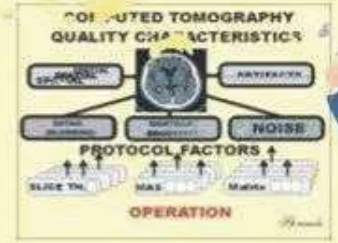
Physics Review Course
Levels of Learning

Sprawls Topics



Classroom

Overview
Organize
Develop Concepts

Notebook

Review
Refresh
Reference for Details and Facts

The Web

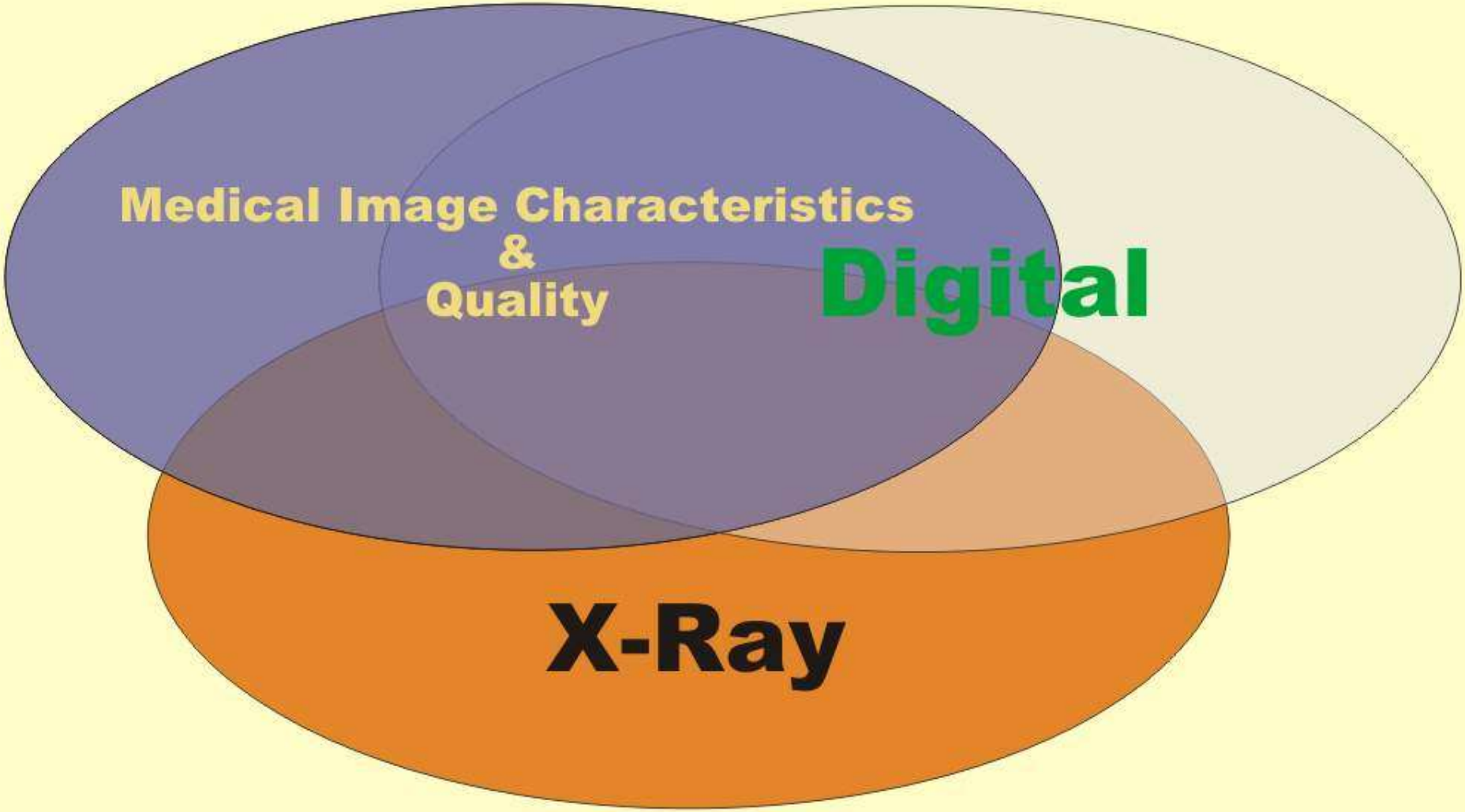
Expanding Scope and Depth
with
Web Based Resources

http://www.sprawls.org/PhysRev

View on Ipad or any other device at

www.sprawls.org/PhysRev

Our Topics



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Objectives

- Identify the image quality characteristics that apply to all medical imaging modalities
- Understand the concept of image optimization
- Review the factors that determine contrast sensitivity in radiographic procedures
- Describe the approach to optimizing contrast and patient exposure
- Identify the sources of blurring in radiography
- See how detail can be optimized in radiography
- Determine the sources of noise in radiography
- See how noise can be optimized in radiography

Our Objectives

Today

Thinking Together

Later

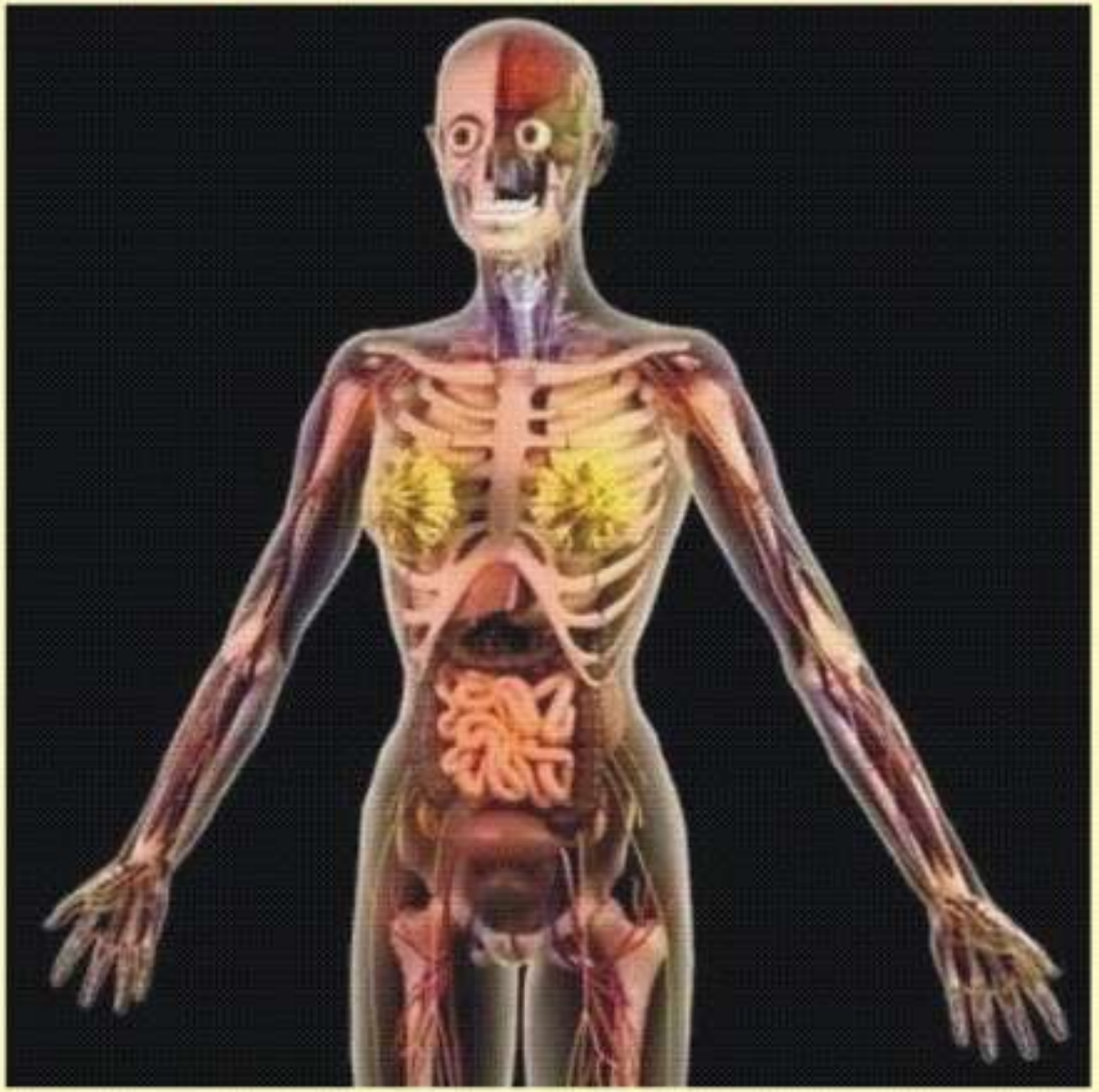
Review and Research

This Presentation
Online Modules
Textbooks

On the web at

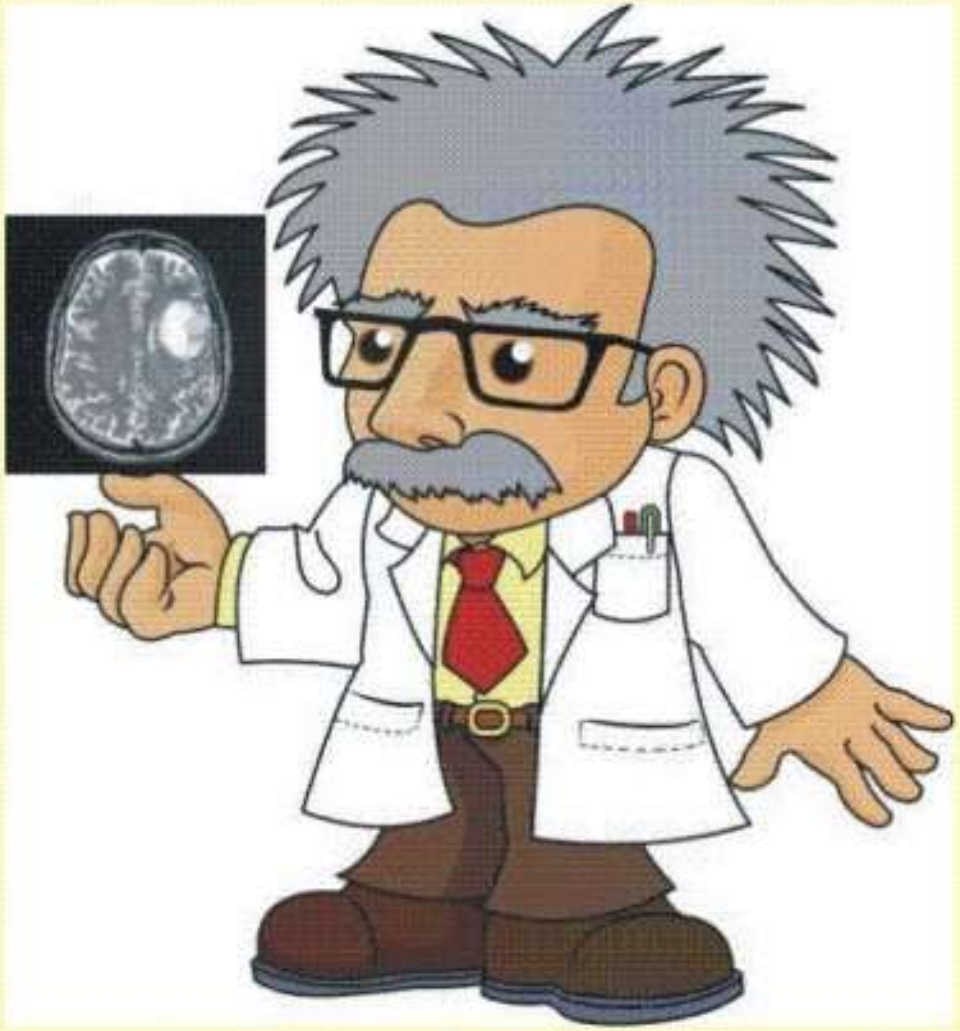
www.sprawls.org

Medicine's Great Challange



See Into the Human Body

Medical Physicists



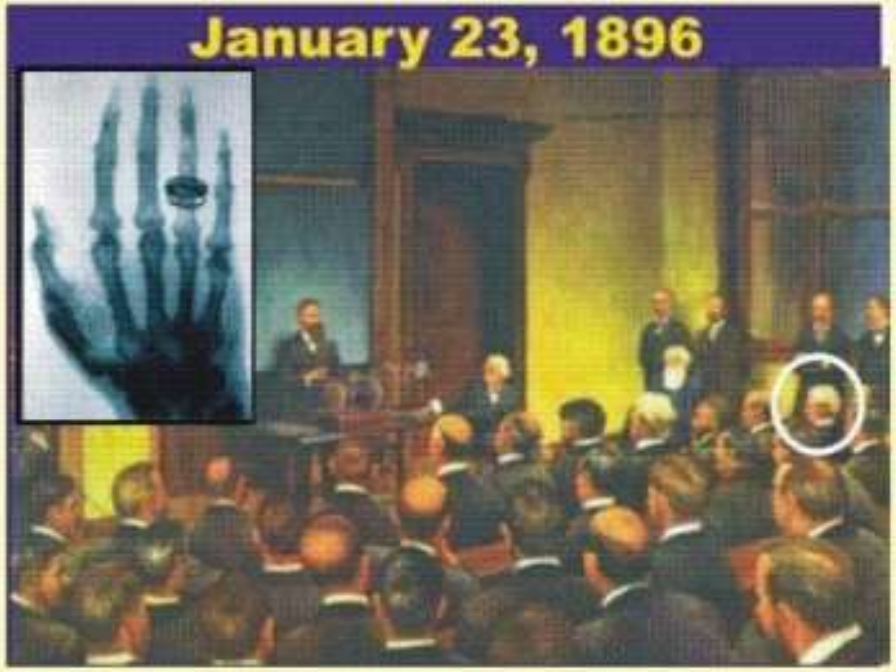
Provide Solutions

January 23, 1896

January 23, 1896

Medical Imaging

Increased Capability and Complexity



Time (Years)

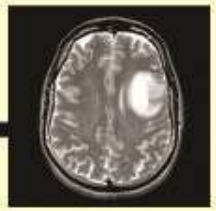
Sprawls

The Imaging Modalities

What is Different? What is Similar?

Radiography

MRI

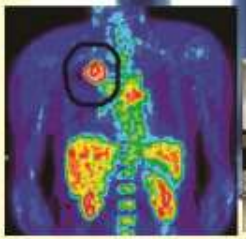


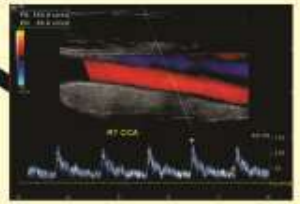
Computed Tomography

Fluoroscopy

Ultrasound

Mammography

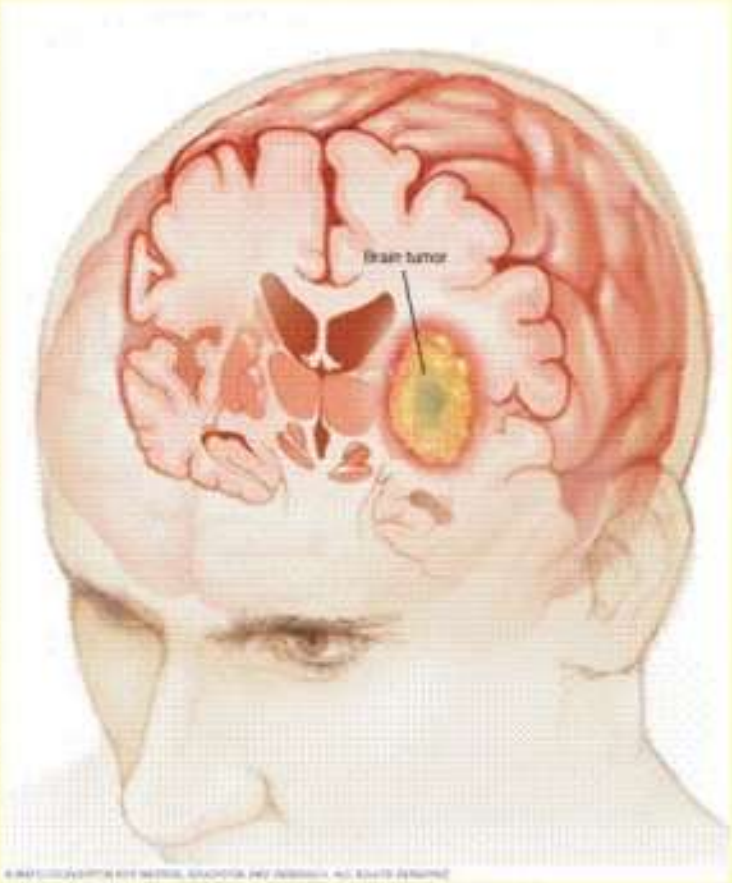




Radionuclide, SPECT, PET

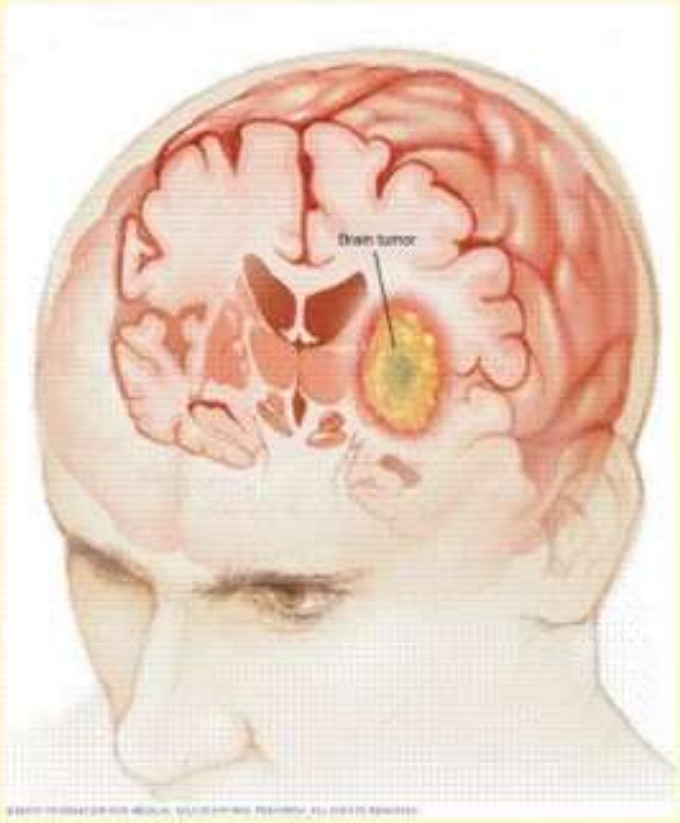
Sprawls

The Medical Image is a **Window** Into the Human Body



Sprawls

The Medical Image is a Window Into the Human Body



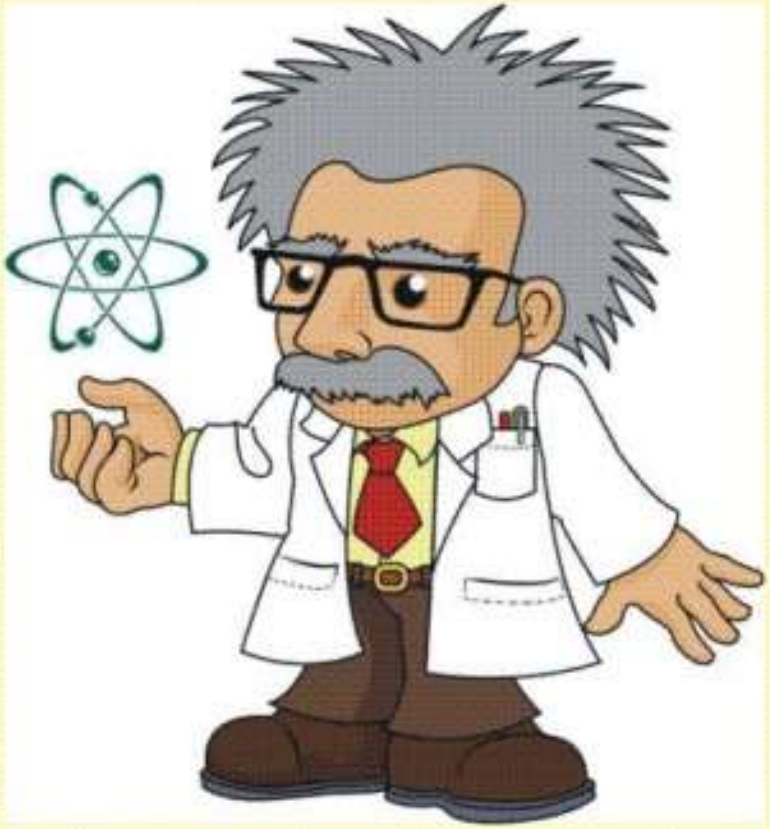
There is No Perfect Window

It is All About Visibility

Sprawls

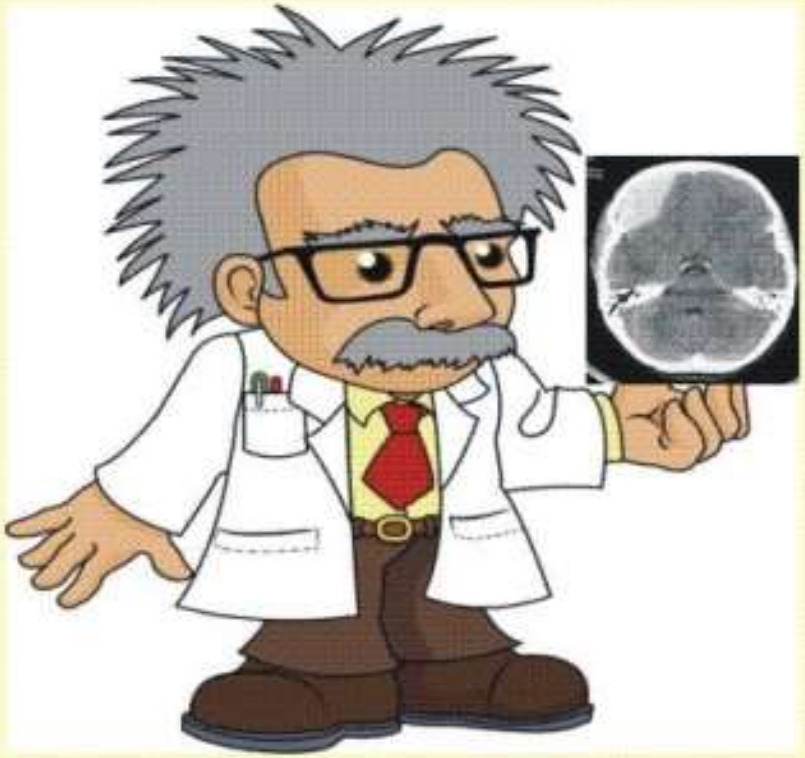
It All Begins With Imaging

The Expanding Role for Medical Physicists



Sprawls

Analyzing & Controling Image Quality



- Geometric
- Artifacts
- Noise
- Blur
- Contrast

Sprawls

What Determines
Medical Image Quality
VISIBILITY

Artifacts

NOISE

Distortion

BLUR

Contrast Sensitivity

Modality & Equipment Design Characteristics

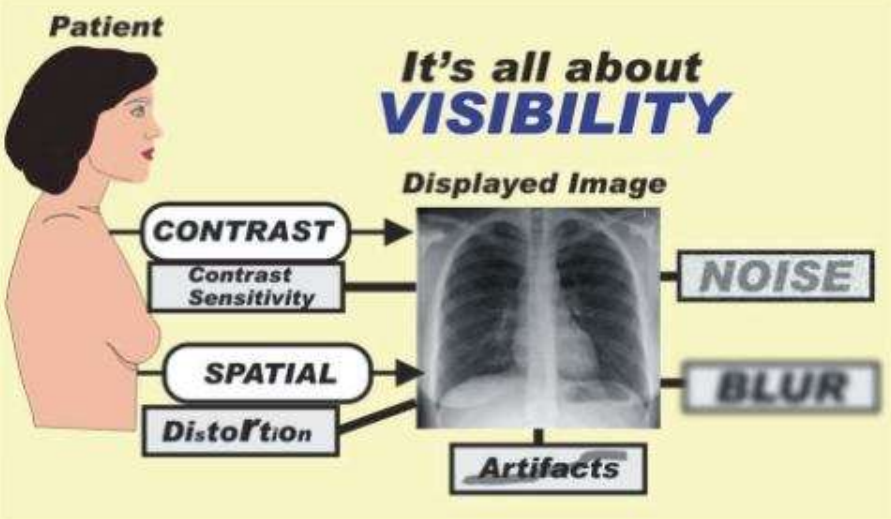
Performance
QA & Maintenance

Operation
Techniques & Protocols

Technology ***The Human Factor*** *Sprawls*

Physics and Quality Characteristics of X-Ray Images (Radiographs)

OVERVIEW



Physics and Quality Characteristics of X-Ray Images (Radiographs)

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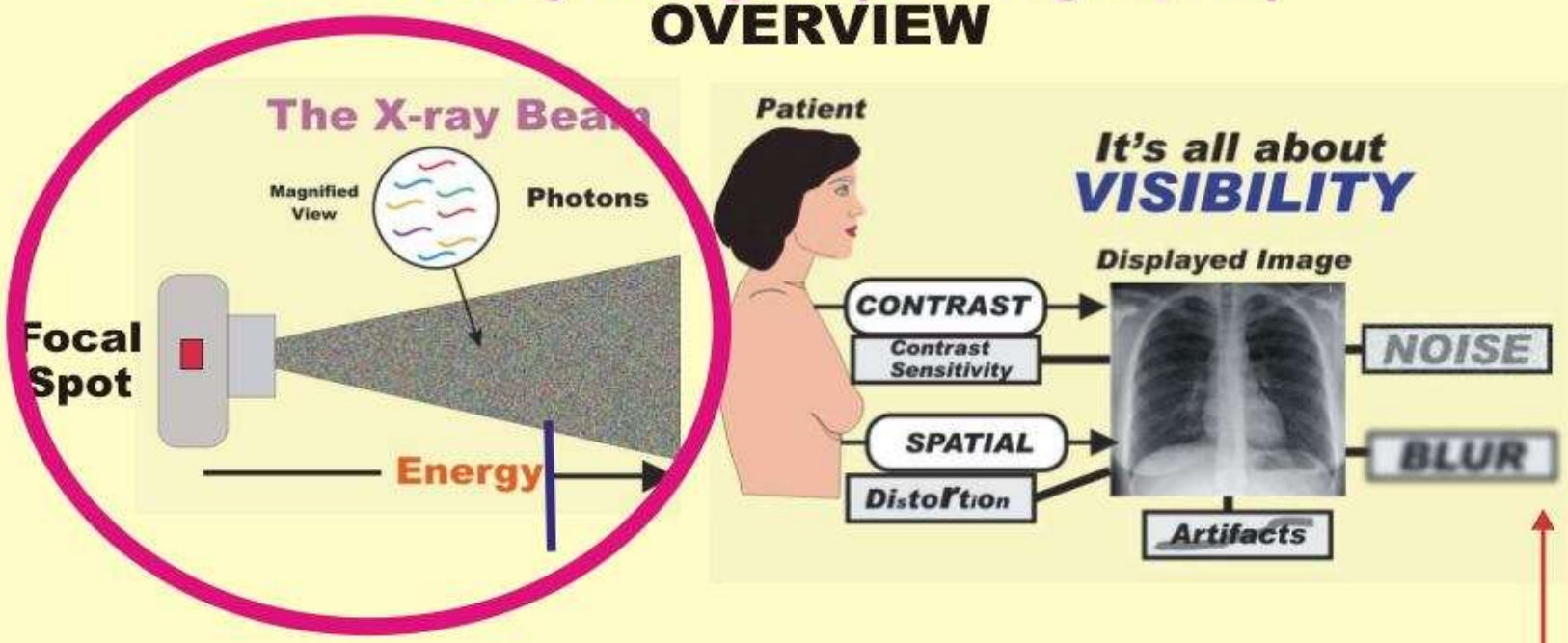

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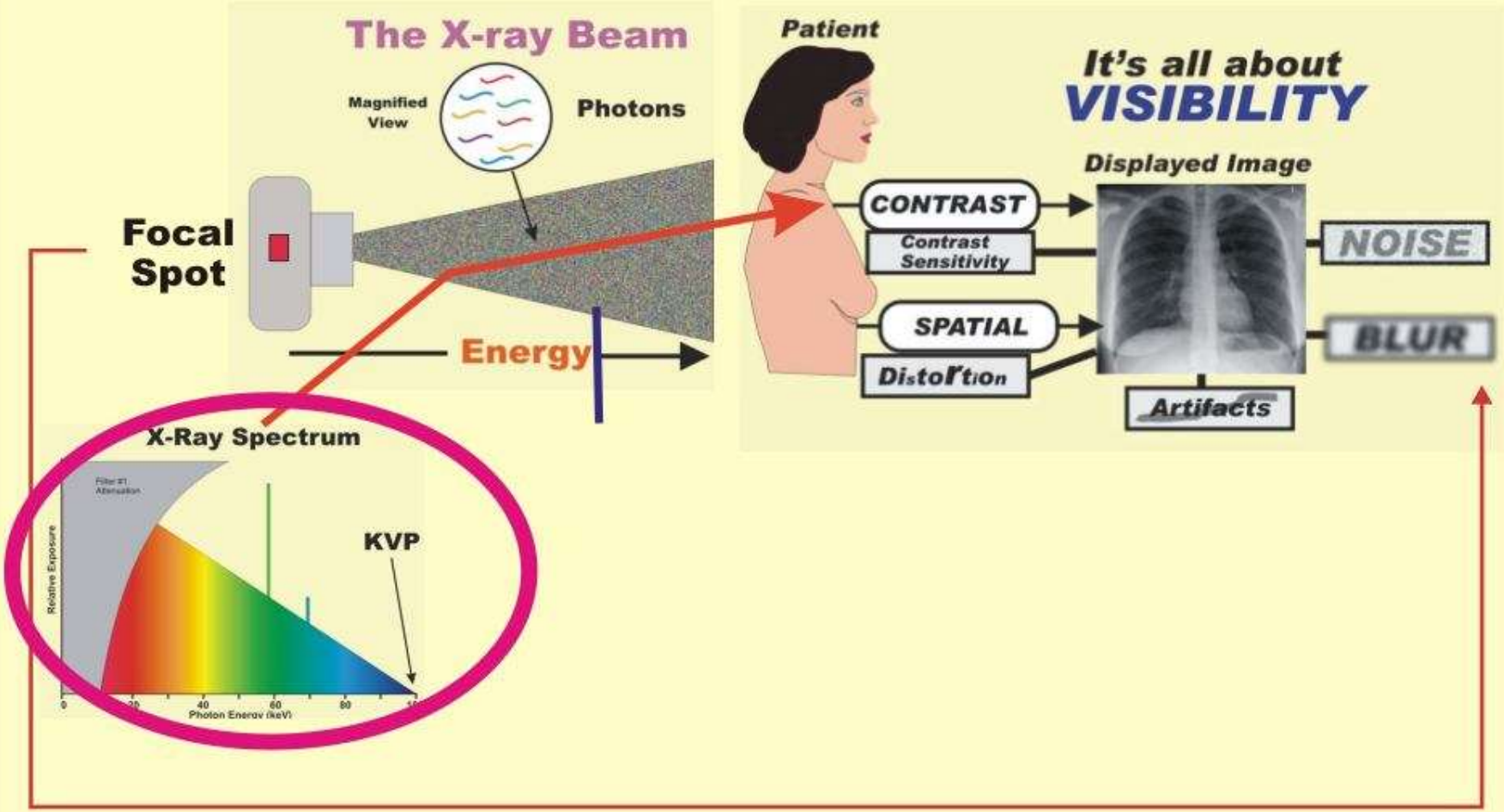

Physics and Quality Characteristics of X-Ray Images (Radiographs)

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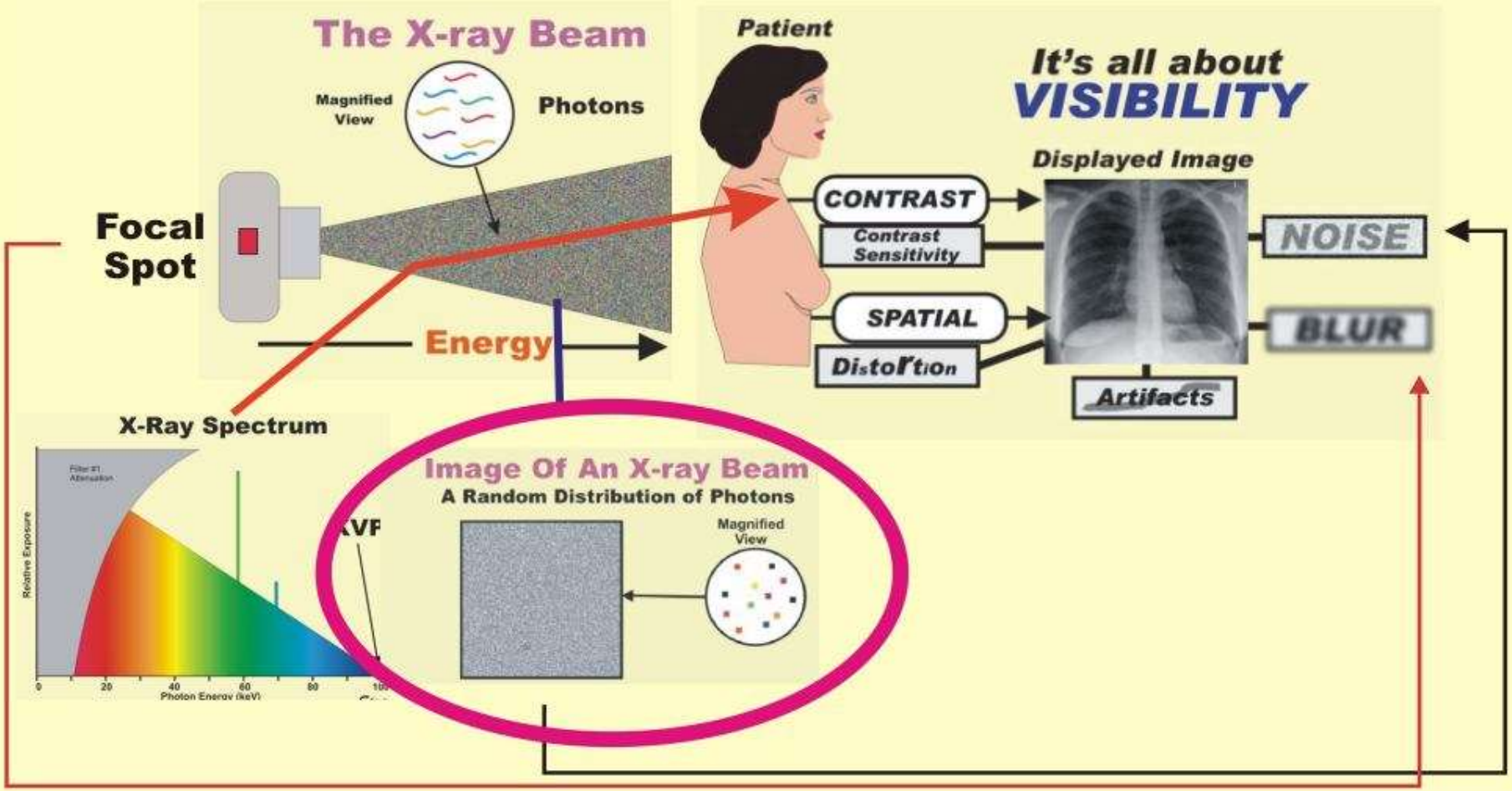
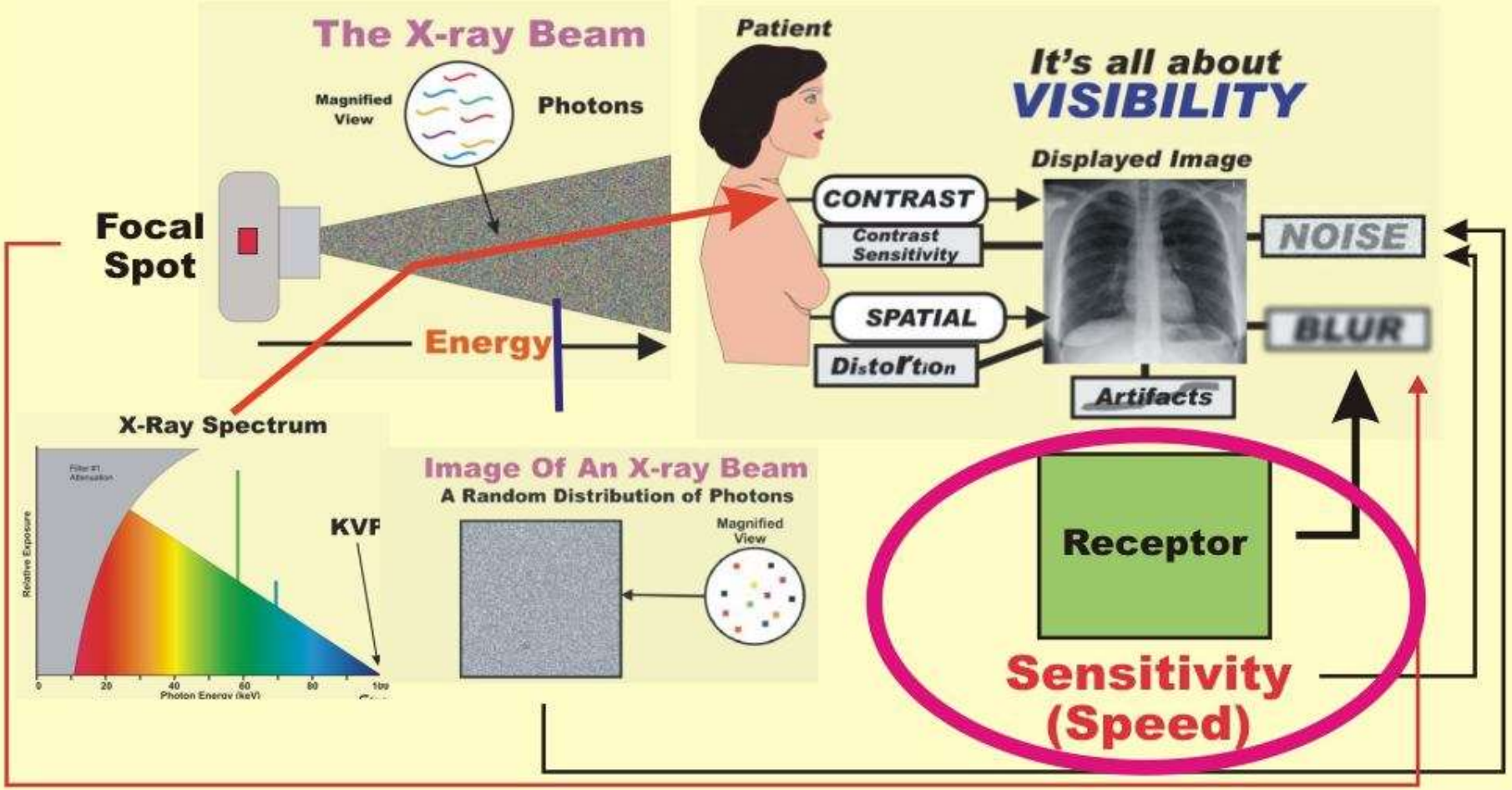


Physics and Quality Characteristics of X-Ray Images (Radiographs)

OVERVIEW



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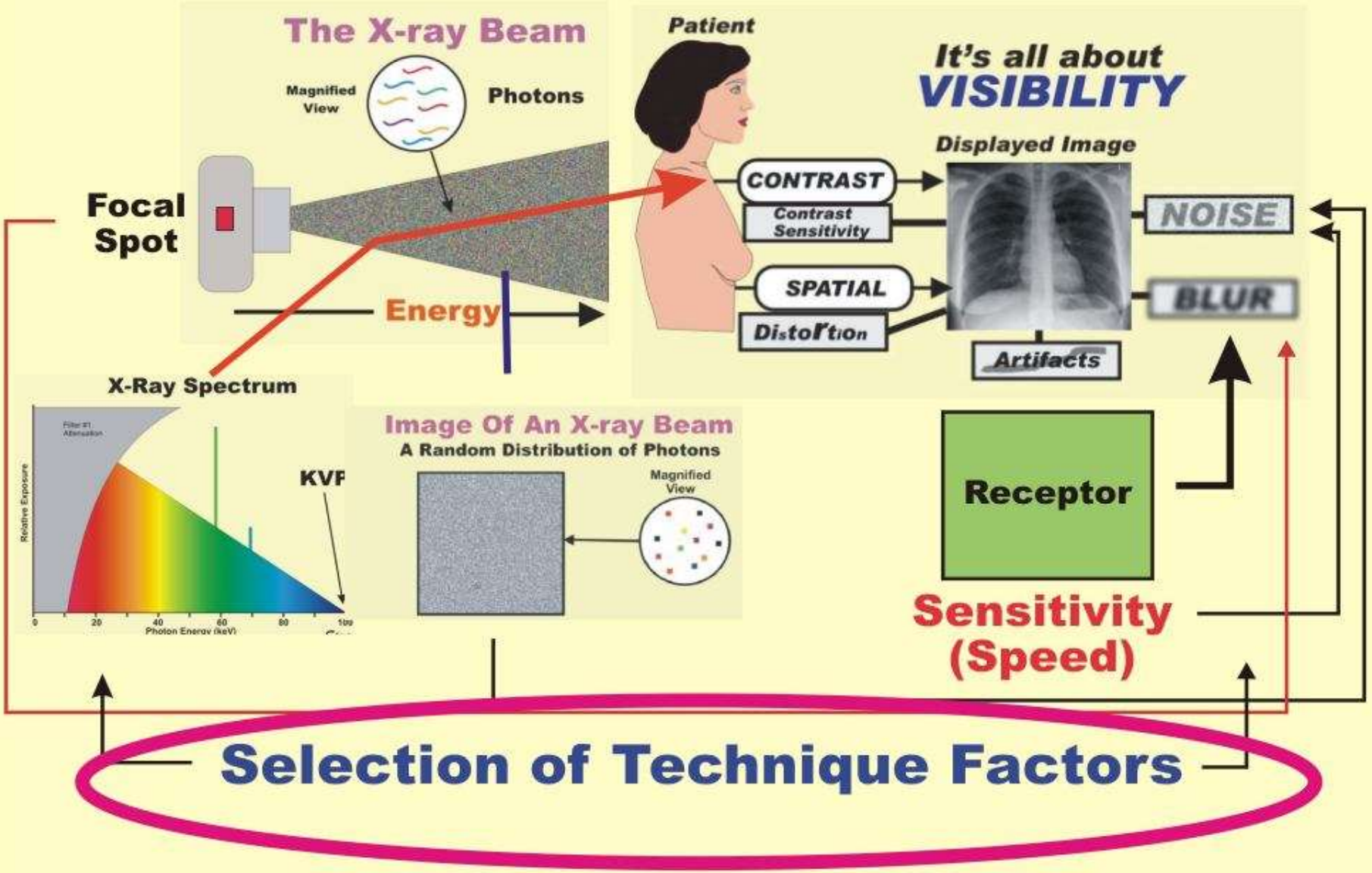
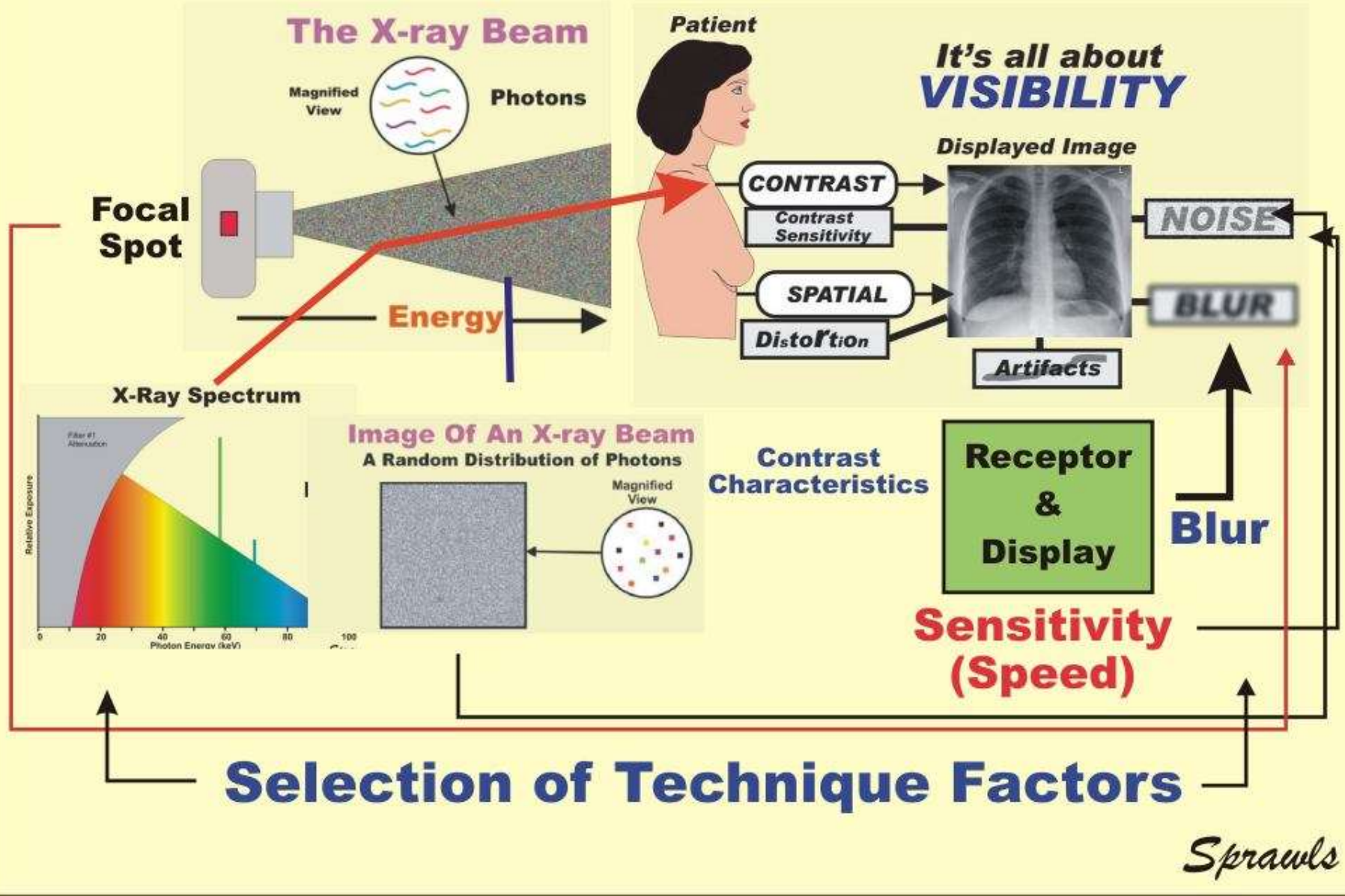
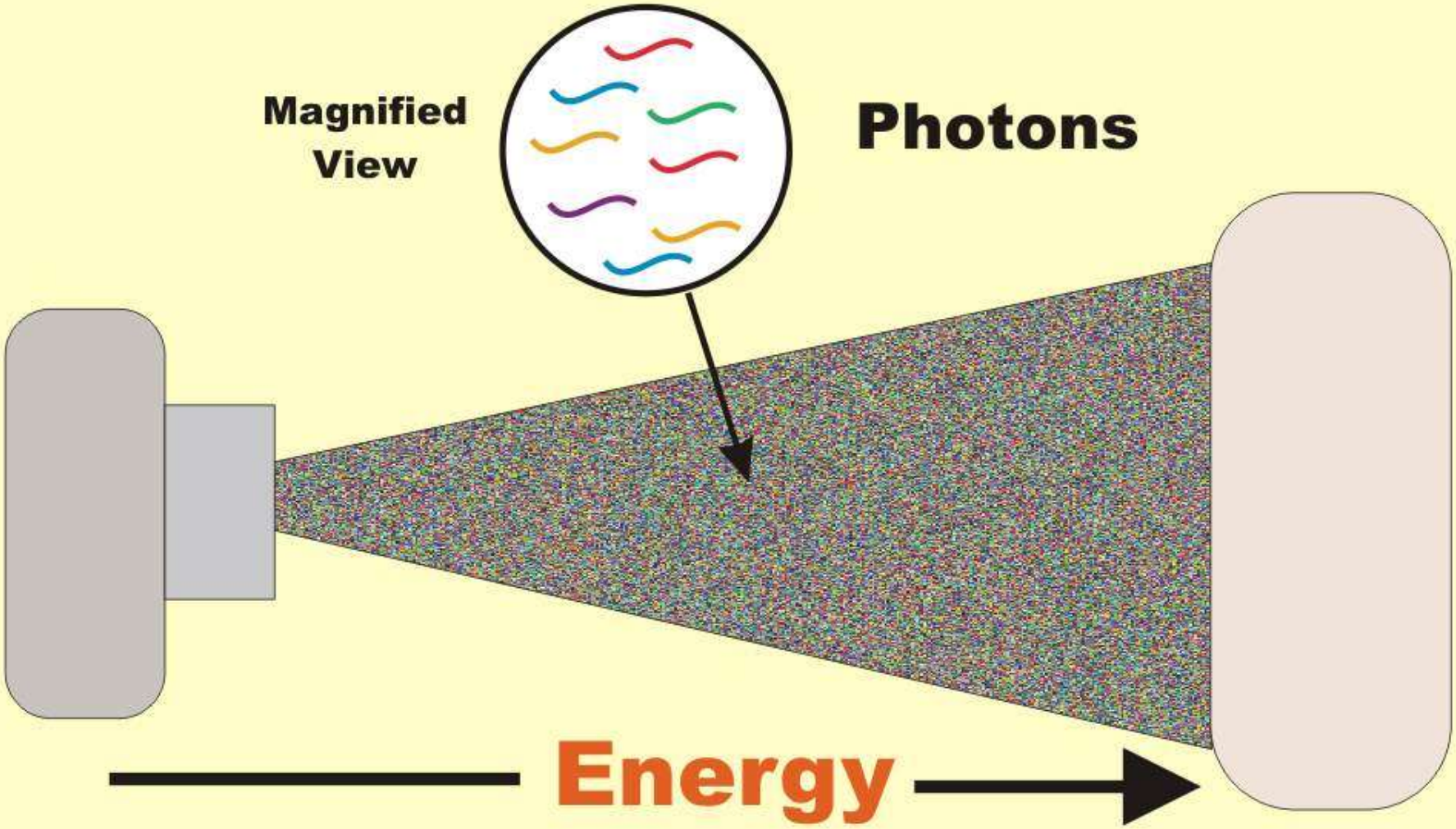


Physics and Quality Characteristics of X-Ray Images (Radiographs)

OVERVIEW



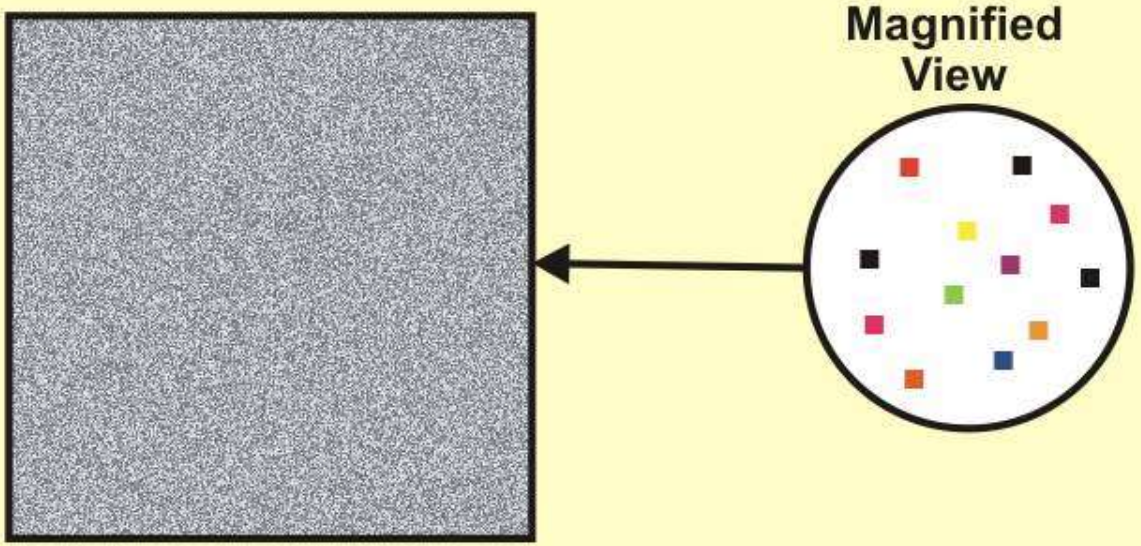
The X-ray Beam



Sprawls

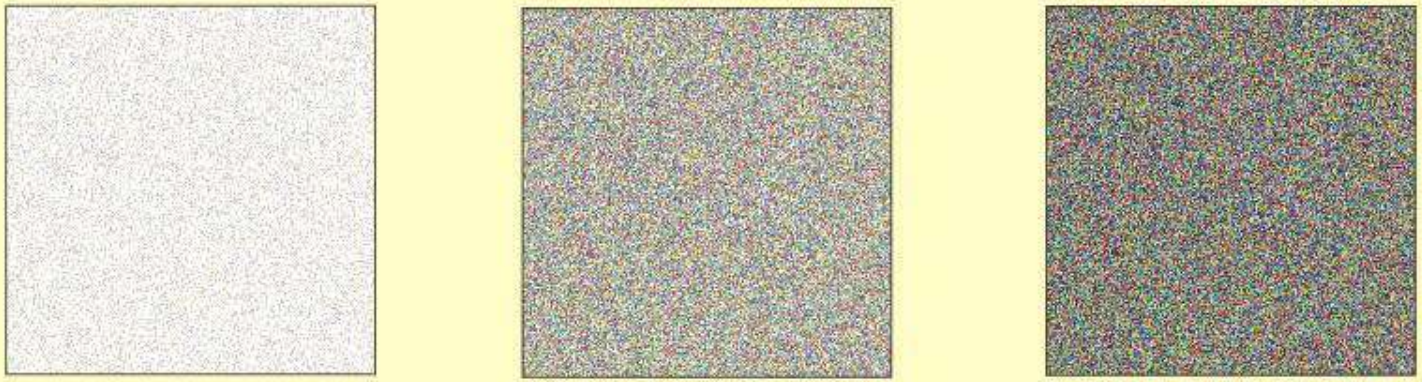
Image Of An X-ray Beam

A Random Distribution of Photons



This is visible in an x-ray image as noise (quantum noise).

High **Medium** **Low**



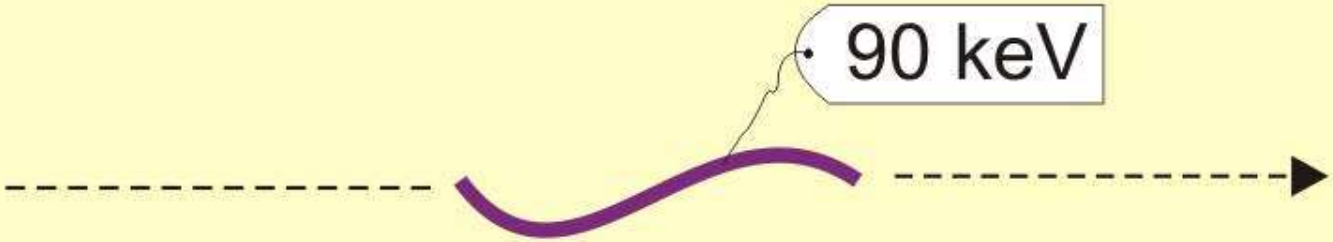
— Photon Concentration (Exposure)→

Sprawls

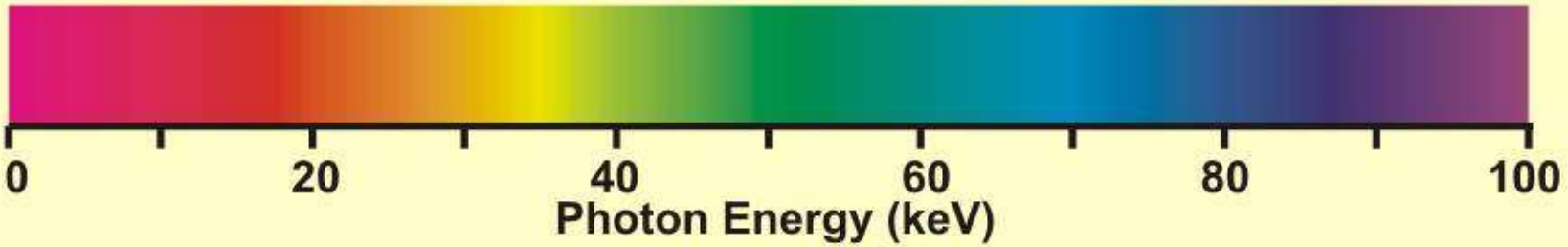
Photons

Individual Units (Quanta) of Energy

Each photon is characterized by its specific energy



The energies of the different photons cover a wide spectrum



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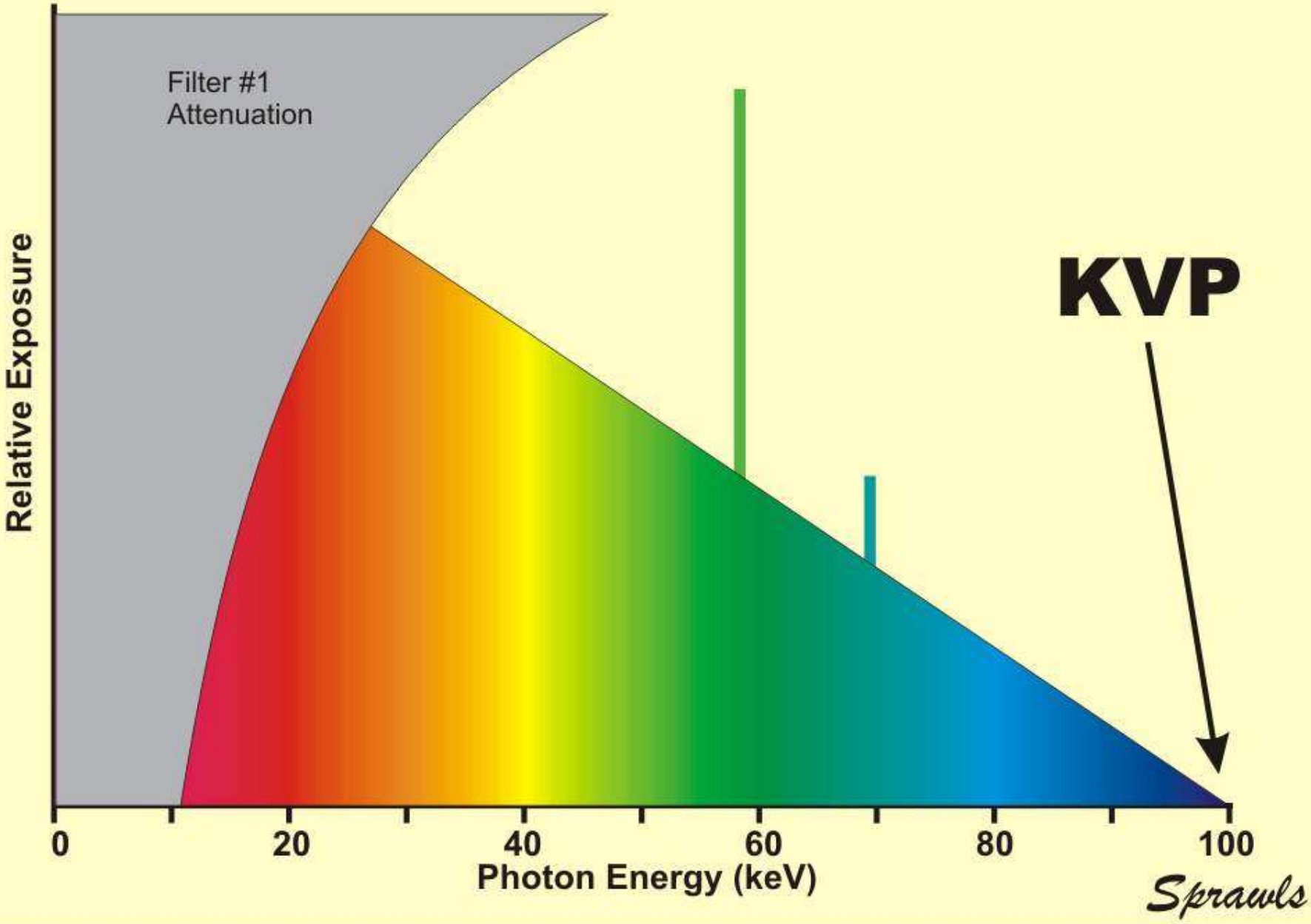
X-Ray Spectrum



Imaging Procedure Optimization

Radiation Dose

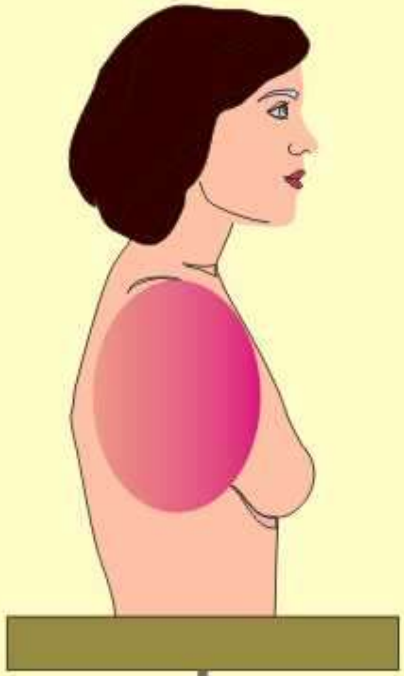
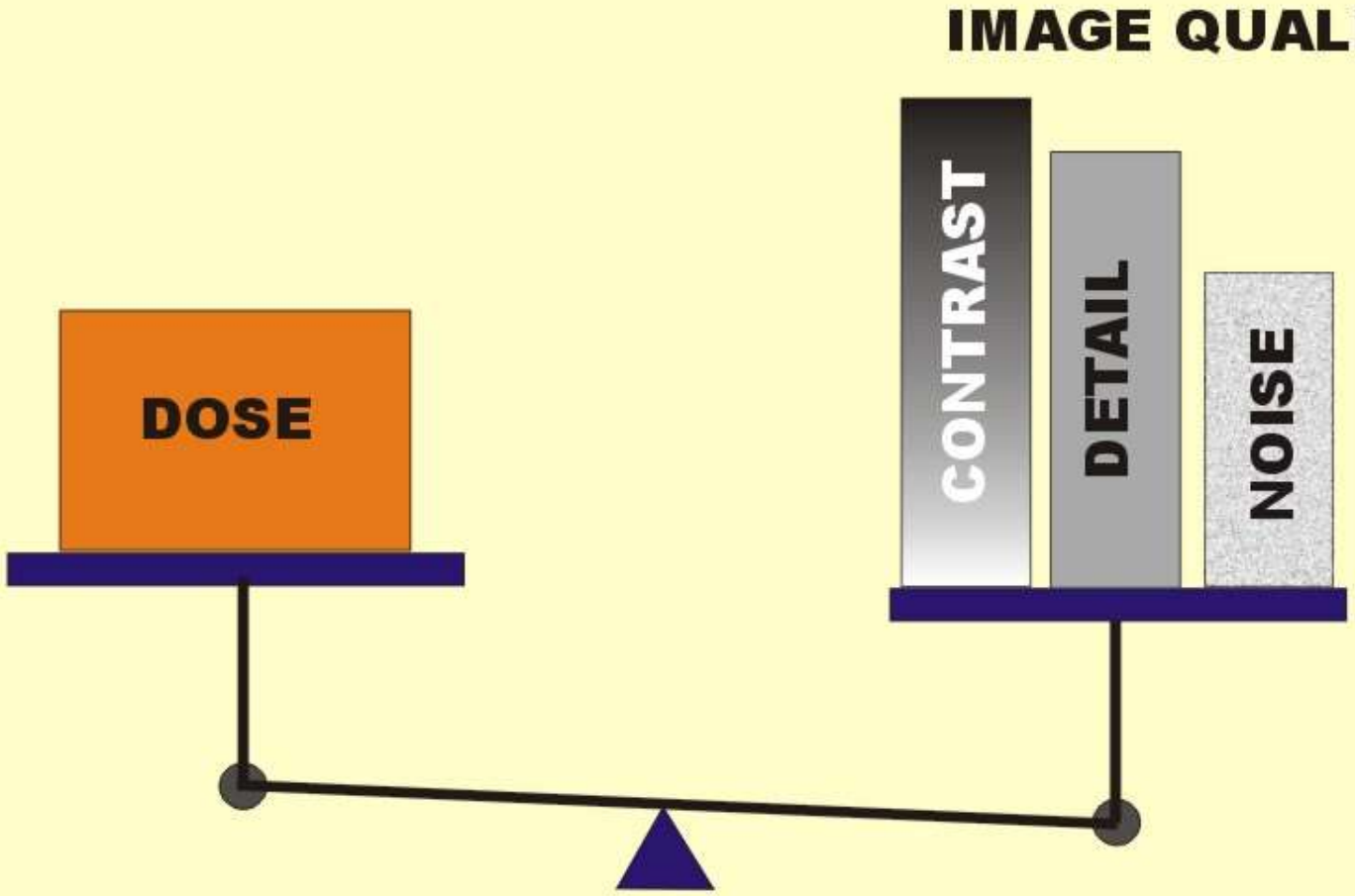


Image Quality

VISIBILITY

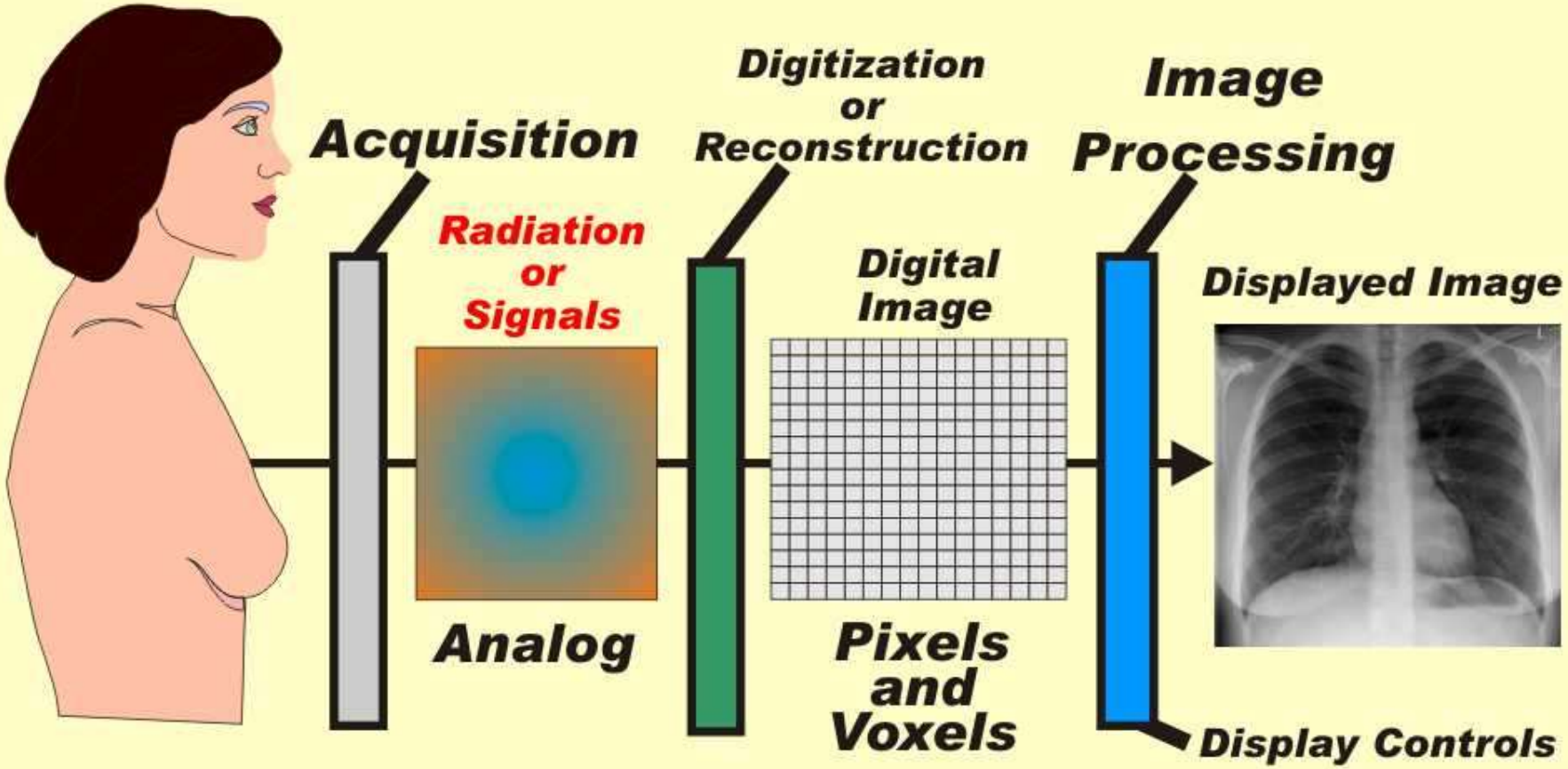
Sprawls

DOSE OPTIMIZATION



Sprawls

The Medical Imaging Process
All Modalities



Sprawls

Medical Image Quality Characteristics

Patient

It's all about VISIBILITY

Displayed Image

CONTRAST

Contrast Sensitivity

SPATIAL

Distortion

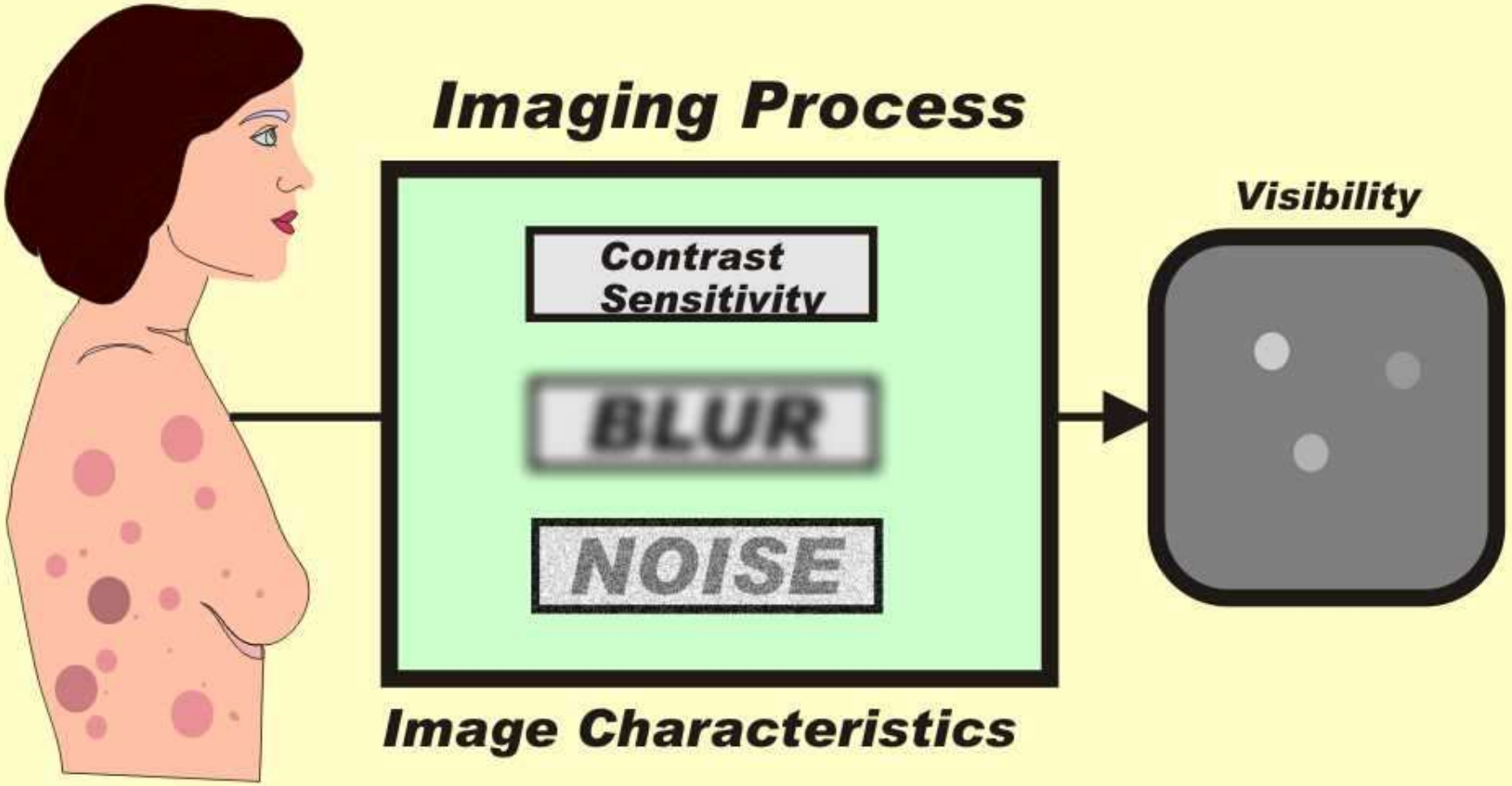
NOISE

BLUR

Artifacts

Sprawls

What Determines Visibility?



Sprawls

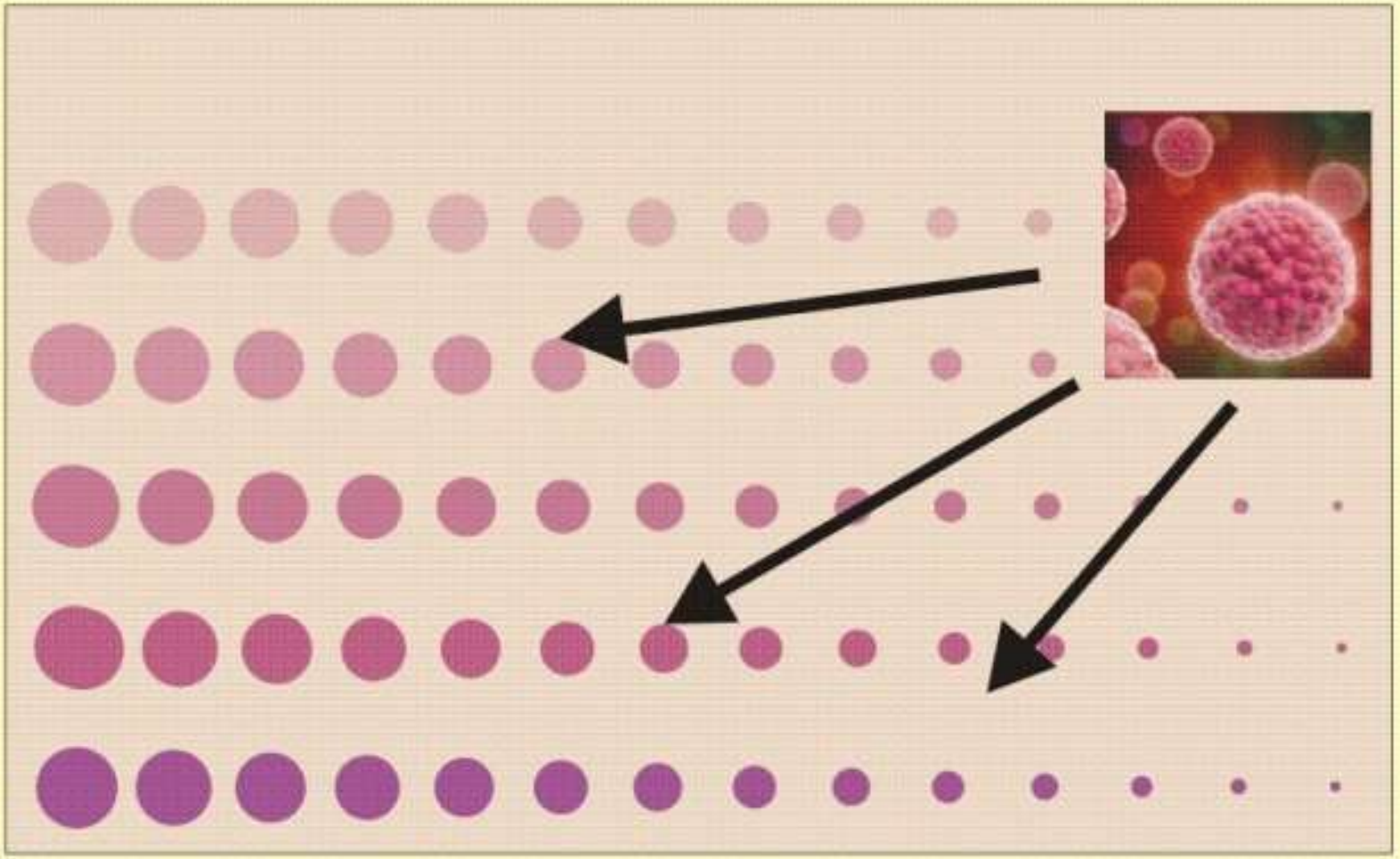
Physical Characteristics of Objects

Effect on Visibility

Sprawls

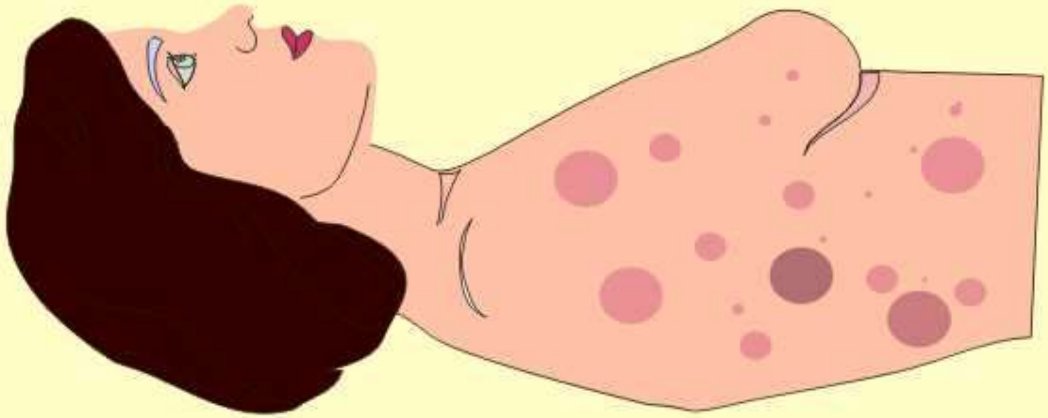
Physical Growth of Cancer

Effect on Visibility



Sprawls

Characteristics of Objects in the Body That Affect Visibility



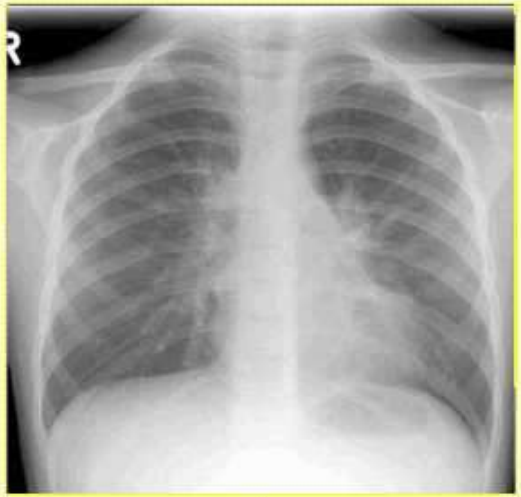
Size (detail)

Physical Contrast

Sprawls

What Do We See?

CONTRAST



Display and Viewing Conditions

Contrast Transfer (Processing)

Receptor Limitations (cut-off)

Scattered Radiation

X-Ray Spectrum

Anatomical Environment

Sprawls

Contrast

Physical

Human Body

Contrast Sensitivity

Imaging Procedure

Visual

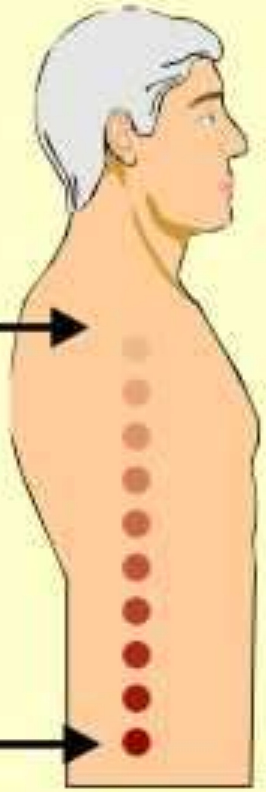
Image

Equipment + Protocol

Sprawls

Objects in the Body

Physical Contrast

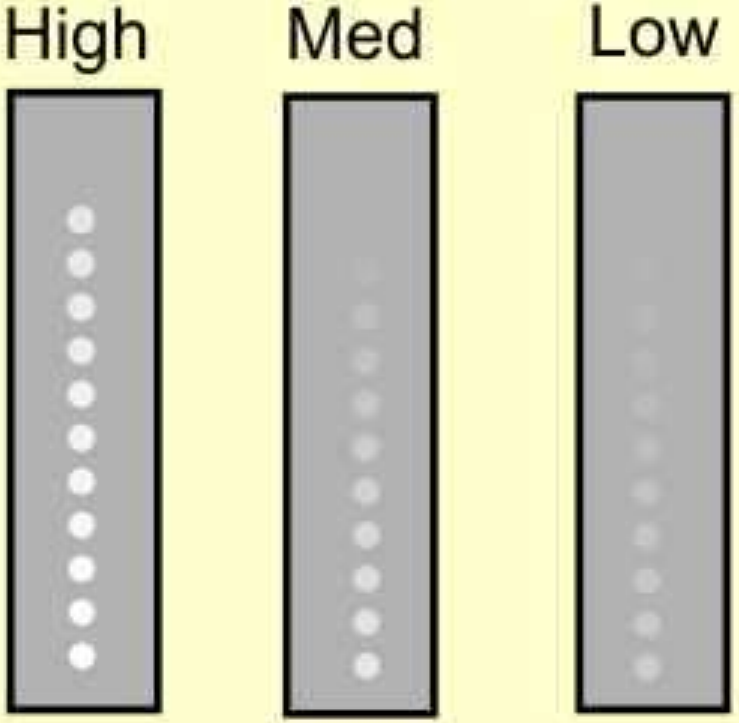


Low
(Soft Tissues, Fluids, etc)

High
(Bones, Bullets, Barium, etc)

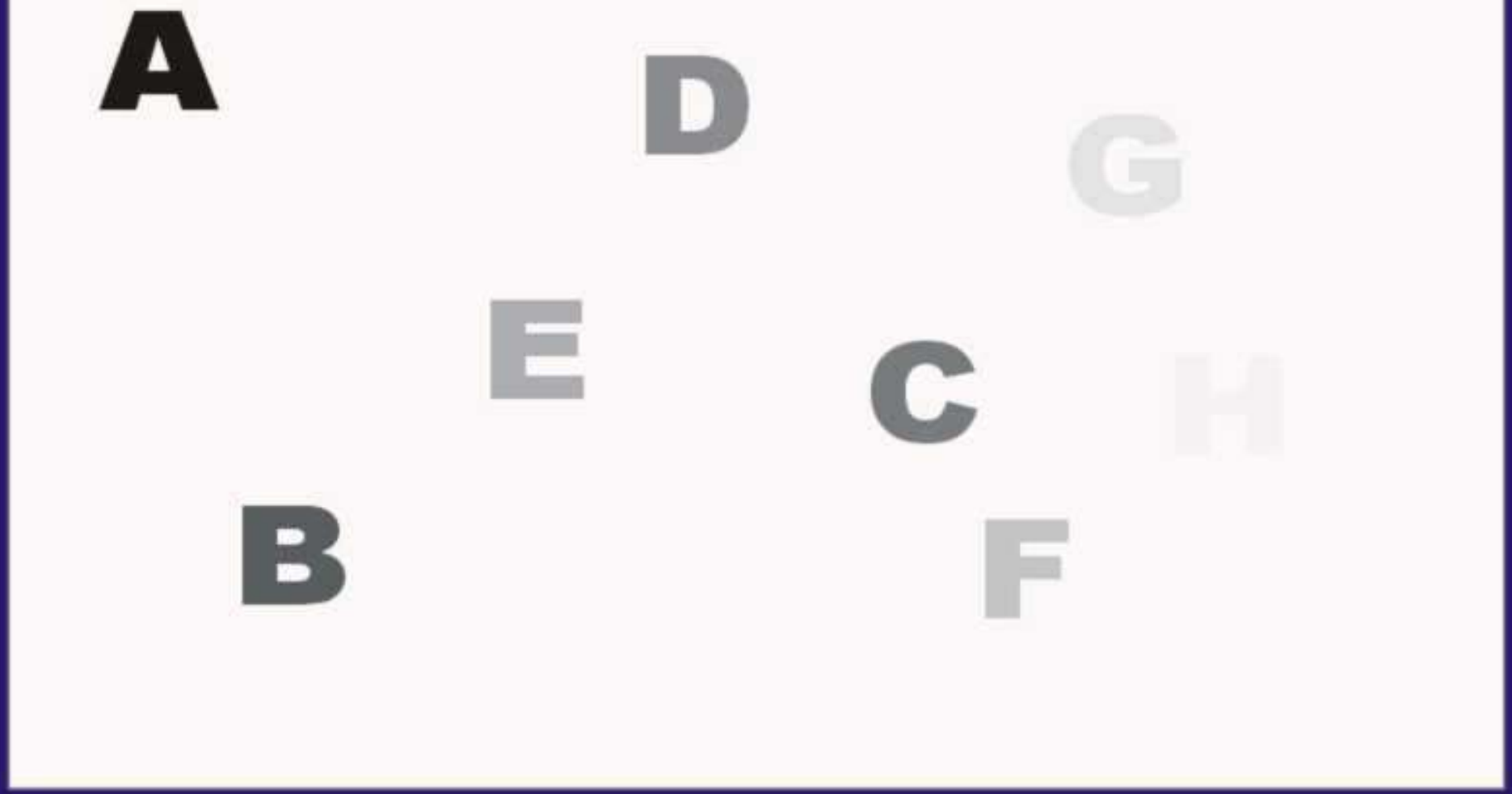
Imaging Procedure

CONTRAST SENSITIVITY



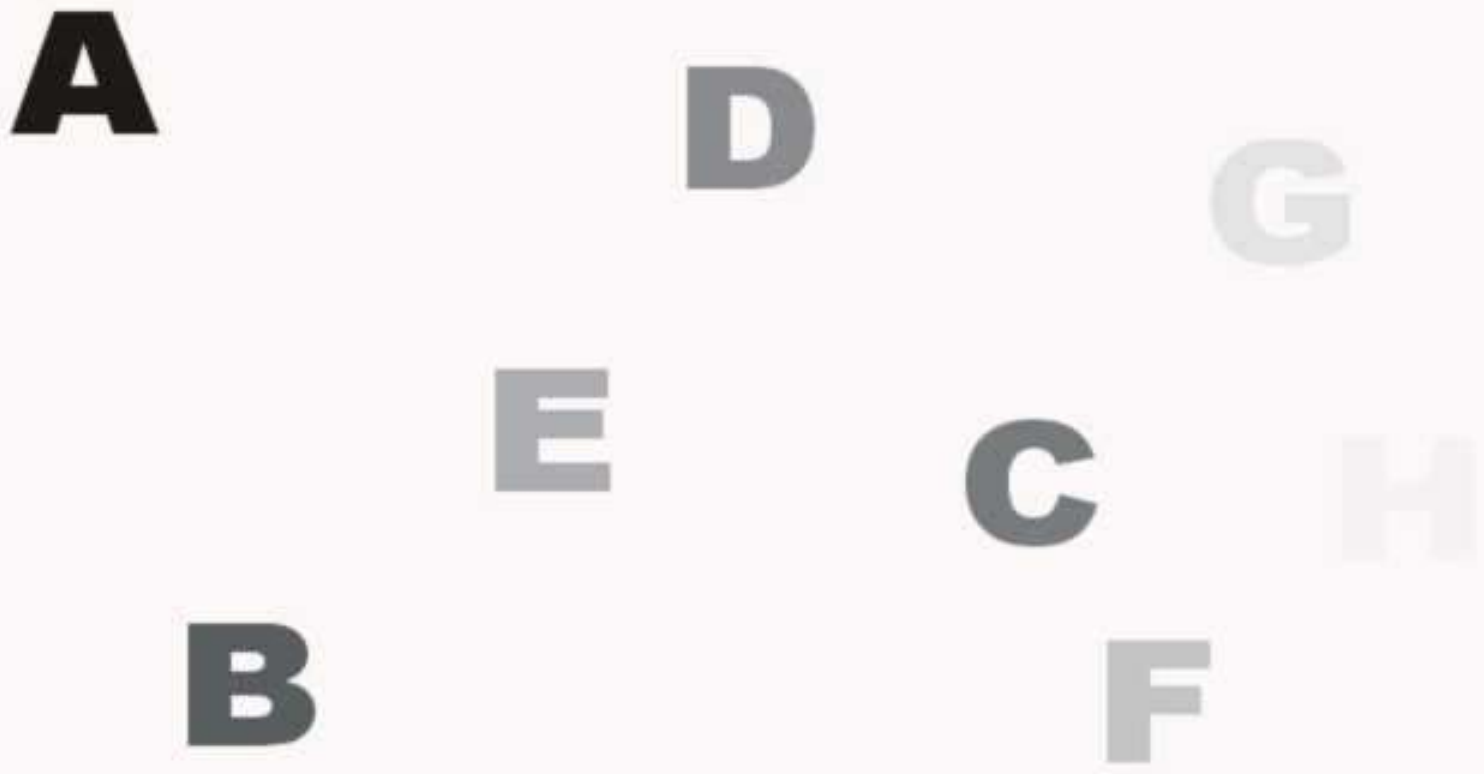
Images

VISION TEST



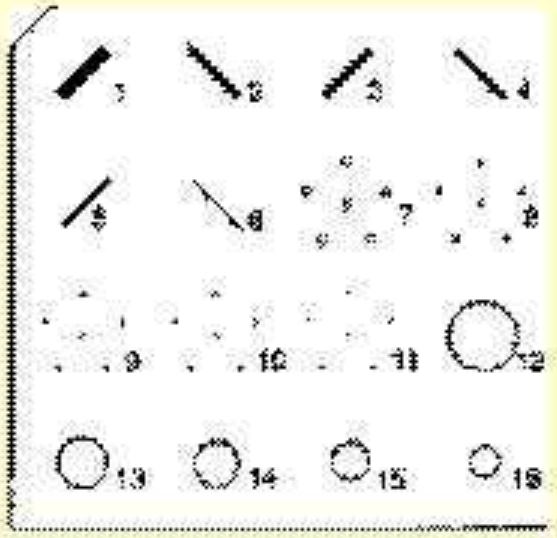
Sprawls

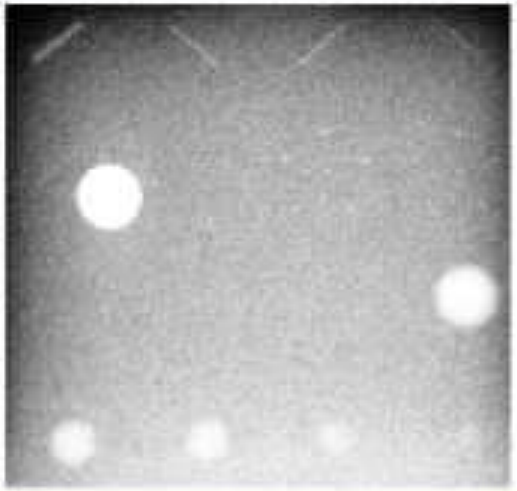
CONTRAST SENSITIVITY



Sprawls

Masses





12.	2.00 mm thick tumor-like mass
13.	1.00 mm thick tumor-like mass
14.	0.75 mm thick tumor-like mass
15.	0.50 mm thick tumor-like mass
16.	0.25 mm thick tumor-like mass

RADIOGRAPHY

CONTRAST SENSITIVITY

Adjusted to

LOW

HIGH

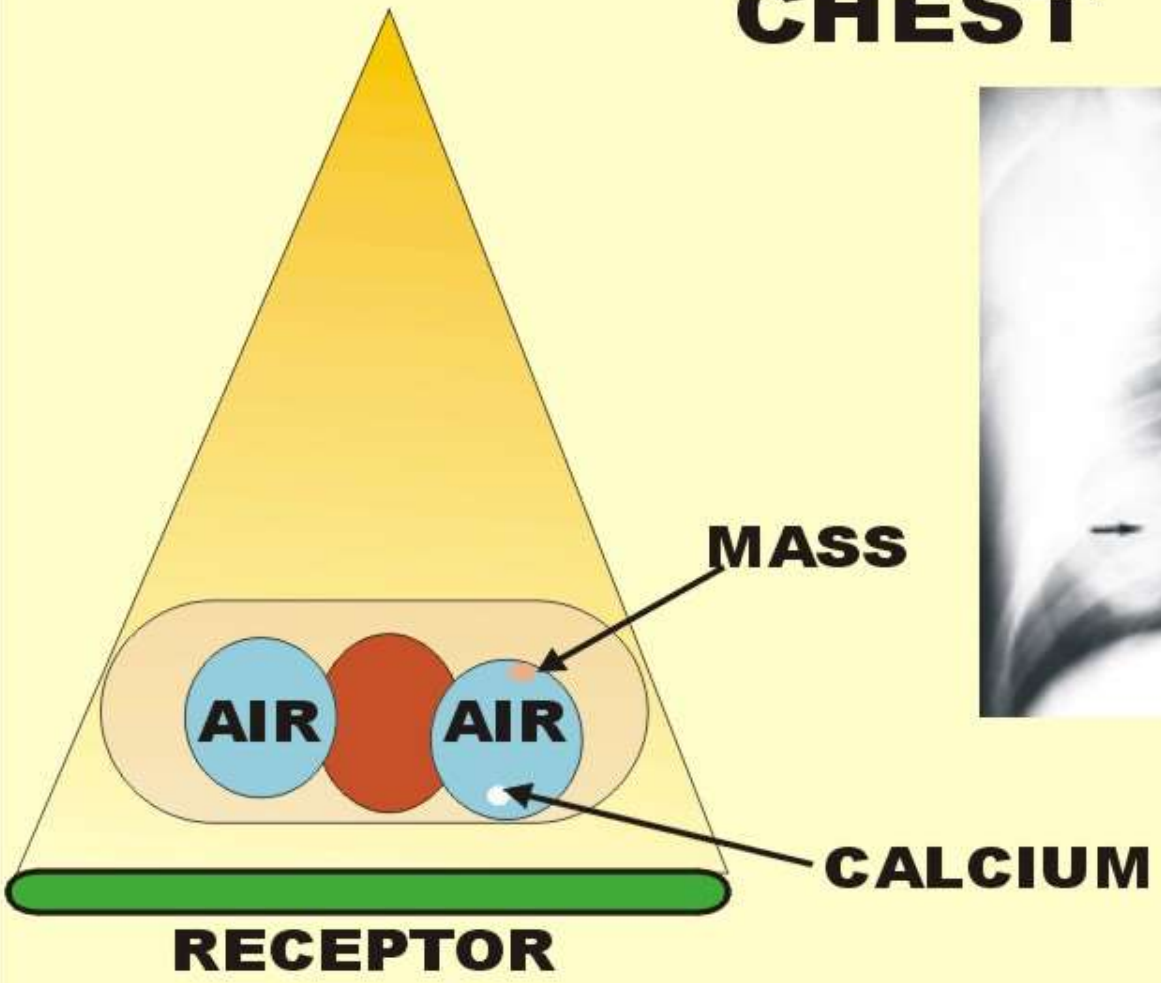
HIGH

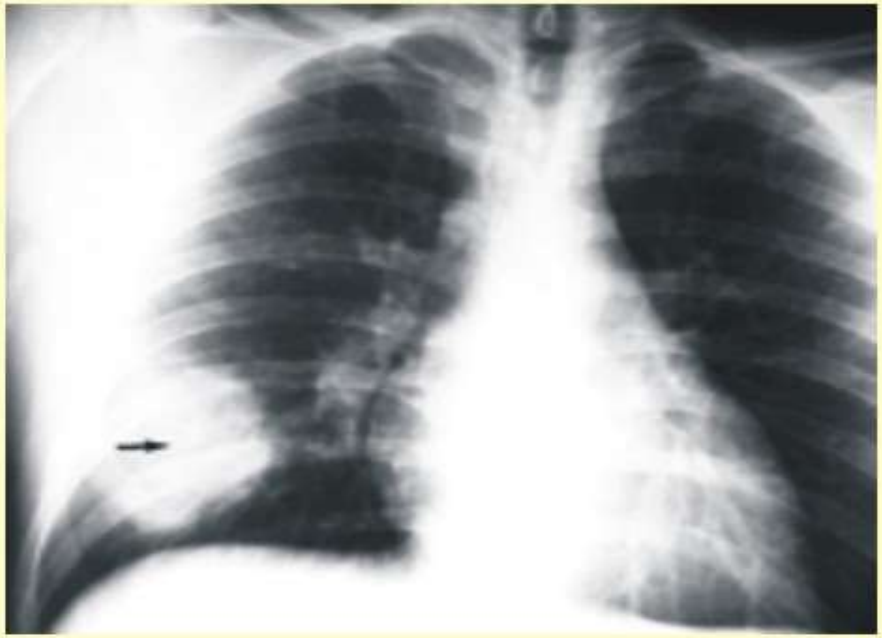
LOW

PHYSICAL CONTRAST
within
BODY

Sprawls

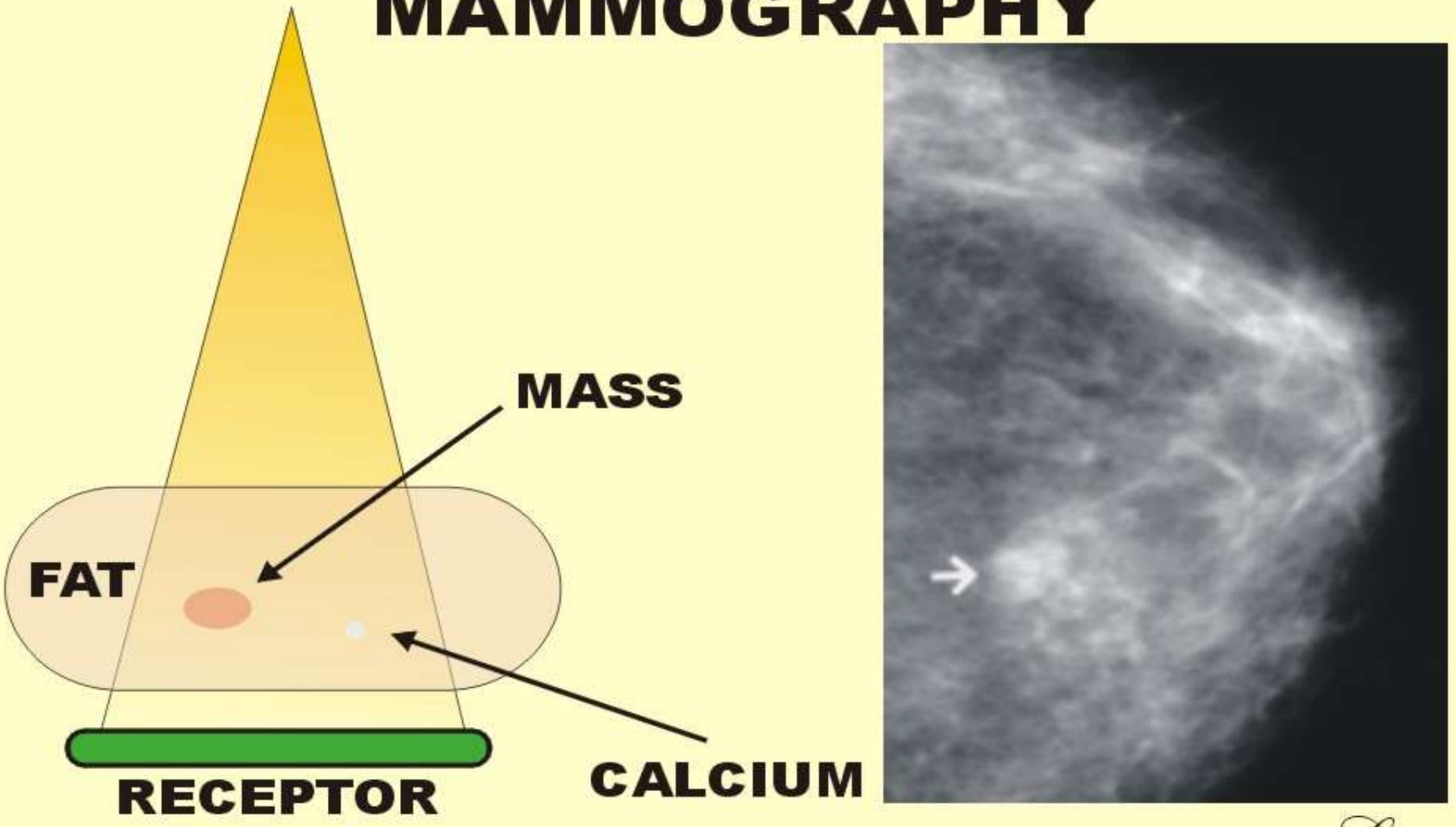
PHYSICAL CONTRAST in CHEST





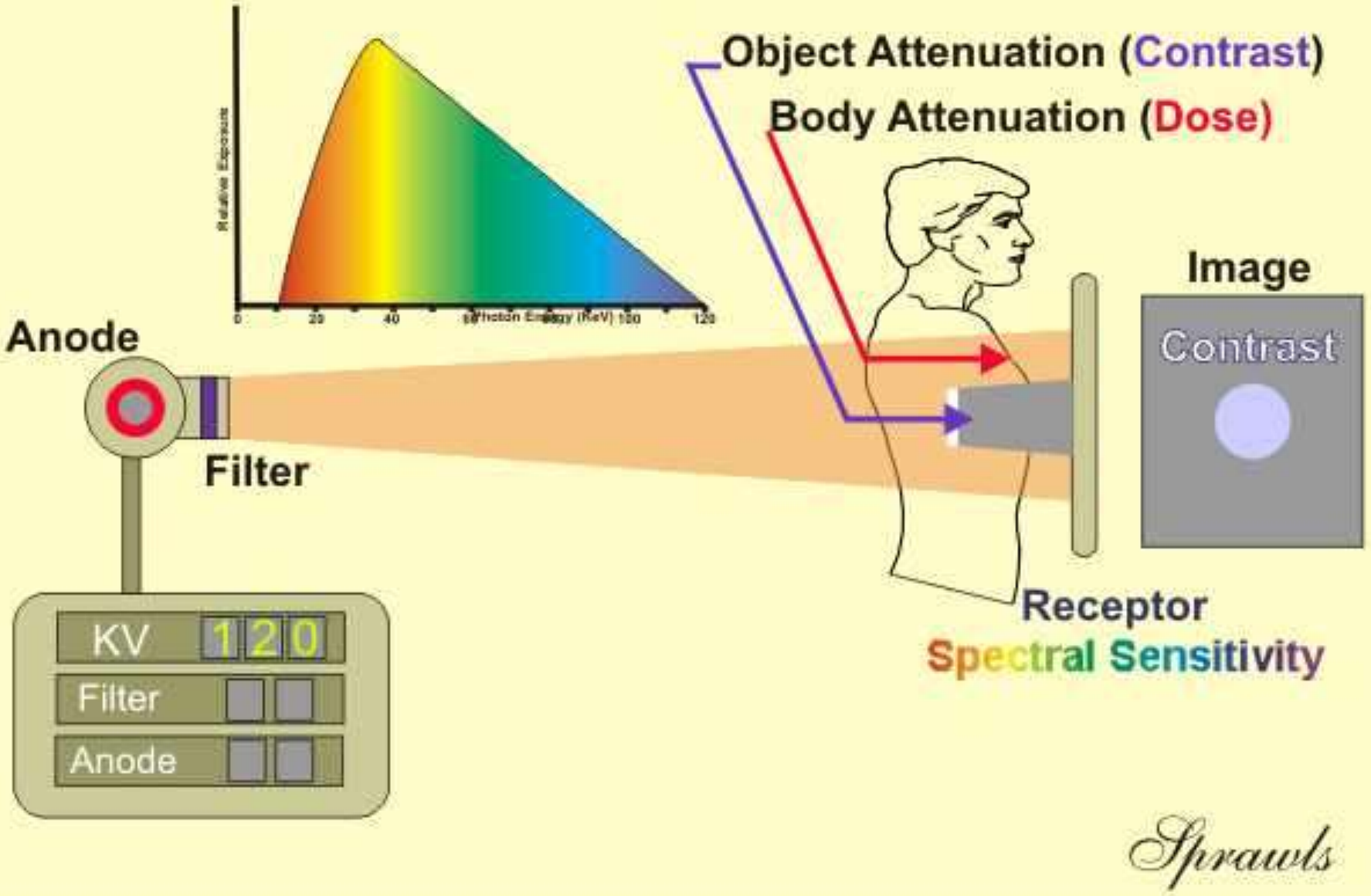
Sprawls

PHYSICAL CONTRAST in MAMMOGRAPHY



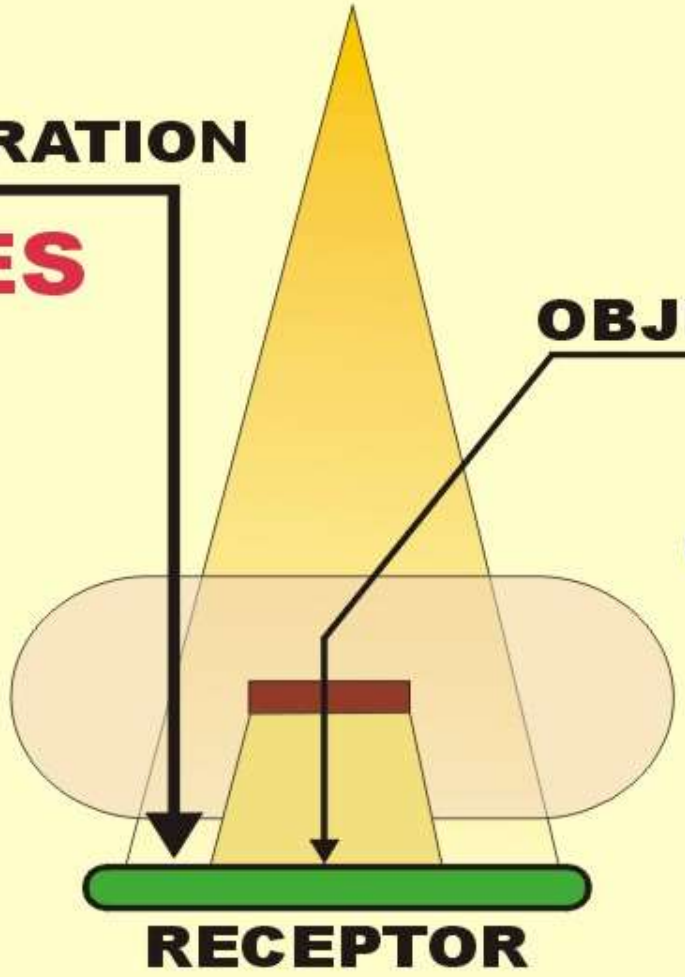
Sprawls

X-Ray Image Contrast



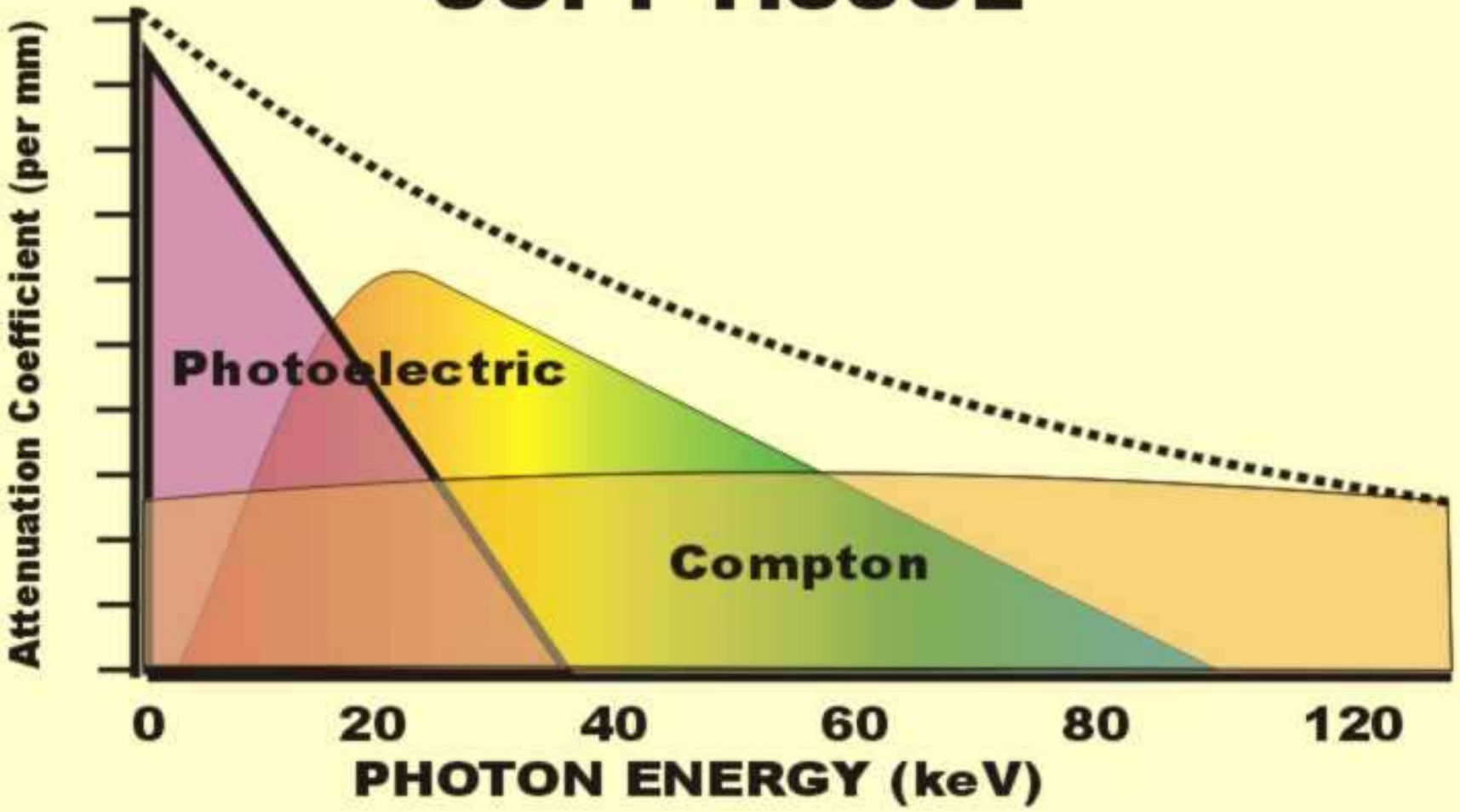
Sprawls

X-RAY BEAM PENETRATION



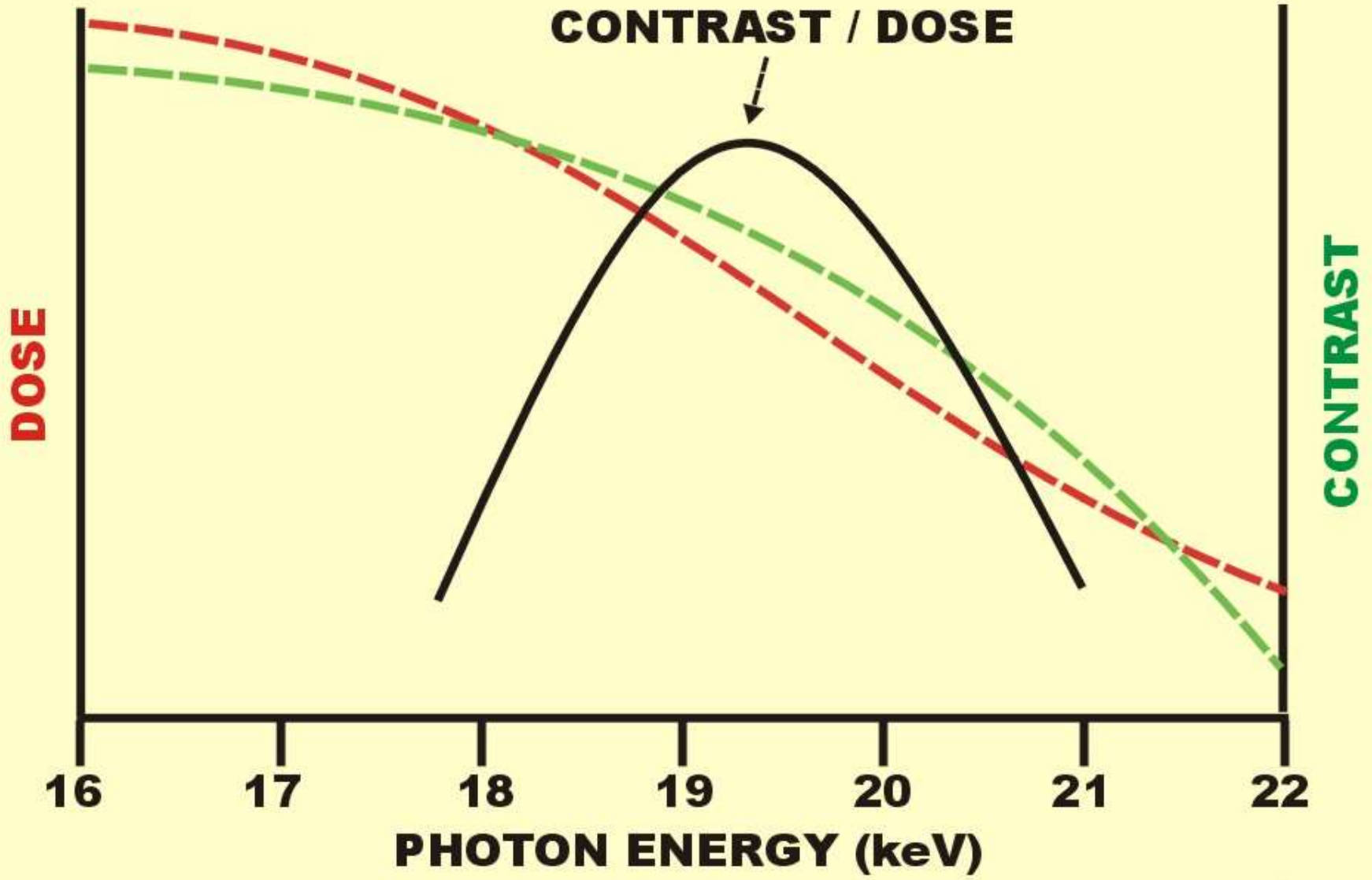
Sprawls

Total Attenuation In SOFT TISSUE



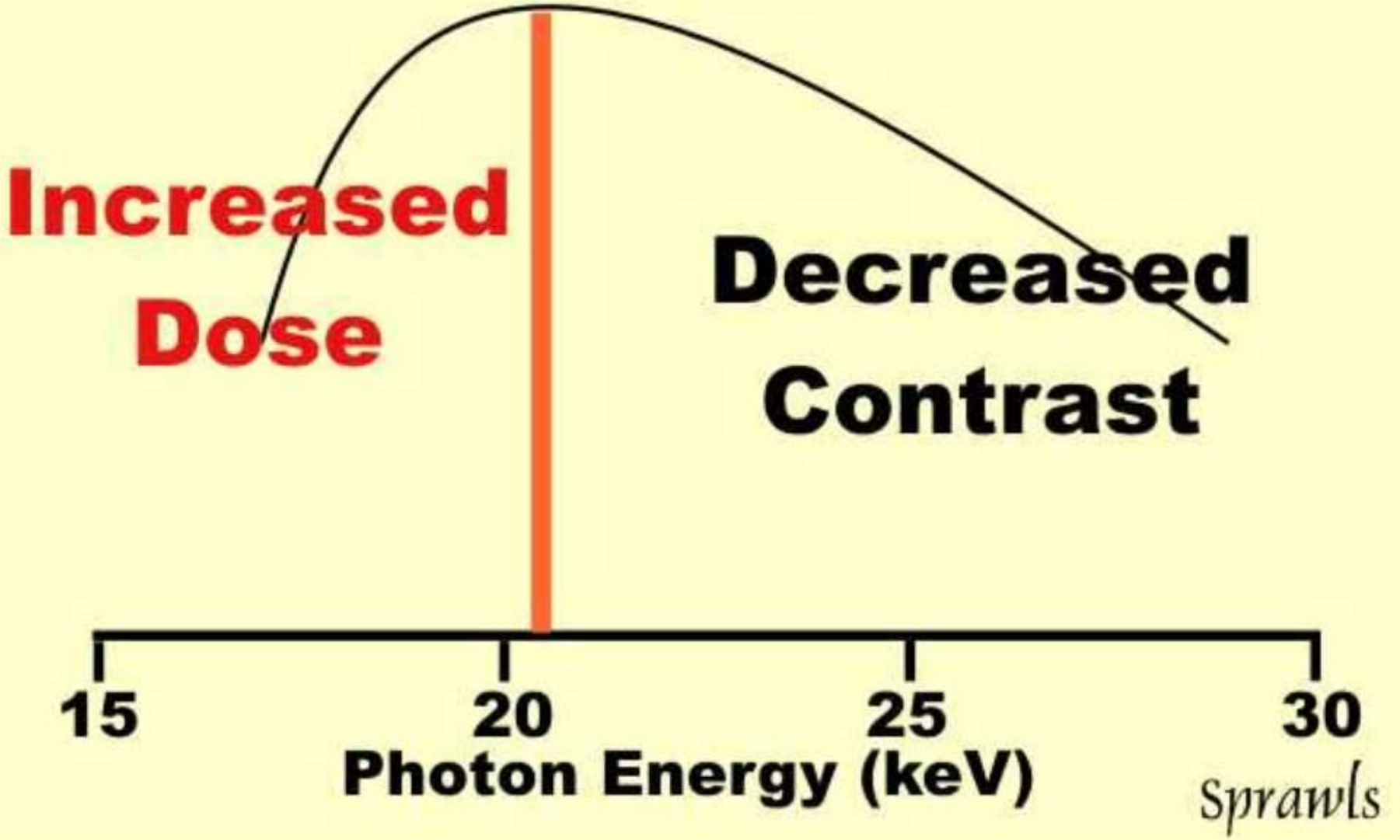
Sprawls

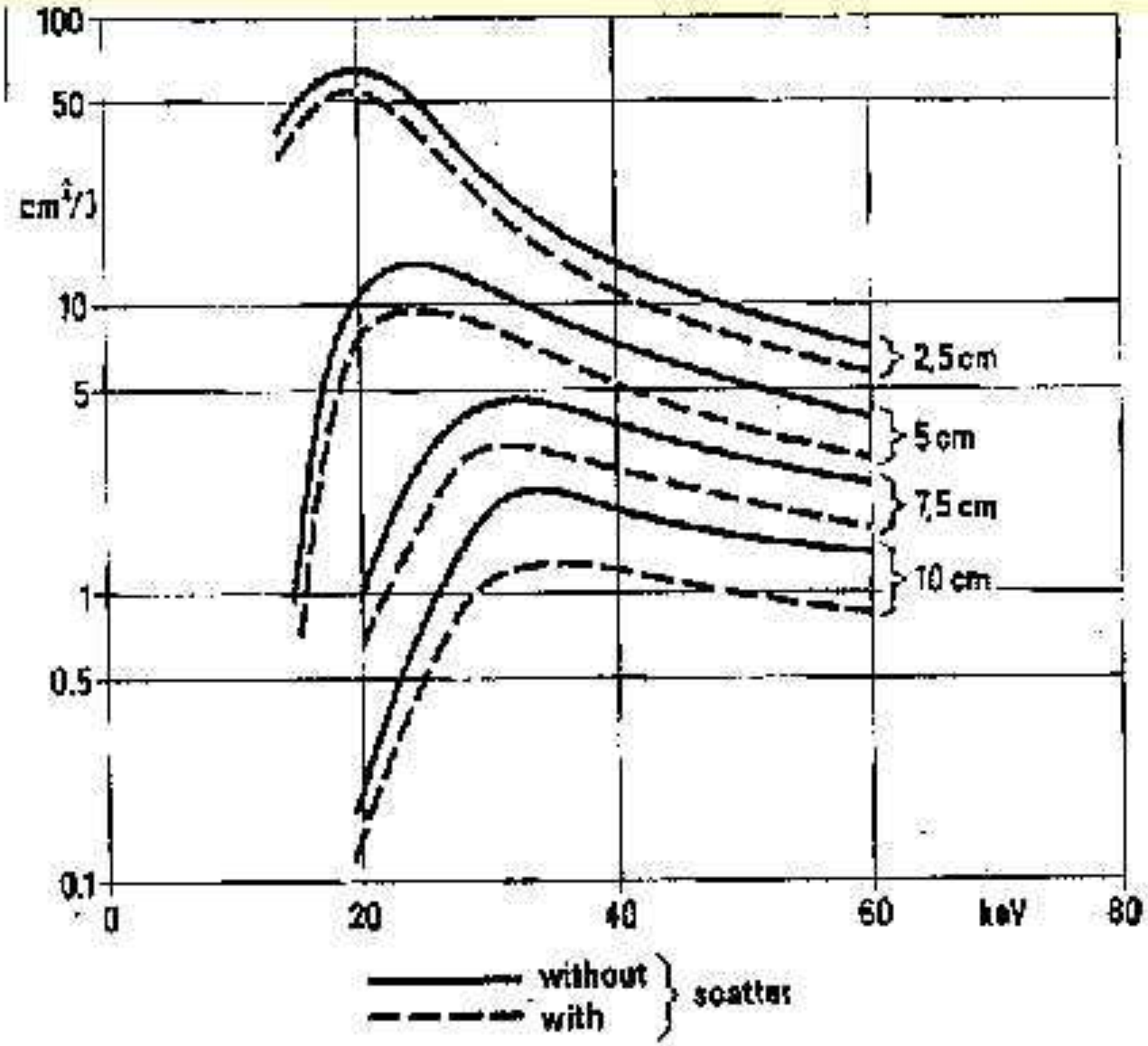
MAMMOGRAPHY



Sprawls

Optimum Photon Energy

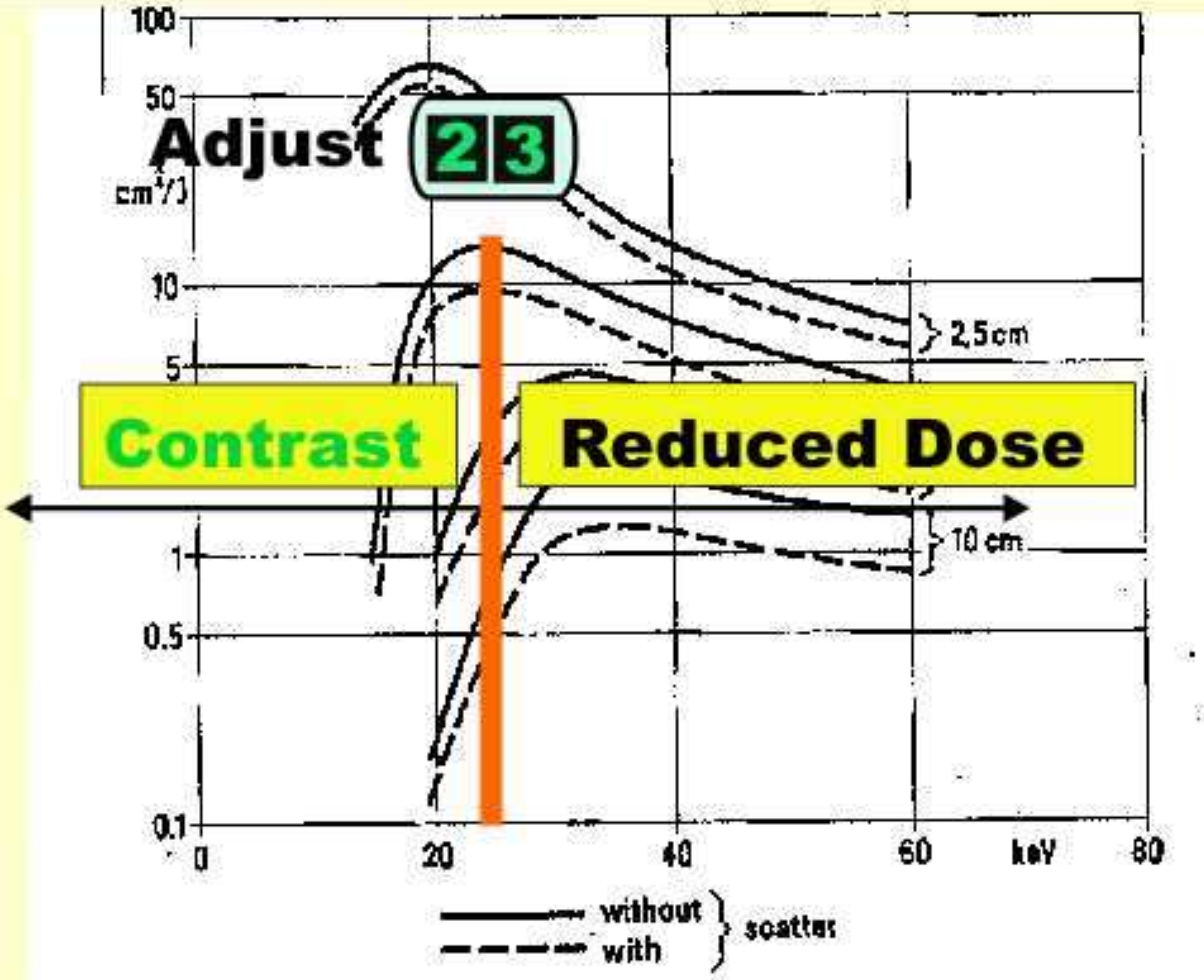




$$\text{Quality Number } G = \frac{(\text{Contrast})^2}{\text{Radiation exposure (J/cm}^2)}$$

(Gajewski and Reiß, Der Radiologe Heft 10/74)

Sprawls

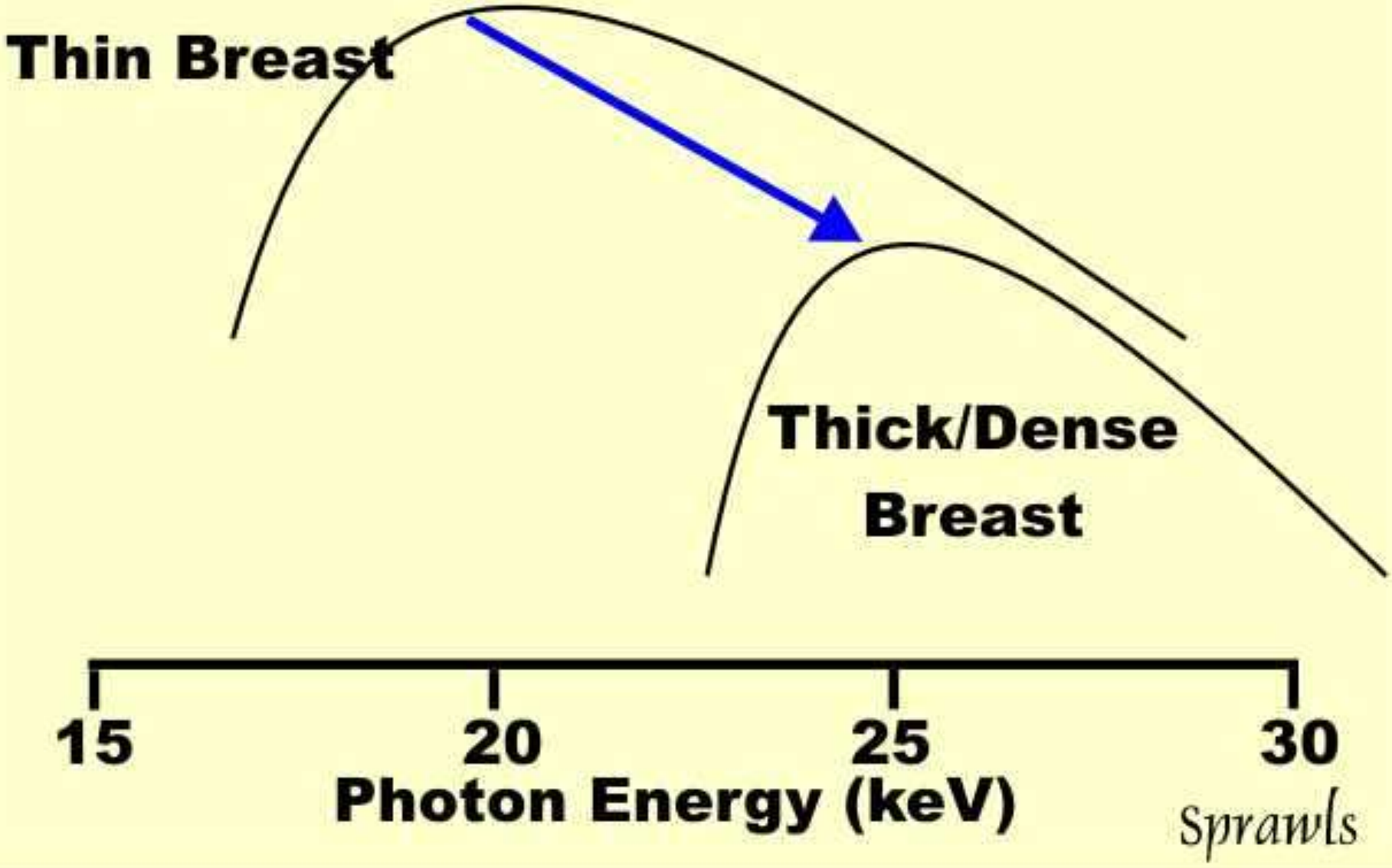


$$\text{Quality Number } G = \frac{(\text{Contrast})^2}{\text{Radiation exposure } (J/cm^2)}$$

(Gajewski and Reiß, Der Radiologe Heft 10/74)

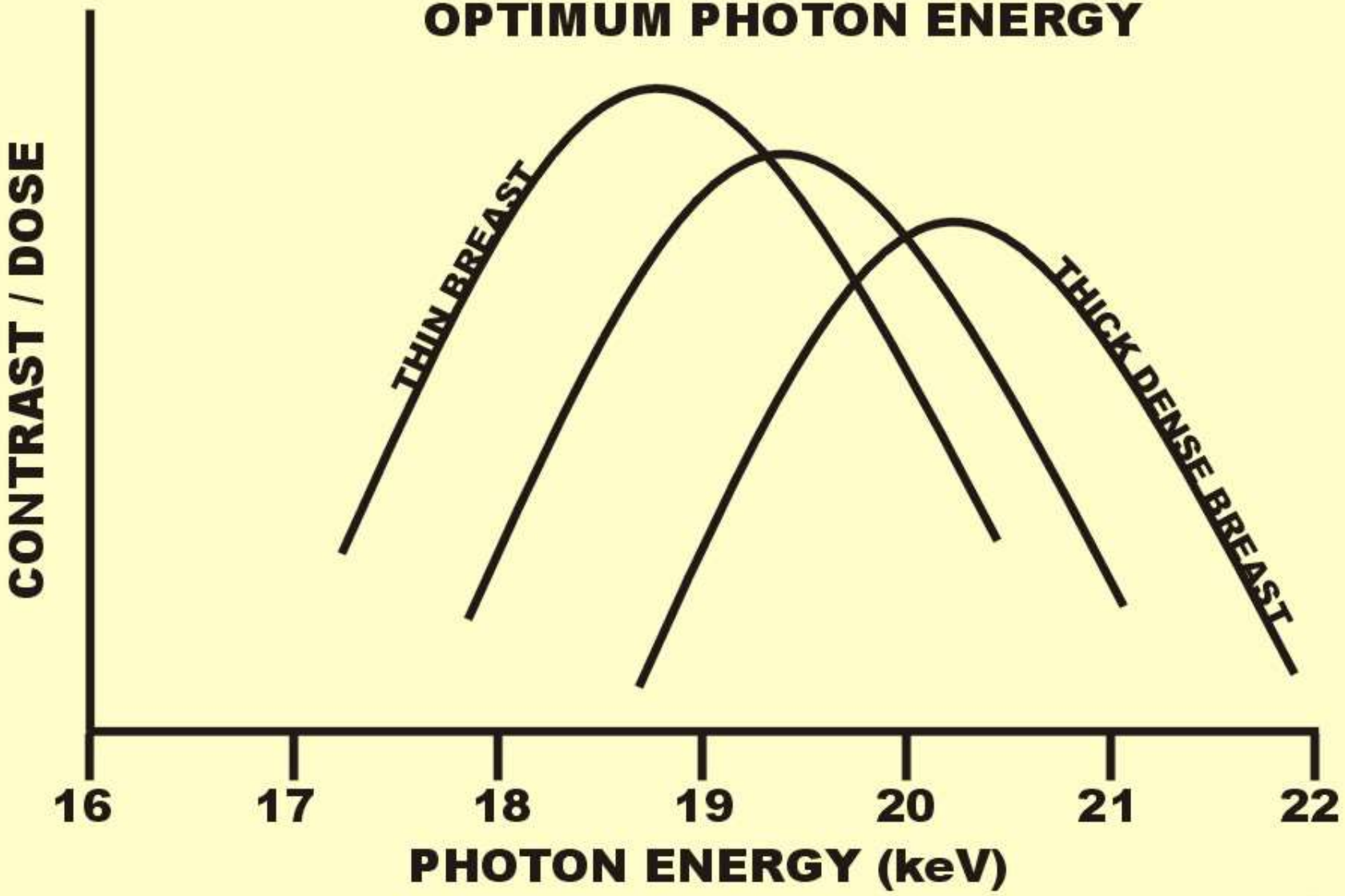
Sprawls

Optimum Photon Eneregy



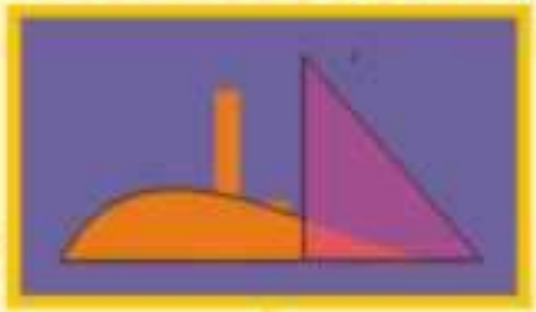
MAMMOGRAPHY

OPTIMUM PHOTON ENERGY



Sprawls

FACTORS AFFECTING
THE X-RAY SPECTRUM
in Mammography



ANODE

- MOLYBDENUM
- RHODIUM
- ~~TUNGSTEN~~

FILTER

- MOLYBDENUM
- RHODIUM
- ~~ALUMINUM~~

KV

30

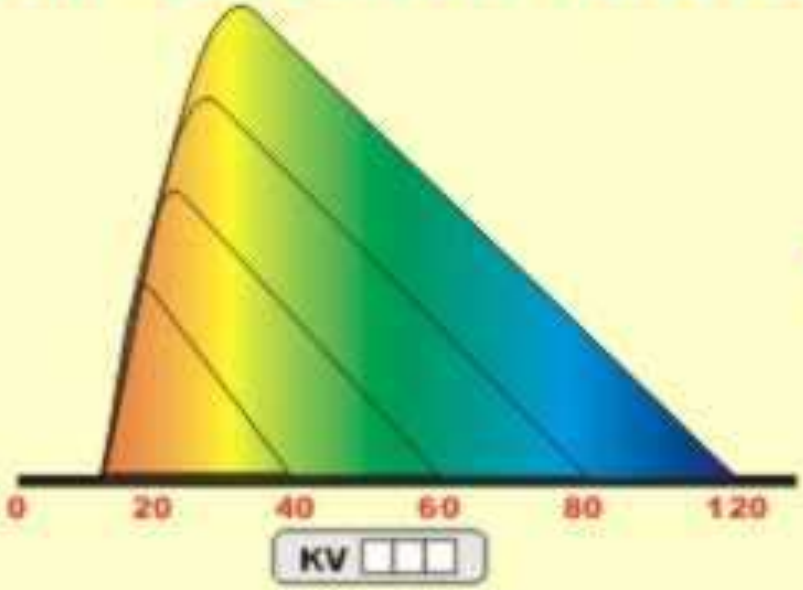
24

Sprawls

FACTORS AFFECTING

THE X-RAY SPECTRUM

in General Radiography



KV

120

50

ANODE

FILTER

TUNGSTEN

ALUMINUM

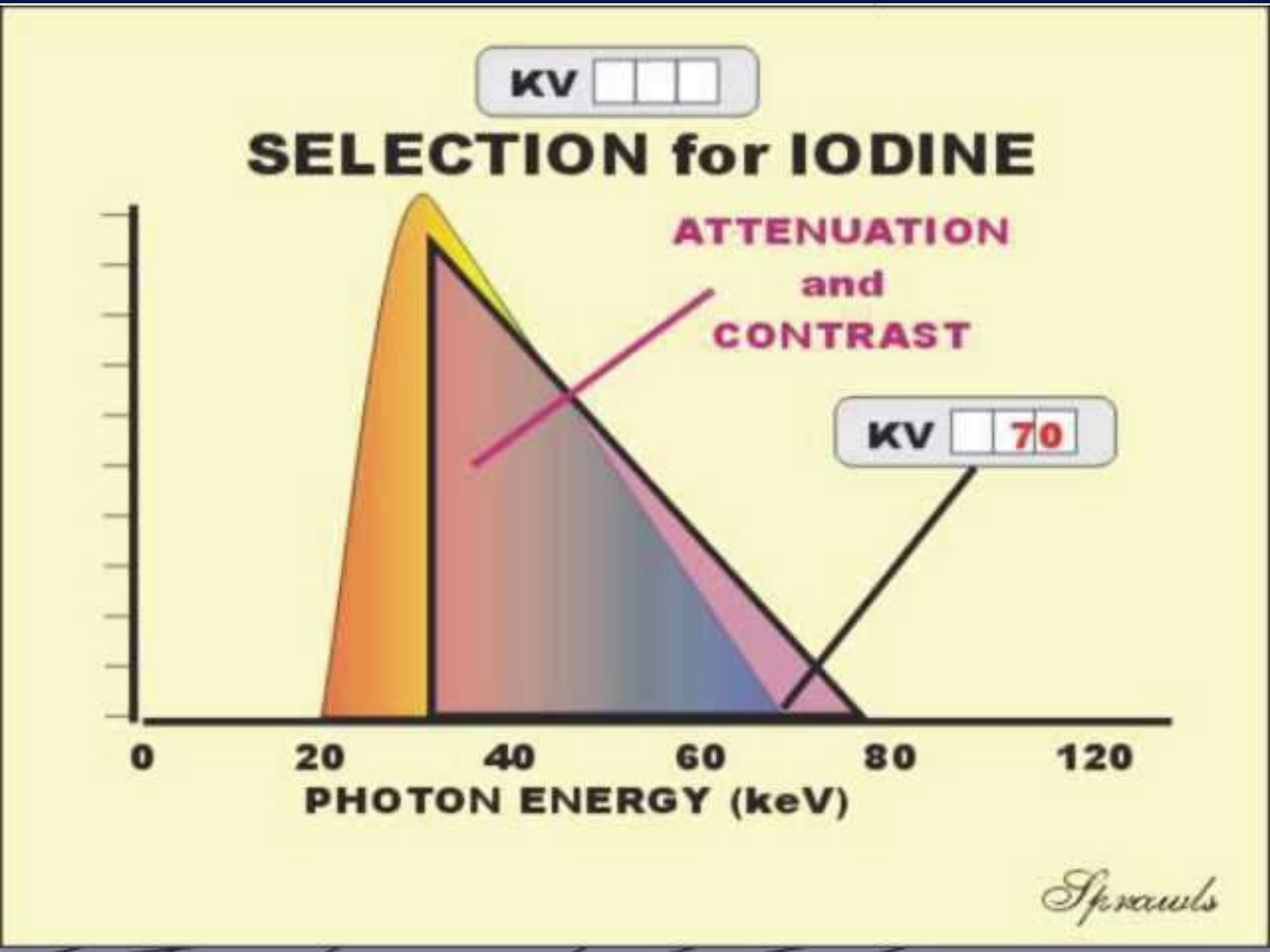
Sprawls

KV

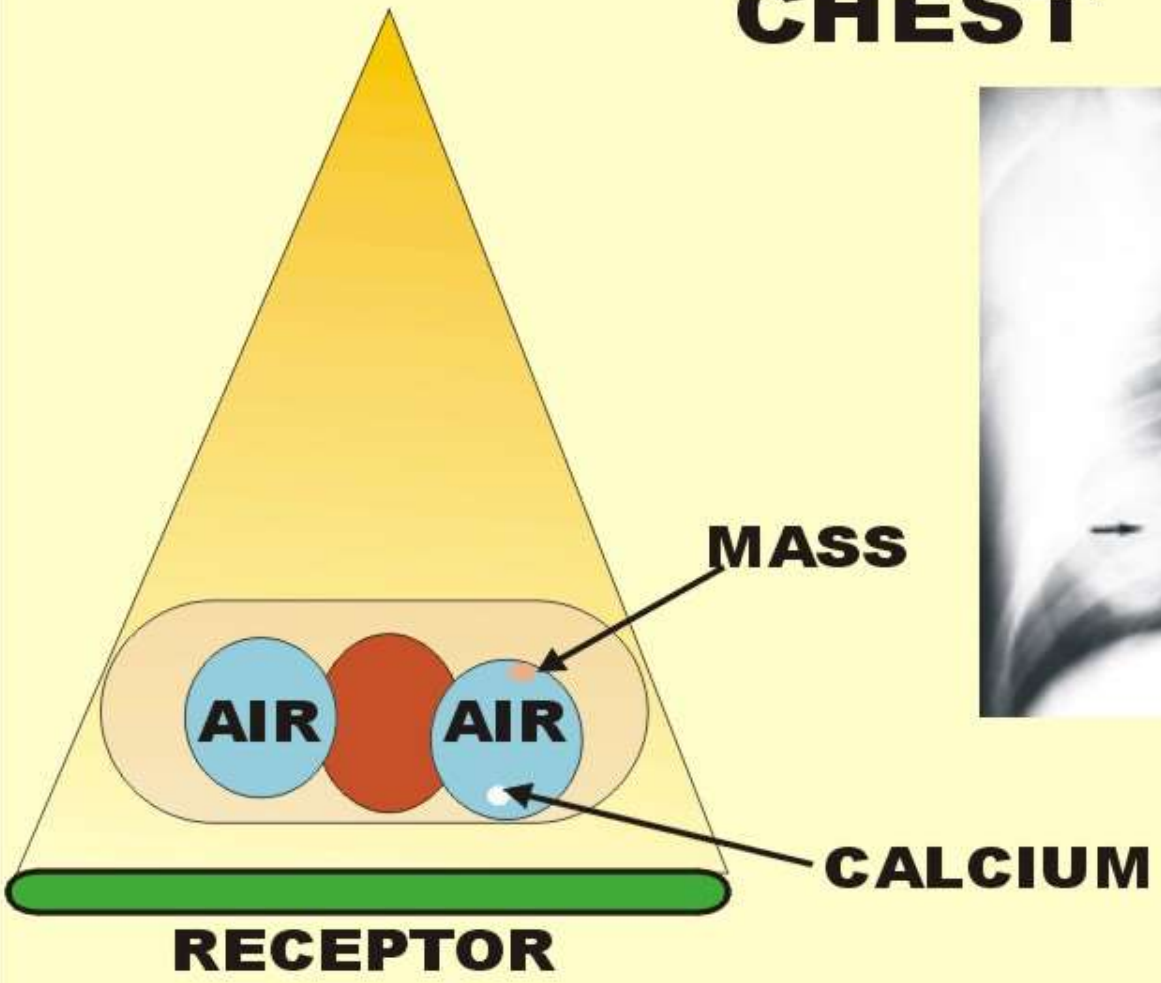
SELECTION

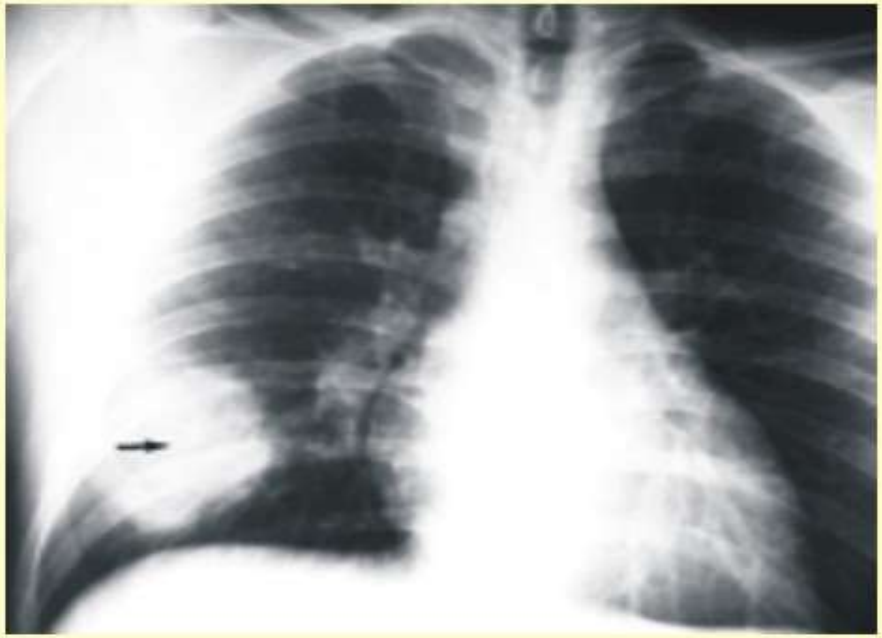
KV

Sprawls


KV
SELECTION for IODINE
ATTENUATION
and
CONTRAST
KV 70
0
20
40
60
80
120
PHOTON ENERGY (keV)
Sprawls

PHYSICAL CONTRAST in CHEST

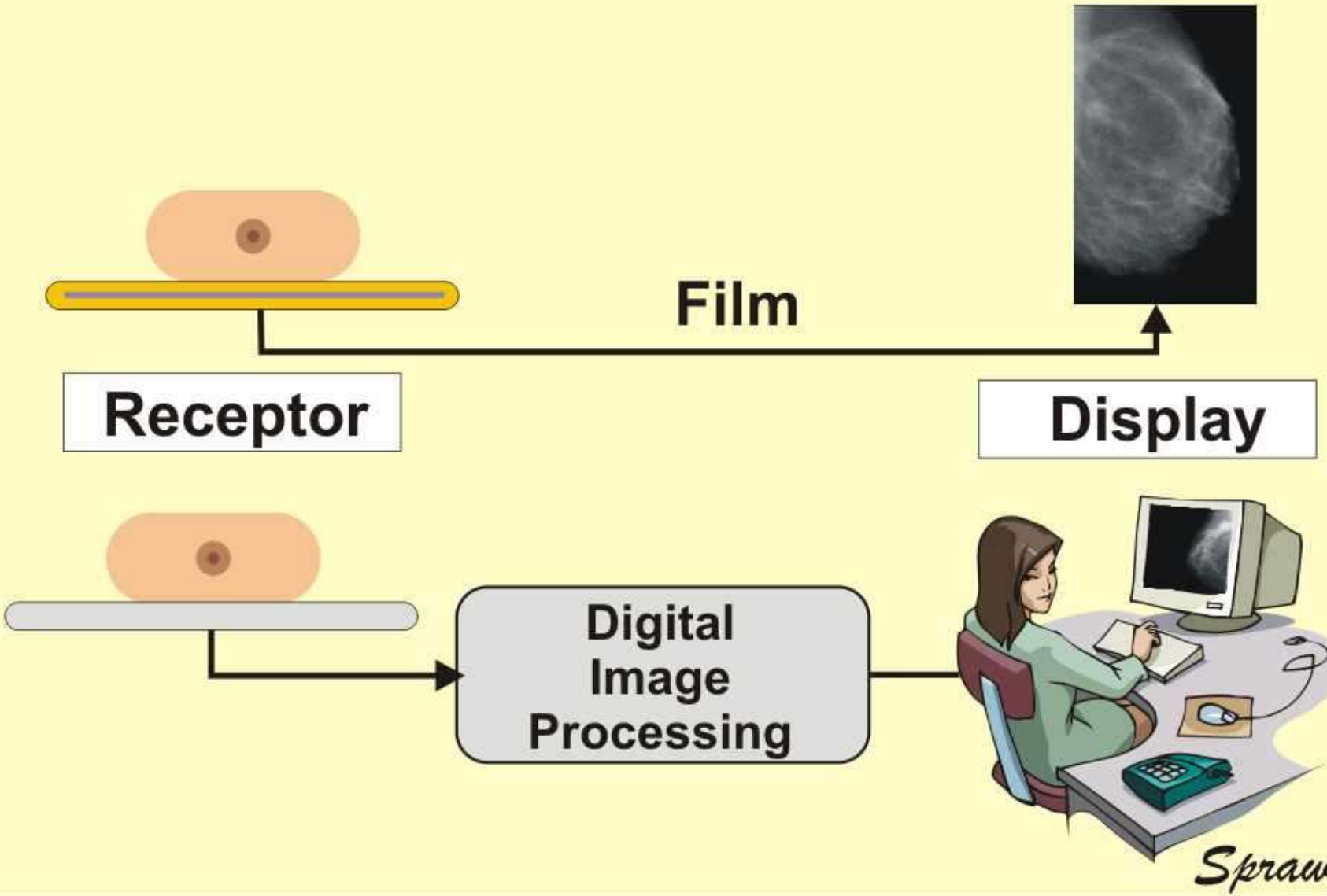




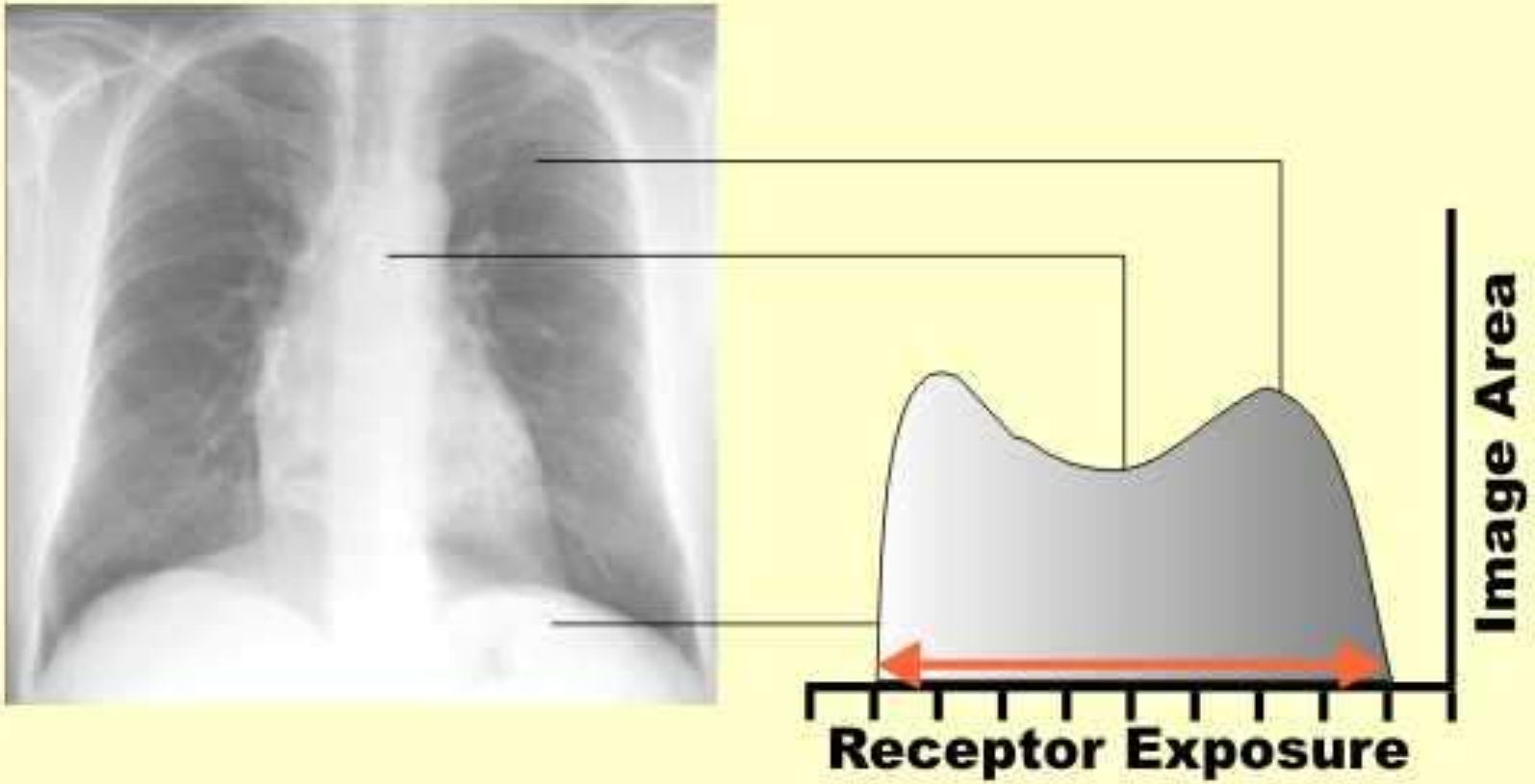
Sprawls

Mammography

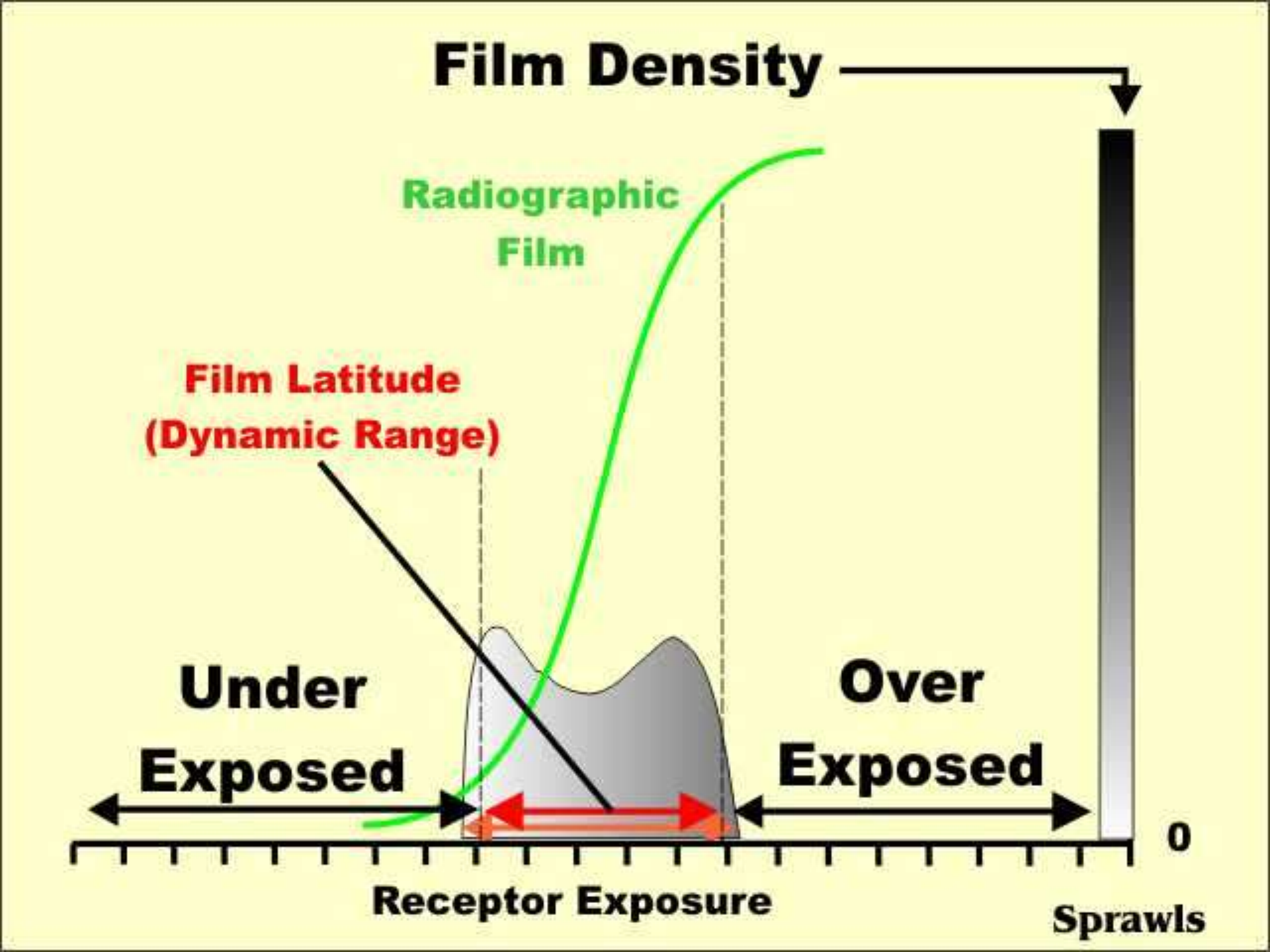
Receptor/Display Contrast Characteristics



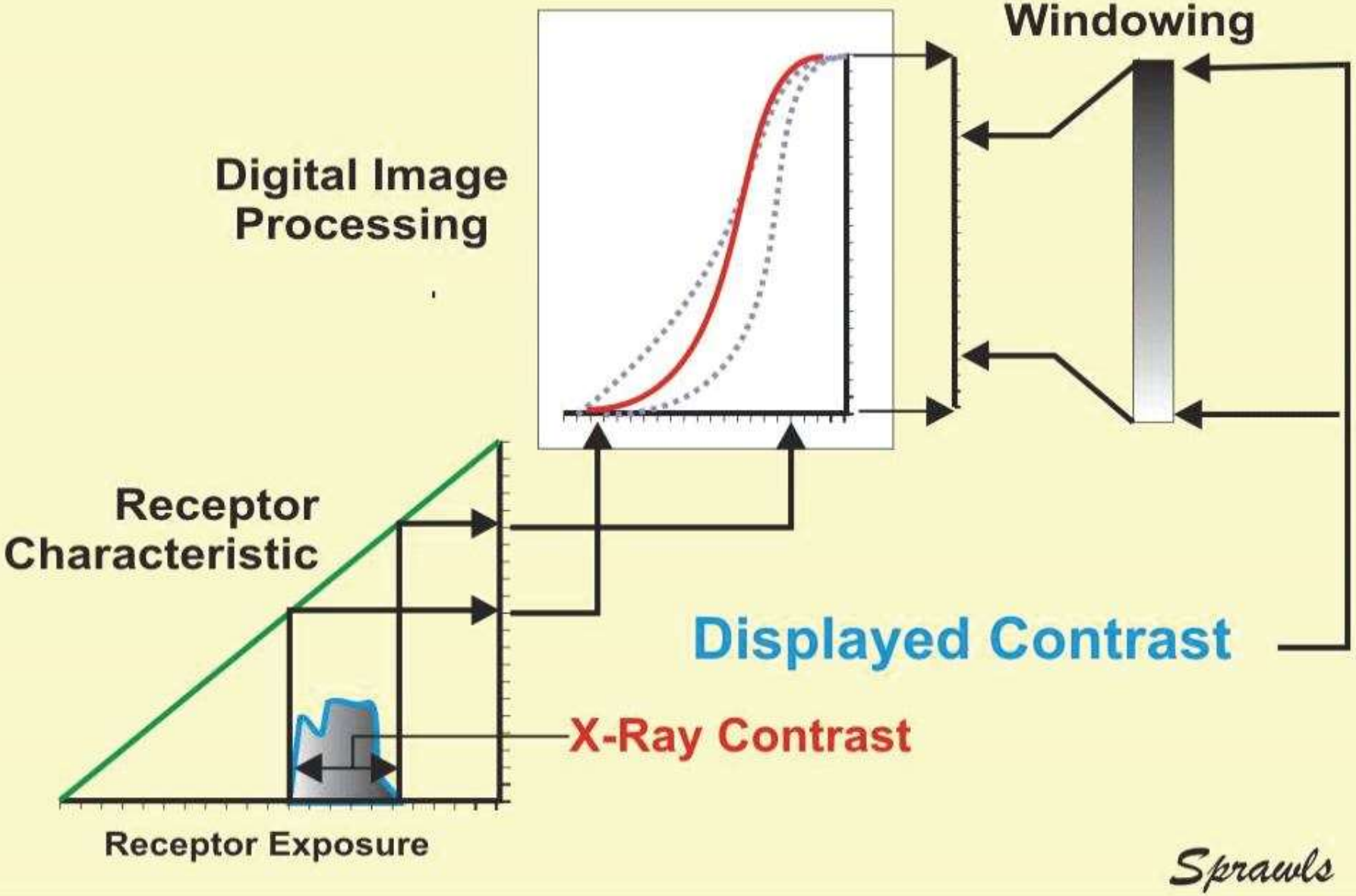
Range of Exposure to the Receptor Histogram



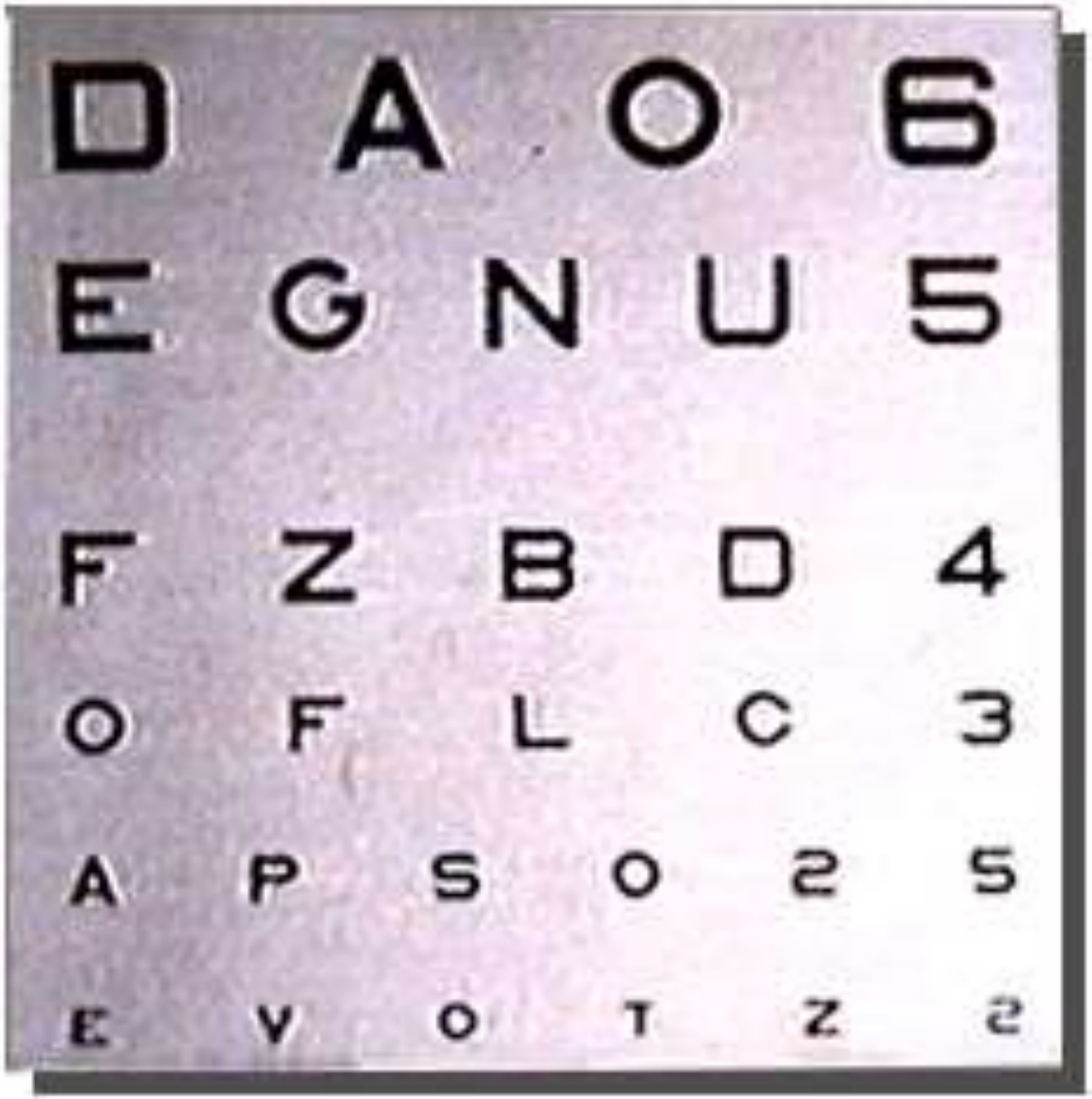
Sprawls


Film Density
Radiographic Film
Film Latitude (Dynamic Range)
Under Exposed
Over Exposed
0
Receptor Exposure
Sprawls

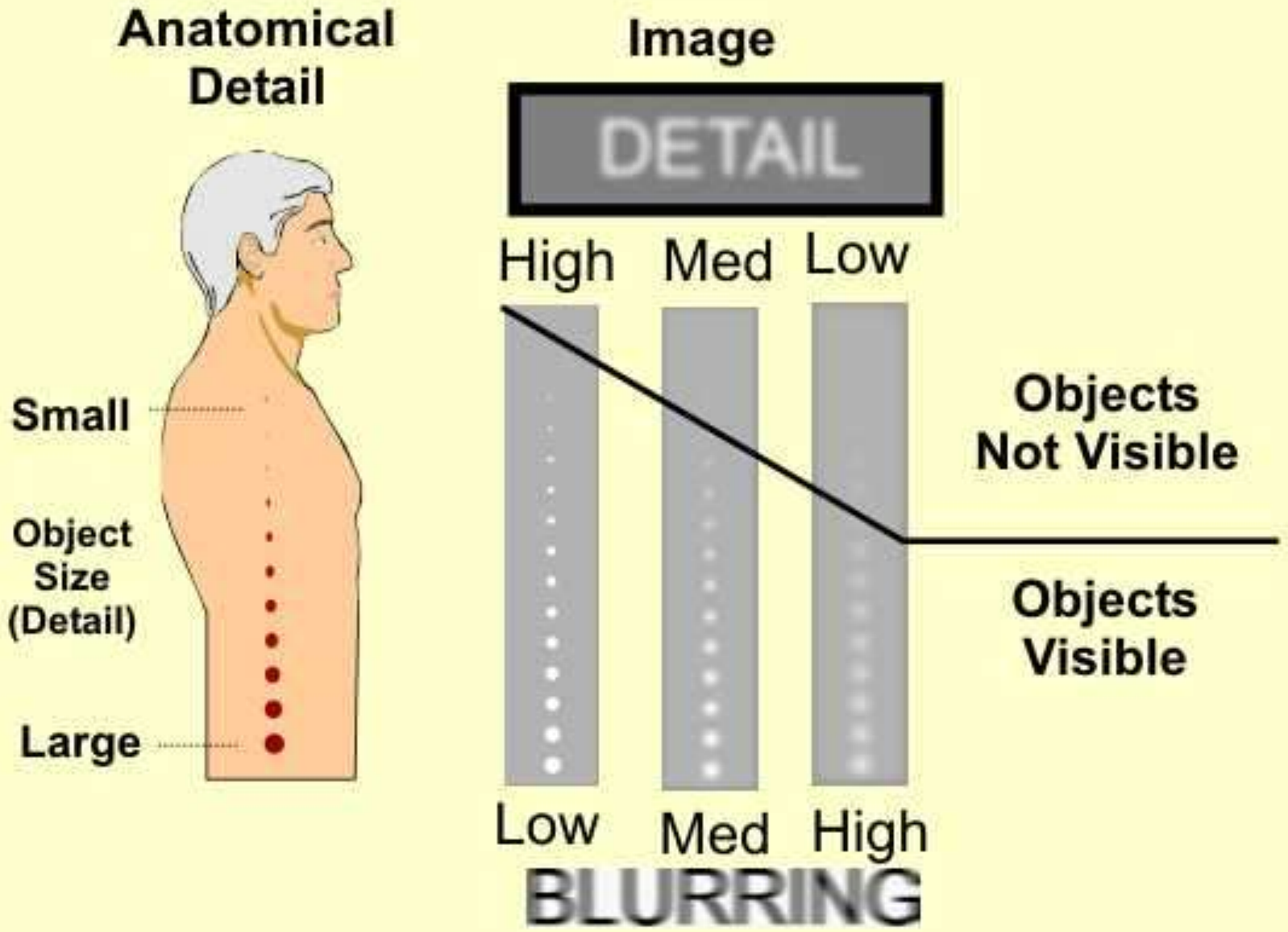
Digital Radiographic Contrast Transfer



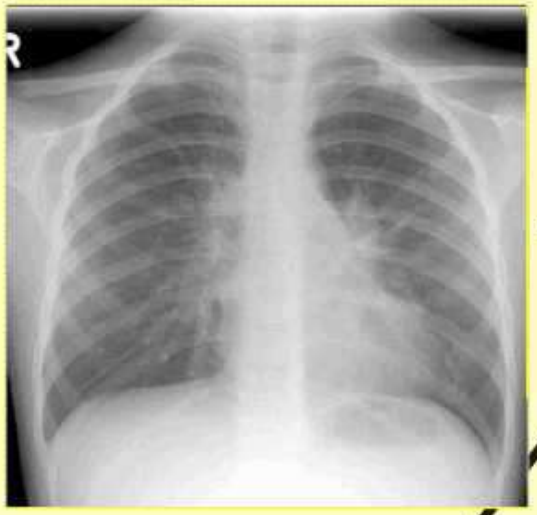
Sprawls


D A O 6
E G N U 5
F Z B D 4
O F L C 3
A P S O 2 5
E V O T Z 2


D A O 6
E G N U 5


Anatomical Detail
Small
Object Size (Detail)
Large
Image
DETAIL
High
Med
Low
Objects Not Visible
Objects Visible
Low
Med
High
BLURRING

Visibility of Detail Limited By



BLUR

Motion

Focal Spot

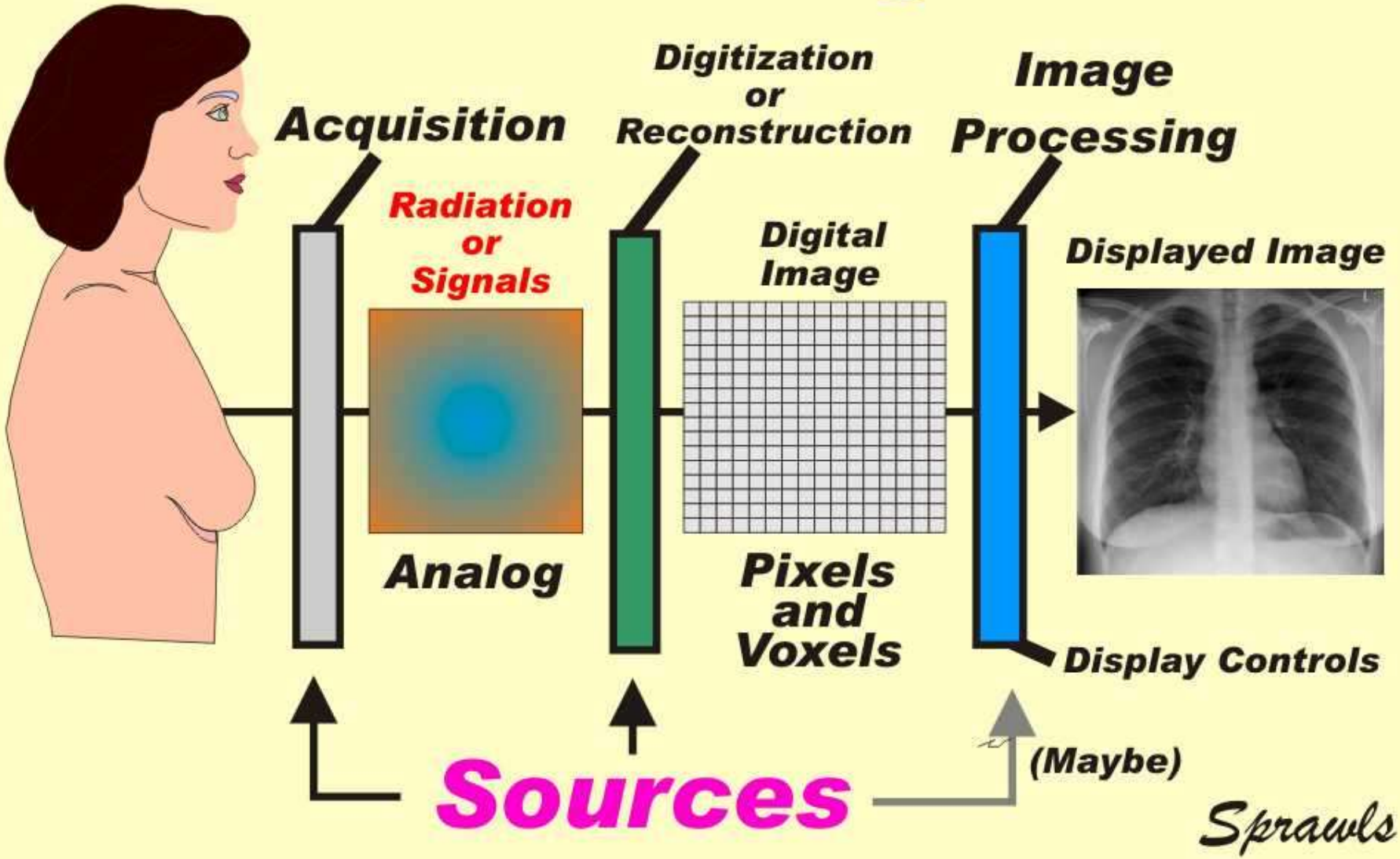
Receptor Digitizing Digital Processing Display

Anatomical Object Location
(Imaging Geometry)

Sprawls

The Medical Imaging Process

Blurring



Sprawls

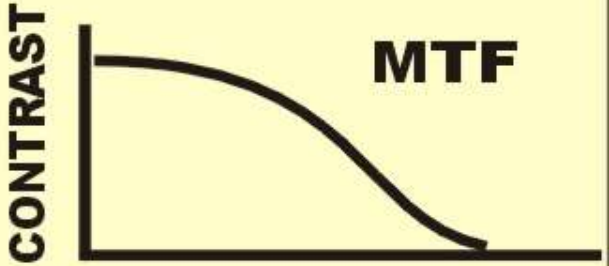
EFFECTS OF BLUR

VISIBILITY of DETAIL

OBJECT SIZE

IMAGE SHARPNESS

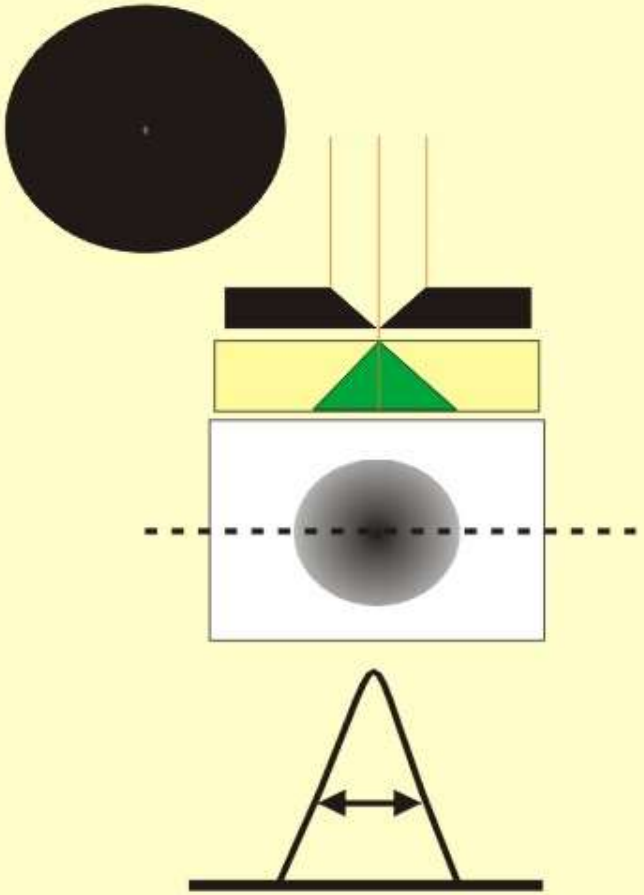
RESOLUTION



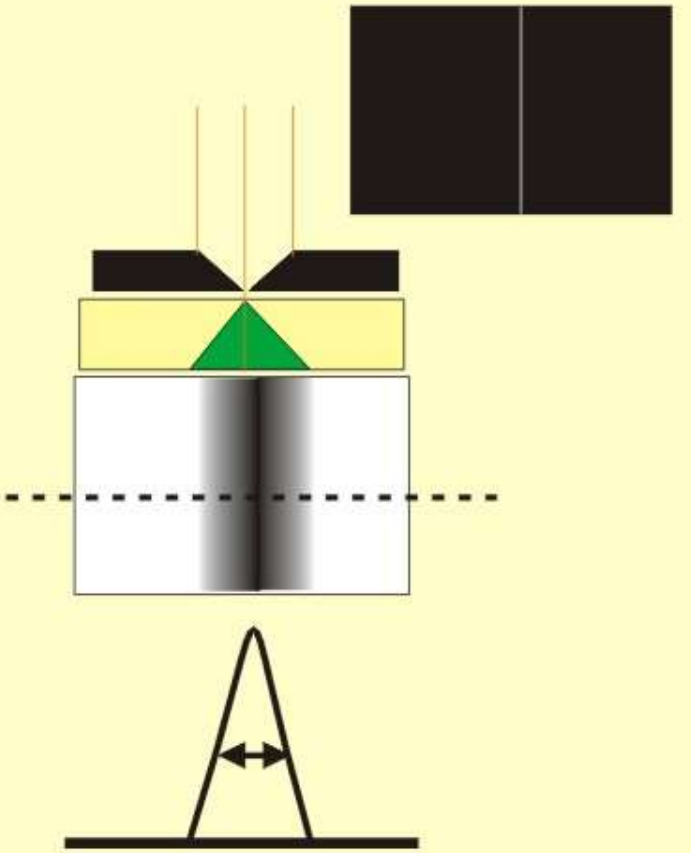
REDUCES

Sprawls

MEASURING BLUR



POINT SPREAD FUNCTION

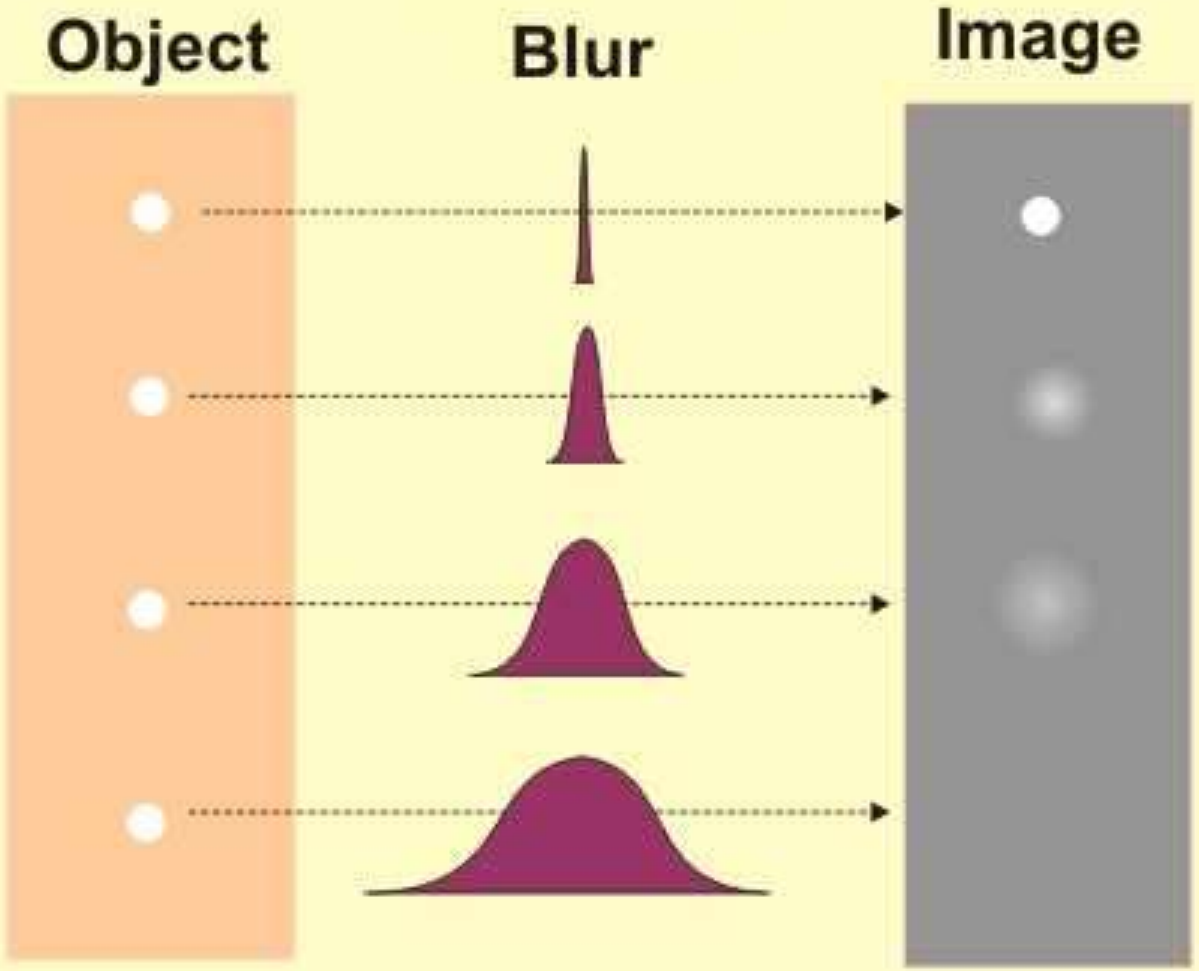


LINE SPREAD FUNCTION

Sprawls

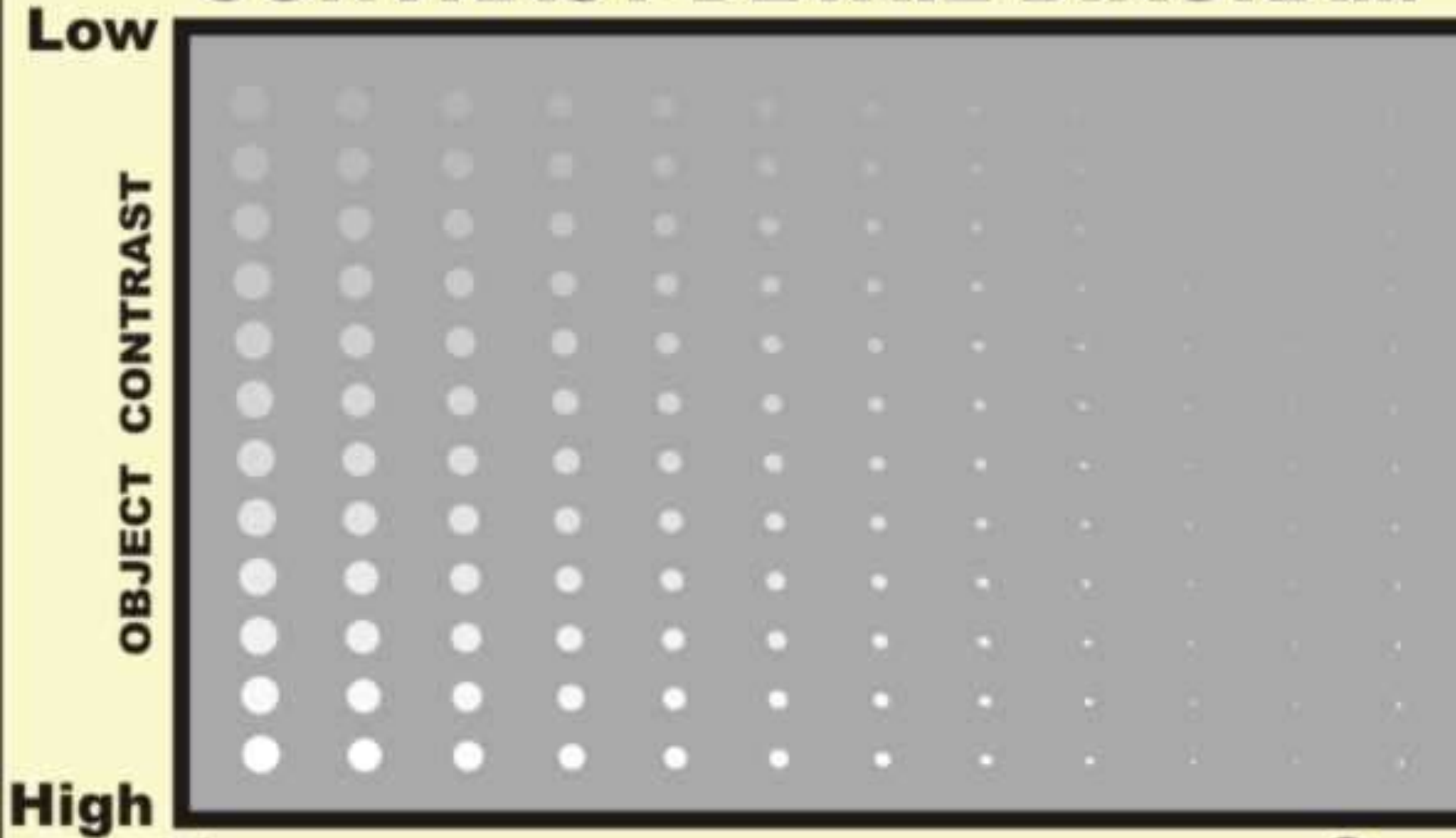
Blurring

Reduces Visibility



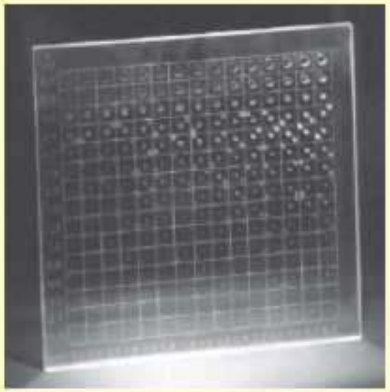
Sprawls

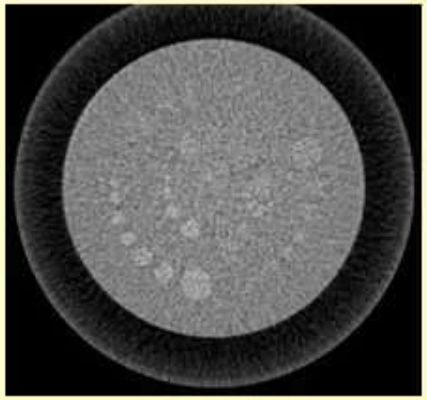
CONTRAST-DETAIL DIAGRAM

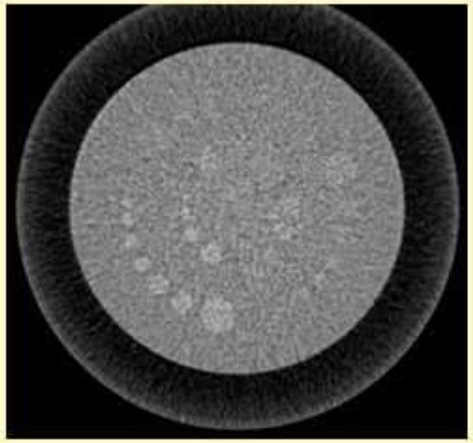


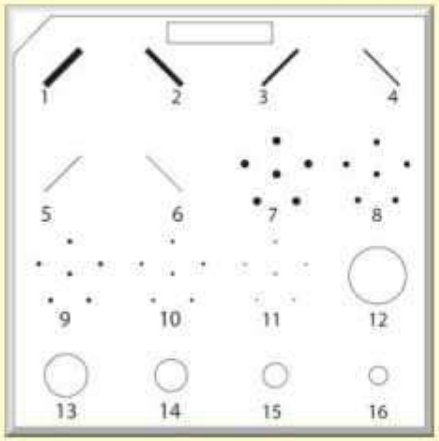
Sprawl

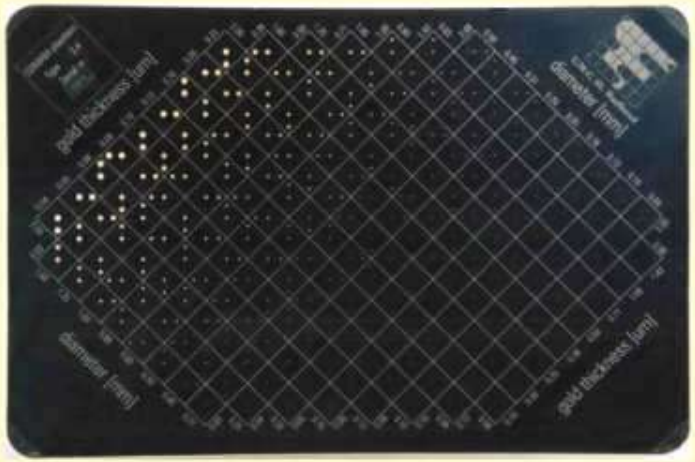
Contrast Detail Phantoms





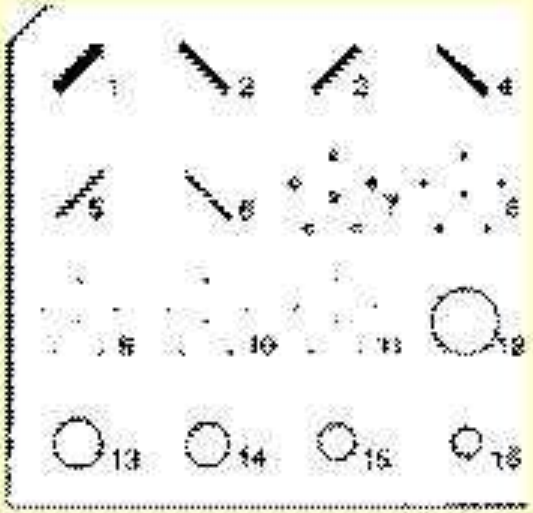


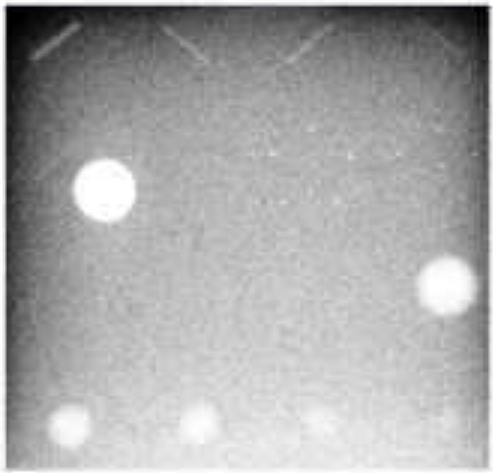




Sprawls

Calcifications

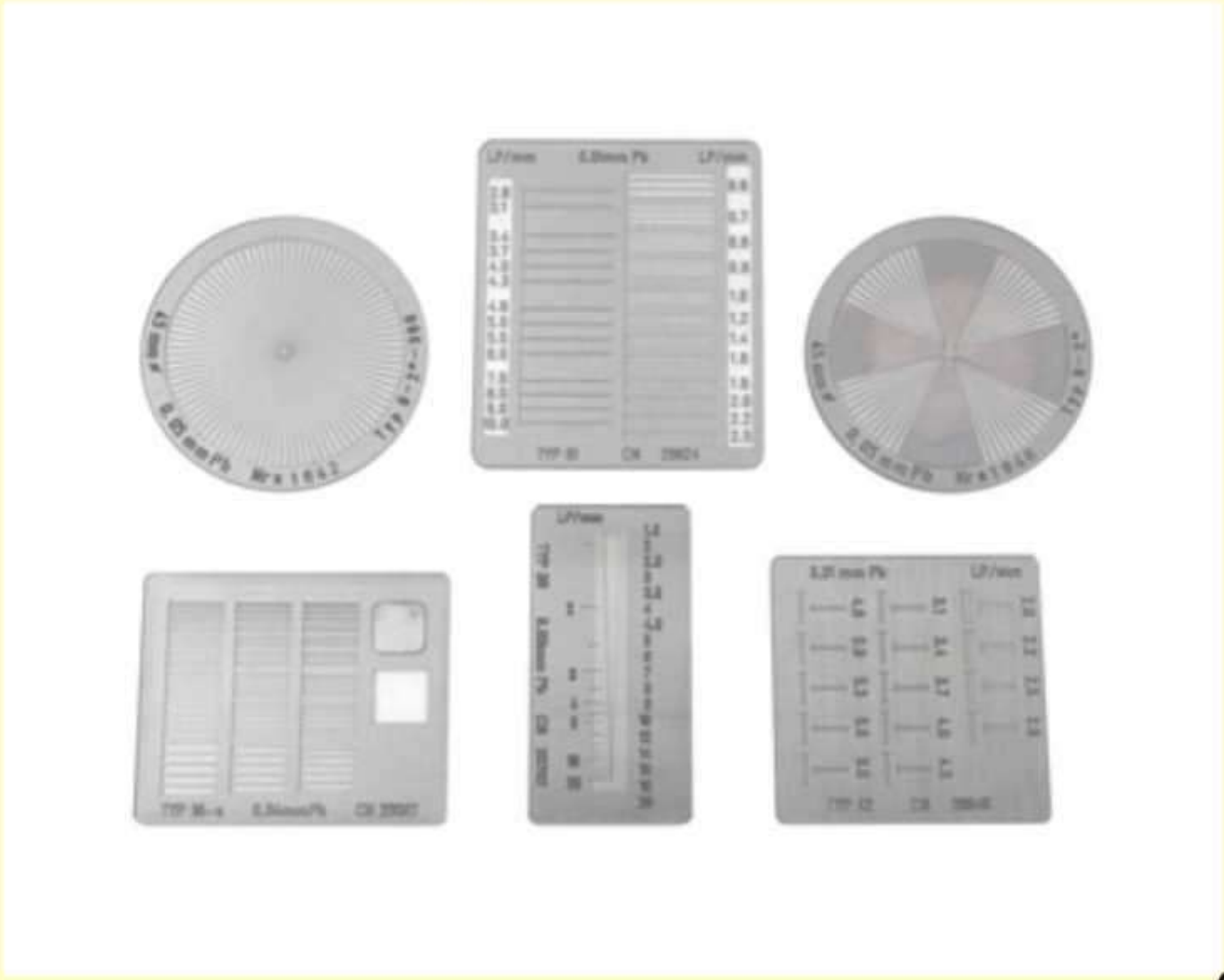




7.	0.54 mm simulated micro-calcification
8.	0.40 mm simulated micro-calcification
9.	0.32 mm simulated micro-calcification
10.	0.24 mm simulated micro-calcification
11.	0.16 mm simulated micro-calcification

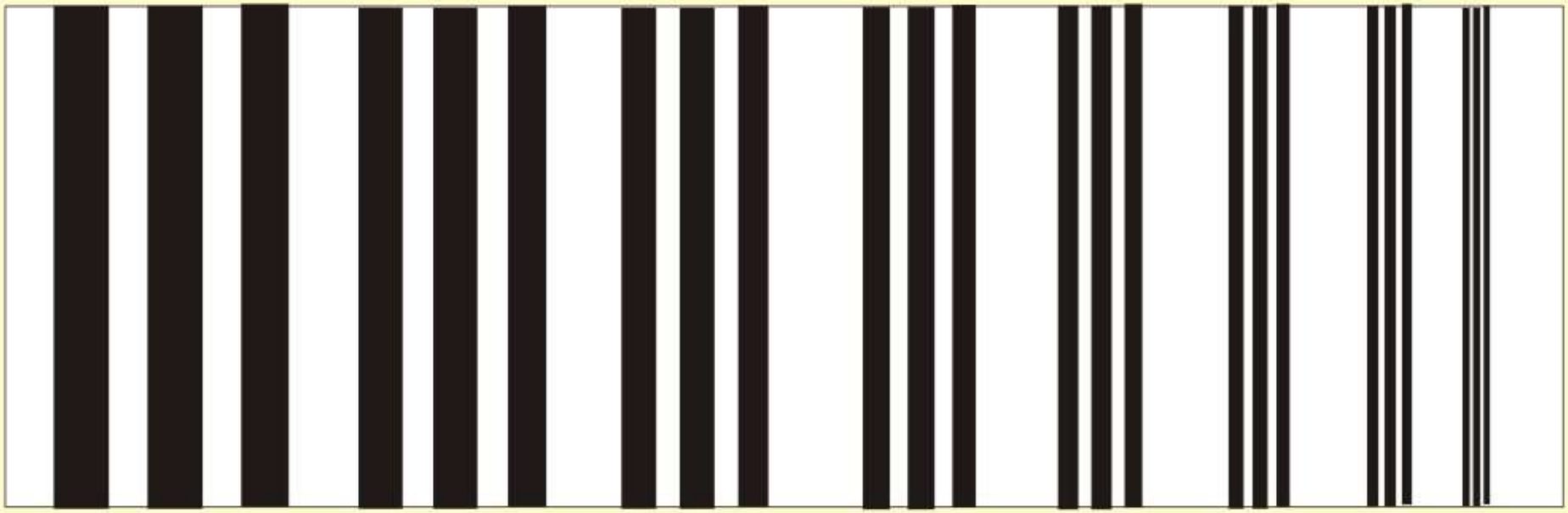
Line-Pair Test Objects

Used to measure the effect of blurring



Sprawls

RESOLUTION TEST PATTERN

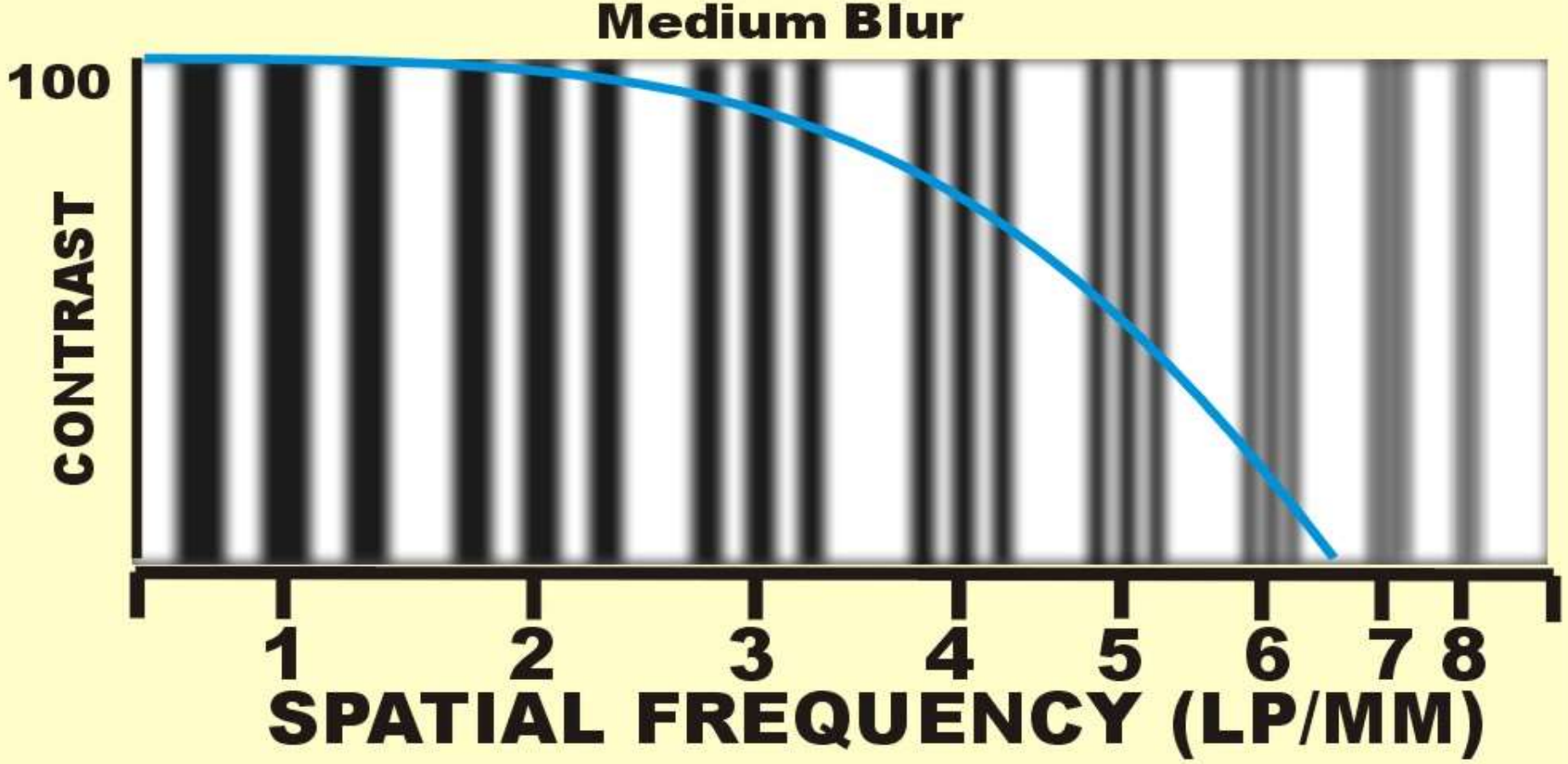


1 2 3 4 5 6 7 8

SPATIAL FREQUENCY (LP/MM)

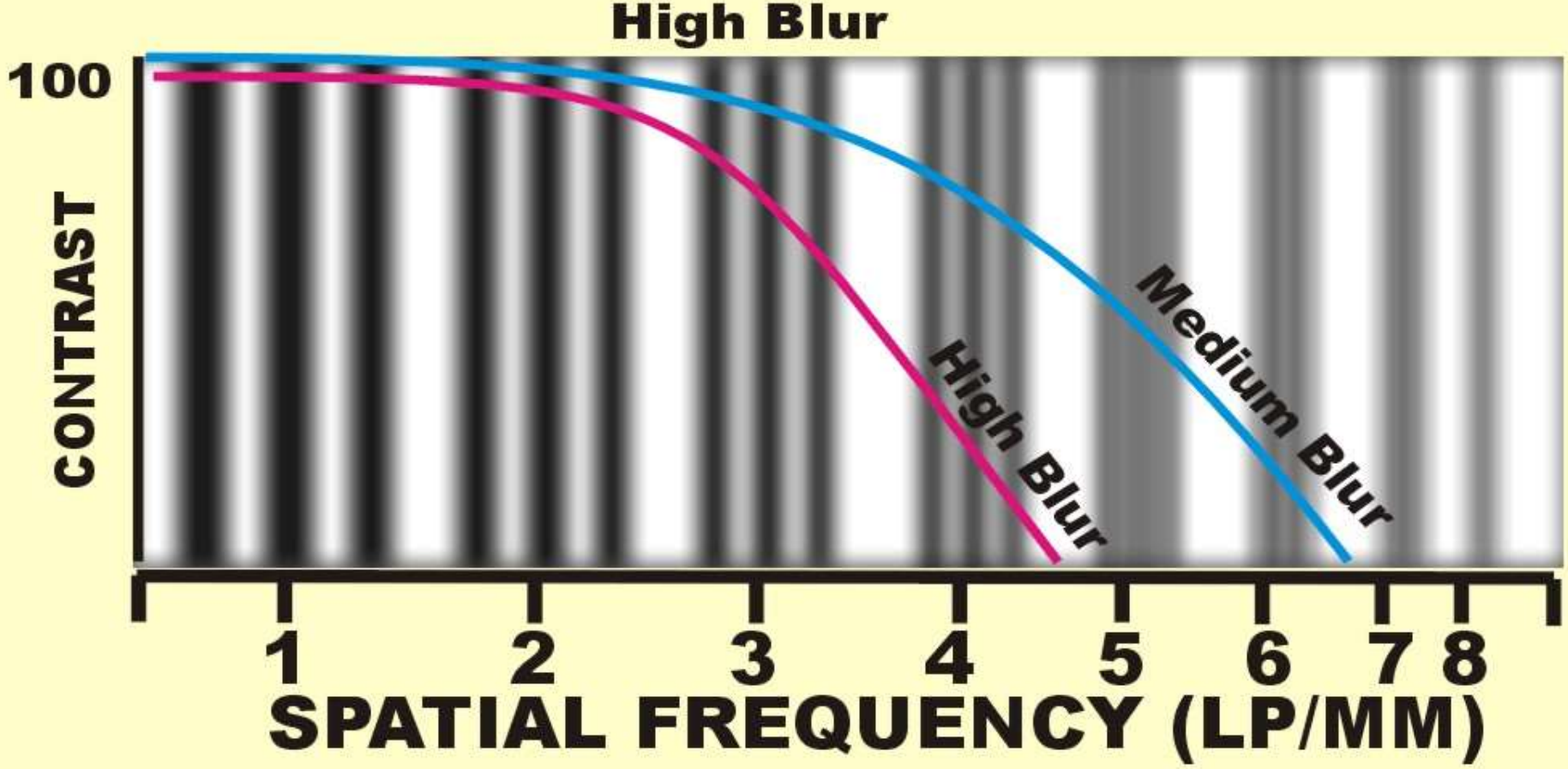
Sprawls

CONTRAST TRANSFER FUNCTION



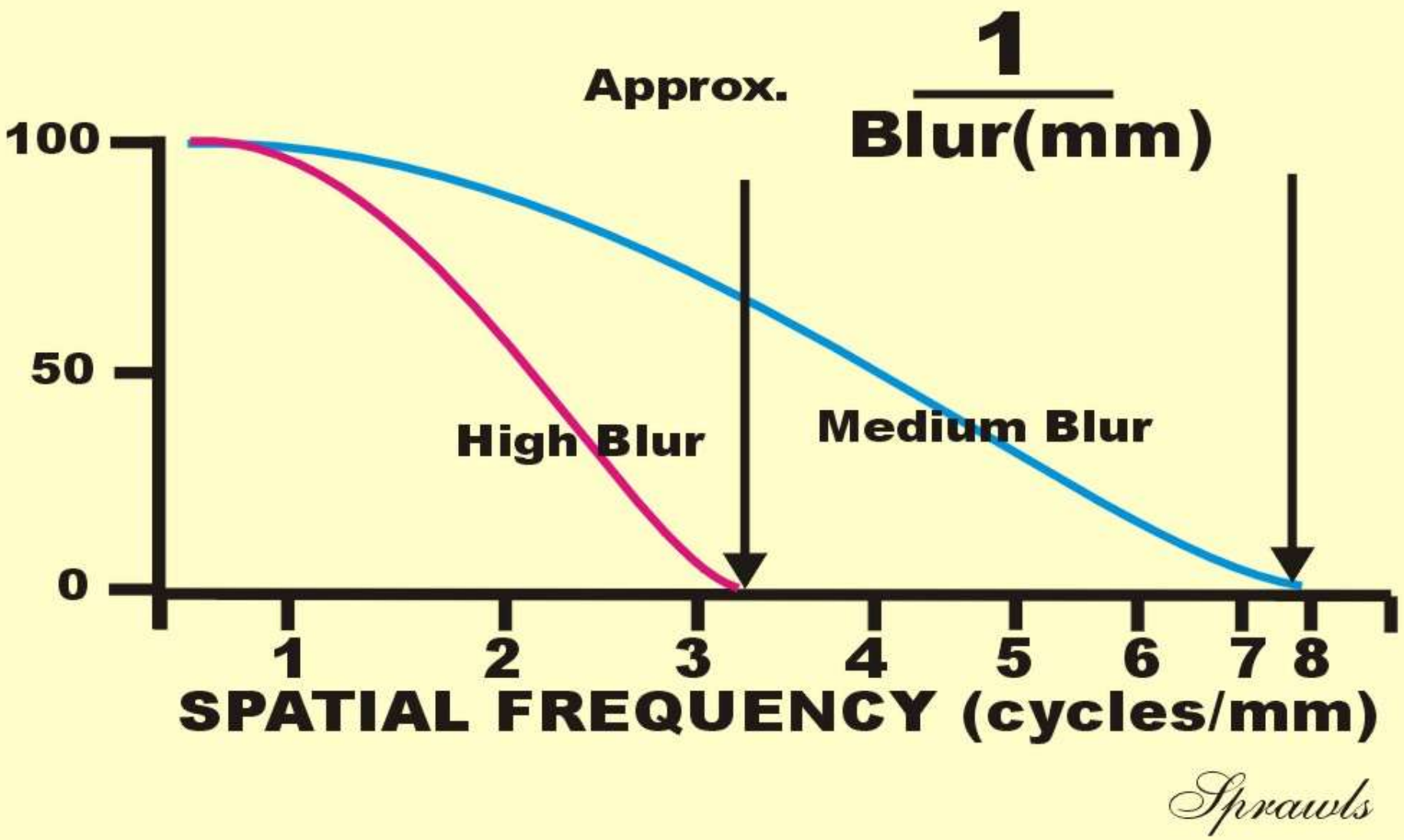
Sprawls

CONTRAST TRANSFER FUNCTION



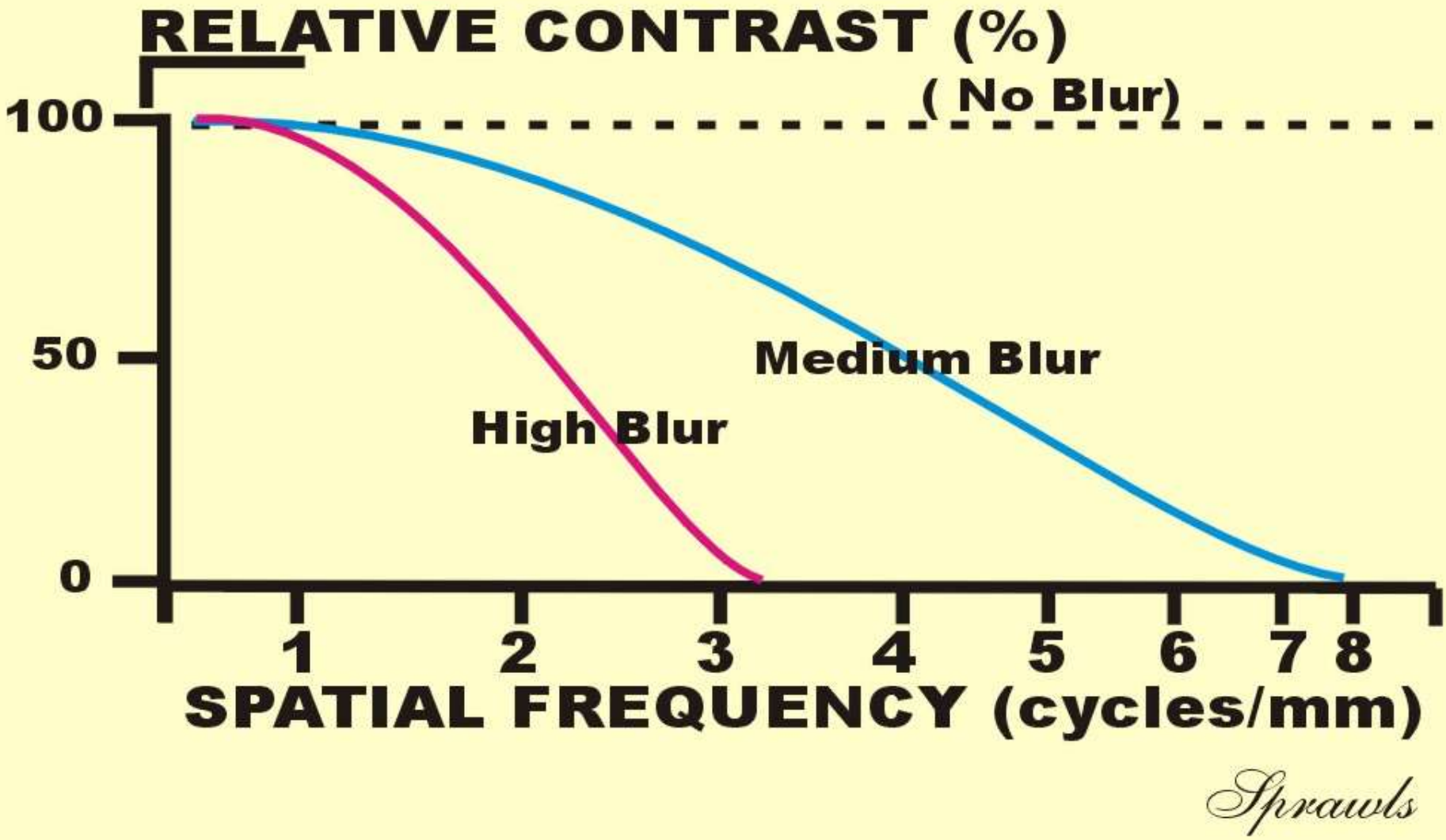
Sprawls

MAXIMUM RESOLUTION



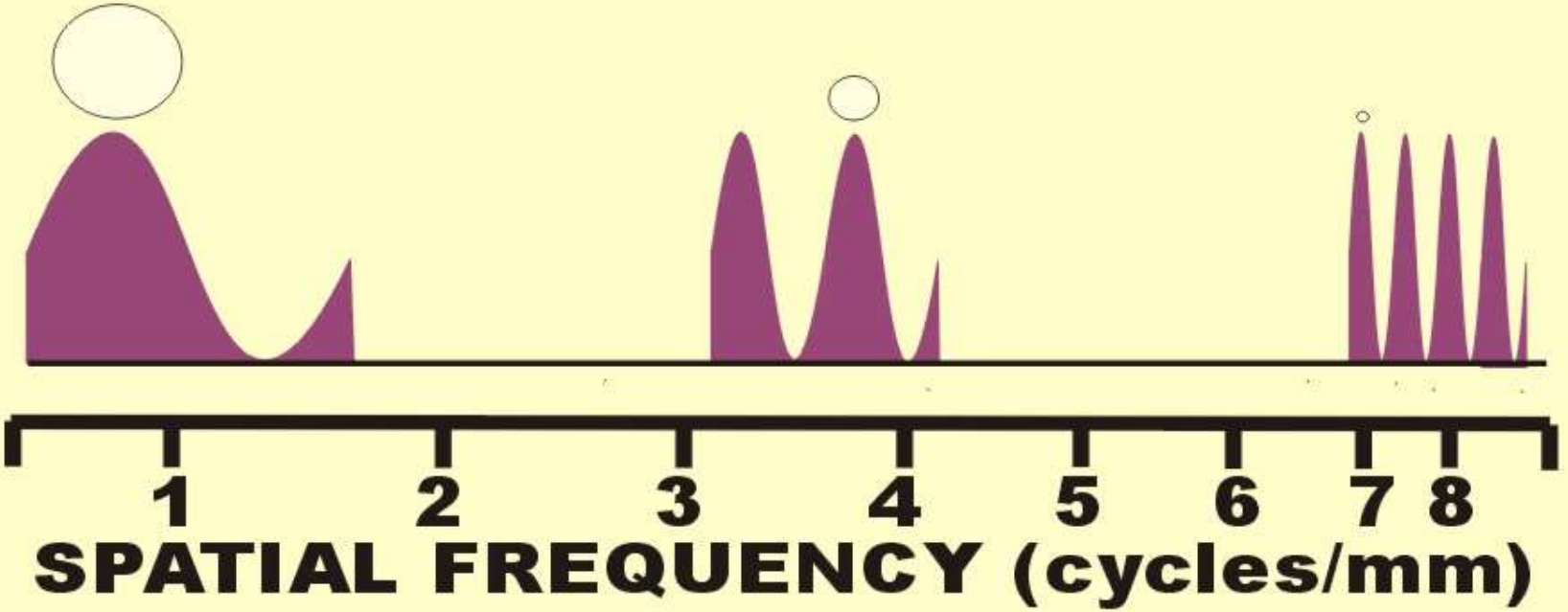
Sprawls

MODULATION TRANSFER FUNCTION



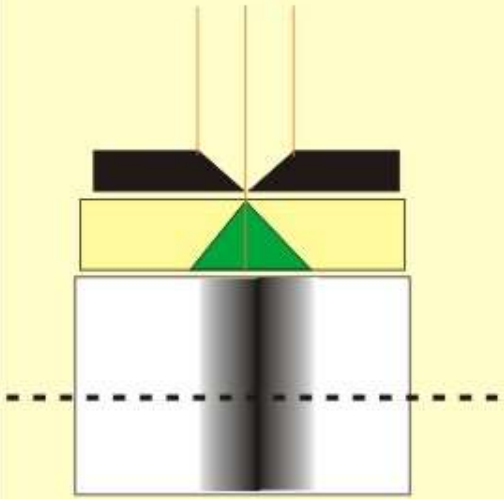
Sprawls

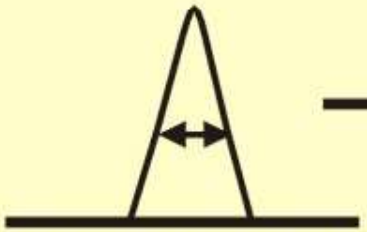
SPATIAL FREQUENCY of OBJECT THICKNESS



Sprawls

CALCULATING MTF

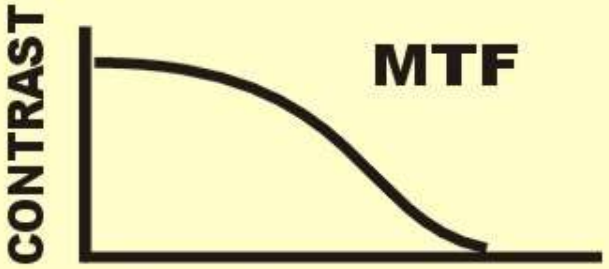




LINE SPREAD FUNCTION (BLUR SIZE)

FOURIER TRANSFORM

RESOLUTION

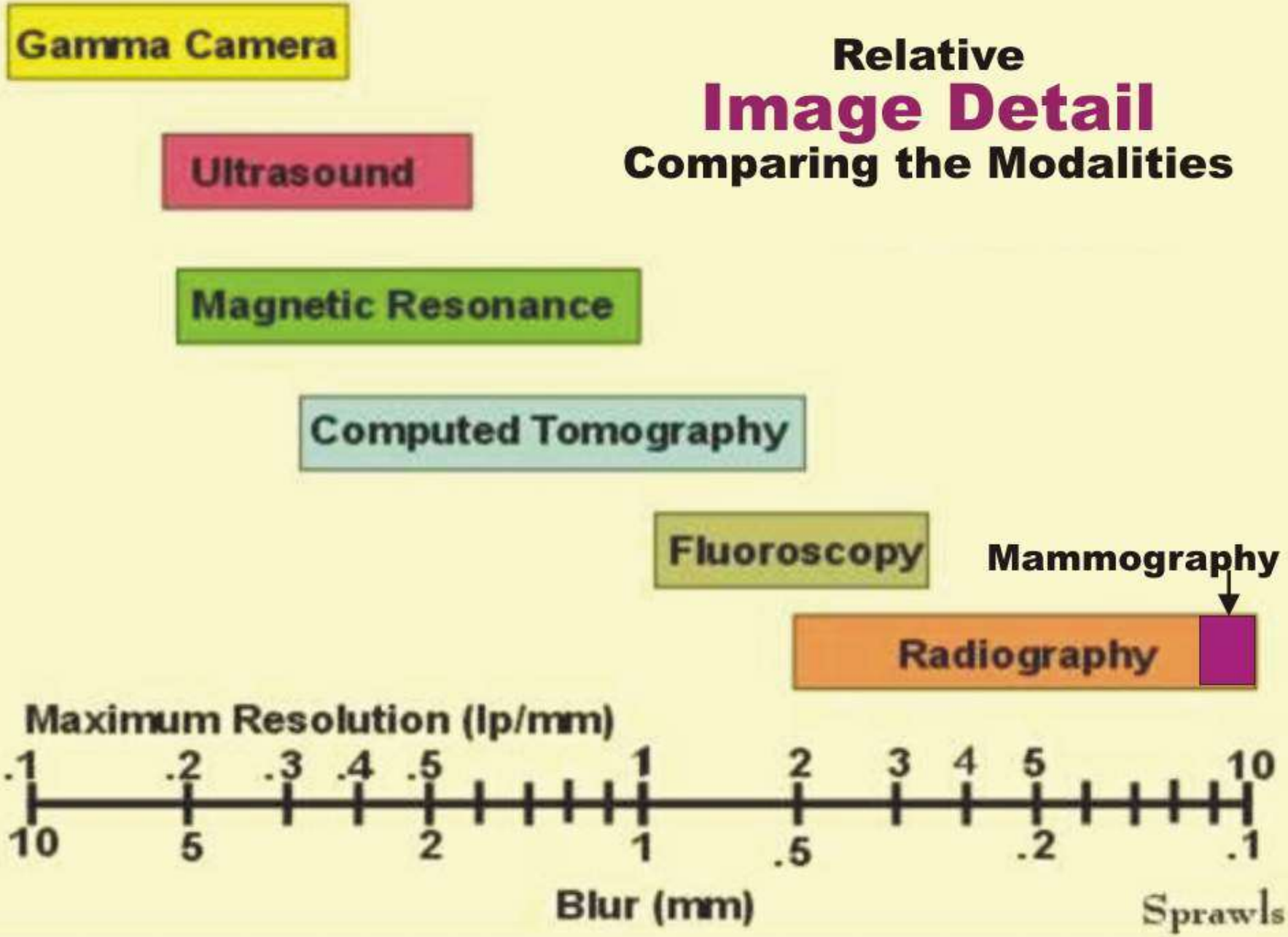


Sprawls

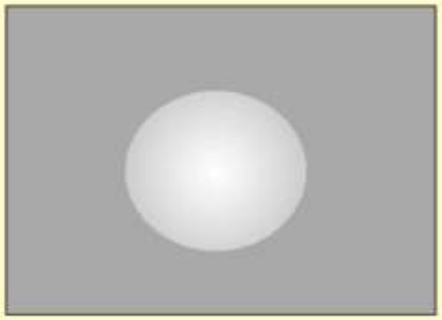
Relative

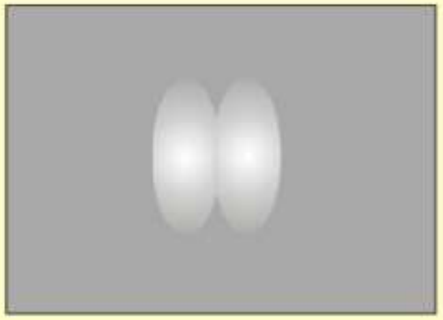
Image Detail

Comparing the Modalities



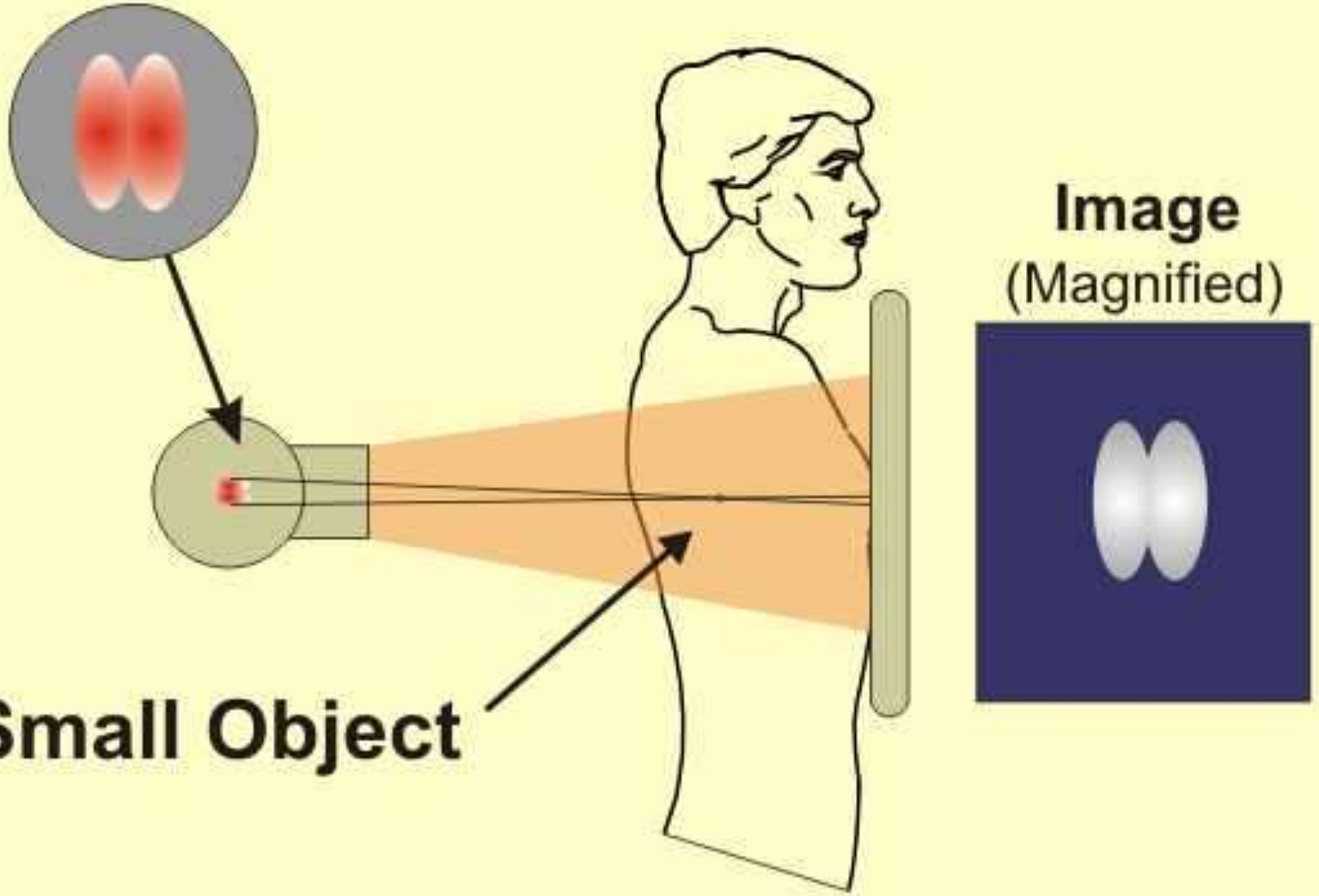
BLUR SHAPES





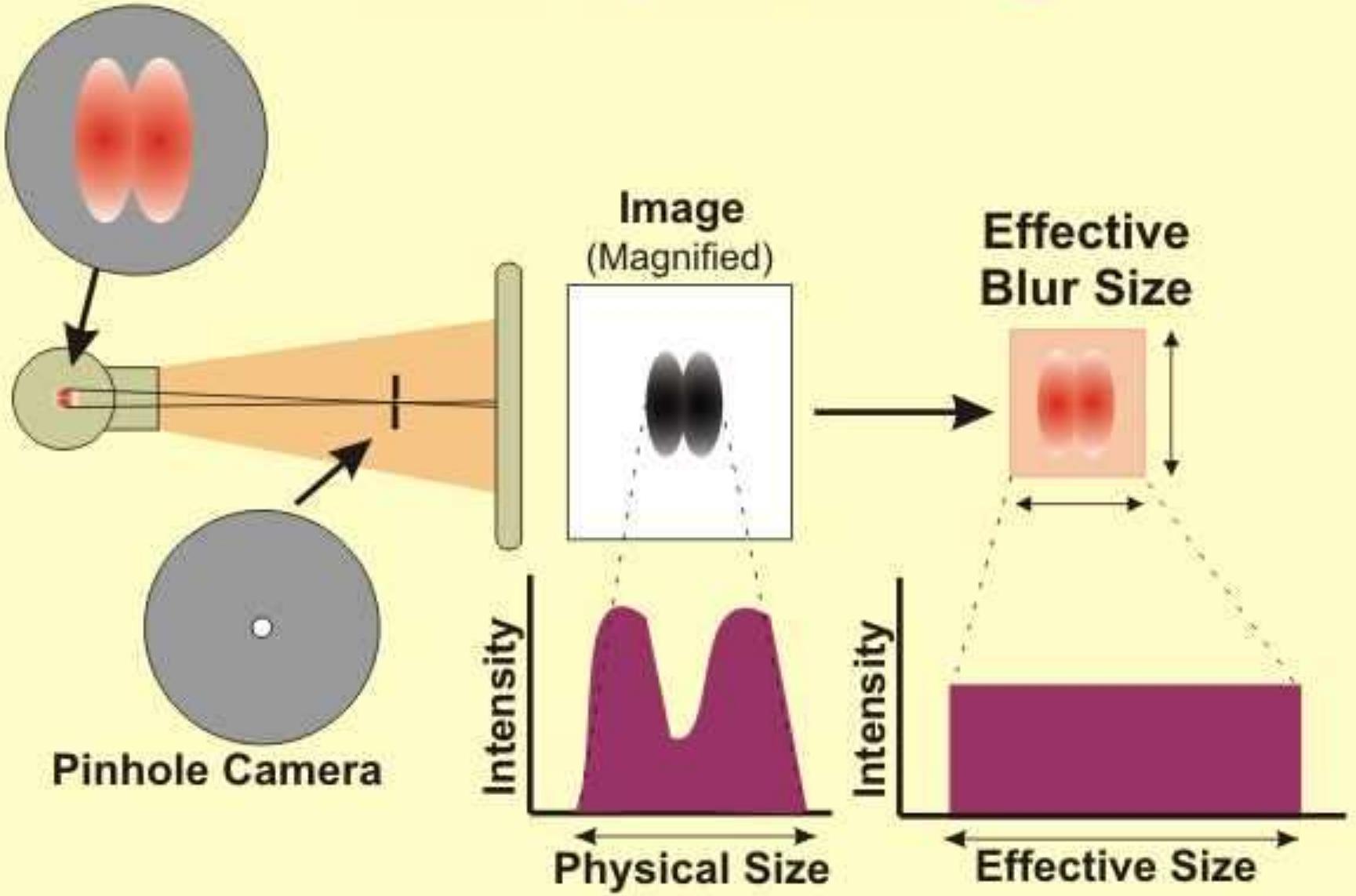
Sprawls

Focal Spot Blurring



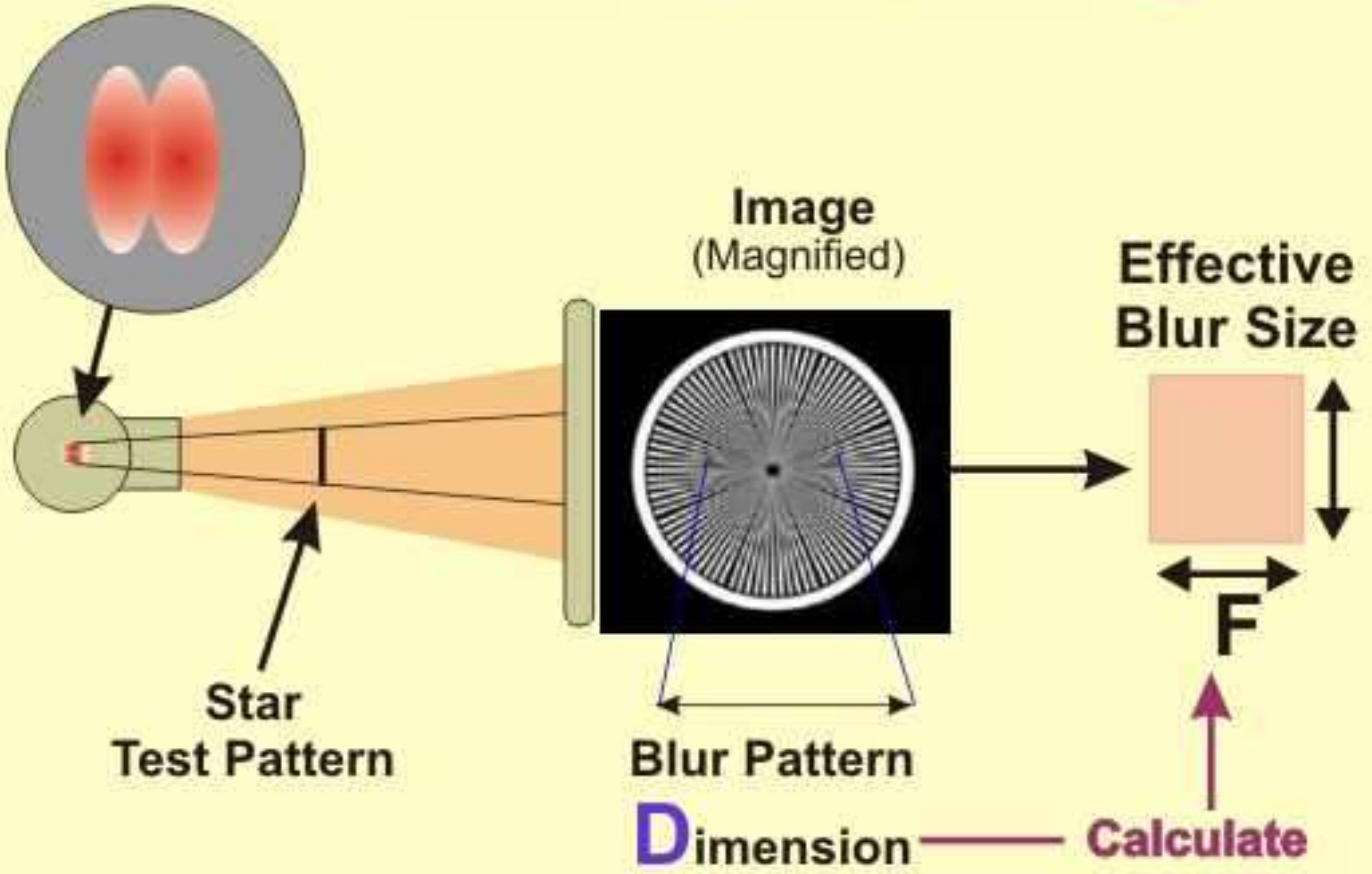
Sprawls

Focal Spot Blurring

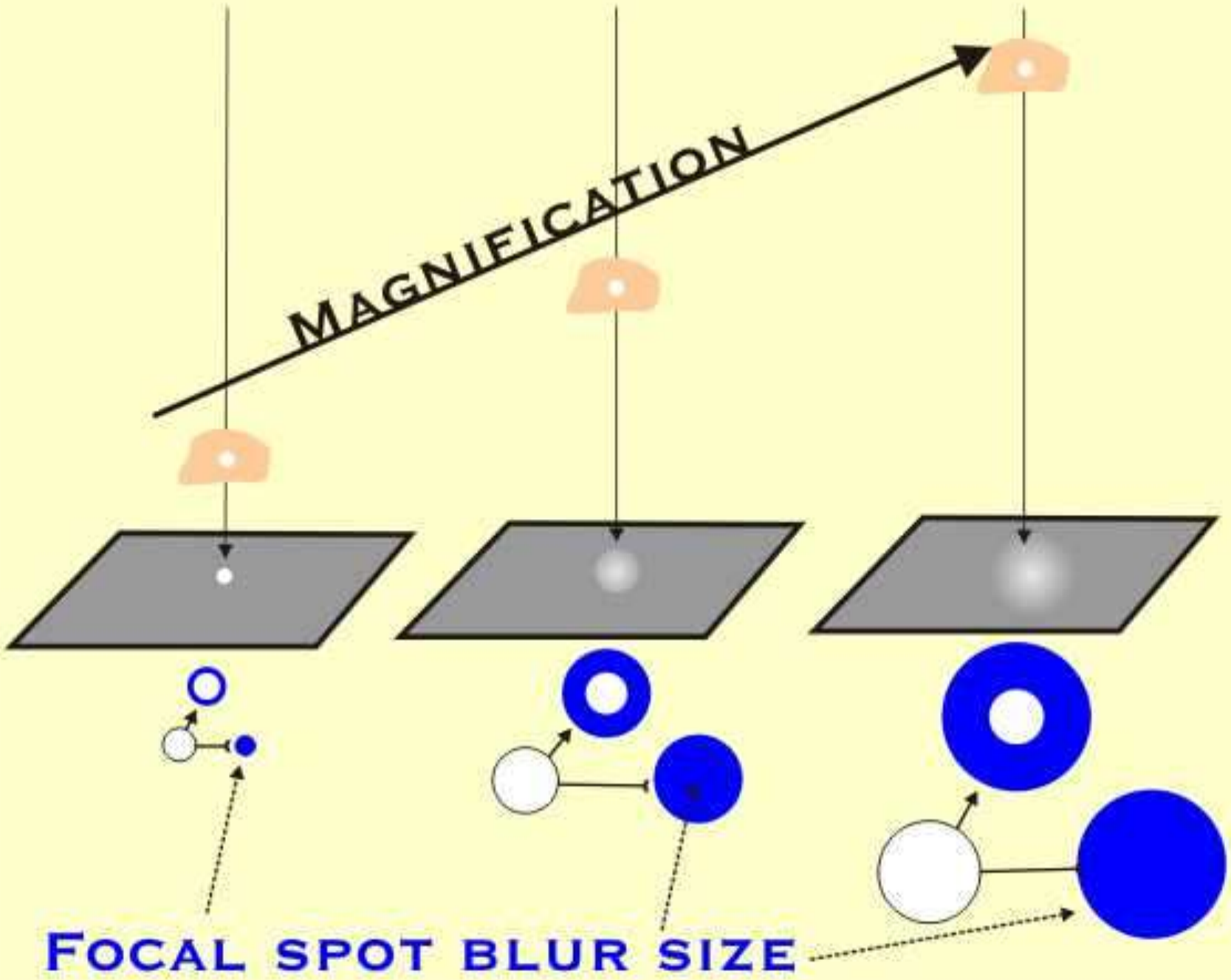


Sprawls

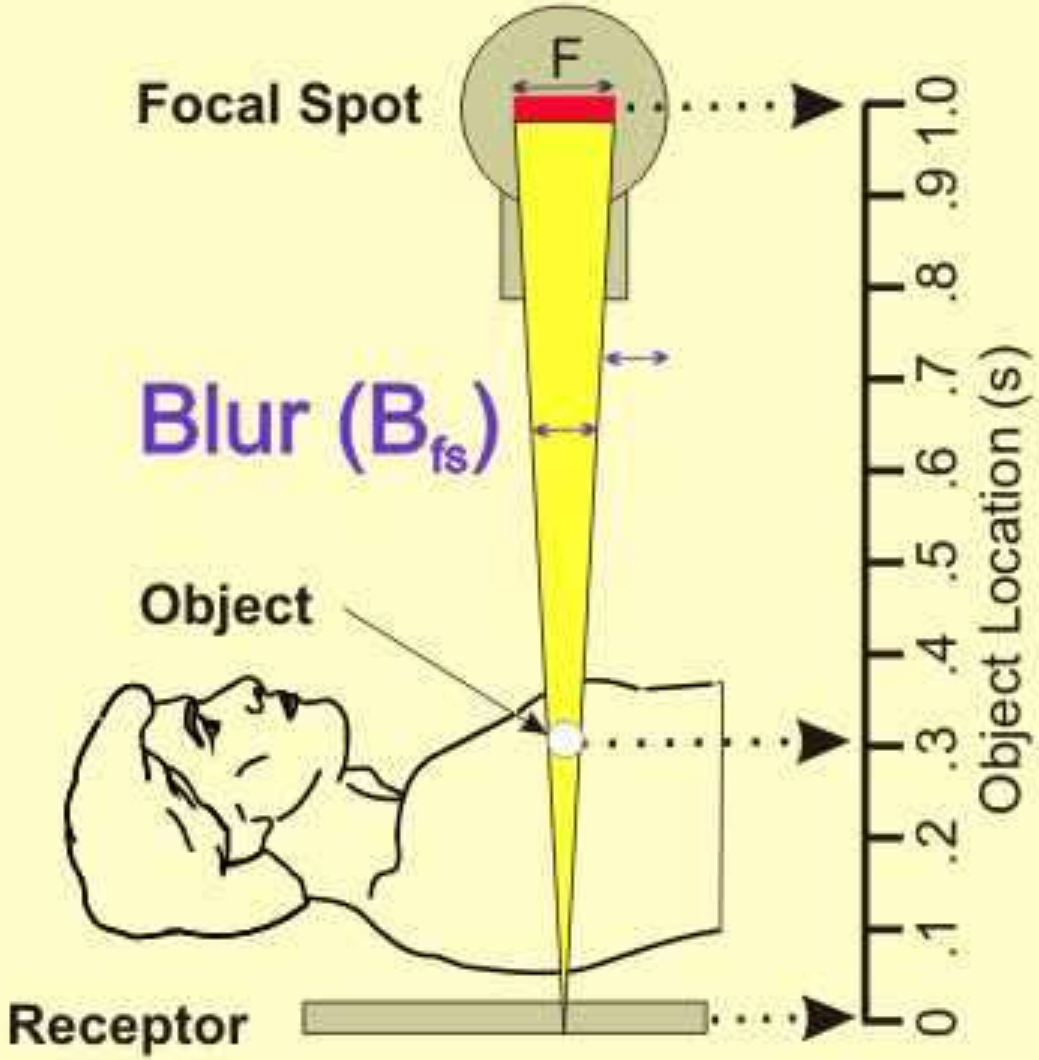
Focal Spot Blurring



Sprawls


MAGNIFICATION
FOCAL SPOT BLUR SIZE

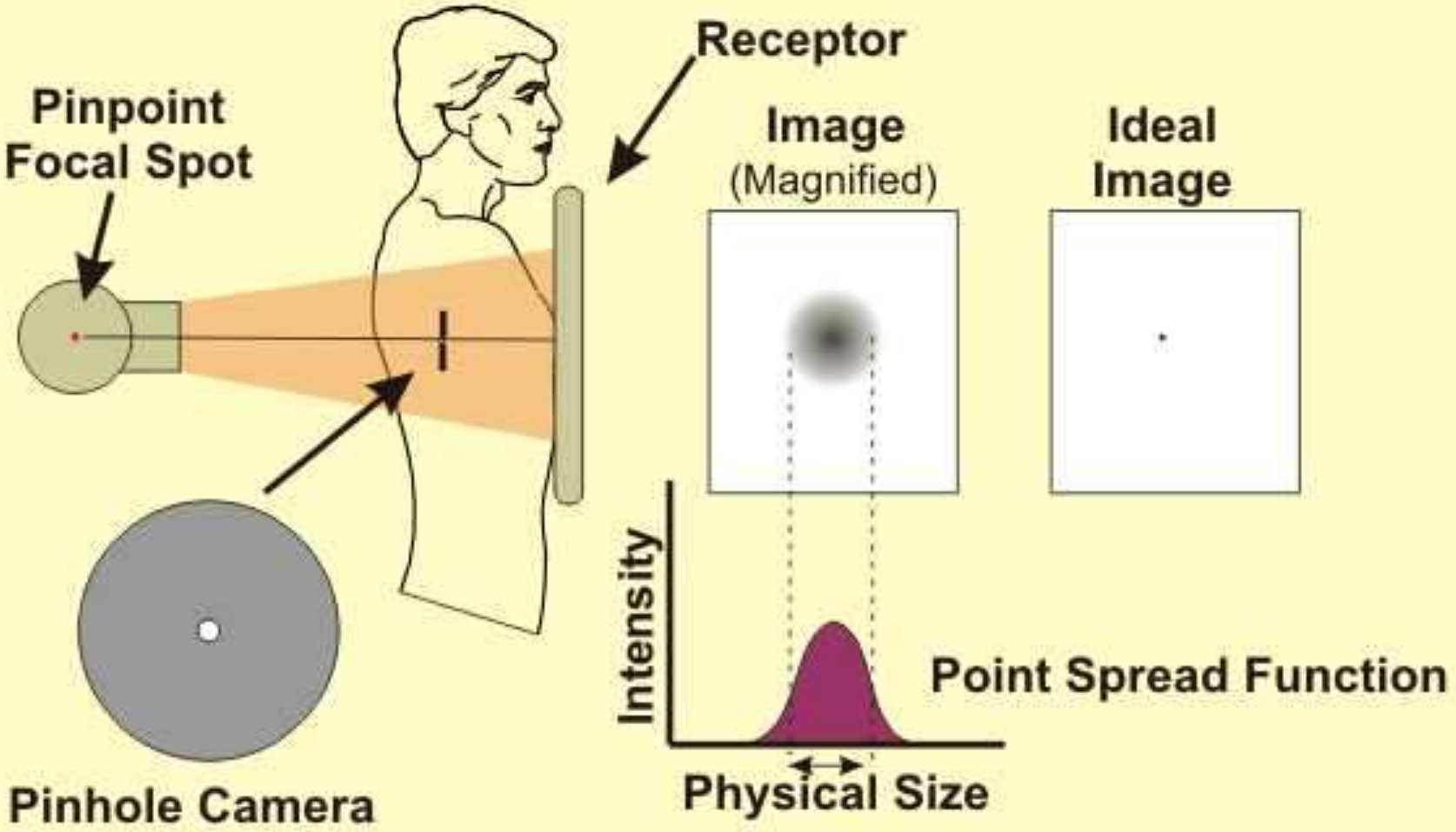
Focal Spot Blurring



$B_{fs} = F \times s$

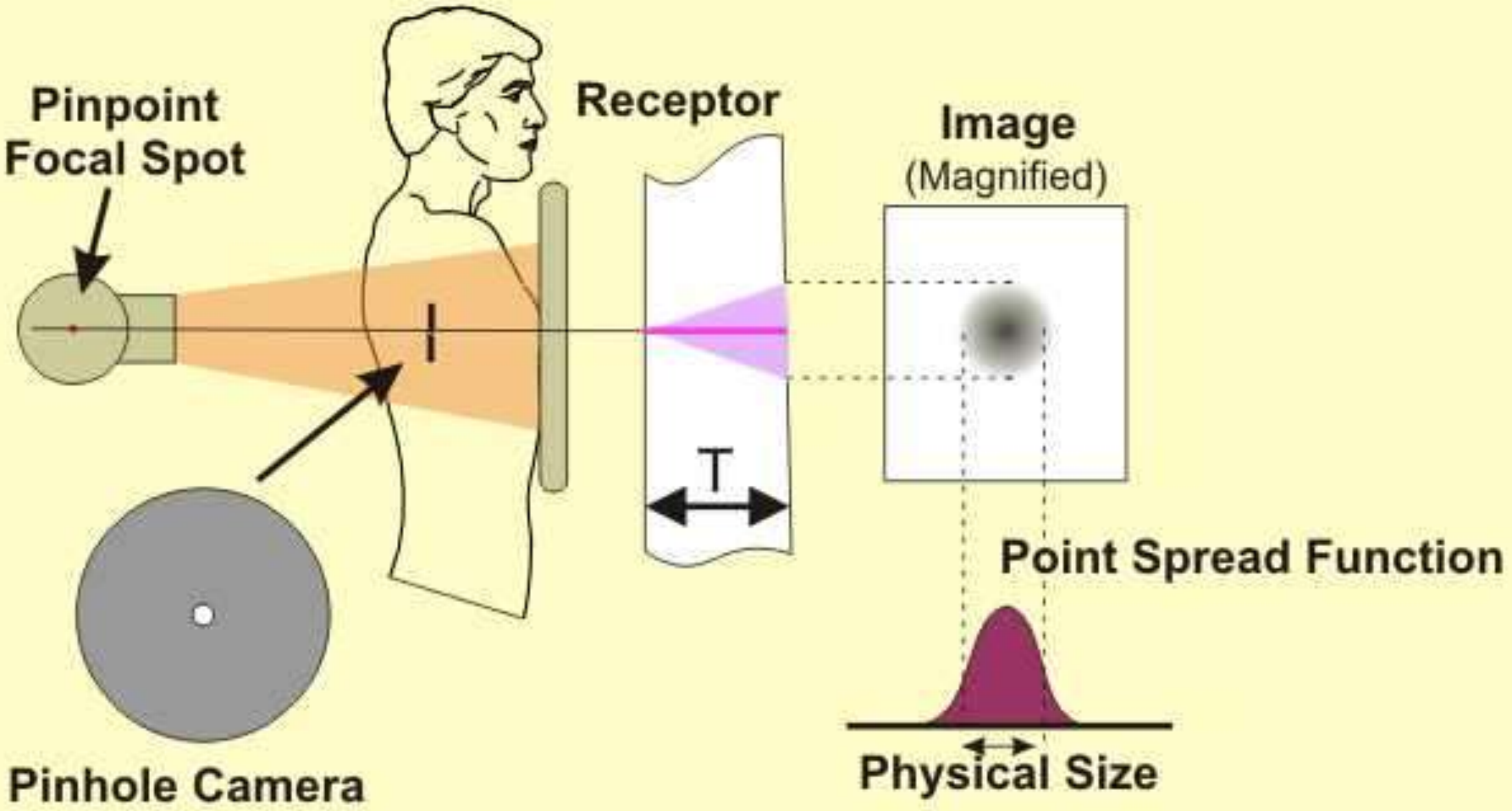
Sprawls

Receptor Blurring



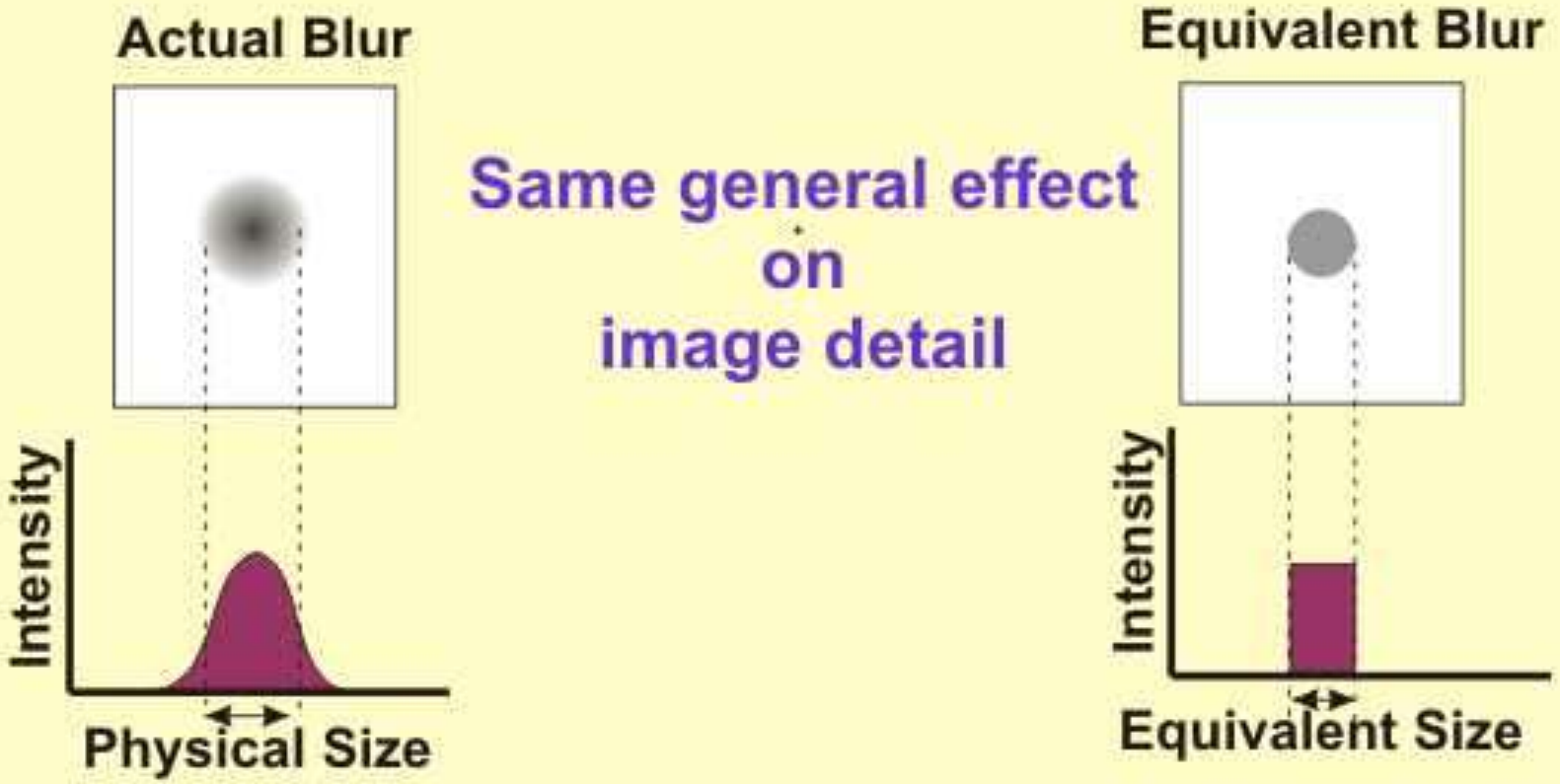
Sprawls

Receptor Blurring



Sprawls

Receptor Blurring



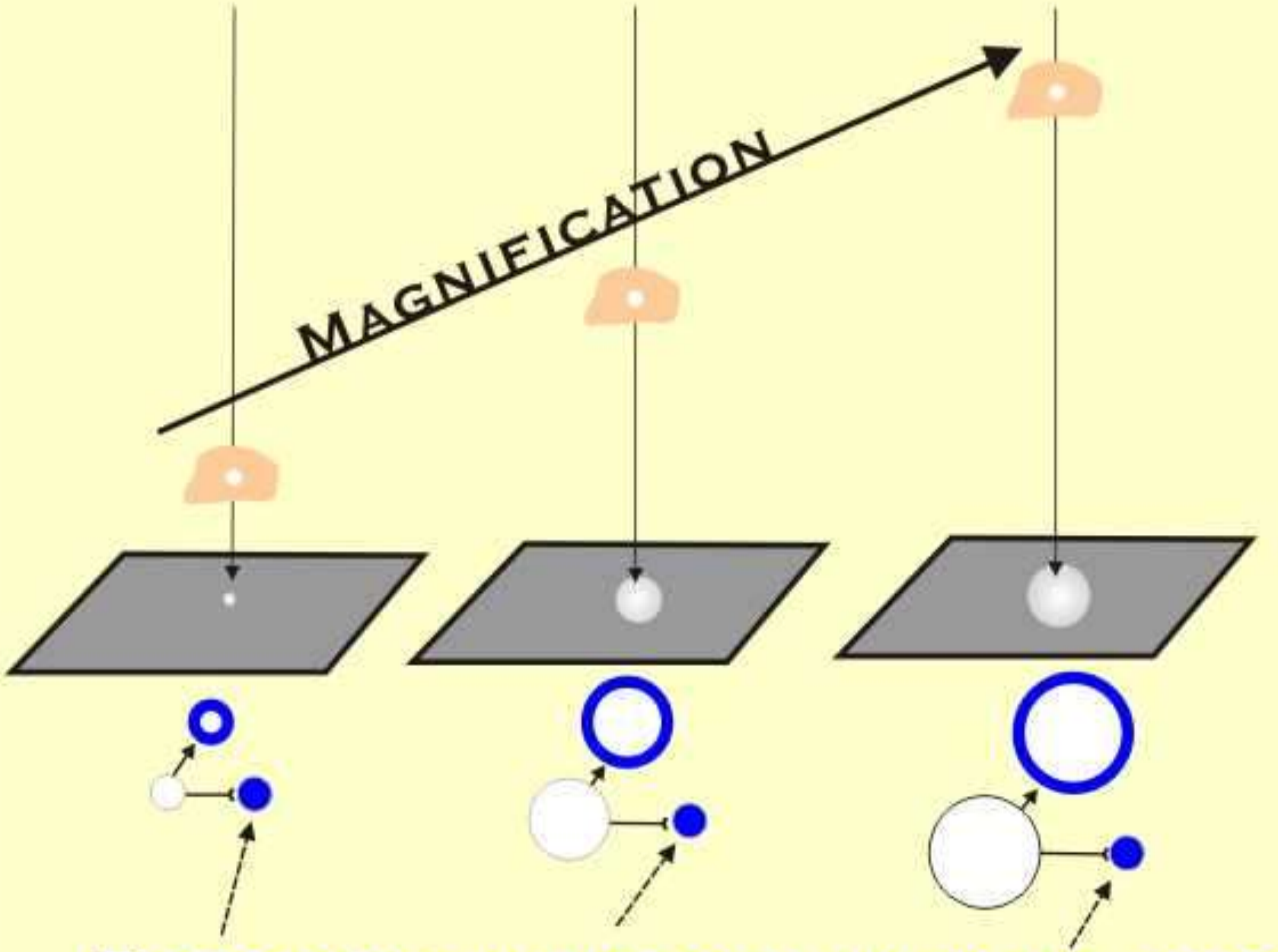
Point Spread Functions

Sprawls

Receptor	Representative Equivalent Blur Value (mm)[1]	Relative Speed [2,3,4,5]	Approximate Receptor Sensitivity[6] (MR)
General Radiography [2,3]			
LANEX Fast/Ortho G, L, C	0.76	600	0.21
LANEX Fast/T-MAT H/RA	0.66	1200	0.10
LANEX Fast/T-MAT G/RA, L/RA, S/RA	0.66	600	0.21
LANEX Regular/Ortho G, L, C	0.64	400	0.32
LANEX Regular/T-MAT H/RA	0.53	800	0.16
LANEX Regular/T-MAT G/RA, L/RA, S/RA	0.53	400	0.32
LANEX Regular/T-MAT C/RA	0.53	400	0.32
LANEX Medium/Ortho G, L, C	0.55	250	0.51
LANEX Medium/T-MAT H/RA	0.44	600	0.21
LANEX Medium/T-MAT G/RA, L/RA, S/RA	0.44	300	0.43
LANEX Medium/T-MAT C/RA	0.44	250	0.51
INSIGHT HC/INSIGHT Film[7]	0.28	350	0.37
INSIGHT Standard/INSIGHT Film[7]	0.28	250	0.51
Extremities [2,4]			
LANEX Fine/Ortho G	0.41	80	1.60
LANEX Fine/T-MAT G/RA	0.23	80	1.60
LANEX Fine/EKTASCAN M (single screen)	0.14	40	3.20
Mammography [5]			
MIN-R/MIN-R M	0.14	100	16.0
MIN-R/MIN-R E (extended cycle)	0.14	150	10.7
MIN-R/MIN-R H	0.14	160	10.0

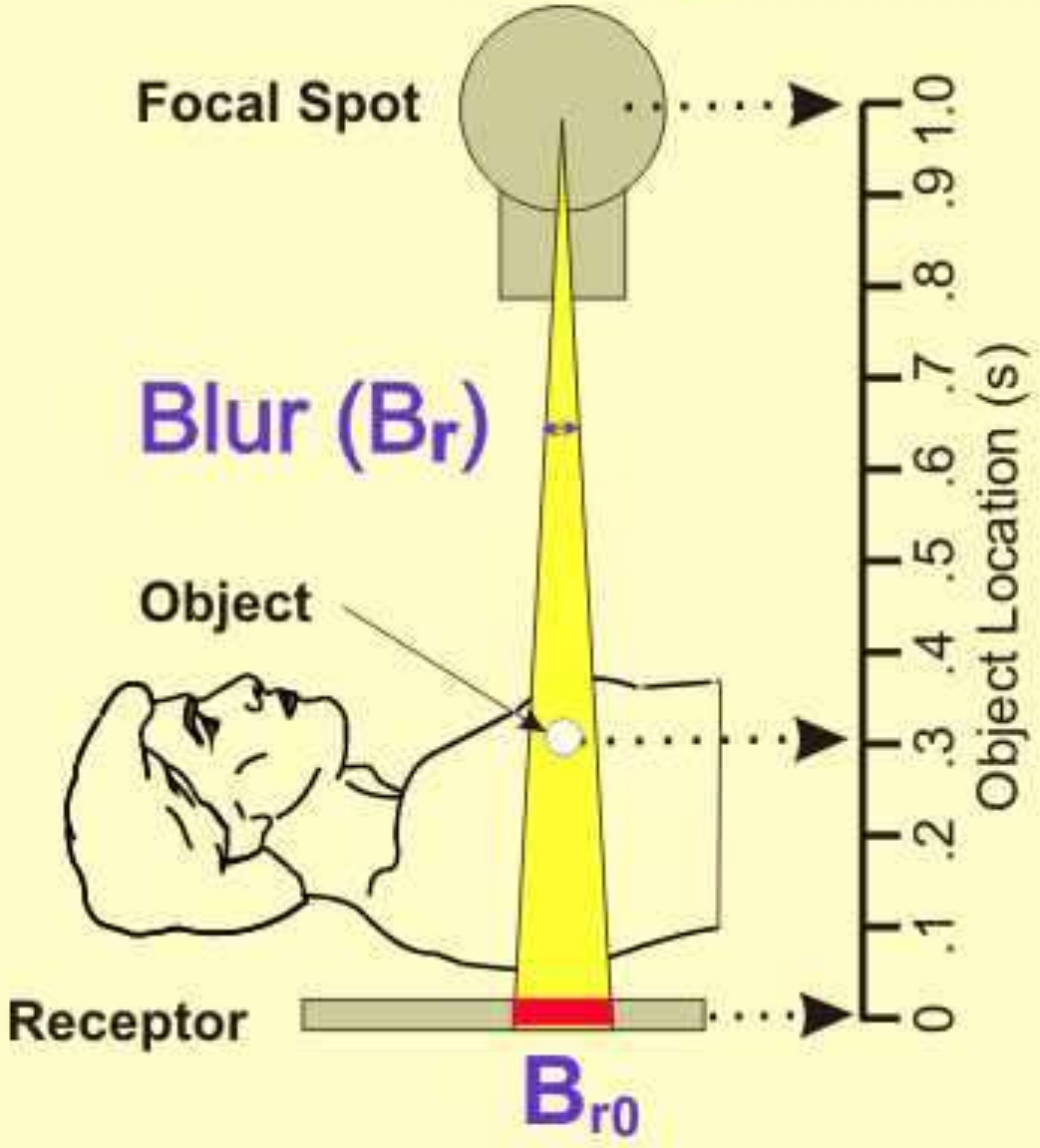
RADIOGRAPHIC RECEPTOR BLUR

- FAST 0.65 mm
- MEDIUM 0.45 mm
- CHEST 0.25 mm
- MAMMO 0.15 mm



RECEPTOR AND DISPLAY BLUR SIZE

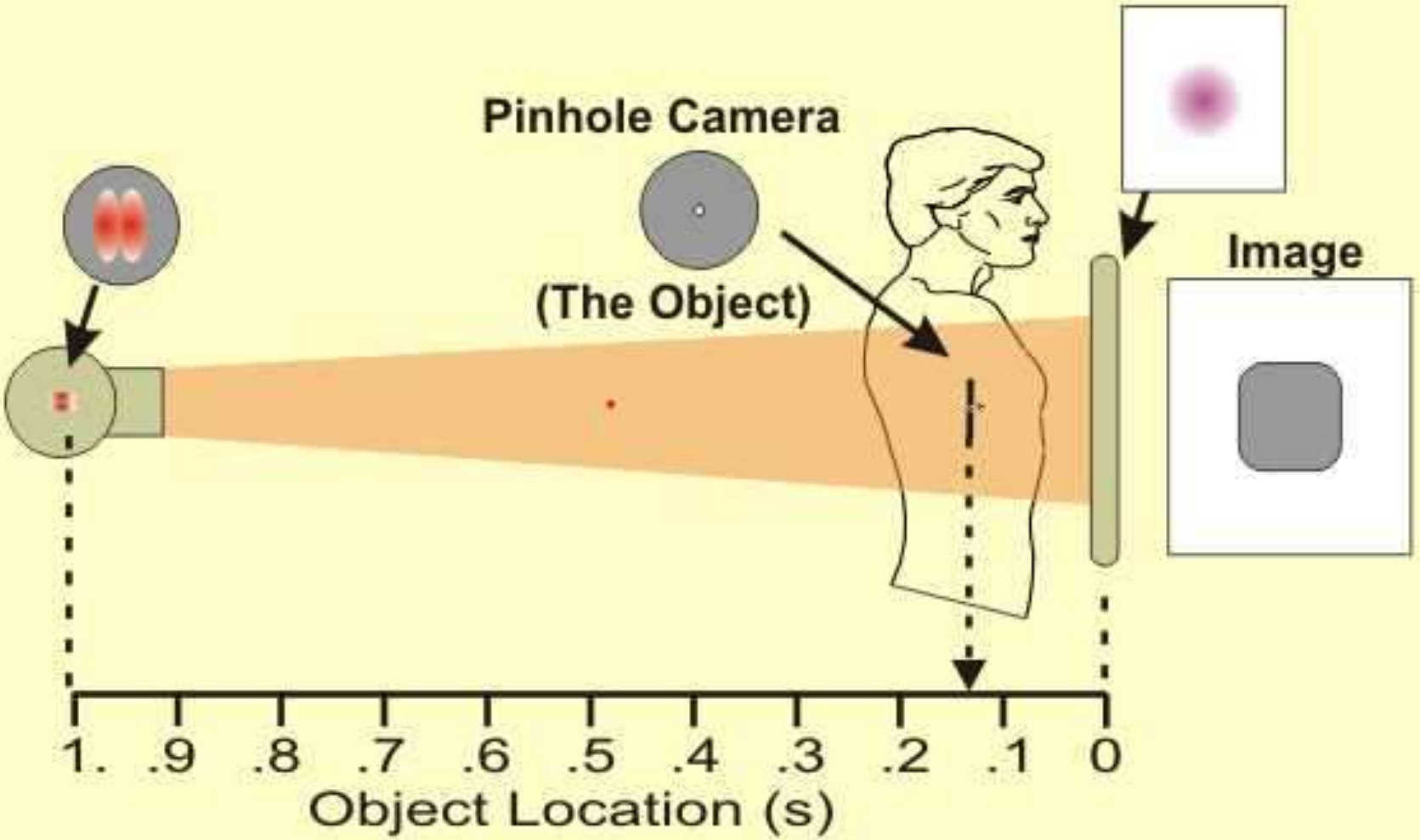
Receptor Blurring



$$B_r = B_{r0}(1-s)$$

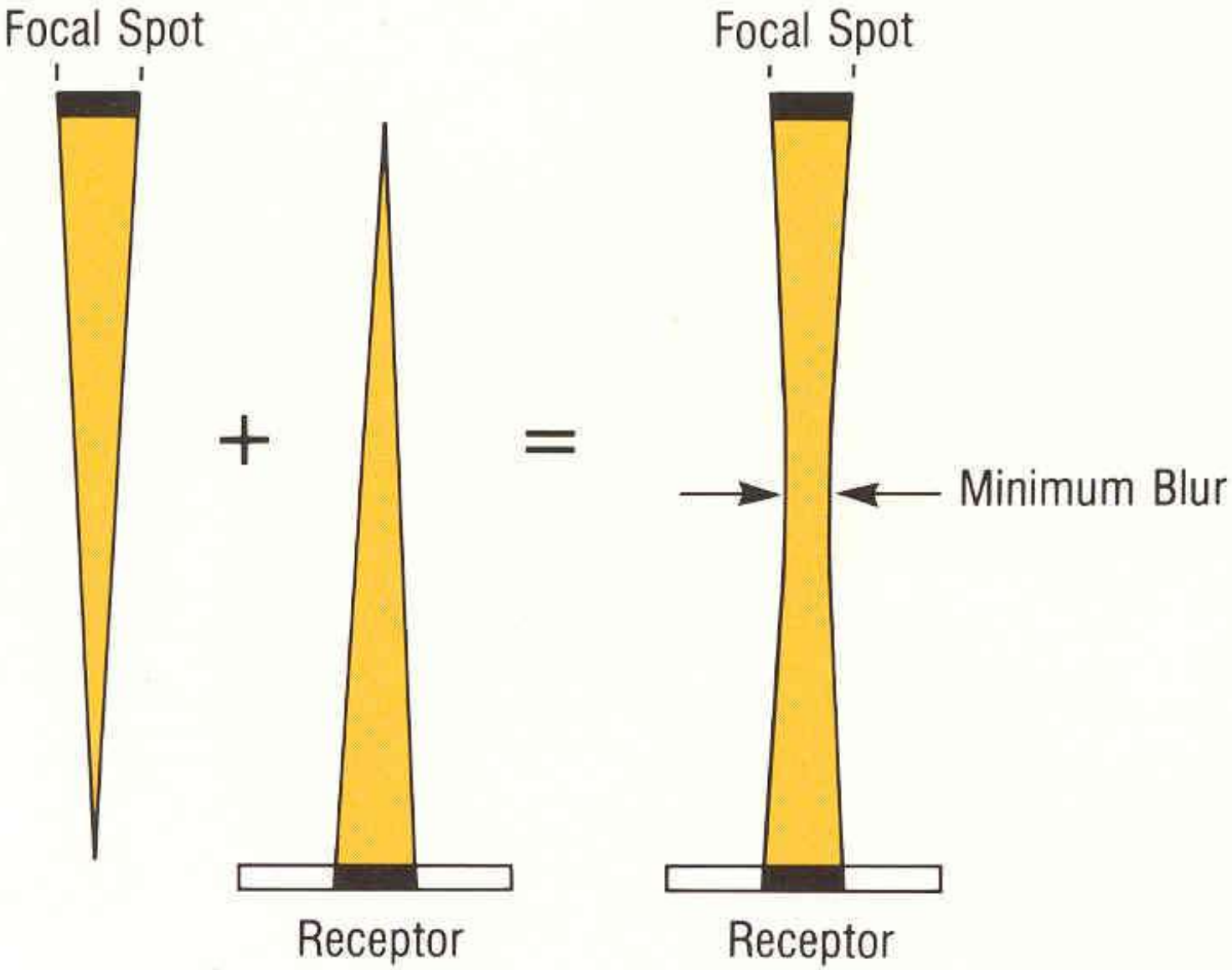
Sprawls

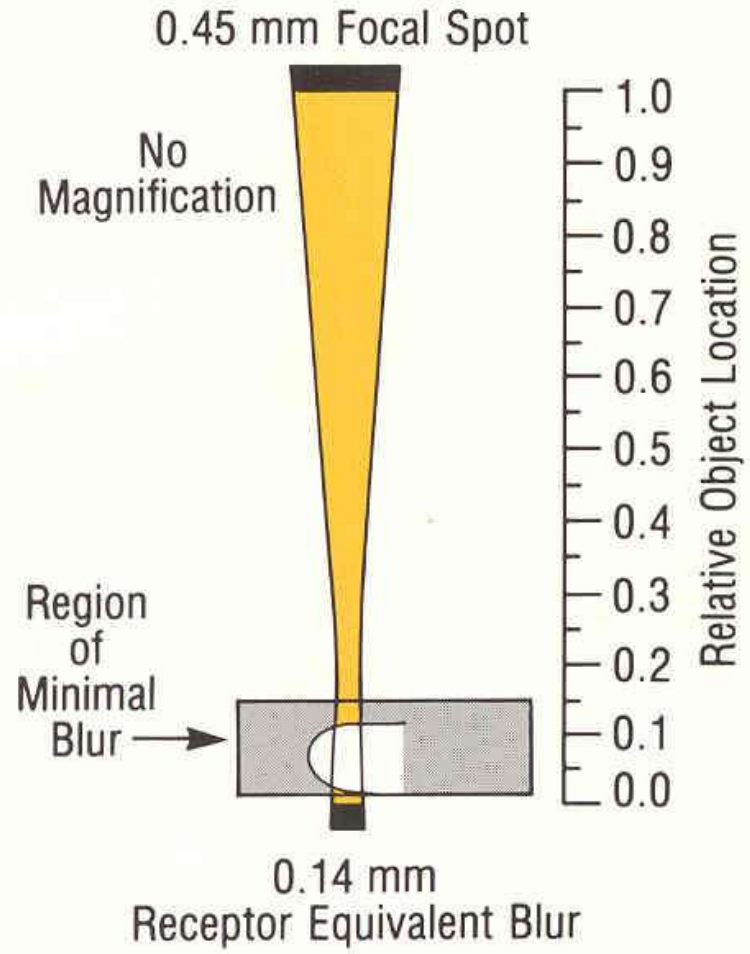
Composite Blur

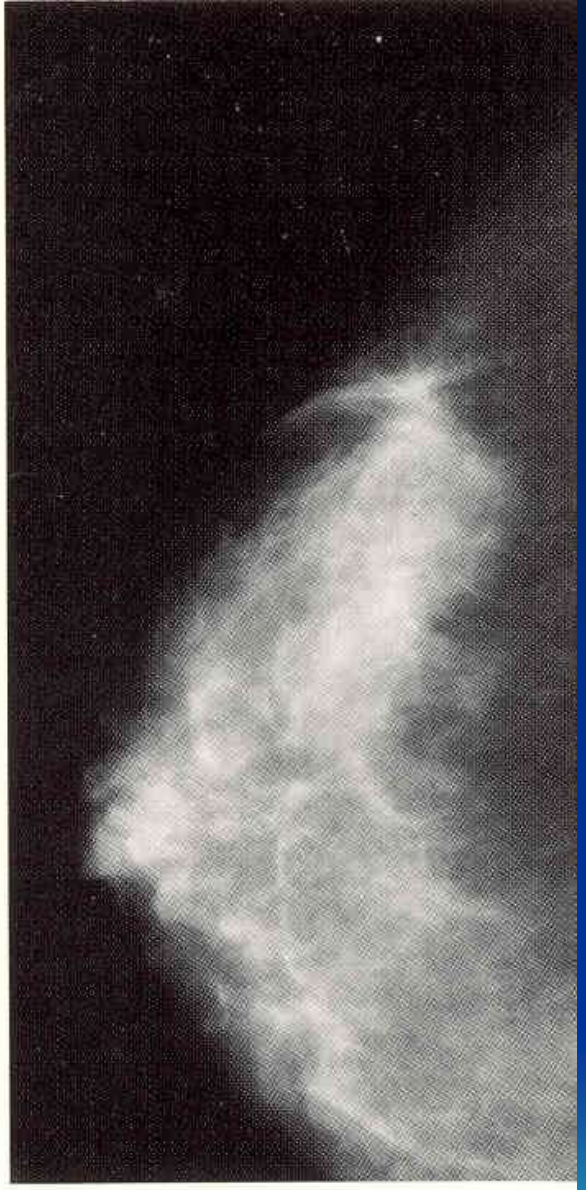


Sprawls

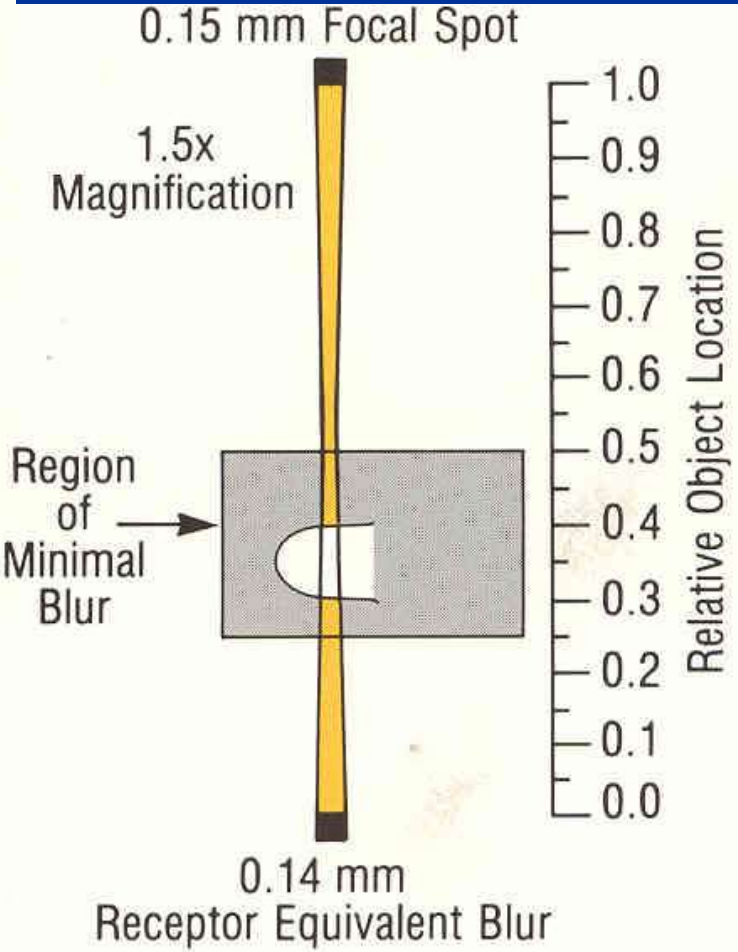
COMPOSITE BLUR

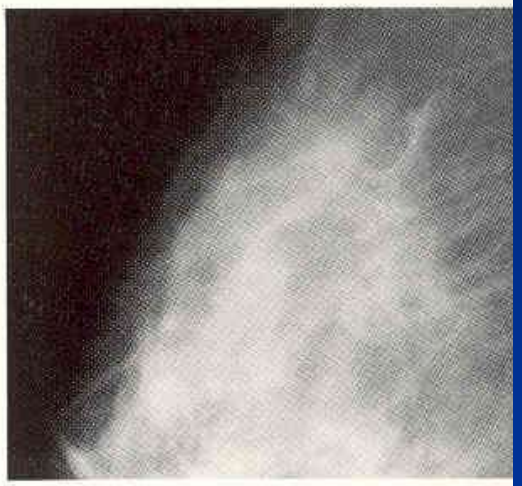






Conventional

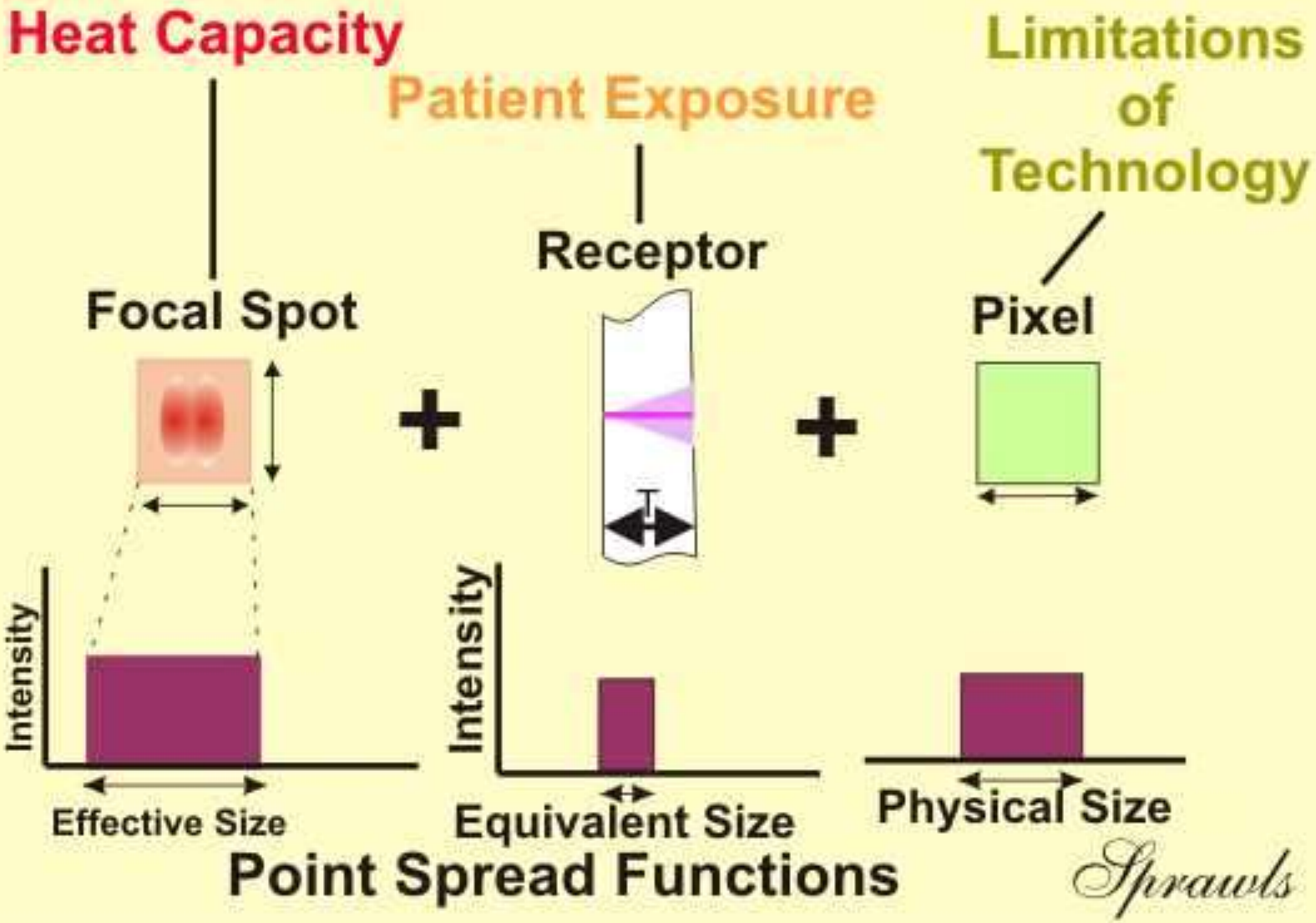




Magnification

Sources of Blurring

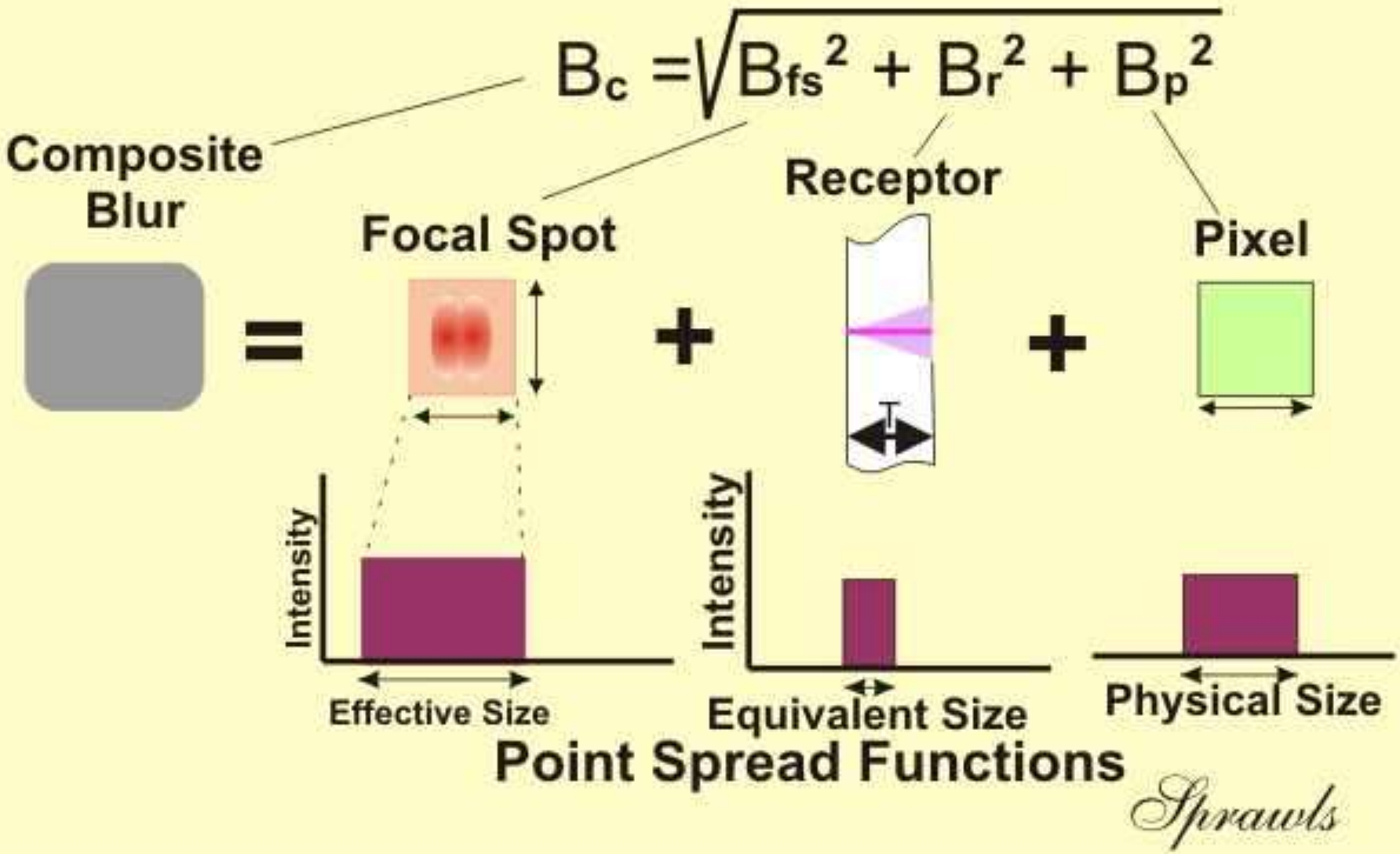
Trade-offs



Composite Blur

Optimization

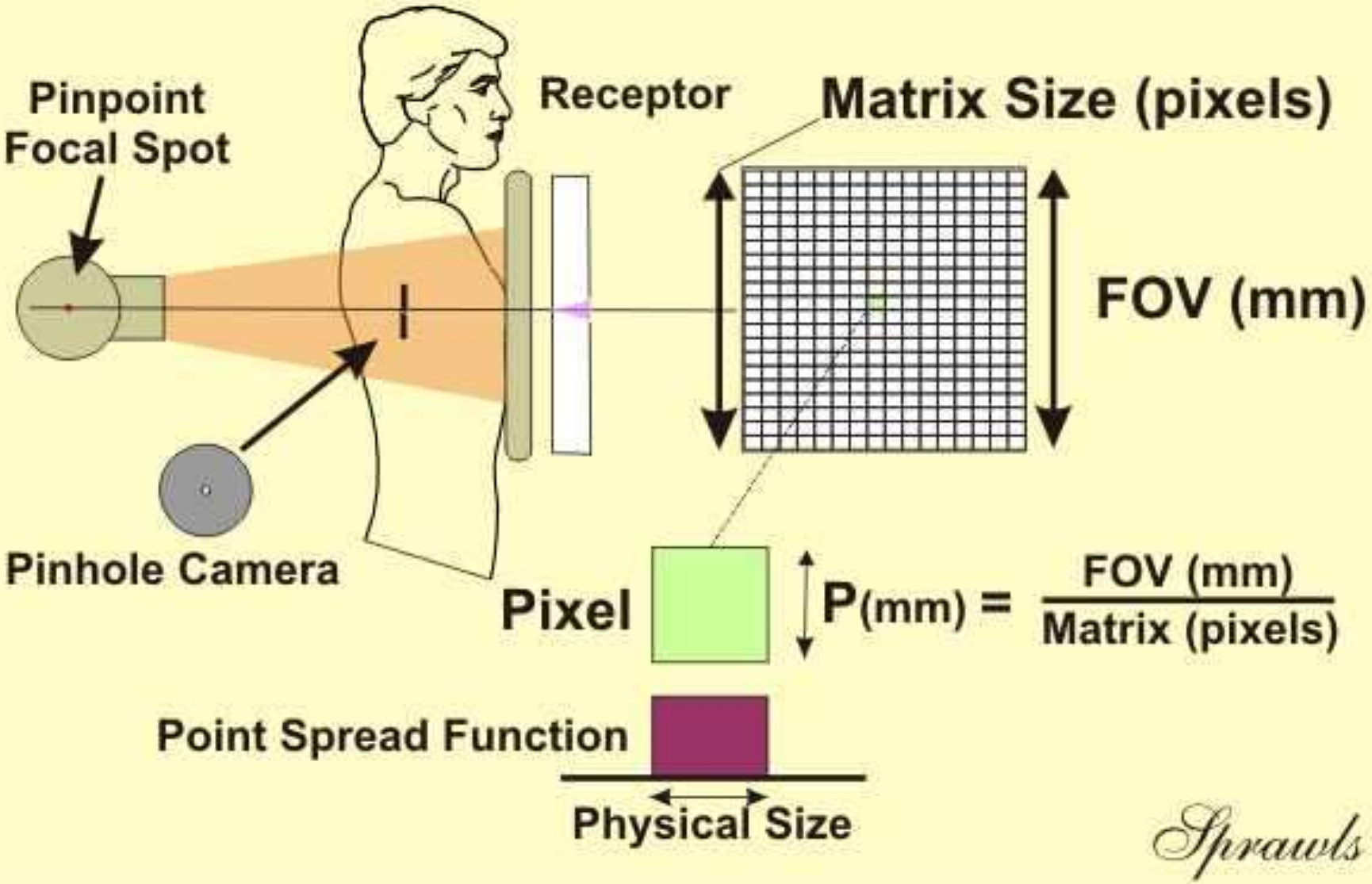
$$B_c = \sqrt{B_{fs}^2 + B_r^2 + B_p^2}$$



Point Spread Functions

Sprawls

Pixel Blurring



Sprawls

Digital Image Blurring

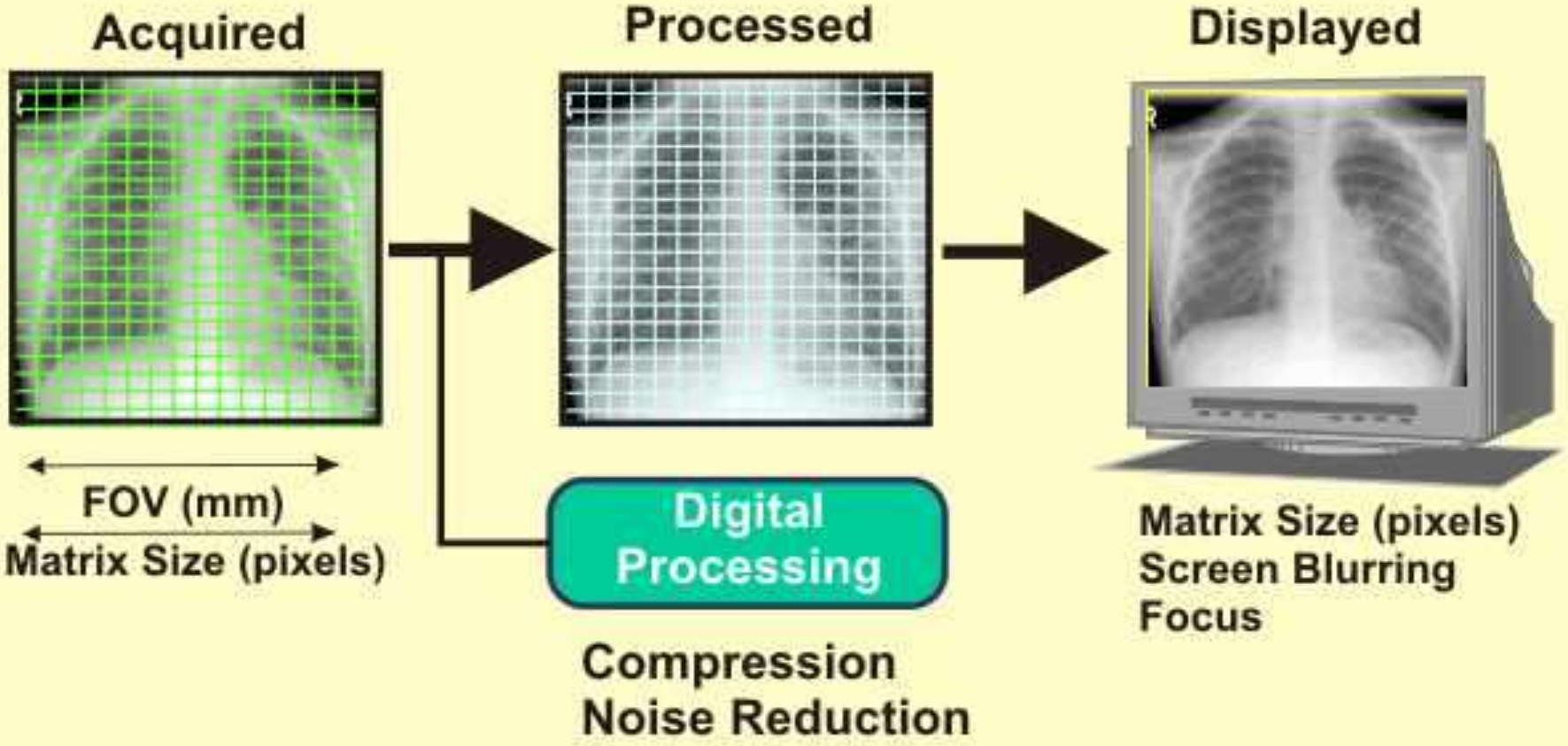


IMAGE NOISE

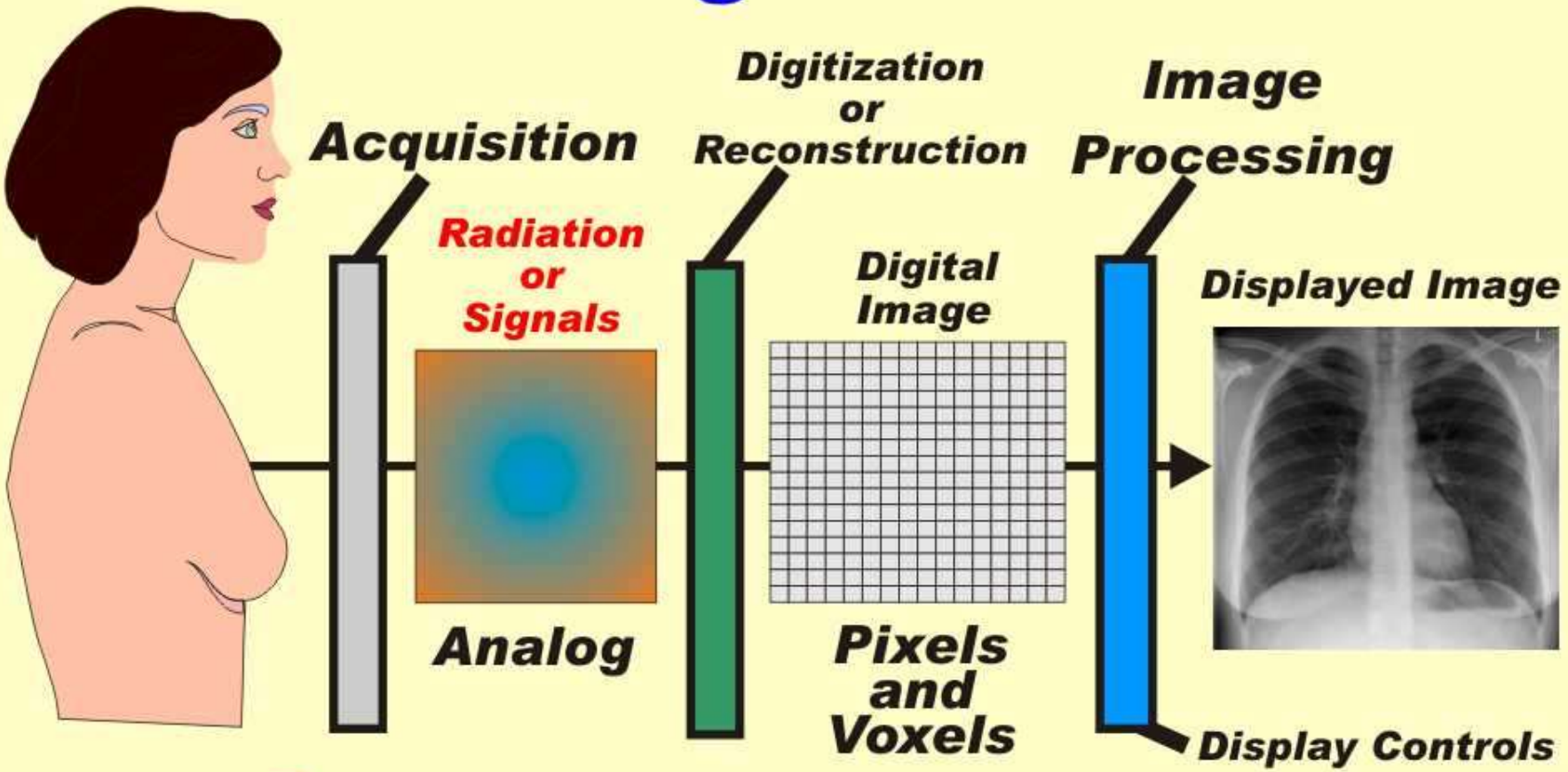
LOW

HIGH

Sprawls

The Medical Imaging Process

Image Noise



Source

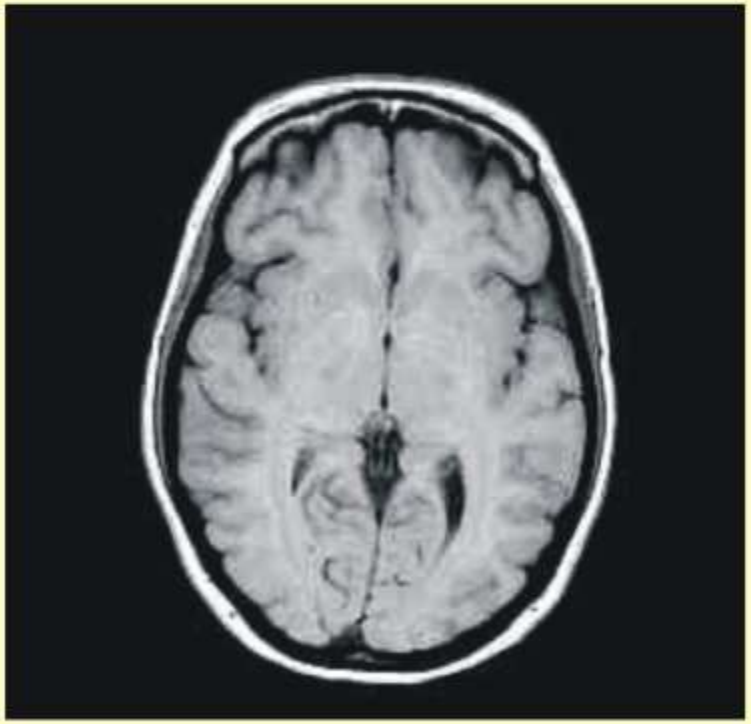
Modified

Sprawls

NOISE

HIGH NOISE

LOW NOISE



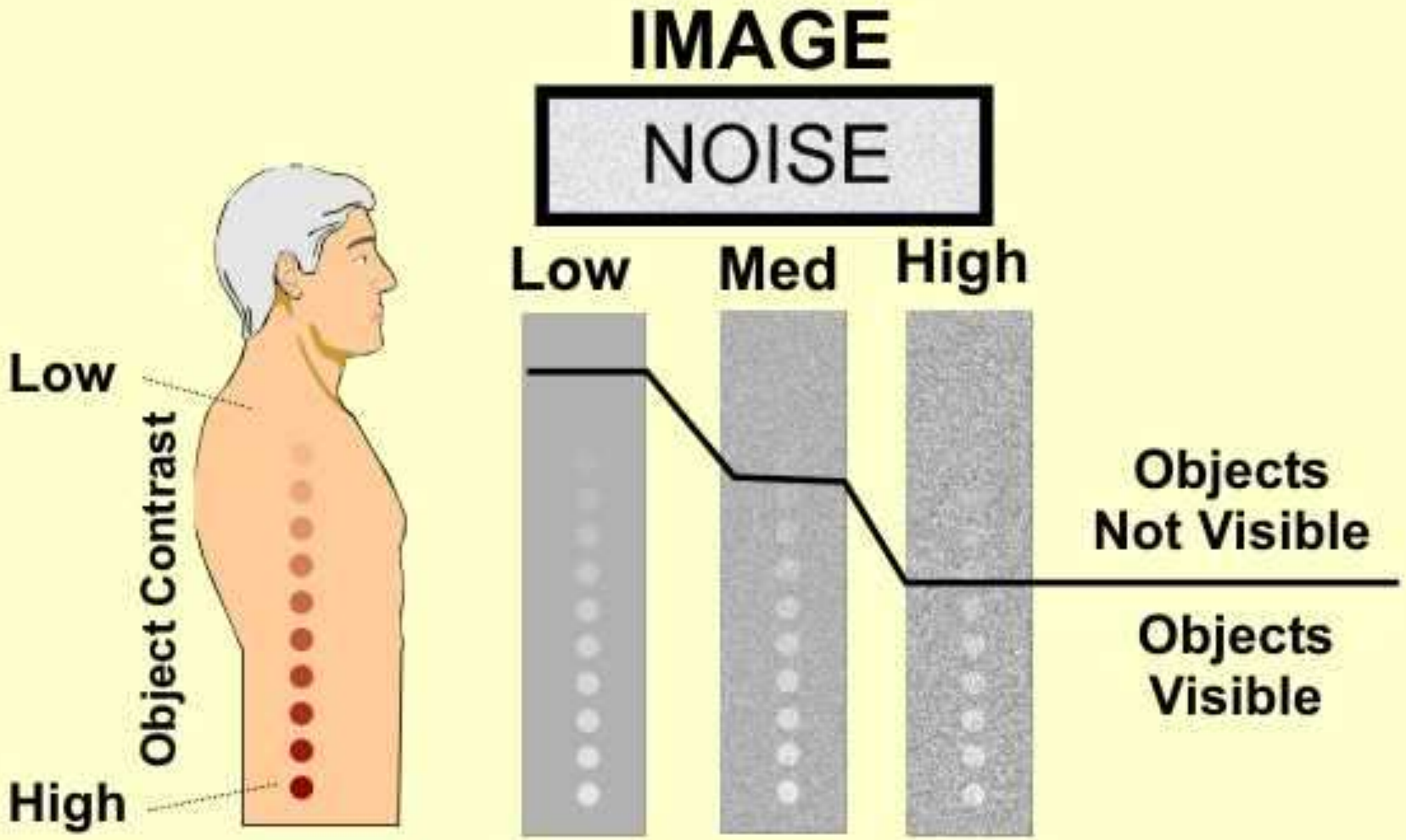
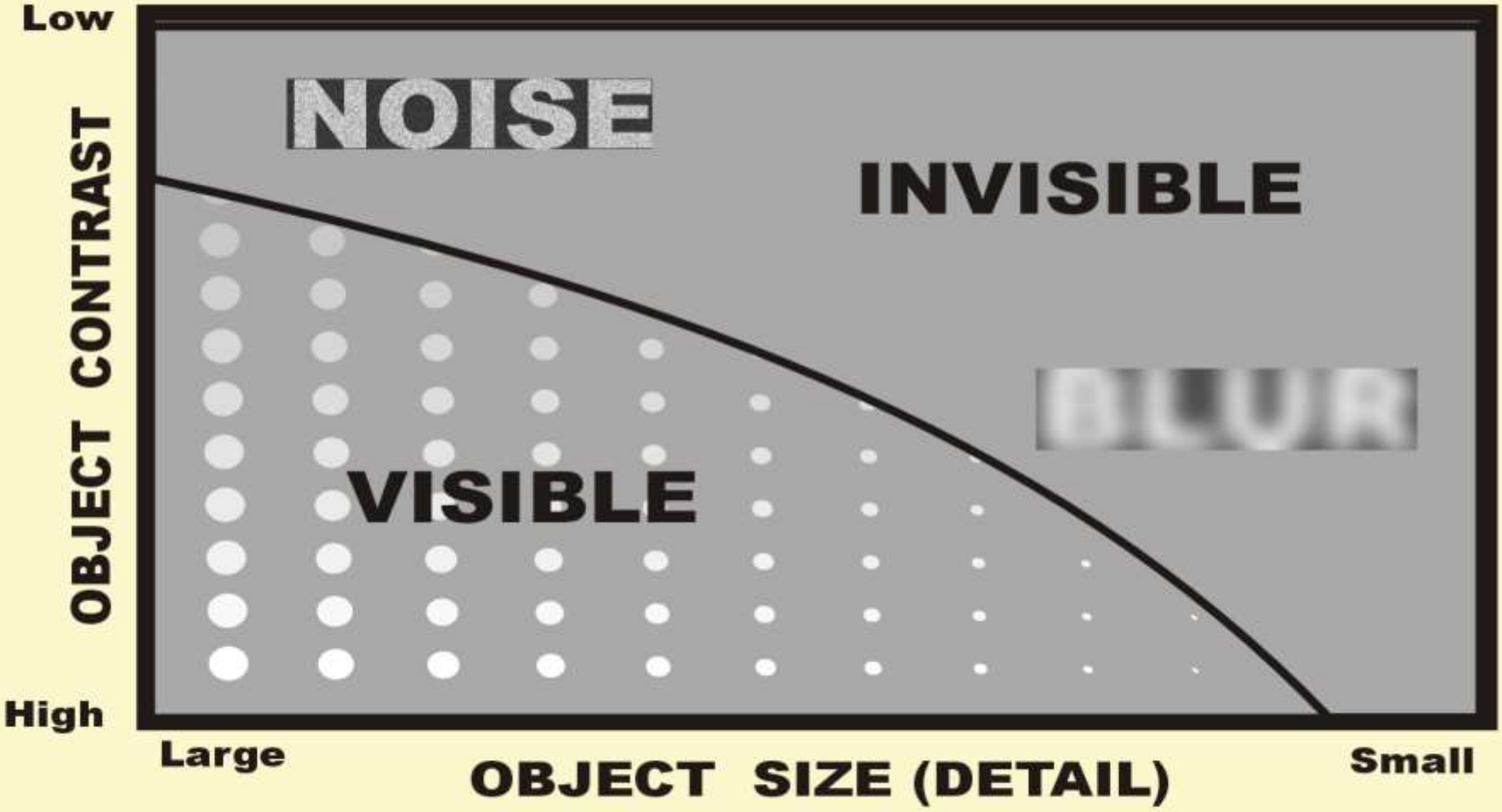


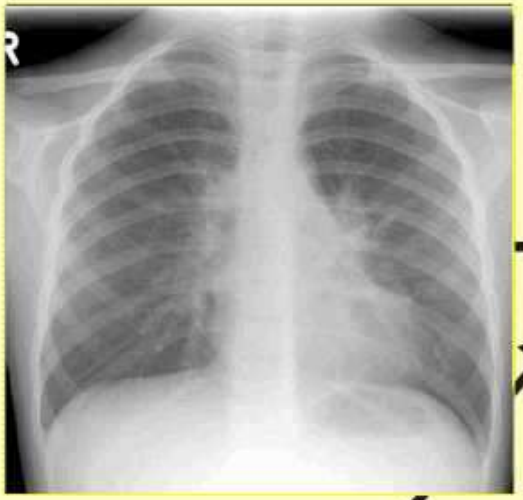
IMAGE
NOISE
Low
Med
High
Low
High
Object Contrast
Objects
Not Visible
Objects
Visible

EFFECT OF NOISE and BLUR

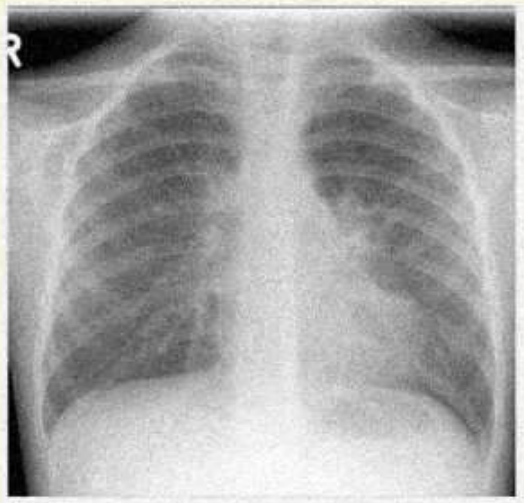


Sprawls

Visibility of Low Contrast Anatomy Limited By



NOISE



Electronic

Receptor/Display Structure

X-Ray Beam

Receptor Exposure

Reduced By

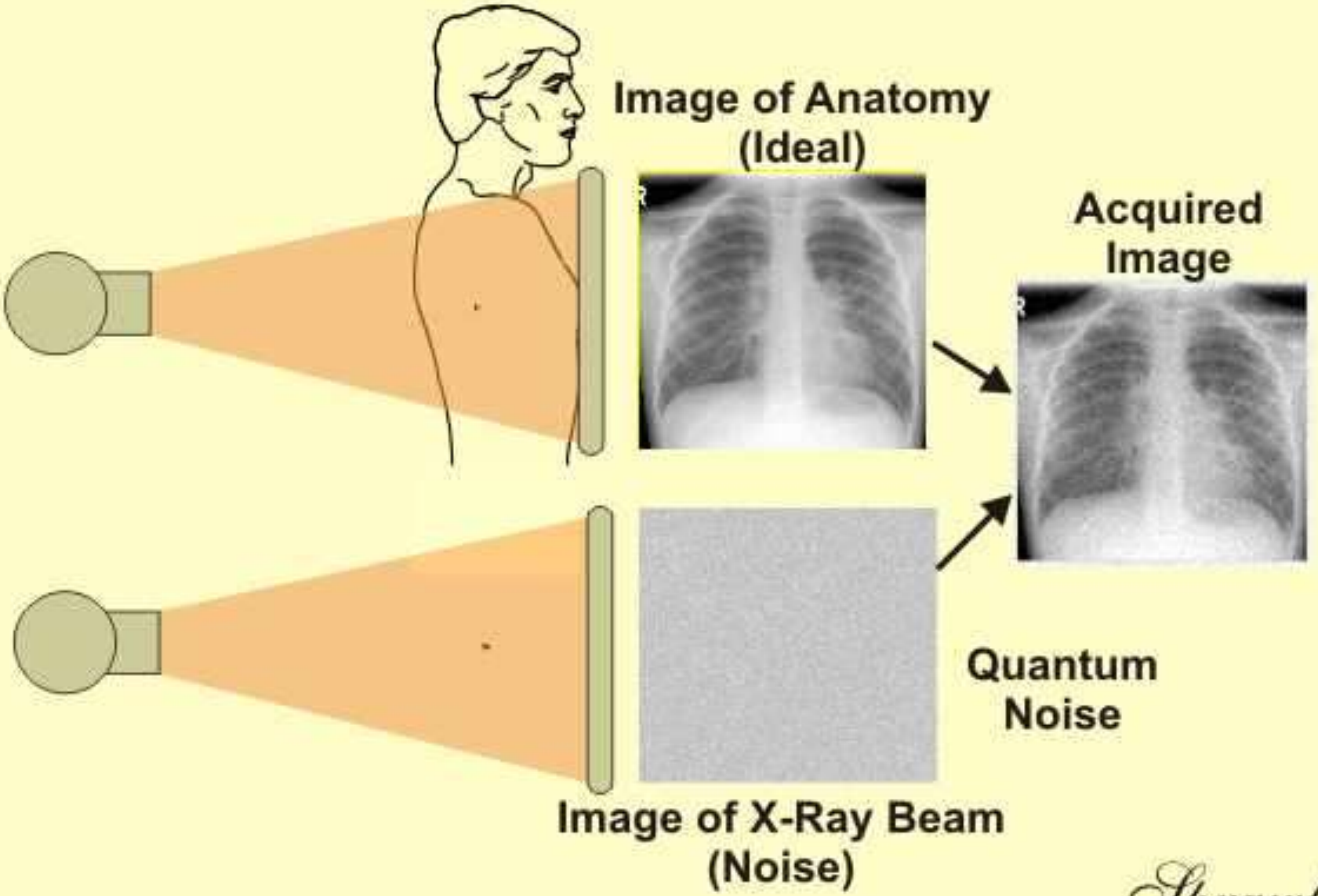
BLUR

(Pixel Size)

Digital Processing

Sprawls

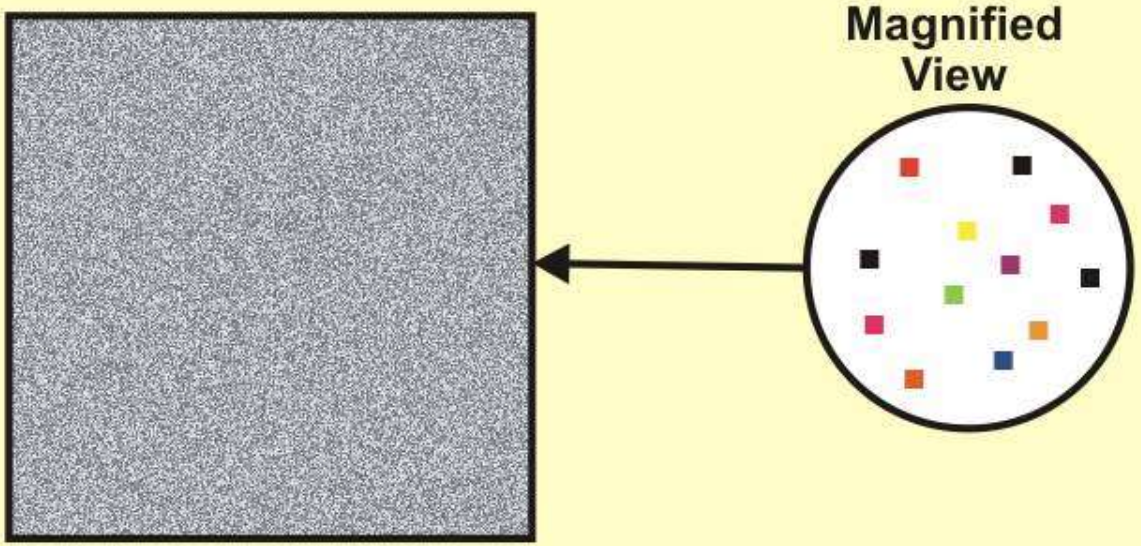
X-Ray Image Noise



Sprawls

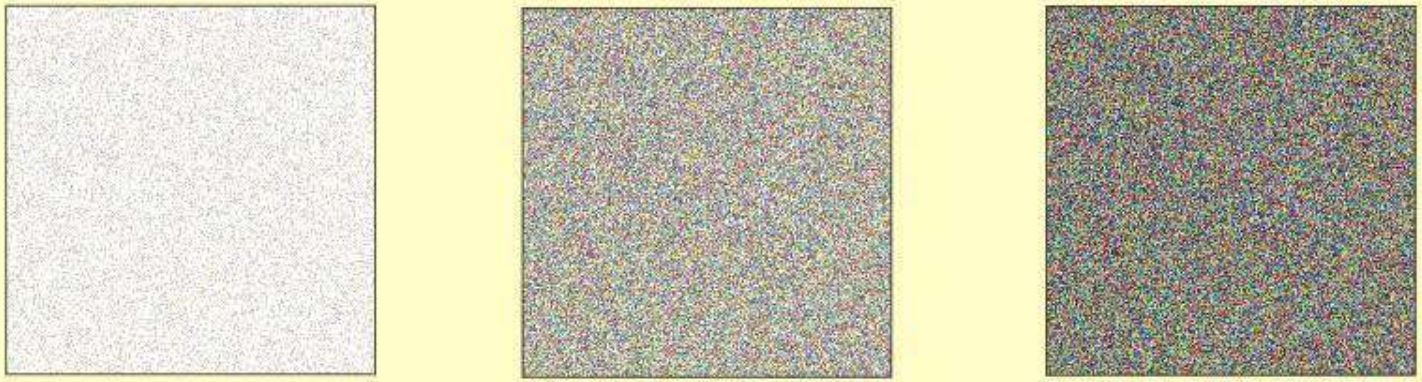
Image Of An X-ray Beam

A Random Distribution of Photons



This is visible in an x-ray image as noise (quantum noise).

High **Medium** **Low**



— Photon Concentration (Exposure)→

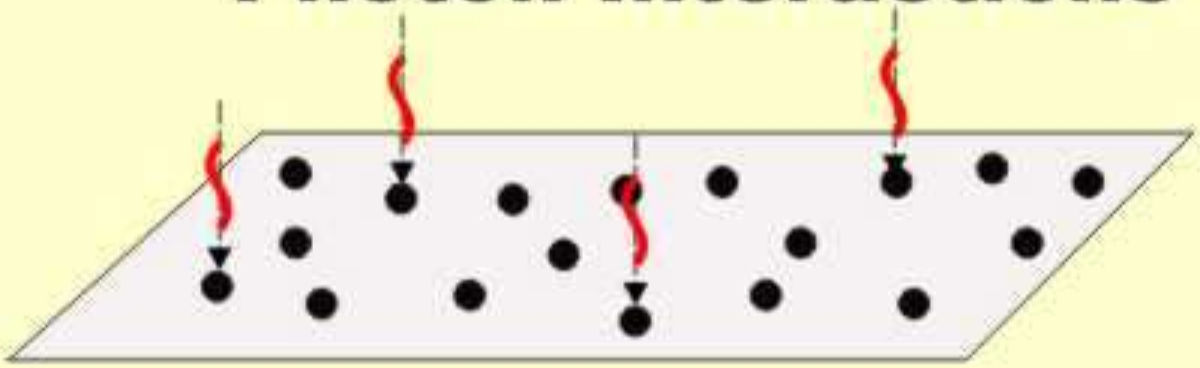
Sprawls

Randomly Distributed

In

Space

Photon Interactions



Produces

Image Noise

Sprawls

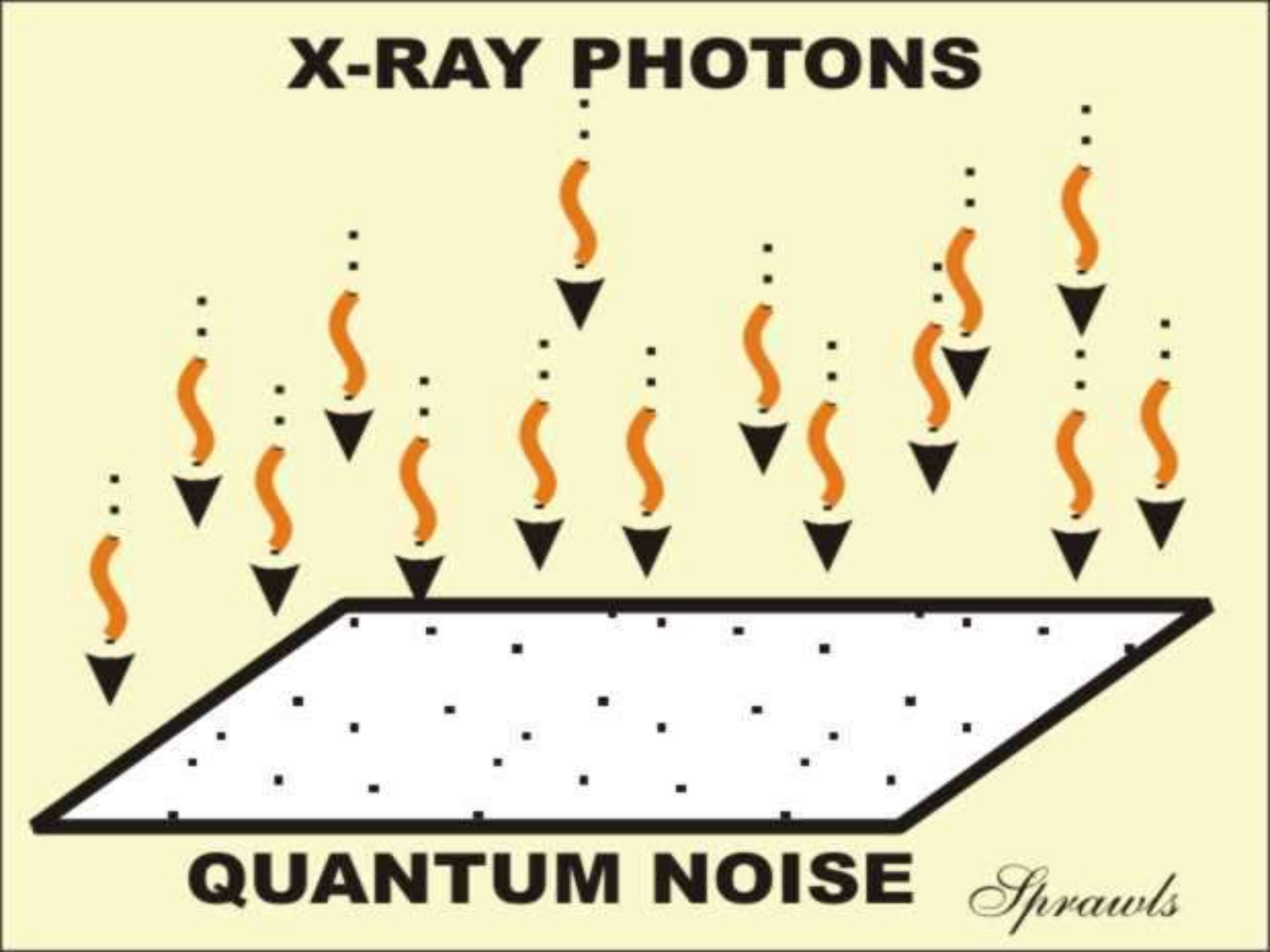
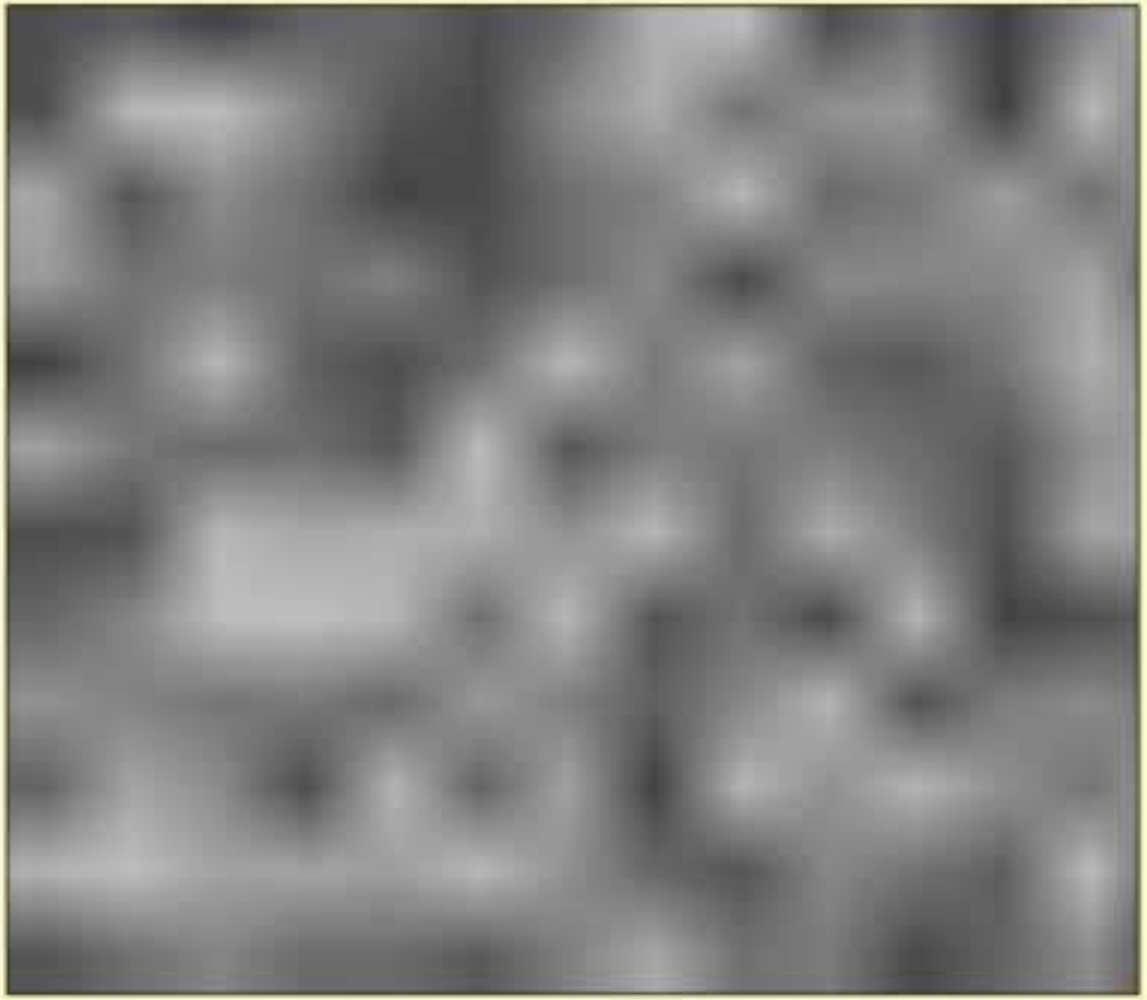

X-RAY PHOTONS
QUANTUM NOISE
Sprawls

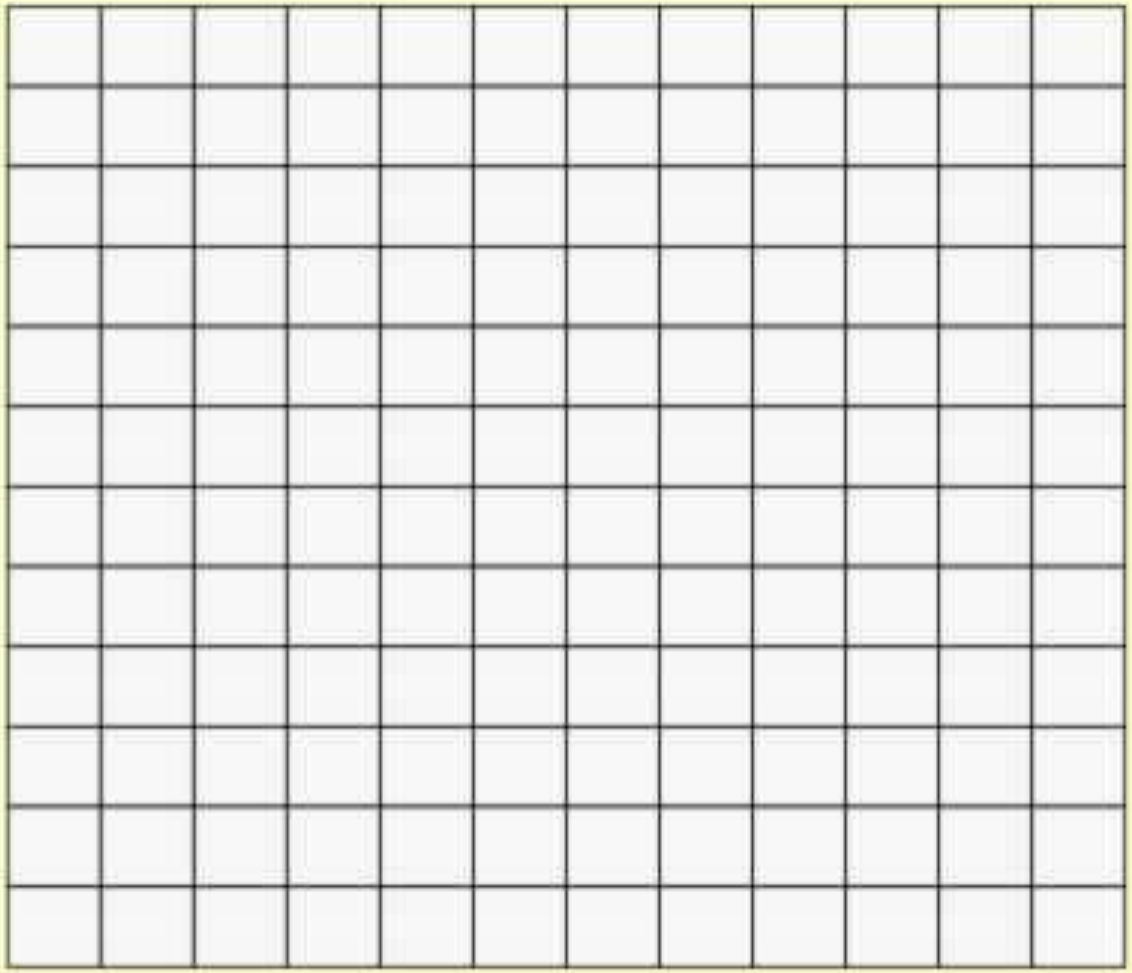
IMAGE RECEPTOR



Small Areas (Pixels)

Sprawls

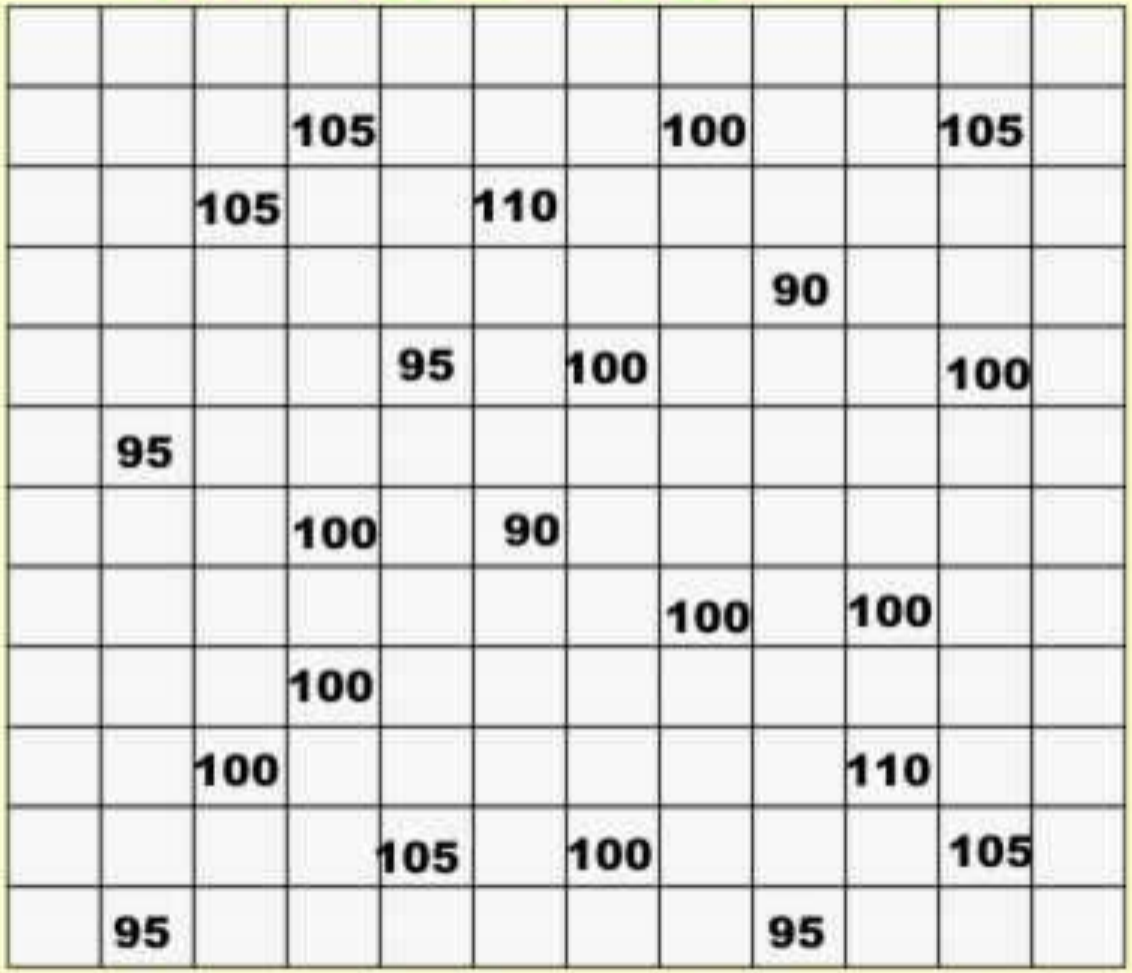
IMAGE RECEPTOR



Small Areas (Pixels)

Sprawls

IMAGE RECEPTOR



(Small Areas/Pixels)

Sprawls

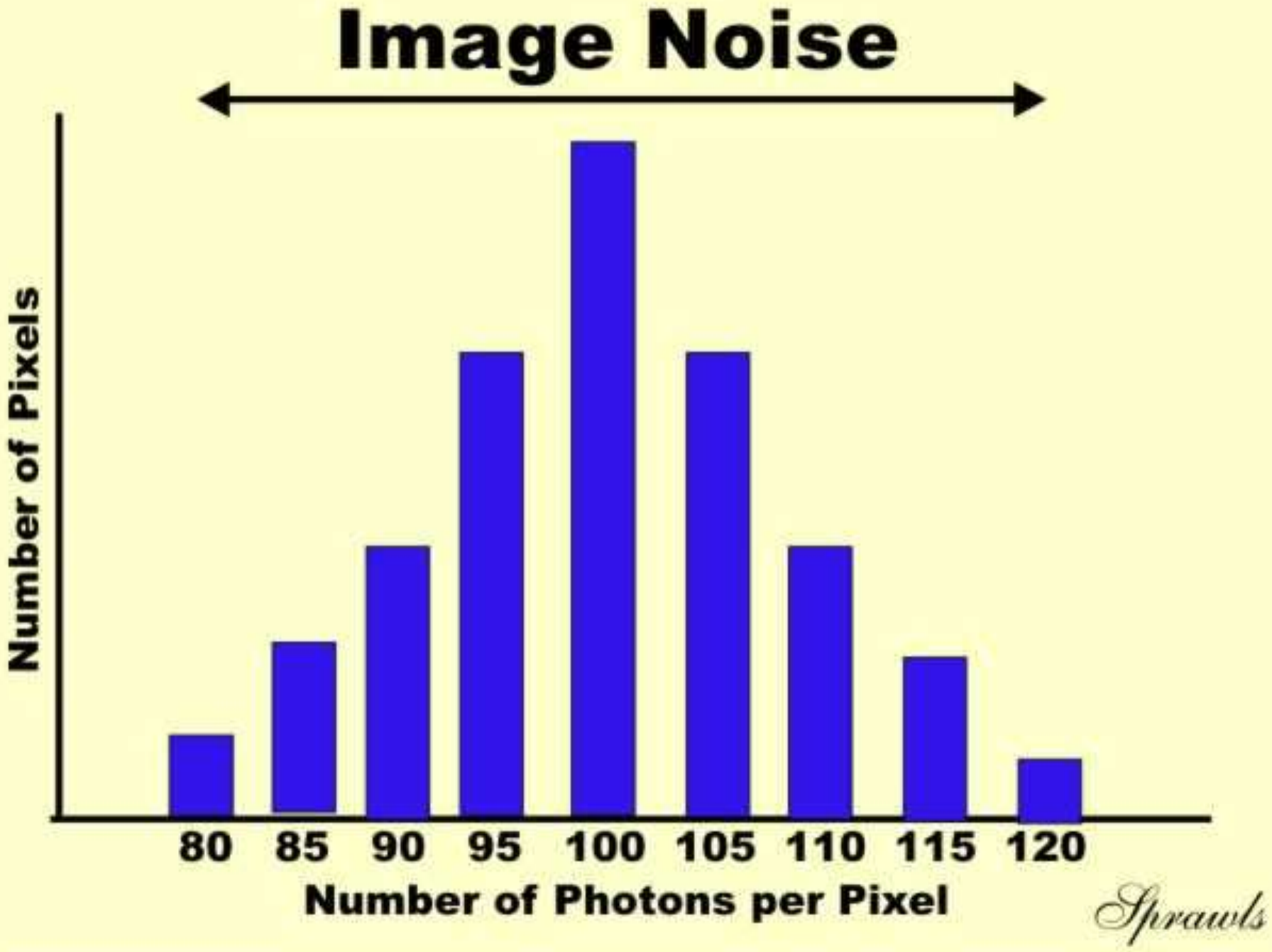


Image Noise
Number of Pixels
80
85
90
95
100
105
110
115
120
Number of Photons per Pixel
Sprawls

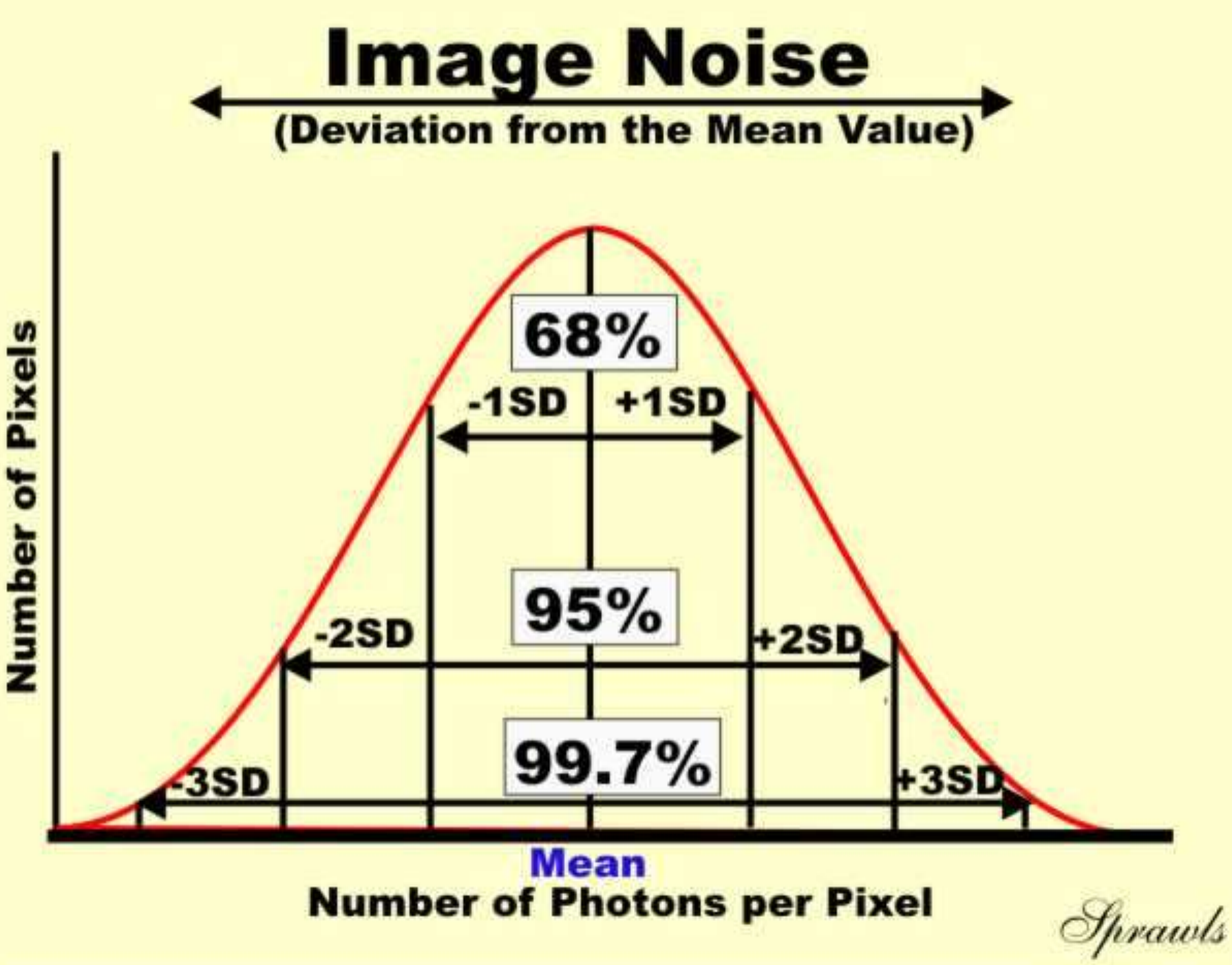


Image Noise
(Deviation from the Mean Value)
Number of Pixels
68%
-1SD
+1SD
95%
-2SD
+2SD
99.7%
-3SD
+3SD
Mean
Number of Photons per Pixel
Sprawls

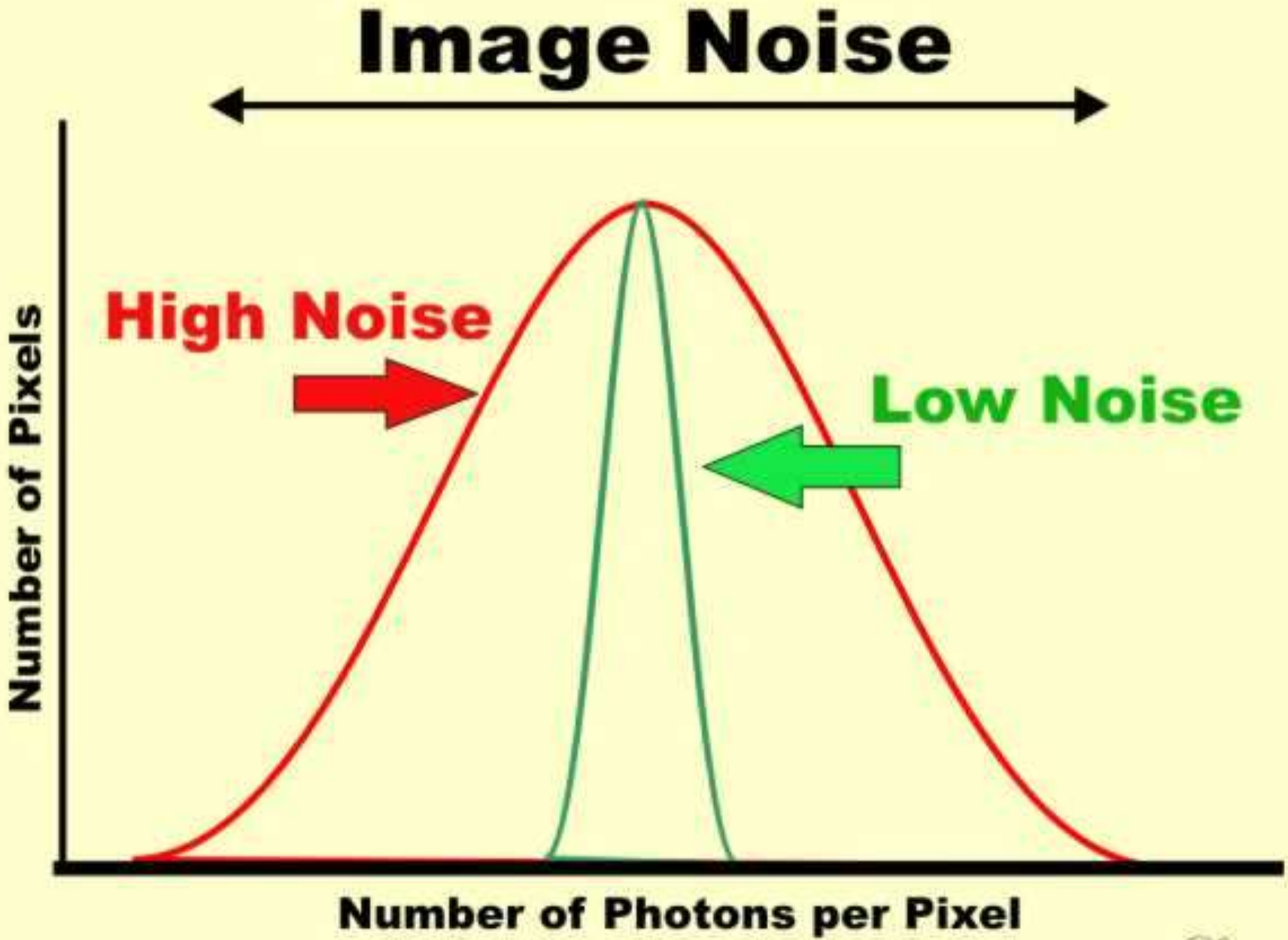


Image Noise
High Noise
Low Noise
Number of Pixels
Number of Photons per Pixel
Sprawls

$$\text{Standard Deviation} = \sqrt{\text{Mean}}$$

Mean	Standard Deviation
100	10 (10%)
1000	32 (3.2%)
10,000	100 (1%)

Sprawls

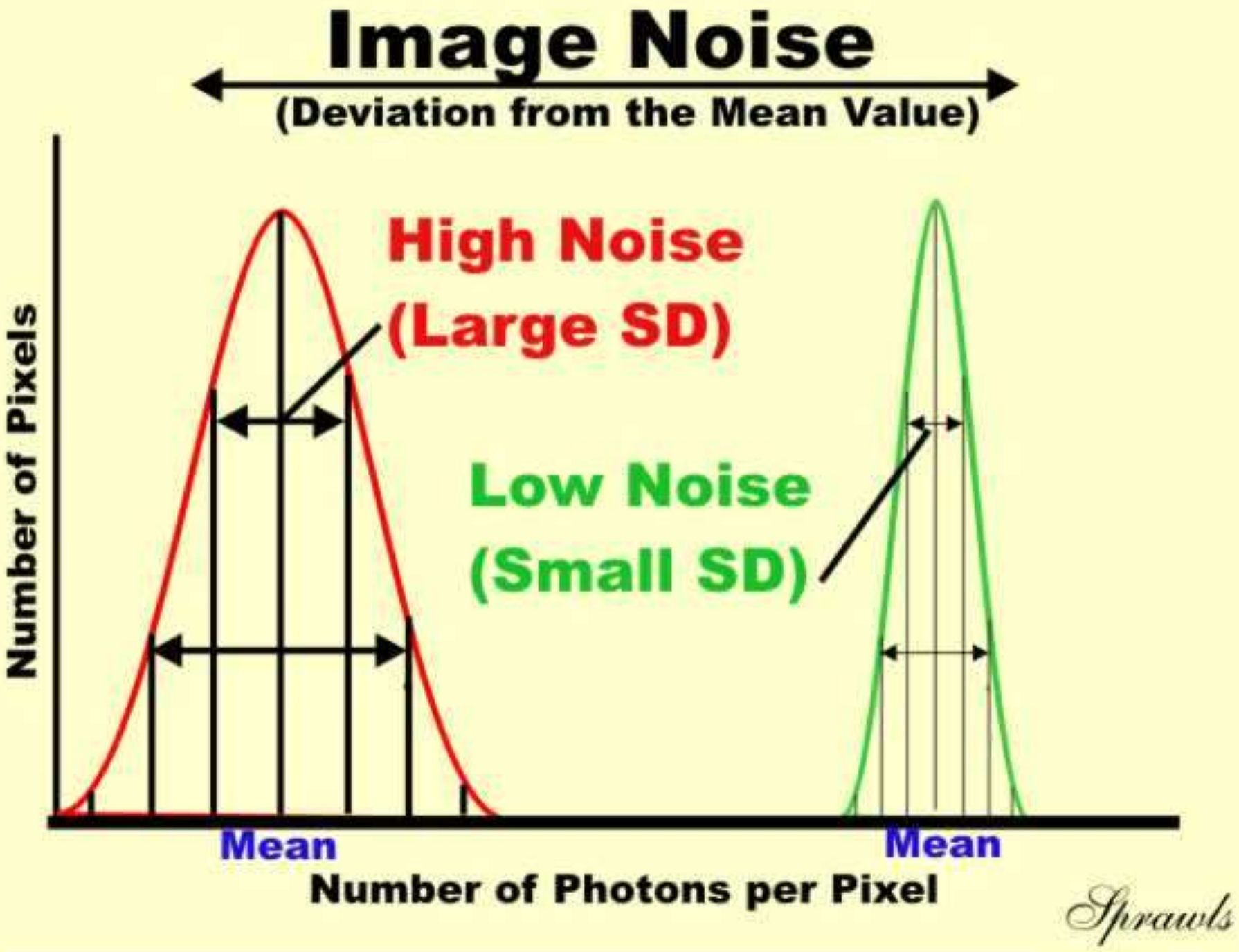
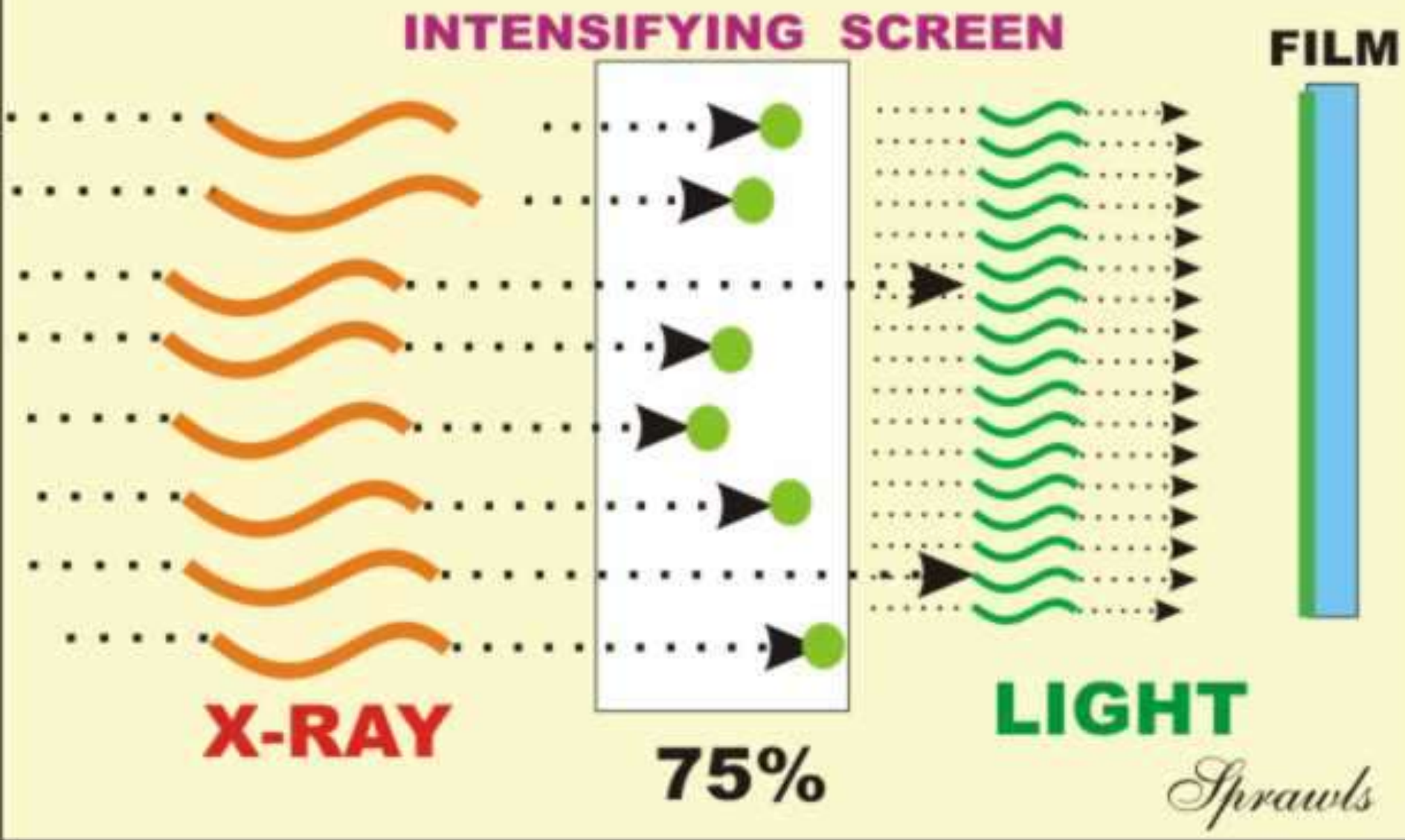


Image Noise
(Deviation from the Mean Value)
High Noise
(Large SD)
Low Noise
(Small SD)
Number of Pixels
Mean
Mean
Number of Photons per Pixel
Sprawls

RADIOGRAPHIC RECEPTOR

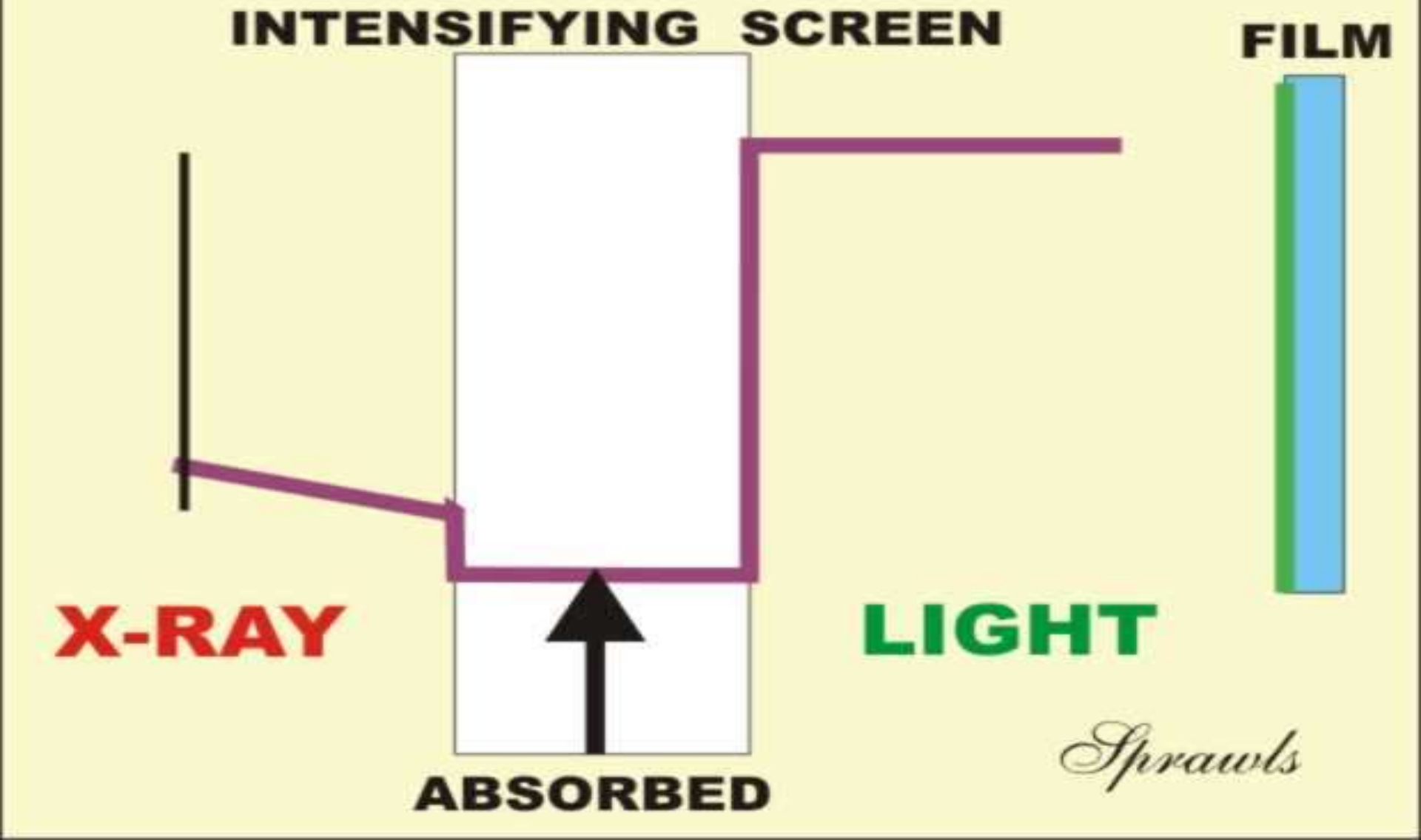
ABSORPTION



Sprawls

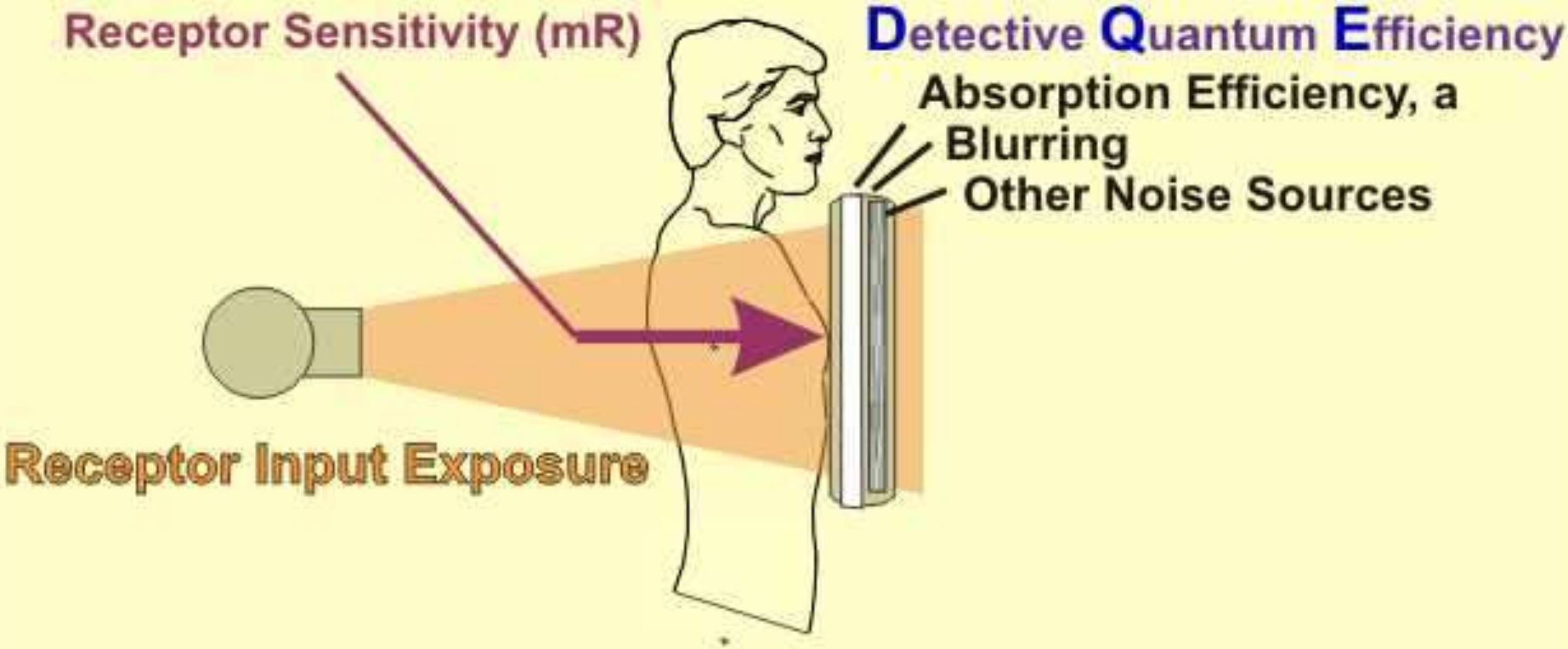
THE QUANTUM SINK

(Photon Concentration)



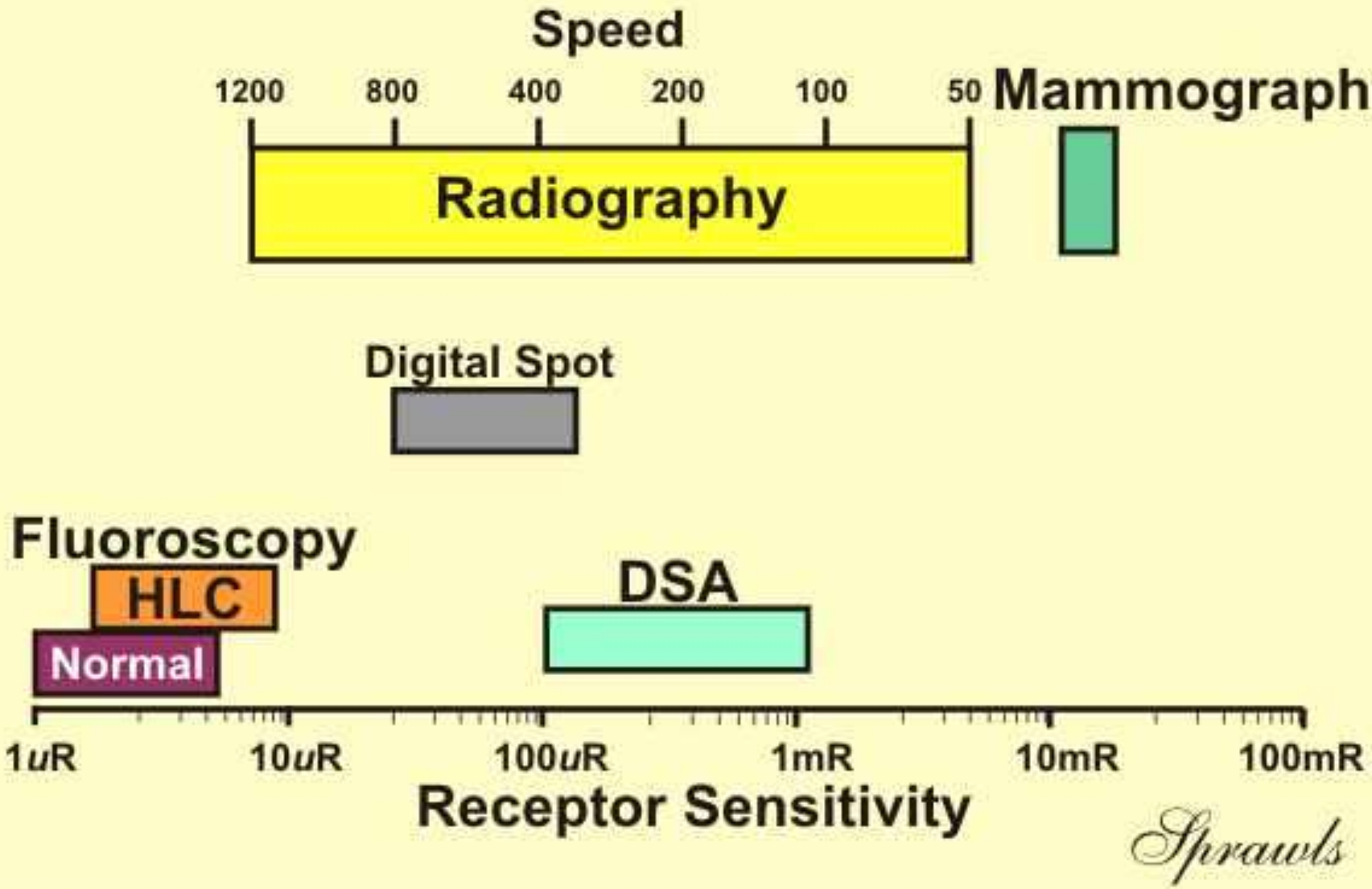
X-Ray Image Noise

Receptor Characteristics



Sprawls

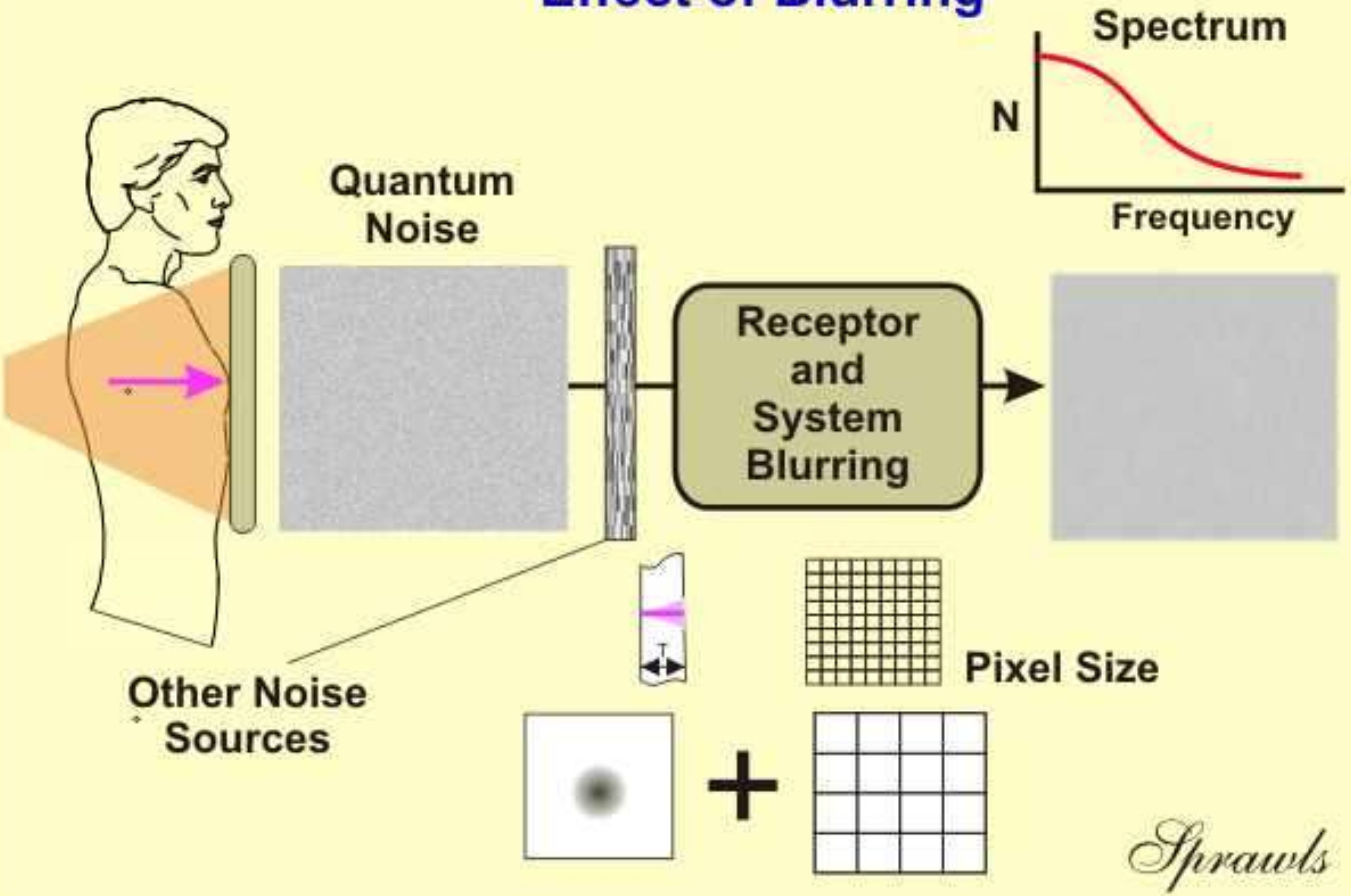
X-Ray Receptor Sensitivity



Sprawls

X-Ray Image Noise

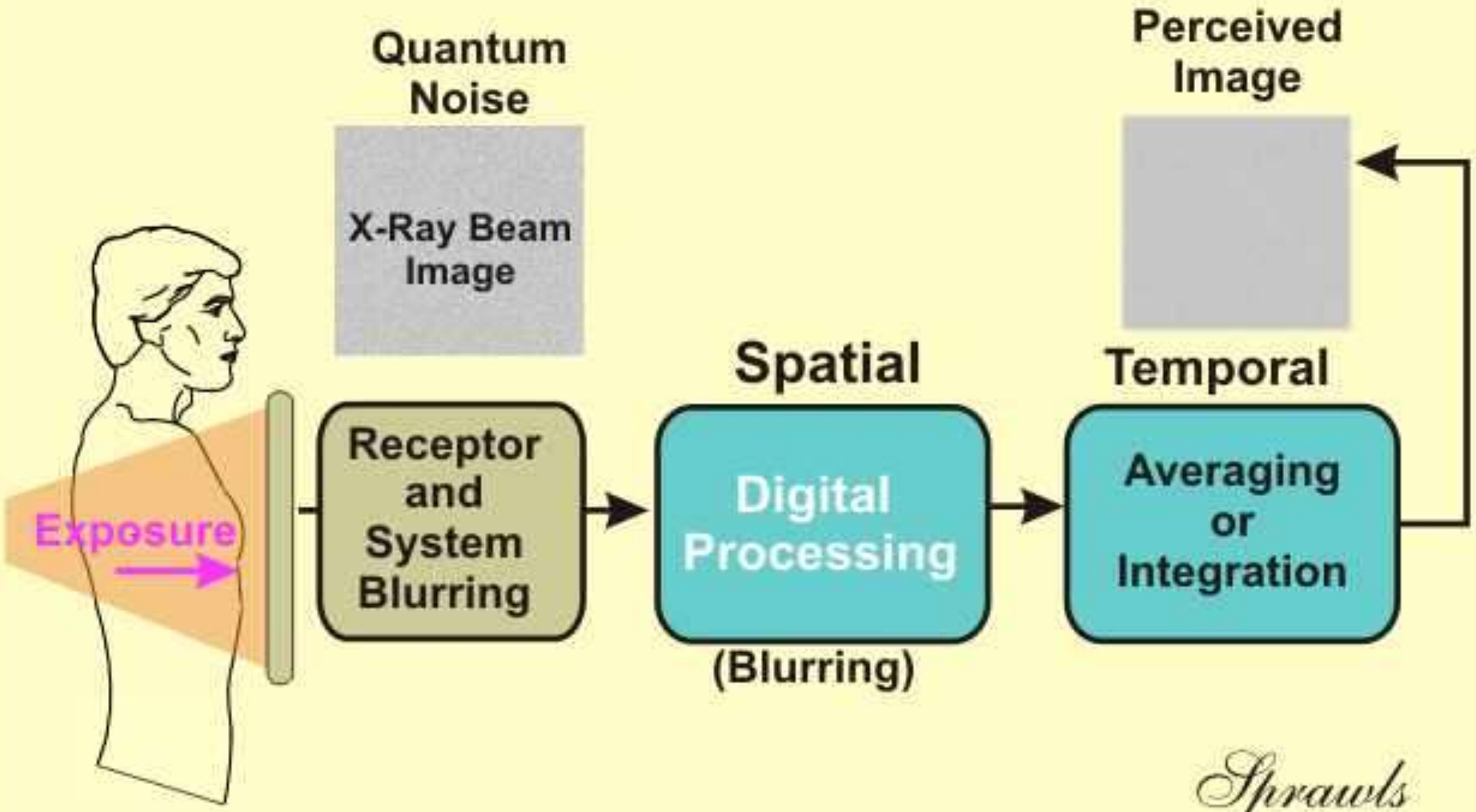
Effect of Blurring



Sprawls

X-Ray Image Noise

Modifying Factors



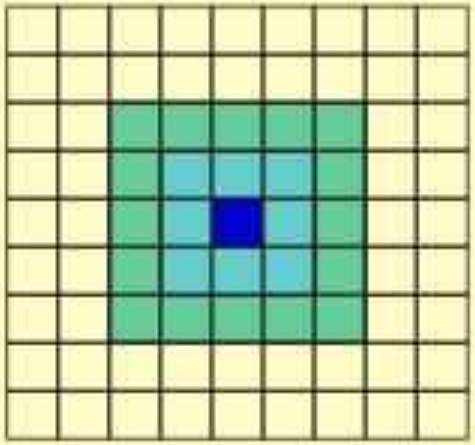
Sprawls

X-Ray Image Noise

Reduction

(Blurring)

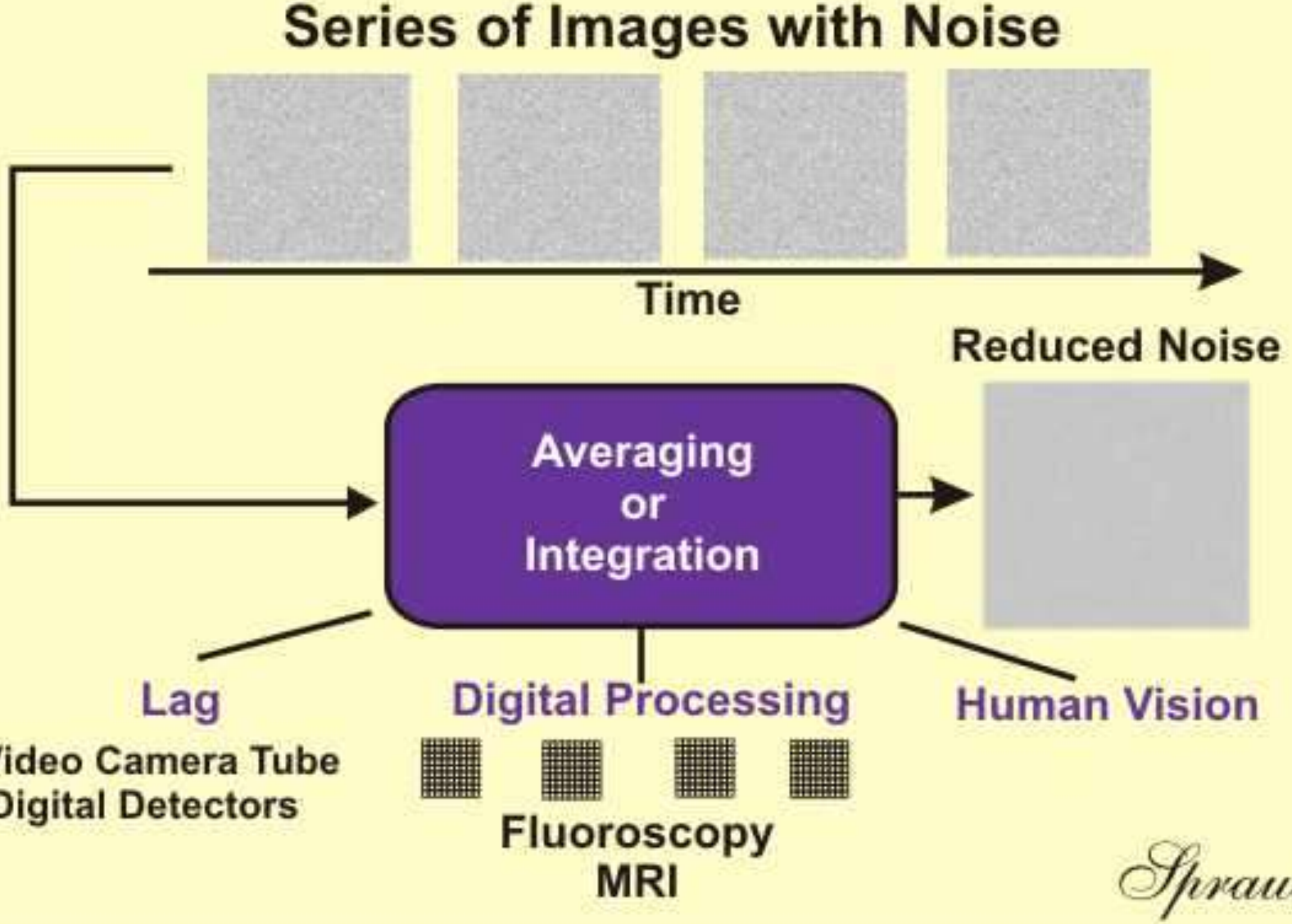
Pixel Averaging



Sprawls

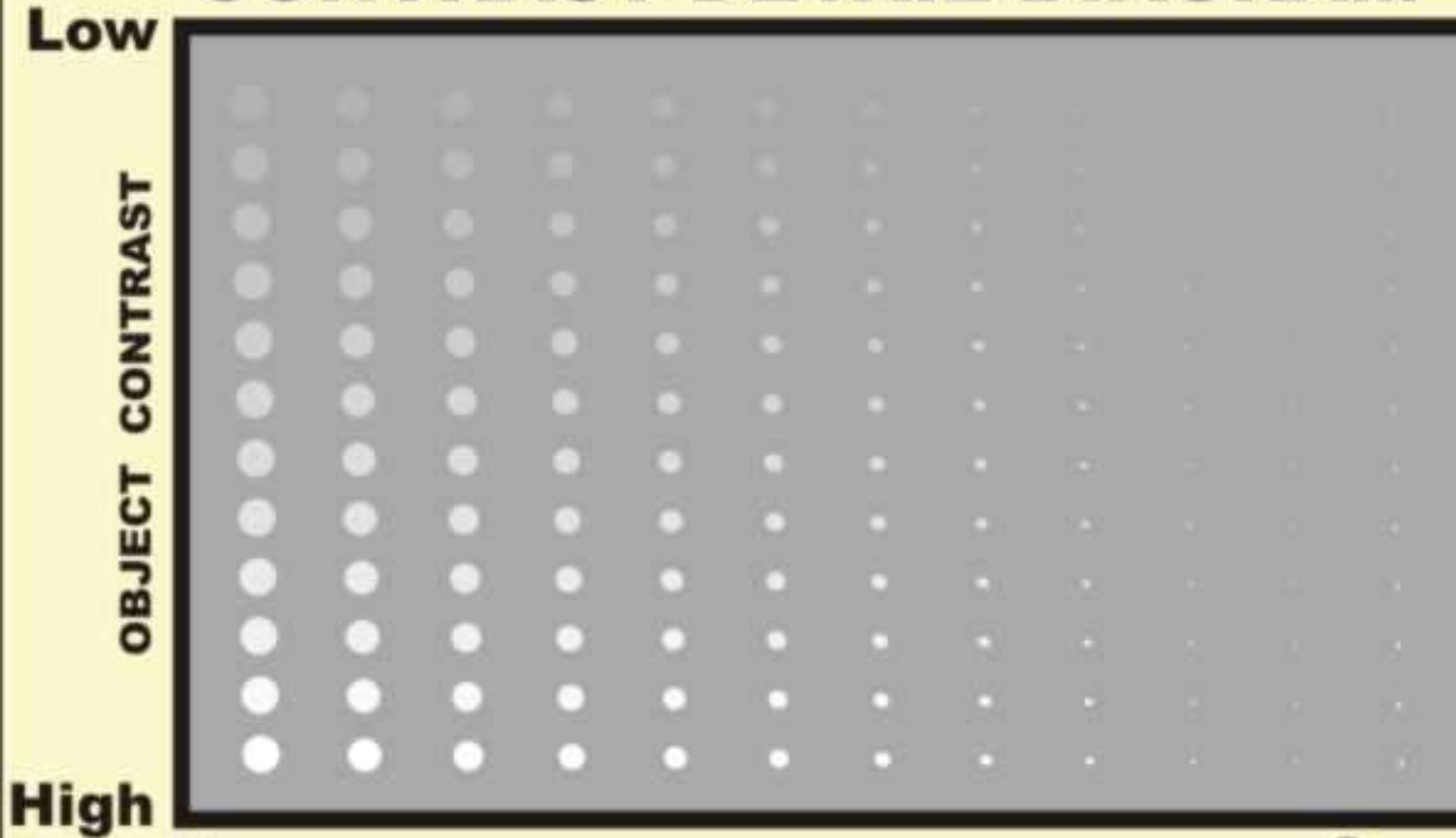
X-Ray Image Noise

Temporal Filtering



Sprawls

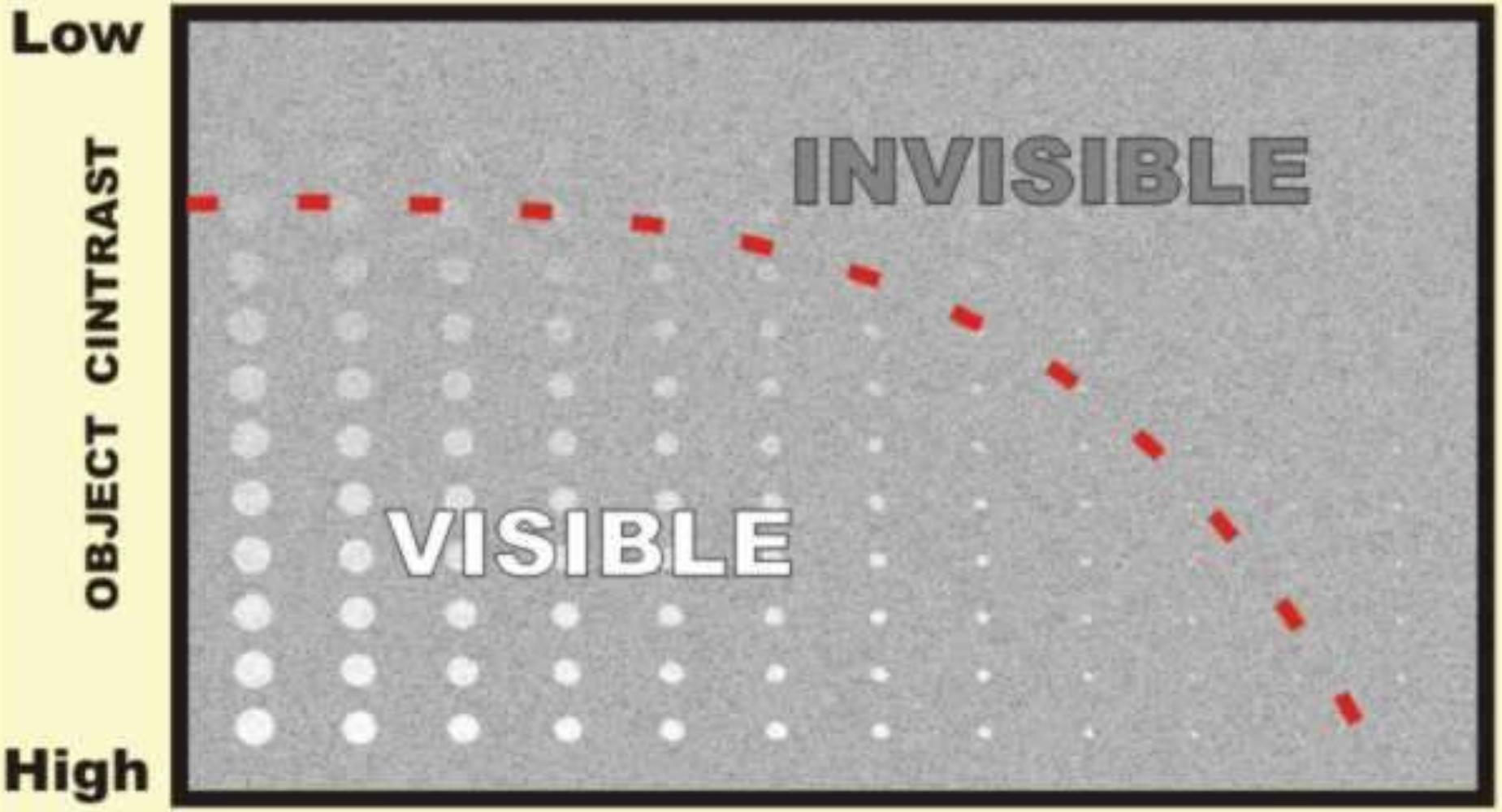
CONTRAST-DETAIL DIAGRAM



Sprawl

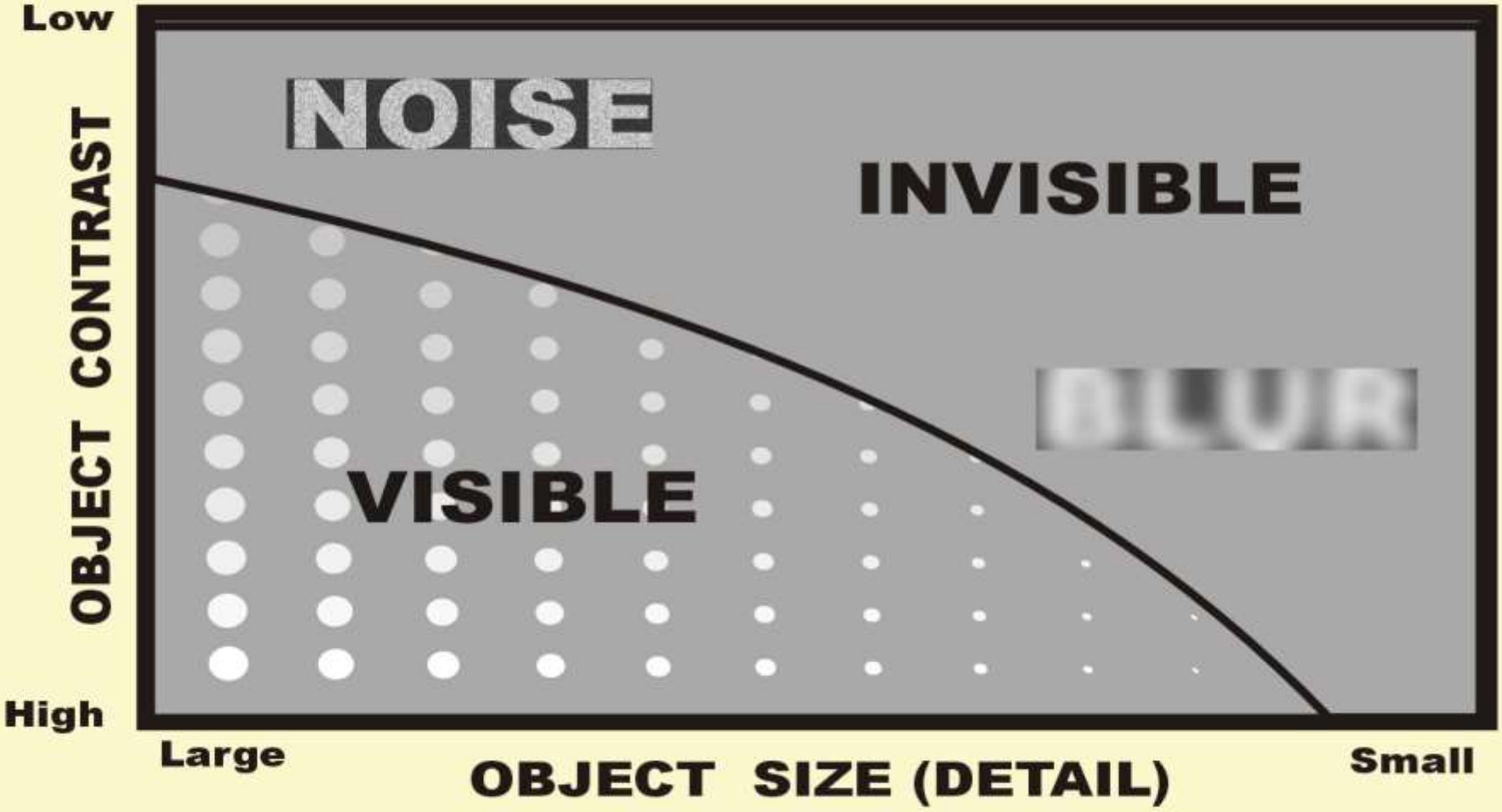
CONTRAST DETAIL DIAGRAM

EFFECT OF NOISE ON VISIBILITY



Sprawls

EFFECT OF NOISE and BLUR



Sprawls

Resources for Additional Study and Teaching

- **http://www.sprawls.org/resources/**
- **http://www.sprawls.org/PhysRev**

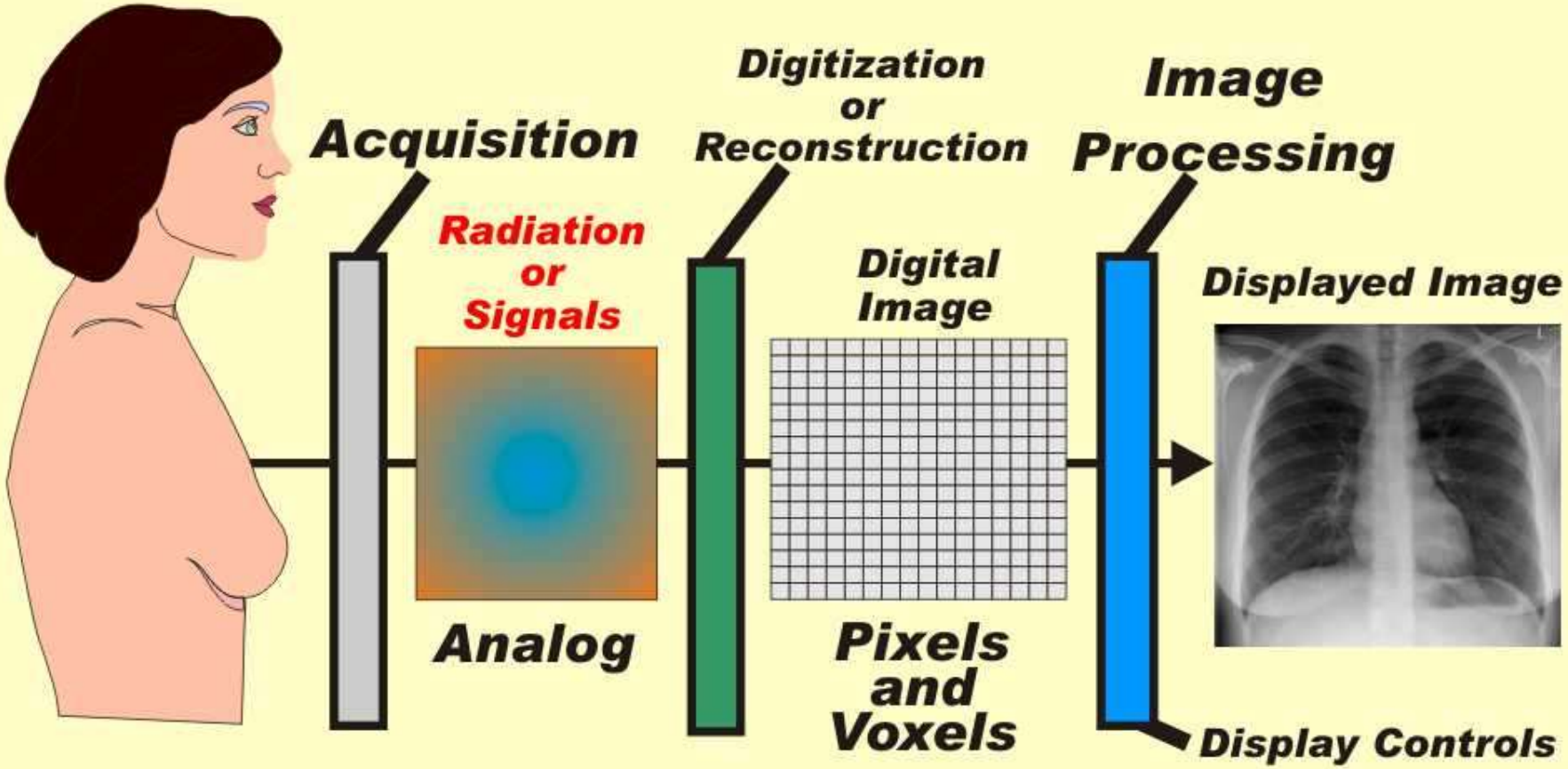
1 Minute Break

Digital Radiography Principles
and
Image Quality Characteristics

Perry Sprawls, Ph.D.
Emory University
sprawls@emory.edu

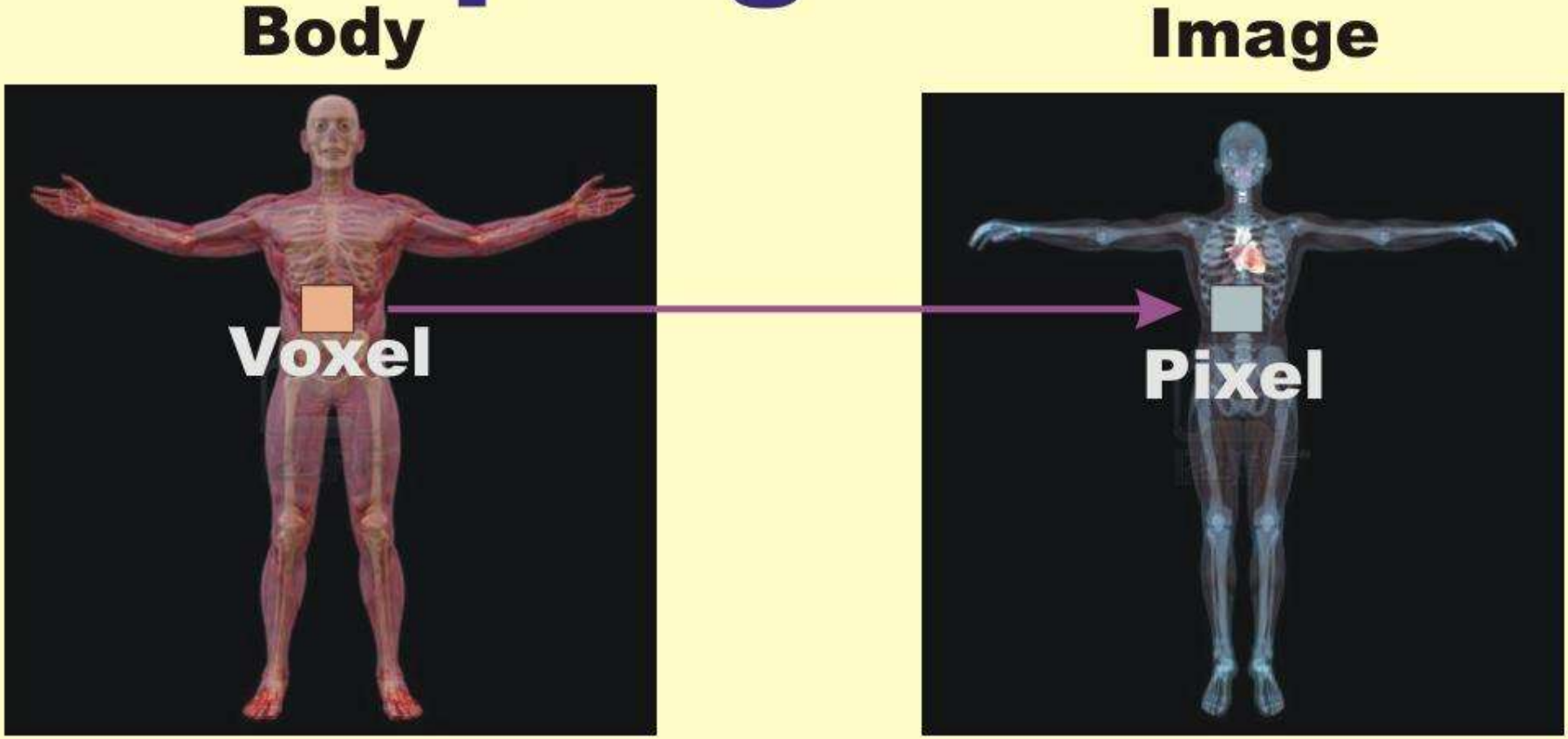
Sprawls Educational Foundation
http://www.sprawls.org

The Medical Imaging Process
All Modalities



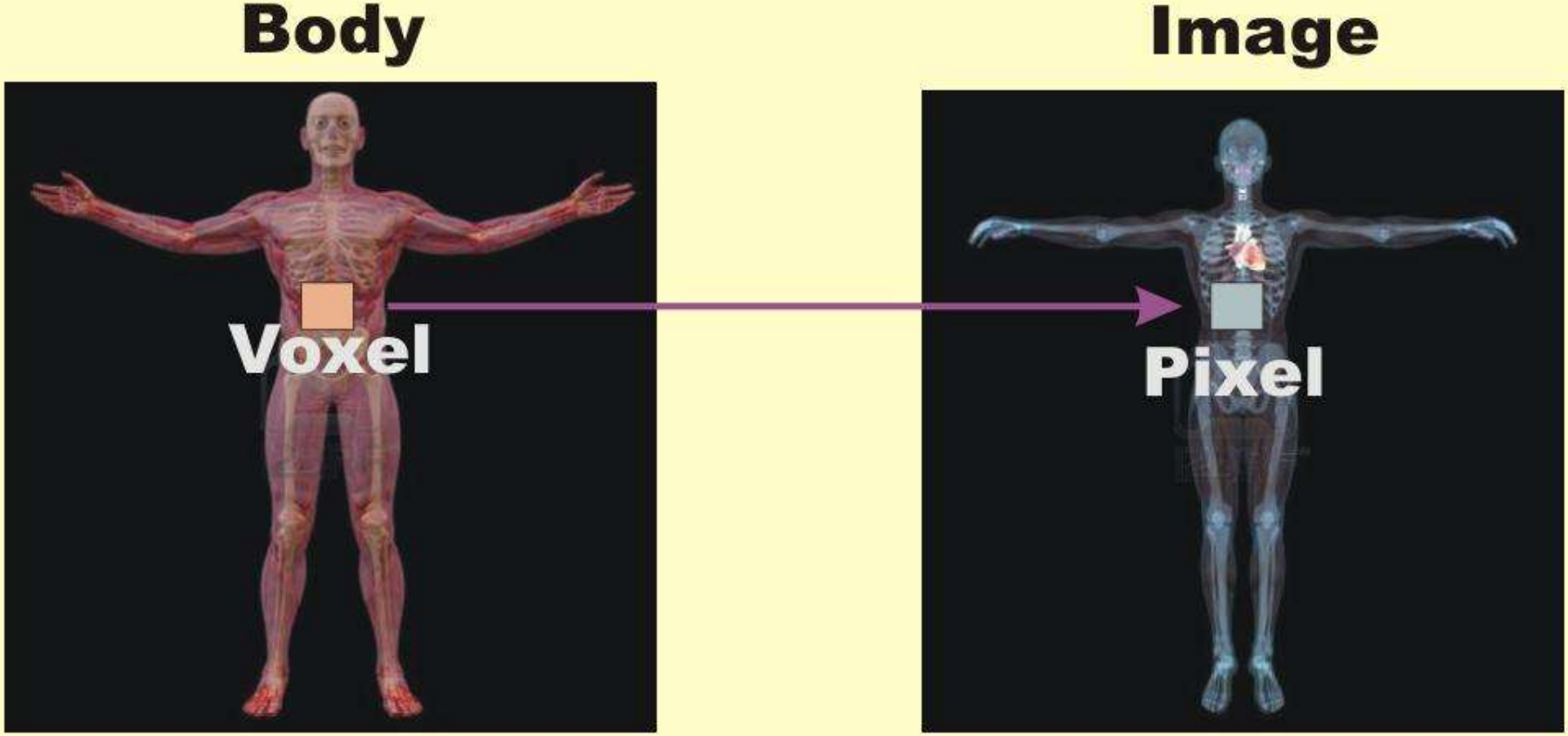
Sprawls

Digitizing is a Sampling Process



Sprawls

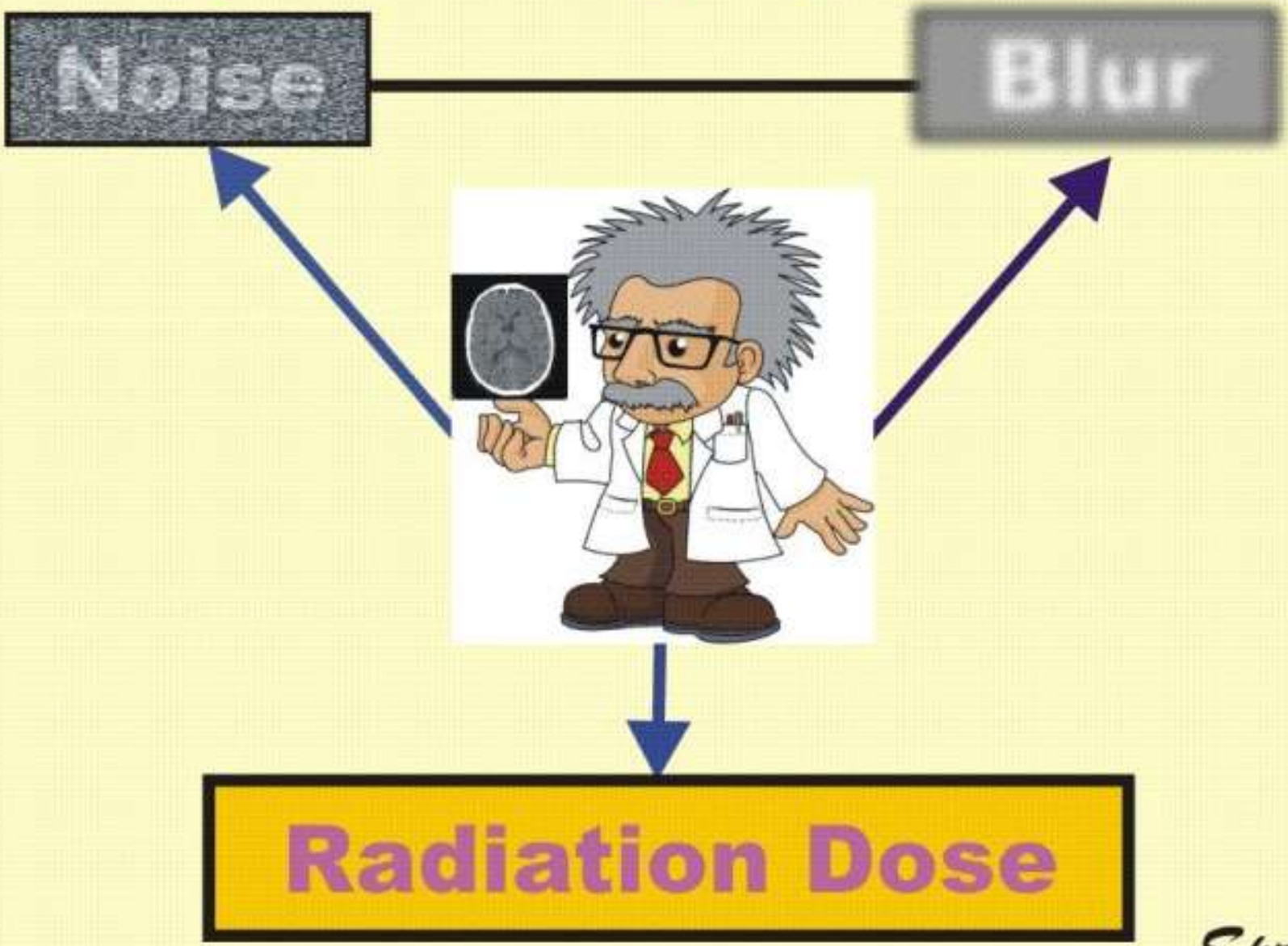
Sample Size (voxels and pixels) is a major factor in Image Quality



Sprawls

What is the dilemma?

Image Quality Optimization



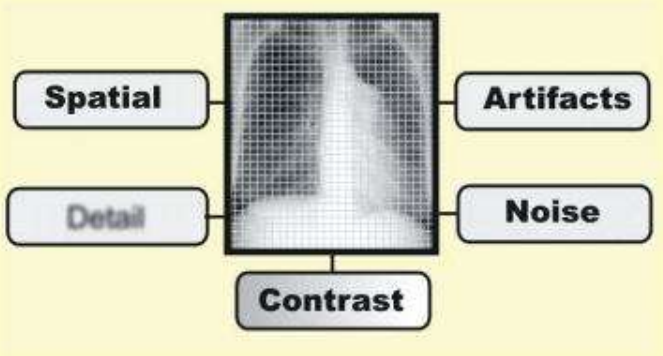
Sprawls

Objectives

- Review the structure of digital images
- Identify the quality characteristics of digital images
- Review the principles of digital radiography
- Describe the factors that determine image quality
- Show the general approach to image quality and patient exposure optimization

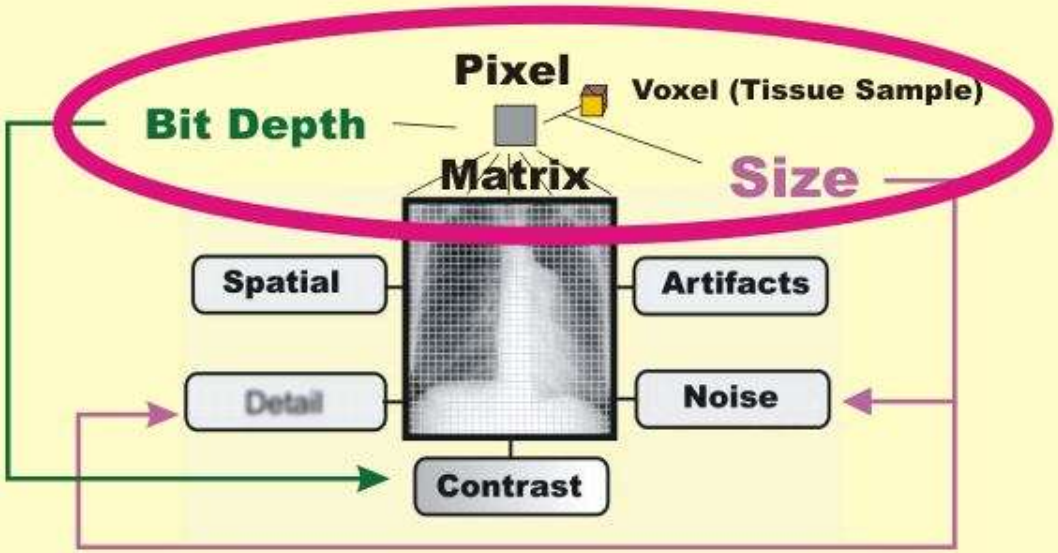
Digital Radiography Physics Principles and Image Quality Characteristics

OVERVIEW



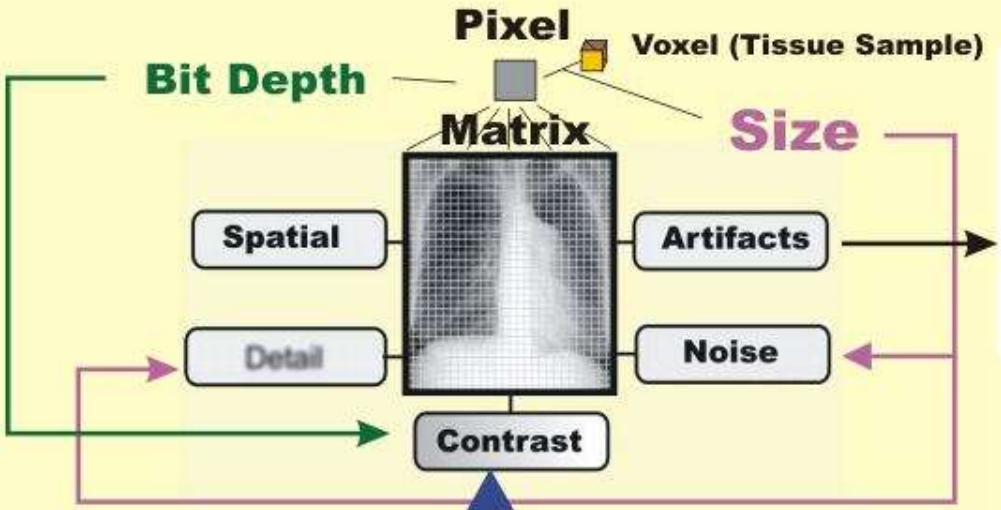
Digital Radiography Physics Principles and Image Quality Characteristics

OVERVIEW

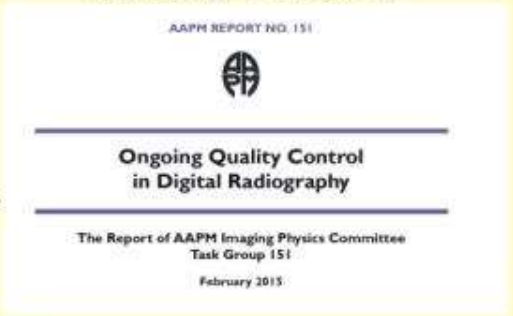


Digital Radiography Physics Principles and Image Quality Characteristics

OVERVIEW



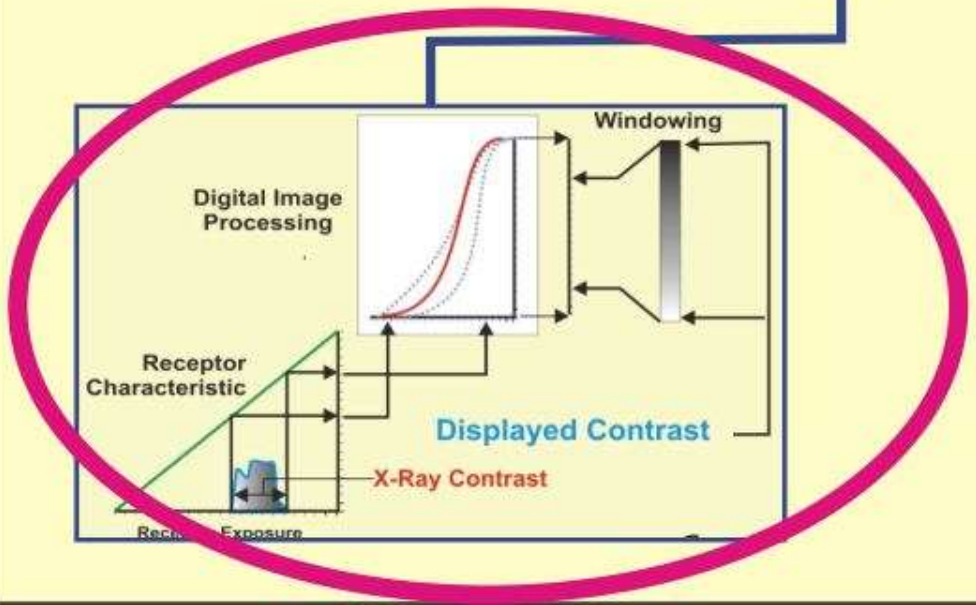
Quality Control


AAPM REPORT NO. 151

Ongoing Quality Control in Digital Radiography

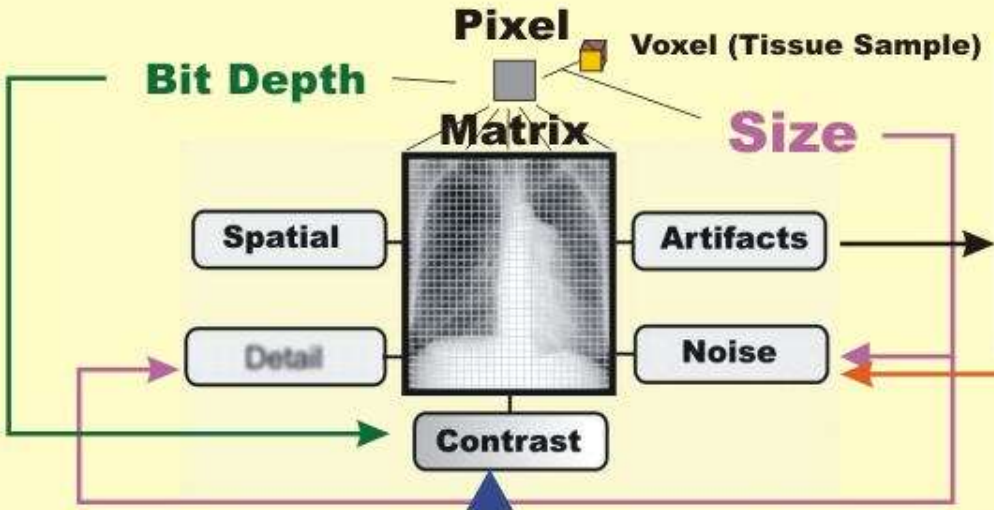
The Report of AAPM Imaging Physics Committee Task Group 151

February 2015

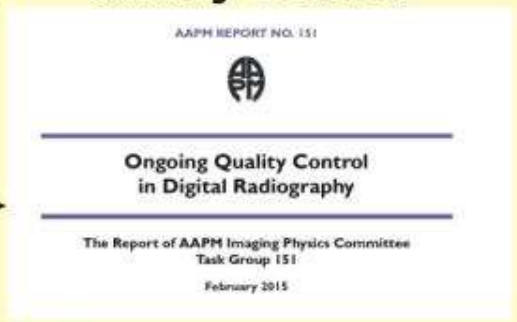


Digital Radiography Physics Principles and Image Quality Characteristics

OVERVIEW



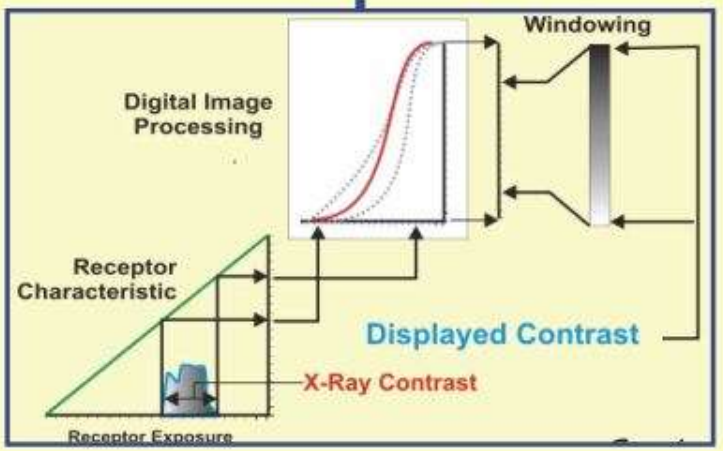
Quality Control

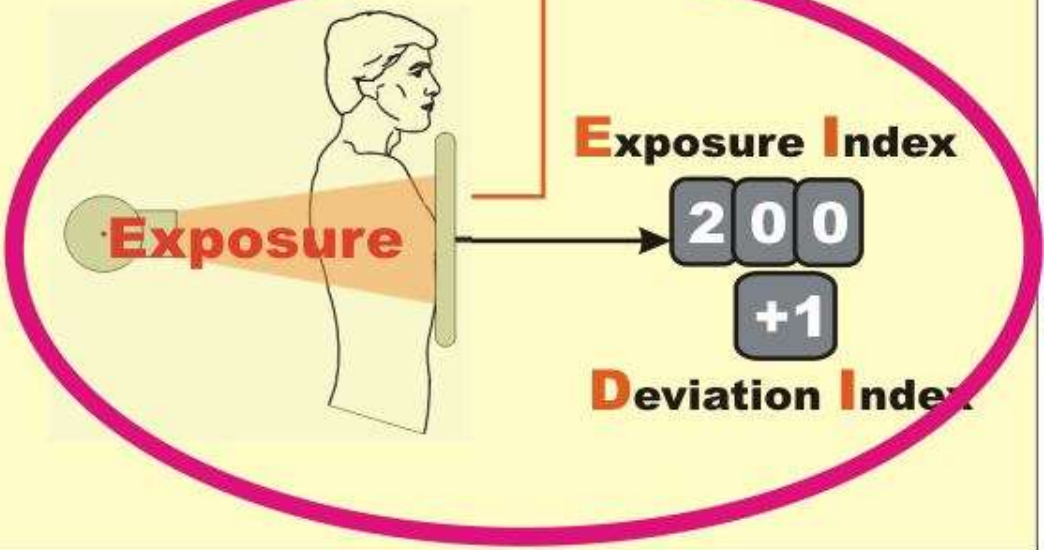

AAPM REPORT NO. 151

Ongoing Quality Control in Digital Radiography

The Report of AAPM Imaging Physics Committee Task Group 151

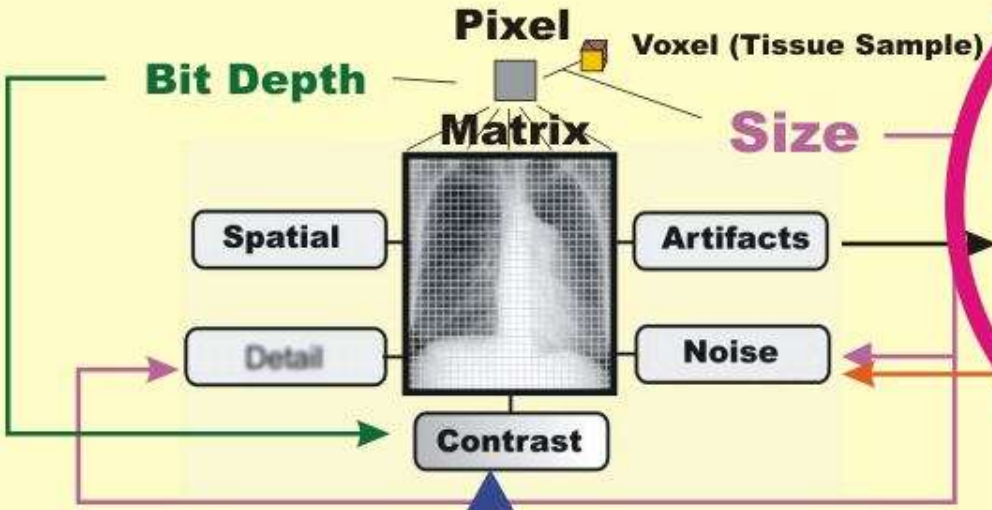
February 2015

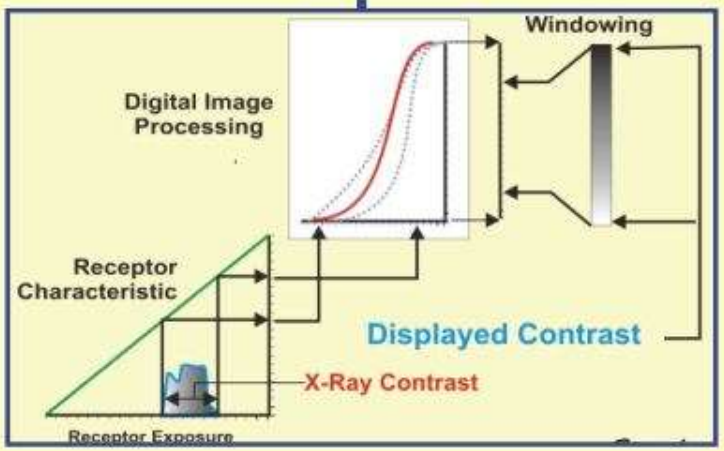




Digital Radiography Physics Principles and Image Quality Characteristics

OVERVIEW





Exposure Index

200

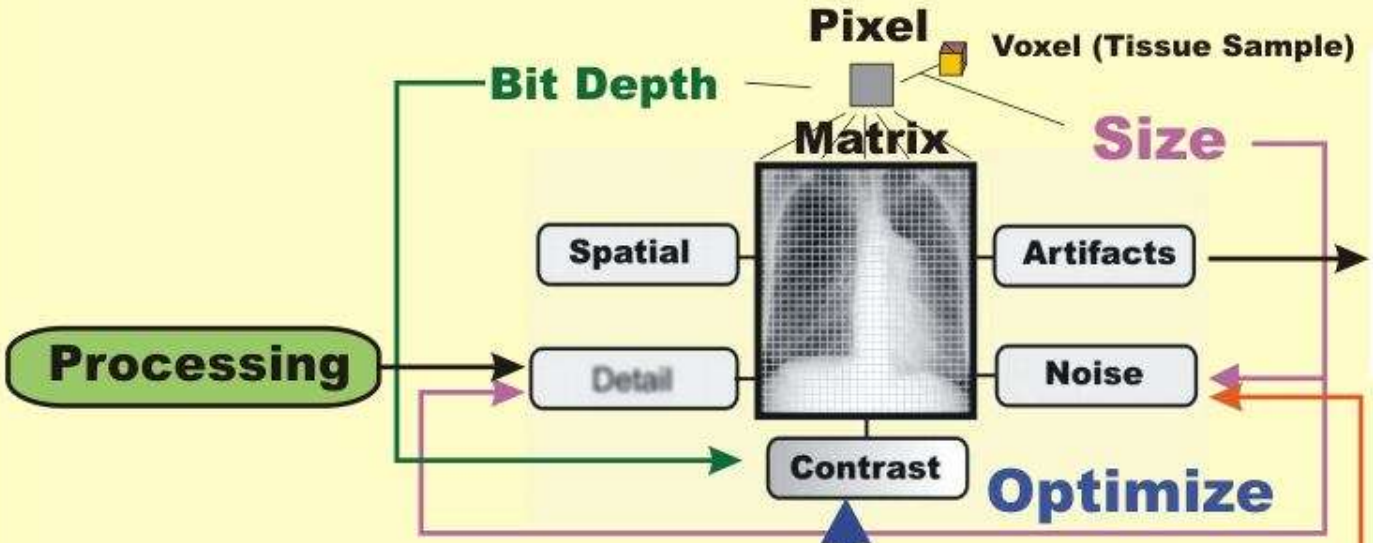
+1

Deviation Index

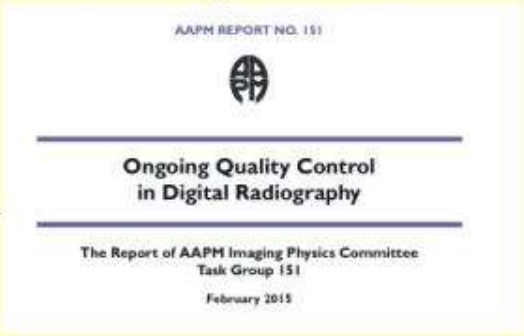
Sprawls

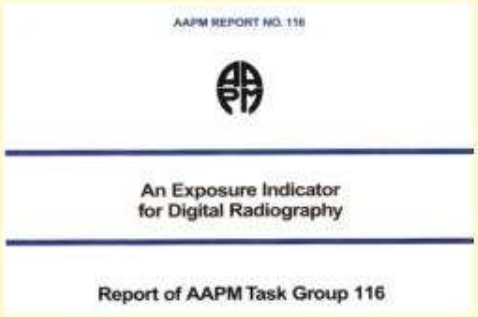
Digital Radiography Physics Principles and Image Quality Characteristics

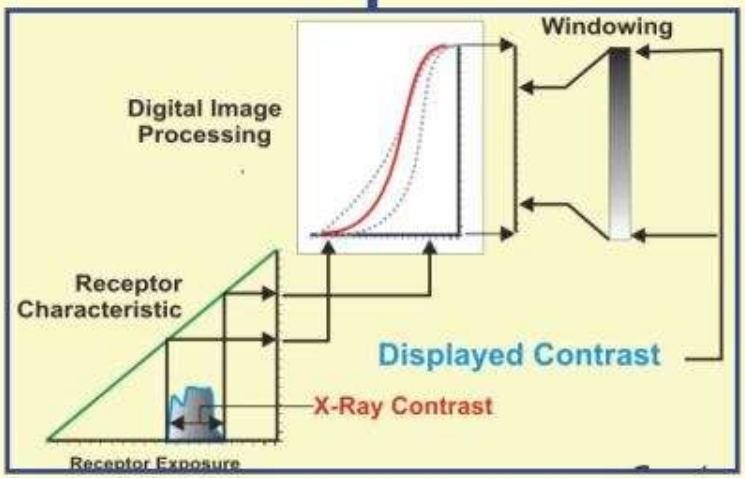
OVERVIEW



Quality Control







Exposure Index

200

+1

Deviation Index

Sprawls

THE DIGITAL ADVANTAGE

WIDE RANGE ACQUISITION

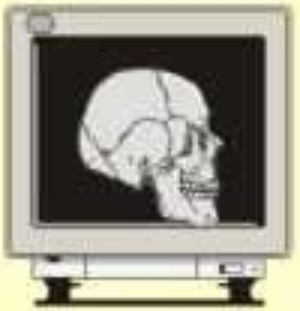
RECONSTRUCTION and REFORMATING

PROCESSING

STORAGE

DISTRIBUTION

CONTROLLED VIEWING AND ANALYSIS



IMAGES

ANALOG

Continuous

DIGITAL

Matrix of Pixels

For Human Viewing

Each Image Point

Brightness

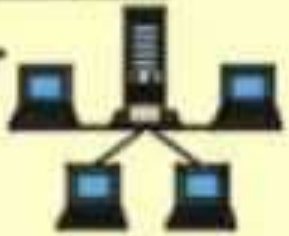
Film Density

Color

Number

56	56	57	56
56	56	57	56
57	57	57	59
58	58	58	60

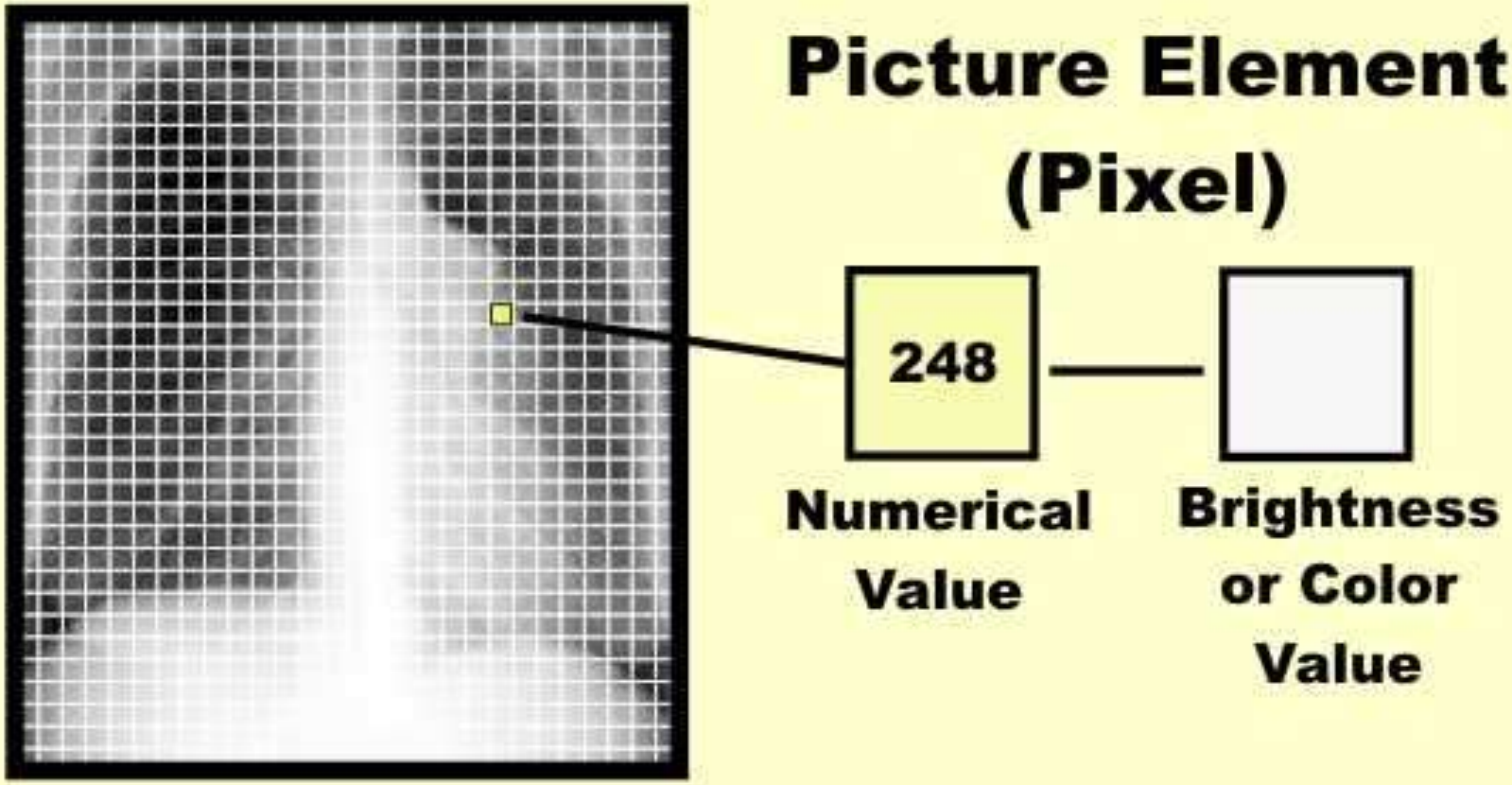
For Computer Systems



Sprawls

Digital Image

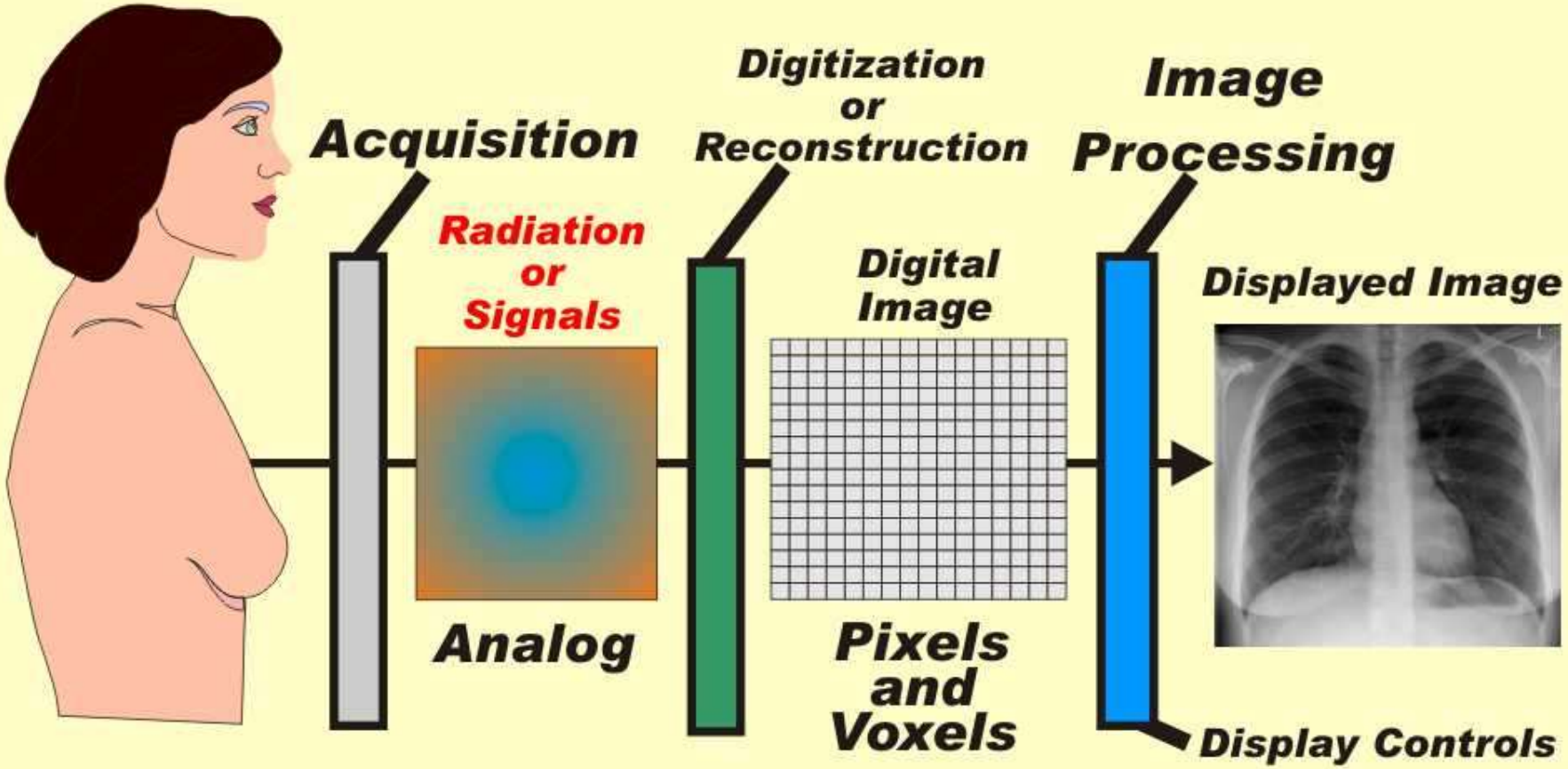
A Matrix of Pixels



For Computer Systems

Sprawls

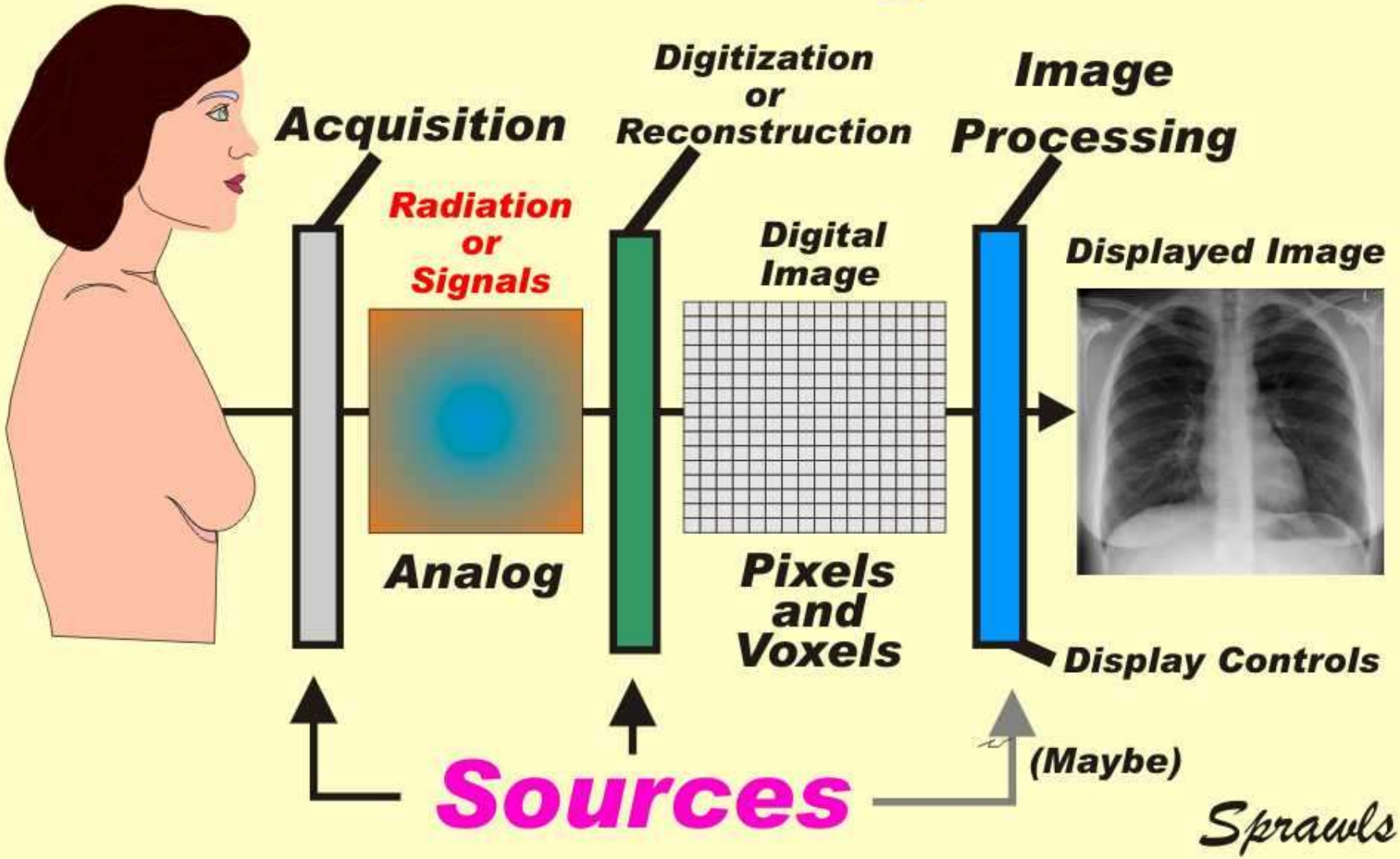
The Medical Imaging Process
All Modalities



Sprawls

The Medical Imaging Process

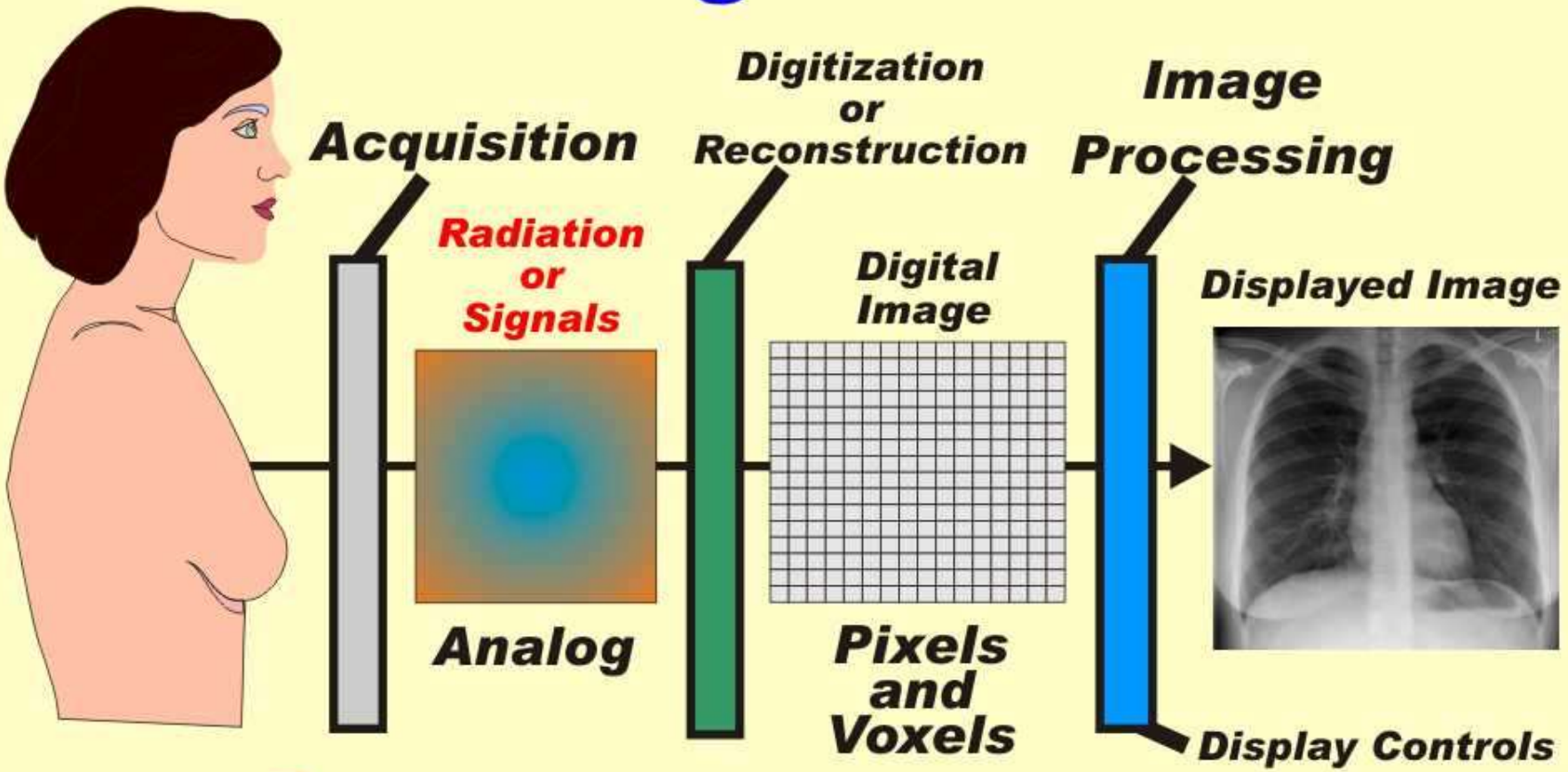
Blurring



Sprawls

The Medical Imaging Process

Image Noise

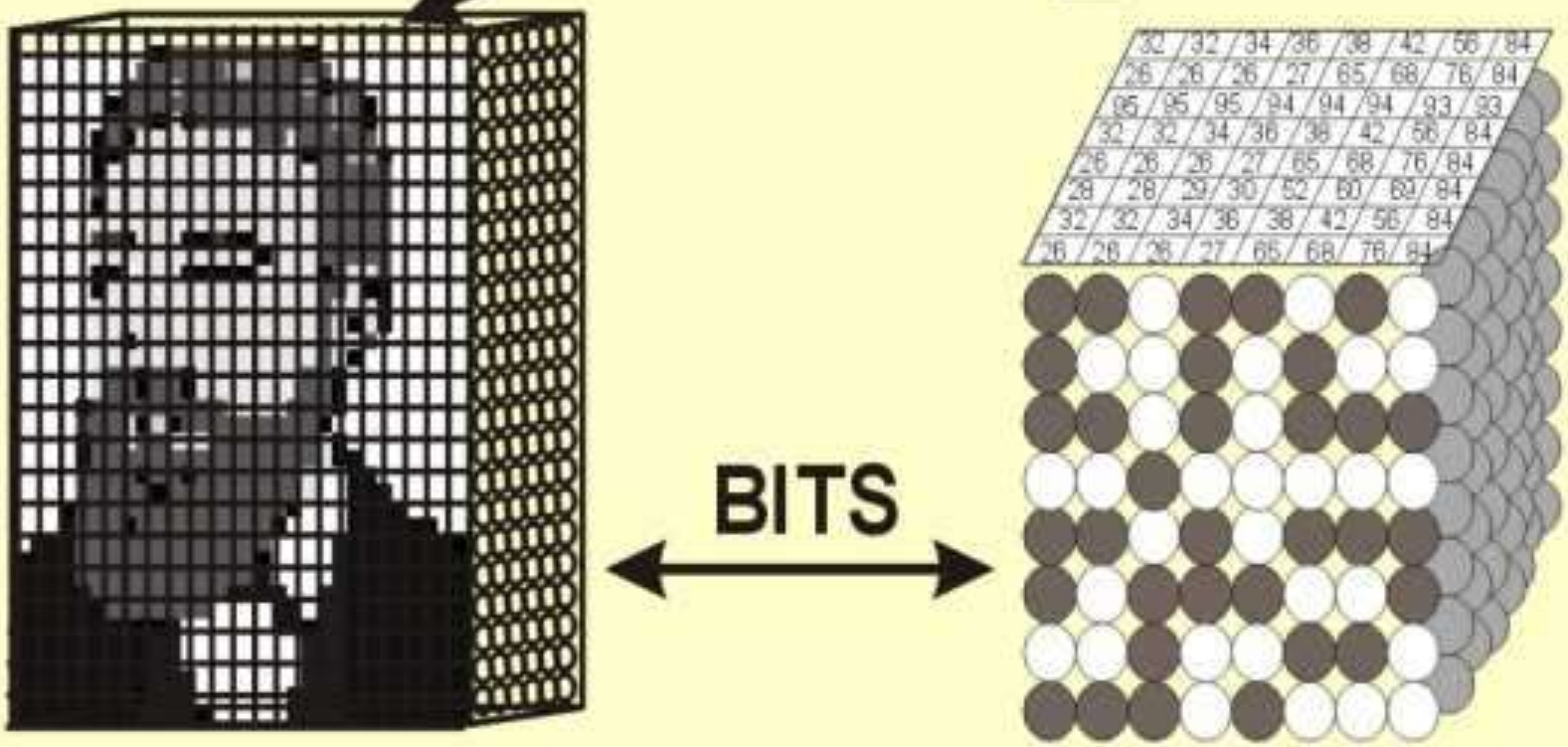


Source

Modified

Sprawls

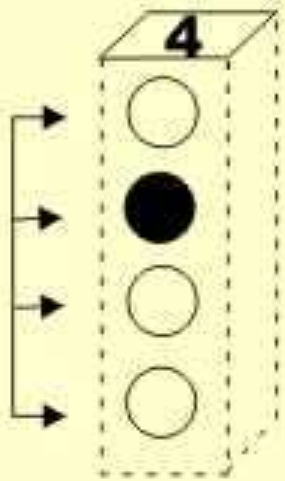
MATRIX of PIXELS



Pixel Bit Depth

Pixel Brightness or Color

Pixel Value

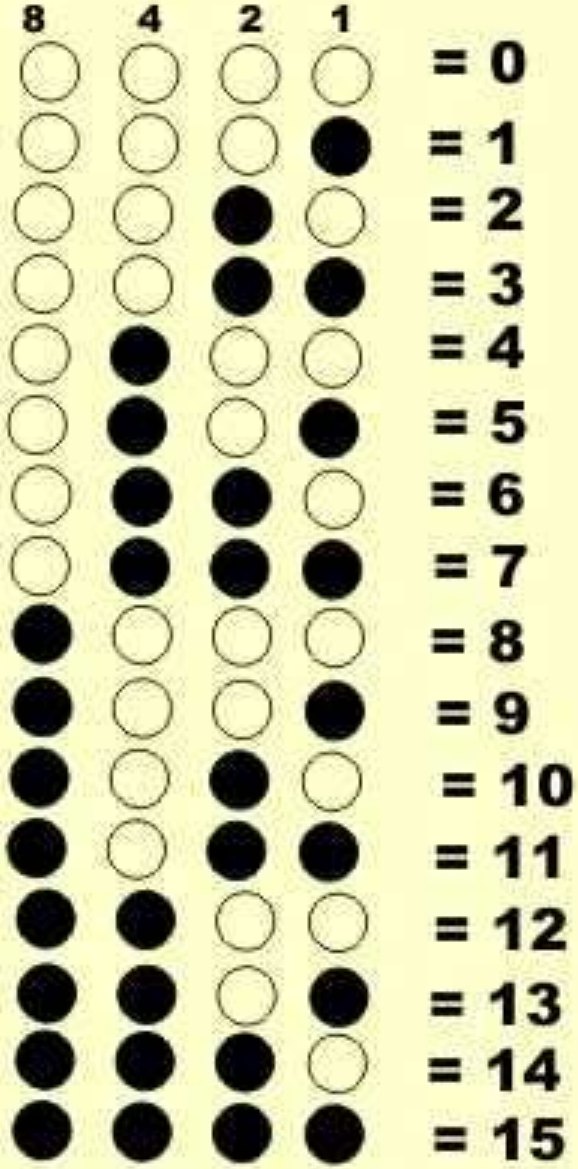


Bits

4 bits can have
16 different values

Sprawls

Values Represented by Four Bits



Number of values

number of bits

$$N = 2^{n}$$

$$16 = 2^{4}$$

Sprawls

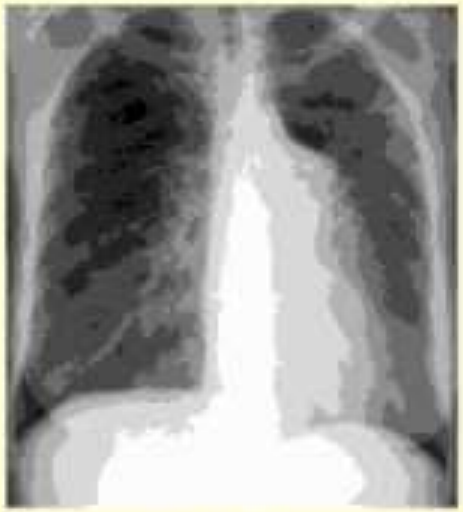
Digital Image Pixel Bit Depth

Bits per Pixel

1

2

4



16

8

256

Brightness (Shades of Gray) Levels

Numerical Size

Bits or Bytes (8 bits)

Number of Pixels

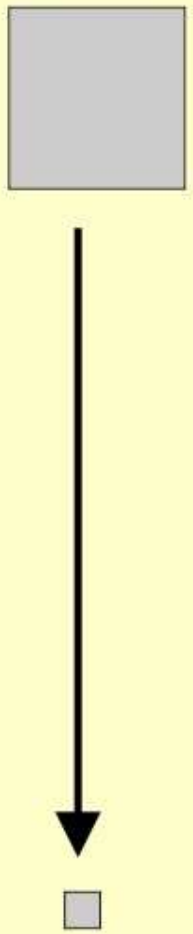
Bits per Pixel
8 - 16 bits
1 - 2 bytes

Matrix		Megabytes
128 x 128 =	16384	**0.016 - 0.032**
256 X 256 =	65536	**0.06 - 0.12**
512 x 512 =	262144	**0.25 - 0.5**
1024 x 1024 =	1048576	**1 - 2**
2048 x 2048 =	4194304	**4 - 8**

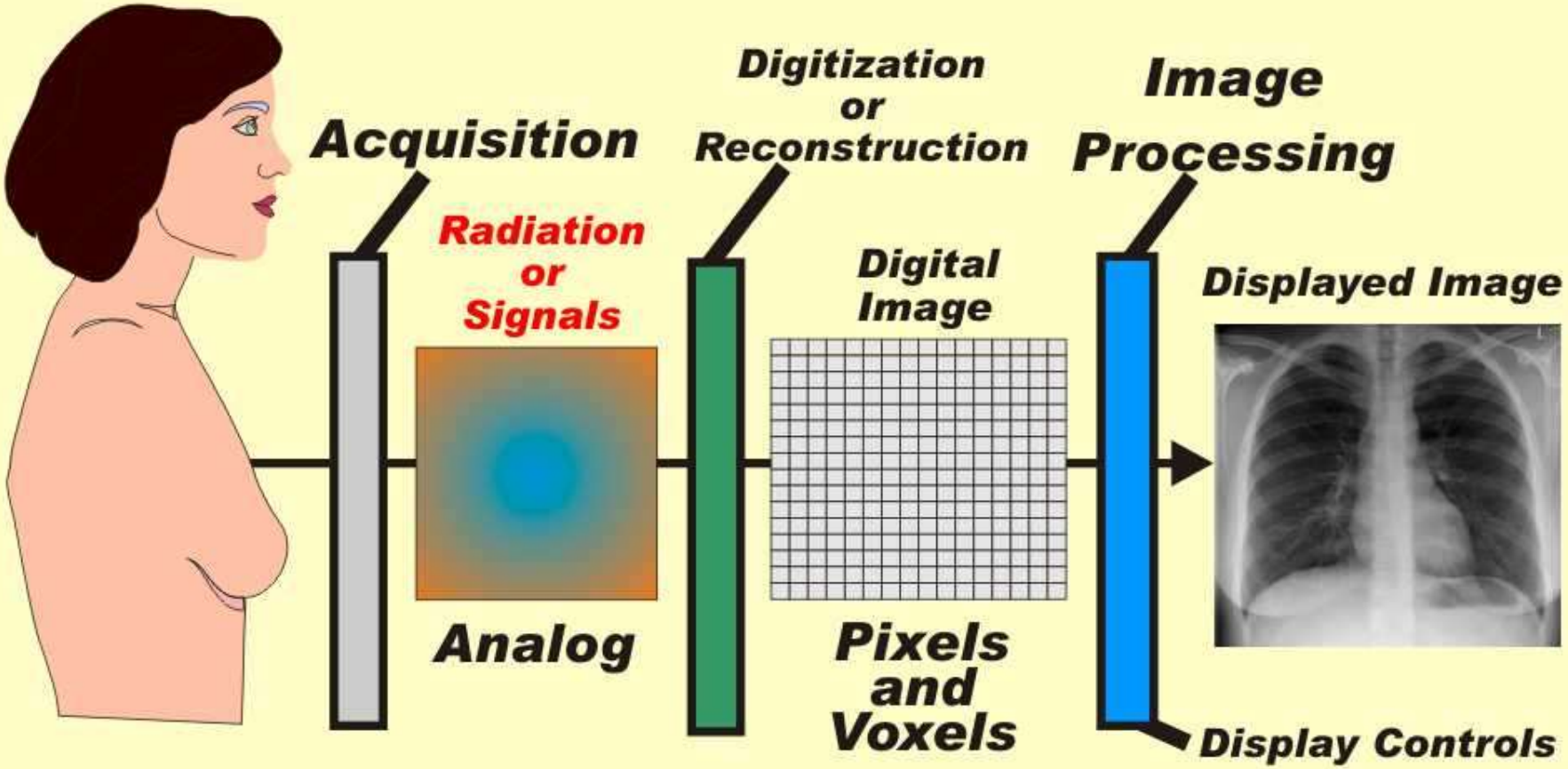
Sprawls

Pixel Size

Modality	Matrix
Radionuclide Imaging	128 x 128
MRI	256 x 256
Ultrasound	256 x 256
CT	512 x 512
Fluoroscopy	1024 x 1024
General Radiography	2048 x 2048
Mammography	4,096 x 5120

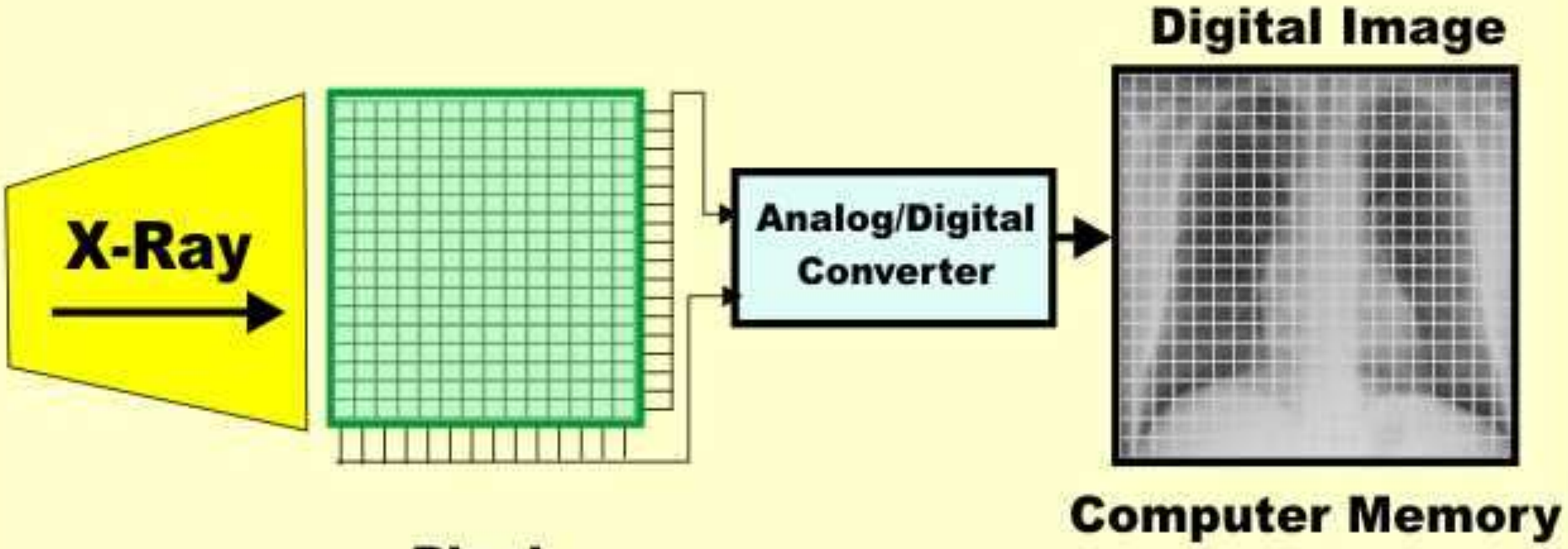


The Medical Imaging Process
All Modalities



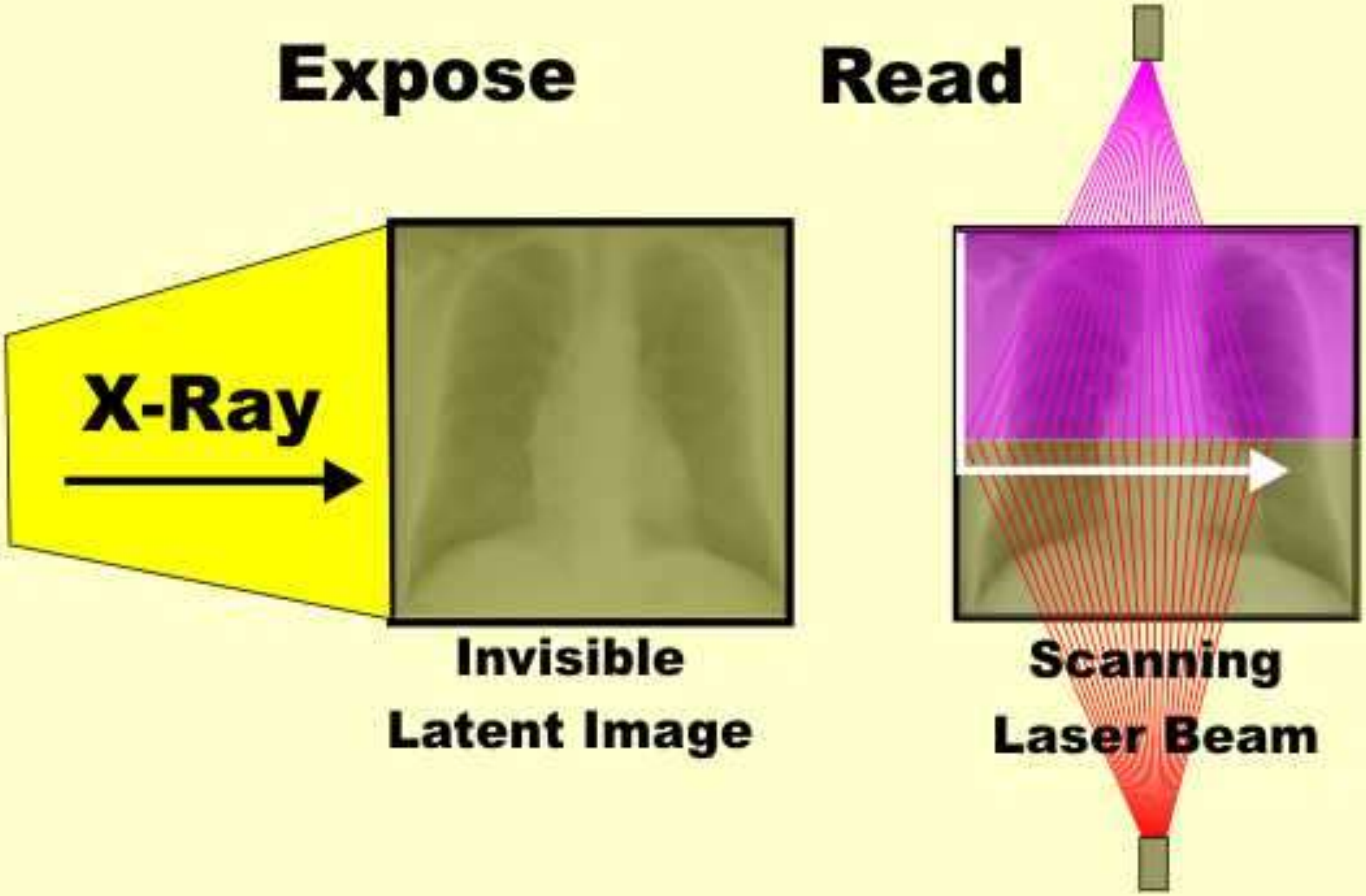
Sprawls

Direct Digital Radiographic Receptor



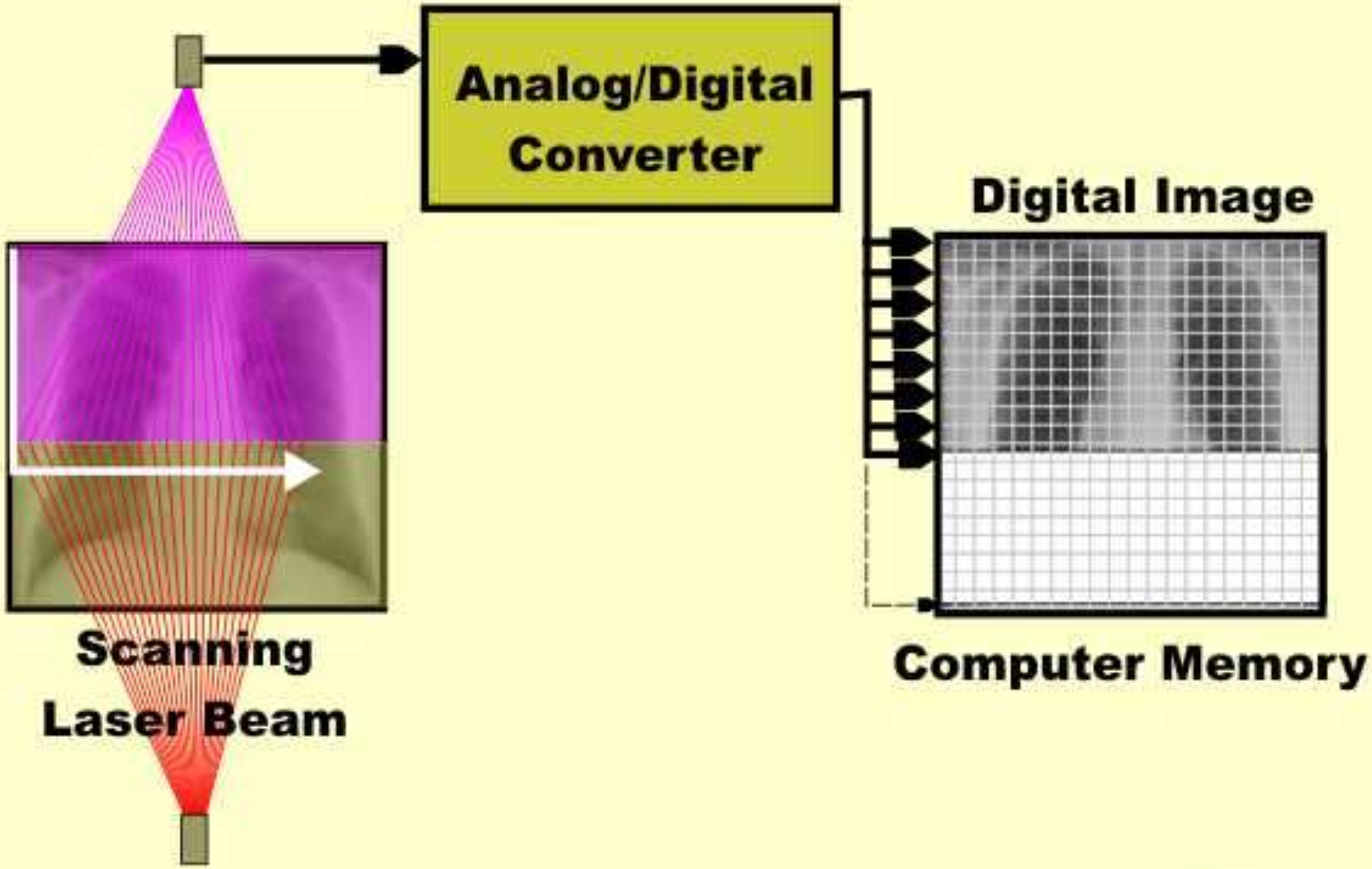
Sprawls

Stimulable Phosphor Receptor



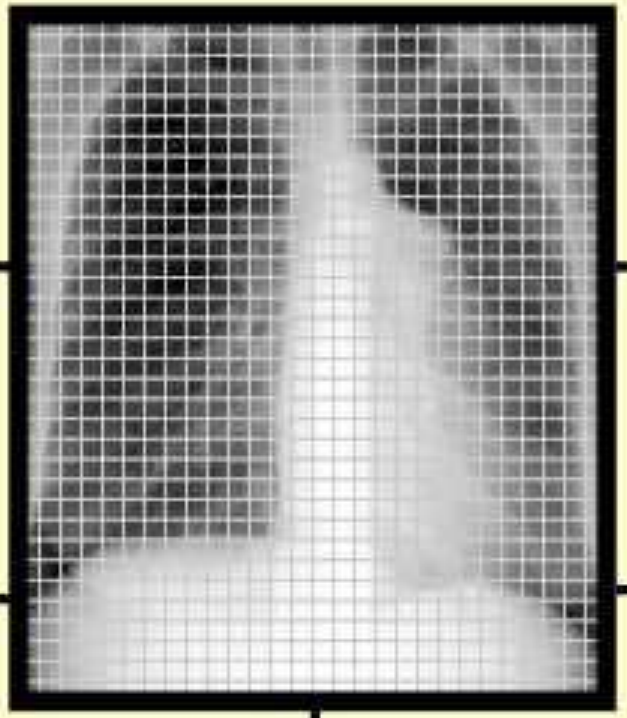
Sprawls

Stimulable Phosphor Receptor
Reading Phase



Sprawls

Digital Radiograph Quality Characteristics



Spatial

Artifacts

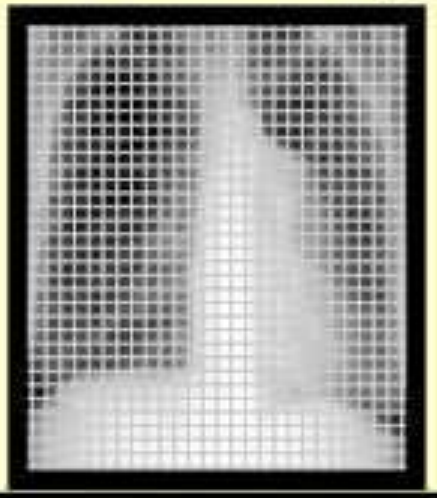
Detail

Noise

Contrast

Sprawls

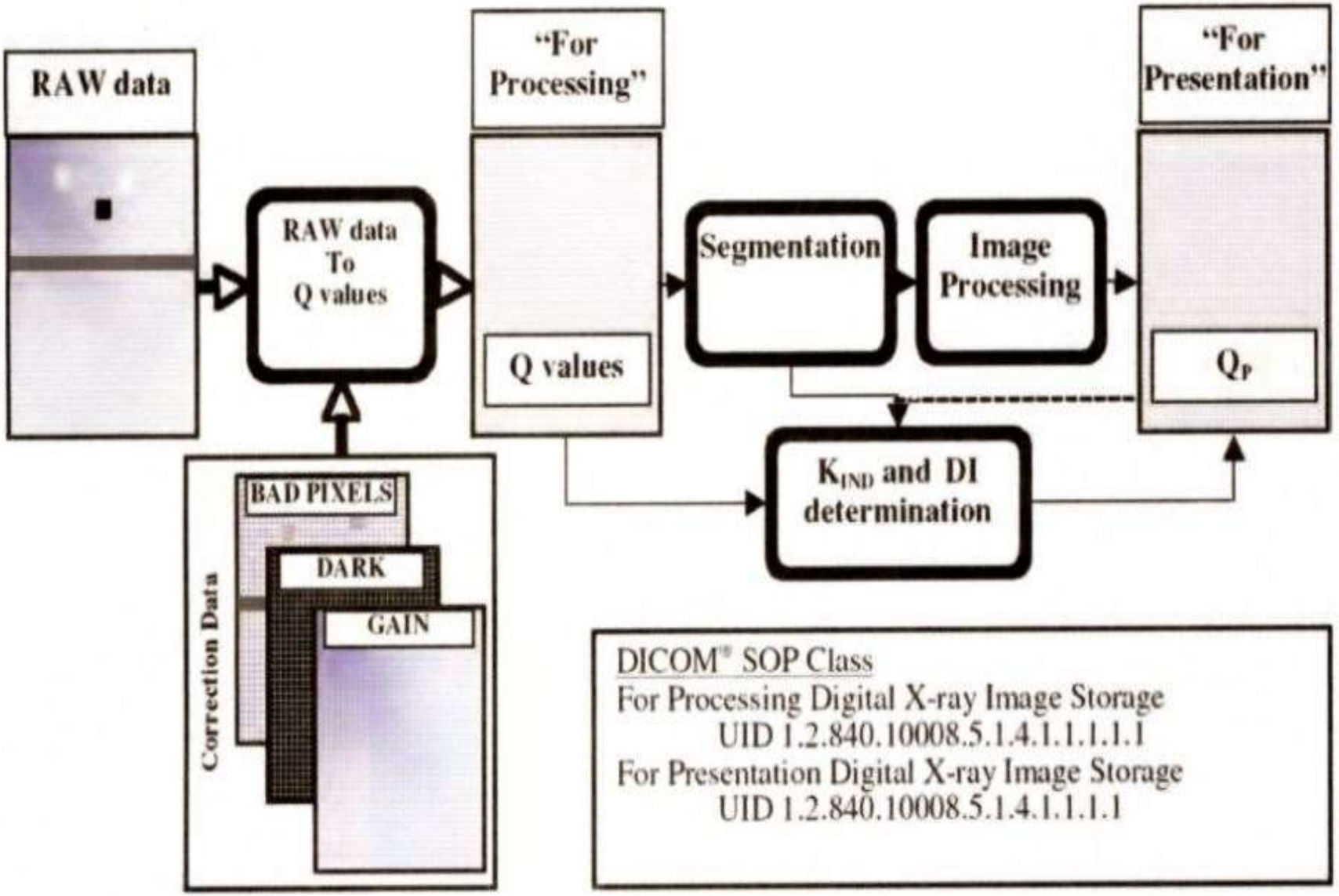
Digital Radiograph

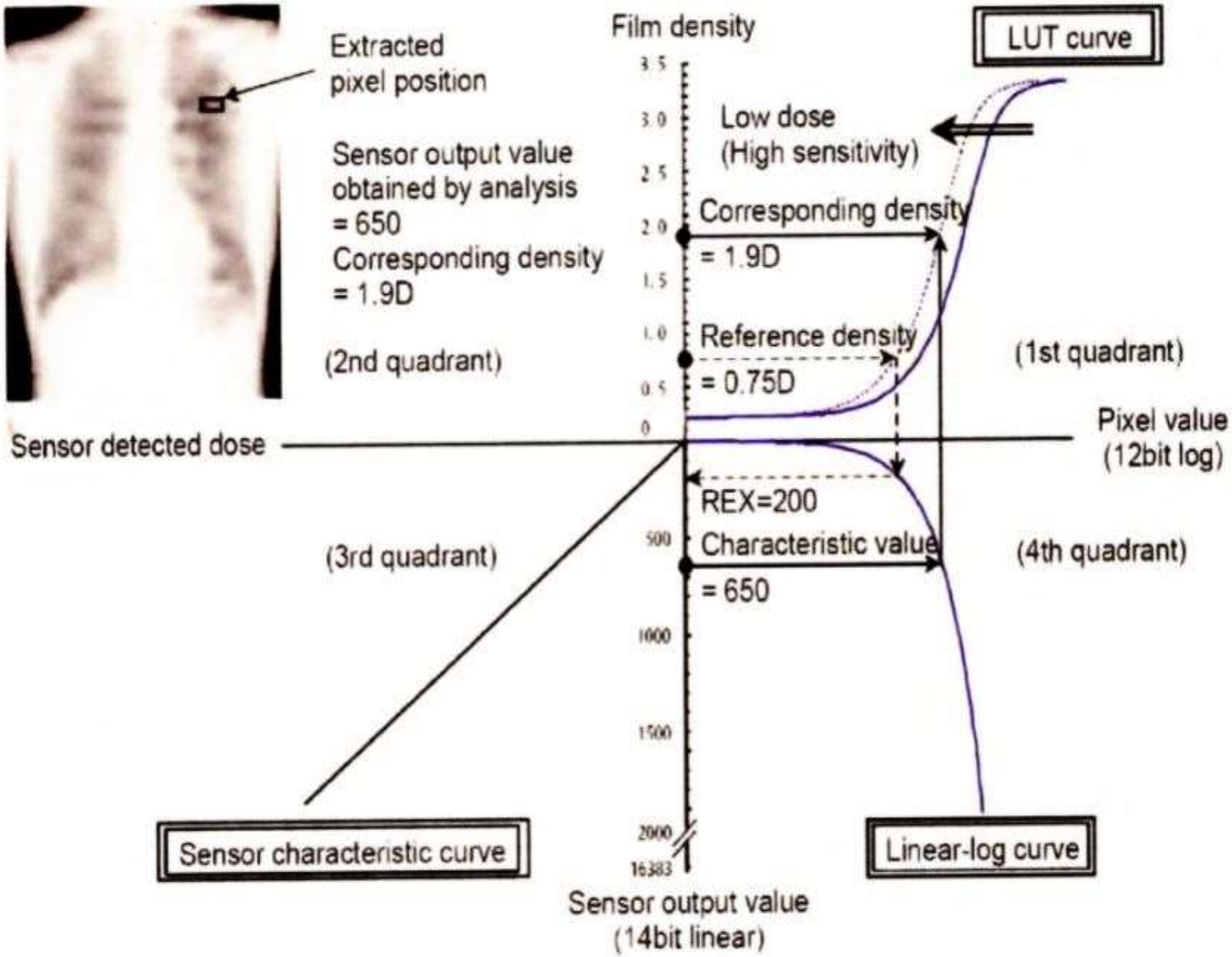


Contrast

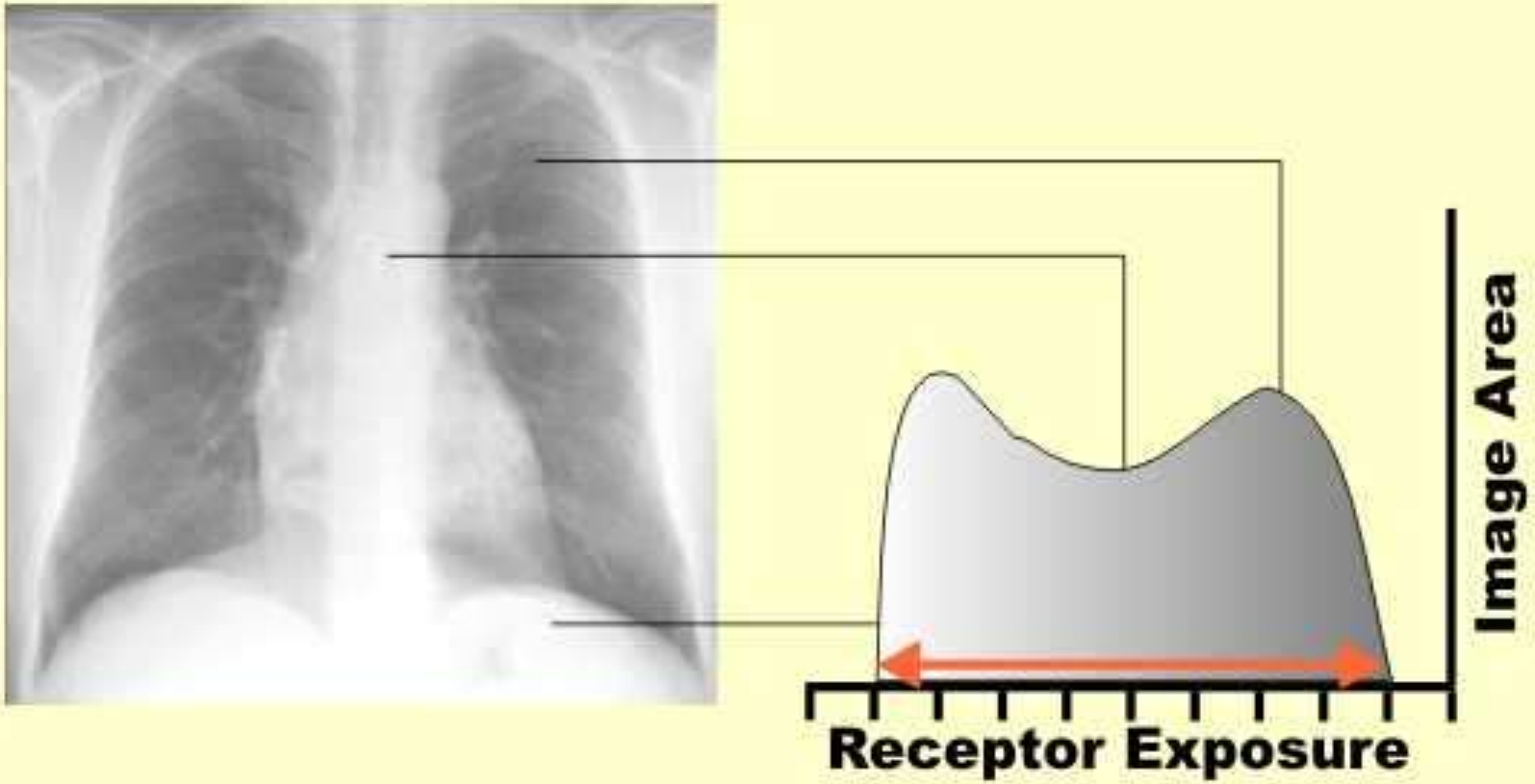
- X-Ray Beam Spectrum
- Digital Image Processing
- Window Level & Width

Sprawls

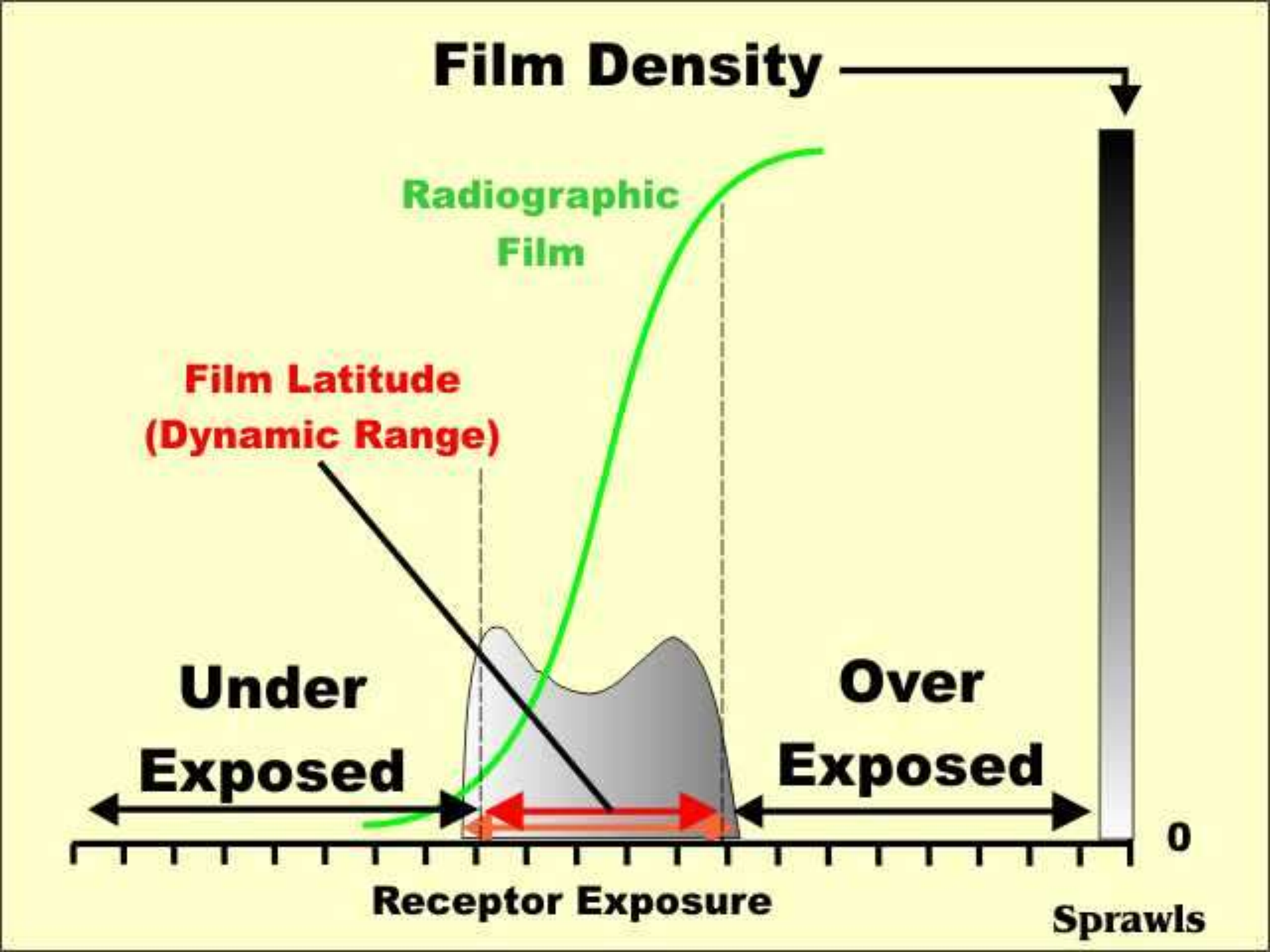

RAW data
RAW data To Q values
"For Processing"
Q values
Segmentation
Image Processing
"For Presentation"
Q_P
K_{IND} and DI determination
Correction Data
BAD PIXELS
DARK
GAIN
DICOM® SOP Class
For Processing Digital X-ray Image Storage
UID 1.2.840.10008.5.1.4.1.1.1.1.1
For Presentation Digital X-ray Image Storage
UID 1.2.840.10008.5.1.4.1.1.1.1

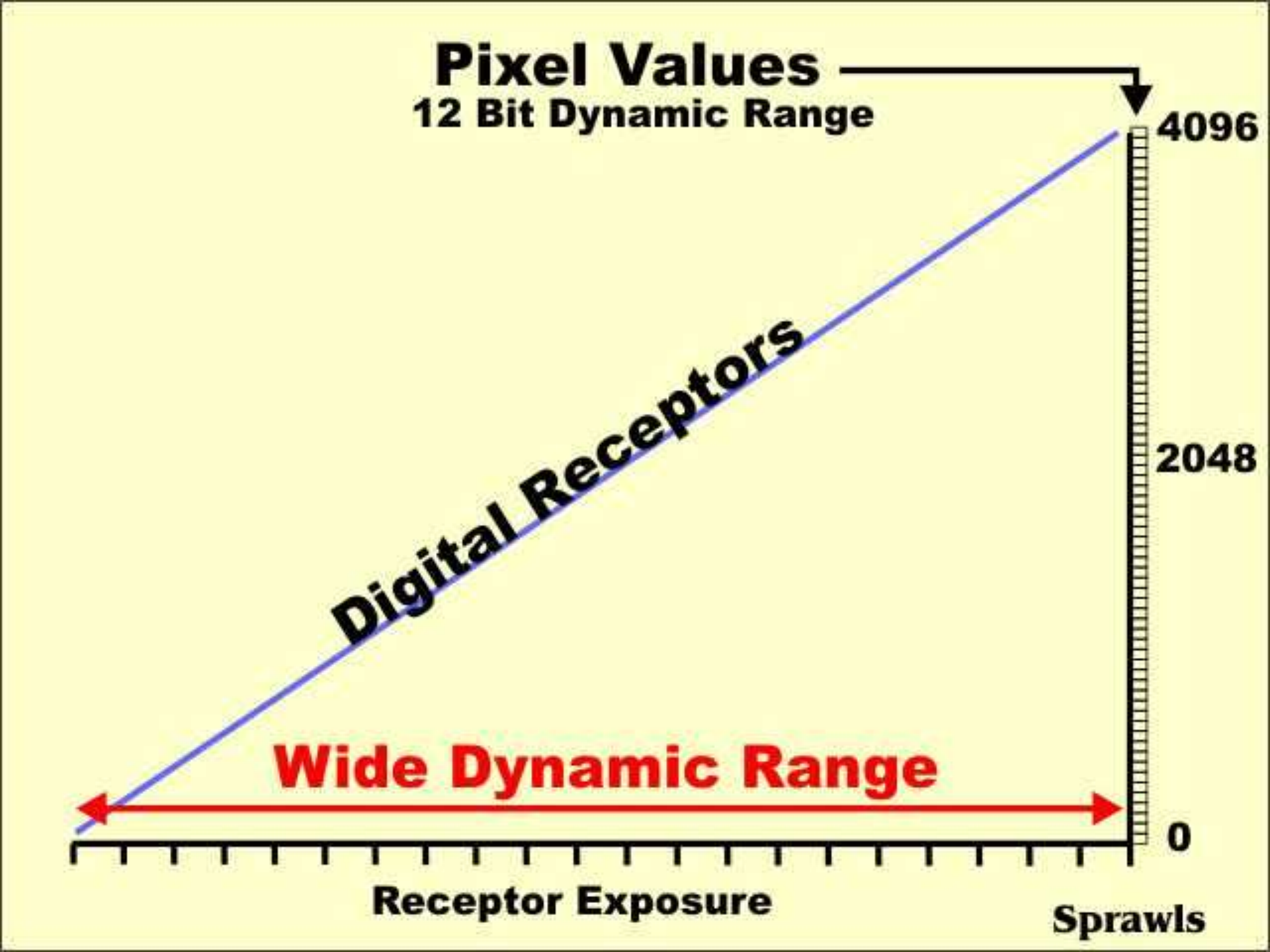

Extracted
pixel position
Sensor output value
obtained by analysis
= 650
Corresponding density
= 1.9D
(2nd quadrant)
Film density
LUT curve
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Low dose
(High sensitivity)
Corresponding density
= 1.9D
Reference density
= 0.75D
(1st quadrant)
Sensor detected dose
Pixel value
(12bit log)
REX=200
Characteristic value
= 650
(3rd quadrant)
(4th quadrant)
500
1000
1500
2000
16383
Sensor characteristic curve
Linear-log curve
Sensor output value
(14bit linear)

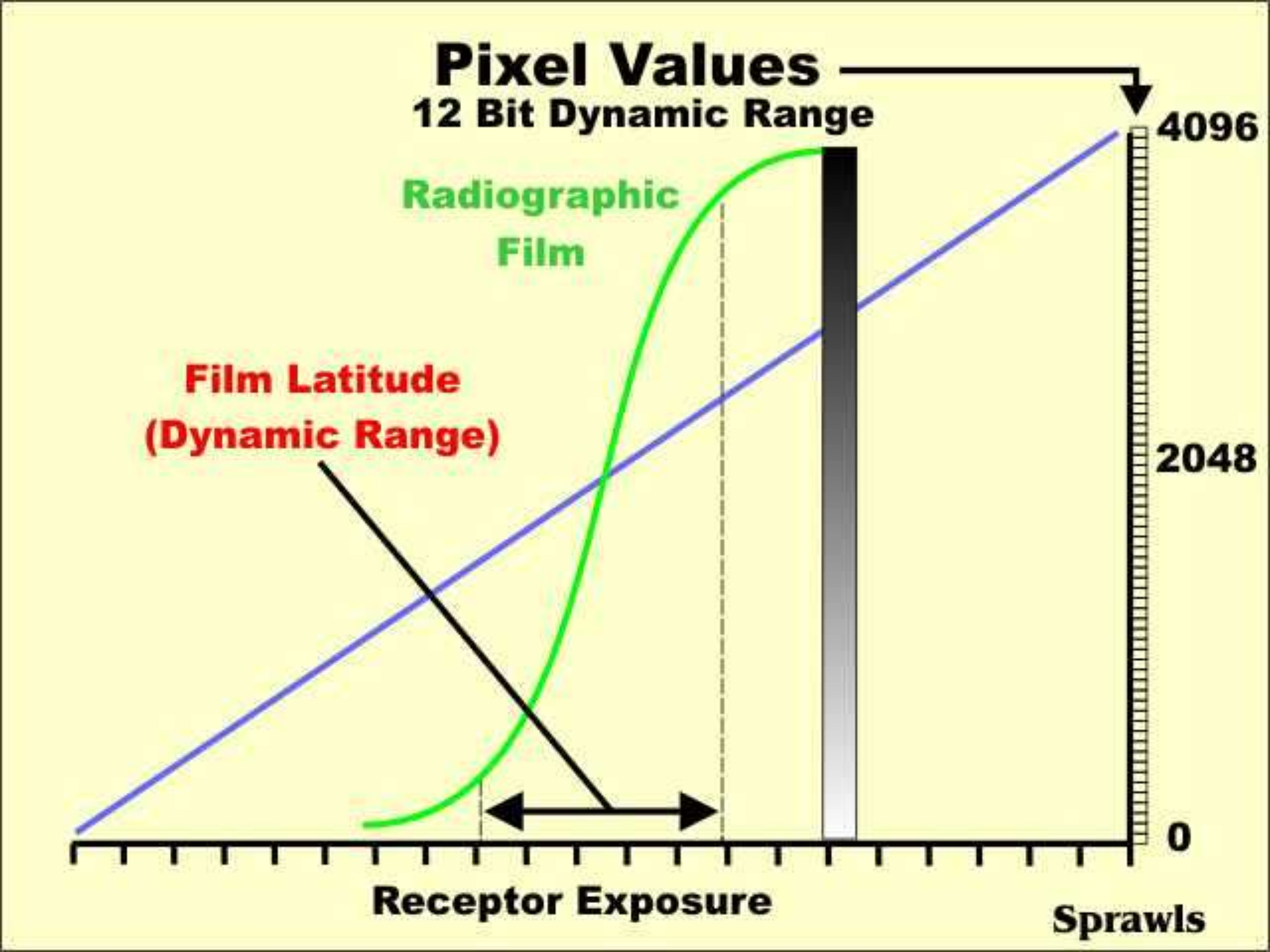
Range of Exposure to the Receptor Histogram

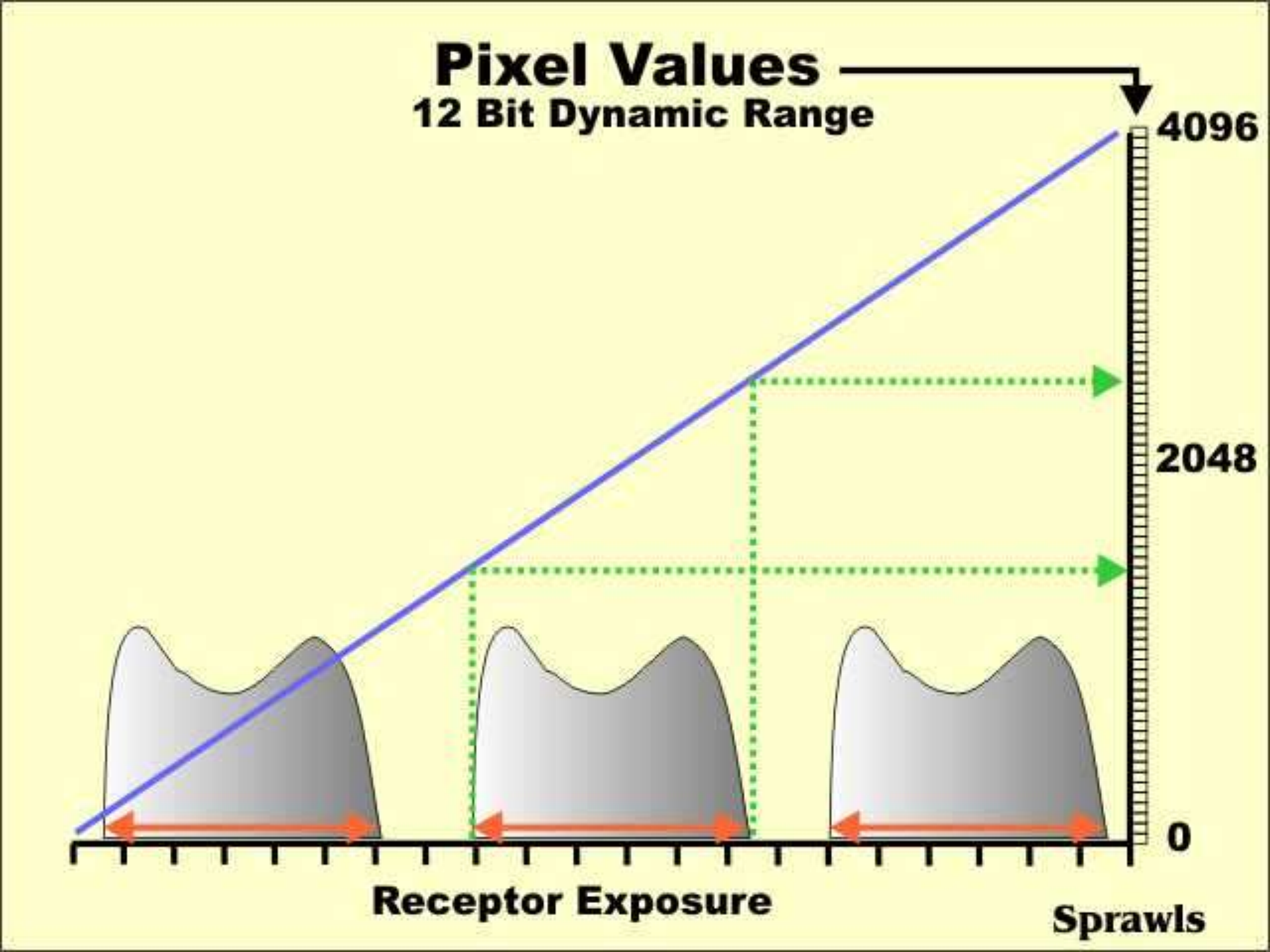


Sprawls


Film Density
Radiographic Film
Film Latitude (Dynamic Range)
Under Exposed
Over Exposed
0
Receptor Exposure
Sprawls


Pixel Values
12 Bit Dynamic Range
4096
2048
0
Digital Receptors
Wide Dynamic Range
Receptor Exposure
Sprawls


Pixel Values
12 Bit Dynamic Range
4096
Radiographic
Film
Film Latitude
(Dynamic Range)
2048
0
Receptor Exposure
Sprawls


Pixel Values
12 Bit Dynamic Range
4096
2048
0
Receptor Exposure
Sprawls

Digital Image Processing

Original

Processed

Processing

Sprawls

Contrast Adjustment

Original

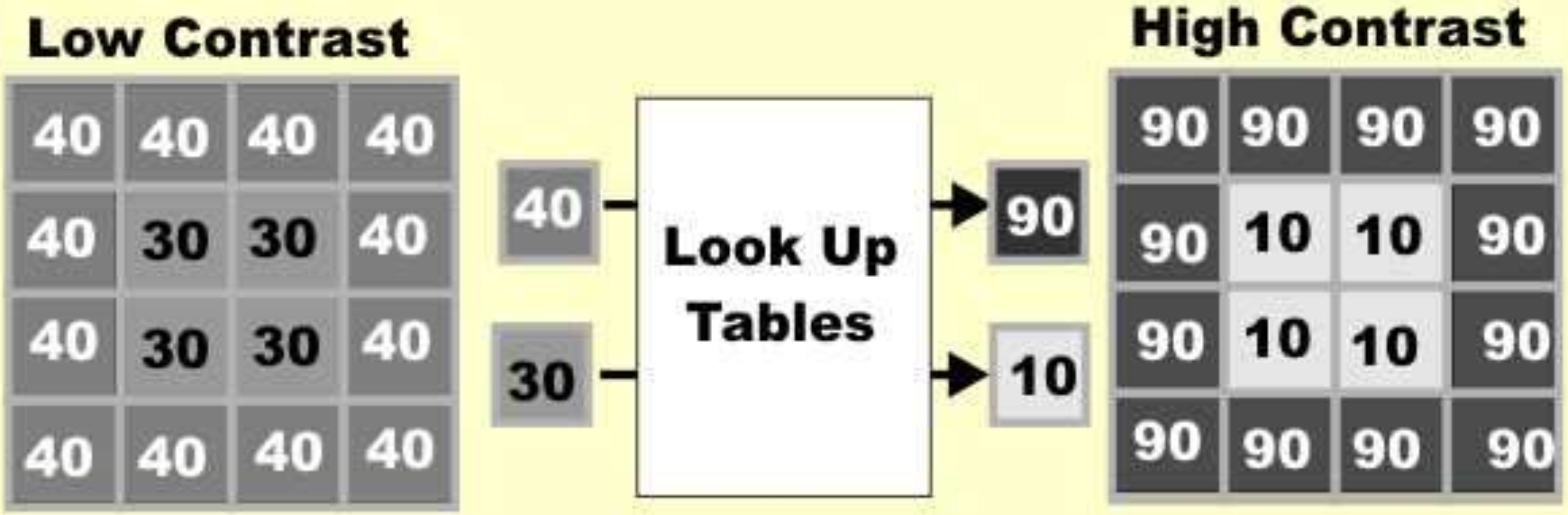
Processed

Look Up Table

Windowing

Sprawls

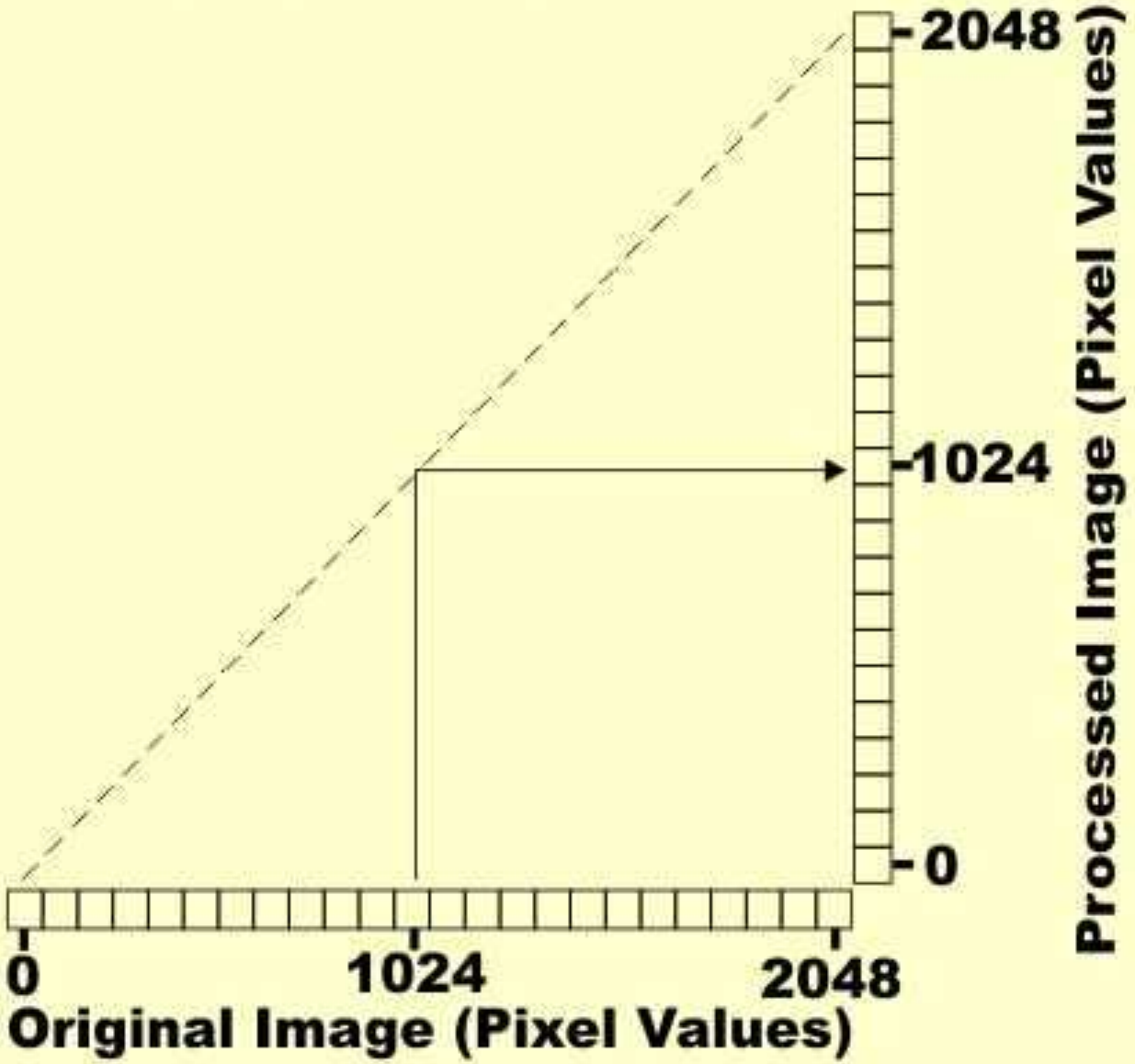
Digital Image Processing
To Change Contrast



Contrast is changed by changing pixel values.

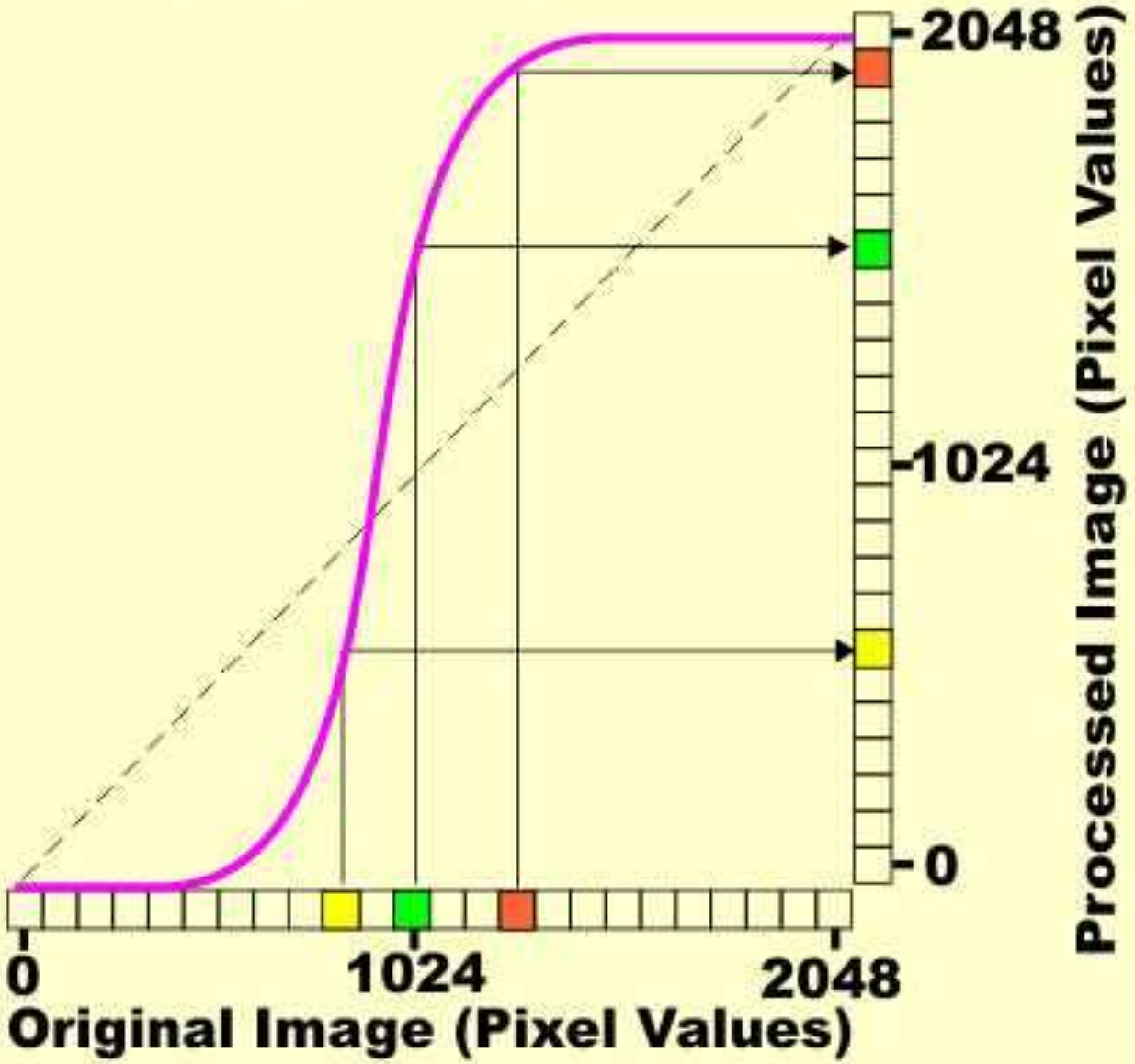
Sprawls

Look Up Table



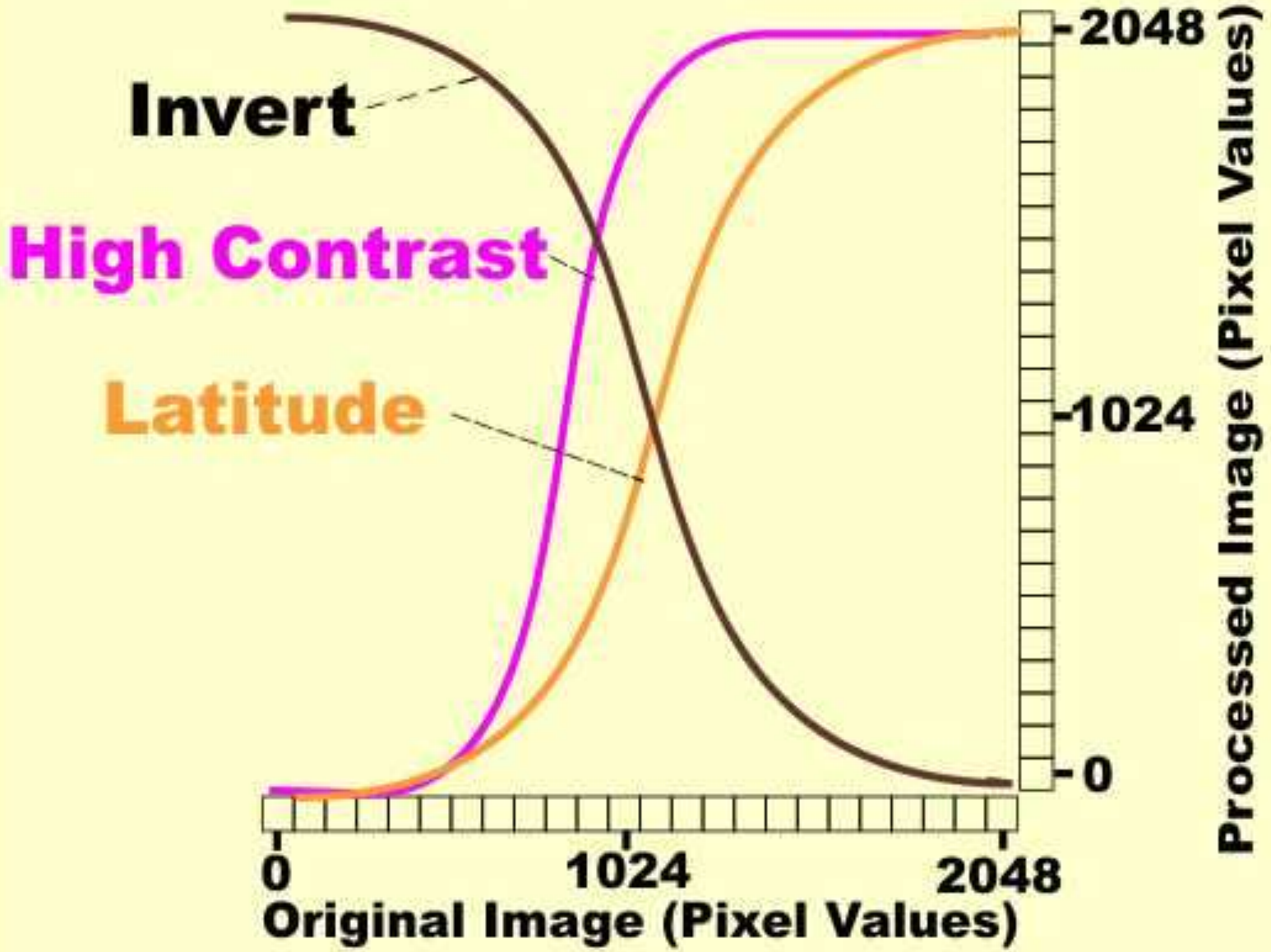
Sprawls

Look Up Table



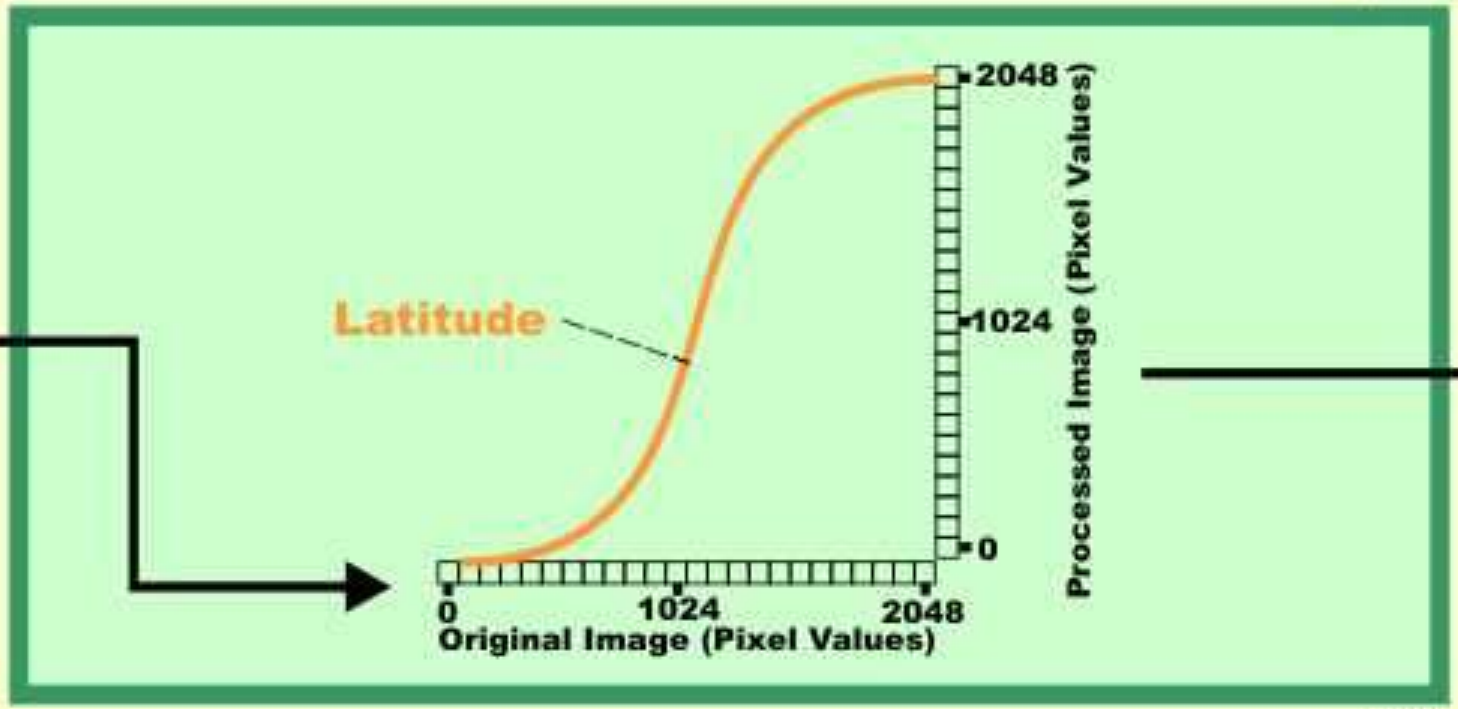
Sprawls

Look Up Table



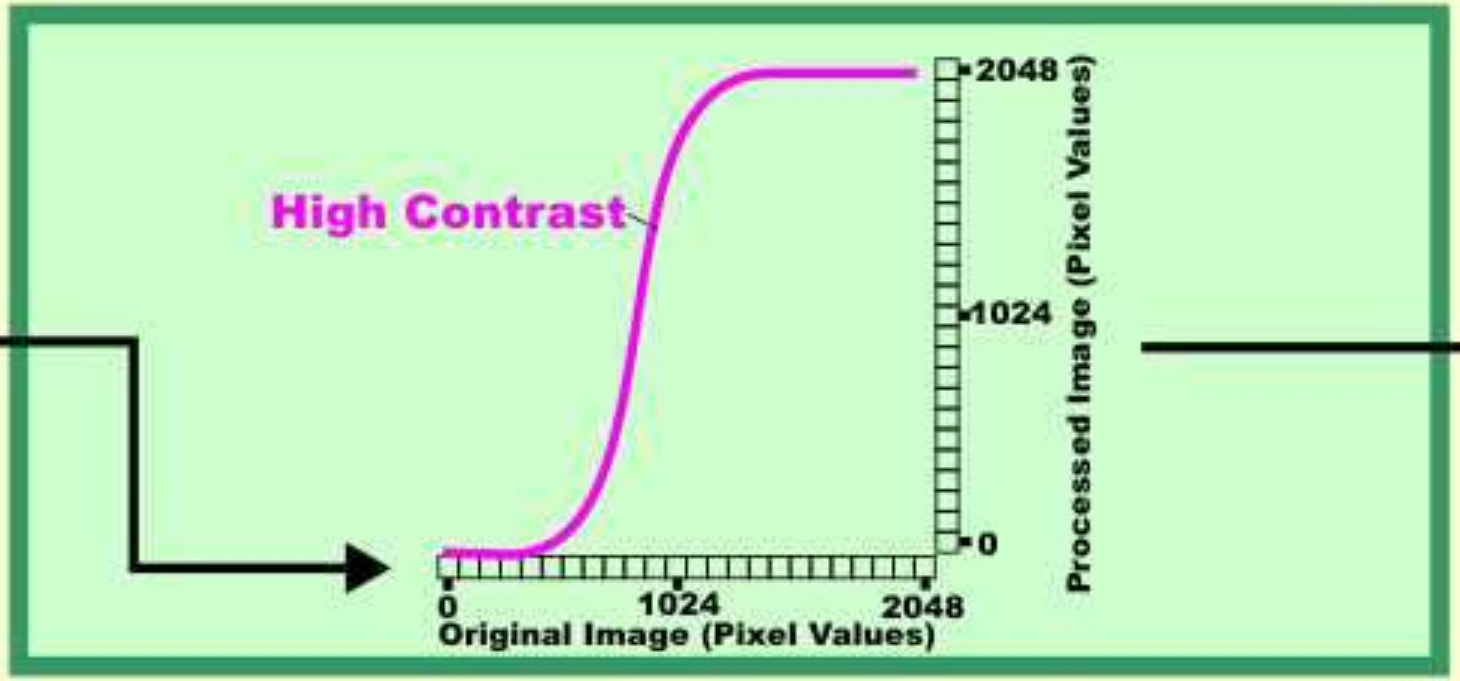
Sprawls

Contrast Processing To Look Like Image Recorded on Chest Film



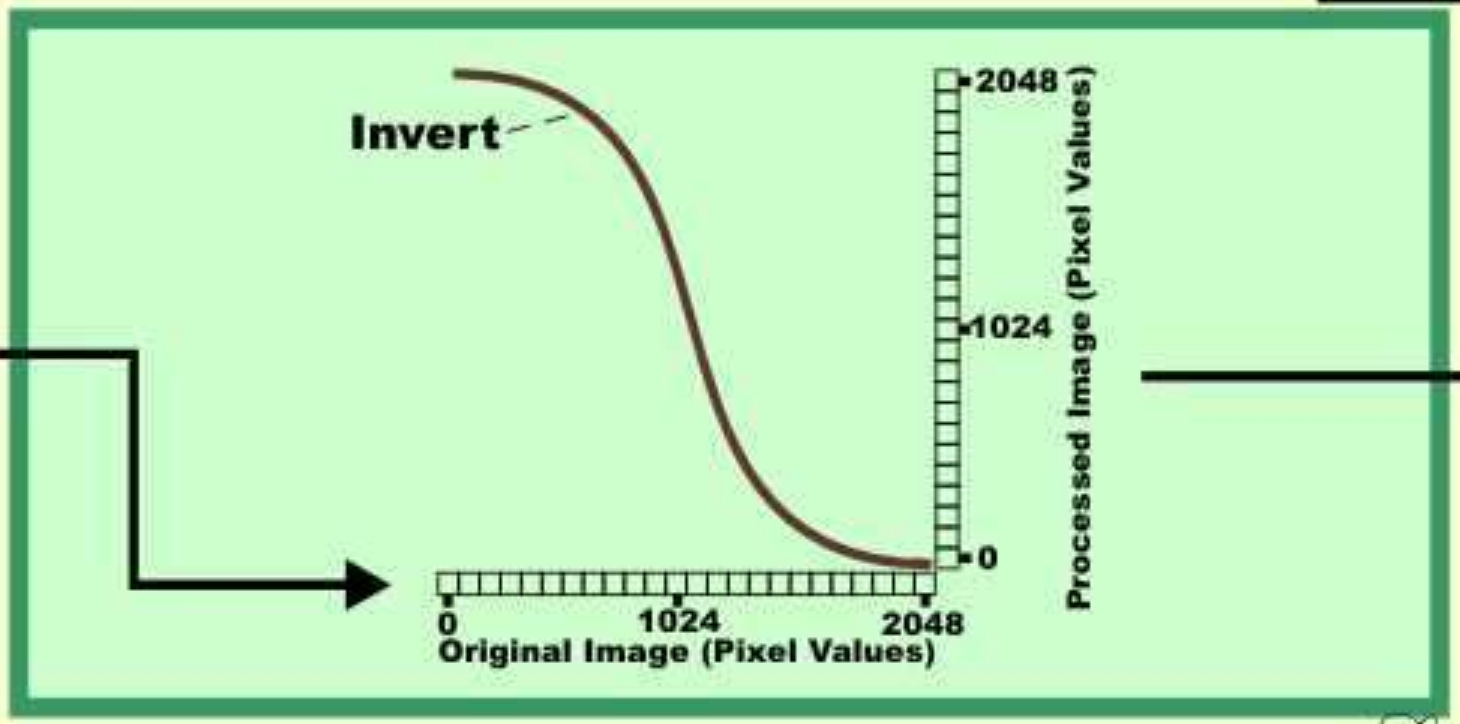
Sprawls

Contrast Processing To Look Like Image Recorded on High Contrast Film



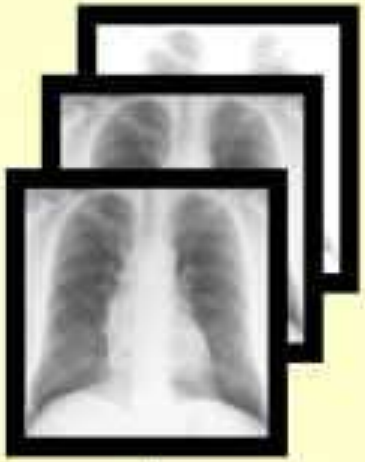
Sprawls

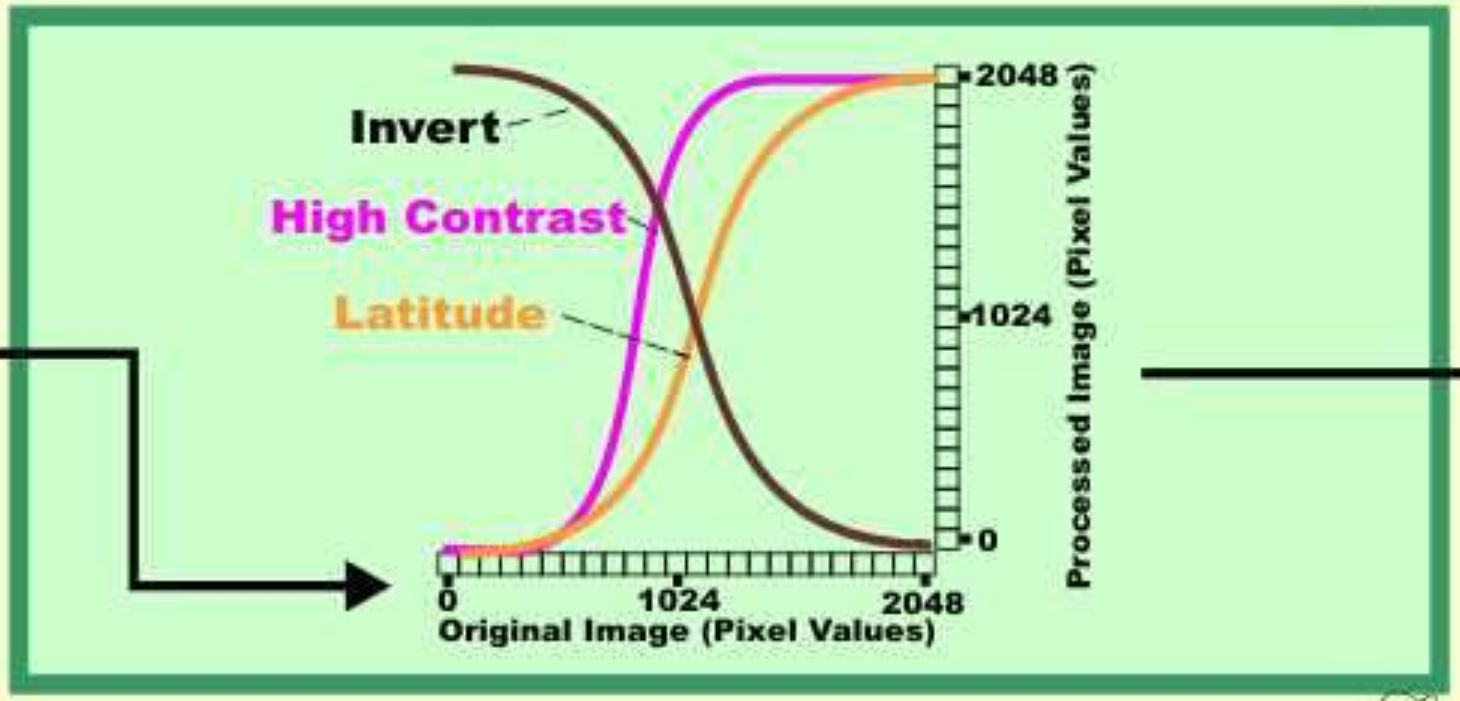
Inverted Brightness Scale



Sprawls

Selection of Look Up Tables for Image Processing





Sprawls

Contrast Adjustment

Original

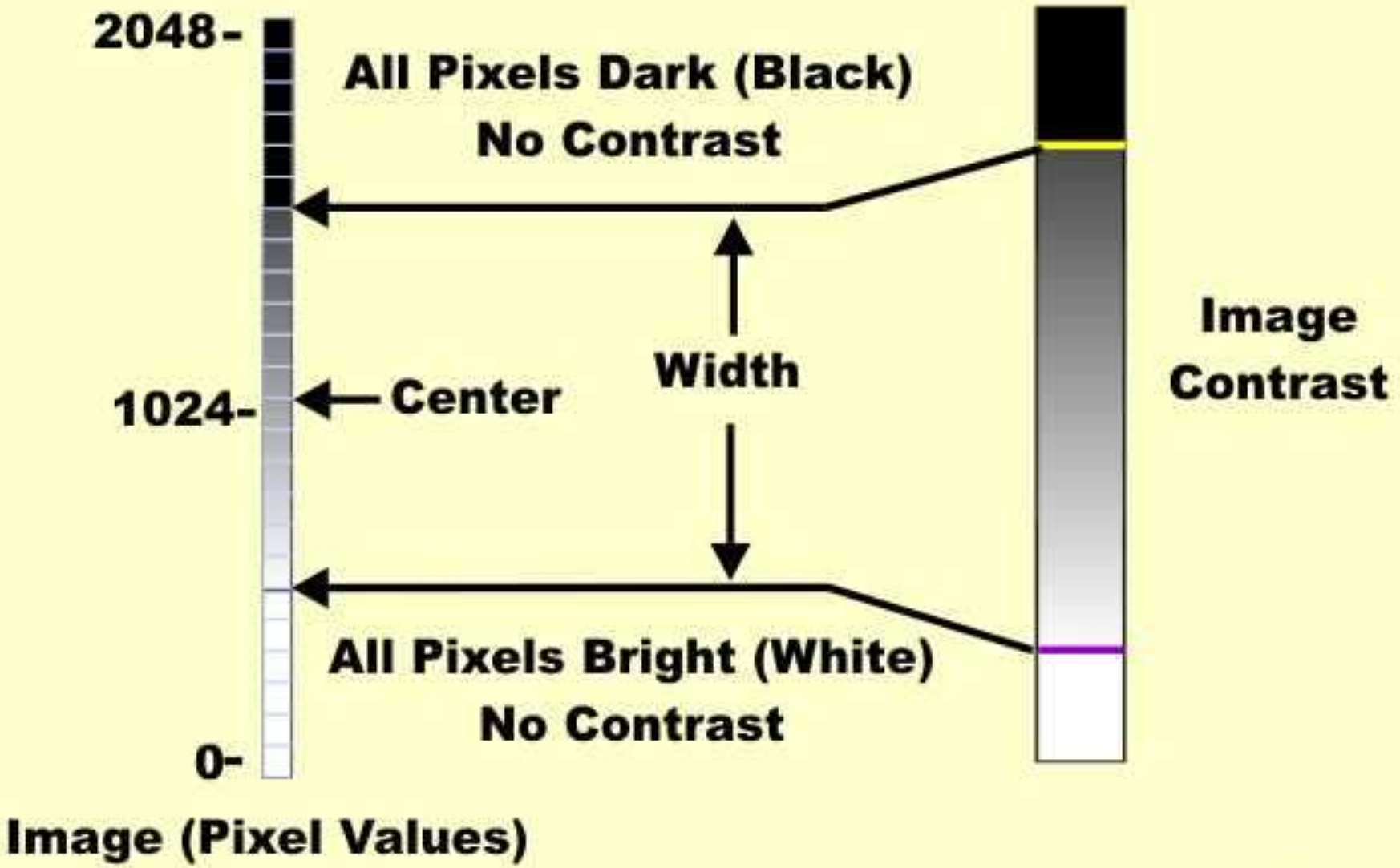
Processed

Look Up Table

Windowing

Sprawls

Digital Image Windowing

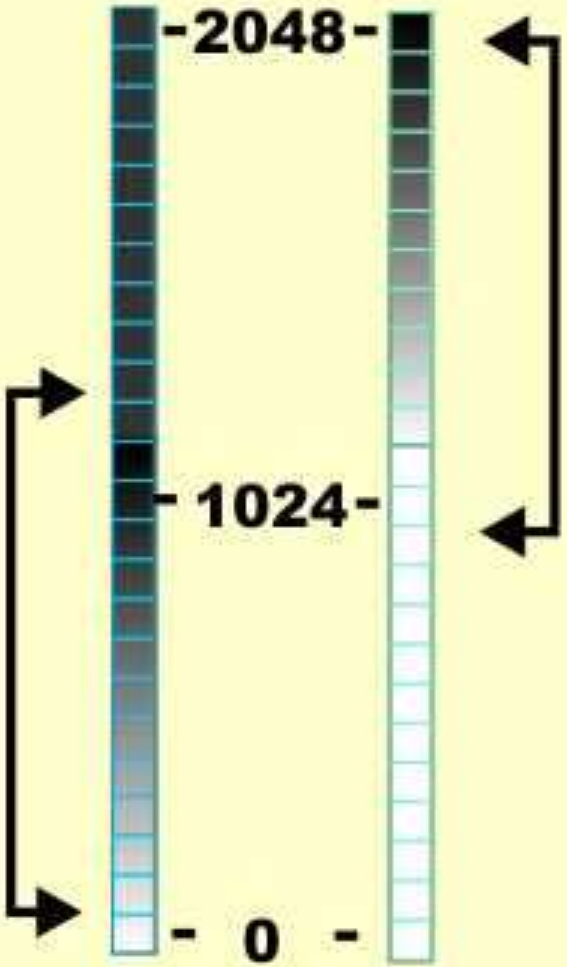


Sprawls

Effect of Window Selection on Contrast

Good Contrast in Lower Range of Pixel Values

Low Window

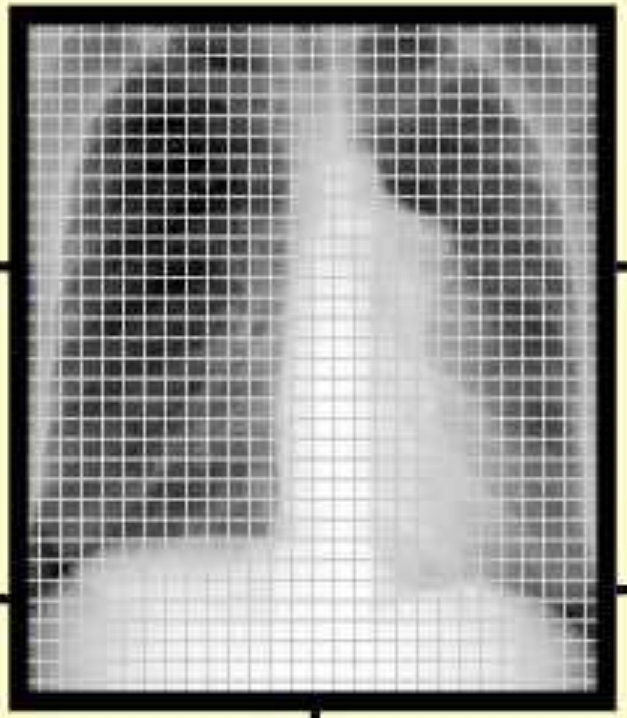


High Window

Good Contrast in Higher Range of Pixel Values

Sprawls

Digital Radiograph Quality Characteristics



Spatial

Artifacts

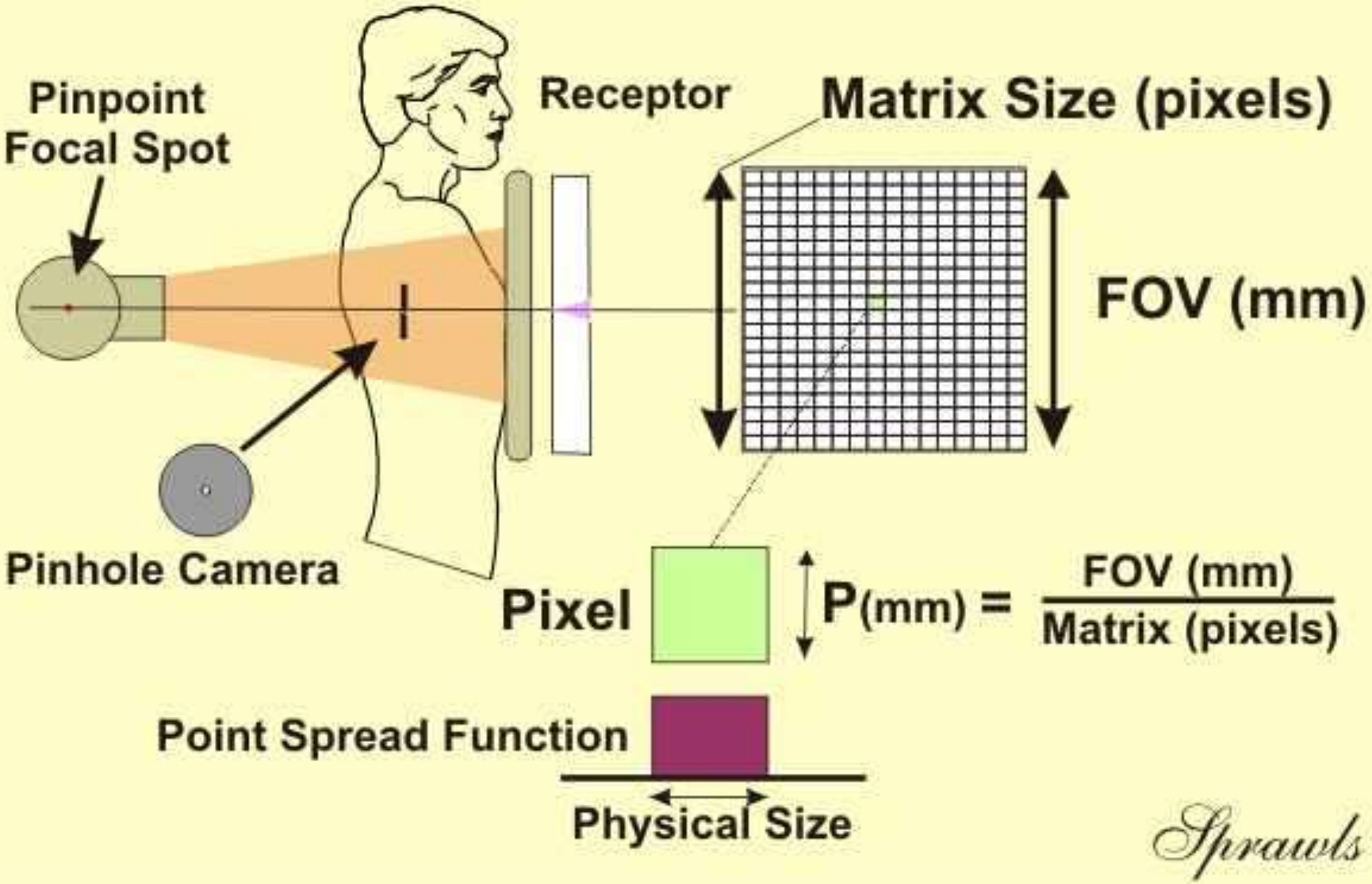
Detail

Noise

Contrast

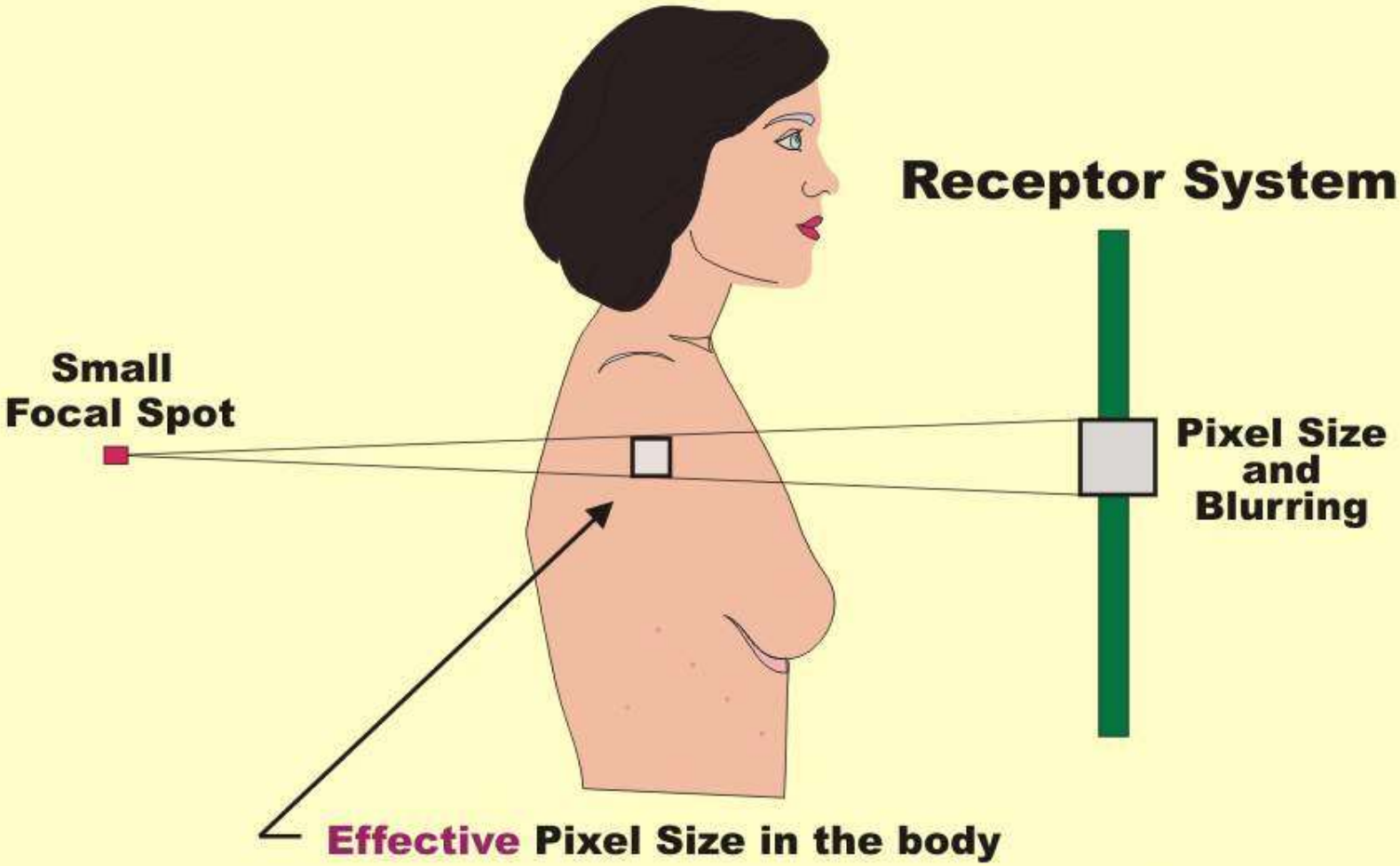
Sprawls

Pixel Blurring



Sprawls

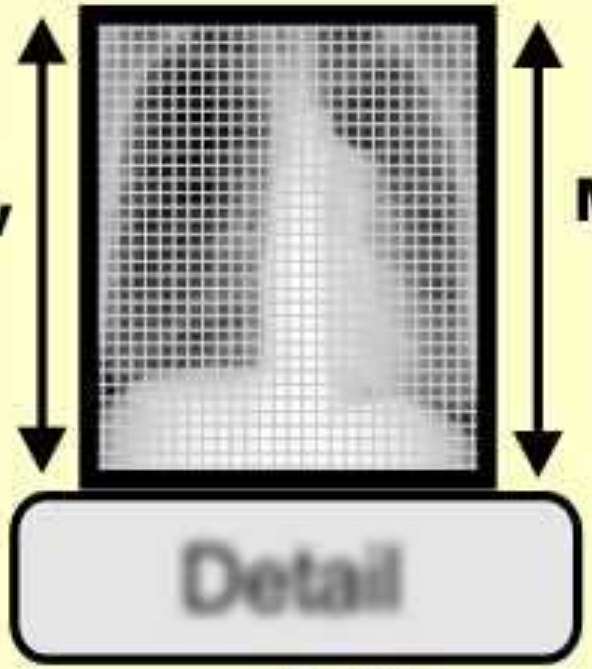
Effect of Magnification on Pixel Size



Magnification can be used to reduce receptor system blurring and improve image detail.

Sprawls

Digital Radiograph



Sources of Blurring

Focal Spot

Motion

Receptor

Pixel Size

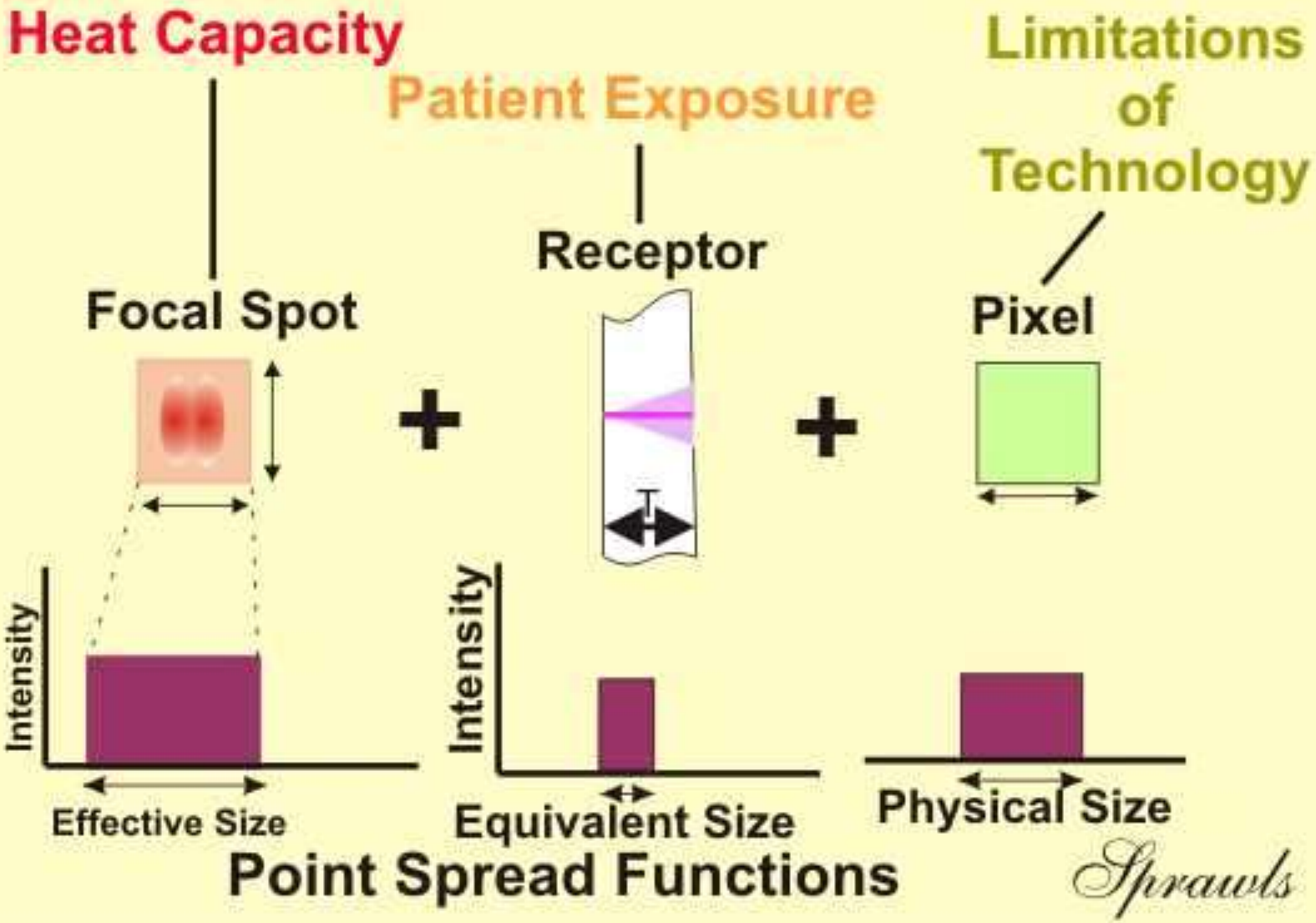
Digital Image Processing

$$\frac{\text{Field of View}}{\text{Matrix Size}}$$

Sprawls

Sources of Blurring

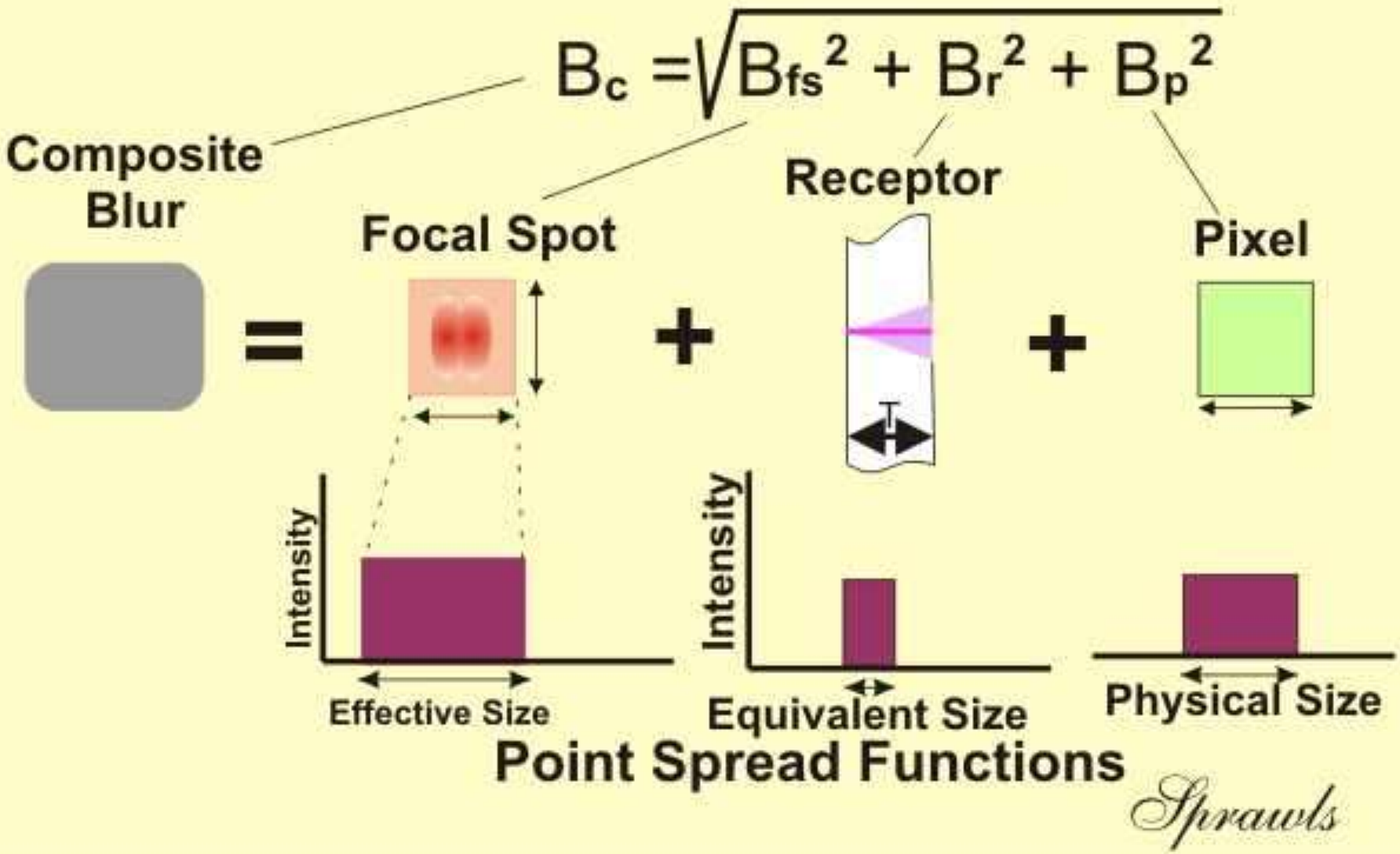
Trade-offs



Composite Blur

Optimization

$$B_c = \sqrt{B_{fs}^2 + B_r^2 + B_p^2}$$

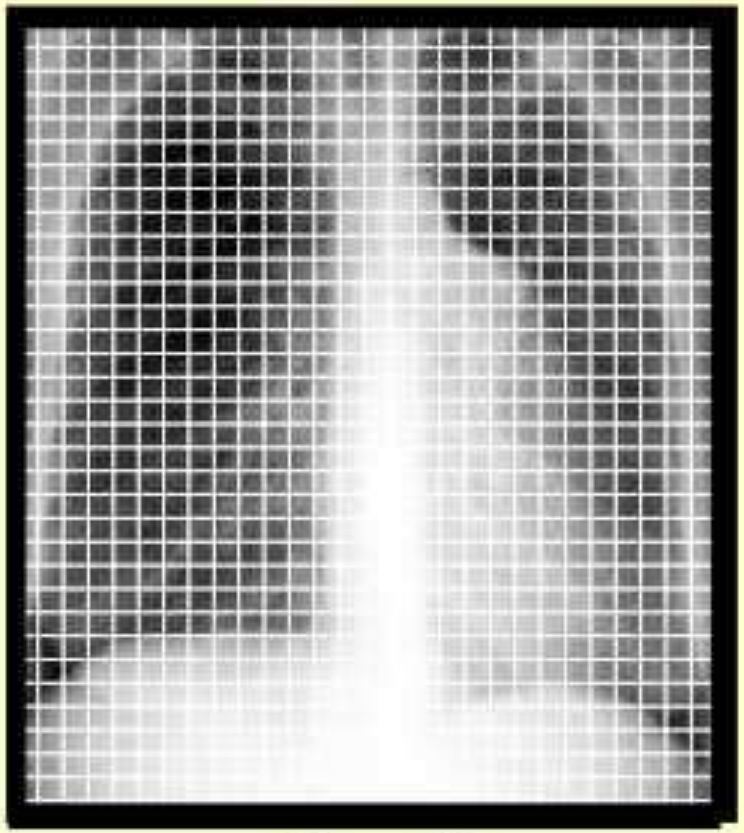


Point Spread Functions

Sprawls

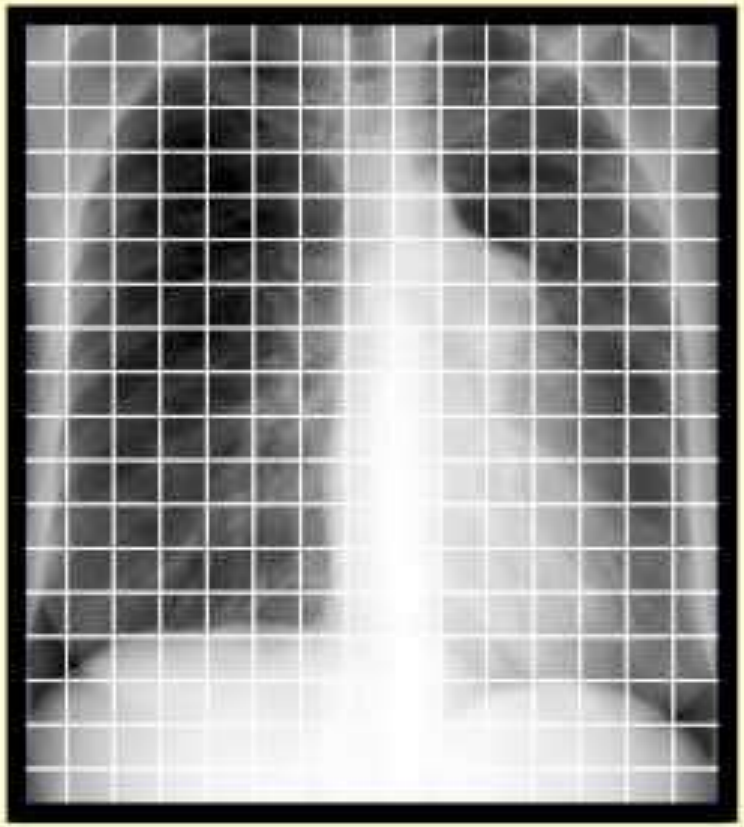
Digital Image Detail
Effect of Matrix Size

Large Matrix



Small

Small Matrix



Large

Pixel Size

Sprawls

Digital Image Detail

Pixel Size

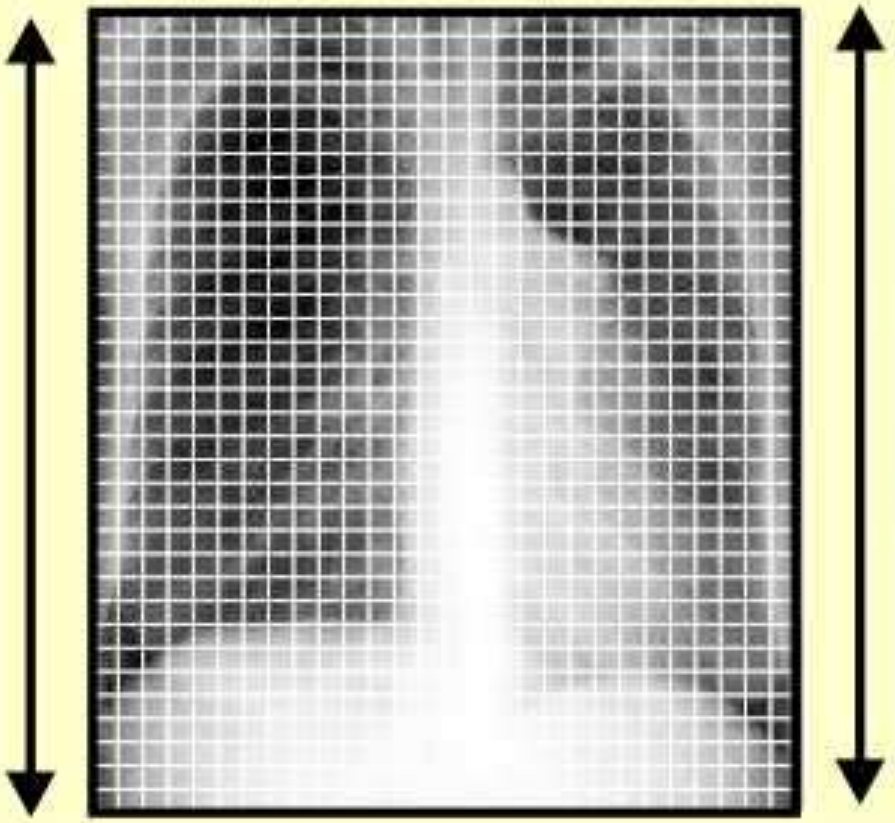


Image Size (mm)

Matrix Size (pixels)

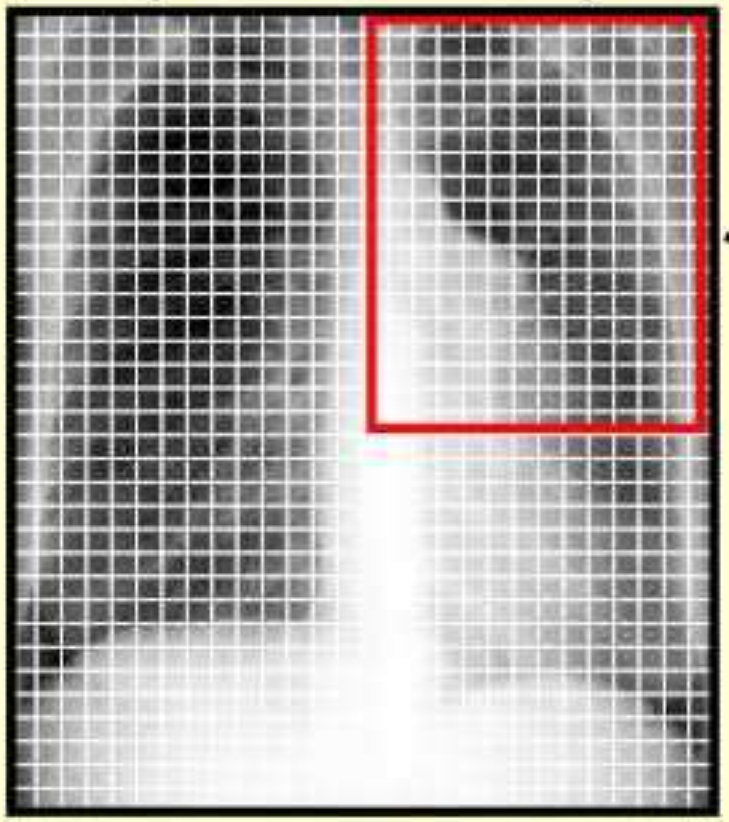
$$\text{Pixel Size} = \frac{\text{Image Size (mm)}}{\text{Matrix Size (pixels)}}$$

Sprawls

Digital Image Detail

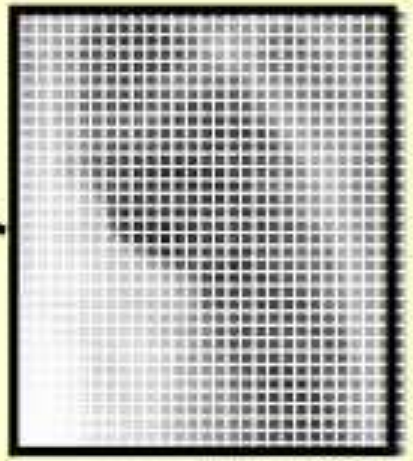
Effect of Image Size

Large Image
(Field of View)



Large Pixels

Small Image
(Field of View)

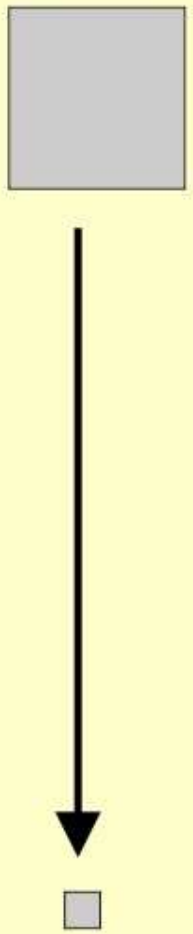


Small Pixels

Sprawls

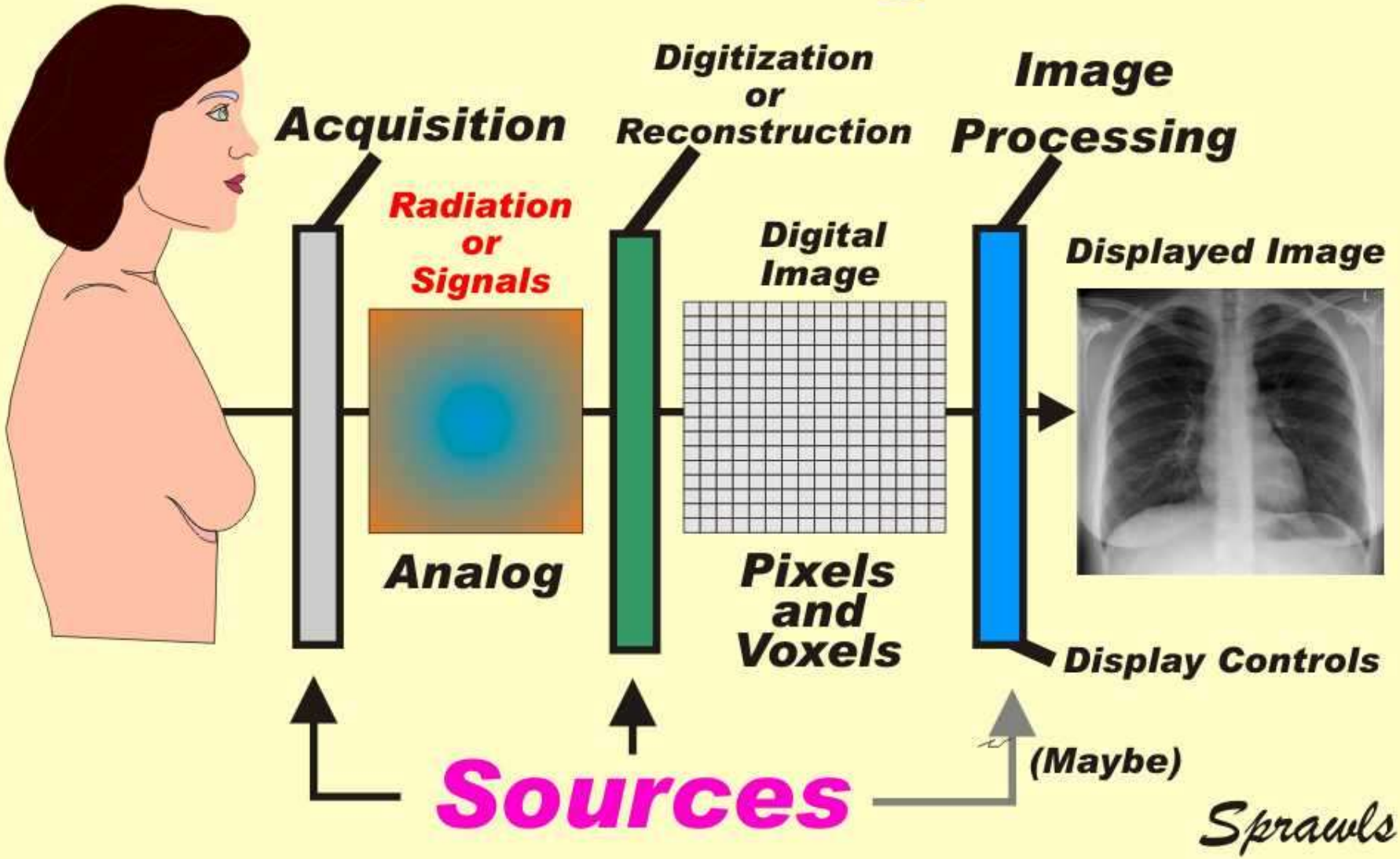
Pixel Size

Modality	Matrix
Radionuclide Imaging	128 x 128
MRI	256 x 256
Ultrasound	256 x 256
CT	512 x 512
Fluoroscopy	1024 x 1024
General Radiography	2048 x 2048
Mammography	4,096 x 5120



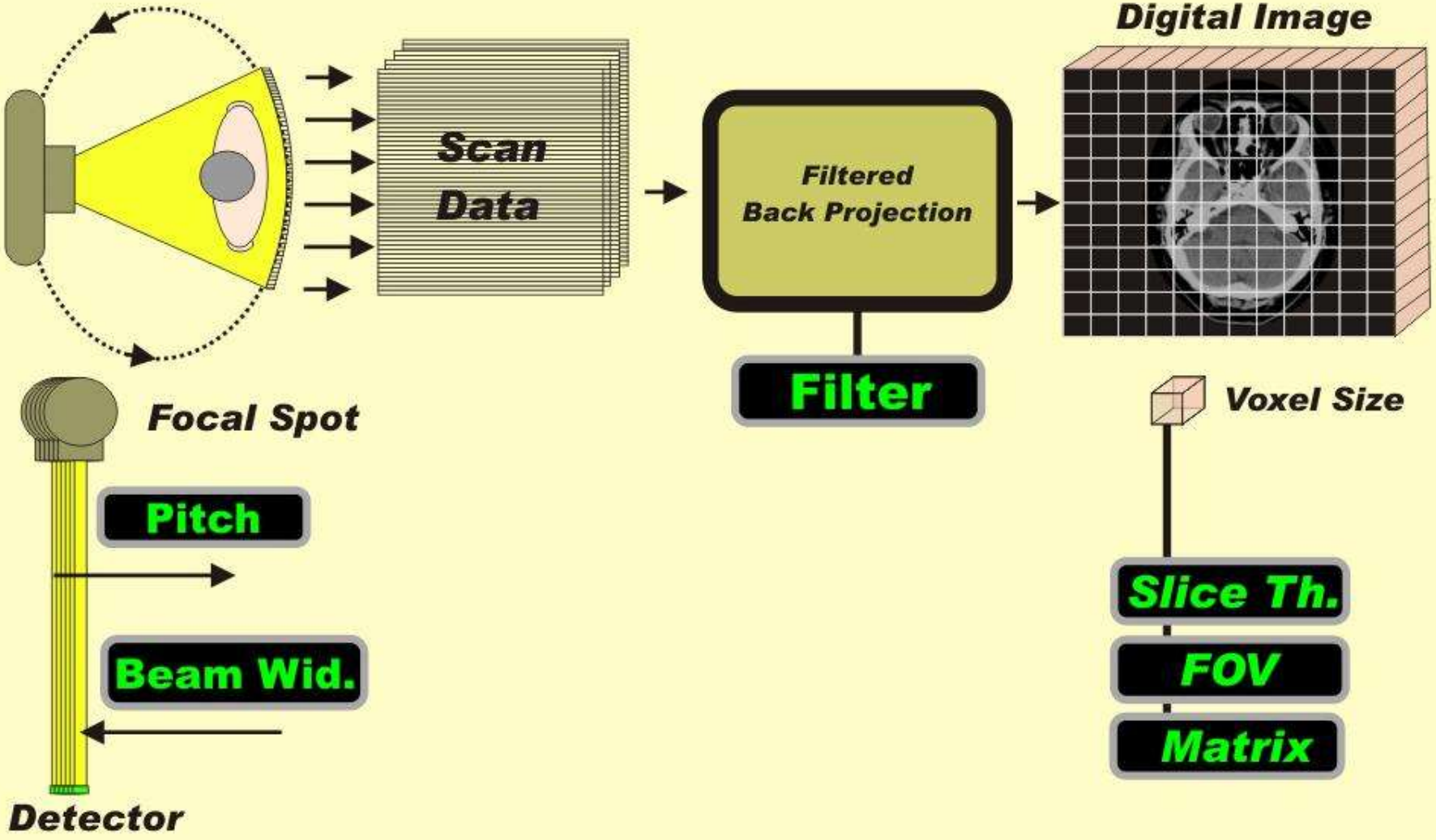
The Medical Imaging Process

Blurring



Sprawls

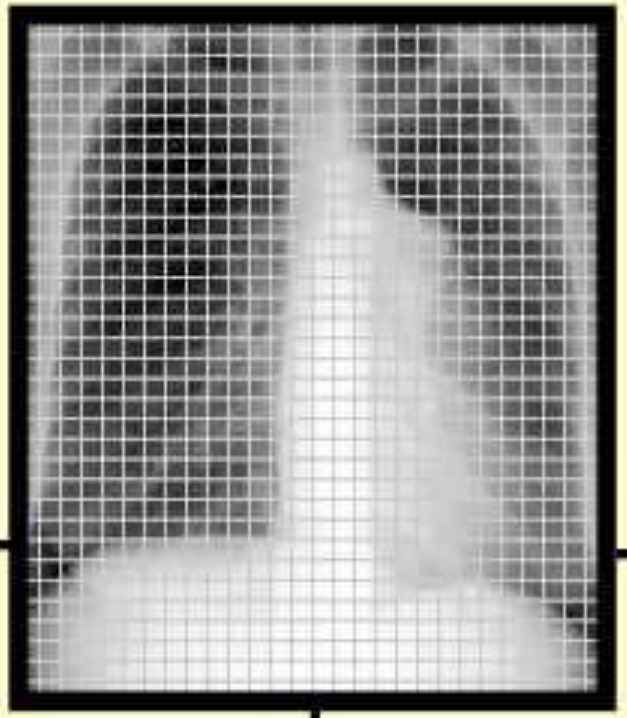
Factors That Determine Image Detail (Sources of Blurring)



Sprawls

Digital Image Processing

Can



Increase Visibility of

Detail

Reduce

Noise

Contrast

Adjust and Optimize

Sprawls

Blurred (Unsharp) Mask Subtraction

Original

Enhanced
Visibility of Detail

Digital
Subtraction
(Original - Mask)

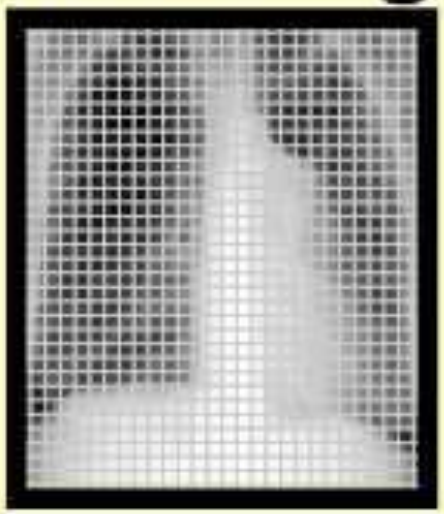
=

Blurring
by
Digital Processing

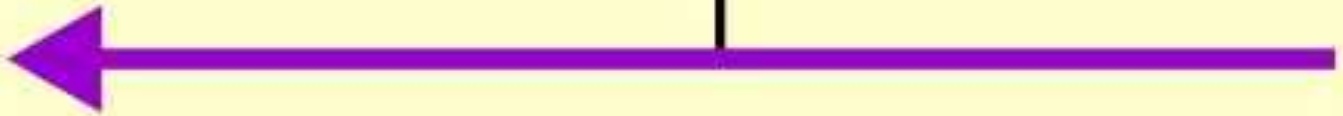
Blurred Mask Image

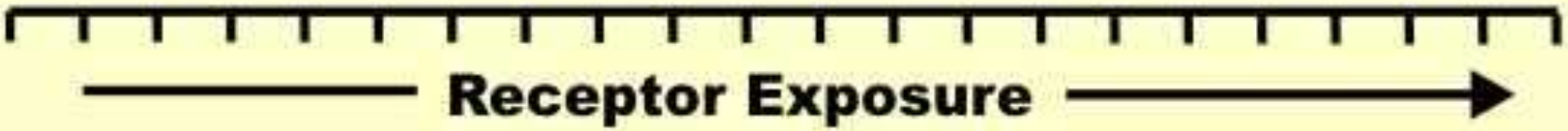
Sprawls

Digital Radiograph



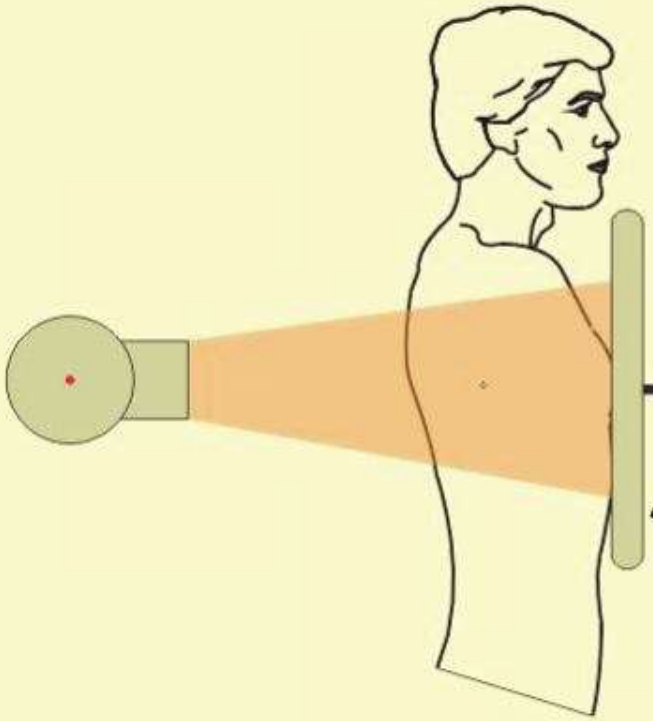
Noise





Sprawls

Receptor Exposure Indicator



Many different names, quantities, and units

200
Display

Exposure Index

+1

Deviation Index

$$DI = \frac{K_{(Indicated)}}{K_{(target)}}$$

Set for specific procedure

Ref: AAPM Report 116

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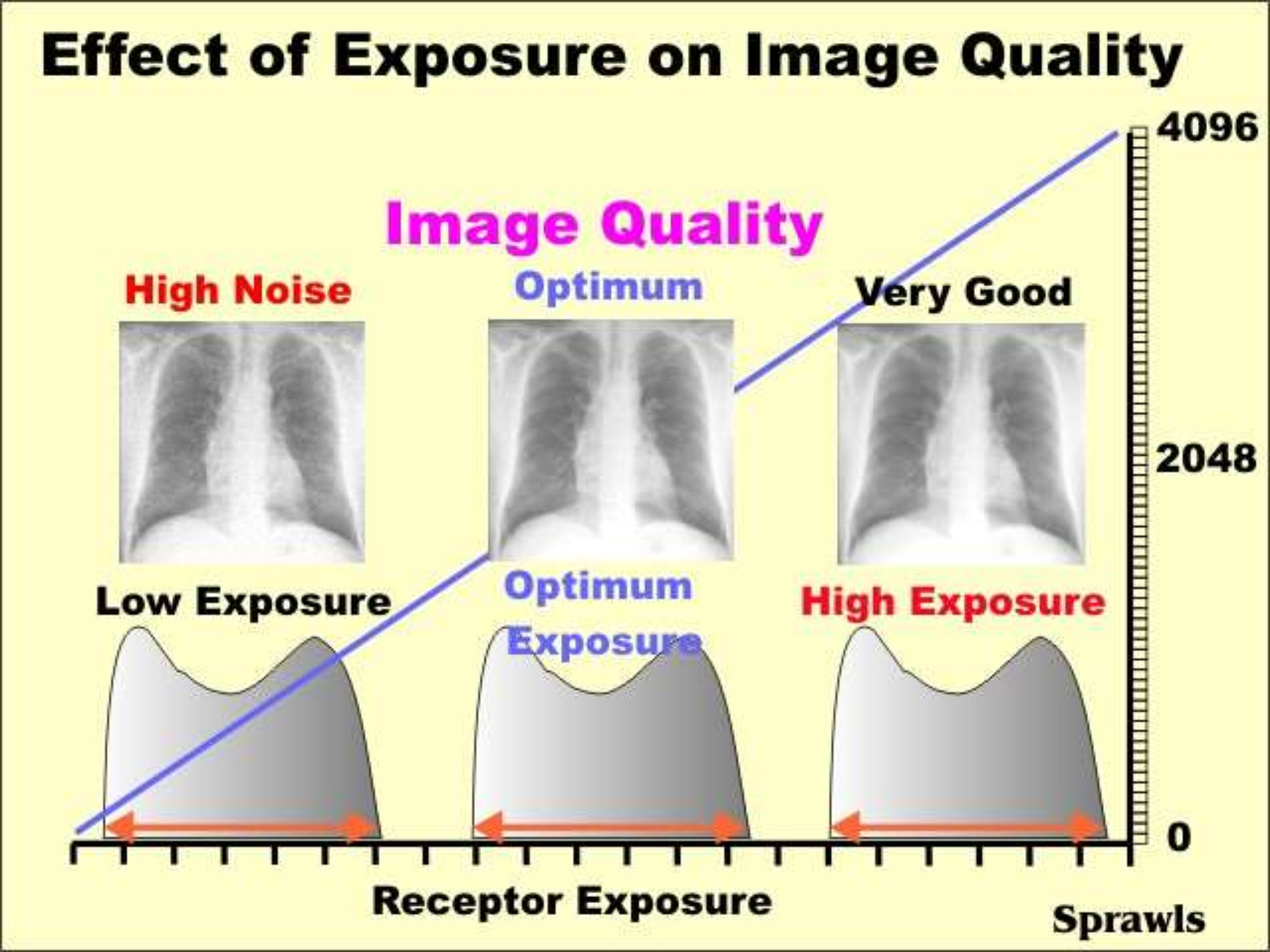
AAPM REPORT NO. 116

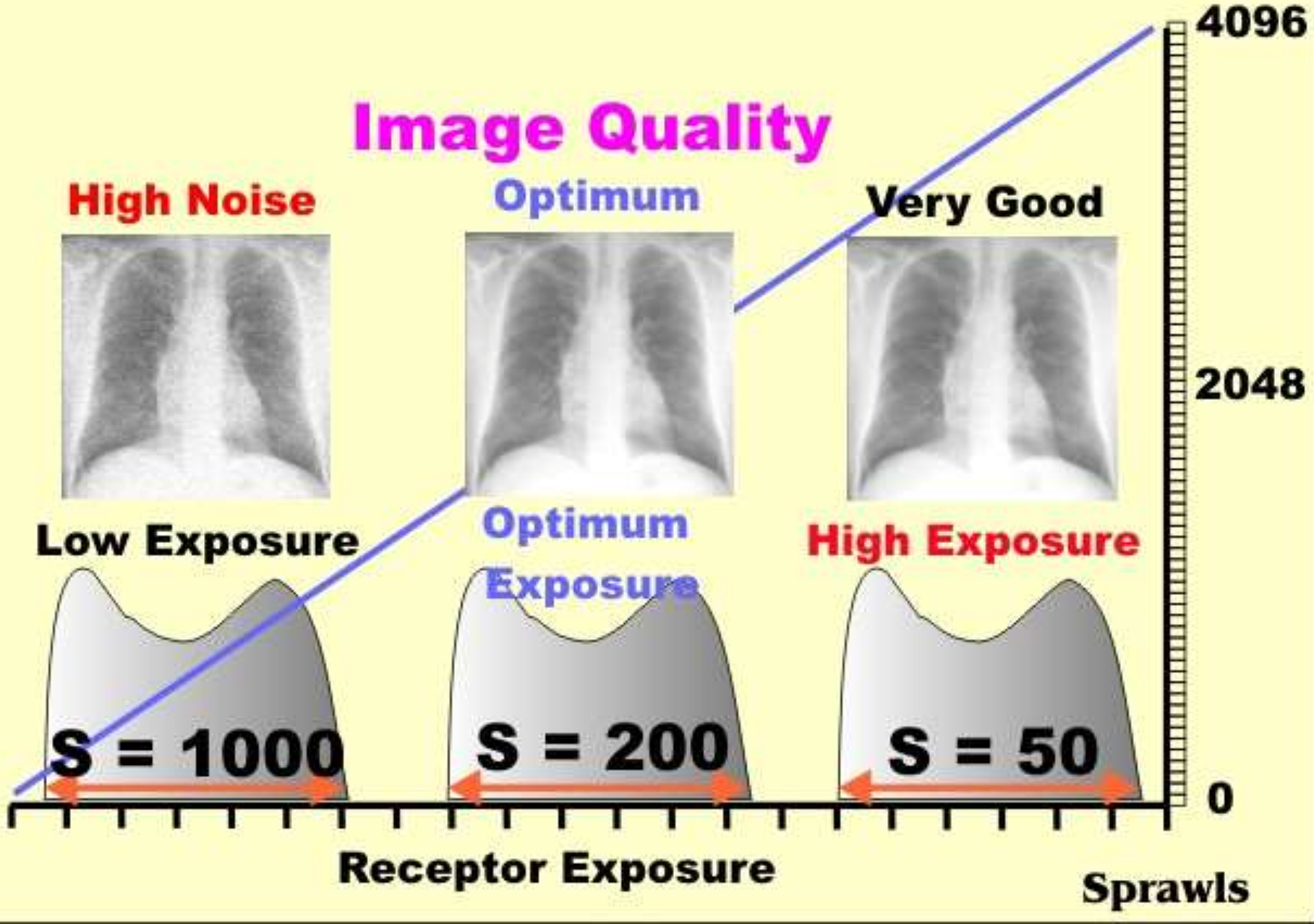
An Exposure Indicator for Digital Radiography

Report of AAPM Task Group 116

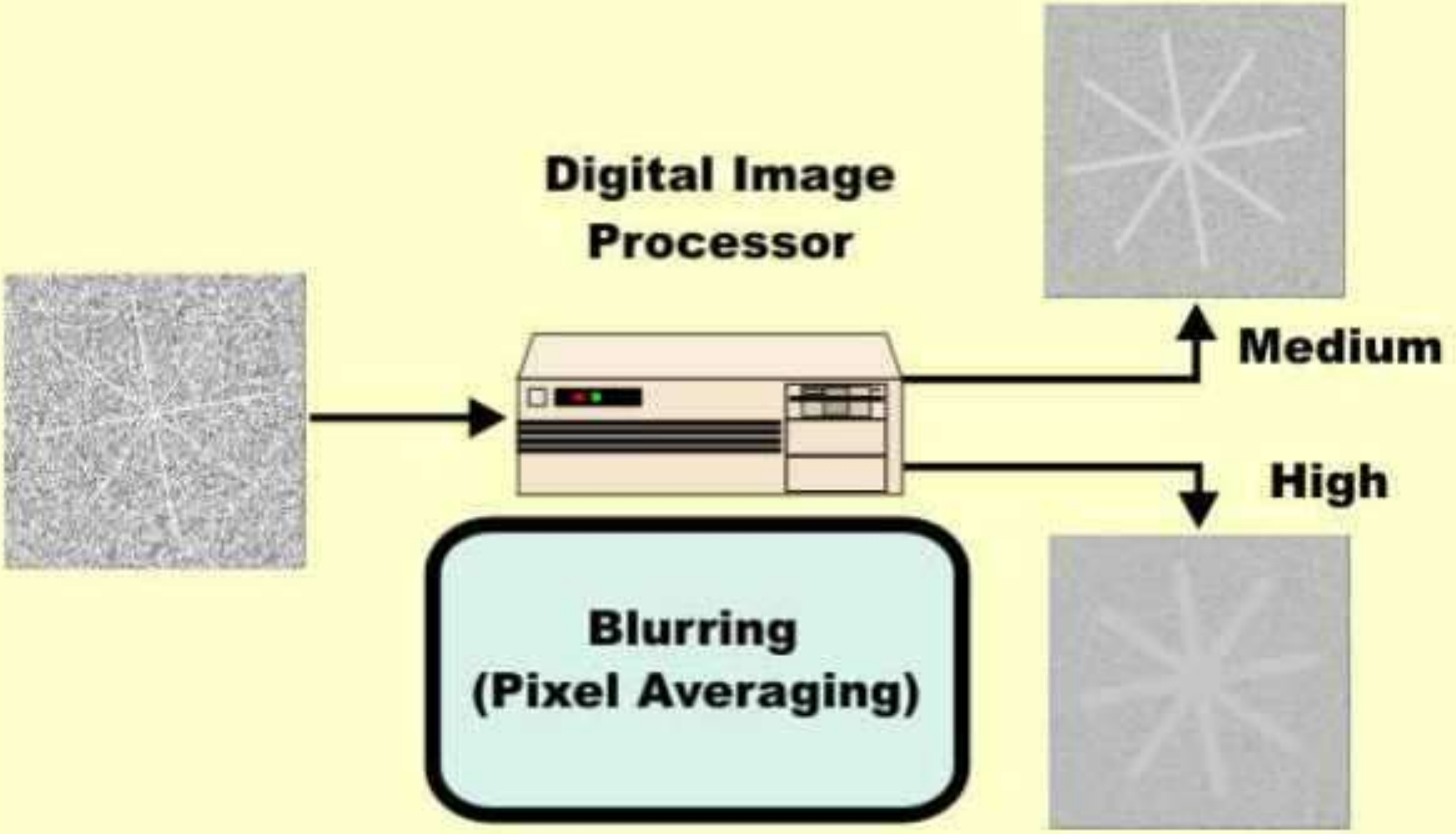
Effect of Exposure on Image Quality



Effect of Exposure on Image Quality



Digital Processing to Reduce Noise



Digital X-ray Imaging

Pixel Size

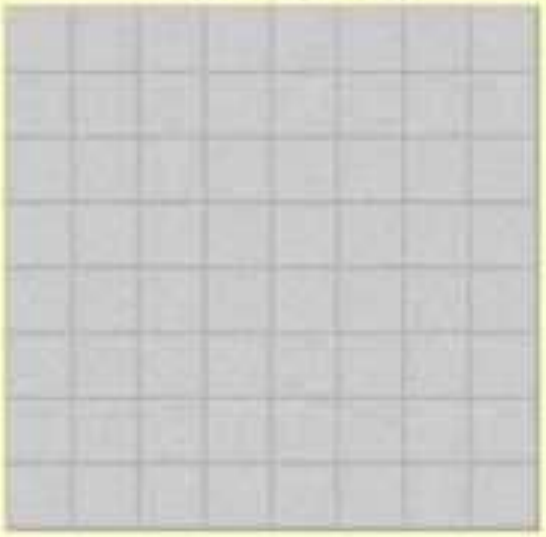
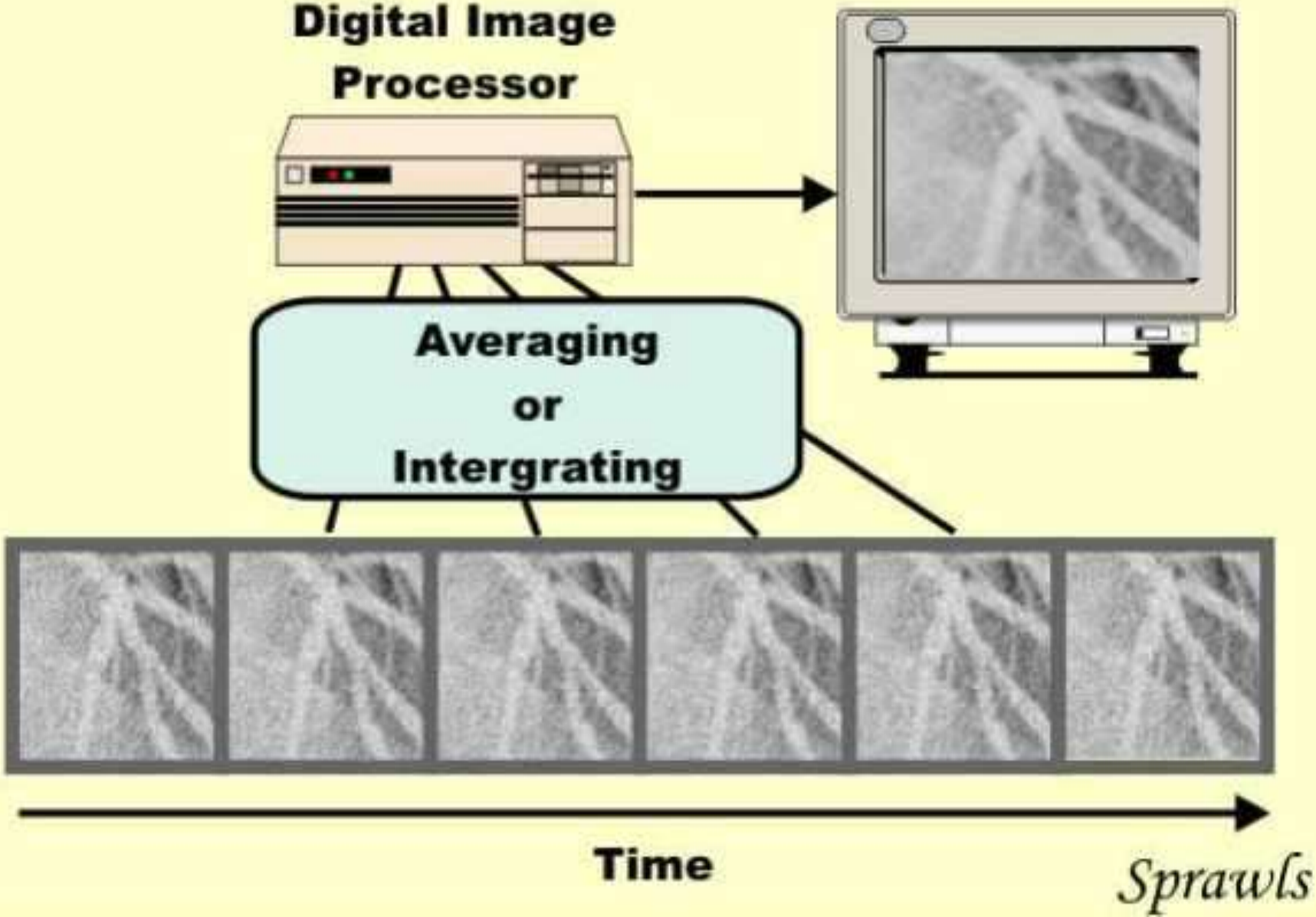
Small	Medium	Large
		
High	Medium	Low

Image Noise

Processing to Reduce Noise



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AAPM REPORT NO. 151

Ongoing Quality Control in Digital Radiography

The Report of AAPM Imaging Physics Committee
Task Group 151

February 2015

Additional Online References

General

http://www.sprawls.org/PhysRev

http://www.sprawls.org/resources

Specific Digital Radiography online modules

http://www.sprawls.org/resources/DICHAR

http://www.sprawls.org/resources/DIGRAD

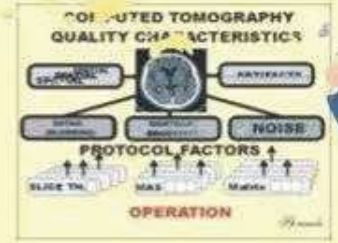
http://www.sprawls.org/resources/DIGPROCESS

http://www.sprawls.org/resources/NETWORKS

http://www.sprawls.org/resources/DIGSTORAGE

Physics Review Course
Levels of Learning

Sprawls Topics



Classroom

Overview
Organize
Develop Concepts

Notebook

Review
Refresh
Reference for Details and Facts

The Web

Expanding Scope and Depth
with
Web Based Resources

http://www.sprawls.org/PhysRev