上海科技大学
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Lecture 8: 2D X-ray Imaging

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Lecture 8: 2D X-ray Imaging

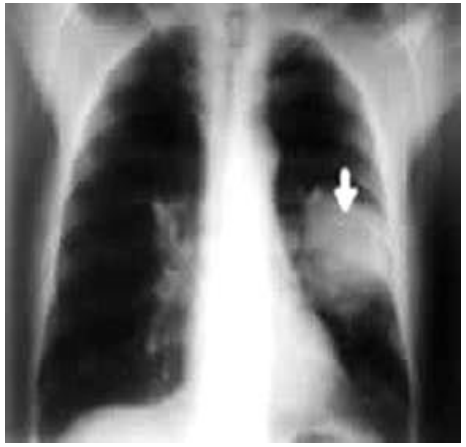
- Introduction to X-ray based Imaging
  - History
  - Radiography
  - Chest X-ray
  - Mammography
  - Fluoroscopy
  - CT

- Contrast Agents
  - Barium based
  - Iodine based

- Signal and Noise in 2D X-ray Imaging
  - Signal
  - Noise

- Spatial Resolution of Digital Radiography
  - Slit based method
  - Edge based method

History of x-ray based imaging



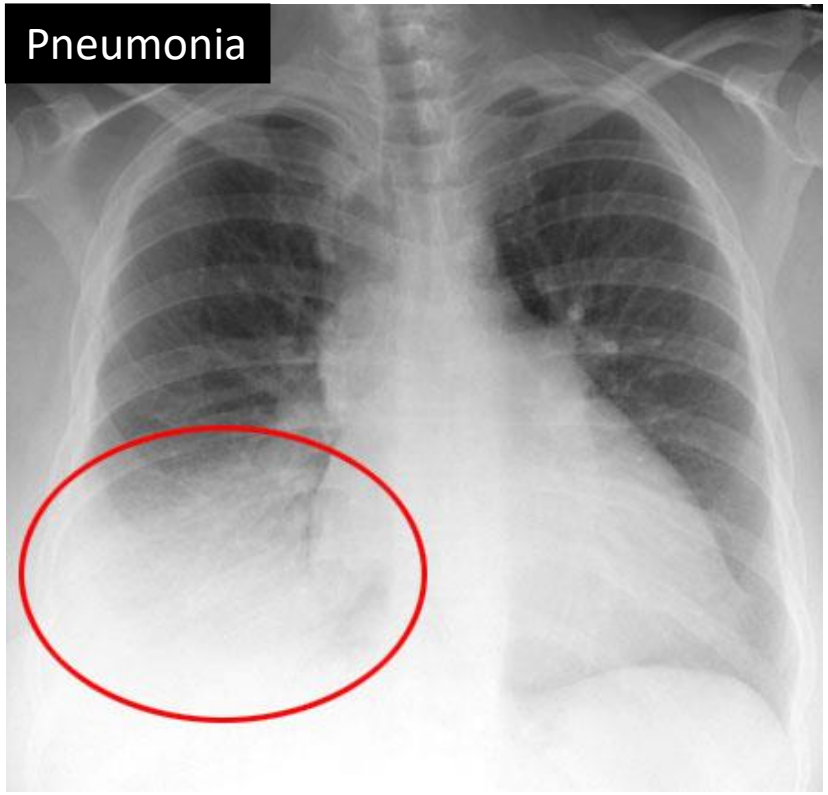
1895 1950 2000

General radiography

radiography of child with constipation

http://www.wakehealth.edu/Urology/Pediatric/Bedwetting-Can-be-Due-to-Hidden-Constipation-Research-Shows.htm

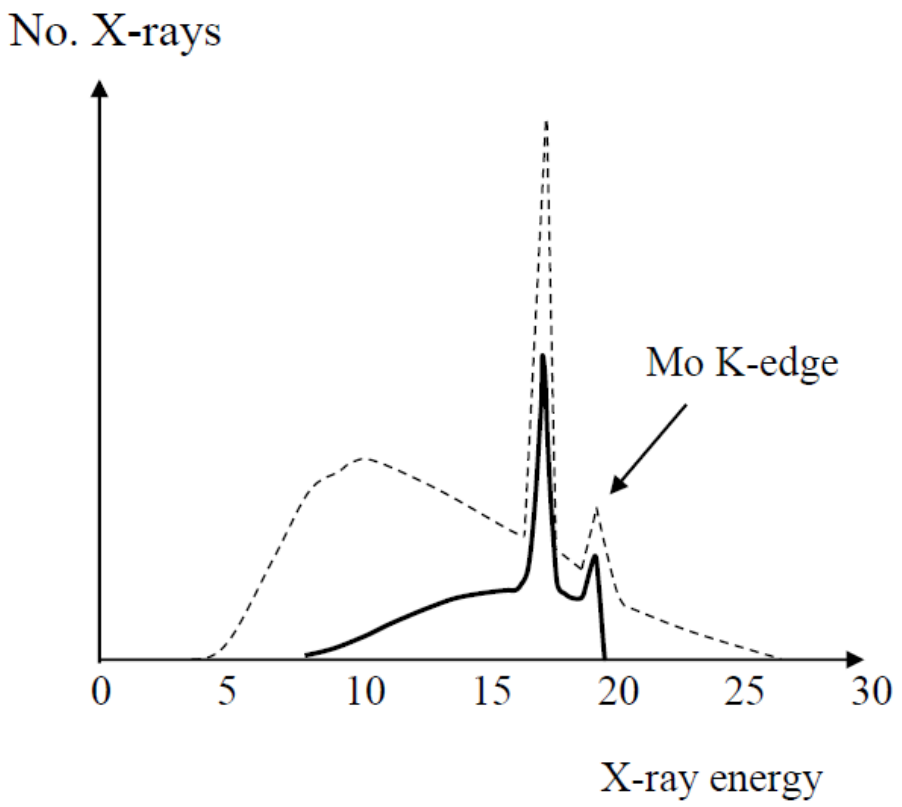
Chest x-ray



Mammography

Breast cancer

X-ray tube for mammography

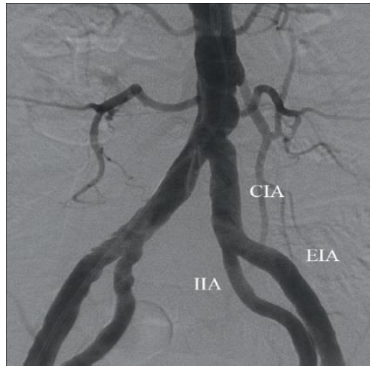


	K-edge	K_α	K_β
Mo	20	17.5	19.6
W	69.5	59.3	67.2

Unit in keV. http://www.csrri.iit.edu/periodic-table.html

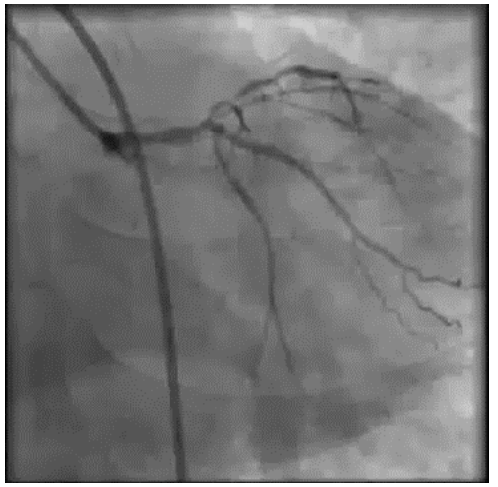
- Mo (K-edge target instead of W target for lower energy x-rays for breast tissues.
- Be window instead of glass window to “preserve” lower energy x-rays.
- Mo (30um) filter to reduce higher energy x-rays (Mo K-edge = 20 kev)

Fluoroscopy & Digital Subtraction Angiography (DSA)



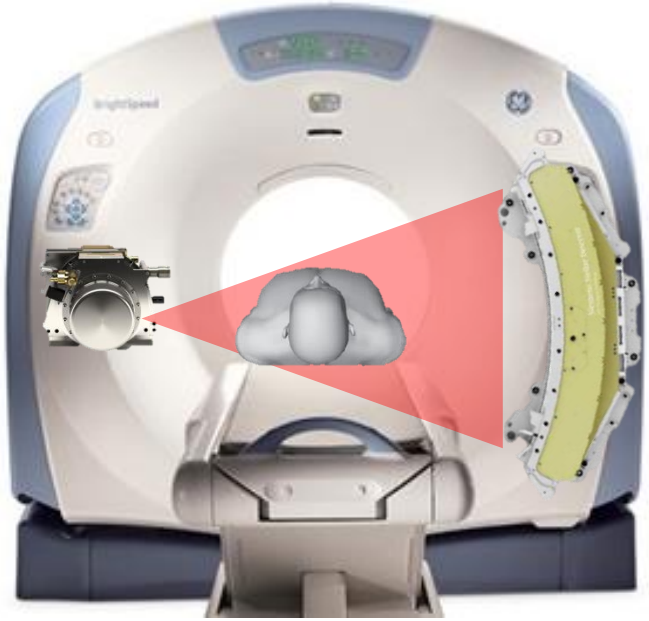
DSA

Fluoroscopy during cardiac **catheterization**



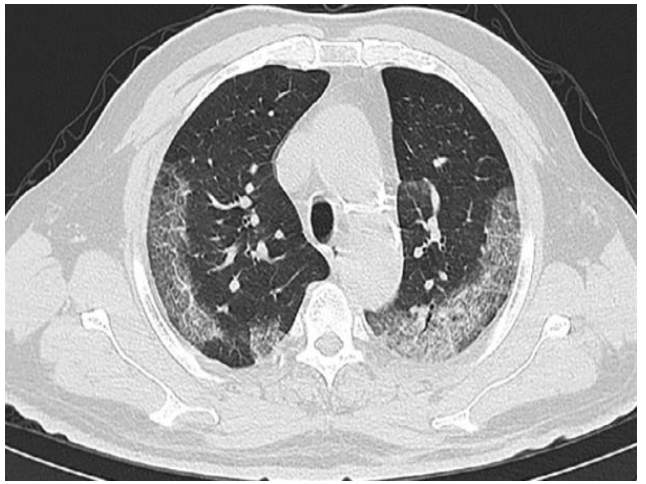
CT (Computed Tomography)

GE Revolution



Healthy

COVID Pneumonia



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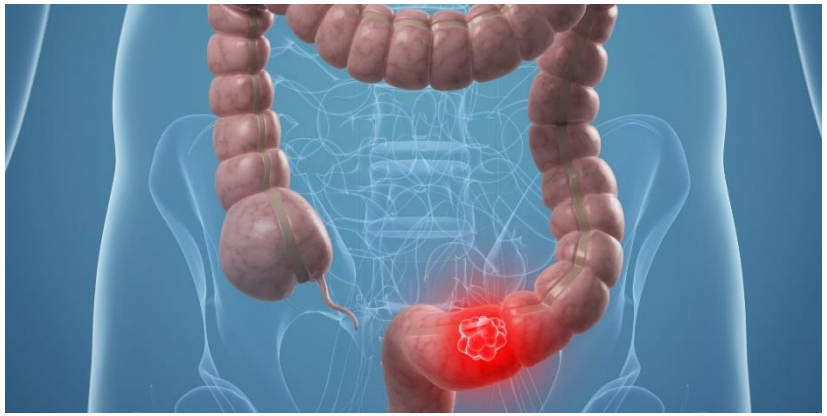
Barium Contrast Agents

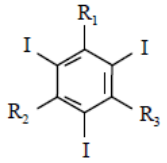
- For GI tract: Barium Sulphate
  - Barium K-edge@ 37.4 keV



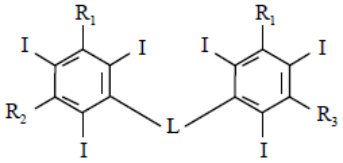
Iodine-based contrast agent

- For blood stream: iodine-based contrast agent
  - Iodine K-edge@33.2 keV

(a)

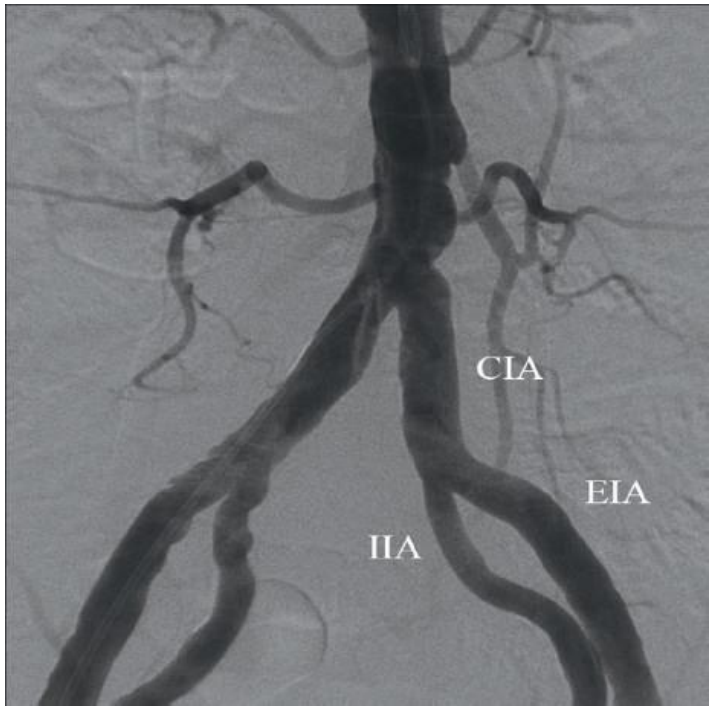


(b)



R1=R2=R3= $CONHCH_2CH(OH)CH_2OH$

L=$N(COCH_3)CH_2CH(OH)CH_2N(COCH_3)$



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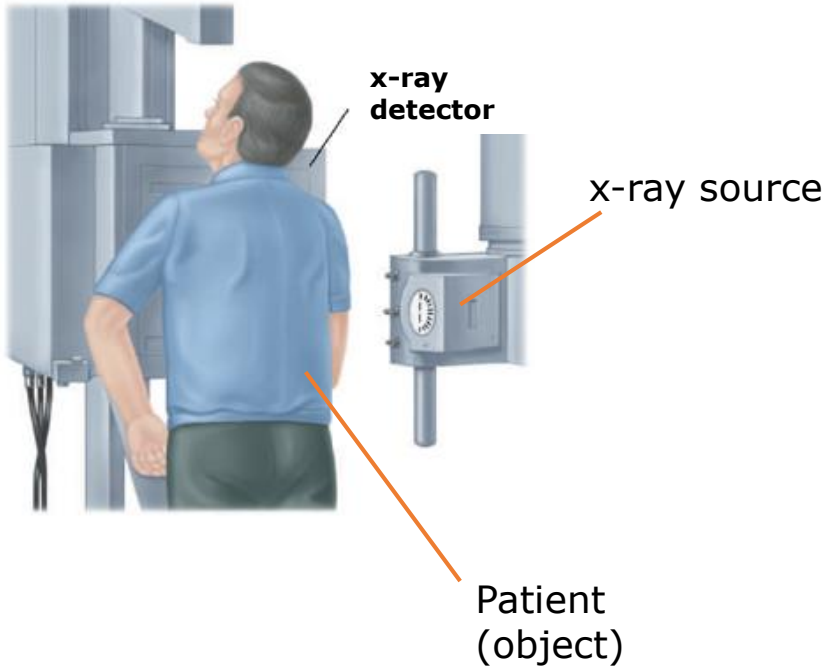
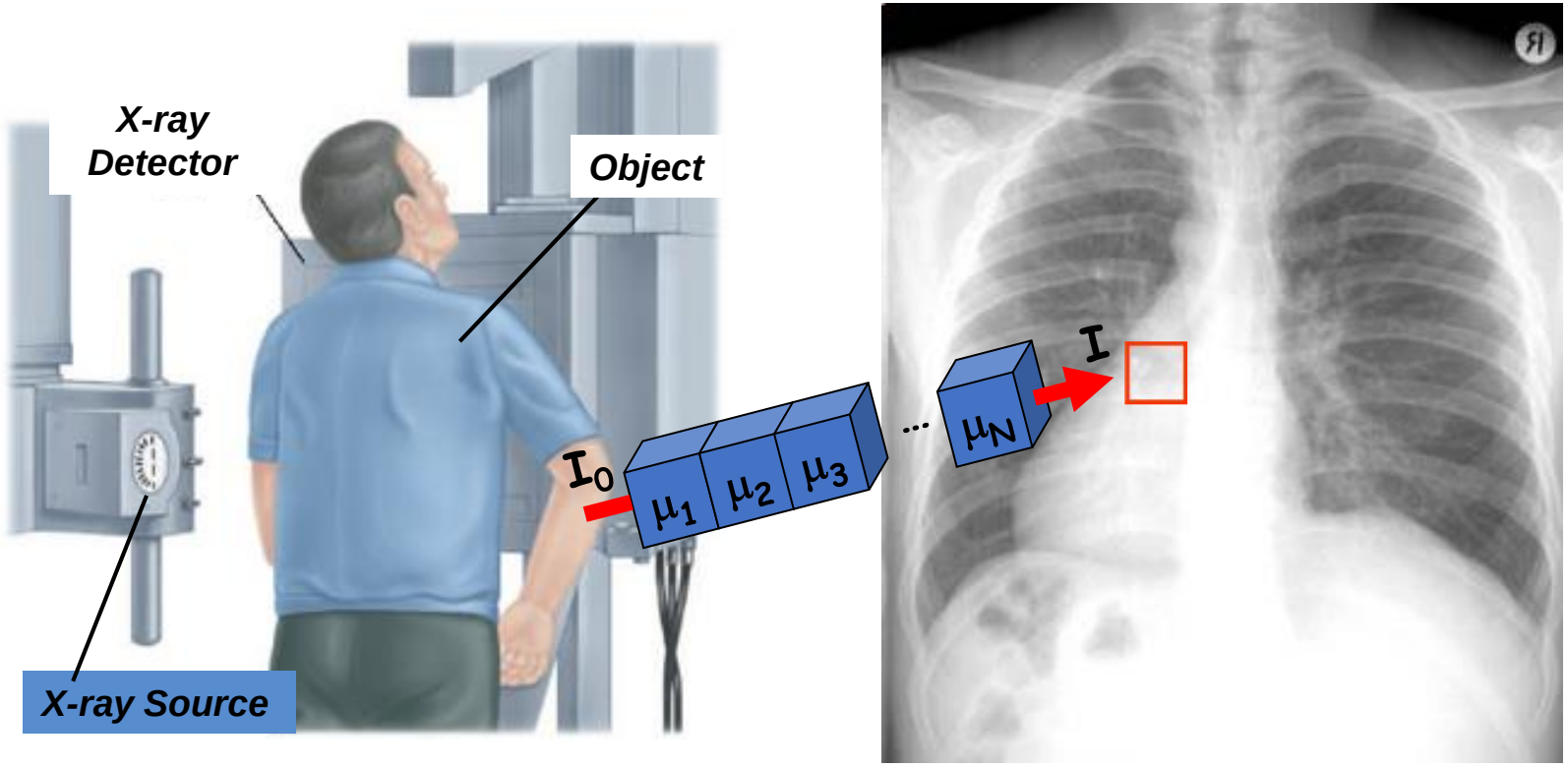
2D X-ray imaging system

Requires:

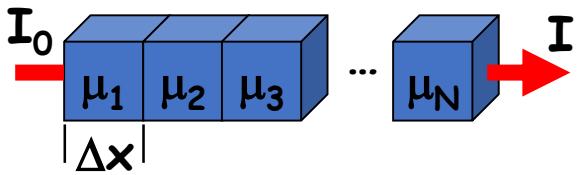
1. X-ray source
2. object
3. X-ray detector



Signal in x-ray images



What signals do we measure?



$$I = I_0 e^{-\sum \mu_i \Delta x} \rightarrow S = \log I_0/I = \Delta x \sum \mu_i$$

I & I_0 are the raw data measured by the detector.

S is the signal pre-processed from the raw data.

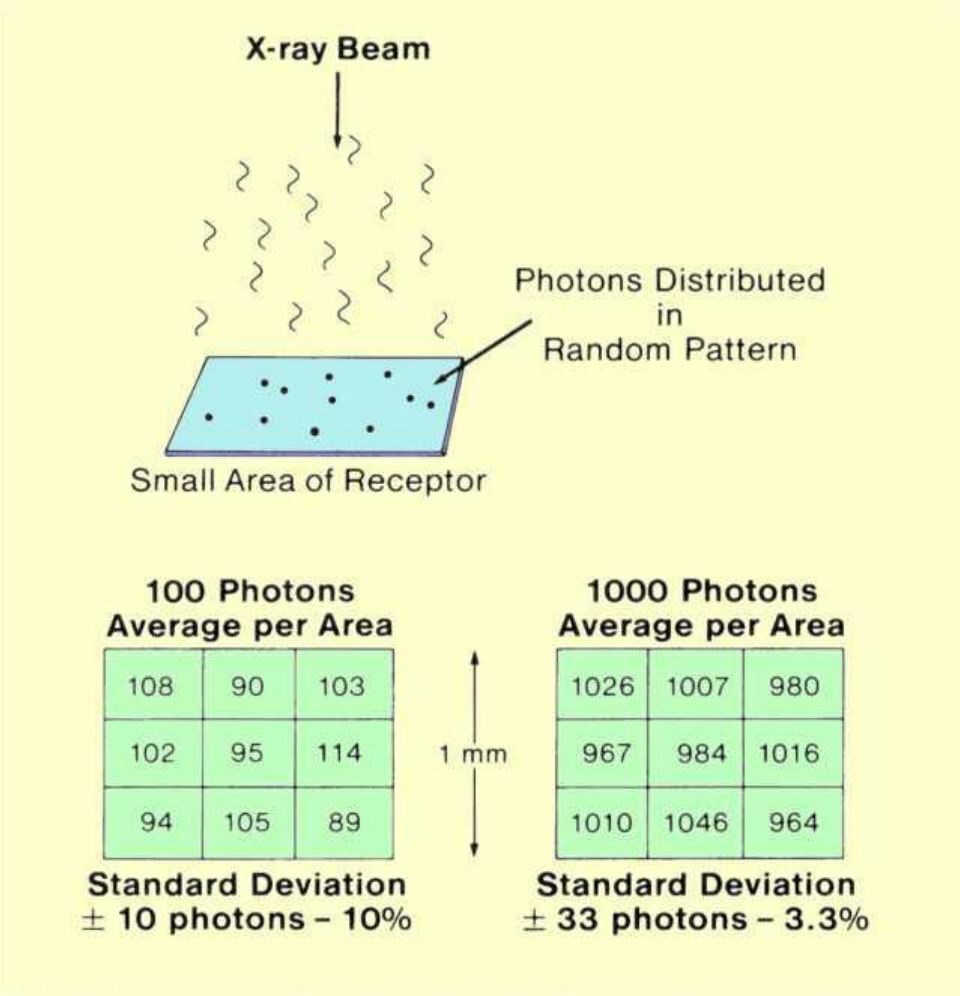
S=**Total** attenuation in the x-ray path length
→ Cannot differentiate attenuation capabilities of different layers along the path!

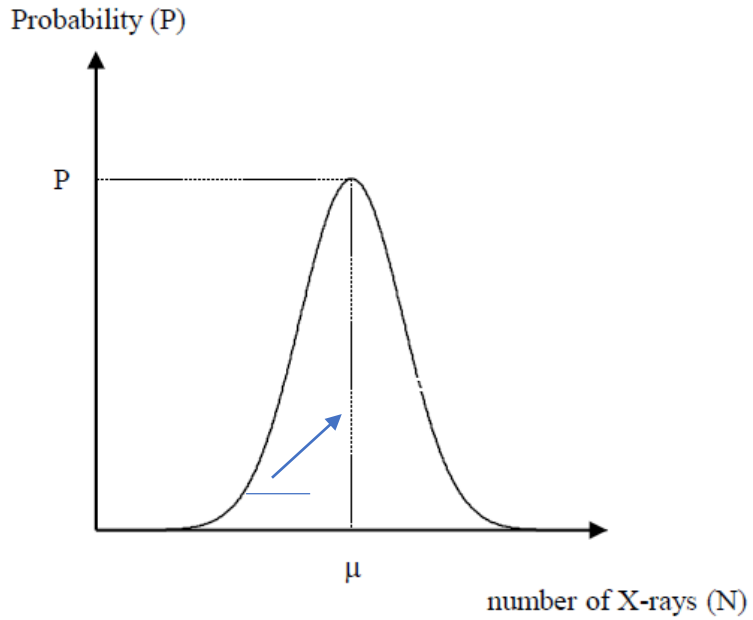
Photon Noise

- Also called quantum noise
- Originates from the discrete (i.e. particle) nature of x-ray photons.
  - If electrons caused it, it is called shot noise
  - If lights caused it, it is called photon noise

  } Same physical nature
- Follows Poison distribution

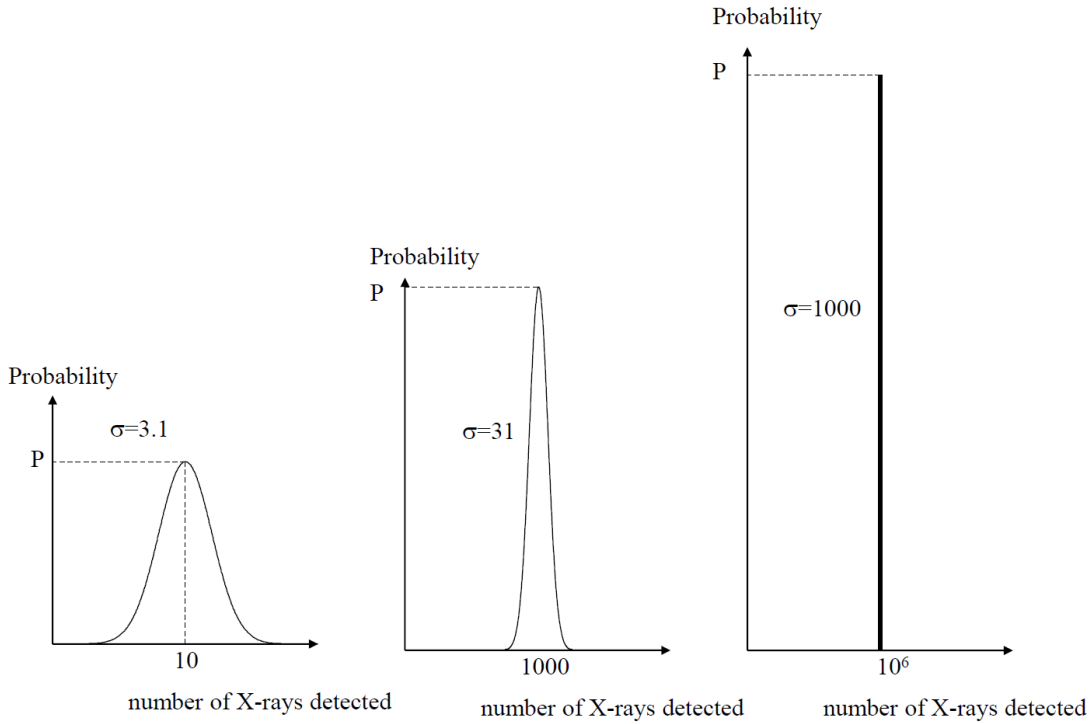
Photon (Quantum) Noise





Photons follow Poisson Distribution

Poisson distribution: the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time and/or space since the last event.



$$P(N) = \frac{\mu^N}{N!} e^{-\mu}$$

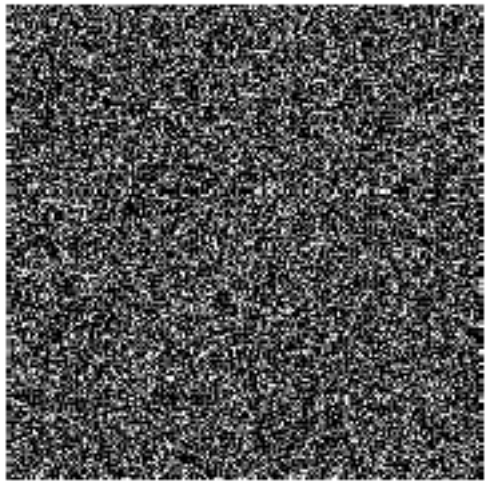
SNR = μ/σ
μ = mean $\sim$ N
σ = standard deviation
$\sim \sqrt{N}$
Therefore,

SNR $\sim$ N/$\sqrt{N}$ = $\sqrt{N}$

To increase SNR by a factor 2, we need to increase N (dose) by a factor of 4!

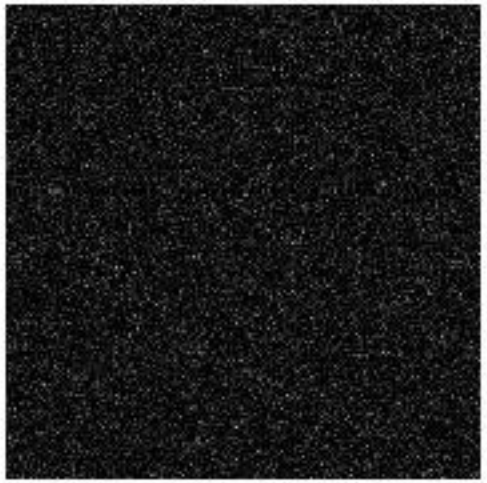
100X times more x-rays

10^4 X-rays



More noisy.

10^6 X-rays



10X higher SNR; less noisy

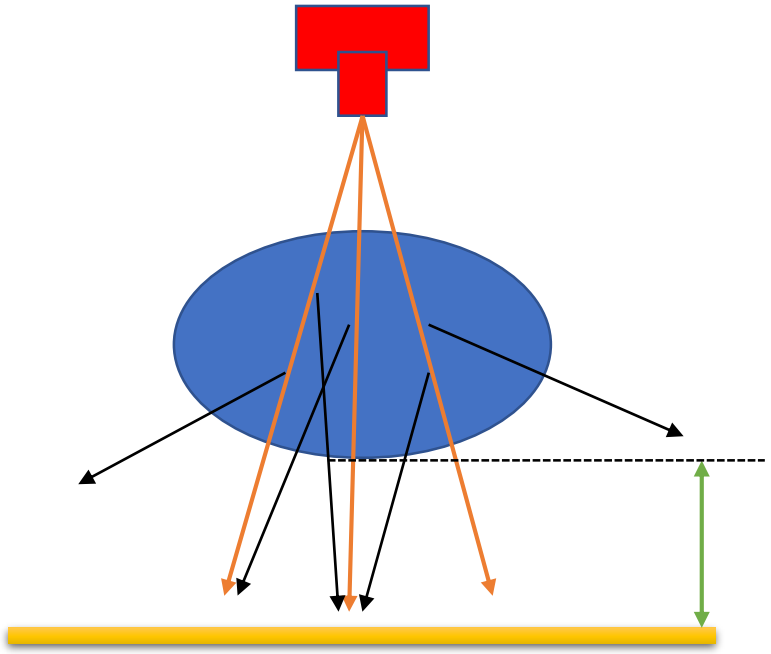
Total noise in x-ray imaging

1. Electronic noise is also called detector (electronic) noise in x-ray imaging.

2. Photon noise is the dominant noise in diagnostic x-ray imaging.

3. Total noise in x-ray imaging ≈ photon noise + detector electronic noise.

Primary and Scattered Radiations



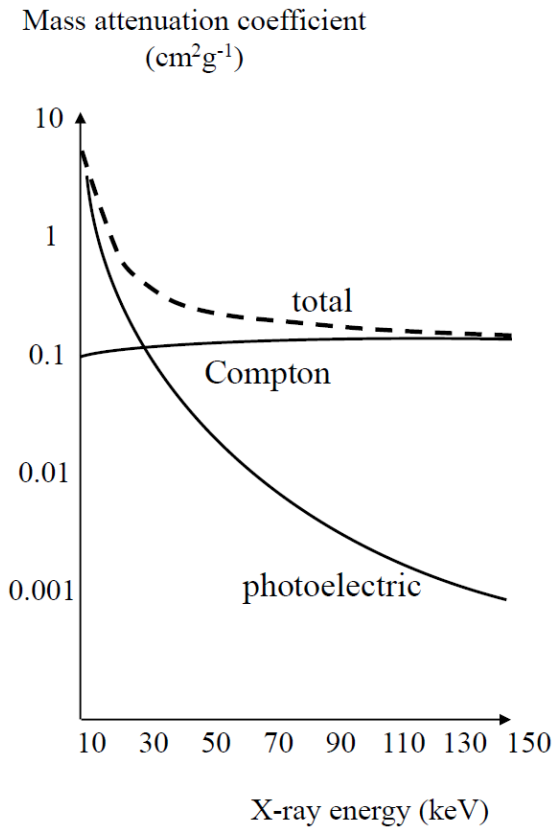
Primary radiations

Scattered Radiations
- Compton scattering

➔The distance between the patient and the detector is called "air gap".
If the air gap is increased, will the scattering radiation increases or decreases?

Factors affecting SNR/CNR

1. X-ray energy spectrum
2. Size of the detector field-of-view (FOV)
3. Size of the object being imaged
4. Geometry of the anti-scatter grid



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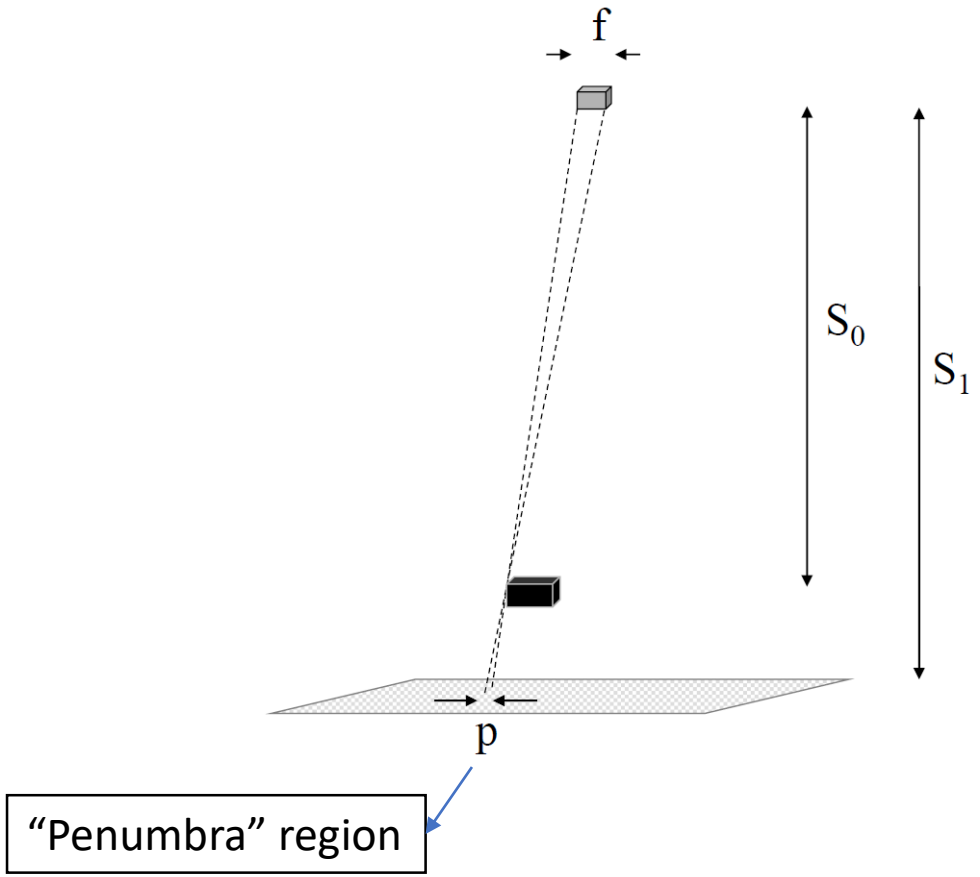
Factors affecting spatial resolution in 2D X-ray imaging

1. X-ray source focal spot size
2. Detector pixel size
3. Geometrical magnification factor
4. Motion & temporal resolution

object

image

“Penumbra” from finite spot size of x-ray source



Geometrical magnification factor, M

$$M = \frac{S_1}{S_0}$$

Penumbra size, P

$$P = \frac{f(S_1 - S_0)}{S_0} = (M - 1)f$$

Penumbra blur at object

$$blur_p = \frac{M - 1}{M} f$$

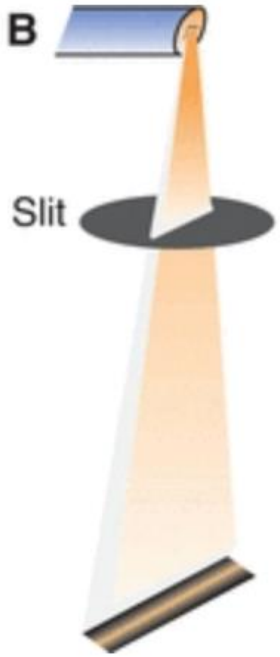
MTF of digital radiography: Slit based method

34 IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 11, NO. 1, MARCH 1992

A Simple Method for Determining the Modulation Transfer Function in Digital Radiography

Hiroshi Fujita, Du-Yih Tsai, Takumi Itoh, Kunio Doi, Junji Morishita, Katsuhiko Ueda, and Akiyoshi Ohtsuka

Finely sampled LSF of the tilted slit



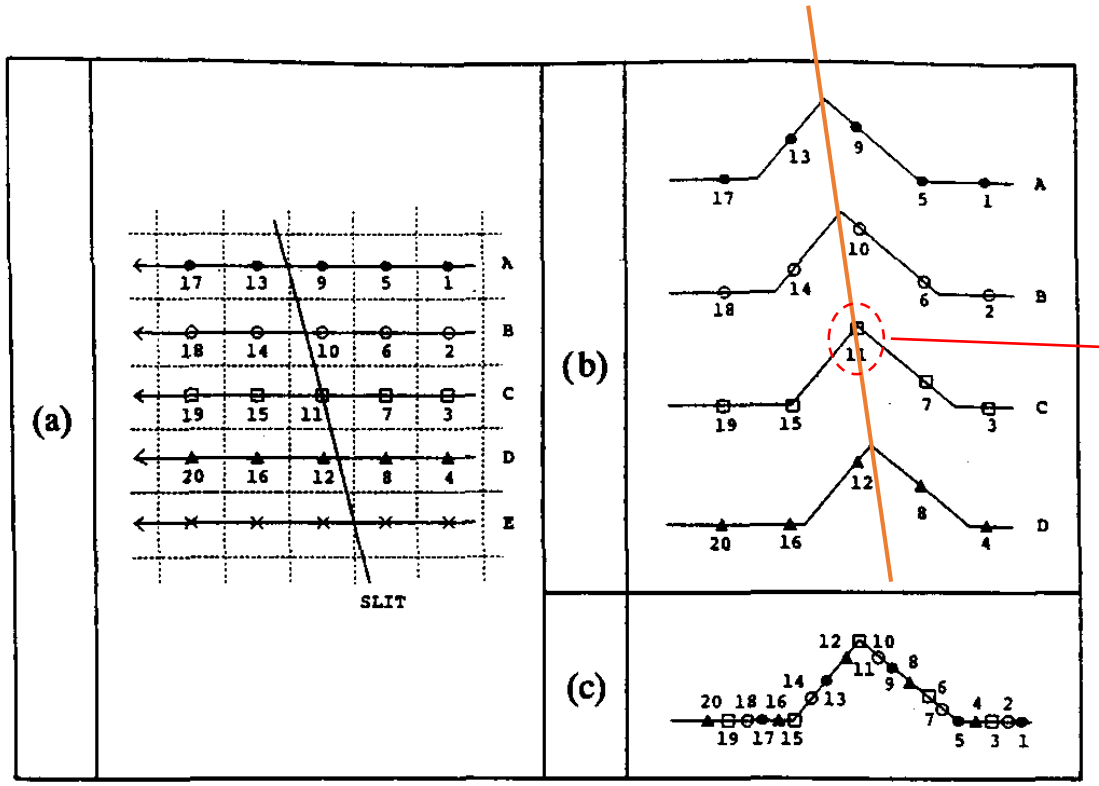
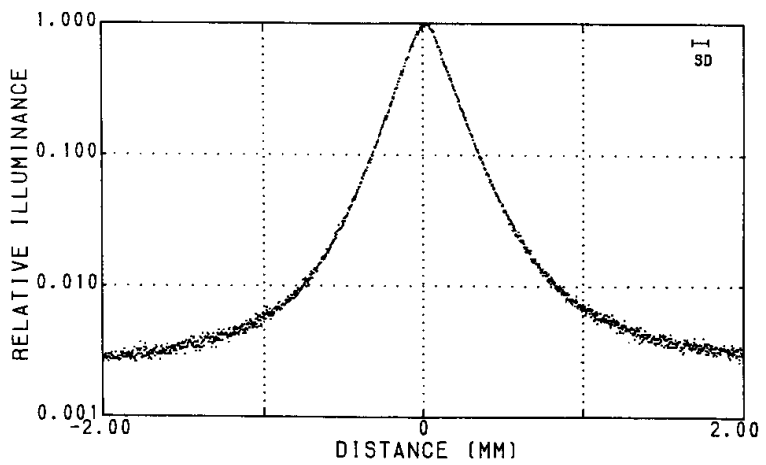


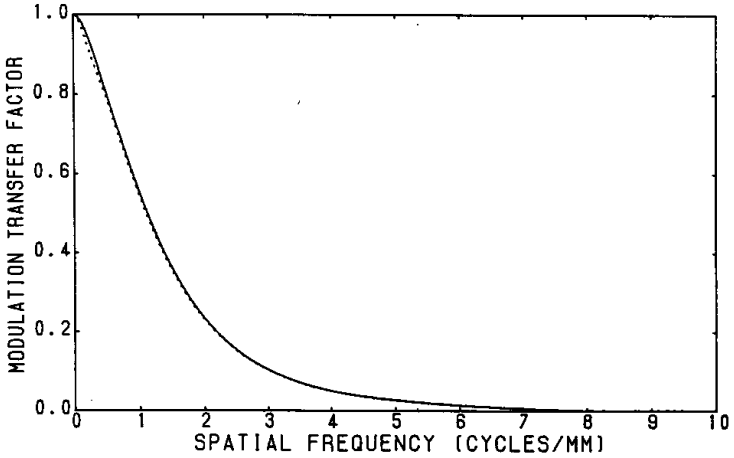
Fig. 1. Schematic diagram showing the generation of a composite (finely sampled) LSF (c) from the LSF's corresponding to the various alignments (b) of the slit (a) relative to the sampling coordinate.

Find another image pixel of the slit, along the slit, and that is N rows away & 1 column away

MTF is obtained from FT of finely sampled LSF



Fourier Transform



MTF of digital radiography: Edge based method

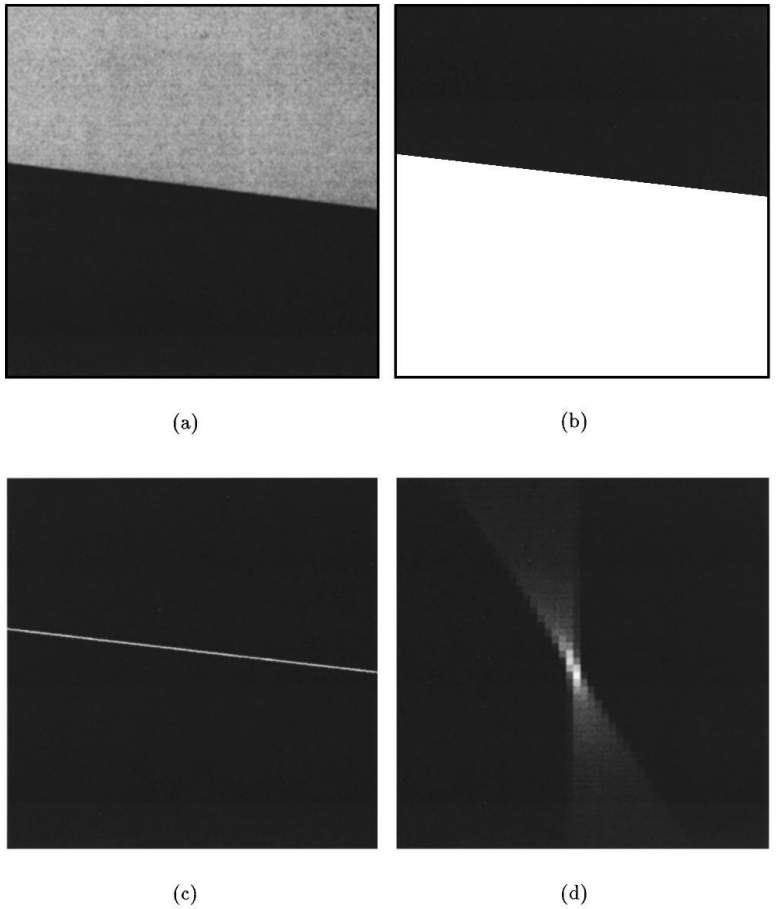
A method for measuring the presampled MTF of digital radiographic systems using an edge test device[a)]

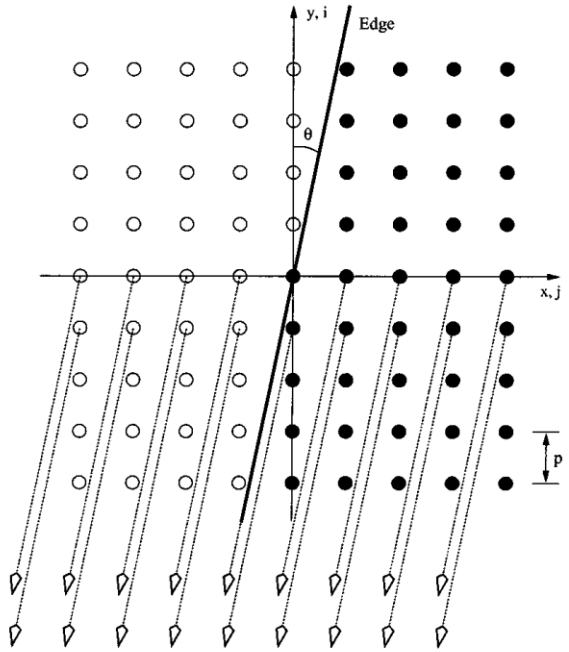
Ehsan Samei[b)] and Michael J. Flynn
Department of Diagnostic Radiology, Henry Ford Health System, Detroit, Michigan 48202 and Department of Nuclear Engineering and Radiological Sciences, The University of Michigan, Ann Arbor, Michigan 48109

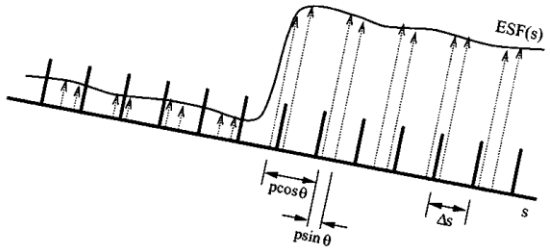
David A. Reimann
Department of Diagnostic Radiology, Henry Ford Health System, Detroit, Michigan 48202

(Received 30 December 1996; accepted for publication 13 October 1997)

Finely sample ESF







ESF perpendicular to the edge, sampled at 0.1 pixel bin size.

numerical differentiation

Fourier Transform