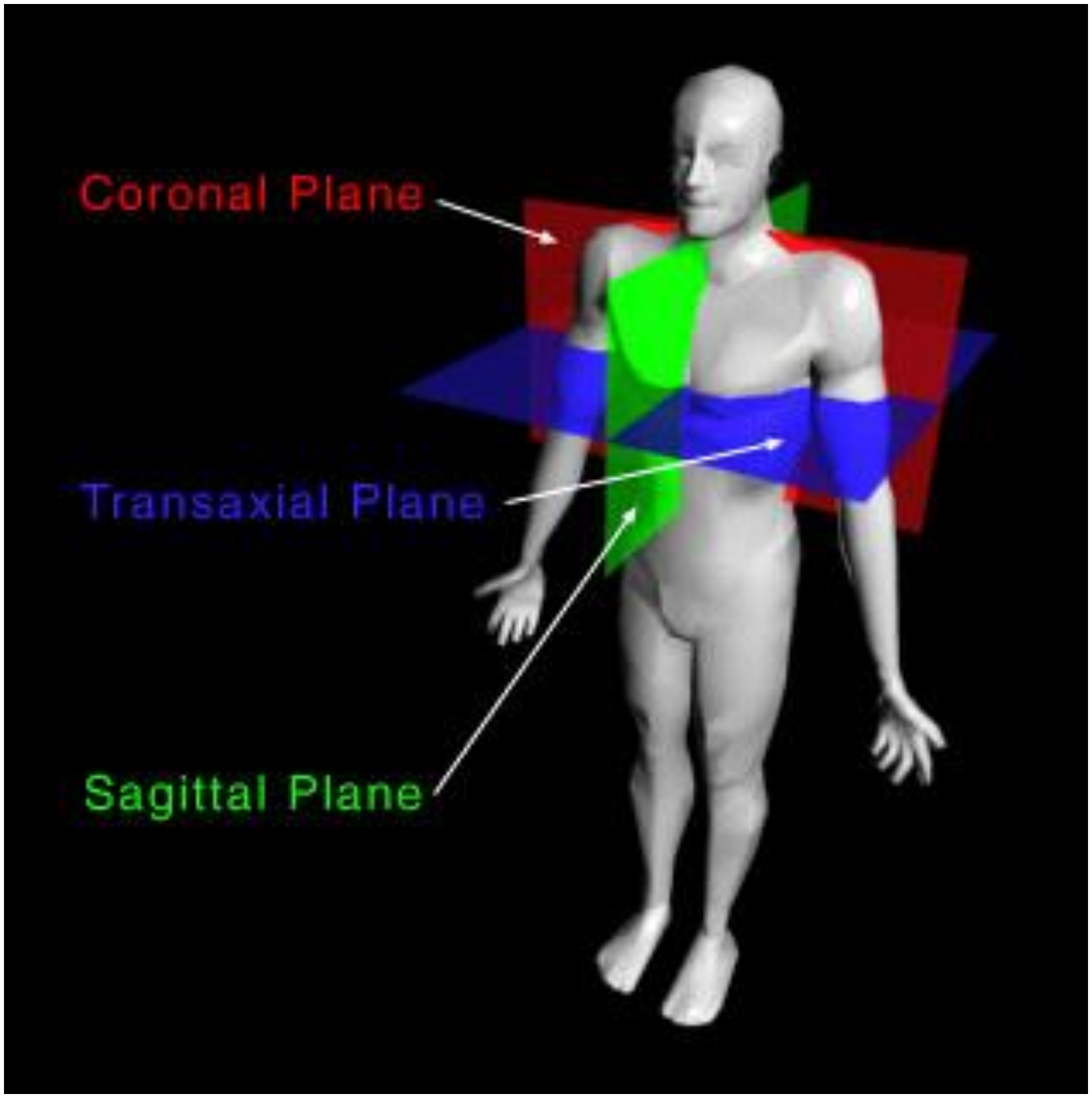
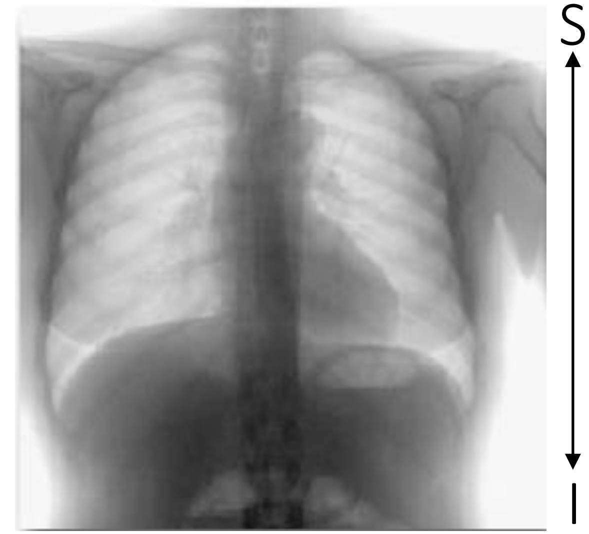
Basic principles of medical imaging

Image elements

Image orientation





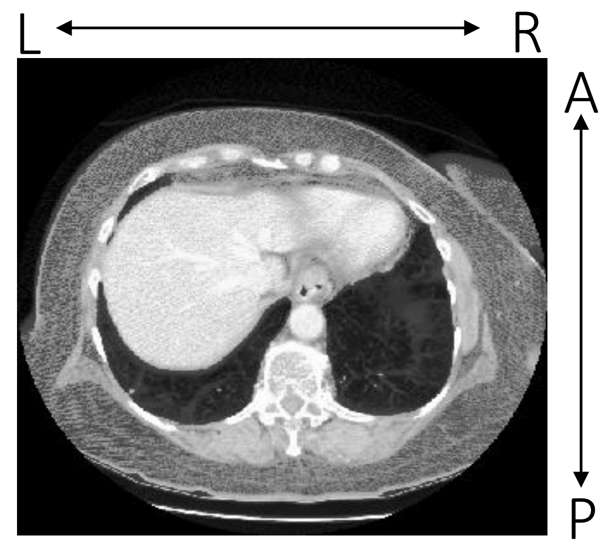


Image elements

Image volume, slice, voxel and field-of-view (FOV)

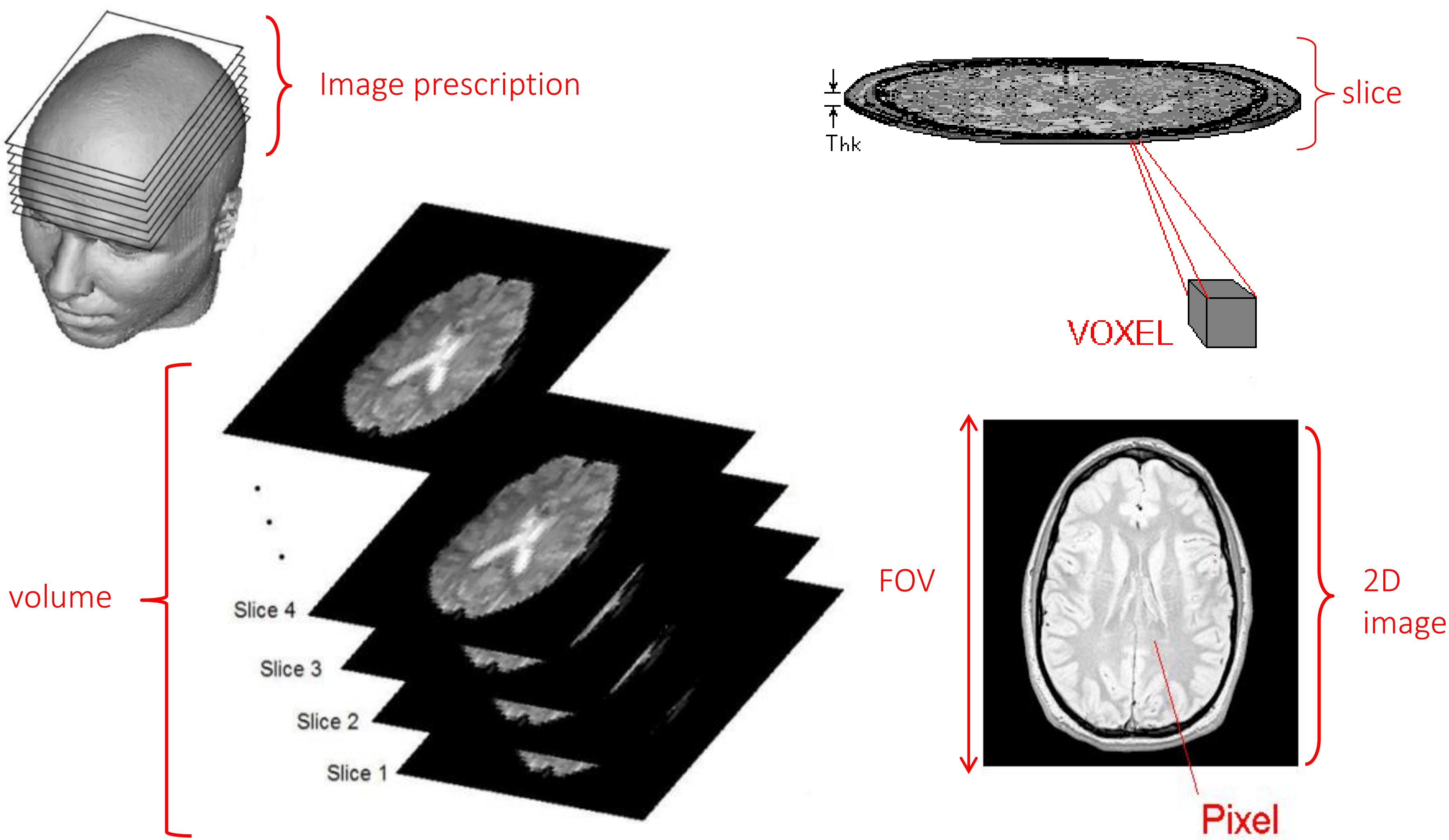
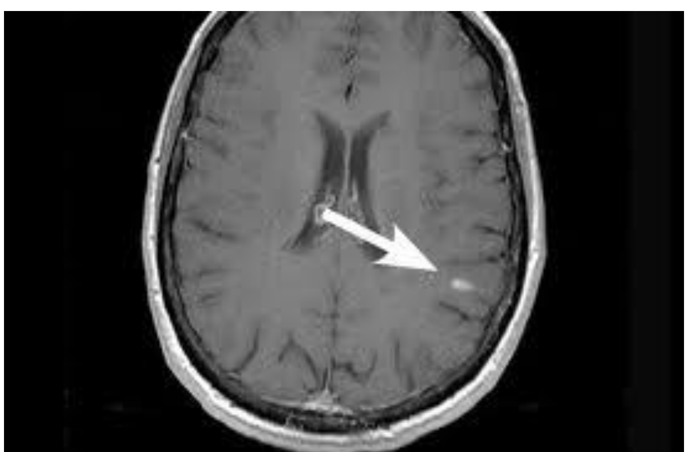


Image elements

Image contrast

Image contrast = difference in image intensity that makes an object distinguishable from another or from the background.

Image contrast depends on the tissue characteristics as well as the contrast sensitivity of the imaging system used.



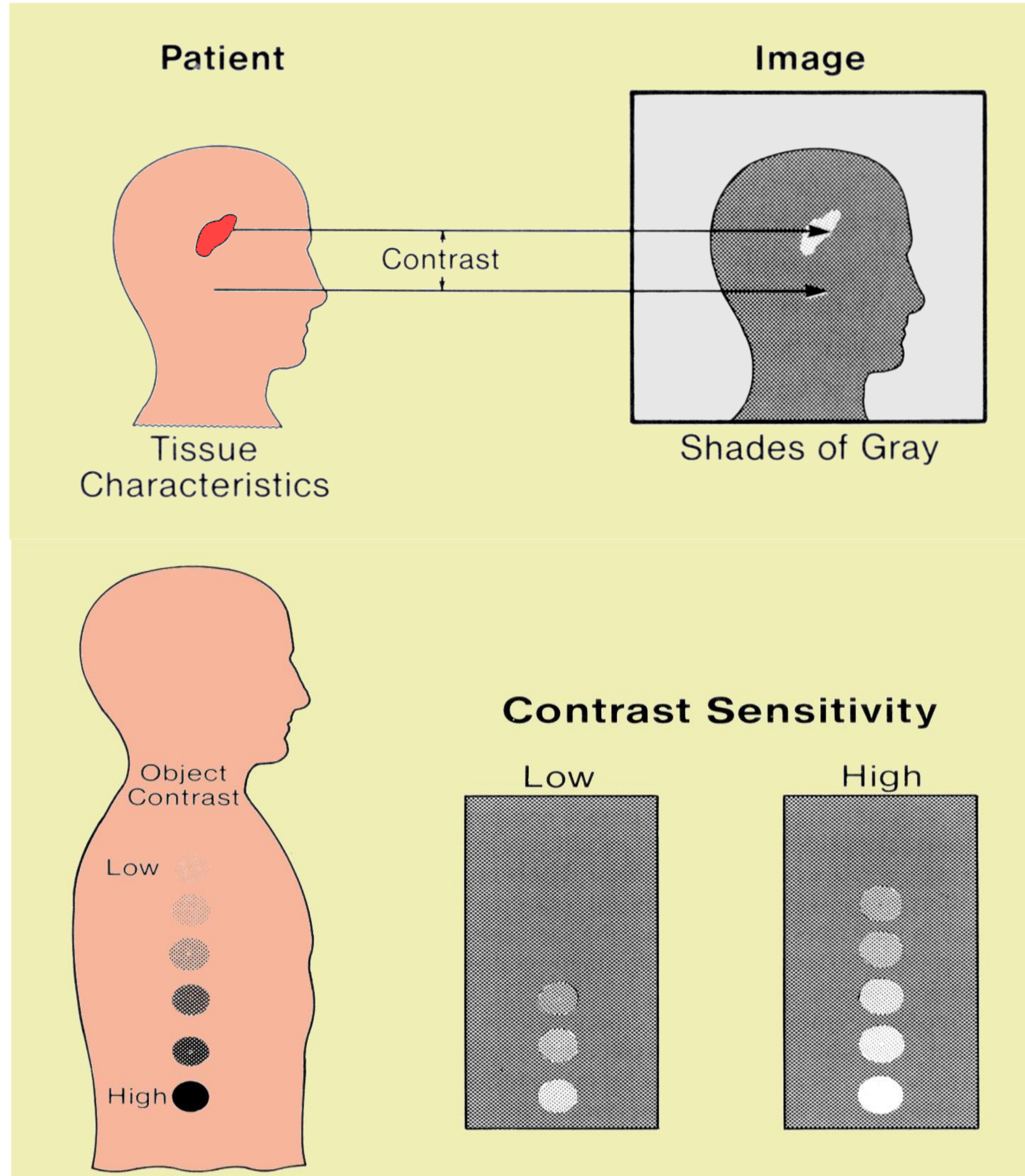
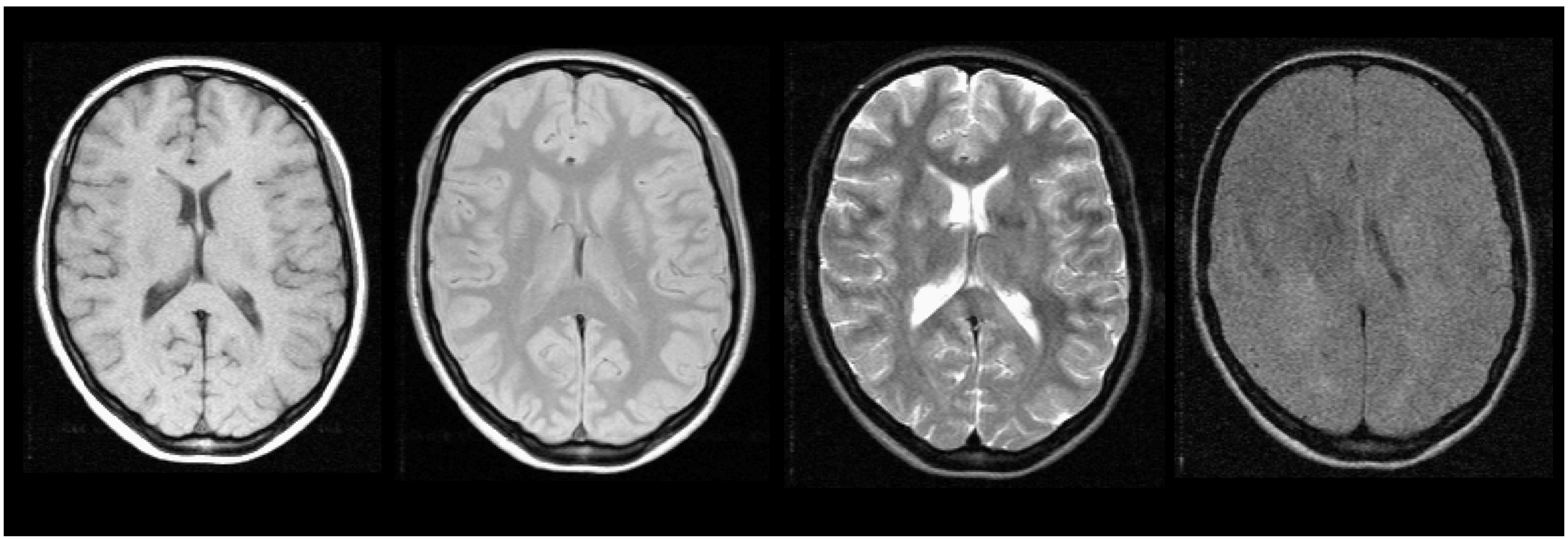


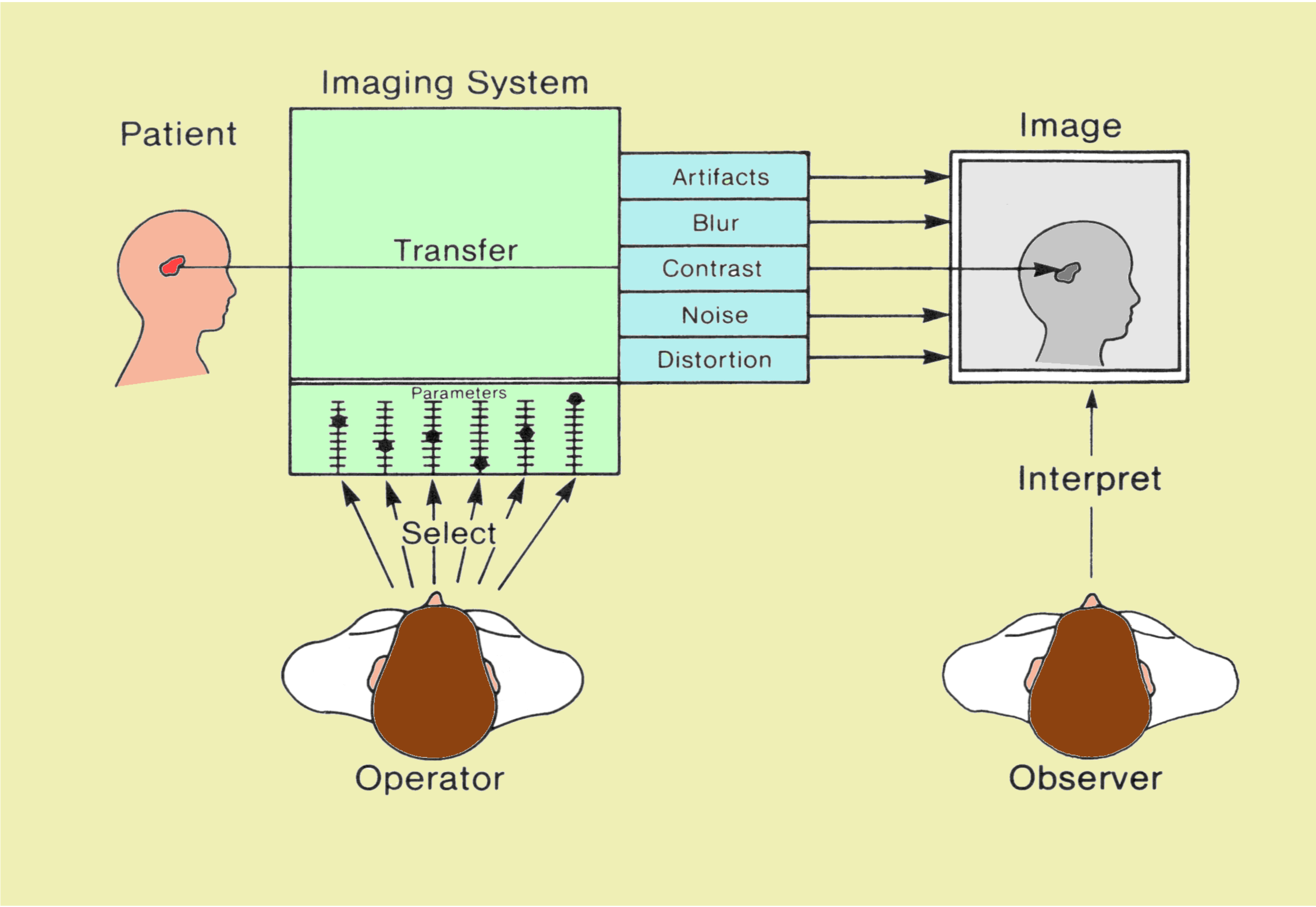
Image elements

Image contrast



Imaging principles

The imaging process

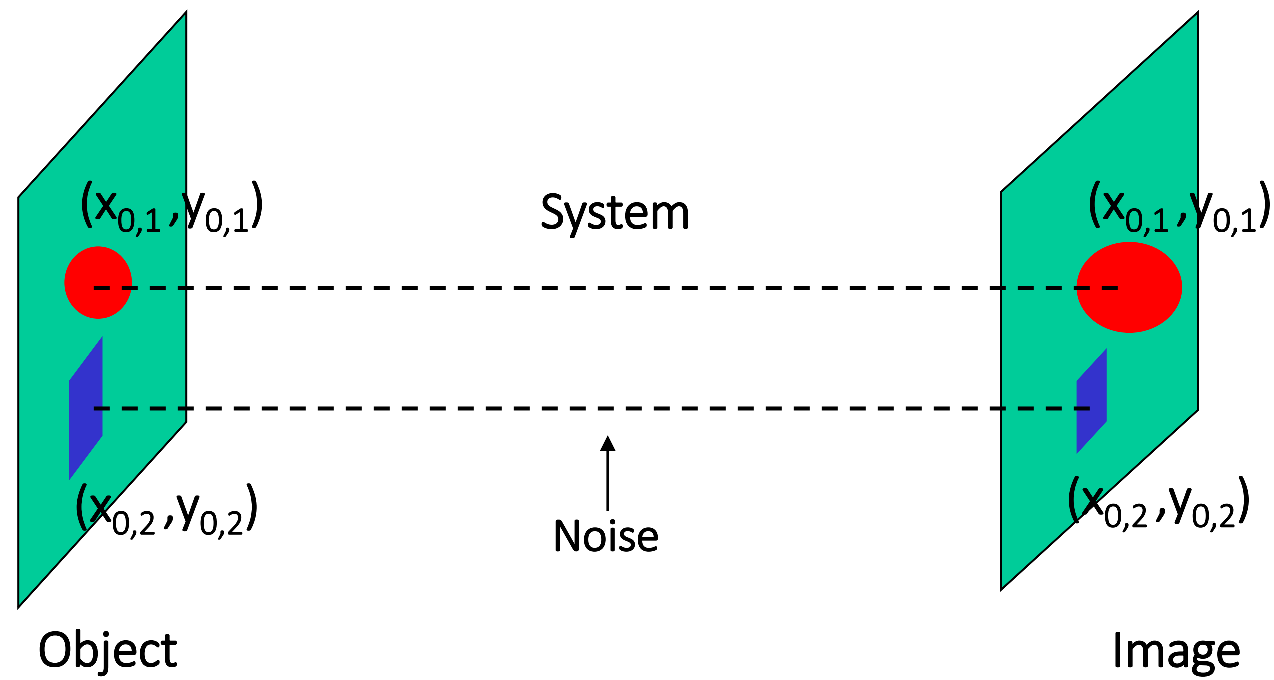


Imaging principles

In general:

$$I(x,y) = S\{O(x,y)\} + N(x,y)$$

$$I(x,y) = S\left\{ \iint\limits_{-\infty \to +\infty} O(x_0, y_0)\,\delta(x - x_0, y - y_0)\,dx_0 dy_0 \right\} + N(x,y)$$



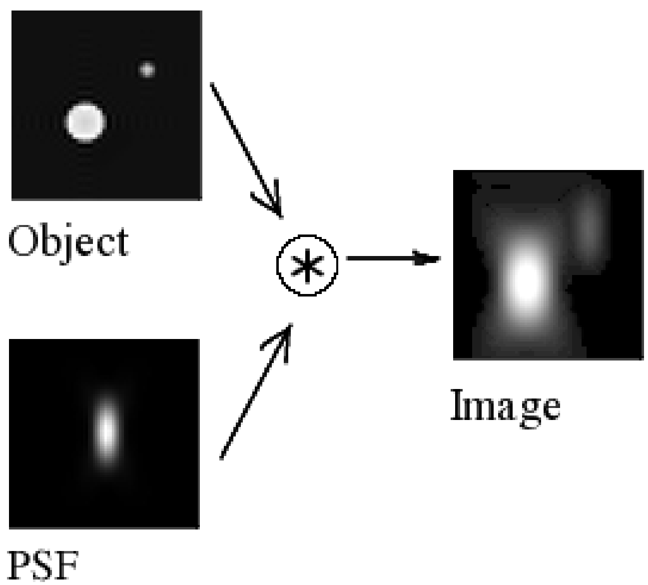
Imaging principles

For a spatially invariant system :

$$I(x,y) = \iint_{-\infty \to +\infty} O(x_0,y_0) PSF(x-x_0, y-y_0) dx_0 dy_0 + N(x,y)$$

$$\boxed{I(x,y) = O(x,y) \otimes PSF(x,y) + Noise}$$

PSF = Point Spread Function



Determinant factors (depend on modality):

$$h_{total} = h_{sensor} \otimes h_{sampling} \otimes h_{reconstruction} \otimes h_{filtering}$$

Ideal PSF:

$h(x,y,z) = \delta(x,y,z) \Rightarrow I = O,\ \delta$ = Dirac's delta

Most common PSF shapes: Gaussian, sinc, ...

Image properties

Spatial resolution

R = smallest distance between two point sources for which the sources can be resolved.

R is related with the system point spread function (PSF):

$$I(x,y,z) = PSF(x,y,z) \otimes O(x,y,z)$$

A common shape for the PSF is a Gaussian - in 1D:

(in this case, R~FWHM in each direction)

$$h(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{\sigma^2} \right),$$

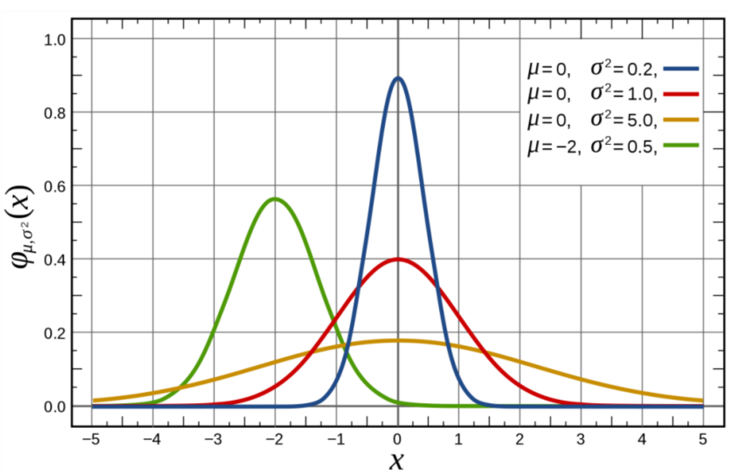
$$FWHM = 2\sqrt{2\ln(2\sigma)} \cong 2.36\sigma$$

The total imaging PSF results from several contributions:

$$PSF_{total} = PSF_1 \otimes \ldots \otimes PSF_N$$

... and so does the final image resolution:

$$R_{final} = \sqrt{R_1^{\ 2} + \ldots + R_N^{\ 2}}$$



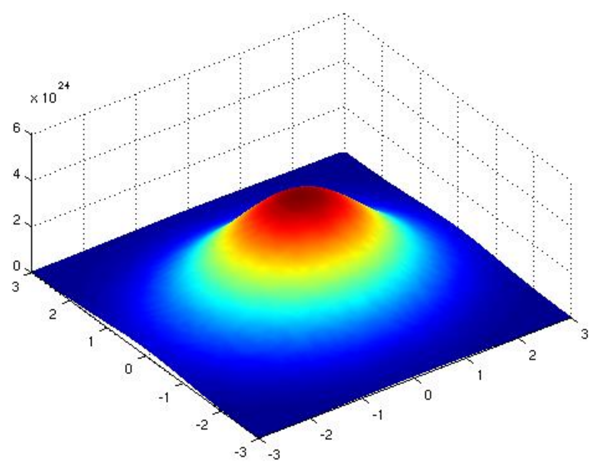


Image properties

Spatial resolution

Image resolution ~ pixel size

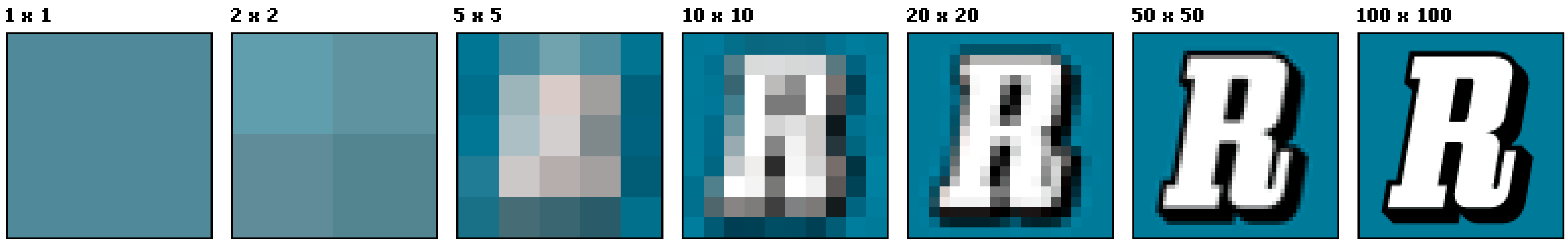


Image resolution = smallest distance between two point sources for which the sources can be resolved.

Image resolution depends on the imaging system and parameters used.

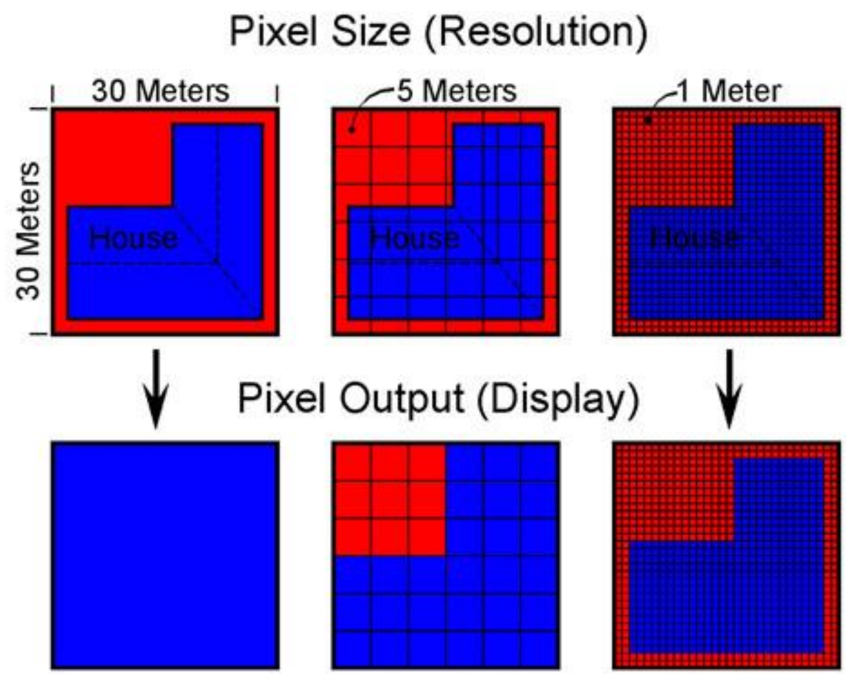


Image properties

Spatial resolution

Image properties

Signal-to-noise-ratio (SNR):

SNR ~ compares the level of a desired signal to the level of background noise.

"Signal processing" definition: $\mathrm{SNR} = \frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}},$ (power of signal over power of noise)

"Medical imaging" definition: $\mathrm{SNR} = \frac{\mu}{\sigma}$ (mean signal over SD of noise)

Image SNR depends on

the available object signal and

on the imaging system noise

characteristics.

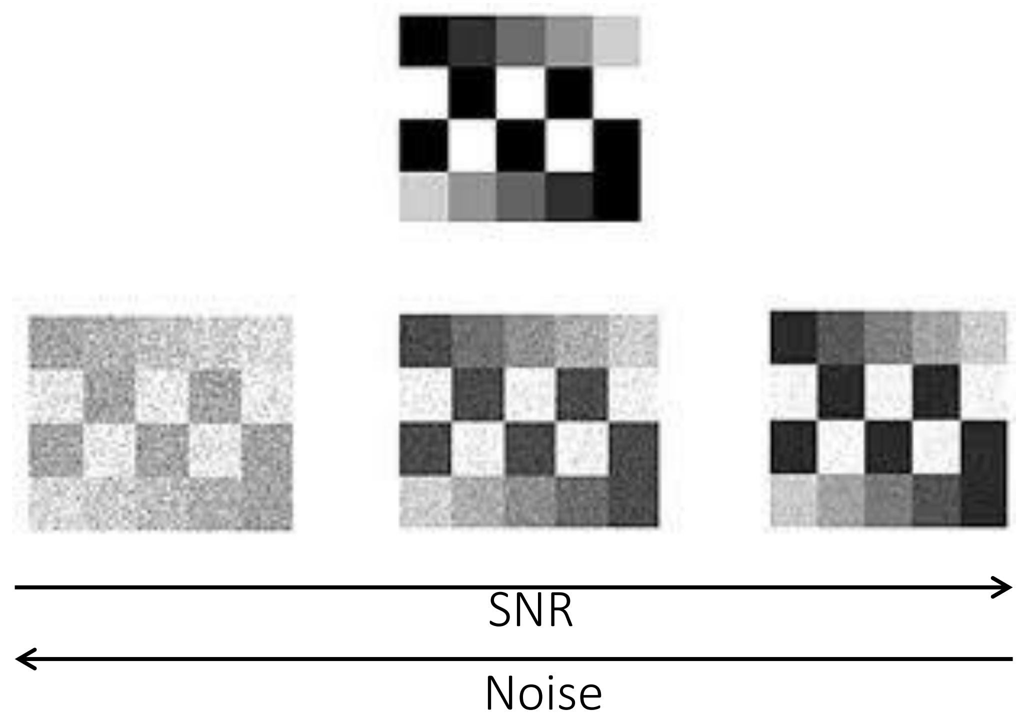


Image properties

Signal-to-noise-ratio (SNR):

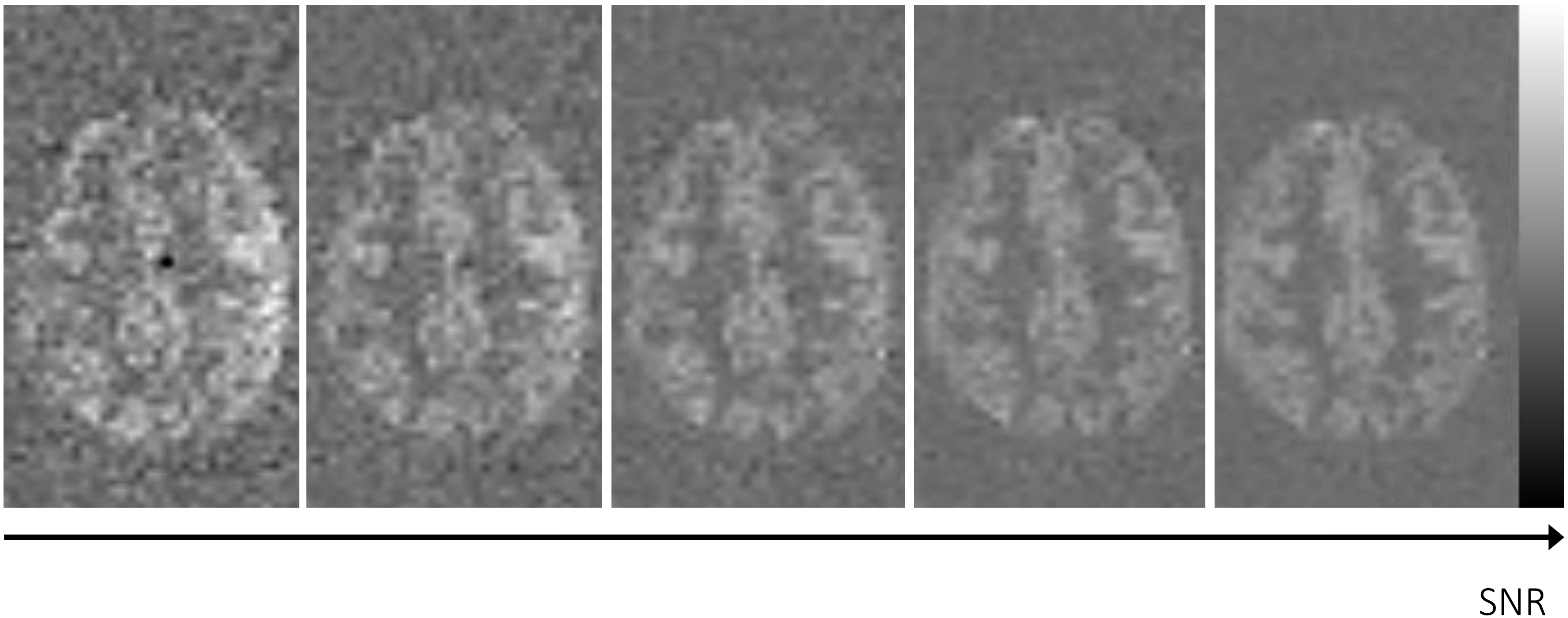


Image properties

Contrast-to-noise ratio (CNR):

CNR ~ compares the image contrast between regions-of-interest A and B to the level of background noise.

$$C = \frac{|S_A - S_B|}{\sigma_o}$$

Image CNR depends on

the tissue contrast,

the object size and the

contrast sensitivity, image

resolution and SNR of the

imaging system.

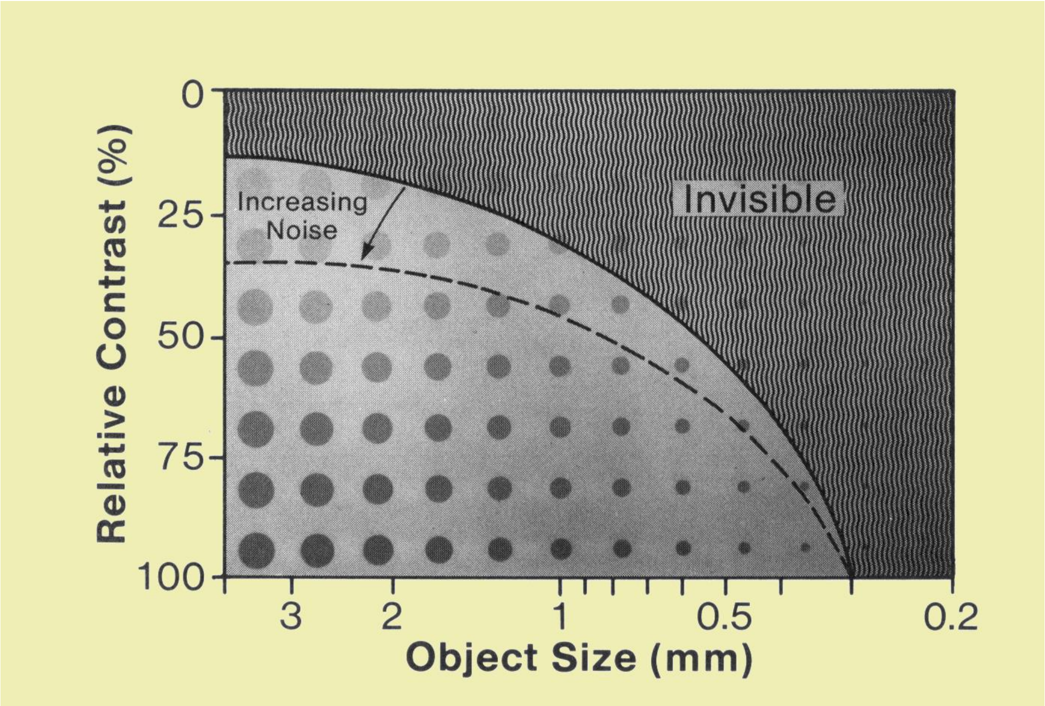


Image properties

Main image characteristics:

Spatial resolution = minimum point separation (R): PSF

Signal-to-noise-ratio (SNR): Object, Noise

Contrast-to-noise ratio (CNR): Object, Noise, PSF

CT, PET, SPECT: $\boxed{SNR = N/\sigma \propto \sqrt{N}}$

N = number of photons X ou γ, following a Poisson distribution,
σ = standard deviation

MRI: $\boxed{SNR = \hat{s}/\sigma_{\xi}\ , SNR_N \propto SNR\sqrt{N}}$

s = mean signal;
σ_{ξ} = standard deviation of the noise
N = number of repetitions