FONDAMENTI DI FISICA MEDICA

PARTE 1: BASI FISICHE DELLA RADIOLOGIA (1CFU)

LECTURE 0 - INTRODUCTION

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Testi di Riferimento

Author	Title	Year
Stephen Keevil, Renato Padovani, Slavik Tabakov, Tony Greener, Cornelius Lewis, editors	Introduction to medical physics *(ebook disponibile nella biblioteca di ateneo)*	2022
Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt, John M. Boone, editors	The essential physics of medical imaging *(disponibile presso la biblioteca tecnico-scientifica)*	2012
Perry Sprawls	The Physical Principles of Medical Imaging *http://www.sprawls.org/resources/*	1993

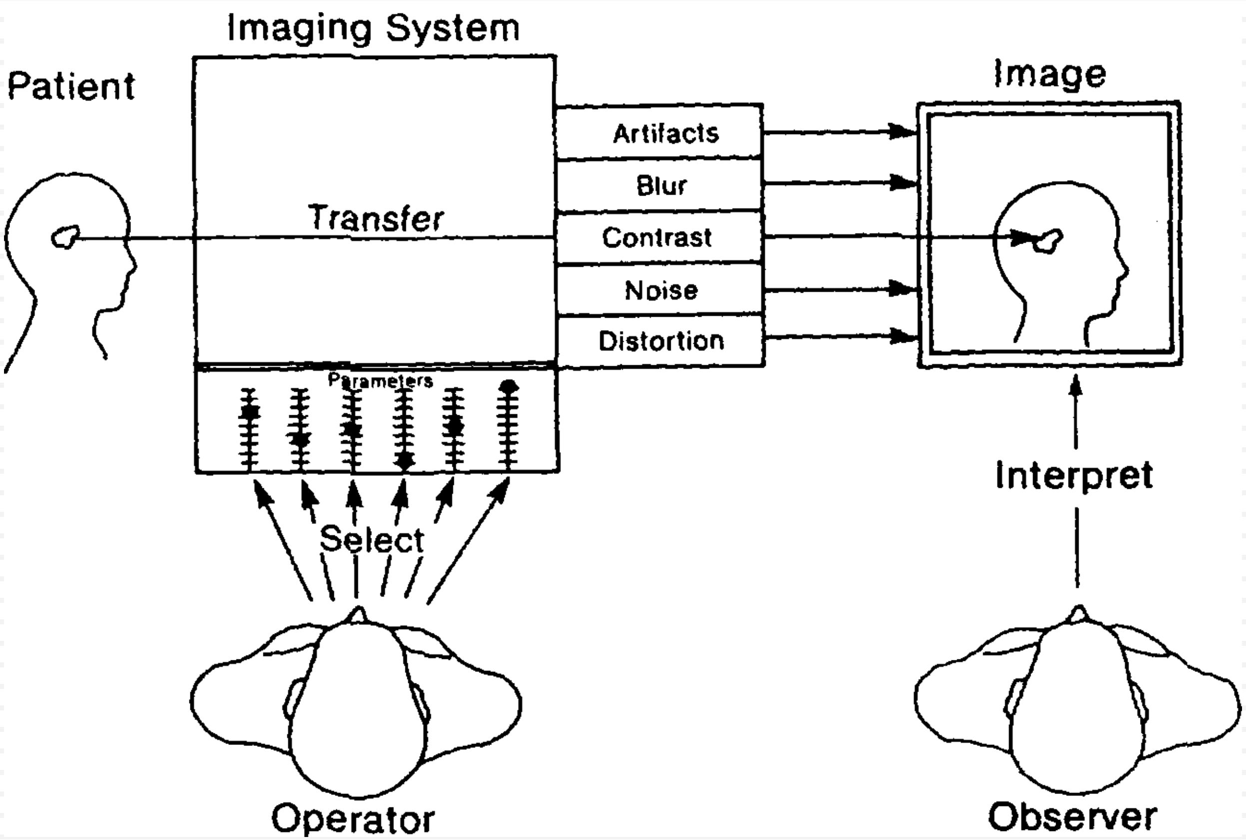
Ulteriori Testi di Riferimento

Author	Title	Year
Paolo Russo, editor.	Handbook of X-ray Imaging	2018
Andreas Brahme, editor.	Comprehensive Biomedical Physics *10 volumi*	2014
Richard Van Metter, Jacob Beutel, Harold Kundel, editors.	Handbook of medical imaging. Volume 1, Physics and psychophysics	2000
Steve Webb, editor.	The Physics of medical imaging	1988
Bracewell, Ronald N.	The Fourier transform and its applications	1986
Hasegawa, Bruce H.	The physics of medical X-ray imaging (or the photon and me: how I saw the light)	1990
Knoll, Glenn F.	Radiation Detection and Measurement	2010
Evans, Robley D.	The Atomic Nucleus	1955

An invitation to Medical Imaging

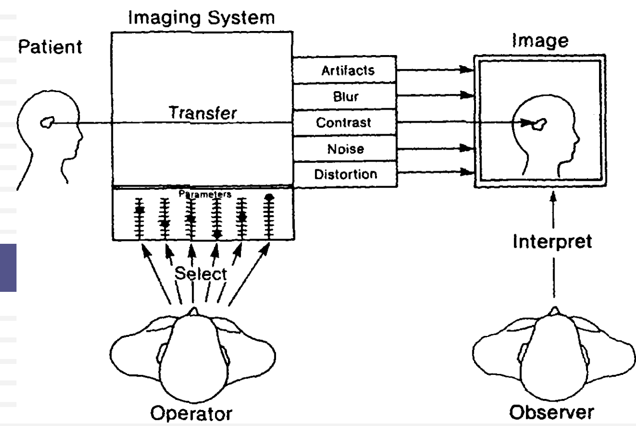
An introduction inspired by the lectures of prof. P. Sprawls (http://www.sprawls.org/) and prof. L. Bertocchi

General Scheme of an Imaging Process



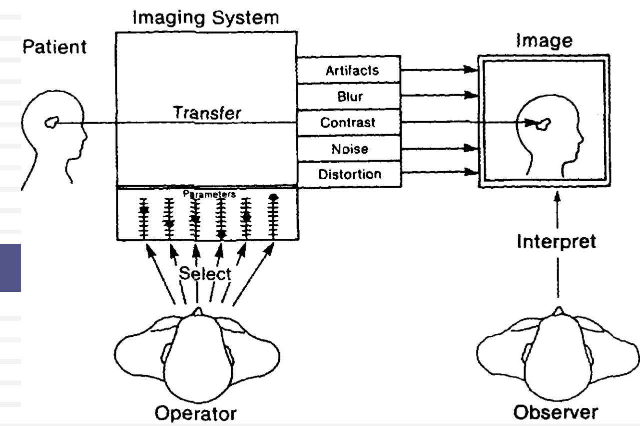
- 5 main components:
  - Patient
  - Imaging System
  - System Operator
  - Image
  - Observer

The role of the operator



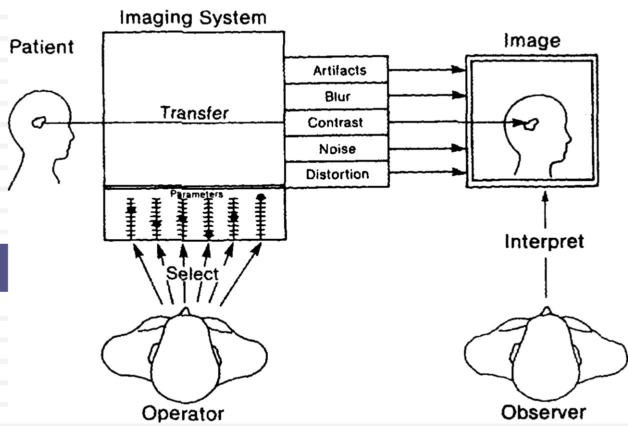
- In this Master Lectures' you shall meet various imaging systems, including:
  - X-rays radiology
  - Images from radioisotopes
  - Magnetic resonance
  - Ultrasounds
- In each <u>imaging method</u> it is possible to vary some physical <u>parameters</u> (the applied potential in an X-ray tube; type and concentration of radioisotopes; magnetic field gradients and their application times…) that are controlled by an <u>operator</u>

The role of the observer



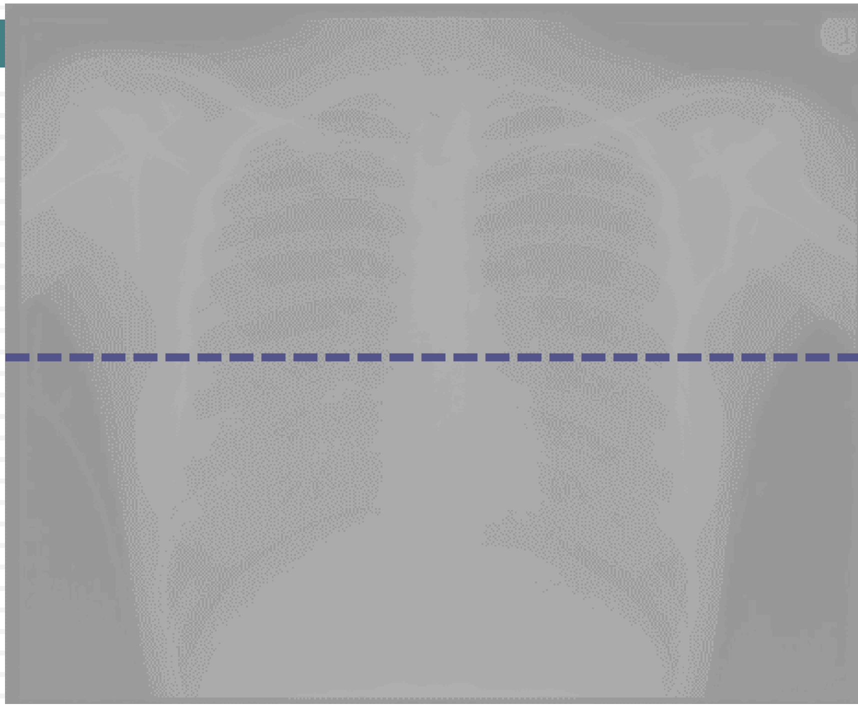
- There are several different methods of <u>creating and/or registering an image</u> (photographic plates; gamma camera; digital detectors; etc.)
- Eventually, the image is analyzed by an <u>observer</u>, in order to get <u>structural</u> (anatomic) or in some case also <u>functional</u> (physiological) information
- The capability of an observer to identify pathologies depends in general upon three factors:
  - a) The image quality
  - b) The observation conditions
  - c) The characteristics of the observer

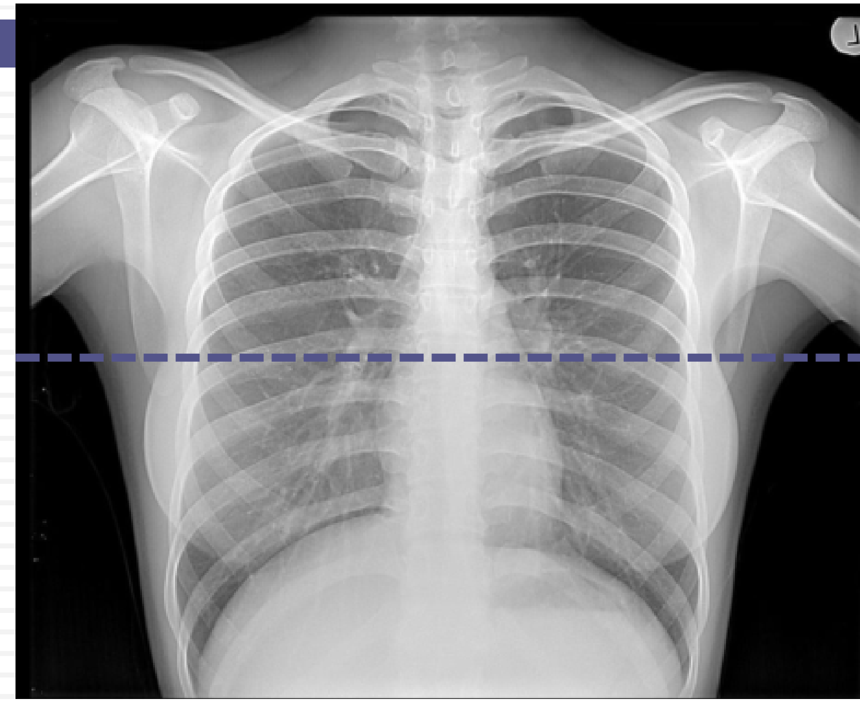
Image quality

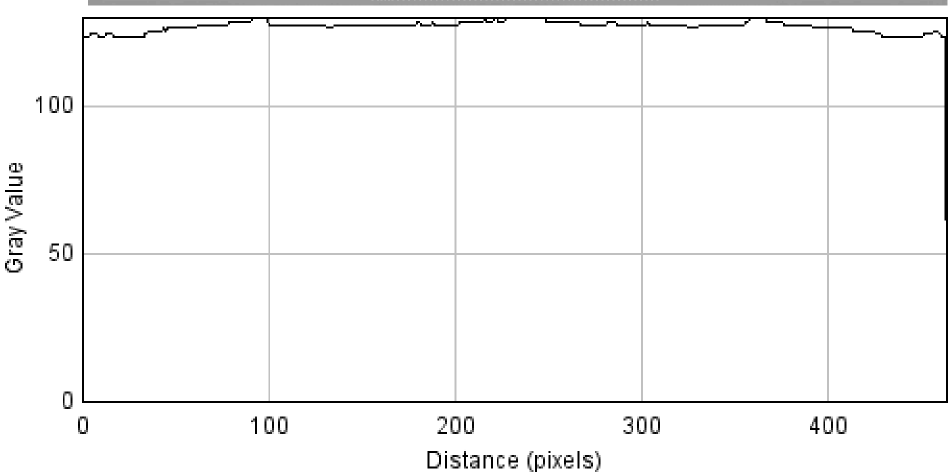


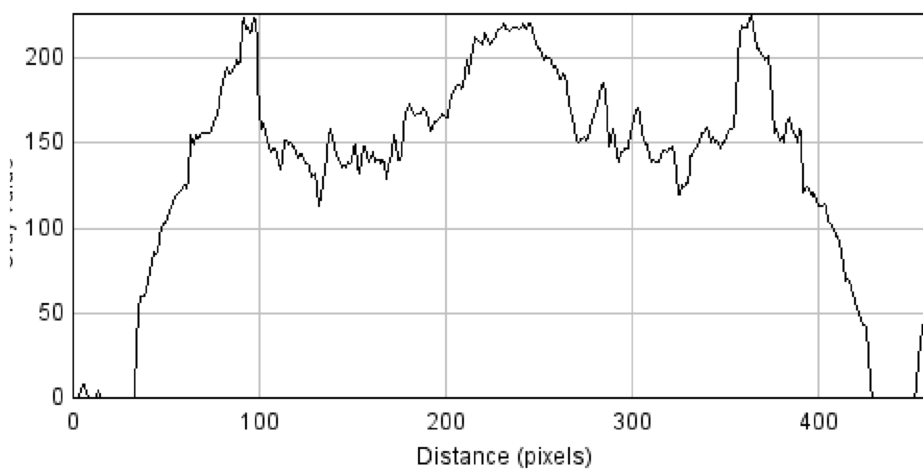
- In our simplified scheme,
  image quality depends from 5 factors:
  - Contrast
  - Blur (detail visibility - spatial resolution)
  - Background Noise
  - Artifacts
  - Distortions
- We will now briefly review these points, which will be studied in detail in the next lectures
- Our brief review will use the simplest imaging method (i.e. planar radiology) as a case study

Contrast

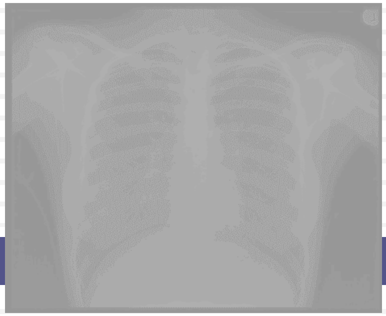


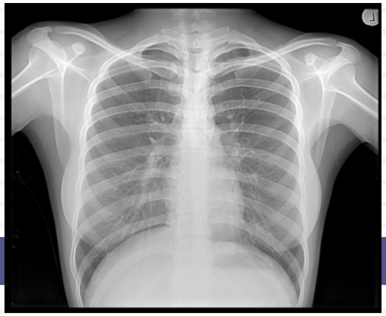



Gray Value
0
50
100
0
100
200
300
400
Distance (pixels)


0
50
100
150
200
0
100
200
300
400
Distance (pixels)

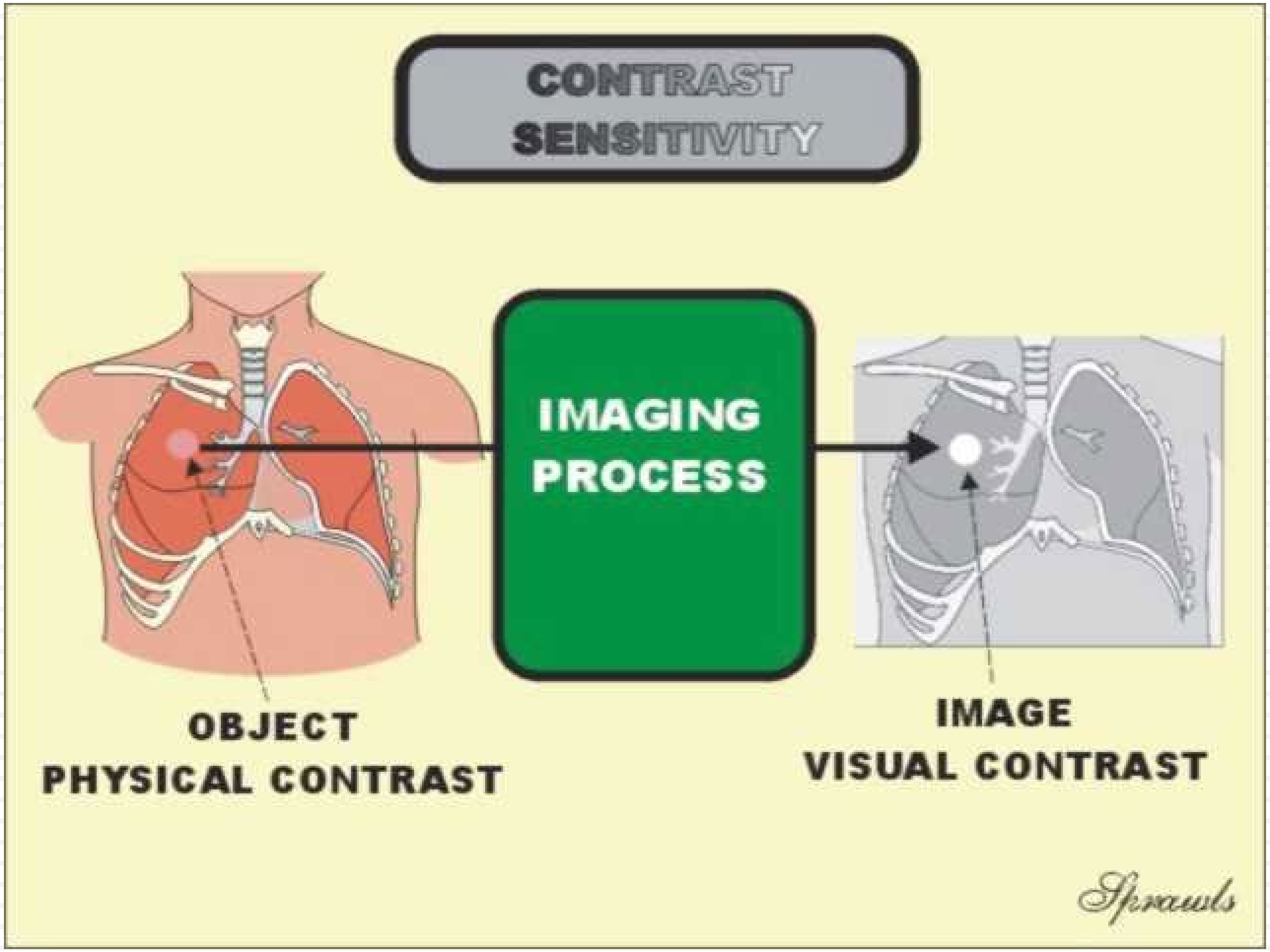
Contrast



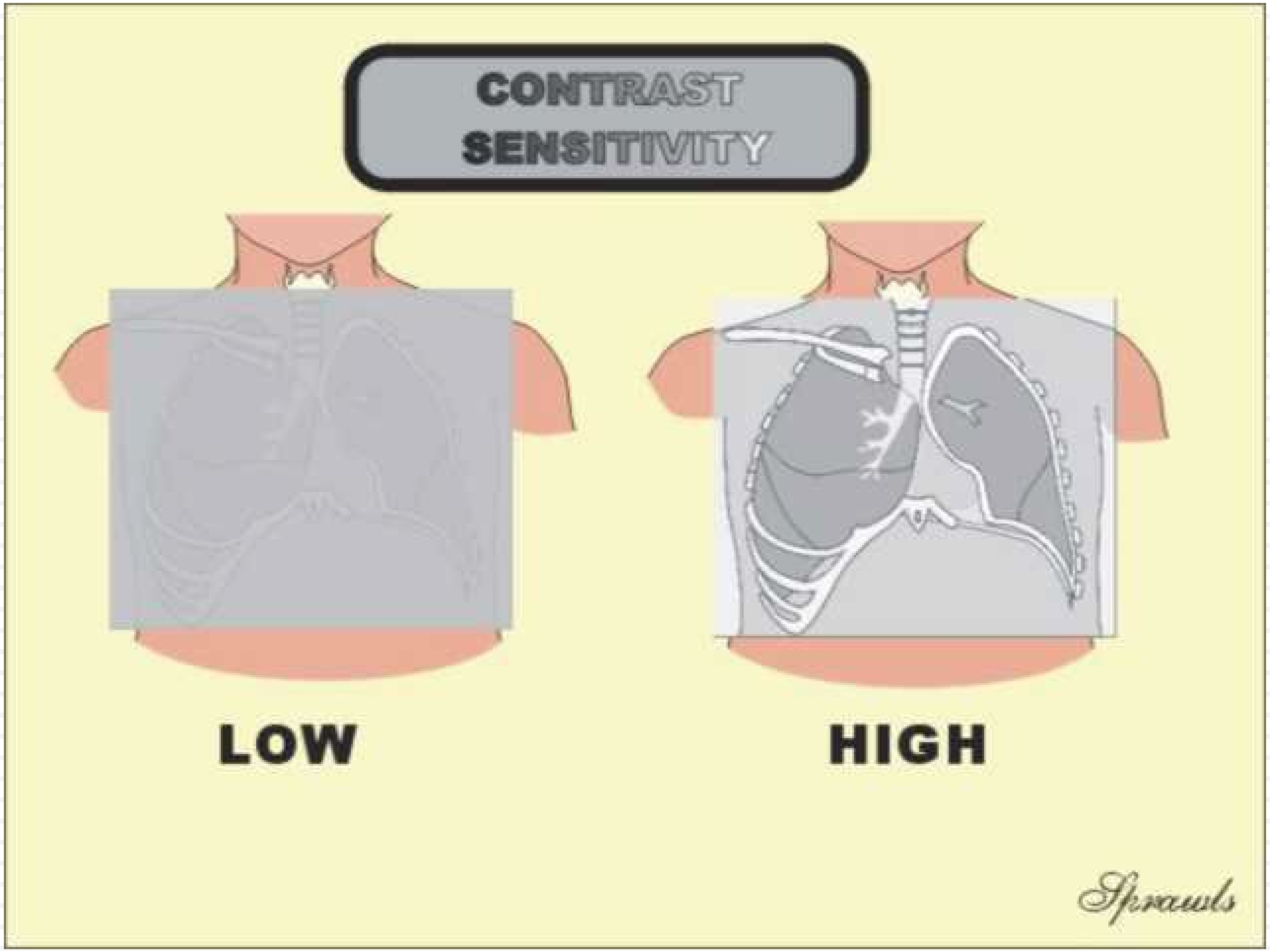


- Contrast represents the difference in one or more characteristics of the object between two specific points in the image.
- In the (digital) image it is typically represented by various tonalities of gray (gray values or gray levels).
- The contrast required to make an object visible depends both upon the imaging method and the characteristics of the imaging system.
- Different imaging methods are sensitive to different contrasts.
  - For example, one method could give evidence to different densities of the tissues, another to different atomic numbers, another to different elastic properties, another to different relaxation times, another to different concentrations of radioactive substances, etc.
  - These differences represent the physical contrast.
- The fundamental characteristic of an imaging method is its contrast sensitivity, i.e. the ability to render a physical contrast as a contrast on the image (image contrast).

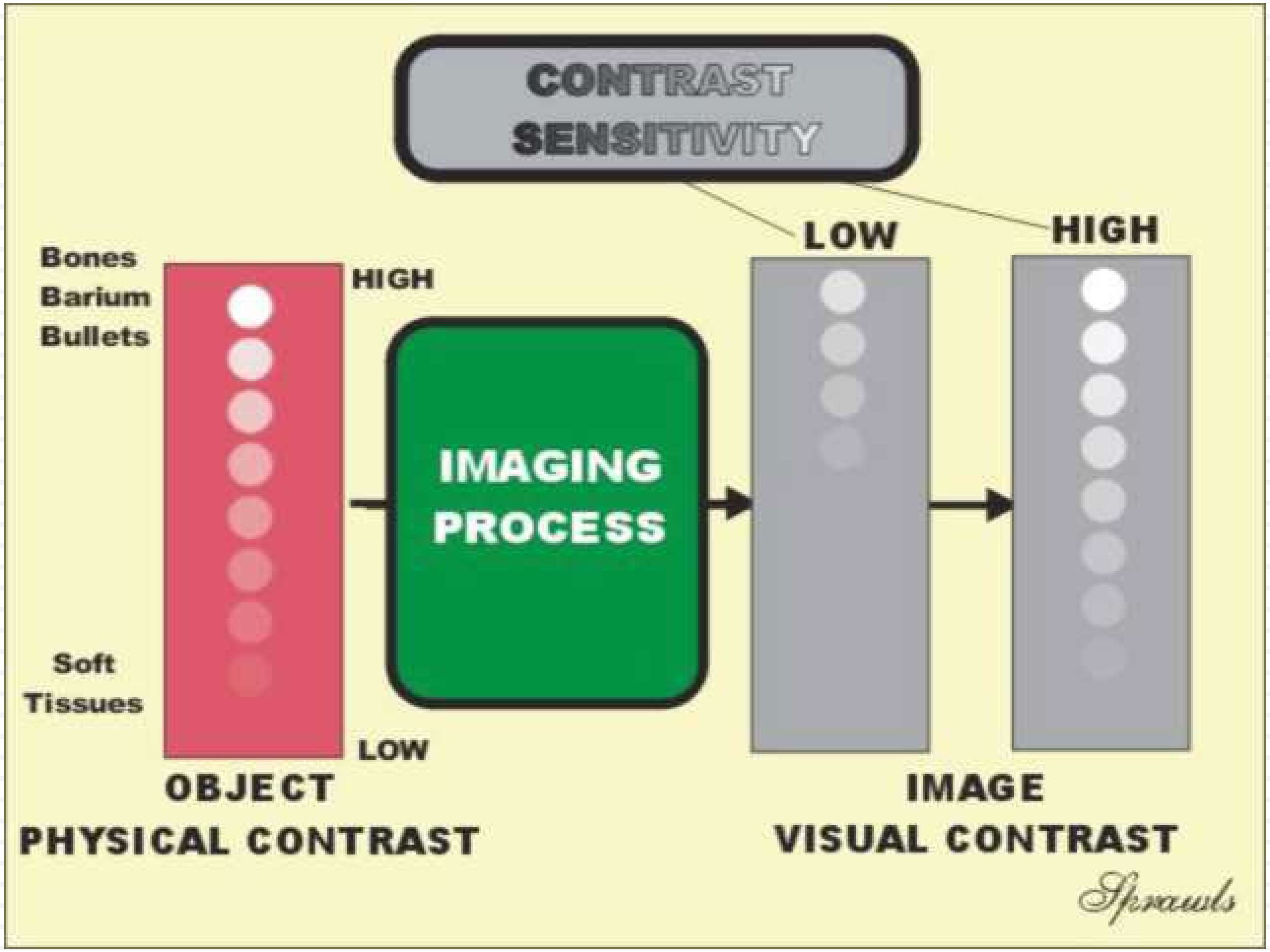
Contrast Sensitivity



Contrast Sensitivity



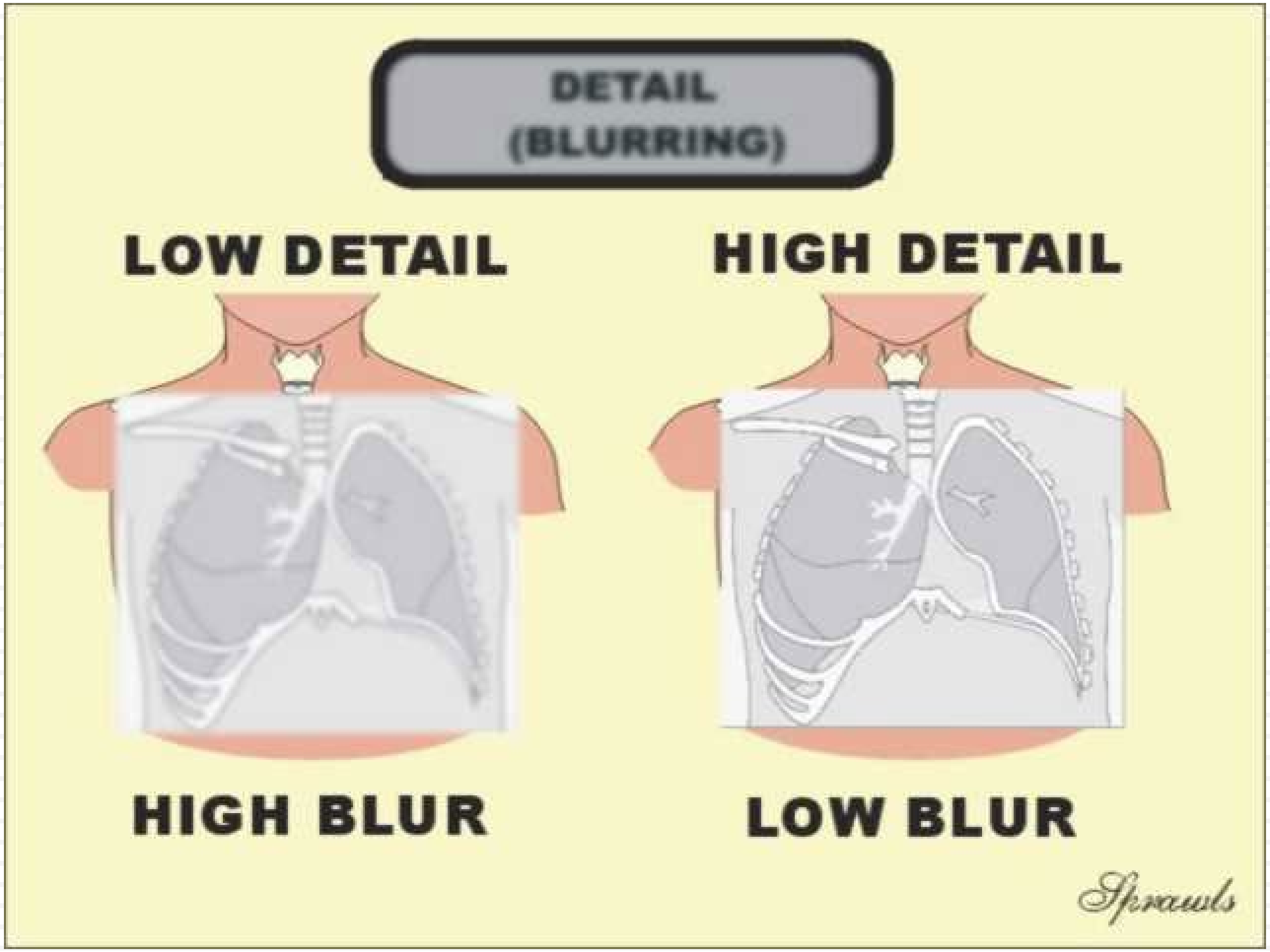
Contrast Sensitivity



Blur (detail visibility – spatial resolution)

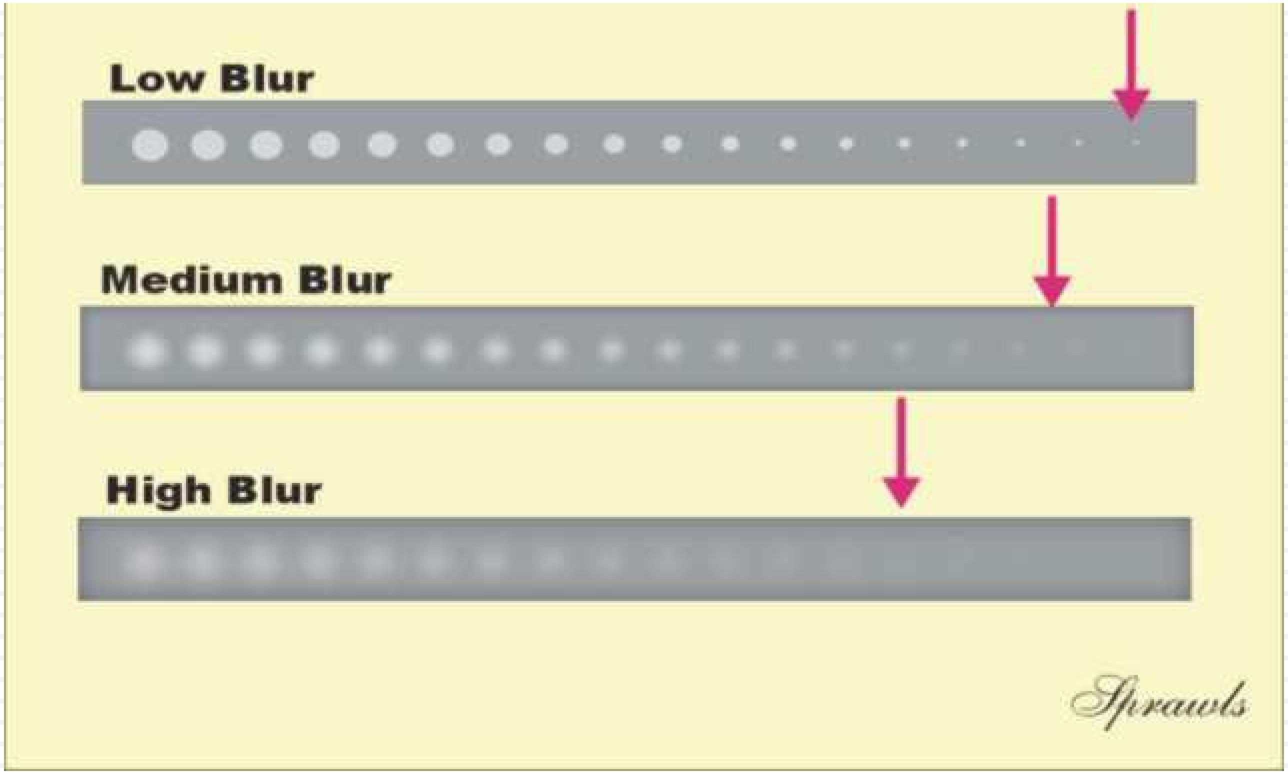
- Inside the body the objects differ not only for their characteristics but also for their dimensions, from the large organs and the bones, to the small calcifications.
- Each imaging method has a lower limit of the dimensions of the objects that can be resolved, and therefore of the details visibility.
- The visibility is limited since every imaging method introduces some "blurring" in the process.

Blur (detail visibility – spatial resolution)

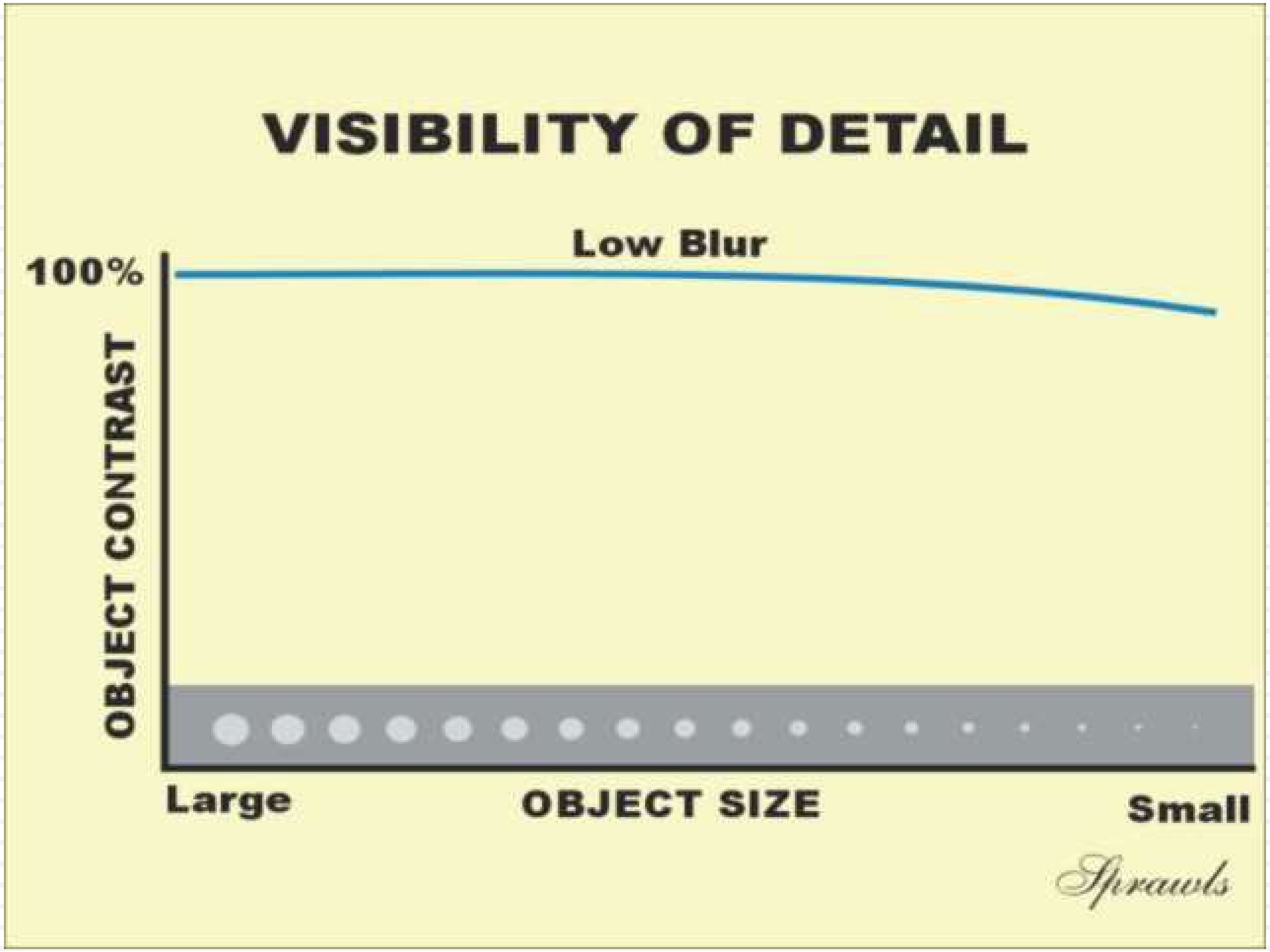


Blur (detail visibility – spatial resolution)

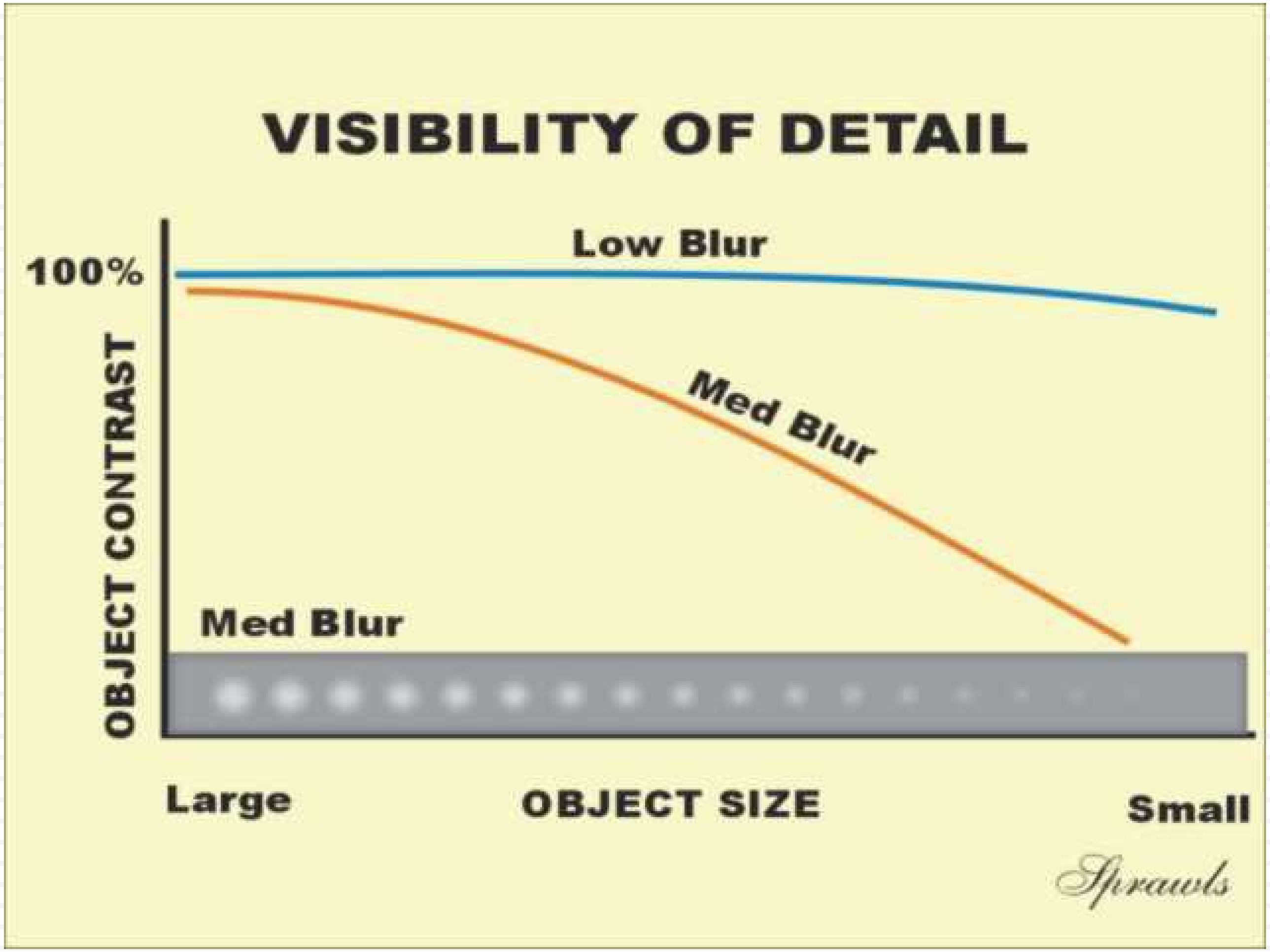
Obviously the blur has a little effect on the visibility of large objects, while it reduces the visibility and the contrast of small objects



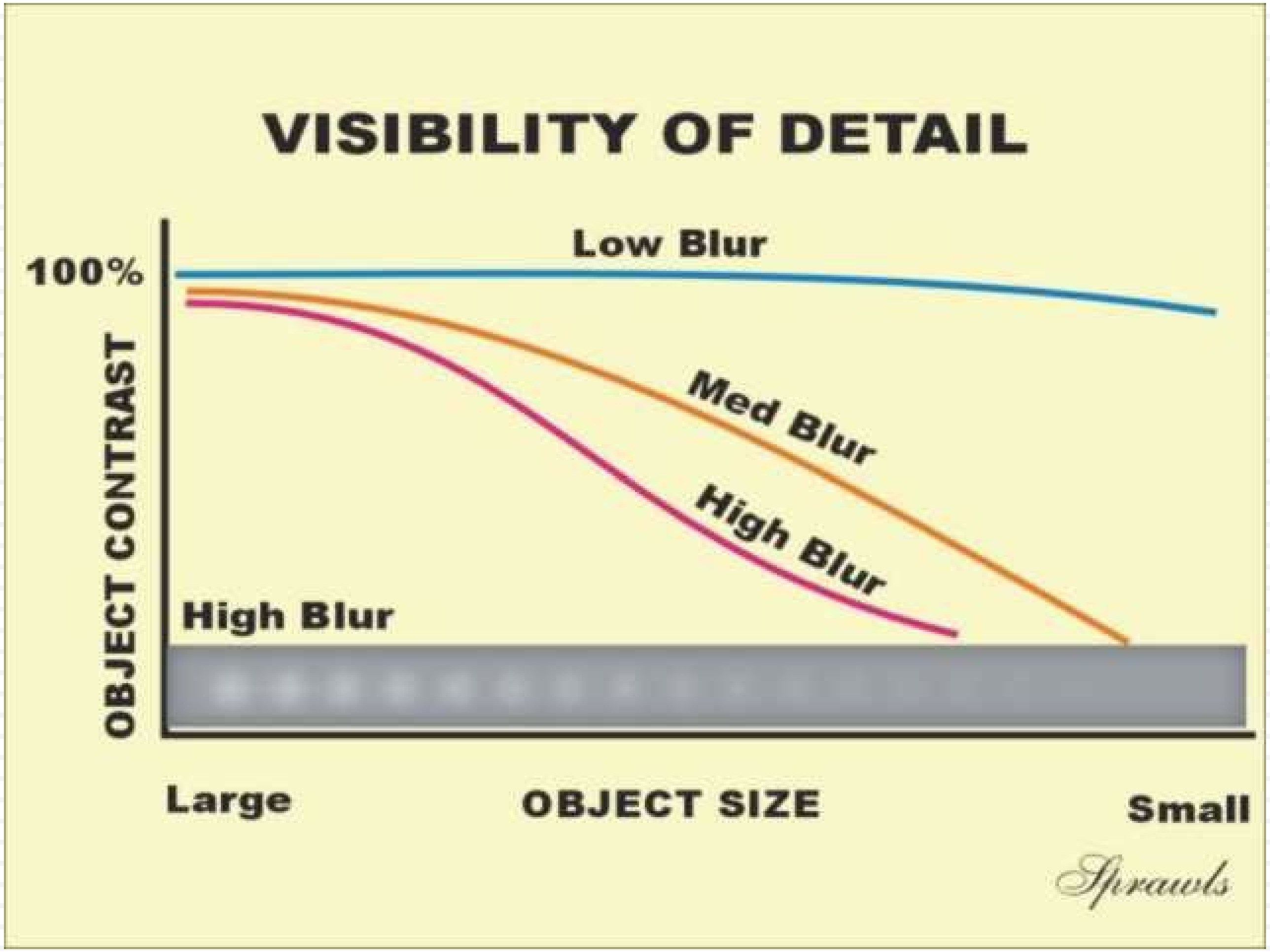
Blur (detail visibility – spatial resolution)



Blur (detail visibility – spatial resolution)

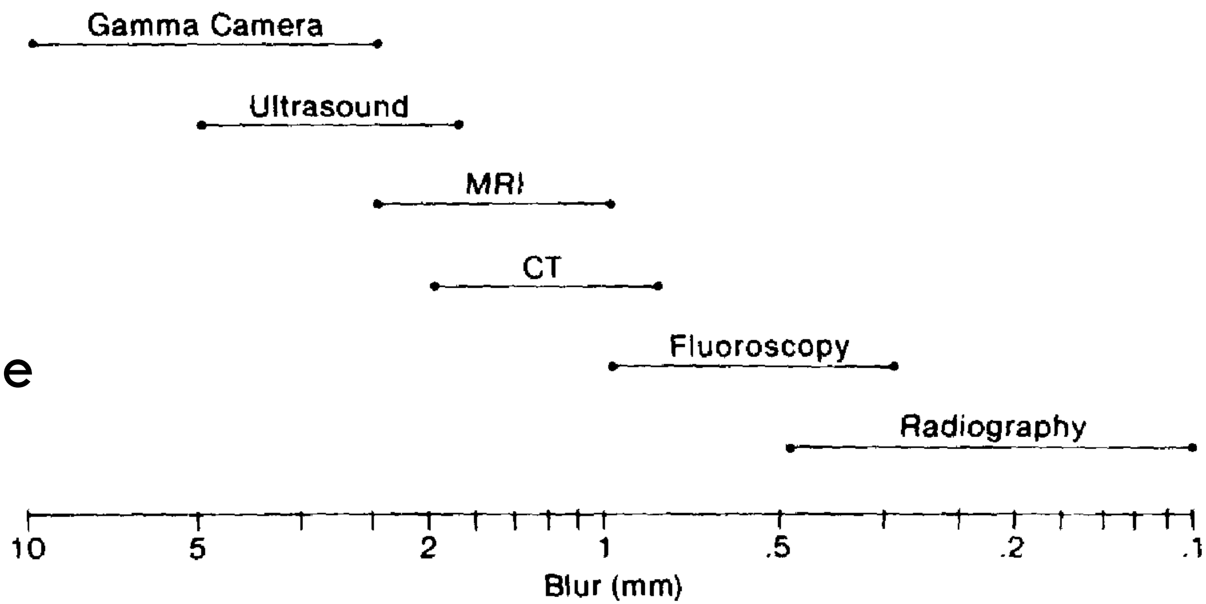


Blur (detail visibility – spatial resolution)



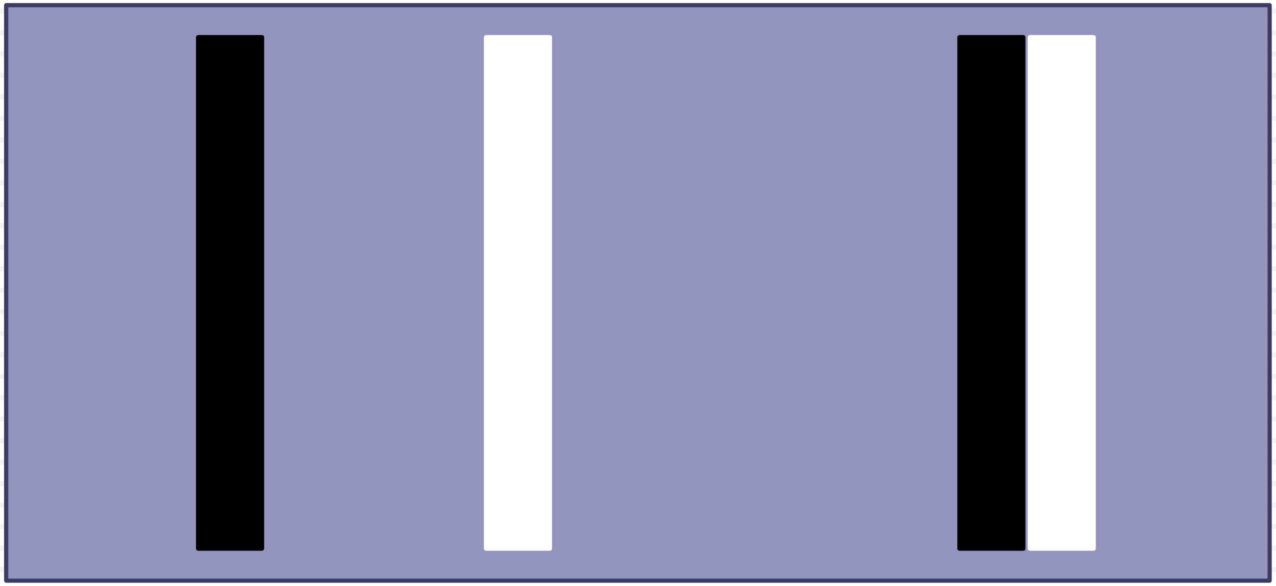
Blur (detail visibility – spatial resolution)

- gamma camera
  - from 10 to 3 mm
- ultrasounds
  - from 5 to 2 mm
- magnetic resonance
  - from 3 to 1 mm
- tomography
  - from 2 to 0.8 mm
- fluoroscopy
  - from 1 to 0.4 mm
- conventional radiography
  - from 0.5 to 0.1 mm (down to 0.05 in mammography)

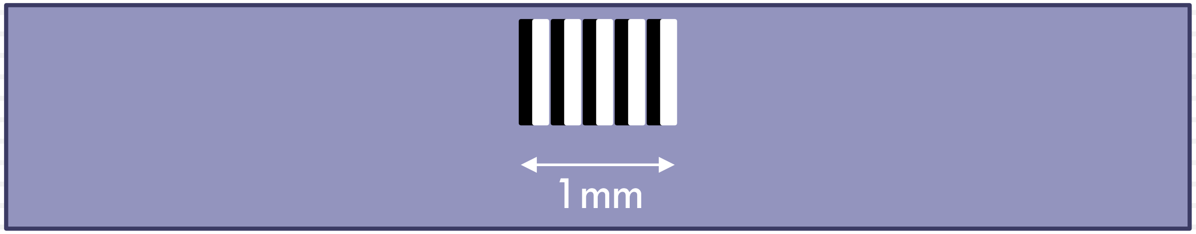


Spatial resolution (lp/mm)

- The spatial resolution of an imaging method is often defined in terms of "line pairs per millimeter", lp/mm
- A line is either a dark line or a light line; a line pair comprises a dark line and an adjacent light line.

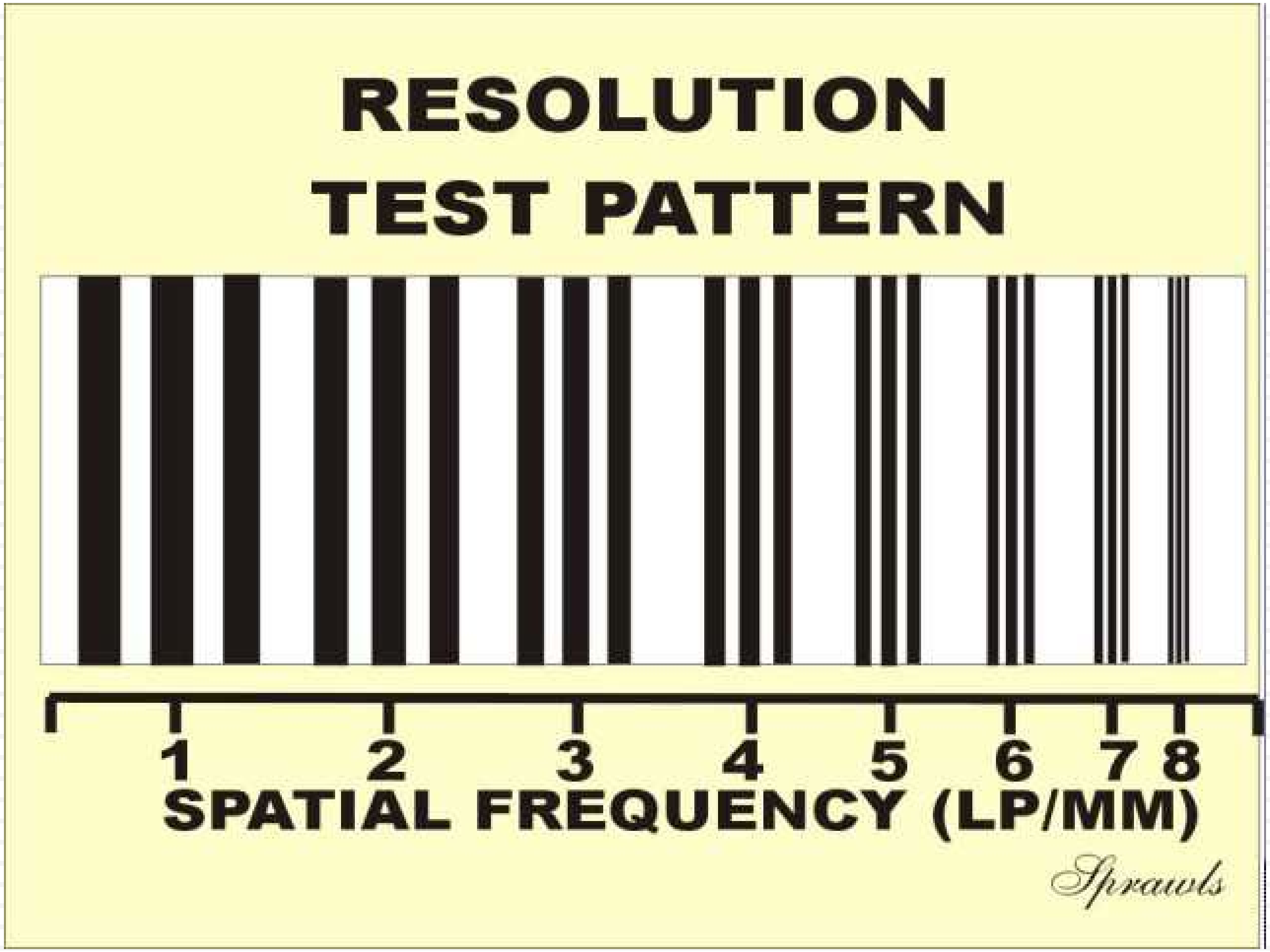


Spatial resolution (lp/mm)

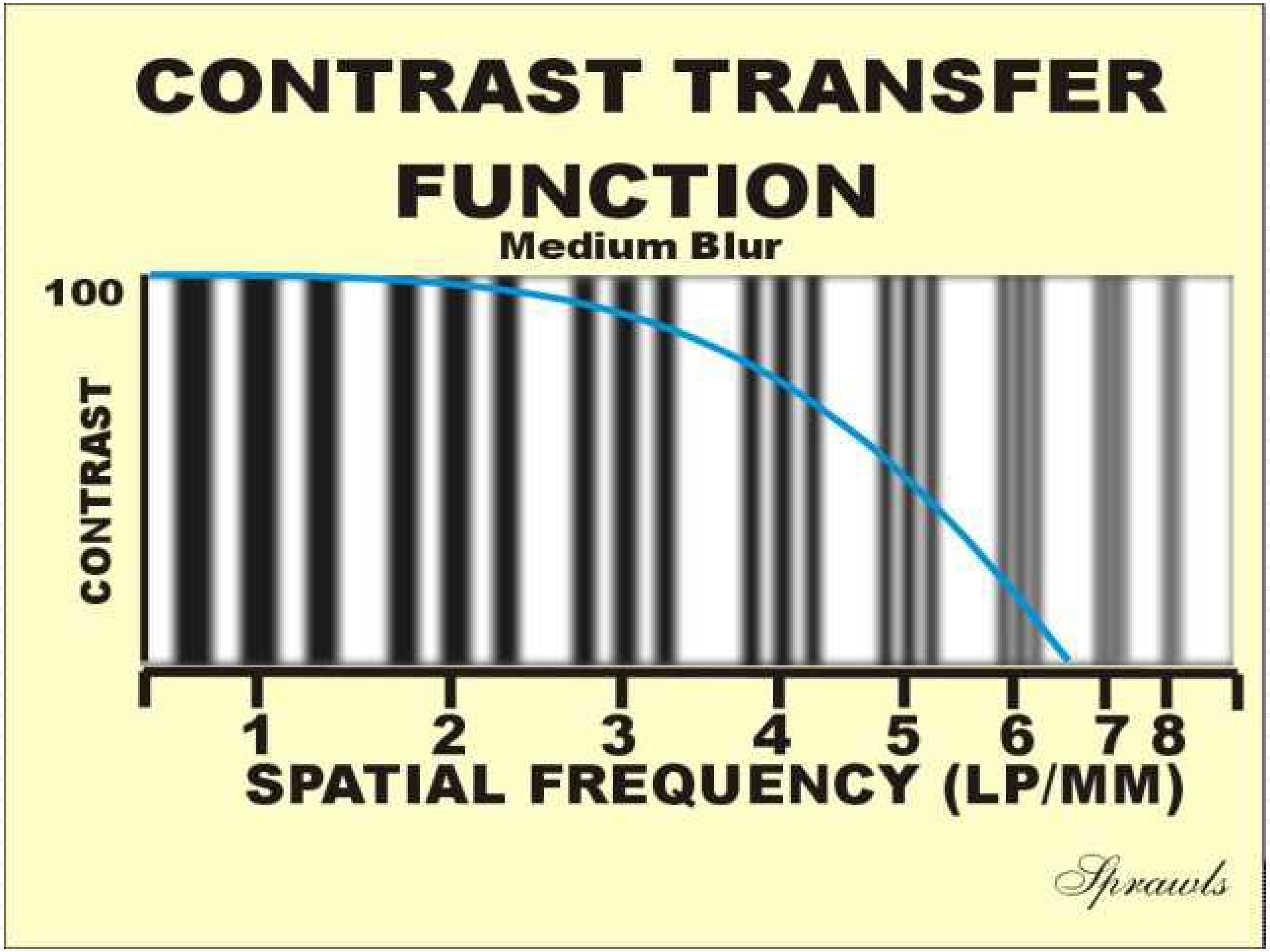


- Example: a resolution of 10 lines per millimeter means that the system can render:
  - 5 dark lines of 0.1 mm alternating with 5 light lines of 0.1 mm.
  - Overall, I have 10 lines in 1 mm, i.e. 5 line pairs per millimeter (5 lp/mm).
- The number of lp/mm defines a spatial frequency
- The higher spatial frequency that the system can render, the better its spatial resolution.

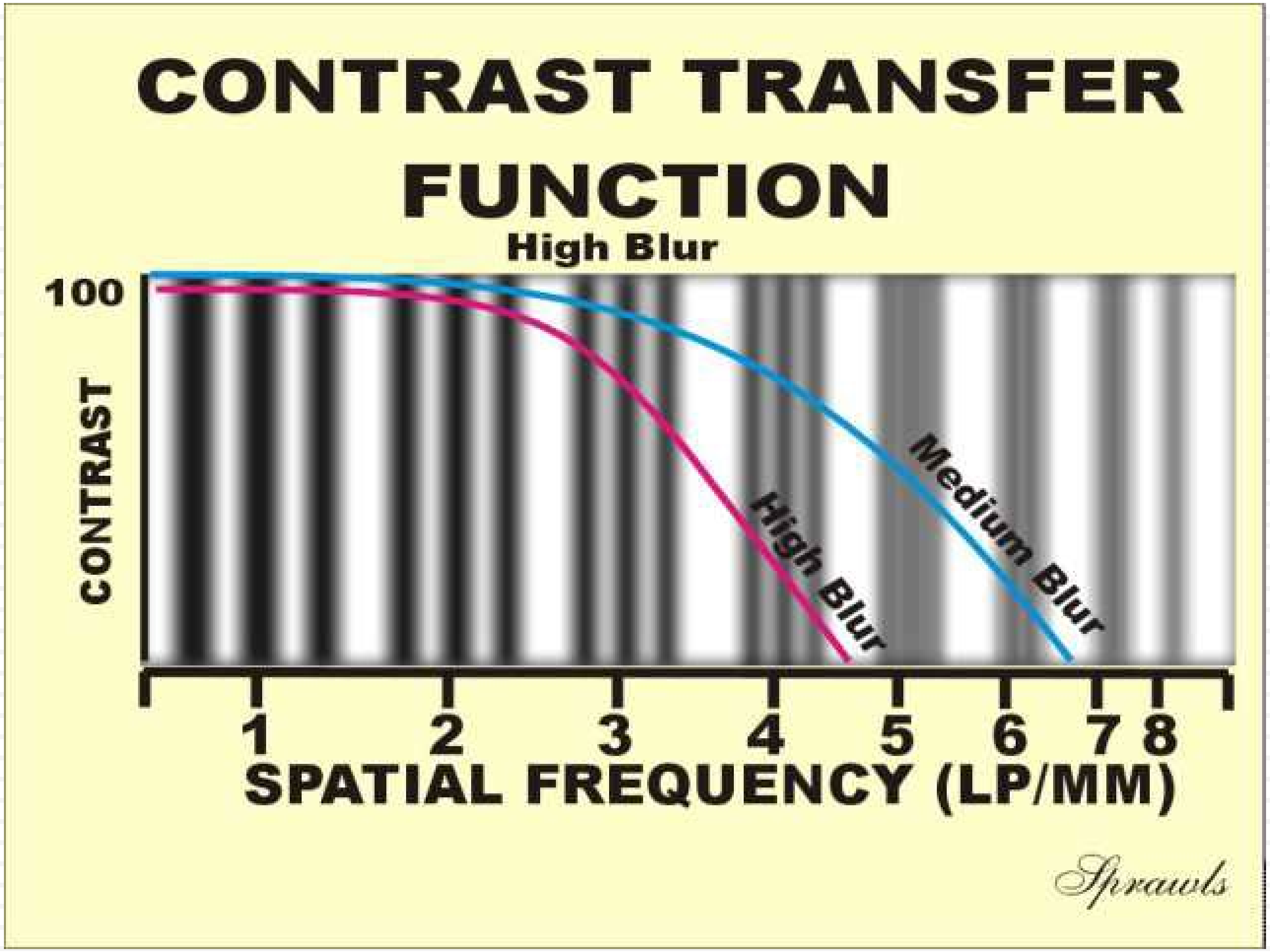
Spatial resolution (lp/mm)



Spatial resolution (lp/mm)

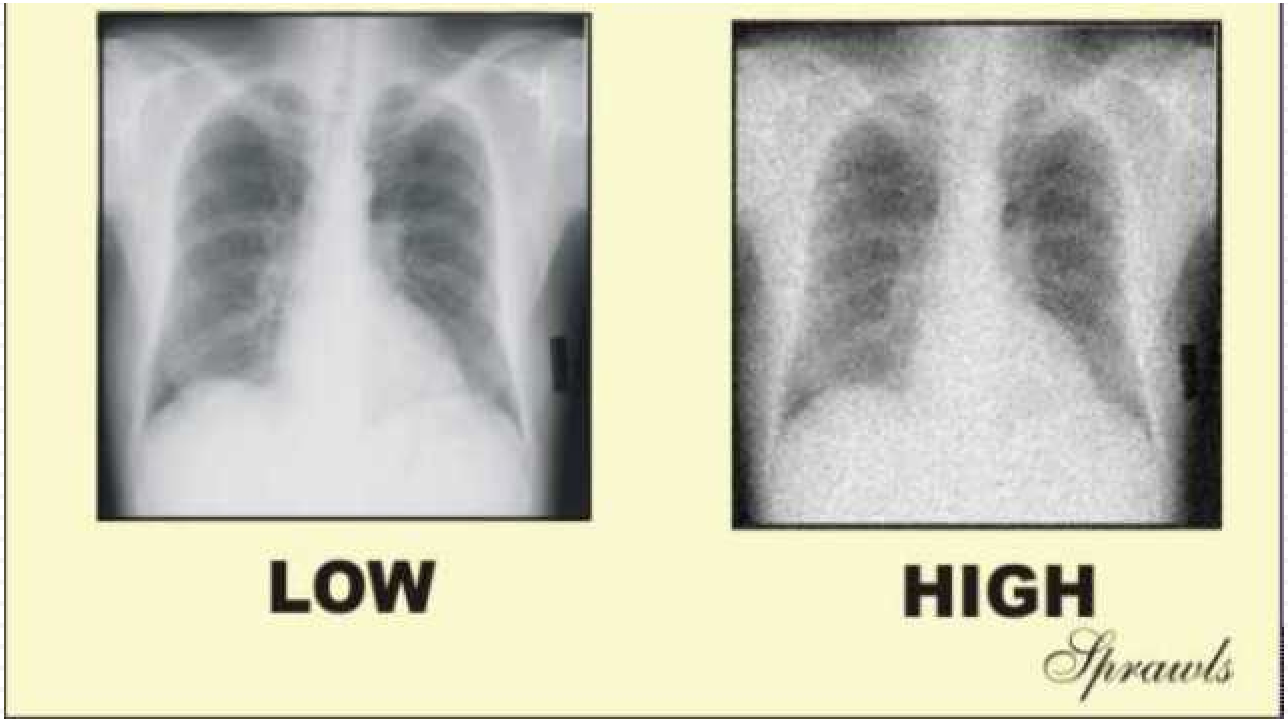


Spatial resolution (lp/mm)

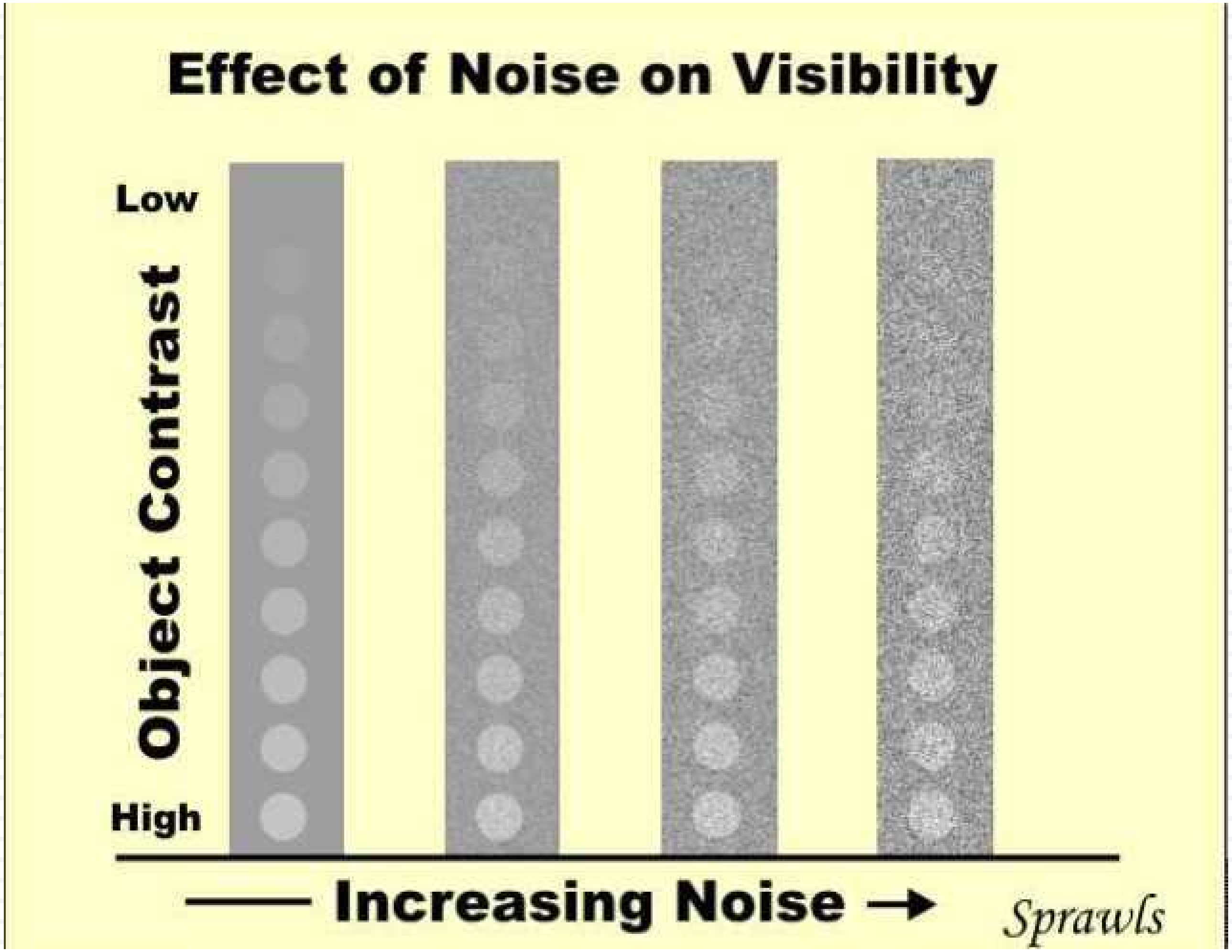


Noise

- The background noise gives a "granular" aspect to the image, and tends therefore to diminish the visibility of small and/or low-contrast objects.

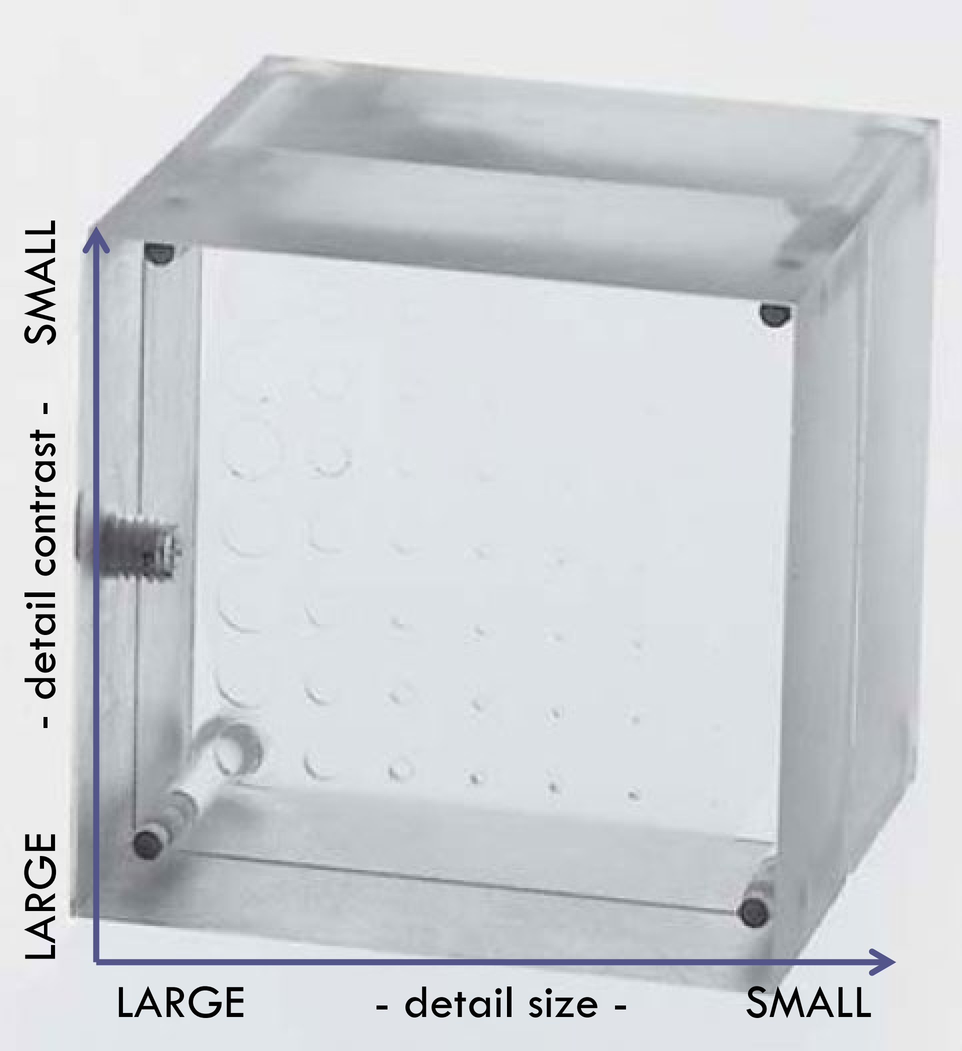


Noise


Effect of Noise on Visibility
Low
Object Contrast
High
Increasing Noise
Sprawls

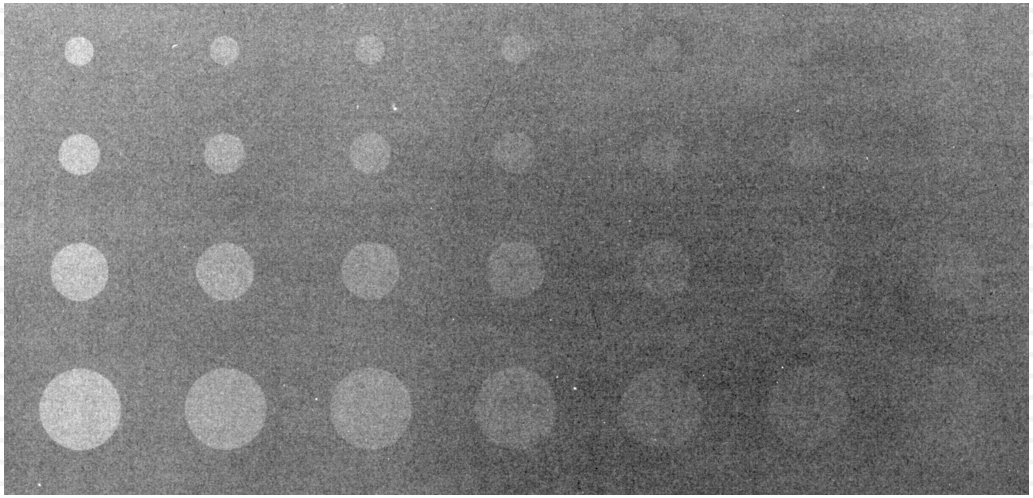
Contrast-Detail (CD) phantom

- A CD phantom allows to quickly assess the Blur and Noise characteristics of an imaging system.
- The phantom contains a matrix of details.
  - All of the details in a given row have a constant contrast.
  - All of the details in a given column have a constant size.

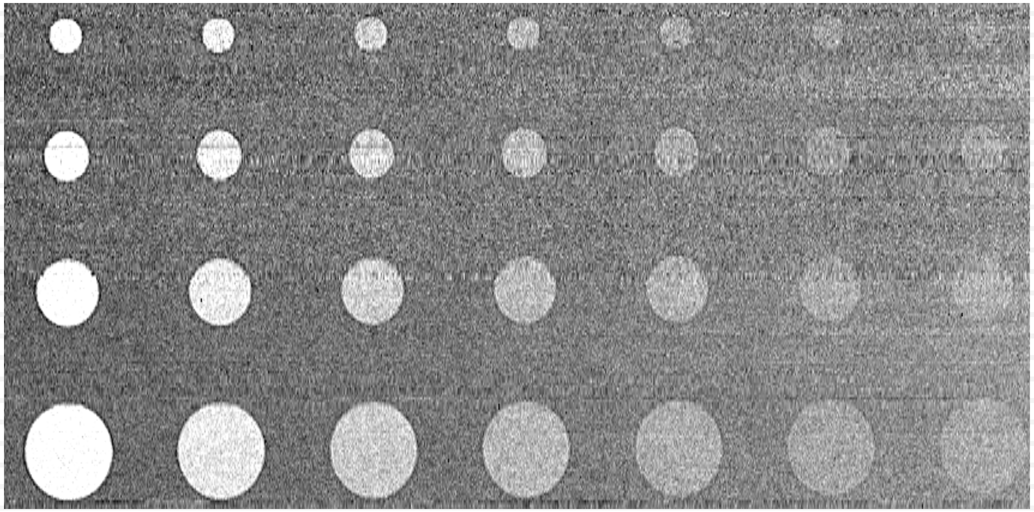


Example: system comparison with CD

1.
Conventional Screen-Film
Mammographic system
26 kVp
Dose: 1.8 mGy

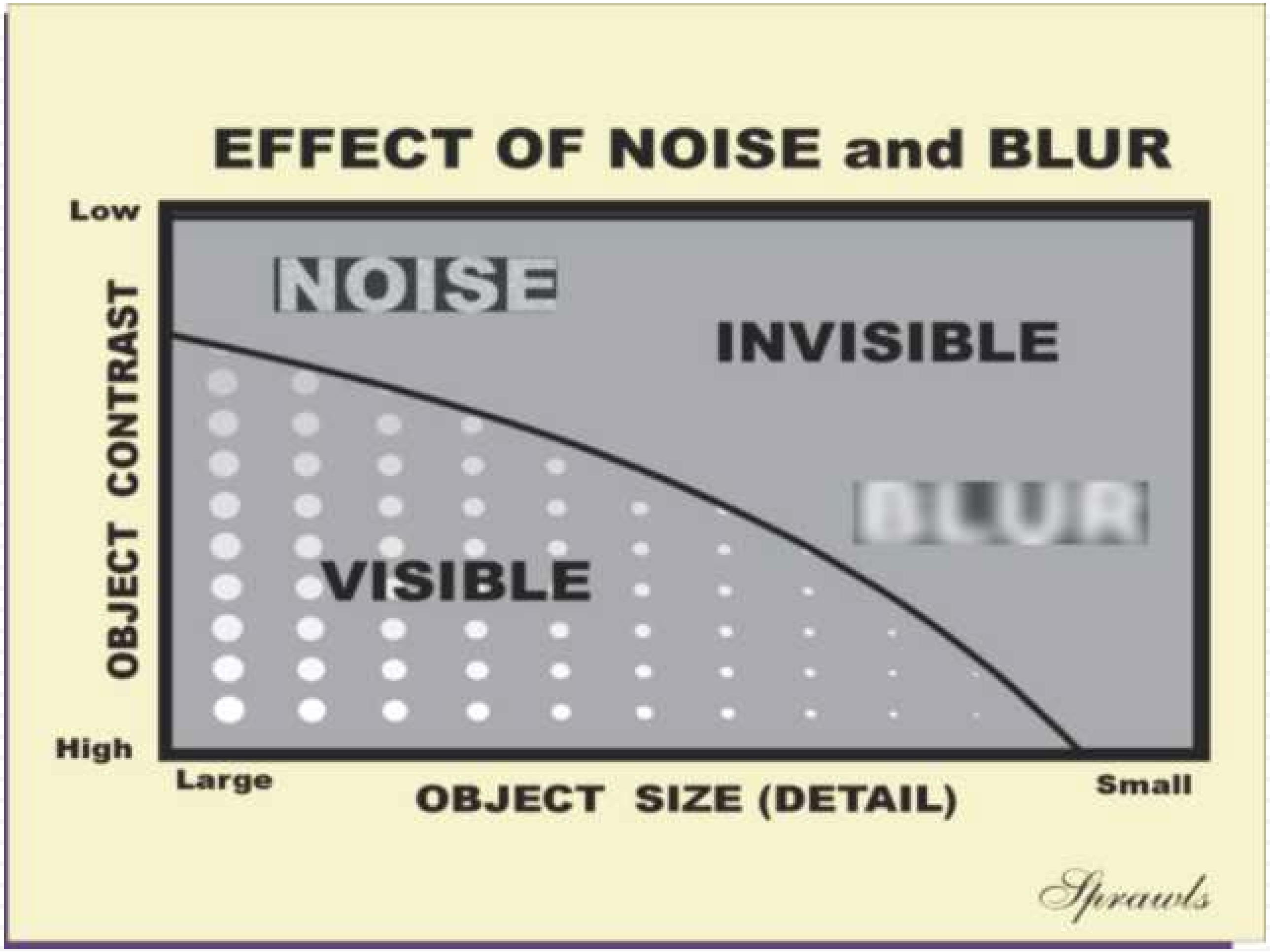


2.
“Frost” Digital detector (INFN)
Single photon counting
Synchrotron radiation
20 keV
Dose: 1.4 mGy



Syrmep group, 2001

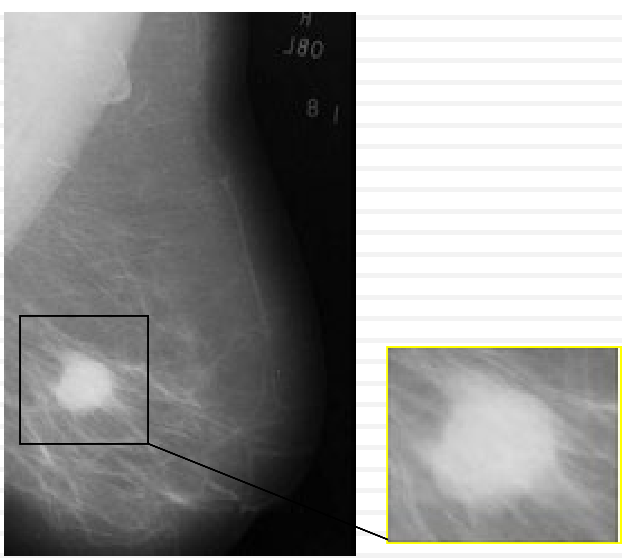
Blur Vs Noise: effect on visibility

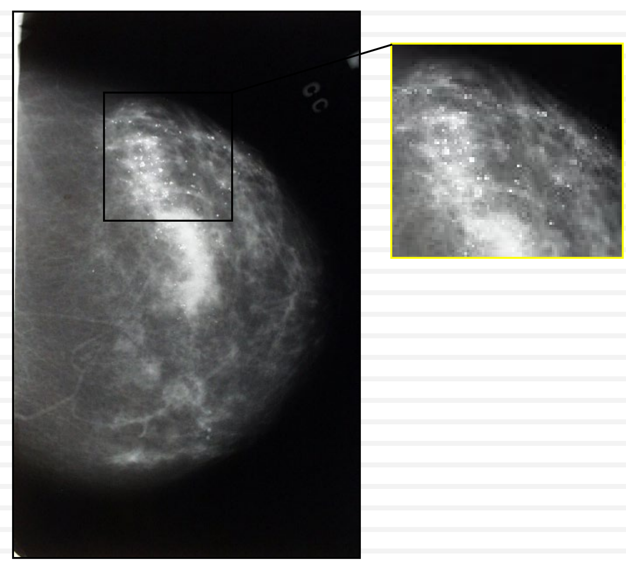


Structural Noise

- An example from mammography
- In mammography, radiologists evaluate the presence of
  - Masses

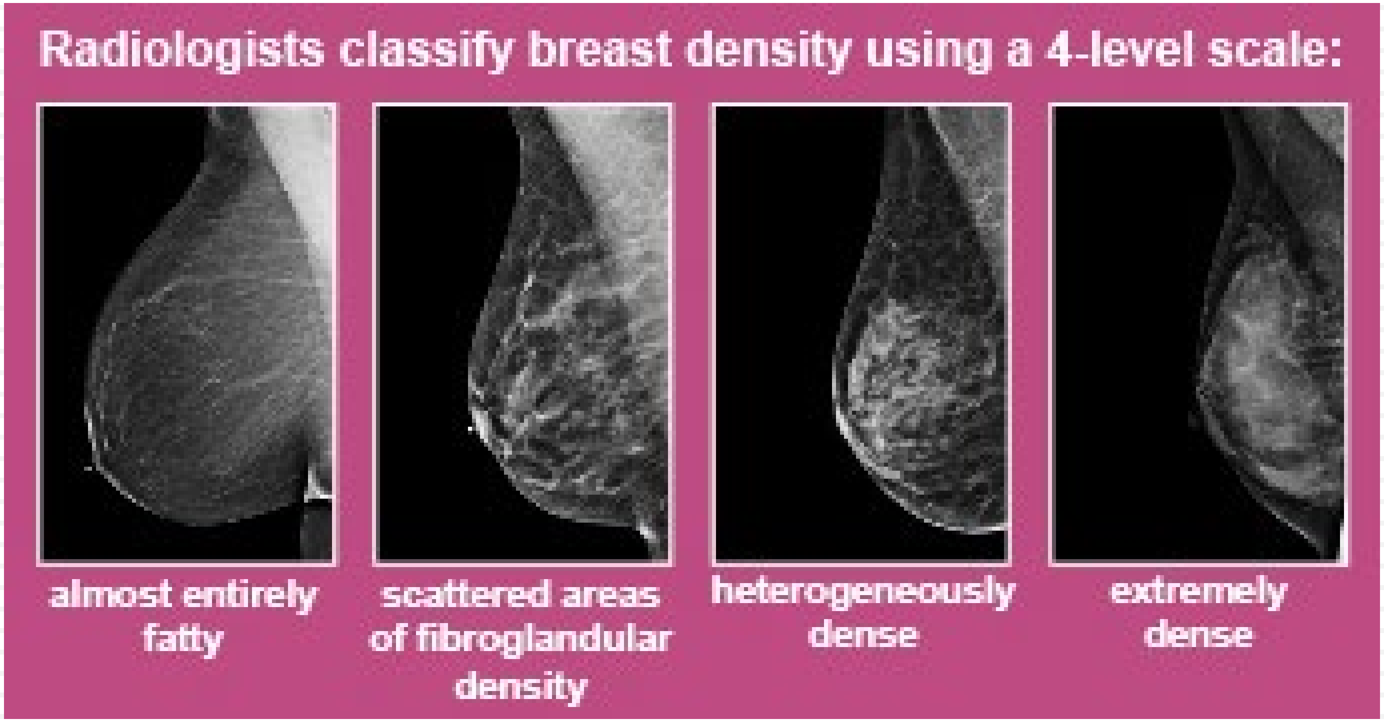
    Micro-calcifications





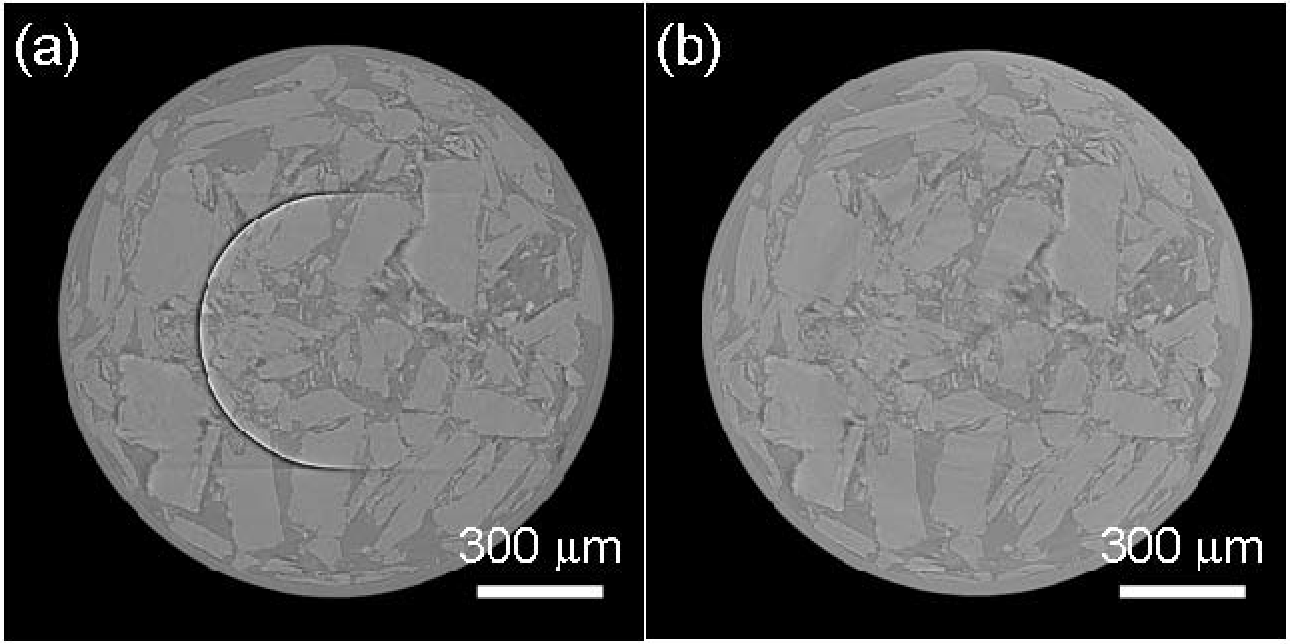
Structural noise

- But these features may be hard to find in dense breasts, due to the presence of healthy glandular tissue (structural noise)



Artifacts

- Most of the imaging techniques produce in the image characteristics that do not correspond to real structures of the object under examination. These "false" characteristics are known as "artifacts".

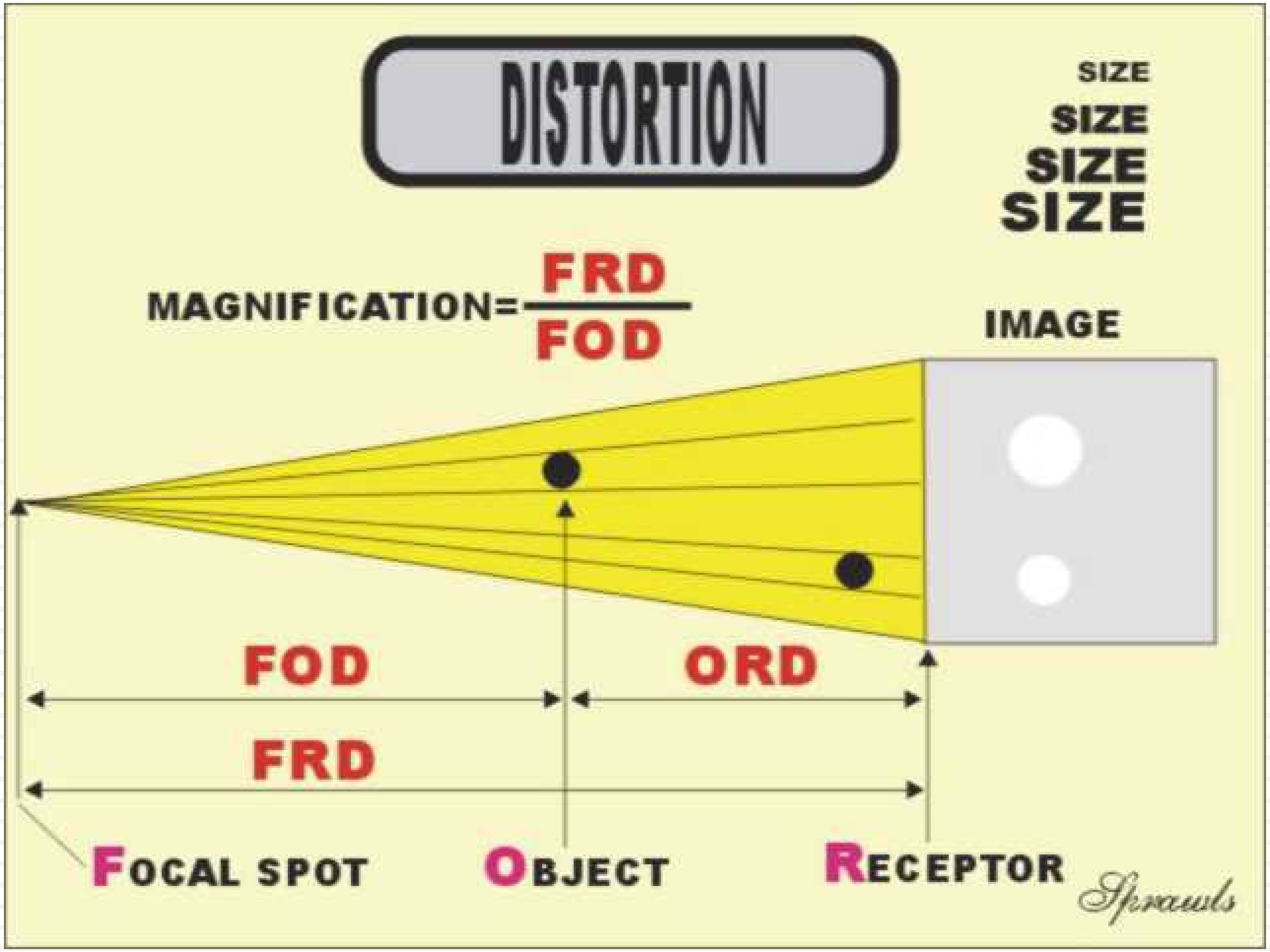


Distortions

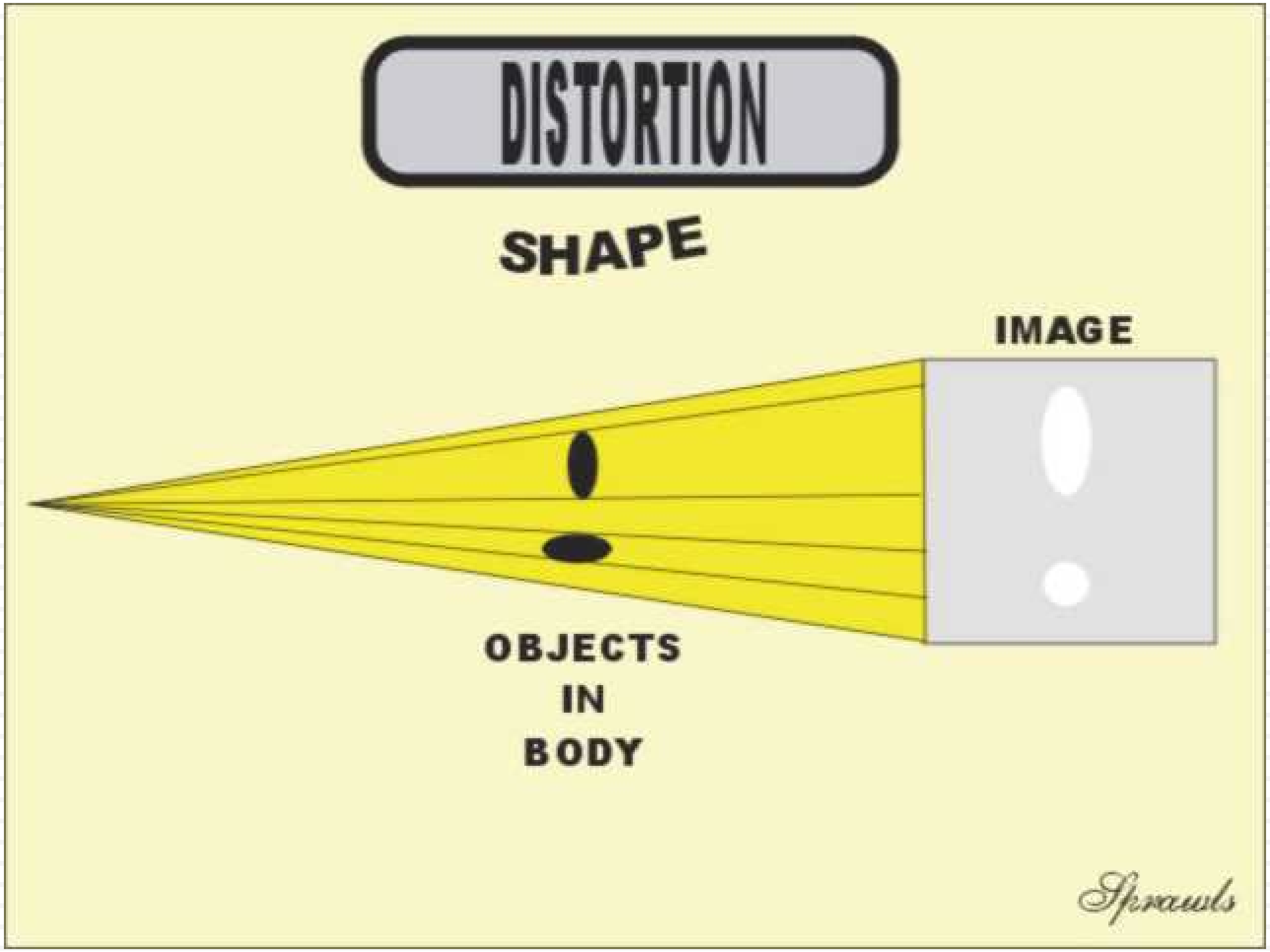
- An image should represent in an accurate way
  - Dimensions
  - Shape
  - Relative positions of the objects.

- Every imaging method can however introduce distortions in all these three factors.

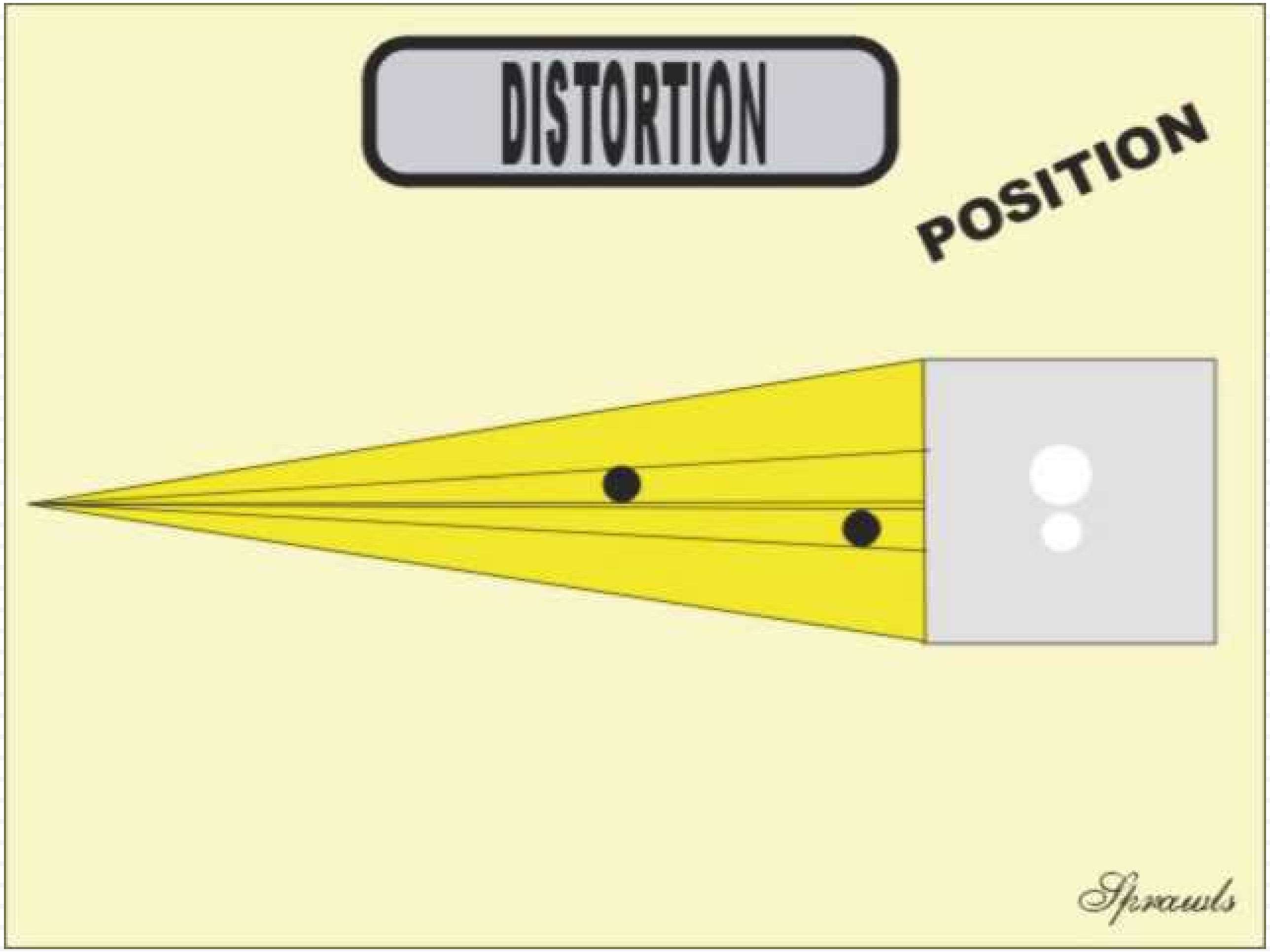
Distortions (size)



Distortions (shape)



Distortions (positions)



General concluding remarks

- In general, it would be advisable to optimize the various parameters of the measurement so that the maximal visibility is obtained.
- In many cases however changing one parameter improves one of the characteristic of the image, but other characteristics are worsened.
- Often one gets an improvement of the image to the detriment, for example, of the total time of the measurement, and this could lead to other possible inconvenients (increase of the exposure to radiations, possible movements of the patients, higher cost, etc.)
- One should therefore look for the best compromise among the different factors, according to the characteristics one desires to know best.