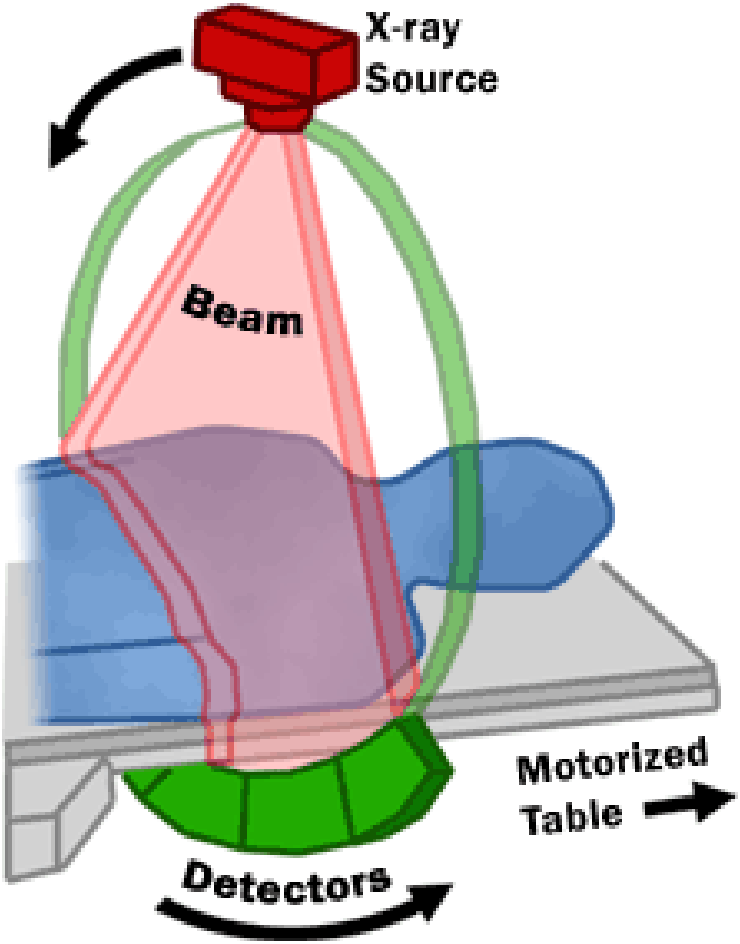
Computerized Tomography

Deep Learning and Image Processing

Computed Tomography (CT) Scan



Principle

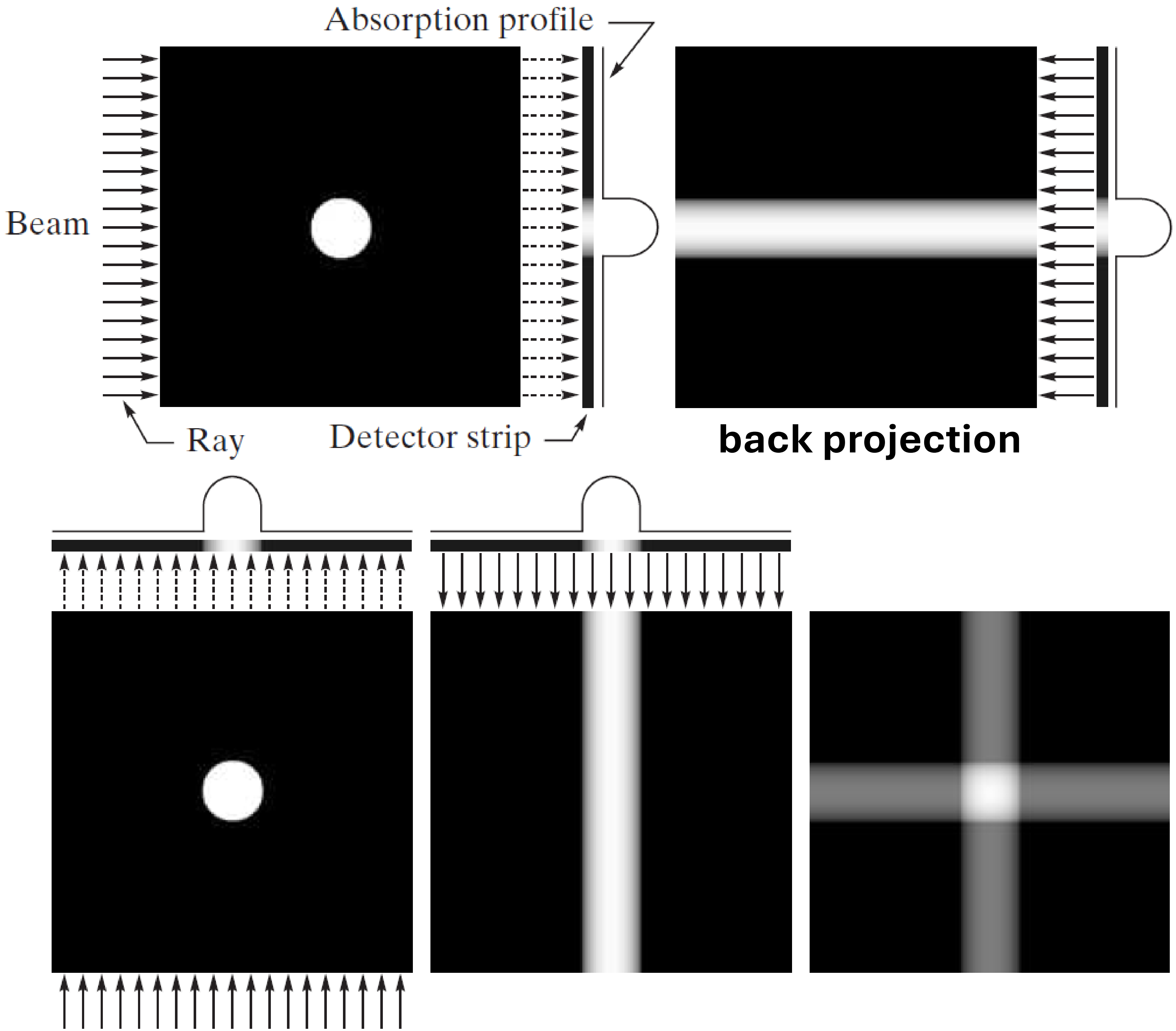
or anything else

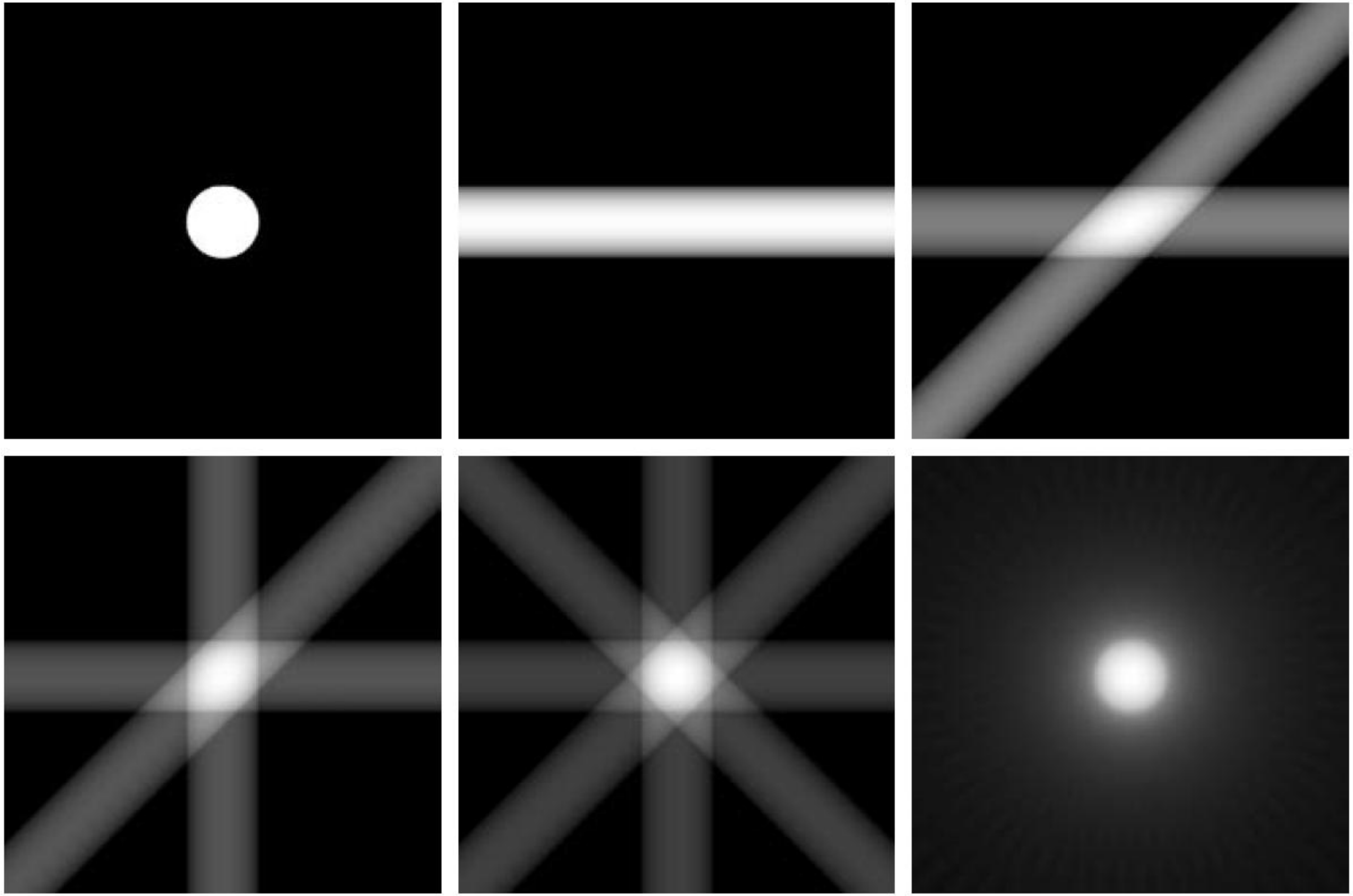
1. irradiate patient with X-rays **from different directions**

2. measure attenuations (absorption) of X-rays after passing through the body (different attenuations by different tissues)

3. use computer to **reconstruct** digital, cross-sectional images of the body interior, which are **free from superpositions**

4. move patient and repeat → 3D image (stacking of 2D slices)


Absorption profile
Beam
Ray
Detector strip
back projection



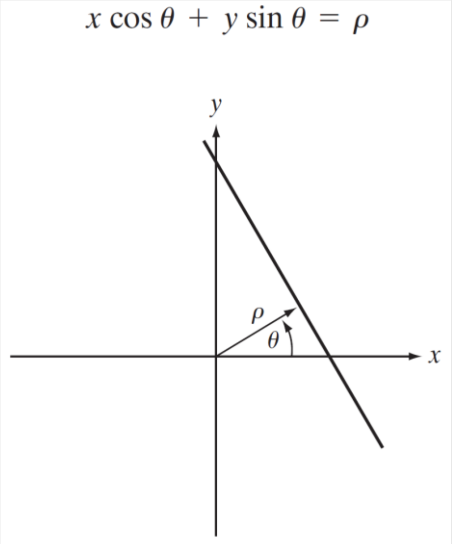
with 32 back projections

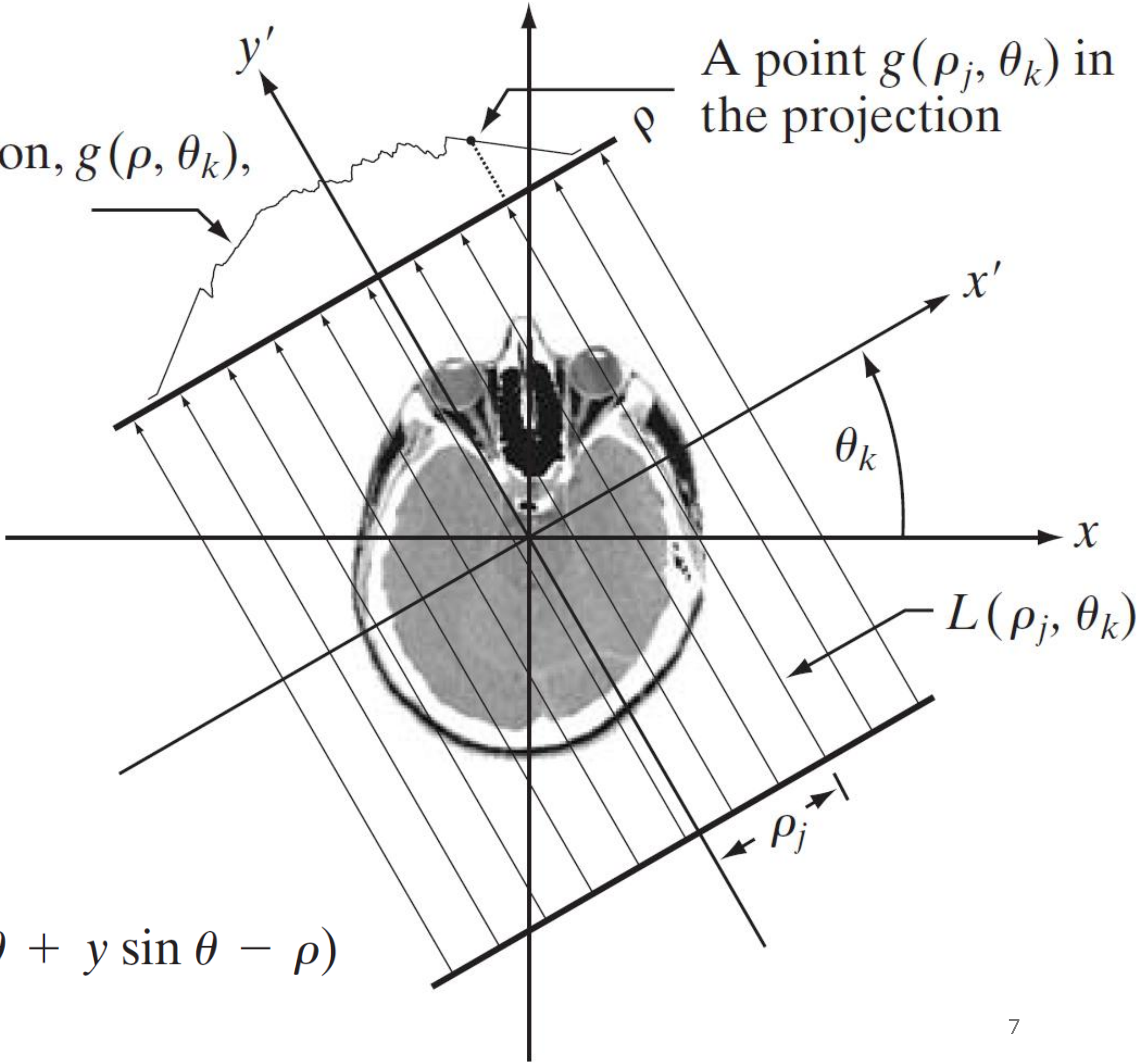
Tomographic Reconstruction

raw data from CT scan: multiple projections of the object (each projected point corresponds to superposition of specific direction)

in math terms: Radon transformation of the scanned structure

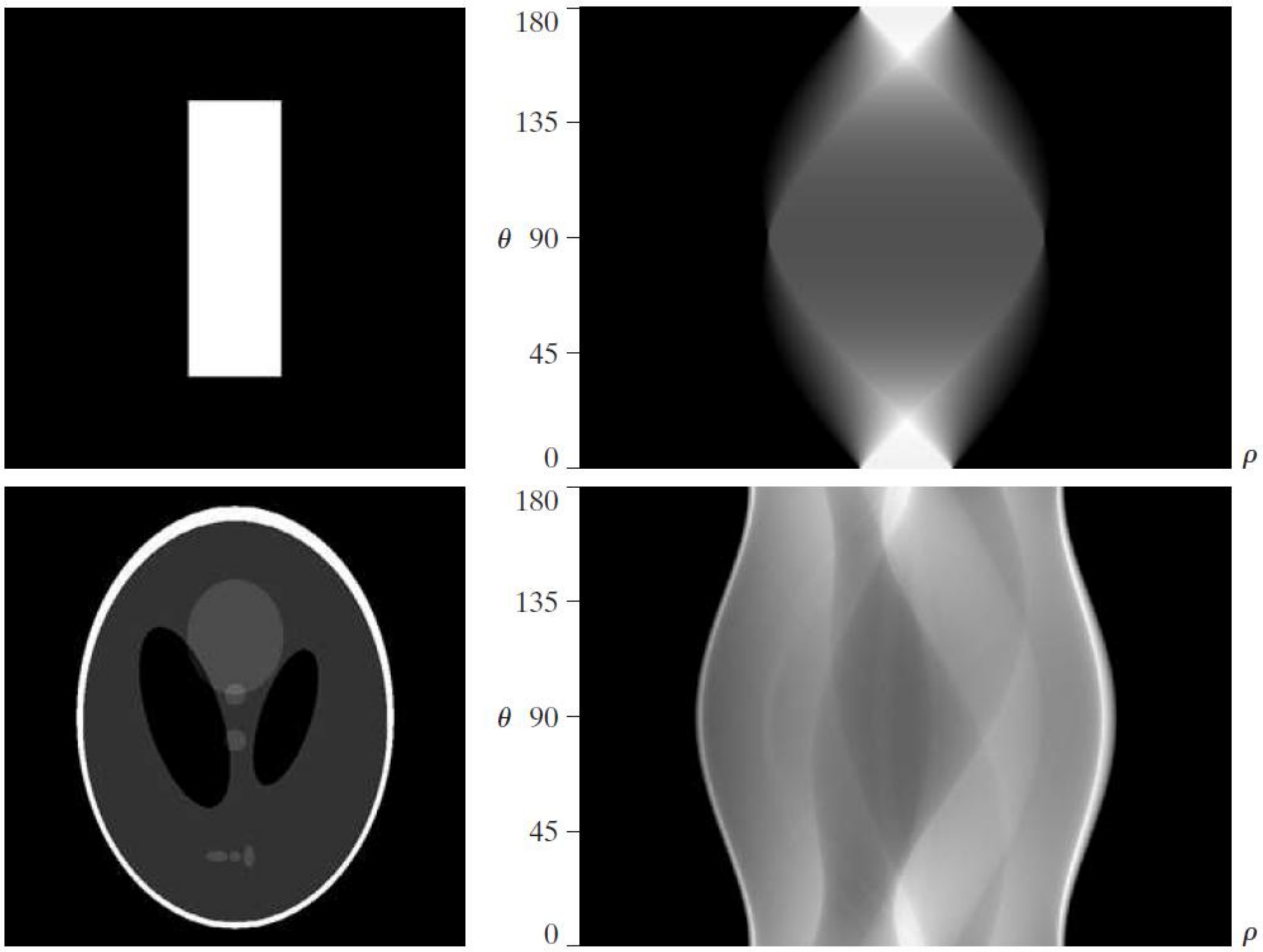
reconstruction: inverse Radon transformation (resulting in two-dimensional image → virtual slice) using normal representation of straight line





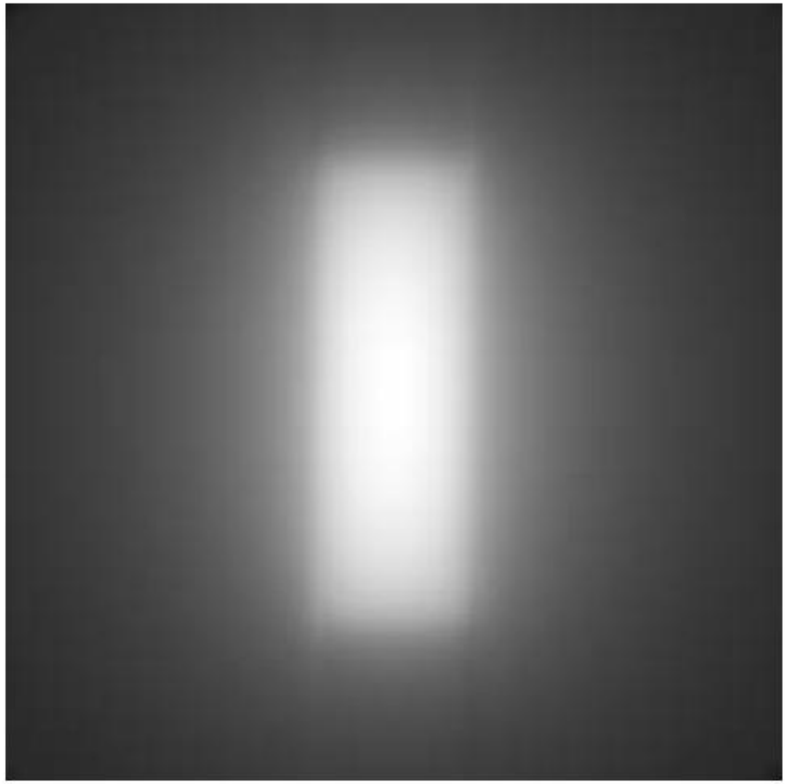
discrete Radon transform:

$$g(\rho, \theta) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y)\delta(x \cos\theta + y \sin\theta - \rho)$$



sinogram:
Radon transform
displayed as image

back projections of the sinograms

single back projection (one direction): $f_\theta(x, y) = g(x \cos\theta + y \sin\theta, \theta)$

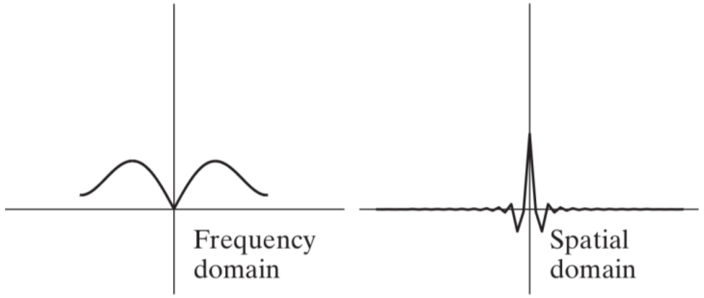
final image by summing over all back projections: $f(x, y) = \sum_{\theta=0}^{\pi} f_\theta(x, y)$

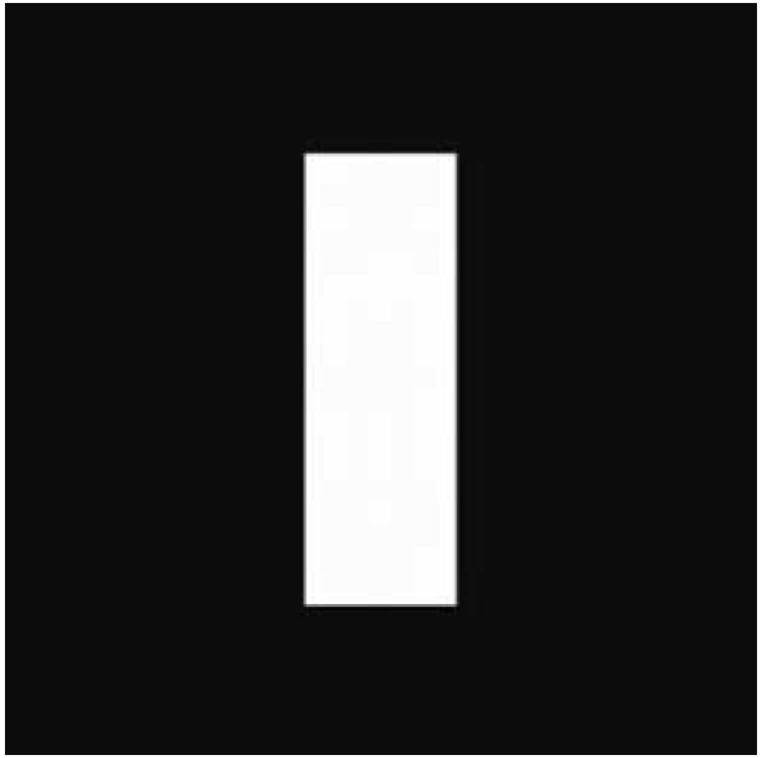
Filtered Back Projection

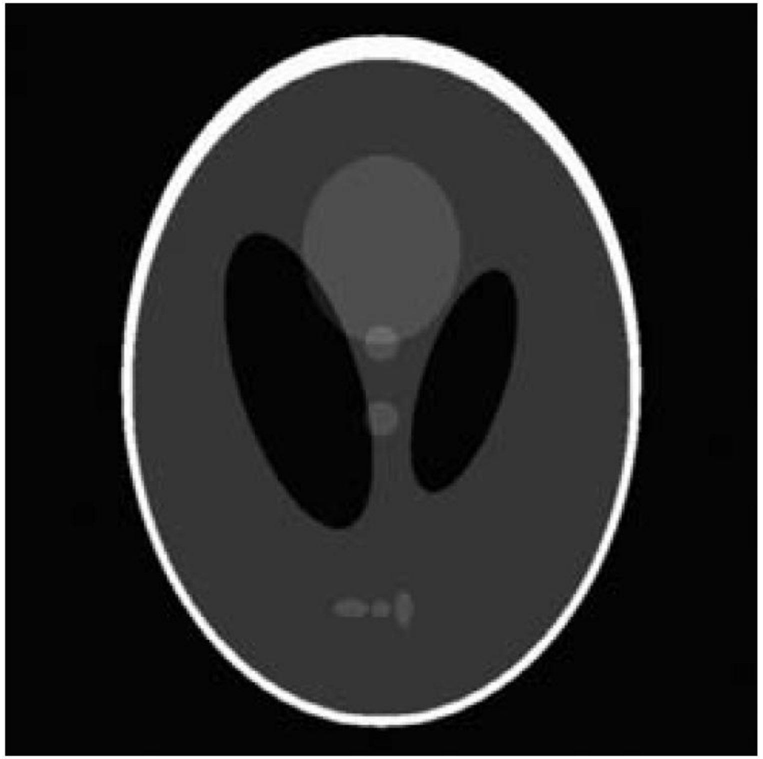
to reduce blurring effect: filter projections before back projection

need for **high-pass filter**

e.g., band-limited ramp filter using a Hamming windowing function:

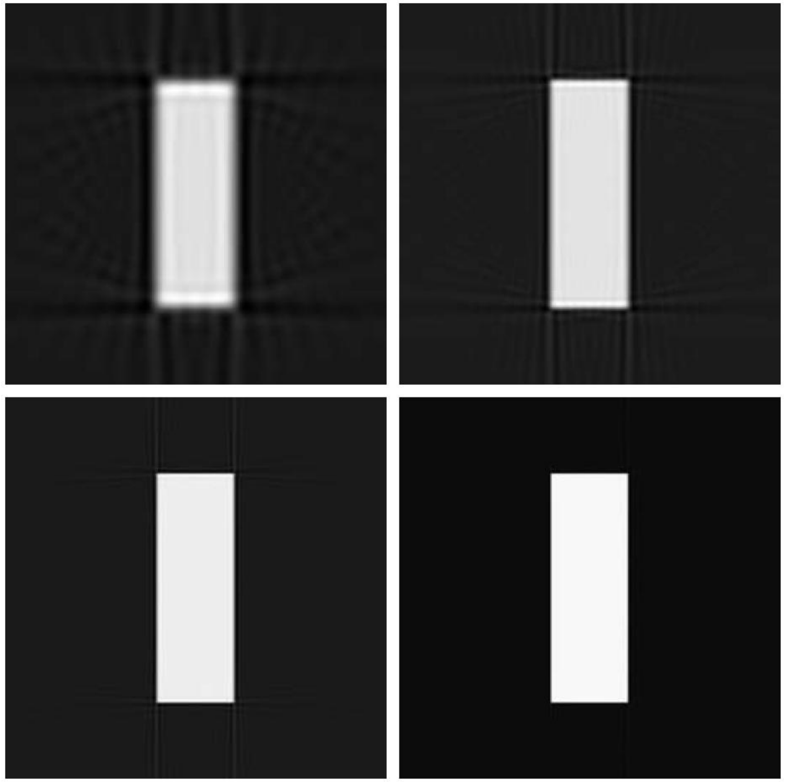




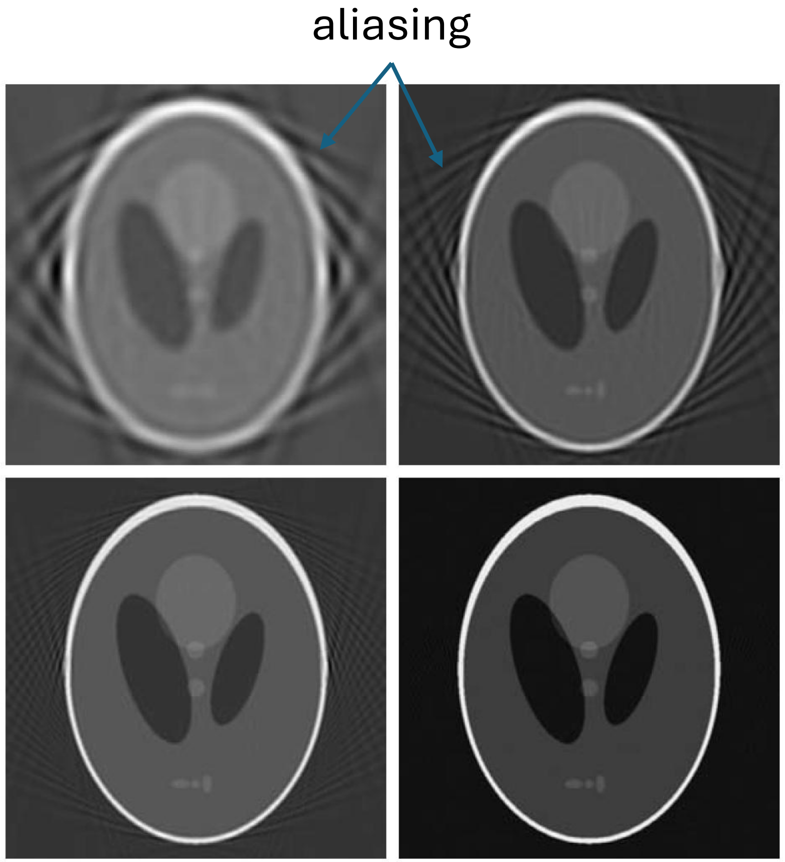


Fan-Beam Filtered Back Projection

so far looked at parallel beams
but modern CT systems use fan-beam geometry: need for many detectors



decreasing angle
increments
(more detectors)



Radiation Dose

need for low-dose method

image quality of filtered back projection susceptible to noise

but large dose increases needed to lower noise (inverse quadratic dependency)

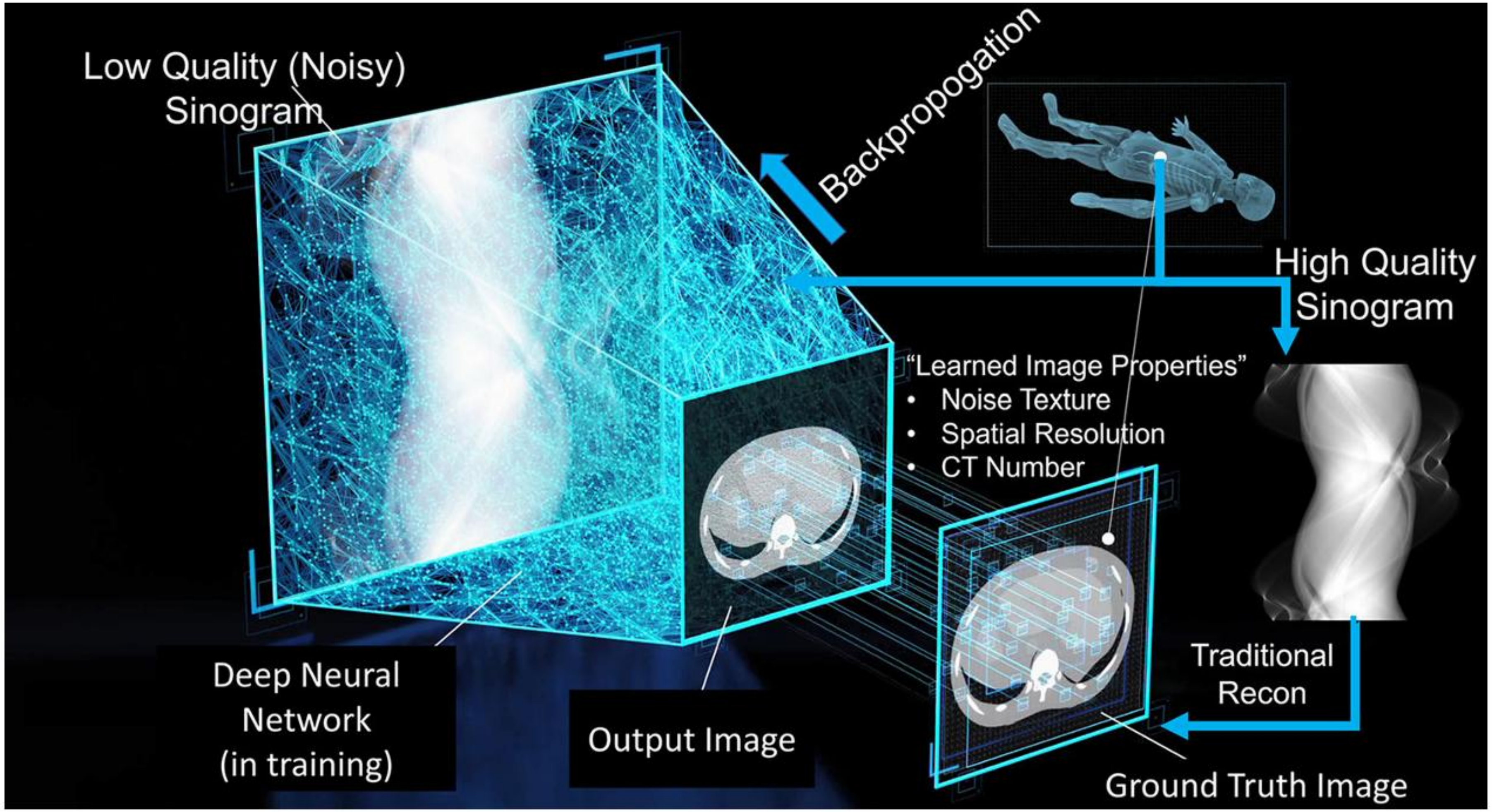
iterative and model-based reconstruction can be used to reduce noise level (regularization)

but worse performance at low doses

Deep Learning Reconstruction

idea: enhance noisy low-dose images to resemble high-dose ones

→ ~30% lower radiation dose at same image quality



Magnetic Resonance Imaging (MRI)

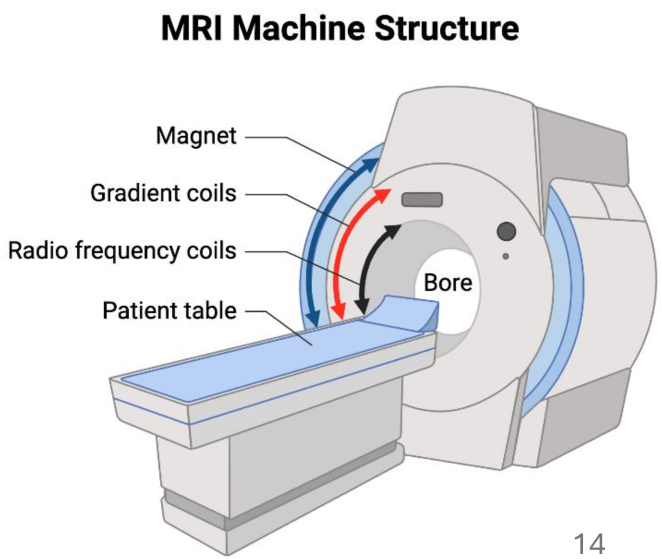
MRI uses magnetic fields and radio waves (instead of X-rays), applying nuclear magnetic resonance of hydrogen nuclei → no ionizing radiation

observed objects directly induce electrical signals (instead of X-ray absorption) → high resolutions possible

drawback: long scan times

deep learning reconstruction also used for MRI

→ faster scans



Other Deep Learning Applications

besides reconstruction, deep learning can also be used for:

- classification and detection (e.g., tumors)
- semantic segmentation (e.g., organs)
- noise reduction and image enhancement
- image registration and fusion across modalities (e.g., CT and MRI)
- quantitative analysis
- anomaly detection