SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

By

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Module 05:
Image Processing

Lecture 12B:
Basics of Digital Image Processing

CONCEPTS COVERED

- What is a digital image?
- What is digital image processing?
- State-of-the-art examples of digital image processing
- Image acquisition
- What is sampling?
- What is spatial resolution?
- What is quantization?
- What is grey-level resolution?
- Contrast enhancement
- Histogram processing

Image – Digital Image

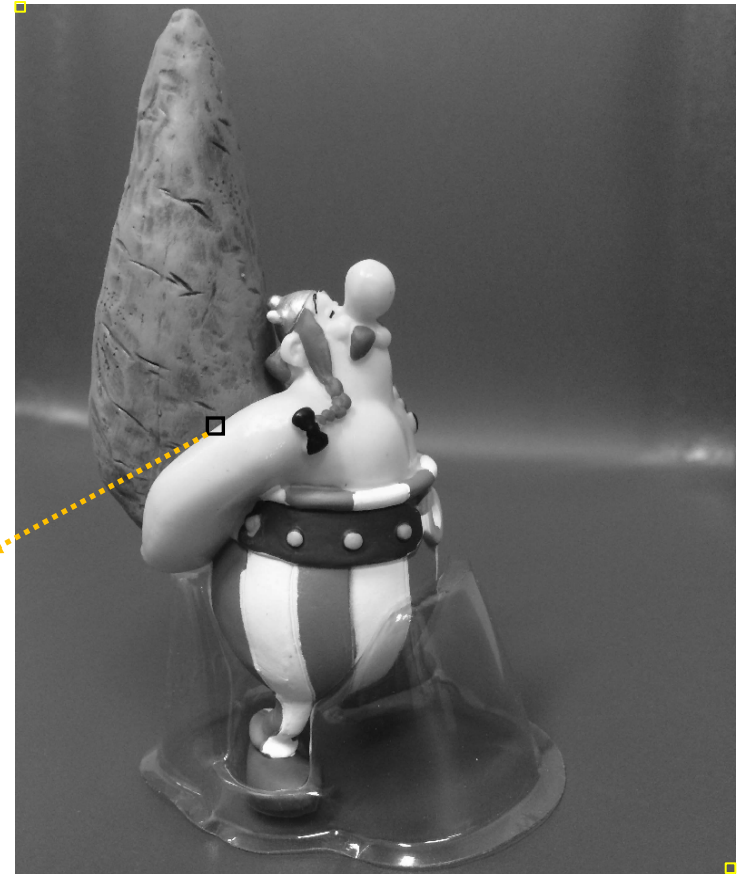
An image is a two-dimensional function f(x,y), where x and y are the spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x,y) is called the intensity of the image at that level.

If x,y and the amplitude values of f are finite and discrete quantities, we call the image a digital image. A digital image is composed of a finite number of elements called pixels, each of which has a particular location and value.

Pixel intensity value

$f(1,1) = 103$

Pixel location



rows columns

83	82	82	82	82	82
82	82	82	81	81	81
82	82	81	81	80	80
82	82	81	80	80	79
80	79	78	77	77	77
80	79	78	78	77	77

$f(2724,2336) = 88$

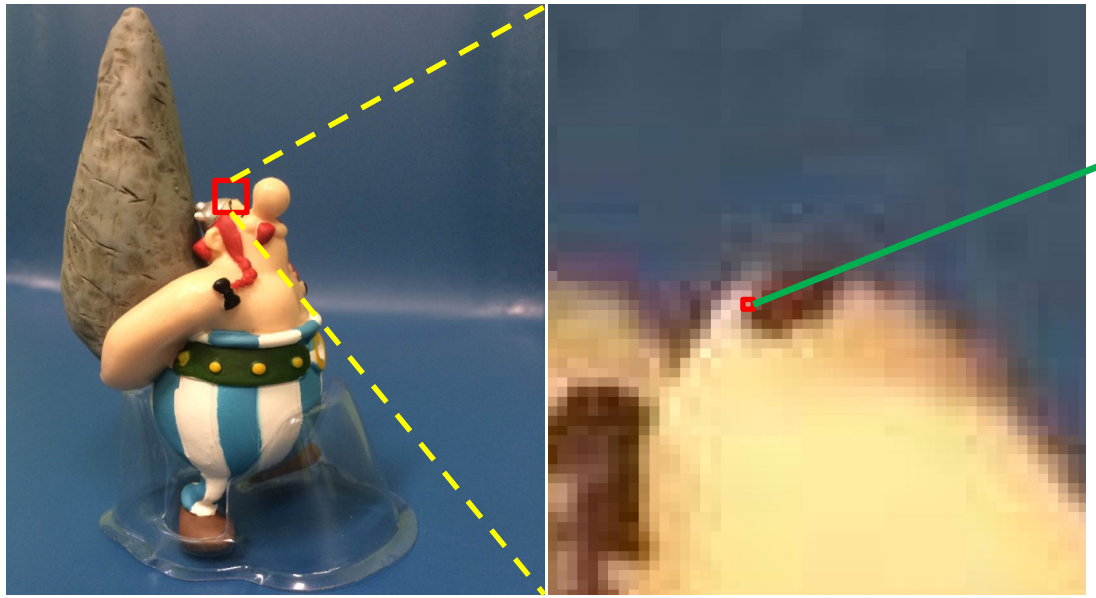
Consider the following image (2724x2336 pixels) to be 2D function or a matrix with rows and columns

In 8-bit representation

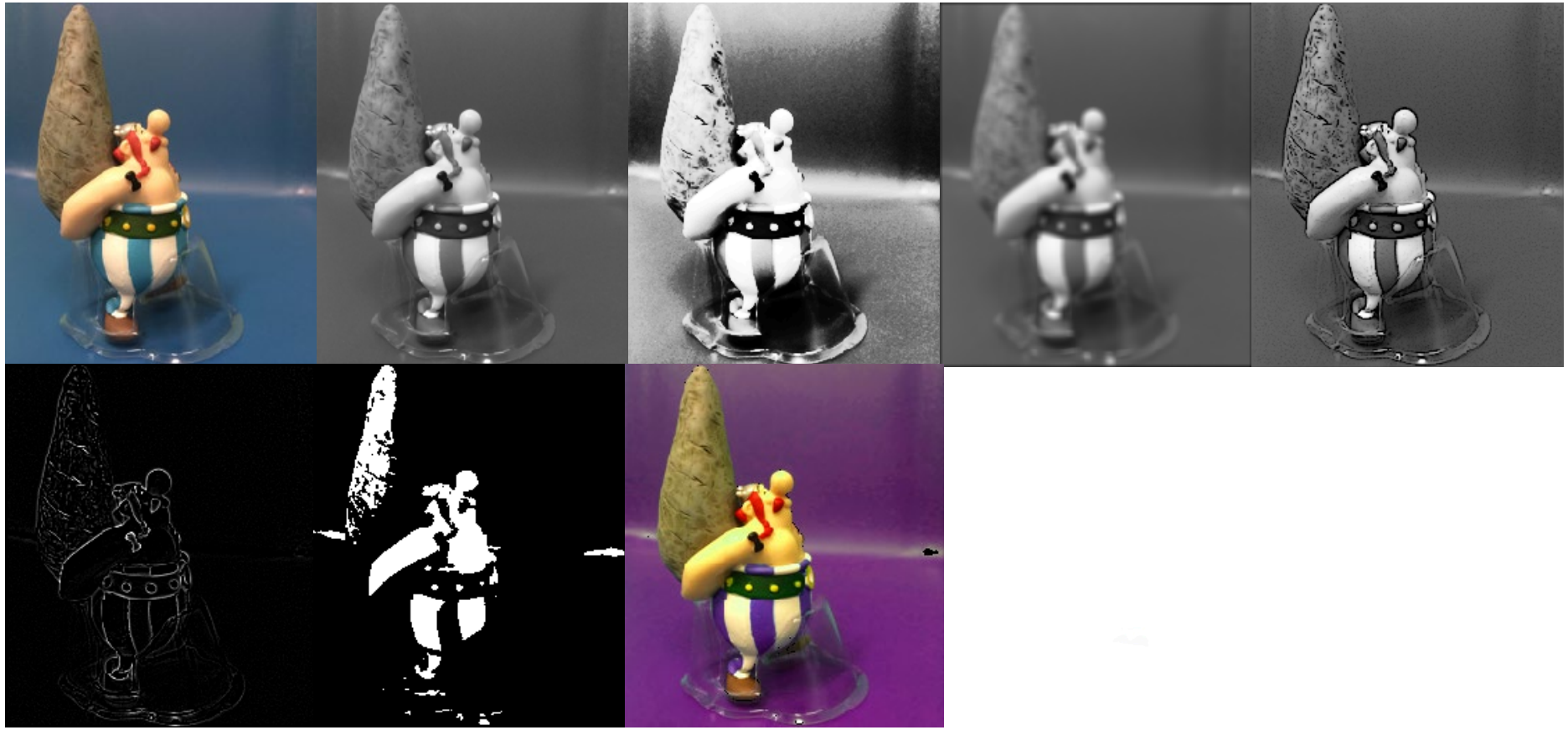
Pixel intensity values change between 0 (Black) and 255 (White)

Digital Image

Remember *digitization* implies that a digital image is an *approximation* of a real scene

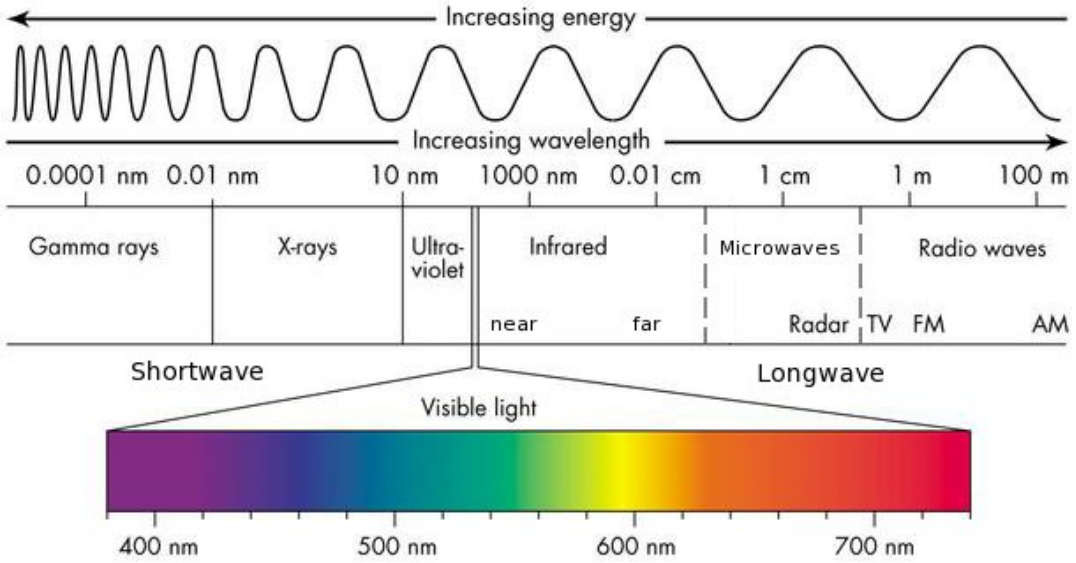


Digital Image Processing

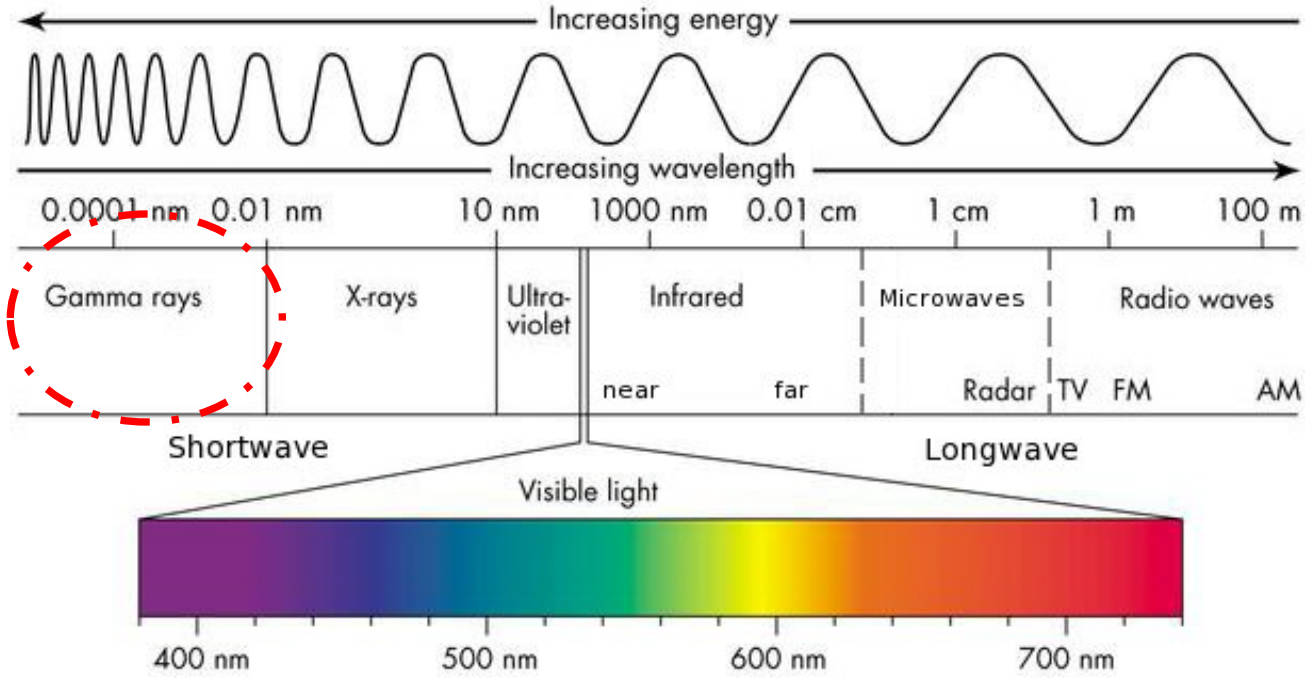


Sources of Digital Images

The principal source for the images is the electromagnetic (EM) energy spectrum.

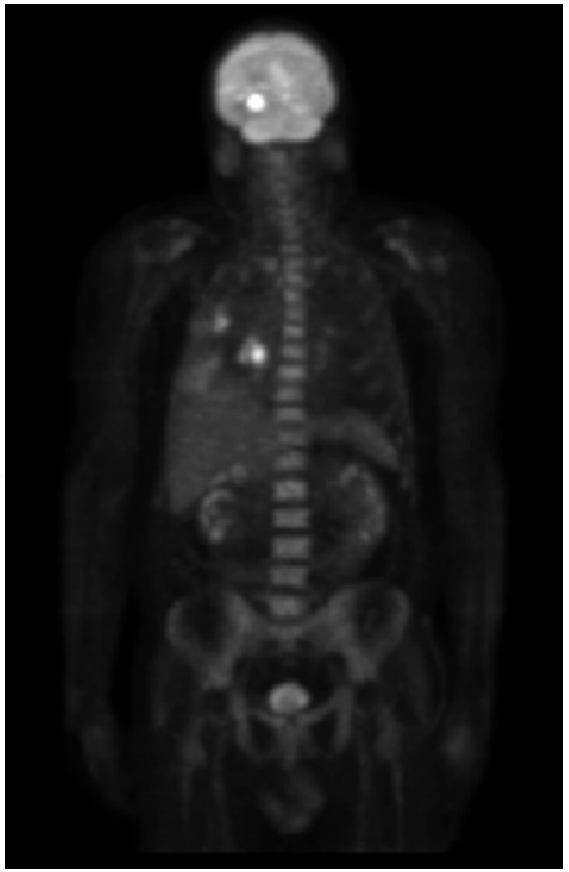


Gamma Rays


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Microwaves
Radio waves
near
far
Radar
TV
FM
AM
Shortwave
Longwave
Visible light
400 nm
500 nm
600 nm
700 nm

Gamma Rays

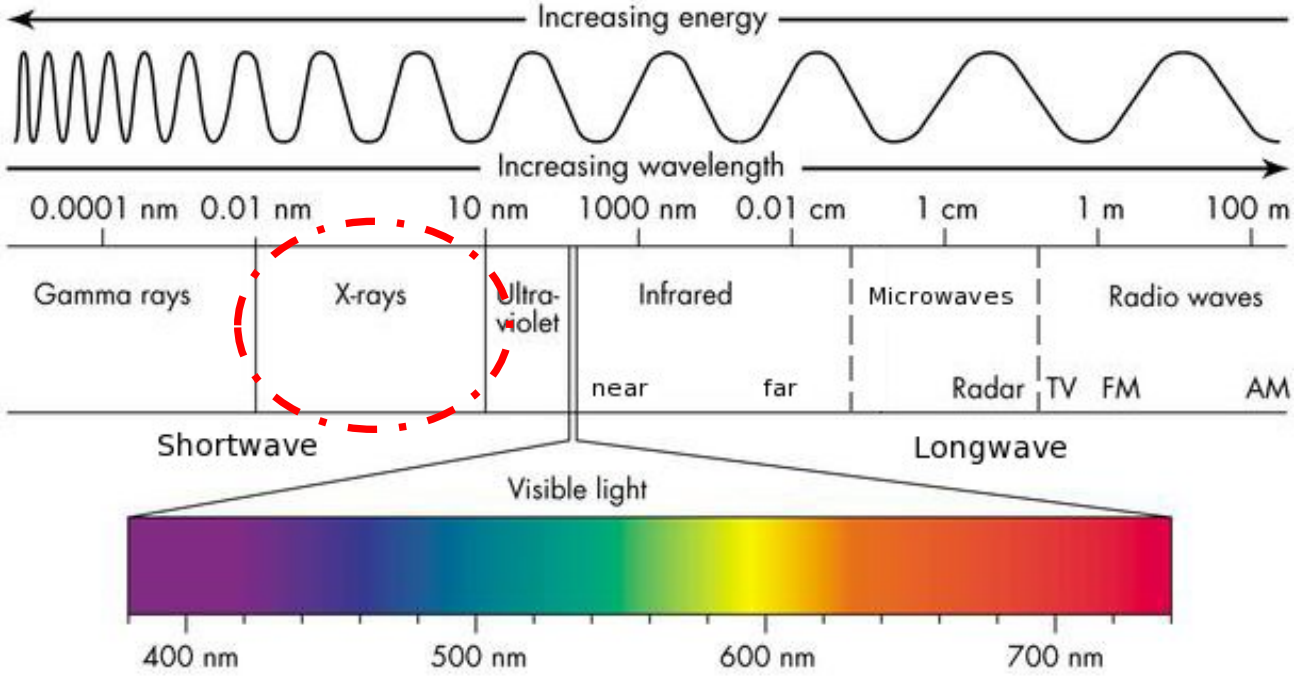
Gamma-Ray Imaging Cherenkov Telescope



Gamma-Ray Imaging İn nuclear medicine

Gamma-Ray imaging of A starburst galaxy about 12 million light-years away

X-Rays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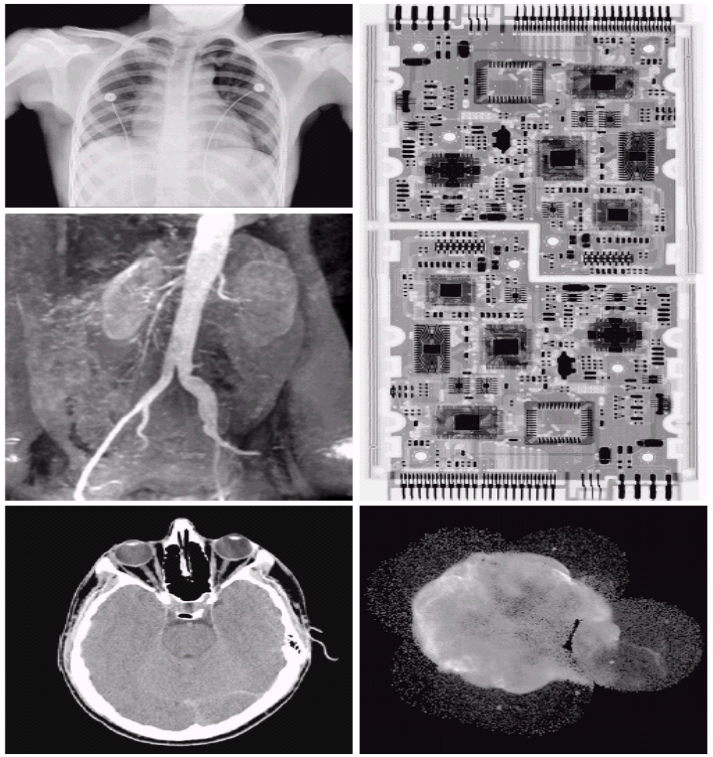
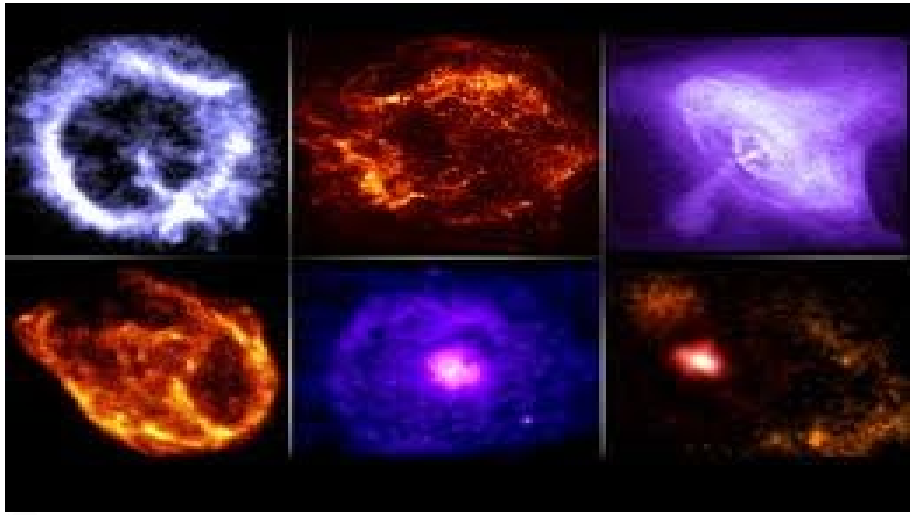
X-Rays

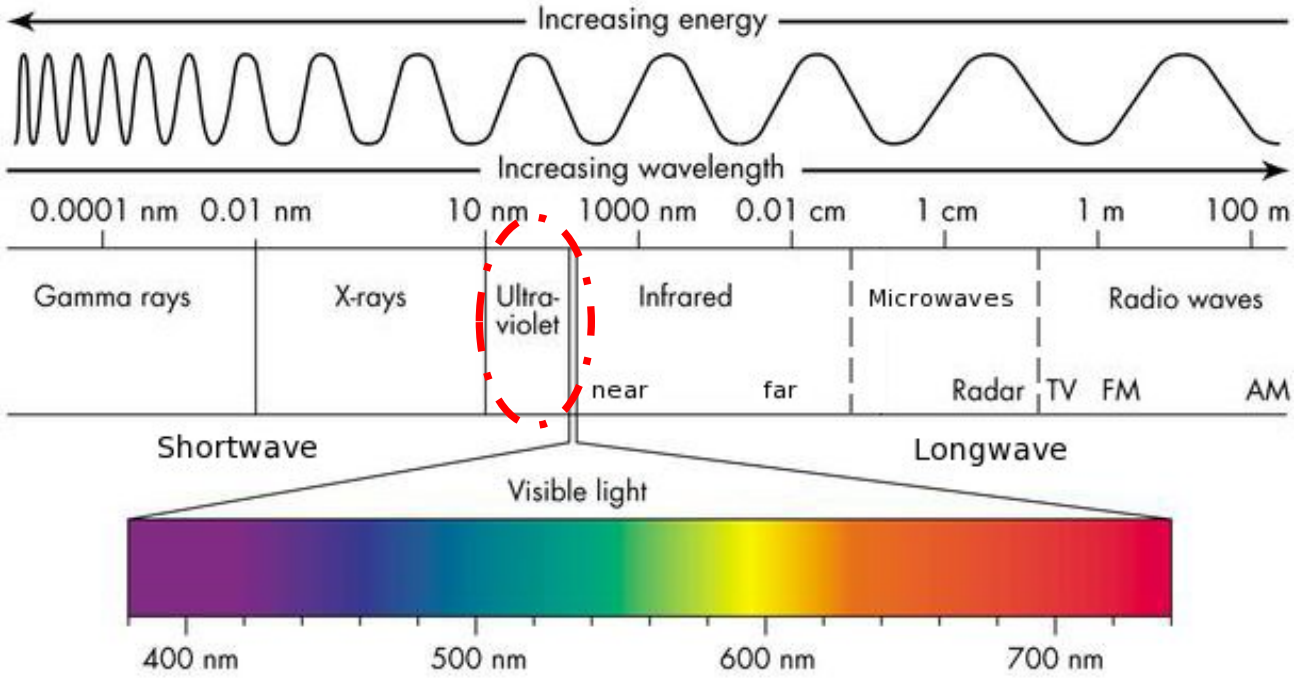


Examples of x-rays imaging

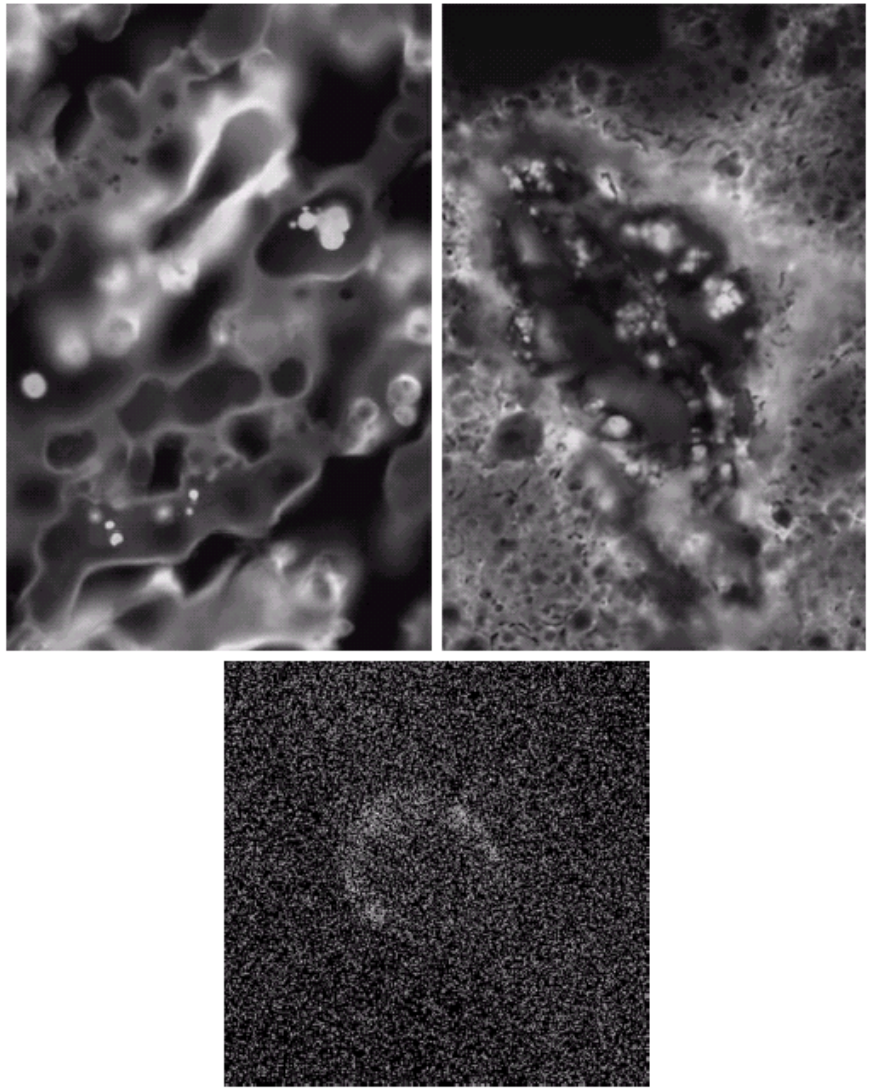


X-ray images from the space
The Chandra X-Ray Observatory

Ultra-Violet



Ultra-Violet



Examples of ultraviolet imaging

(a) Normal corn

(b) Smut corn

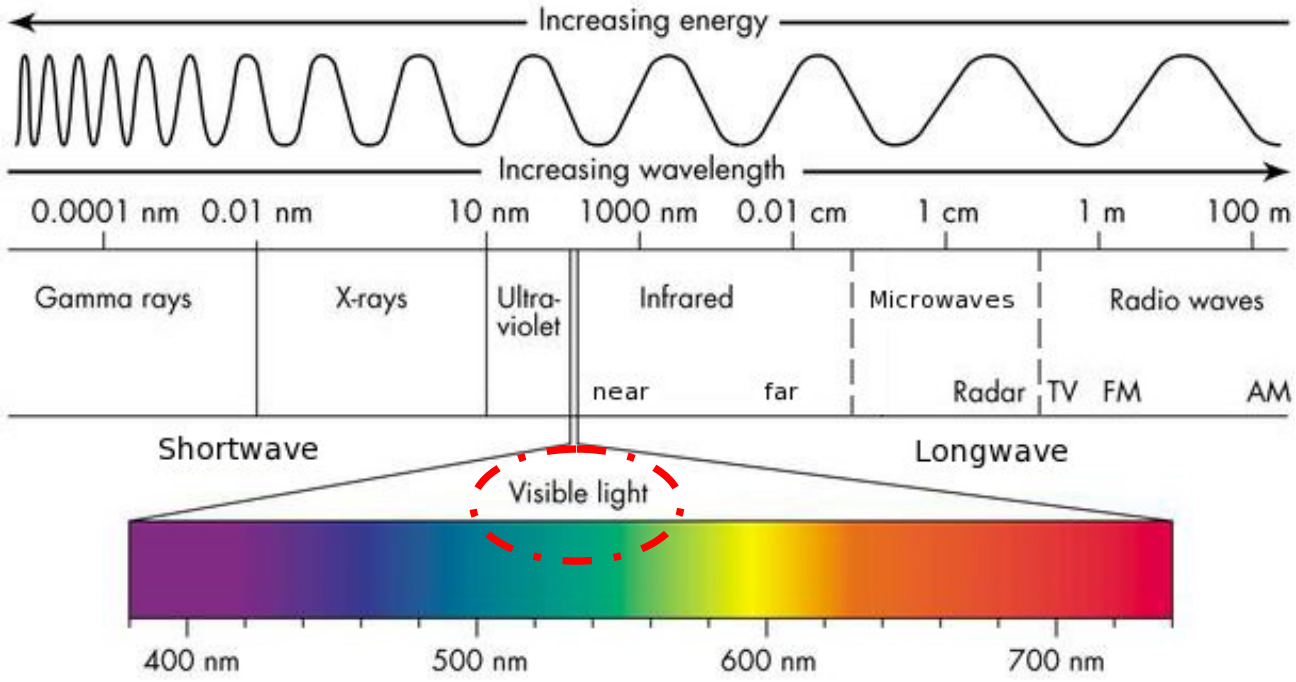
(c) Cygnus Loop

(Images courtesy of (a) and (b)

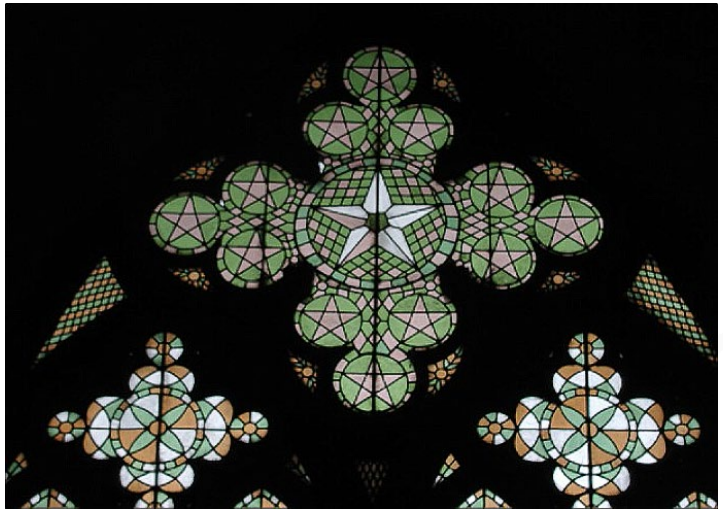
Dr Michael W. Davidson,

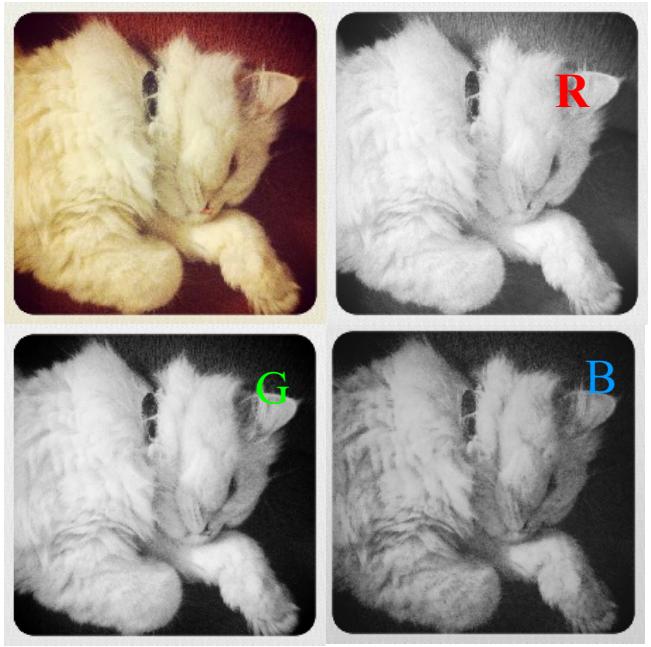
Florida State University, (c) NASA.)

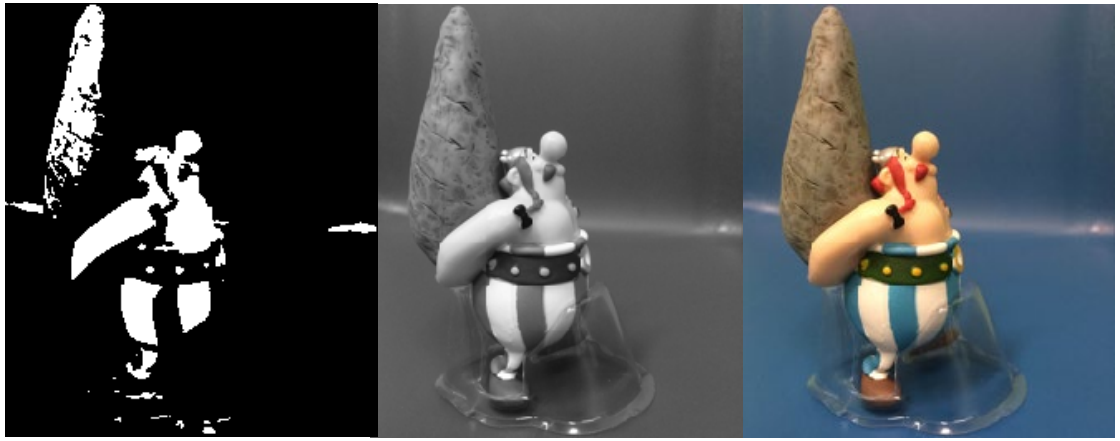
Visible Light



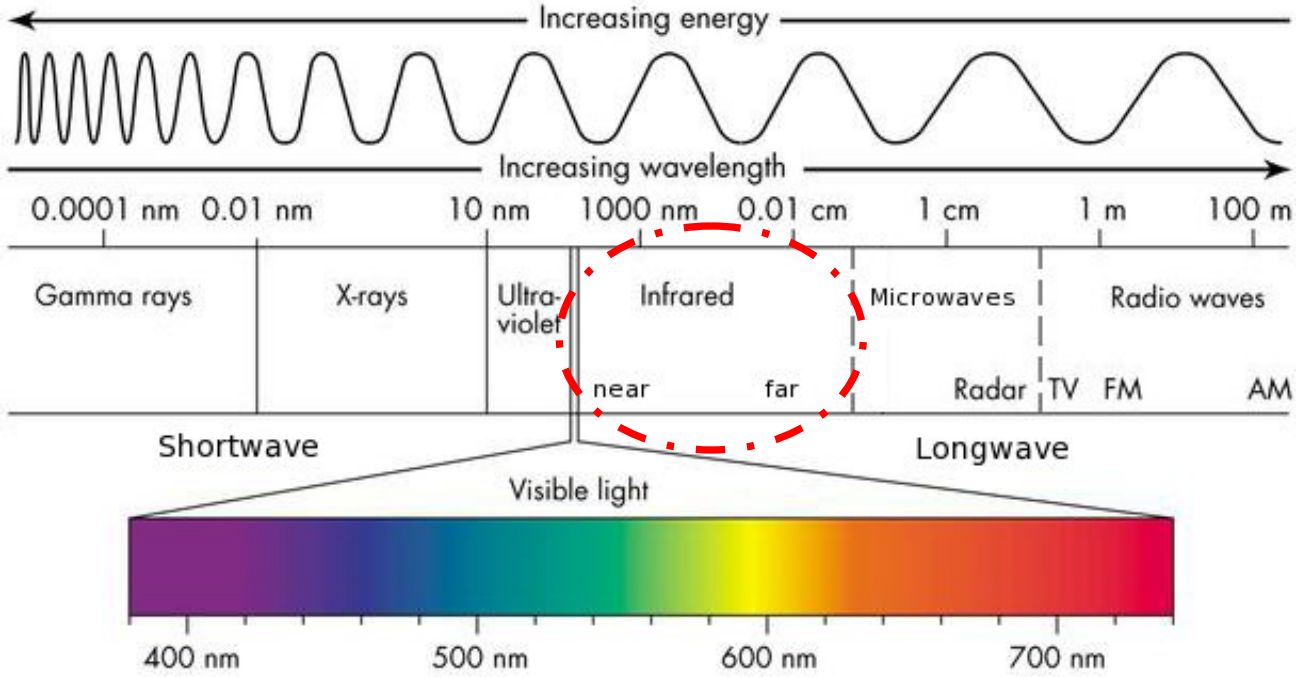
Visible Light







Infrared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Increasing wavelength
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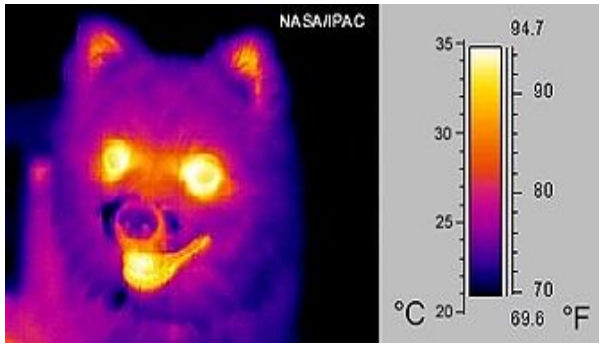
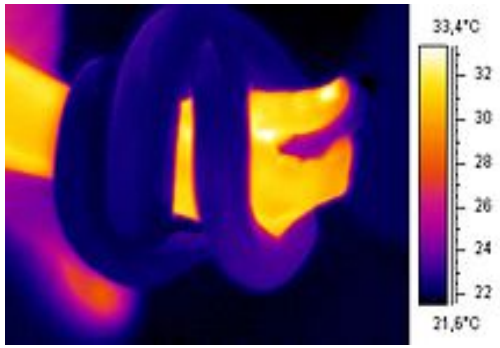
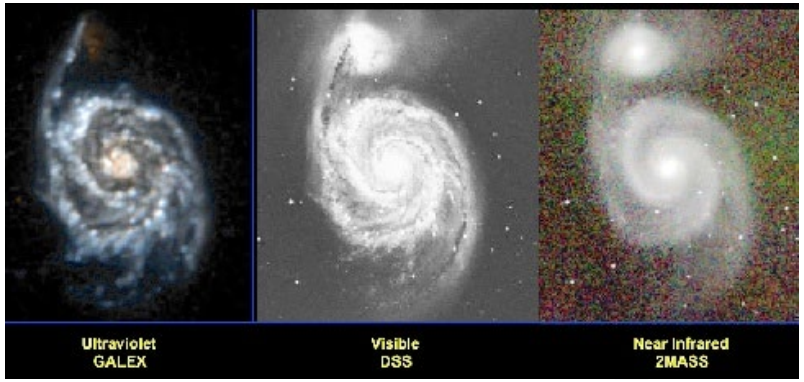
Infrared



infrared ("thermal") image

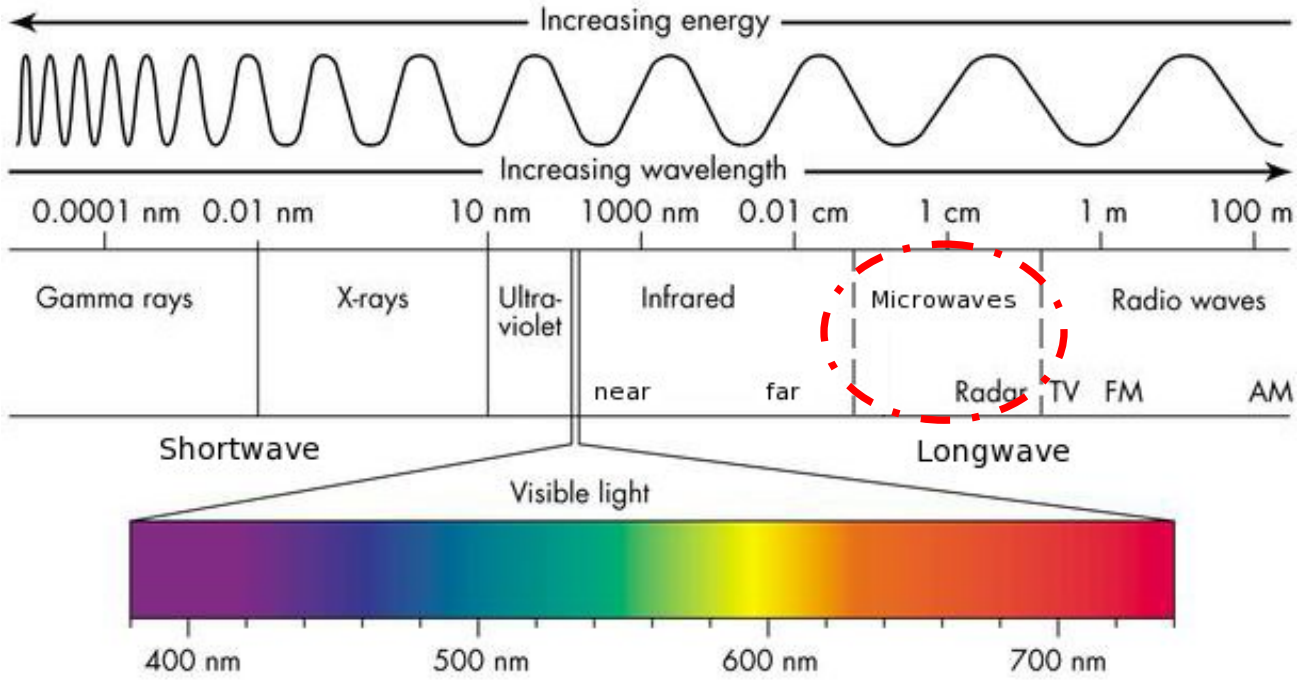


Snake around the arm



Messier 51 in ultraviolet (GALEX), visible (DSS), and near infrared (2MASS). *Courtesy of James Fanson.*

Microwaves


Increasing energy
Increasing wavelength
0.0001 nm
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1000 nm
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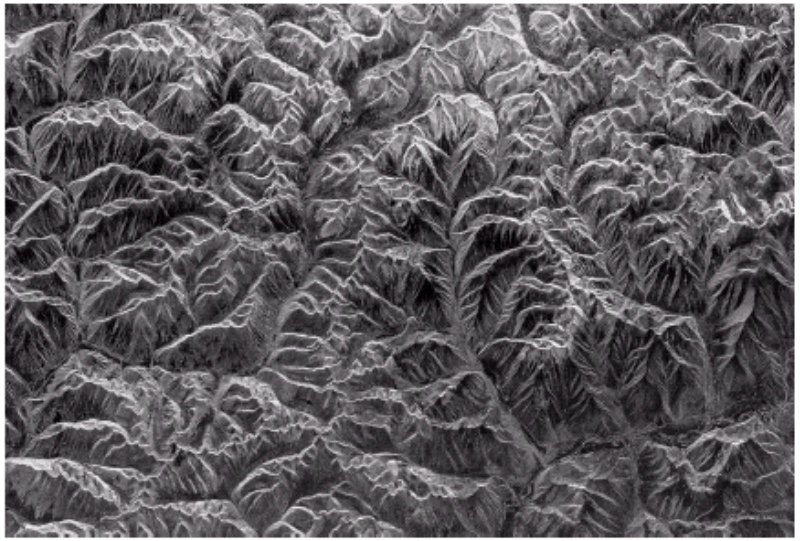
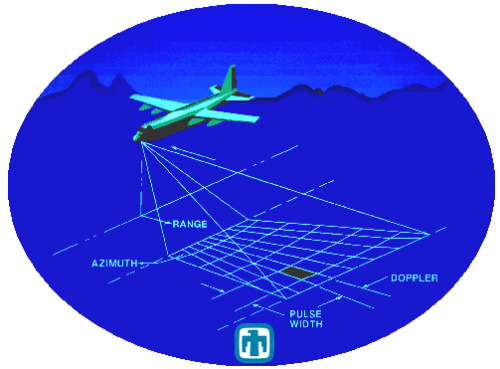
Microwaves

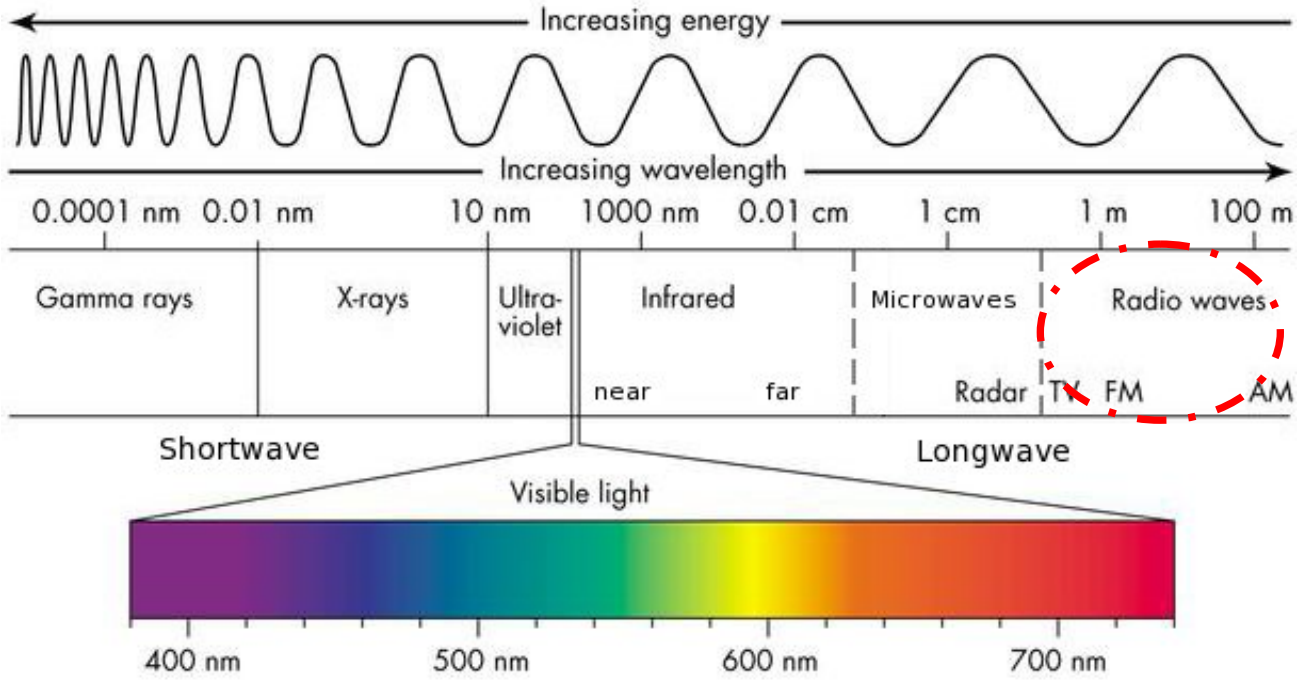




Synthetic Aperture Radar System

Spaceborne radar image of mountains in southeast Tibet (Courtesy of NASA)

Radio Waves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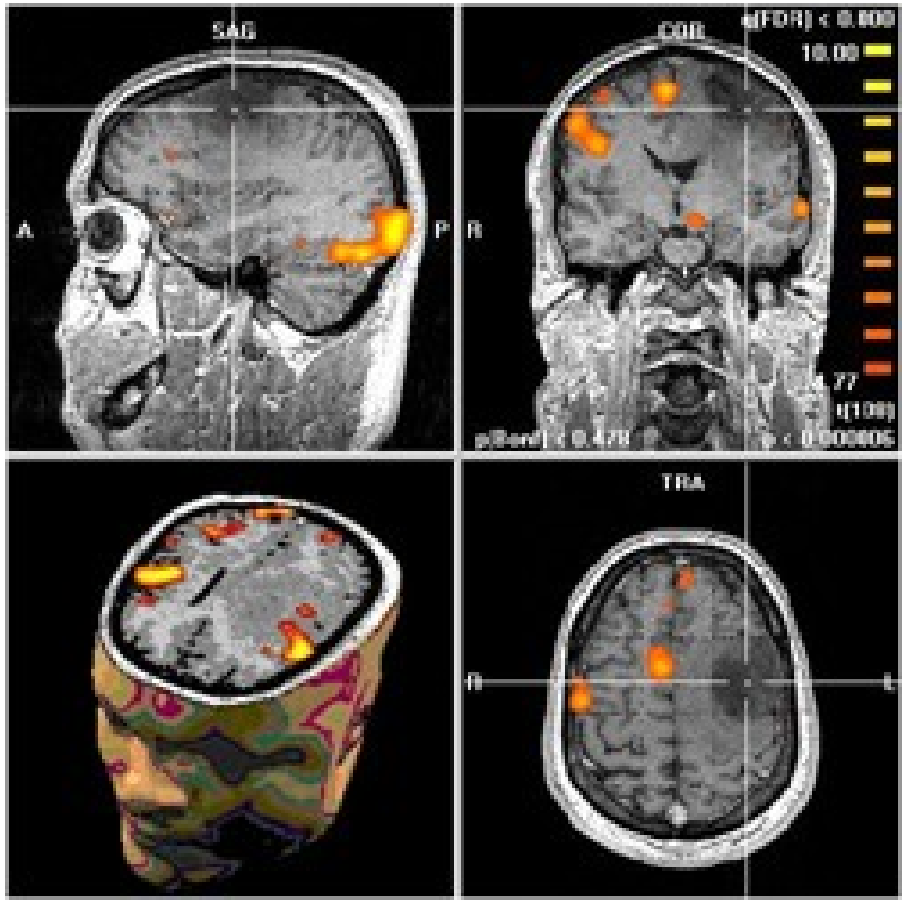
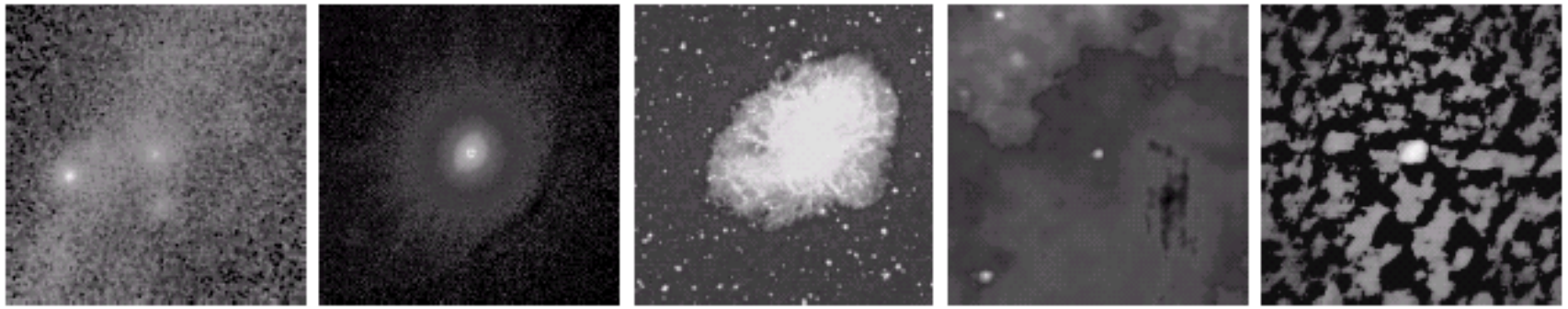
Radio Waves



MRI image slices from the brain

Digital Images based on the EM Spectrum

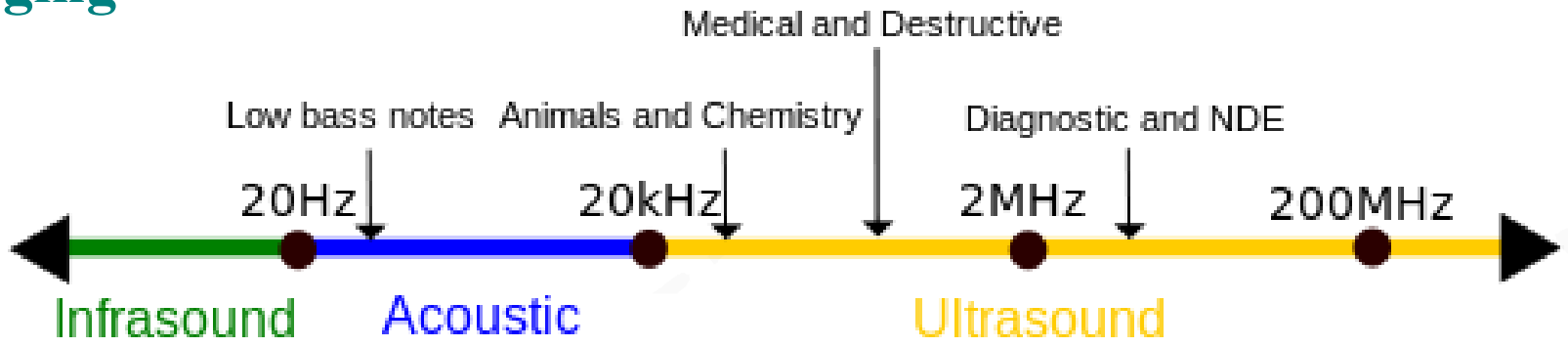
An example showing Imaging in all of the bands



Images of the Crab Pulsar (in the centre of images) covering the EM spectrum

Visible light

Ultrasound Imaging



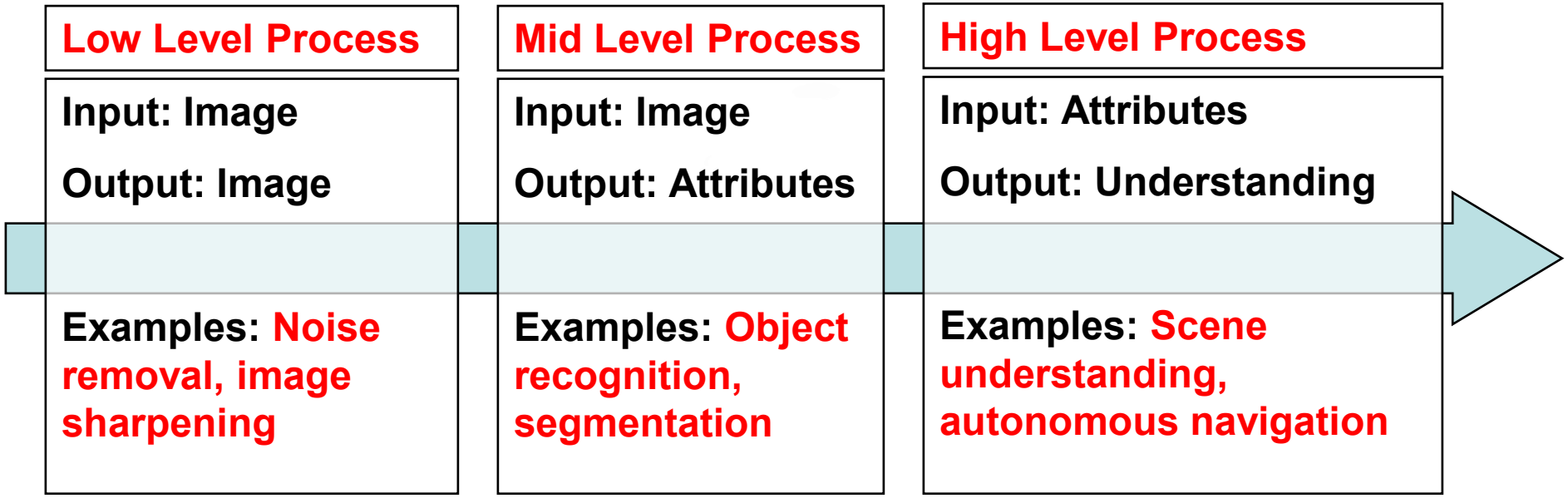
Ultrasonic spectrum

Ultrasonic Baby image during pragnancy

Ultrasound image acquisition device

Levels of Image Processing

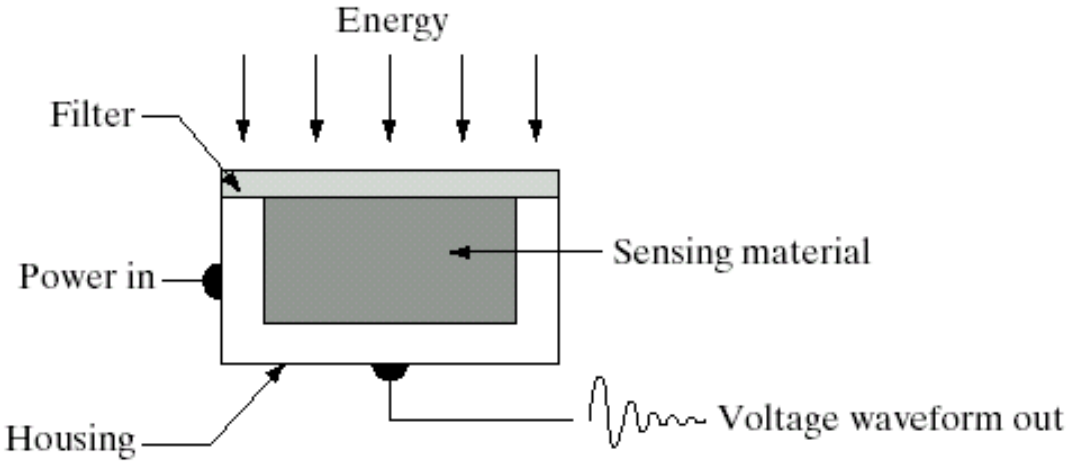
The continuum from image processing to computer vision can be broken into low--, mid- and high-level processes.



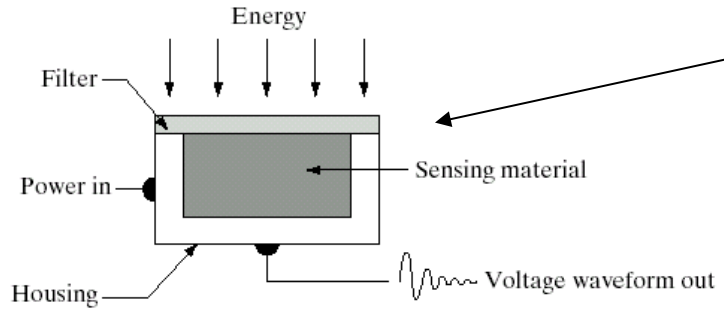
Acquisition of Images

The images are generated by the combination of an *illumination source* and the reflection or absorption of energy from that source by the elements of the *scene* being imaged.

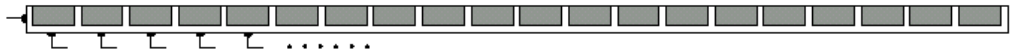
Imaging sensors **are used to transform the** ***illumination energy*** **into digital images.**



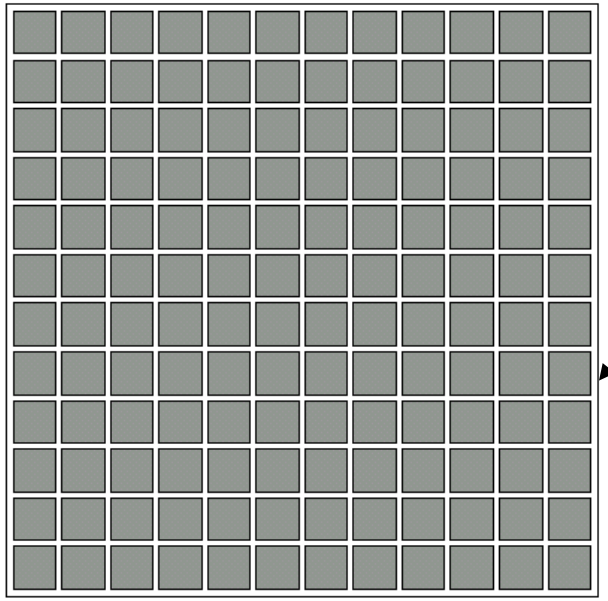
Types of Image Sensors



Single Sensor



Line Sensor



Array Sensor

(a) Single imaging sensor,

(b) Line sensor,

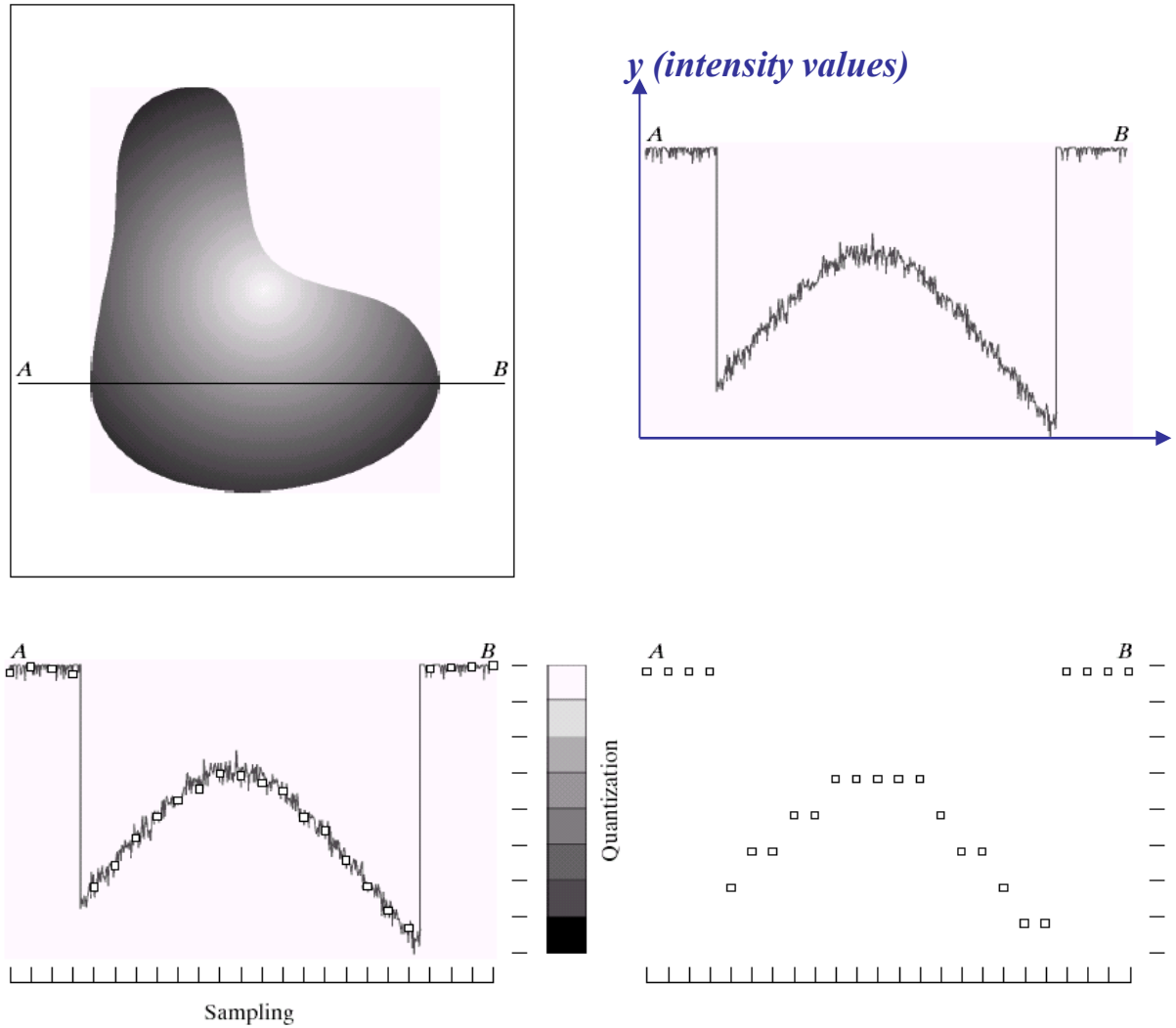
(c) Array sensor

Key stages in digital image processing

Sampling : related to coordinates values

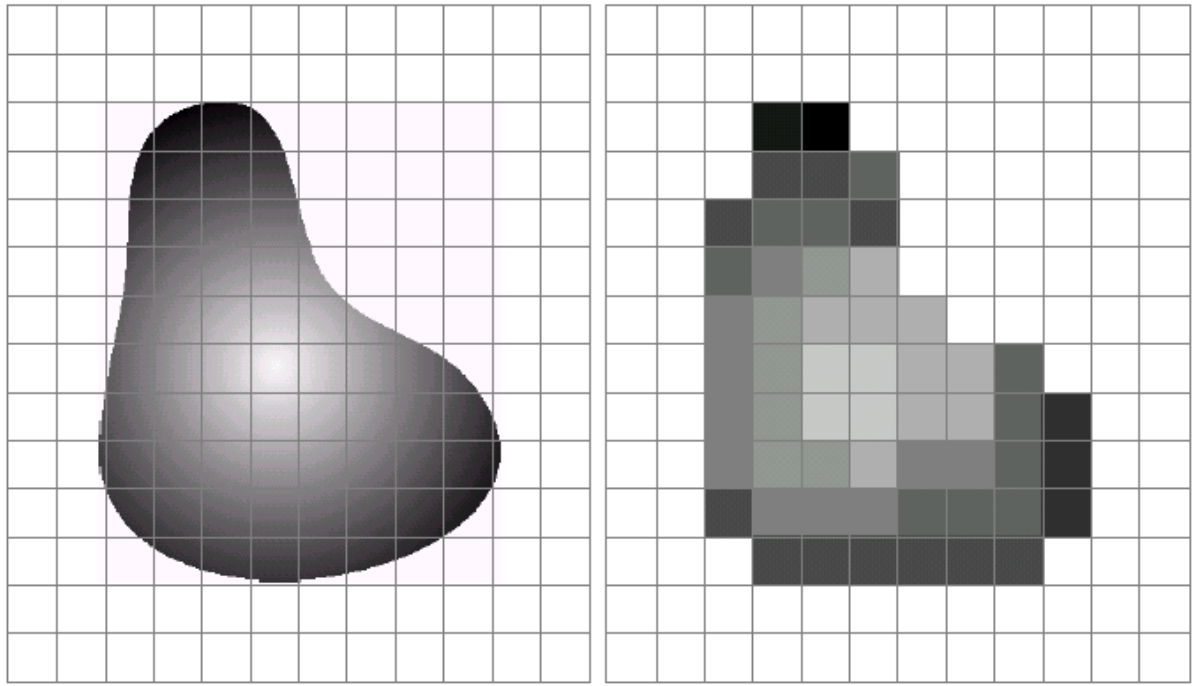
(Nyquist frequency)

Quantisation : related to intensity values



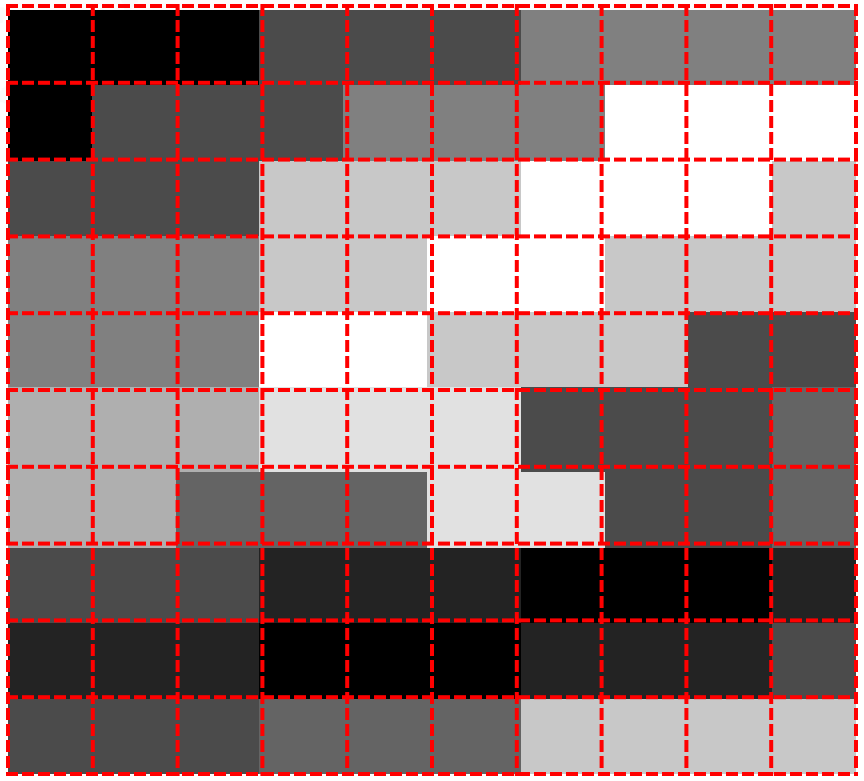
a b
c d

Generating a digital image. (a) Continuous image. (b) A scaling line from A to B in the continuous image illustrates the concepts of sampling and quantisation. (c) sampling and quantisation. (d) Digital scan line.



a b

(a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.



0	0	0	75	75	75	128	128	128	128
0	75	75	75	128	128	128	255	255	255
75	75	75	200	200	200	255	255	255	200
128	128	128	200	200	255	255	200	200	200
128	128	128	255	255	200	200	200	75	75
175	175	175	225	225	225	75	75	75	100
175	175	100	100	100	225	225	75	75	100
75	75	75	35	35	35	0	0	0	35
35	35	35	0	0	0	35	35	35	75
75	75	75	100	100	100	200	200	200	200

Sampling

1024

512

256

128

64

32

Sampling

1024

512

256

128

64

32

Quantisation

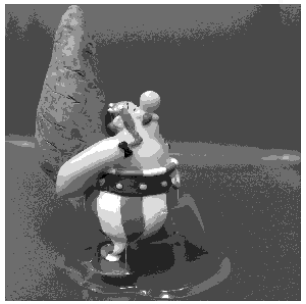
8-bit

7-bit

6-bit

5-bit

4-bit



3-bit

2-bit

1-bit

Image Enhancement

Spatial Domain Methods: manipulates the pixel of a given image for enhancement.

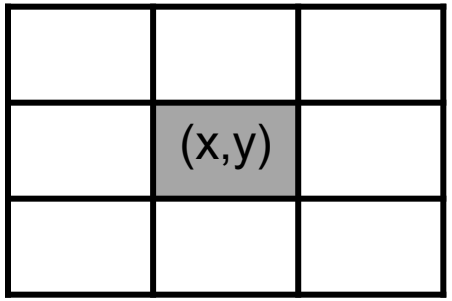
Frequency Domain Methods: manipulates the Fourier transform of a given image for enhancement.

$$g(x,y)=T[f(x,y)]$$

f(x,y) : input

g(x,y) : output

T : transformation function



3x3 neighborhood (mask)

Image Enhancement in Spatial Domain

Point Processing: enhancement at any point in an image depends only the gray-level at that point.

Mask Processing/Filtering: where the values of the mask coefficients determine the nature of the process.

Contrast Stretching

Contrast: is the difference in visual properties making an object/image distinguishable from other objects and the background.

Resizing Images

Zooming : Creating new pixel locations

Assigning gray-level values to these locations

Solution: Interpolation

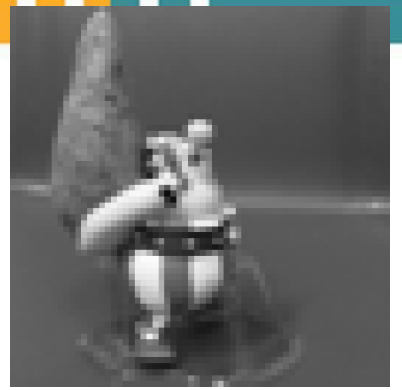
3 main type of 2D Interpolations :

Nearest neighbor interpolation

Bilinear interpolation

Bicubic interpolation

Nearest Neighbor



Bilinear

Bicubic

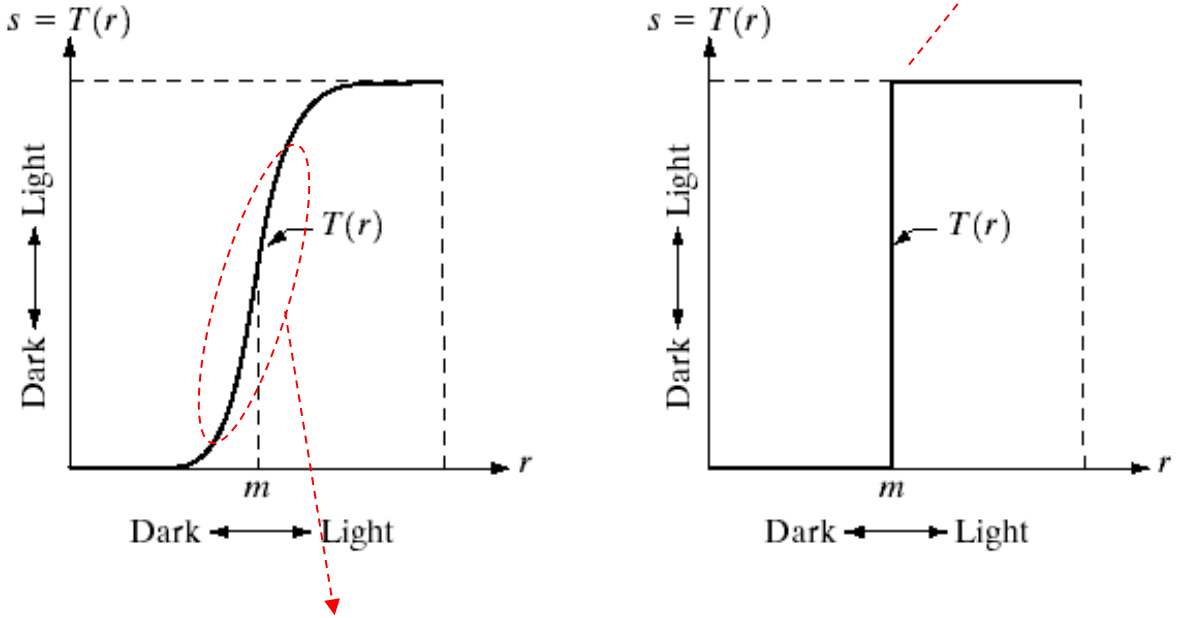
128 → 1024

64 → 1024

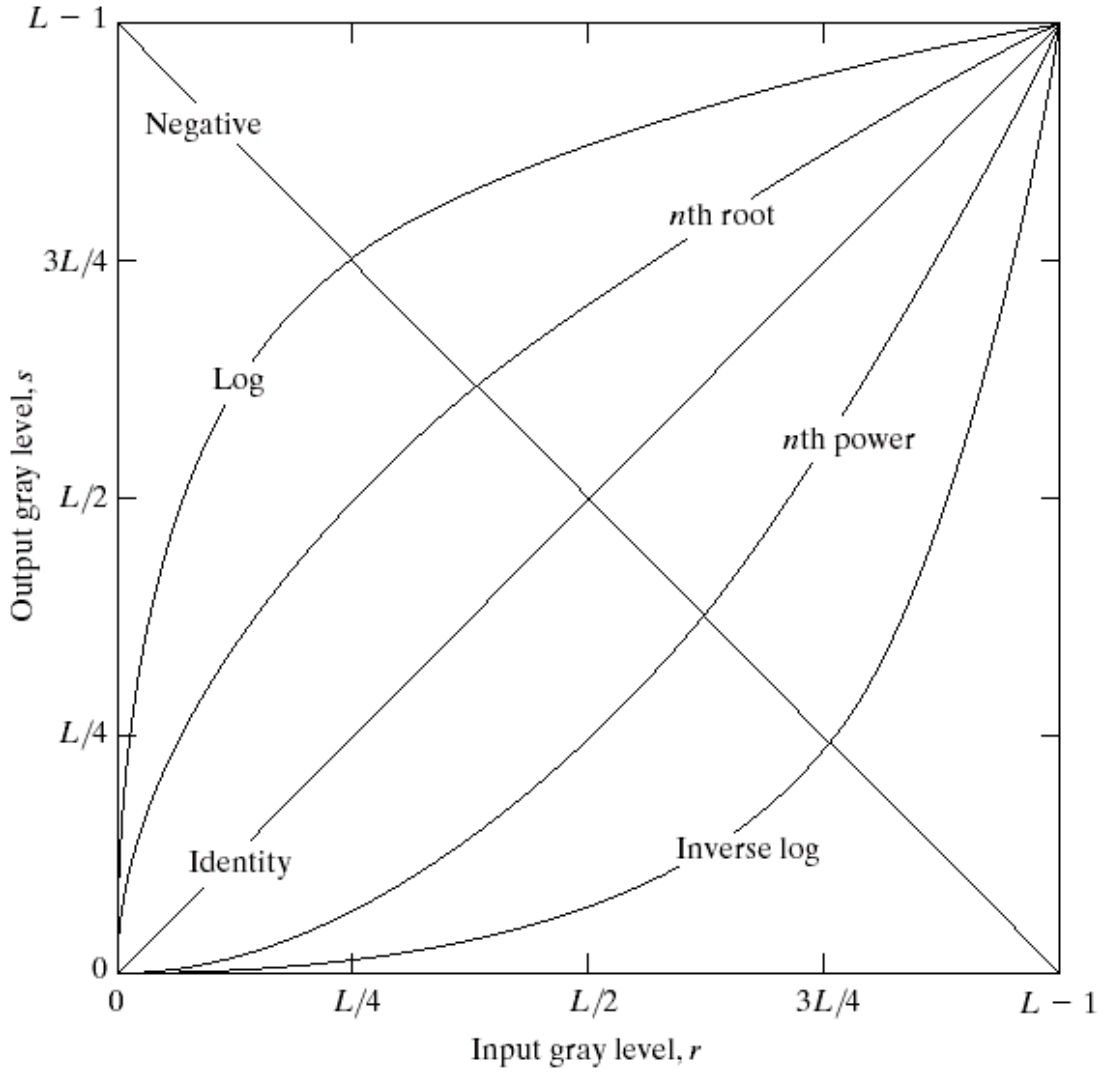
Contrast Enhancement

Contrast Stretching: improves the contrast in an image by stretching the range of intensity values to span a desired range of values.

Converts to black & white



Linear Part contributes to the contrast stretching



Some basic grey-level transformation functions used for contrast enhancement

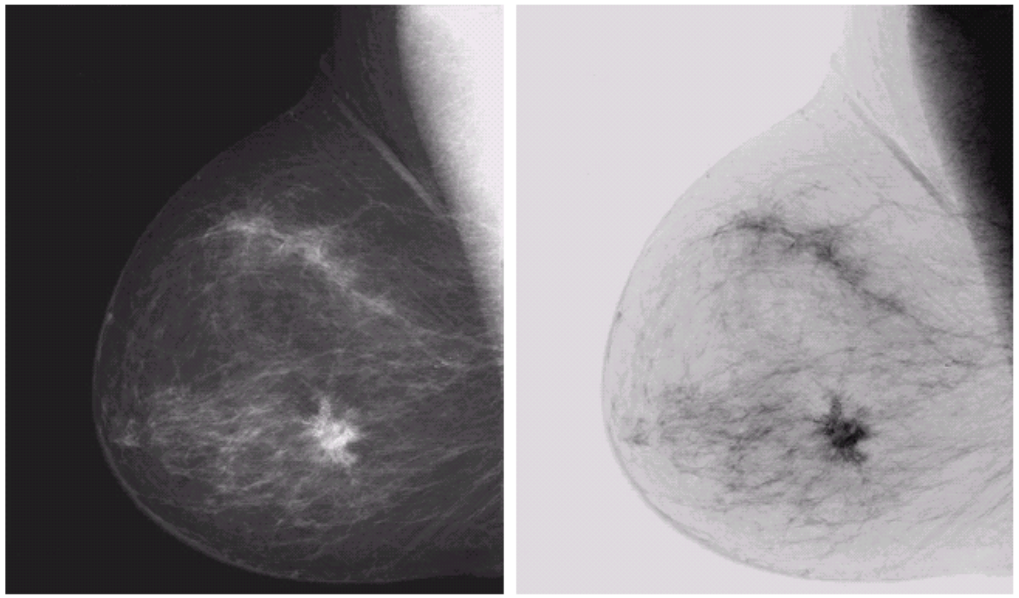
L=2k

k: number of bits used to represent each pixel

Image Negatives

$$s = (L-1) - r$$

s is the pixel value of the output image and r is the pixel value of the input image.

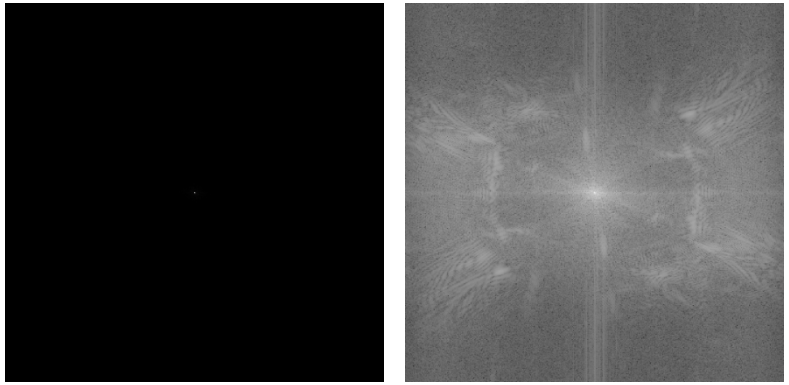


(left) Original digital mammogram. (right) Negative image obtained using the negative transformation

Logarithmic Transformations

$$s = c \log(1 + r)$$

s is the pixel value of the output image and r is the pixel value of the input image.

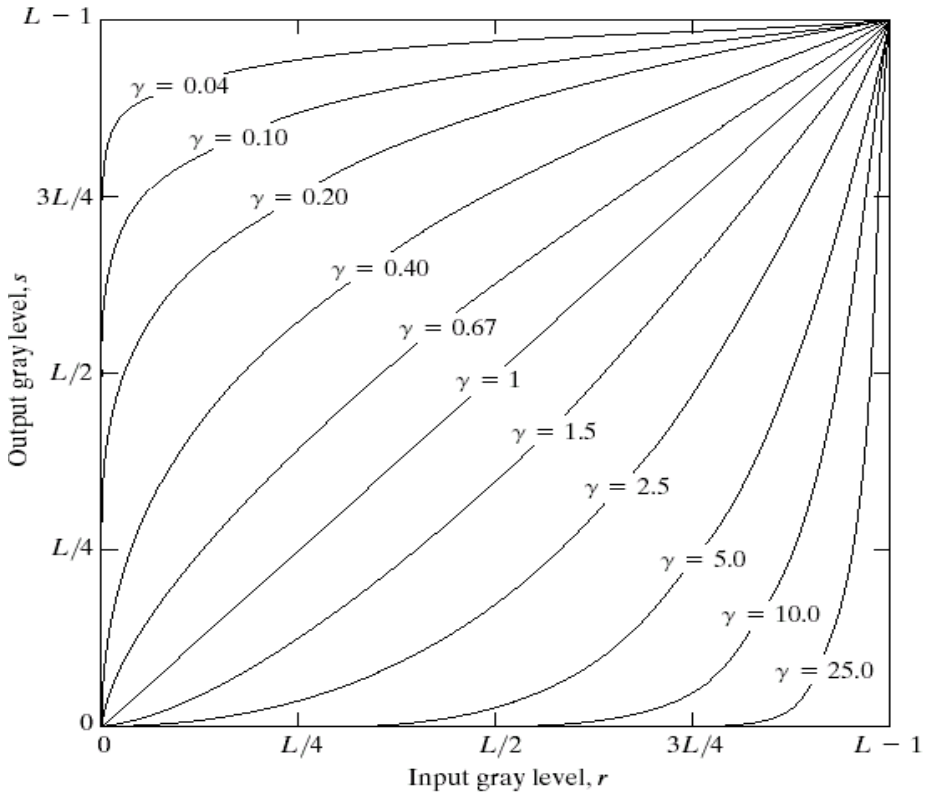


(left) Fourier spectrum of Barbara's image. (right) Result of applying the log transformation

Logarithmic Transformations

$$s = c\ r^{\gamma}$$

s is the pixel value of the output image and r is the pixel value of the input image. ($\gamma \geq 0$ and $0 \leq r \leq 1$)



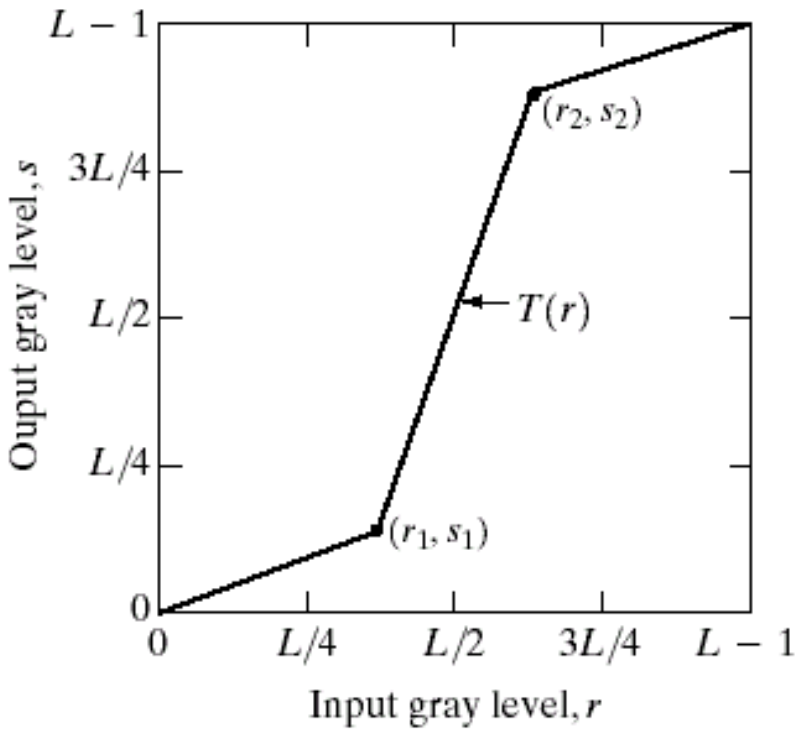
Plots for various values of γ (c=1)

Logarithmic Transformations

a b
c d

(a) original image. (b) γ = 0.5 .
(c) γ = 0.3 . (d) γ = 0.7.

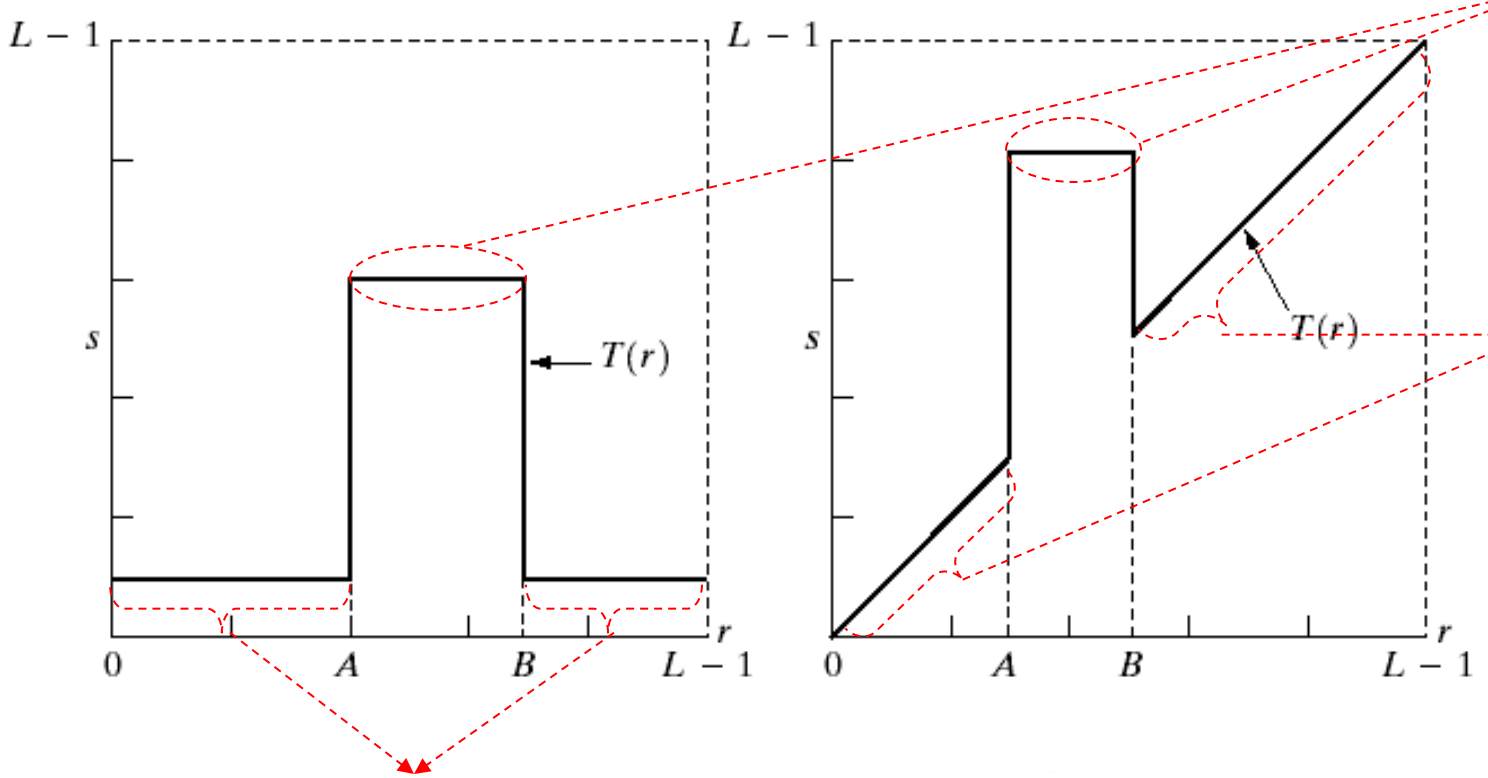
Piecewise-Linear Transformations



An example of piecewise linear transformation function

Piecewise-Linear Transformations

grey-level slicing



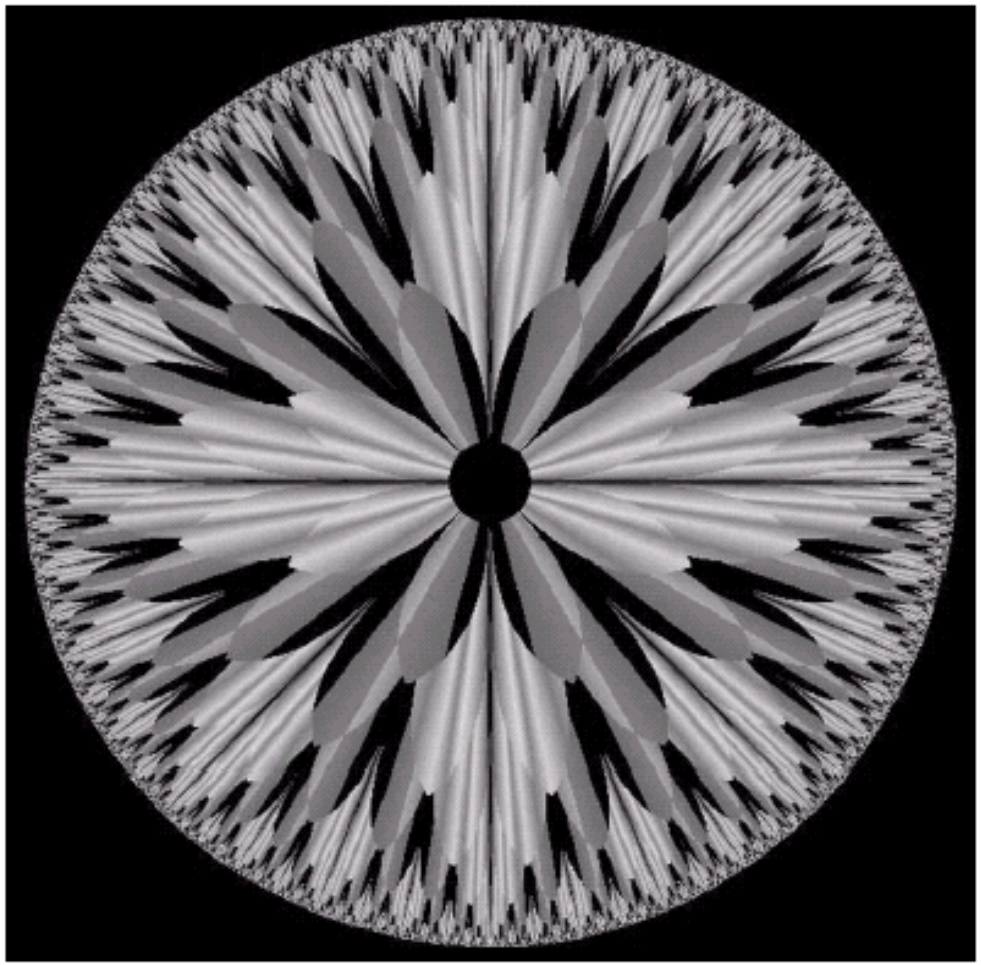
Pixel values between [A,B] are highlighted

Other pixel values are preserved

Other pixel values are darkened

Piecewise-Linear Transformations

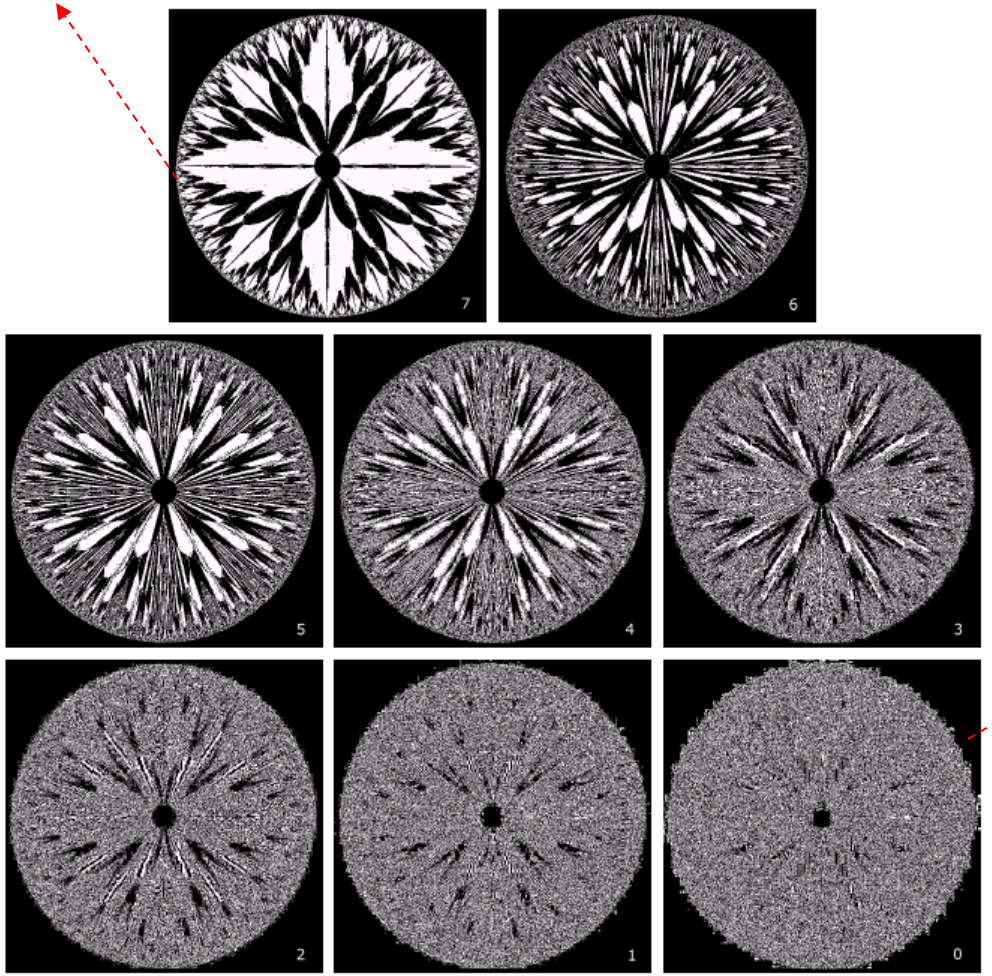
Bit Plane slicing



An 8-bit fractal image

Piecewise-Linear Transformations

Bit Plane slicing

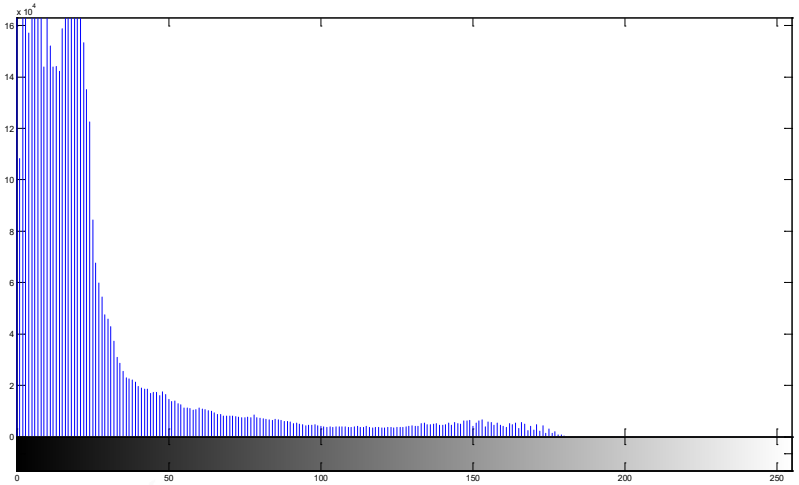


Histogram Processing

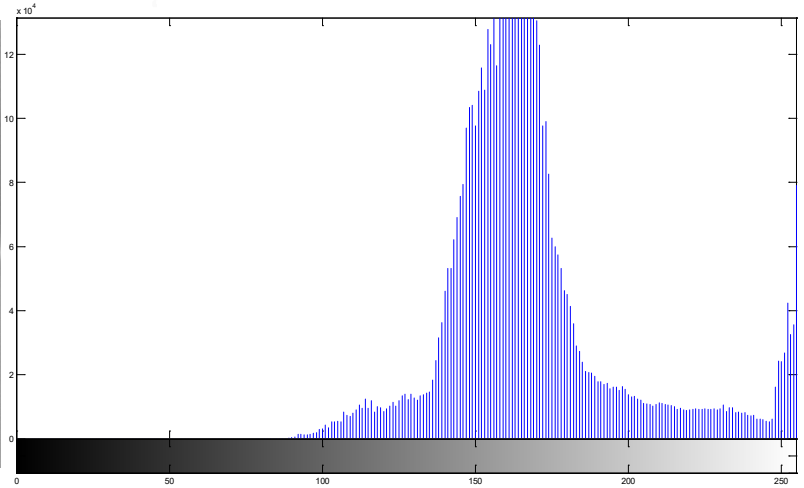
Histogram : is the discrete function $h(r_k)=n_k$, where r_k is the k^{th} gray level in the range of [0, L-1] and n_k is the number of pixels having gray level r_k.

Normalized histogram : is $p(r_k)=n_k/n$, for k=0,1,…,L-1 and $p(r_k)$ can be considered to give an estimate of the probability of occurrence of ray level r_k.

Histogram of 4 basic grey-level characteristics

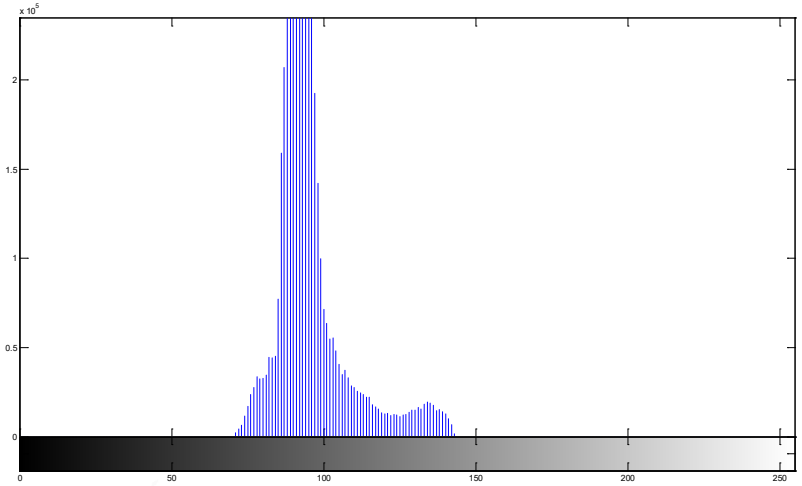


Dark image

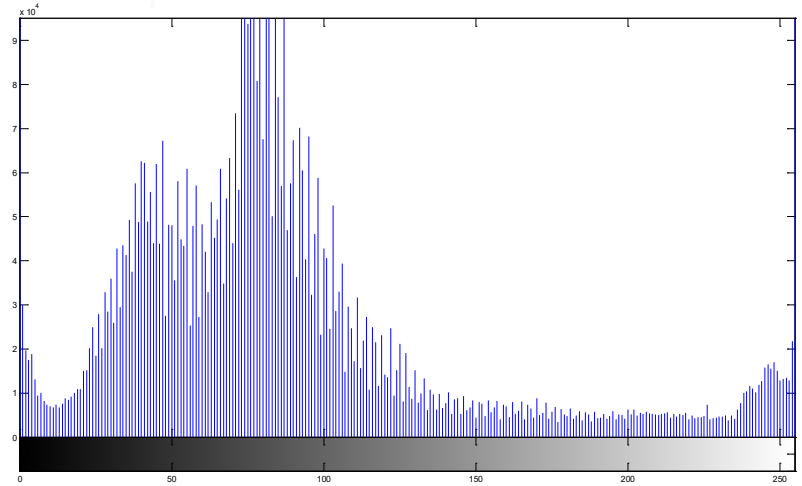


Bright image

Histogram of 4 basic grey-level characteristics



Low contrast image



High contrast image

Question 1

01. What are the types of images you know?

A. Binary

B. Black and white

C. Grayscale

D. Color

E. All of these

Answer E. All of these

Question 2: Fill the blanks

02. A color image has _____, _____, and _____ pixels.

Answer. Red, green, and blue

Question 3

03. The size of each pixel in a binary image is _____.?

A. One bit

B. Two bit

C. Four bit

D. Eight bit

E. Sixteen bit

Answer A. One bit

You may note it

Storage requirements for all the image types

- **Binary – 1 bit per pixel.**
- **Black and white – 8 bits per pixel.**
- **Grayscale – 8 bits per pixel.**
- **Color – 24 bits per pixel (R, G, and B channels together).**

REFERENCES

- Gonzalez, R. C., Woods, R. E. (2008). Digital image processing. Upper Saddle River, N.J.: Prentice Hall. ISBN: 9780131687288 013168728X 9780135052679 013505267X
- A Baskar, Muthaiah Rajappa, Shriram K Vasudevan, and T S Murugesh (2023) Digital Image Processing, First edition published 2023 by CRC Press, ISBN: 9781003217428 (ebk), DOI: 10.1201/9781003217428
- https://sisu.ut.ee/imageprocessing/avaleht

CONCLUSION

- **Basics of Digital Image**
- **Image Acquisition**
- **Image Processing**
- **Image Enhancement**


THANK YOU