Introduction to Medical Imaging

BME/EECS 516

Douglas C. Noll

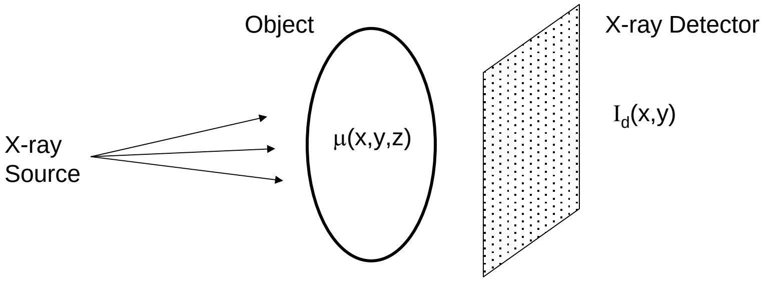
Medical Imaging

- Non-invasive visualization of internal organs, tissue, etc.
  - I typically don't include endoscopy as an imaging modality
- Image – a two-dimensional signal, $I(x,y)$
  - I typically include non-imaging sensing (e.g. 1D techniques) as an imaging modality

Major Modalities

- Projection X-ray
- X-ray Computed Tomography
- Nuclear Medicine
- Ultrasound
- Magnetic Resonance Imaging

Projection X-ray Imaging

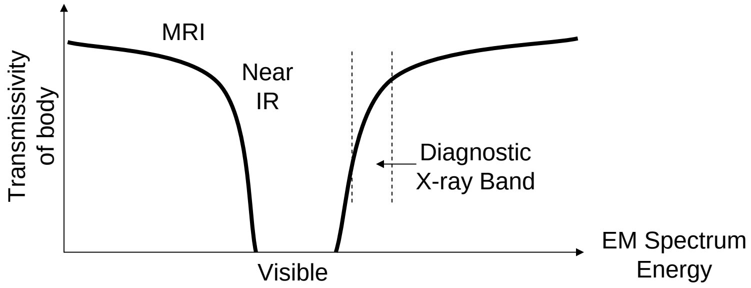


- Image records transmission of x-rays through object

$$I_d(x,y) = I_0 \exp(-\int \mu(x,y,z) d\vec{l})$$

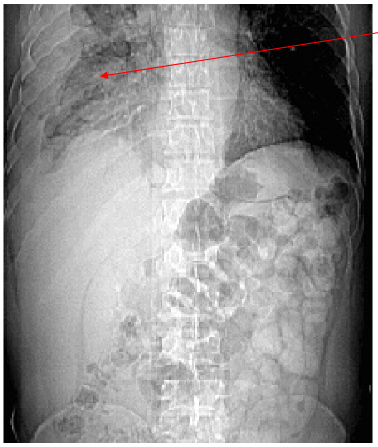
- The integral is a line-integral or a “projection” through obj
- $\mu(x,y,z)$ – x-ray attenuation coefficient, a tissue property, a function of electron density, atomic #, …

Projection X-ray Imaging



- X-ray imaging requires interactions of x-ray photons with object – work in a specific energy band
  - Above this band – body is too transparent
  - Below this band – body is too opaque, photons scatter
  - Well below this band – wavelengths are too long (poor resolution)
- One problem with x-ray imaging: no depth (z) info

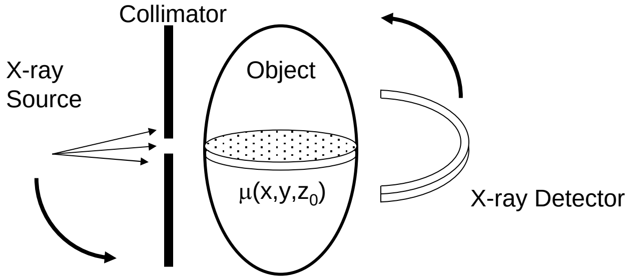
Projection X-ray Imaging



Projection Image

Cross-sectional Image

X-ray Computed Tomography



Collimator

X-ray
Source

Object

$\mu(x,y,z_0)$

X-ray Detector

- Uses x-rays, but exposure is limited to a slice (or a couple of slices) by a collimator
- Source and detector rotate around object – projections from many angles
- The desired image, $I(x,y) = \mu(x,y,z_0)$, is computed from the projections

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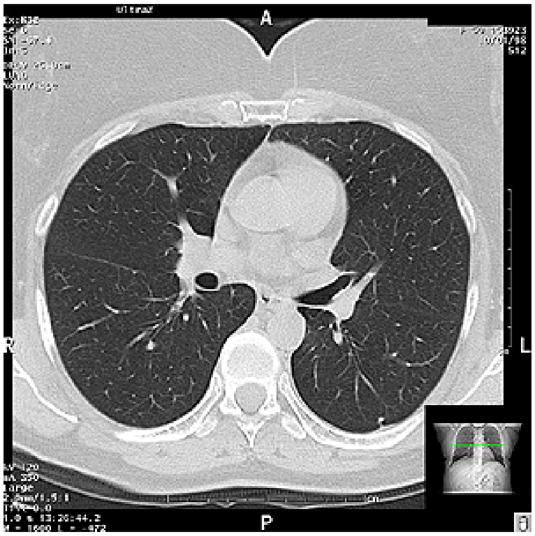
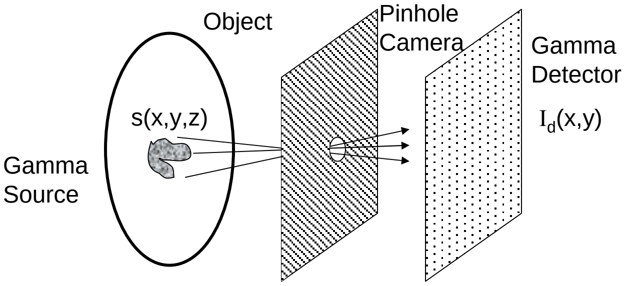
X-ray Computed Tomography



Nuclear Medicine



- The body is the gamma ray source and the image records transmission of gamma photons

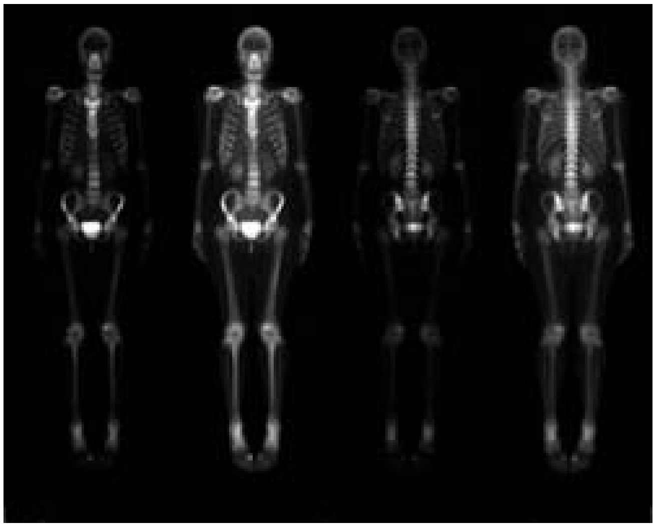
$$I_d(x,y) = \int s(x,y,z) d\vec{l}\,)$$

- The integral is a line-integral or a “projection” through obj
- Source s(x,y,z) usually represents a selective uptake of a radio-labeled pharmaceutical

Nuclear Medicine

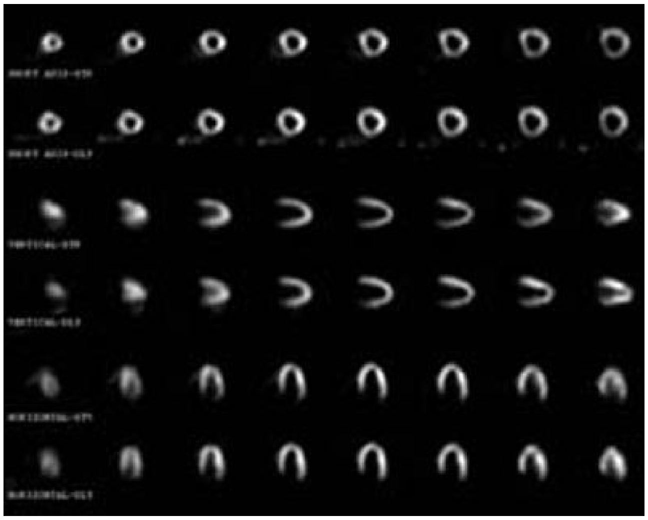
- Issue: Pinhole Size
  - Large pinhole – more photons, better SNR
  - Large pinhole – more blur, reduced resolution
- Issue: Half-life
  - Long half lives are easier to handle, but continue to irradiate patient after imaging is done
- Issue: Functional Specificity
  - Pharmaceuticals must be specific to function of interest
  - E.g. Thallium, Technicium
- Issue: No depth info
  - Nuclear Medicine Computed Tomography (SPECT, PET)

Nuclear Medicine (SPECT)



Bone Scan

Nuclear Medicine (SPECT)



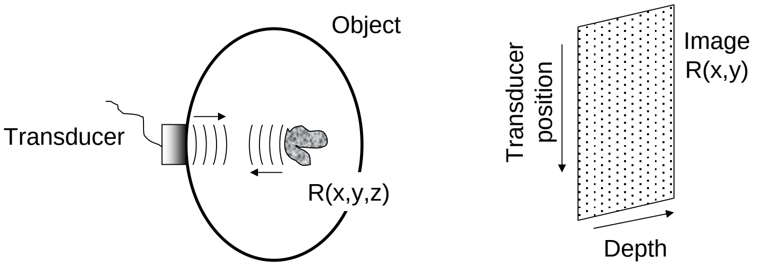
Short Axis

Long Axis

Long Axis

Cardiac (Left Ventricle) Perfusion Scan

Ultrasound Imaging



- Image reflectivity of acoustic wave, R(x,y,z).
- Depth – A function of time (ping-echo)
- Lateral – Focusing of wavefronts
- Direct imaging (e.g. vs. computed) modality – echo data is placed directly into image matrix

Ultrasound Imaging

- Issue: Transmit Frequency
  - Increase in frequency reduces wavelength:

$$\lambda = c / f_0$$

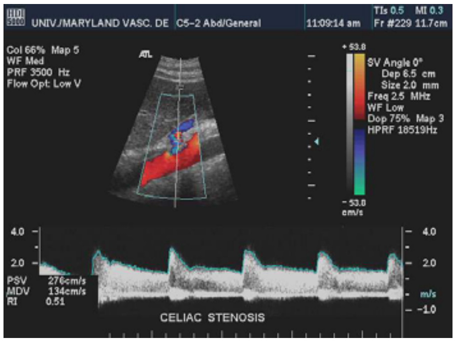
  - Reduced (improved) resolution size (2-3 λ)
  - Also improved lateral resolution (diffraction):

$$\Delta x = \lambda z / D$$

  - Increases attenuation (and thus, range of depth)
- Issue: Flow
  - Can use Doppler effect to image flow
- Issue: Speckle
  - Most noise in US is speckle (signal dependent)

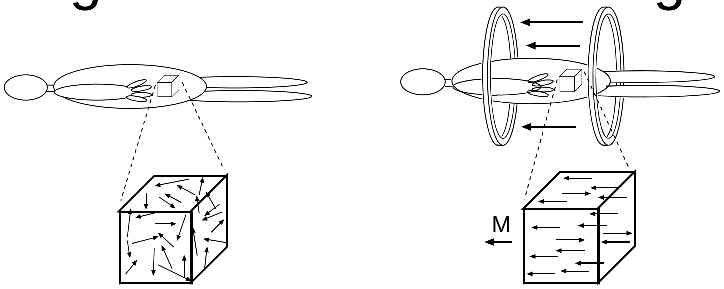
Ultrasound Imaging

High-Resolution



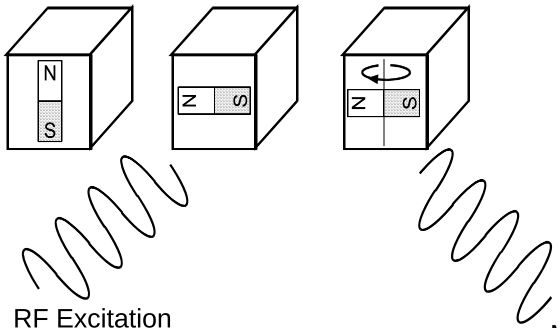
Color Doppler

Magnetic Resonance Imaging



- Atomic nuclei and hydrogen nuclei, ^1H, in particular, have a magnetic moment
  - Moments tend to become aligned to applied field
  - Creates magnetization, m(x,y,z) (a tissue property)
- MRI makes images of m(x,y,z)

Magnetic Resonance Imaging



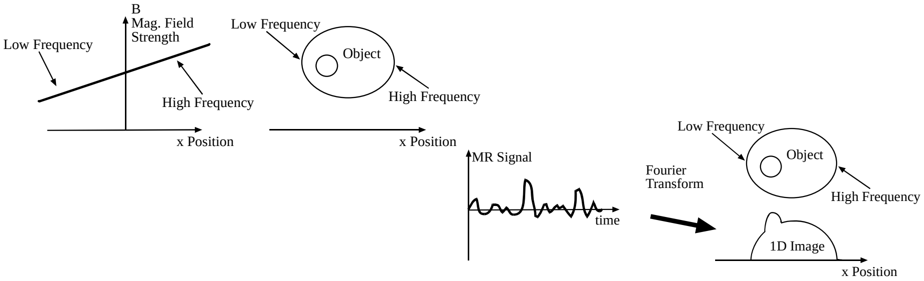
RF Excitation
(Energy into tissue)

Magnetic fields
are emitted

- The magnetization is excited into an observable state
- Magnetization emits energy at a resonant frequency:

$$\omega_0 = \gamma \mathbf{B}_0$$ (63 MHz at 1.5 T)

Magnetic Resonance Imaging

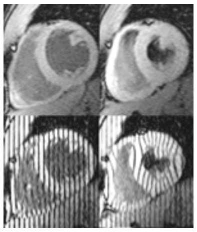


- Frequency is proportional to magnetic field
  - We can create a frequency vs. space variation:

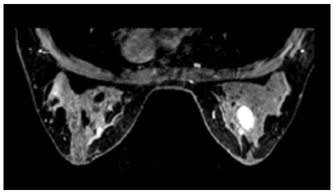
$$\omega(x) = \gamma\,(\mathbf{B}_0 + G_x x)$$

  - Use Fourier analysis to determine spatial location
- Interestingly, λ is much larger than resolution – not imaging EM direction, but using its frequency

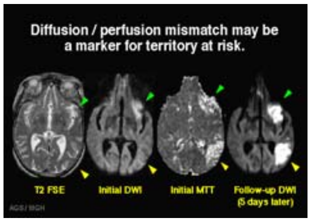
MRI



cardiac



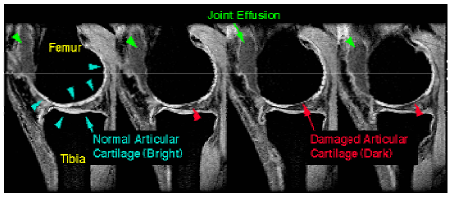
cancer



Diffusion / perfusion mismatch may be a marker for territory at risk.

stroke

neuro function



joint

lung