The EUROPEAN SCIENTIFIC INSTITUTE

In ARCHAMPS, 7 Km from downtown GENEVA

Fifty minutes from Chamonix-Mont-Blanc

organises two schools

ESMP : European School of Medical Physics

In partnership with the European Federation of Organisations in Medical Physics (EFOMP)

2012 :15th SESSION of ESMP

Lecture presented in Archamps (Salève Building) by :

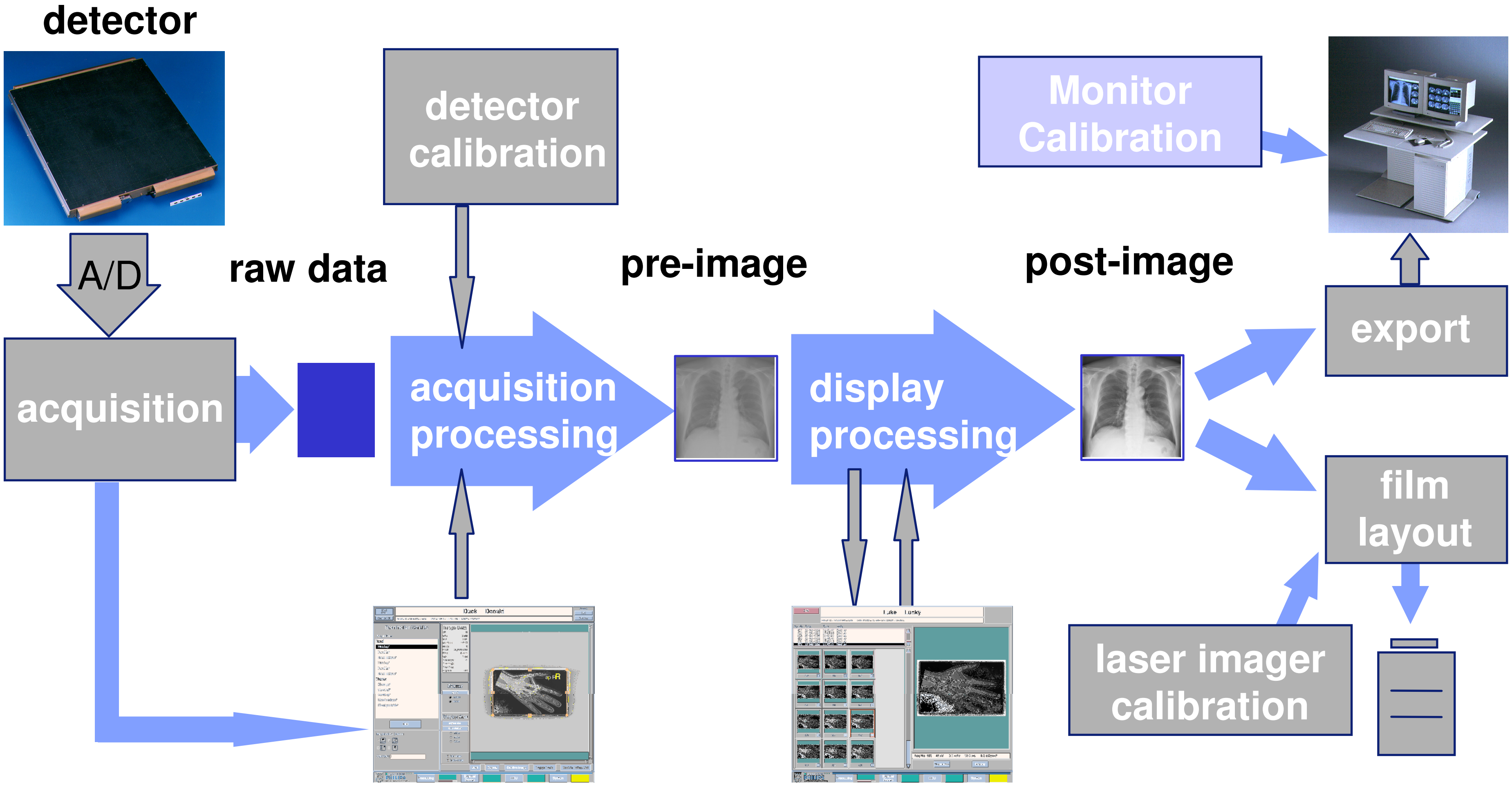
Karl-Freidrich KAMM (Hamburg)

Basic Aspects -
Quality and Processing
of Digital Images

Karl-Friedrich Kamm

Hamburg-Norderstedt, Germany

Steps of image processing



detector

A/D

raw data

acquisition

detector calibration

acquisition processing

pre-image

display processing

post-image

Monitor Calibration

export

film layout

laser imager calibration

Check of exposure

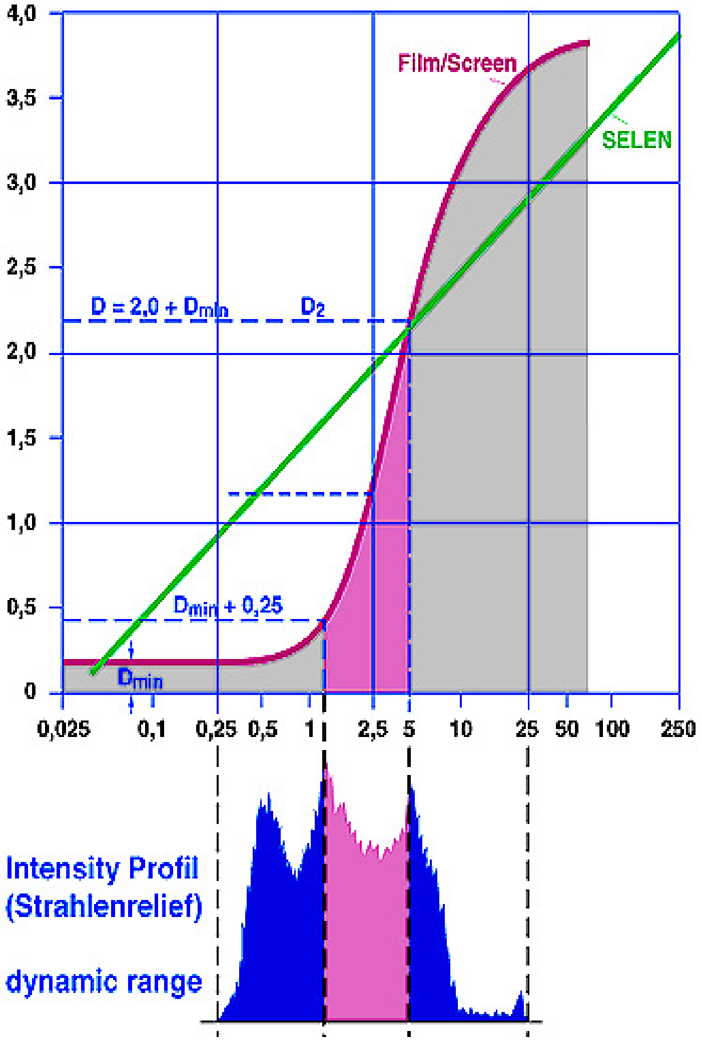
Survey image

Film

Properties of detection

Optical
Density /
pixel value

output



characteristic
curve
(characteristic
function)

Exposure
Dose (µGy)

input

Definitions of Contrast

1. Modulation $m = \frac{L_1 - L_2}{L_1 + L_2}$ $0 \ldots 1$

2. Contrast $k_1 = \frac{L_1 - L_2}{L_1}$ $0 \ldots 1$,

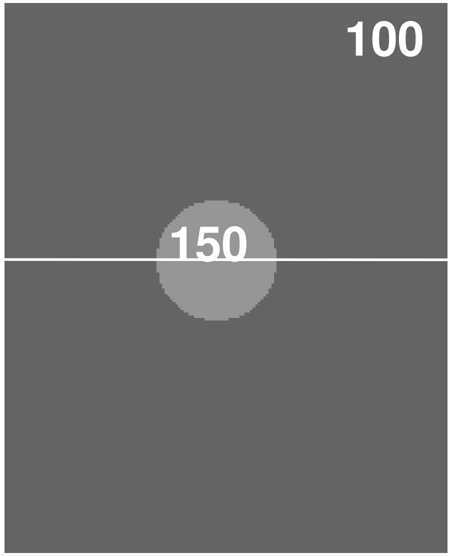
3. Contrast $k_2 = \frac{L_1 - L_2}{L_2}$ $0 \ldots \infty$,

4. Film Contrast $k_1 = \log\frac{L_1}{L_2} = D_1 - D_2$ $0 \ldots \infty$

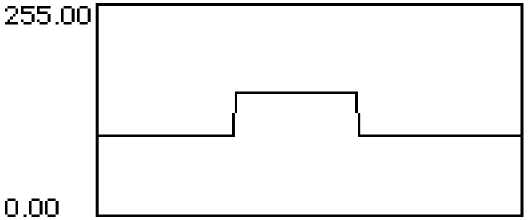
L = Luminance, Intensity, $L_1 > L_2$ **D = Optical Density**

Definition of Contrast

Image



Intensity



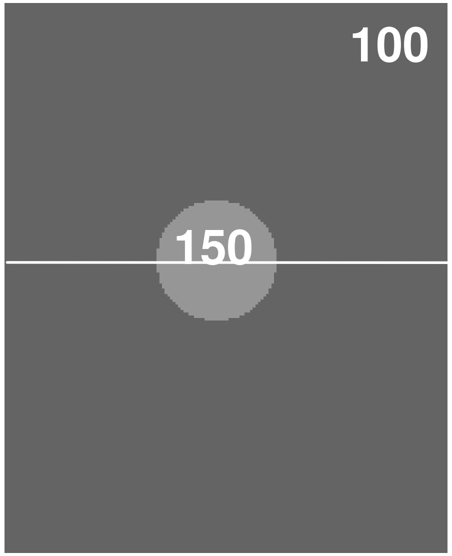
Crosscut

$$\text{Contrast} = \frac{150 - 100}{100} = 0.5$$

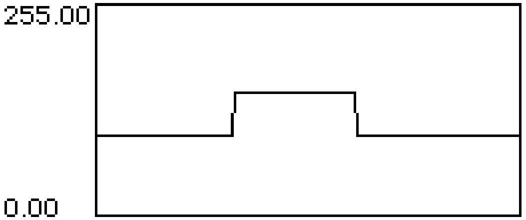
$$\text{Contrast} = \frac{\text{Intensity of object - Intensity of environment}}{\text{Intensity of environment}}$$

Definition of Modulation

Image



Intensity



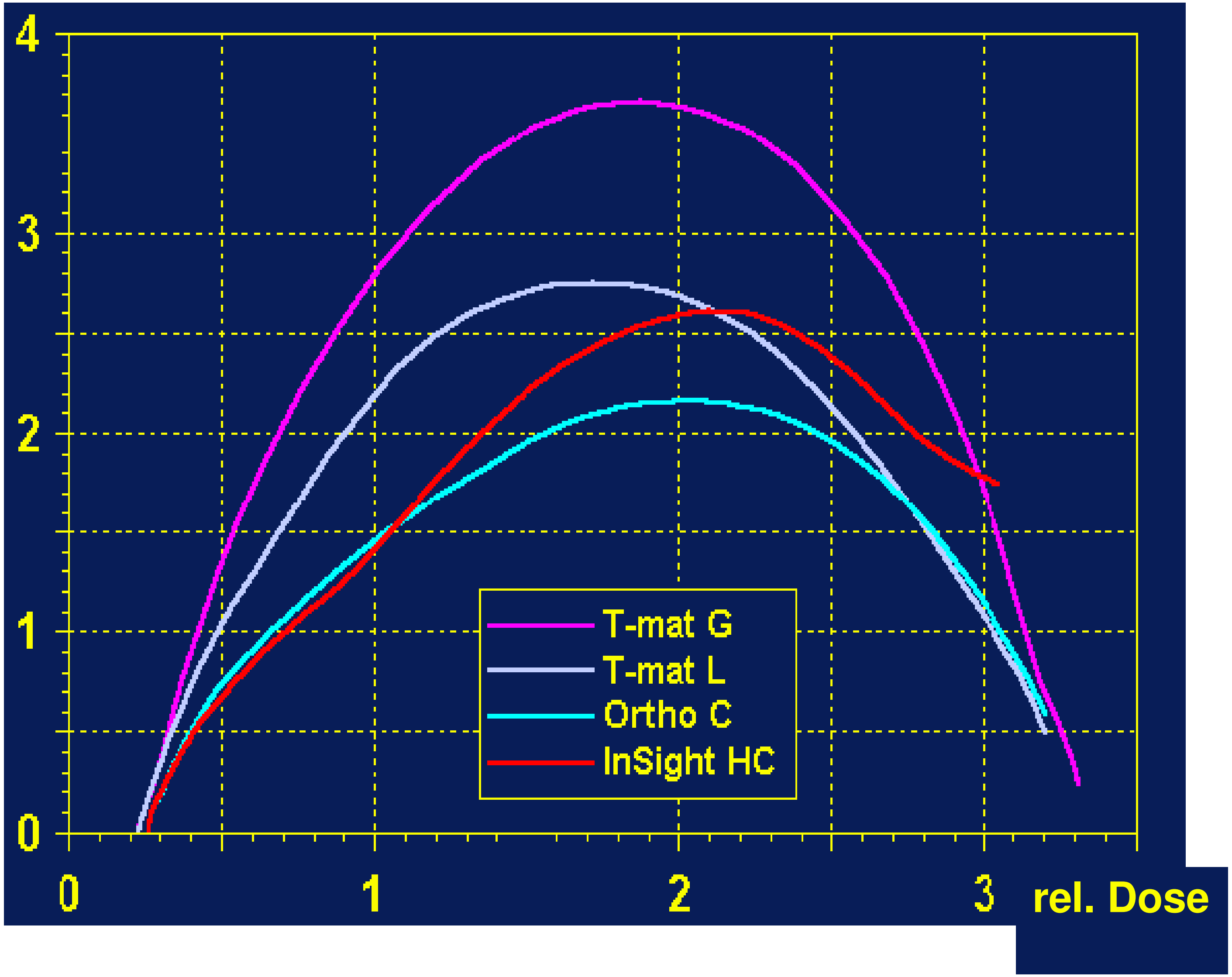
Crosscut

$$\text{Modulation} = \frac{150 - 100}{100 + 150} = 0.2$$

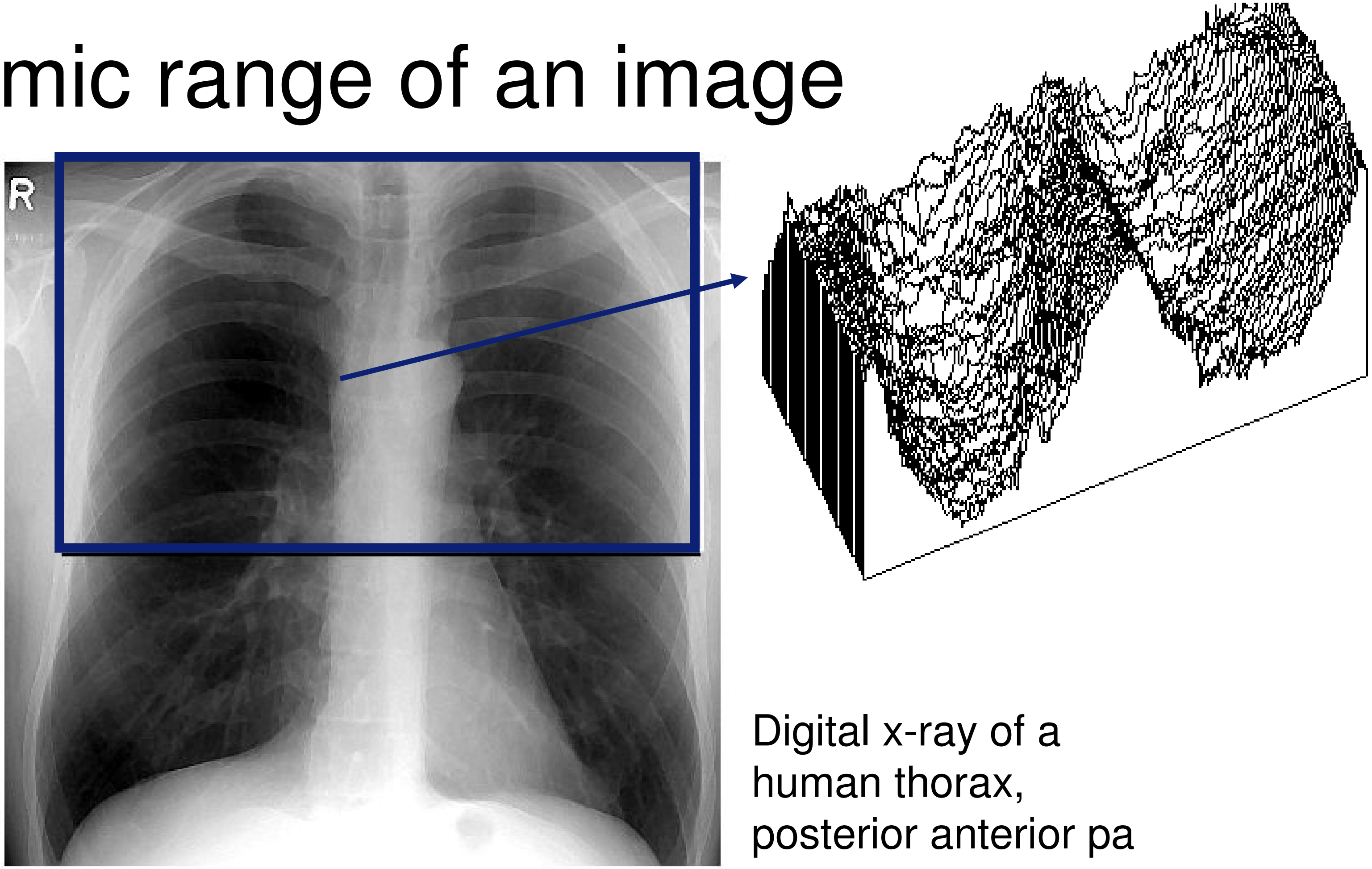
$$\text{Modulation} = \frac{\text{Intensity of object} - \text{Intensity of environment}}{\text{Intensity of environment} + \text{Intensity of object}}$$

Range : 0 . . . 1

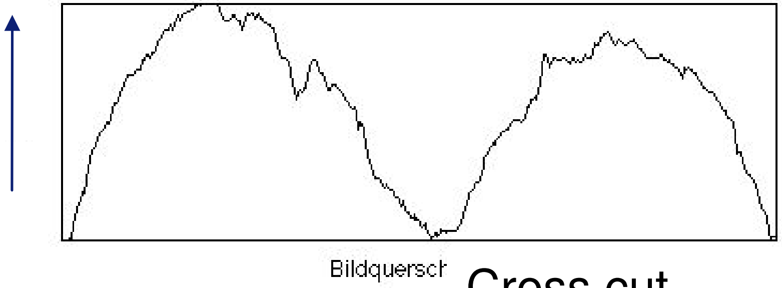
Contrast curves classical film screen combinations



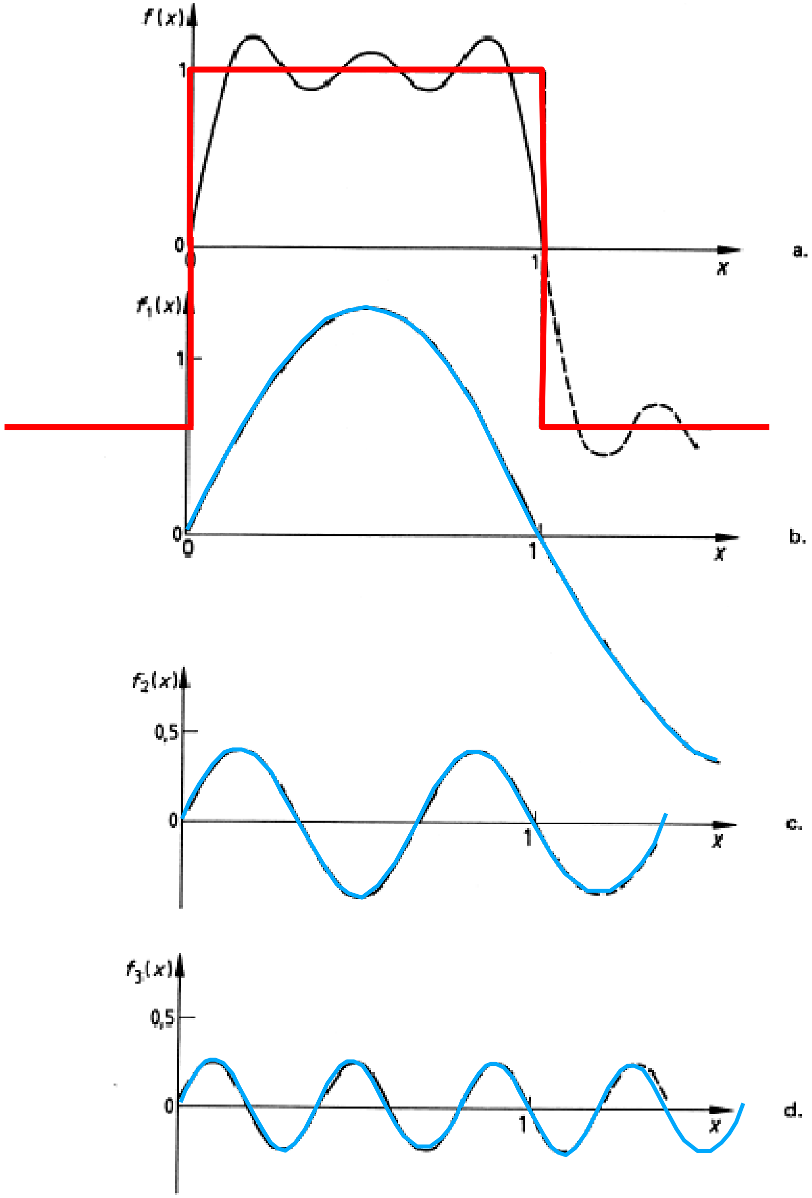
Dynamic range of an image



Digital x-ray of a
human thorax,
posterior anterior pa



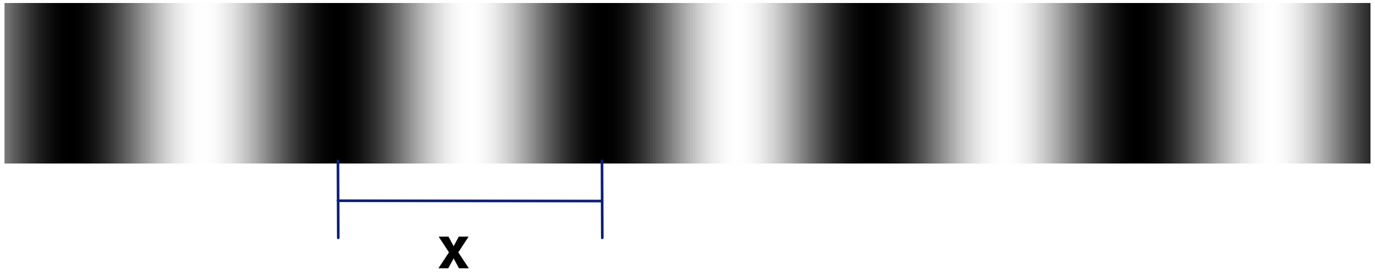
Fourier Transformation



decomposition of an arbitrary signal

by a sum of well defined signals, e.g. sinusoidal waves

Definition of Spatial Frequency



Spatial Frequency = Number of periodical variations of bright and dark areas in an image,
related to the distance
(so called Line pairs , Lp)

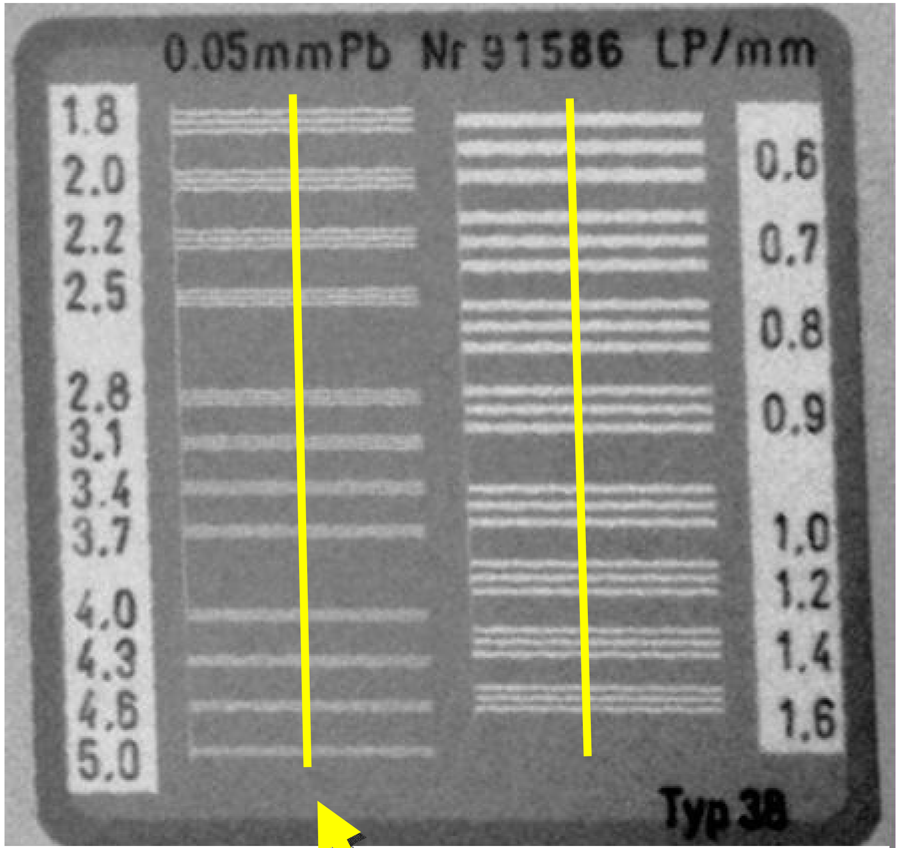
$$f = \frac{1}{x}$$

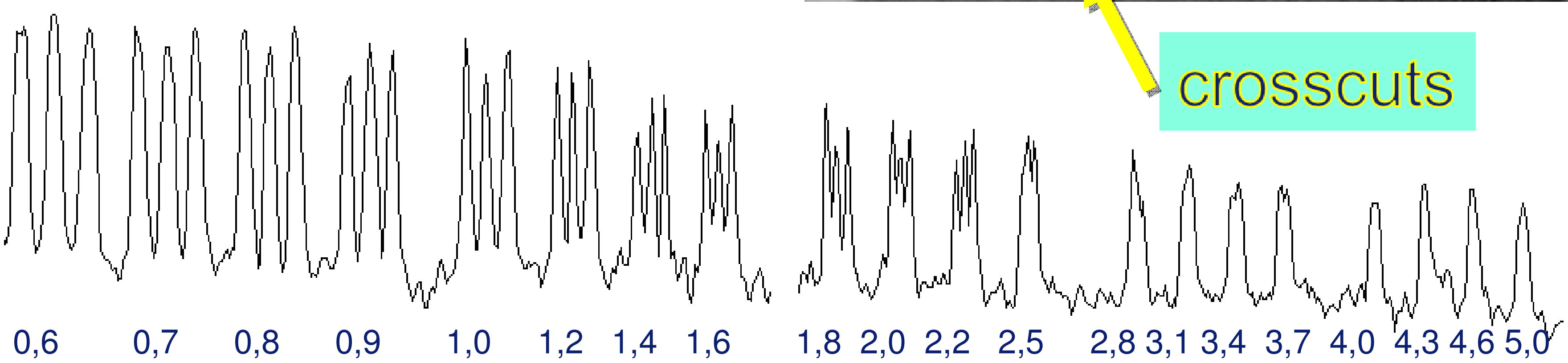
Unit: mm^{-1}

resolution test object

leaden stripes, Pb
with varying width and
0.05 mm thickness

Unit: line pairs per mm

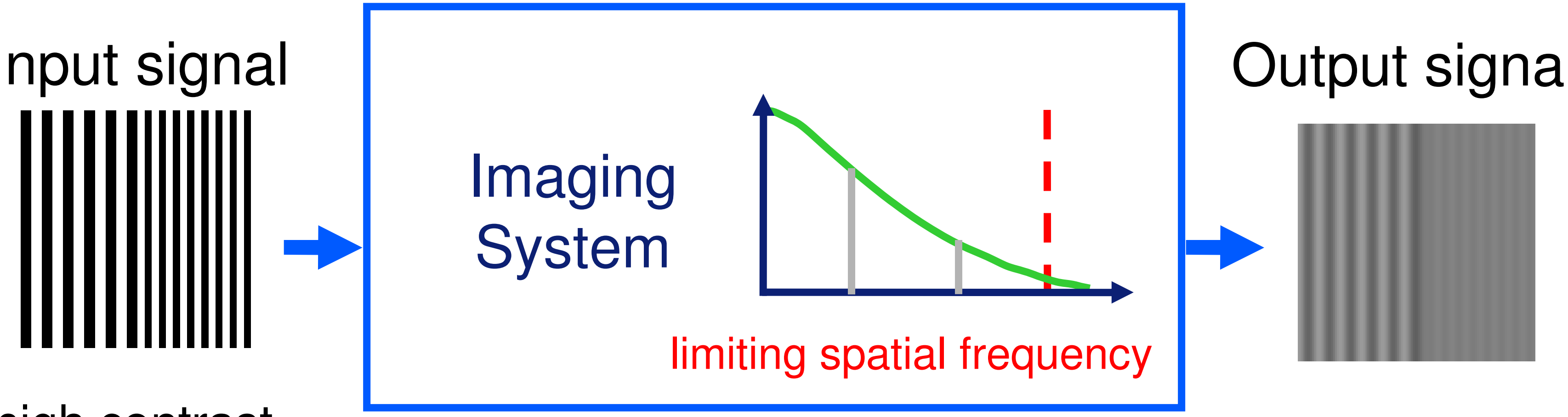




Measurement of the Modulation Transfer Function, MTF

bar pattern with different frequencies but same amplitude

system response with same frequencies but different amplitudes



Input signal

Imaging System

limiting spatial frequency

Output signal

high contrast test structures, two frequences

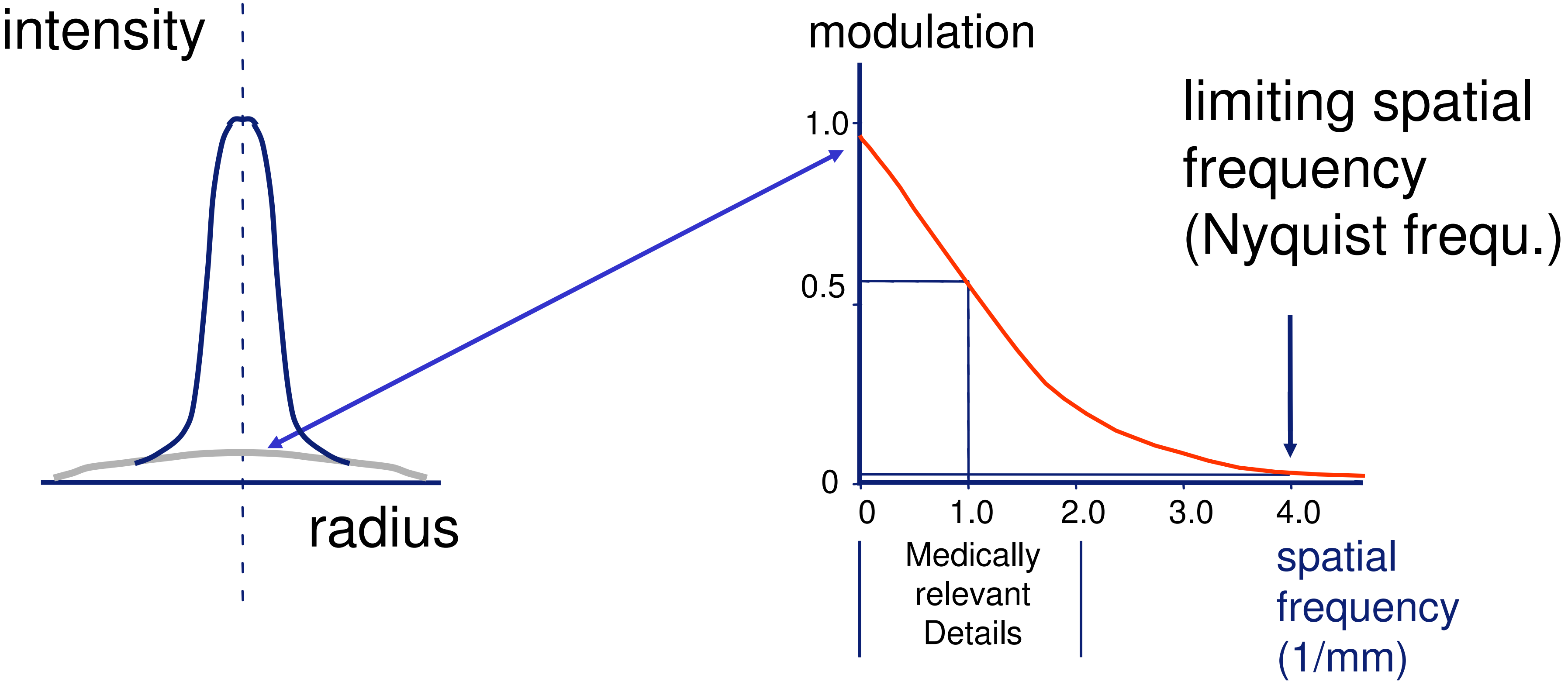
two frequencies with reduced contrast

Point Spread Function
PSF

Modulation- Transfer - Function
MTF

Spatial domain ⟷ Frequency domain

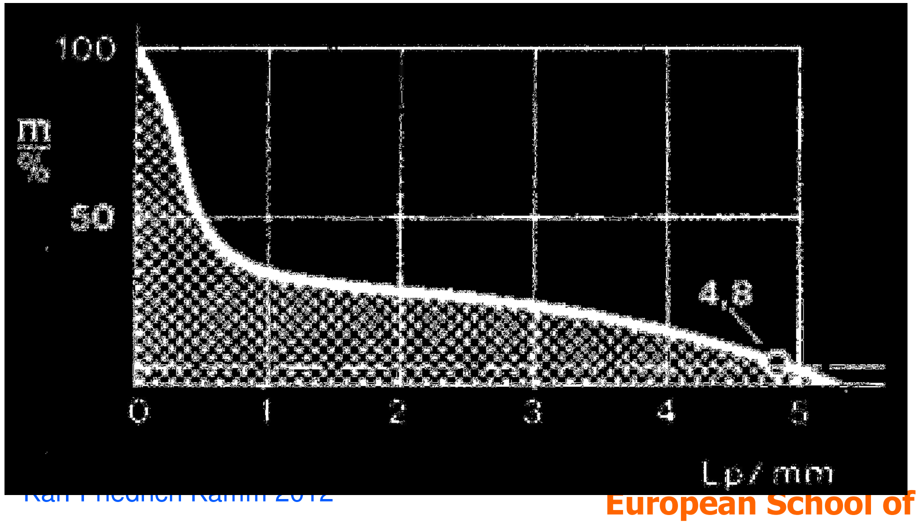
Fourier -Transformation

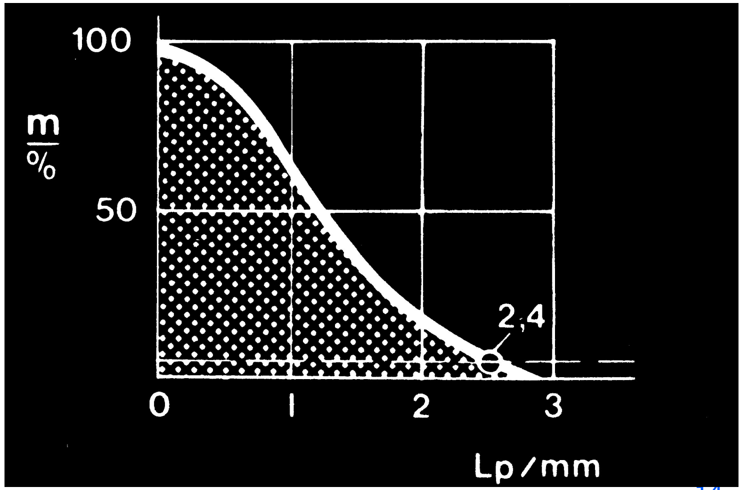


Comparison of Modulation Transfer Functions

same input image
+
different imaging system
+
resulting MTFs

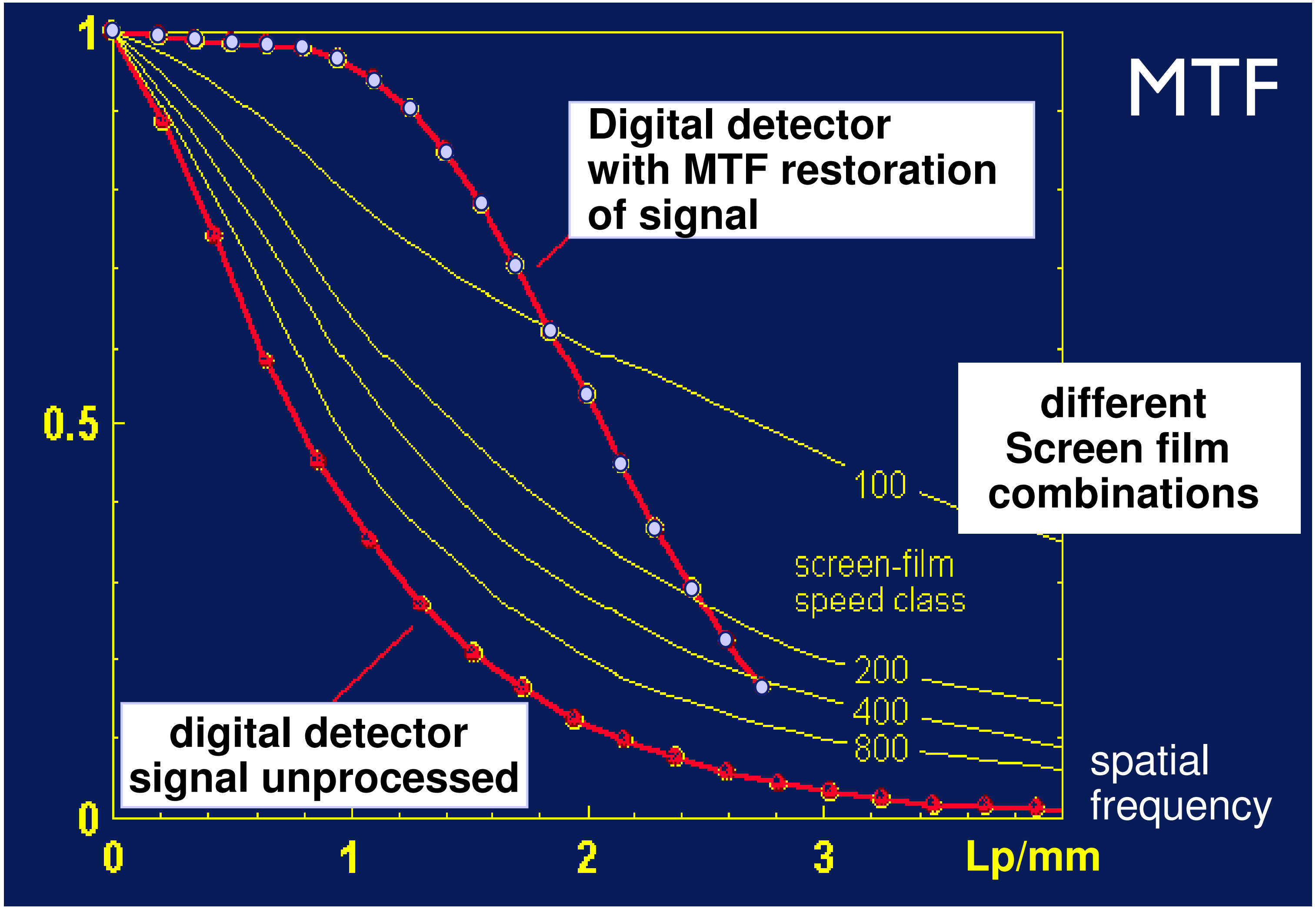
by
Heynacher,Köber,1964



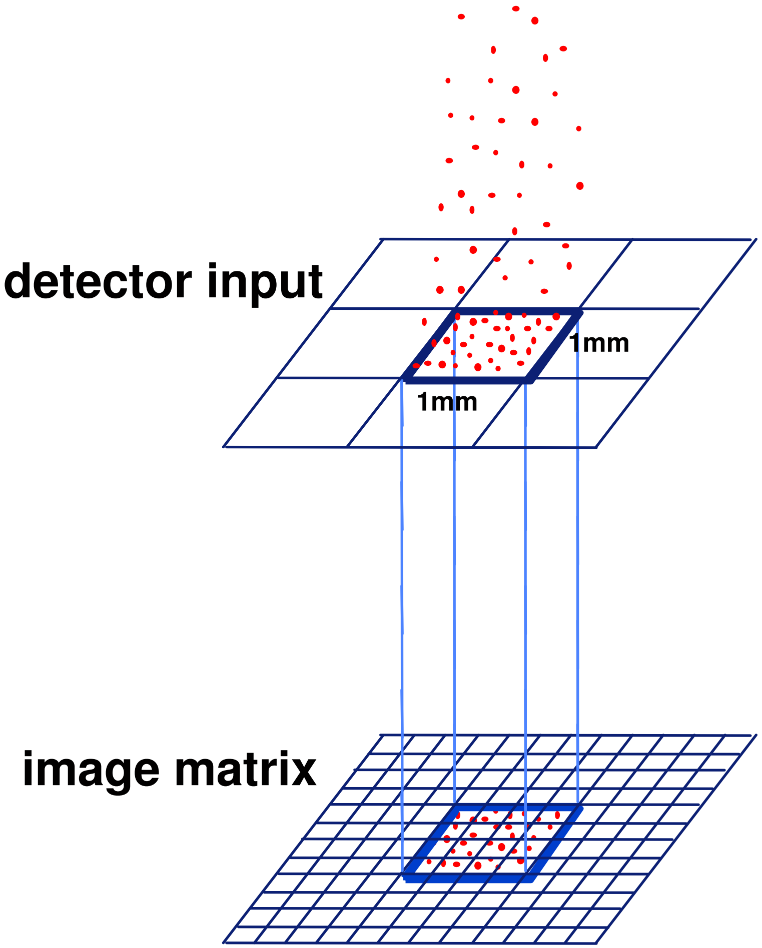


Comparison of Modulation Transfer Functions

Modulation



Quanta per pixel



radiation dose
at entrance of detector
Kerma
(kinetic energy released on matter)

2.5 µGy

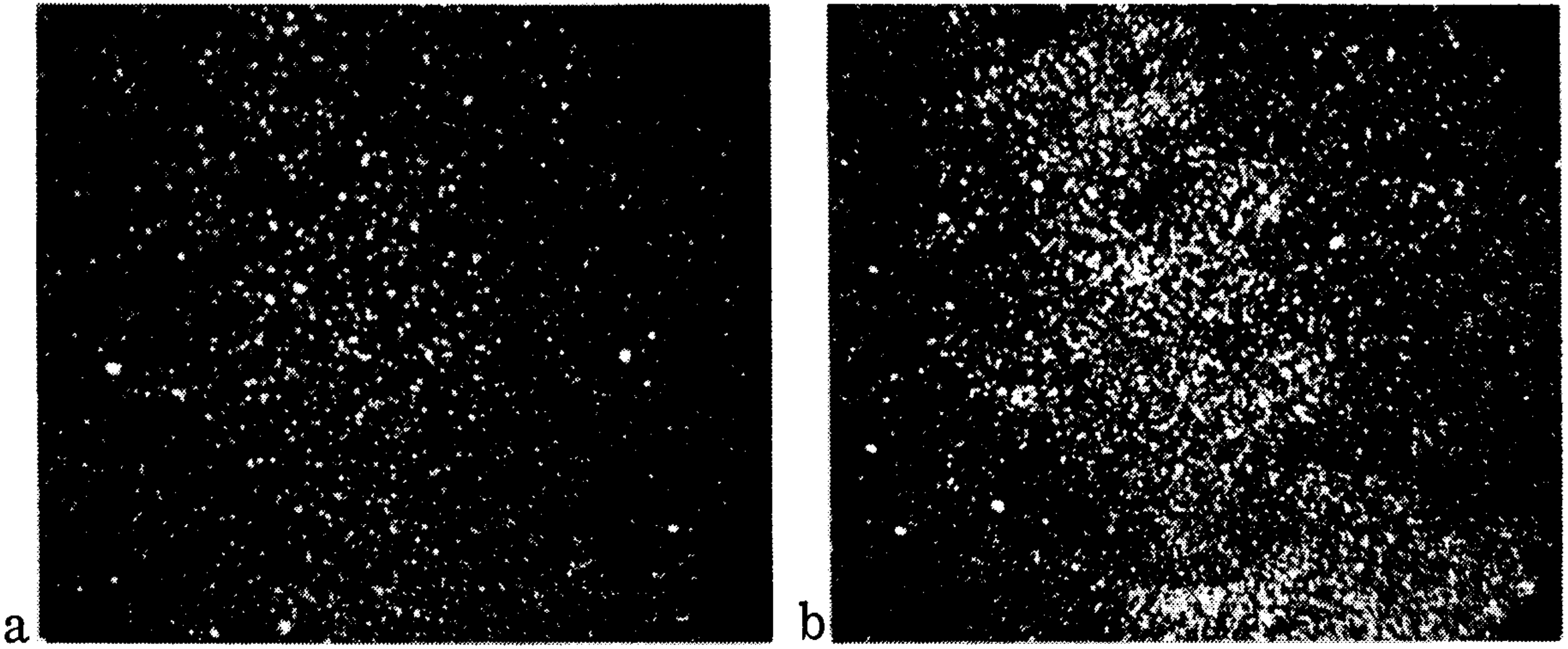
equivalent to

70.000 quanta / mm^2

~ 4.400 quanta / pixel

~ 250 µm pixel size

Influence of noise

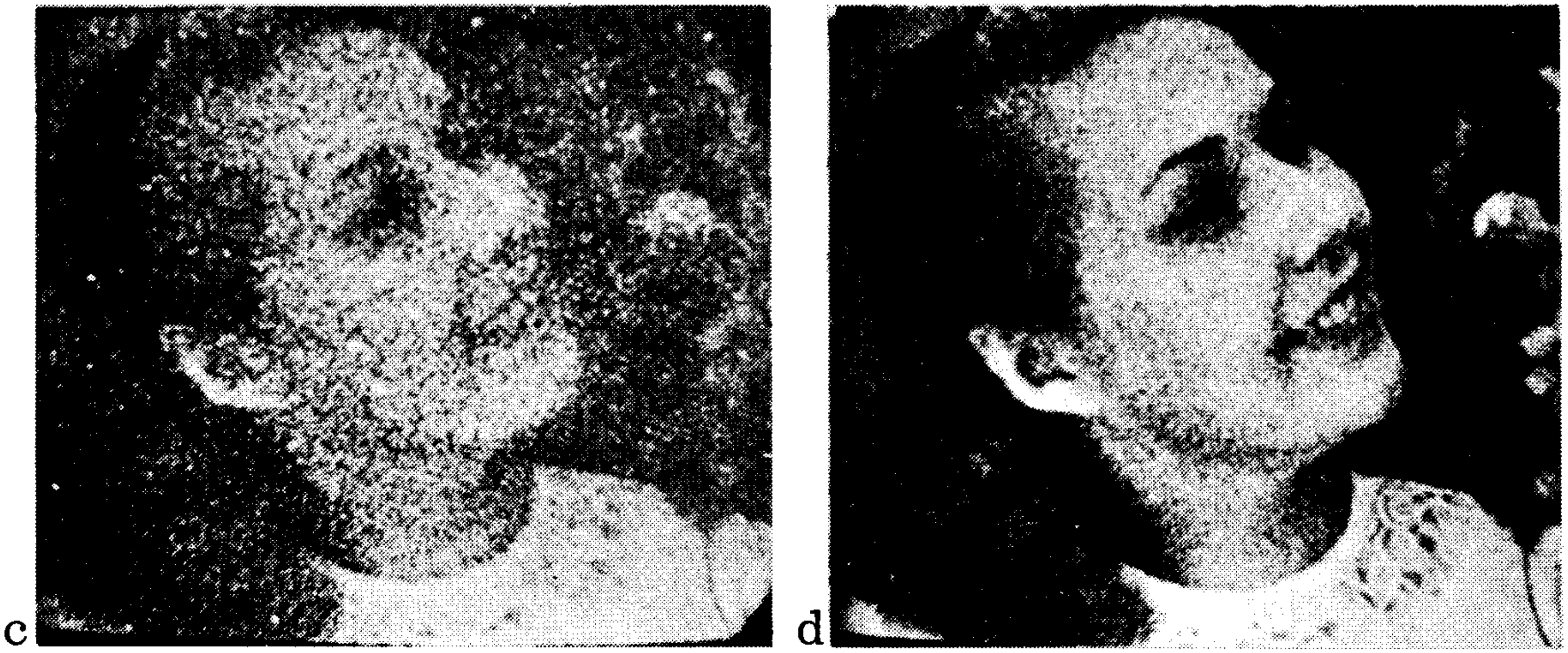


3000 Photons

12 000 Photons

From A. Rose, Vision, 1973

Influence of noise



93 000 Photons 760 000 Photons

From A. Rose, Vision, 1973

Influence of noise

e

3 600 000 Photons

f

28 000 000 Photons

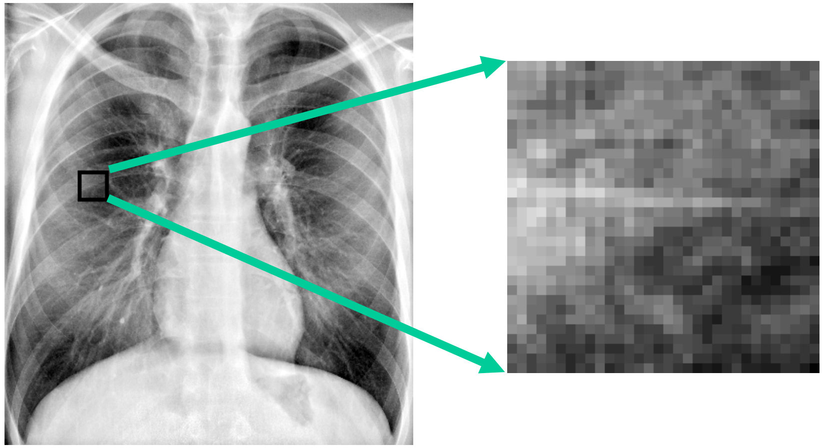
From A. Rose, Vision, 1973

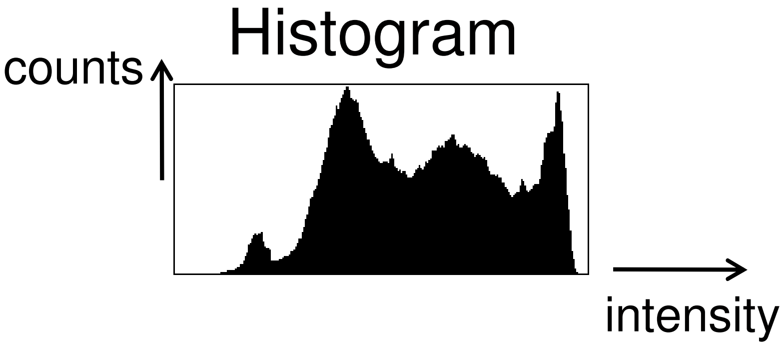
Histogram of an image

procedure:

- discretisation of the image
    - small fields and
    - defined number of intensity steps
- determination of the mean intensity value of each field
- evaluation of all fields
- counting the number of fields for each intensity step
- graphical representation of all counts for all intensity steps

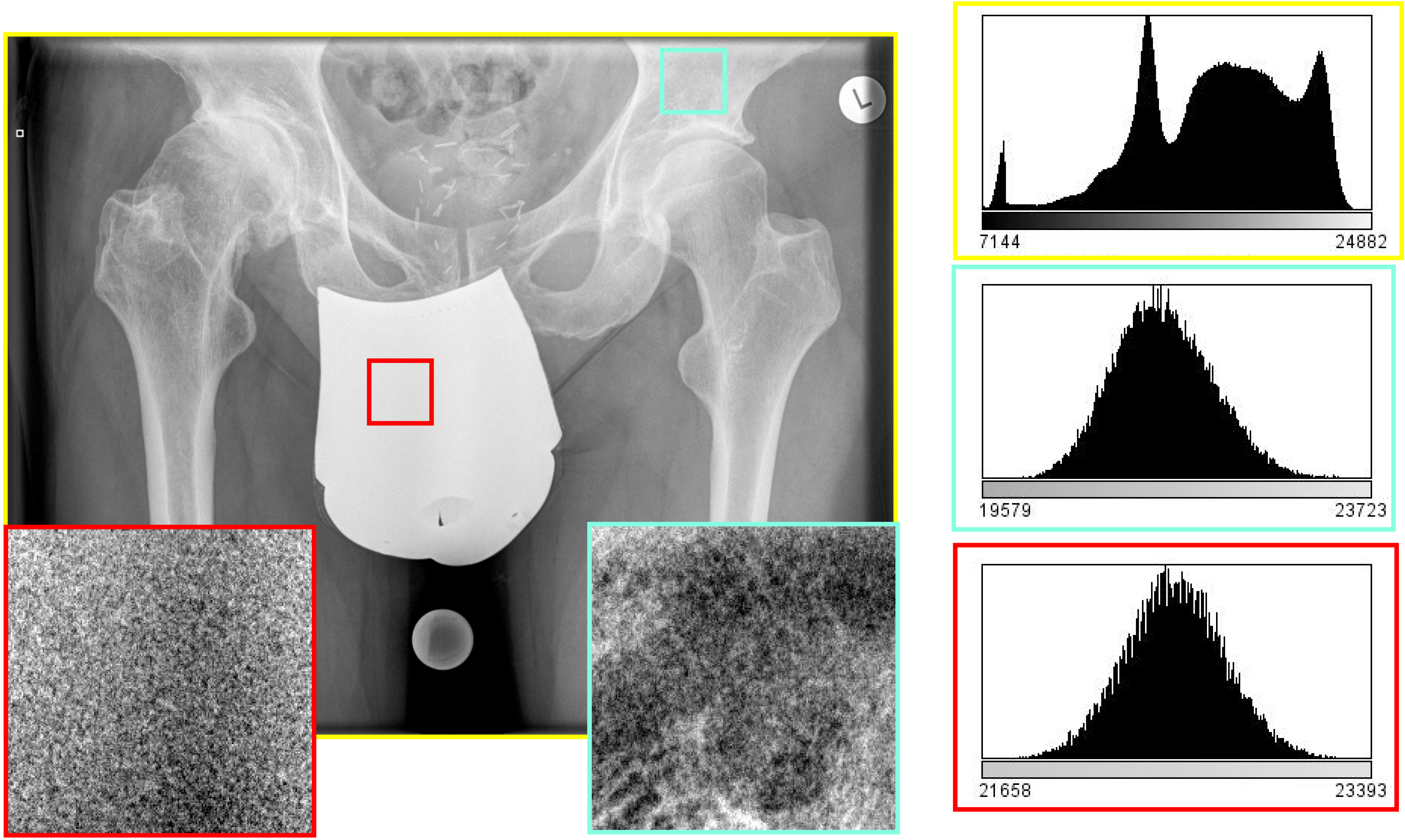
„characteristic“ for a specific exposure



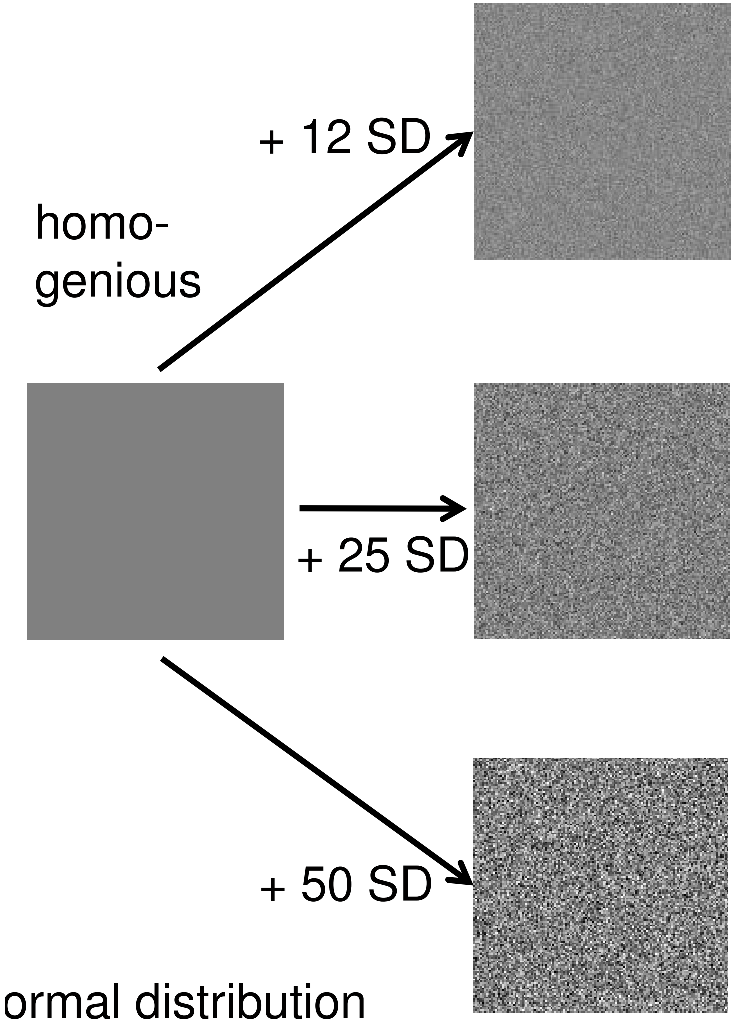


„characteristic“ for a specific exposure

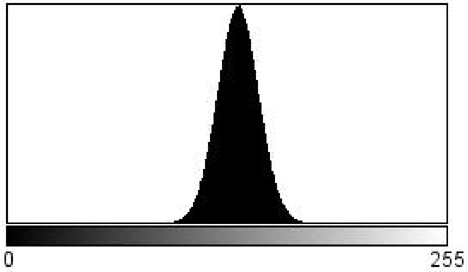
Histograms of a hip x-ray image



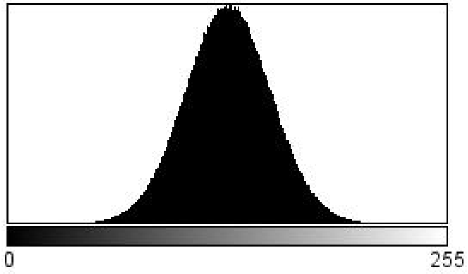
Characteristics of noise



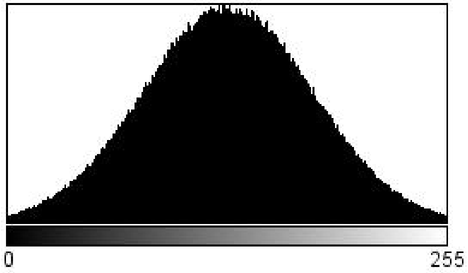
ormal distribution
according to Gauß



```
Count: 640000      Min: 76
Mean: 134.011      Max: 194
StdDev: 12.004     Mode: 135 (21471)
```



```
Count: 640000      Min: 10
Mean: 127.969      Max: 242
StdDev: 25.020     Mode: 129 (10248)
```



```
Count: 640000      Min: 0
Mean: 127.943      Max: 255
StdDev: 48.044     Mode: 123 (5212)
```

different noise characteristics added to a homogeneously grey image

properties:

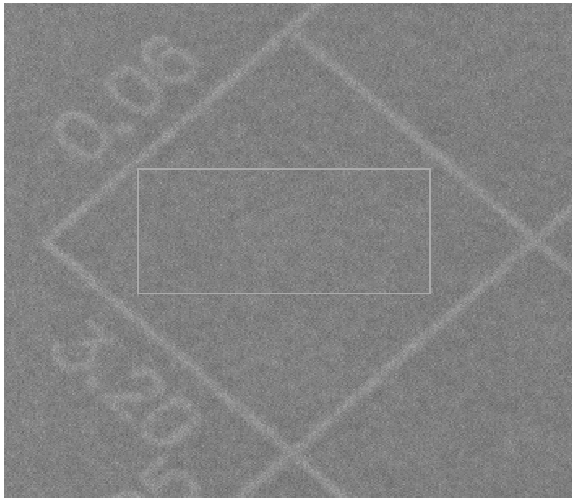
- mean value μ
- mean deviation: σ

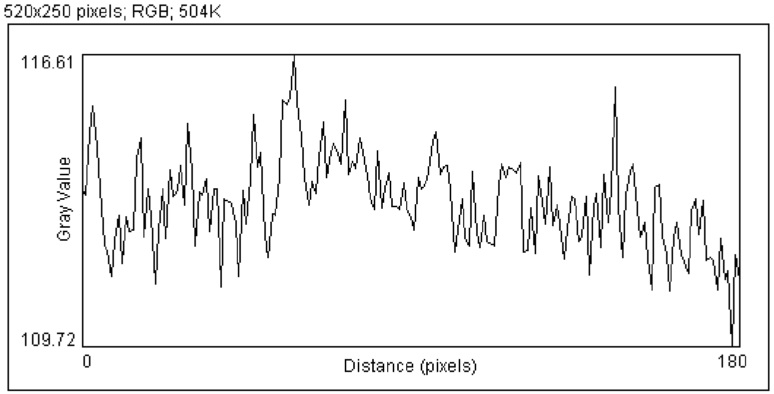
standard deviation SD

Contrast - Detail Test Object

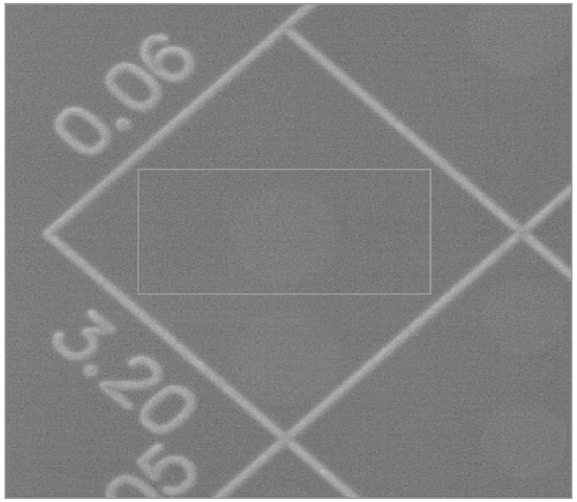
example:
Mammography
CDMAM

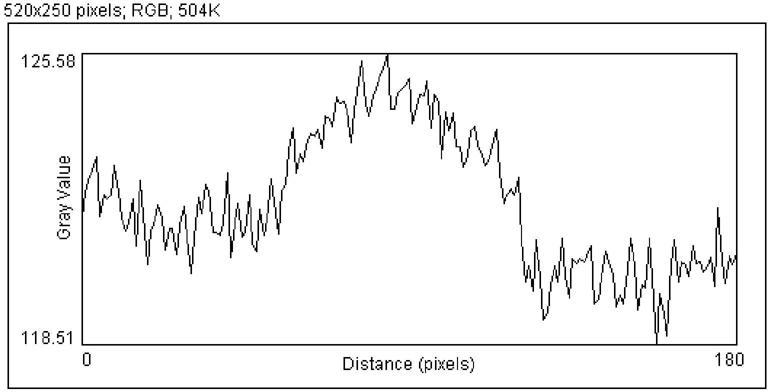
low
radiation
dose





high
radiation
dose





Signal - Noise - Ratio

Measure for the amount of noise within an image , related to the mean signal

Definition: Signal – Noise – Ratio (CNR)

$$\text{SNR} = \frac{\text{Mean of the Signal}}{\text{Standard Deviation of the noise}}$$

Contrast - Noise - Ratio

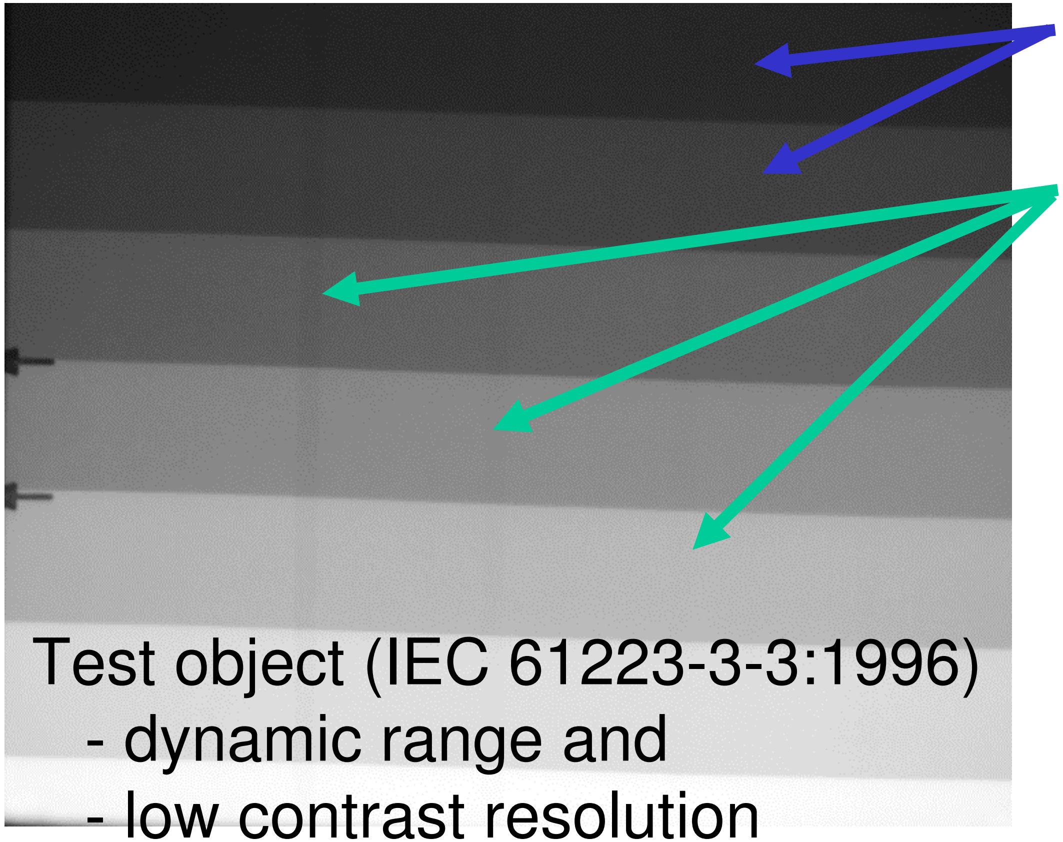
Measure for the amount of noise within an image , related to the contrast of an object

Definition: Contrast– Noise – Ratio (CNR)

$$\text{CNR} = \frac{\text{contrast of the Signal}}{\text{Standard Deviation of the noise}}$$

Also: signal difference to noise ratio SDNR

Test object for low contrast resolution and dynamic range



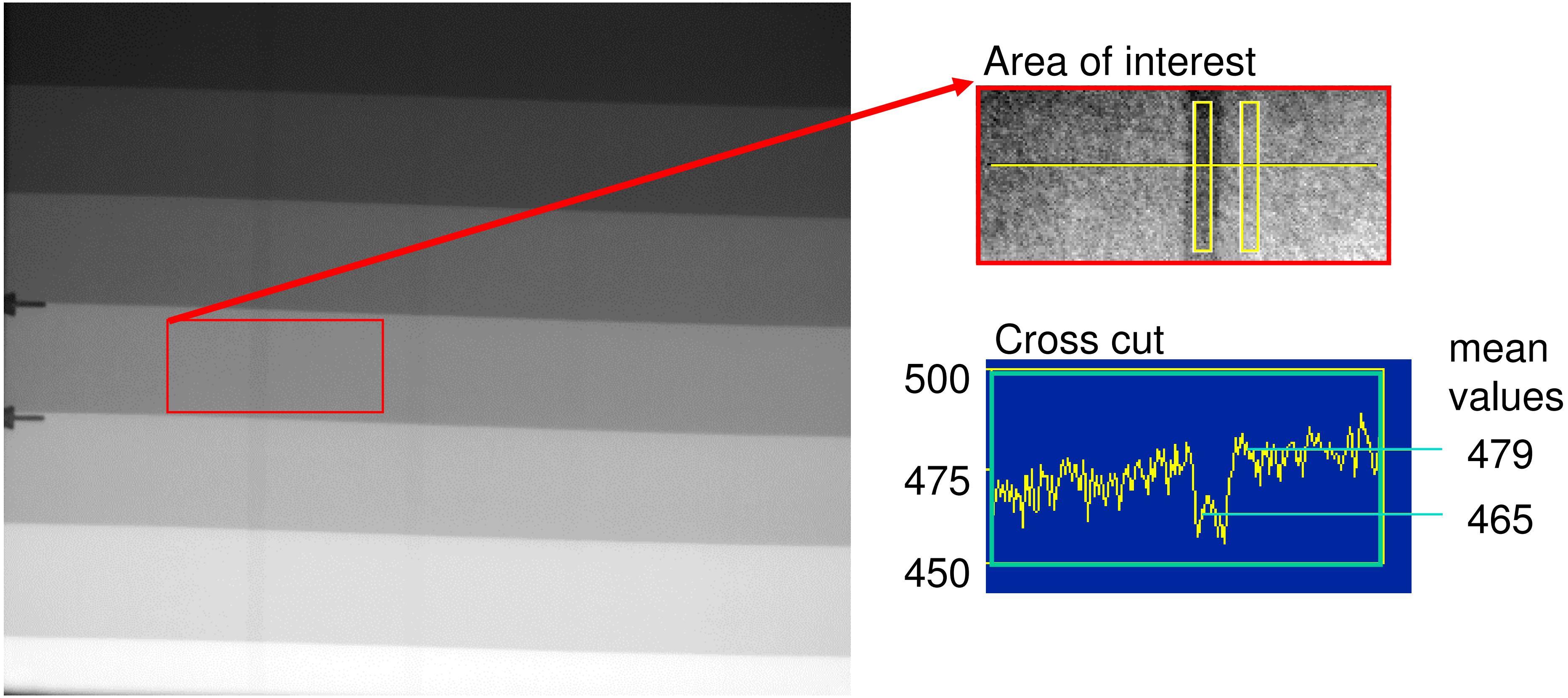
exposure of a staircase (horizontal Cu stripes)

with low contrast objects (vertical Al stripes)

Test object (IEC 61223-3-3:1996) to measure
- dynamic range and
- low contrast resolution

of a DSA (Digital Subtraction Angiography) system

Example: Signal to Noise Ratio



standard deviation (root mean square) $\sigma = 5.3$

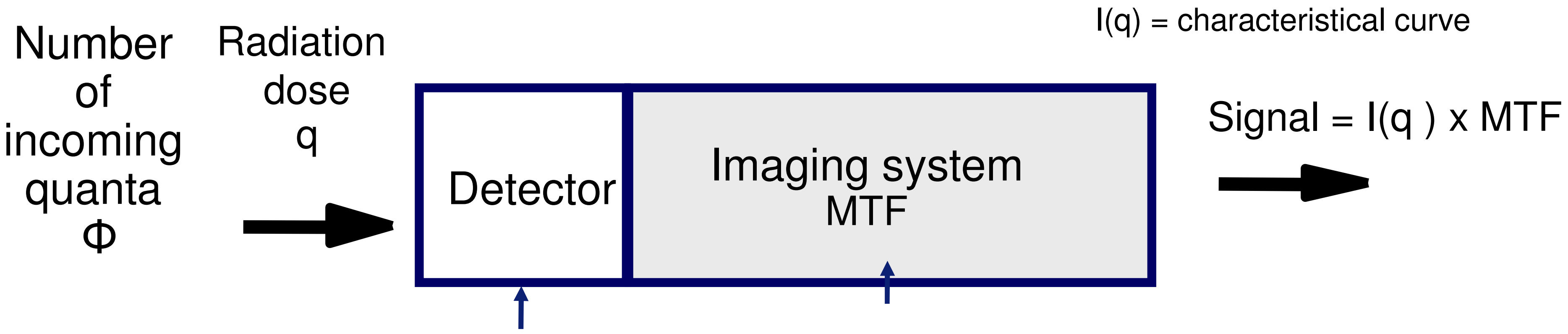
Noise Equivalent Quanta

$$\mathrm{NEQ} = \frac{I(q)^2 \ \mathrm{MTF}(u)^2}{\mathrm{NPS}(q,u)}$$

Detective Quantum Efficiency

$$\mathrm{DQE}(q,u) = \frac{I(q)^2 \,\mathrm{MTF}(u)^2}{\Phi \ \mathrm{NPS}(q,u)}$$

Φ:	radiation fluence
q:	radiation dose
u:	spatial frequency
I(q)	intensity transfer function (characteristic curve)
MTF(u):	Modulation Transfer Function
NPS(q,u):	Noise Power Spectrum



Quantum-noise

Detector-noise

System noise

noise-power-spectrum (Wiener Spectrum)

$$\sigma = \frac{\text{Signal}}{\text{noise}}$$

$$\sigma = \sqrt{(\Phi)}$$

Poisson distribution

Detective Quantum Efficiency (DQE)

$$\text{DQE} = \frac{\left(\frac{\text{Signal}}{\text{noise}}\right)^2_{\text{output}}}{\left(\frac{\text{Signal}}{\text{noise}}\right)^2_{\text{input}}} = \frac{\text{NEQ}}{\Phi}$$

Noise Equivalent Quanta (NEQ)

$$\text{NEQ} = \left(\frac{\text{Signal}}{\text{noise}}\right)^2_{\text{output}}$$

ideal detector, ideal system

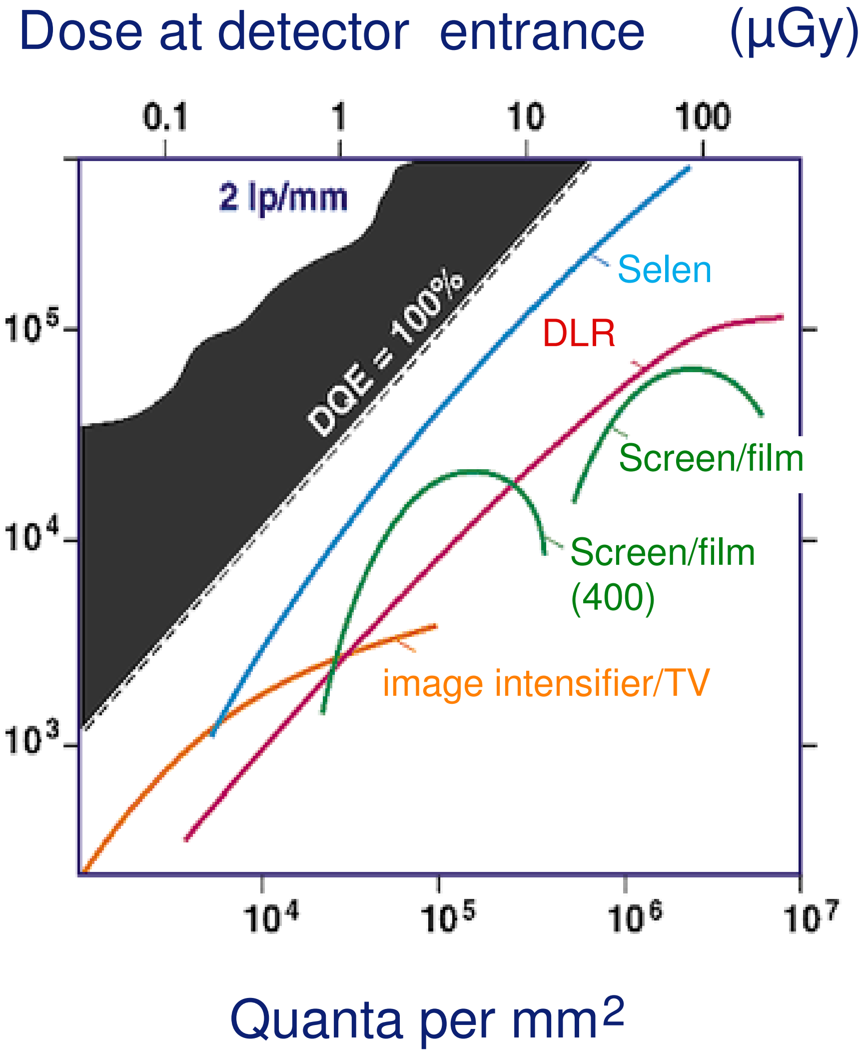
$$\text{NEQ} = \sigma^2 = \Phi \qquad \text{DQE} = 1$$

NEQ Noise equivalent Quanta

NEQ = (signal / noise) ^{2}

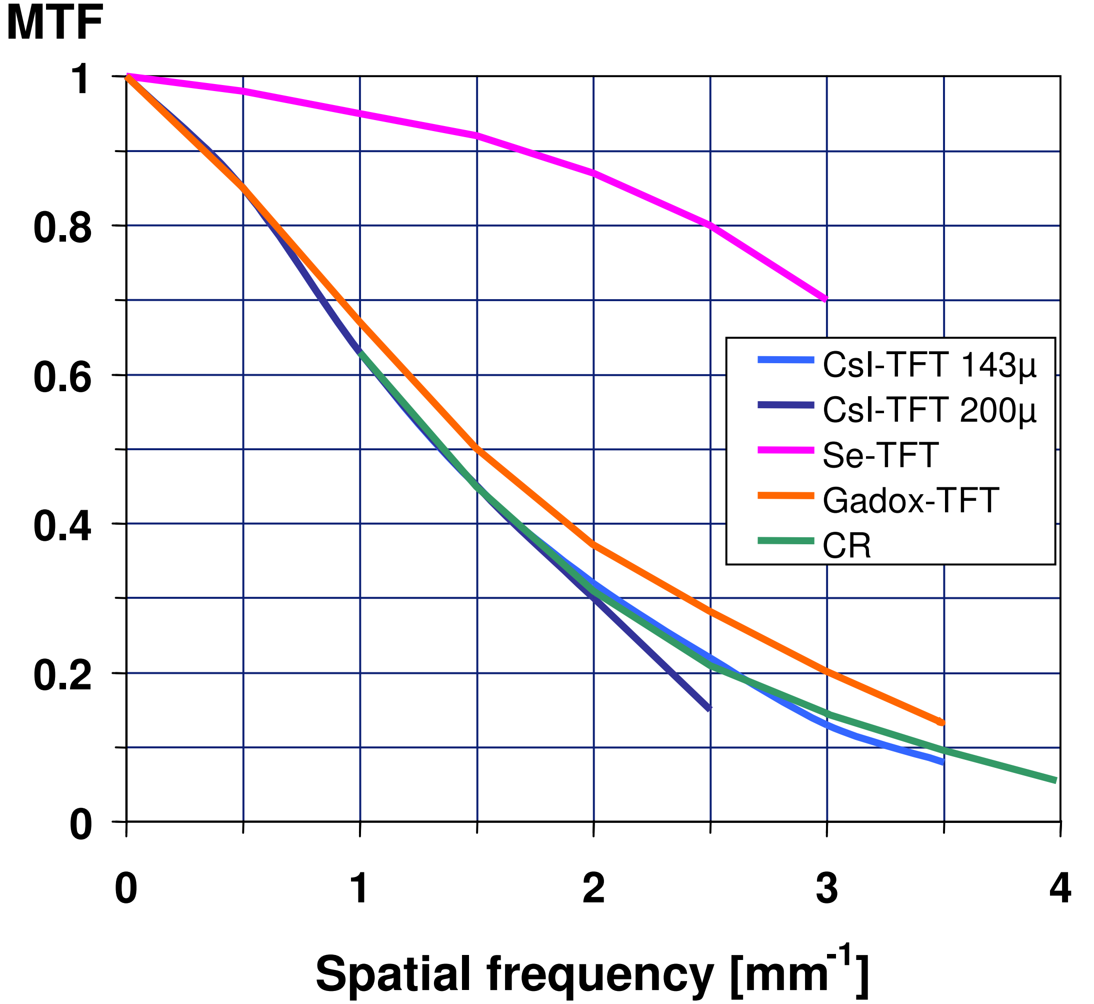
squared SNR
at output
of imaging system

comparison of
detector principles



Modulation Transfer Function (MTF)

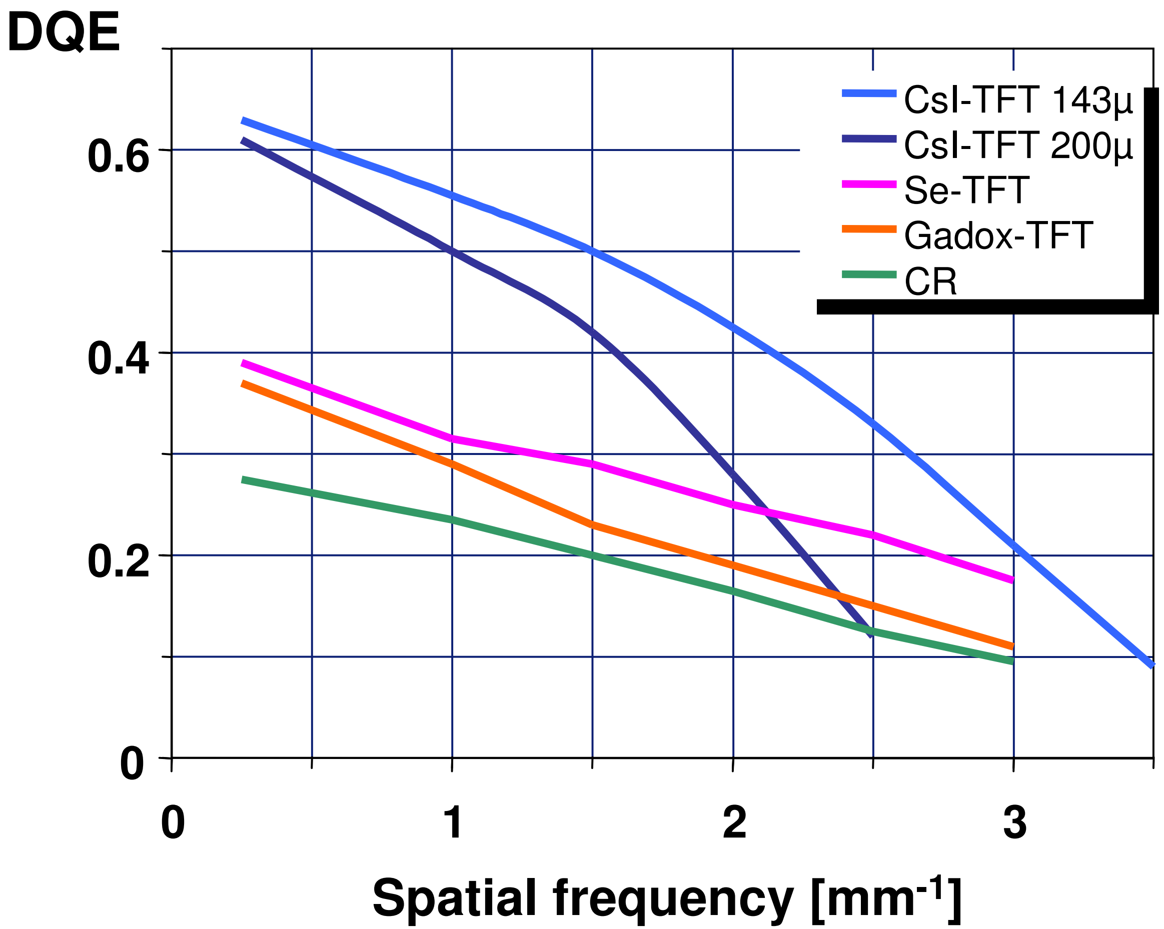
Comparison of detector technologies



NHS /KCARE U.K. 2005

MTF describes signal transfer without influence of noise.

Detective Quantum Efficiency



NHS /KCARE U.K. 2005

higher DQE

= greater dose reduction potential

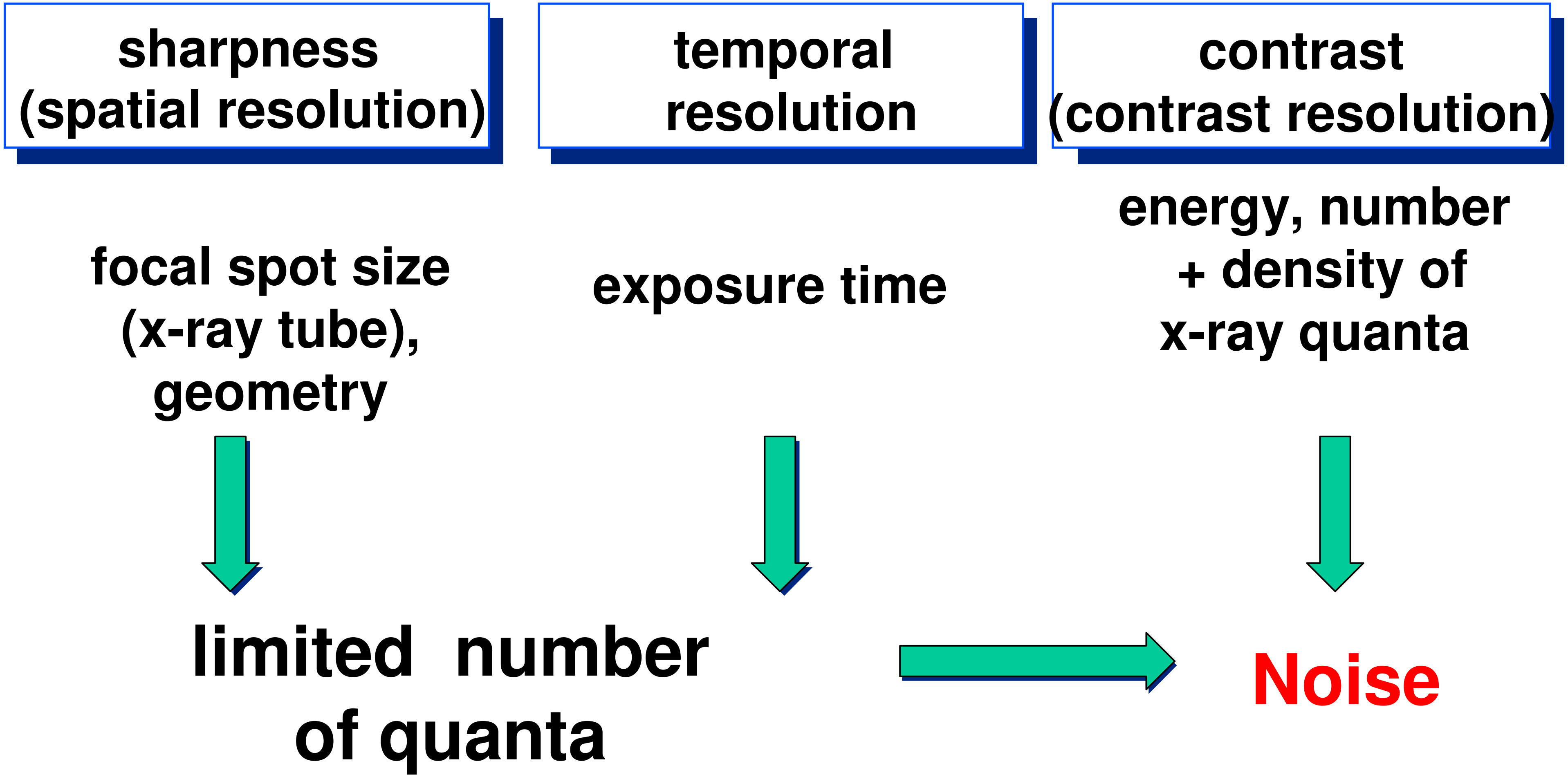
Only Cesium Iodide flat-panel detectors have significantly improved DQE values

Important Factors for Image Quality

- Detector Technology
- DQE – Detective Quantum Efficiency
- Resolution / Image Matrix
- Active Detector Area
- Dynamic Range
- Image Processing

Detector, AND Image Processing is important

Image Quality



sharpness
(spatial resolution)

temporal
resolution

contrast
(contrast resolution)

focal spot size
(x-ray tube),
geometry

exposure time

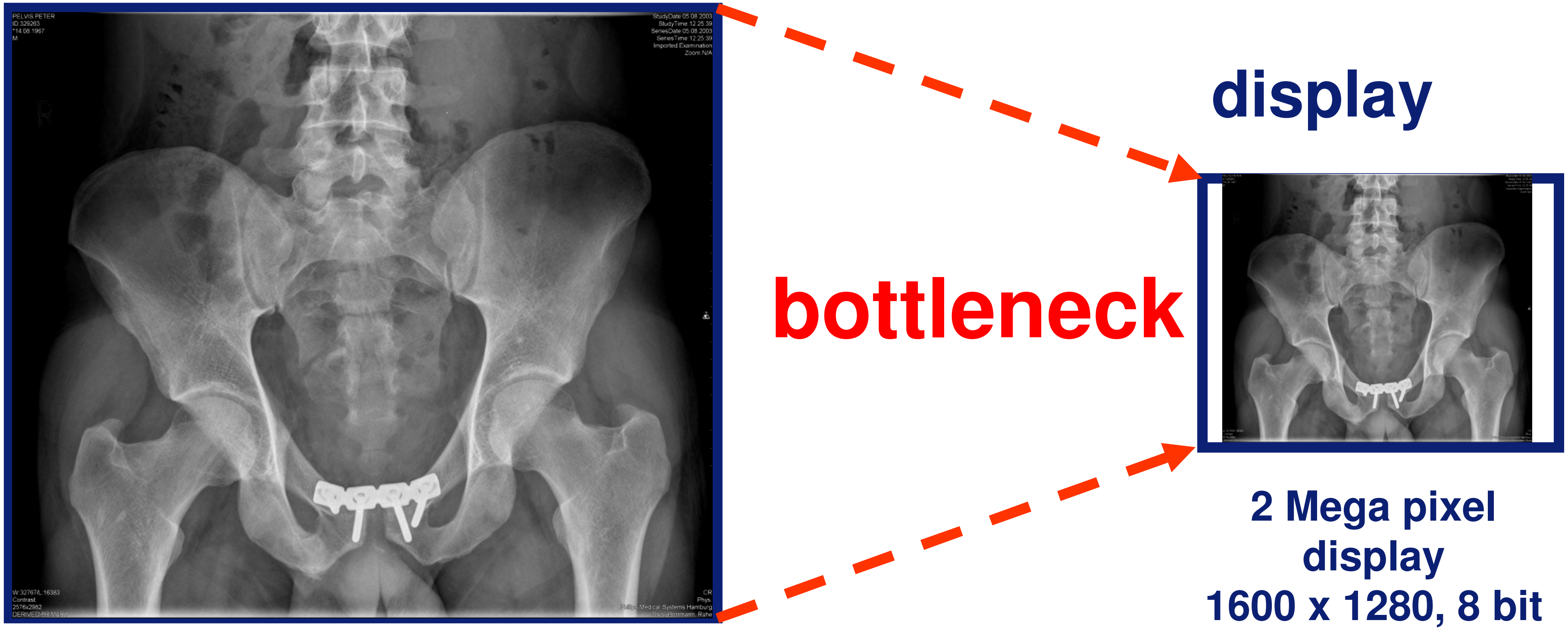
energy, number
+ density of
x-ray quanta

limited number
of quanta

Noise


PHILIPS

presentation dilemma



display

bottleneck

2 Mega pixel
display
1600 x 1280, 8 bit

Pelvis
digital flat detector
3000 x 3000 Pixel = 9 M Pixel
> 16 000 pixel values
(14 bit)

large matrix + large range of pixel values
are difficult to display

Pelvis survey

Original image matrix
2982 pixel x 2576 pixel

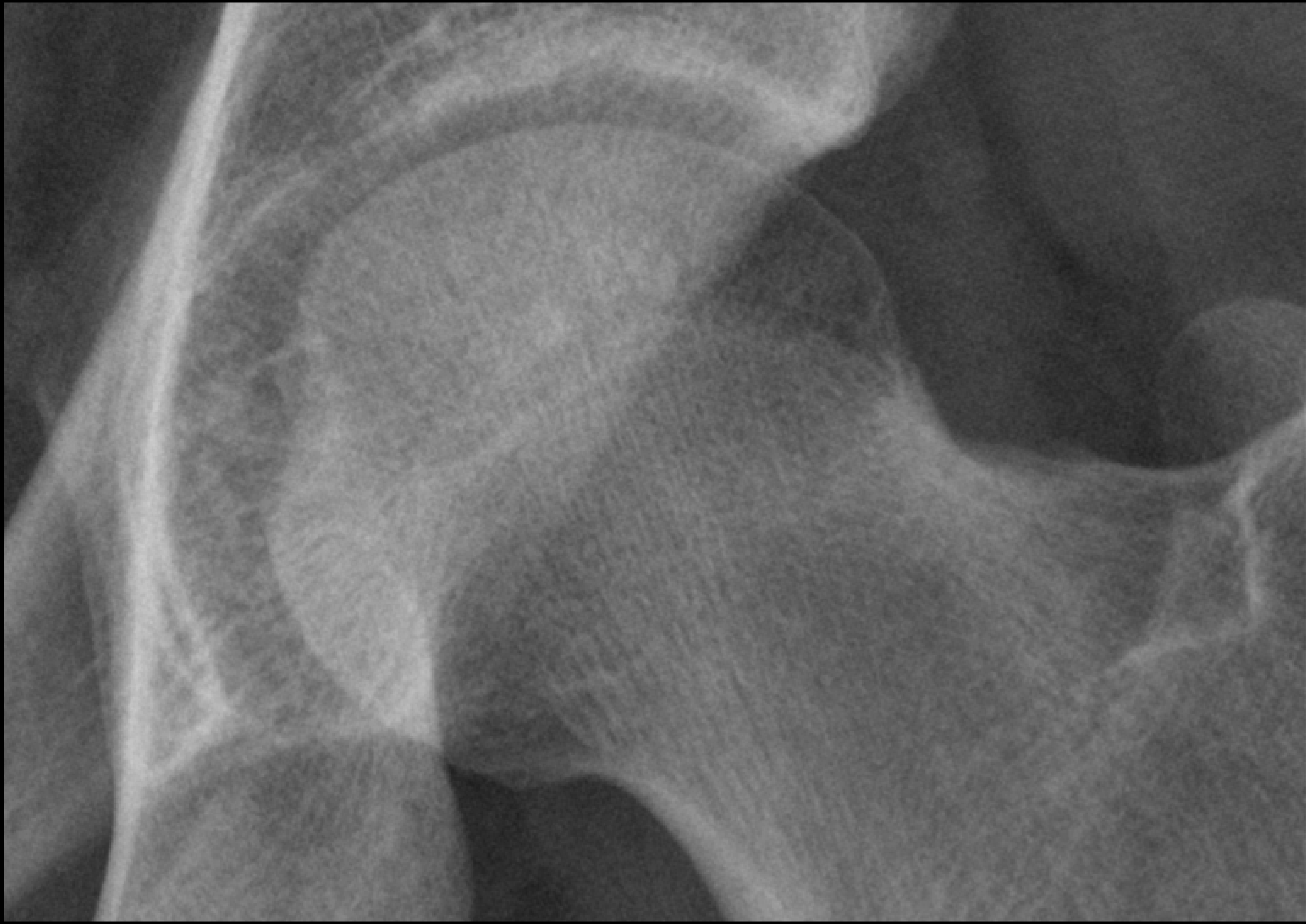
Reduced to
1600 pixel x 1280 pixel
for a survey

e.g.
only each 3. pixel
and each 3. row
is displayed
(pixel cropping)

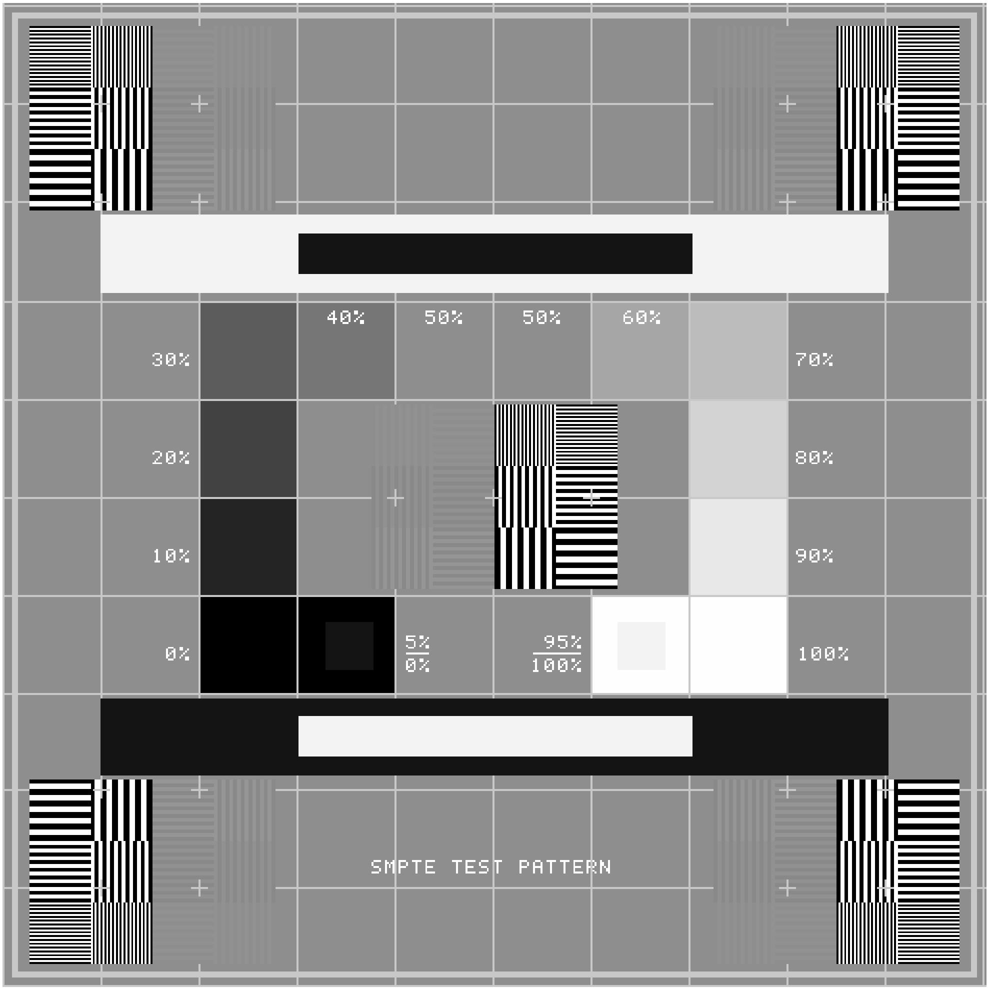
Pelvis - ROI

768 pixel x 596 pixel

each pixel
is
displayed
within a
section



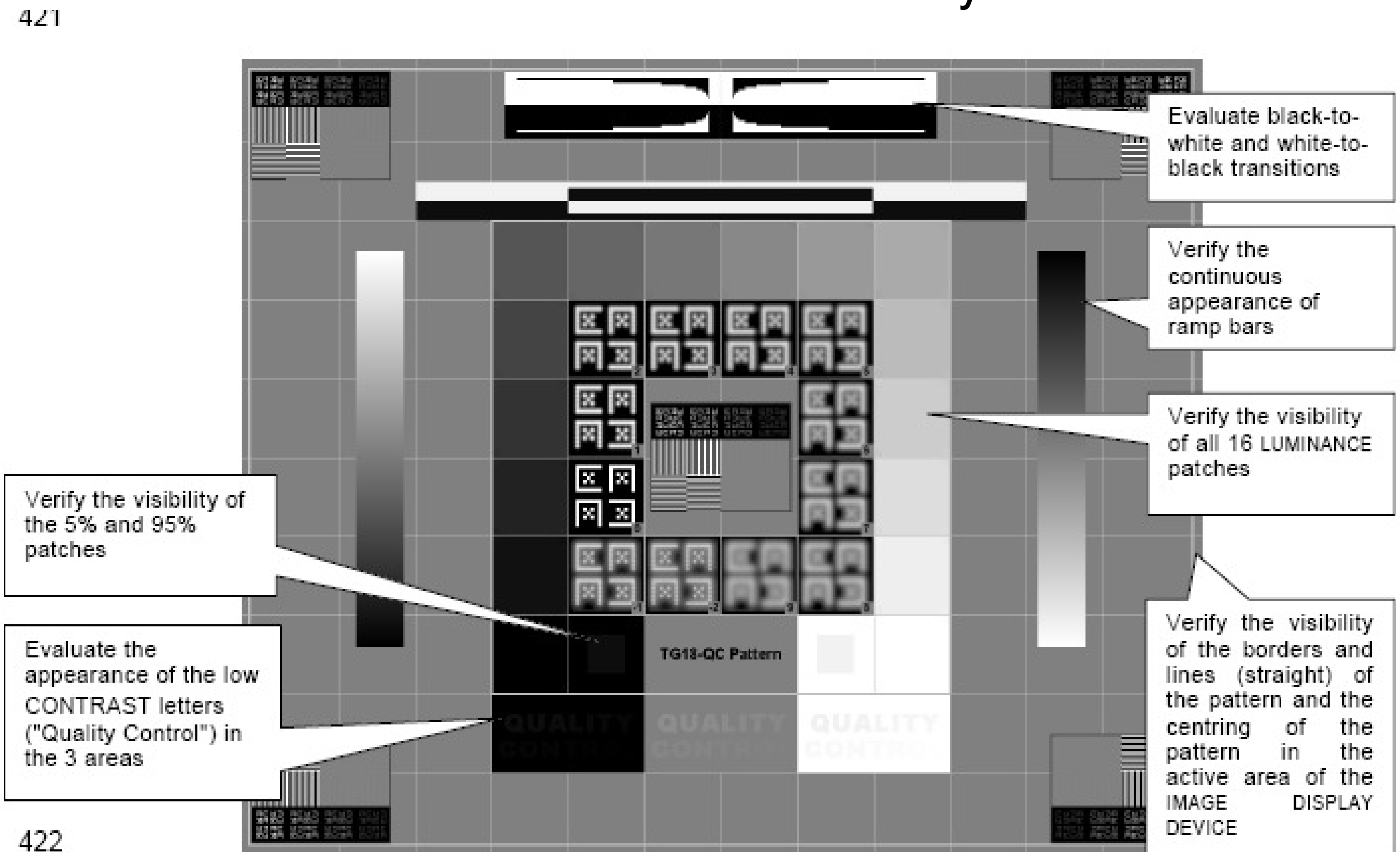
SMPTE Testpattern 512 x 512



SMPTE Society of Motion Picture Television Engineers

Test Image AAPM TG18 - QC

American Association of Physicists in Medicine



Evaluate black-to-white and white-to-black transitions

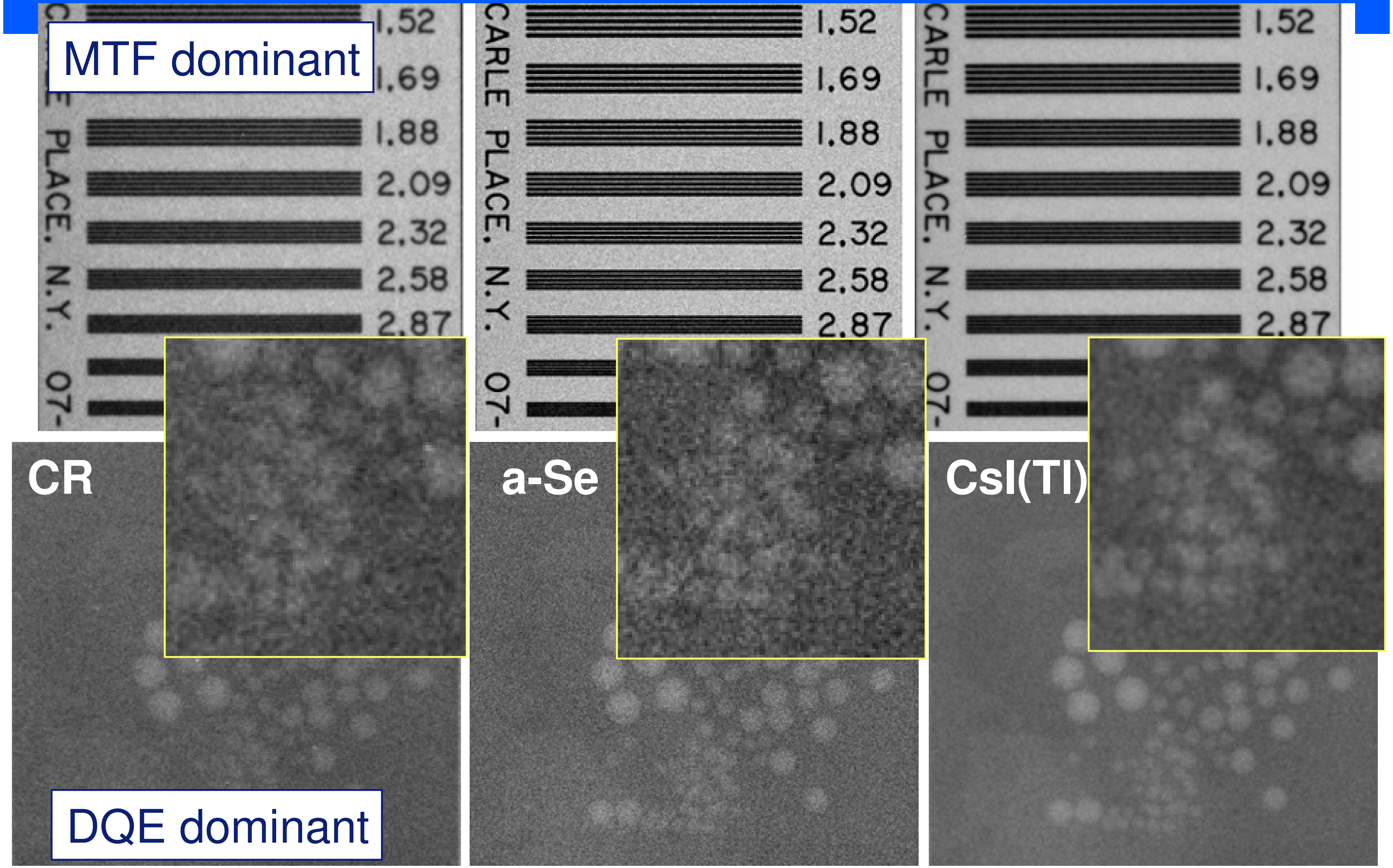
Verify the continuous appearance of ramp bars

Verify the visibility of all 16 LUMINANCE patches

Verify the visibility of the 5% and 95% patches

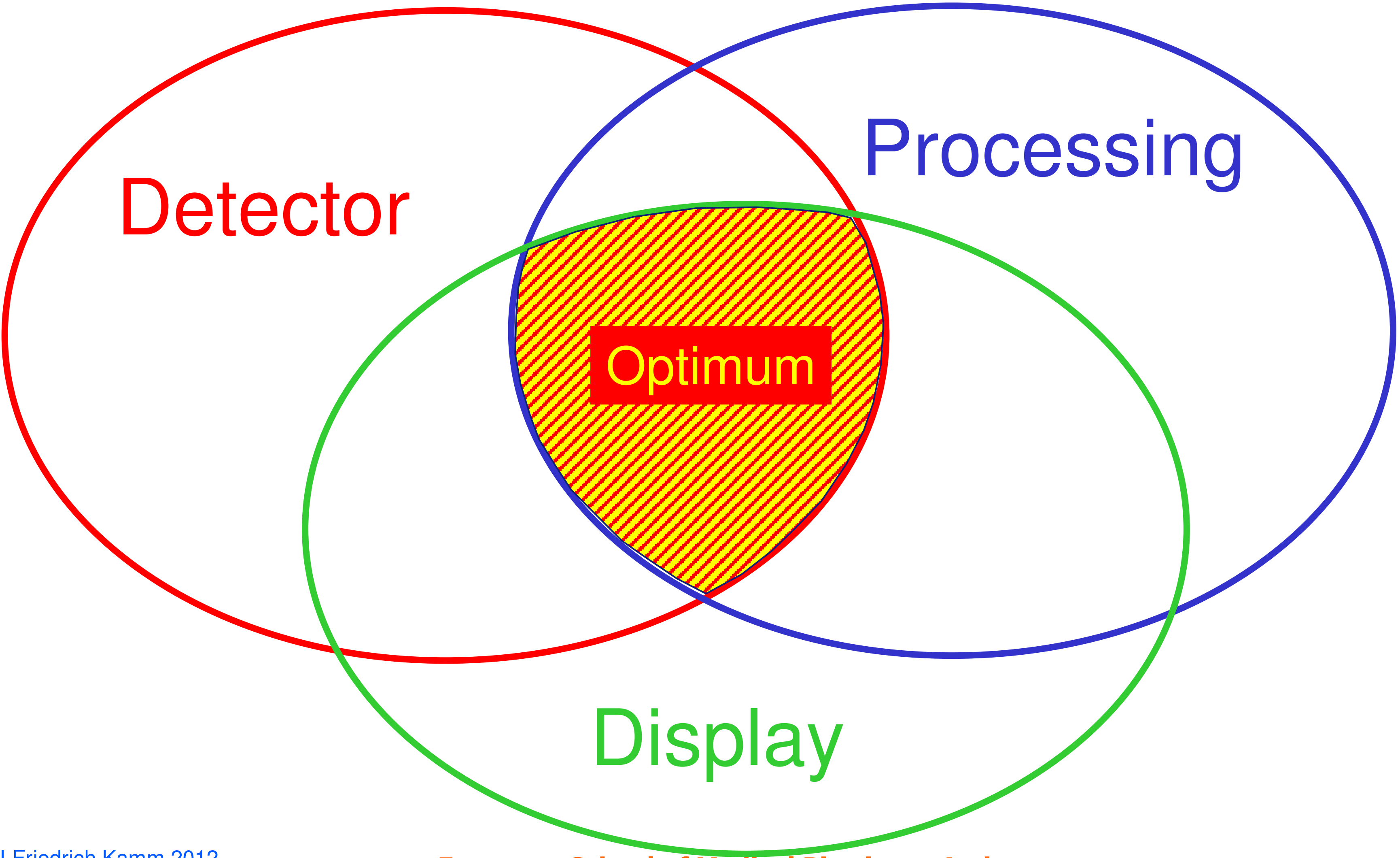
Evaluate the appearance of the low CONTRAST letters ("Quality Control") in the 3 areas

Verify the visibility of the borders and lines (straight) of the pattern and the centring of the pattern in the active area of the IMAGE DISPLAY DEVICE



(Courtesy: J. Yorkston Eastman Kodak Company)

Important Factors for Image Quality



Literature on fundamentals of medical imaging

- Bushberg, J., et al. The essential Physics of medical imaging, Williams & Wilkins, Baltimore, 2001

- SPIE Handbook of medical Imaging 2000

- Dainty J.C.;Shaw R., Image Science - principles, analysis and evaluation of photographic-type imaging process, Academic Press, London, 1974

Literature **on fundamentals of medical imaging**

Electronic book:

- Medical Imaging Physics, Fourth Edition, by William R. Hendee and E. Russell Ritenour

  ISBN: 0-471-38226-4 Copyright C 2002 Wiley-Liss, Inc. **1**