CAP 5516
Medical Image Computing
(Spring 2025)

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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

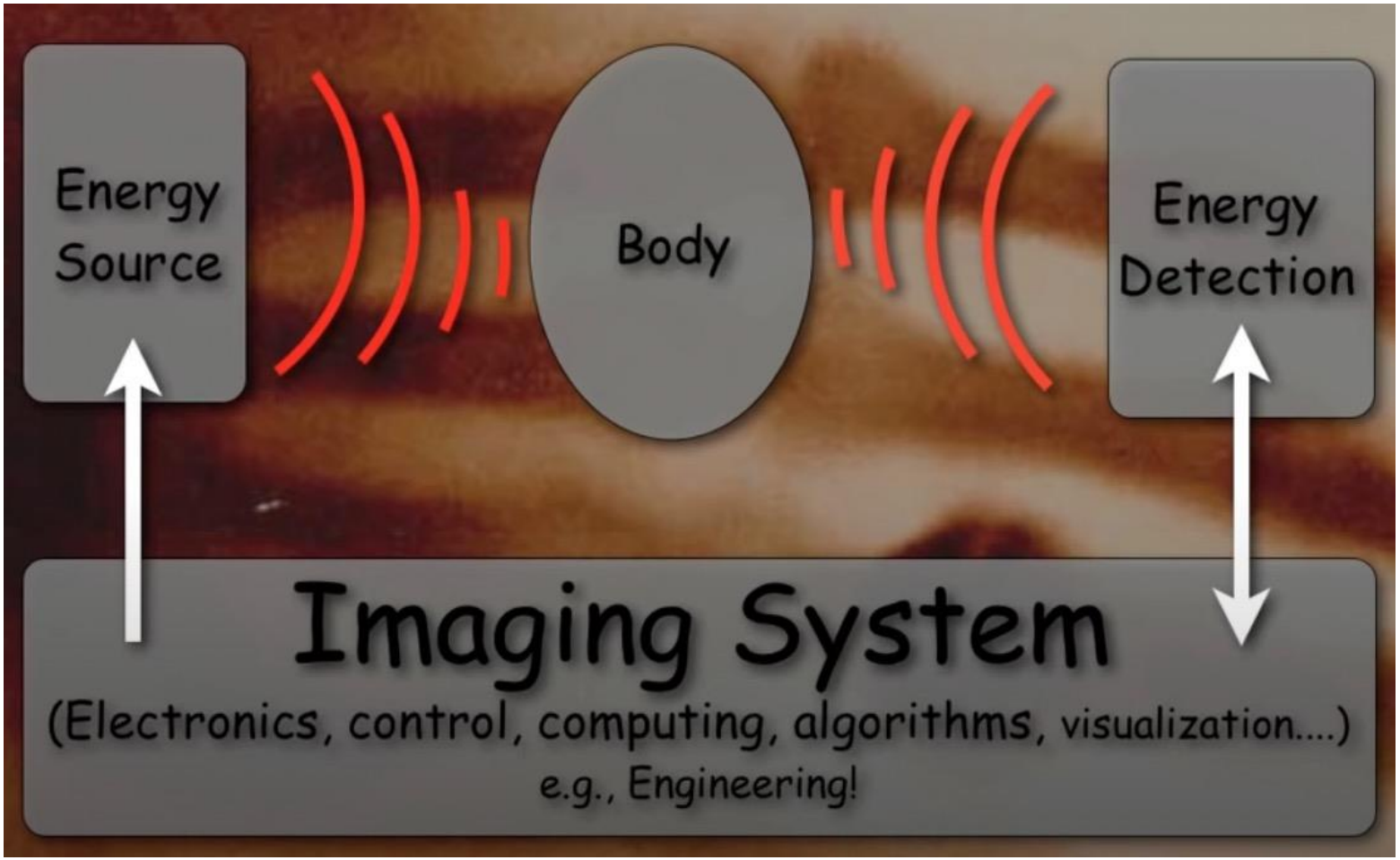
Radiology is **a branch of medicine that uses imaging technology to diagnose and treat disease**.

Medical Imaging

- What medical imaging modalities do you know?
  - **X-ray** [Electromagnetic]
  - **CT** (Computer Tomography) [Electromagnetic]
  - **Ultrasound** [Sound waves]
  - **MRI** (Magnetic Resonance Imaging) [Magnetic]
  - **Nuclear medicine imaging** (including positron-emission tomography (PET)) [Nuclear]

  …

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)

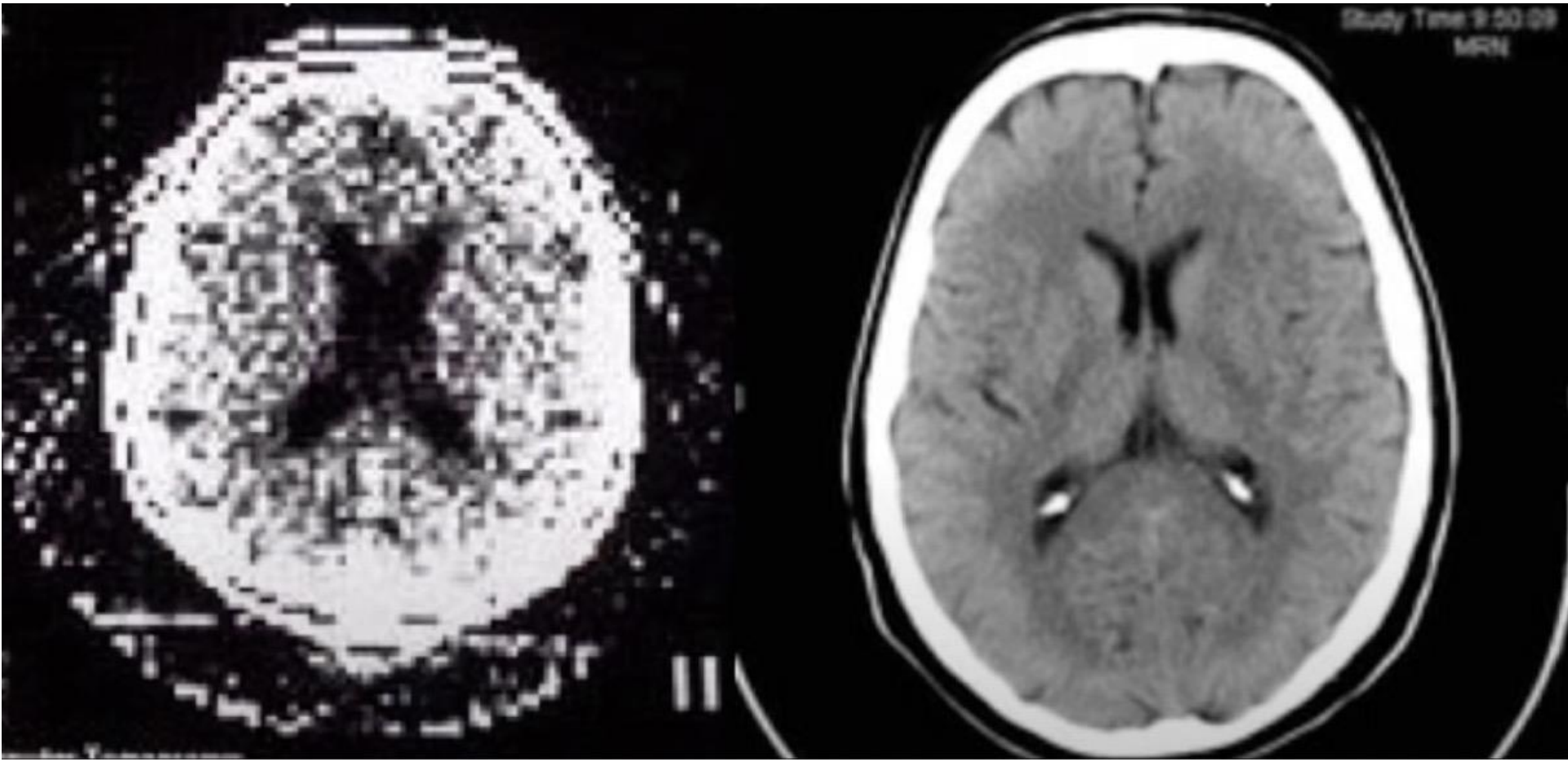
X-ray (today)

Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

Early CT (1975)

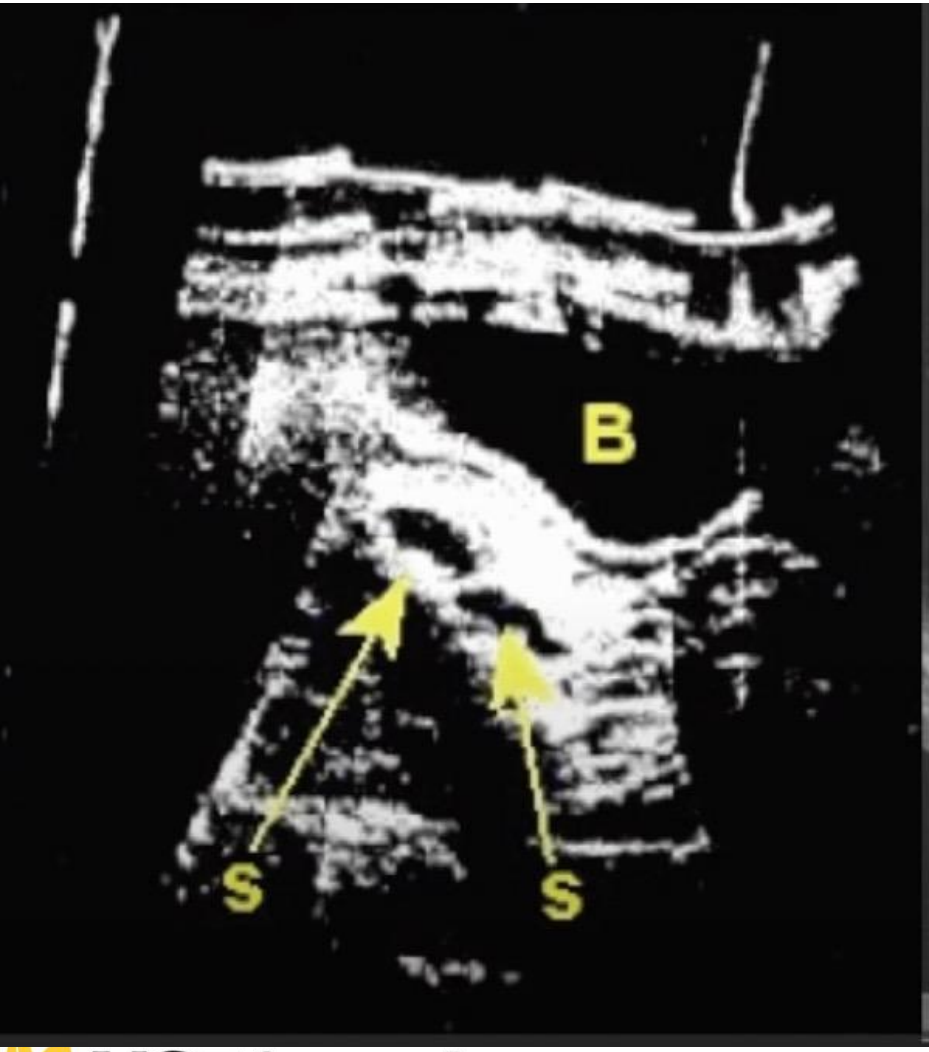
CT (today)



Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

Early ultrasound (1959)

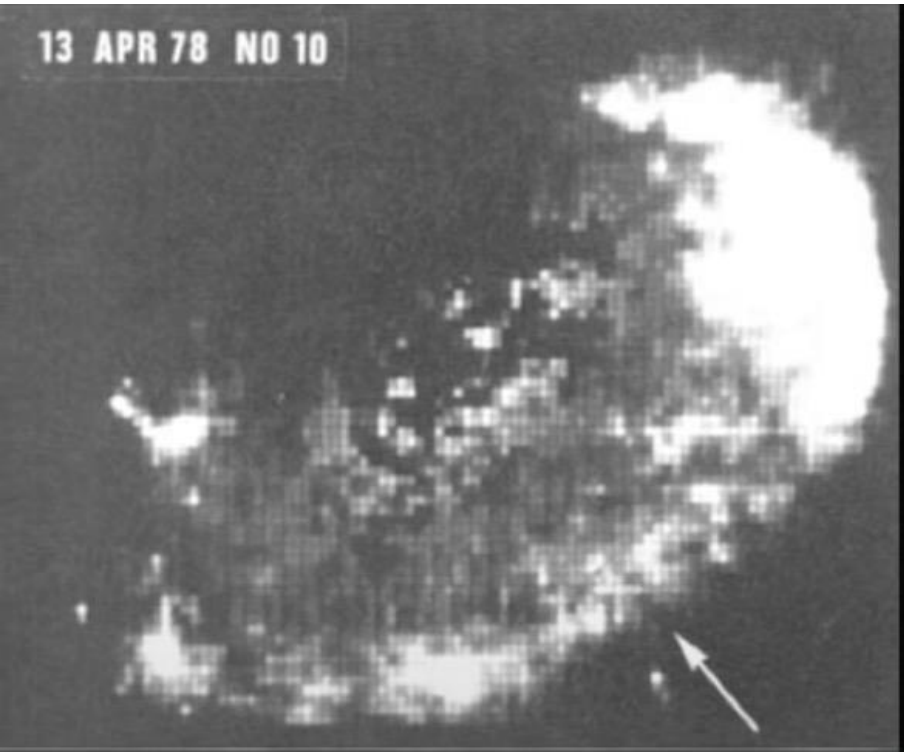


Ultrasound (today)

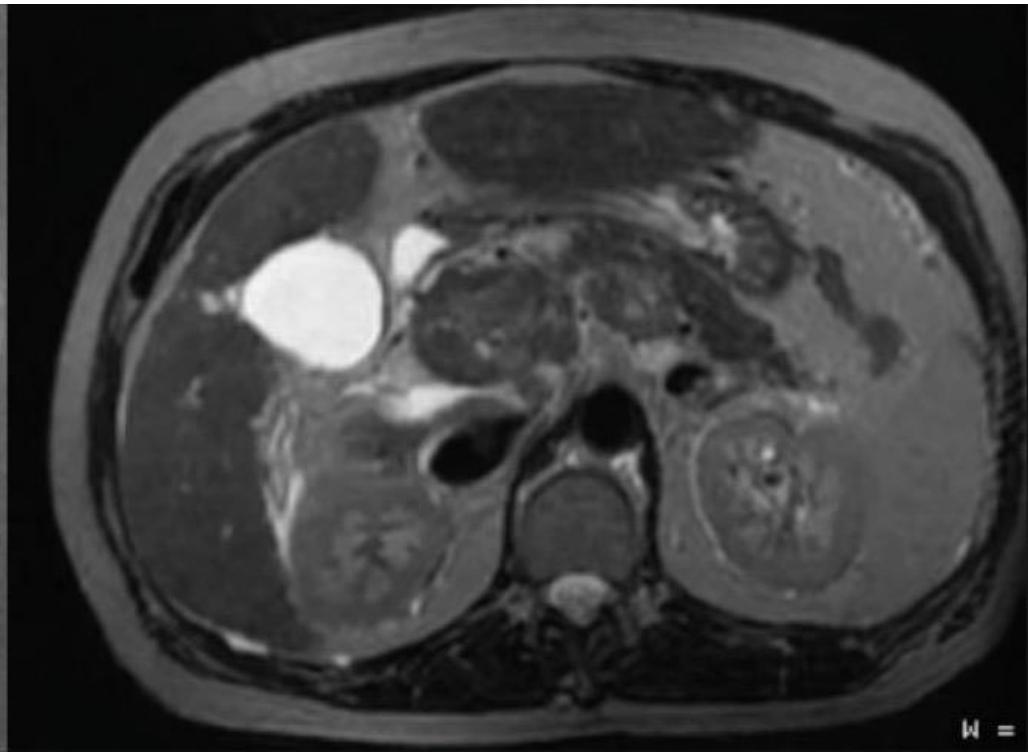
Credit: Michael (Miki) Lustig, UC Berkeley

Engineering Advances

Early MRI (1978)

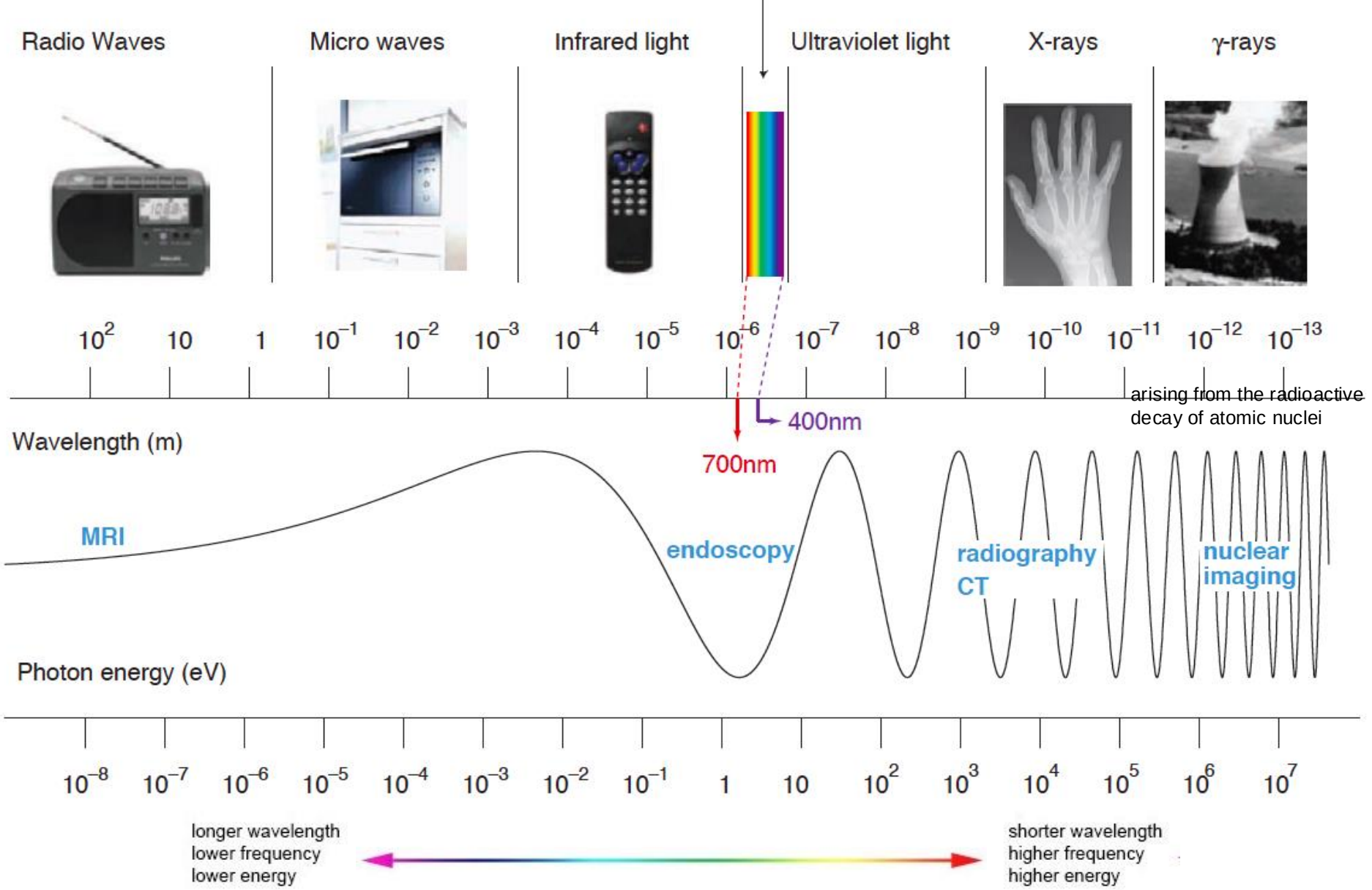


MRI (today)



Credit: Michael (Miki) Lustig, UC Berkeley

Brief Introduction to Imaging Modalities



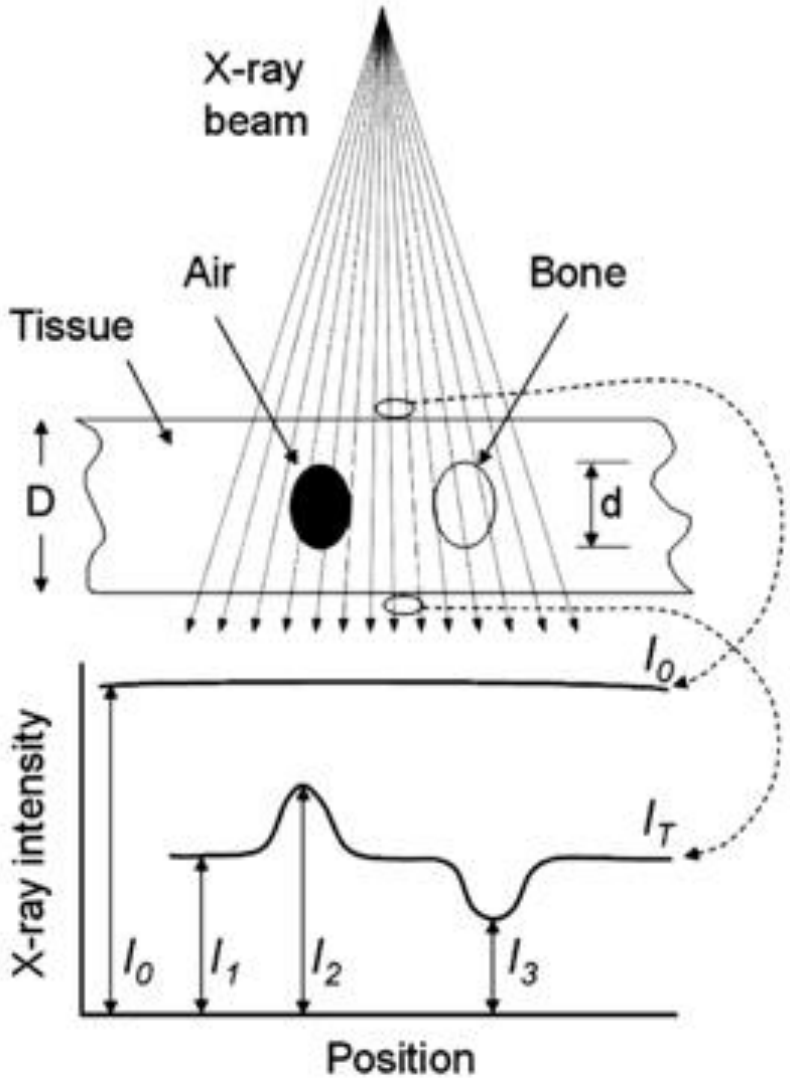
The electromagnetic (EM) spectrum is the range of all types of EM radiation. Radiation is energy that travels and spreads out as it goes.

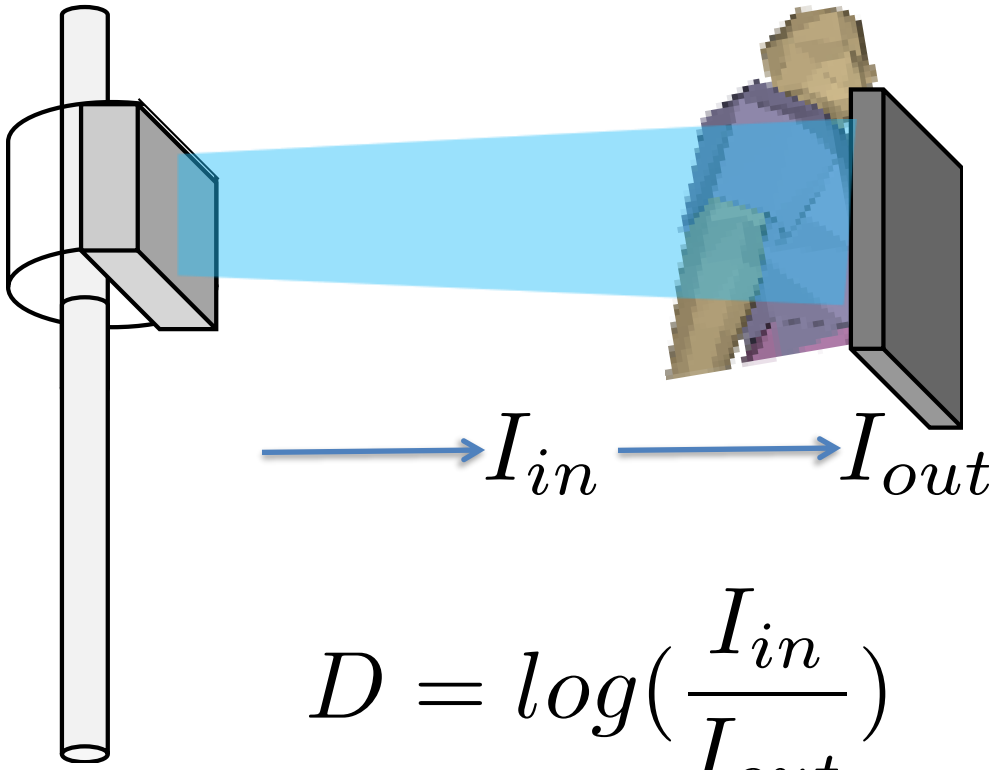
X-Ray Imaging / Radiography

- 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.*

<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

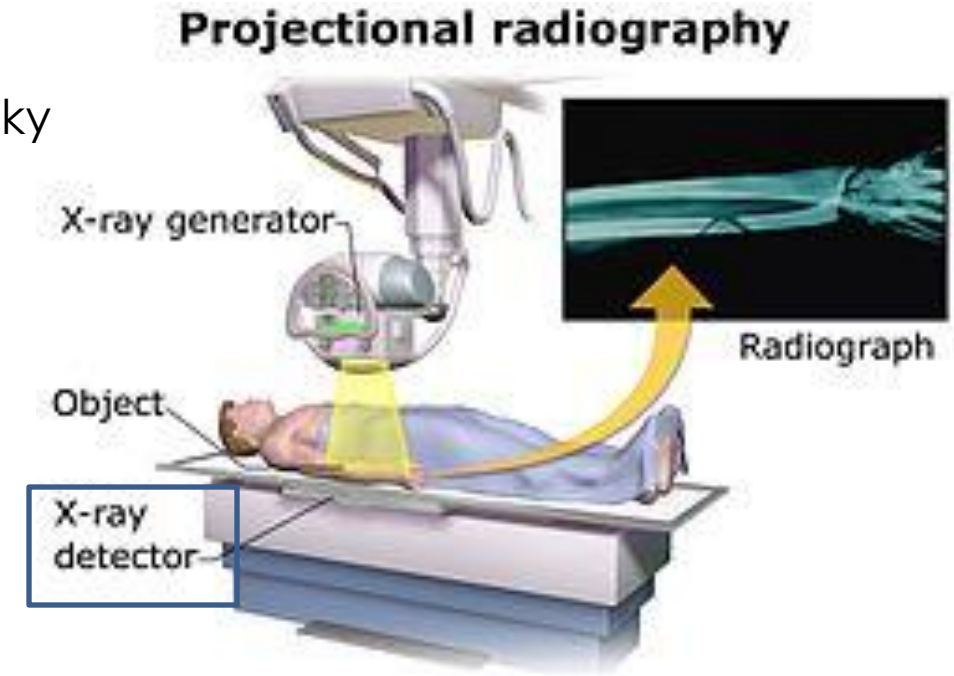


Image source: https://en.wikipedia.org/wiki/X-ray_machine

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

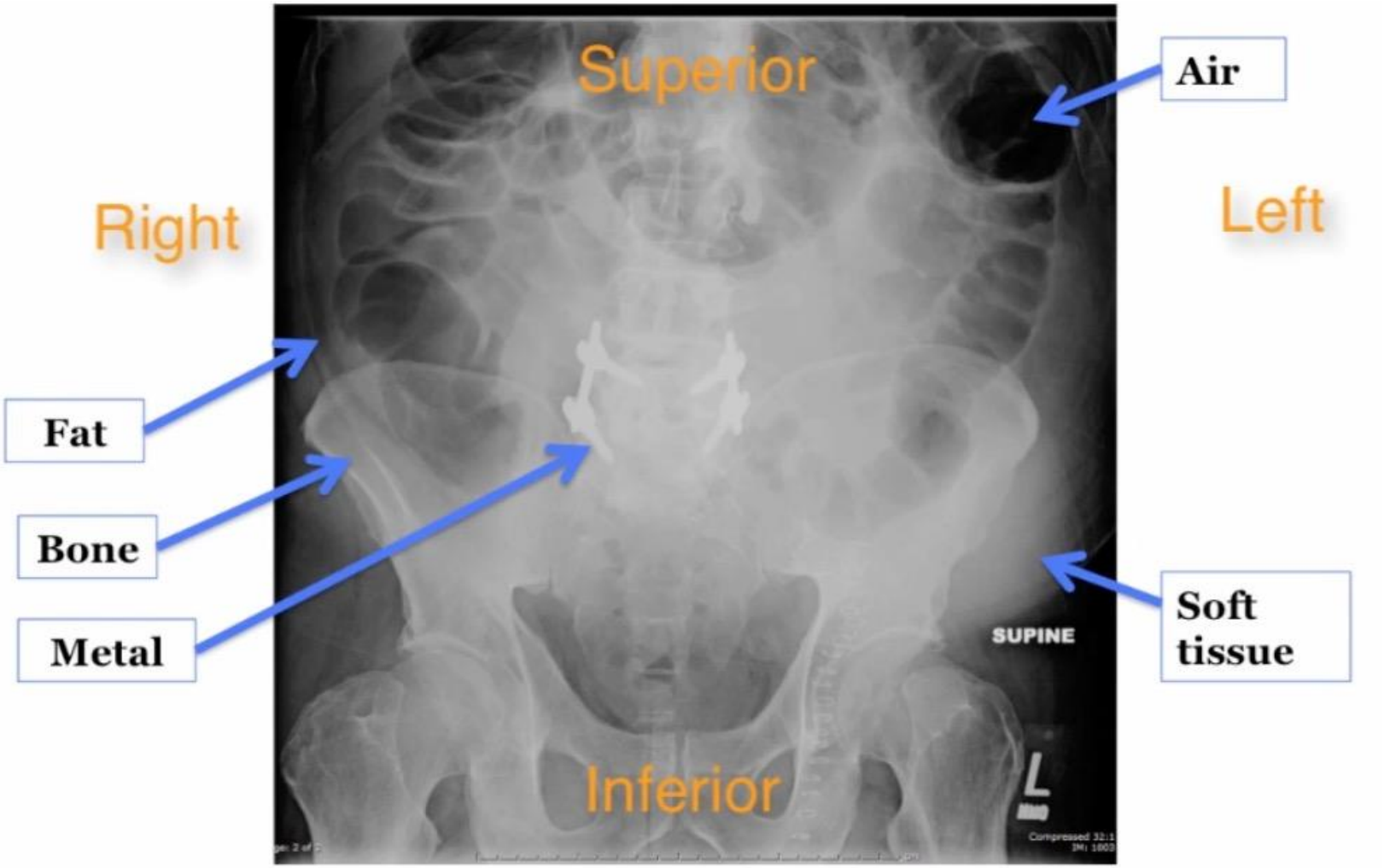
X-Ray Imaging / Radiography – 5 Basic Densities

- Air → Pass through (black)
- Fat
- Fluid/Soft tissue
- Bone
- Metal → Attenuated (bright white)

↕ Different shades of gray

Credit: Dr. Mahan Mathur, MD
Source: https://www.youtube.com/watch?v=tW2SjlMGj0Q

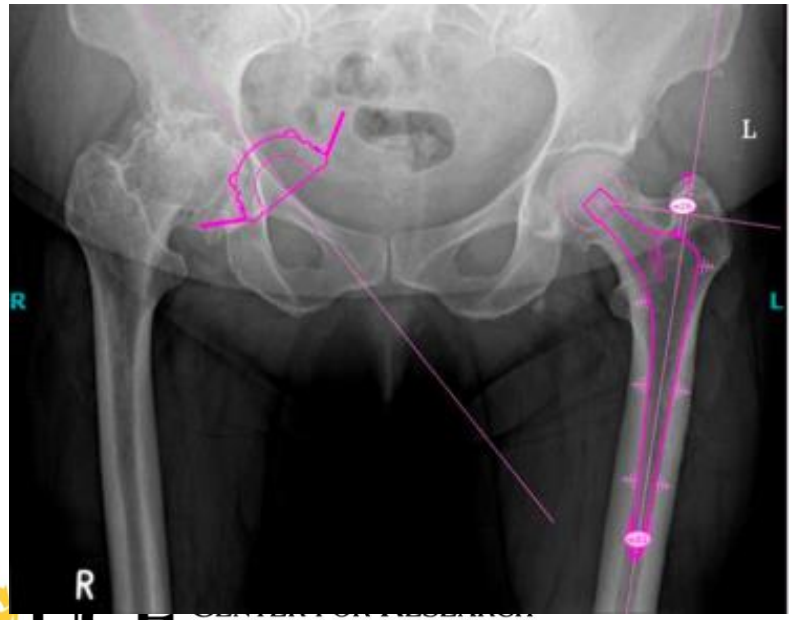
X-Ray Imaging / Radiography – 5 Basic Densities

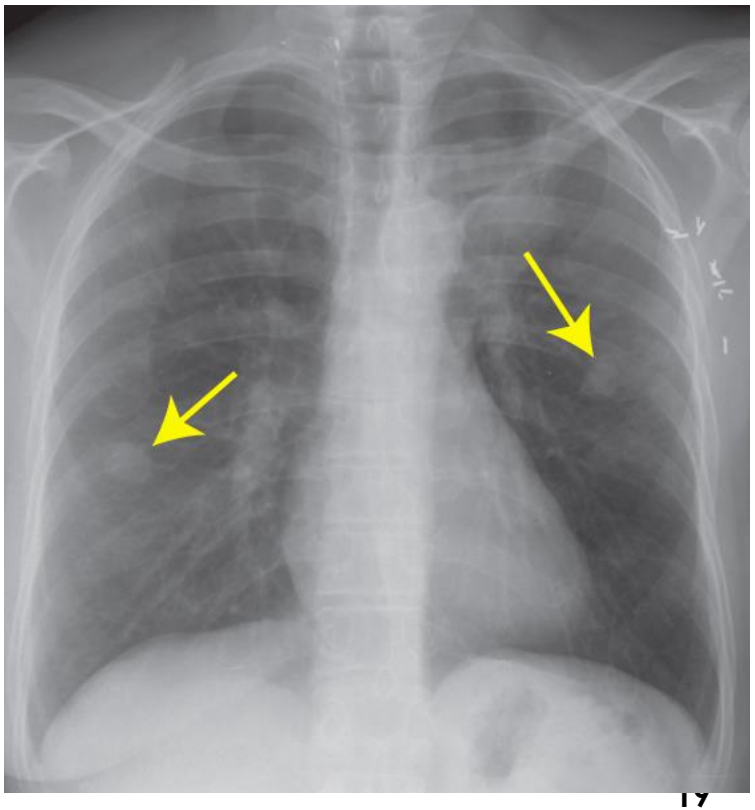


Credit: Dr. Mahan Mathur, MD
Source: https://www.youtube.com/watch?v=tW2SjlMGj0Q

Basics Use of X-Rays

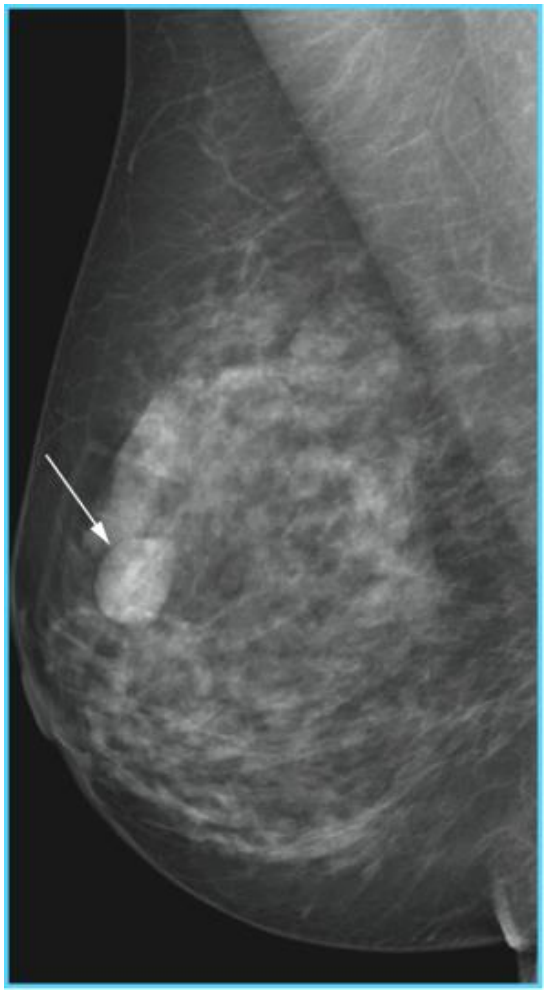
- Dental examinations
- Surgical markers prior to invasive procedures
- Mammography (A radiograph of the breast that is used for cancer detection and diagnosis).
- Orthopedic evaluations
- Chest examination (Tuberculosis (TB))
- Age estimation (forensic)





Clinical Examples – X-Rays

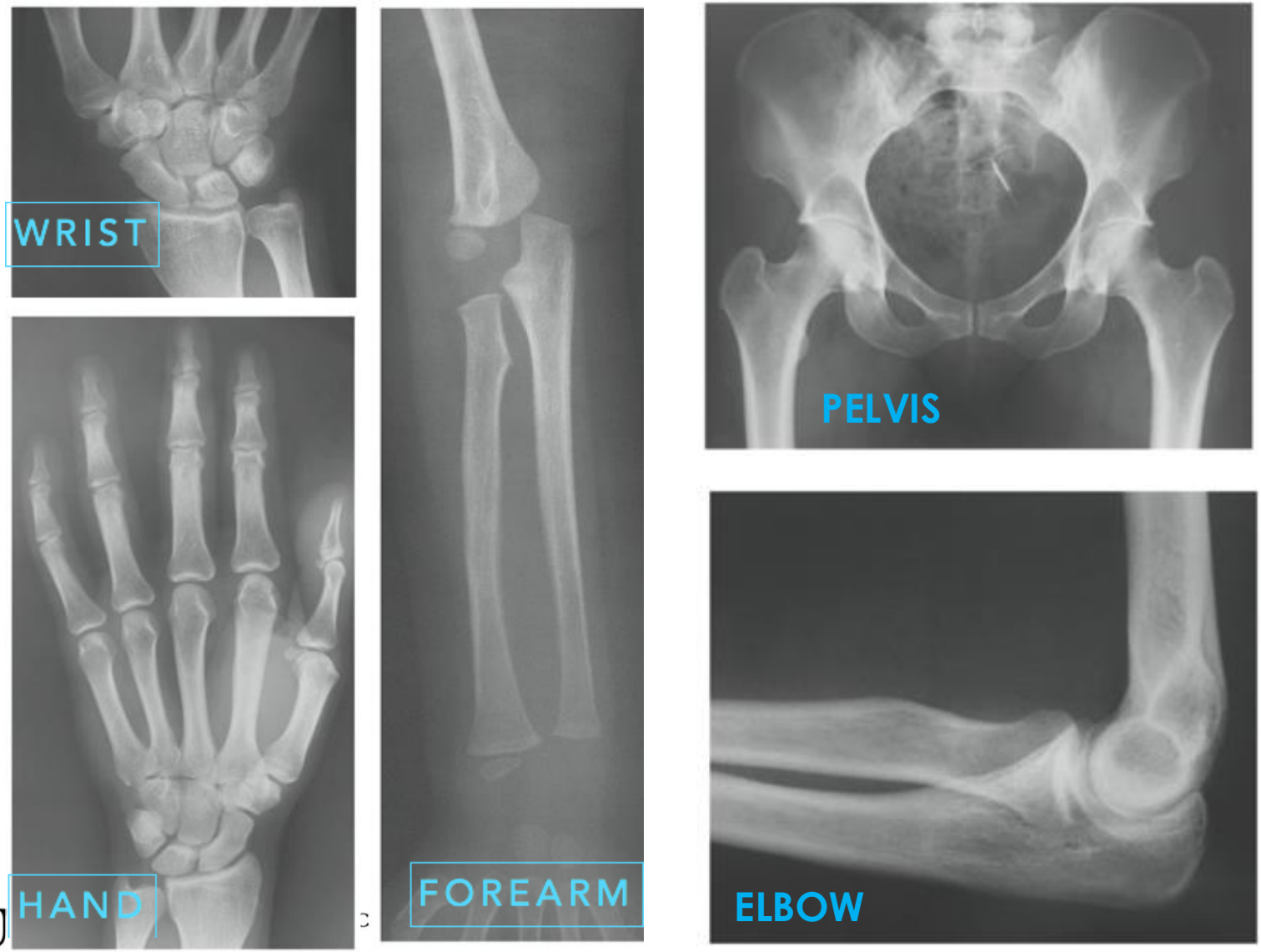
Benign
(noncancerous)



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.

Clinical Examples – X-Rays

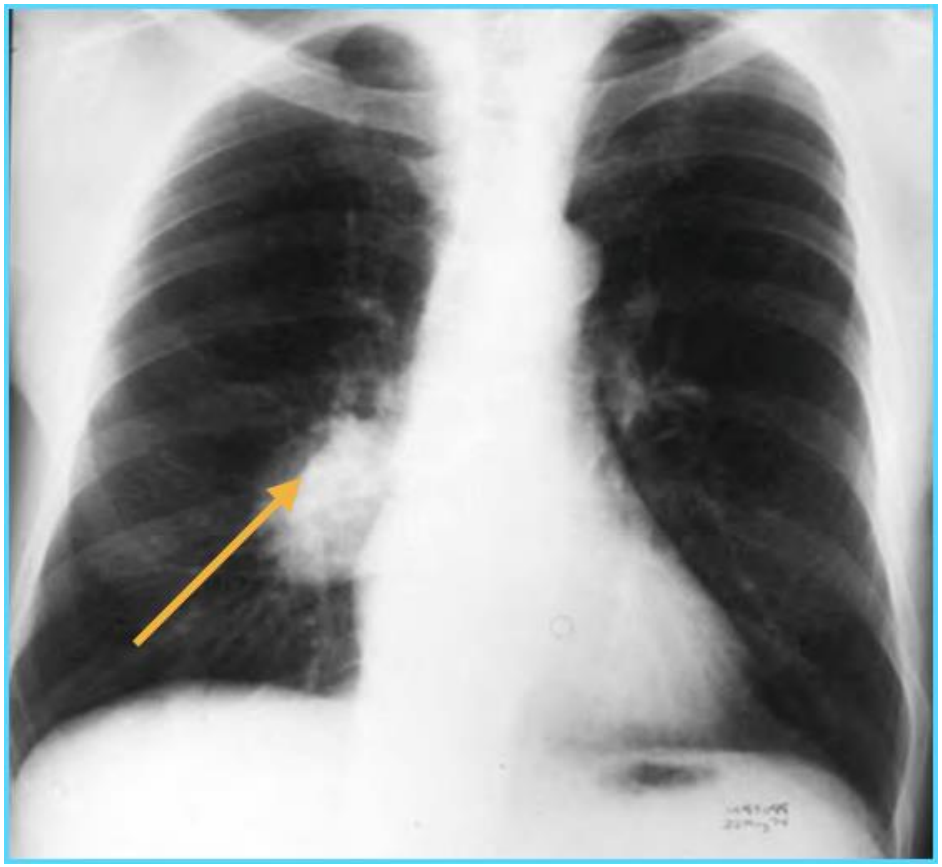


Clinical Examples – X-Rays

Fractures detection (multiple views)

Credit: Dr. Mahan Mathur, MD
Source: https://www.youtube.com/watch?v=tW2SjlMGj0Q

How Radiologists Search Abnormal Patterns in Chest X-Rays?



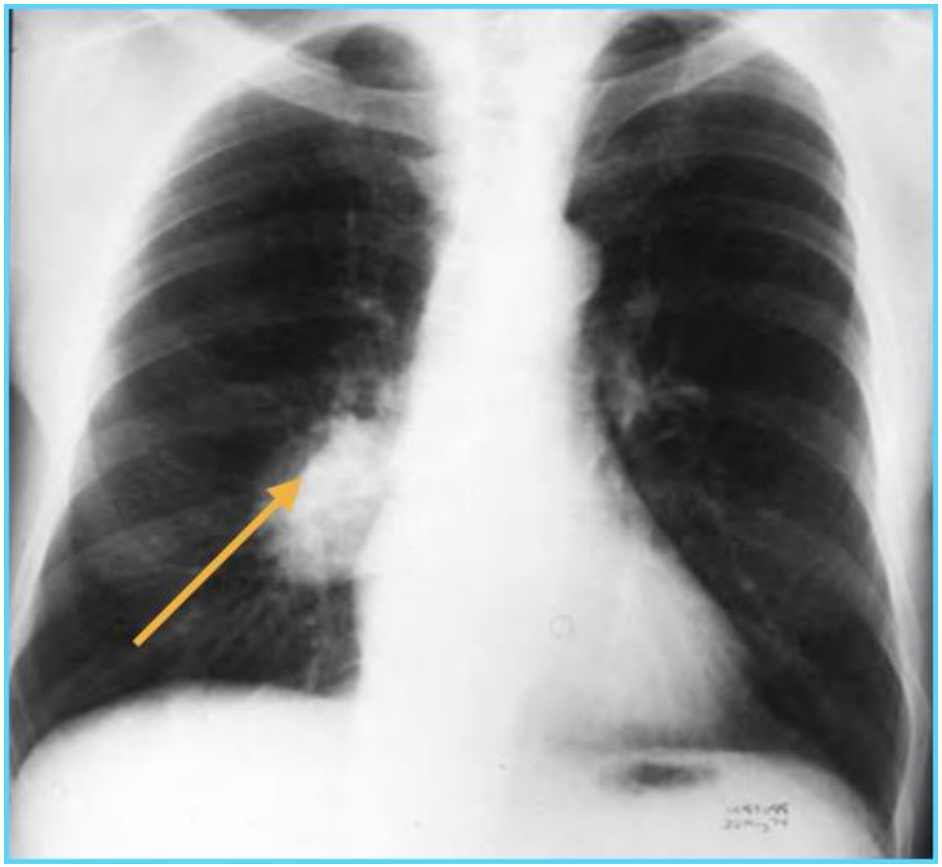
Radiologists often report the following

- 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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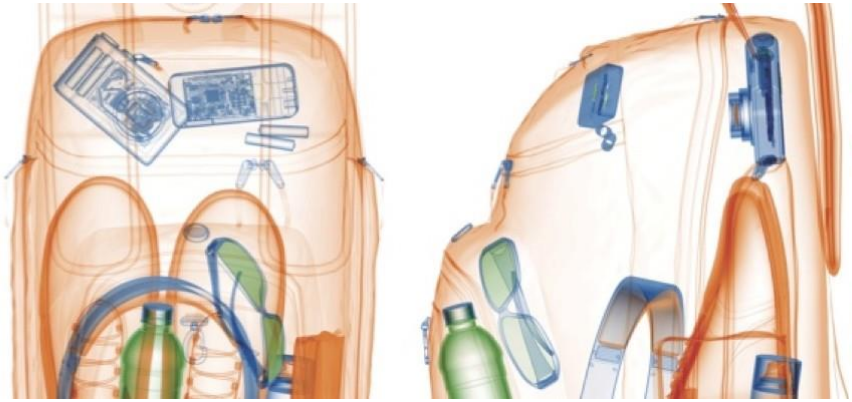
- Shadowing

Computer algorithms can solve/simplify these problems for improved healthcare

Other X-ray use cases?

X-ray for security scanning



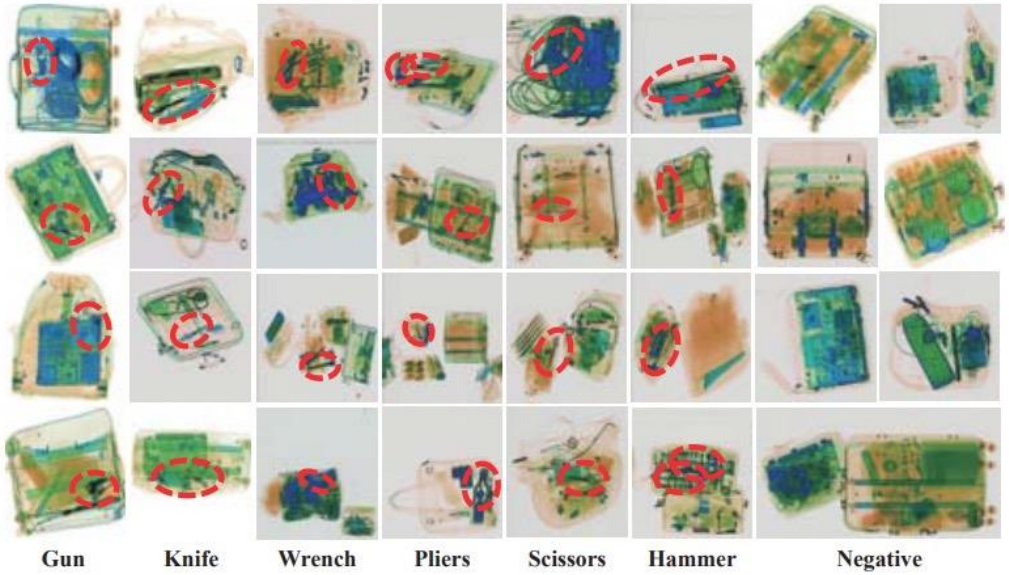
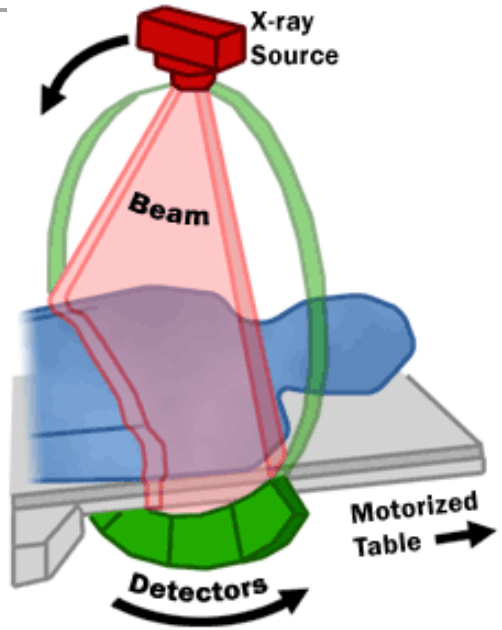


Figure 1. Example images in the presented SIXray dataset with six categories of prohibited items. Challenges include large variety in object scale and viewpoint, object overlapping and complex backgrounds (please zoom in for details).

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

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.



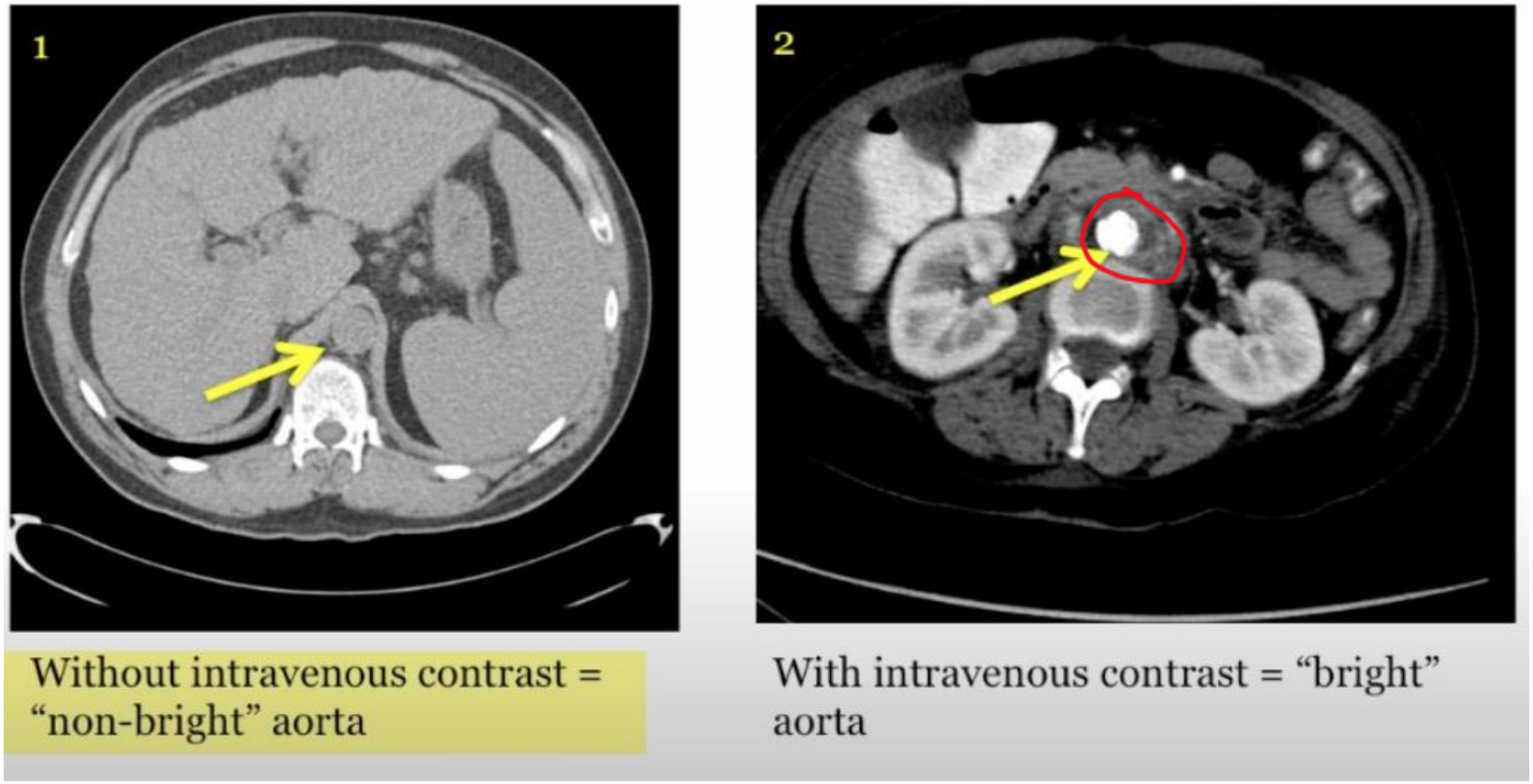
Source: https://www.fda.gov/radiation-emitting-products/medical-x-ray-imaging/computed-tomography-ct

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 (e.g. iodine or other dense materials) 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.

Computed Tomography (CT)



The aorta is a large, cane-shaped vessel that delivers oxygen-rich blood to your body.

Credit: Dr. Mahan Mathur, MD
Source: https://www.youtube.com/watch?v=SdYUniRMtz4

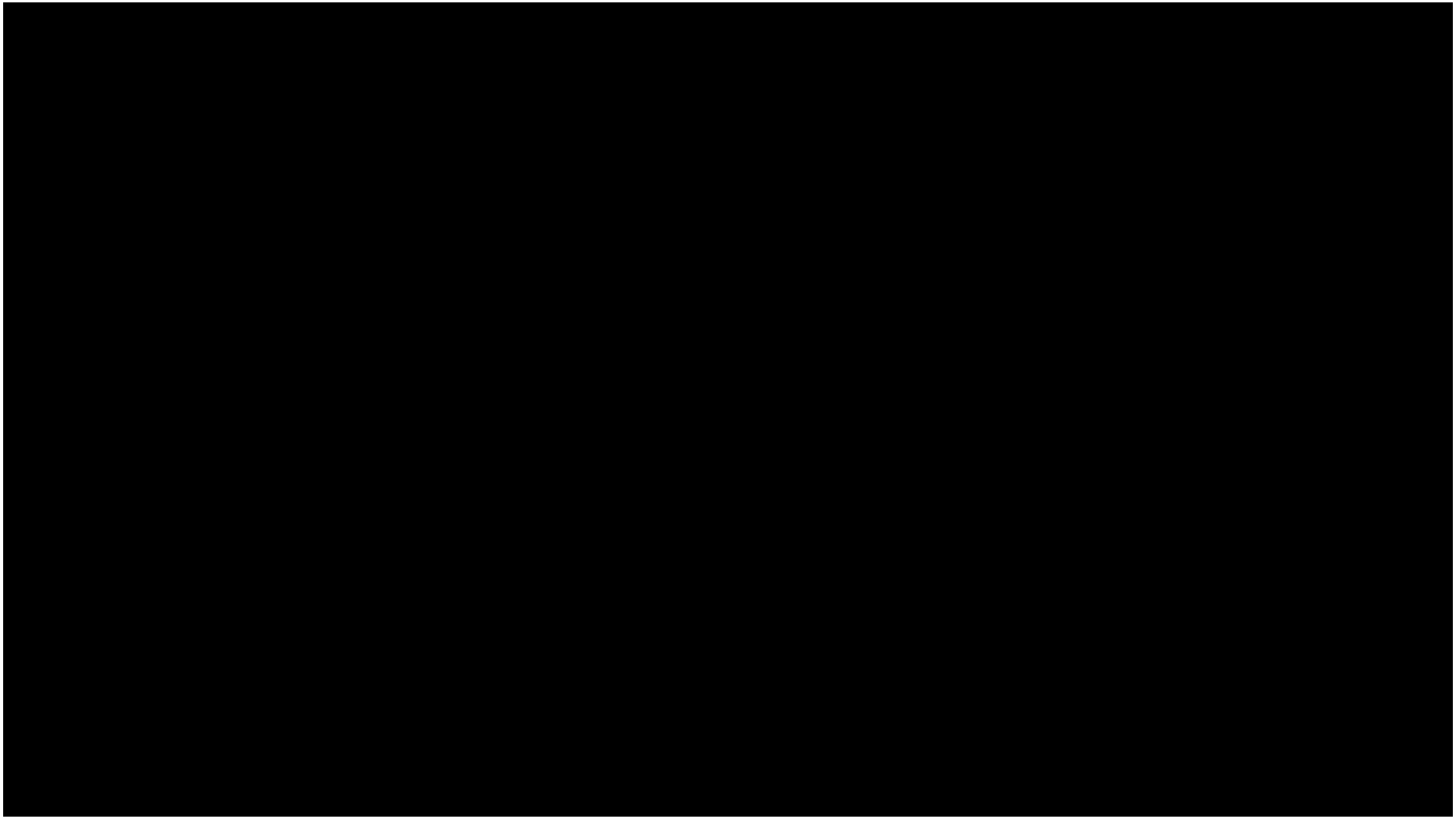
CT Imaging

C-arm

CT

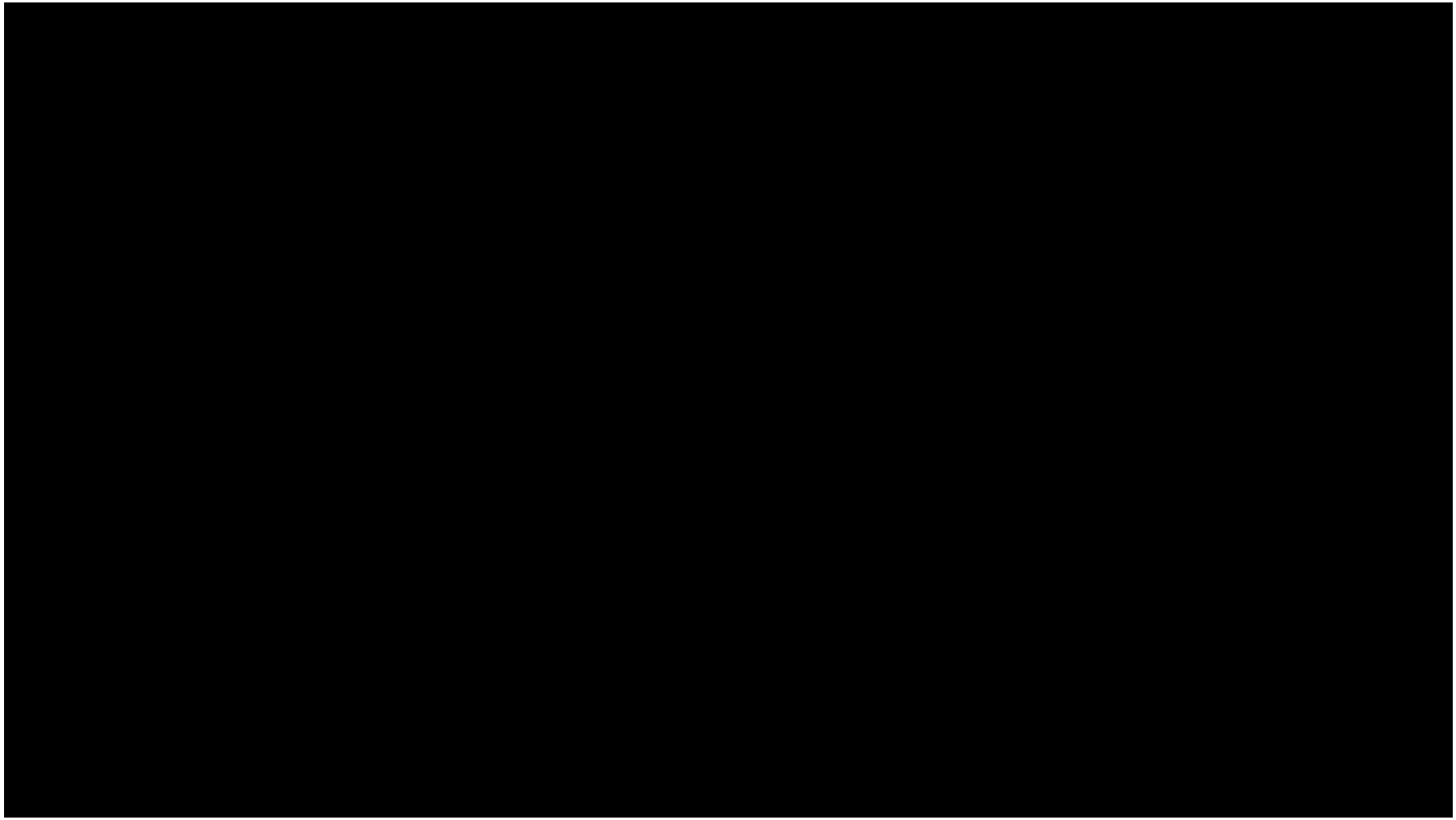
Micro-CT

CT Imaging



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

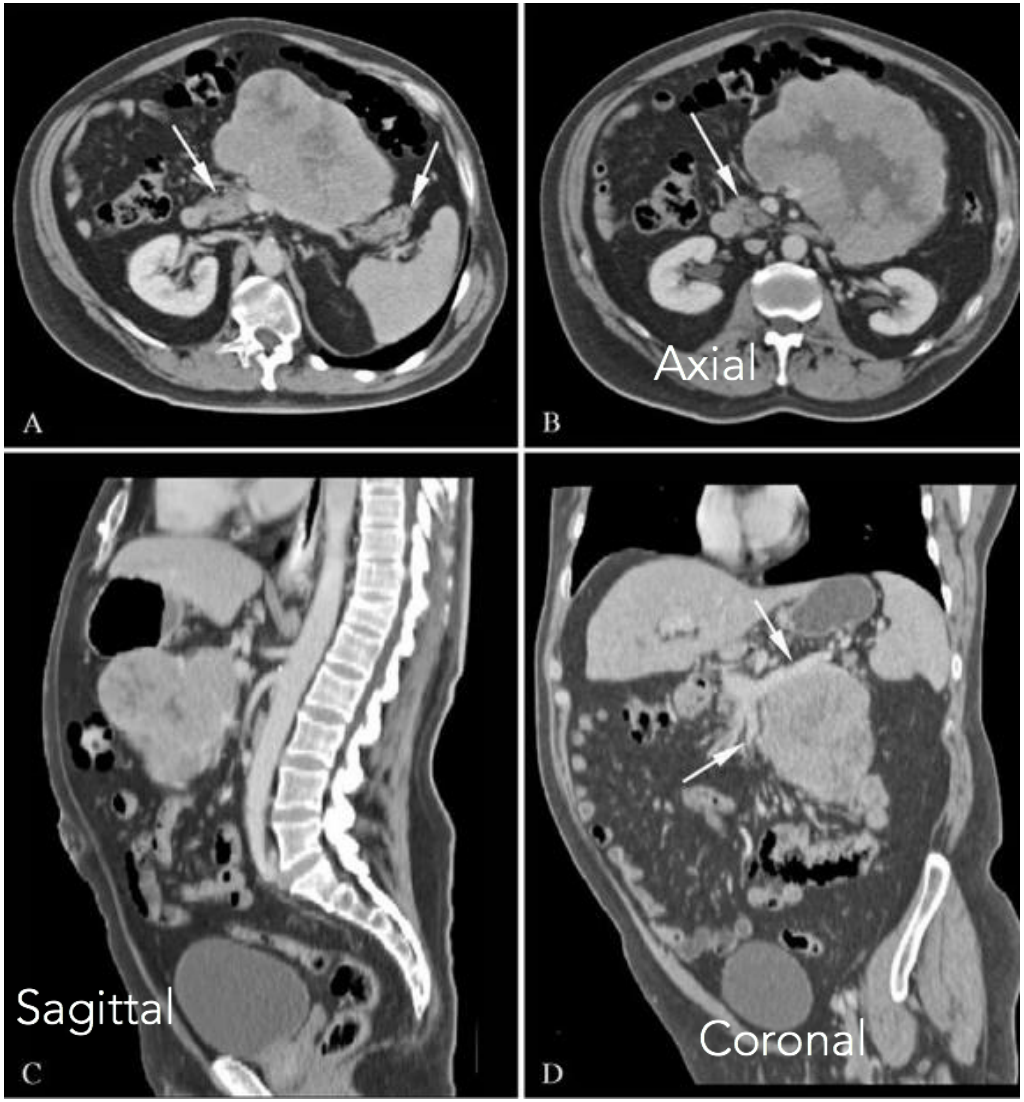
CT Imaging

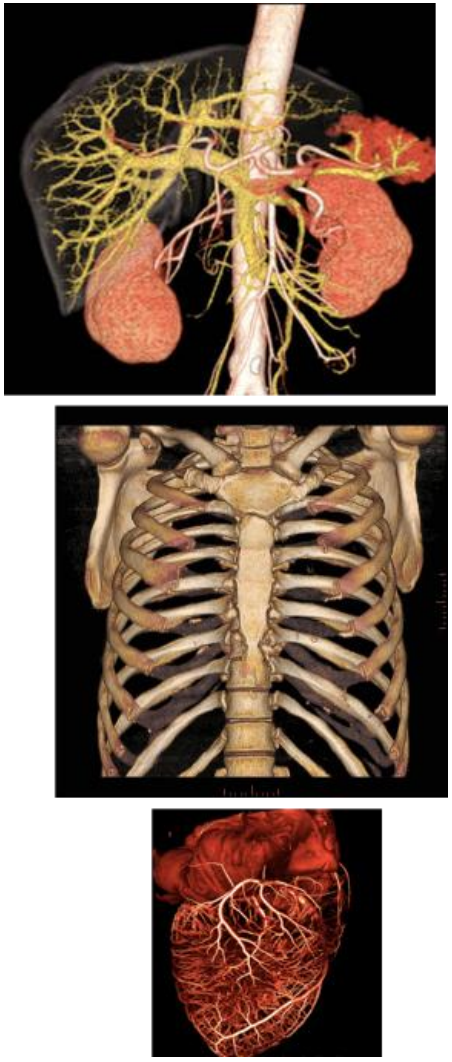


Radiographer Films Inside of a CT scanner spinning at full speed

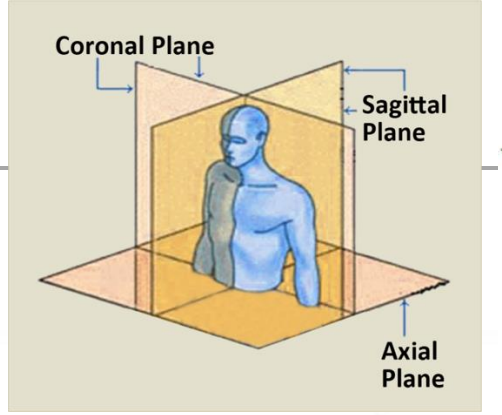
Source: https://www.youtube.com/watch?v=pLajmU4TQuI

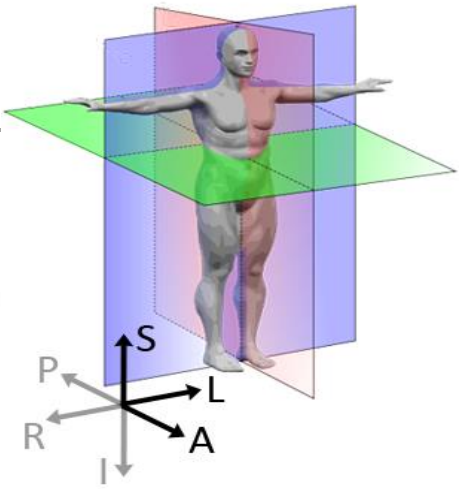
3D Nature of CT





3D View Terminology



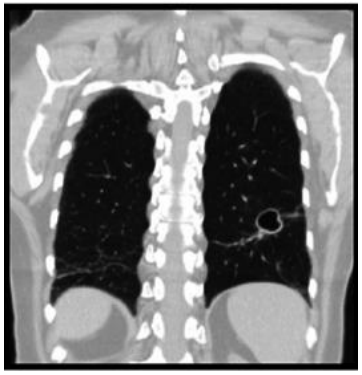


(L,R)

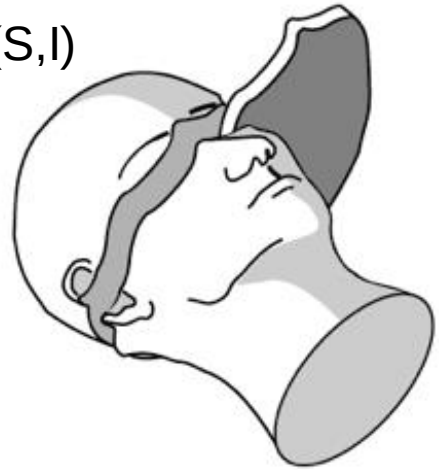
A Sagittal

(A,P)

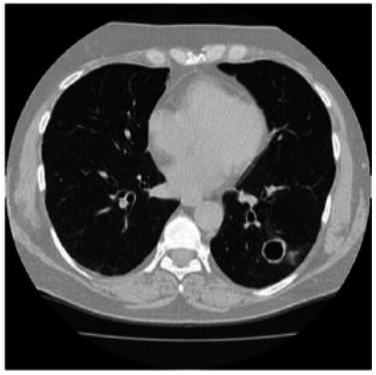
B Coronal



(S,I)

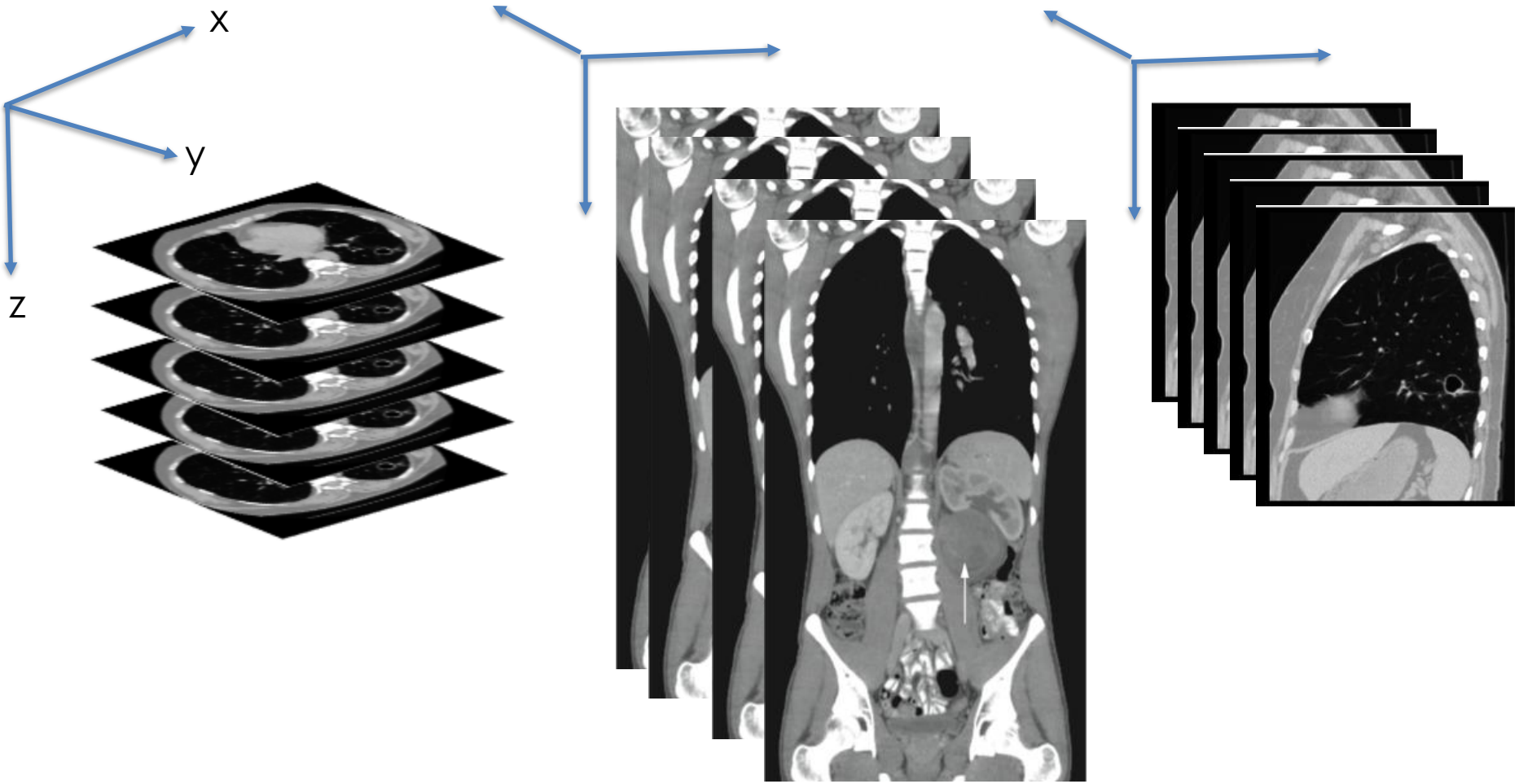


C Axial



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

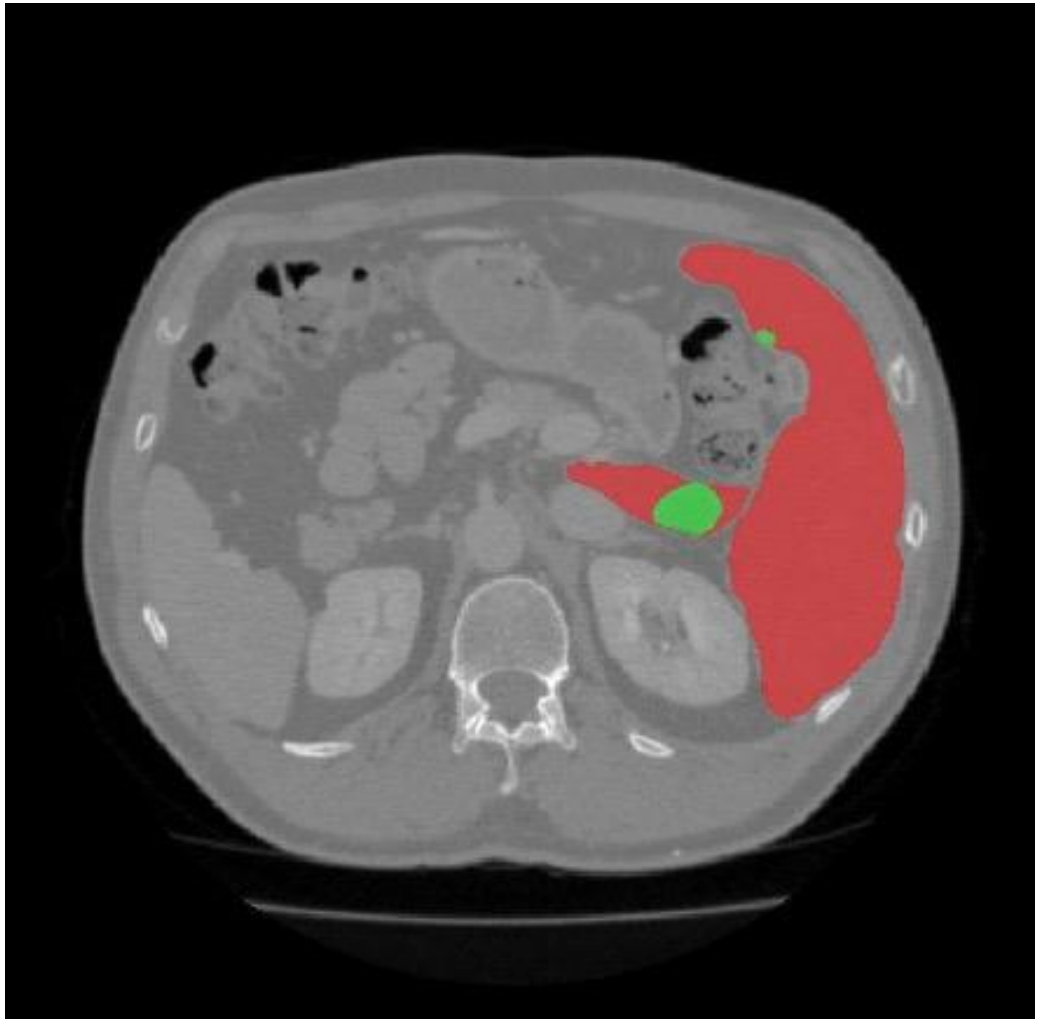
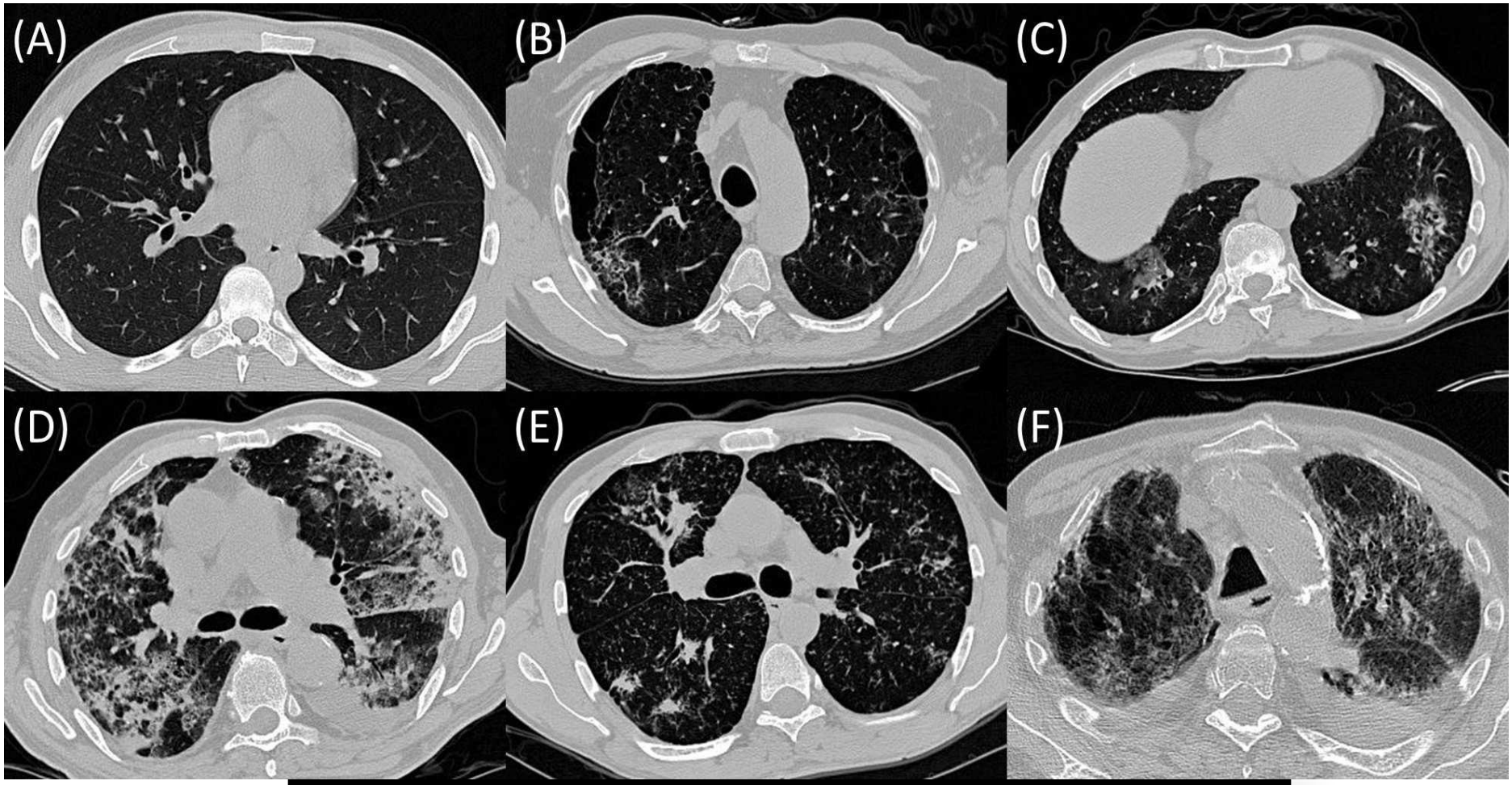


Image from the *Liver Tumor Segmentation (LiTS) 2017 challenge*

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

Summary (X-ray vs. CT)

X-ray

- **How it Works**: A single X-ray beam passes through the body, creating a 2D image (like a shadow).
- **Pros**:
  - Quick & widely available
  - Lower cost & lower radiation dose
- **Cons**:
  - Overlapping structures can hide details
  - Limited soft tissue detail
- **Use Cases**: First-line for fractures, chest/lung checks, basic skeletal exams

Summary (X-ray vs. CT)

CT

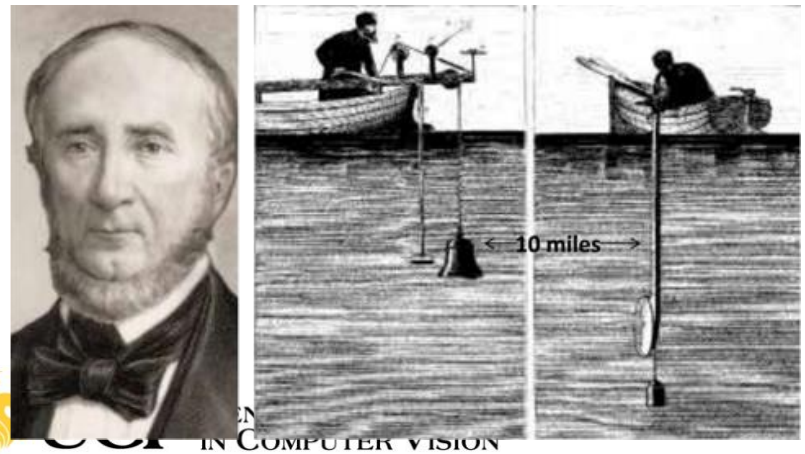
- **How it Works**: Multiple X-ray projections taken at different angles are reconstructed into cross-sectional (slice) images and 3D volumes.
- **Pros**:
  - Detailed, slice-by-slice view
  - Better soft tissue contrast
  - 3D reconstruction capability
- **Cons**:
  - Higher radiation dose
  - More expensive & larger equipment
- **Use Cases**: Trauma assessment, tumor detection, vascular imaging, surgical planning

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

Used for submarine navigation throughout the early 20th century



Came into medical use towards 1950s

Credit: Dr. Mahan Mathur, MD

US Imaging Technology

1942-Karl Dussik - Neurologist

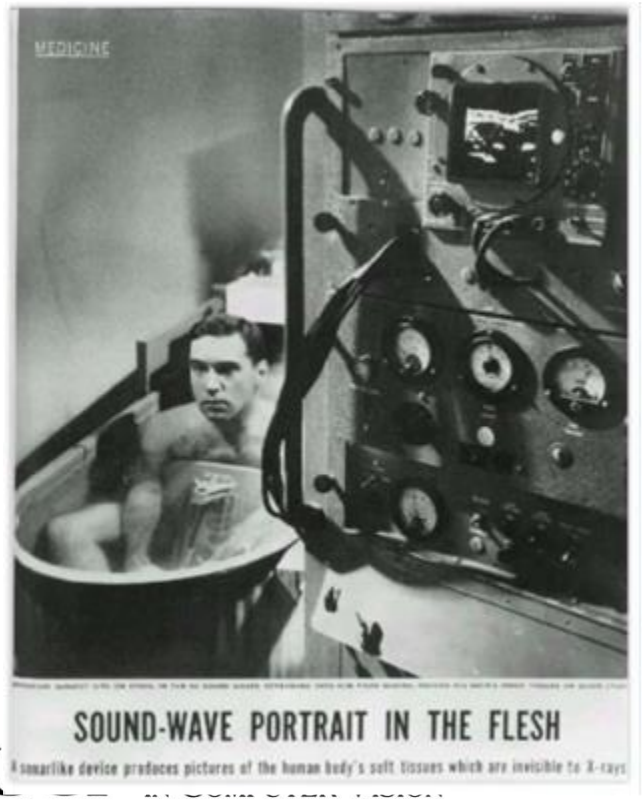
First physician to use US for medical diagnosis

1948-George Ludwig - MD

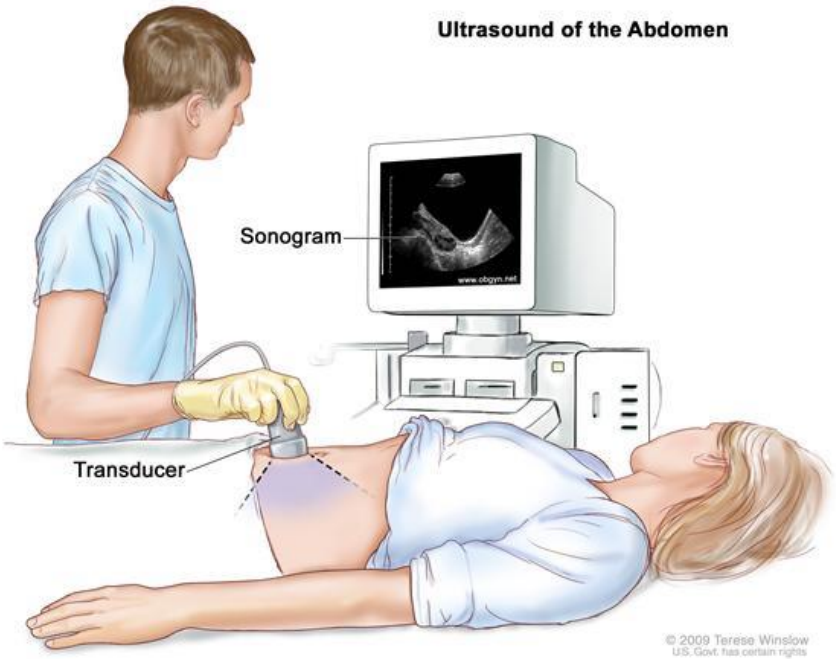
First described the use of US to diagnose gallstones

1958-Ian Donald

Pioneers in OB-GYN



Principle of US Imaging

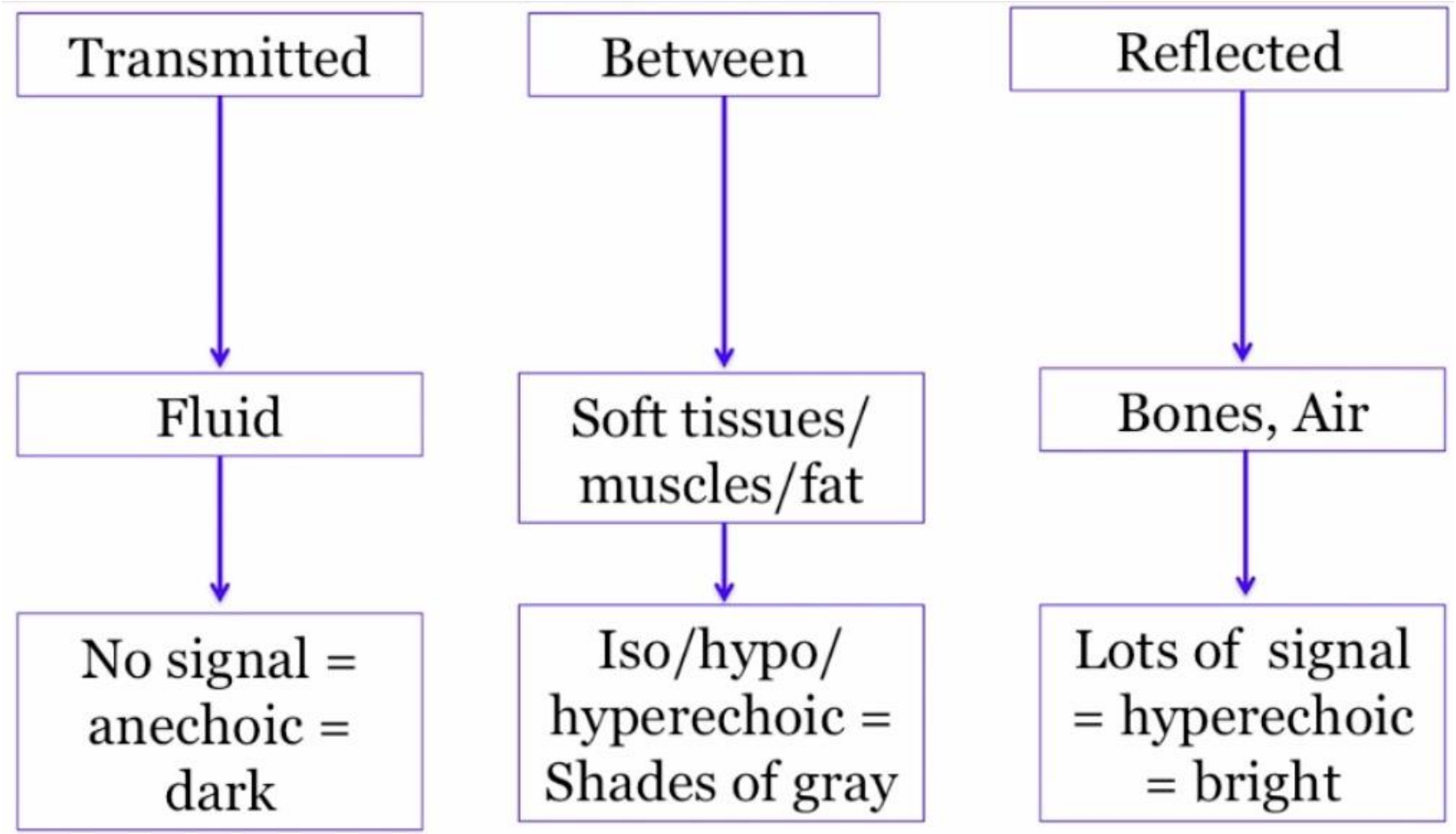


An ultrasound transducer

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.
- 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.

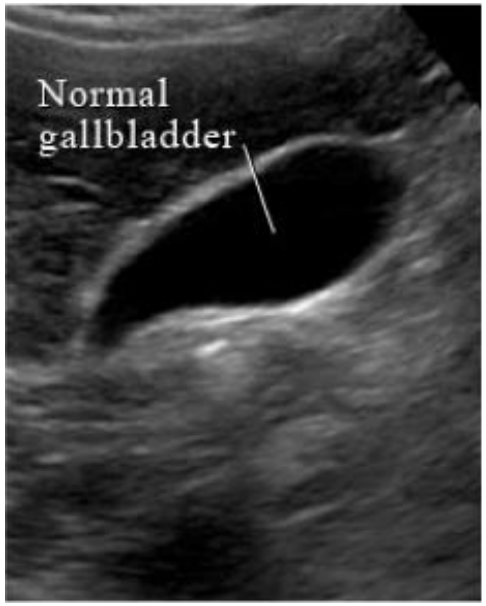
Principle of US Imaging



Credit: Dr. Mahan Mathur, MD
Source: https://www.youtube.com/watch?v=gT0zV0XYKek&t=14s

Features of US Imaging

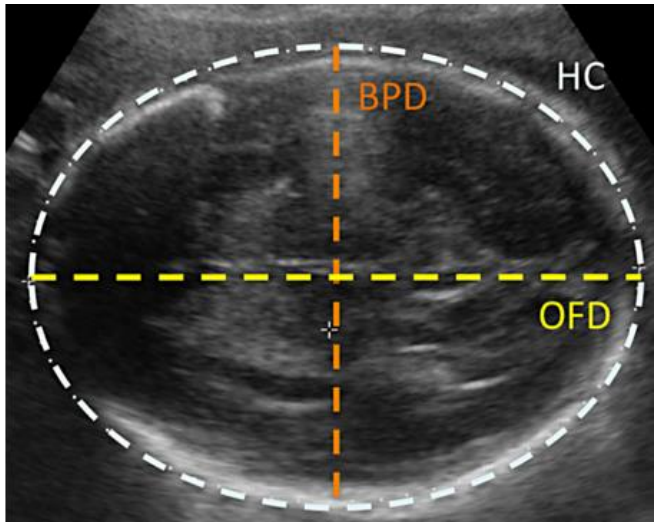
- Resolution:
  - **low resolution** and low SNR in deep region
- Ability of **imaging soft tissue**
- imaging in **real time**

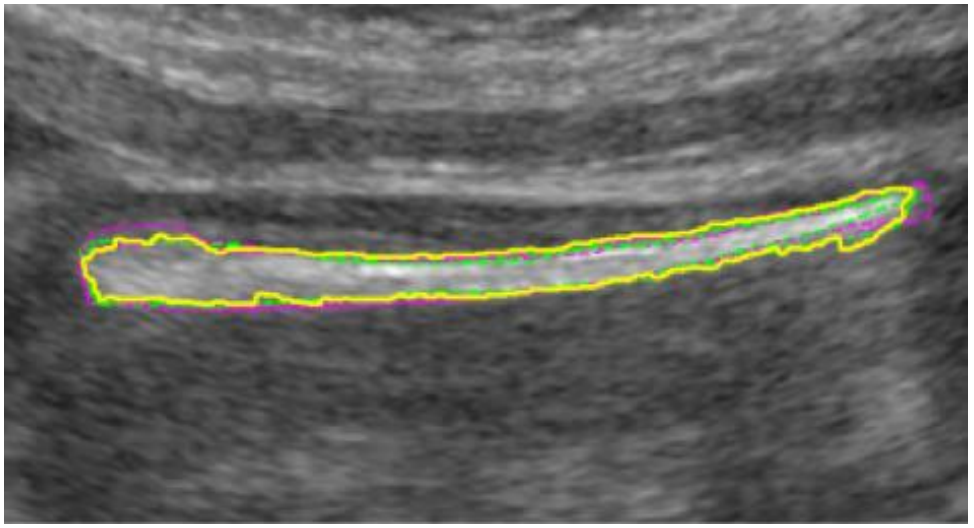


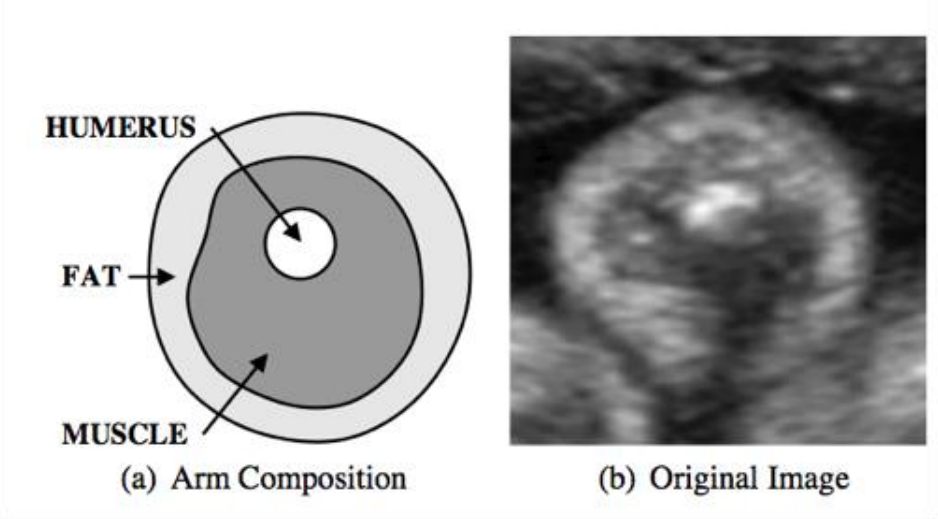
Clinical Use of US Imaging

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





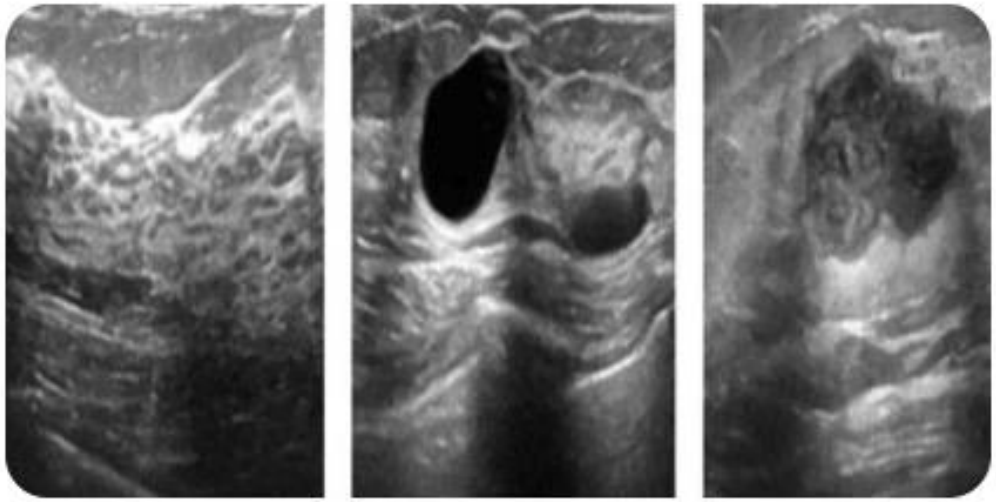


Bone, fat, and physical length Measurements –unborn babies (Image Credit: S. Rueda, Oxford Univ.)

Clinical Use of US Imaging

Breast Ultrasound

Breast ultrasound images can produce great results in classification, detection, and segmentation of breast cancer when combined with machine learning.



https://www.kaggle.com/datasets/aryashah2k/breast-ultrasound-images-dataset

Haojun, et. Al., A Foundational Generative Model for Breast Ultrasound Image Analysis, https://arxiv.org/pdf/2501.06869

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

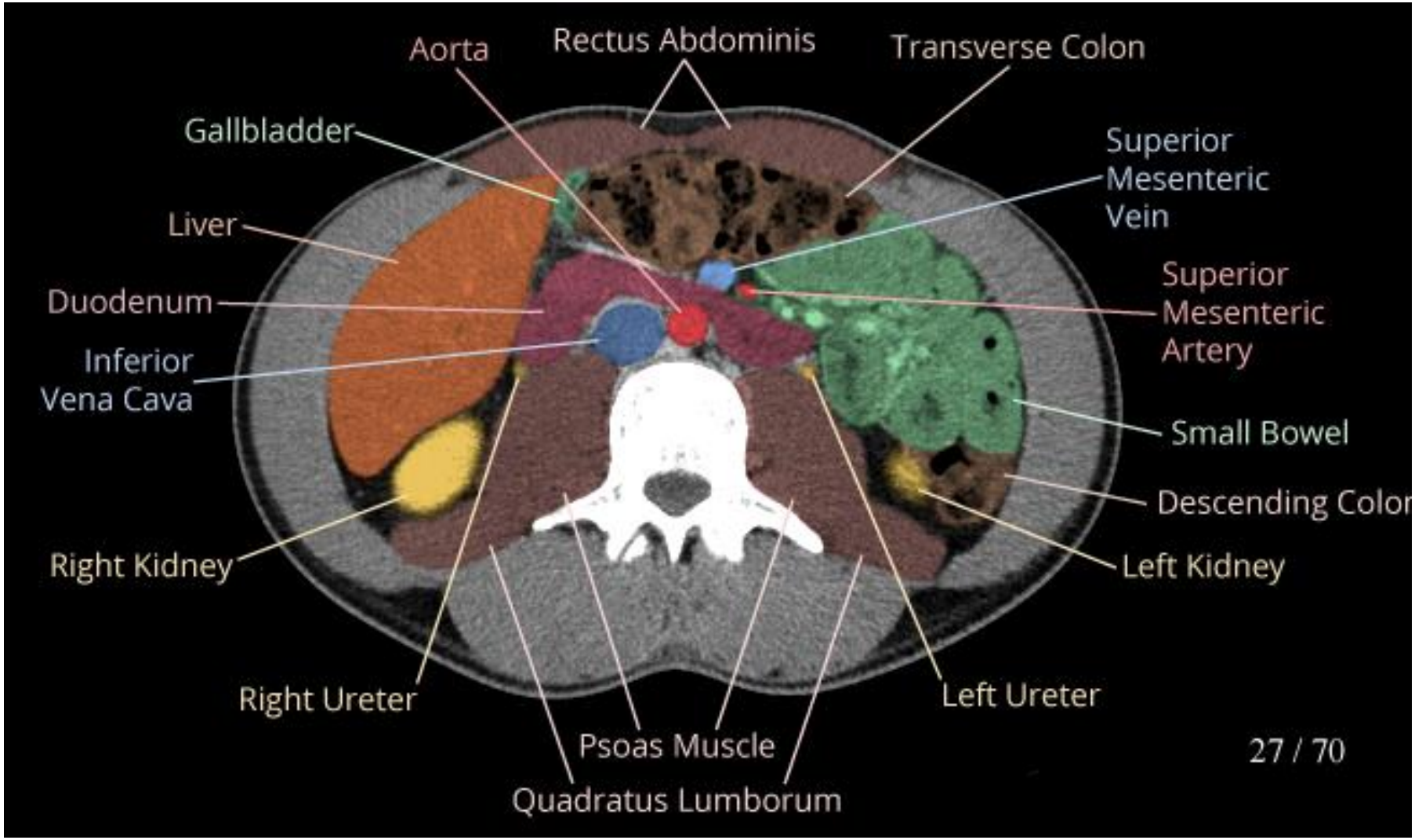
- Diagnostic ultrasound is generally regarded as safe and does not produce ionizing radiation like that produced by x-rays.
- Ultrasound energy has the potential to produce biological effects on the body.
- Ultrasound waves can heat the tissues slightly.

- Demo of ITK software

An abdominal CT scan, or computed tomography scan, is a detailed X-ray image of the abdomen that can help diagnose a variety of conditions

The KiTS19 Challenge Data: 300 Kidney Tumor Cases with Clinical Context, CT Semantic Segmentations, and Surgical Outcomes

Heller, Nicholas, Niranjan Sathianathen, Arveen Kalapara, Edward Walczak, Keenan Moore, Heather Kaluzniak, Joel Rosenberg et al. "The kits19 challenge data: 300 kidney tumor cases with clinical context, ct semantic segmentations, and surgical outcomes." arXiv preprint arXiv:1904.00445 (2019).



Abdominal CT Anatomy

https://www.casestacks.com/medical-school/radiographic-anatomy/abdomen/

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

Thank you!

Question?

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