CAP 5516
Medical Image Computing
(Spring 2022)

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Lecture 3: Introduction to Medical Image Computing (1)

Image credit: https://www.syberscribe.com.au/blog/the-ins-and-outs-of-medical-imaging/

Medical Imaging

- What is medical imaging?
  - Medical imaging is used to produce images of organs and tissues within the body for use in diagnosis and treatment.
  - Different types of medical imaging are used for seeing different things within the body.

Medical Imaging

- Why is medical imaging important?
  - Medical imaging allows doctors to find diseases in their early stages, which leads to better outcomes for patients
  - Assist in decisions regarding treatment and future care of the issue

Radiology is **a branch of medicine that uses imaging technology to diagnose and treat disease**.

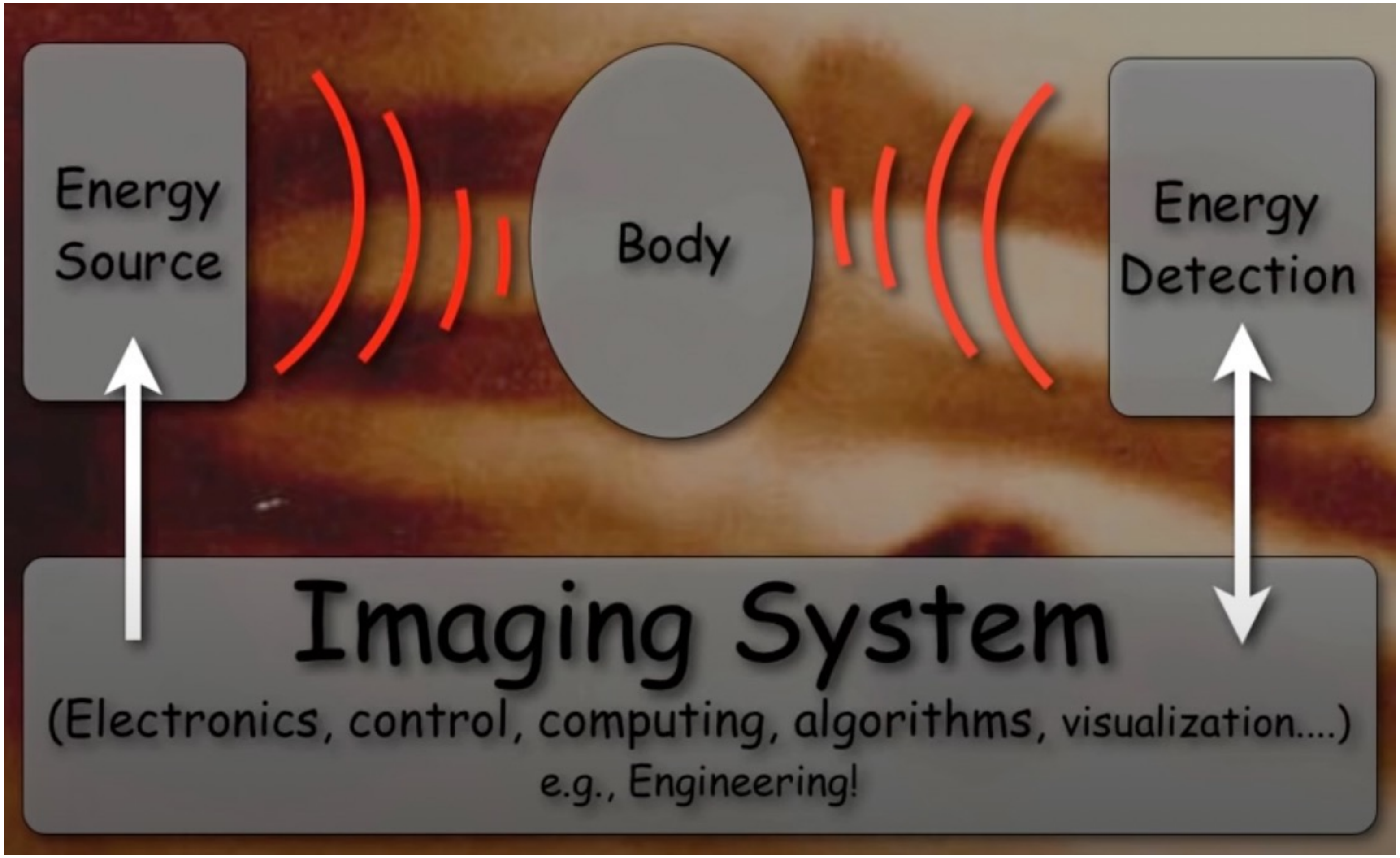
Medical Imaging

- What medical imaging modalities do you know?

  – **CT** (Computer Tomography)
  – **MRI** (Magnetic Resonance Imaging)
  – **Ultrasound**
  – **X-ray**
  – **Nuclear medicine imaging** (including positron-emission tomography (PET))

  …

Medical Imaging System (Basic Concept)



Credit: Michael (Miki) Lustig, UC Berkeley

Medical Imaging System Requirements

- Diagnostic contrast
- Sensitivity
- Specificity
- Function
- High spatial-resolution
- High temporal-resolution
- Safe
- Fast
- Inexpensive
- Easy to use

- Can’t satisfy all
- Often several used to make diagnosis

Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

1st X-ray (1895)

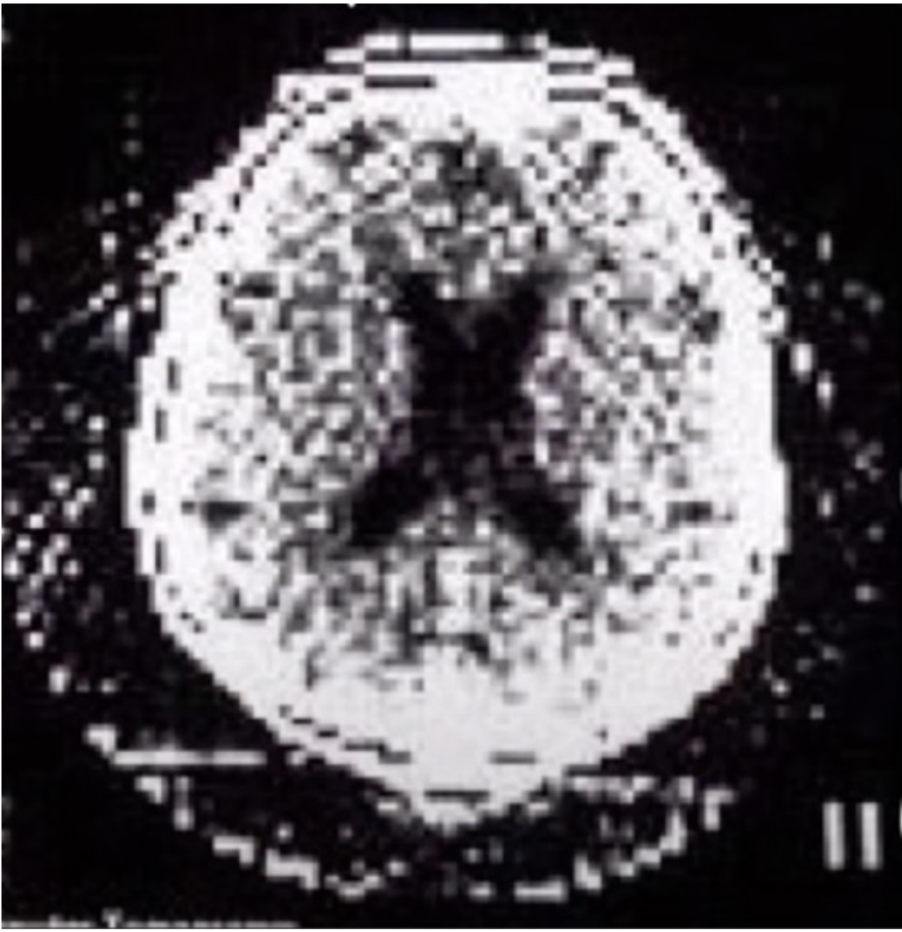
X-ray (today)

UCF Center for Research in Computer Vision

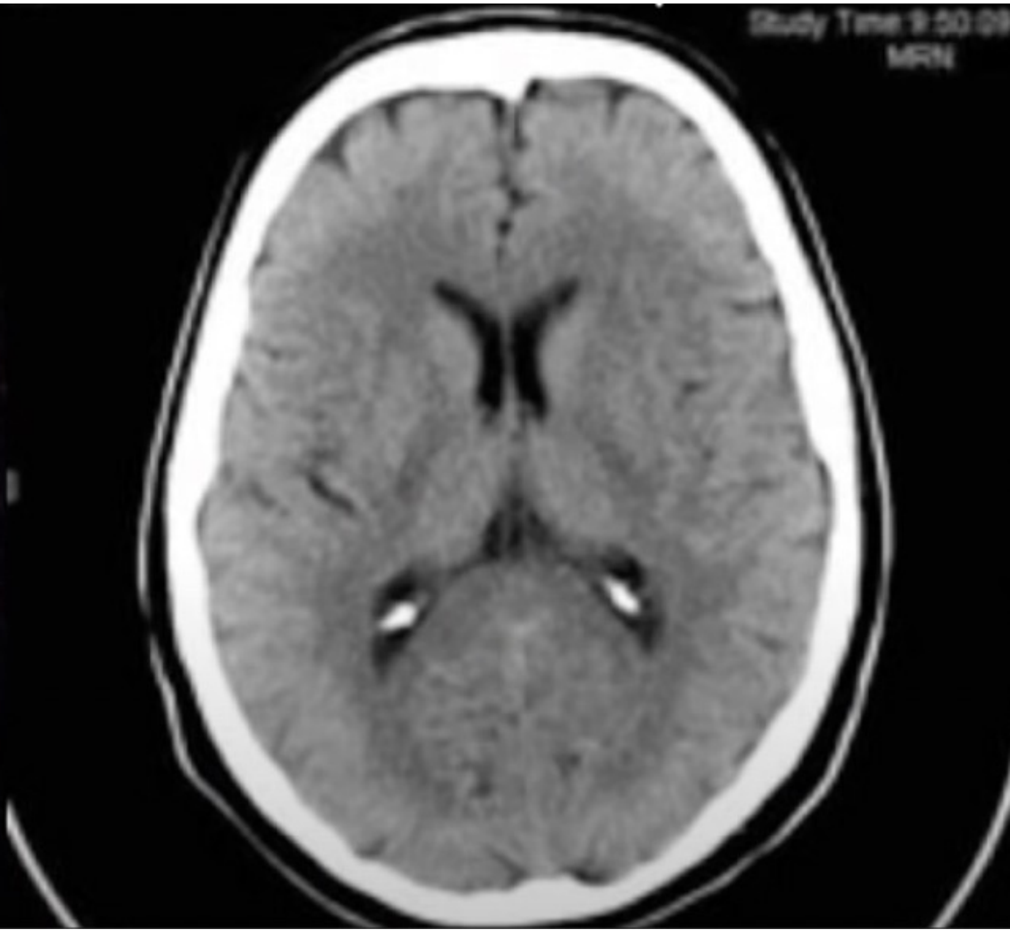
Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

Early CT (1975)



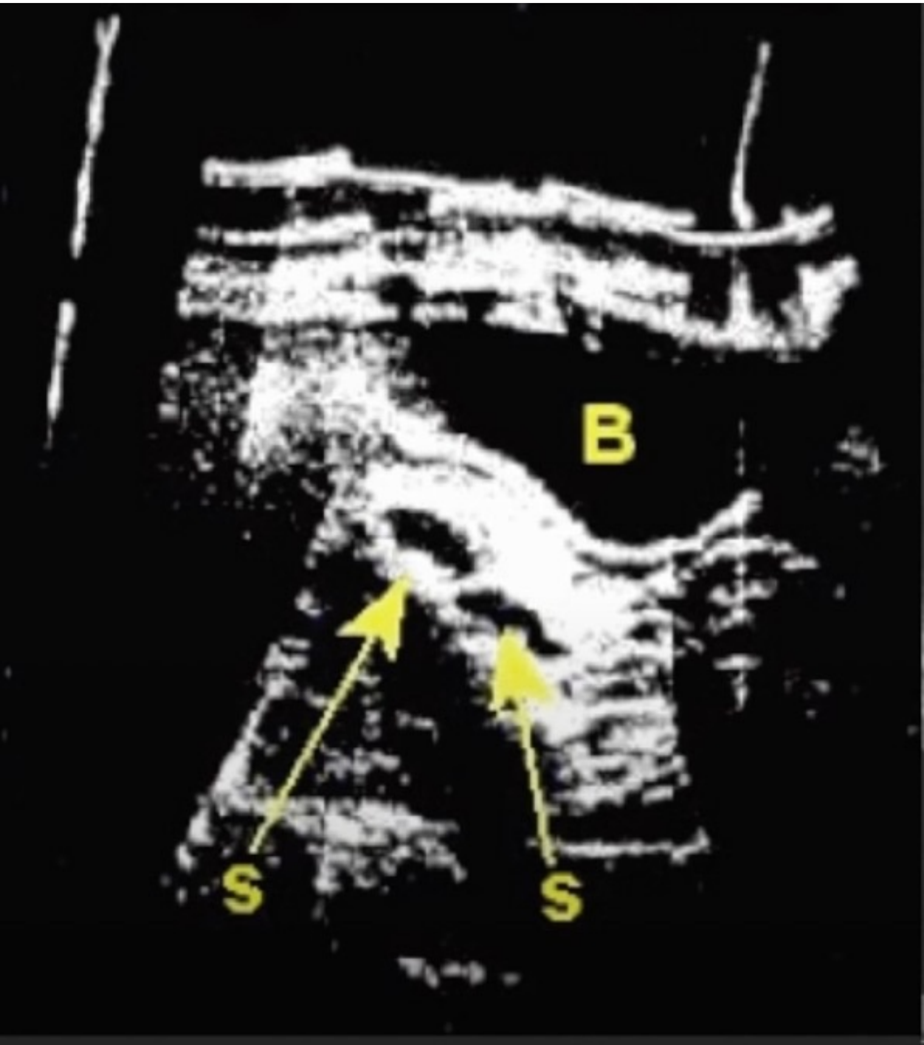
CT (today)



Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

Early ultrasound (1959)

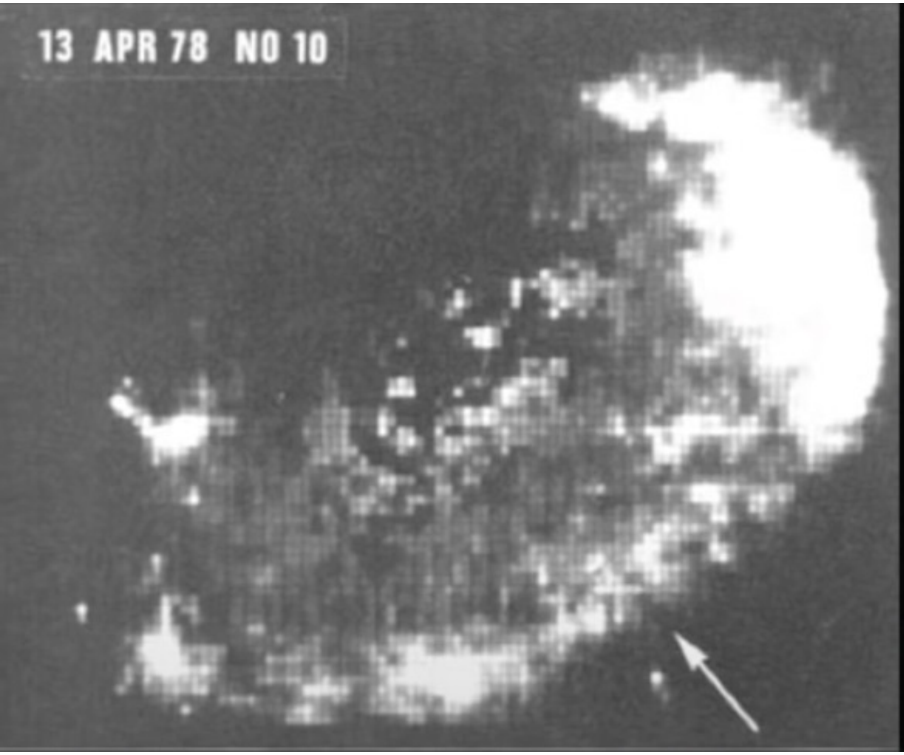


Ultrasound (today)

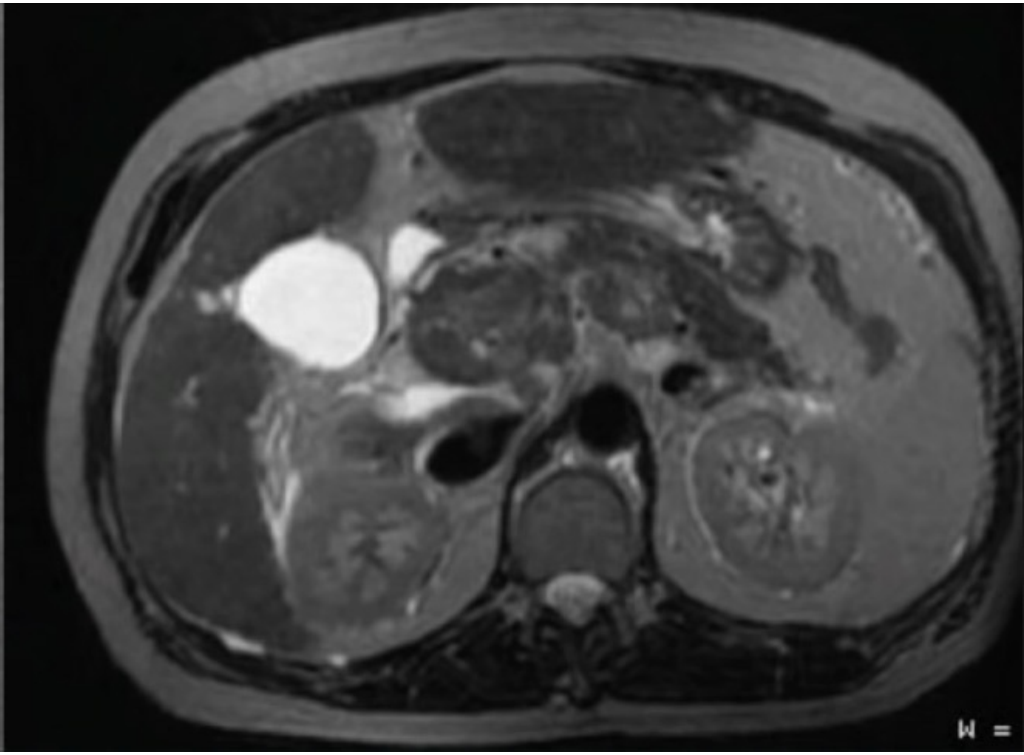
Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

Early MRI (1978)

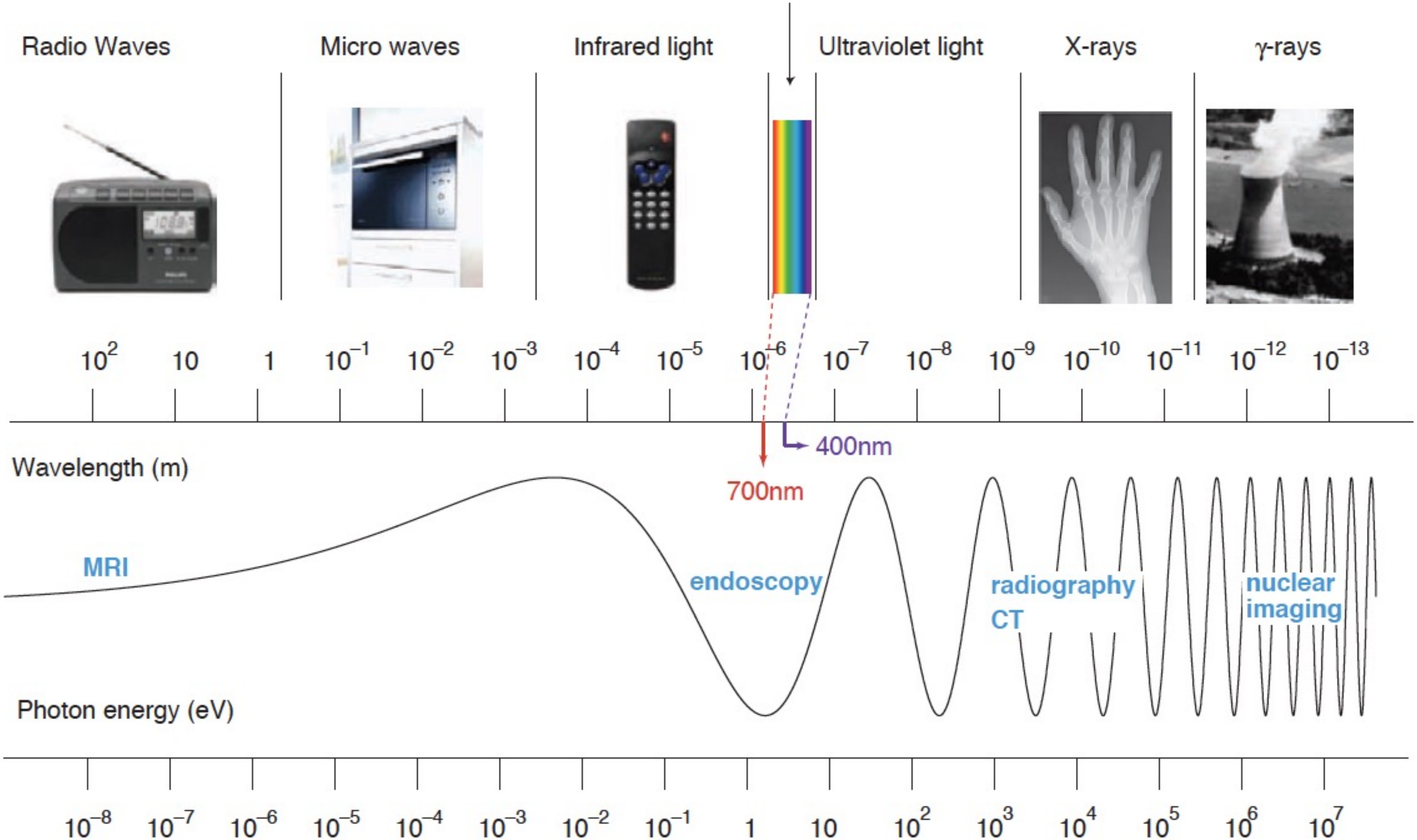


MRI (today)



Credit: Michael (Miki) Lustig, UC Berkeley

Brief Introduction to Imaging Modalities



ELECTROMAGNETIC SPECTRUM (P. Suetens)

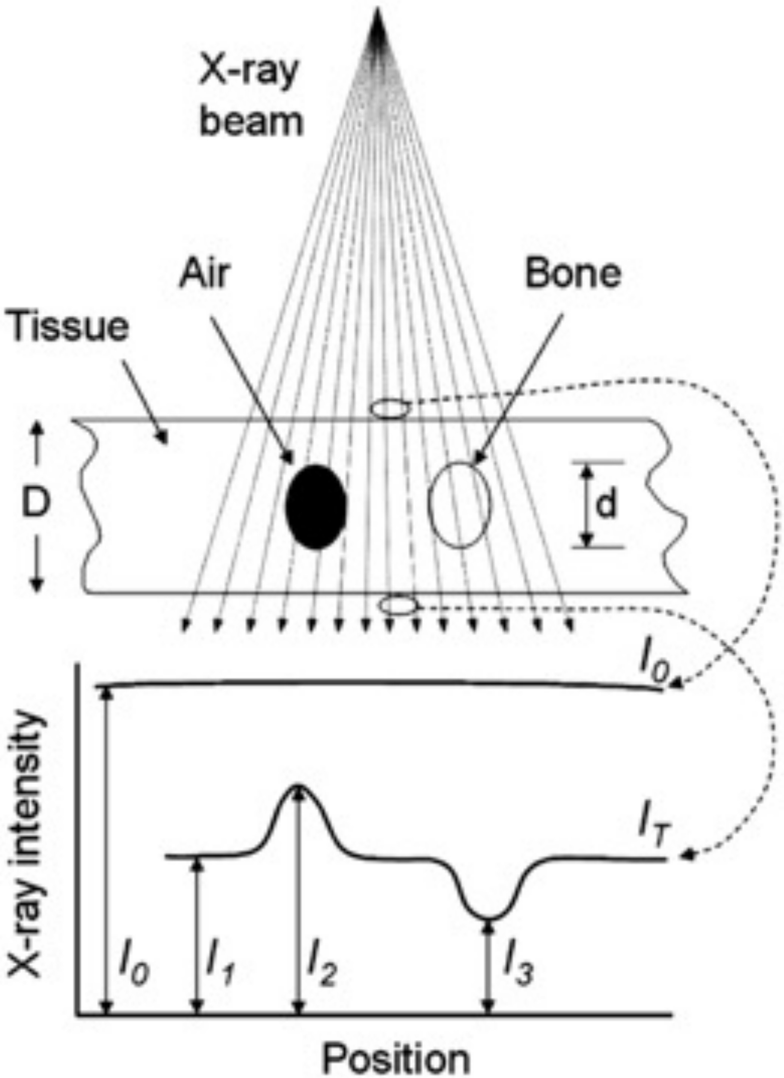
X-Ray Imaging / Radiography

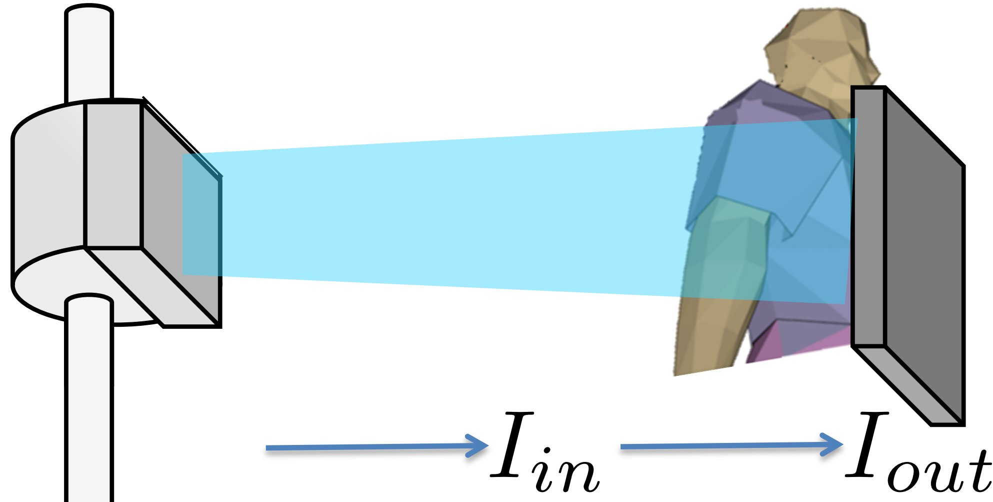
- The first published medical image was a radiograph of the hand of the German physicist Wilhelm Conrad Roentgen’s wife in 1895. *Nobel Prize in Physics 1901.*

First Medical x-ray
Bertha's hand, Dec 22, 1895

<u>routine diagnostic radiography (2D images):</u>
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

Image source: https://dicomsolutions.com/product/65kw-stationary-overhead-x-ray-machine-w-elevating-float-top-table/?gclid=CjwKCAiAxJSPBhAoEiwAeO_fP59PgGek4riEg9D0N7KAbaxCaooXQvUE9Nr_yNZ_BNNESgjJ9NijxxoCj6sQAvD_BwE

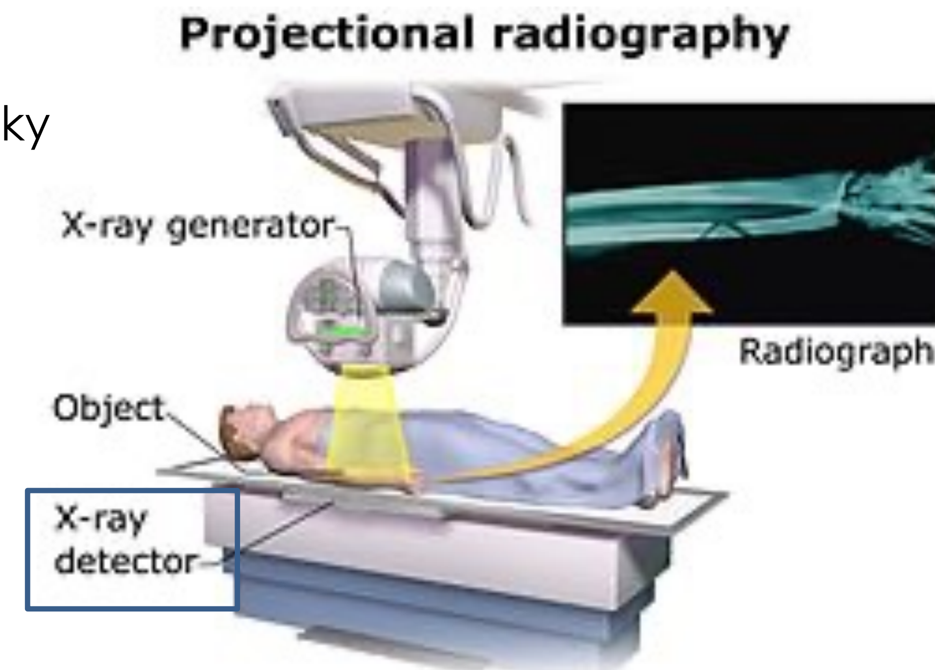


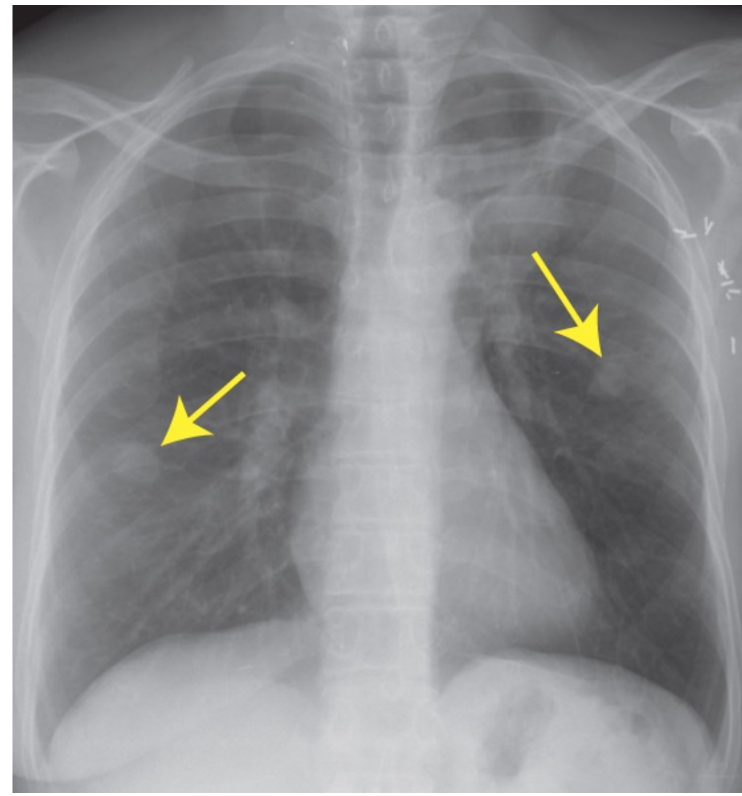
Image source: https://en.wikipedia.org/wiki/X-ray_machine

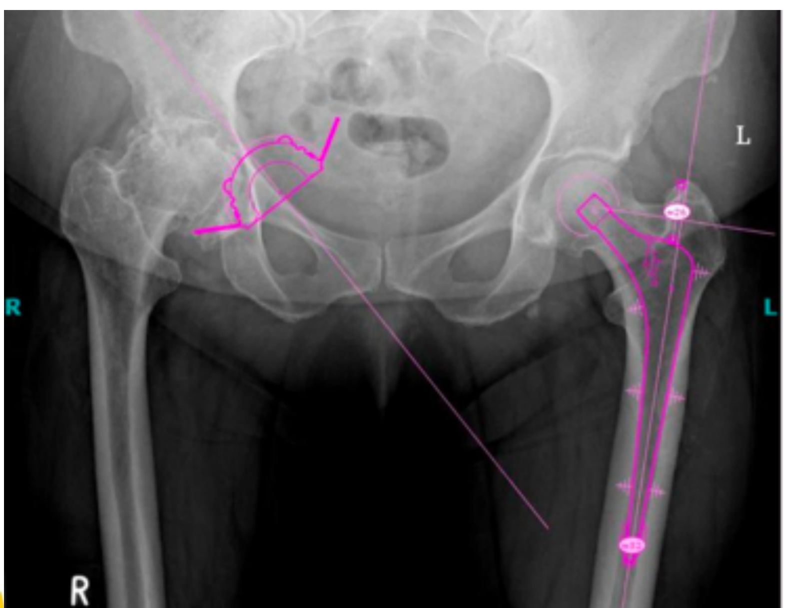
More details about x-ray and x-ray in operation: https://www.youtube.com/watch?v=-633zoLcHHo

https://www.nibib.nih.gov/science-education/science-topics/x-rays

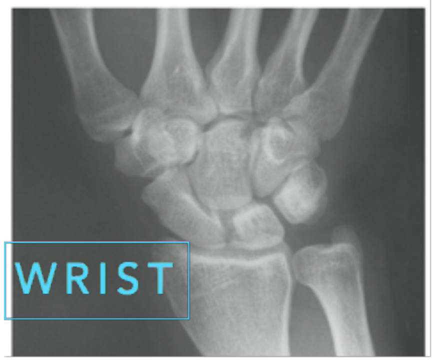
Basics Use of X-Rays

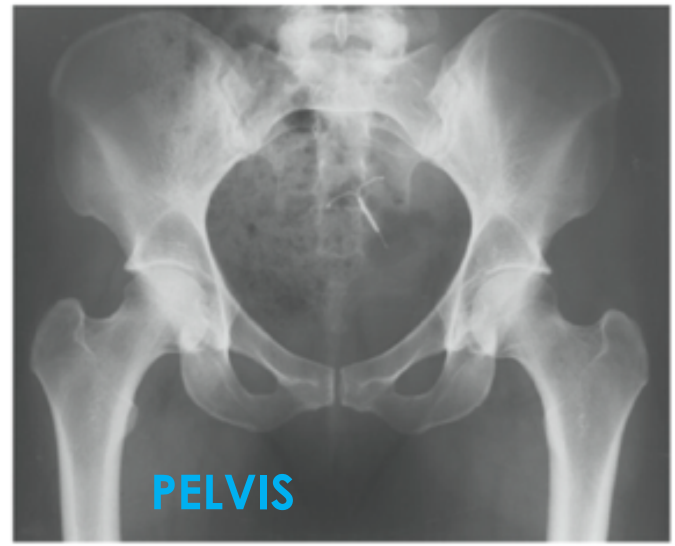
- Dental examinations
- Surgical markers prior to invasive procedures
- Mammography
- Orthopedic evaluations
- Chest examination (Tuberculosis)
- Age estimation (forensic)



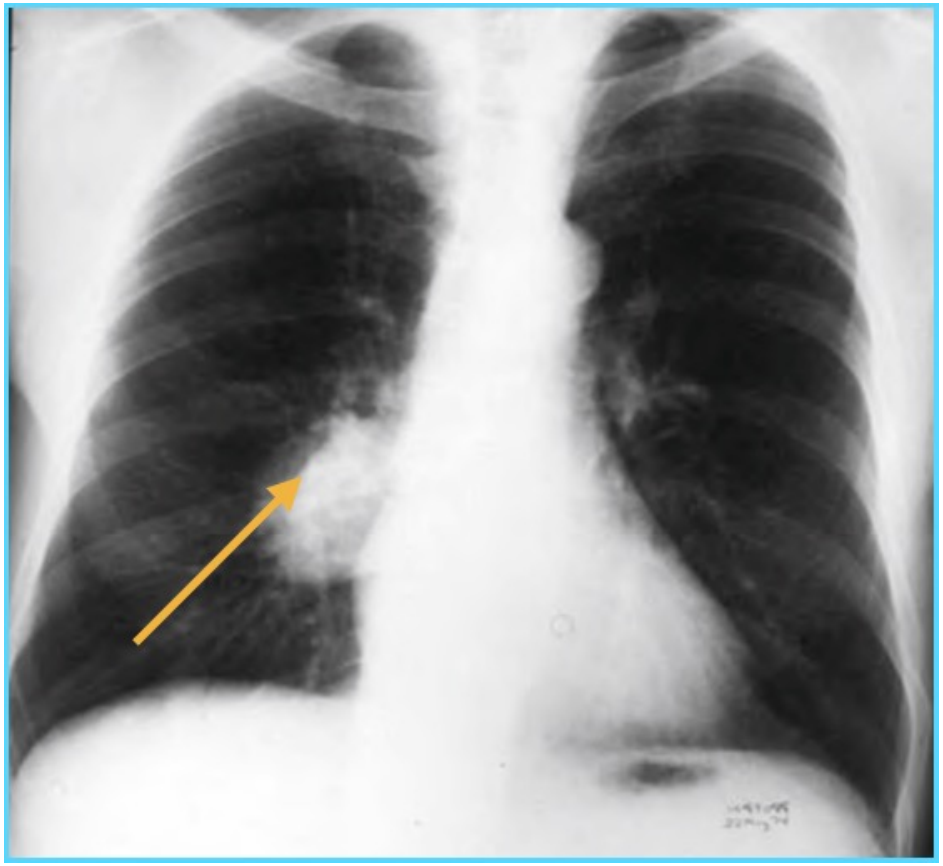


Clinical Examples – X-Rays





How Radiologists Search Abnormal Patterns in Chest X-Rays?



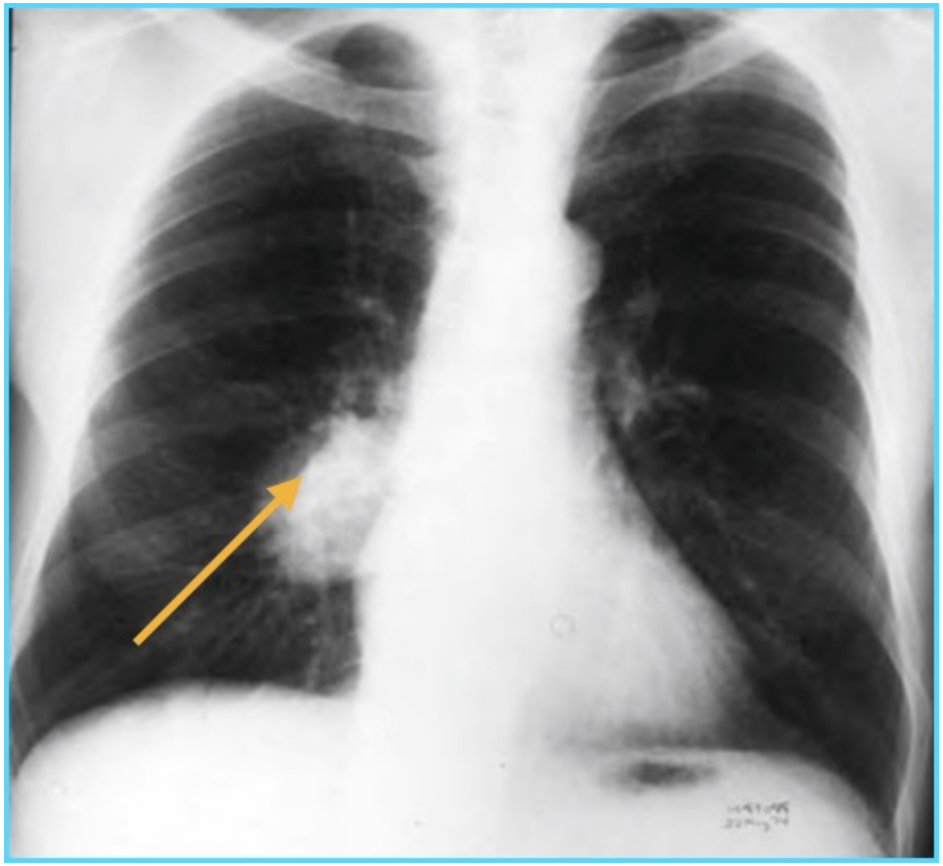
Radiologists often report the following

- 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

How Radiologists Search Abnormal Patterns in Chest X-Rays?



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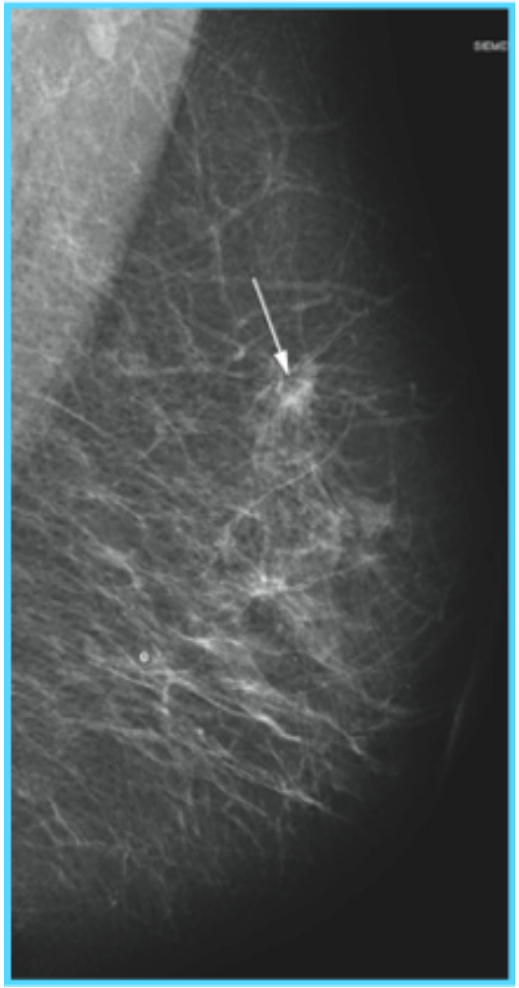
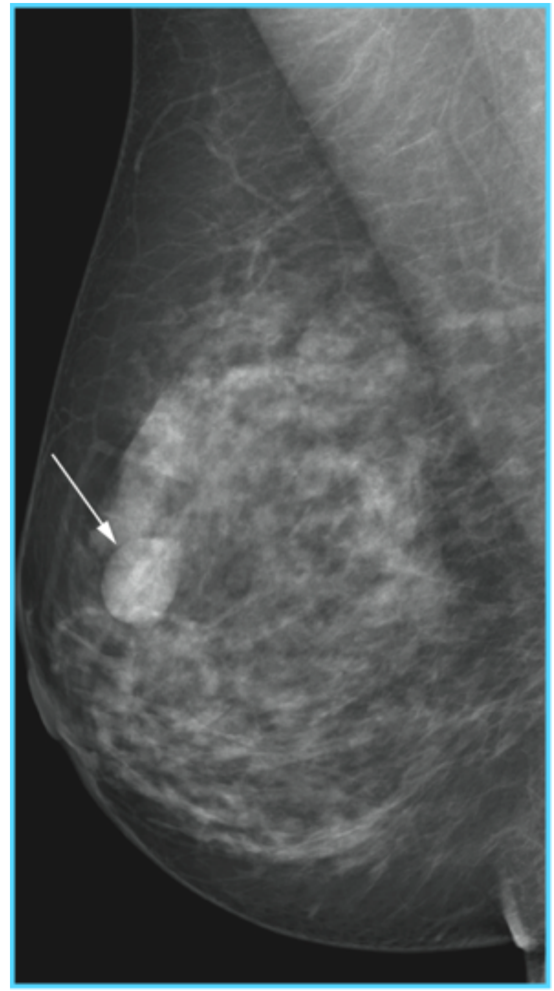
Computer algorithms can solve/simplify these problems for improved healthcare

Another Example for X-ray Imaging

Benign
(noncancerous)





Malignant
(cancerous)

The radiologist will look for **areas of white, high-density tissue and note its size, shape, and edges**. A lump or tumor will show up as a focused white area on a mammogram.

Other X-ray use cases?

X-ray for security scanning

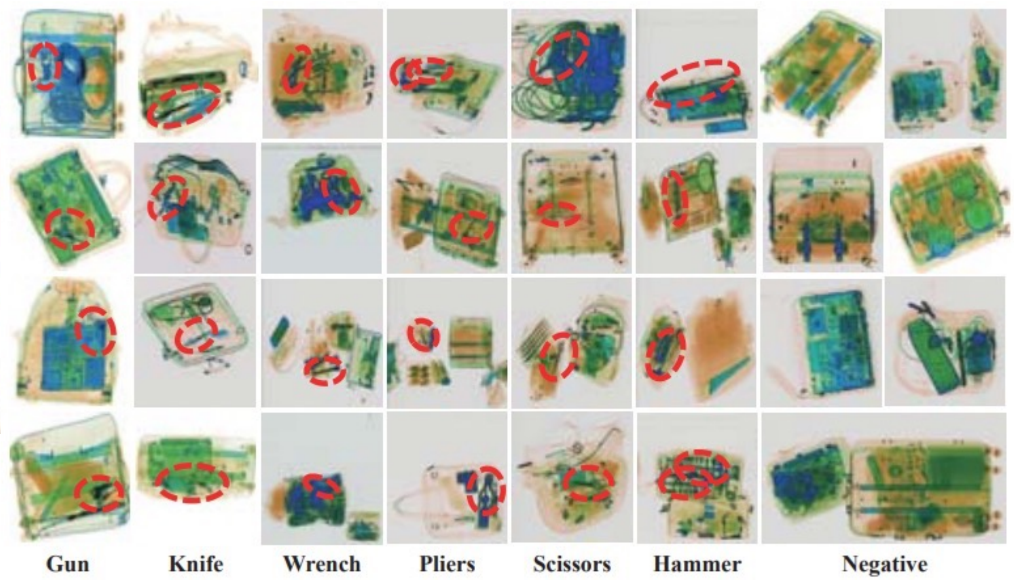


Figure 1. Example images in the presented SIXray dataset with six categories of prohibited items. Challenges include large variety in object scale and viewpoint, object overlapping and complex backgrounds (please zoom in for details).

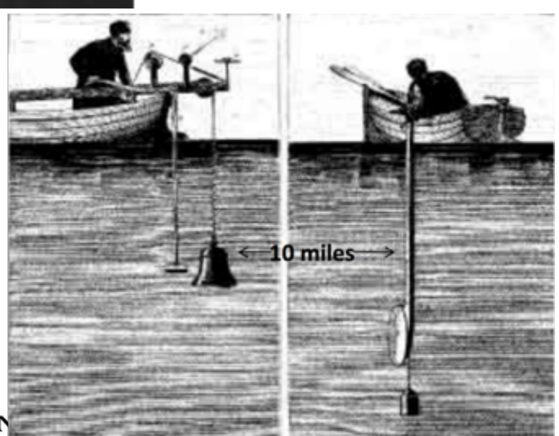
Miao, Caijing, et al. "Sixray: A large-scale security inspection x-ray benchmark for prohibited item discovery in overlapping images." CVPR 2019

Ultrasound (US) Imaging

- Sound frequency a human ear can detect? (20Hz to 20KHz)
- 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

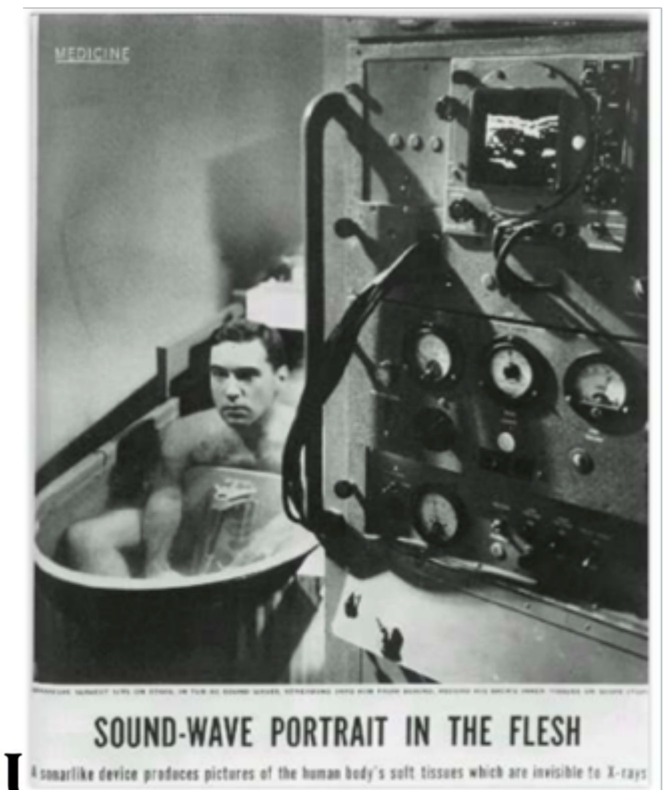
1826-Jean Daniel Colladon - Physicist
Uses church bell (early transducer) under water to calculate speed of sound through water prove sound traveled faster through water than air.



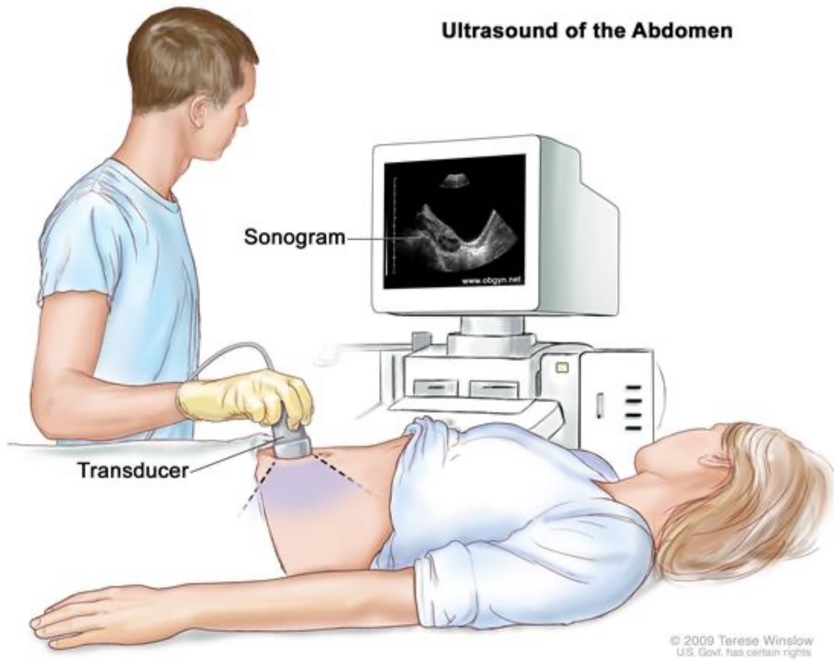
1880-Pierre&Jacques Curie
discover the Piezo-Electric Effect (ability of certain materials to generate an electric charge in response to applied mechanical stress.

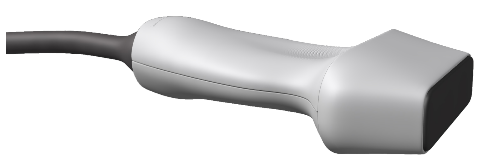
US Imaging Technology

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





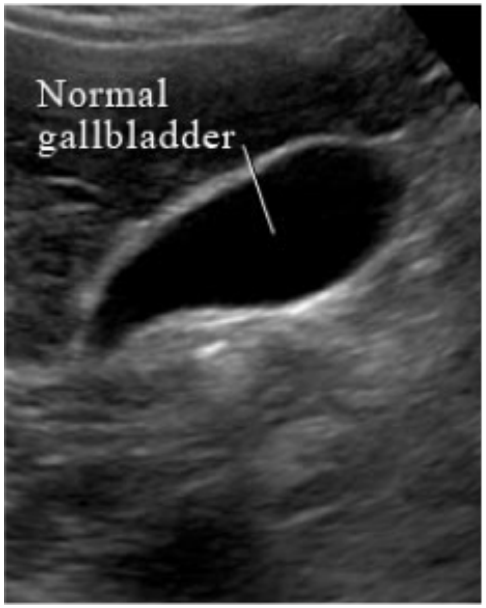
An ultrasound transducer

Source: https://www.nibib.nih.gov/science-education/science-topics/ultrasound

- Ultrasound waves are produced by a transducer, which can both emit ultrasound waves, as well as detect the ultrasound echoes reflected back.
- The transducer sends out a beam of sound waves into the body.
- The sound waves are reflected back to the transducer by boundaries between tissues in the path of the beam (e.g. the boundary between fluid and soft tissue or tissue and bone).
- When these echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner.
- Using the speed of sound and the time of each echo's return, the scanner calculates the distance from the transducer to the tissue boundary.
- These distances are then used to generate two-dimensional images of tissues and organs.

Features of US Imaging

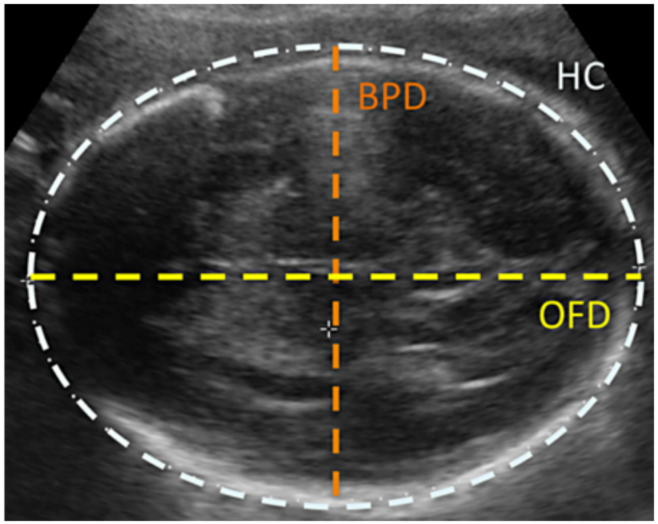
- Resolution:
  - **<u>low resolution</u>** and low SNR in deep region
- Ability of **<u>imaging soft tissue</u>**
- imaging in **<u>real time</u>**

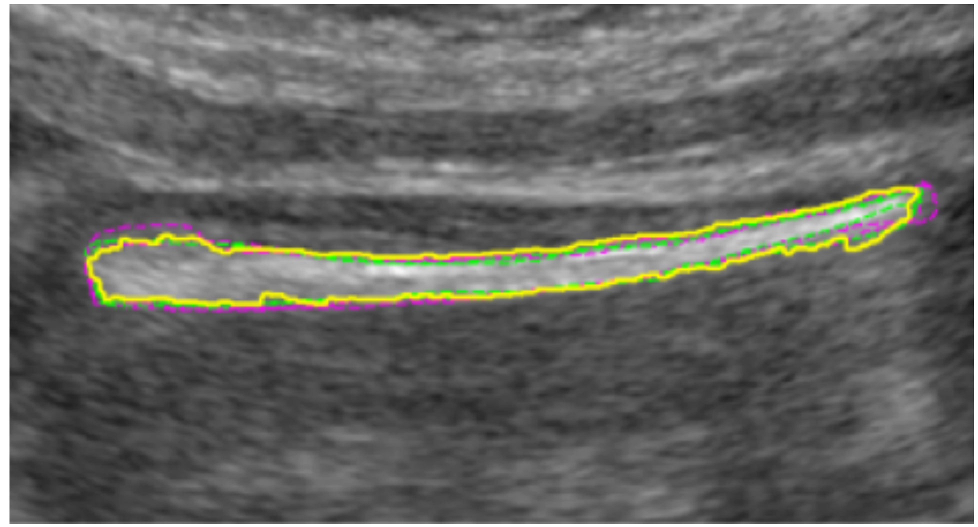


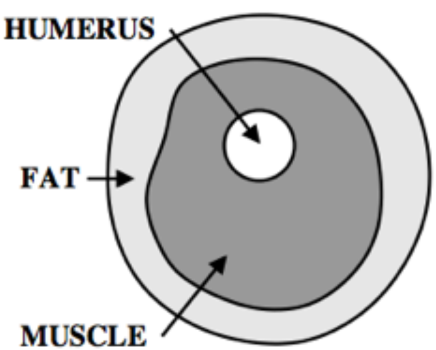
Clinical Use of US Imaging

A fetal ultrasound (sonogram) is an imaging technique that uses **sound waves to produce images of a fetus in** the uterus.

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.)

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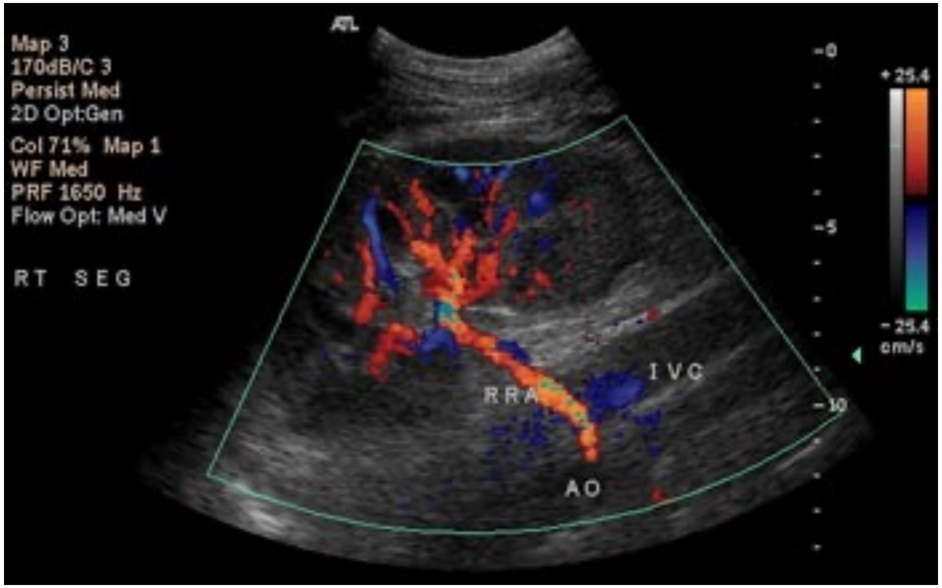
Clinical Use of US Imaging

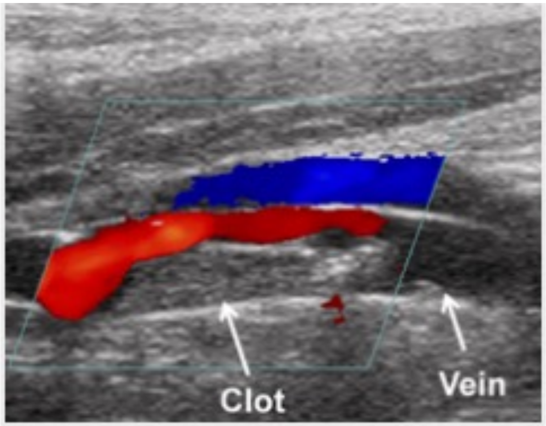
Renal Artery Ultrasound

- Renal artery ultrasound is a test to check for problems in the renal arteries, the blood vessels that supply your kidneys.
- This provides detailed pictures of these blood vessels to help determine the extent and cause of restricted blood flow caused by renal artery narrowing.

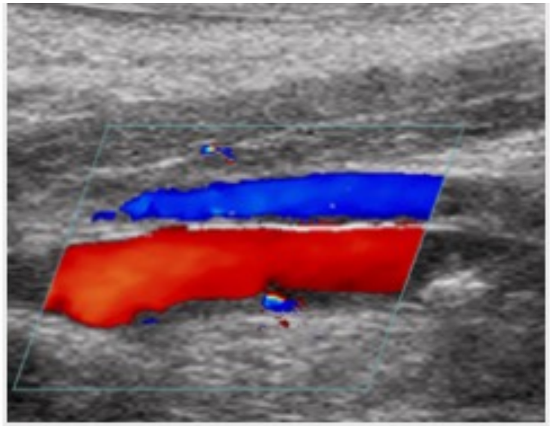


Source: https://health.ucdavis.edu/vascular/lab/exams/renal.html

Clinical Use of US Imaging



Ultrasound color Doppler shows a clot blocking blood flow in a pig. Source: Zhen Xu, Ph.D., Univ. of Michigan



After 5-minute histotripsy treatment the clot is gone and full blood flow is restored in the blood vessel. Source: Zhehn Xu, Ph.D., Univ. of Michigan

Researchers at the University of Michigan are investigating the clot-dissolving capabilities of a high intensity ultrasound technique, called histotripsy, for the non-invasive treatment of deep-vein thrombosis (DVT). This technique uses short, high-intensity pulses of ultrasound to cause clot breakdown.

Source: https://www.nibib.nih.gov/science-education/science-topics/ultrasound

Benefits of US Imaging

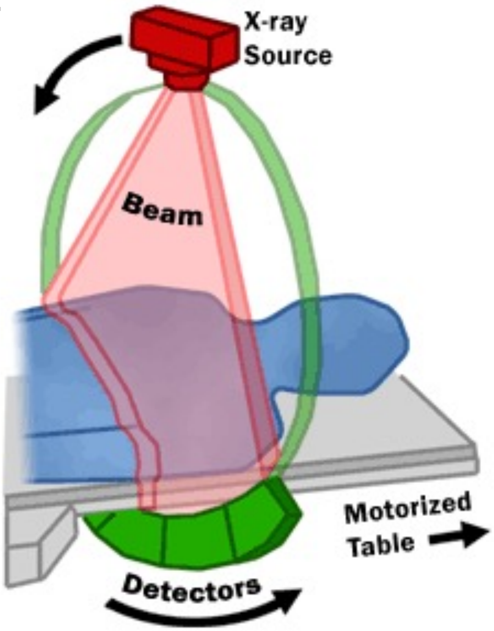
- Most ultrasound scanning is noninvasive (no needles or injections).
- Ultrasound is widely available, easy to use, and less expensive than most other imaging methods.
- Ultrasound imaging is extremely safe and does not use radiation.
- Ultrasound scanning gives a clear picture of soft tissues that do not show up well on x-ray images.
- Ultrasound is the preferred imaging modality for the diagnosis and monitoring of pregnant women and their unborn babies.
- Ultrasound provides real-time imaging. This makes it a good tool for guiding minimally invasive procedures such as needle biopsies and fluid aspiration.

Risks of US Imaging

- Diagnostic ultrasound is generally regarded as safe and does not produce ionizing radiation like that produced by x-rays.
- Ultrasound energy has the potential to produce biological effects on the body.
- Ultrasound waves can heat the tissues slightly.

Computed Tomography (CT)

- Computed tomography (CT scan or CAT scan) is a noninvasive diagnostic imaging procedure that uses a combination of X-rays and computer technology to produce horizontal, or axial, images (often called slices) of the body.
- A narrow beam of x-rays is aimed at a patient and quickly rotated around the body, producing signals that are processed by the machine's computer to generate cross-sectional images—or "slices"—of the body.
- These slices are called tomographic images and contain more detailed information than conventional x-rays.



Source: https://www.fda.gov/radiation-emitting-products/medical-x-ray-imaging/computed-tomography-ct

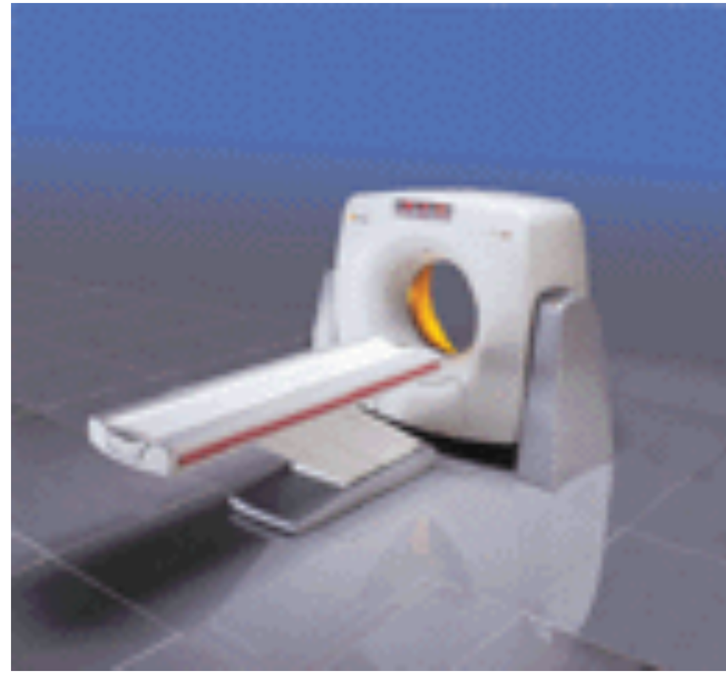
Source: https://www.nibib.nih.gov/science-education/science-topics/computed-tomography-ct

CT Contrast Agent

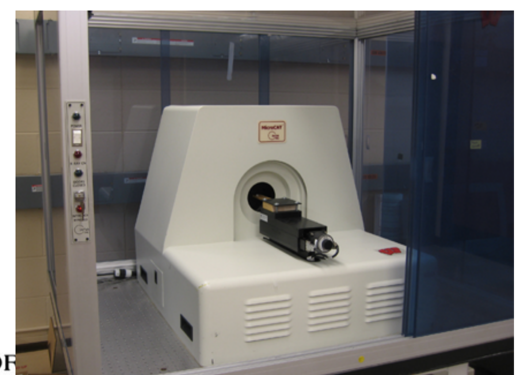
- As with all x-rays, dense structures within the body—such as bone—are easily imaged, whereas soft tissues vary in their ability to stop x-rays and, thus, may be faint or difficult to see.
- Intravenous (IV) contrast agents have been developed that are highly visible in an x-ray or CT scan and are safe to use in patients.
- Contrast agents contain substances that are better at stopping x-rays and, thus, are more visible on an x-ray image. For example, to examine the circulatory system, a contrast agent based on iodine is injected into the bloodstream to help illuminate blood vessels. This type of test is used to look for possible obstructions in blood vessels, including those in the heart.

CT Imaging

C-arm

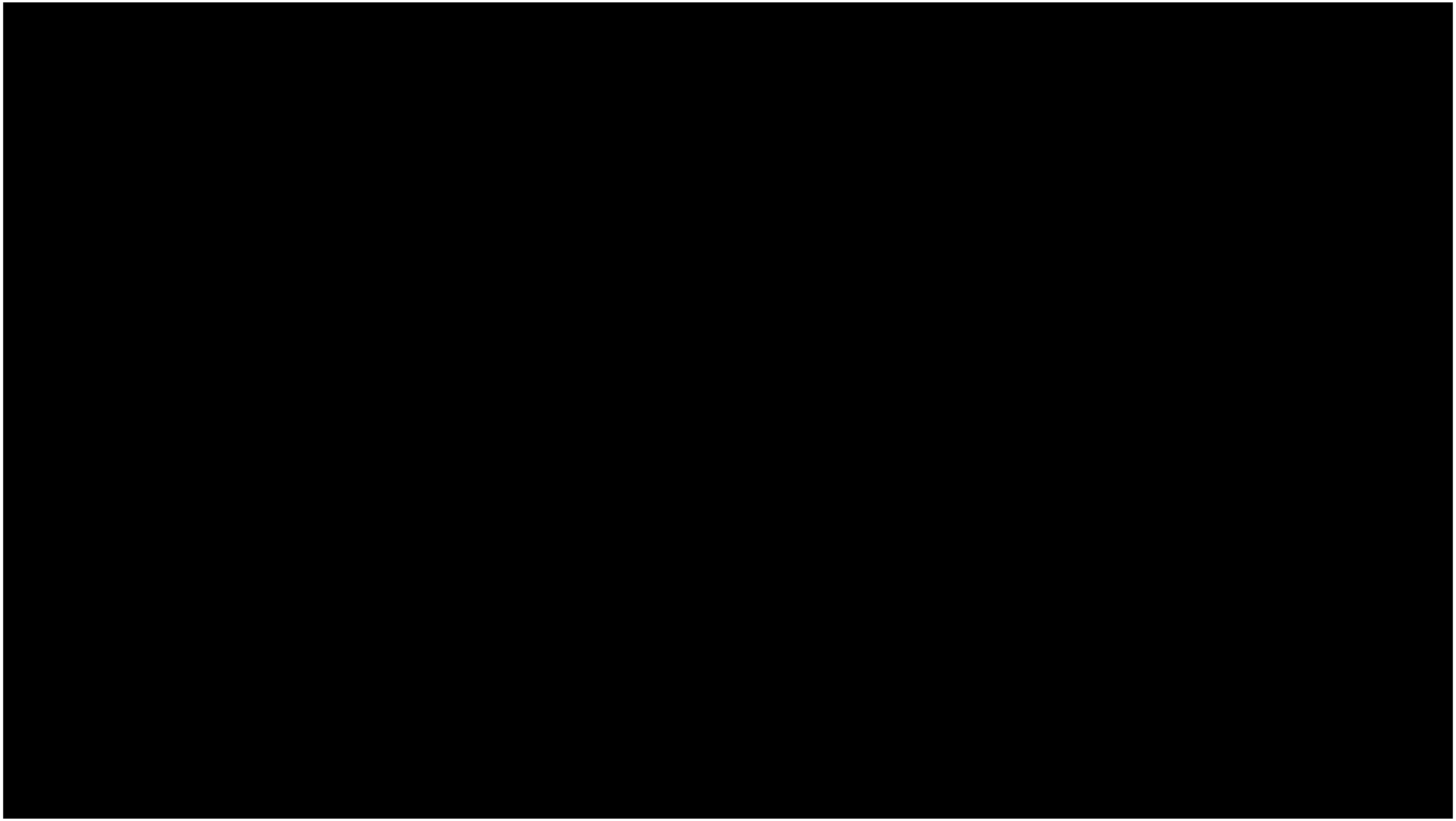


CT



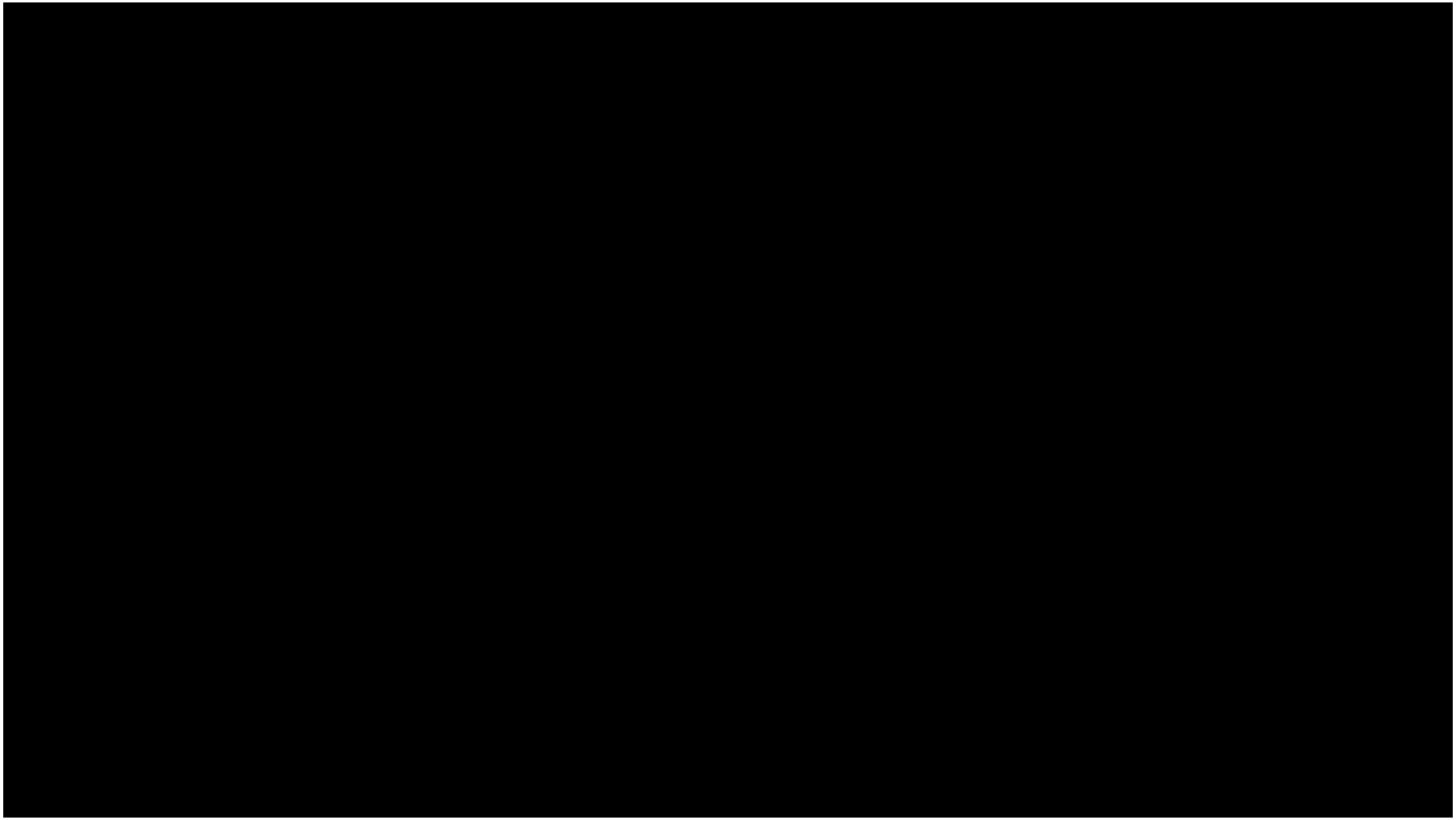
Micro-CT

CT Imaging



Source: https://www.youtube.com/watch?v=gaiCtdo6CLE&t=1s

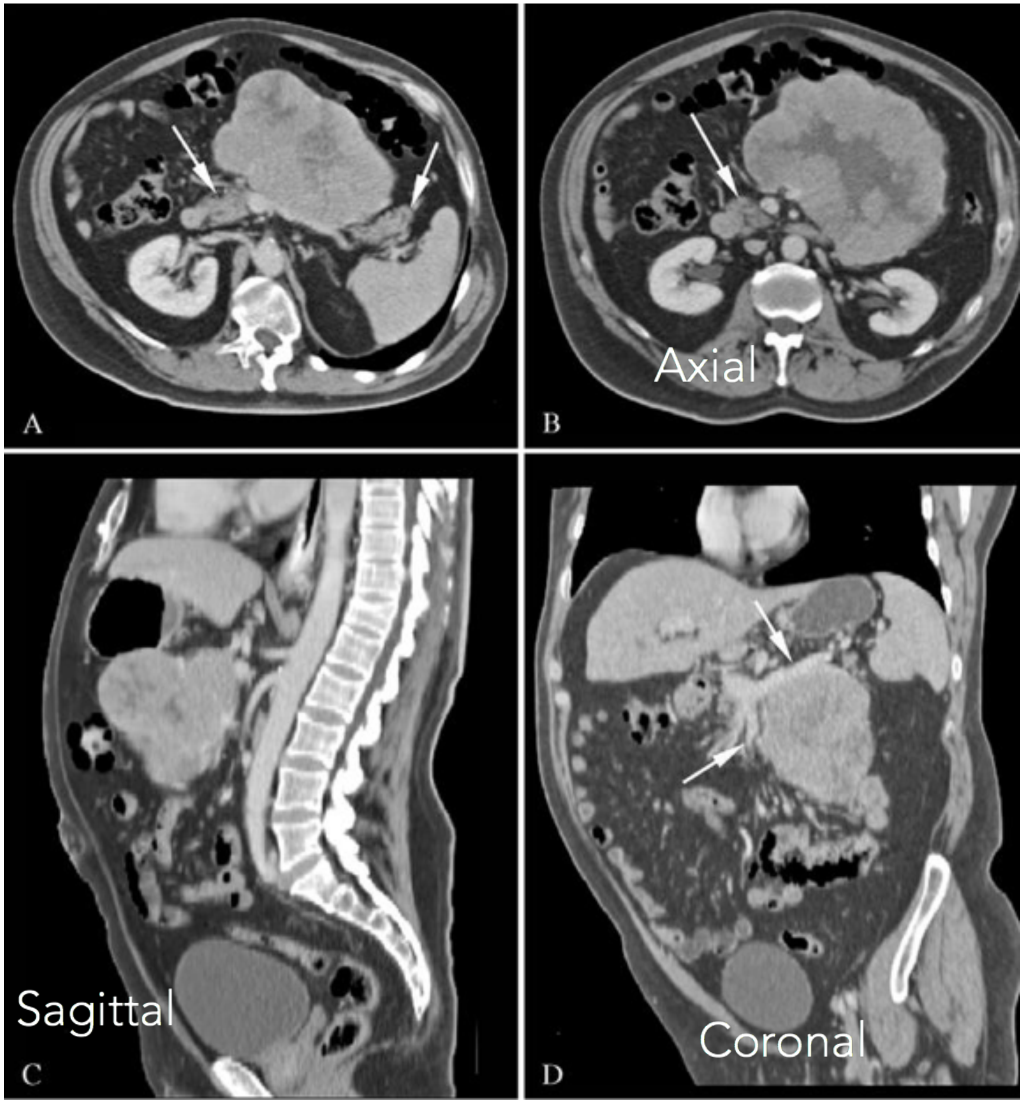
CT Imaging

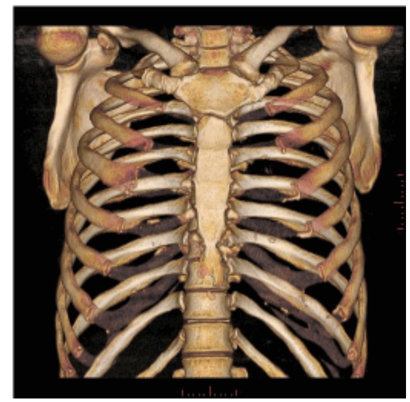


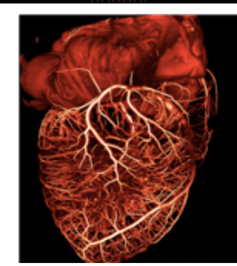
Radiographer Films Inside of a CT scanner spinning at full speed

Source: https://www.youtube.com/watch?v=pLajmU4TQuI

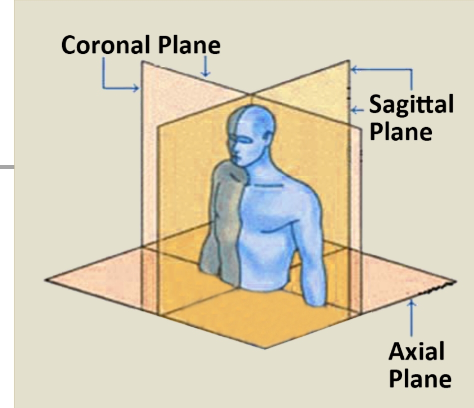
3D Nature of CT

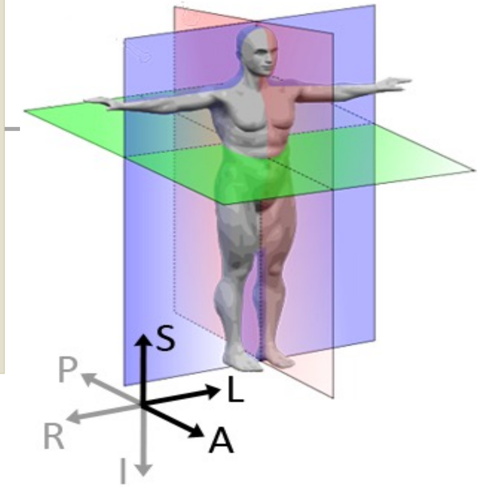


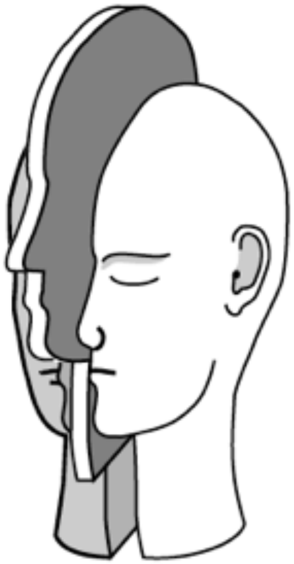




3D View Terminology



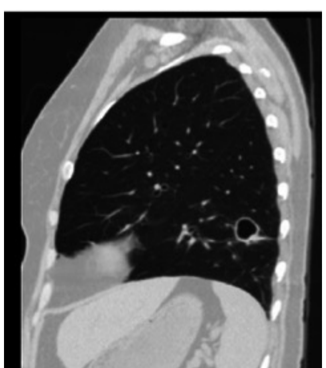




A Sagittal

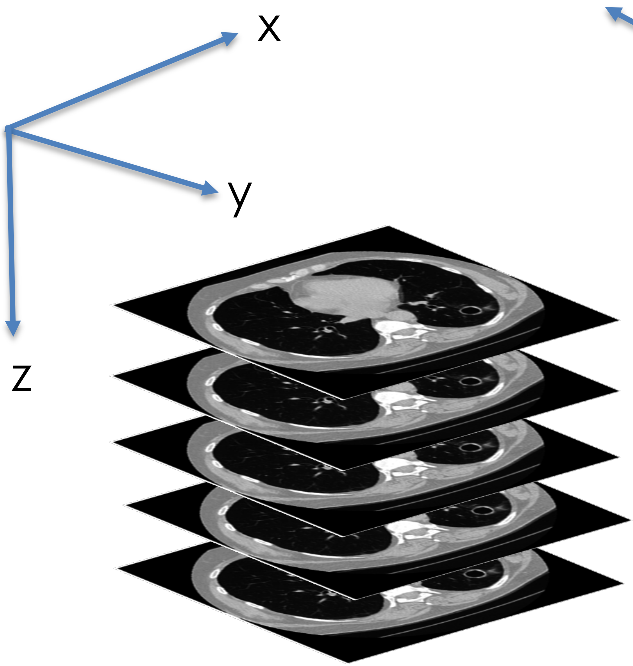
B Coronal

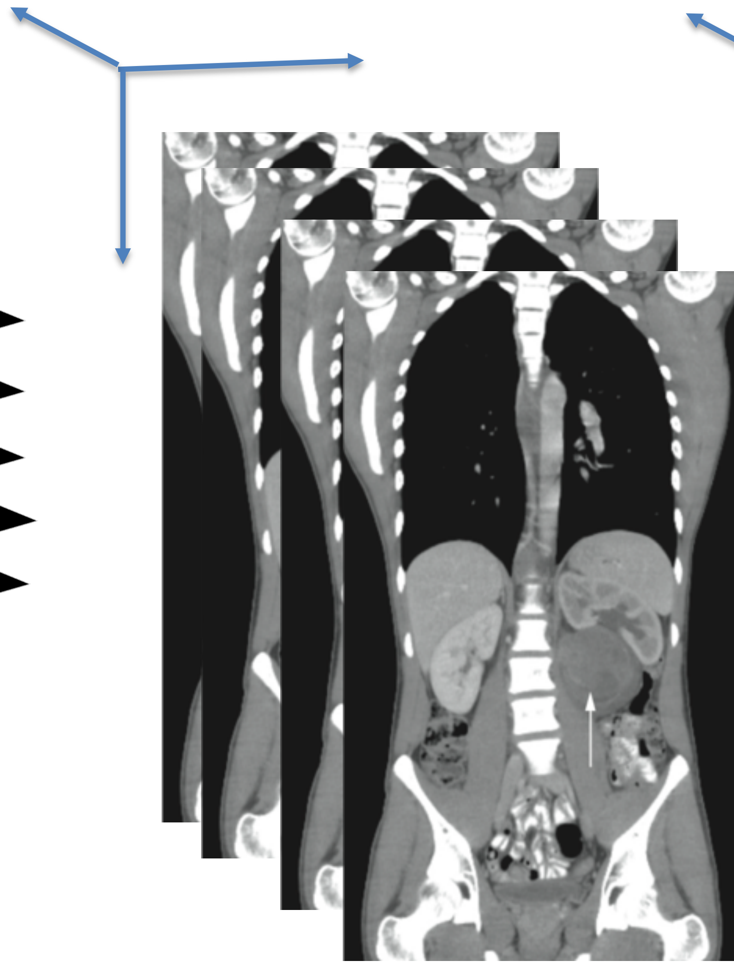
C Axial

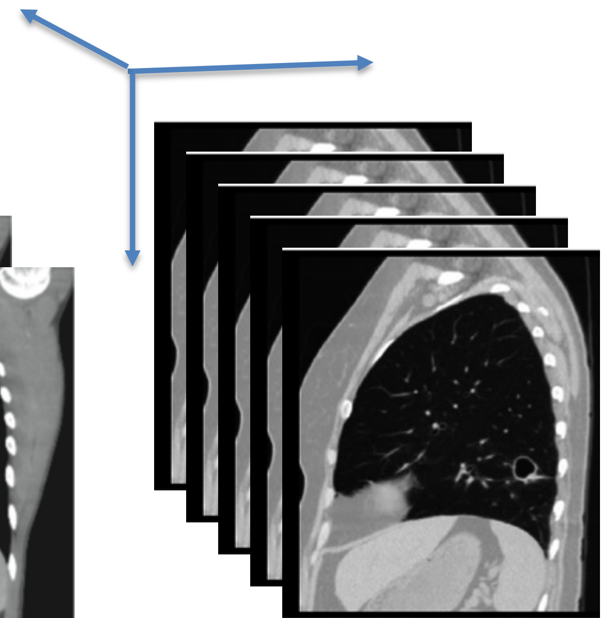


Anatomical space
R: right
L: left
A: anterior
P: posterior
I: inferior
S: superior

3D Images







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

CT Imaging Example: Tumor

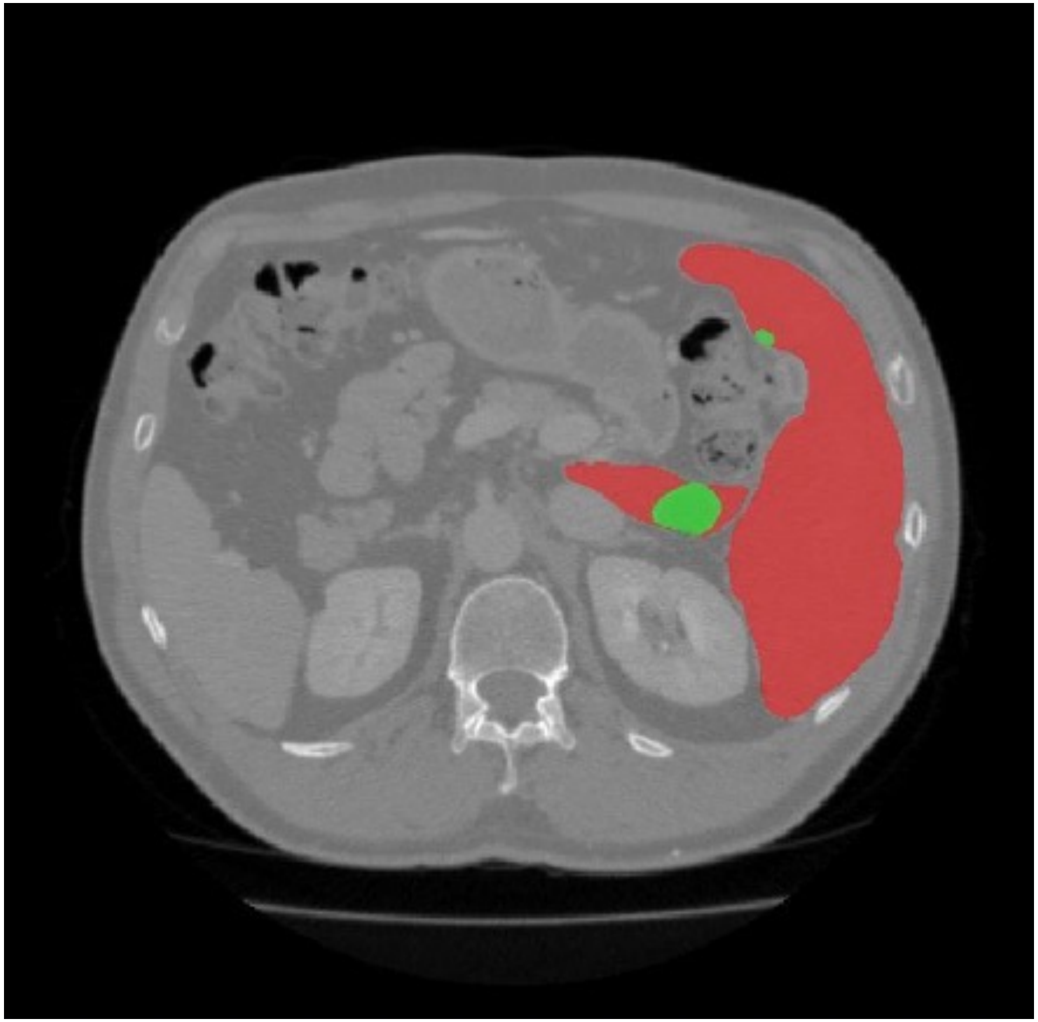
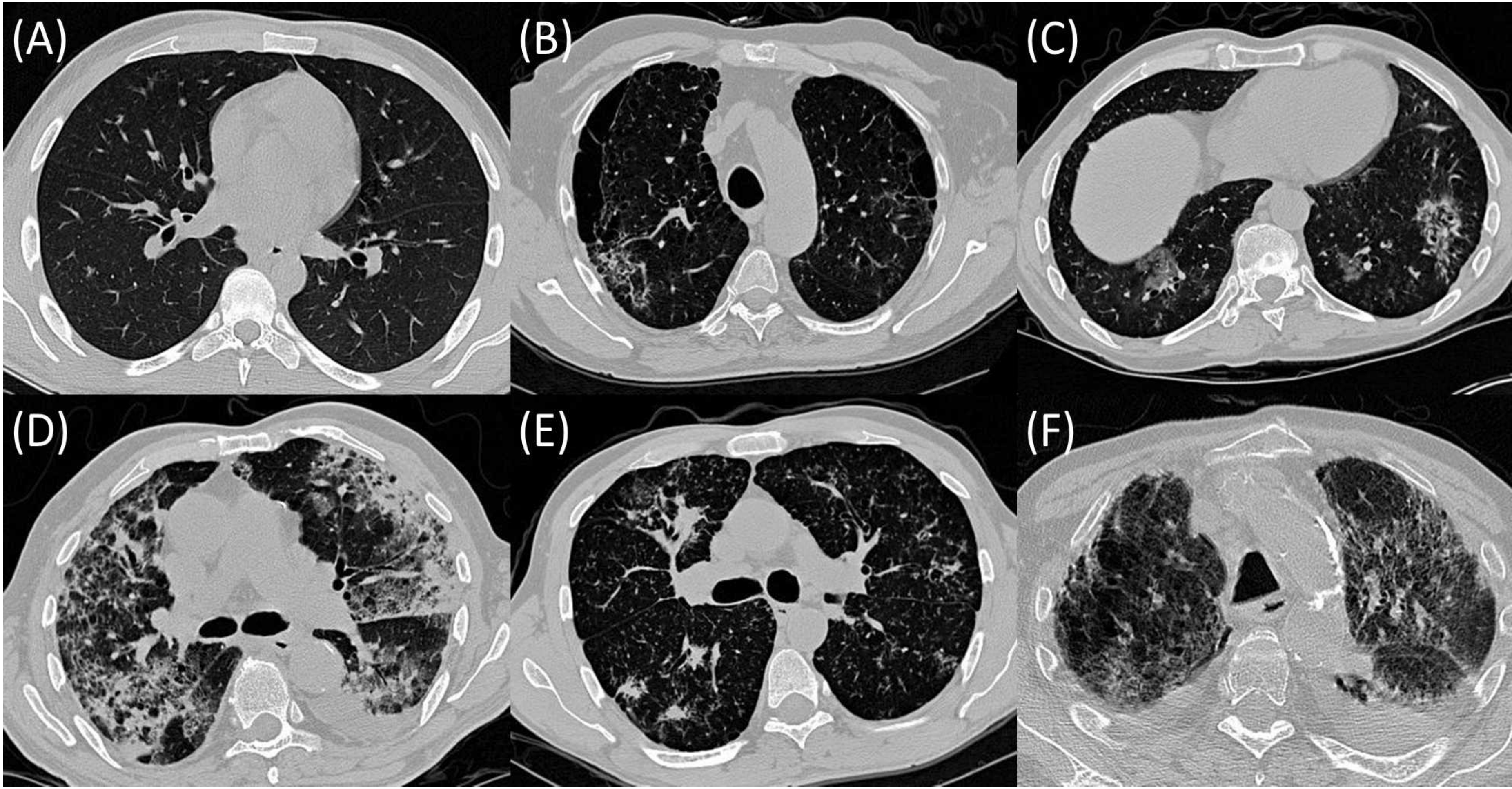


Image from the *Liver Tumor Segmentation (LiTS) 2017 challenge*

CT liver tumor segmentation
The red regions denote the liver and the green regions denote tumors

CT Imaging Example: Lung



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

Thank you!

Question?

Slides credits: some of the slides are adapted from Ali Borji, Mubarak Shah

References and Slide Credits

- P. Suetens, Fundamentals of Medical Imaging, Cambridge Univ. Press.
- **ITK.org**
- **siemens.com**
- **slicer.org**
- MRI lecture (basic): https://www.youtube.com/watch?v=jWRIKNeCXjI
- Some slides are adapted from Dr. Ulas Bagci's course materials