CAIRO UNIVERSITY

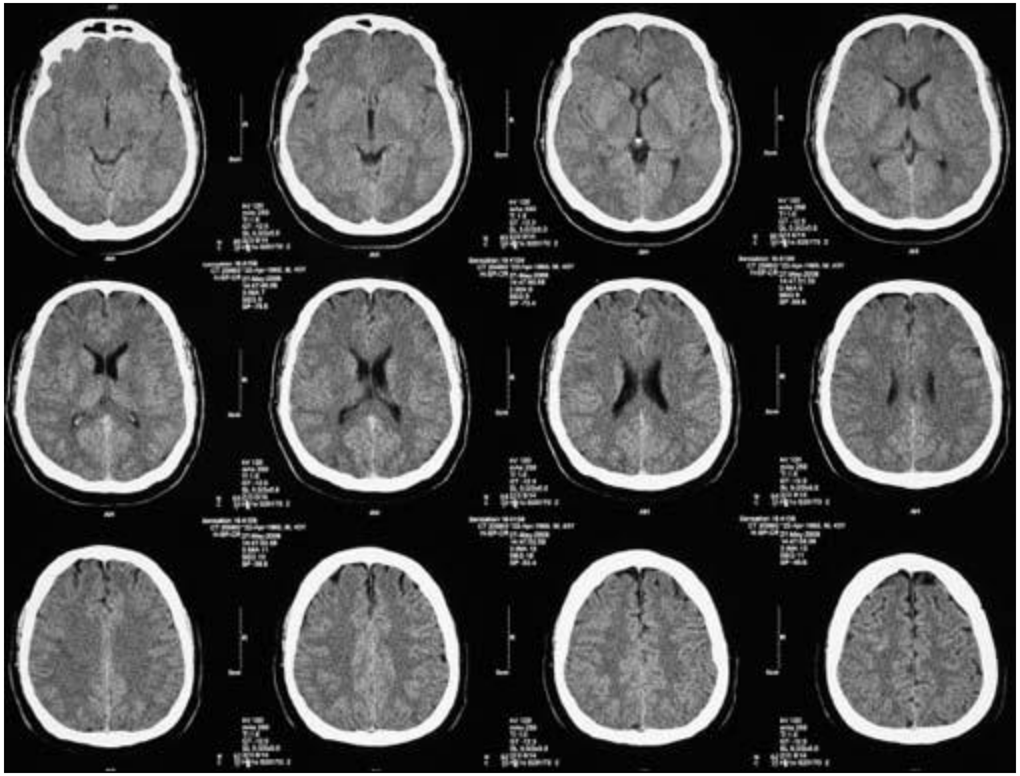
MEDICAL EQUIPMENT II - 2011
COMPUTED TOMOGRAPHY

Lecture 4

Prof. Yasser Mostafa Kadah

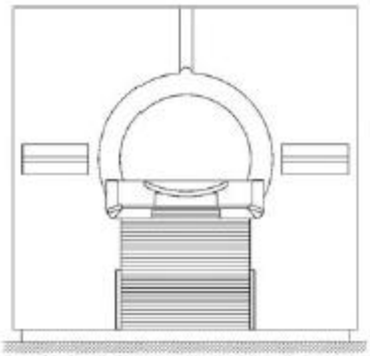
Computed Tomography

- X-ray based imaging method
- Main feature: sectional imaging rather than projection imaging



Computed Tomography Components

- **Gantry** with a central opening, into which the patient is moved during the examination.
- **X-ray tube**, the source of the X-rays that pass through the body situated in the gantry in the form of a series of projections;
- **Detector** array converts the projection values, in the form of radiation intensities, into electrical quantities. Usually, the whole detector array rotates synchronously with the X-ray tube around the test object
- **Table** allows the patient to be maneuvered easily into position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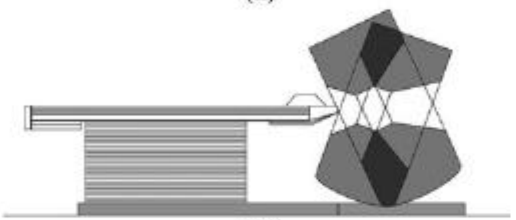
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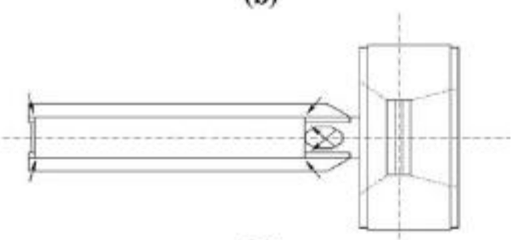
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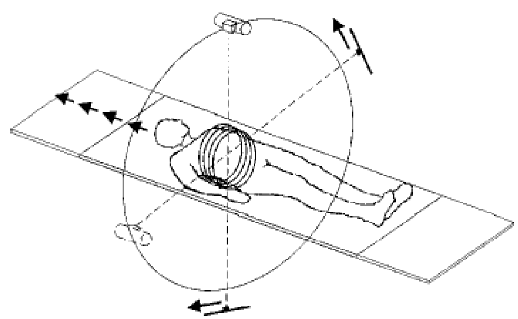
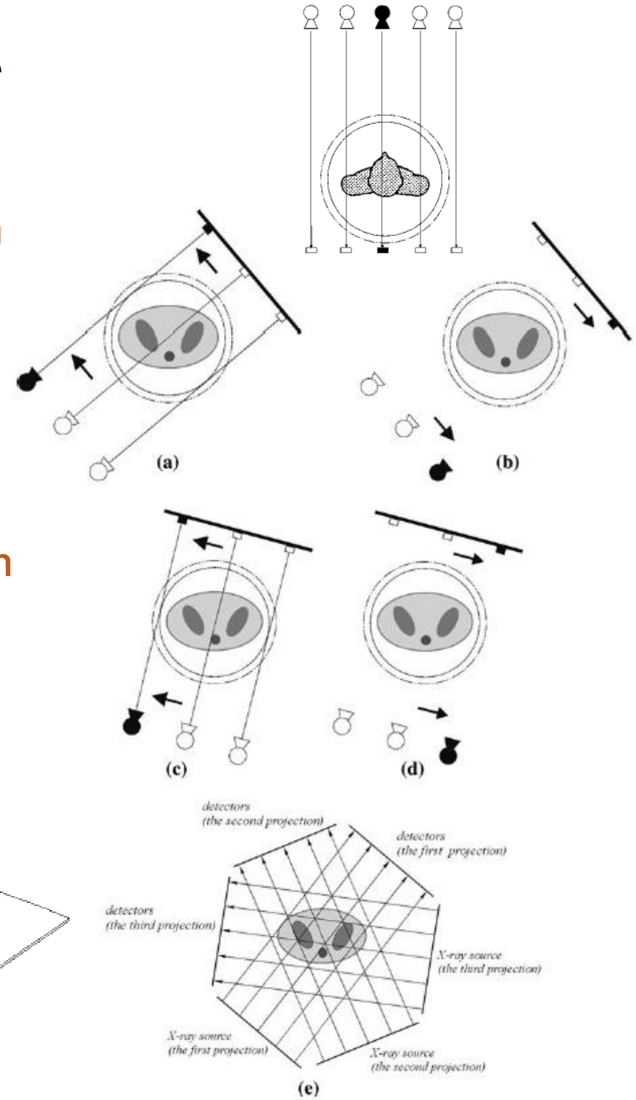
CT Scanner Design

- One of three basic tube-detector projection systems
- A projection system using a parallel beam of radiation
  - Parallel-beam system
- A system using a beam of radiation in the shape of a fan
  - Fan-beam system
- A system using a beam of radiation in the shape of a cone
  - Cone-beam system

First-Generation CT Scanners

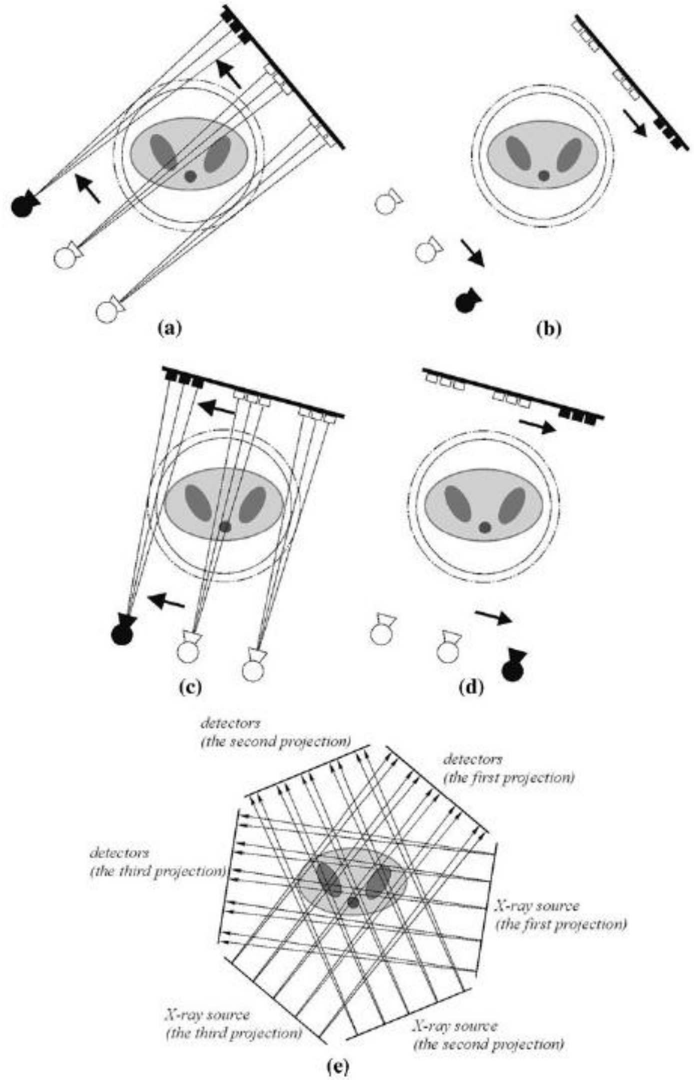
- Pencil beam or translation/rotation single detector CT scanners
  - belong to the parallel-beam projection system
- Two components to the movement of the rigidly coupled tube-detector system
  - lateral movement to make a single projection
  - circular movement about the central opening in the gantry to gather all projections necessary to form the image
- Very slow (5 min/slice)





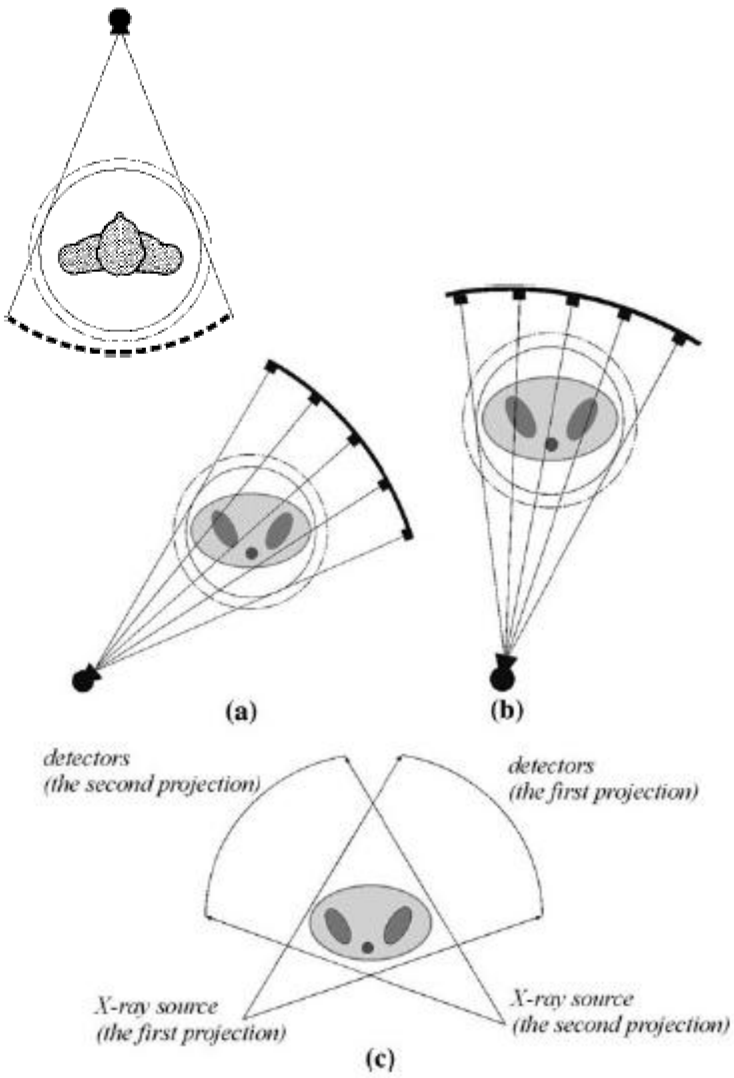
Second-Generation CT Scanners

- Partial fan beam or translation/rotation multiple detector scanners
- 3-52 detectors in the array
  - enable the projections to cover a larger area of the patient's body at any one time
  - results in reduction of number of projections needed to reconstruct an image
  - Faster!



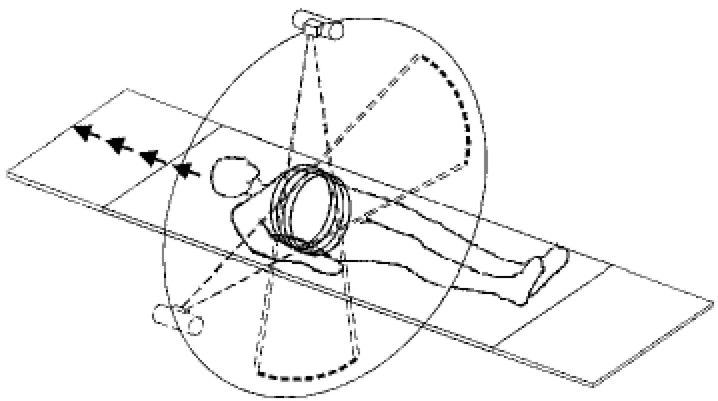
Third-Generation CT Scanners

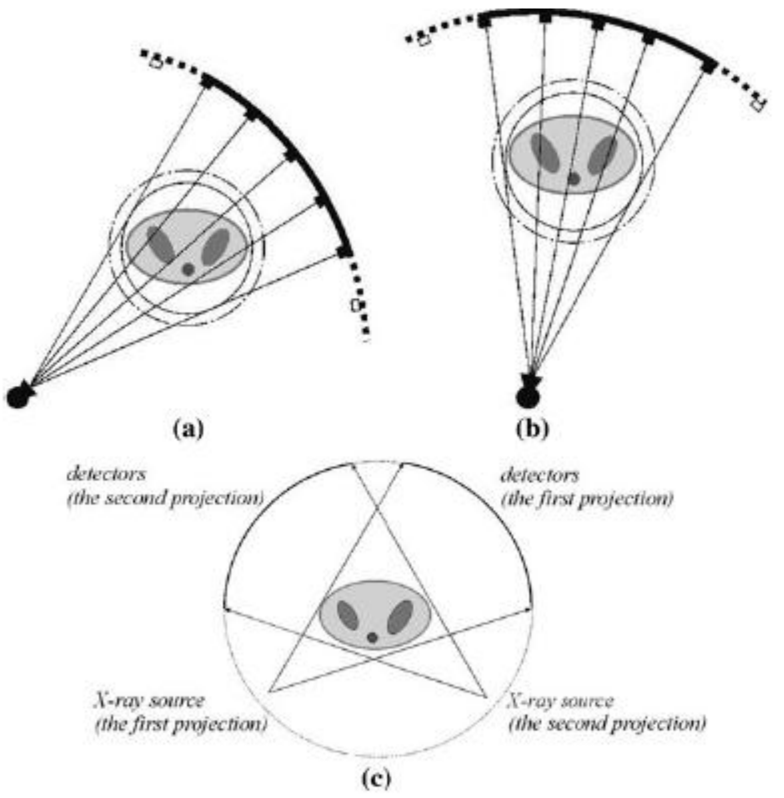
- Elimination of lateral movement of tube-detector system
- Fan-beam or continuous rotation scanner
  - Fan beam of radiation (40-55 degrees) to encompass whole object
- Increase number of detectors in the array moving synchronously with rotating X-ray tube (up to 1,000 detectors)
- Much faster: 5 s/slice



Fourth-Generation CT Scanners

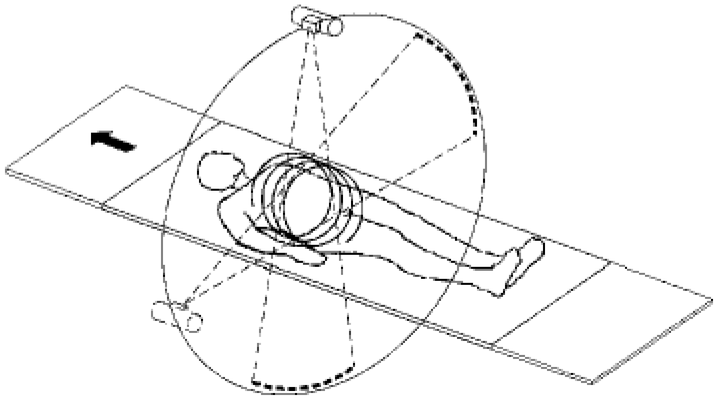
- Differ only slightly from the third generation
  - Rotation of the detector array is eliminated by arranging it on a stationary ring
  - “Rotate-fixed” scanner

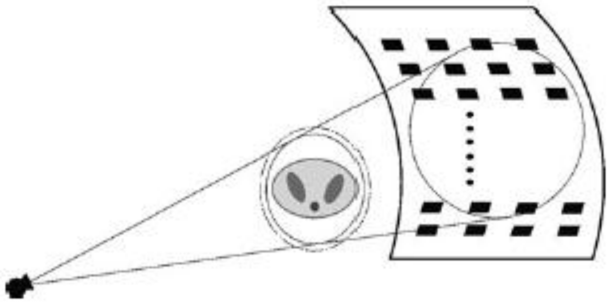




Spiral Scanners

- Fan beam scanning + table motion
- Single-slice spiral CT scanner (SSCT)
- Multi-slice spiral CT (MSCT)
  - 8-34 rows of detectors
- Cone beam spiral CT (CBCT)
  - possible to increase width of detector array to 16 or even 320 elements
  - Allowing simultaneous acquisition of up to 256 adjacent image slices
  - No collimation losses: less x-ray power
  - Faster, higher resolution scanning





Hounsfield Units

- It is common practice in medical applications to use units on the Hounsfield scale: Hounsfield units (HU) .
  - Value usually varies in the range -1,000 (air) to 3,000 (bone), making it necessary to apply a so-called window (center C and width W).

$$\text{CT number} = 1000\frac{(\mu - \mu_w)}{\mu_w}$$

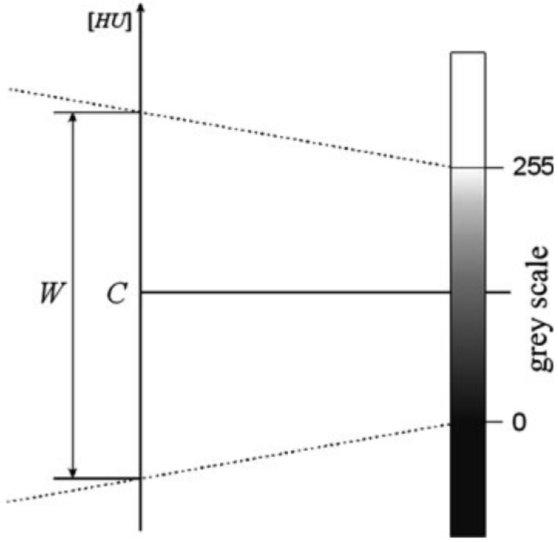
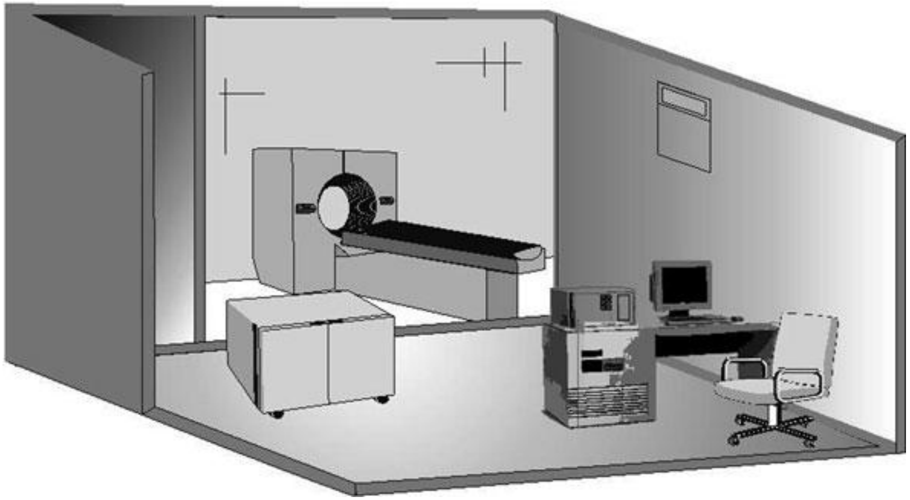


Fig. 3.41 The same slice viewed with different values of window parameters: the left image with the pulmonary window ($C = -600$, $W = 1,600$), the right image with the mediastinal window ($C = 50$, $W = 350$)

CT Installation

- CT room must meet several requirements
  - it must have floors with adequate load-carrying capacity
  - its walls must be constructed of X-ray absorbing material (this is usually a barium (Ba) plaster)
  - the floor should be lined with material that is both anti-slip and antistatic
- Separate rooms for CT scanner and radiographers;
  - Separated by special protective window-glass (containing lead, Pb)



CT Scanner Physical Elements

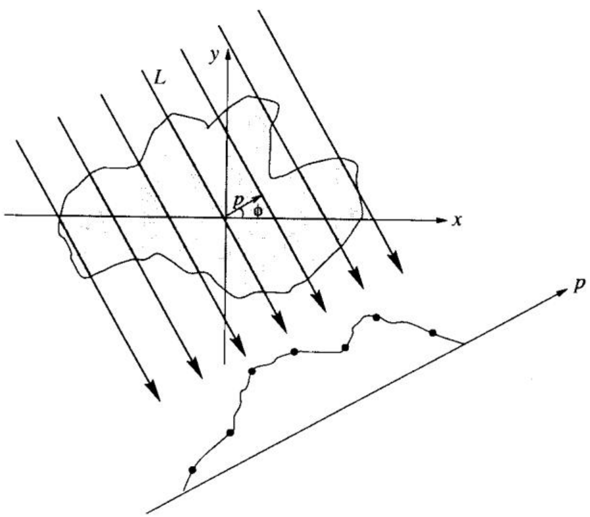
- A CT scanner consists of the following main elements
  - a data acquisition system that carries out the X-ray projections
  - a computer to reconstruct the images from the projections and to assist in the analysis of the reconstructed images
  - a variable power supply
  - a monitor to display the routine operation of the computer system and to act as an interactive interface in the diagnosis of reconstructed images
  - a documentation camera to produce an image on film similar to traditional X-ray images
  - other data archiving systems, such as tape or disk, collectively referred to as storage devices

Image Reconstruction Problem

- For an $N \times N$ image, we have N^2 unknowns to estimate
  - Sufficient equations must be available
  - In most cases the problem can be formulated as a linear system
  - Simplest case when the acquired data correspond directly to the image points (i.e., diagonal linear system matrix), e.g., ultrasound imaging.

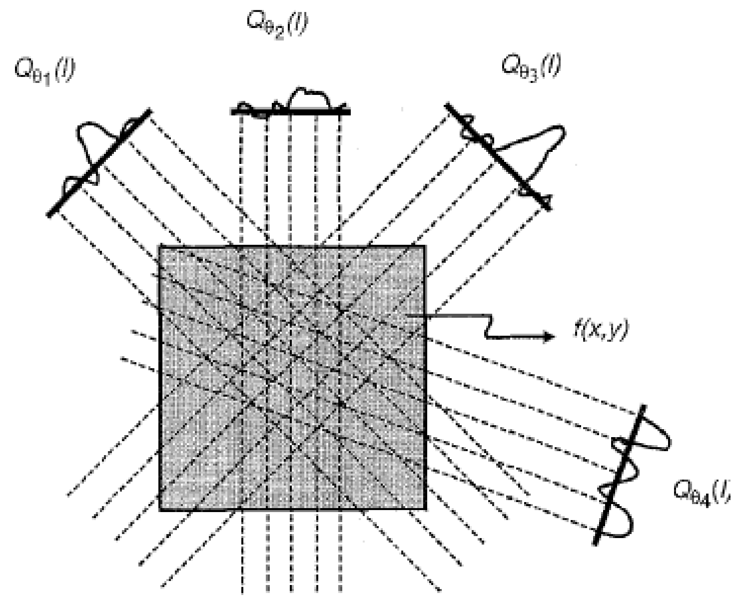
Conventional Projection Imaging

- The image points represents the line integral of the tissue property along the incident ray
  - Plain x-ray imaging
  - Difficulty to discern overlapping structures along projection ray
- Question: Can we gain more information by projecting in different directions?
  - Different directions provide different equations about the different parts of the image
  - How many directions are needed?



Computed Tomography: Reconstruction from Projections

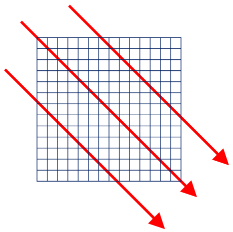
- Collects data from projections at different angles and attempts to construct a “cross-section” that resolves the location ambiguity present in projection images
- Example: X-ray computed tomography



Mathematical Formulation

- Let image points be expressed as I(x,y)
- The projection data at an angle θ can be expressed as,

$$P_\theta(\rho) = \sum_{x,y} \alpha_\rho^\theta(x,y) \cdot I(x,y)$$

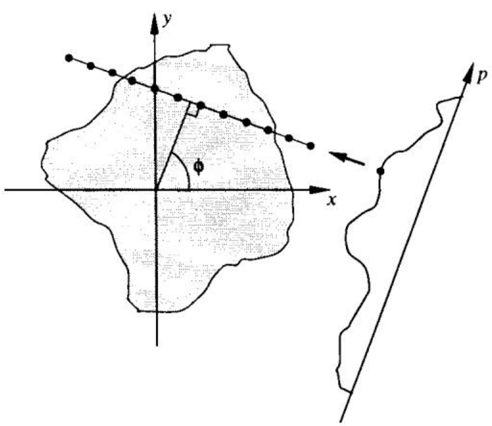


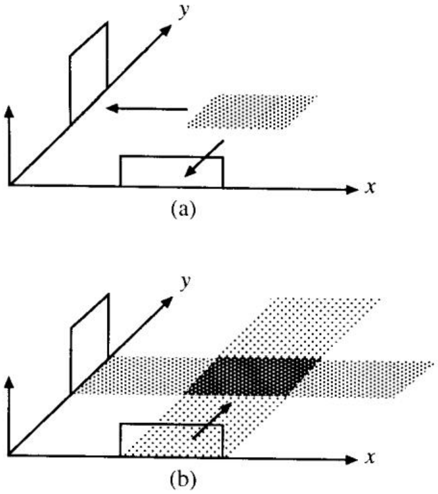
- From all projections, a linear system representation of the problem can be constructed as,

$$\begin{bmatrix} P_{\theta_1}(\rho_1) \\ P_{\theta_1}(\rho_2) \\ \vdots \\ P_{\theta_n}(\rho_m) \end{bmatrix} = \vec{P} = \begin{bmatrix} \alpha_{\theta_1}^{\rho_1}(x_1,y_1) & \alpha_{\theta_1}^{\rho_1}(x_1,y_2) & \cdots & \alpha_{\theta_1}^{\rho_1}(x_N,y_N) \\ \alpha_{\theta_1}^{\rho_2}(x_1,y_1) & \alpha_{\theta_1}^{\rho_2}(x_1,y_2) & \cdots & \alpha_{\theta_1}^{\rho_2}(x_N,y_N) \\ \vdots & \vdots & \cdots & \vdots \\ \alpha_{\theta_n}^{\rho_m}(x_1,y_1) & \alpha_{\theta_n}^{\rho_m}(x_1,y_2) & \cdots & \alpha_{\theta_n}^{\rho_m}(x_N,y_N) \end{bmatrix} \cdot \begin{bmatrix} I(x_1,y_1) \\ I(x_1,y_2) \\ \vdots \\ I(x_N,y_N) \end{bmatrix} = A \cdot \vec{I}$$

Back-Projection Method

- Start from a projection value and back-project a ray of equal pixel values that would sum to the same value
- Back-projected ray is added to the estimated image and the process is repeated for all projection points at all angles
- With sufficient projection angles, structures can be somewhat restored



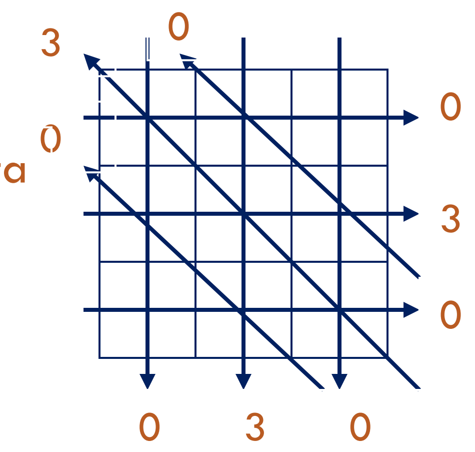


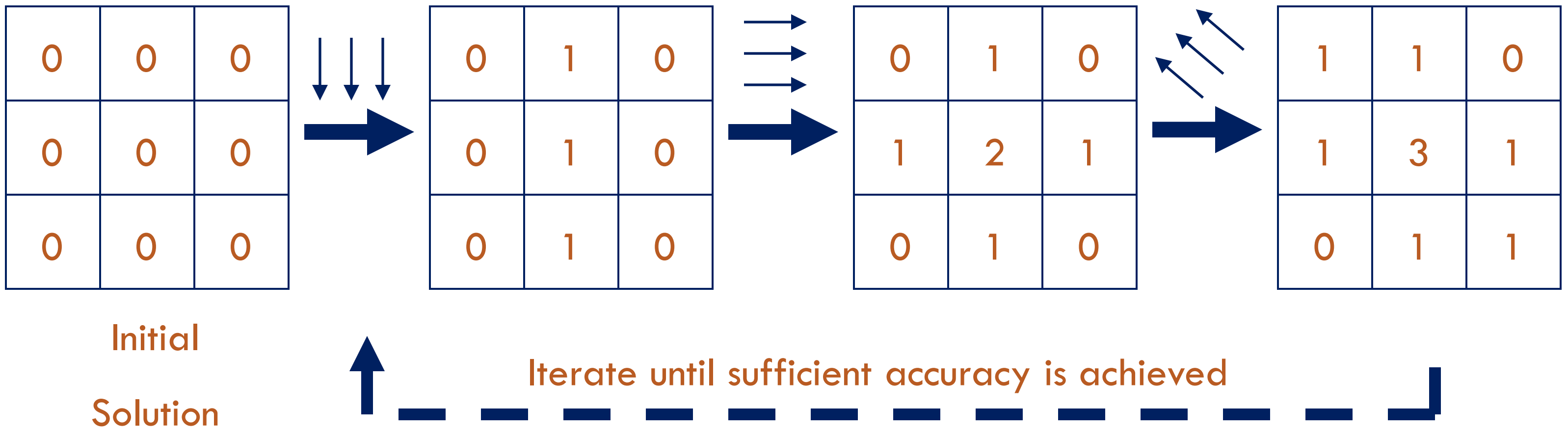
Back-Projection Example

True Image

0	0	0
0	3	0
0	0	0

Projection Data





Algebraic Reconstruction Technique (ART)

- A low-complexity iterative solver to the algebraic reconstruction problem
- Starts with an initial estimate and tries to push the estimate closer to the true solution
  - Instead of back-projecting the average ray value, the error between the projection computed from current estimate and the true is used

$$Update = P_\theta(\rho) - \sum_{x,y} \alpha_\rho^\theta(x,y) \cdot \hat{I}(x,y)$$

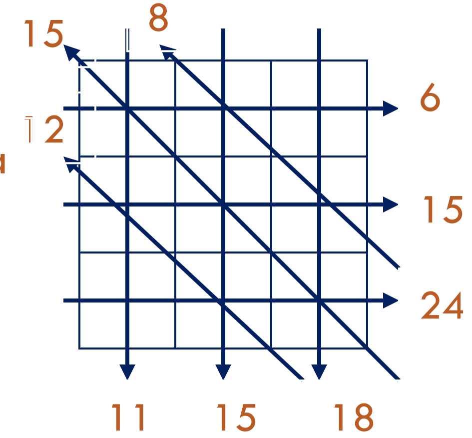
ART Example

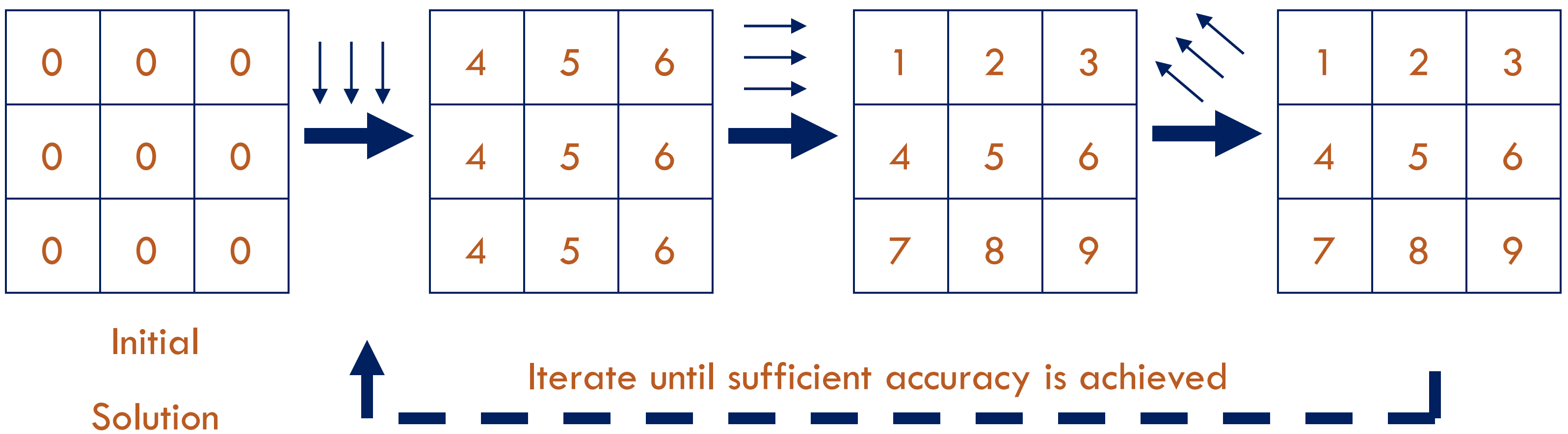
True

Image

1	2	3
4	5	6
7	8	9

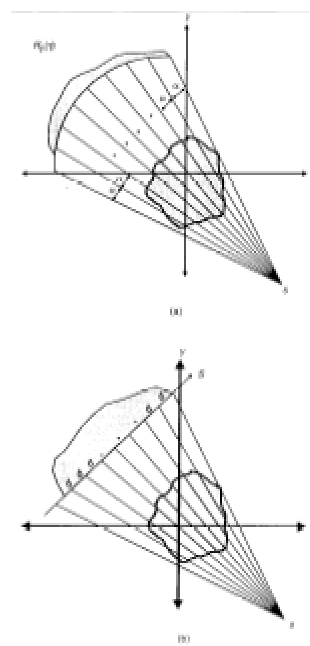
Projection Data

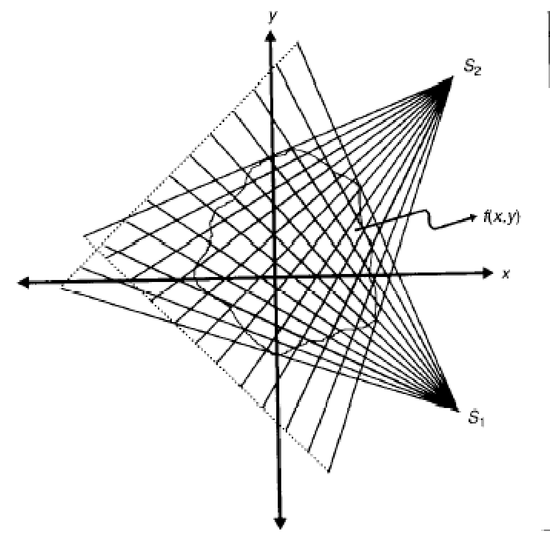




Problem Extensions: Fan Beam Problem

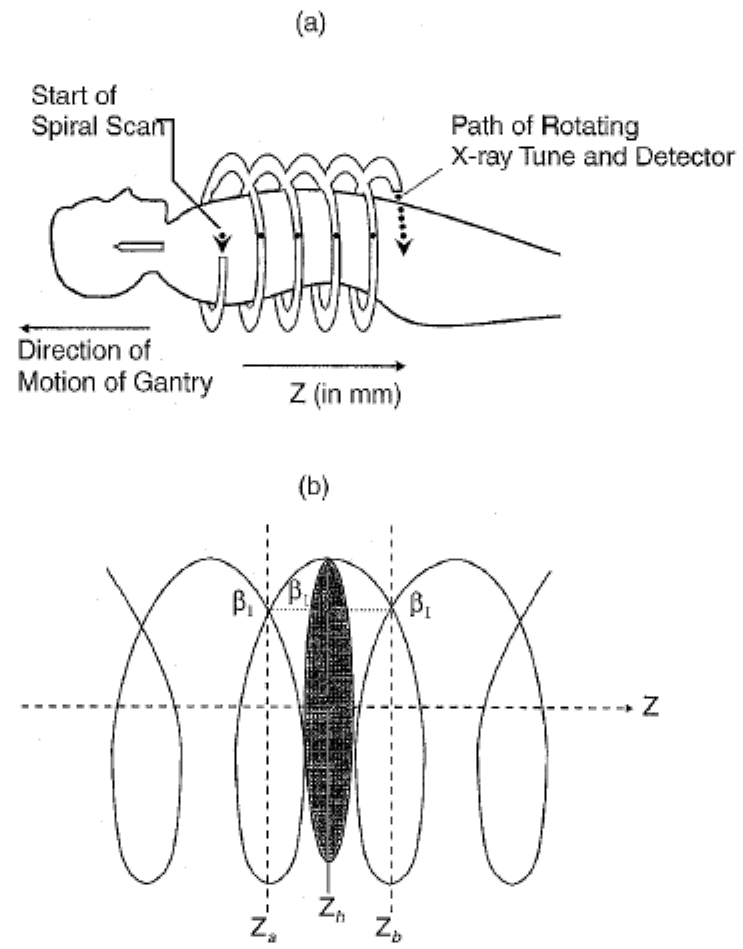
- In newer CT generations, fan beams are used to gain more efficiency in hardware implementation
- Detectors may be aligned on a line or a circular arc
- A modification of the algebraic reconstruction method is used to compute the image





Problem Extensions: Spiral CT

- A much more efficient way of acquiring a volume in CT
- Instead of acquiring a slice then shifting the table, the table moves continuously during the acquisition
- To compute a slice, interpolated projections are obtained from the 3D spiral then reconstructed as a regular 2D slice



Covered Material

- Parts of chapter 3 of Cierniak textbook
- Parts of chapter 15 of Hendee and Ritenour textbook