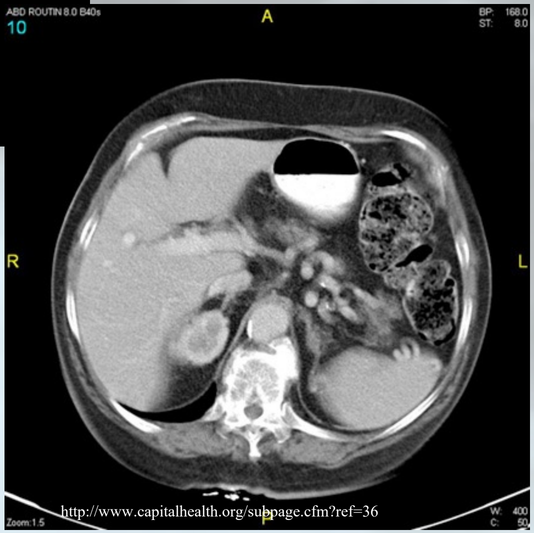
Computed Tomography



Computed Tomography

- *Introduction*

- *Computed Tomography*, CT for short (also referred to as CAT, for Computed Axial Tomography), utilizes X-ray technology and sophisticated computer software to create images of cross-sectional "slices" through the body.

- CT exams and CAT scanning provide a quick overview of pathologies/anatomy and enable rapid analysis and treatment plans.

- Tomography is a term that refers to the ability to view an anatomic section or slice through the body.

- Anatomic cross sections are most commonly referred to as transverse axial tomography.

- The CT scanner was developed by Godfrey Hounsfield in the late 1960s.

- This x-ray-based system created projection information of x-ray beams passed through the object from many points across the object and from many angles (projections).

- CT produces cross-sectional images and also has the ability to differentiate tissue densities, which creates an improvement in contrast resolution.

Computed Tomography

- Introduction

- The x-ray tube in a CT scanner is designed to produce a fan shaped beam of x-rays that is approximately as wide as your body.
- The x-ray tube on a CT scanner is more heavy duty than tubes used for standard film imaging since the unit rotates and they operate at slightly higher energies.
- Opposite the patient is an array of detectors that measure the intensity of the x-ray beam at points laterally across the patient's body.
- Modern CT scanners use solid state detectors that have very high efficiencies.
- Solid state detectors are made of a variety of materials that create a semiconductor junction similar to a transistor.
- Ultrafast ceramic detectors use rare earth elements such as silicon, germanium, cadmium, yttrium or gadolinium, which create a semiconducting p-n junction.
- Ceramic solid-detectors are very fast, can be extremely stable, and are produced to form an array of very small, efficient detectors that can cover a large area.

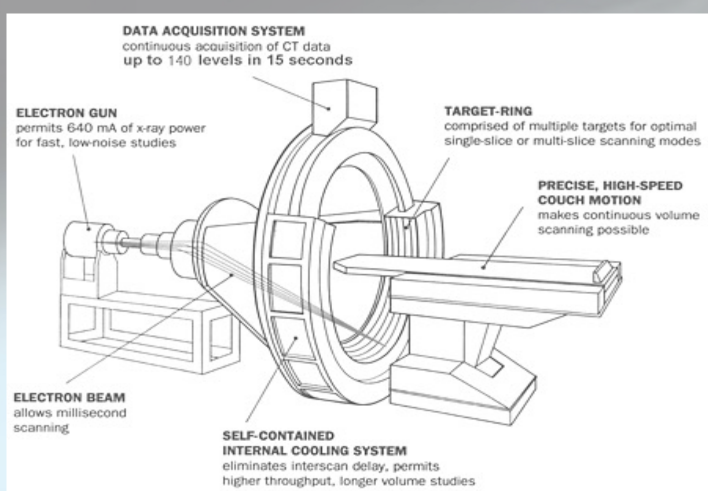
Computed Tomography

- The basics

- The x-rays are produced in a part of the ring and the ring is able to rotate around the patient.

- The target ring contains an array of detectors and is internally cooled to reduce electronic noise in the detectors and to cool the anode.

- The patient is put into the system using a precise high speed couch.

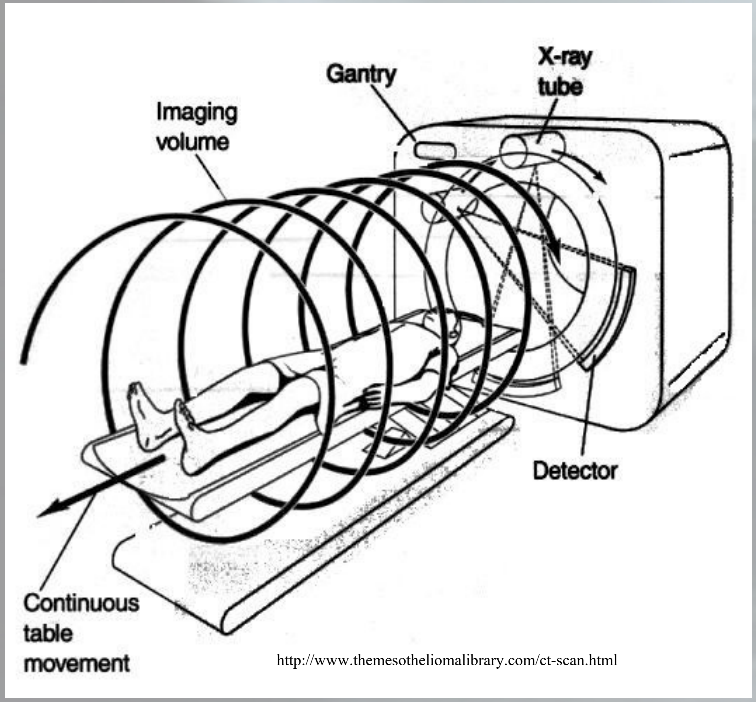


http://www.themesotheliomalibrary.com/ct-scan.html

http://www.endocrinesurgery.ucla.edu/images/adm_tst_ct_scan.jpg

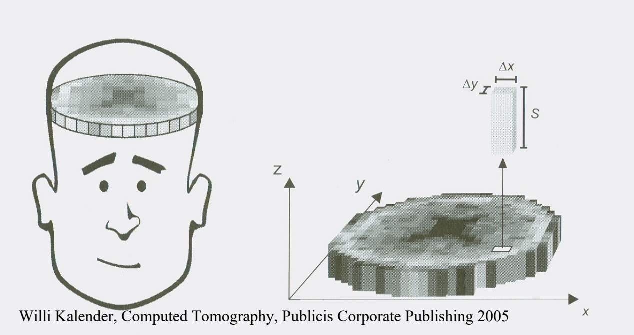
Computed Tomography

- The basics of image formation



- The x-ray tube and detectors rotate around the patient and the couch moves into the machine.
- This produces a helical sweep pattern around the patient.
- The patient opening is about 70cm in diameter.
- The data acquired by the detectors with each slice is electronically stored and are mathematically manipulated to compute a cross sectional slice of the body.

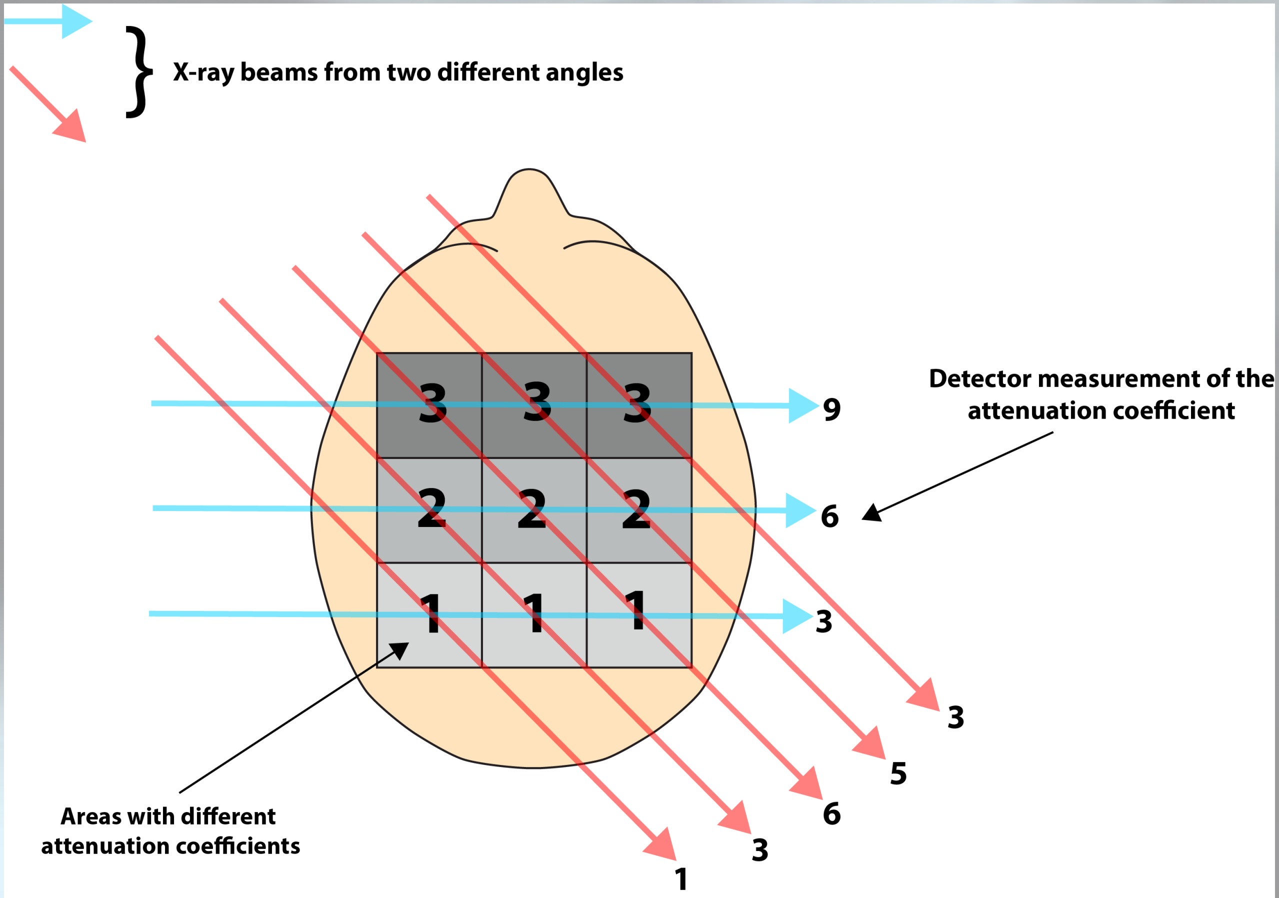
- Three-dimensional information can be obtained by comparing slices taken at different points along the body.
- Or the computer can create a 3D image by stacking together slices.
- As the detector rotates around many cross-sectional images are taken and after one complete orbit the couch moves forward incrementally.



Willi Kalender, Computed Tomography, Publicis Corporate Publishing 2005

Computed Tomography

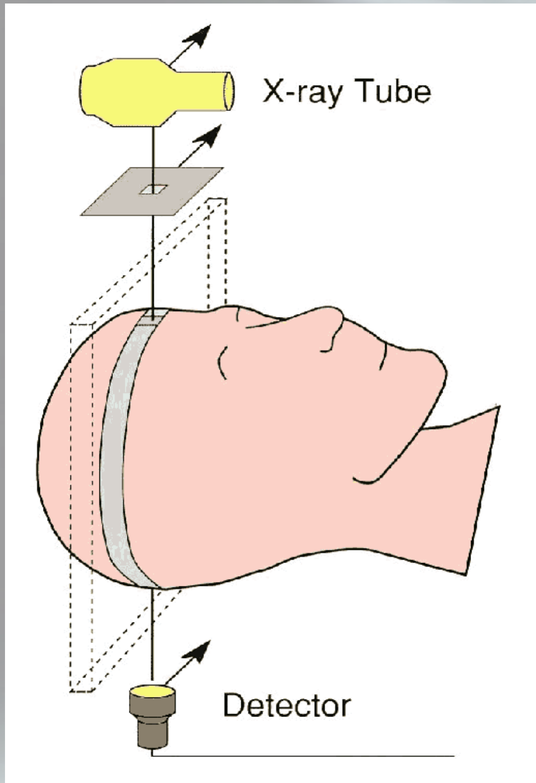
- The basics of image formation

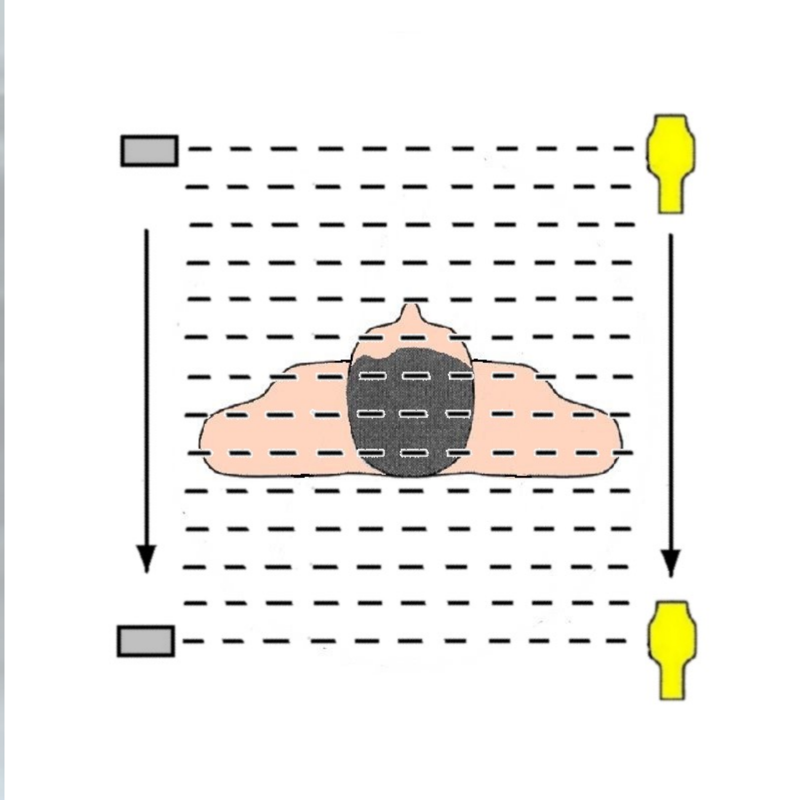


https://maxfacts.uk/diagnosis/tests/ct-scans

Computed Tomography

- The basics of image formation





- Here the x-ray tube and detector array makes many sweeps past the patient.
- The x-ray tube and detector array is capable of rotating around the axis of the patient.
- Each scan tries to determine the composition of each transverse cross section.

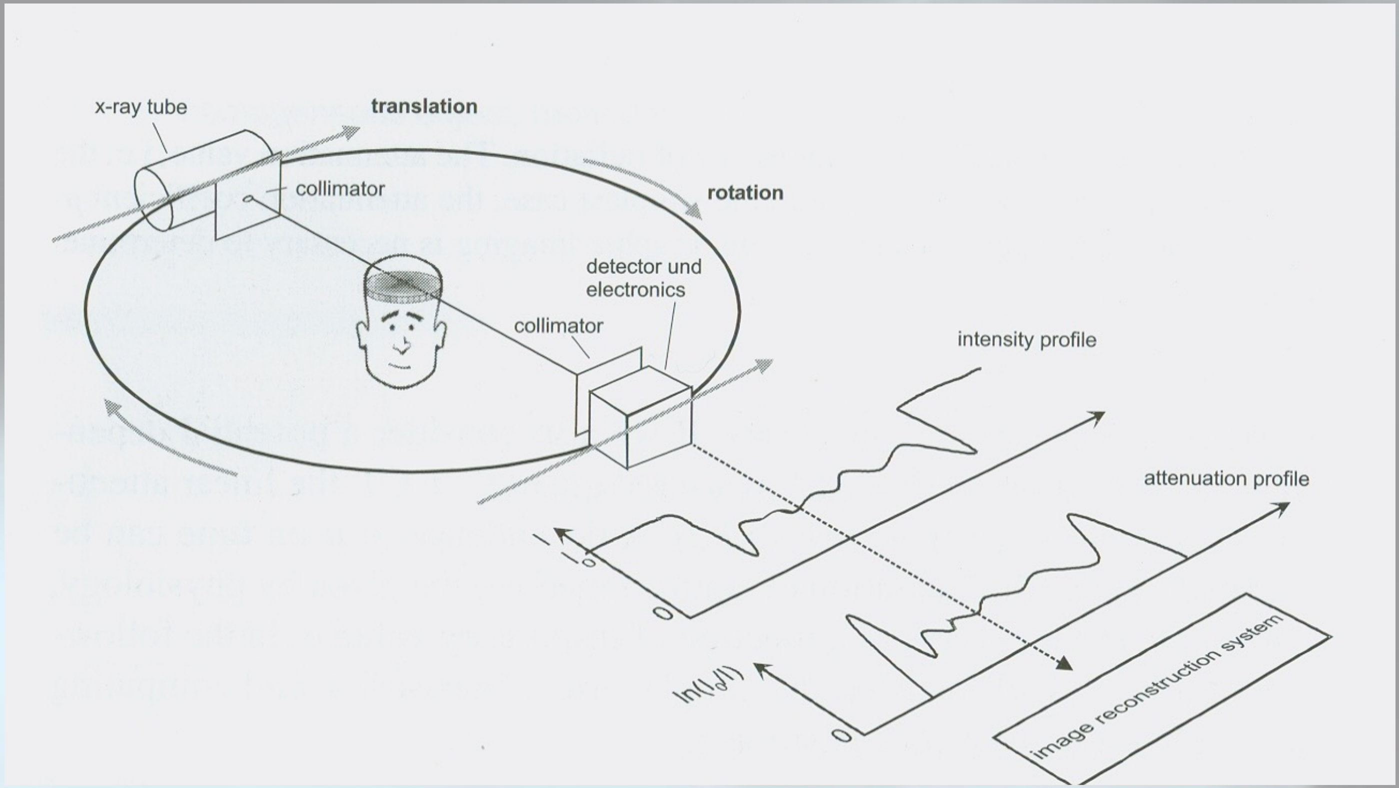
Computed Tomography

- The basics of image formation

- As the x-ray tube and detectors swing around an intensity profile mapping is created.

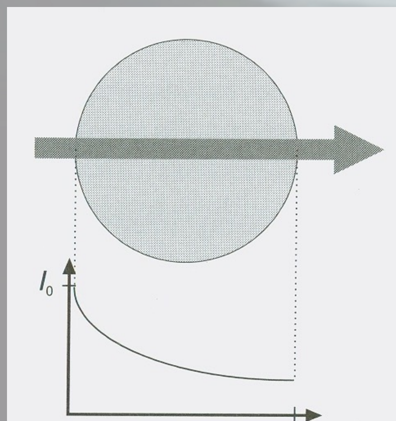
- This could also be written as an attenuation profile which is the incident intensity minus the transmitted intensity.

- This generates a set of *N*x*N* equations that will be solved simultaneously for μ (x,y) in the image reconstruction system.

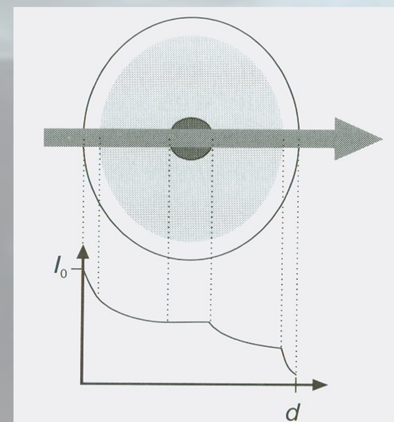


Computed Tomography

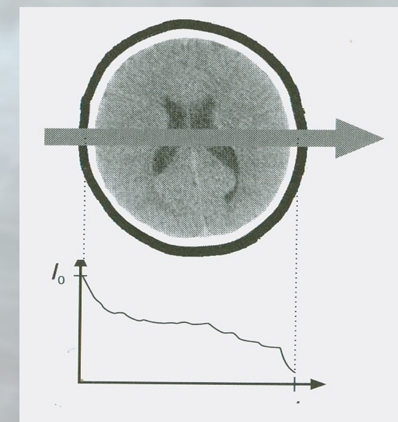
- The basics of image formation



Homogeneous object, monochromatic radiation



Inhomogeneous object, monochromatic radiation



Inhomogeneous object, polychromatic radiation

$$I = I_o e^{-\mu x} \rightarrow \mu_x = \frac{1}{x}\ln\left(\frac{I}{I_o}\right)$$

$$I = I_o e^{-\mu_1 x_1 - \mu_2 x_2 - \mu_3 x_3 - \dots} = I_o e^{-\int_0^d \mu \, ds} \rightarrow \mu_i = ?$$

$$\mu(x,y) = ?$$

In a CT scan we measure the intensity of radiation. The attenuation coefficient, μ, is easily determined if you have a homogeneous object. The incident intensity needs to be known and for inhomogeneous objects we need many scans to determine μ (x,y).

Computed Tomography

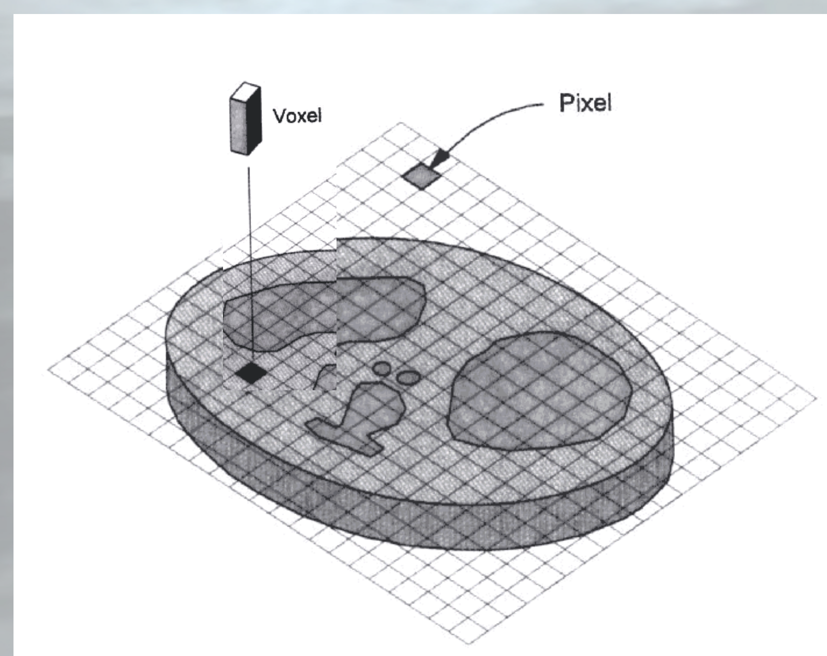
- The basics of image formation

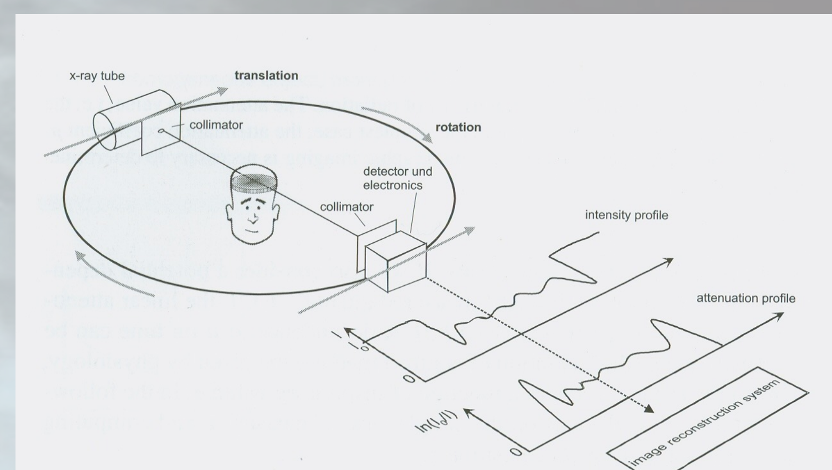
- *Pixel* – picture element – a 2D square shade of gray.

- *Voxel* – volume element – a 3D volume of gray.

- This is a result of a computer averaging of the attenuation coefficients across a small volume of material. This gives depth information.

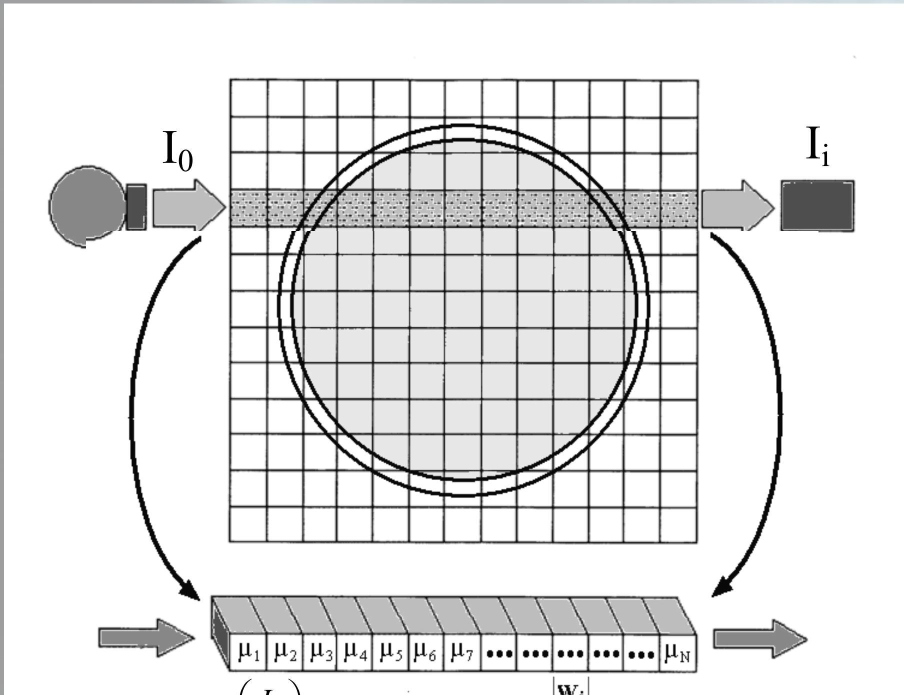
- Each voxel is about 1mm on a side and is as thick as 2 – 10mm depending on the depth of the scanning x-ray beam.





Computed Tomography

- The basics of image formation



$$\ln\left(\frac{I_0}{I_i}\right) = \mu_1 w_1 + \mu_2 w_2 + \mu_3 w_3 + \ldots + \mu_n w_n$$

The detectors see the forward projected x-rays and measure the intensity, given that the x-ray intensity without the body present is known.

The intensity I_i written as sum of attenuation coefficients along a given x-ray path.

This generates a shade of gray and a number associated with this shade.

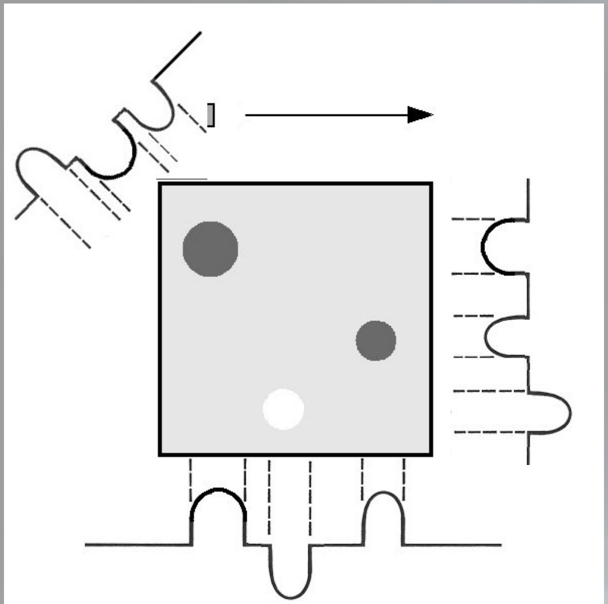
Then the detector changes angles and the process repeats.

The images are reconstructed by a method called *back projection*, or tracing backwards along the x-rays forward path to reconstruct the image and calculating the absorption due to a localized region.

This a mathematically tedious process but is handled easily with computers.

Computed Tomography

- The basics of image formation



- The top scan we see that there are lighter and darker regions somewhere in it, but we don't know whether the light/dark regions are high, low, or in the middle. In other words, we know where the light region is horizontally but not vertically.

- So, by stretching it out we're kind of saying, "We don't know where the light spot is vertically, so for now give it *all* vertical values!"

- Now do a vertical scan and now we've taken the light/dark spots whose location we know vertically and "smeared" it out across all horizontal positions.

- You can see where the light areas cross and it gets even more light there and we can start to form an image.

- By "adding" more shadows, medium light lines would eventually disappear, and we'd have a more complete and higher resolution image.

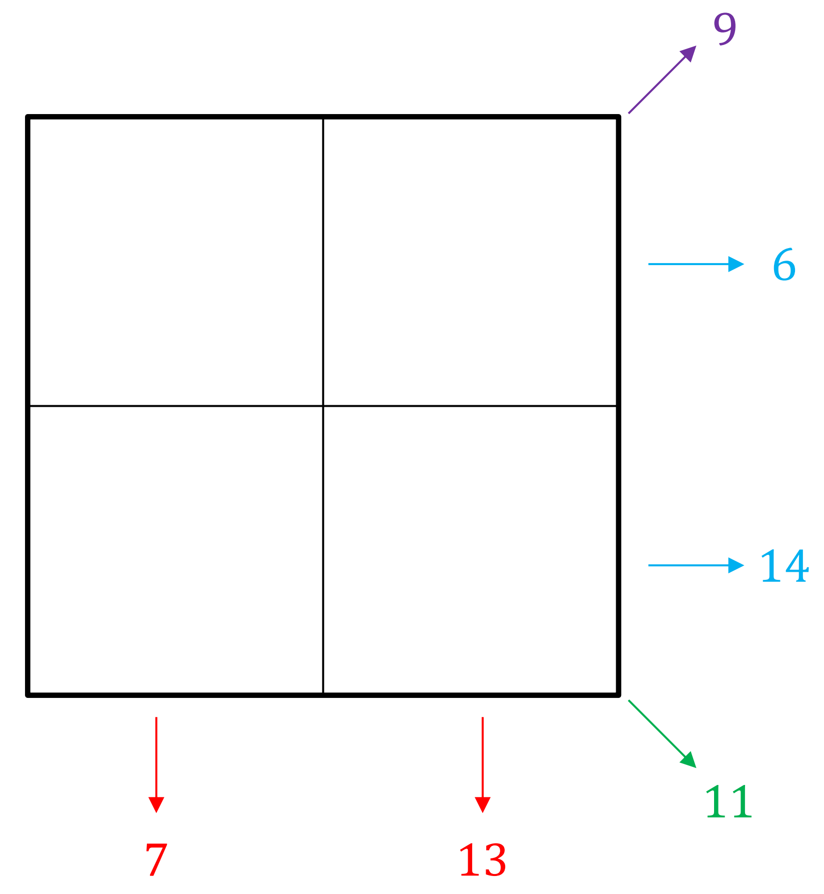
Computed Tomography

- The basics of image formation

What are the four x-ray "attenuation" coefficients?

In other words, what numbers do we put in each of the 4 boxes, which represent my 4-pixel image?

The projections are shown for four different scan angles.



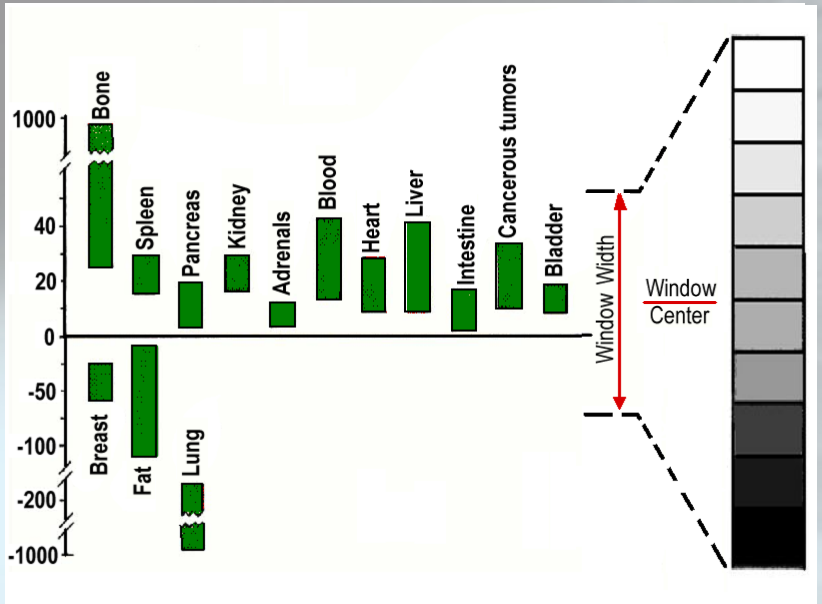
Computed Tomography

- Hounsfield Units or CT numbers

- CT numbers (or *Hounsfield units*) represent the percent difference between the x-ray attenuation coefficient for a voxel and that of water multiplied by a constant.

- Water has a CT number of zero and the numbers can be positive or negative depending on the absorption coefficient.

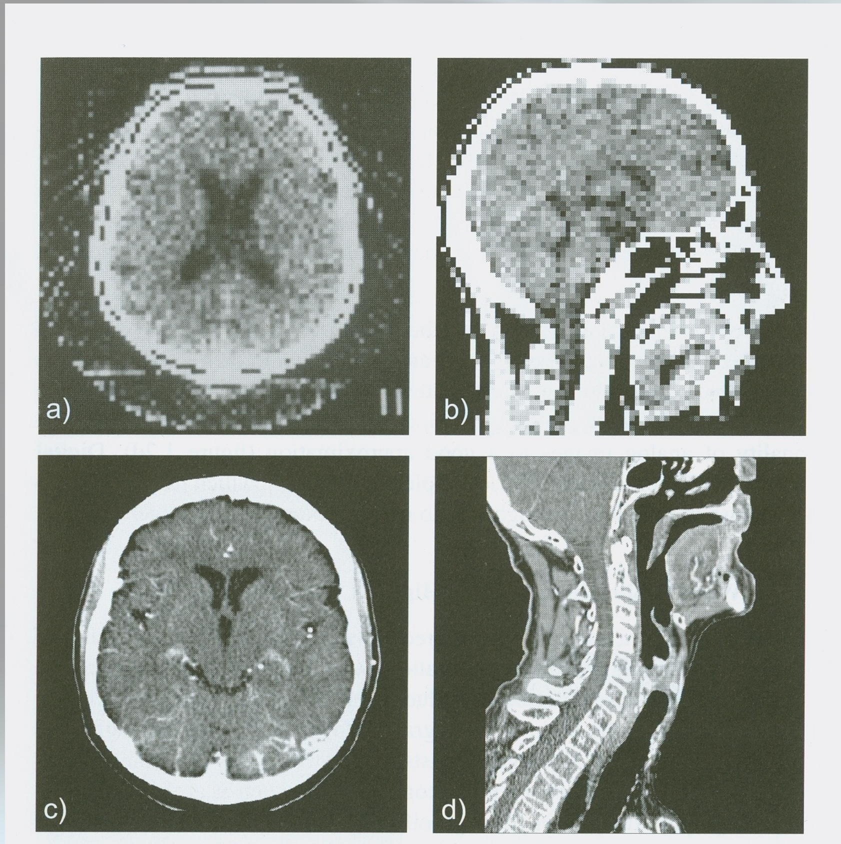
- This is how we assign a shade of gray, and 1000 is just a scaling factor set by the CT manufacturer.



$$CT\# = \left(\frac{\mu_{structure} - \mu_{water}}{\mu_{water}} \right) \times 1000$$

Computed Tomography

- *Image Quality*



Number of Pixels

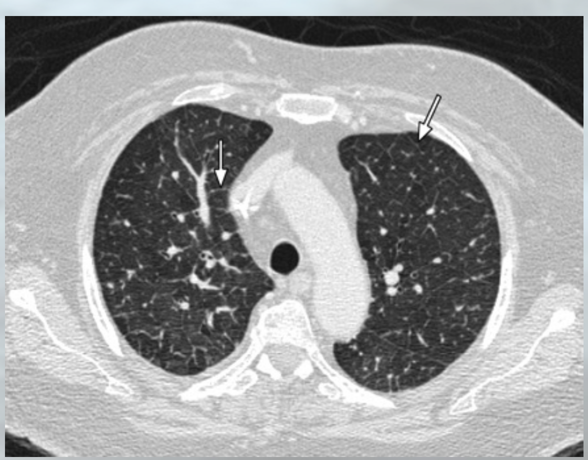
- In images *a* and *b* we have an 80 x 80 images matrix and you can easily see the discrete pixels.

- In images *c* and *d* we have a 1024 x 1024 image matrix. Here the individual pixels are not seen and the image quality increases.

Computed Tomography

- Image Quality

•*Contrast Resolution* – The ability to differentiate between different tissue densities in the image



• *High Contrast* - Ability to see small objects and details that have high density difference compared with background.

- These have very high-density differences from one another.

- Ability to see a small, dense lesion in lung tissue and to see objects where bone and soft tissue are adjacent

• *Low Contrast* - Ability to visualize objects that have very little difference in density from one another.

- Better when there is very low noise and for visualizing soft-tissue lesions within the liver.

- Low contrast scans can differentiate gray matter from white matter in the brain.

Computed Tomography

- Imaging artifacts

- Artifacts can degrade image quality and affect the perceptibility of detail.
- Includes
  - Streaks – due to patient motion, metal, noise, mechanical failure.
  - Rings and bands – due to bad detector channels.
  - Shading - can occur due to incomplete projections.

Streaks

Rings and bands

Shading

Computed Tomography

- Advantages & Disadvantages

Advantages:

- Desired image detail is obtained
- Fast image rendering
- Filters may sharpen or smooth reconstructed images
- Raw data may be reconstructed post-acquisition with a variety of filters

Disadvantages

- Multiple reconstructions may be required if significant detail is required from areas of the study that contain bone and soft tissue
- Need for quality detectors and computer software
- X-ray exposure