Biomedical Imaging & Analysis

Lecture 3, Part 2. Fall 2014

Image Formation & Visualization (II):

CT, SPECT

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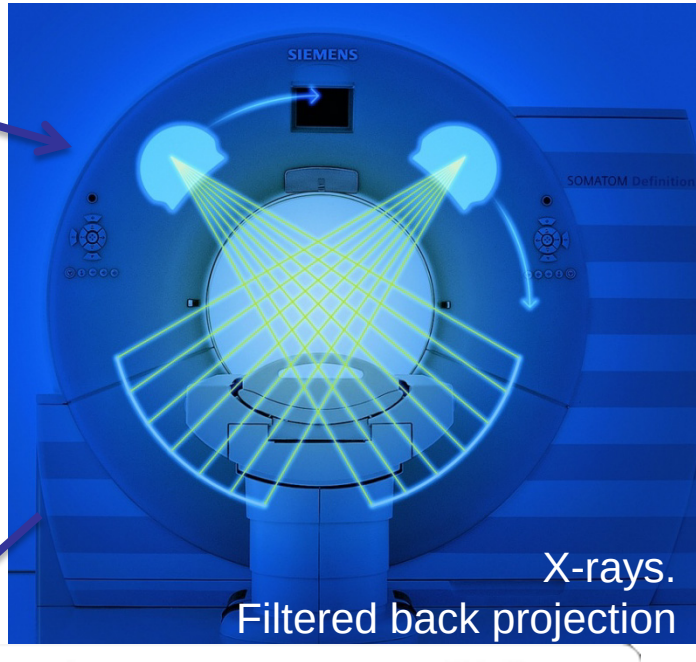
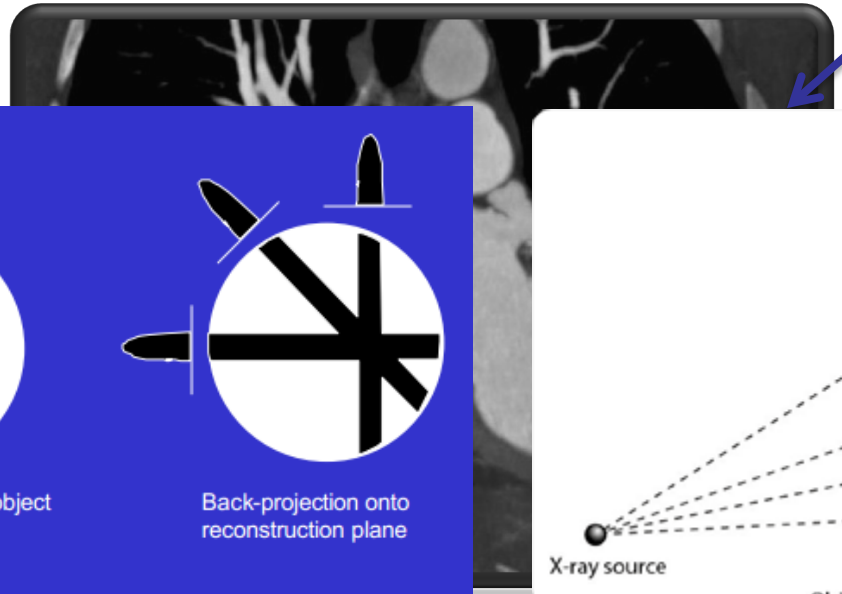
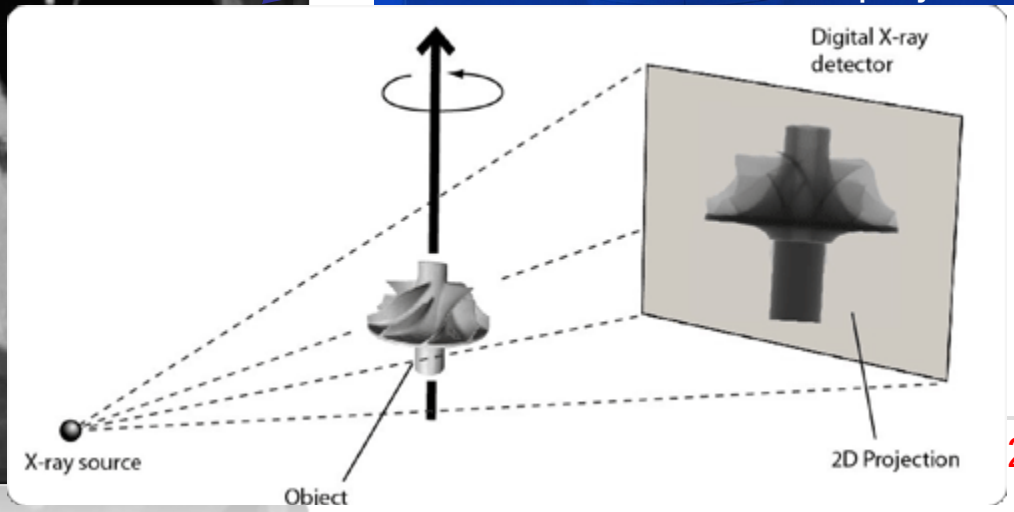
CT: Physics meets Clinic

http://www.youtube.com/watch?v=ra7sw0kNvTw



X-rays.
Filtered back projection

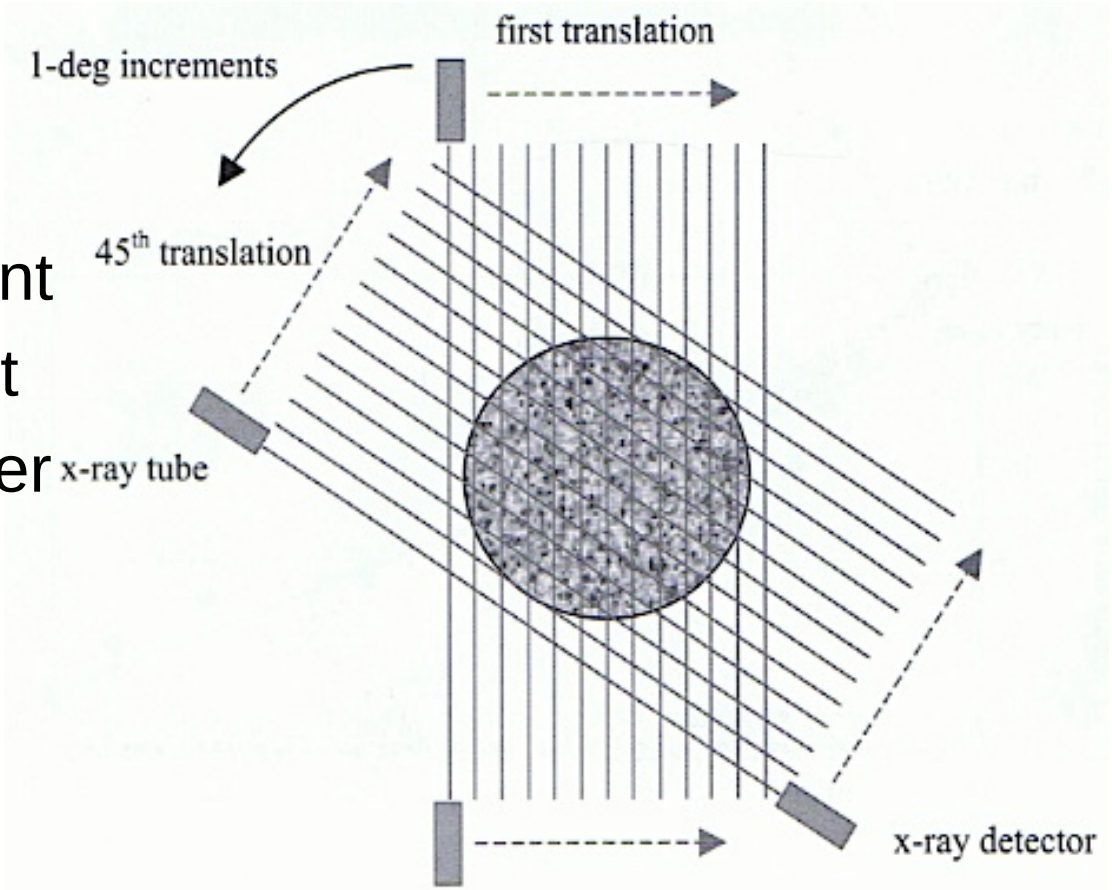




CT scanners: 1st generation

1st generation (1971): one pencil beam at a time

- Single detector
- Translate across patient
- Rotates around patient
- Very slow – minutes per slice



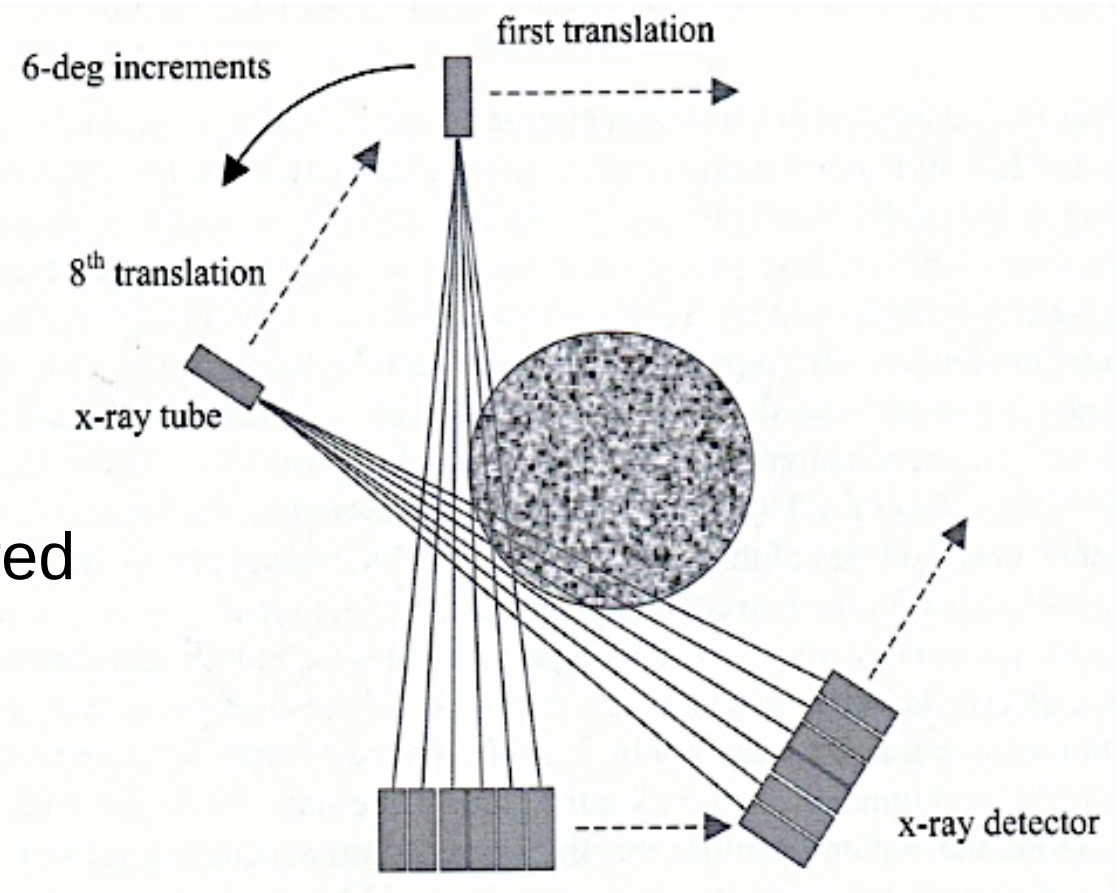
CT scanners: 2nd generation

2nd generation: multiple pencil beams

- Narrow fan beam
- Multiple detectors
- Multiple angle acquisition at each position

- Larger angle rotate
- Translation still required

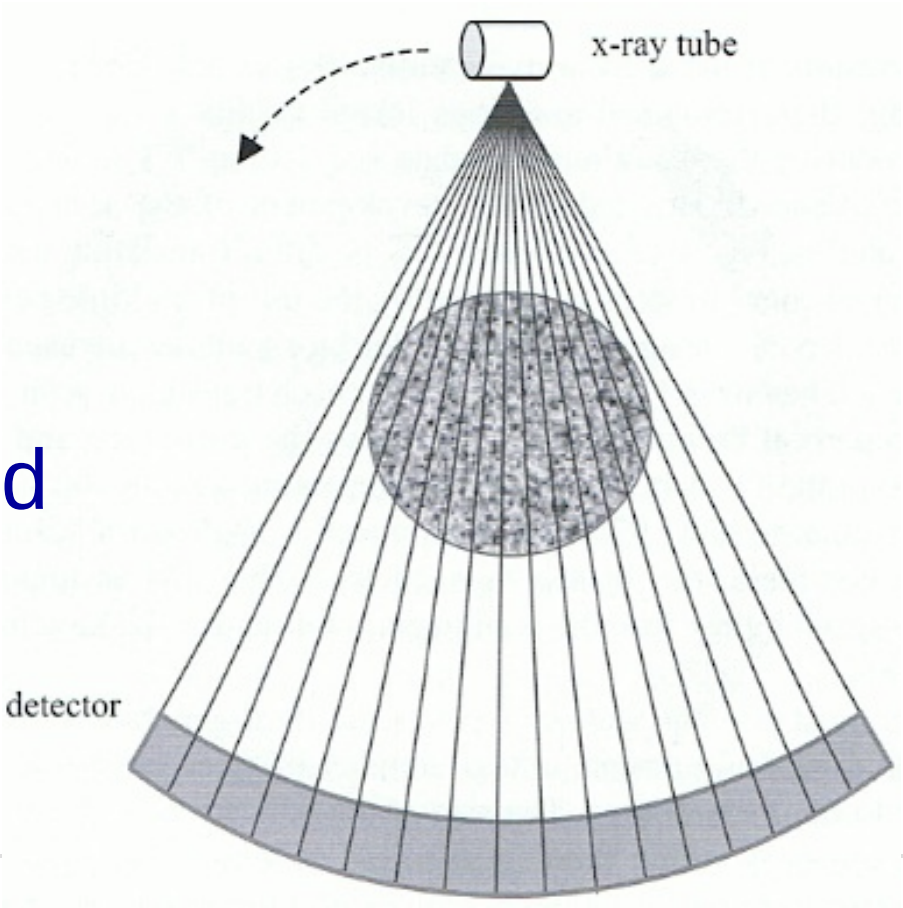
- 20 sec per slice



CT scanners: 3rd generation

3rd generation: multiple rotating detectors are located on an arc concentric to the X-ray source

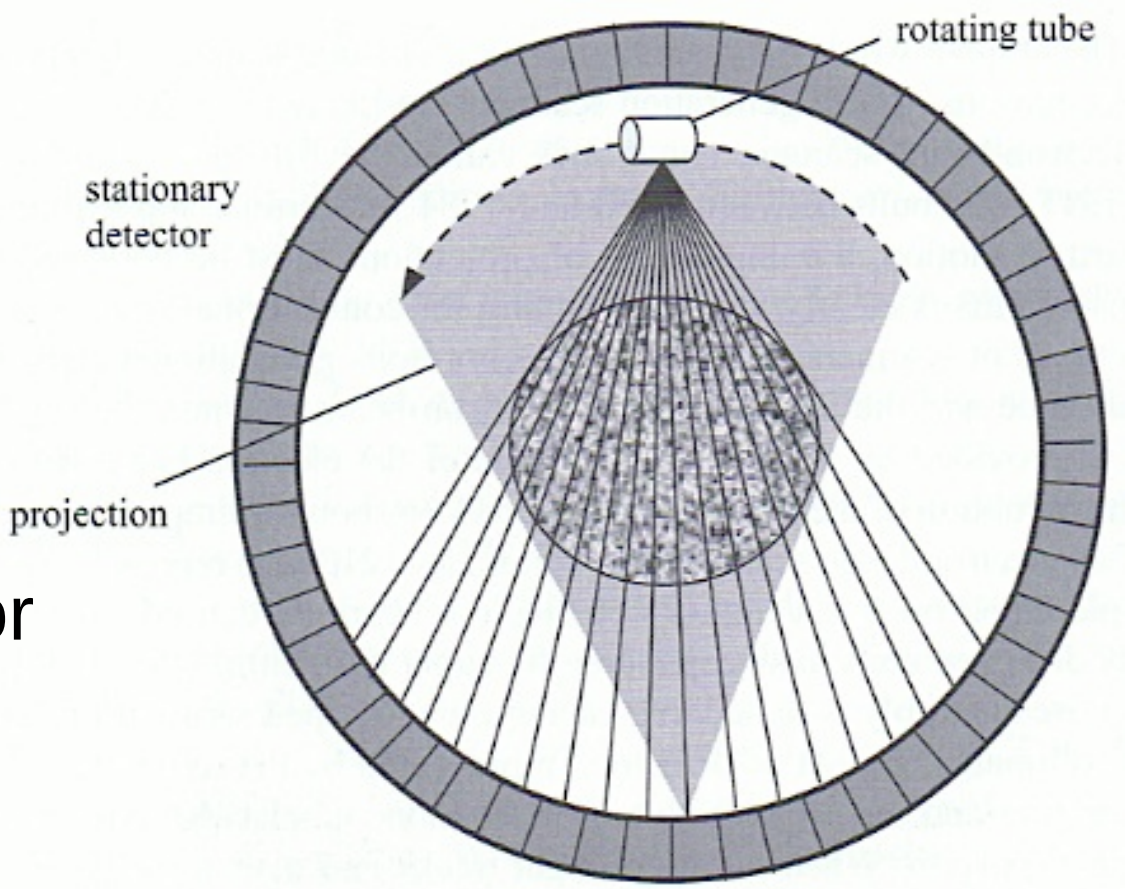
- Fan beam
- Rotation only
- No translation required
- 0.5 sec per rotation



CT scanners: 4th generation

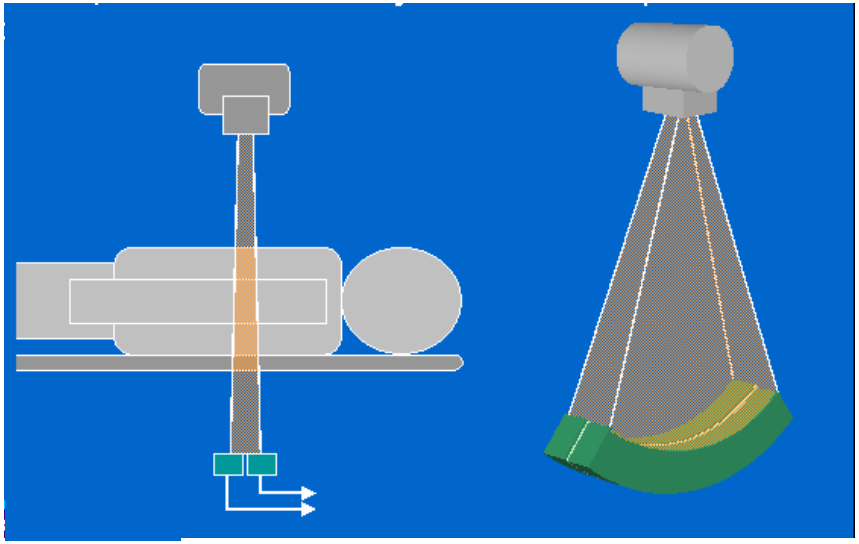
4th generation: the detector forms enclosed ring and remains stationary during the entire scan.

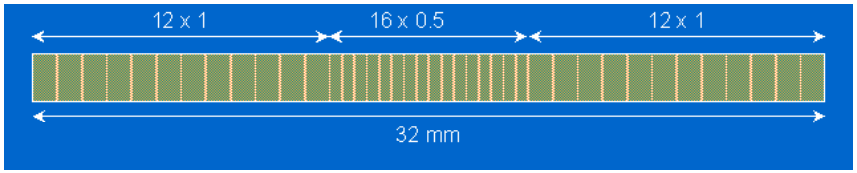
- Only tube rotates
- Fan beam with its apex at the detector



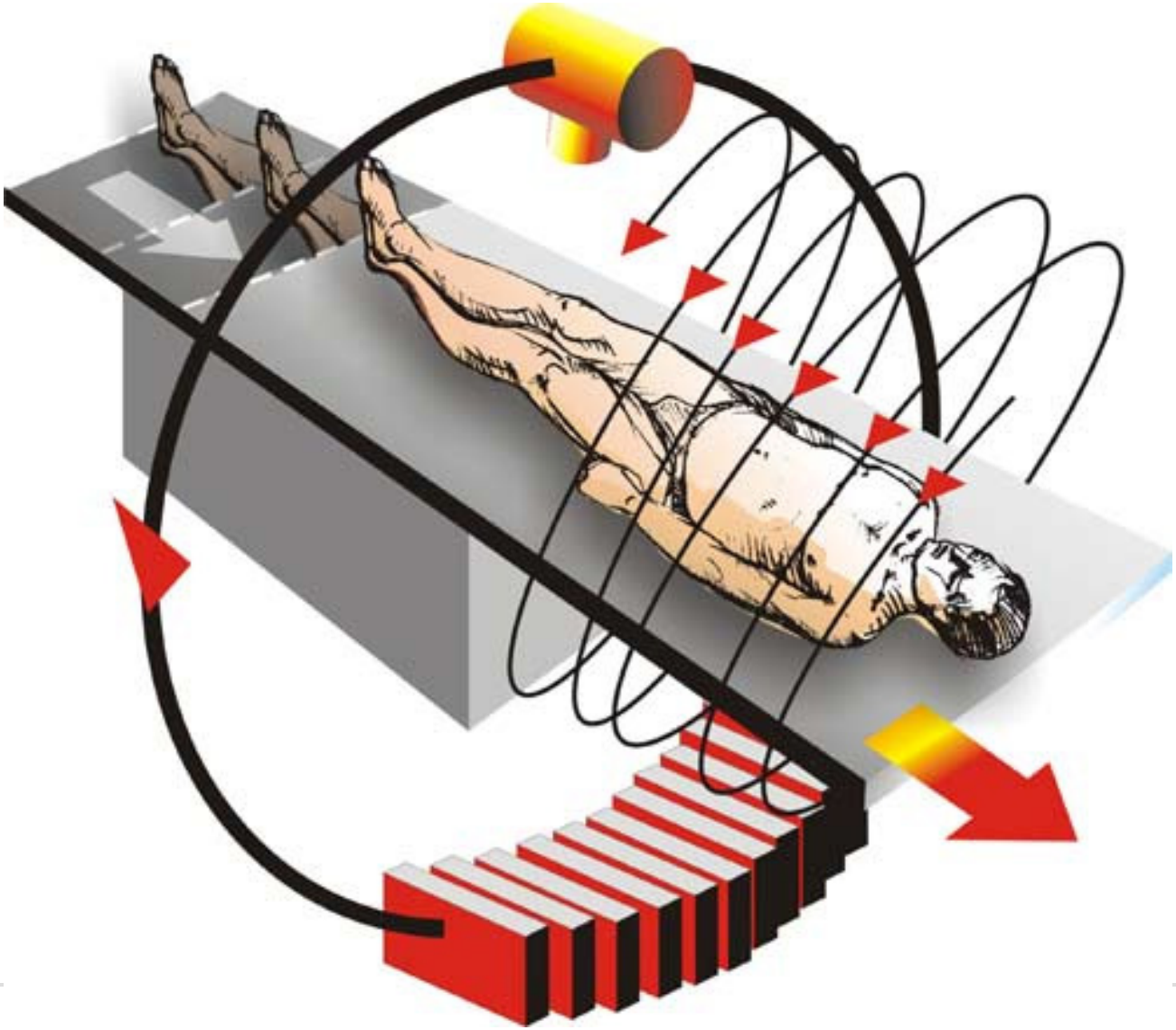
CT: Multi Slice – *the general idea*

- Reducing time of acquisition:
  - Increasing the number of detectors and widening the beam allows multiple slices to be acquired for each position of the x-ray source



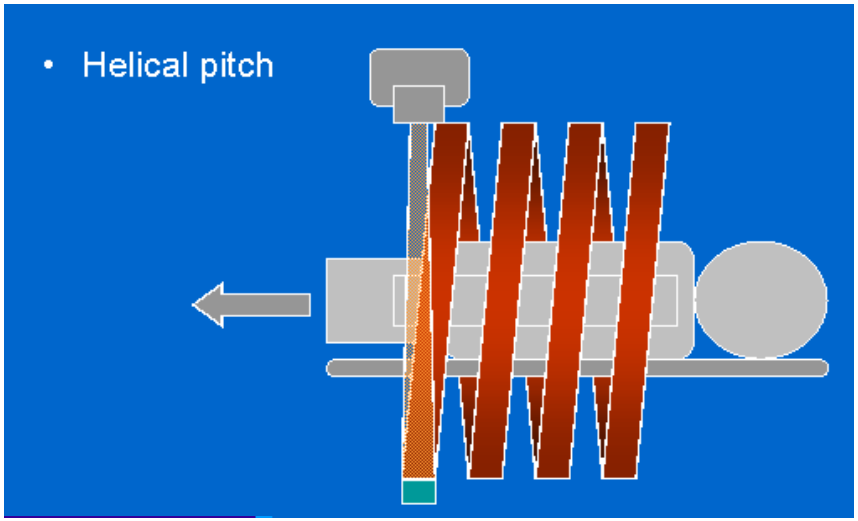


CT scanners: **Helical**



CT: Helical Multi Slice

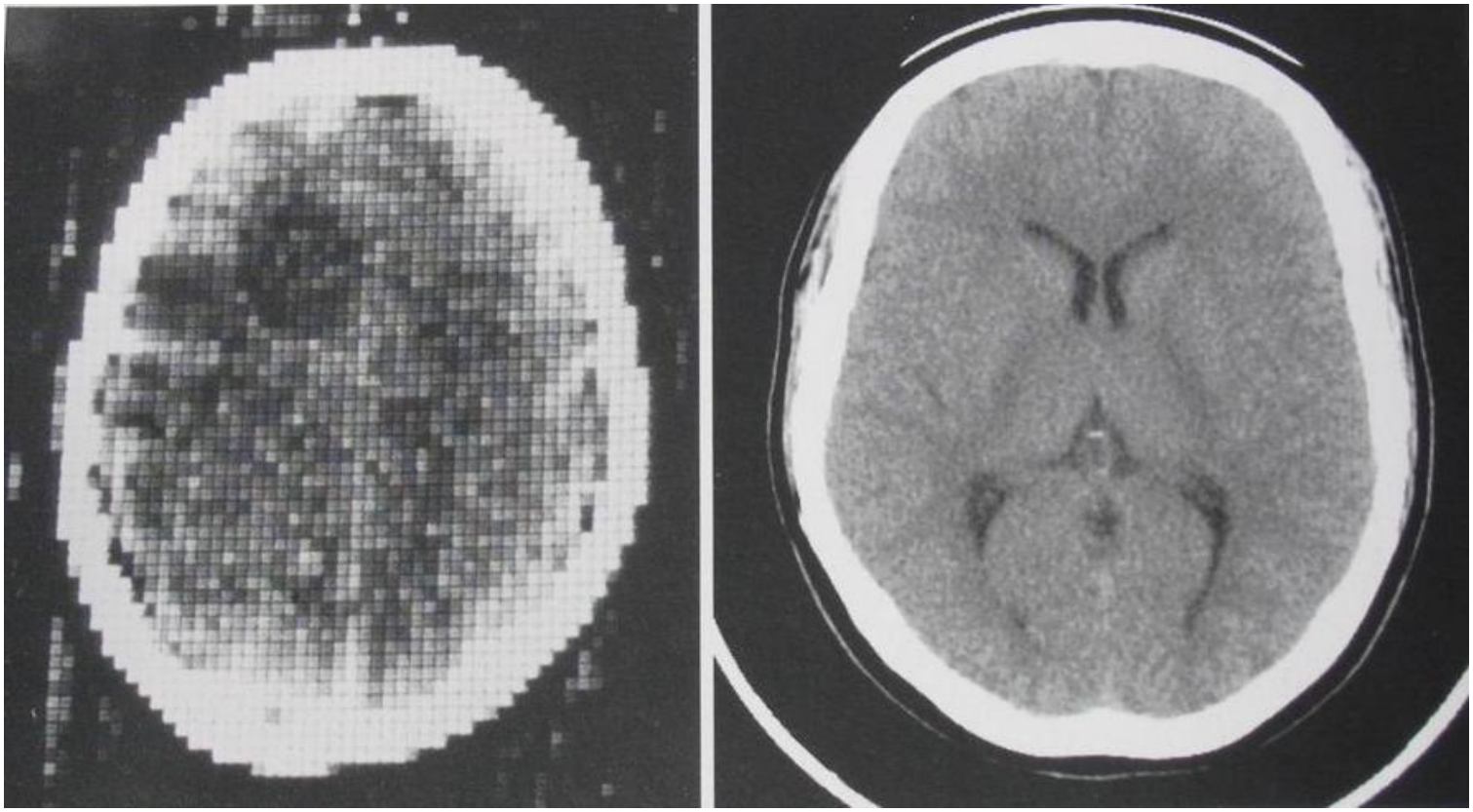
- In a multi-slice CT scanner, the table moves at a certain pitch
  - Table travel / slice width
- Only one of the hundreds of projections is acquired for any given slice
- All other projections have to be interpolated from the data



CT scanning technology

- Planar, parallel or fan (cone)-beam
- Spiral (helical)
- Single slice or multi-slice
- Takes about 1sec/acquisition
- Current spiral units can take 4–32 and even 64 slices simultaneously!
- Reconstruction using variations of Fast Fourier Transforms (FFT).
- Mostly preoperative, some intraoperative units

Image reconstruction quality

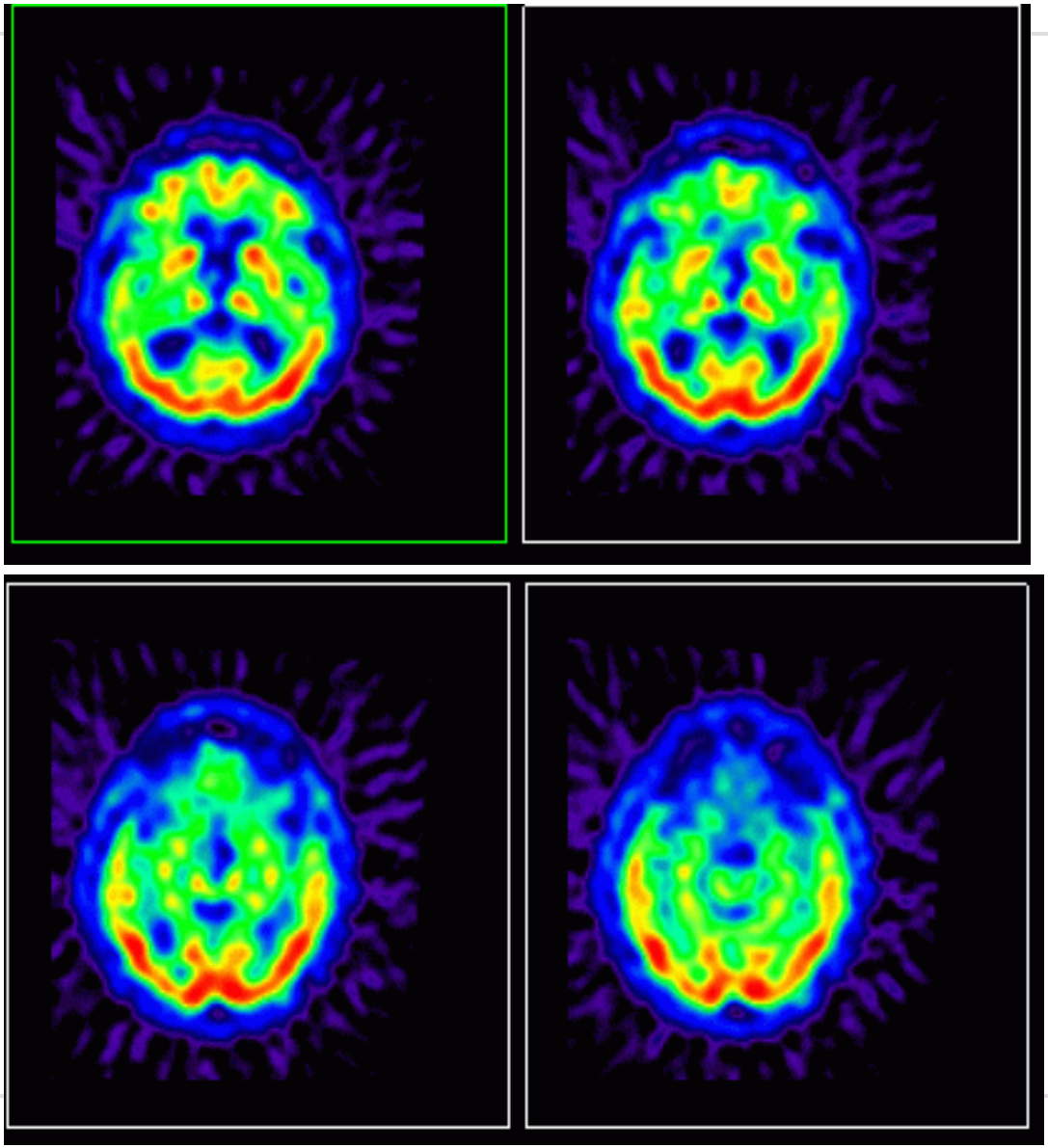


1972 2001

Nuclear Medicine Imaging (NMI)

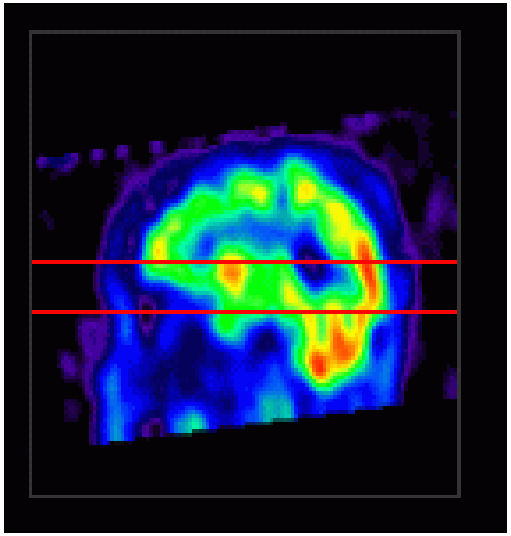
- Same Tomographic slicing principle as CT.
- Source of photons or positrons is injected in the body. Shortly after, radiation of metabolism is measured.
- Poor spatial resolution.
- Expensive machine AND installation ($4-5M).
- Expensive and time-consuming .
- Provides functional information and poor structural information.

Nuclear medicine images



Lateral

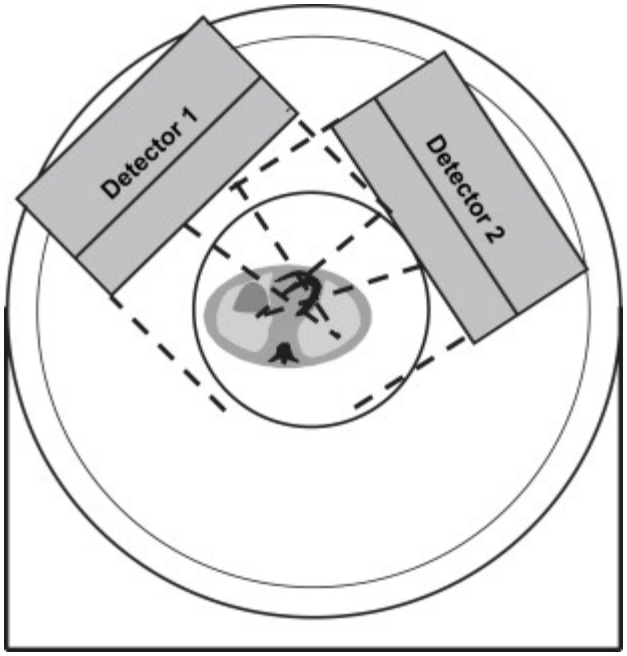
Reconstruction

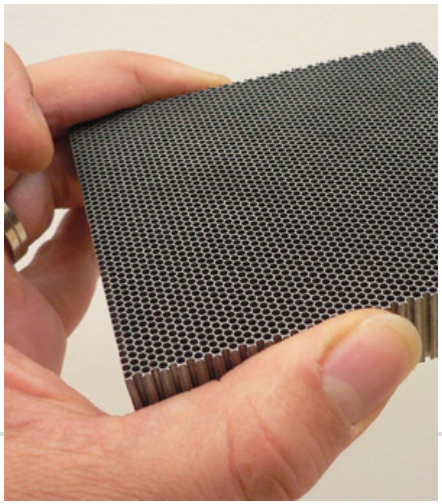


SPECT: Single Photon Emission Tomography

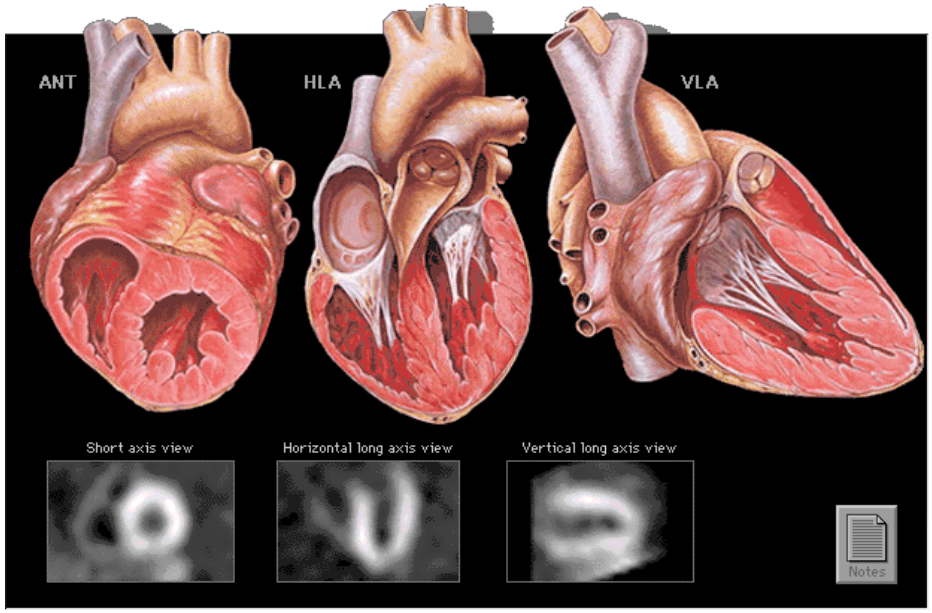
- Radiopharmaceutical (radiotracer) emits gamma radiation (photons)
  - ^{99m}Tc is one example
  - Images reflect physiological function of the organ that takes up the agent
  - Gamma camera is used as the detector
    - Large diameter scintillation crystal backed by photomultiplier tubes

SPECT: Physics meets Clinic



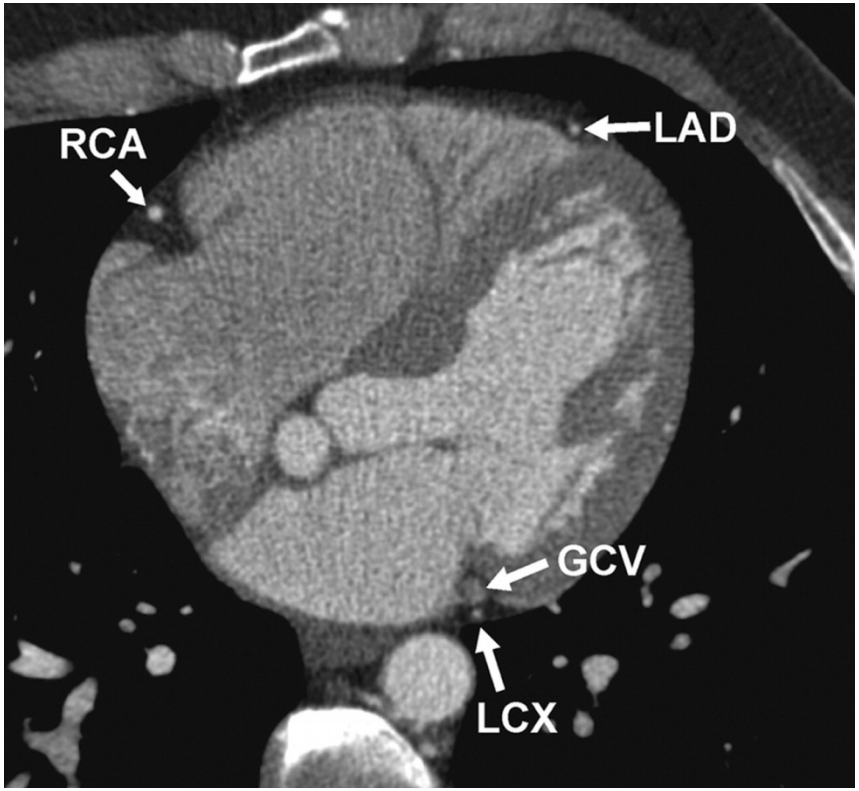


Nuclear SPECT

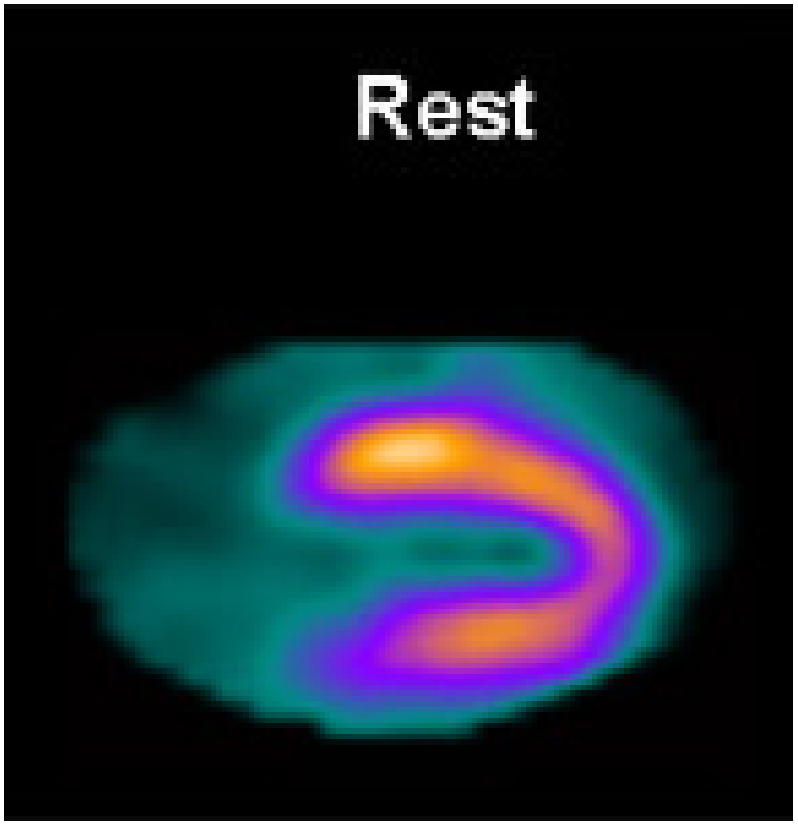


CT vs. SPECT

CT ~500 Projections



SPECT ~ 64 Projections



SPECT **Detection**

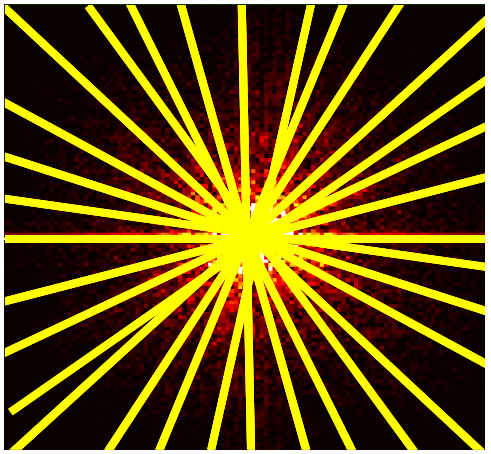
- 140 KeV gamma photons are emitted from ^{99m}Tc
  - Detection is via an array of PM tubes, which convert scintillation into a voltage
  - Individual scintillations are summed to give intensity information
  - Signal requires collimation to relate it to a ray-path through the body

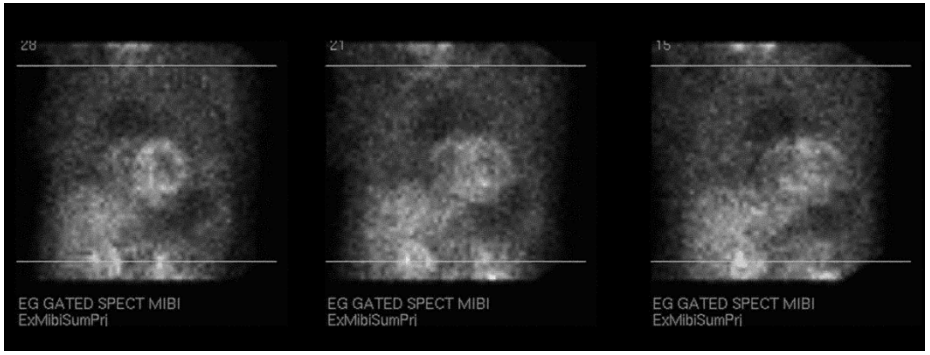
SPECT **Scatter**

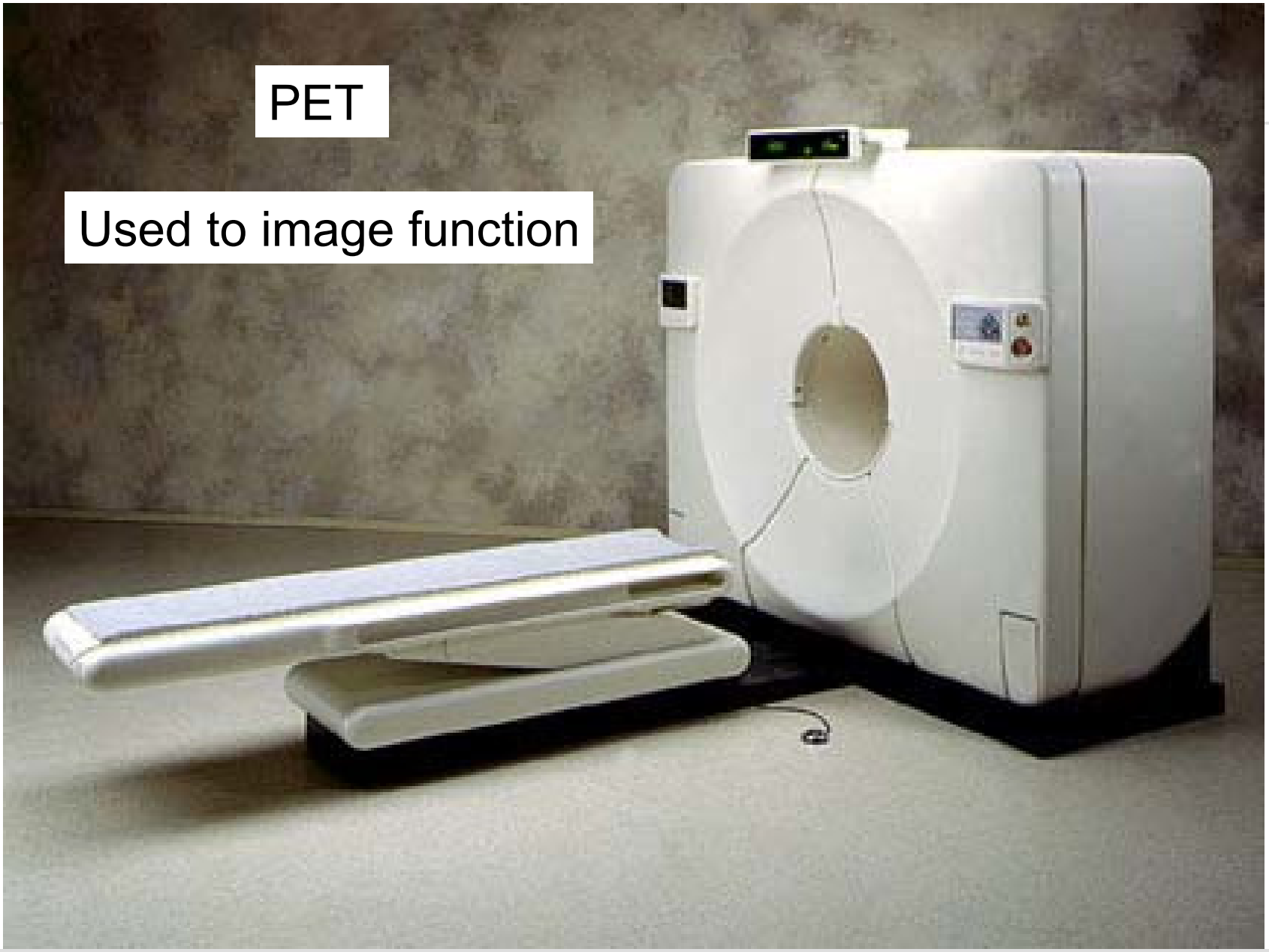
- As gamma photons interact with electrons in the body, they lose energy and scatter
- Thus, detection of high energy photons corresponds to photons that have not undergone scatter
  - Limiting sensitivity to a narrow bandwidth of energy near the peak improves fidelity of the projective image
  - Collimator is a pin-hole device to only allow through non-scattered gamma rays
    - More sever collimation results in lower sensitivity in the image

SPECT Projections

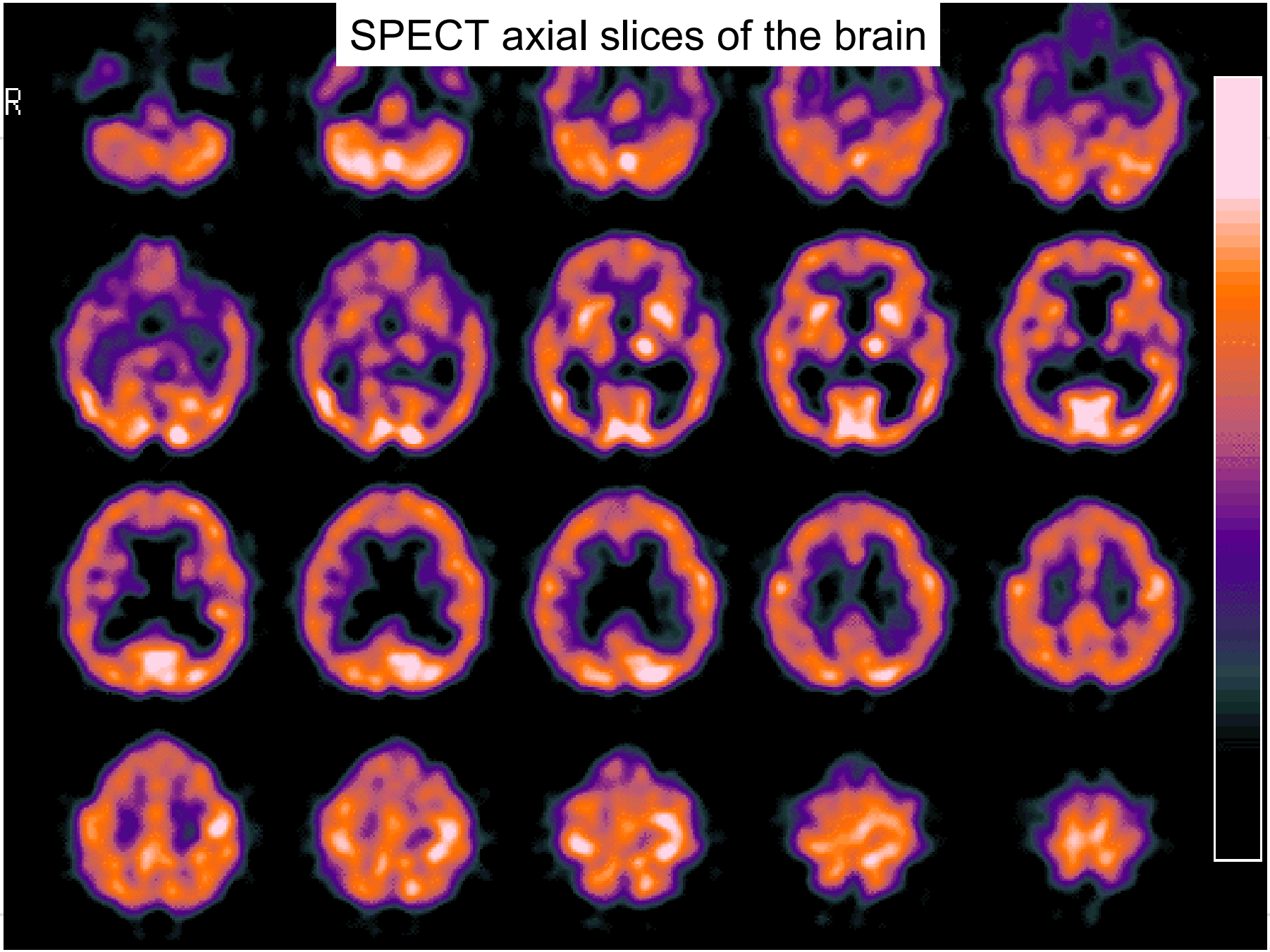
- Ultimately, the set of projections generated in SPECT have the same properties as projections in CT.
- However, unlike CT the SPECT scanner moves very slowly
  - Stop and shoot mode
- The rotation time of detector significantly impacts the number of projections that can be acquired in a convenient time.






PET
Used to image function

SPECT axial slices of the brain



SPECT images of the heart

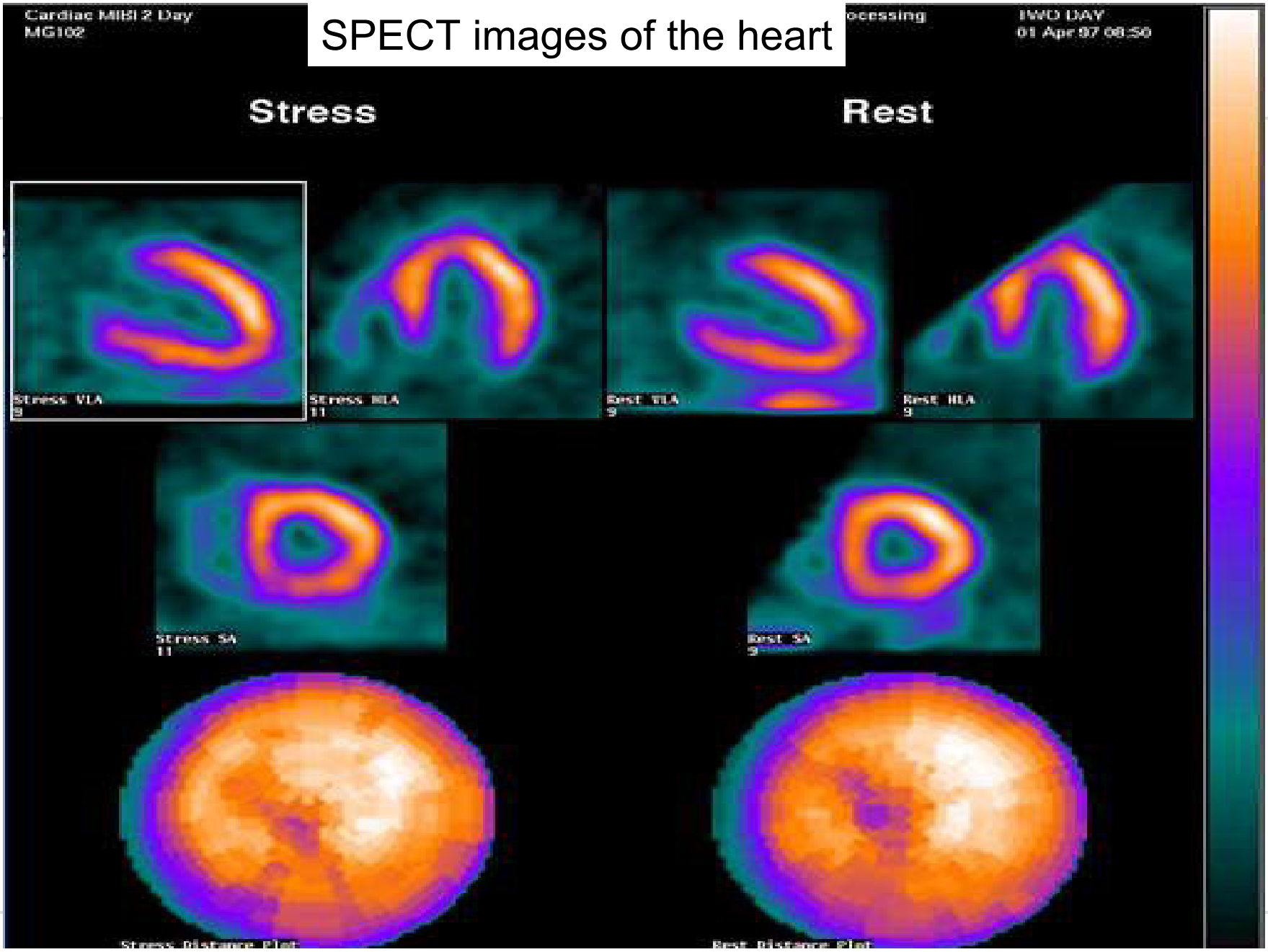
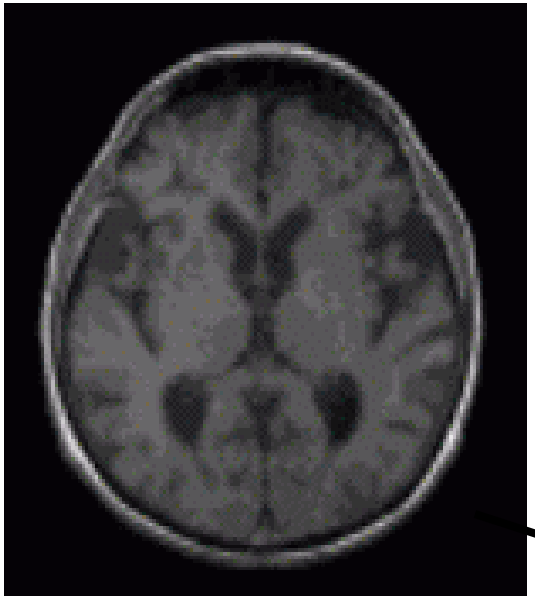
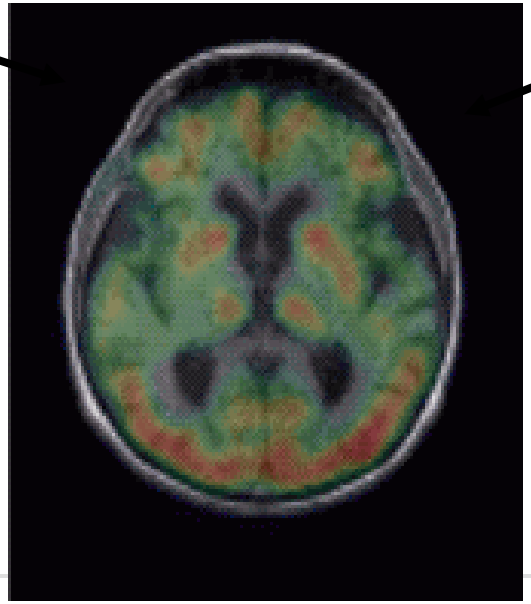


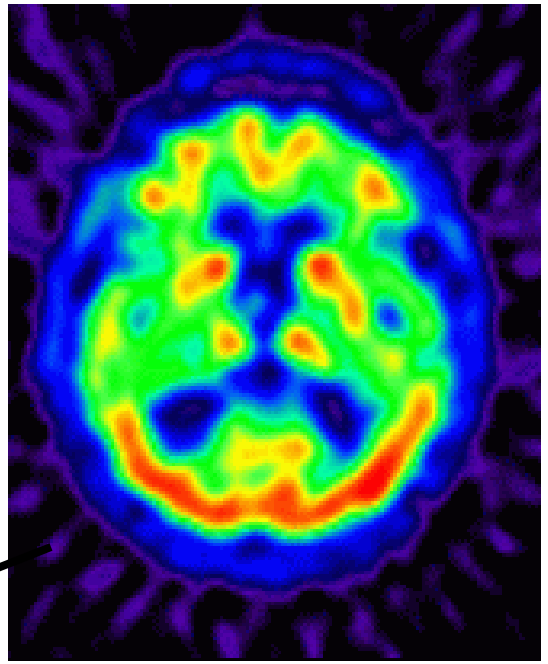
Image Fusion: MRI and NMI



MRI (anatomy)

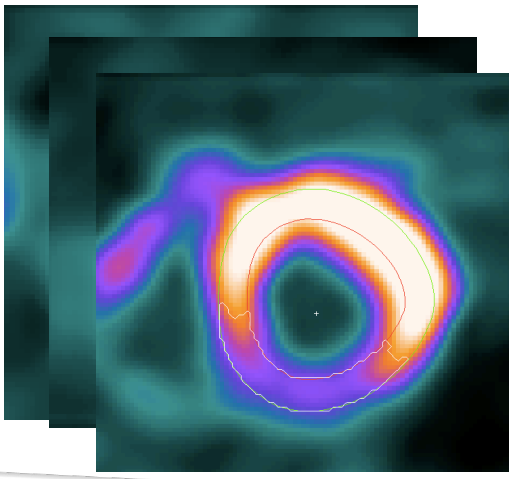
Fused slice

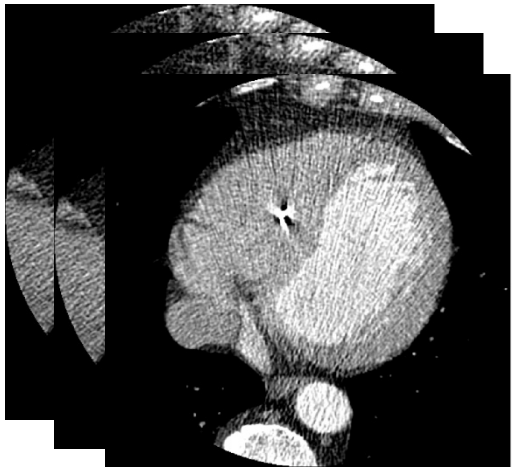


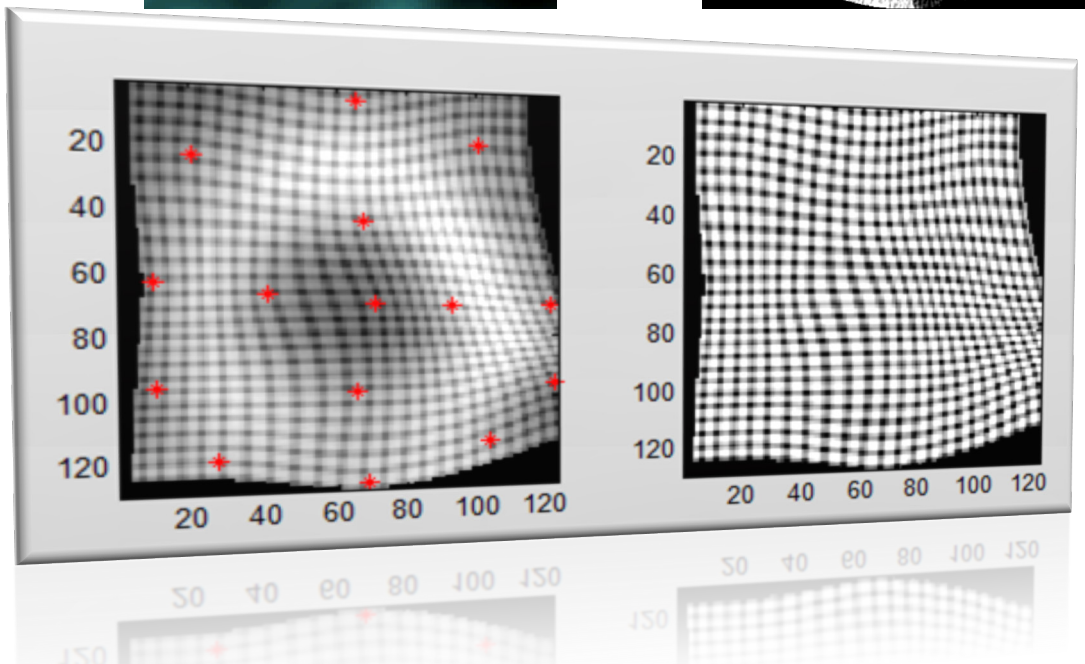


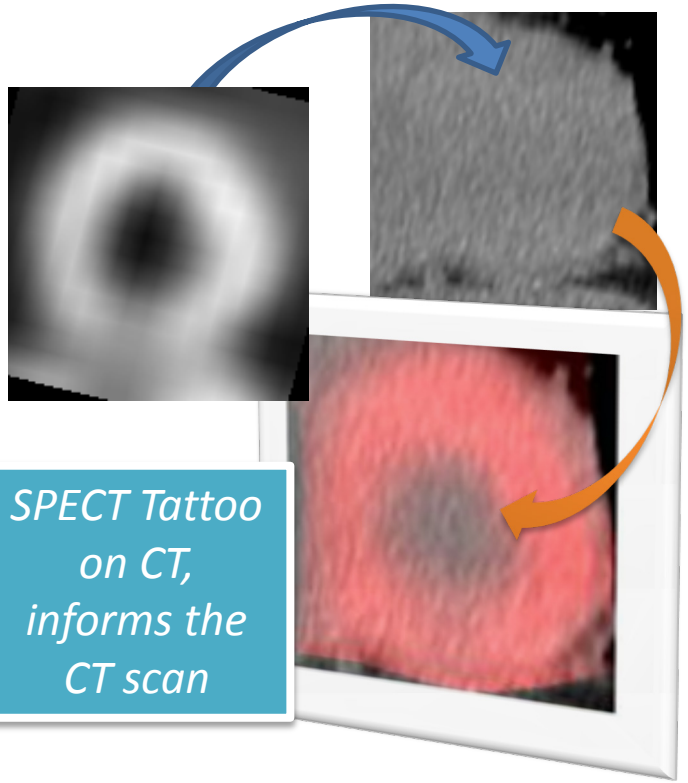
NMI (functional)

Image Fusion: SPECT + CT





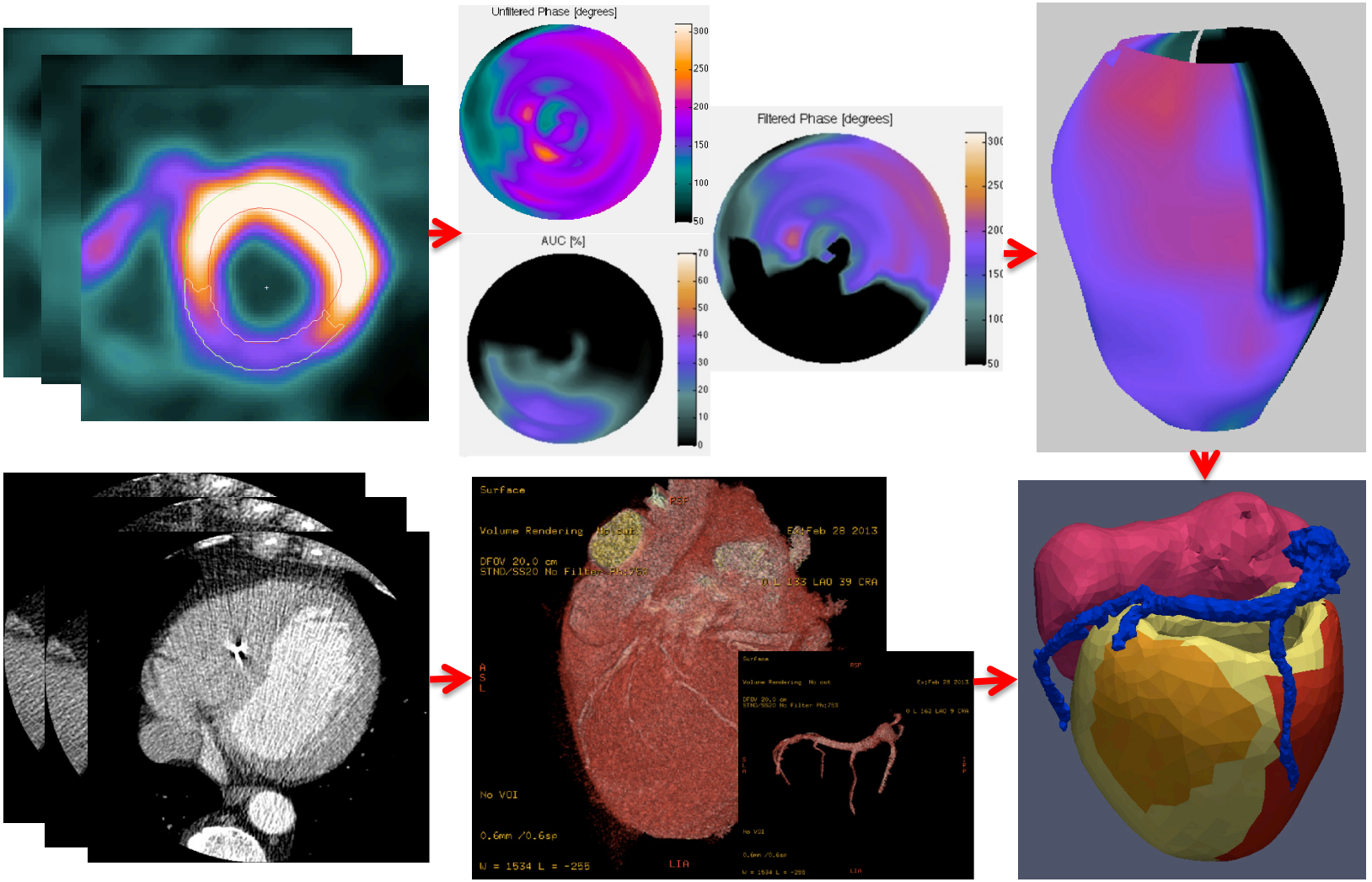




SPECT Tattoo on CT, informs the CT scan

Optimal fusion of ALL available Pre-Operative Medical Images

Maneuver catheters and leads into physics defined targets – real-time!



Summary

- Of all the various physical characteristics that could be used to compare imaging modalities, we have focused here on **k-space**:
  - Affects scanner design
  - Affects data acquisition efficiency
  - Provides a common language to describe and compare each modality
  - Further consideration of k-space permit scanner advances and design features to be developed

CT Literature

Introductory books on CT

Kak, Slaney, *Principles of Computed Tomography, IEEE Press, 1988*

- available as a free pdf file in the web

Buzug, *Computed Tomography*, Springer, 2008

Excellent modern introduction, covering everything from history to spiral CT

Hsieh: *Computed Tomography*, Wiley, 2009

Another nice modern introduction, the GE version of Buzug's book

Original papers

J. Radon: *Über die Bestimmung von Funktionen durch ihre Integralwerte längs gewisser Mannigfaltigkeiten.*, Berichte über die Verhandlungen der königlich sächsischen Gesellschaft der Wissenschaften, Vol 69, 1917, 262-77

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S. Kaczmarz: *Angenäherte Auflösung von Systemen linearer Gleichungen*, Bull. Internat. Acad. Polon.Sci. Lettres A, pages 335-357, 1937

R.N. Bracewell, A.C. Riddle: *Inversion of Fan-Beam Scans in Radio Astronomy*, Astrophysical Journal, vol. 150, 427-434, 1967

G.N. Hounsfield: *Computerized transverse axial scanning (tomography): Part I. Description of the system*, Br J Radiol. 1973 Dec;46(552):1016-22

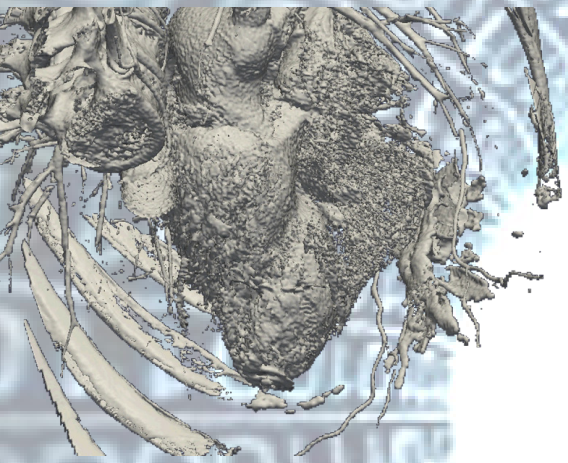
What’s next?

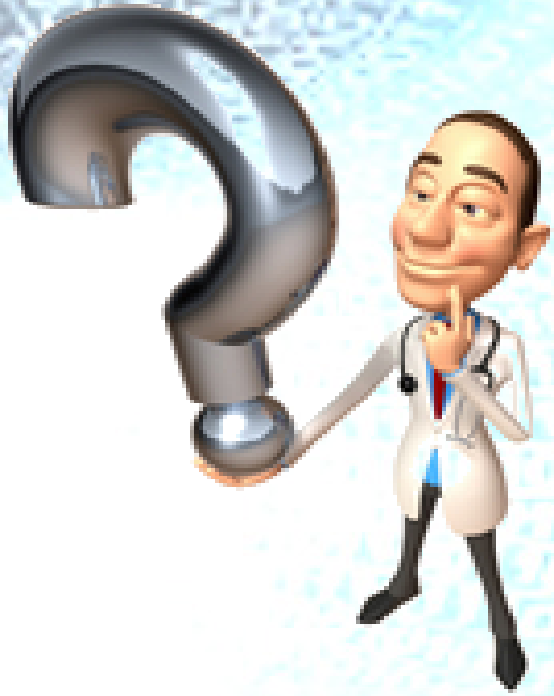
Ultrasound

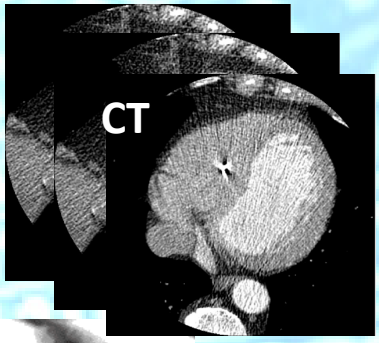
PSFs & Optical Imaging Systems

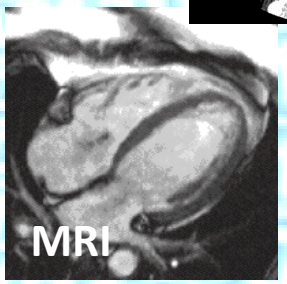
BIA 2014

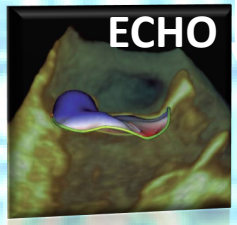
Carnegie Mellon University











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