Overview of
CT Projection
&
Reconstruction

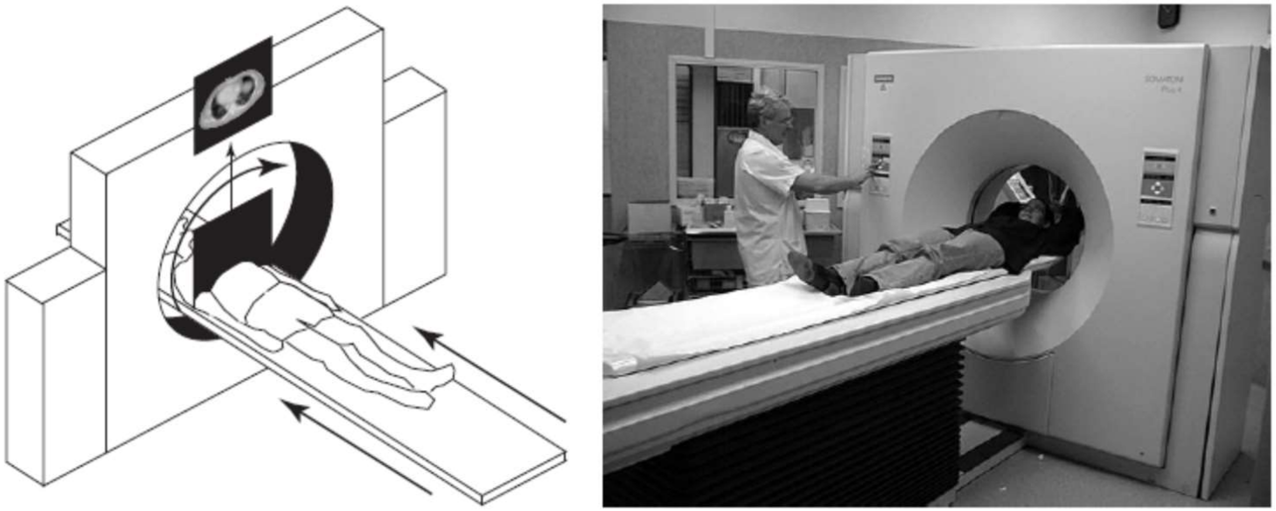
X-ray Computed Tomography

- An imaging modality that produces cross-sectional images
- Images represent X-ray attenuation properties of the body
- Tomo (=slices) graphy (=to write)
- Use a thin x-ray beam, a set of lines is scanned covering the entire field of view.
- This process is repeated for a large number of angles, yielding line attenuation measurements for all possible angles and for all possible distances from the center.
- Based on all these measurements, the actual attenuation at each point of the scanned slice can be reconstructed.
- Description of X-ray physics, production, and interactions NOT in this class.

X-ray Computed Tomography

- History of CT starting in 1895
- Rontgen reported the discovery of what he called “a new kind of rays”
- Rontgen received the first Nobel prize in Physics in 1901
- Reconstruction of a function from its projections was first formulated by Radon in 1917

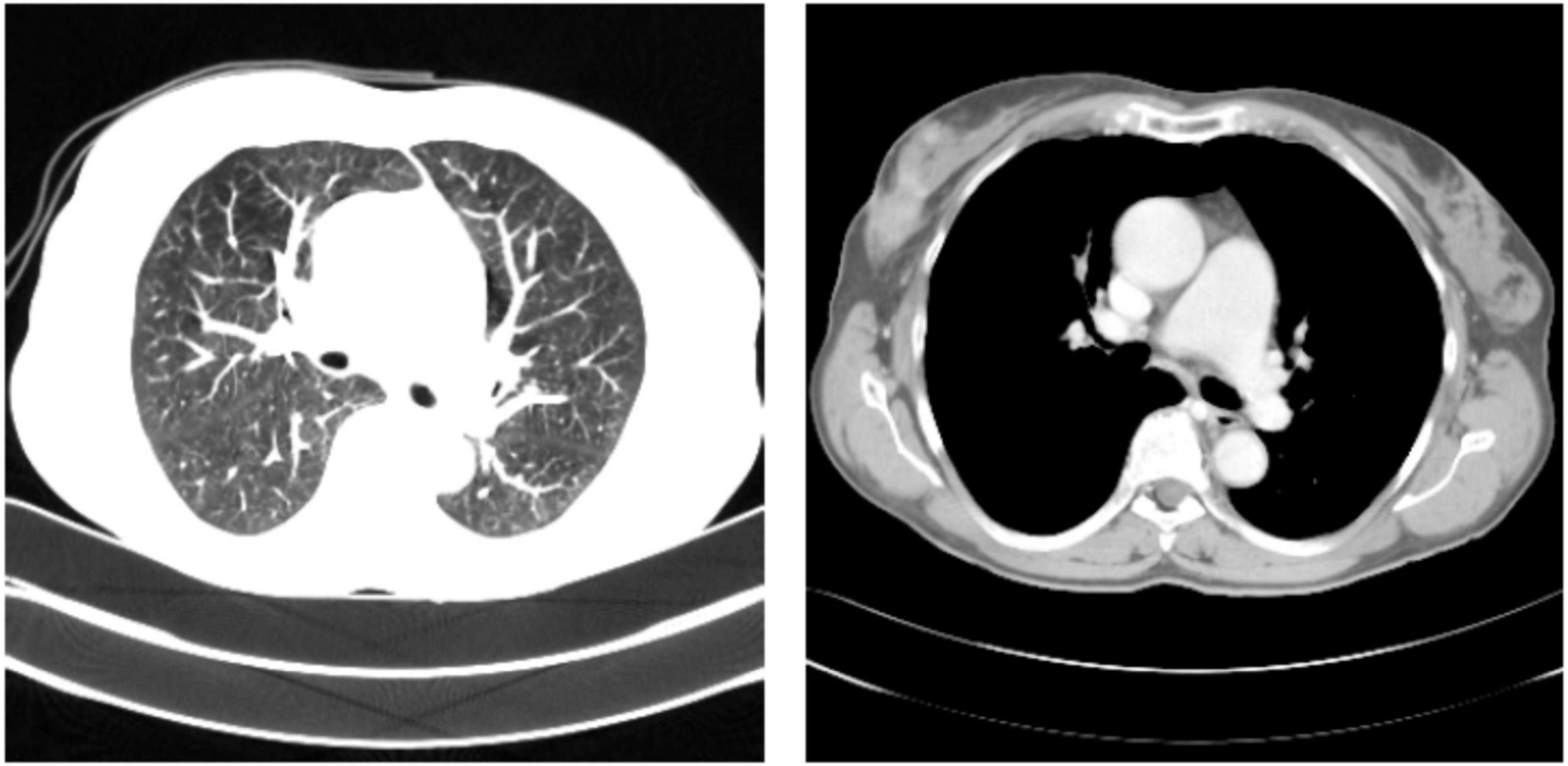
X-ray CT Scanner



(a) (b)

Figure 5.1: *Schematic representation (a) and photograph (b) of a CT scanner.*

The first CT scanner was developed by Godfrey N. Hounsfield in 1972.
Later A. M. Cormack worked on mathematical and experimental methods.
Hounsfield and Cormack shared the Nobel Prized in 1979.



(a) (b)

Figure 5.4: *CT-image of the chest with different window/level settings:(a) for the lungs (window 1500 and level -500) and (b) for the soft tissues (window 350 and level 50).*

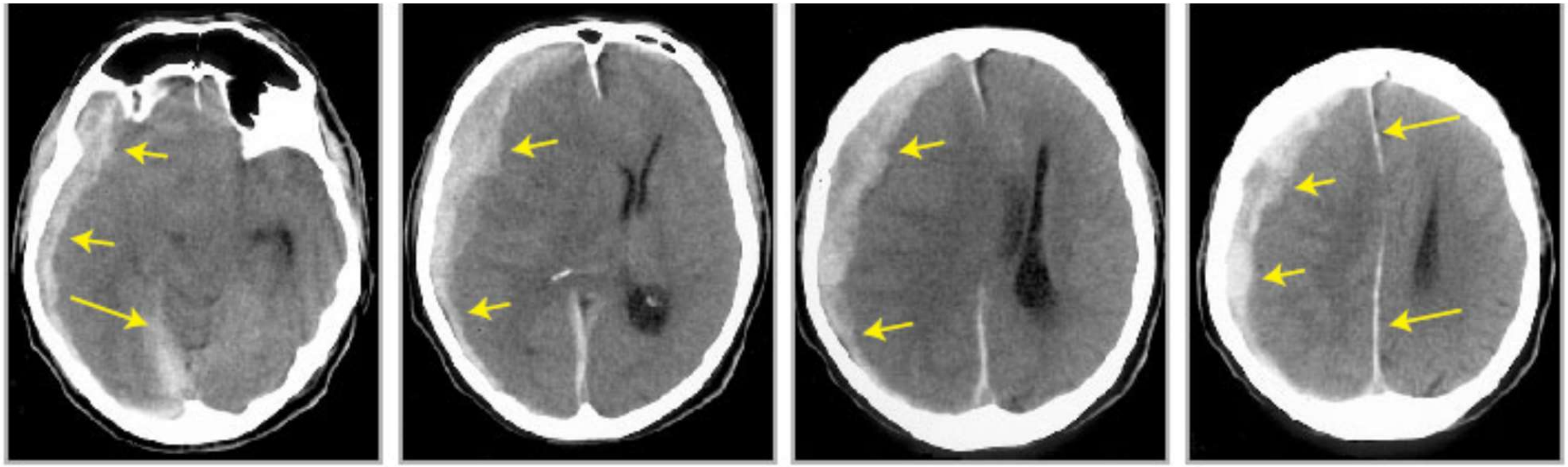
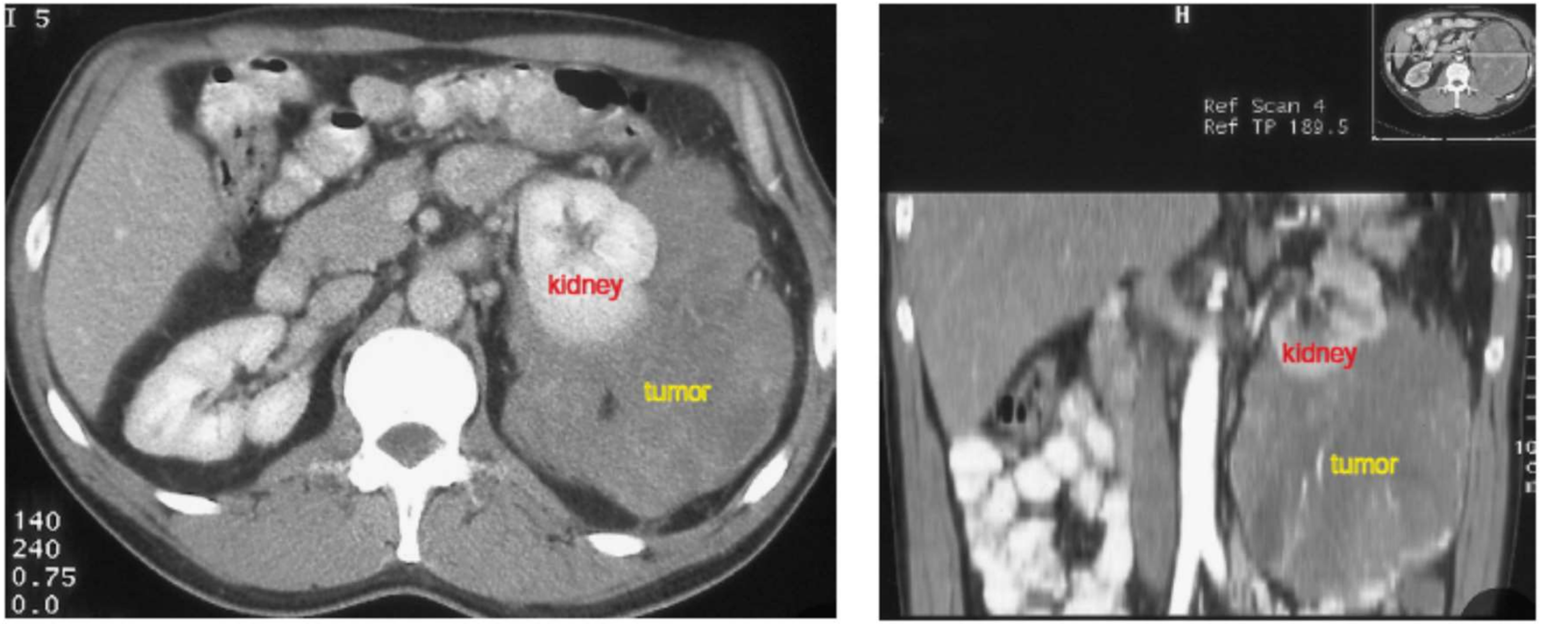
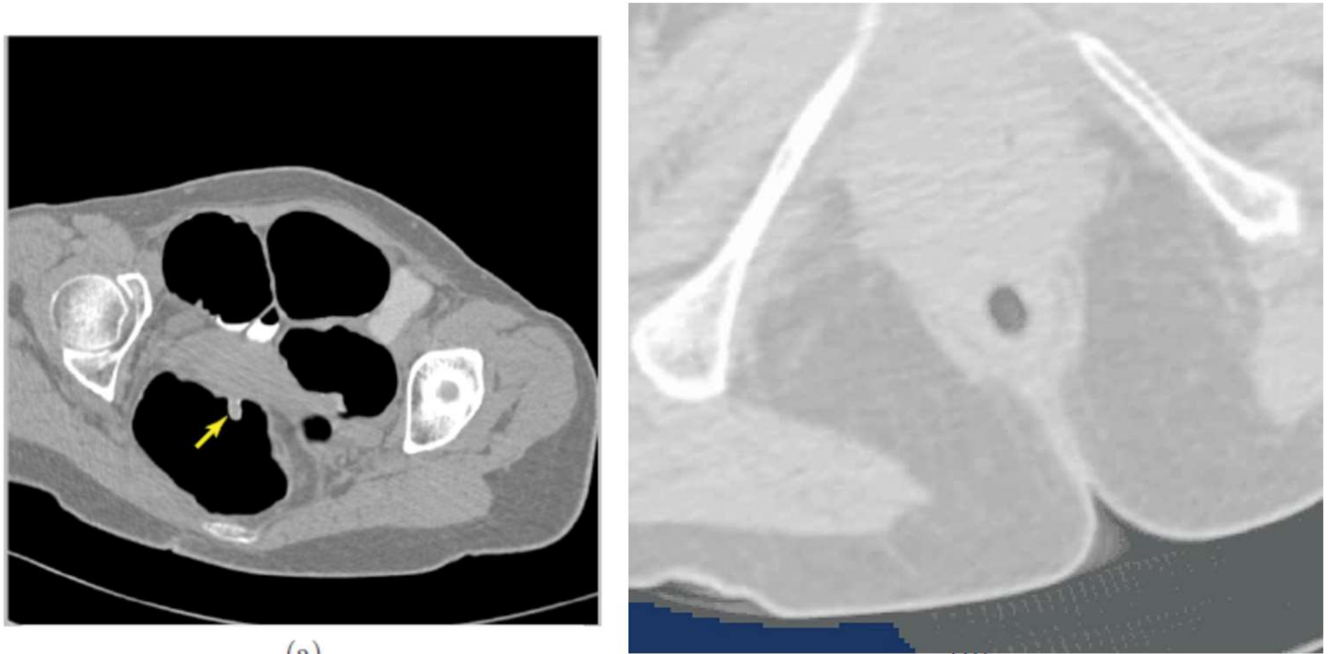


Figure 5.27: *Subsequent CT slices through the brain show a subdural haemorrhage as a hyperdense region along the inner skull wall (short arrows). This blood collection causes an increased pressure on the brain structures with an important displacement of the midsagittal line (long arrows) (courtesy of prof. G. Wilms, dept. of radiology).*



(a) (b)

Figure 5.29: *(a) Axial CT slice through the kidney showing a perirenal liposarcoma in the nephrographic phase after intravenous injection of contrast medium. (b) Reformatted coronal CT slice at the level of the aorta of the same patient. (courtesy of prof. R. Oyen, dept. of radiology).*



(a) (b)

Figure 5.30: *(a) A CT slice through the colon shows a polypus (arrow). (b) A virtual colonoscopy program creates a depth view of the colon with polypus (arrow) and allows the clinician to automatically navigate along the inner wall (courtesy of dr. M. Thomeer, dept. of radiology & G. Kiss, lab. Medical Image Computing). More about 3D visualization in chapter 10.*

Basic Scanning in CT

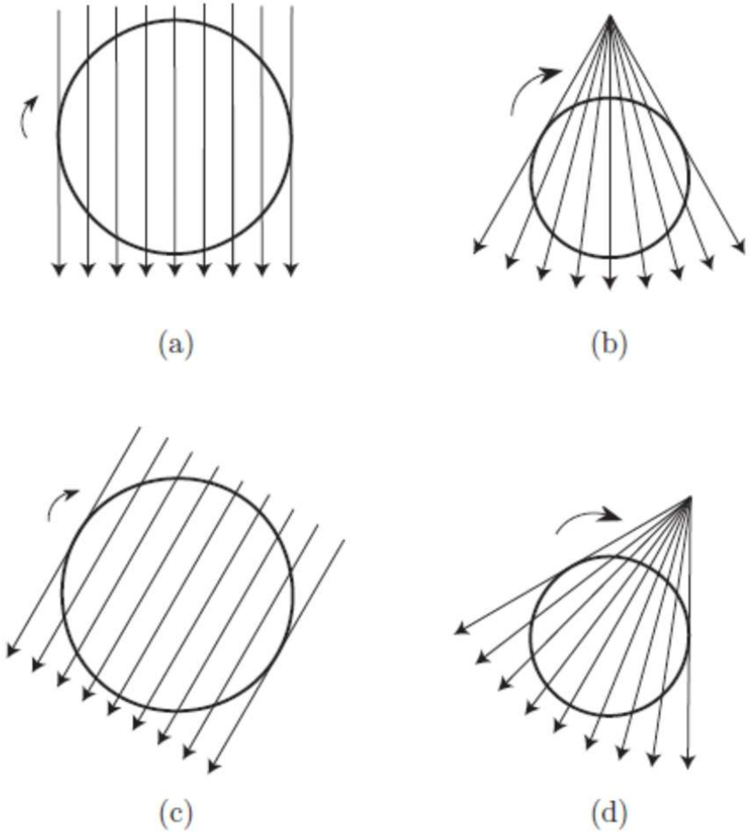
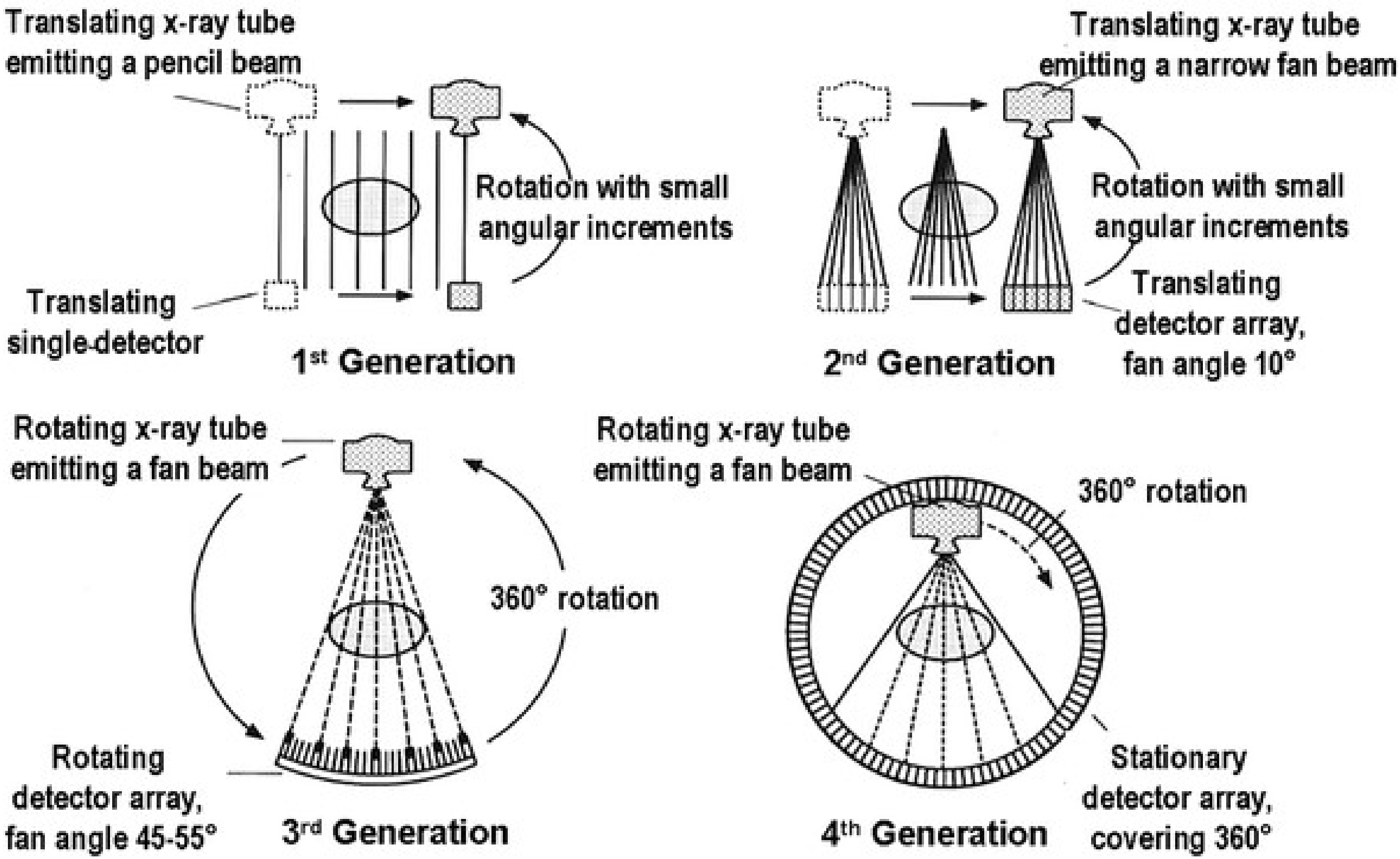


Figure 5.2: *Basic scanning procedure in CT. A set of lines is scanned covering the entire field of view: (a) parallel-beam geometry and (b) fan-beam geometry. This process is repeated for a large number of angles (c-d)*

Generations of X-ray CT



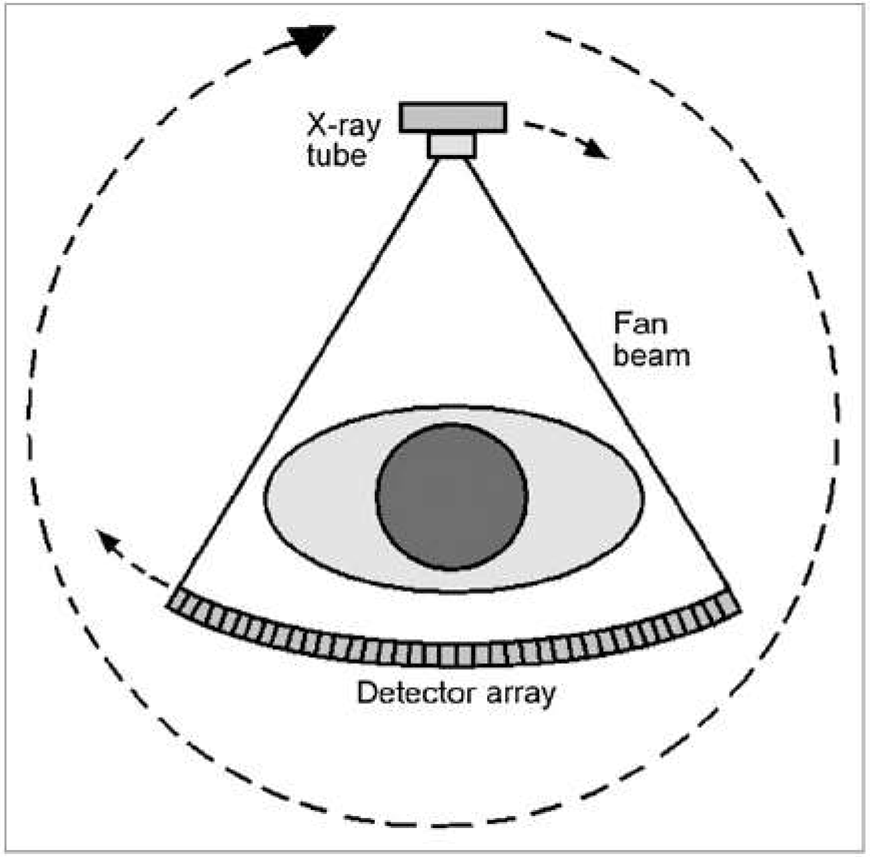


FIGURE 8. Third-generation geometry. Time-consuming and mechanically complex translation motion was eliminated by opening x-rays into fanbeam. Large array of detectors measured data across width of fan. Tube and detectors were rigidly linked and underwent single rotational motion.

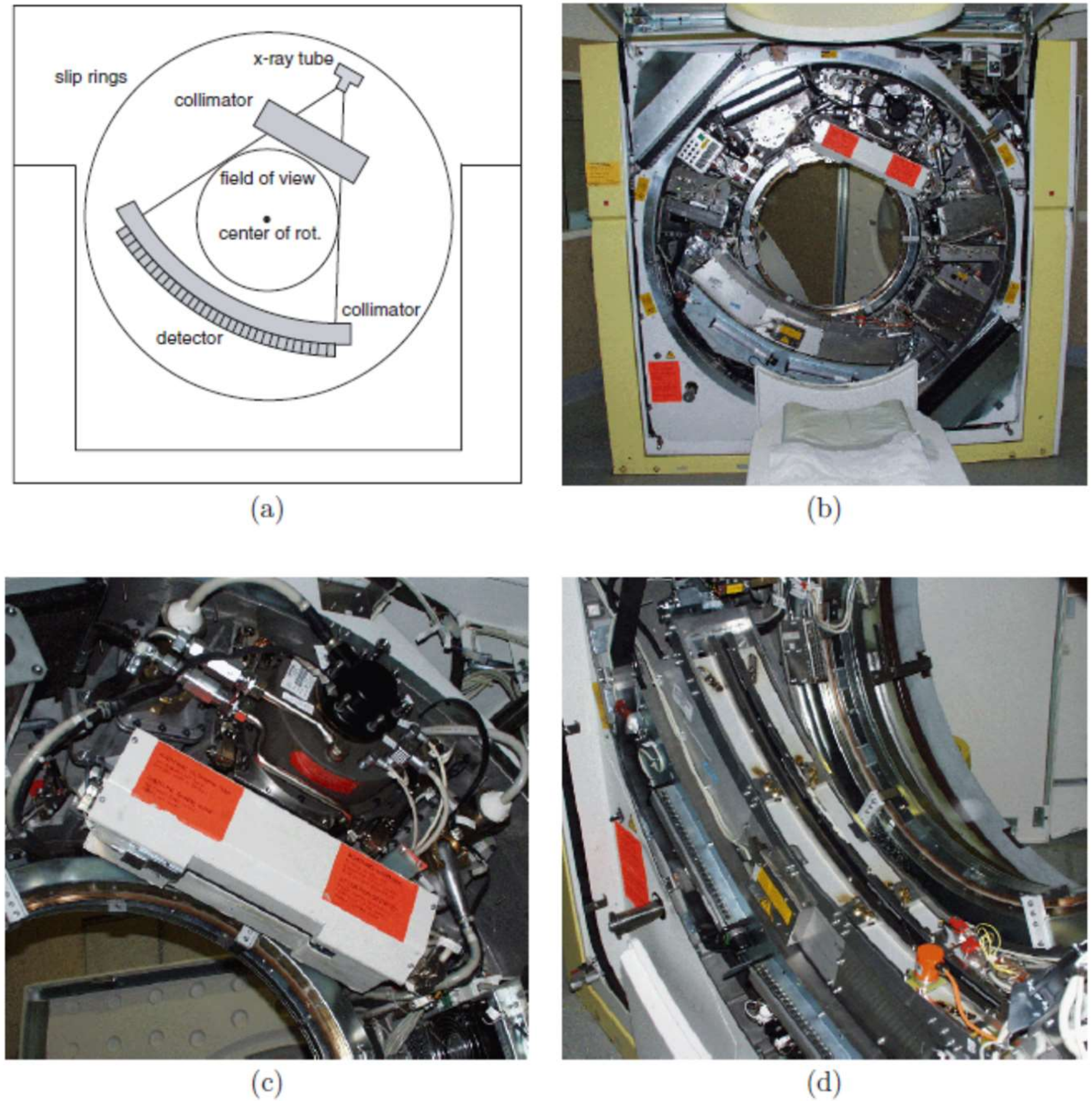
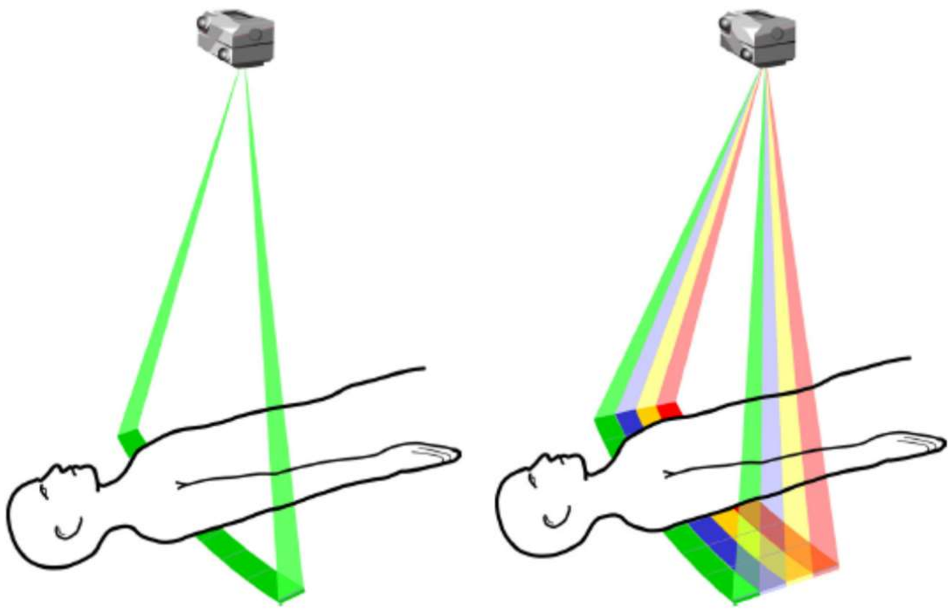


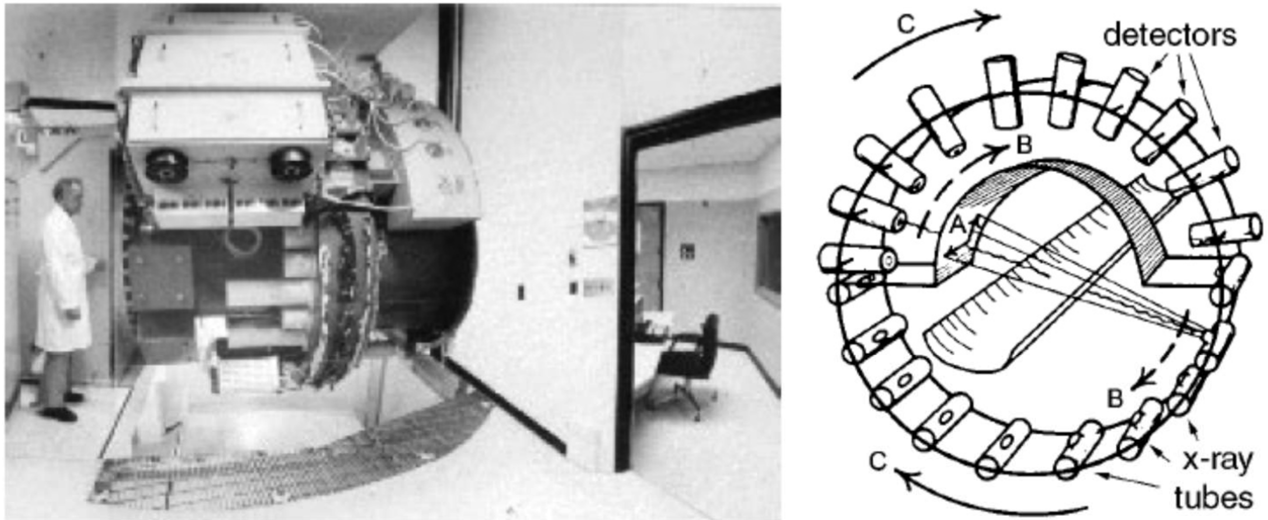
Figure 5.20: *(a-b) The basic internal geometry of a third generation spiral CT scanner. (c) X-ray tube with adjustable collimating split. (d) Detector array with post-patient collimator.*



(a) (b)

Figure 5.22: *(a) Single-slice CT versus (b) multi-slice CT: a multi-slice CT scanner can acquire four slices simultaneously by using four adjacent detector arrays (Reprinted with permission of RSNA).*

Figure 5.24: *Multi-slice CT scanner with four detector arrays (not visible). The external design of a multi-slice scanner is apparently not different from that of a conventional single slice scanner (see figure 5.1).*



(a) (b)

Figure 5.25: *(a) The dynamic spatial reconstructor or DSR. (b) Schematic overview of the DSR: 14 x-ray tubes are placed on a 160° circular arc and 14 2D detectors are located diametrically opposite to the x-ray tubes (Reprinted with permission of dr. R. Robb, Mayo Foundation).*

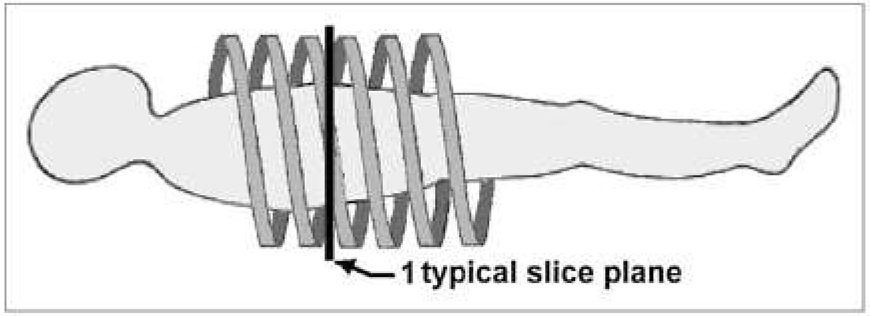
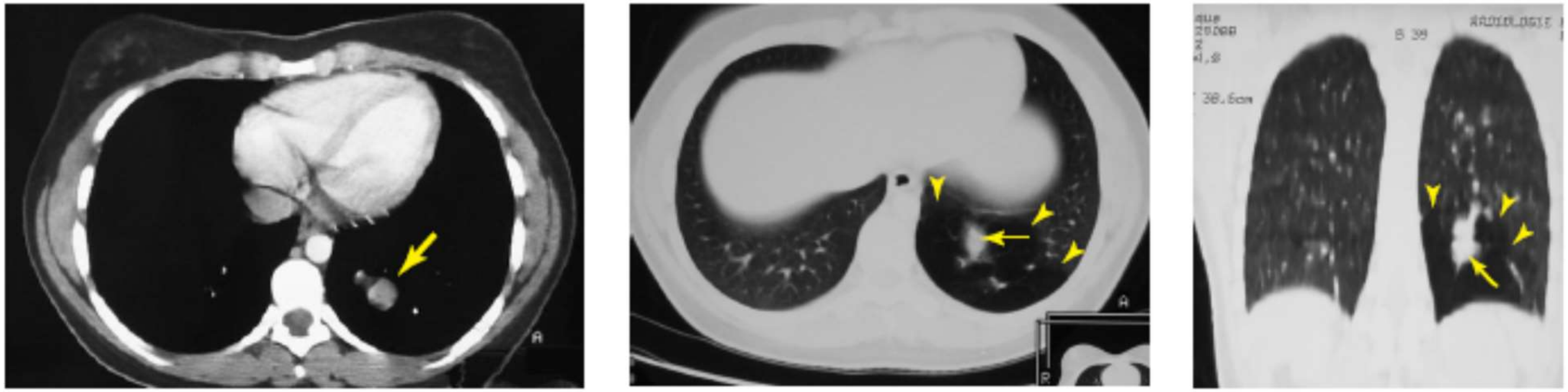


FIGURE 11. Helical CT. Improved body CT was made possible with advent of helical CT (or spiral CT). Patient table is moved smoothly through gantry as rotation and data collection continue. Resulting data form spiral (or helical) path relative to patient; slices at arbitrary locations may be reconstructed from these data.

Spiral CT Scans



(a) (b) (c)

Figure 5.28: *Spiral CT of the chest. (a) Mediastinal and (b) lung window/level settings, and (c) coronal resliced image. The images show a congenital malformation of the lung located in the left lower lobe. Notice the two components of the lesion: a dense multilobular opacity (arrow) surrounded by an area of decreased lung attenuation (arrow heads) (courtesy of prof. J. Verschakelen, dept. of radiology).*

Parallel Beam CT

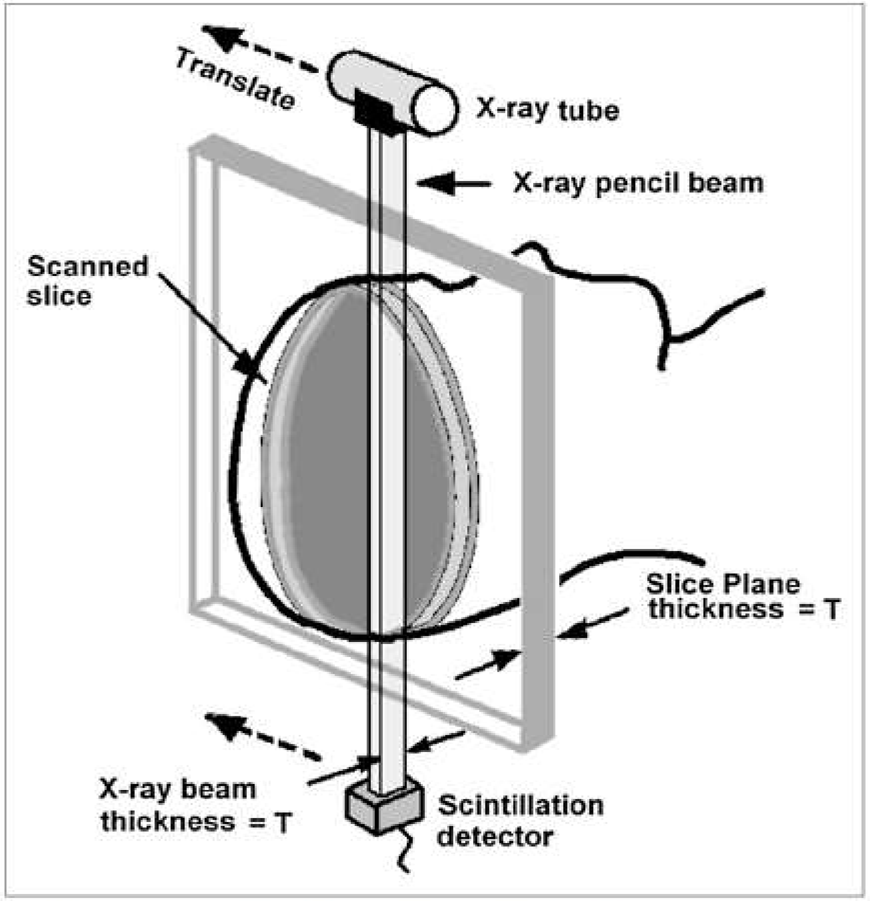


FIGURE 1. CT arrangement. Axial slice through patient is swept out by narrow (pencil-width) x-ray beam as linked x-ray tube–detector apparatus scans across patient in linear translation. Translations are repeated at many angles. Thickness of narrow beam is equivalent to slice thickness.

Parallel Beam CT

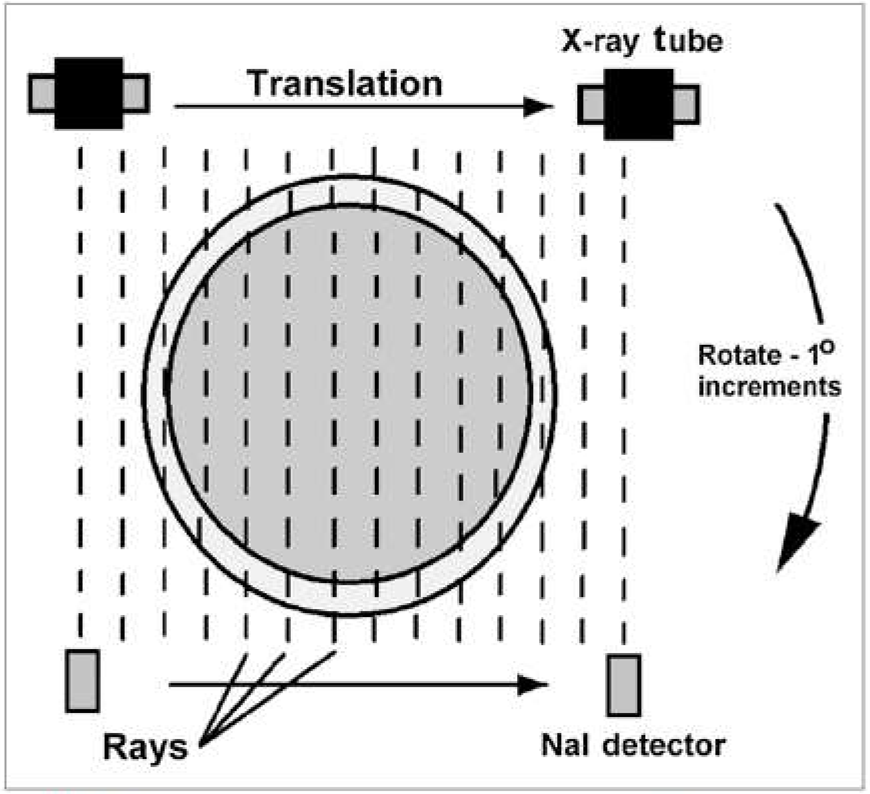


FIGURE 2. x-Ray transmission measurements. Measurements are obtained at many points during translation motion of tube and detector. x-Ray path corresponding to each measurement is designated a ray, and set of rays measured during translation is designated a view. Views are collected at many angles (in 1° increments in this example) to acquire sufficient data for image reconstruction.

Attenuation Cofficients

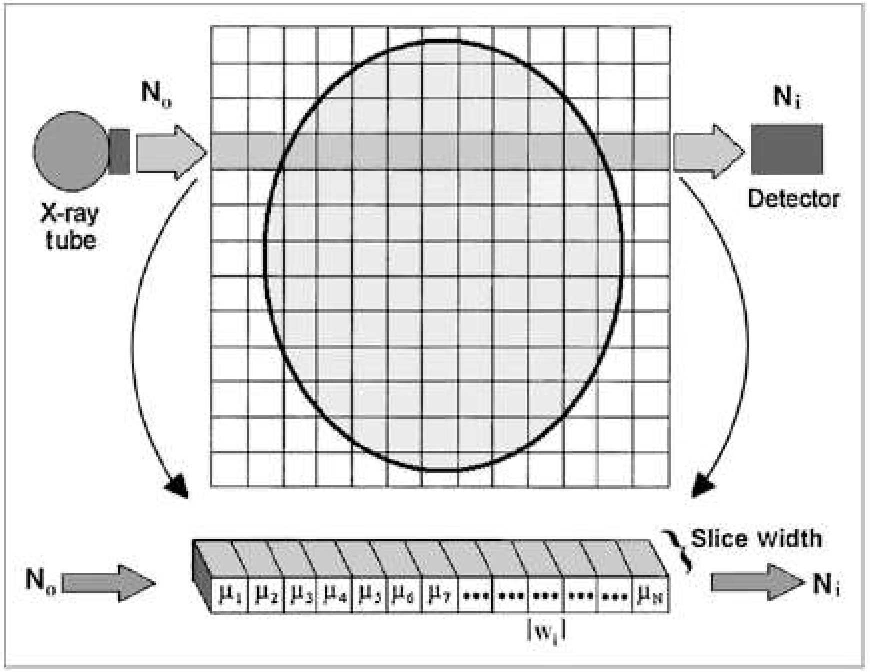


FIGURE 3. Reconstruction matrix. Hounsfield envisioned scanned slice as being composed of matrix of small boxes of tissue called voxels, each with attenuation coefficient μ. x-Ray transmission measurements (N_i) can be expressed as sum of attenuation values occurring in voxels along path of ray for N_i.

Geometry Coordinate System

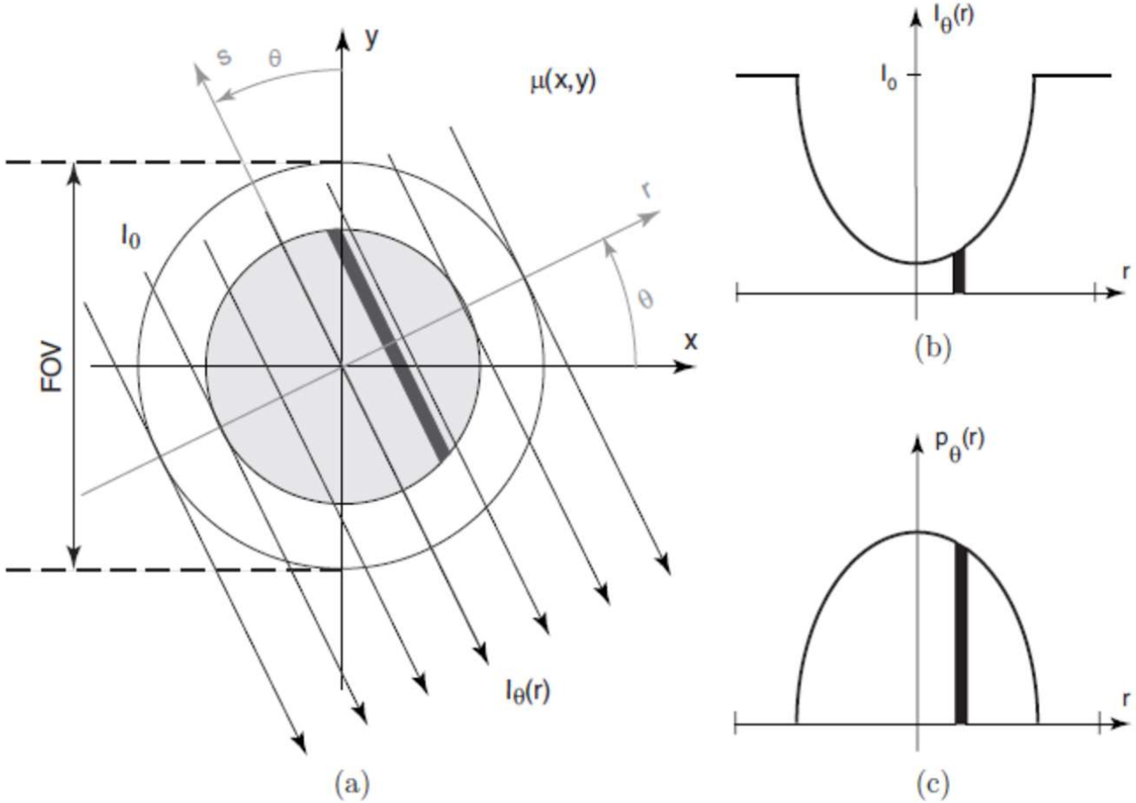
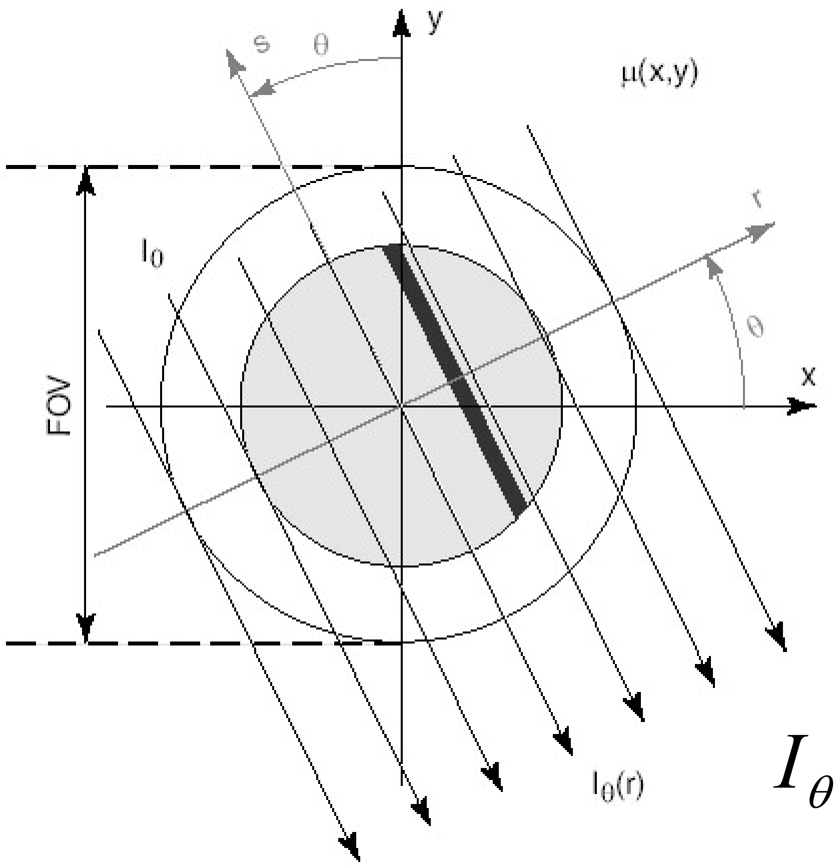


Figure 5.5: *(a) Parallel beam geometry with coordinate systems. The x-ray beams make an angle θ with the y-axis and are at distance r from the origin. (b) An intensity profile $I_\theta(r)$ is measured for every view (defined by an angle θ). I_0 is the unattenuated intensity. (c) The attenuation profiles $p_\theta(r)$, obtained by log-converting the intensity profiles $I_\theta(r)$ are the projections of the function $\mu(x, y)$ along the angle θ.*

Computed Tomography: Projection = Ray Sum



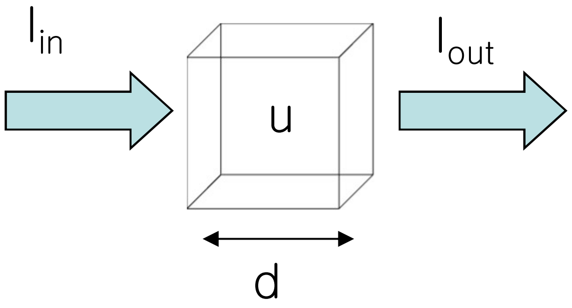
Parallel-beam geometry

$$I_\theta(r) = I_0 \exp[-\int_{L_{r,\theta}} \mu(x,y)ds]$$

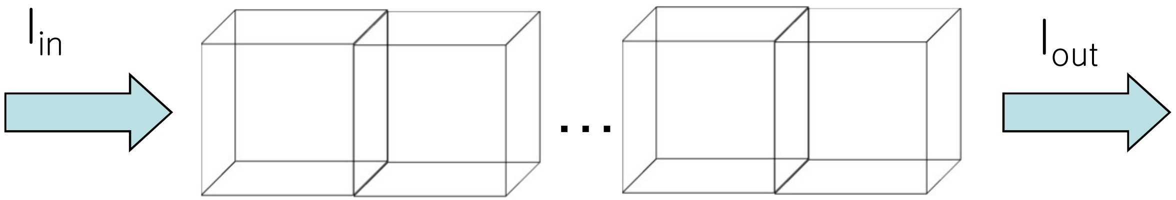
Ray-Sum

- $f(x,y)$ represents the actual linear attenuation coefficient μ or $\mu(x,y)$
- A X-ray or ray is theoretically a line with no width or cross-sectional area
- Each ray is best specified in terms of its own coordinate (r,Φ)
- Φ is the angle of the ray with respect to the y axis
- r is its distance from the origin

Computed Tomography:
Projection Data = Ray Sum



$$\mathbf{I_{out} = I_{in}\, exp\, (-\mu\, d)}$$



$$I_{out} = I_{in} \exp[-\int_{x_{in}}^{x_{out}} \mu(x)dx]$$

Sinogram

Forward Problem (Project 4A)

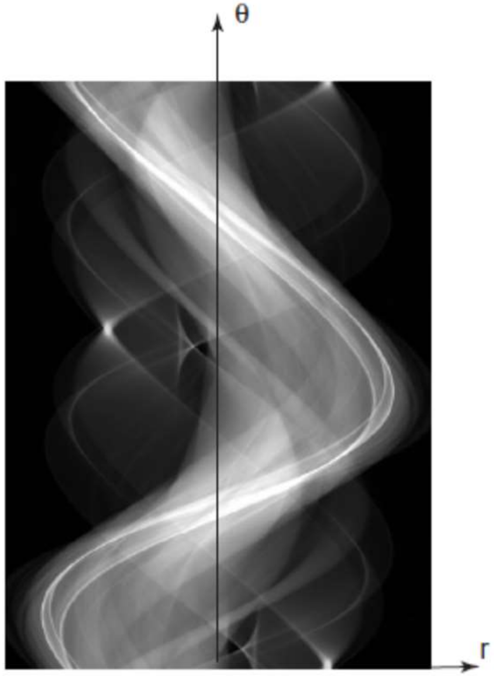


Figure 5.6: *A sinogram is a 2D dataset* $p(r, \theta)$ *obtained by stacking the 1D projections* $p_\theta(r)$.

A Single Dot and its Sinogram

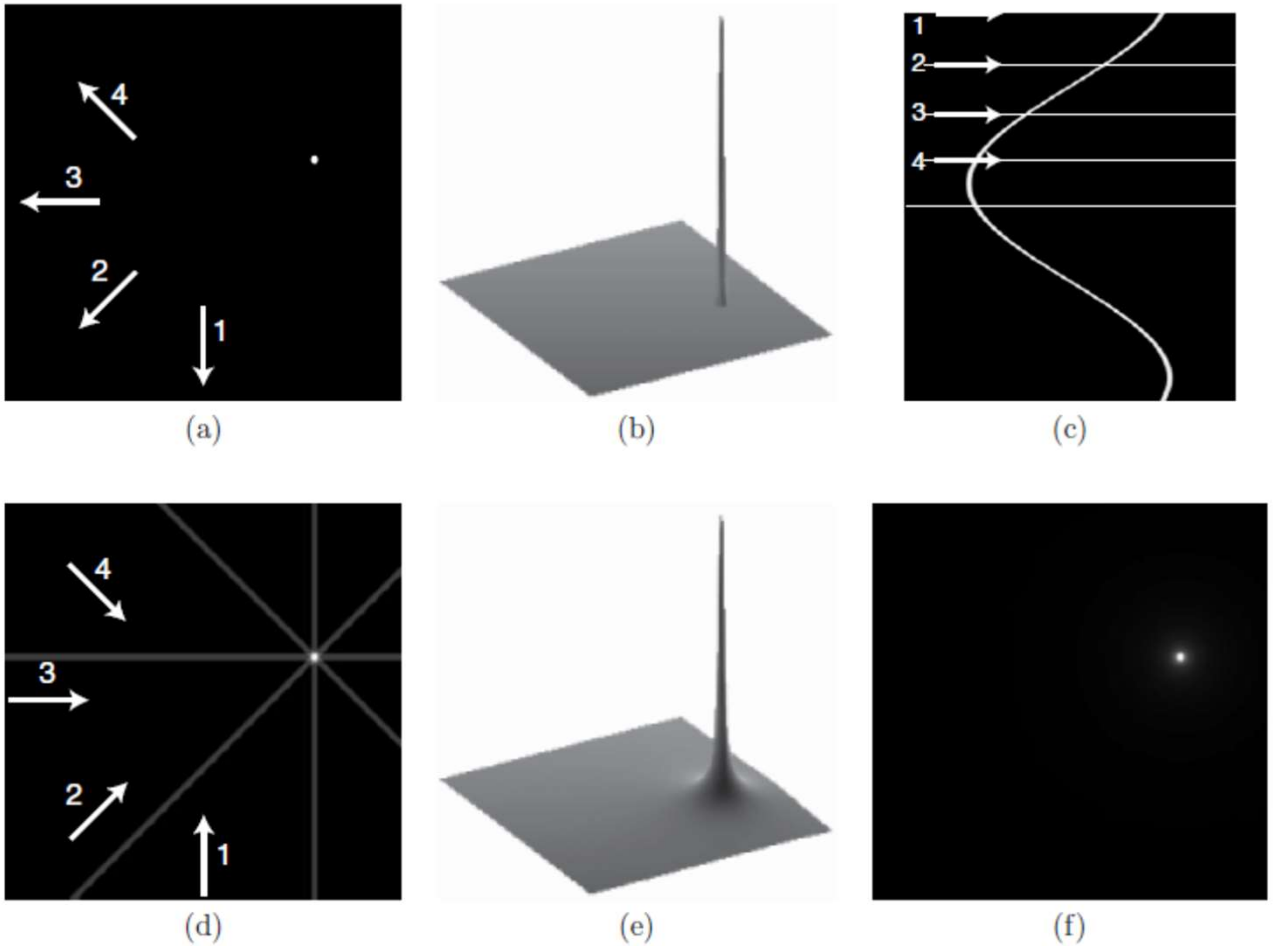
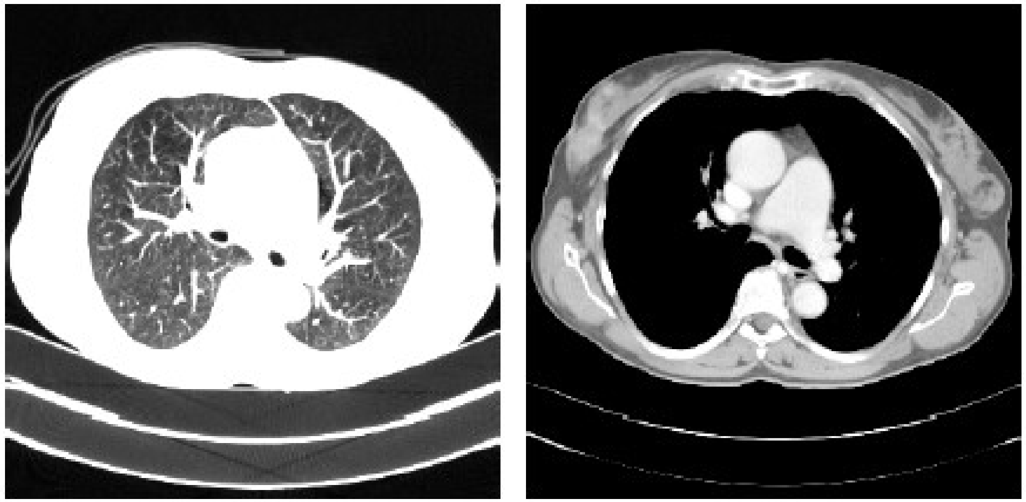


Figure 5.7: *(a-b) Image and surface plot of a distribution $\mu(x, y)$ containing one single dot. The arrows indicate four arbitrary projection directions. (c) 360°-sinogram obtained by projecting $\mu(x, y)$. The arrows indicate the views that correspond to the four projection directions in (a). (d) Back-projection (see section ??) of the four views chosen in (a). (e-f) Surface plot and image of the straightforward back-projection of the entire sinogram in (c).*

CT Image of the Chest Reconstruction (to be continued)

Figure 5.6: *A sinogram is a 2D dataset $p(r, \theta)$ obtained by stacking the 1D projections $p_\theta(r)$.*

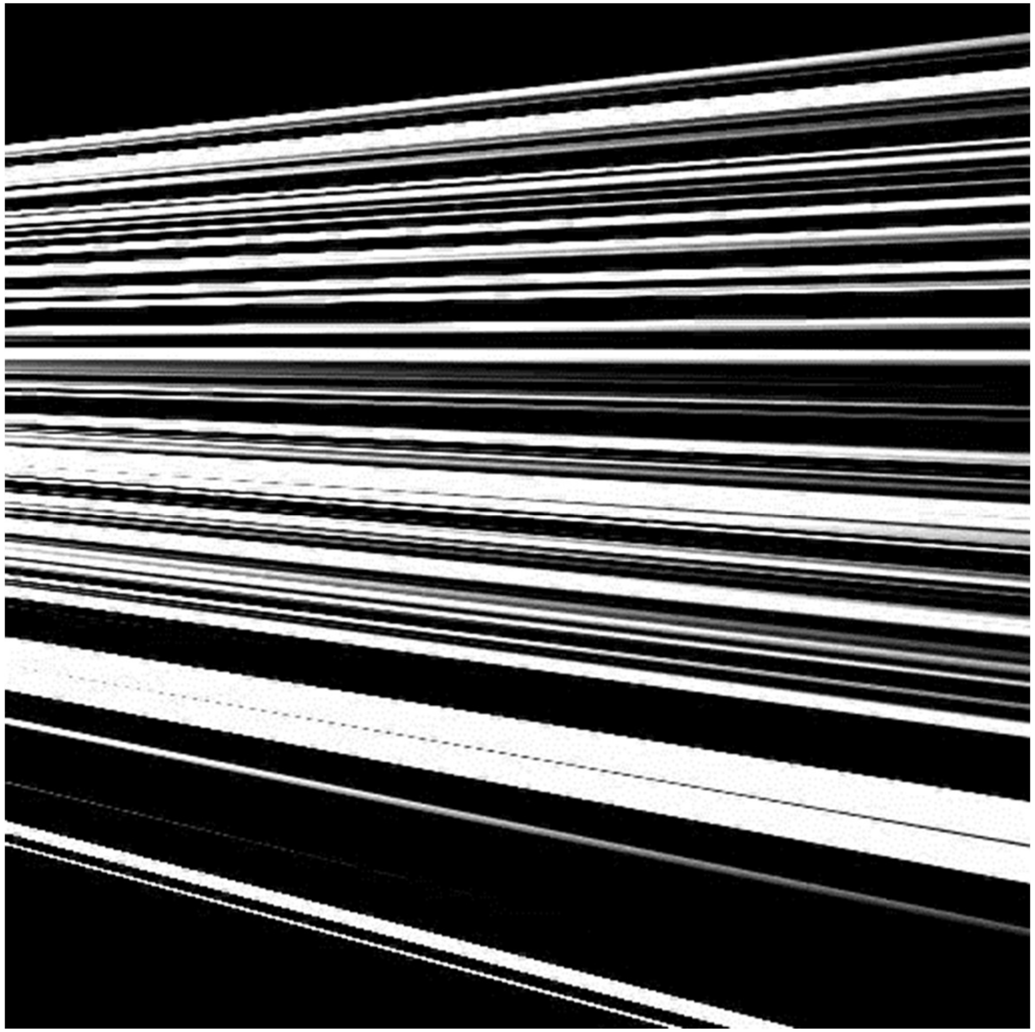
Inverse Problem (Project 4B & 4C)



(a) (b)

Figure 5.4: *CT-image of the chest with different window/level settings:(a) for the lungs (window 1500 and level -500) and (b) for the soft tissues (window 350 and level 50).*

CT Reconstruction



Inverse Problem (Project 4B & 4C)