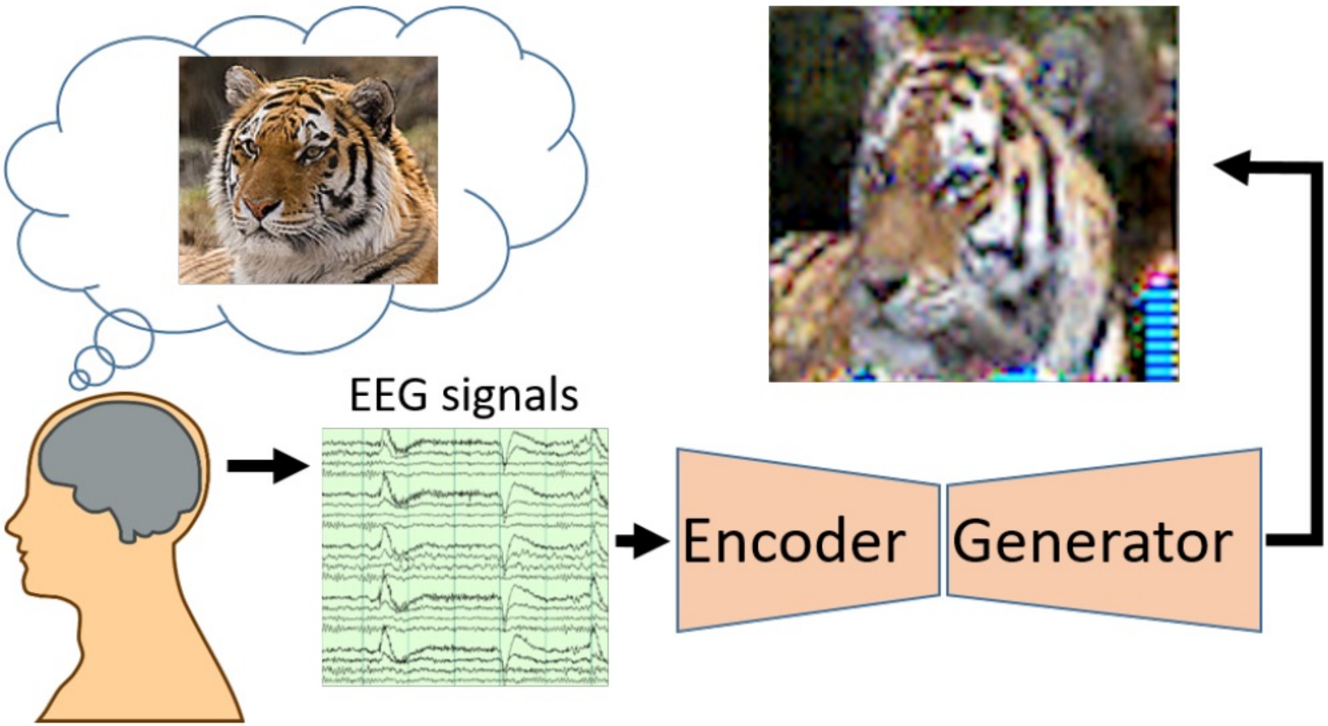




Active Regions

Functional MRI (fMRI)

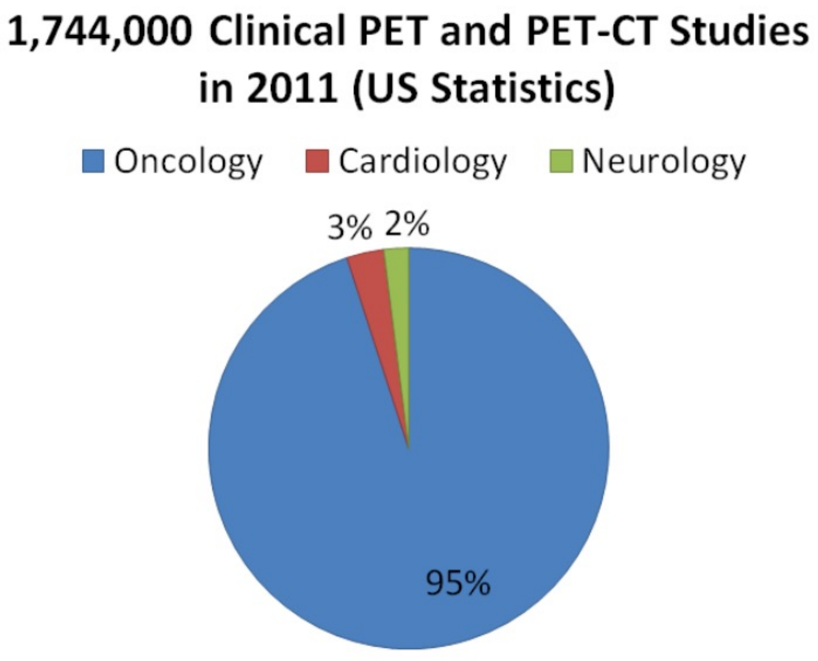




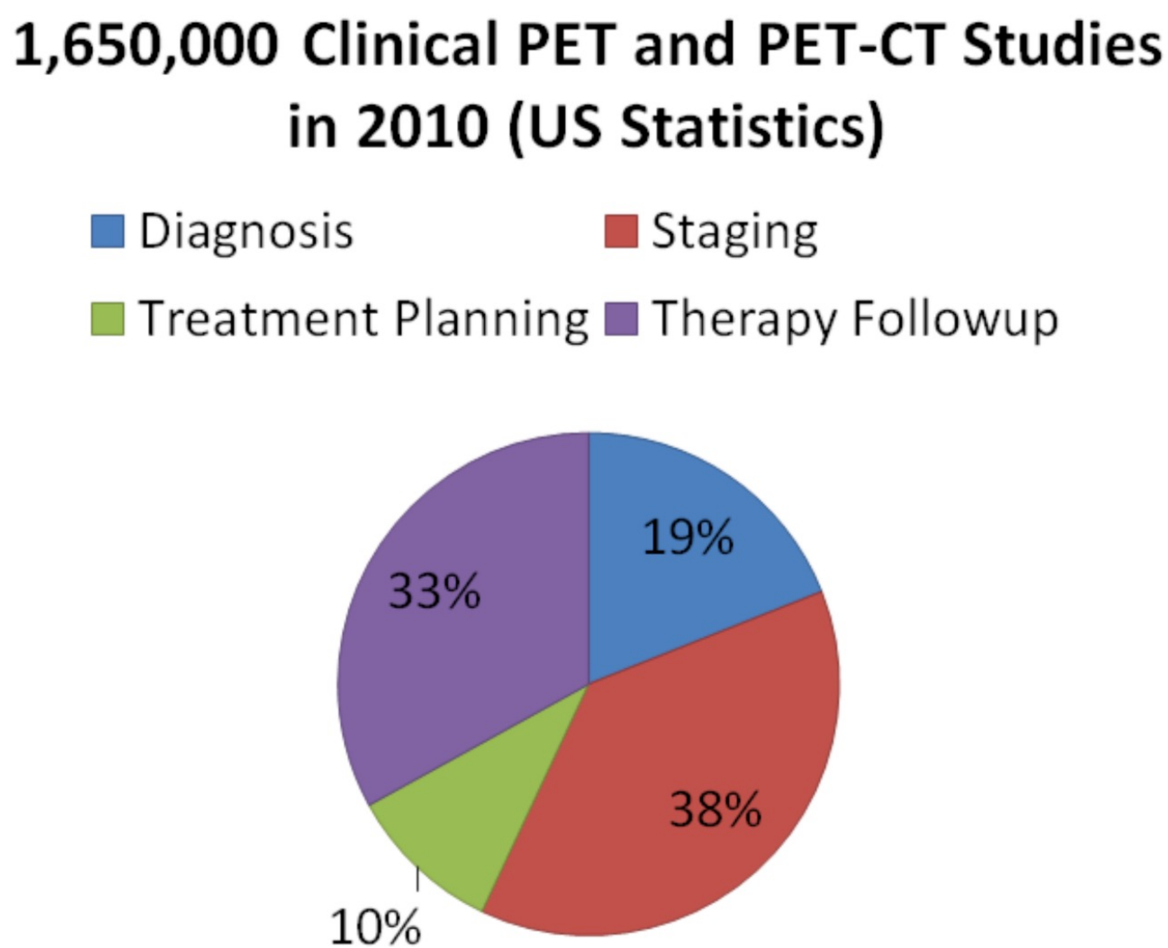
ThoughtViz: Visualizing Human Thoughts Using Generative Adversarial Network

Nuclear Medicine Imaging – PET/SPECT

- PET: Positron Emission Tomography
- SPECT: Single Photon Emission Tomography



Nuclear Medicine Imaging – PET/SPECT



Positron Emission Tomography Scan

- A positron emission tomography (PET) scan is an imaging test that can help reveal the metabolic or biochemical function of your tissues and organs.

- The PET scan uses a radioactive drug (tracer) to show both normal and abnormal metabolic activity.

- A PET scan can often detect the abnormal metabolism of the tracer in diseases before the disease shows up on other imaging tests, such as computerized tomography (CT) and magnetic resonance imaging (MRI).

Positron Emission Tomography Scan

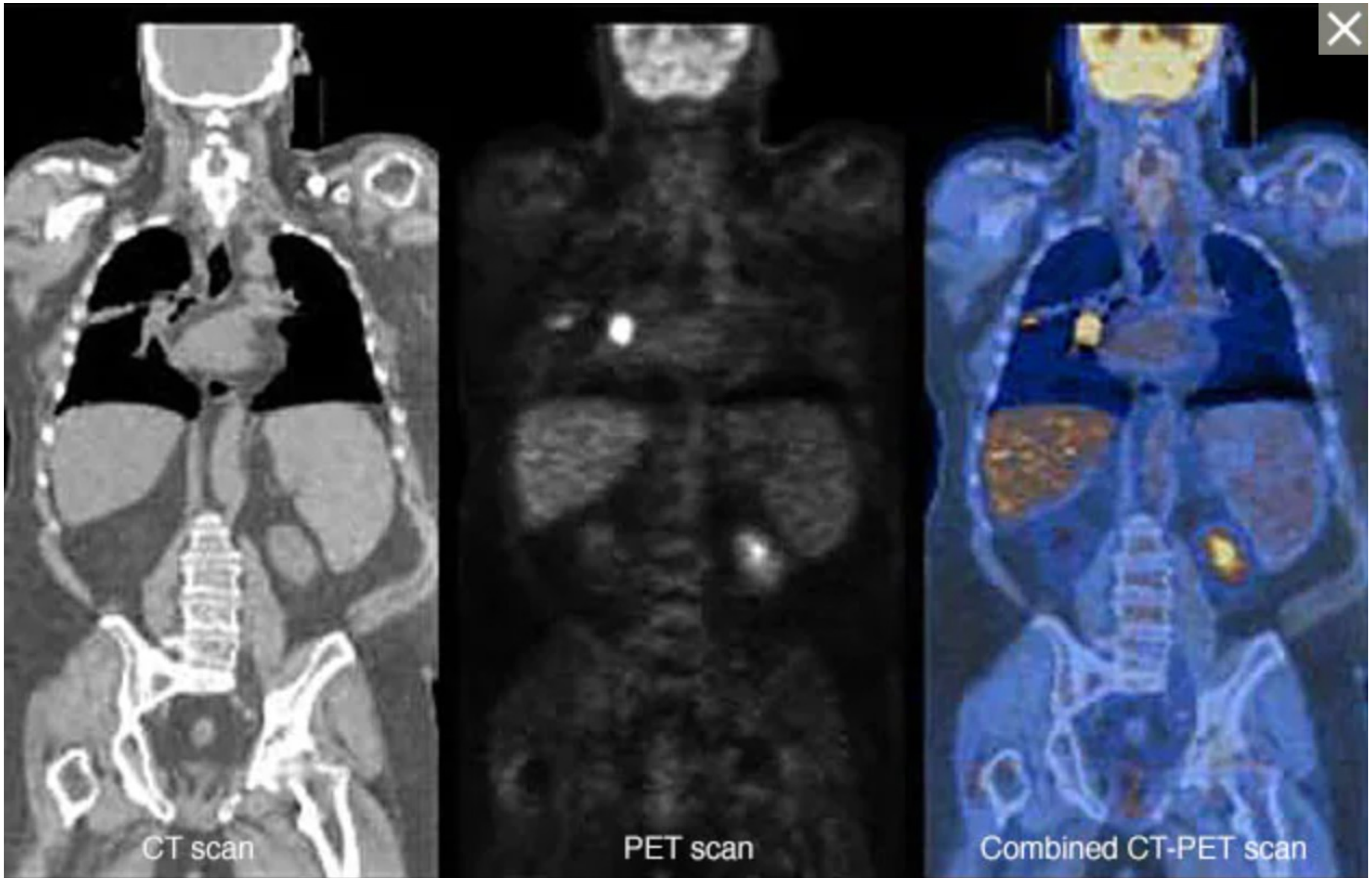
- The tracer is most often injected into a vein within your hand or arm.
- The tracer will then collect into areas of your body that have higher levels of metabolic or biochemical activity, which often pinpoints the location of the disease.
- The PET images are typically combined with CT or MRI and are called PET-CT or PET-MRI scans.

Positron Emission Tomography Scan

Positron emission tomography

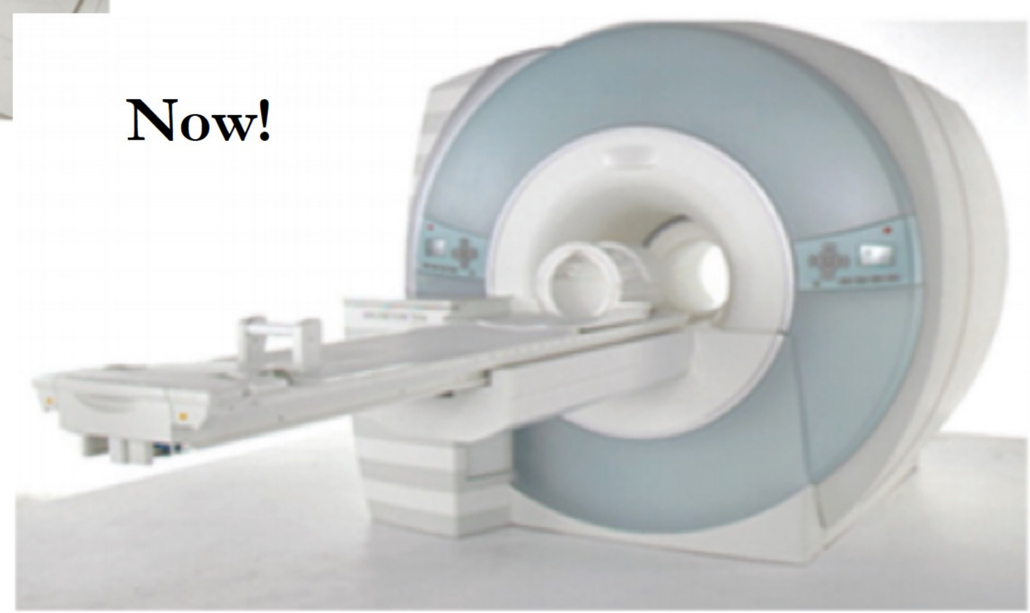
During a positron emission tomography (PET) scan, you lie on a narrow table that slides into a doughnut-shaped hole. The scanner takes about 30 minutes to produce detailed images of metabolic activity in your tissues and organs.

Positron Emission Tomography Scan



Serial and Simultaneous MRI/PET

Past



Prices

US<CT-Scan<MRI<PET-SCAN

Imaging Modalities - Summary

- Medical image analysis/computing is a highly active research field.
- Measurement is the key in MIC!
- Volumetry, morphometry, quantification, visualization are all necessary methods in diagnostic radiology applications.
- Different imaging modalities are in use for different clinical purpose(s)
- Imaging modalities have distinct properties from each other

References and Slide Credit

- CAP 5937 (Fall 2016) Lecture Presentations
- siemens.com
- P. Suetens, Fundamentals of Medical Imaging, Cambridge Univ. Press.