MTU BE 4775 / BE 5775

Medical Devices

10 September 2014 – Lecture # 03

Diagnostic Devices – Imaging Systems (MRI and CT)

Medical Imaging Technologies

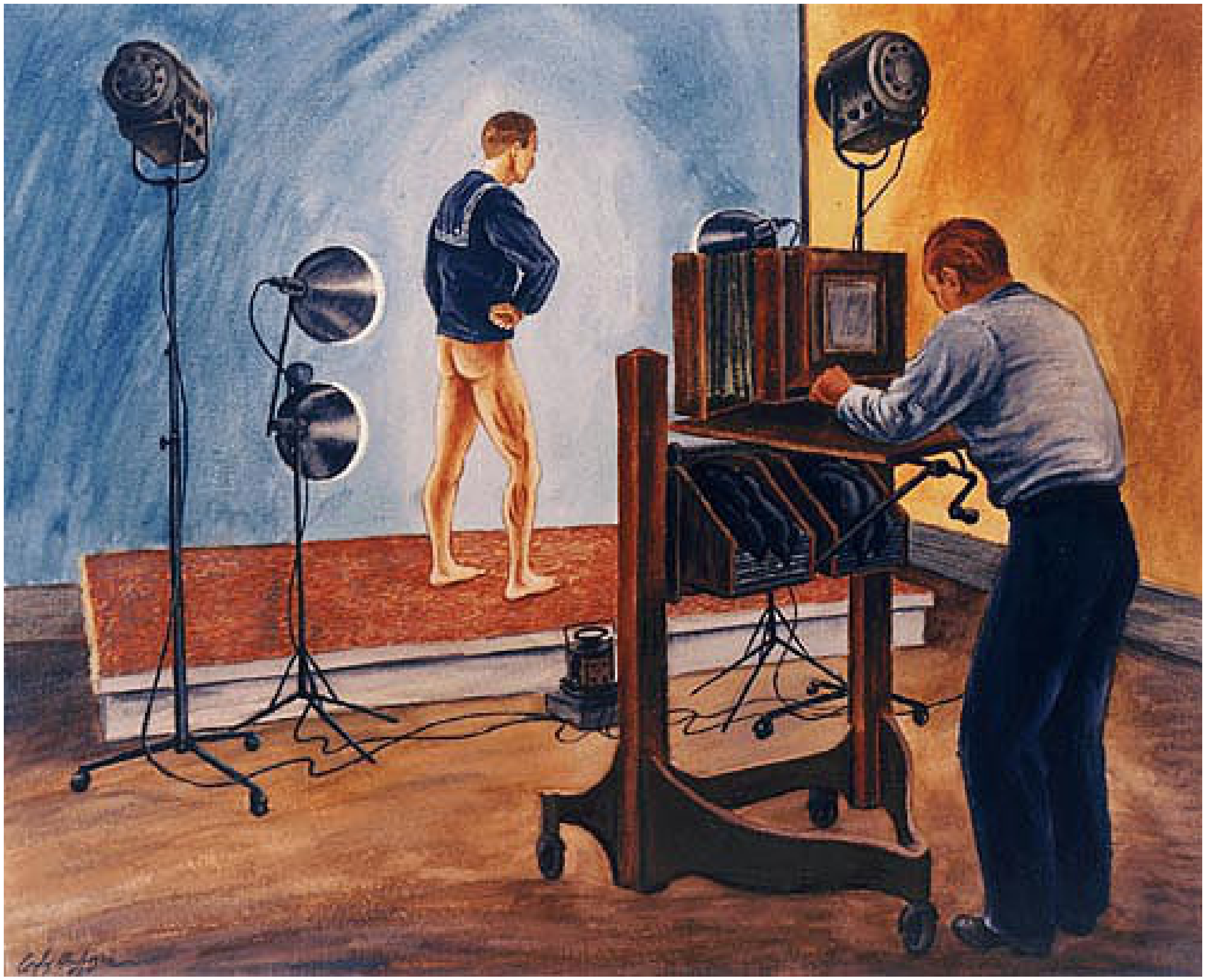
- Radiography (X-Ray flouroscopy)
- **Magnetic Resonance Imaging (MRI)**
- Functional Imaging (PET)
- Ultrasound (Static / 3D)
- Thermography (IR)
- **Tomography (CT)**
- Doppler (US)
- Microscopy (Pathology)

Medical Imaging

- Diagnostic tool
- First rule of diagnosis: Look at patient
- Internal as well as external views
- Two and three-dimensional views
- Involves radiation
  - Ionizing vs. Nonionizing
  - Sound
  - Light – visible and infrared
  - X-ray
  - Gamma rays
  - Particles
  - Thermal
- Image processing

Medical Illustration

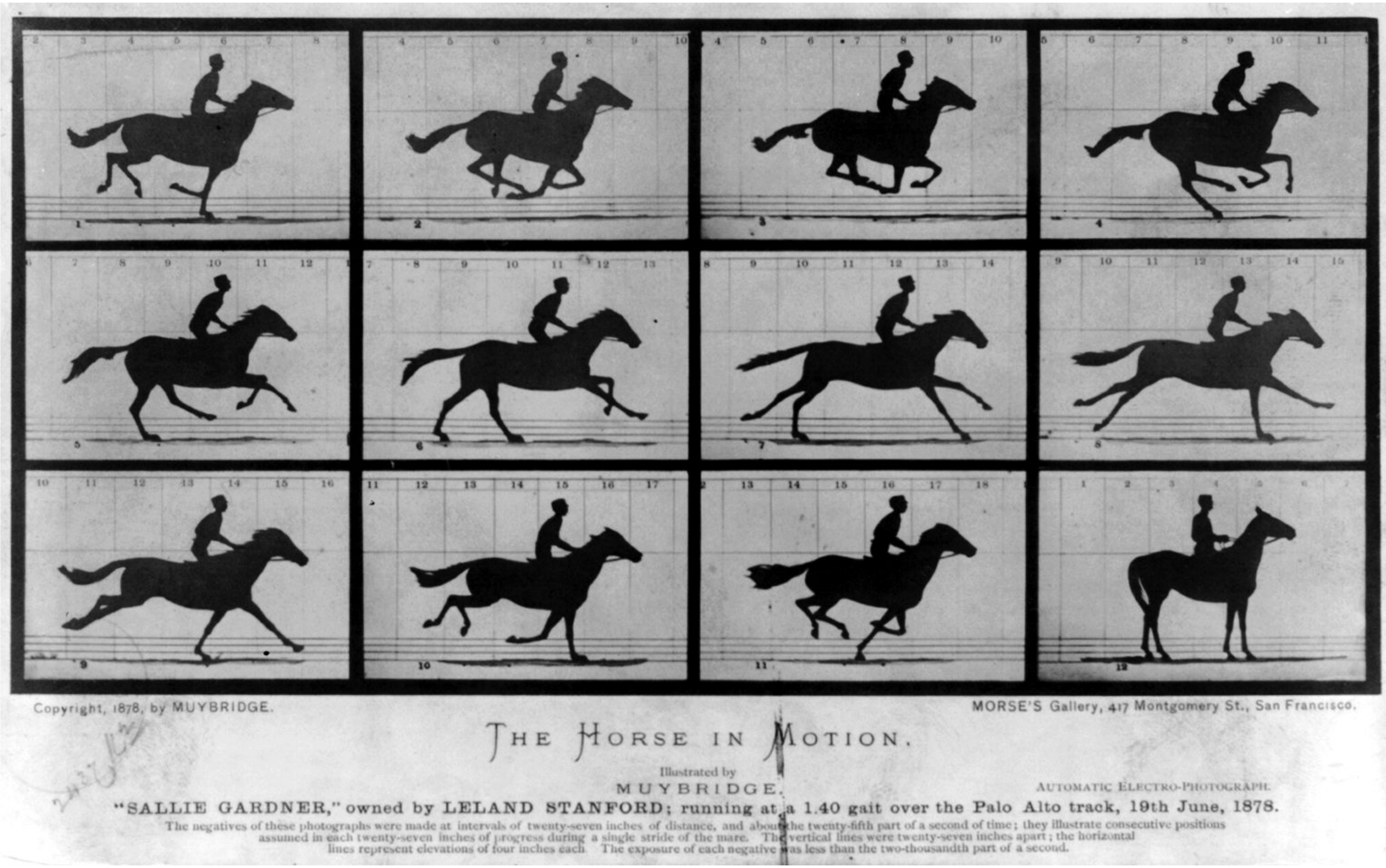
Medical Photography



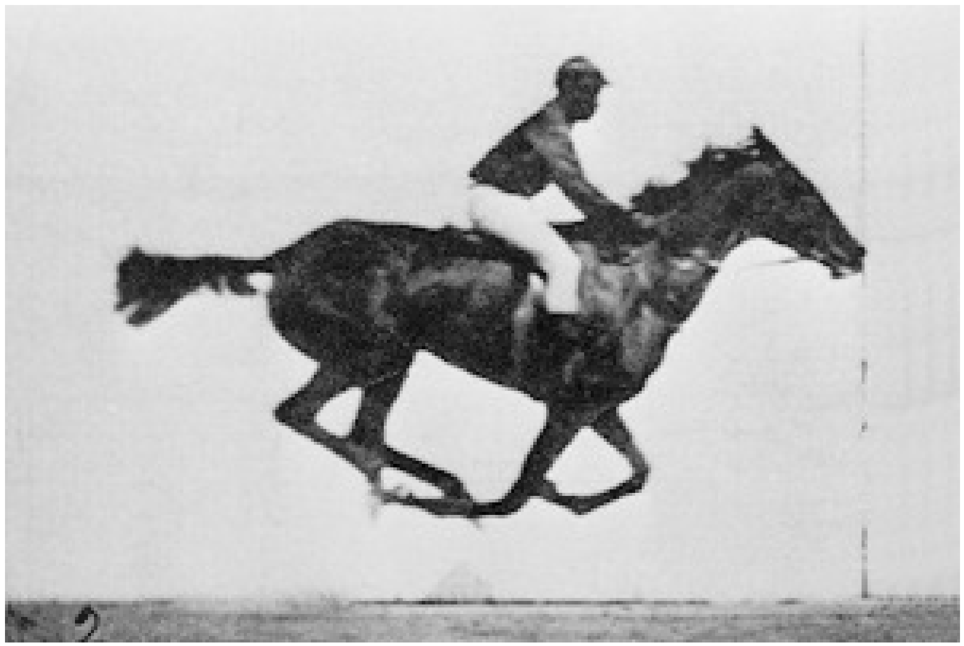
10 SEP 2014

From: www.history.navy.mil/ ac/medica/88159a.jpg

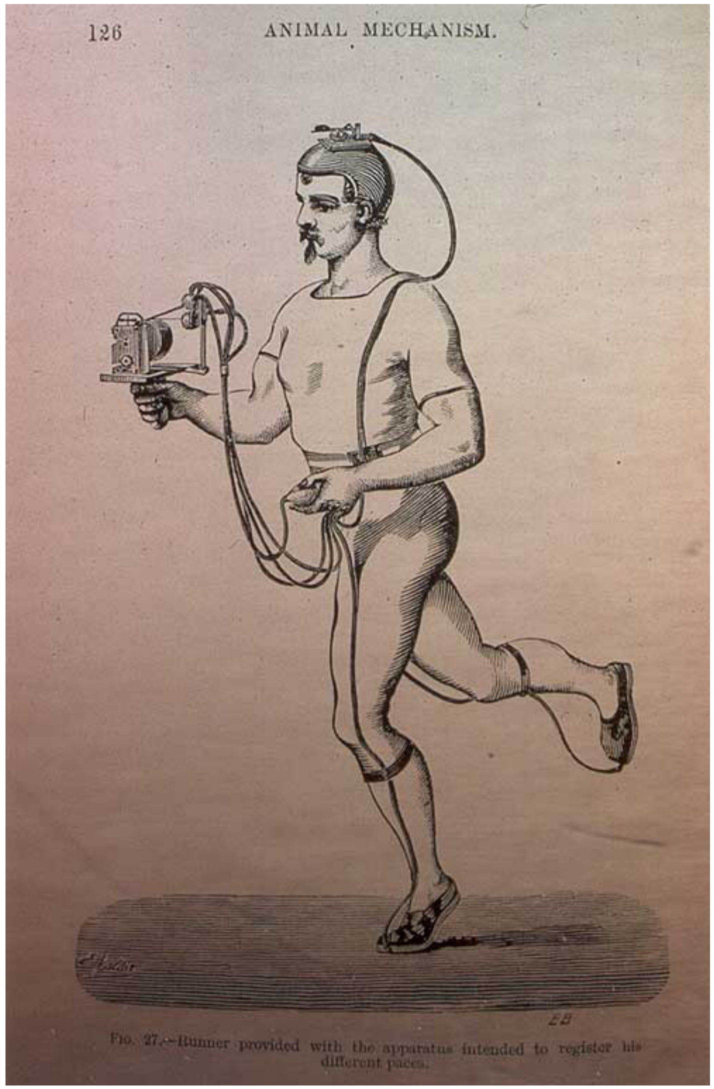
Early Biomechanics: Eadweard Muybridge



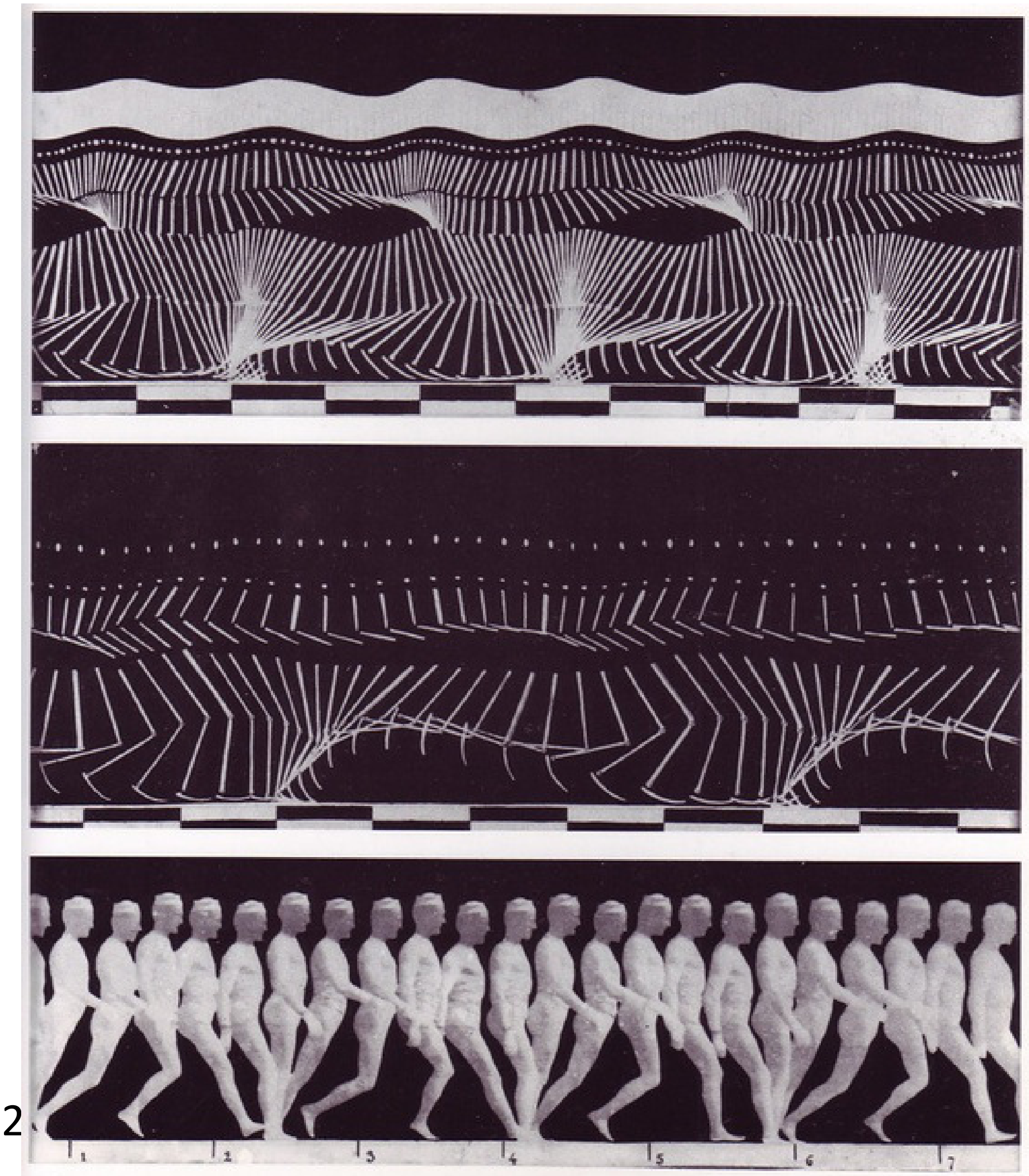
Horse Movie - 1887



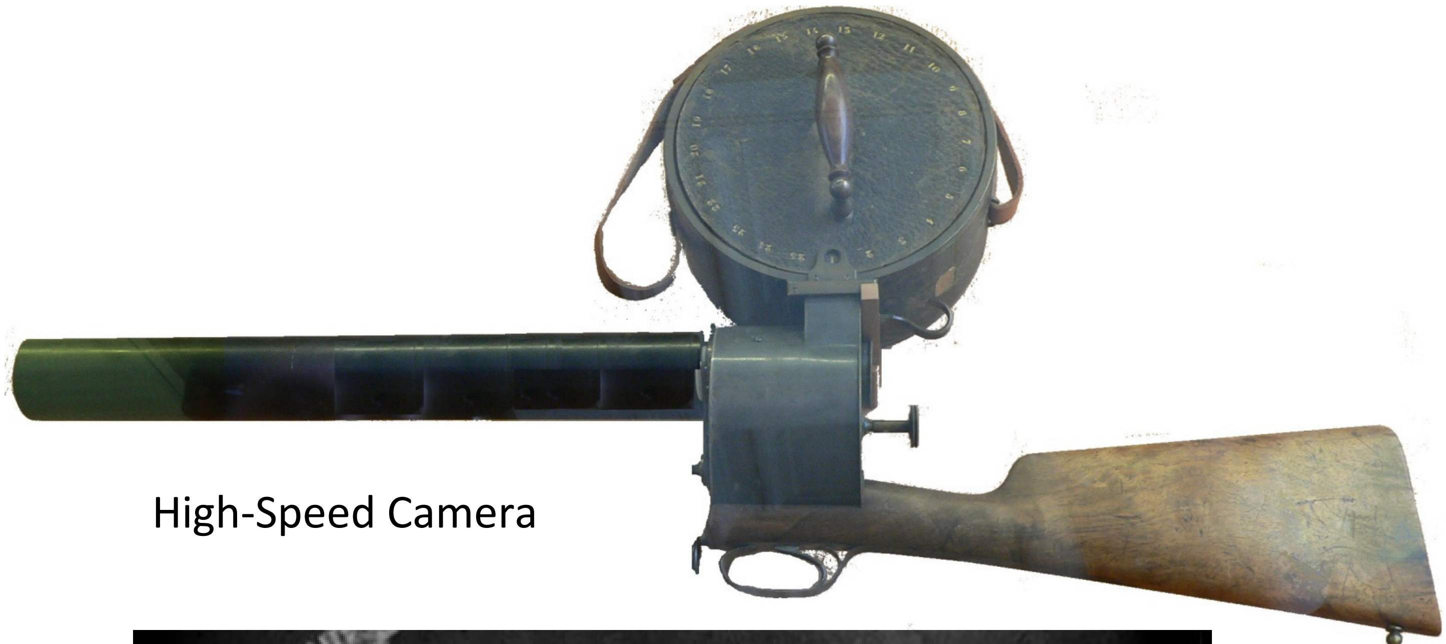
Early Form of Ambulatory Recording
Eadweard Muybridge



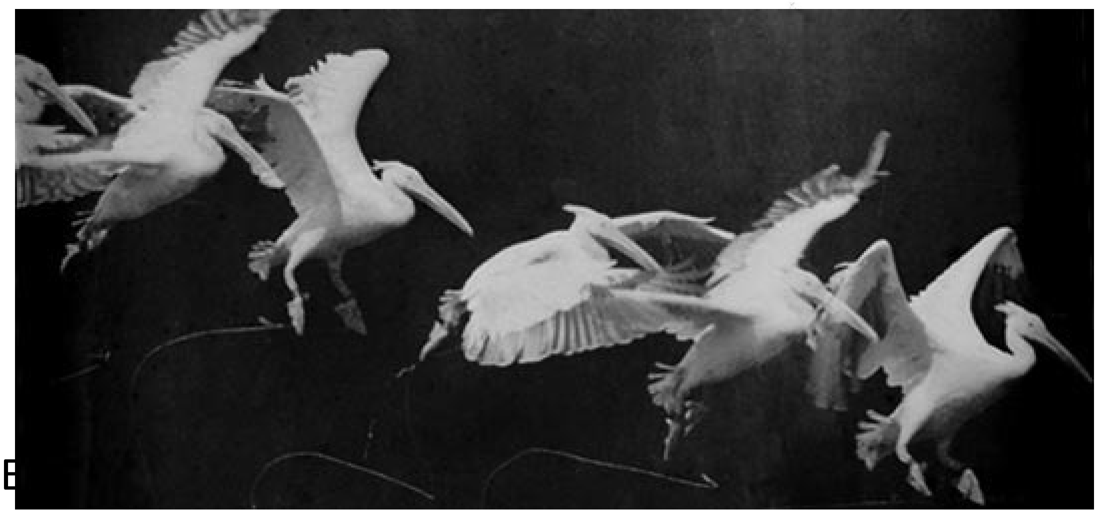
A More Scientific Approach Taken by **Étienne-Jules Marey**



A More Scientific Approach Taken by **Étienne-Jules Marey**

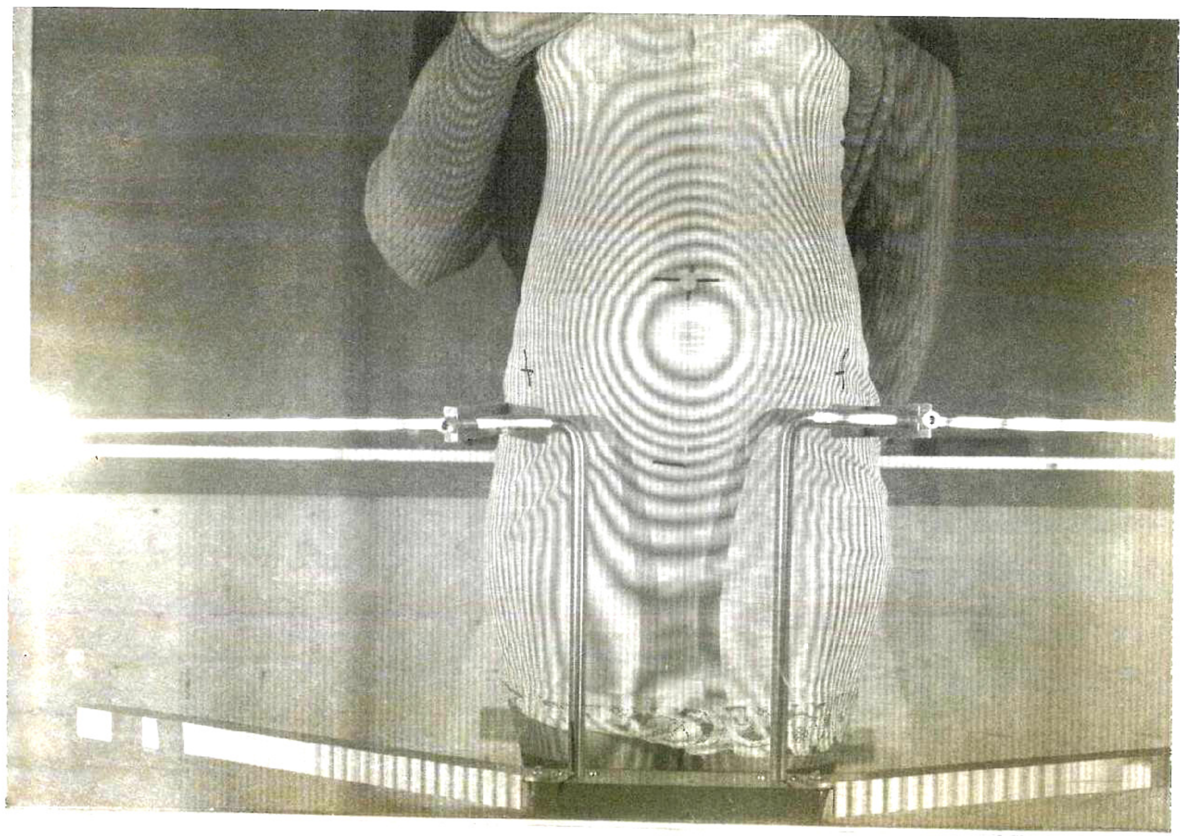


High-Speed Camera

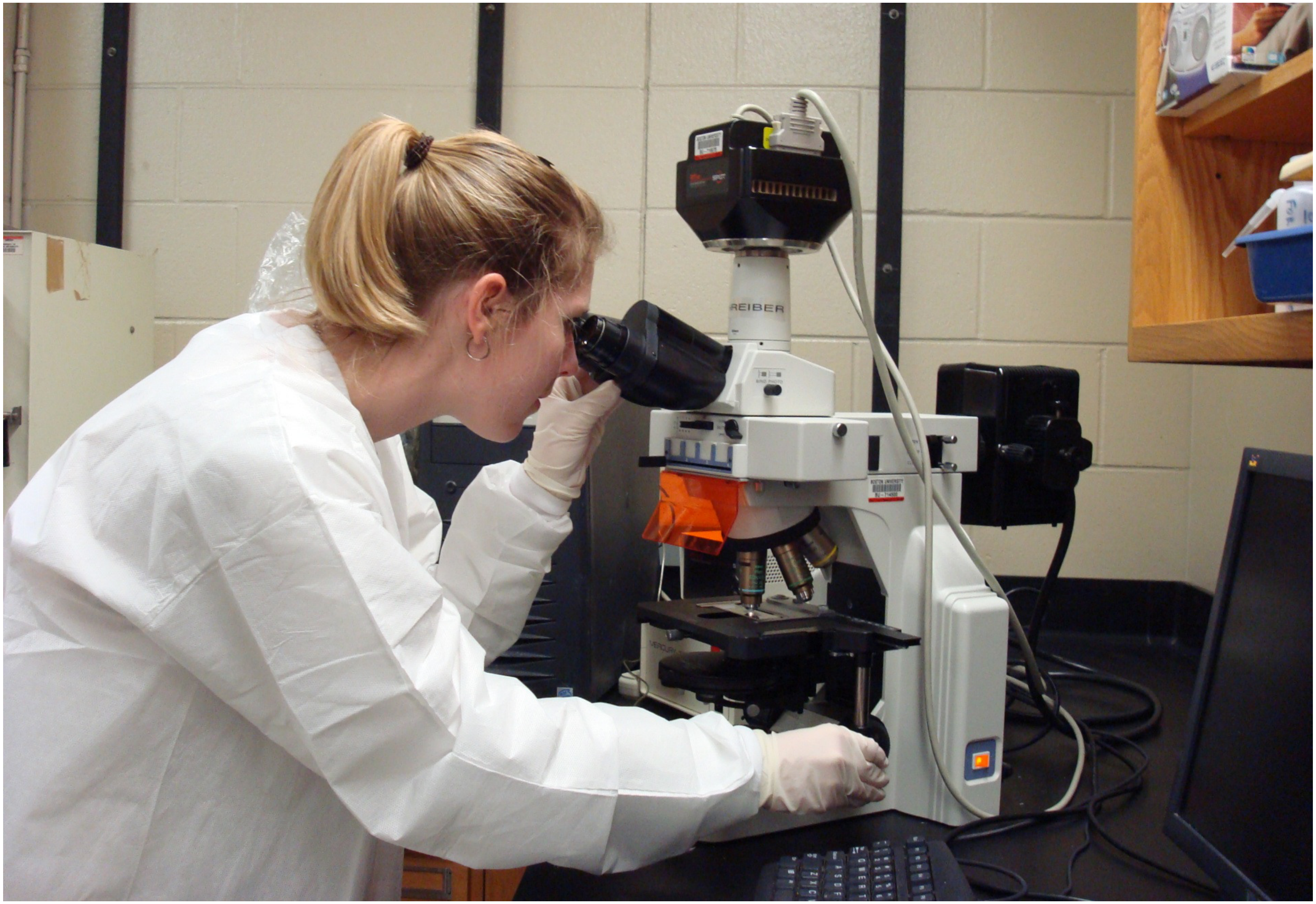


Example of what can be done with such a device

Photography can be used for quantitative visual measurements



Light Microscopy



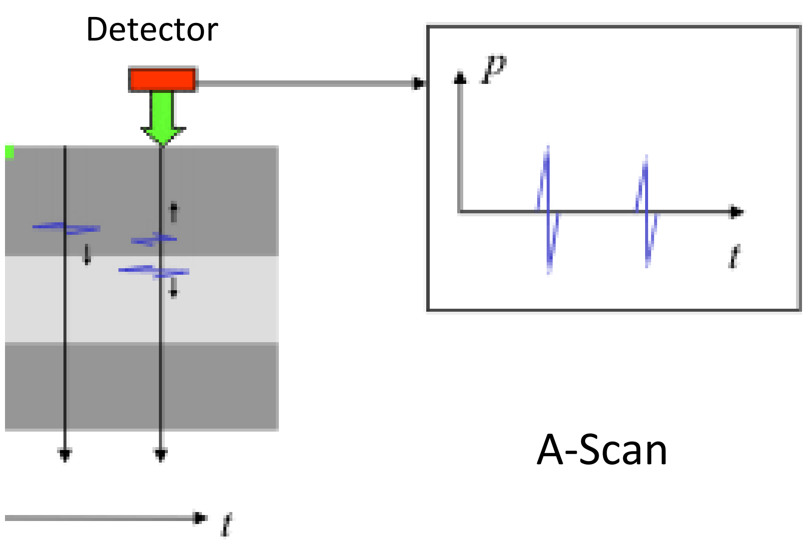
Ultrasound

- High-frequency sound waves – 20 KHz to 20 MHz
- Reflections from tissue interfaces
- Web tutorial at: http://www.qub.ac.uk/edu/niesu/physics/medical/usfolder/us-set.html
- Used in soft tissue imaging
  - Fetal examinations
  - Heart studies
  - Tumor detection and sizing
  - Cyst detection and sizing

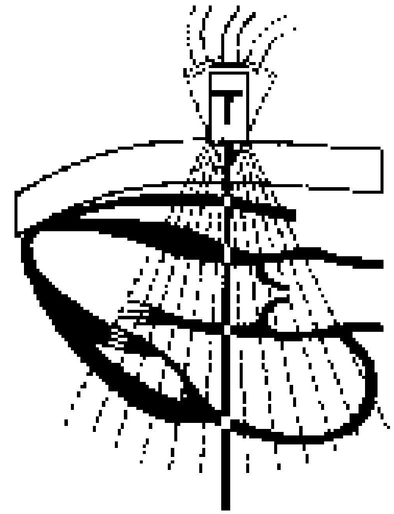
Ultrasound Examination

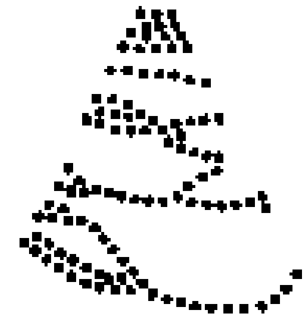
www.hophoto.com/ images/medicallrg.jpg

Ultrasound Principle



A-Scan





B-Scan

Velocity of ultrasound in soft biologic tissue is 1,500 m/s

$$d = c(\Delta t)$$

Where d is the distance traveled
c is the velocity of sound in the material
and Δt is the time it takes to travel d

Basic Ultrasound Properties

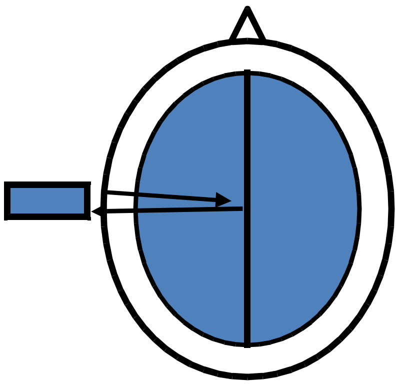
Velocity

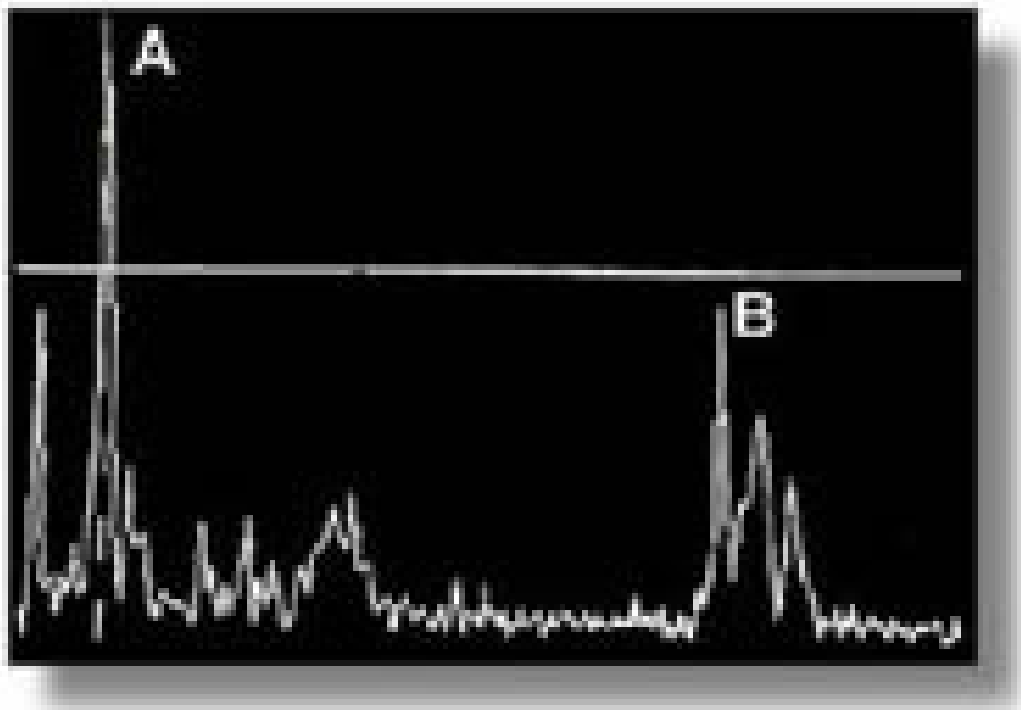
- 1,500 m/s in water (biologic soft tissue)
- 330 m/s in air (STP)
- 2,400 – 4,200 m/s in bone
- 5,800 – 6,000 m/s in steel

Absorption

- Much greater in air and bone than in water

Ultrasound A-Scan



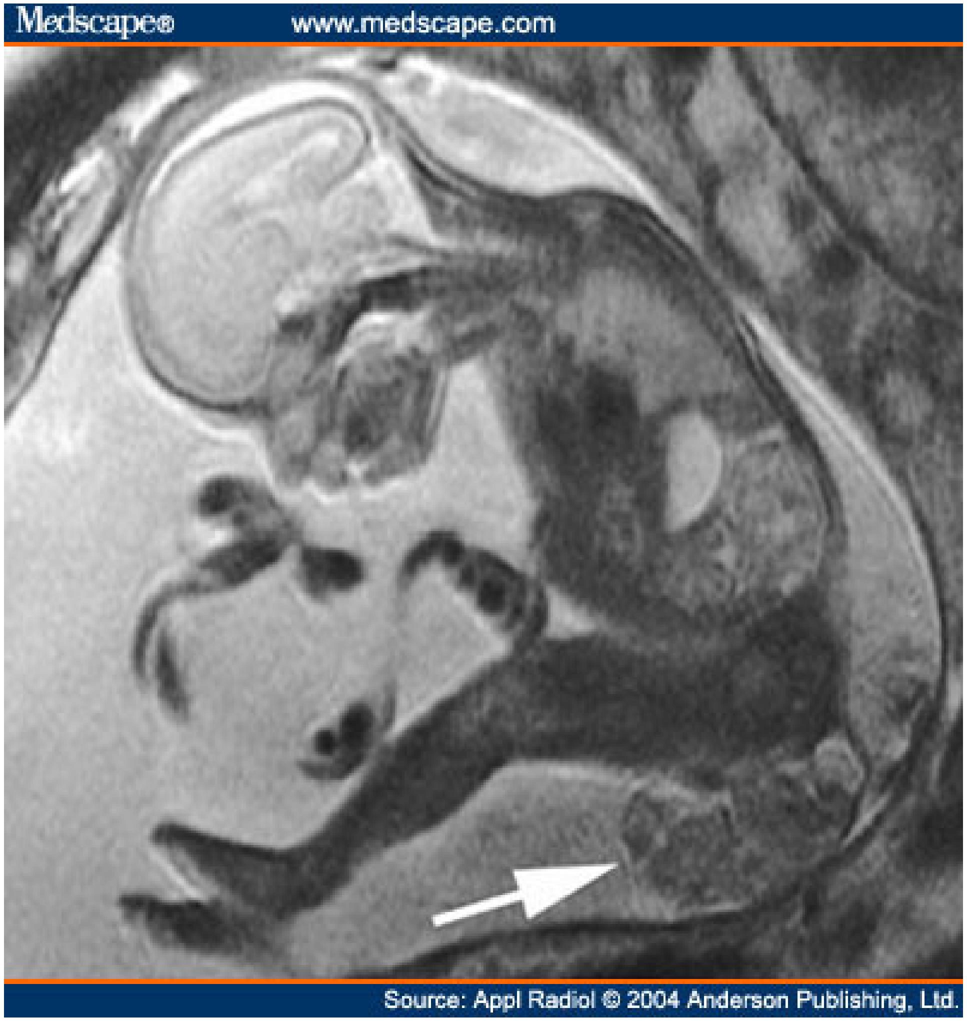


Note: the ultrasound pulse travels twice the distance to the falx.

Ultrasound B-Scan

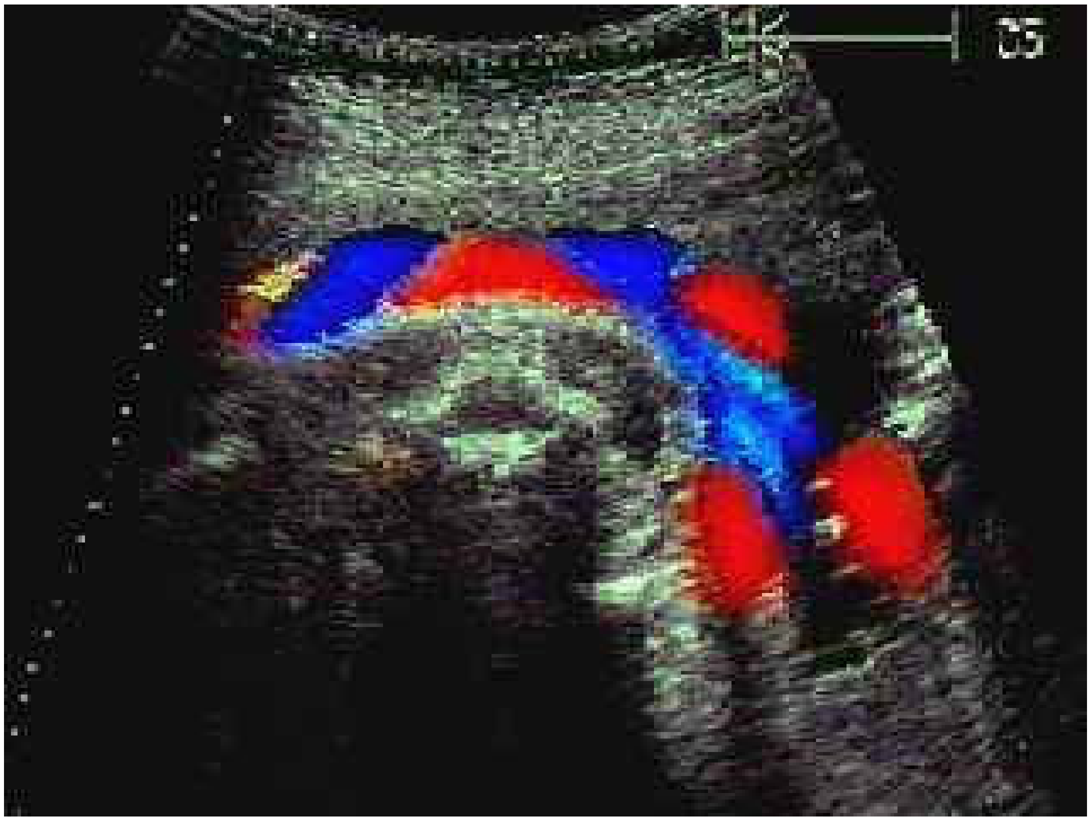
Fetal head in uetro

Ultrasonic B-Scan



www.medscape.com/.../ 08/470837/470837_fig.html

Color Doppler Image of the Umbilical Cord in Utero



3-Dimensional Ultrasound Images

www.fetalfotosusa.com/ Slides/SamplesM.html

Question

Which type of ultrasound B-scan is least likely to provide a good image?

A. Lateral view of the brain

B. Eyes

C. Lungs

D. Kidney cysts

E. Pregnant uterus

Question

Which type of ultrasound B-scan is least likely to provide a good image?

A. Lateral view of the brain

B. Eyes

C. Lungs

D. Kidney cysts

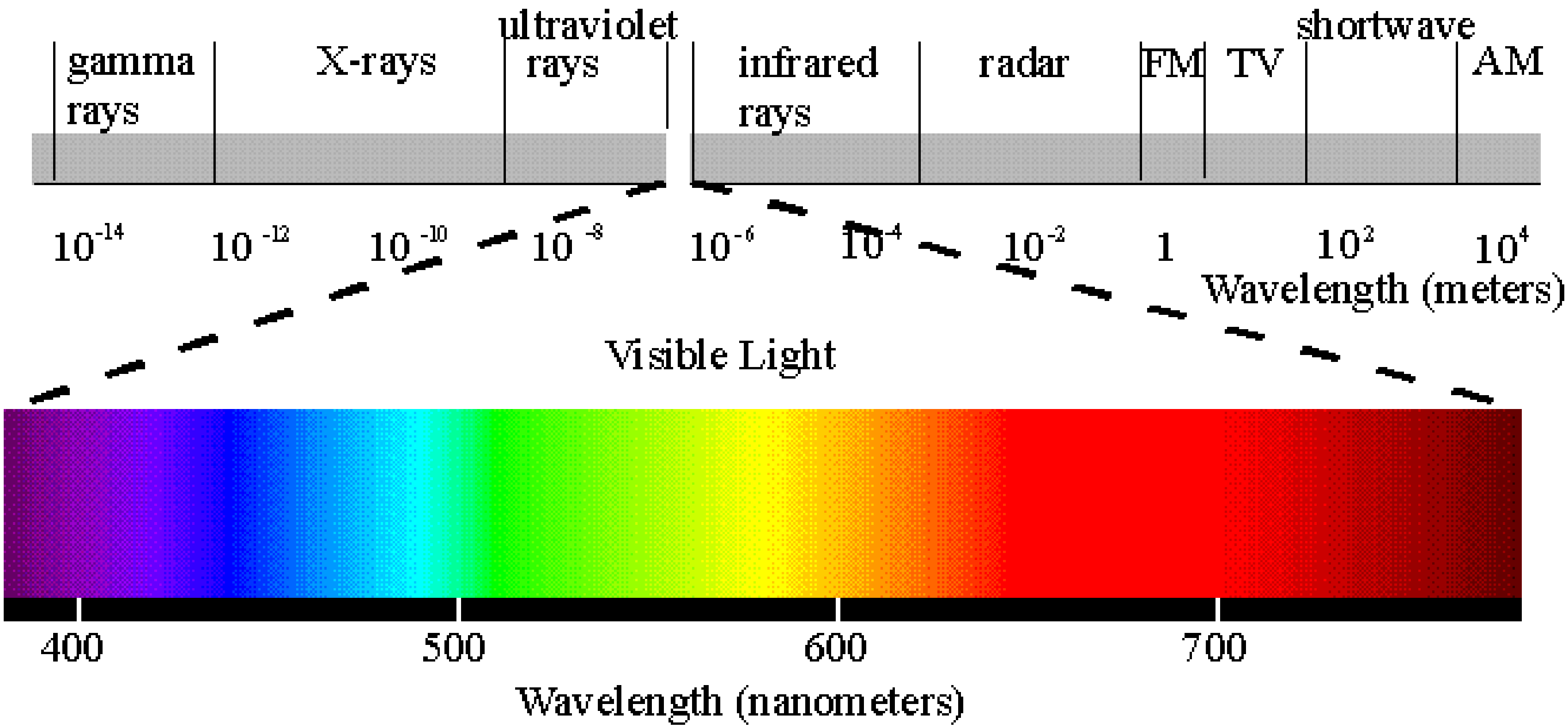
E. Pregnant uterus

X- Rays

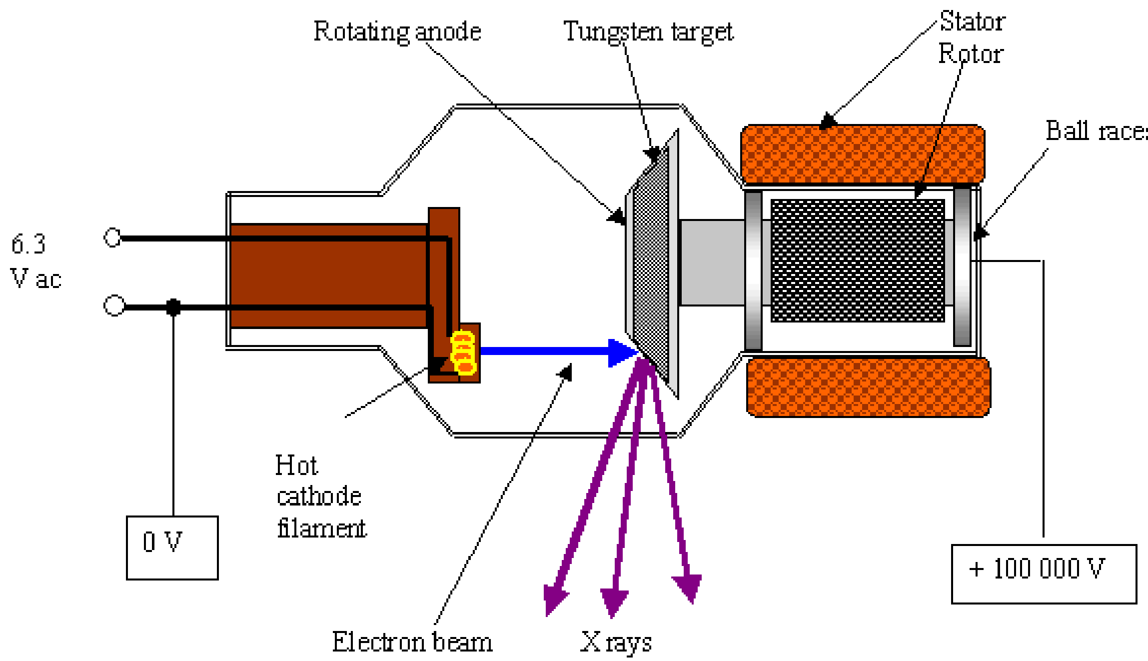
Wilhelm Conrad Röntgen

First x-ray: Frau Röntgen’s Hand

Electromagnetic Spectrum

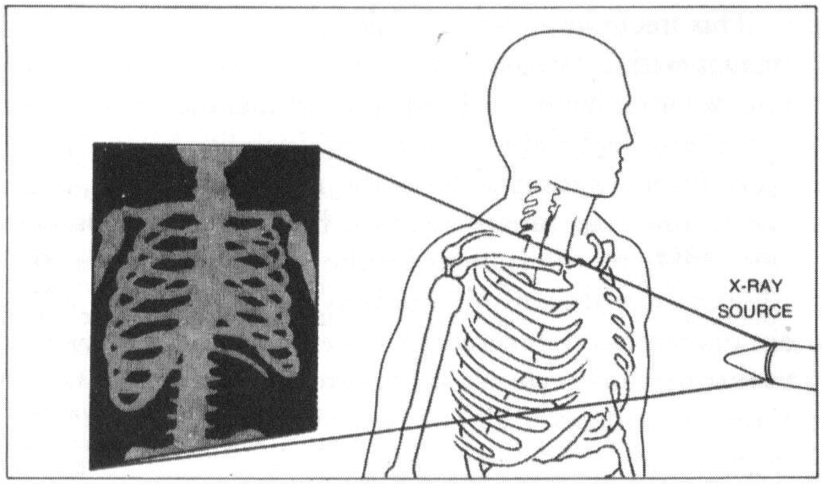


X-Ray Tube

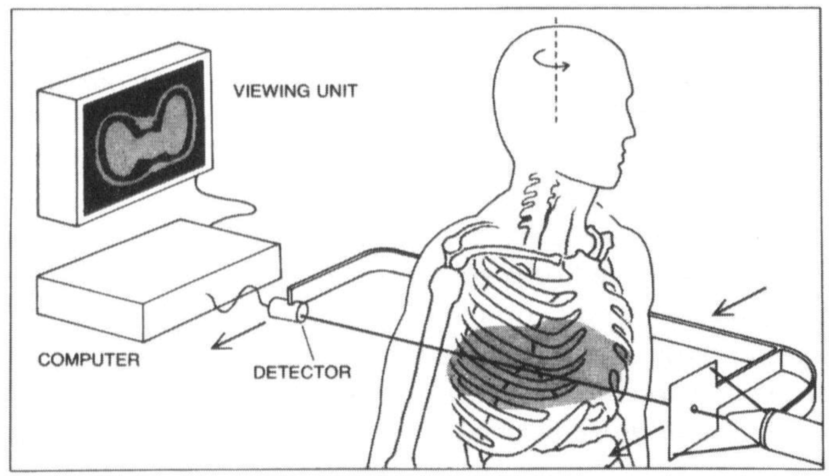

Rotating anode
Tungsten target
Stator
Rotor
Ball races
6.3
V ac
0 V
Hot
cathode
filament
Electron beam
X rays
+ 100 000 V

Clinical X-Ray Machine

X-Ray Imaging

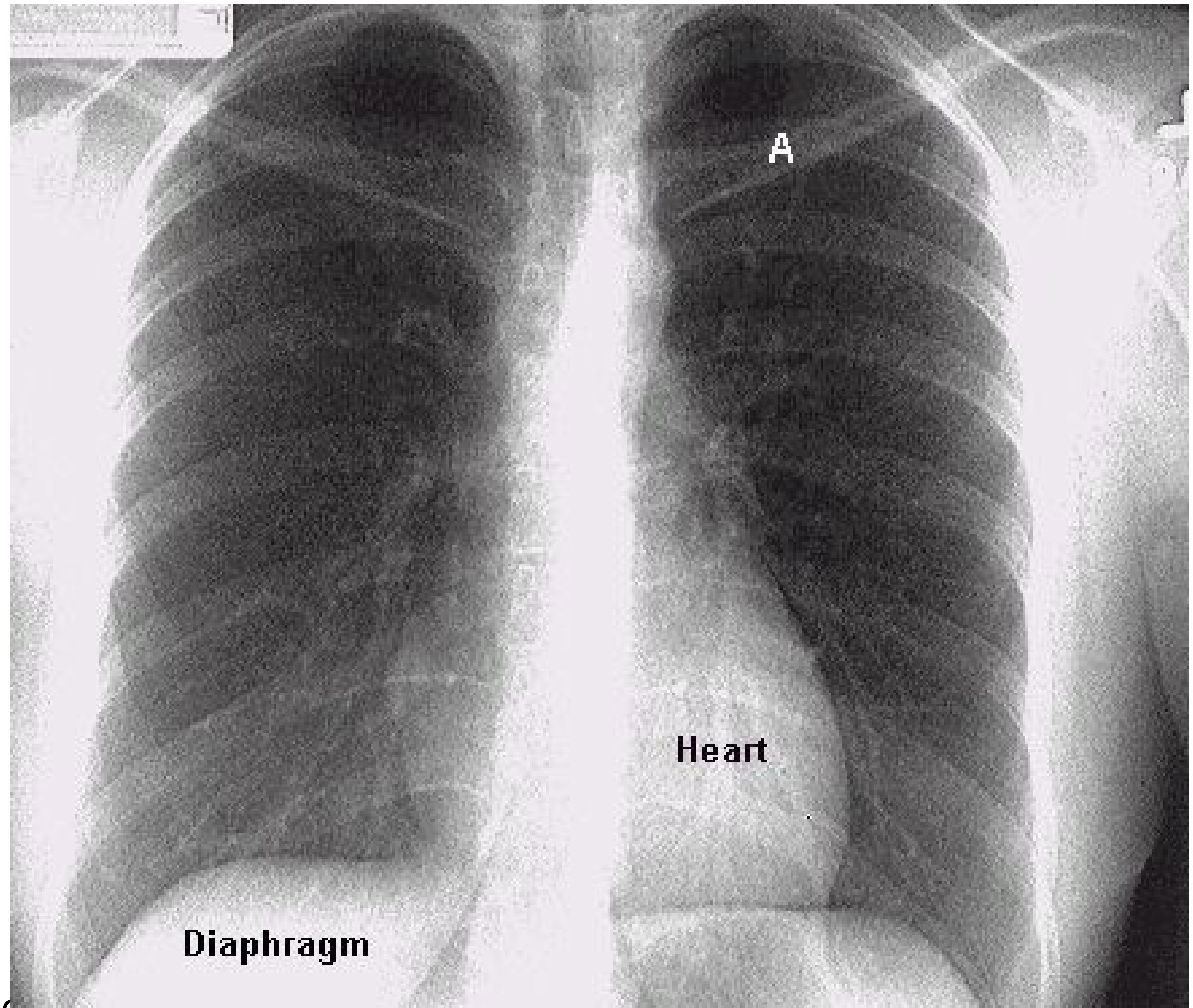


Planar Film



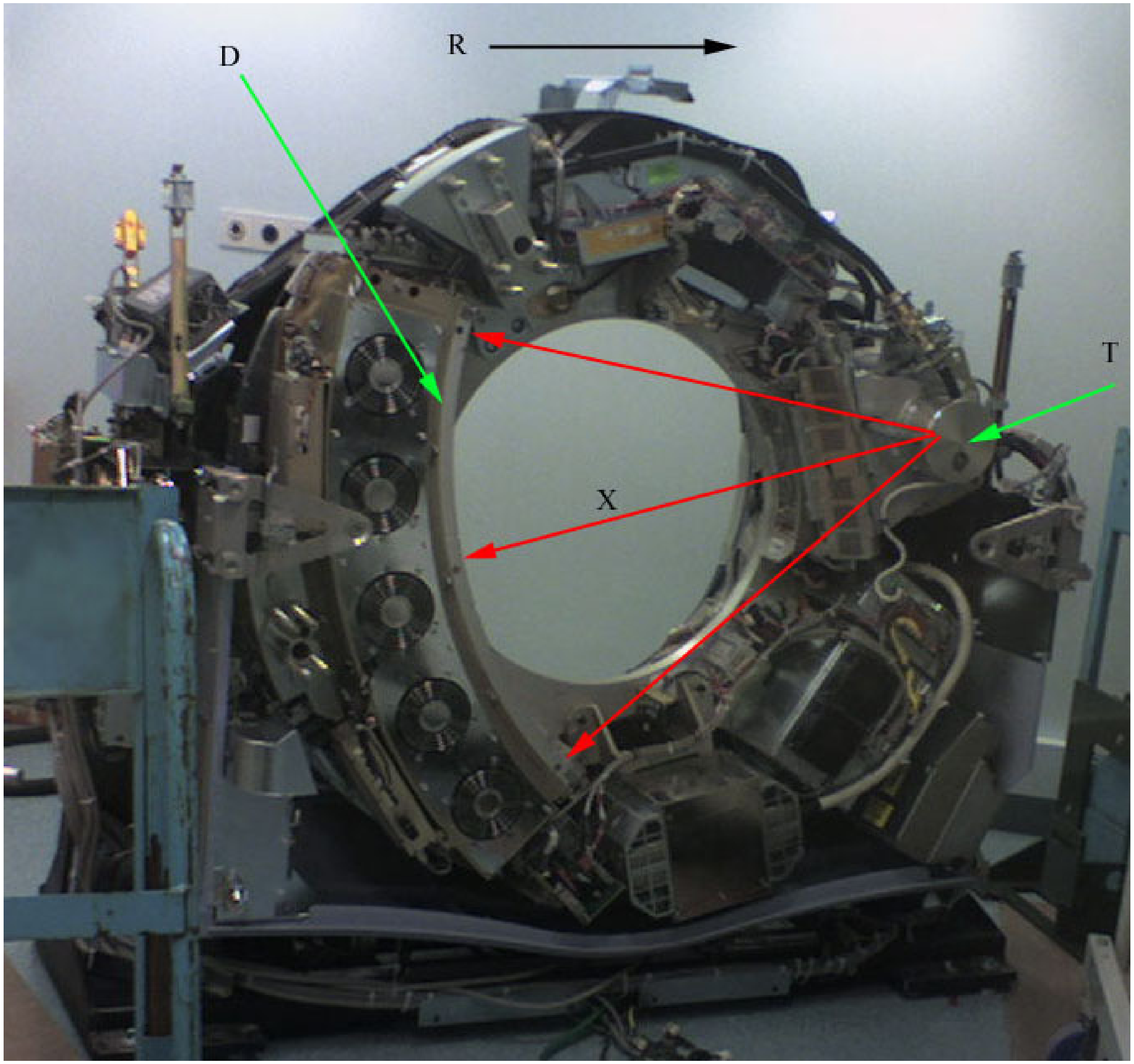
Computed Tomography
(CT Scan)

Normal Chest X-Ray



Computer Tomography (CT) Scanner

Internal View of CT Scanner



T - X-ray tube

D - X-ray detectors

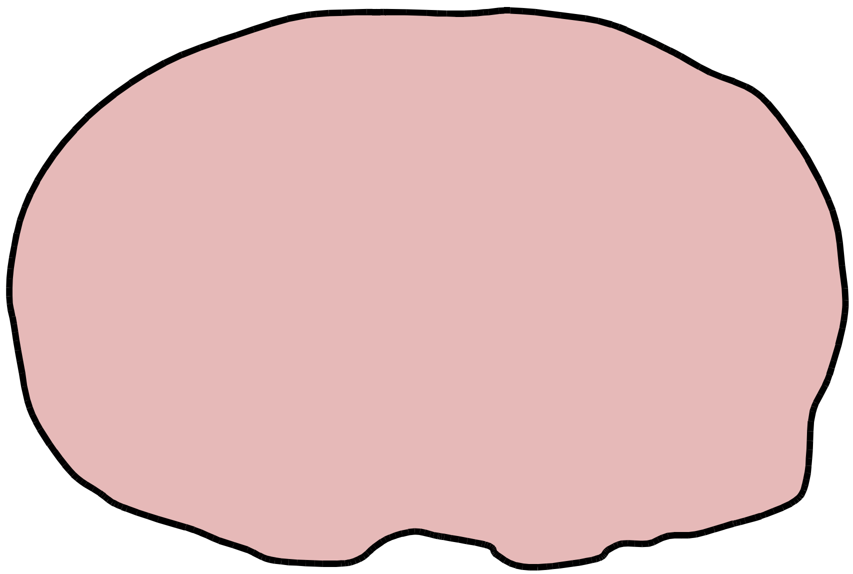
X - X-ray beam

R - Gantry rotation

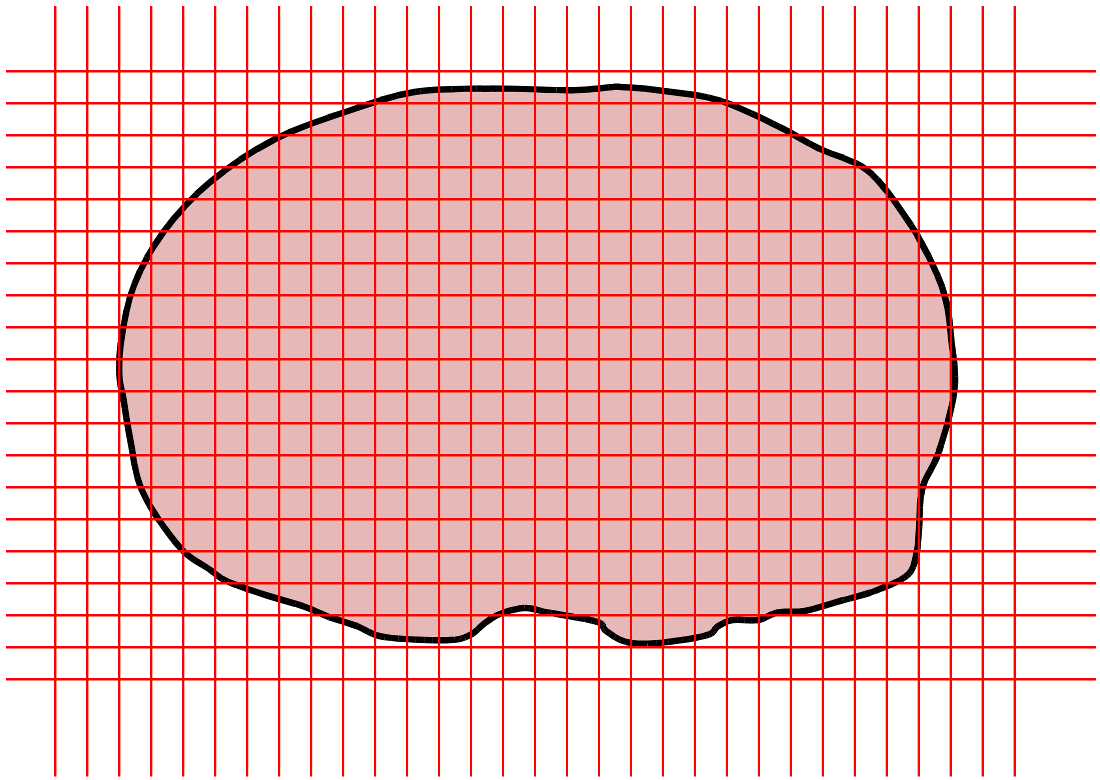
http://en.wikipedia.org/wiki/File:Ct-internals.jpg

Back Projection

Start with a Cross Section of the Body

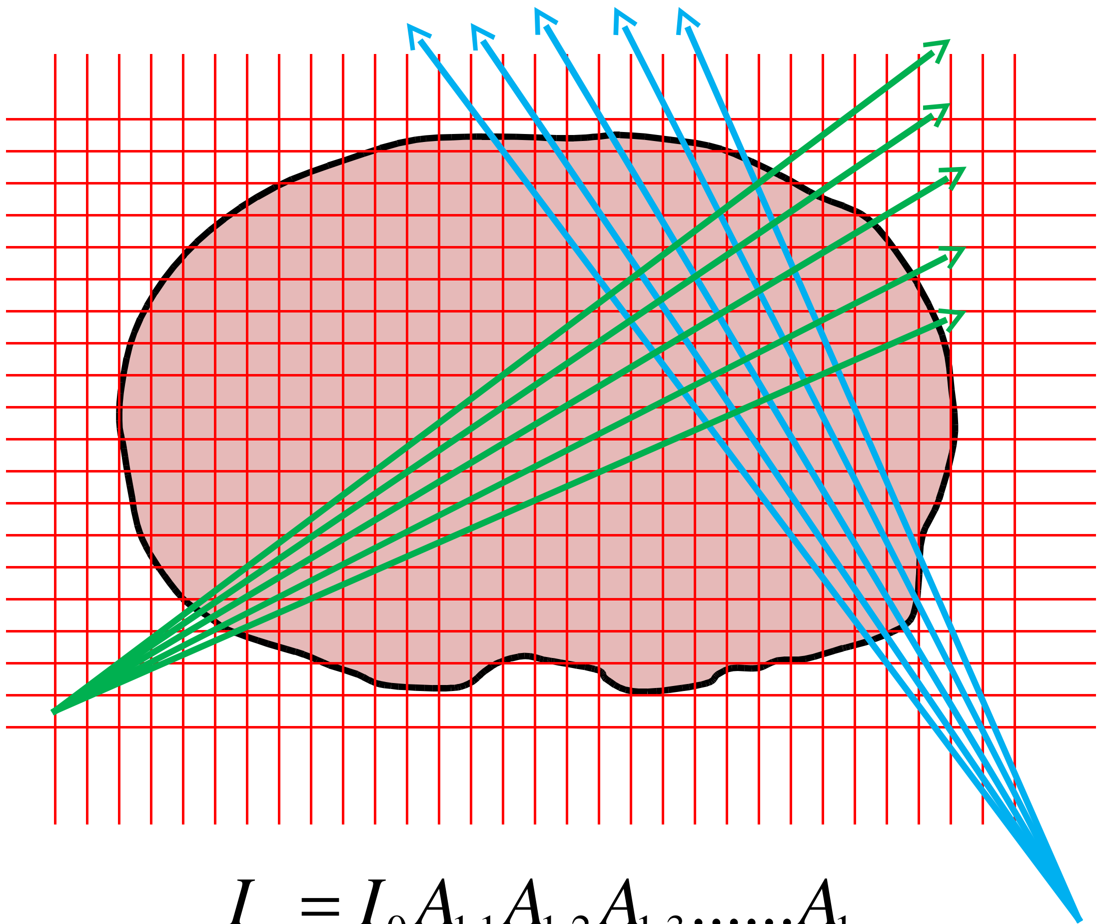


Back Projection
Break into Pixels



Back Projection

Pass Multiple X-ray Beams

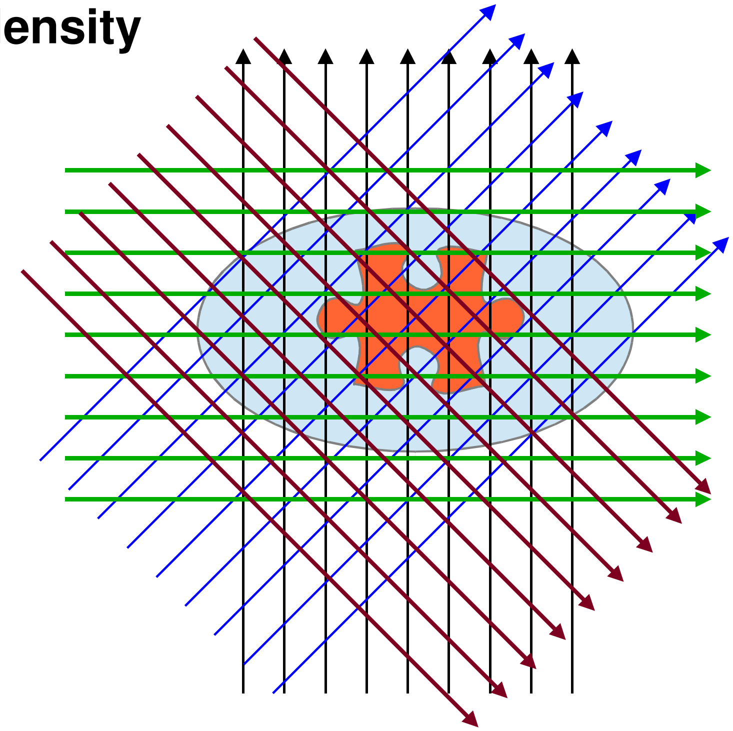


$$I_x = I_0 A_{1,1} A_{1,2} A_{1,3} \ldots\ldots A_{1,n}$$

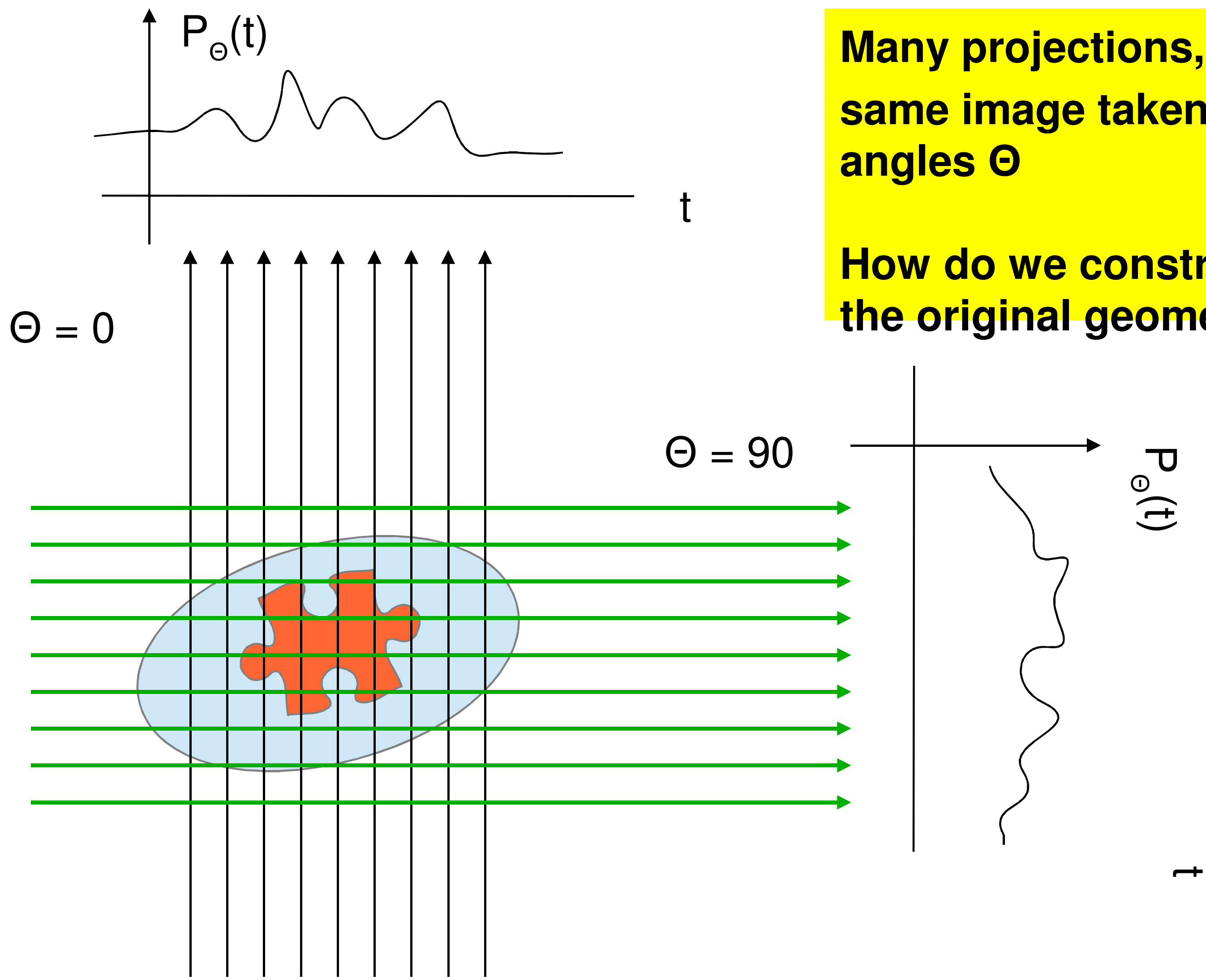
Computer Tomography (CT)

CT: Obtain multiple projections from different angles

Solve for the object geometry and the density



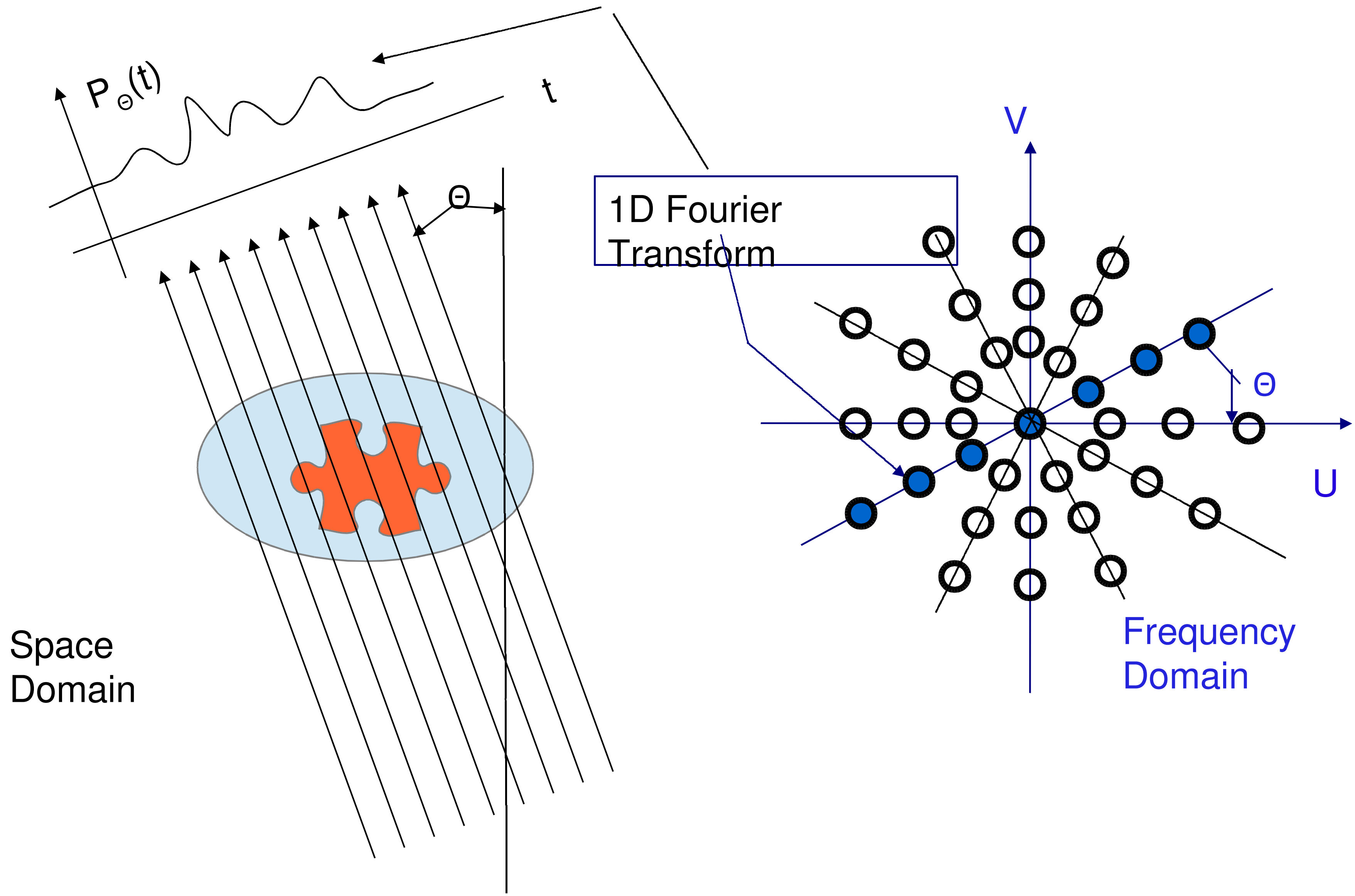
Parallel Projections in CT



Many projections, $P_\Theta(t)$, of the same image taken from different angles Θ

How do we construct the image of the original geometry?

Fourier Slice Theorem for CT



Non-Uniformity of Representation

In the frequency domain, sample density is very high around the origin (U = V = 0), but the density decreases as one moves away from the origin.

U = V = 0 corresponds to the image segments where there is no change (not very interesting).

We can emphasize the variations in the image by adding a weighing function that DE-emphasizes the origin.

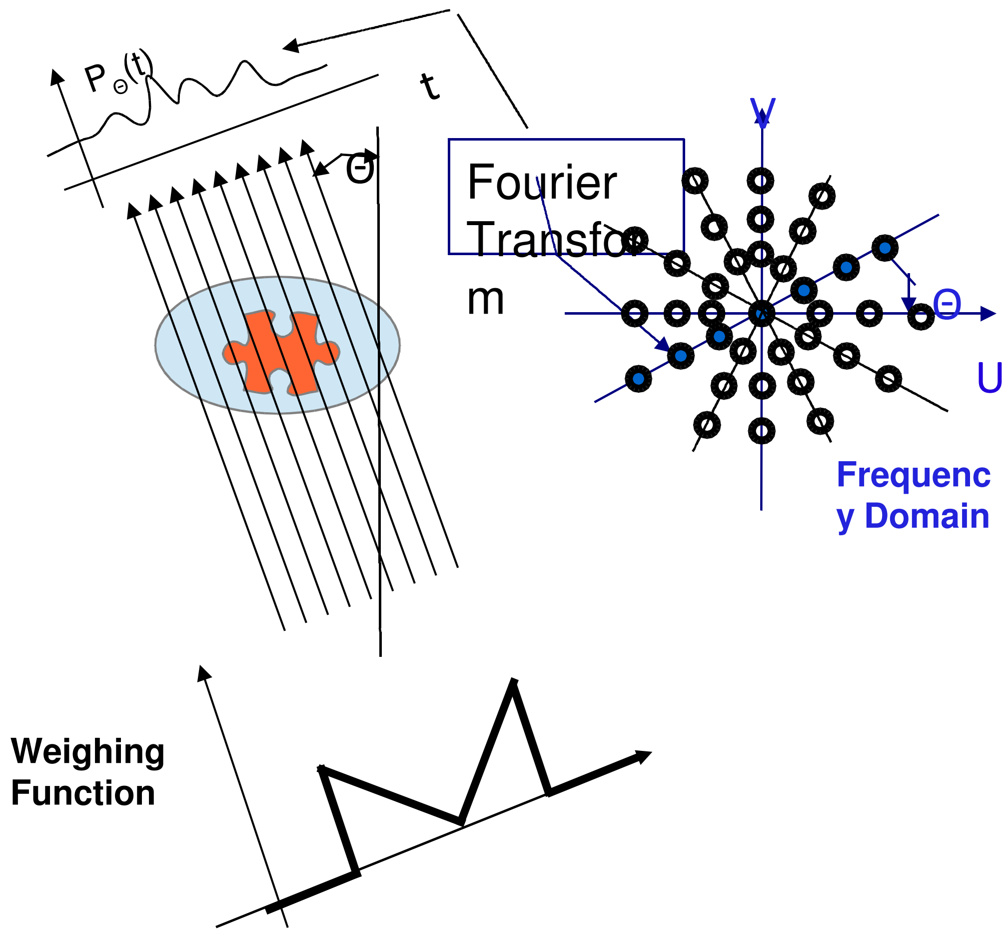
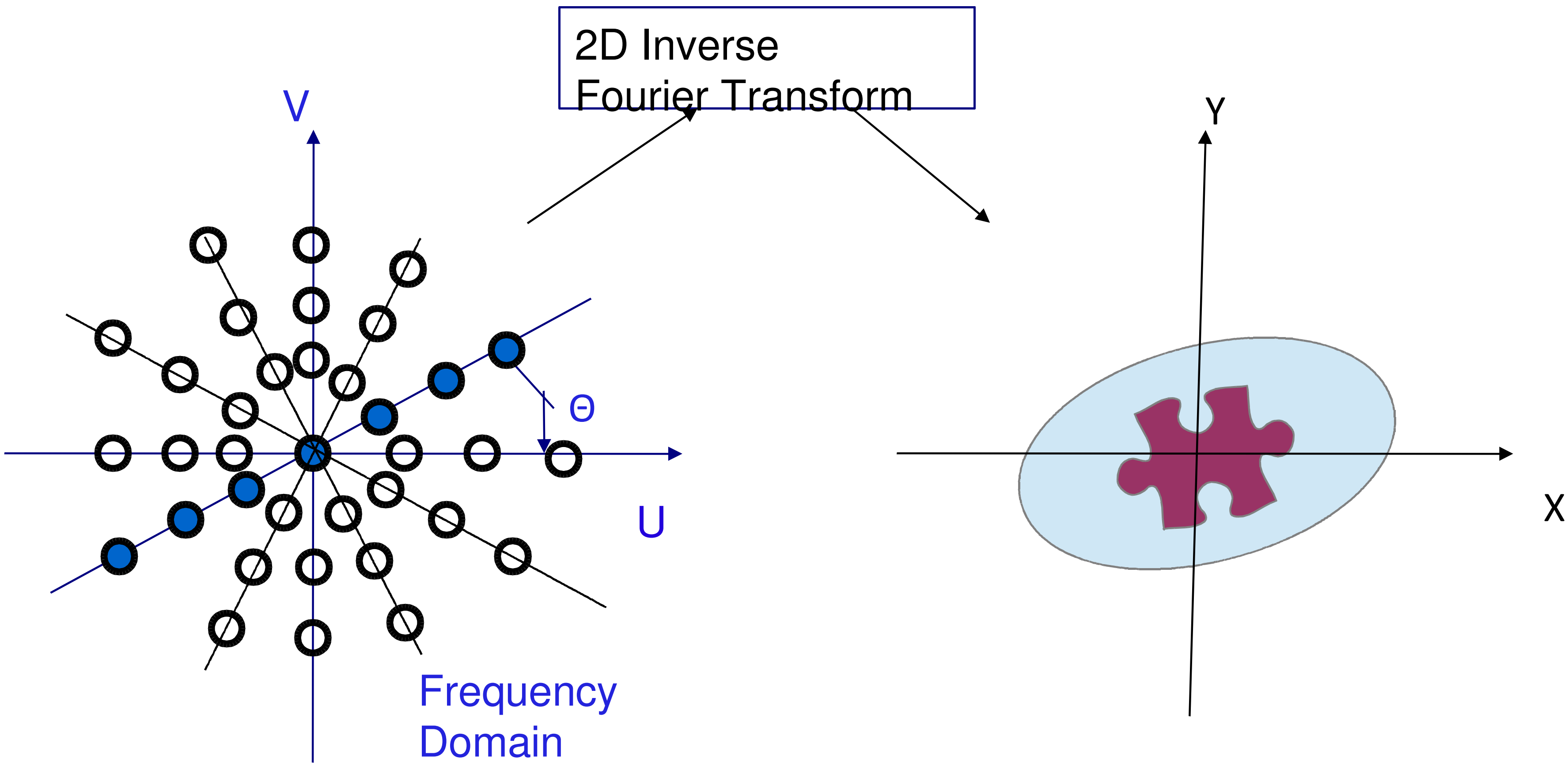
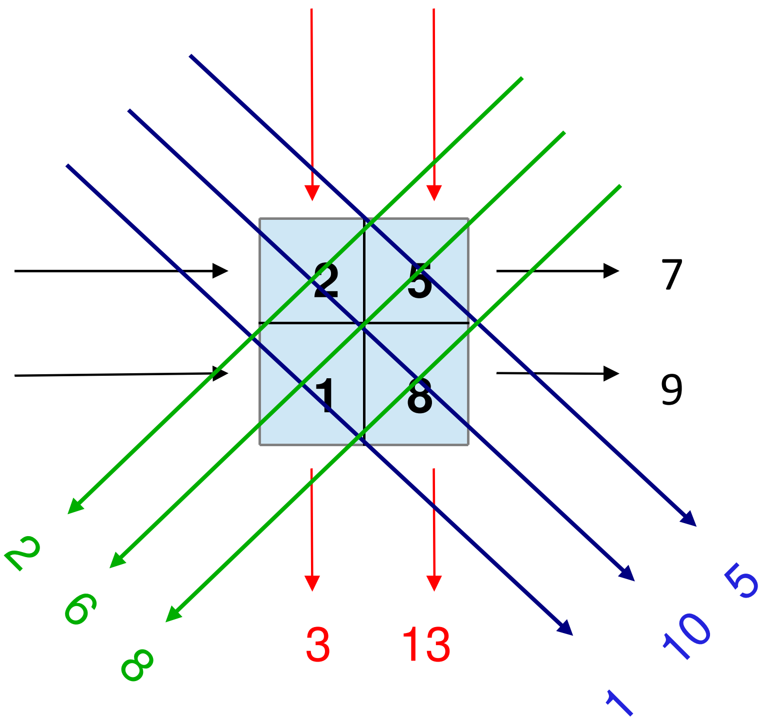


Image Reconstruction



A Simplified Example



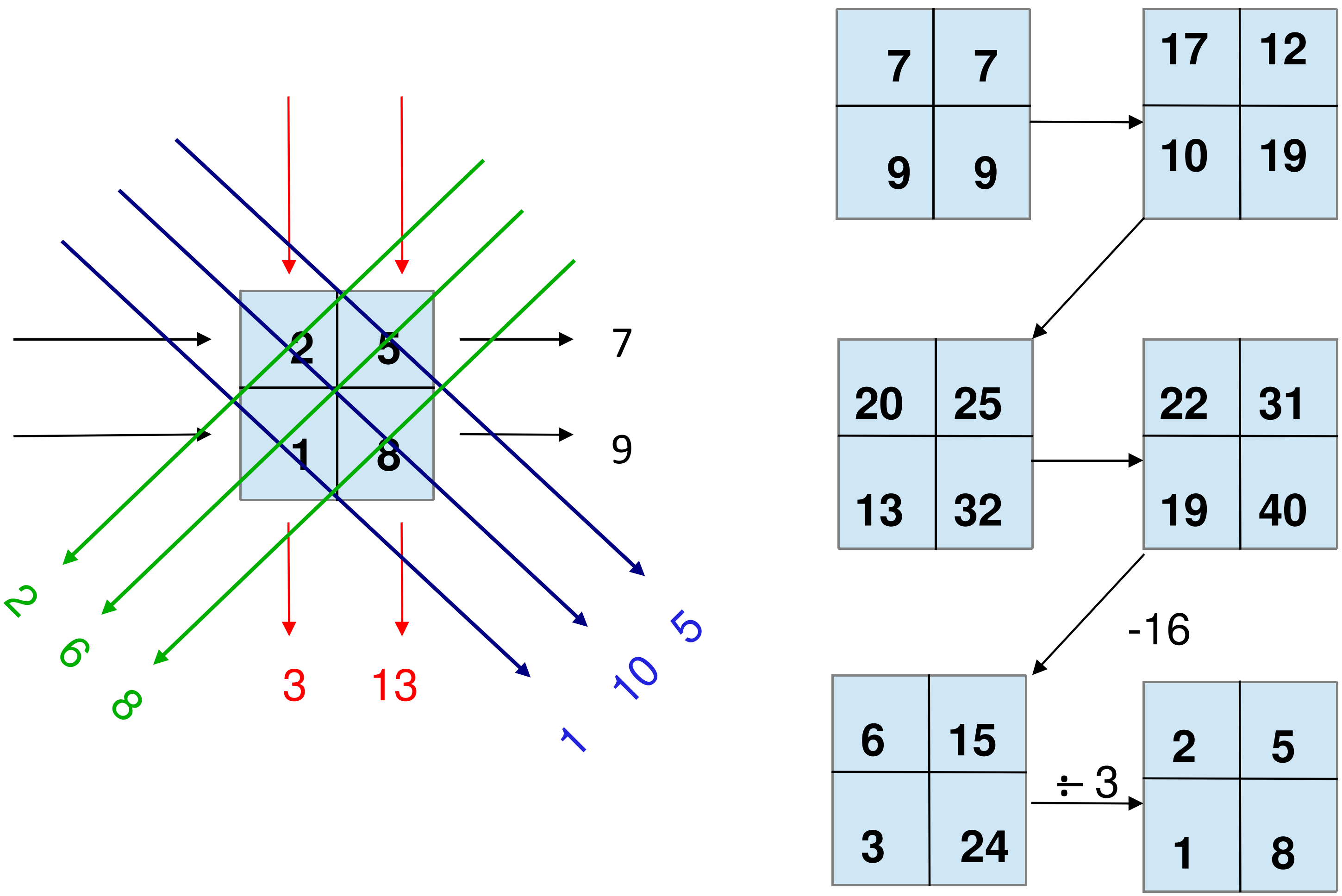
Assume that the object to be imaged can be represented by a 2 x 2 matrix.

We do not know the values in the 2 x 2 object, but we know the values resulting from the projections.

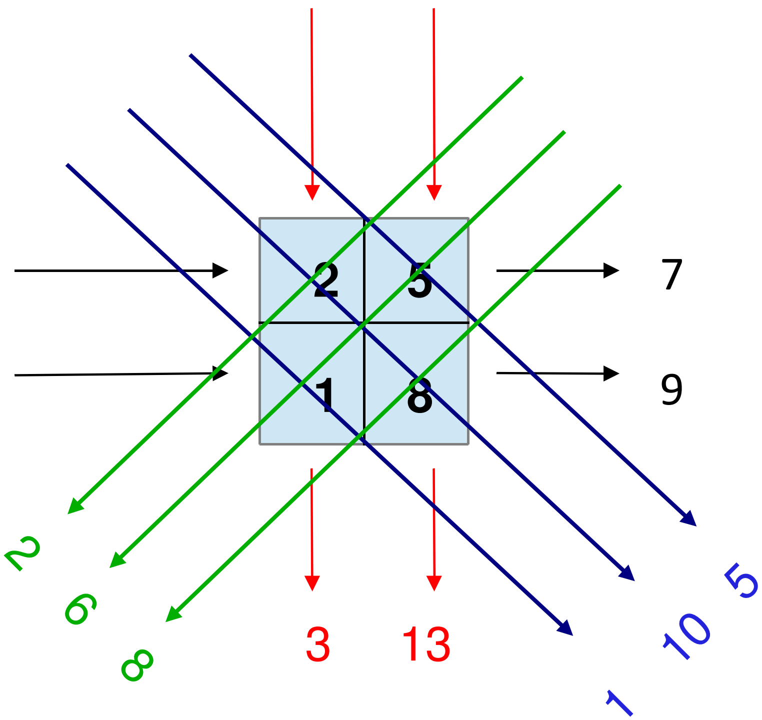
Can we find the values of the object (i.e. numbers in the 2x2 matrix) using the values of the projections?

40

Solution to the Example



Homework

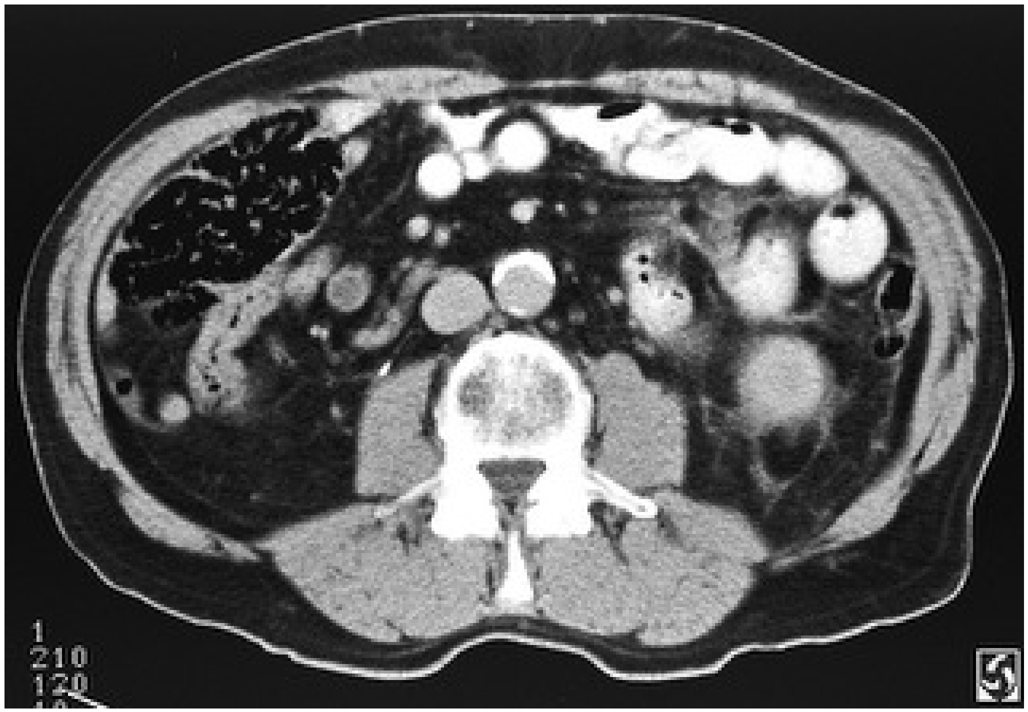


How many projections would you need if the original object was represented by an n x n matrix? Justify your answer by showing an algebraic solution to the problem.

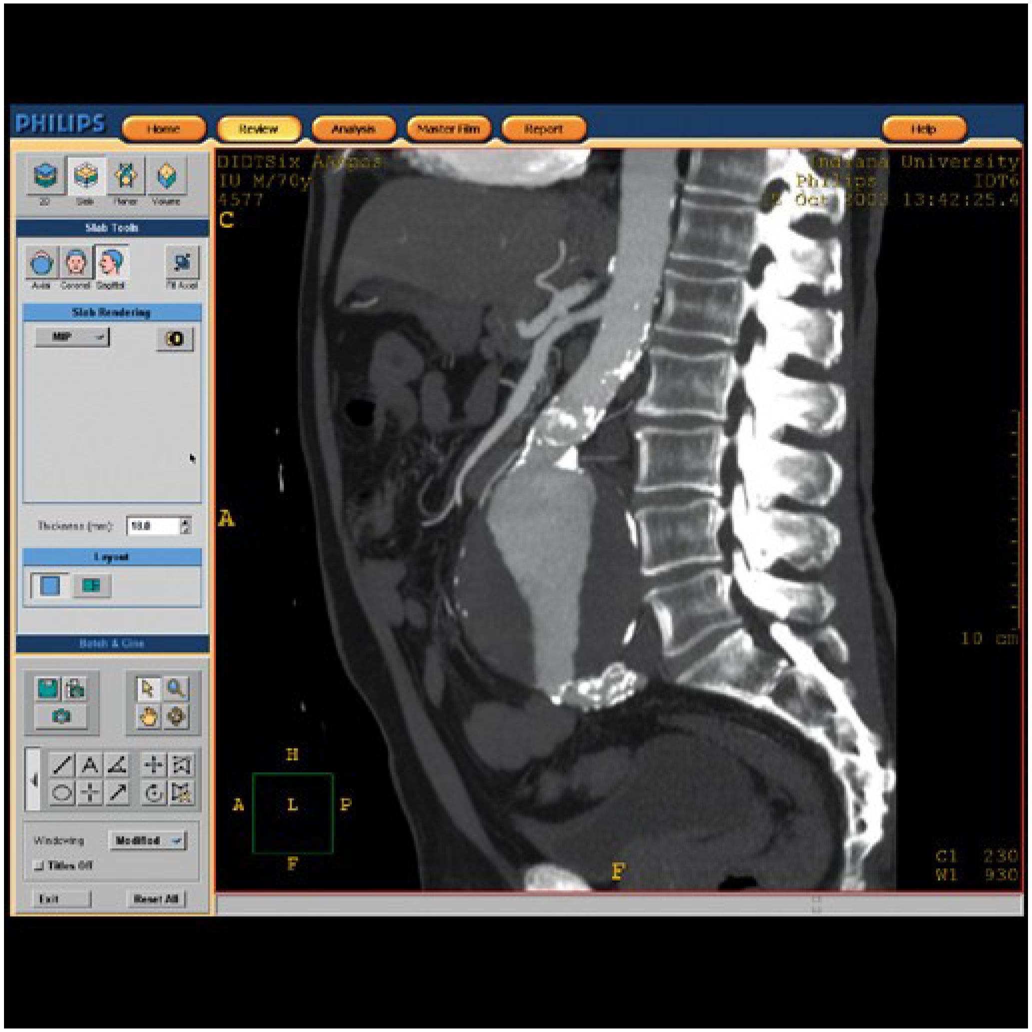
Due on Monday, 15 September 2014 at noon Eastern Time.

Back Projection

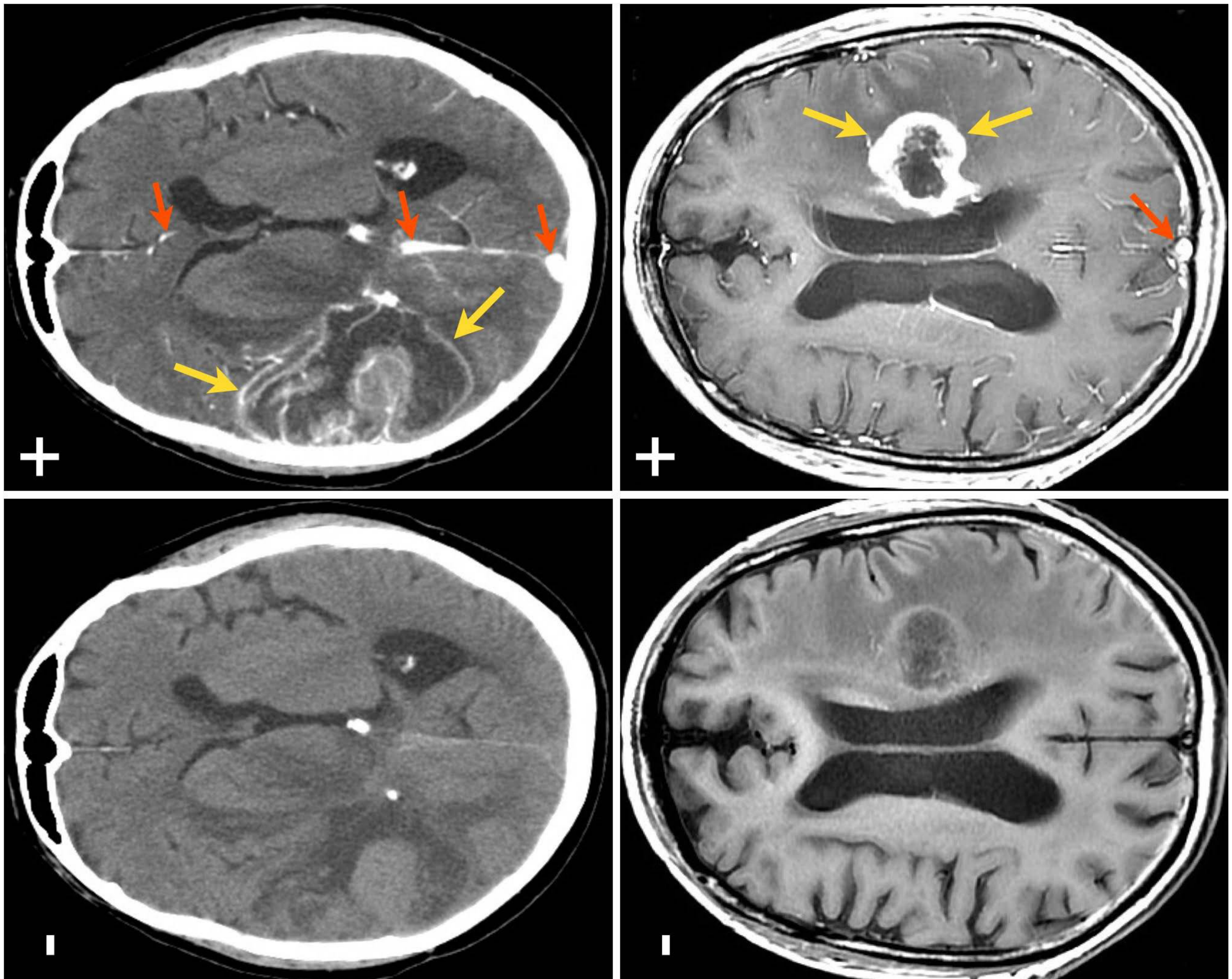
Solve Multiple Simultaneous Equations



CT Images


PHILIPS
Home
Review
Analysis
Master Film
Report
Help
Slab Tools
Slab Rendering
Layout
Indiana University
10 cm
H
A
L
P
F
C1 230
W1 930

CT Images



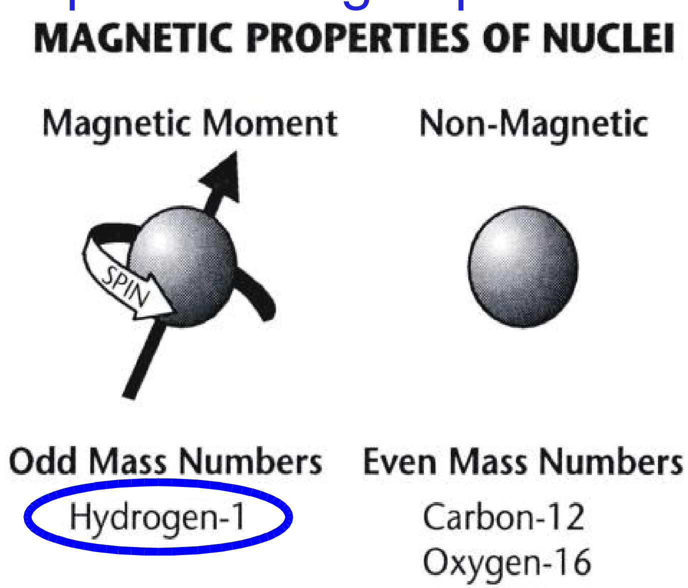
3-D Reconstruction from CT Scans

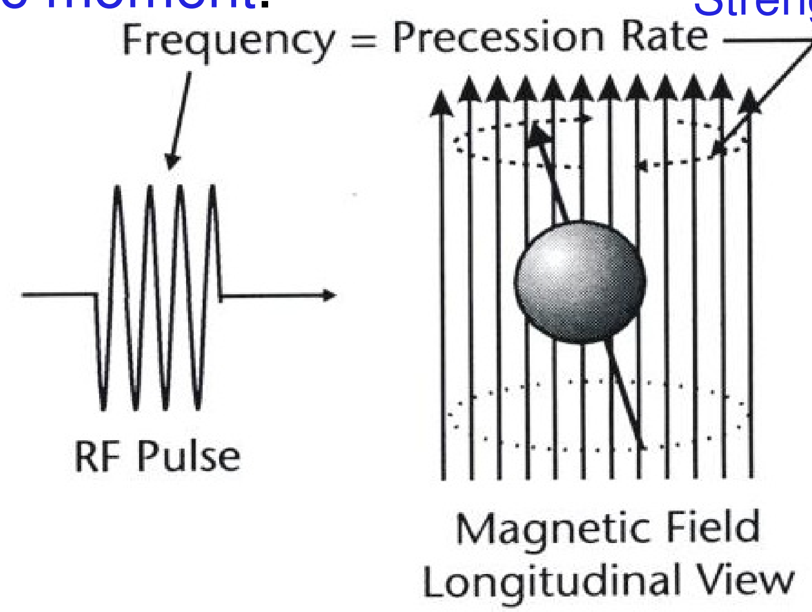
Magnetic and Non-magnetic Nuclei

- Protons and neutrons make up a nucleus.
- Both have an intrinsic angular momentum or spin.
- Pairs of protons and neutrons align to cancel spin.
- Even mass numbers → No net spin.
- Odd mass numbers net spin characteristic.
- Spin of charged particle → magnetic moment.

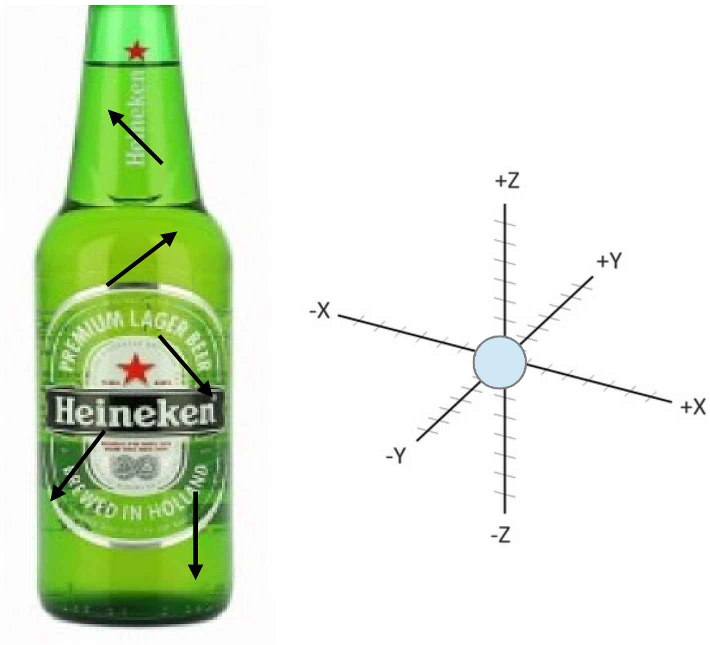
Precession Frequency, Gyrometric Ratio, Magnetic Field Strength

$$\omega = \gamma B$$





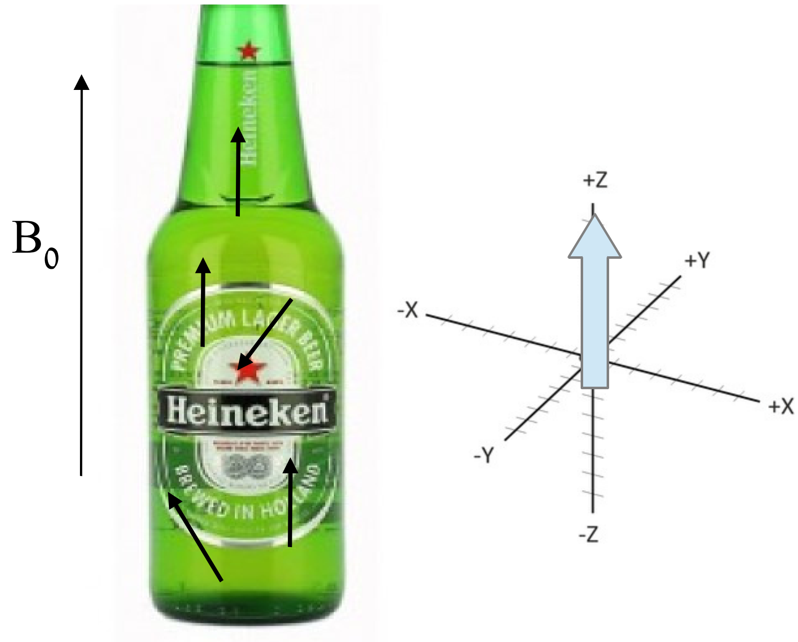
Matter in Magnetic Field



No external magnetic field present

Net magnetization is zero

Mx = My = Mz = 0



External magnetic field present

Net magnetization is non-zero

TEMP

Mx = My = 0, Mz = Mo α ($N \gamma^2 B_0$)/T

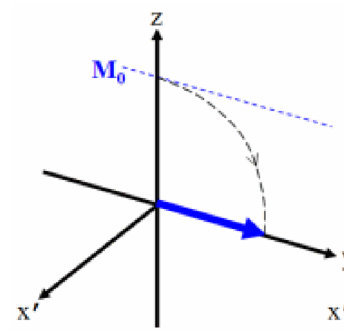
Number of Nuclei

Gyrometric ratio

Generation of the MRI Signal

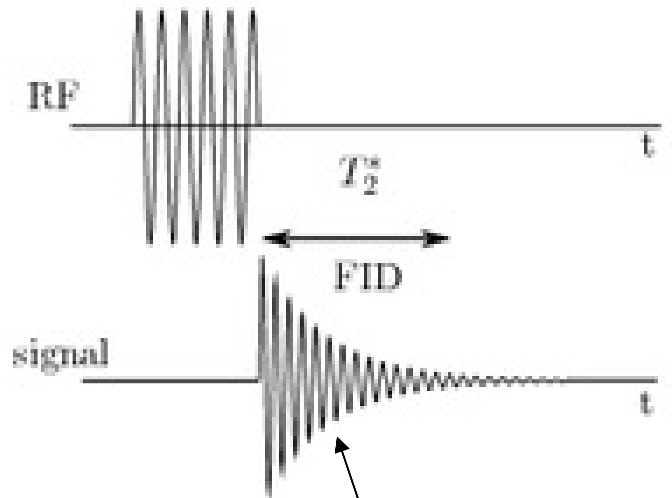
FID: Free induction decay

Received signal = $A_0 \sin(\omega t)\, e(-t/T_2)$

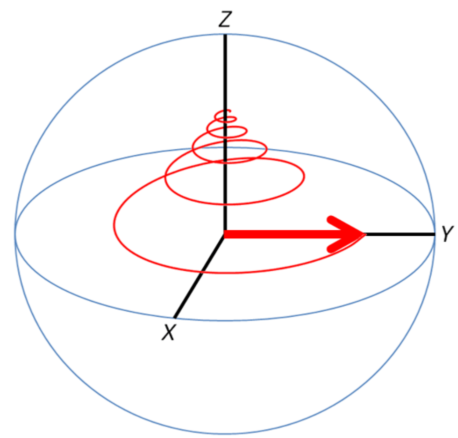


RF pulse is applied to "tip" the spinning nucleus.

Once the RF pulse ends, the nucleus will wobble (precess) until it aligns back with the Z-axis.



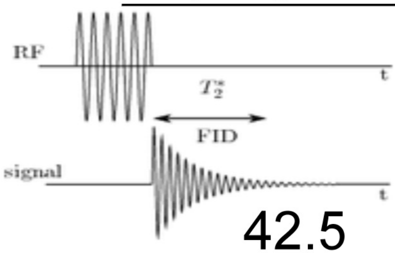
Component along the X-axis as a function of time, which can be picked up by an antenna.

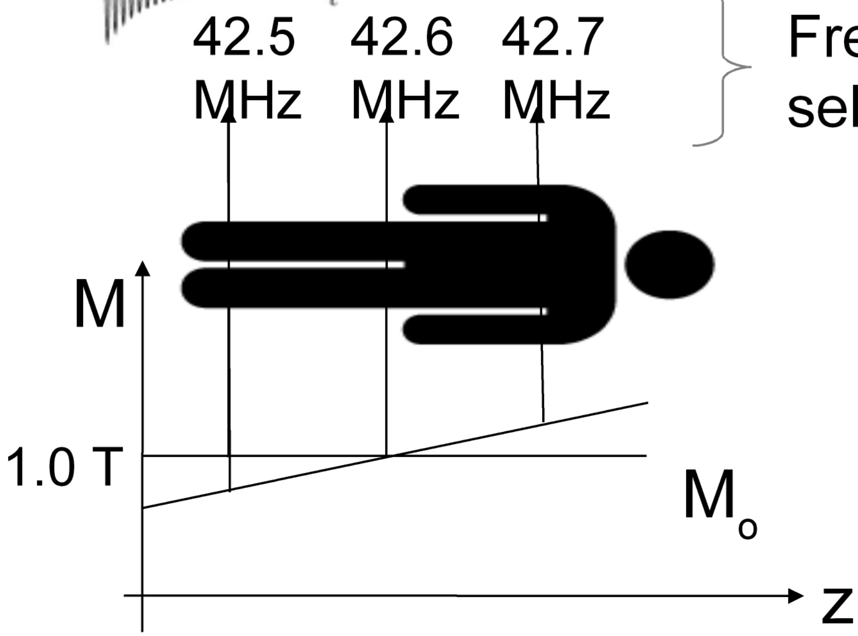


Slice Selection in MRI

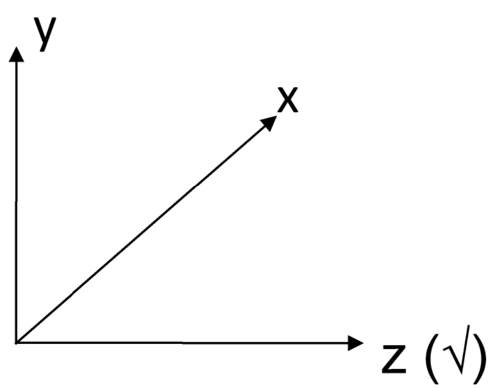
Strength of the magnetic field at point [x,y,z]:

$$M(x, y, z, t) = M_o + xG_x(t) + yG_y(t) + zG_z(t)$$





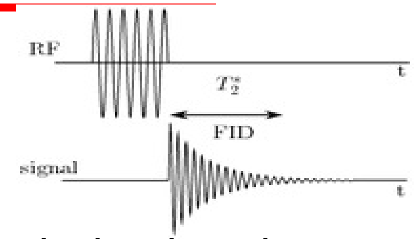
Frequency of RF excitation for the selection of the slice at a given **z**.



Rows & Columns within a Slice

Magnitude of the magnetic field at point [x,y,z]:

$$M(x, y, z, t) = M_o + xG_x(t) + yG_y(t) + zG_z(t)$$



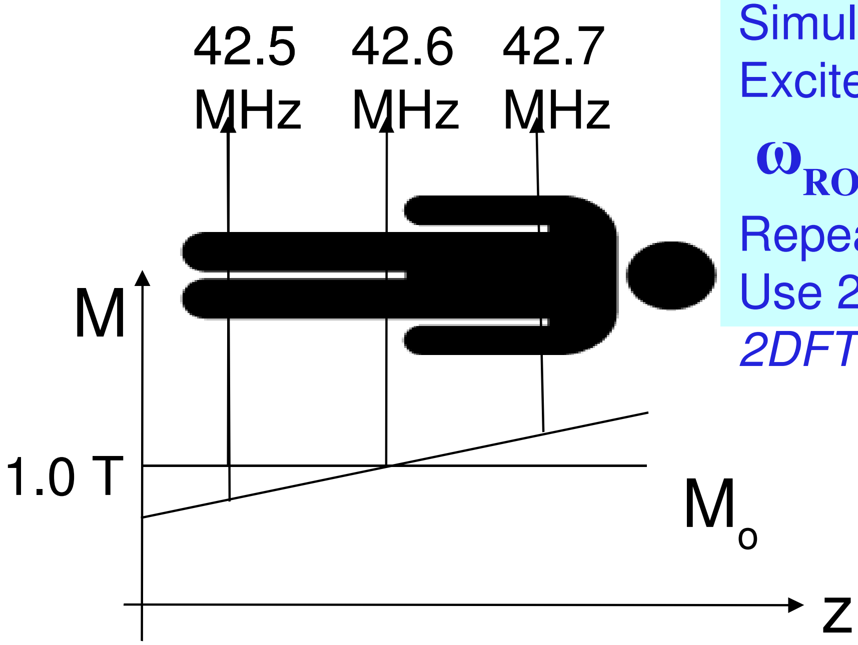
FID: Free induction decay

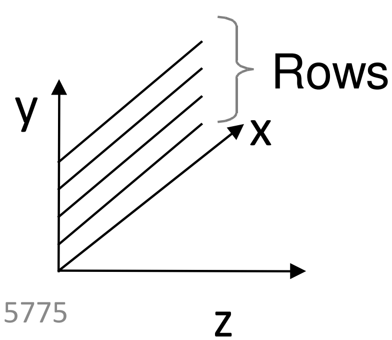
FREQUENCY ENCODING TECHNIQUE:

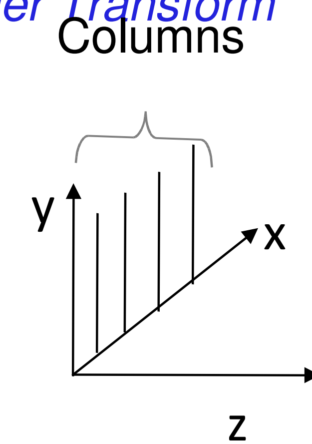
Turn off the original Z gradient while receiving FID
Simultaneously, turn on the gradient in *Y direction*
Excited protons experience a different B field

$$\omega_{ROW} = \gamma\ B_{ROW}$$

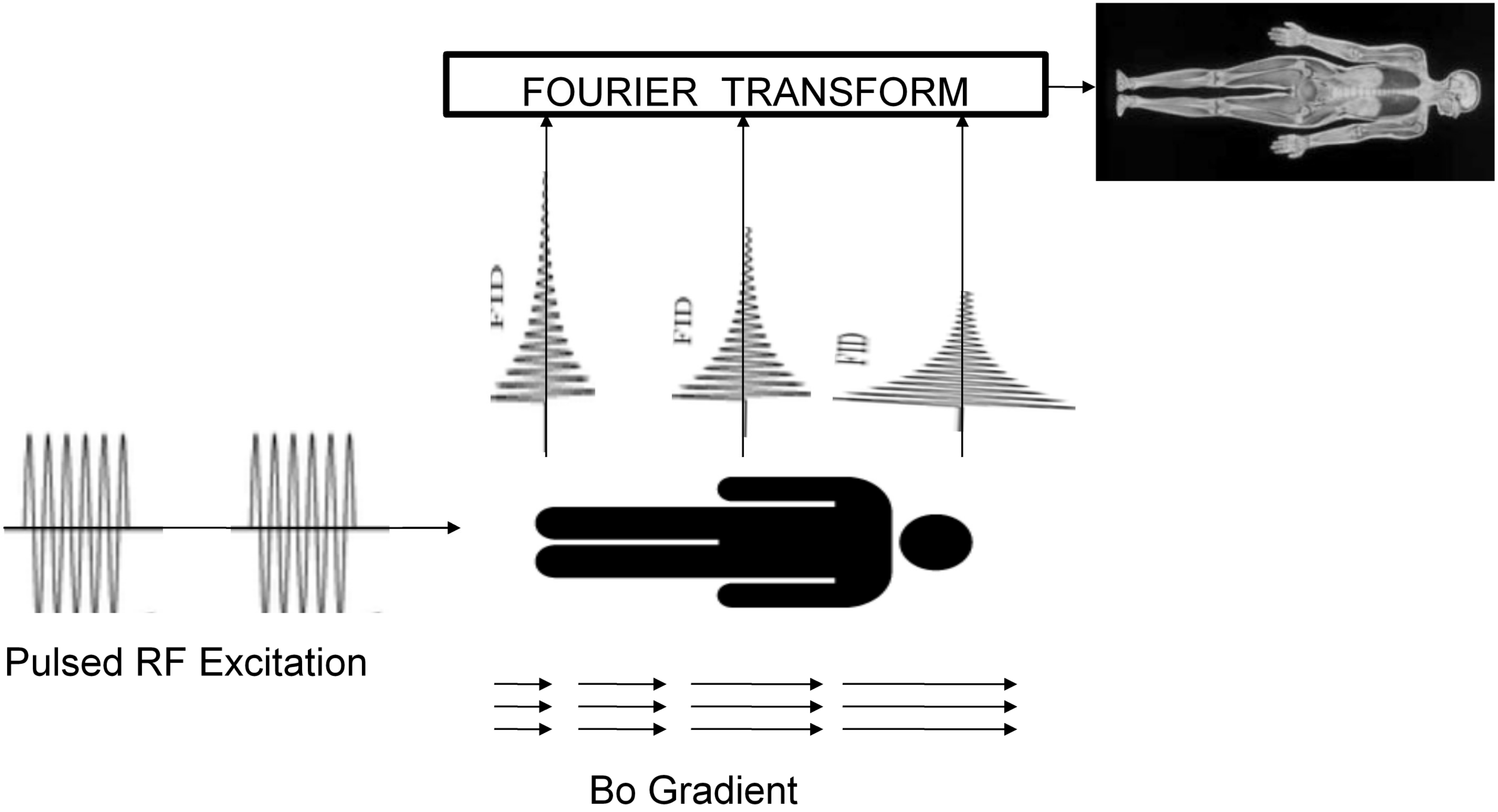
Repeat the process for *X direction* → Columns
Use 2DFT to generate the image from row&col data
2DFT: Two Dimensional Fourier Transform





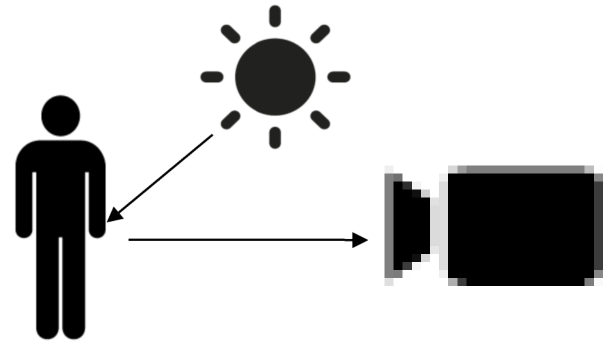


Overall MRI Process

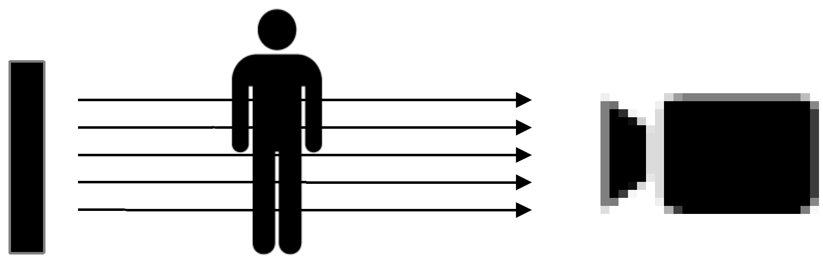


Summary: Three Options for Imaging

- Reflection
  - Photography
  - Ultrasound



- Transmission
  - X-ray
  - CT-Scan



- Emission
  - PET
  - MRI