ISEL
ÁREA DEPARTAMENTAL DE ENGENHARIA
DE ELETRÓNICA E TELECOMUNICAÇÕES
E DE COMPUTADORES - ADEETC

PROCESSAMENTO DE IMAGEM E BIOMETRIA

IMAGE PROCESSING AND BIOMETRICS

1. **IMAGE FUNDAMENTAL CONCEPTS**

Summary

- Digital Image
  - Definition, acquisition, formation, and display
- Digital Image Processing (DIP)
- Key concepts and measures
  - Spatial Resolution
  - Depth Resolution
  - Histogram
  - Energy, Power, and Average Intensity
  - Brightness
  - Contrast
  - Entropy
- MATLAB toolbox for DIP
- Exercises

Digital image: a definition

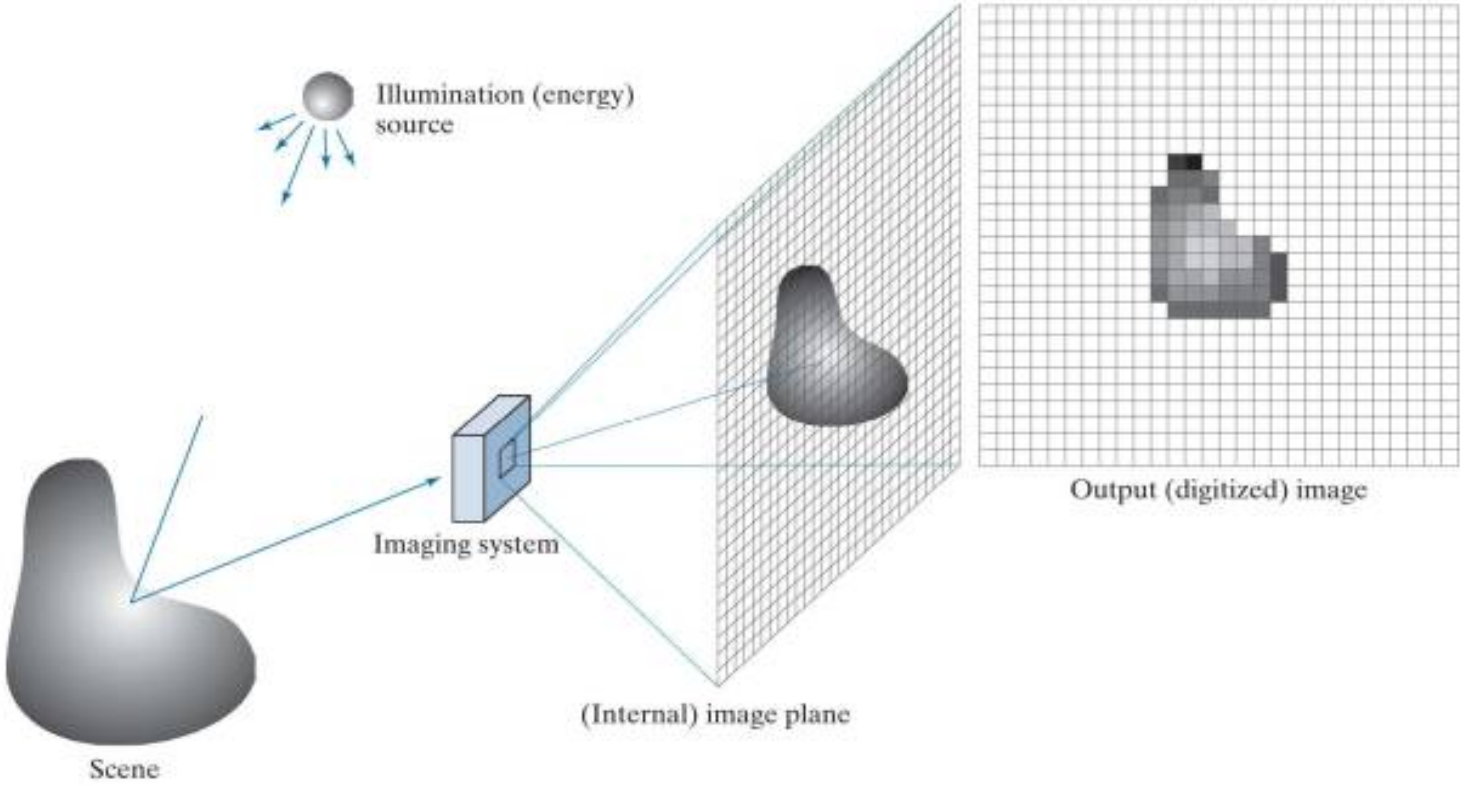
- Bi-dimensional function of two spatial coordinates
  - f(x, y), in which x and y are the spatial coordinates
  - I[m,n], in which m and n are the spatial coordinates

- The amplitude for a pair of coordinates (x, y) is the image intensity or the **gray level** of the image

- When x, y, and the amplitude are discrete values we have a **digital image**

- Each element of the image is named ***pixel*** (PIcture X ELement)

Digital image: acquisition (1)



a
b c d e

FIGURE 2.15
An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Digital image: acquisition (2)

Figure 2.16(a) shows a continuous image *f* that we want to convert to digital form. An image may be continuous with respect to the *x*- and *y*-coordinates, and also in amplitude. To digitize it, we have to sample the function in both coordinates and also in amplitude. Digitizing the coordinate values is called *sampling*. Digitizing the amplitude values is called *quantization*.

a b
c d

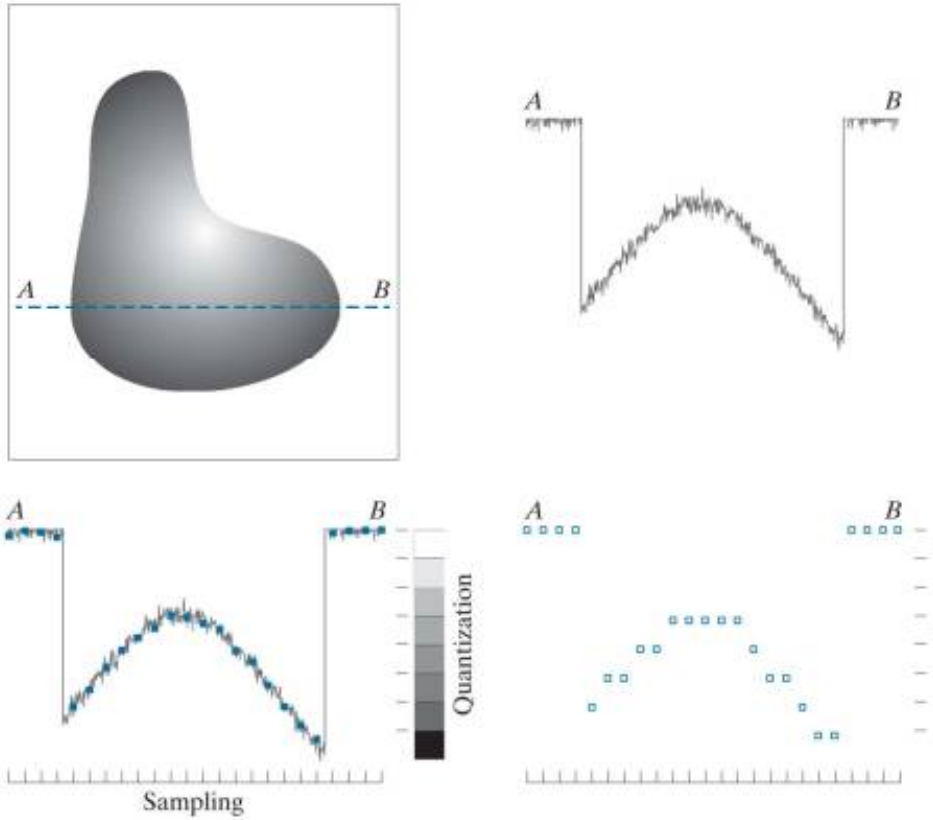


FIGURE 2.16
(a) Continuous image. (b) A scan line showing intensity variations along line *AB* in the continuous image. (c) Sampling and quantization. (d) Digital scan line. (The black border in (a) is included for clarity. It is not part of the image).

Digital image: acquisition (3)

a b

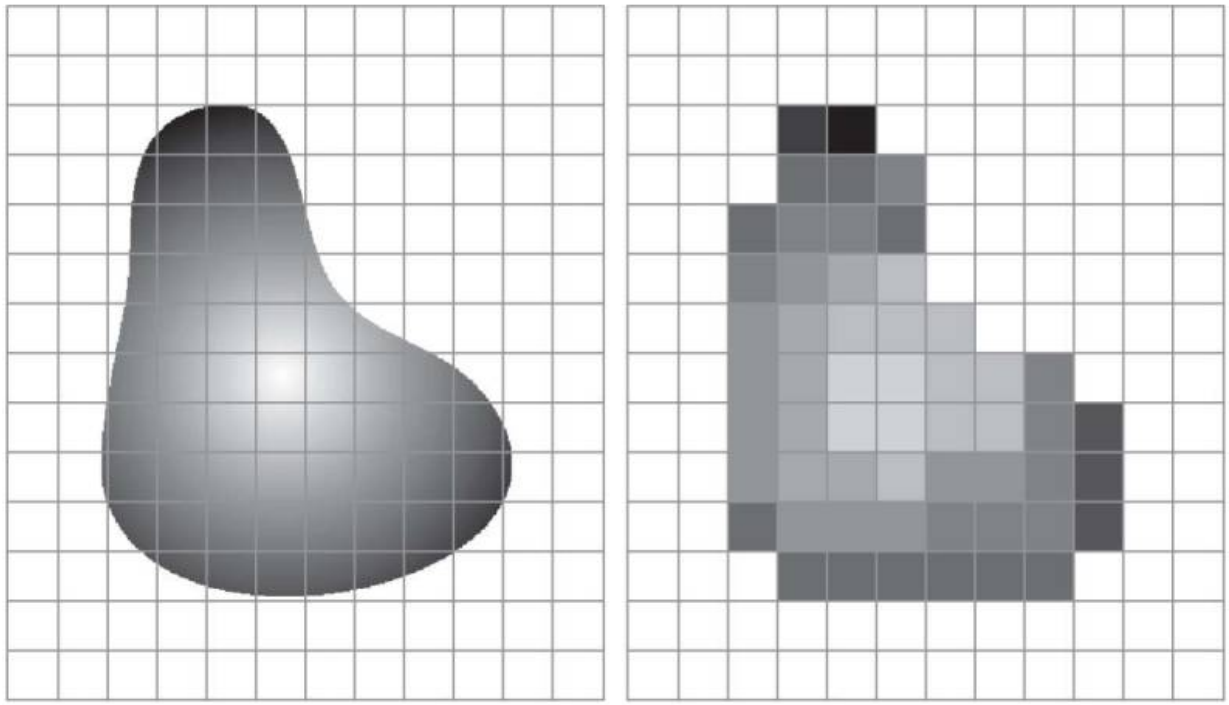
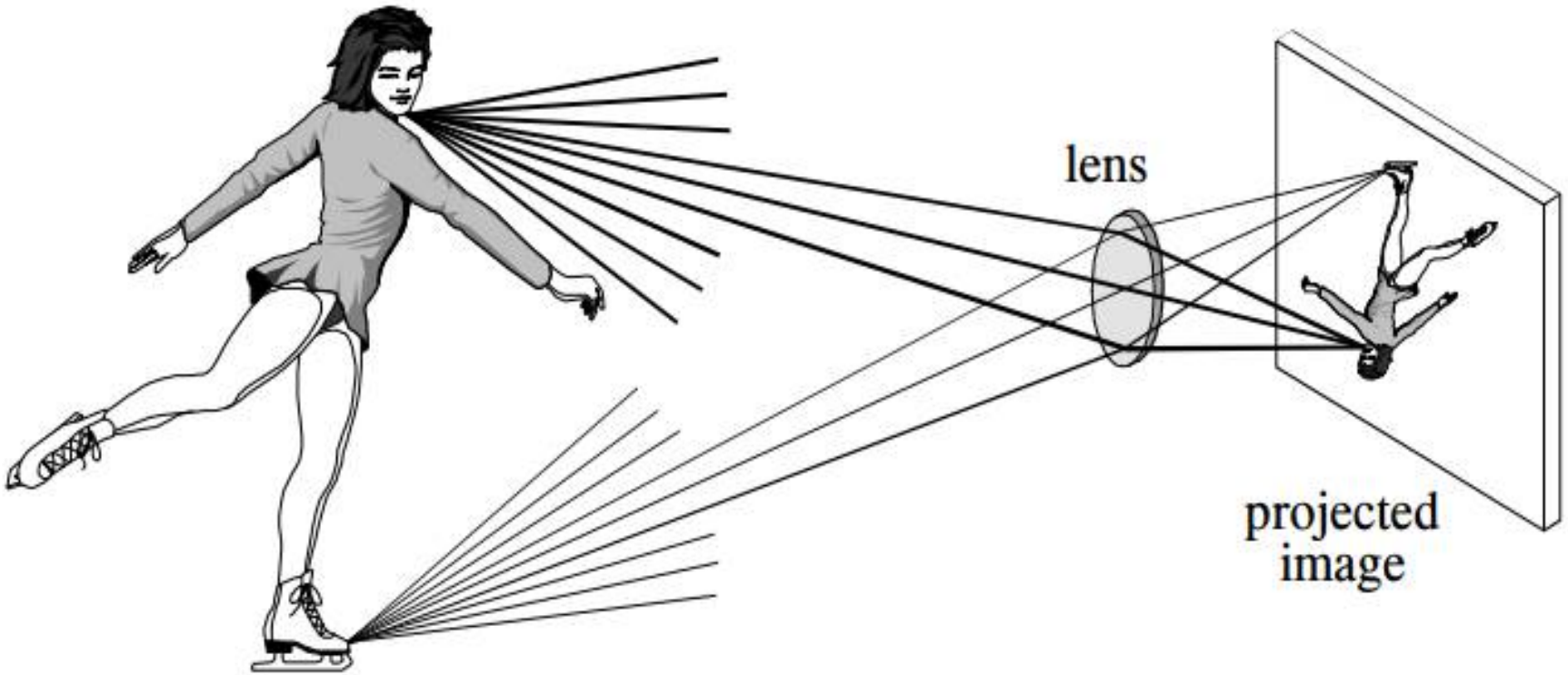
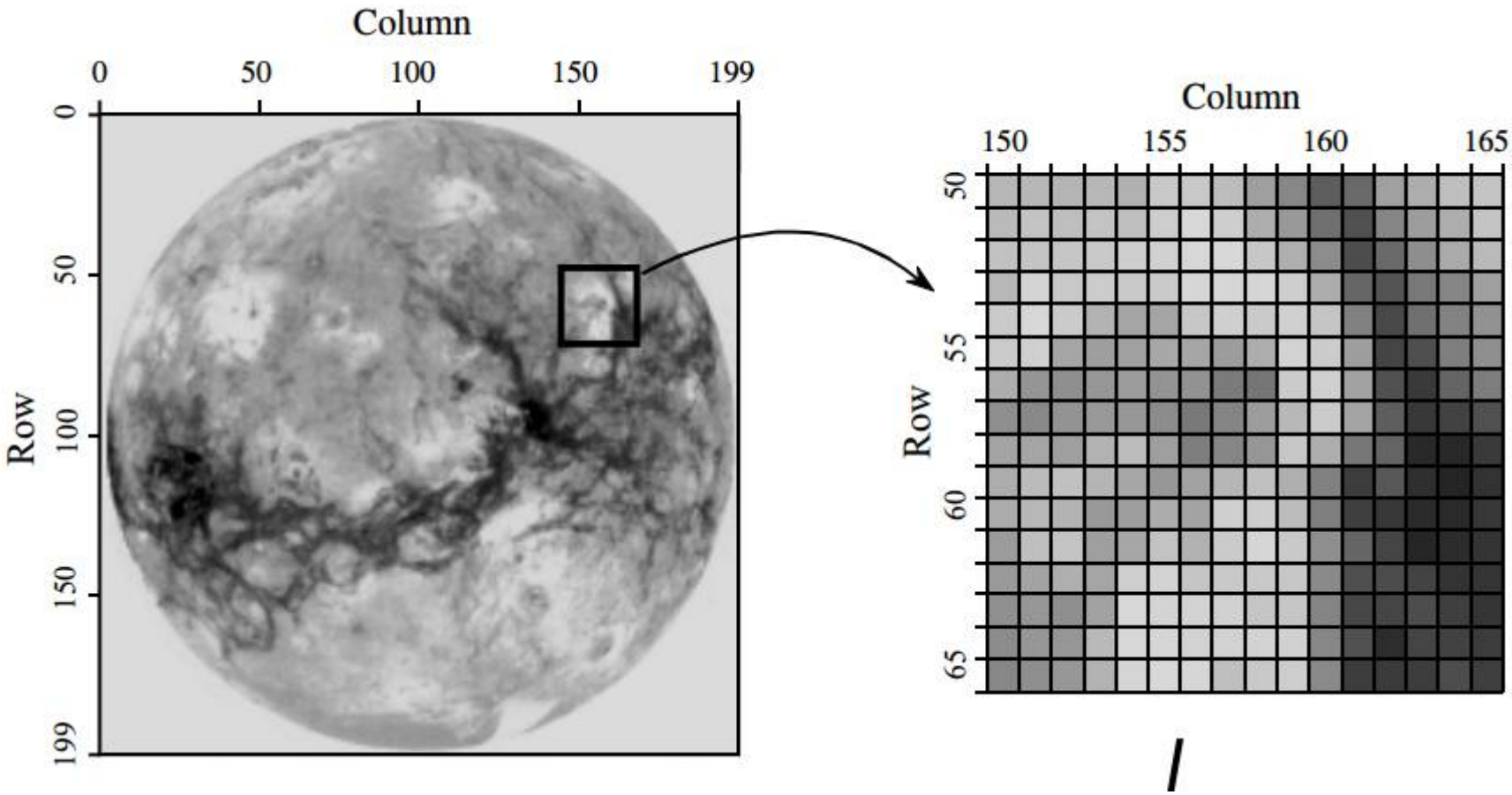


FIGURE 2.17
(a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Digital image: acquisition (3)



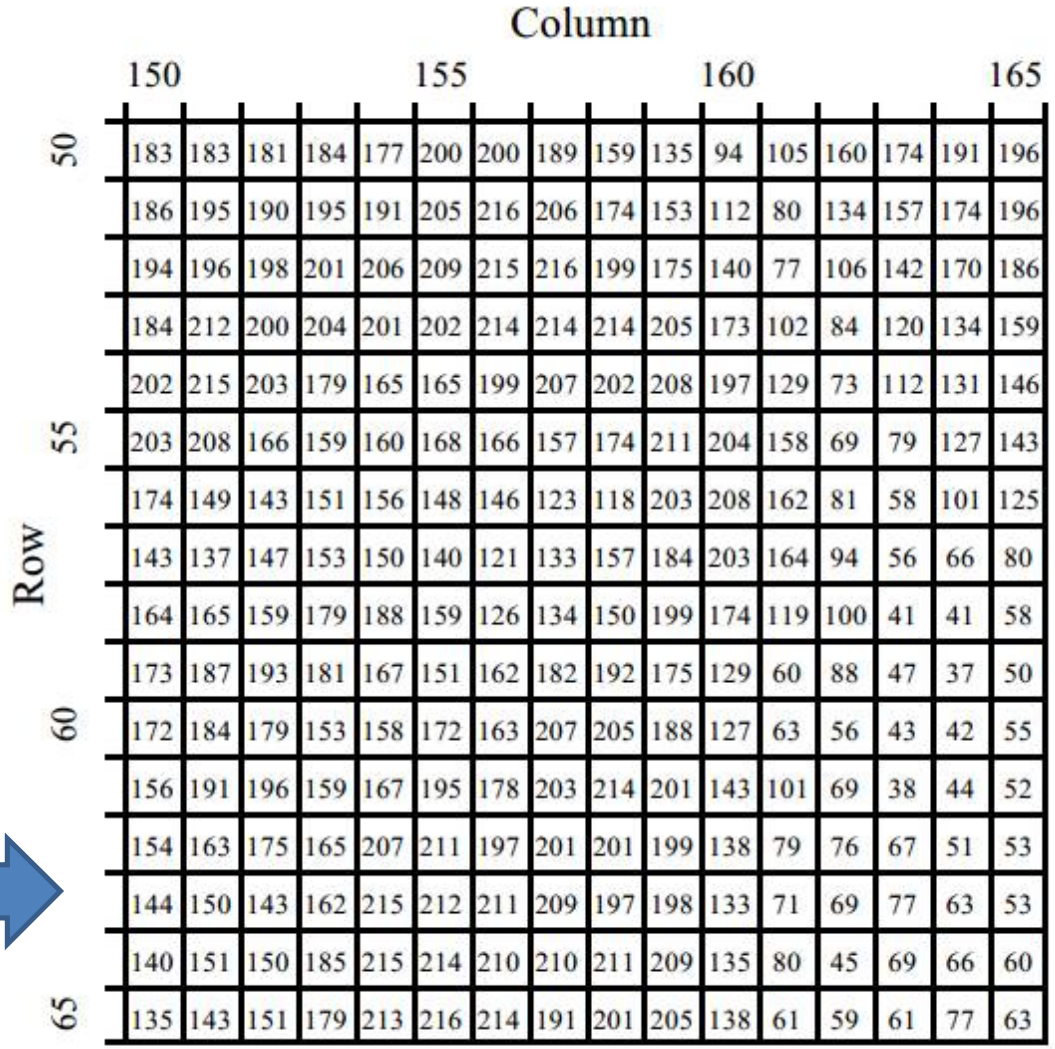
Digital image: representation (1)



Digital image: representation (2)

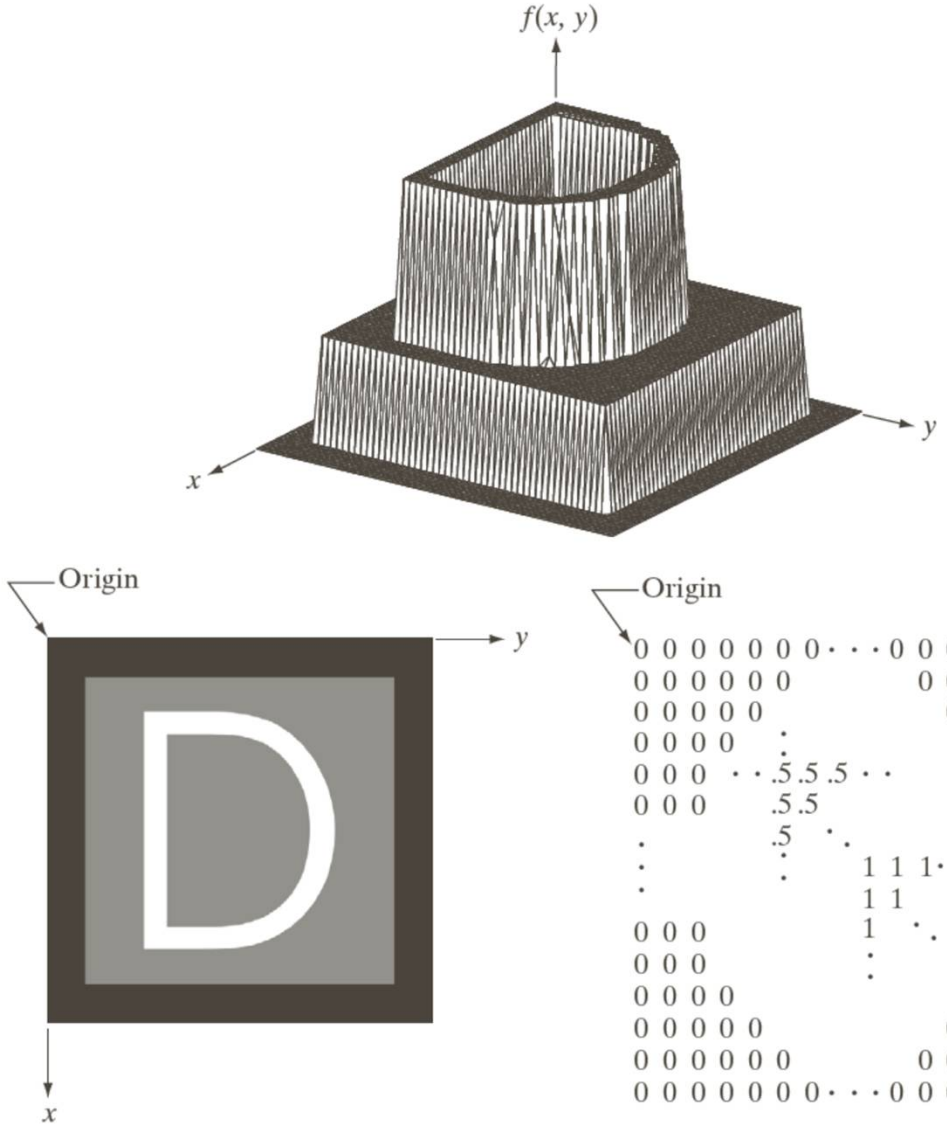
FIGURE 23-1
Digital image structure. This example image is the planet Venus, as viewed in reflected microwaves. Digital images are represented by a two-dimensional array of numbers, each called a *pixel*. In this image, the array is 200 rows by 200 columns, with each pixel a number between 0 to 255. When this image was acquired, the value of each pixel corresponded to the level of reflected microwave energy. A *grayscale* image is formed by assigning each of the 0 to 255 values to varying shades of gray.

Pixel values ranging from 0 to 255 (non-negative values)



Row \ Column	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165
50	183	183	181	184	177	200	200	189	159	135	94	105	160	174	191	196
51	186	195	190	195	191	205	216	206	174	153	112	80	134	157	174	196
52	194	196	198	201	206	209	215	216	199	175	140	77	106	142	170	186
53	184	212	200	204	201	202	214	214	214	205	173	102	84	120	134	159
54	202	215	203	179	165	165	199	207	202	208	197	129	73	112	131	146
55	203	208	166	159	160	168	166	157	174	211	204	158	69	79	127	143
56	174	149	143	151	156	148	146	123	118	203	208	162	81	58	101	125
57	143	137	147	153	150	140	121	133	157	184	203	164	94	56	66	80
58	164	165	159	179	188	159	126	134	150	199	174	119	100	41	41	58
59	173	187	193	181	167	151	162	182	192	175	129	60	88	47	37	50
60	172	184	179	153	158	172	163	207	205	188	127	63	56	43	42	55
61	156	191	196	159	167	195	178	203	214	201	143	101	69	38	44	52
62	154	163	175	165	207	211	197	201	201	199	138	79	76	67	51	53
63	144	150	143	162	215	212	211	209	197	198	133	71	69	77	63	53
64	140	151	150	185	215	214	210	210	211	209	135	80	45	69	66	60
65	135	143	151	179	213	216	214	191	201	205	138	61	59	61	77	63

Digital image: representation (3)



a
b c

FIGURE 2.18
(a) Image plotted as a surface.
(b) Image displayed as a visual intensity array.
(c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).

Digital Image Processing (DIP)

- DIP refers to the set of algorithms that process a digital image on a digital computer

- A DIP algorithm may produce as output:
  - an image or a set of images
  - a set of measures/descriptors of the input image
  - a combination of both previous outputs mentioned above

Concepts and Measures

1. Spatial resolution
2. Depth resolution
3. Histogram
4. Energy
5. Power
6. Average Intensity
7. Brightness
8. Contrast
9. Entropy

1. Spatial Resolution (1)

- Spatial Resolution refers to the number of rows times the number of columns (M rows x N columns)
- The M x N product is the total number of pixels on the image
- If M=N, then we have a square image; otherwise, it is a rectangular image
- The spatial resolution can also be defined by:
  - DPI – *Dots Per Inch,* for printing devices
  - PPI – *Points Per Inch,* for display devices

1. Spatial Resolution (2)

Different spatial resolutions
In DPI

(a) 1250 (b) 300

(c) 150 (d) 75

1. Spatial Resolution (3)

a b c
d e f

FIGURE 2.24 (a) Image reduced to 72 dpi and zoomed back to its original size (3692 × 2812 pixels) using nearest neighbor interpolation. This figure is the same as Fig. 2.20(d). (b) Image shrunk and zoomed using bilinear interpolation. (c) Same as (b) but using bicubic interpolation. (d)–(f) Same sequence, but shrinking down to 150 dpi instead of 72 dpi [Fig. 2.24(d) is the same as Fig. 2.20(c)]. Compare Figs. 2.24(e) and (f), especially the latter, with the original image in Fig. 2.20(a).

2. Depth Resolution (1)

- The *depth resolution* or the *pixel depth*, refers to the number of bits per pixel, *n*
- The total number of image levels is $L=2^n$
- Some common values for *n*:
  - n=24 bit/pixel, color image, with three bands R, G, and B, with 2^{24}=16 777 216 distinct colors
  - n=8 bit/pixel, monochrome image, with 256 gray levels, ranging from 0 to 255
  - n=1 bit/pixel, binary image
- The M x N x n product is the total number of bits occupied by the image

2. Depth Resolution (2)

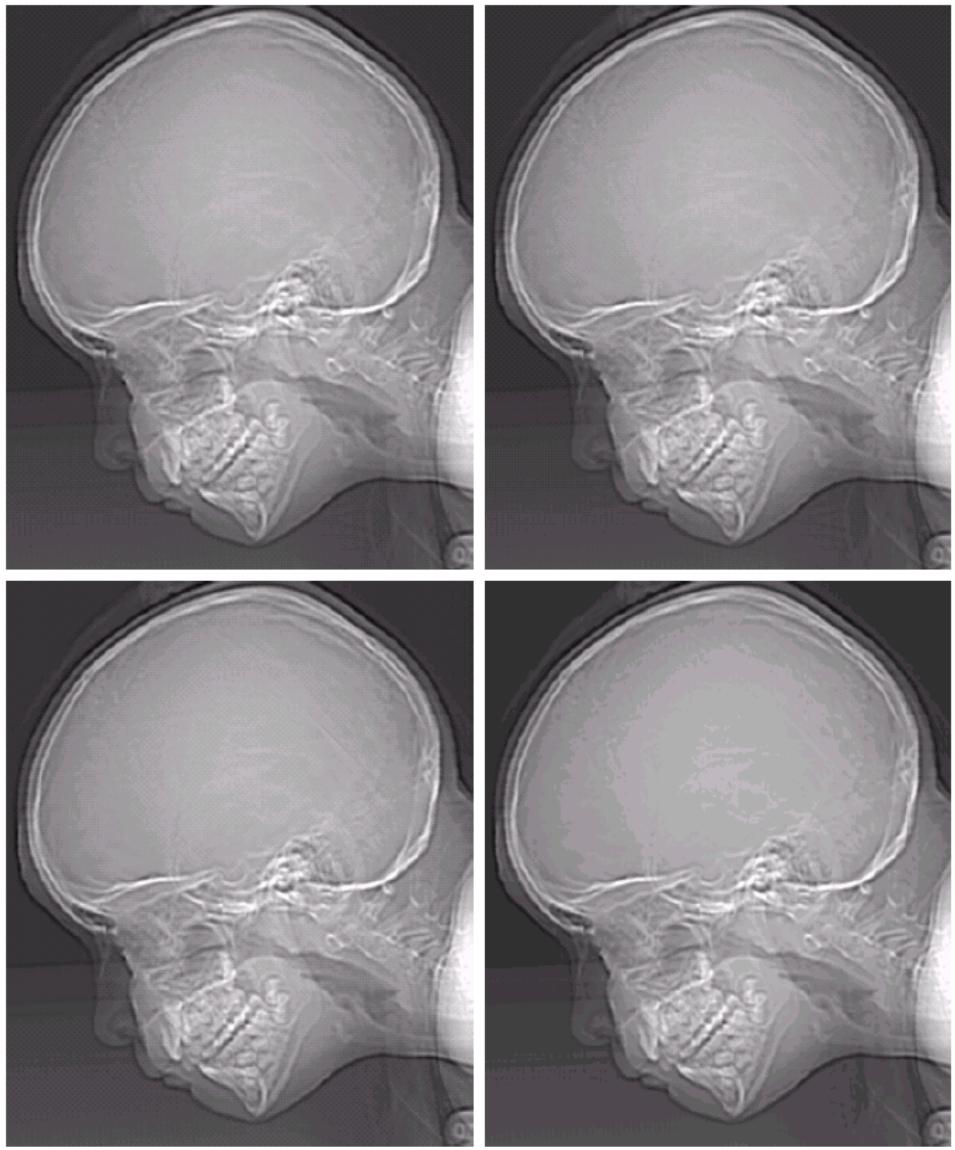
Color, monochrome and binary versions of a given image

Colorida - RGB

Niveis de cinzento

Binária

2. Depth Resolution (3)



a b
c d

FIGURE 2.21
(a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Monochrome image with spatial resolution of
452 x 374 pixels, with different number of grayscale levels, L

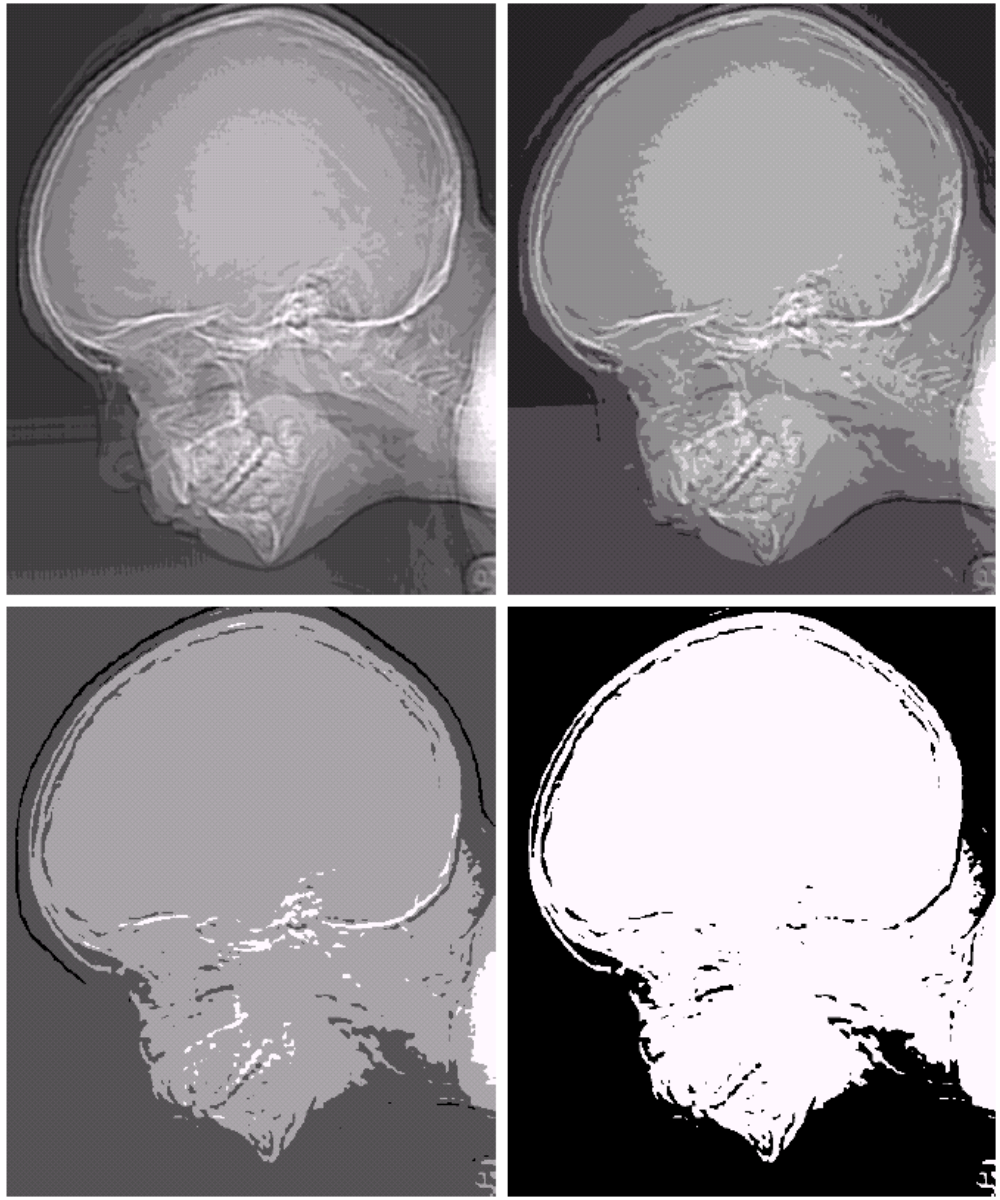
(a) L=256 (b) L=128

(c) L=64 (d) L=32

2. Depth Resolution (4)

e f
g h

FIGURE 2.21
(Continued)
(e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



Monochrome image with spatial resolution of 452 x 374 pixels, with different number of grayscale levels, L

(e) L=16 (f) L=8

(g) L=4 (h) L=2

2. Depth Resolution (5)

Bitplane decomposition (8 bitplanes)

a b c
d e f
g h i

FIGURE 3.14 (a) An 8-bit gray-scale image of size 500 × 1192 pixels. (b) through (i) Bit planes 1 through 8, with bit plane 1 corresponding to the least significant bit. Each bit plane is a binary image.

2. Depth Resolution (6)

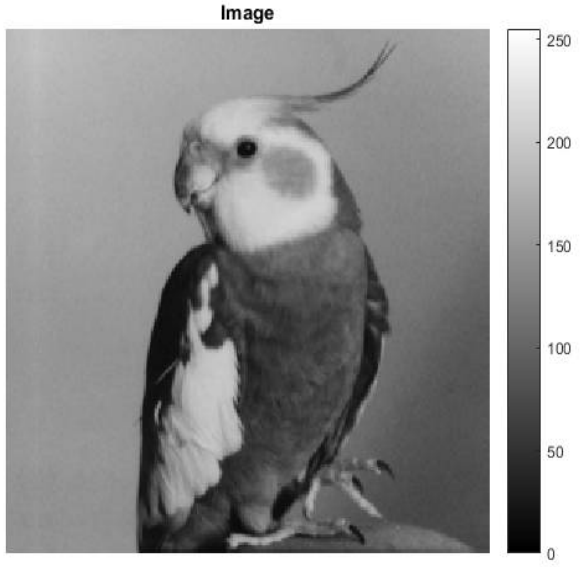
Image reconstruction through bitplane combination

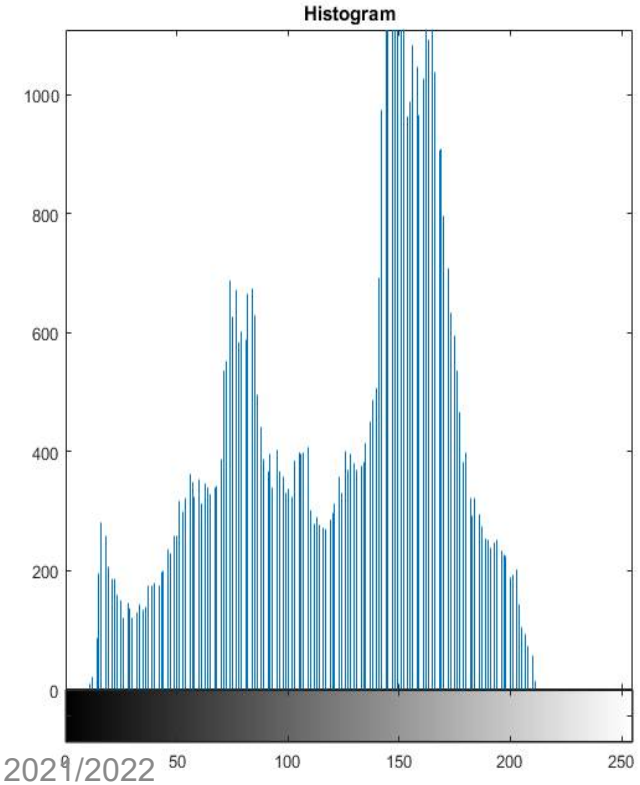
a b c

FIGURE 3.15 Images reconstructed using (a) bit planes 8 and 7; (b) bit planes 8, 7, and 6; and (c) bit planes 8, 7, 6, and 5. Compare (c) with Fig. 3.14(a).

3. Histogram (1)

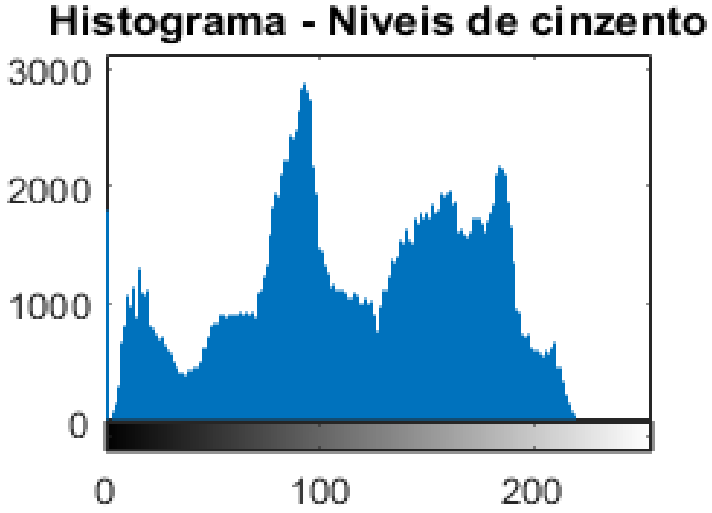
- The histogram reports the number of times that each level occurs
- The sum of all the occurrences in the histogram equals the total number of pixels on the image

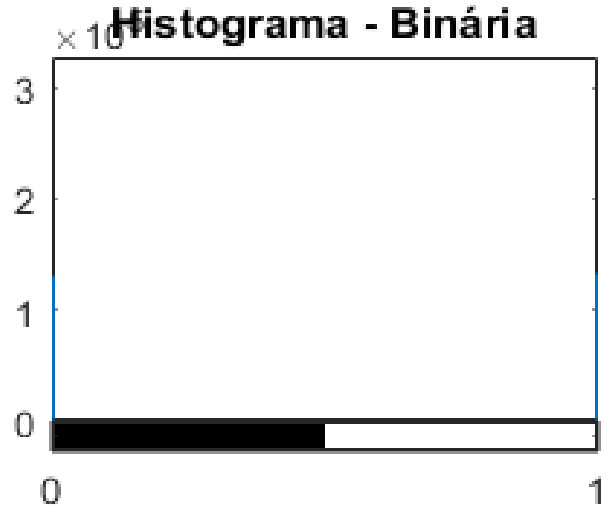




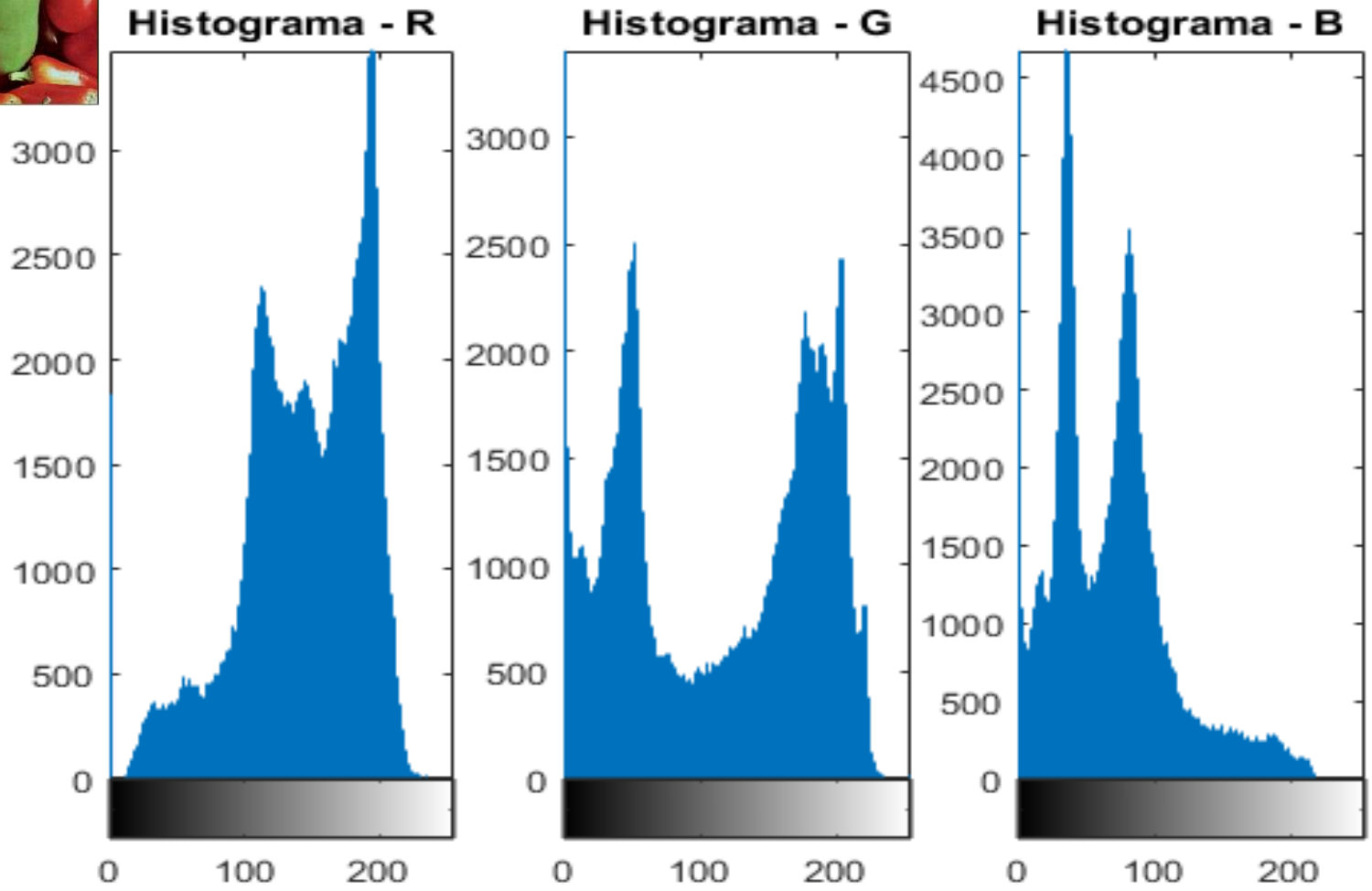
Pixel info: (X, Y) Pixel Value

3. Histogram (2)





3. Histogram (3)



Histogram for each R, G, and B band, for a color image

4. Energy

- Energy is the sum of the squares of all the pixel values
- The square of the value of each pixel is the instant/spatial power of the pixel

$$E_f = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f^2(x,y)$$

$$E_I = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} I^2[m,n]$$

$$0 \leq Energy \leq MN(L-1)^2$$

5. Power

- Power is the average energy per pixel

$$P_f = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f^2(x,y) = \frac{1}{MN}E_f$$

$$P_I = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I^2[m,n] = \frac{1}{MN}E_I$$

$$0 \leq Power \leq (L-1)^2$$

6. Average Intensity

- The average intensity is the mean value of all the pixels in the image

$$m_f = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)$$

$$m_I = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I[m,n]$$

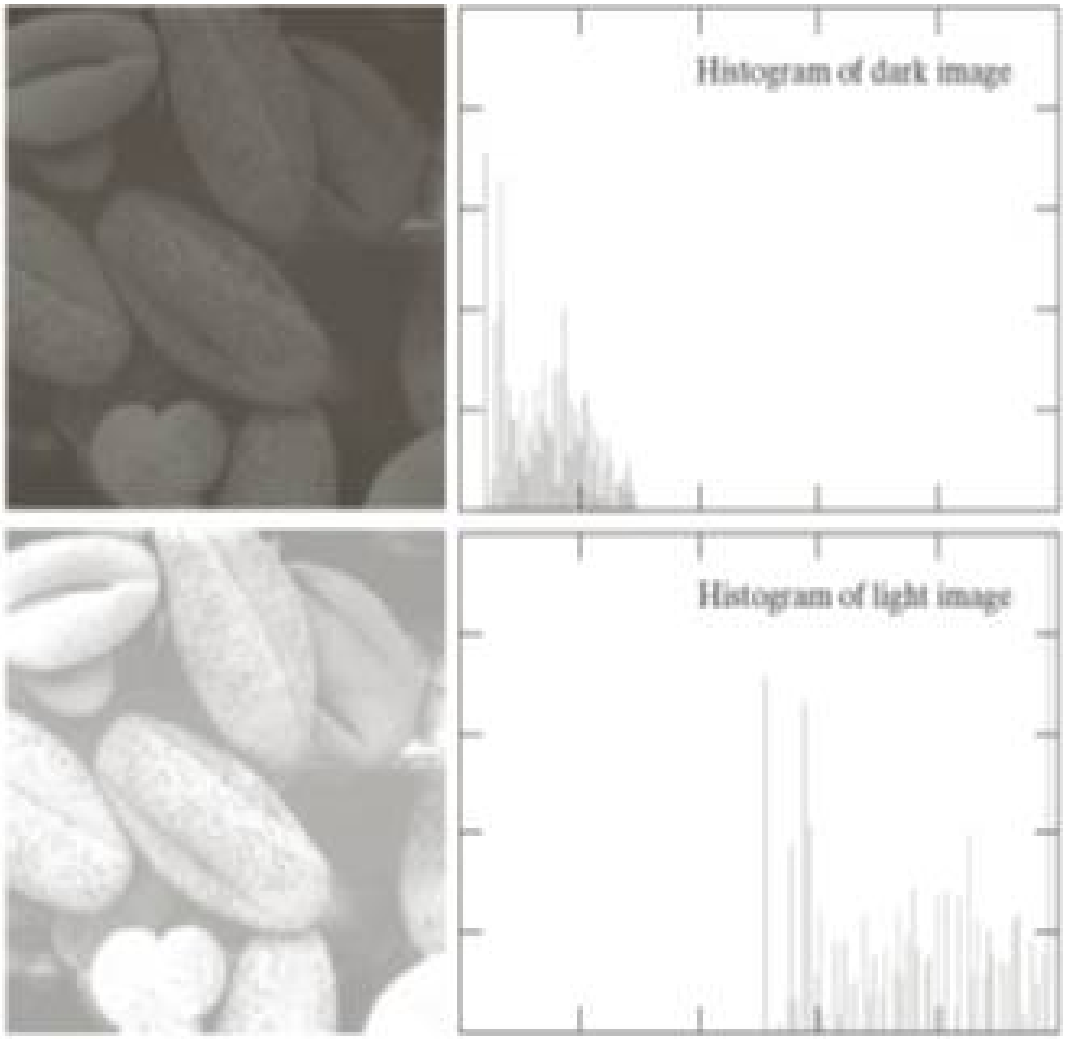
$$0 \leq Average\_Intensity \leq L-1$$

7. Brightness (1)

Low Brightness

Medium Brightness

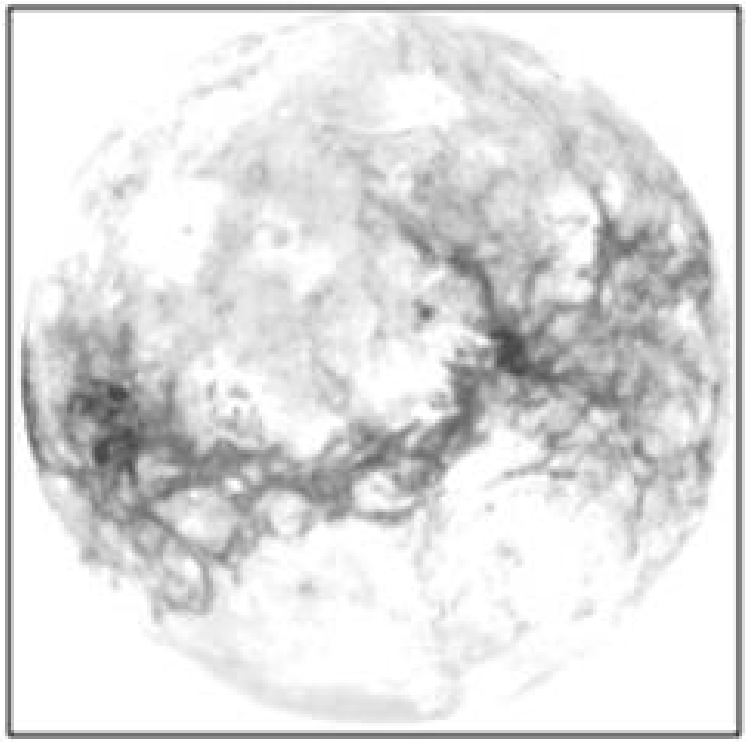
7. Brightness (2)



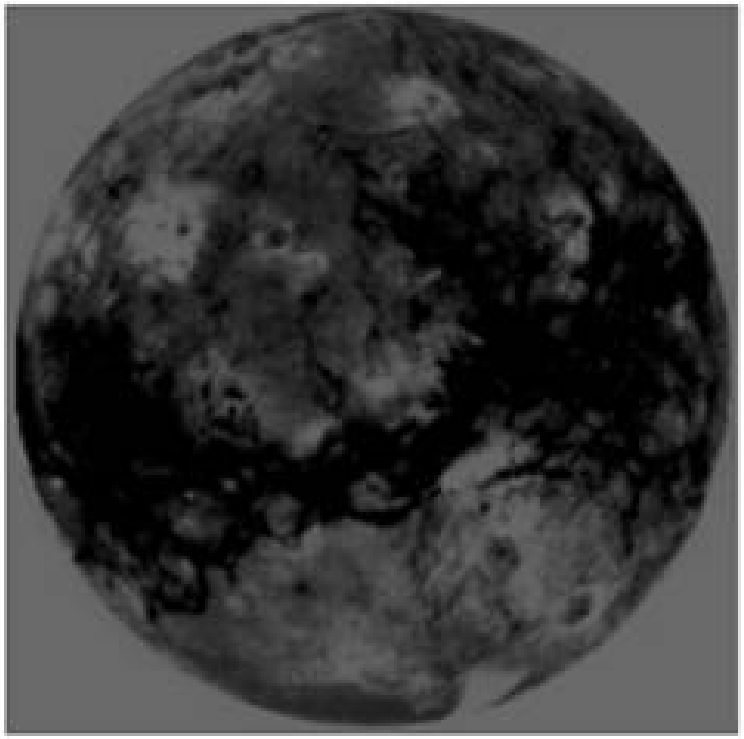
Low brightness
The histogram is on the left-hand-side

Excessive brightness
The histogram is on the right-hand-side

7. Brightness (3)



a. Brightness too high

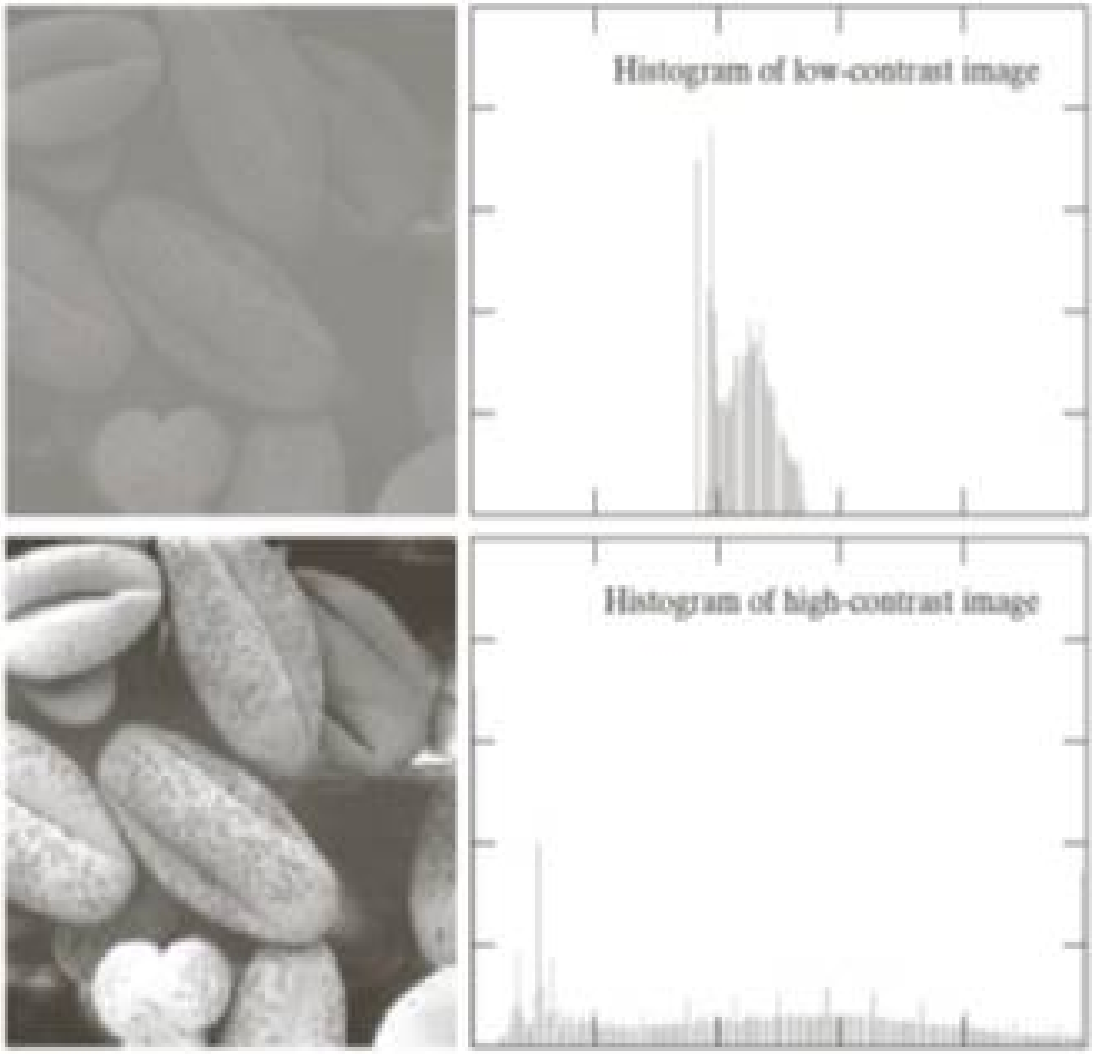


b. Brightness too low

Image saturation towards the maximum intensity

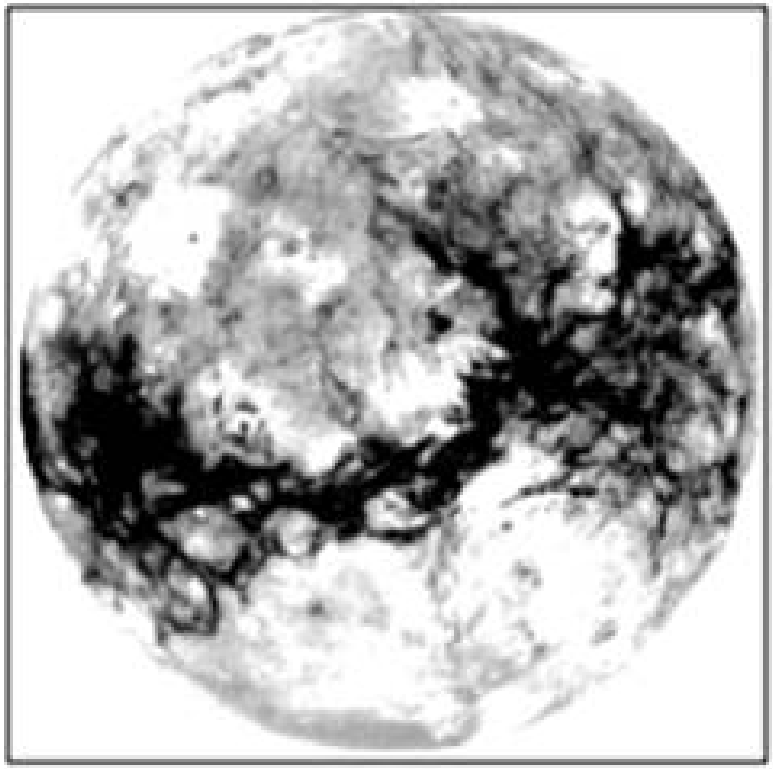
Image saturation towards the minimum intensity

8. Contrast (1)

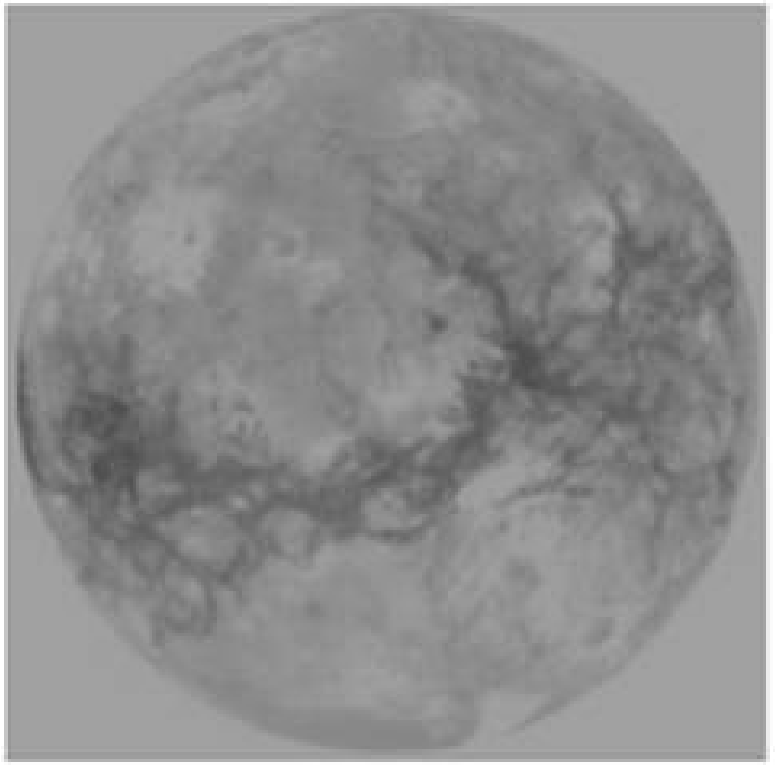


- **Low contrast**
- **The histogram has ocurrences on a small range of distinct gray levels**
- **High contrast**
- **The histogram has ocurrences spread on a large number of distinct gray levels**

8. Contrast (2)

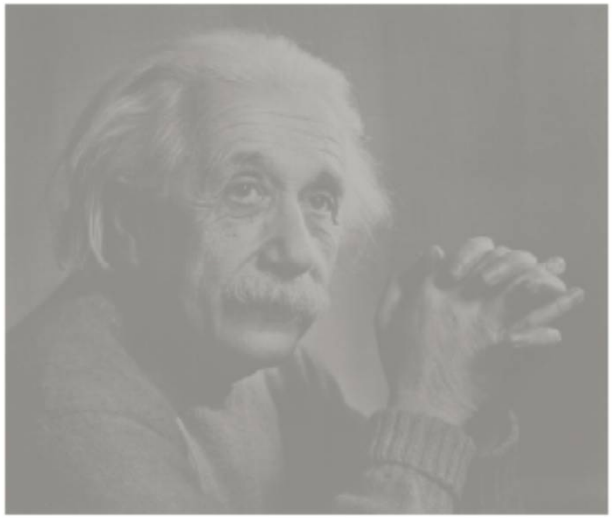


c. Contrast too high

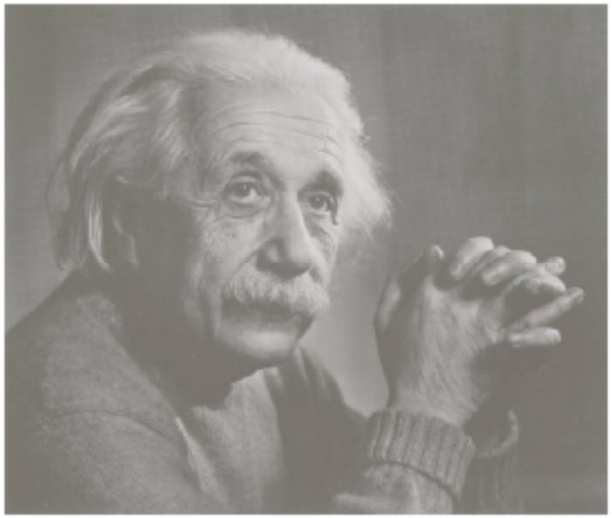


d. Contrast too low

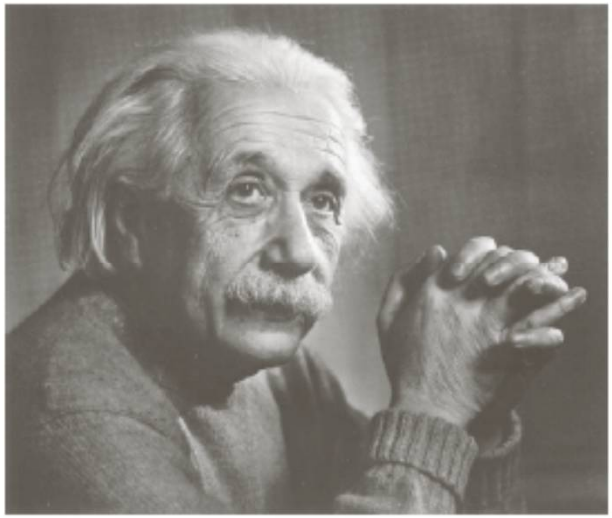
8. Contrast (3)



Low Contrast

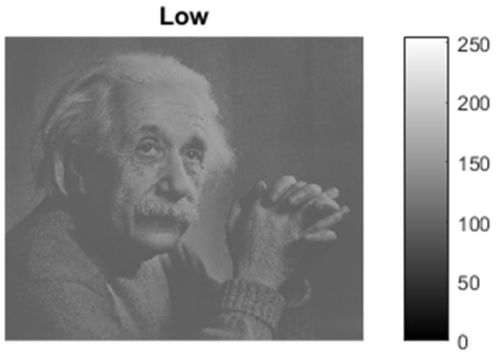


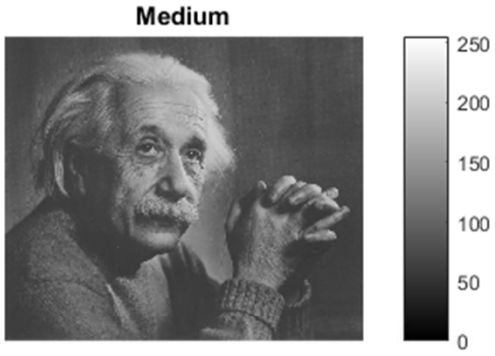
Medium Contrast

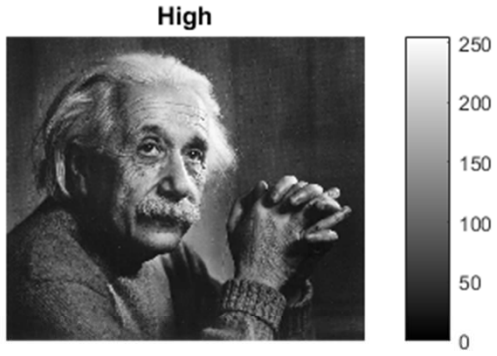


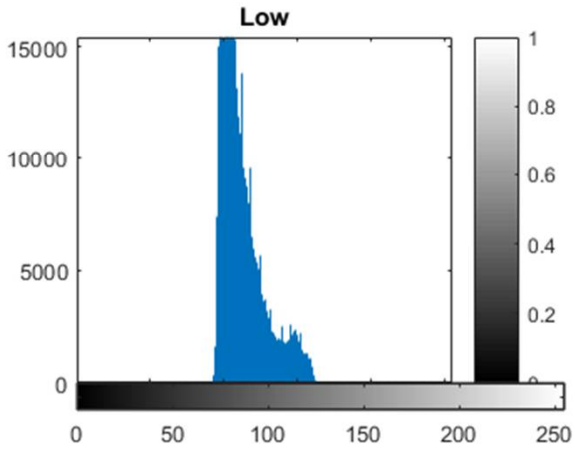
High Contrast

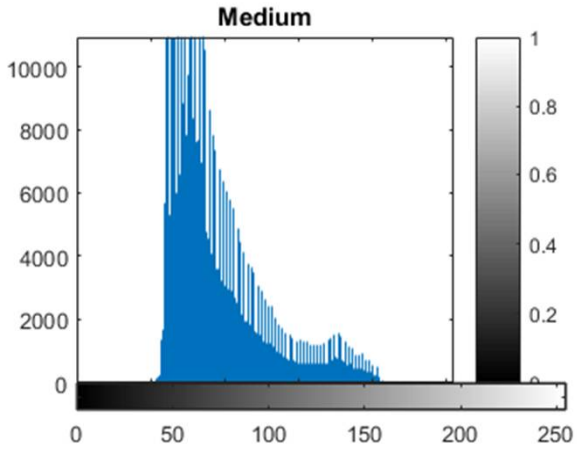
8. Contrast (4)

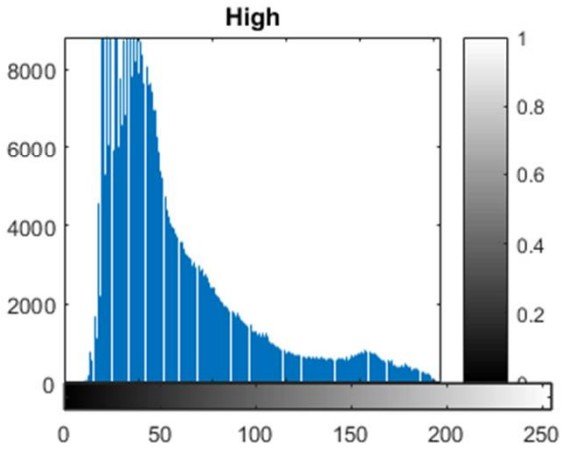

Low
250
200
150
100
50
0


Medium
250
200
150
100
50
0


High
250
200
150
100
50
0


Low
15000
10000
5000
0
0
50
100
150
200
250
1
0.8
0.6
0.4
0.2


Medium
10000
8000
6000
4000
2000
0
0
50
100
150
200
250
1
0.8
0.6
0.4
0.2


High
8000
6000
4000
2000
0
0
50
100
150
200
250
1
0.8
0.6
0.4
0.2

8. Contrast (5)

- The **brightness** of an image can be assessed by its average intensity value; the higher the average intensity, the higher the brightness

- The **contrast** of an image can be evaluated by the histogram dispersion

  - histogram with distinct gray levels, on a small range of values, yields an image with low contrast

  - histogram with distinct gray levels, on a large range of values, yields an image with high contrast

• Let mi and mx, be the minimum and the maximum intensity values of an image. Then, the **contrast of an image is directly proportional to**:

- C1 = mx – mi
- C2 = (mx + 1) / (mi + 1)
- C3 = 20 log10 ((mx + 1) / (mi + 1))

9. Entropy (1)

Entropy is a measure of image predictability

- Low entropy – highly predictable image
- High entropy – less predictable image

$$H(X) = -\sum_{x} p(x) \log_2 p(x) \ \text{[bit/symbol]}$$

- p(x) is the probability of ocurrence of each pixel value x

9. Entropy (2)

The entropy values are in the range:

$$0 \leq H(\mathrm{X}) \leq log_2(L)$$

$$0 \leq H(\mathrm{X}) \leq \mathrm{n}$$

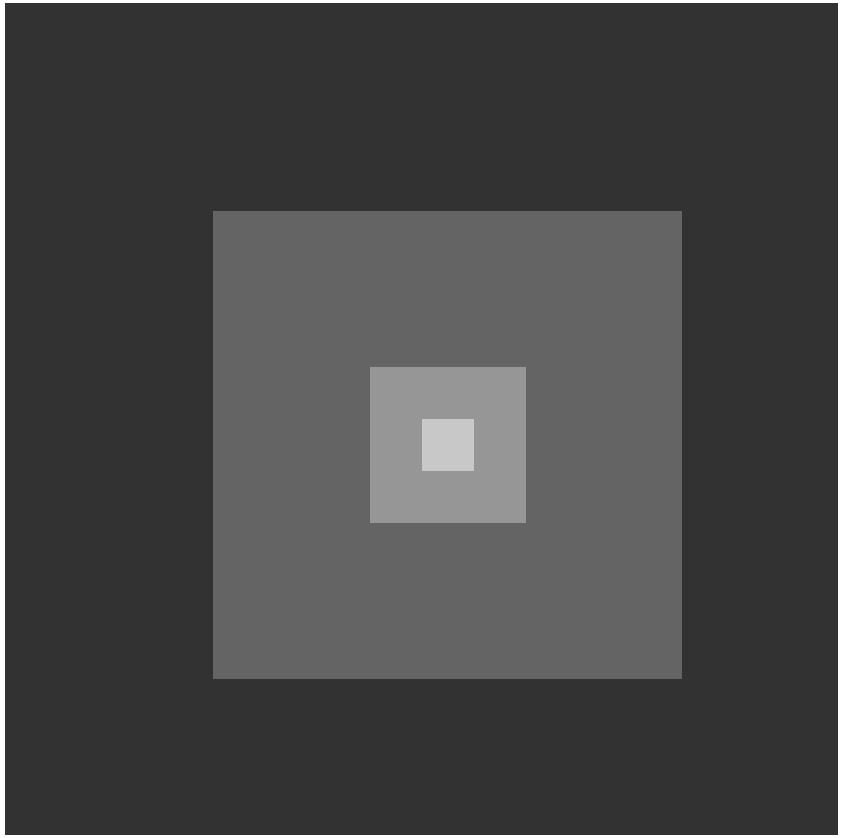
- The extreme lower value is attained when all the pixels have same value
- The extrem upper value is attained for images with an uniform histogram
- n is the number of bit/pixel (the depth resolution)
- L is the number of levels

9. Entropy (3)

Some examples

H(X)= 7.0097

H(X)= 1.0774



MATLAB
Image Processing Toolbox functions

- The MATLAB image processing toolbox

https://www.mathworks.com/products/image.html

https://www.mathworks.com/videos/introduction-to-matlab-with-image-processing-toolbox-90409.html

- Input/output, image information and histograms
  - *imread*, read an image from a file
  - *imwrite*, write an image to a file
  - *imfinfo*, get some details on the image (spatial resolution, depth resolution, encoding, …)
  - *imshow, imagesc, imshowpair, montage,* display images
  - *imhist*, display the histogram of an image
  - *impixelinfo*, display the value of a pixel at coordinates x and y

Exercises

2. A tabela apresenta o histograma da imagem monocromática I, de resolução $M \times M$, com 8 níveis de cinzento.

Pixel	0	1	2	3	4	5	6	7
Ocorrências	0	128	0	30	20	10	10	58

   a) {1,5} Relativamente à imagem I, indique: o valor de M; o número de bit por *pixel*; o valor mínimo de intensidade; o valor médio de intensidade; o valor máximo de intensidade; a energia; a potência.

1. {R1‖TG} Considere a imagem monocromática I, quadrada de resolução espacial 8×8, com profundidade de $n = 8$ bit/pixel. A imagem possui linhas com valor constante, tal que a primeira linha tem o valor 11, a segunda tem o valor 22, a terceira tem o valor 33 e assim sucessivamente até à última linha que possui o valor 88.

   a) {1,25||1,0} Indique o valor médio e a potência de I.

   b) {1,25||1,0} Apresente o histograma de I.

   c) {1,25||1,0} Com $I_2 = 2 \times I$, indique o valor médio e a potência de I_2. Compare com os valores apresentados na alínea a). Comente.

Bibliography

- The images displayed in these slides are from:
  - R. Gonzalez, R. Woods, *Digital Image Processing*, 4th edition, Prentice Hall, 2018, ISBN 0133356728
  - S. Smith, *The Scientist and Engineer's Guide to Digital Signal Processing*, Newnes, 2003, ISBN 0-750674-44-X [chapter 23]