EE-415 Fundamentals of Tomographic Medical Imaging

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Outline

- What is medical imaging
- History
- Projection Imaging
- Computerized Tomography (CT)
- Nuclear Source Imaging (PET, SPECT)
- Ultrasonic Imaging
- Magnetic Resonance Imaging
- Electrical Impedance Imaging

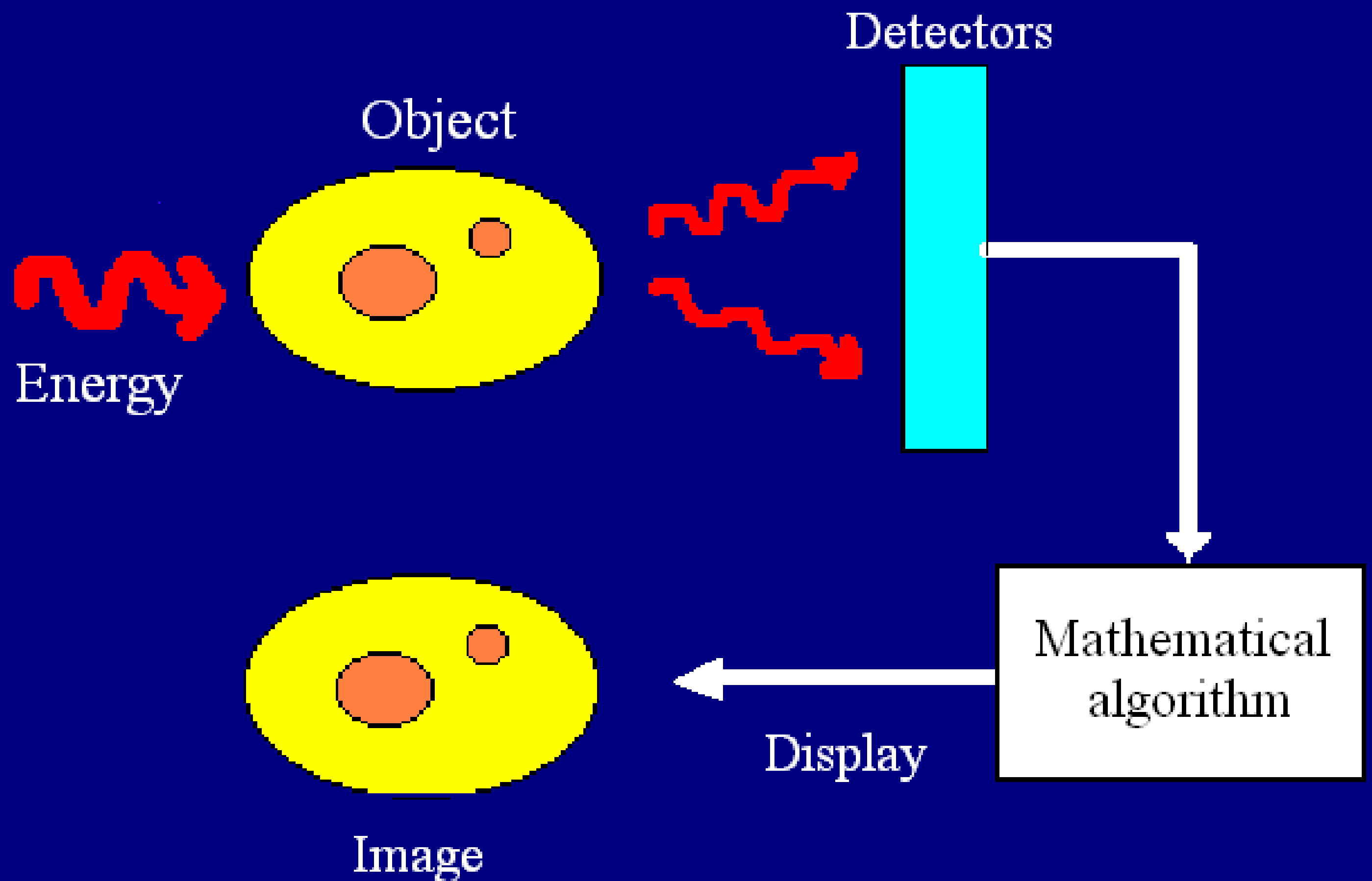
What is medical imaging?

Medical imaging is a collection of techniques, that are developed to measure and display distribution of a physical property in living subjects, specifically in humans.

Why is it useful?

Medical imaging, not only provides useful information for diagnosis but also serves to assist in planning and monitoring the treatment of malignant disease.

Simplified block diagram of a Medical Imaging System



Which energy types are used for imaging?

- X-ray
- Nuclear (radio-isotope) sources,
- Ultrasonic waves,
- Magnetic fields,
- Electrical currents,
- Mechanical,
- Optical waves etc.

What are the physical properties of interest?

- X-ray absorption coefficient,
- Radionuclide concentration,
- Ultrasonic properties,
- Spin density and spin relaxation,
- Electromagnetic properties,
- Mechanical properties,
- Optical properties.

Why are we interested in these physical properties?

Certain physical property may vary

- between different healthy tissue types,
- with the physiological state of a tissue type,
- with the pathological condition of a tissue type.

Why are there so many imaging modalities?

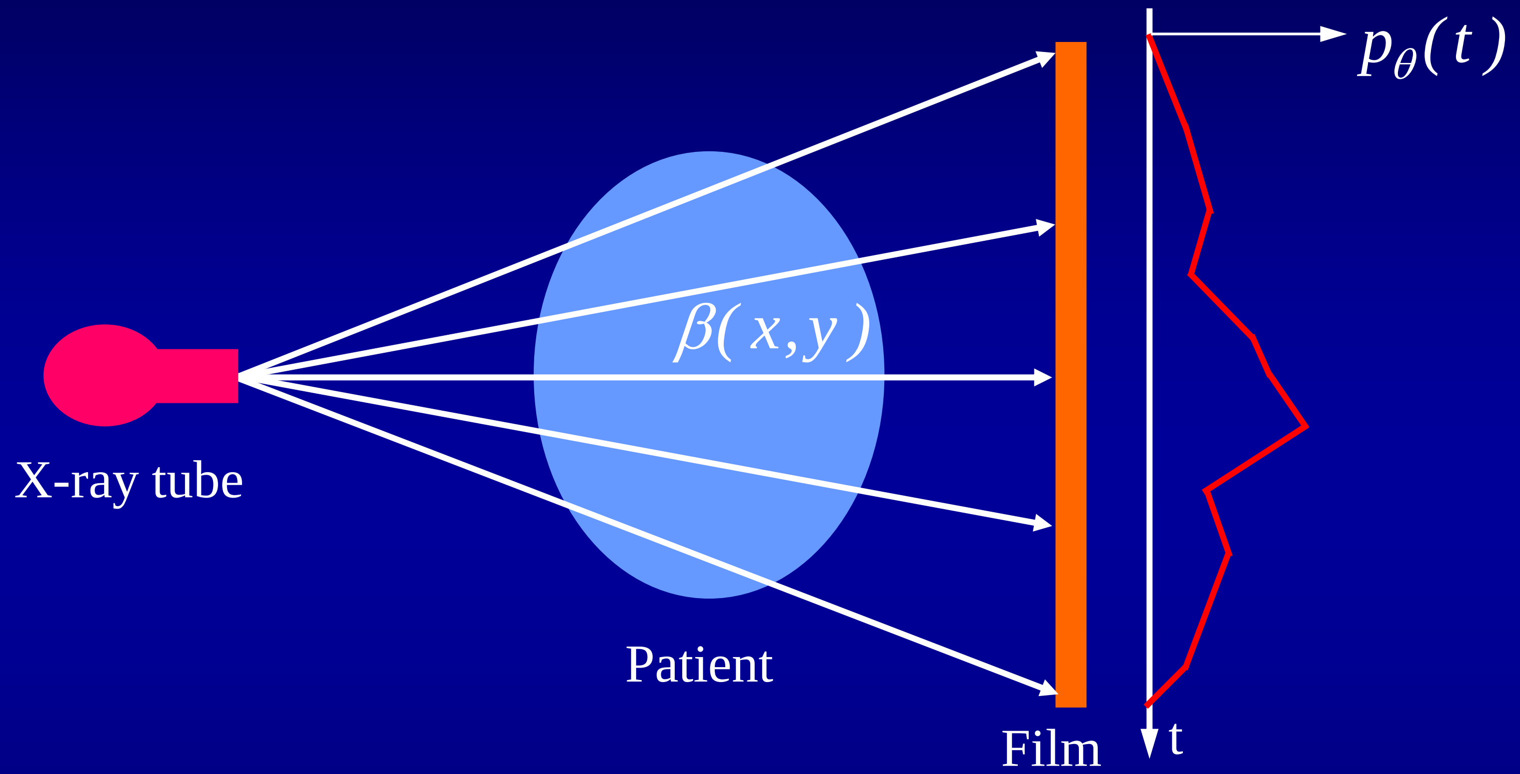
- All imaging modalities are based on the physics of the interaction of energy and matter.

- Different imaging modalities are based on physical interaction of different energy types with biological tissues and thus provide images of different physical properties of the tissues.

History

- Discovery of X-rays, 1895,
- Radon transform, 1917,
- NMR principles, 1946,
- Nuclear medicine scan, 1948,
- Ultrasound imaging, 1952,
- Positron tomography, 1953,
- Single Photon Emission CT, 1971
- Development of X-ray CT, 1972,
- NMR Imaging, 1976,
- Impedance Tomography, 1982.

X-ray Projection Radiography



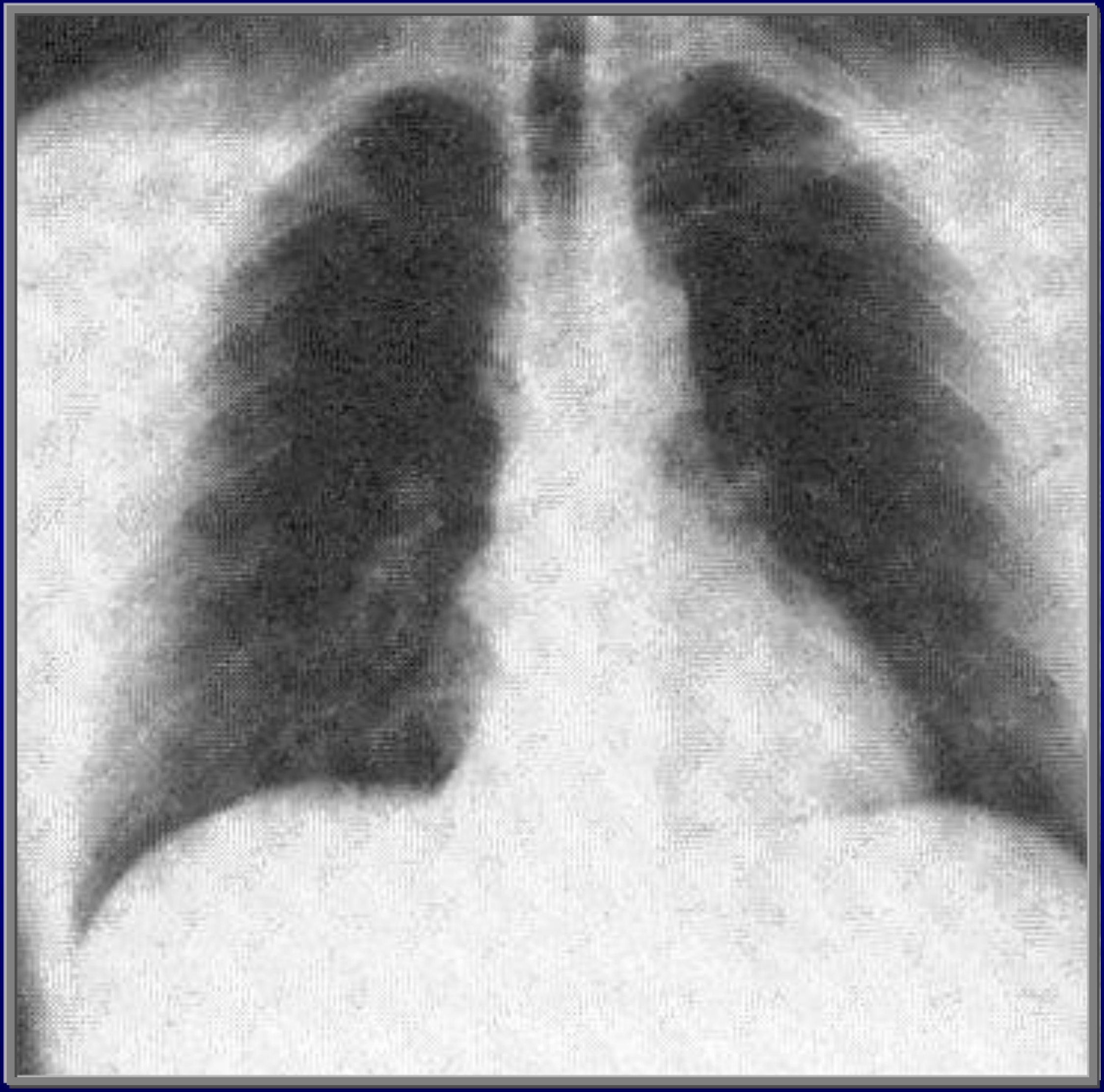
$$p_\theta(t) = \int \beta(x,y)\,ds = \int_{-\infty}^{+\infty}\!\!\int \beta(x,y)\,\delta(x\cos\theta + y\sin\theta - t)\,dx\,dy$$

Radon Transform

Attenuation Coefficients for Biological Tissues at 60 keV

Tissue	Attenuation coefficient (cm^{-1})
Blood	0.215
Brain matter	0.210
Water	0.203
Fat	0.185
Bone	0.400
Air	0.0002

Typical Chest X-ray Radiograph



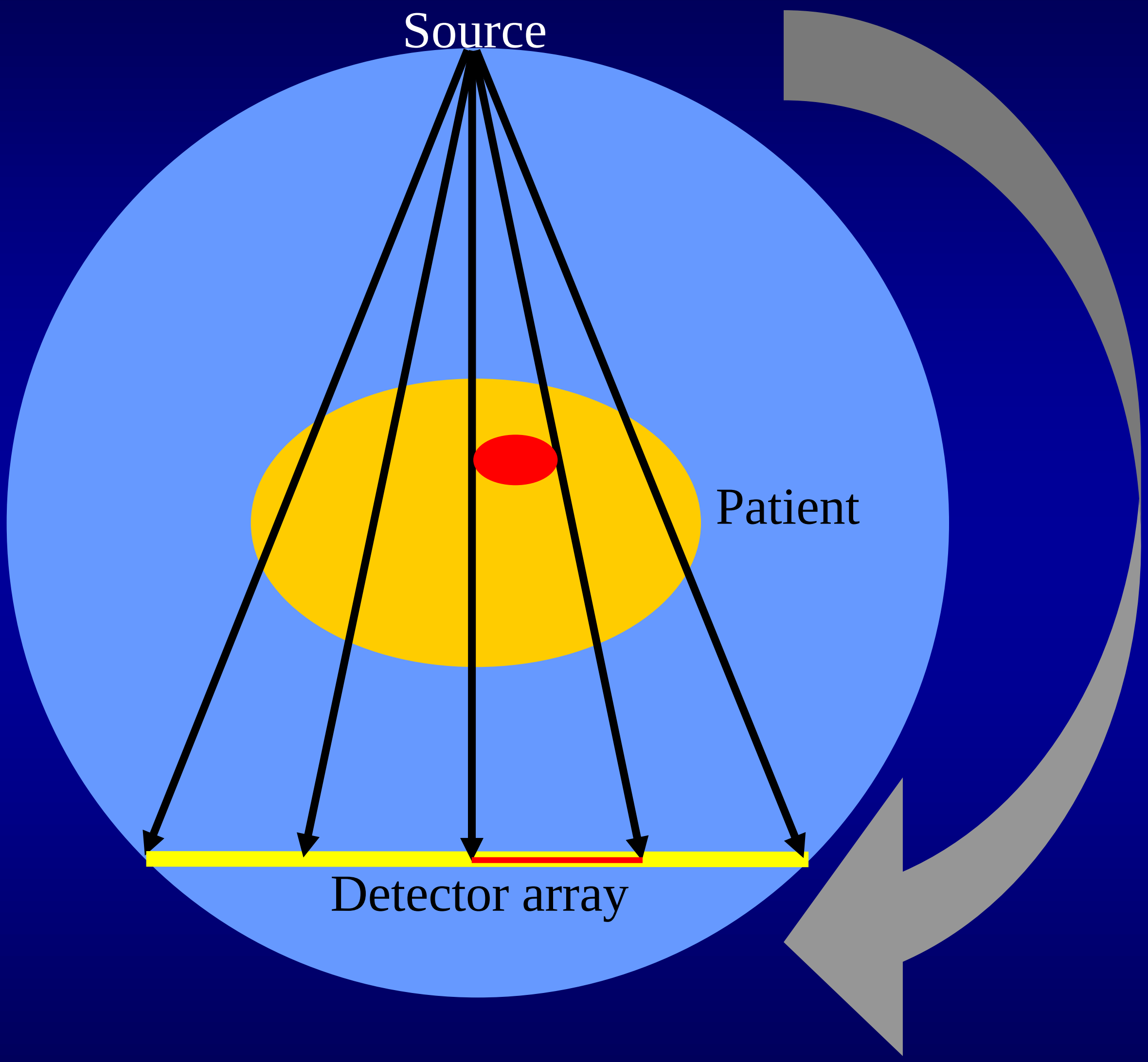
Tomographic Imaging

cut image

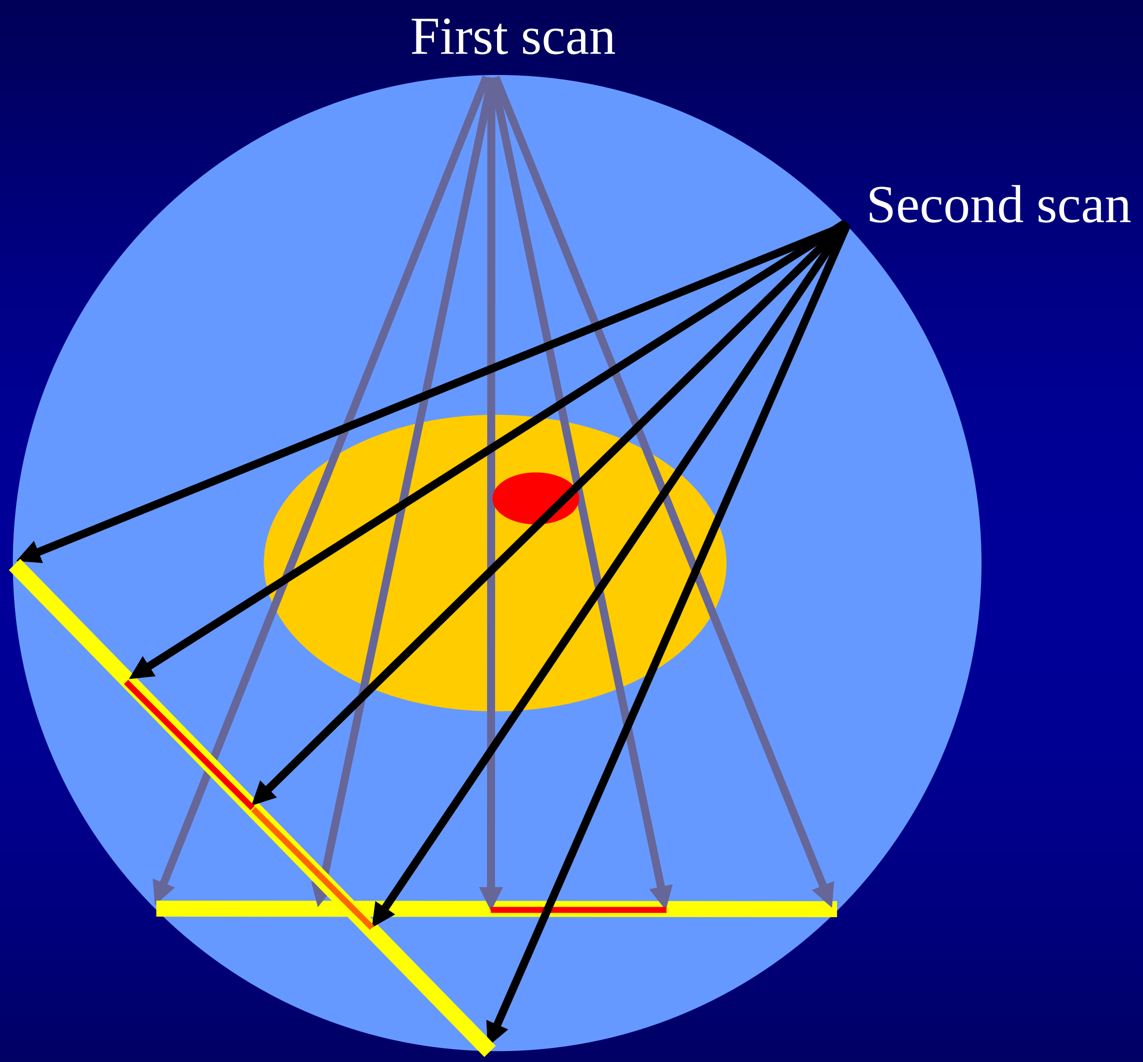
3-dimensional subject

2-dimensional slice

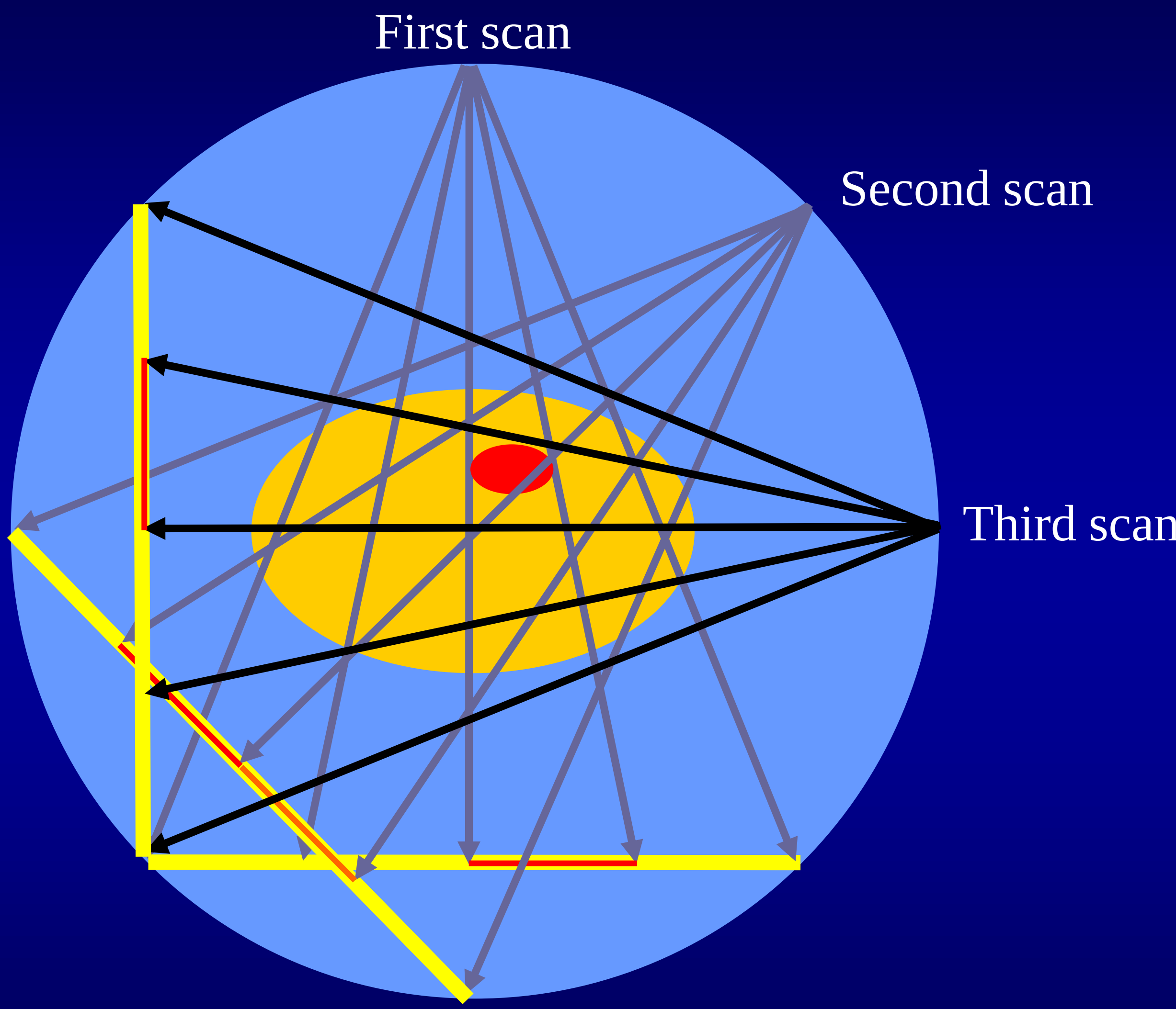
X-ray CT



CT Scan



CT Scan



CT Scan

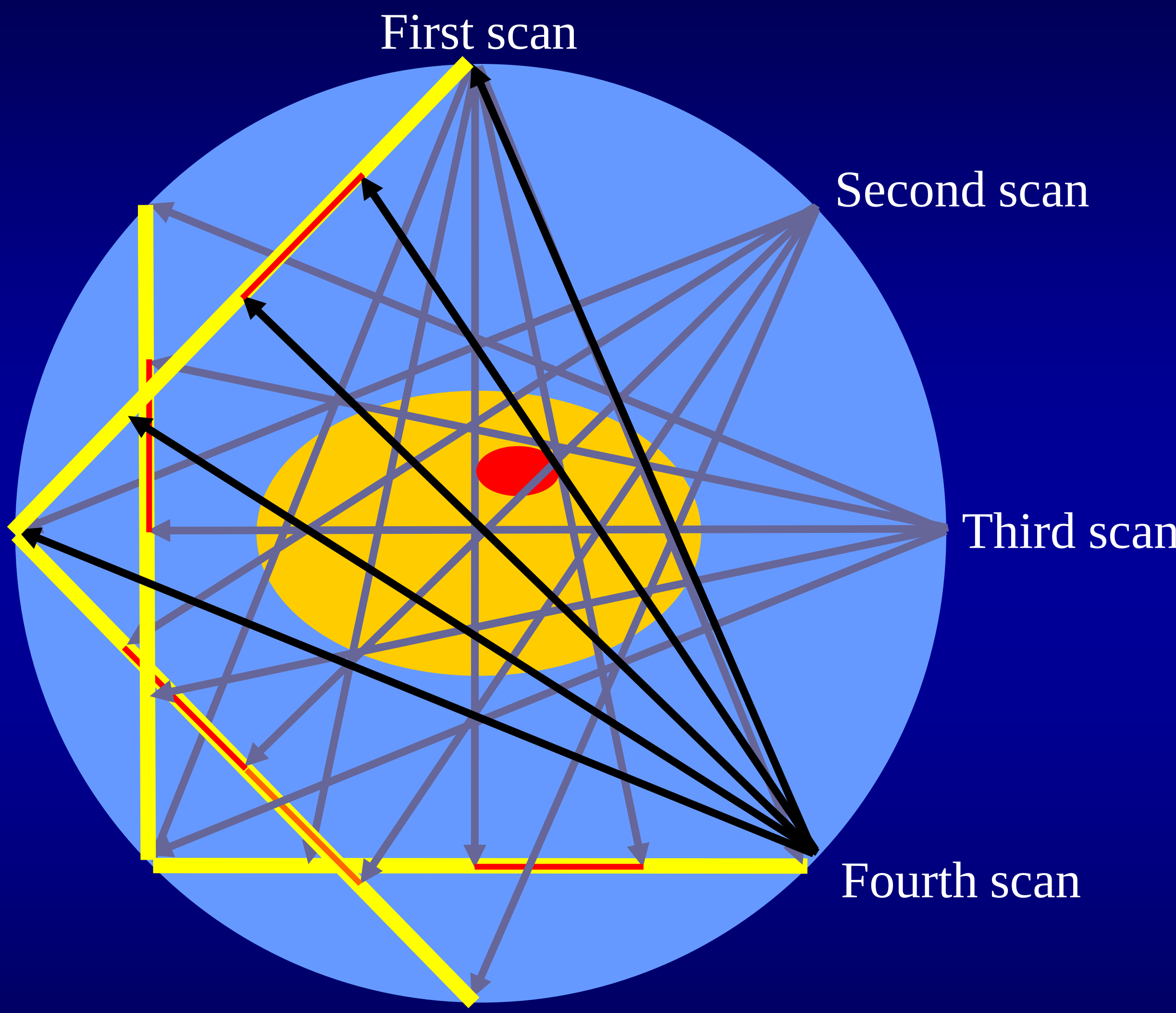
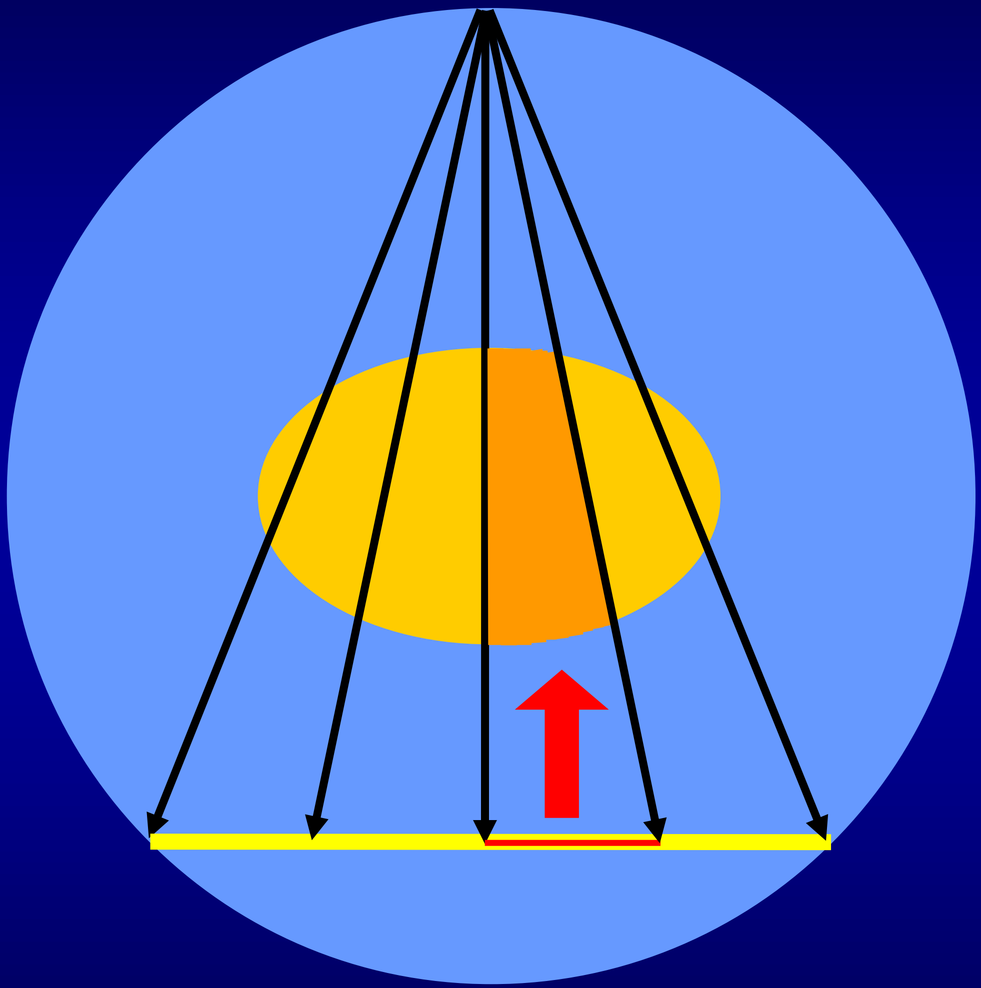
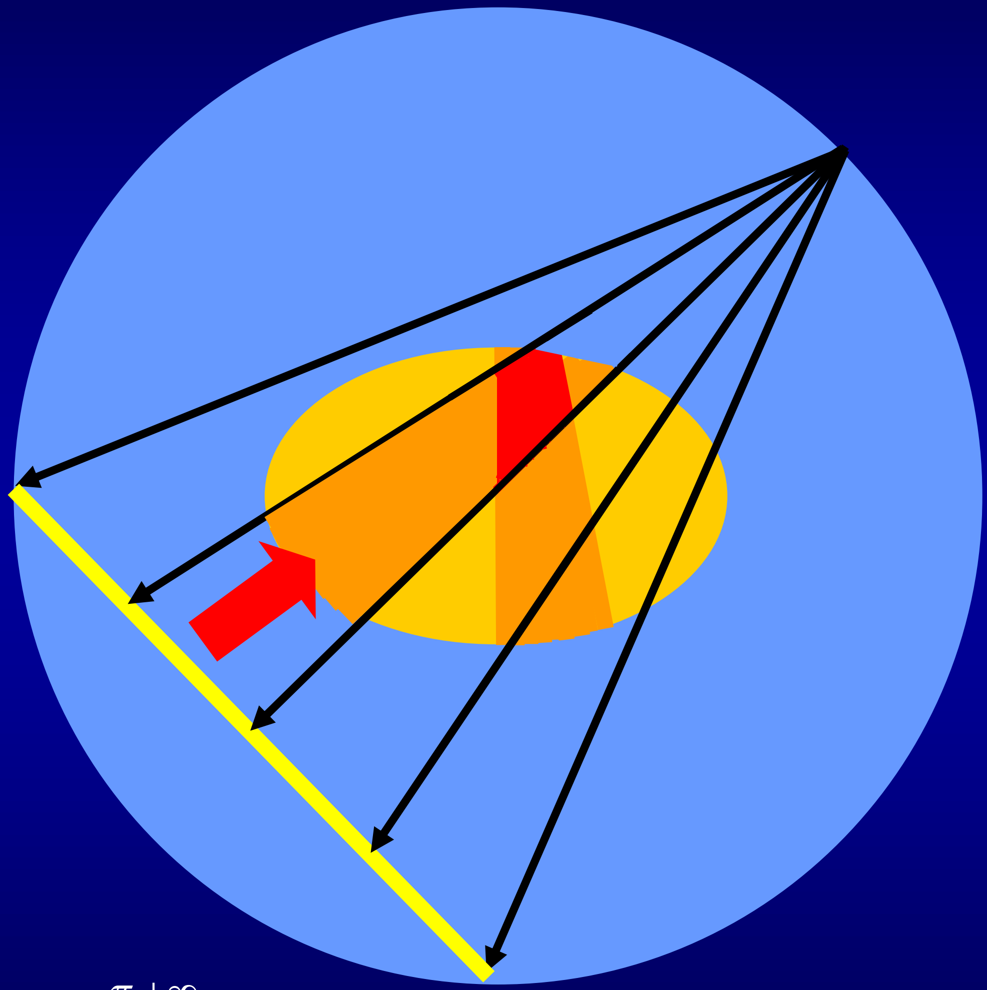


Image Reconstruction - Backprojection



$$\beta_{b,\theta}(x,y) = \int_{-\infty}^{+\infty} p_\theta(t)\delta(x\cos\theta + y\sin\theta - t)dt$$

Image Reconstruction - Backprojection



$$\beta_b(x,y) = \int_0^{\pi} \int_{-\infty}^{+\infty} p_\theta(t)\delta(x\cos\theta + y\sin\theta - t)\,dt\,d\theta$$

Filtered Backprojection

Backprojected image represents a blurred version of the original distribution:

$$\beta_b(x,y) = \beta(x,y) ** \frac{1}{r} \;\; \Rightarrow \;\; F_2\{\beta_b(x,y)\} = F_2\{\beta(x,y)\} \cdot \frac{1}{\rho}$$

This blurring effect can be removed as,

$$\beta_{bf}(x,y) = F_2^{-1}\{\rho \cdot F_2\{\beta_b(x,y)\}\}$$

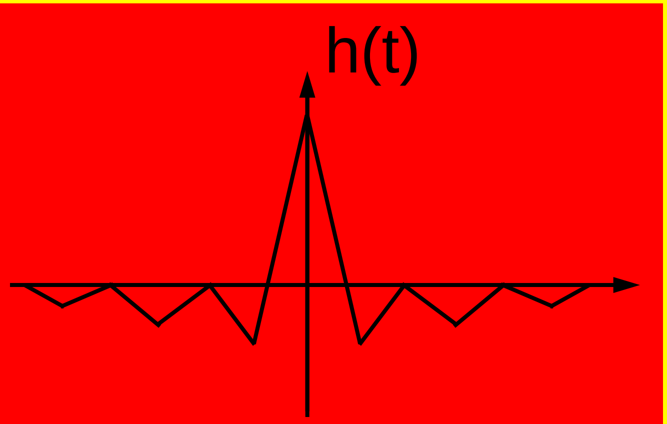
Filtering can be applied to projections prior to backprojection which is computationally more effective:

$$F_1^{-1}\{F_1\{p_\theta(t)\} \cdot |\rho|\} = p_\theta(t) ** F_1^{-1}\{|\rho|\}$$

Filtered Backprojection

Measure projections from all possible view angles

Convolve all projections with the filtering function



Backproject the filtered projections

Performance of CT

- Spatial resolution of 1 mm. (minimal distance between two pixels which can be discriminated is 1 mm.)
- Contrast resolution of 1 % (i.e, pixel density which is 1% different than the background density can be discriminated.)
- Soft tissue contrast is low.
- Invasive : X-rays are harmful for living organisms i.e. contains ionizing radiation.

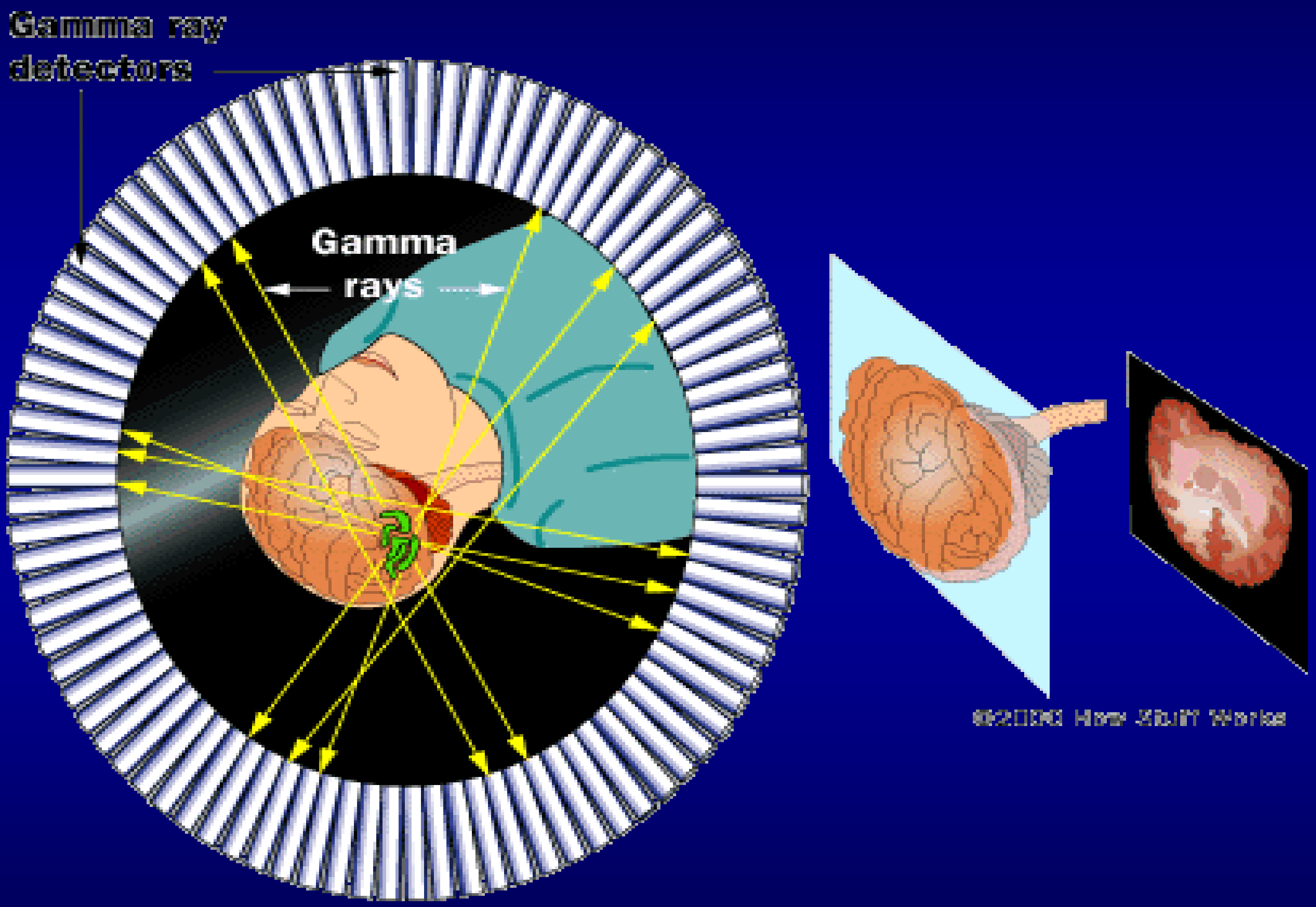
Nuclear Source Imaging

- **Planar Scintigraphy :**
  - Radioisotopes (radionuclides) are injected to the body,
  - They emit radiation which can be detected by photon detectors and the position of the isotopes can be determined,
  - Two-dimensional representations of the projections of three-dimensional activity distributions are reconstructed.

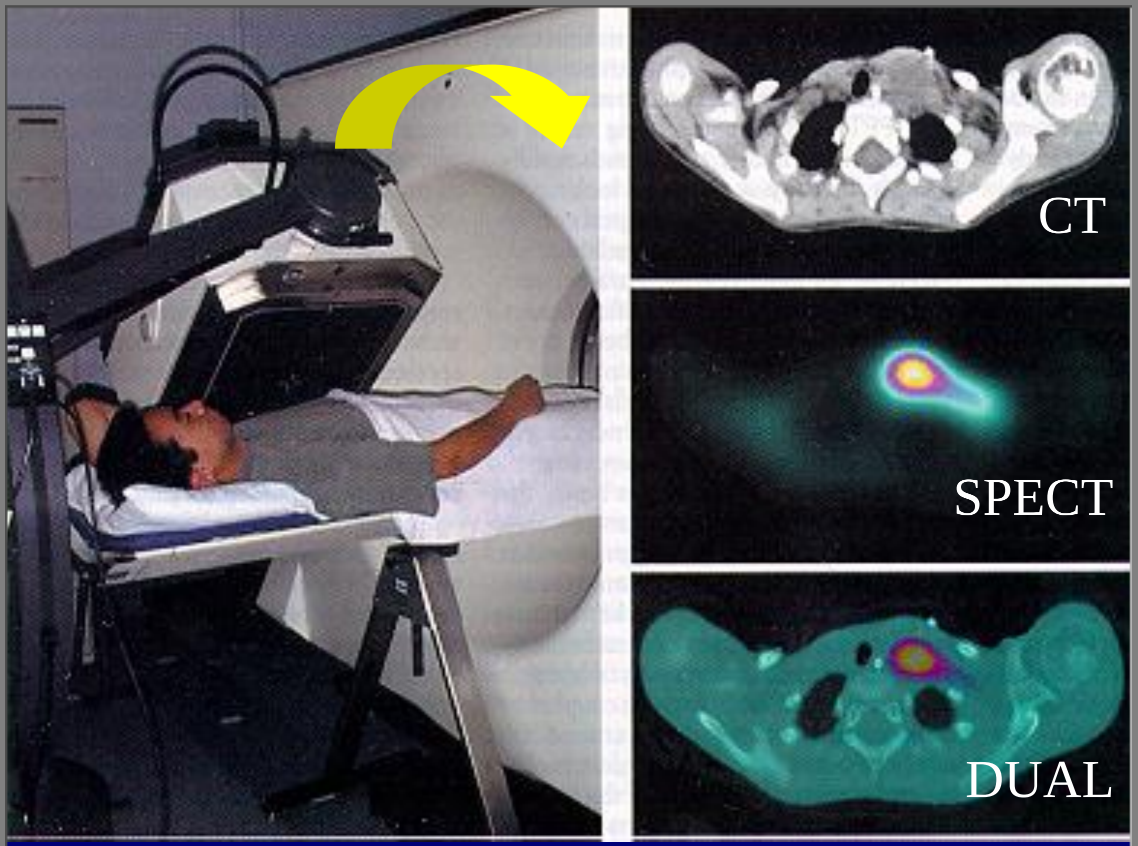
Nuclear Source Imaging

- **Emission Computed Tomography:** is a technique to obtain cross sectional images of activity,
  - **SPECT:** Single gamma ray is emitted per nuclear disintegration.
  - **PET:** Two gamma rays are emitted when a positron from a nuclear disintegration annihilates in tissue.

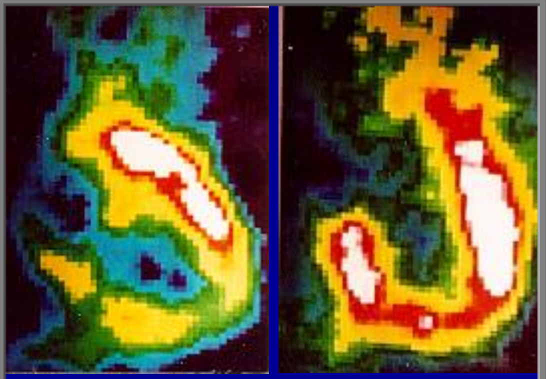
Nuclear Medicine - Brain



SPECT and PET



SPECT | Neuroblastoma



PET perfusion scan of heart

$$p_\theta(t) = \int_{-\infty}^{+\infty}\int A(x,y)\,\delta(x\cos\theta + y\sin\theta - t)\,e^{-\int_s \beta(s)ds}\,dxdy$$

Advantages and Disadvantages of Nuclear Source Imaging

- Functional images can be obtained,
- Spatial resolution is poor,
- Good tissue specific contrast,
- Involves ionizing radiation.

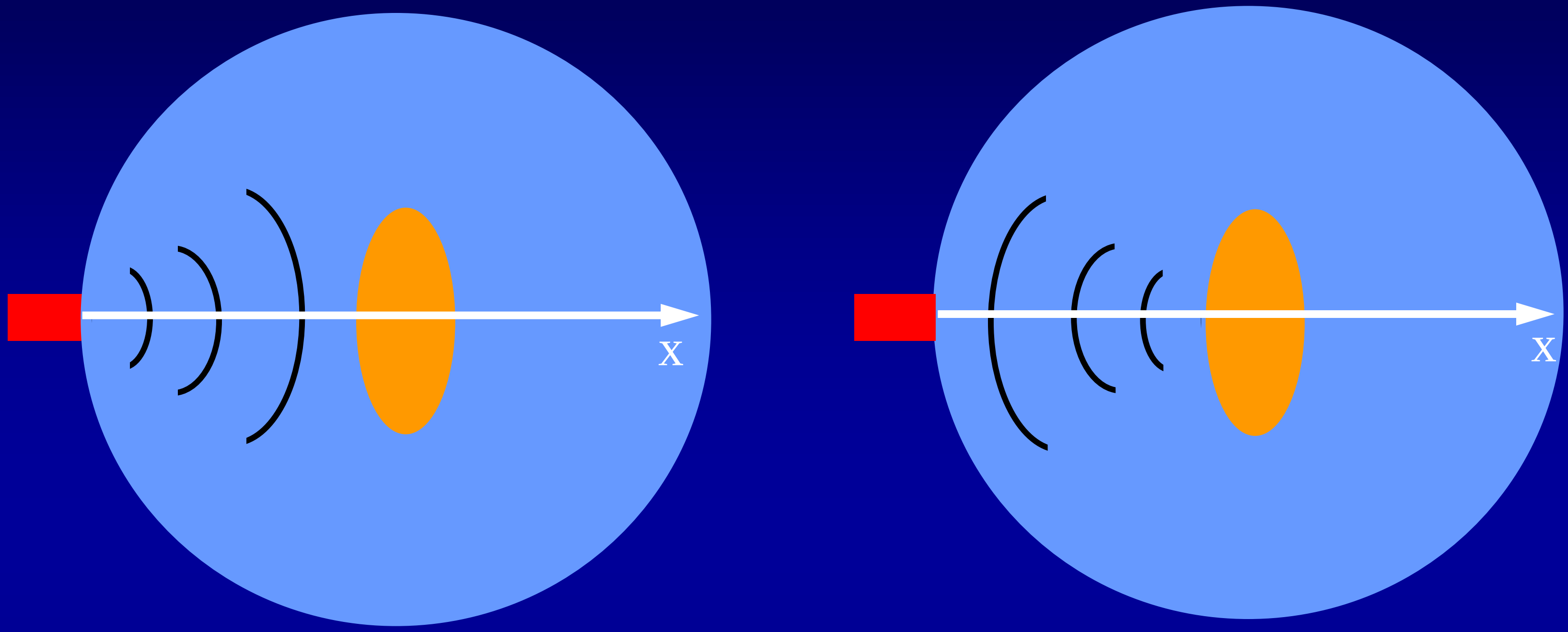
Ultrasonic Imaging

- Body is probed by Ultrasonic waves,
- Ultrasound wave propagates through the body,
- Fraction of the ultrasound waves are reflected at various tissue interfaces along the wave path, producing echoes,
- The reflected echo signals are measured and used to reconstruct the reflection coefficient distribution along the path.

Reflectivity of normally incident waves

Materials at interface	Reflectivity
Brain-skull bone	0.66
Fat-bone	0.69
Fat-blood	0.08
Muscle-blood	0.03
Muscle-liver	0.01
Soft tissue-water	0.89
Soft tissue-air	0.99

Ultrasound Imaging

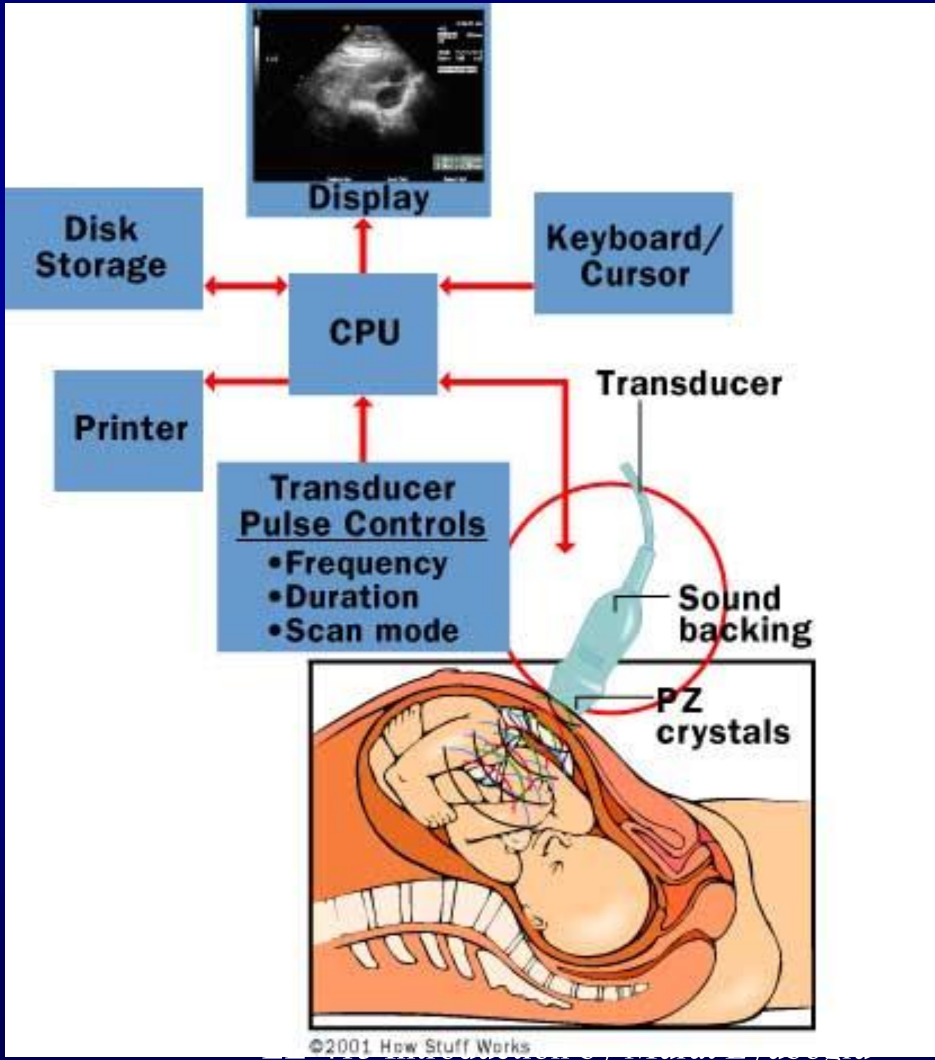


Burst of US wave is transmitted　　Reflected wave is measured

$$p_r(t) = \int_{-\infty}^{+\infty} p_t\left(t - 2\frac{x}{c}\right) f(x)\,dx$$

f(x): total reflectivity from a line at x

Ultrasound imager

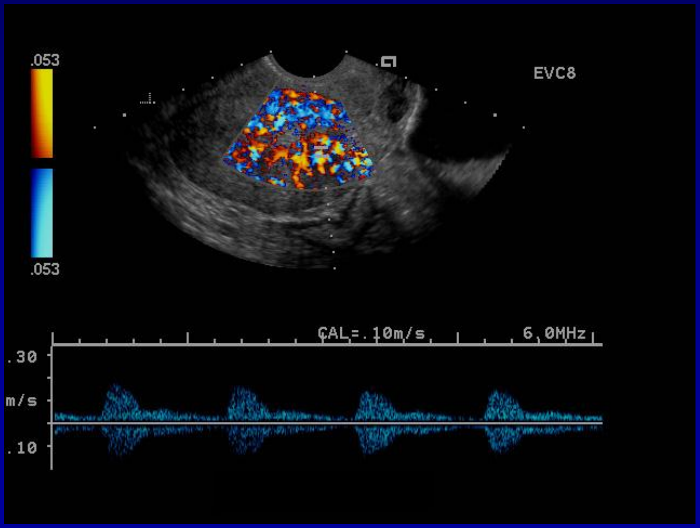


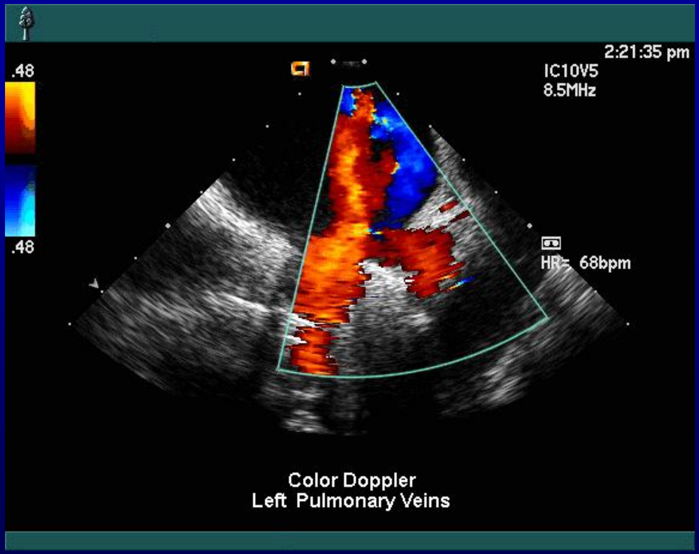
Ultrasound Imaging

Ultrasound scanner

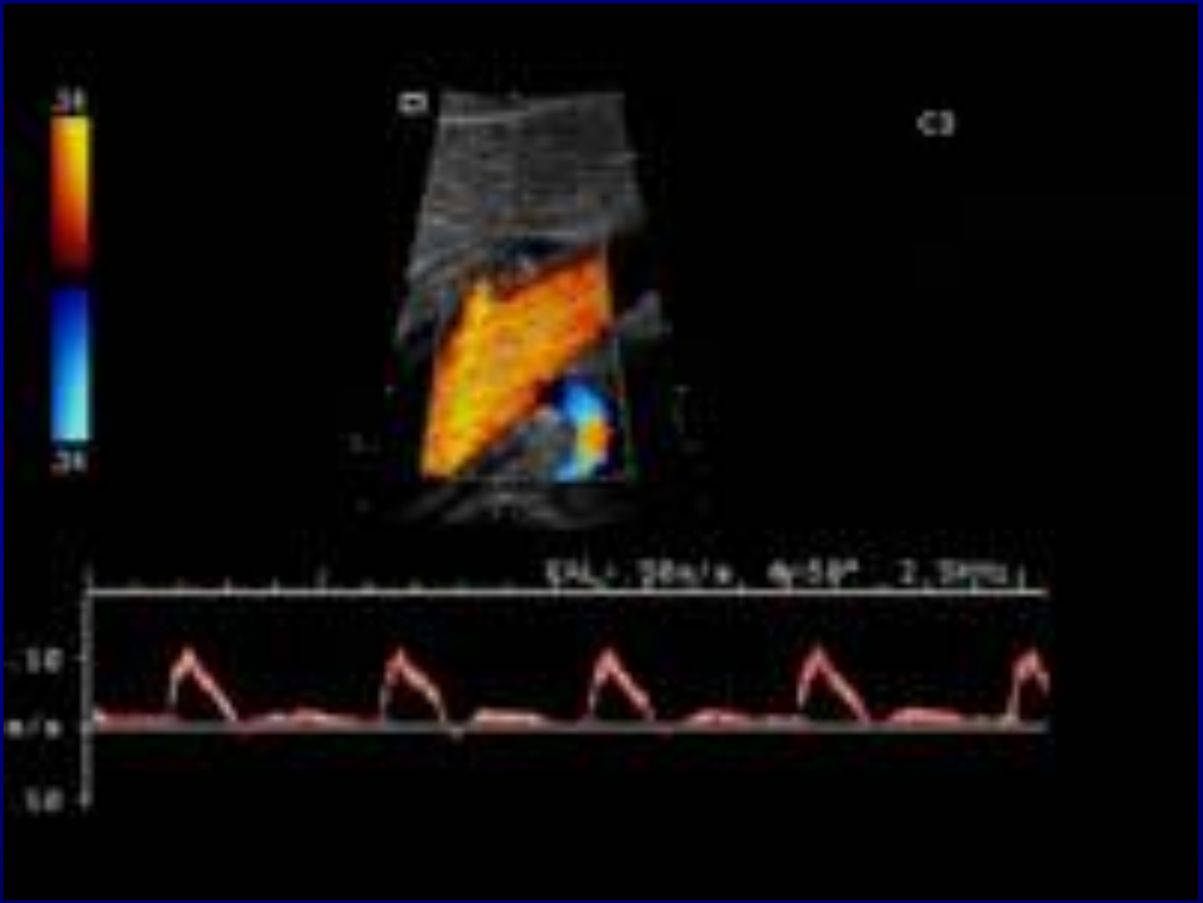
US image of a fetus hand

Ultrasound Doppler

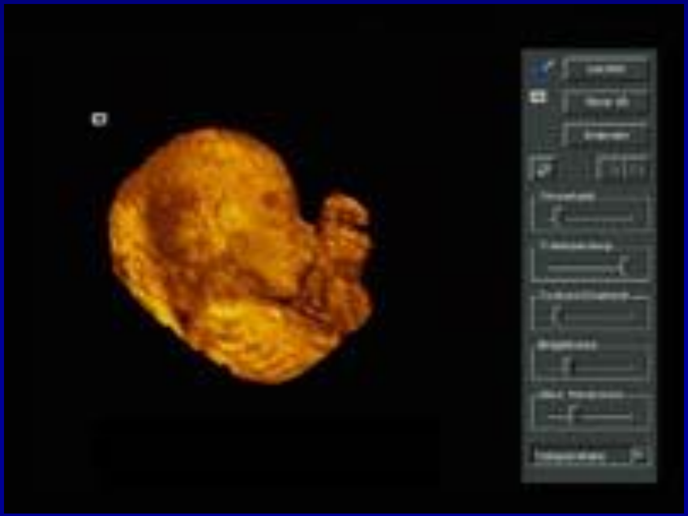


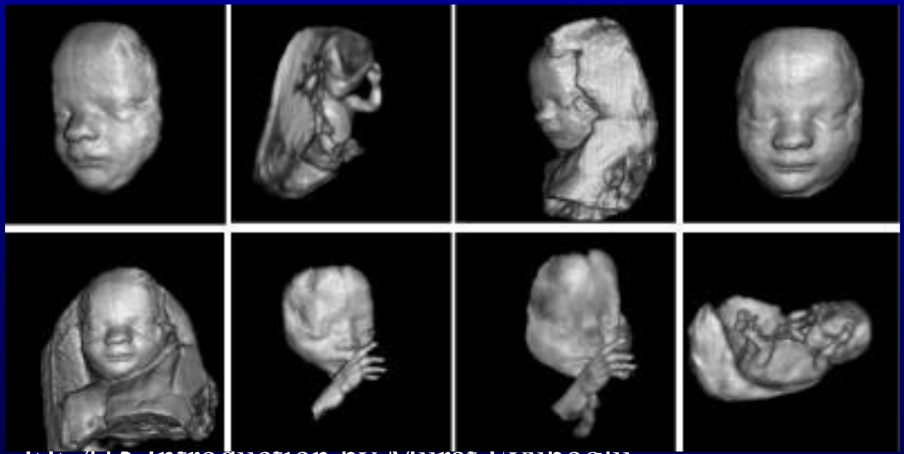


B-Scan ultrasound



3D ultrasound





What is your infant upto?

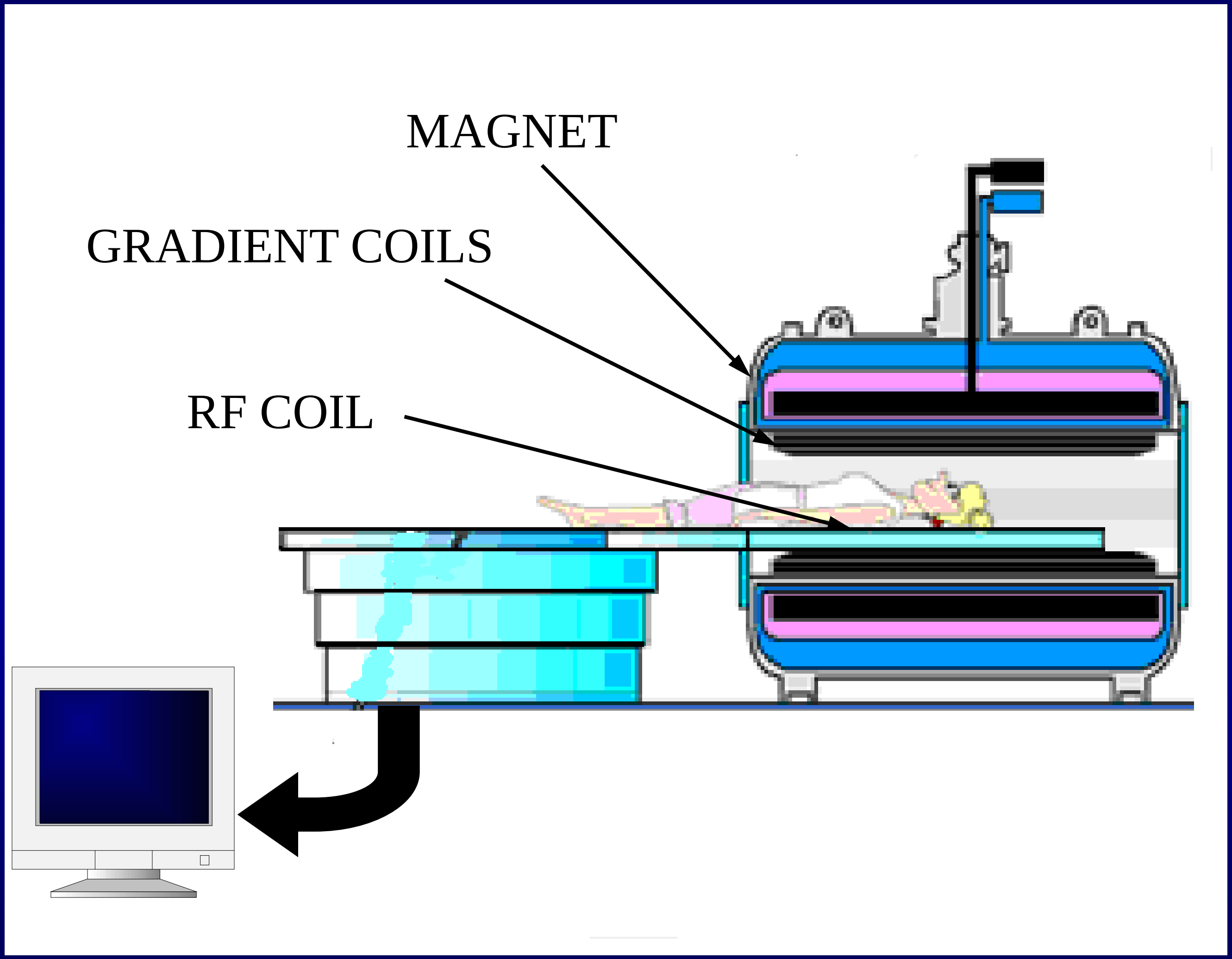
Advantages and Disadvantages of Ultrasound

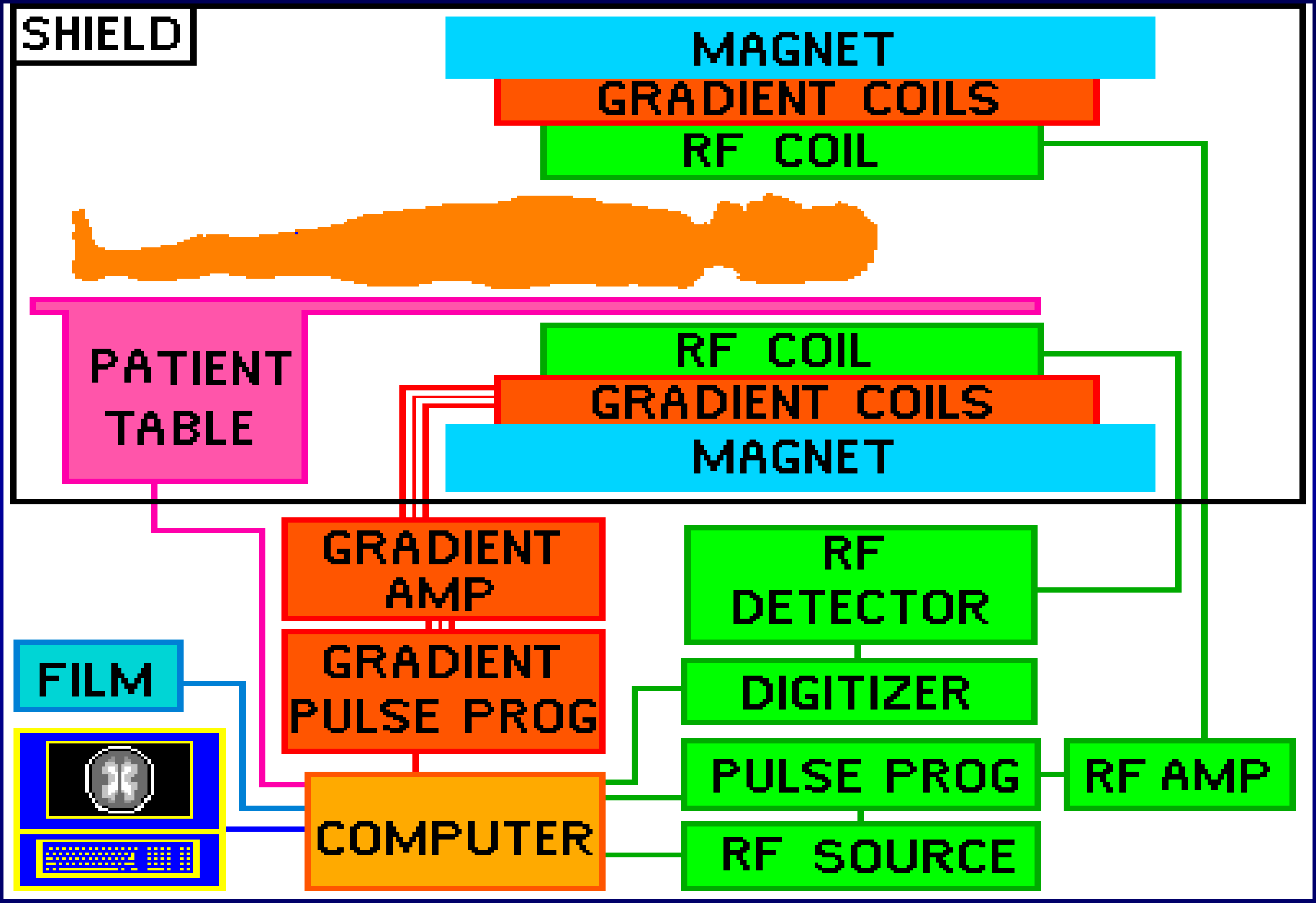
- Functional images can be obtained,
- Involves no ionizing radiation,
- Portable.

Magnetic Resonance Imaging

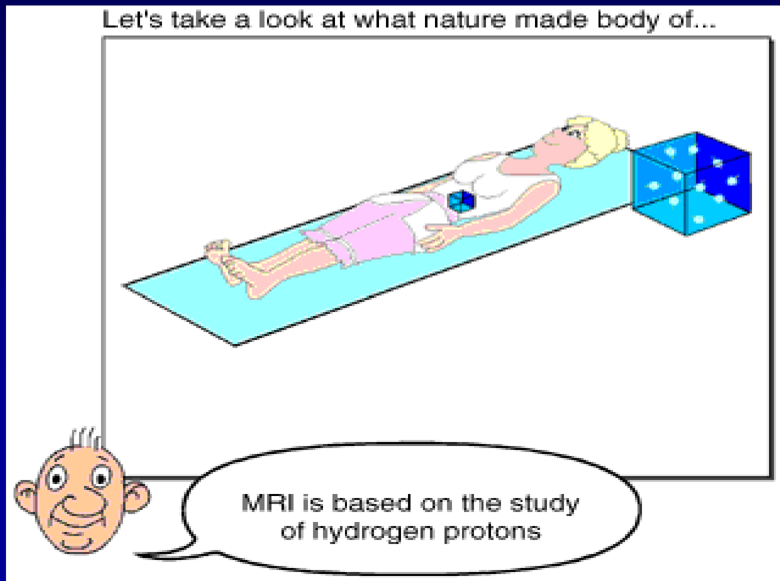
MR imaging system

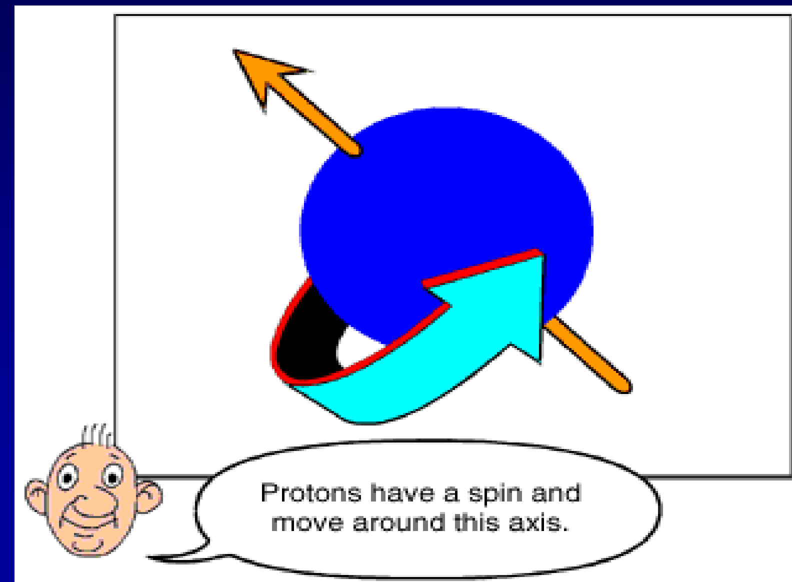
Magnetic Resonance Imaging

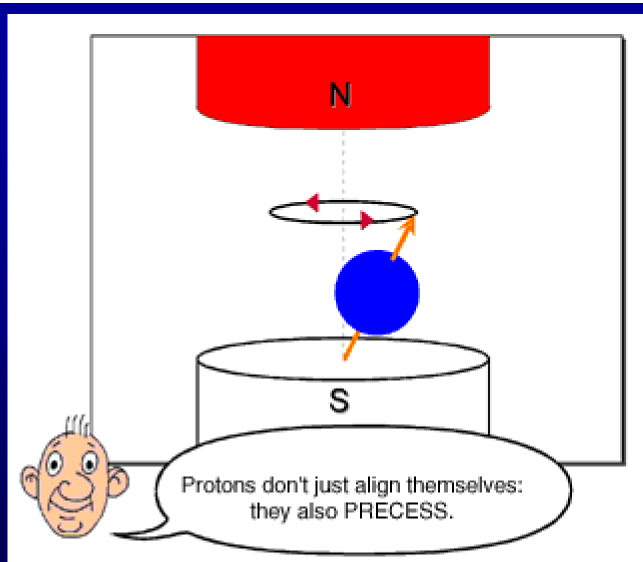


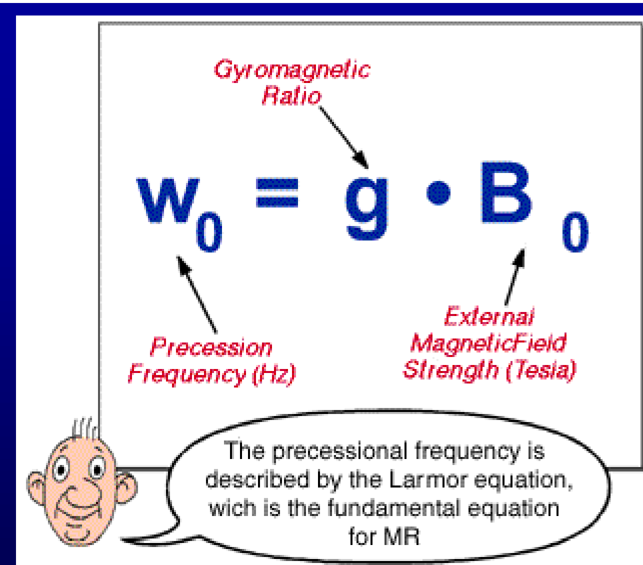

SHIELD
MAGNET
GRADIENT COILS
RF COIL
PATIENT TABLE
RF COIL
GRADIENT COILS
MAGNET
GRADIENT AMP
RF DETECTOR
FILM
GRADIENT PULSE PROG
DIGITIZER
PULSE PROG
RF AMP
COMPUTER
RF SOURCE

Magnetic Resonance Imaging

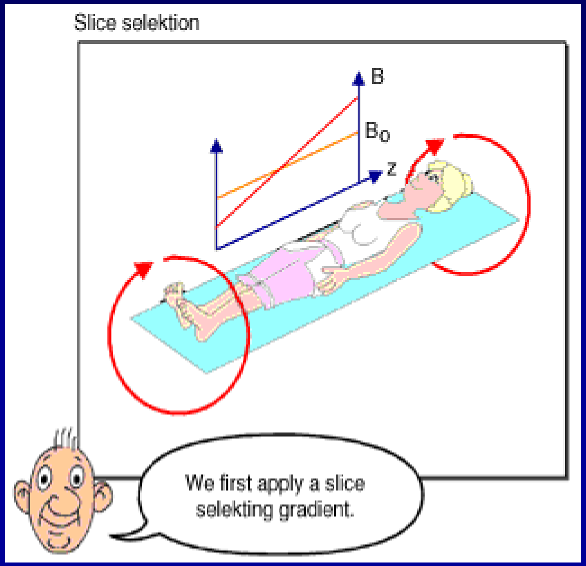


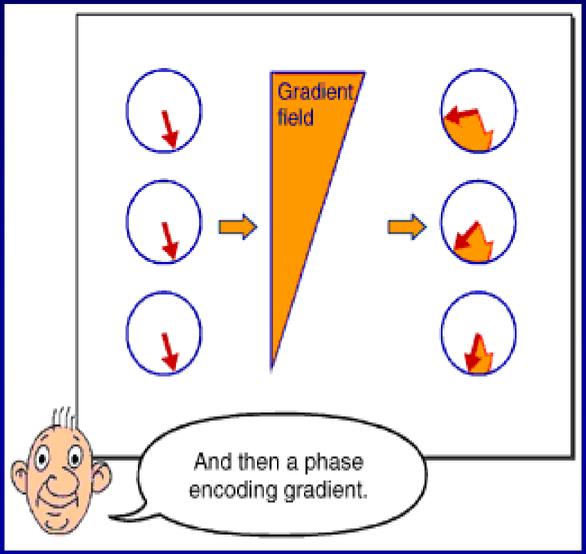


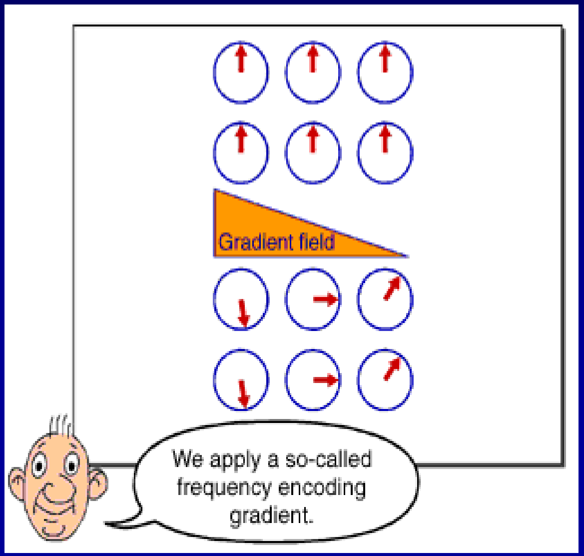




Use of gradient fields in MRI



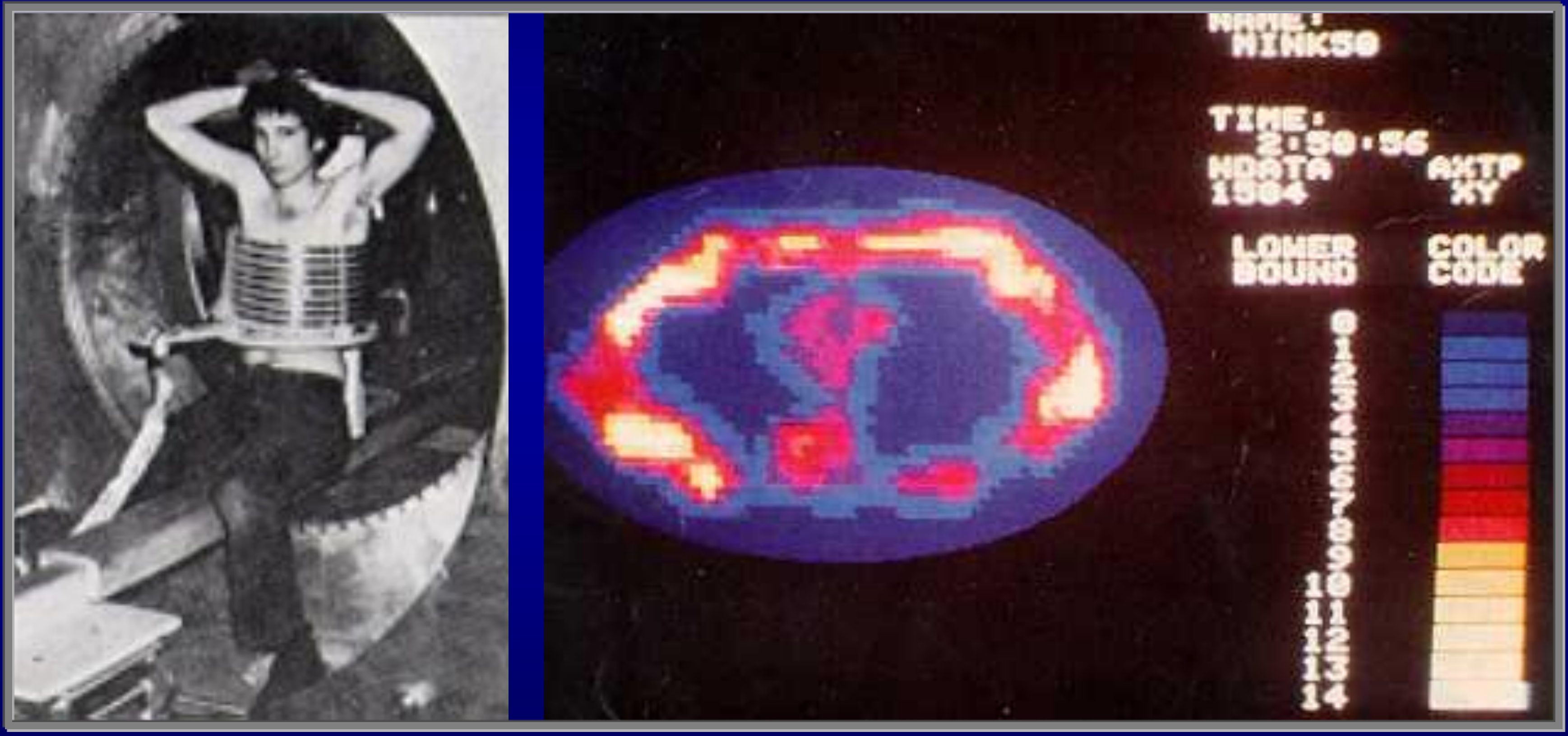




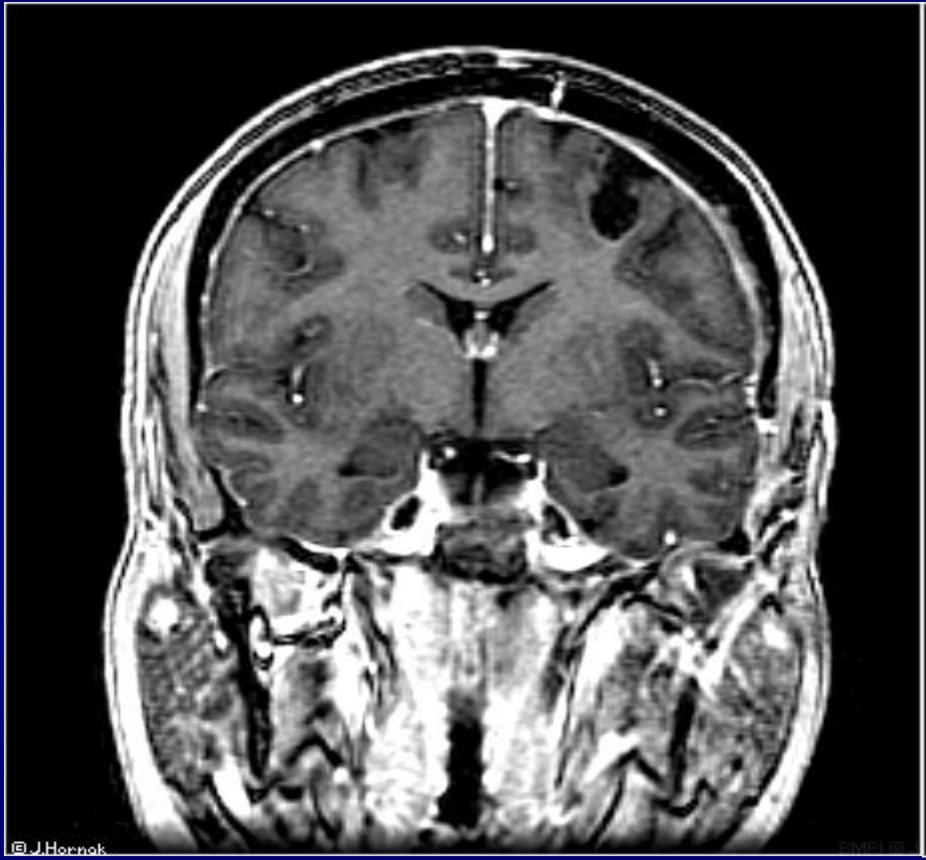
$$S(t) = K \iint M(x,y) exp\left\{ -j \left[(\gamma G_x x)t + (\gamma G_y y)t_y \right] \right\} dxdy$$

The emitted magnetization signal is measured which is the 2-dimensional Fourier Transform of the spin density (proton density) distribution.

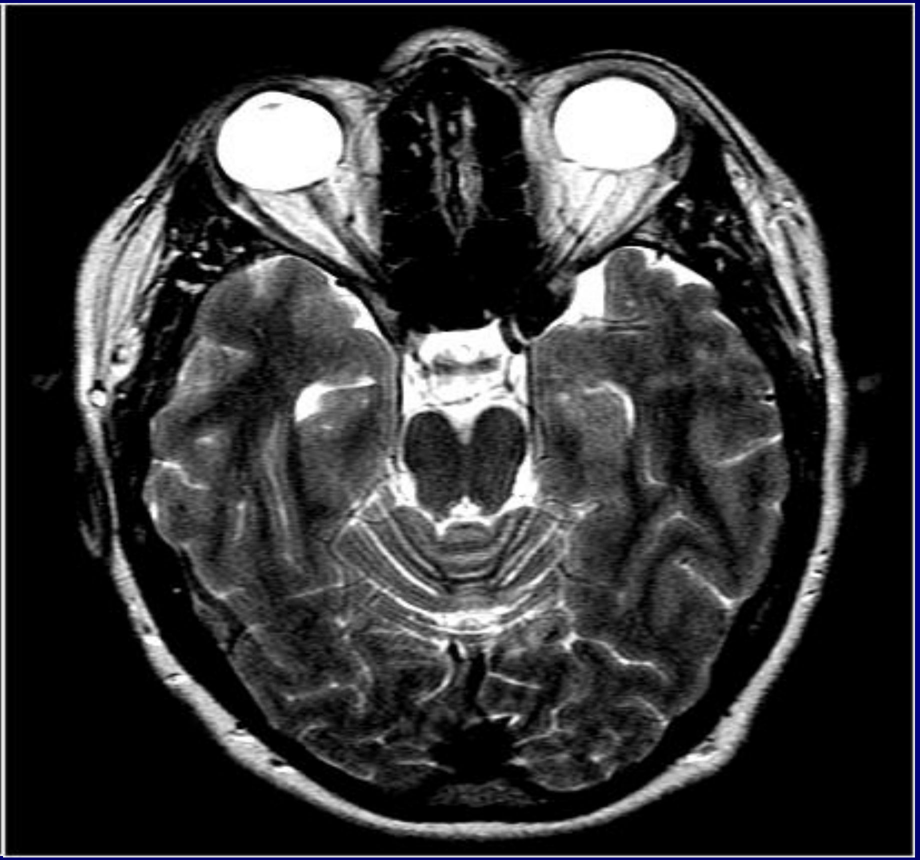
First in-vivo MRI experiment in 1977, by Damadian, Minkoff and Goldsmith



MR Images of human head



Coronal Slice of Head



Axial Slice of Head

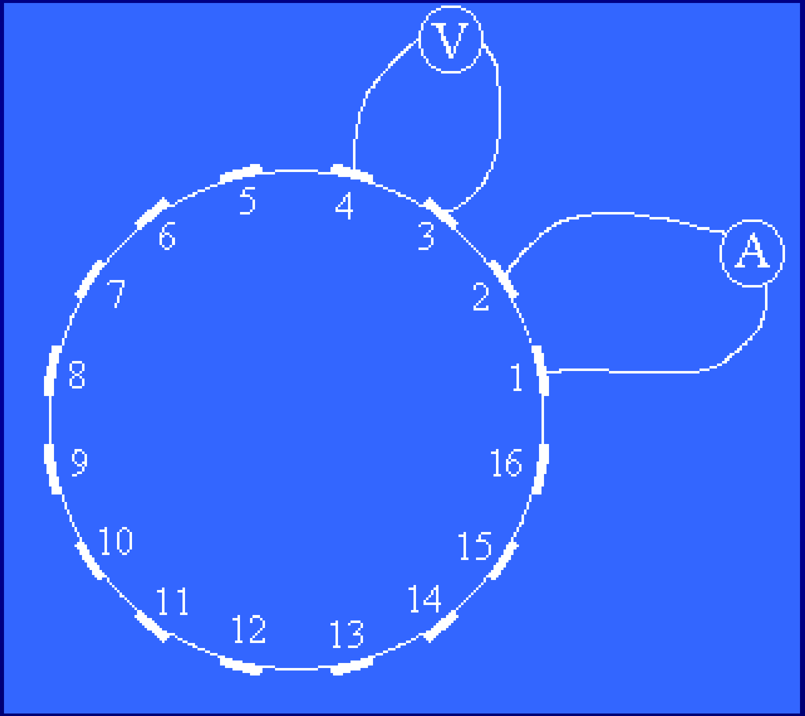
Advantages and Disadvantages of MRI

- Superior spatial resolution,
- Good soft tissue contrast,
- Functional imaging is possible,
- Involves no ionizing radiation,
- Relatively expensive.

Electrical Impedance Tomography

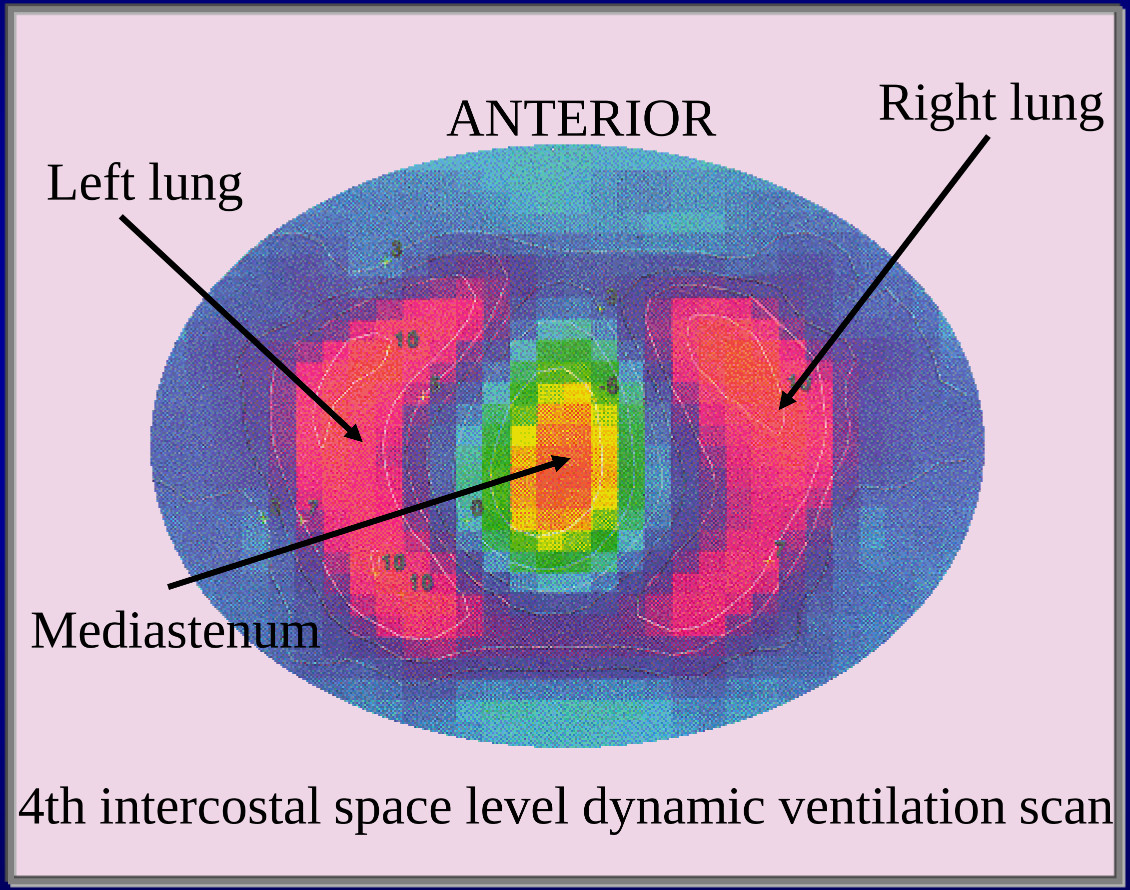
EIT : *cross-sectional imaging of electrical impedance*

- injected EIT
- induced EIT

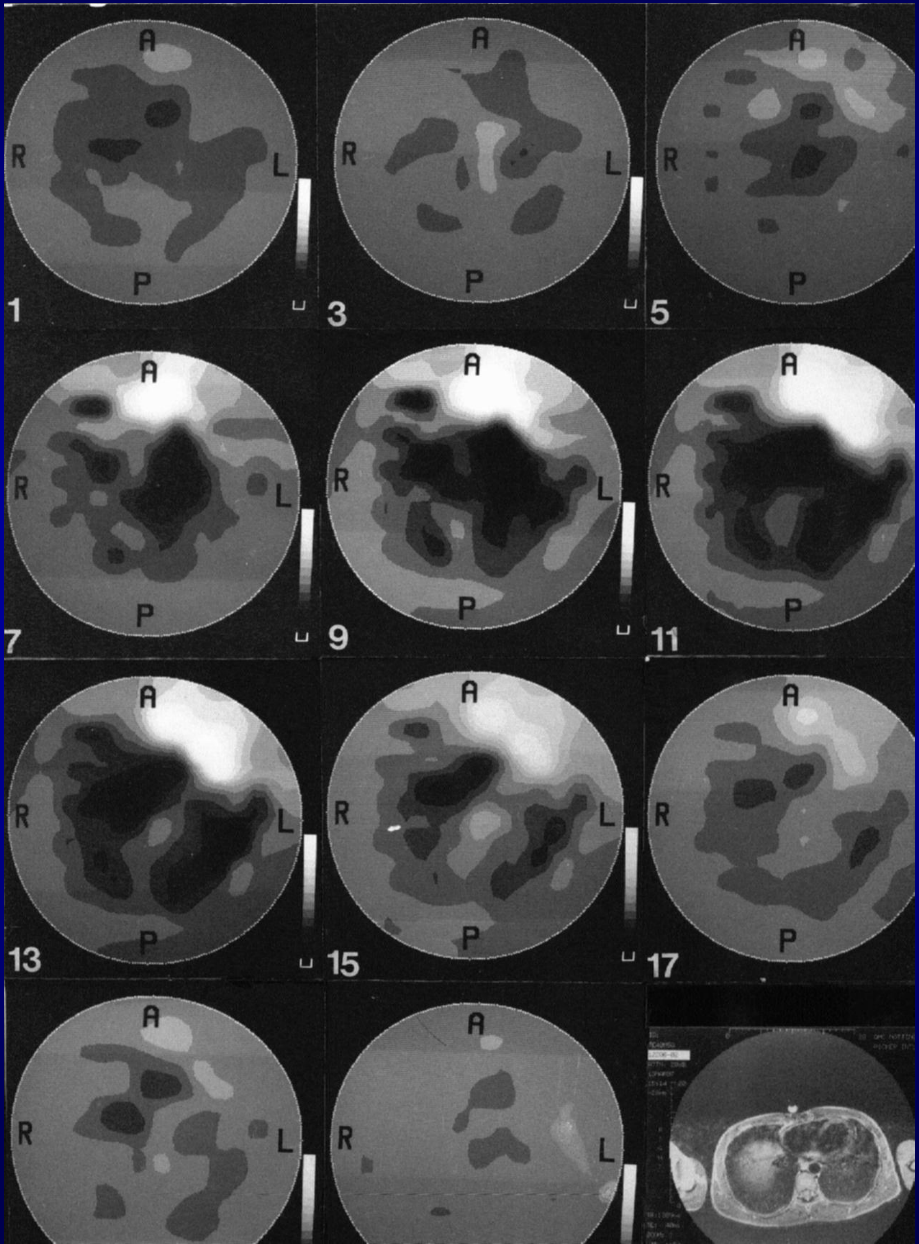


Electrical Impedance Tomography

ACEIT ventilation scan



Cardiac Gated EIT Images



Advantages and Disadvantages of EIT

- Functional images can be obtained,
- Good soft tissue contrast,
- Involves no ionizing radiation,
- Poor and position dependent spatial resolution,
- Low sensitivity to inner regions.