جَامعة
المَنارة
MANARA UNIVERSITY

Digital Image Processing

المحاضرة الثانية

Digital Image Fundamental

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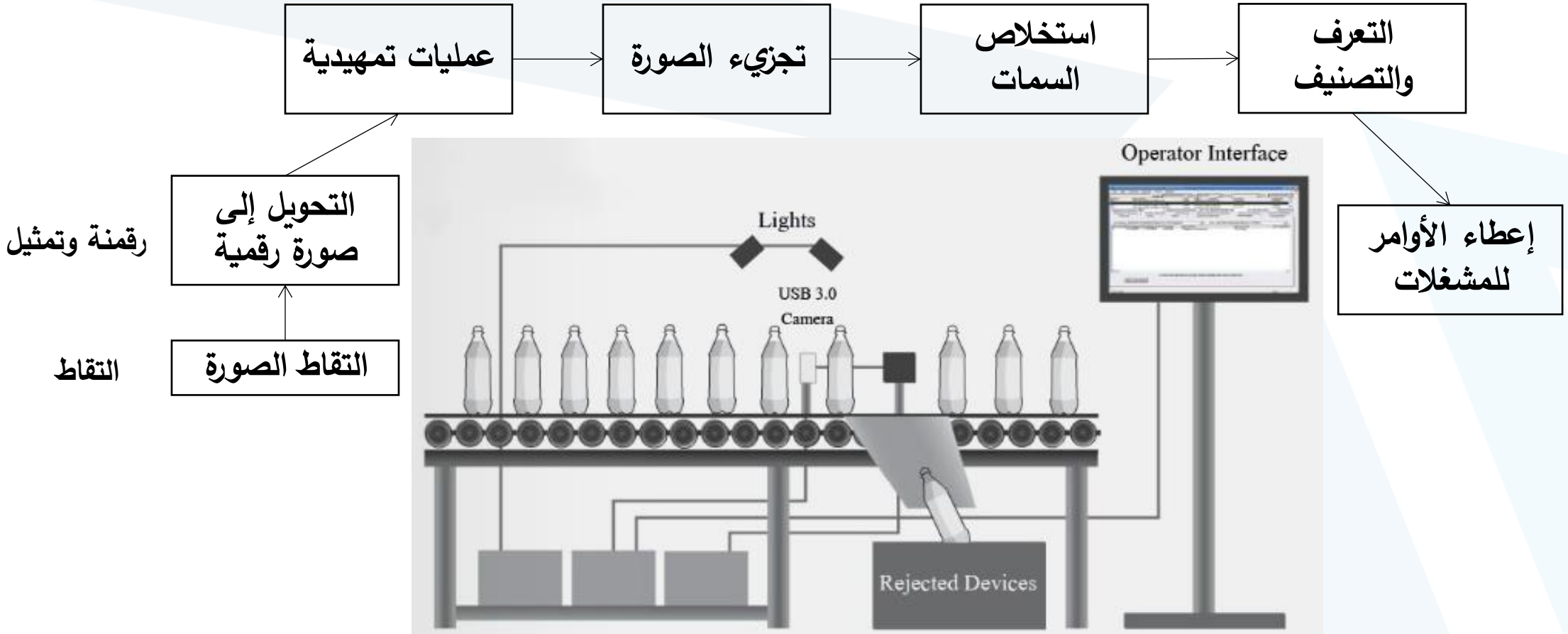
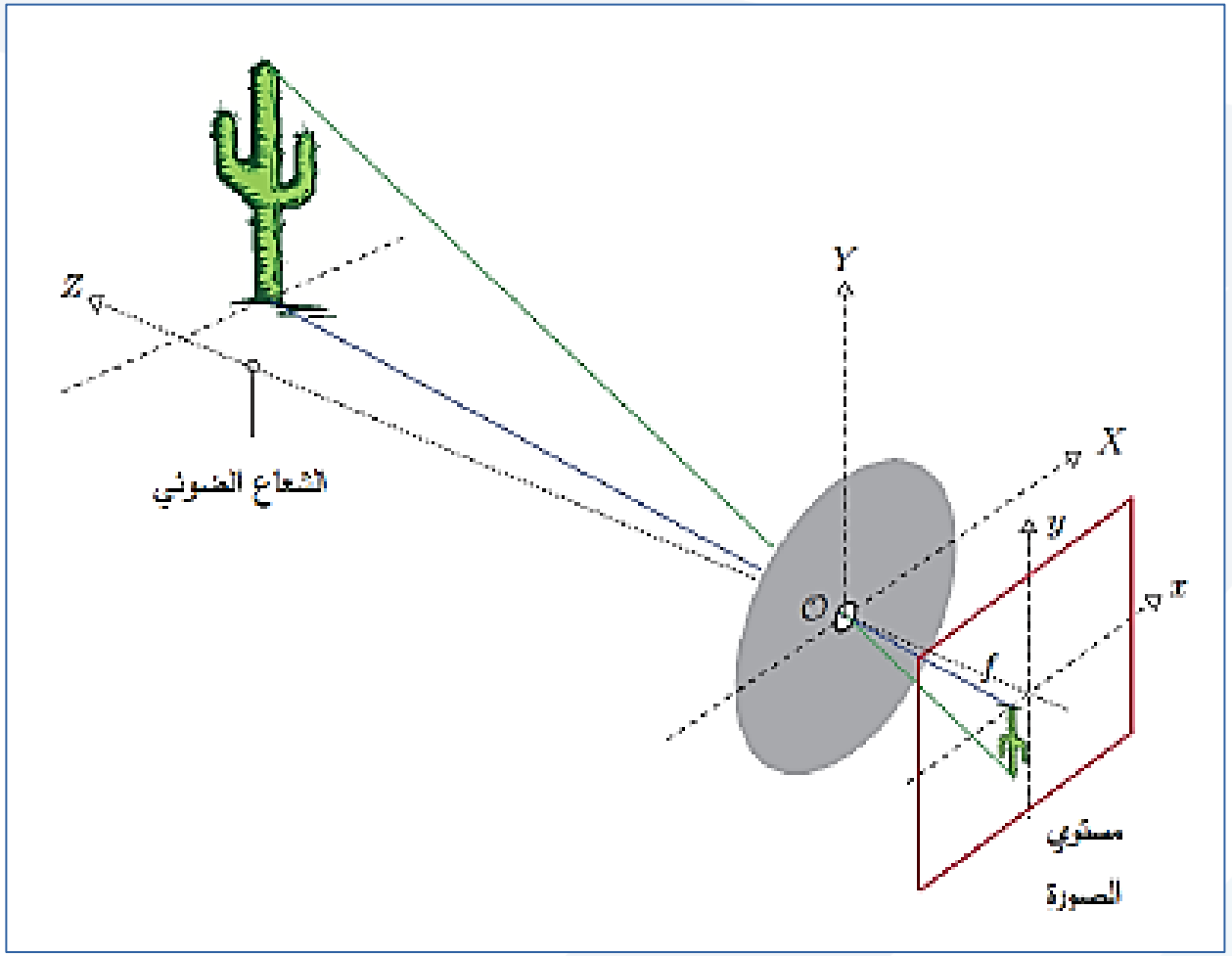
2025 الفصل الصيفي

مثال تطبيقي: مكونات نظام تصنيف ميكانيكي



التقاط الصور

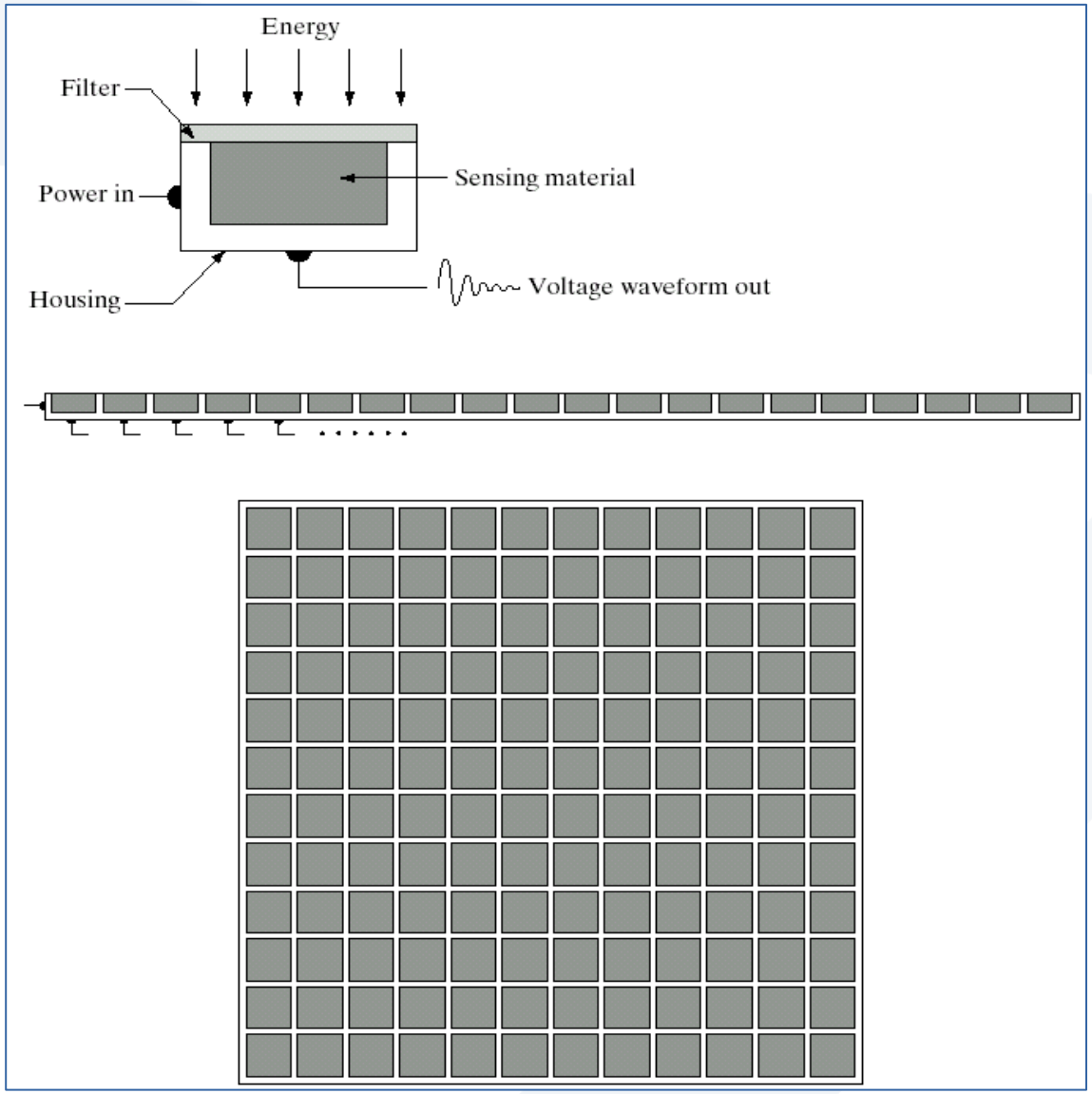


- يعرف التقاط الصور بأنه عملية الحصول على الصورة من مصدر ما بحيث تصبح هذه الصور جاهزة لأي عملية معالجة قادمة
- أبسط نموذج للحصول على الصور هو الكاميرا ذات الثقب
  - يعكس نموذج هذه الكاميرا العلاقة الرياضية بين إحداثيات نقطة في الفراغ وانعكاس هذه النقطة على مستوي الصورة

$$x = -f X/Z$$

$$y = -f Y/Z$$

Image Sensors



Single sensor

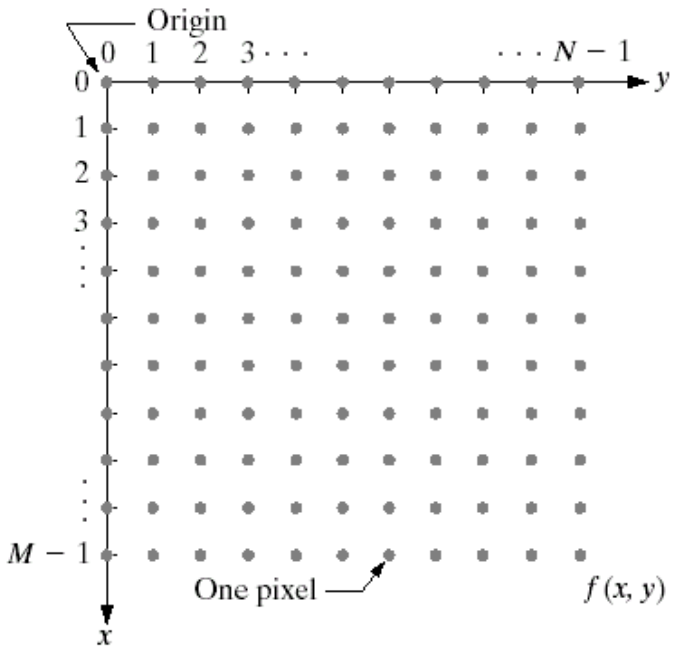
Line sensor

Array sensor

تمثيل الصورة الرقمية

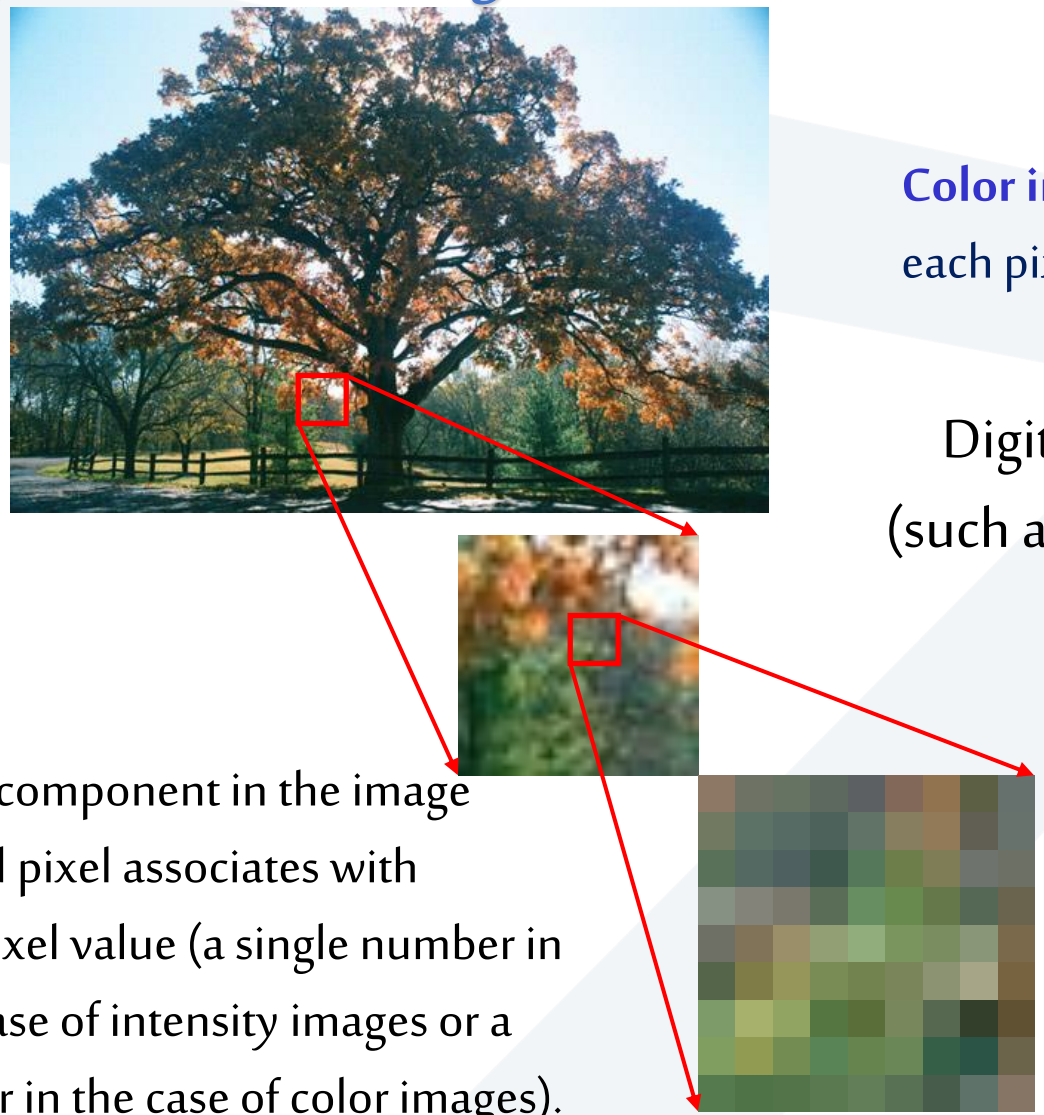
تمثل الصورة الرقمية بالمصفوفة الآتية

Digital image: an image that has been discretized both in Spatial coordinates and associated value.



$$f(x,y) \cong \begin{bmatrix} f(0,0) & f(0,1) & \cdots\cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots\cdots & f(1,N-1) \\ . & . & \cdots\cdots & \\ . & . & \cdots\cdots & \\ . & . & \cdots\cdots & \\ . & . & \cdots\cdots & \\ f(M-1,0) & f(M-1,1) & \cdots\cdots & f(M-1,N-1) \end{bmatrix}$$

Digital Image Types : RGB Image
Digital Colored Image



Color image or RGB image:

each pixel contains a vector representing red, green and blue components.

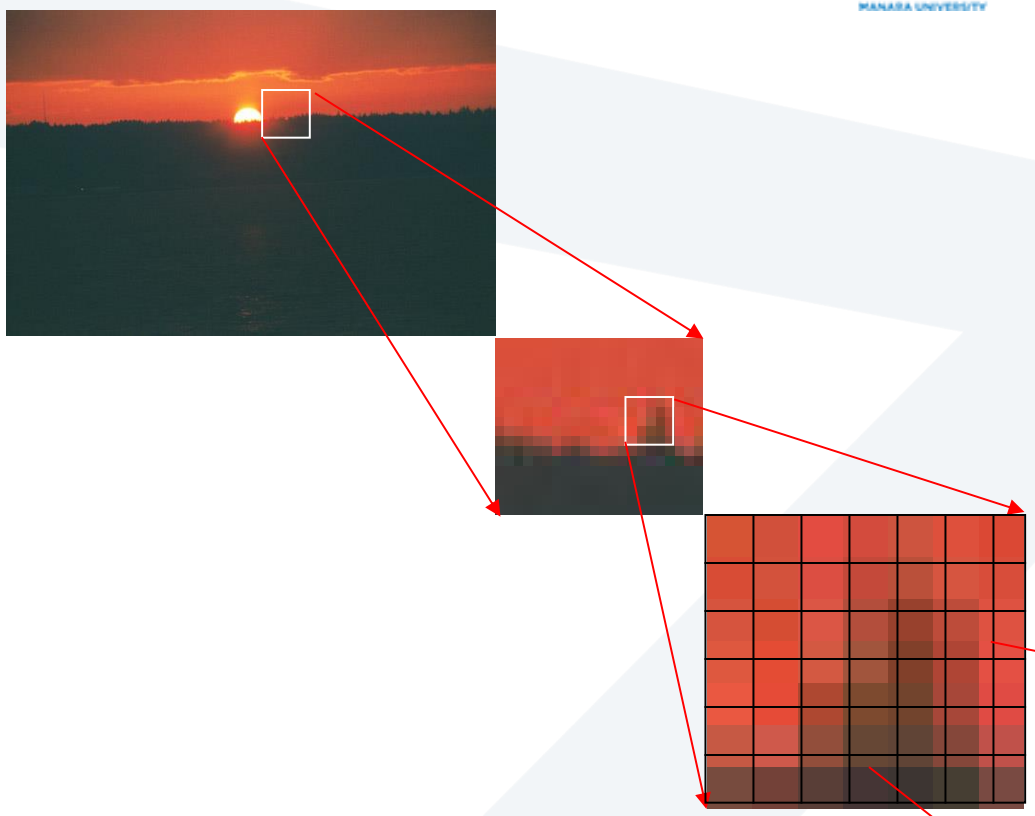
Digital image = a multidimensional array of numbers (such as intensity image) or vectors (such as color image)

Each component in the image called pixel associates with the pixel value (a single number in the case of intensity images or a vector in the case of color images).

RGB components

$$\begin{bmatrix} 10 & 10 & 16 & 28 \\ 9 & \begin{bmatrix} 65 & 70 & 56 & 43 \\ 6 & 99 & 26 & 70 \\ 32 & 54 & 96 & 56 \end{bmatrix} & 37 & 67 \\ 15 & \begin{bmatrix} 25 & 60 & 13 & 90 \\ 21 & 54 & 47 & 96 \\ 15 & 87 & 39 & 43 \end{bmatrix} & 22 & 96 \\ 32 & \begin{bmatrix} 85 & 85 & 65 & 39 \\ 54 & 65 & 65 & 87 \\ 32 & 65 & 87 & 99 \end{bmatrix} & 42 & 78 \\ & & & 67 \\ & & & 92 \\ & & & 99 \end{bmatrix}$$

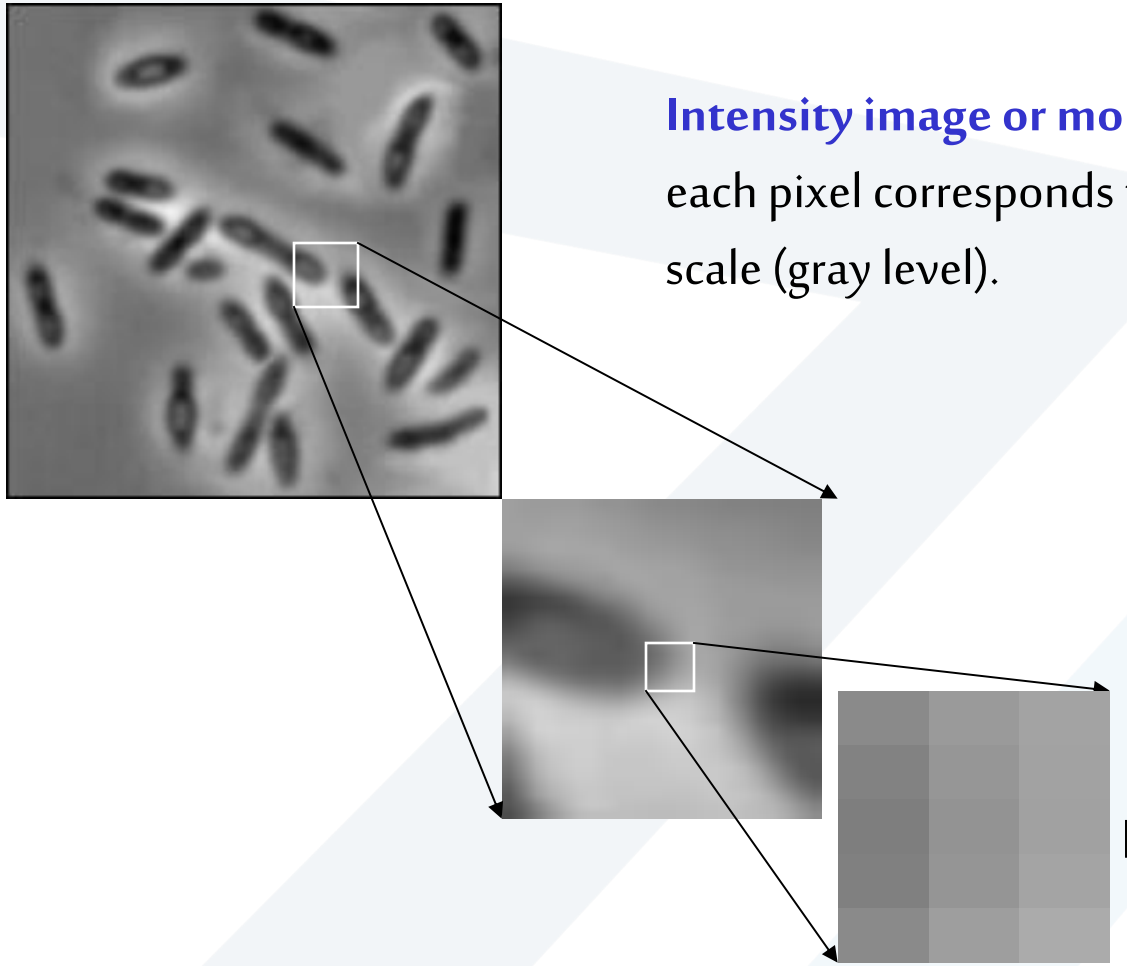
Digital Image Types : RGB Image
Digital Colored Image



$$\begin{bmatrix} 10 & 10 & 16 & 28 \\ 9 & 6 & 26 & 37 \\ 15 & 25 & 13 & 22 \\ 32 & 21 & 34 & 47 \end{bmatrix} \begin{bmatrix} 65 & 70 & 56 & 43 \\ 99 & 70 & 96 & 67 \\ 60 & 90 & 96 & 42 \\ 15 & 87 & 39 & 43 \end{bmatrix} \begin{bmatrix} 78 \\ 56 \\ 67 \\ 92 \end{bmatrix}$$
$$\begin{bmatrix} 54 & 85 & 85 & 39 \\ & 65 & 65 & 87 \\ & 32 & & 99 \end{bmatrix}$$

Digital Image Types :

Intensity Image or gray image



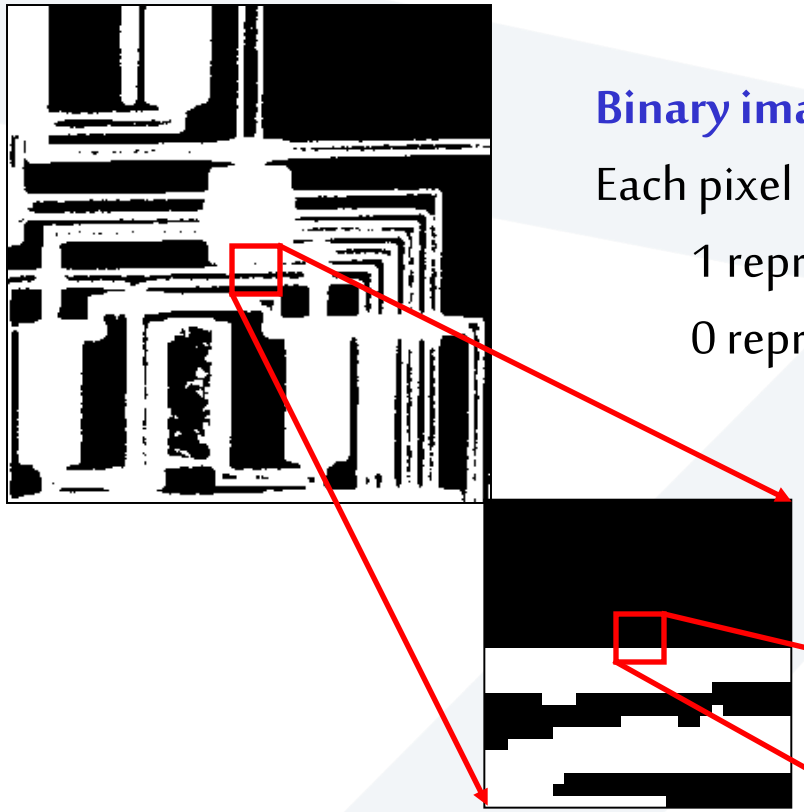
Intensity image or monochrome image

each pixel corresponds to light intensity normally represented in gray scale (gray level).

Gray scale values

$$\begin{bmatrix} 10 & 10 & 16 & 28 \\ 9 & 6 & 26 & 37 \\ 15 & 25 & 13 & 22 \\ 32 & 15 & 87 & 39 \end{bmatrix}$$

Image Types : Binary Image



Binary image or black and white image

Each pixel contains one bit :

1 represent white

0 represents black

Binary data

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

أمثلة عن أنواع الصور المختلفة

صورة رمادية

صورة ثنائية

صورة ملونة

صورة مفهرسة

التحويل بين أنواع الصور في Matlab

	Binary BW	Grayscale I	Truecolor RGB	Indexed X, map
BW	-	x	x	gray2ind
I	im2bw	-	x	gray2ind
RGB	im2bw	rgb2gray	-	rgb2ind
X, map	im2bw	rgb2gray	ind2rgb	-

صيغ ملفات الصور

- يعطي نوع ملف الصورة معلومات عن التخزين في الذاكرة والأرشفة وتبادل بيانات الصور

- معايير اختيار صيغة مناسبة لصورة ما:
  - نوع وحجم الصورة
  - المساحة التخزينية وضغط الصورة (Lossy, Lossless)
  - التوافق
  - مجال التطبيق

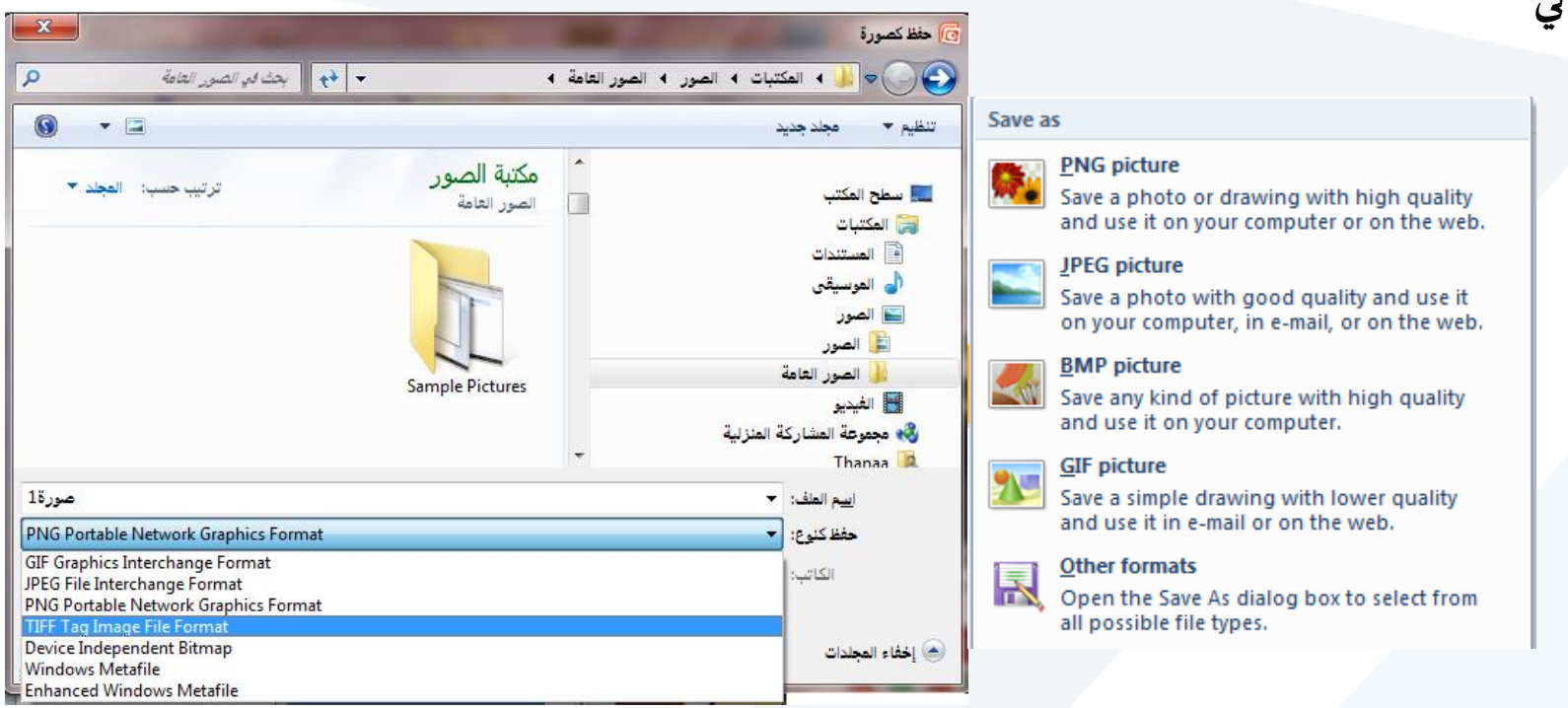
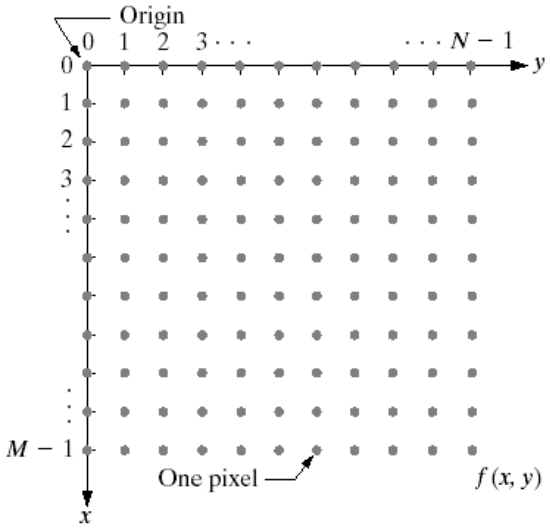


Image "After snow storm"



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An image that has been discretized both in Spatial coordinates and associated value.

An image: **a multidimensional function of spatial coordinates**.

- **Spatial coordinate** (point set): (x,y) for 2D case such as photograph, (x,y,z) for 3D case such as color image
- **The** function f (value set) may represent intensity (for monochrome images) or color (for color images) or other associated values.

An element of the image, (x,y),$f(x,y)$ is called a **pixel** where:

- x,y is called the pixel location and
- $f(x,y)$ is the pixel value at the location x,y

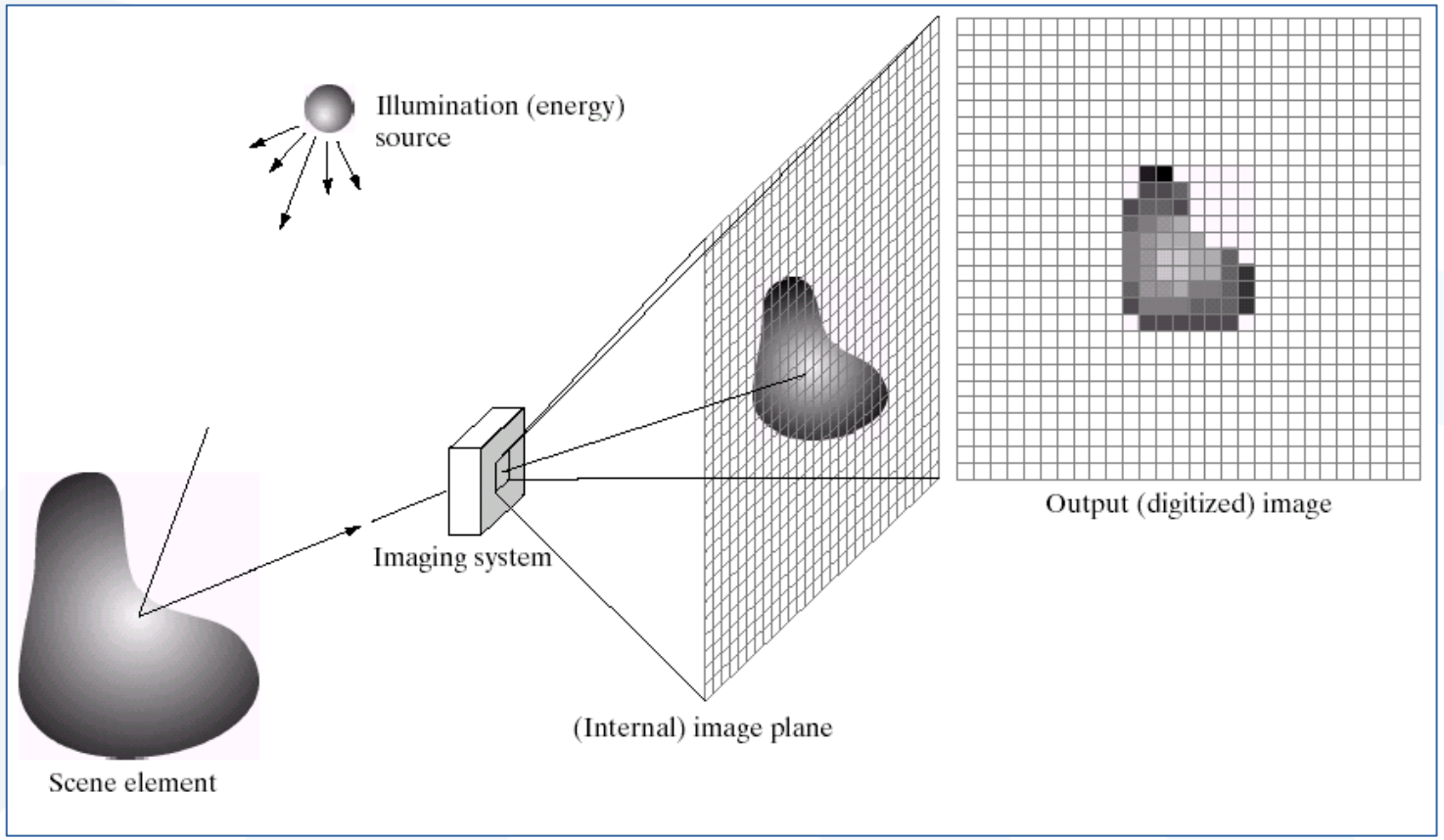
Digitization Process

To convert continuous image (in real life) to digital image (in computer) we use Two processes:

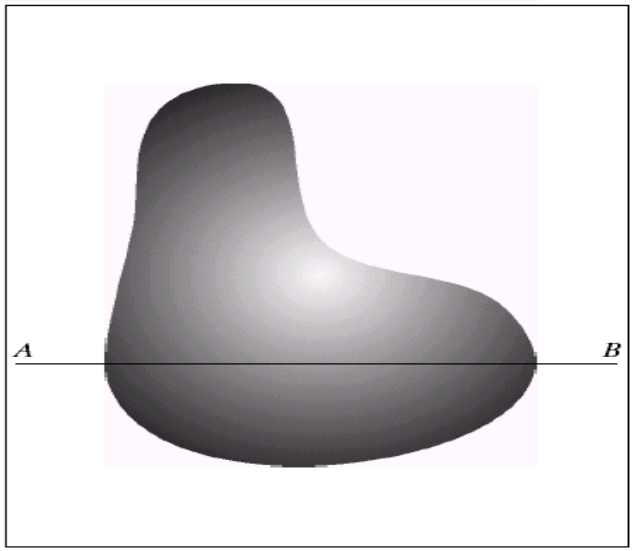
Sampling: digitizing the coordinate values

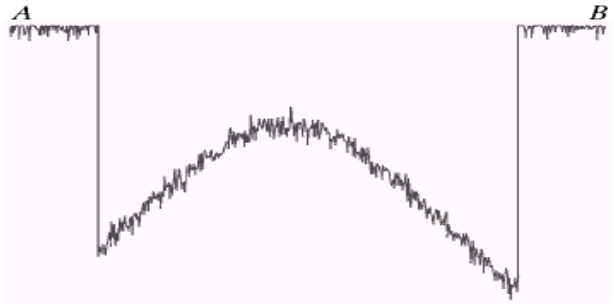
Quantization: digitizing the amplitude values or intensities.

- Thus, when x, y and f are all finite, discrete quantities, we call the image a digital image.

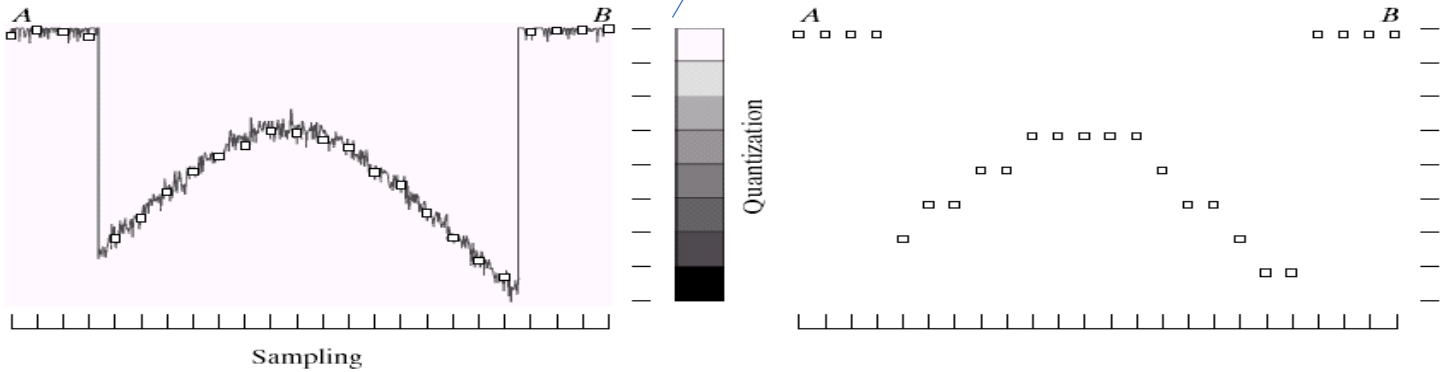


Digitization Process- Sampling and Quantization function

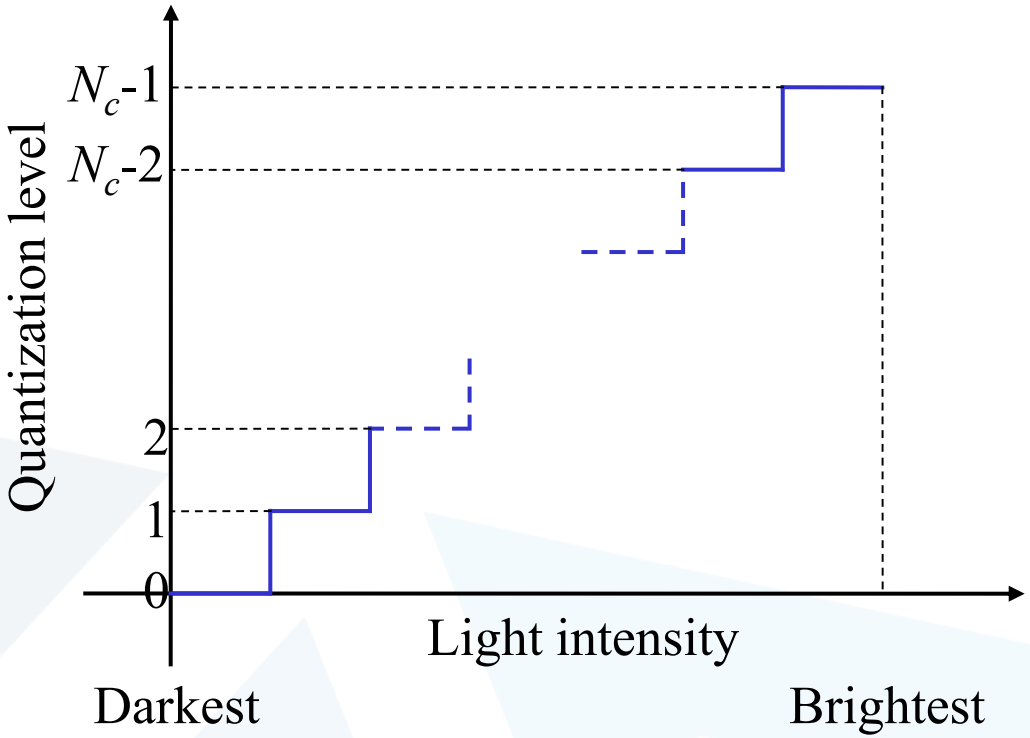




Gray-level scale that divides gray-level into 8 discrete levels from b(0) to w(7)



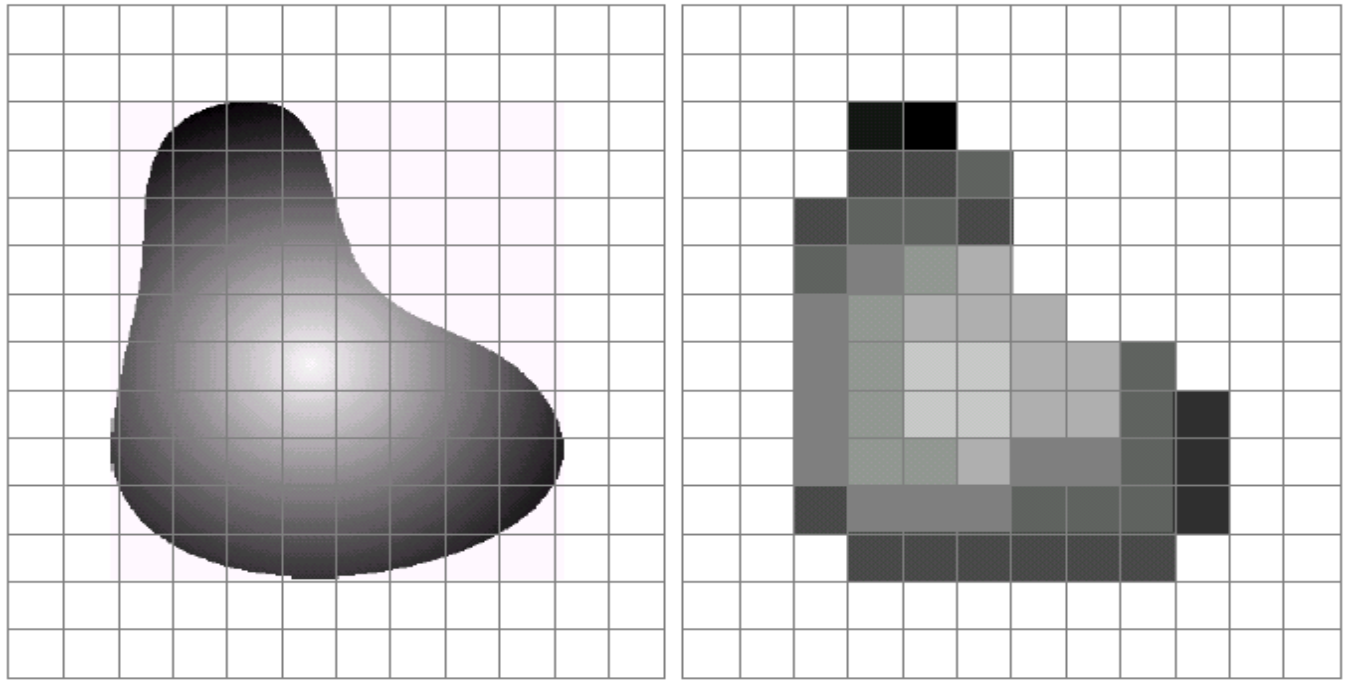
sample is a small white square, located by a vertical tick mark as a point x,y



- **Image sampling**: discretize an image in the spatial domain (digitizing coordinates)
- **Image quantization**: discretize or convert continuous pixel values (each sample gray level value) into discrete numbers (digital quantity) -> digitizing intensities

Digitization Process- Sampling and Quantization function

The continuous image VS the result of digital image after sampling and quantization



a b

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

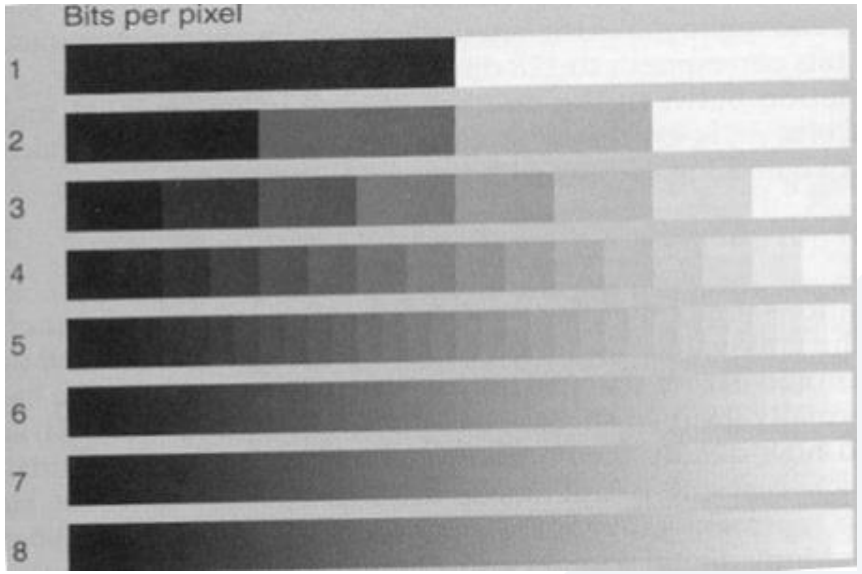
عمق البت bit depth أو
عمق البكسل pixel depth

- **BIT DEPTH** is determined **by the number of bits used to define each pixel**. The greater the bit depth, the greater the number of tones (grayscale or color) that can be represented.
- **Pixel depth**, also known as bit depth, refers to the amount of information stored in each pixel of a digital image. It is typically measured in bits per pixel (bpp), with common values being 1 bpp (black and white), 8 bpp (grayscale)

يعتمد عدد سويات الشدة الضوئية المستخدمة L لتمثيل الصورة على k عدد البتات المخصصة لترميز كل بكسل، وهو ما يدعى عمق البت أو عمق البكسل

مثال: $k=8$

$$L = 2^k \quad \text{where } k = \text{No. of bits representing each pixel value}$$



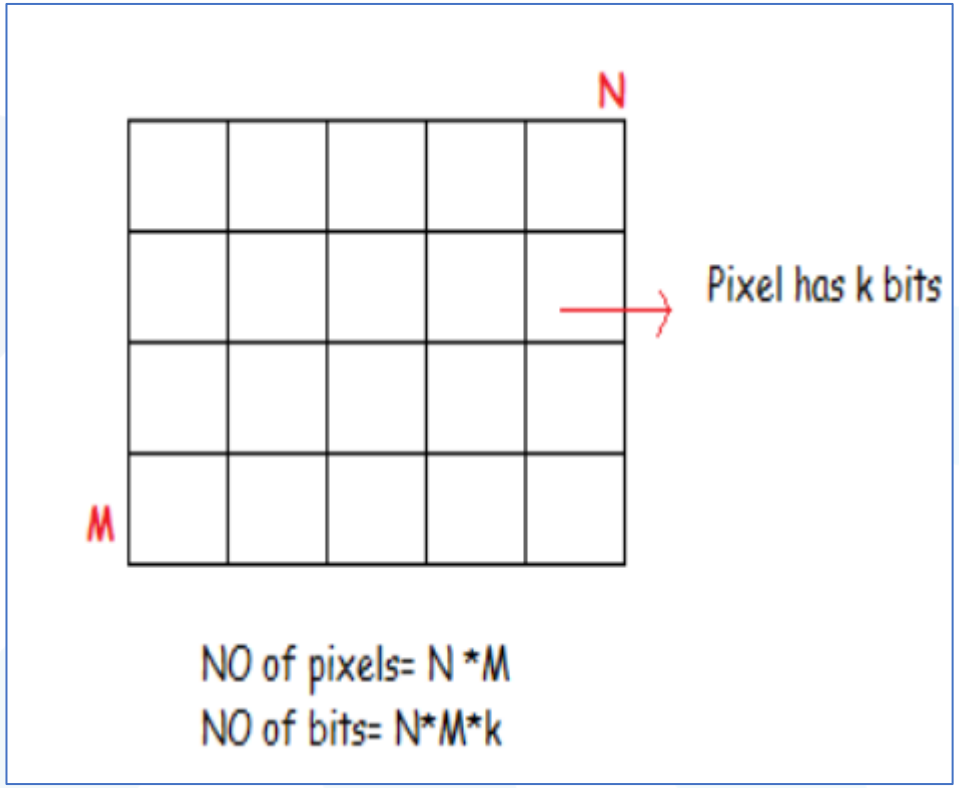
L=256 ; [0-255] No. of colors or gray levels OR **Color resolution/ color depth/ levels**:

- **Color depth** refers to the maximum number of colors an image can contain. Color depth is determined by the bit depth of an image (the number of binary bits that define the shade or color of each pixel in a bitmap). For example, a pixel with a bit depth of 1 can have two values: black and white.

b= M*N*K حجم الصورة بالبتات

Number of storage of bits:

- N * M: the no. of pixels in all the image.
- K: no. of bits in each pixel
- L: grayscale levels the pixel can represent: L= 2^K
- all bits in image= N*N*k



EX: Here: M=N=32, K=3, L = 2^3 =8

# of pixels=N*N = 1024 . (because in this example: M=N)

# of bits = N*N*K = 1024*3= 3072 bits.

تصنيف الصور اعتمادا على عمق البت

الصور الرمادية (صور الشدّة الضوئية)

عدد القيم في البكسل	بت/البكسل	مجال القيم	الاستخدامات
1	1	0.....1	صورة ثنائية: المستندات والفاكس وعرض الخطوط والرسوم.
1	8	0.....255	الصور الشائعة: التصوير والطباعة والنسخ.
1	12	0....4095	صور عالية الدقة: التصوير والطباعة والنسخ.
1	14	0....16383	صور احترافية: التصوير والطباعة والنسخ.
1	16	0....65535	الصور الأعلى دقة: مجالي الطب والفلك.

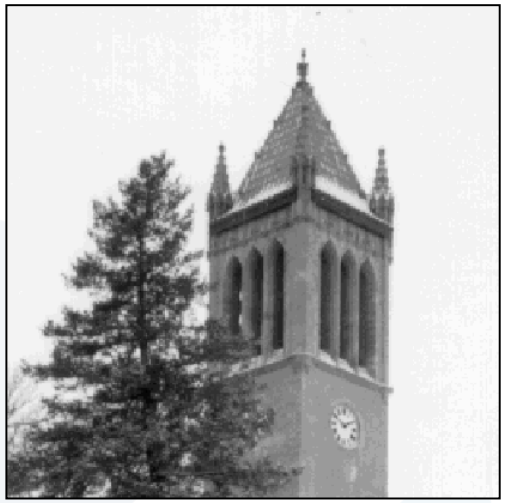
الصور الملونة

عدد القيم في البكسل	بت/البكسل	مجال القيم	الاستخدامات
3	24	$[0... 255]^3$	RGB الشائعة: التصوير والطباعة والنسخ.
3	36	$[0... 4095]^3$	RGBعالية الدقة: التصوير والطباعة والنسخ.
3	42	$[0... 16383]^3$	RGB الاحترافية: التصوير والطباعة والنسخ.
4	32	$[0... 255]^4$	CMYK: الطباعة الملونة.

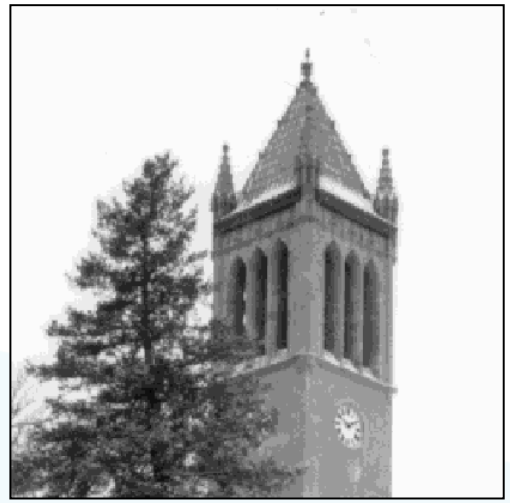
Effect of Quantization Levels

256 levels

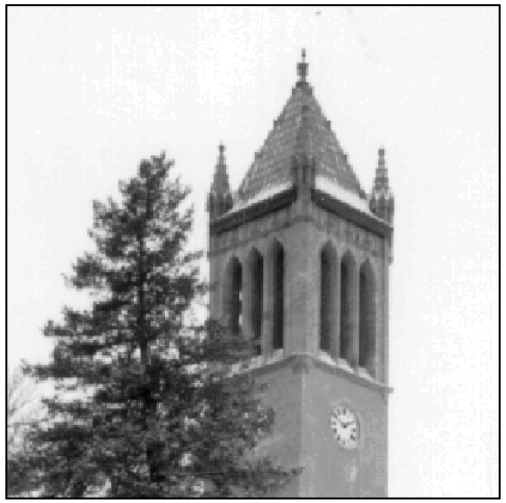
128 levels



16 levels



8 levels



64 levels

32 levels

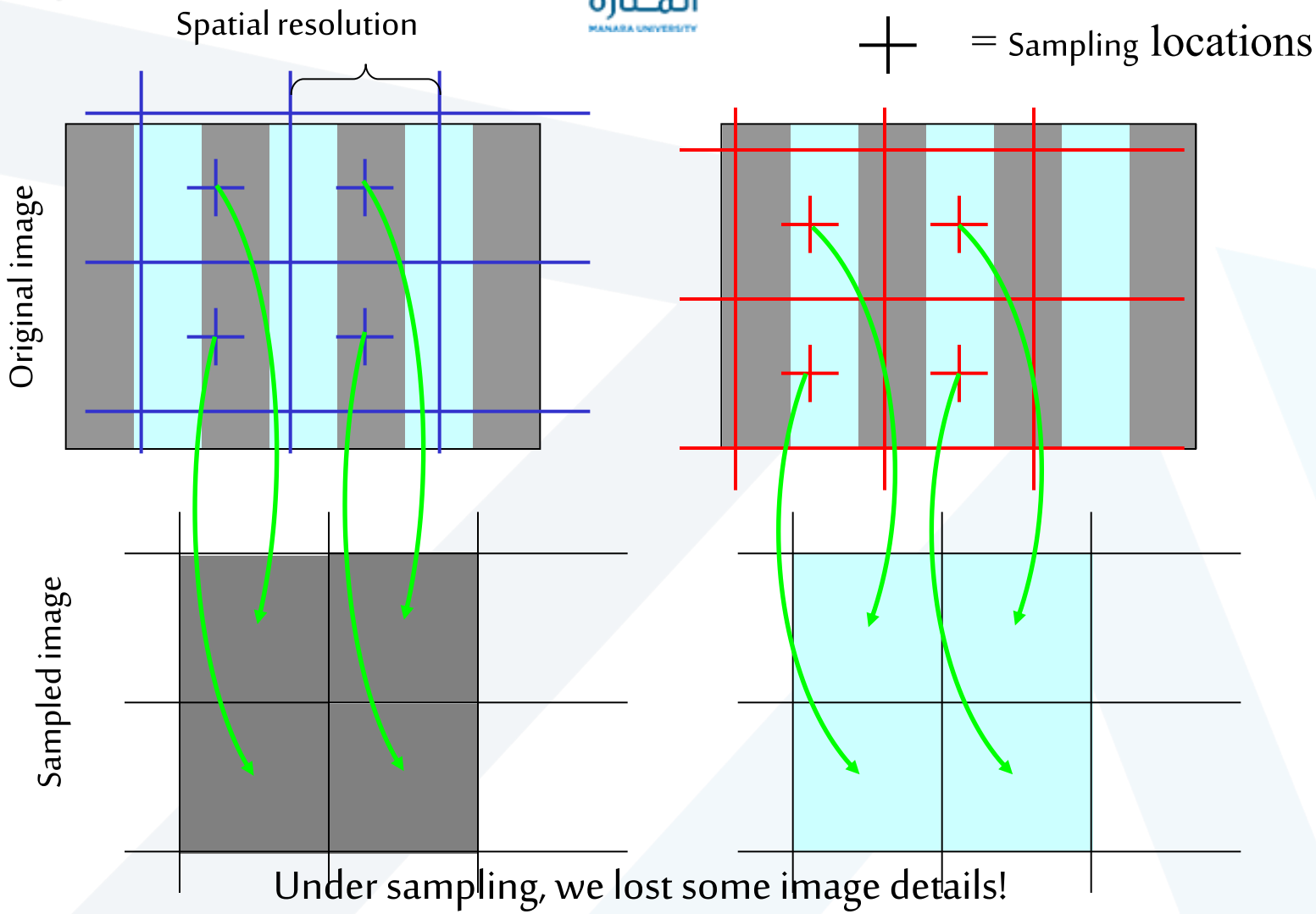
In this image, it is easy to see false contour.

4 levels

2 levels

Effect of Spatial Resolution

How to choose the spatial resolution

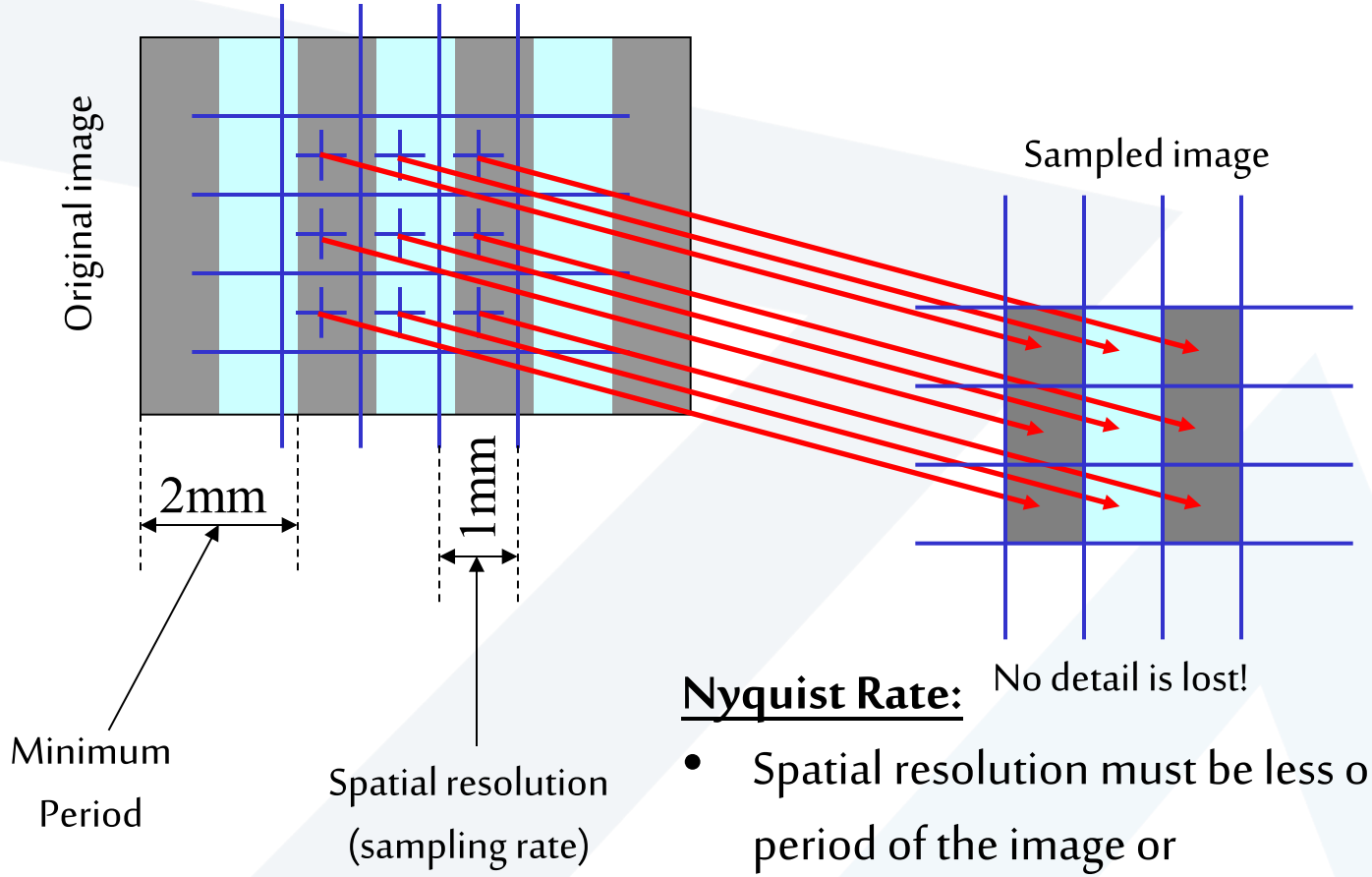


Under sampling, we lost some image details!

Effect of Spatial Resolution

How to choose the spatial resolution :

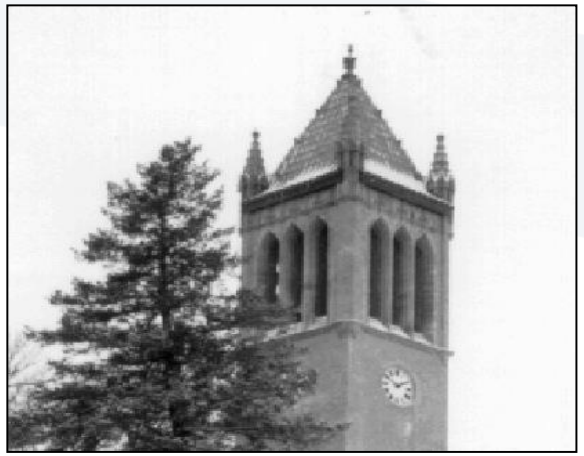
Nyquist Rate



Nyquist Rate:

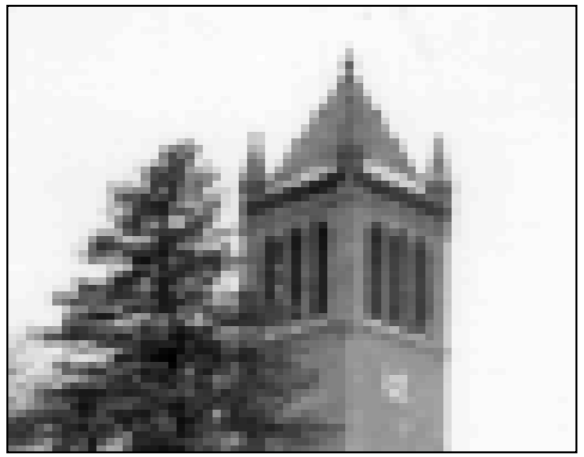
- Spatial resolution must be less or equal half of the minimum period of the image or
- sampling frequency must be greater or Equal twice of the maximum frequency.

Effect of Spatial Resolution

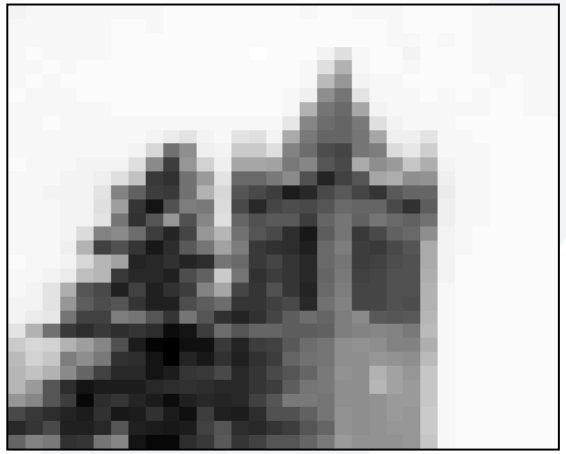


256x256 pixels

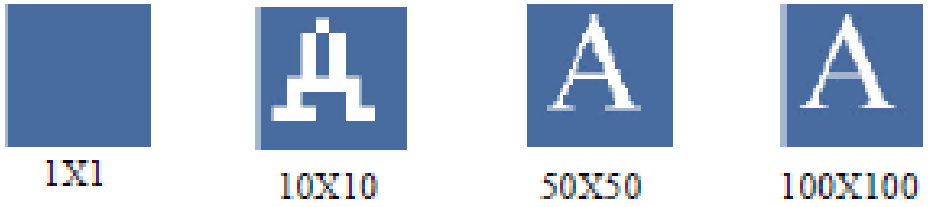
128x128 pixels



64x64 pixels



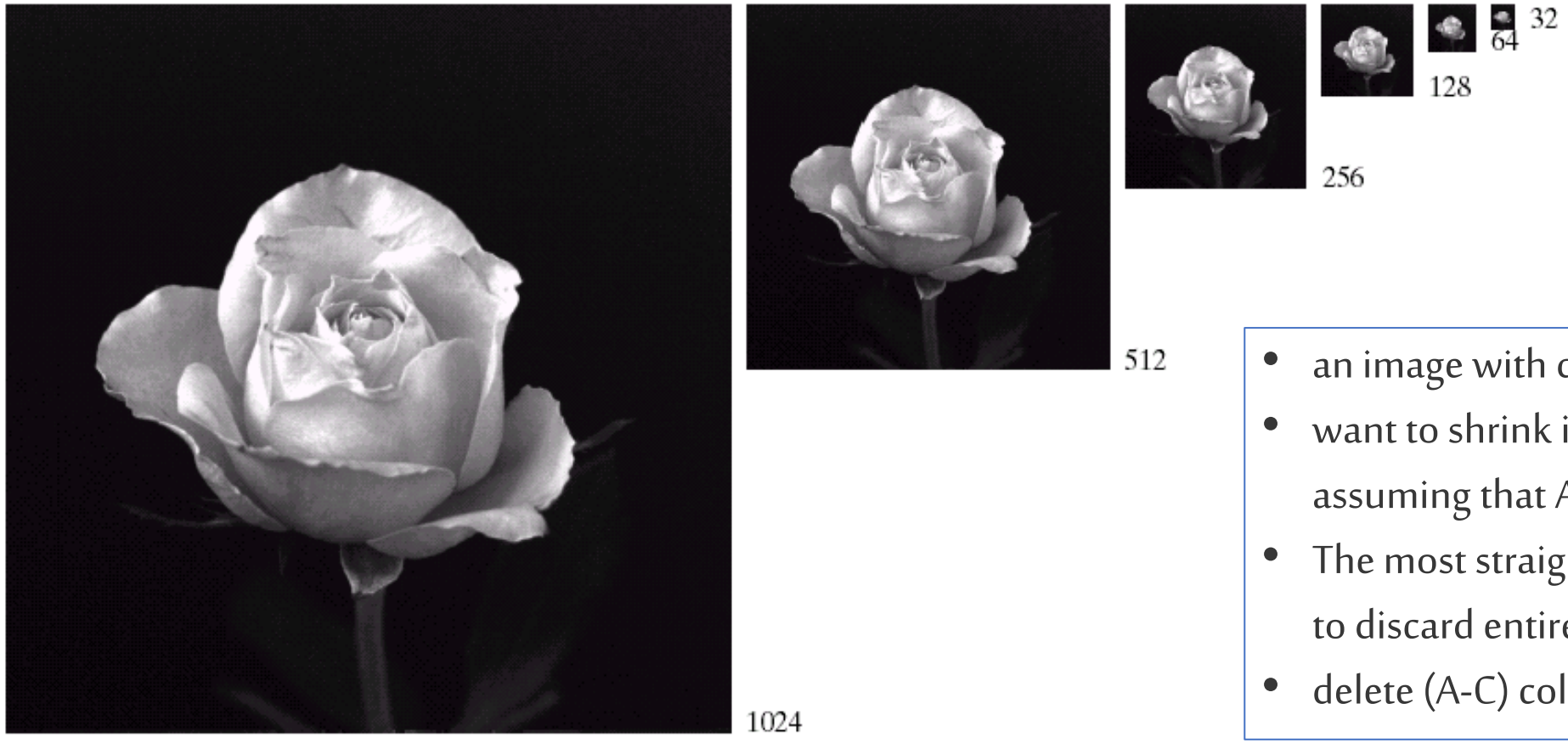
32x32 pixels



insufficient spatial resolution-> appearance of checkerboard pattern in the image

Effect of Spatial Resolution Downsampling

Downsampling:
"shrinking" an image's dimensions you are essentially throwing away image information.
(note: this is NOT the same as image compression),

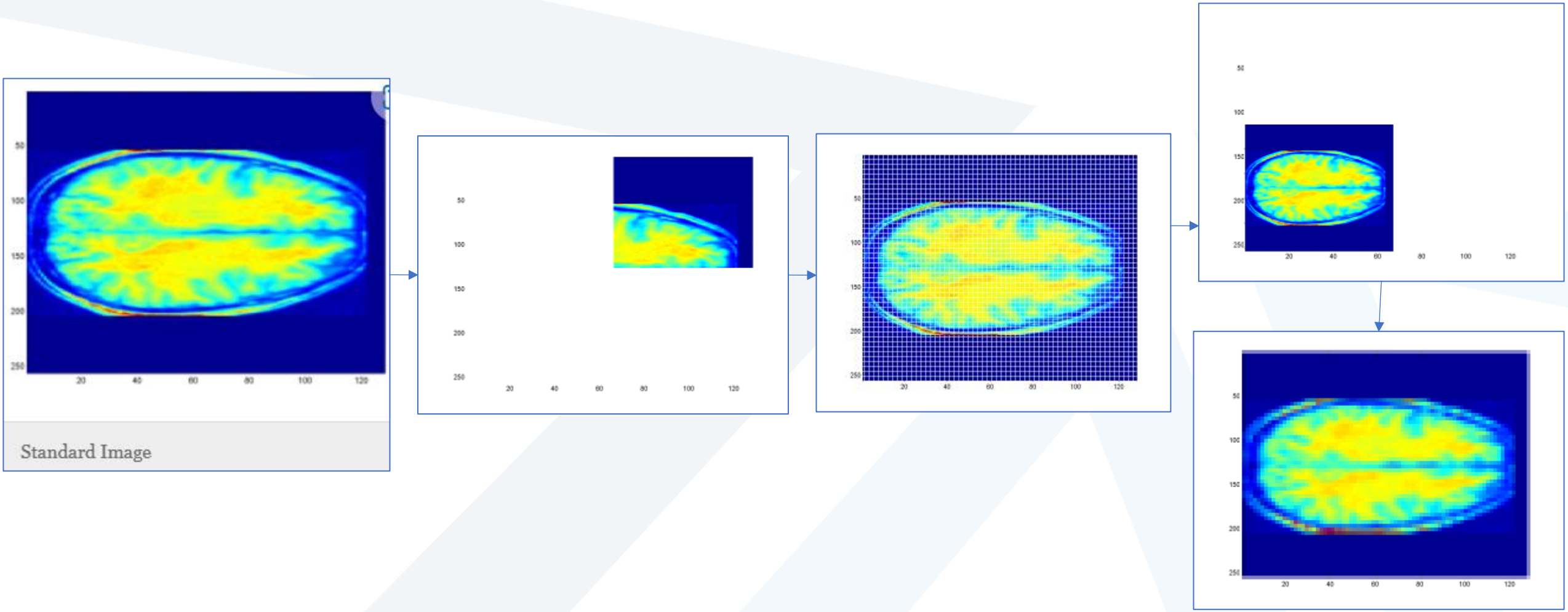


- an image with dimensions AxB,
- want to shrink it to the dimensions of CxD, assuming that A>C and B>D.
- The most straightforward way to do this is to discard entire columns/rows of data.
- delete (A-C) columns, and (B-D) rows.

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

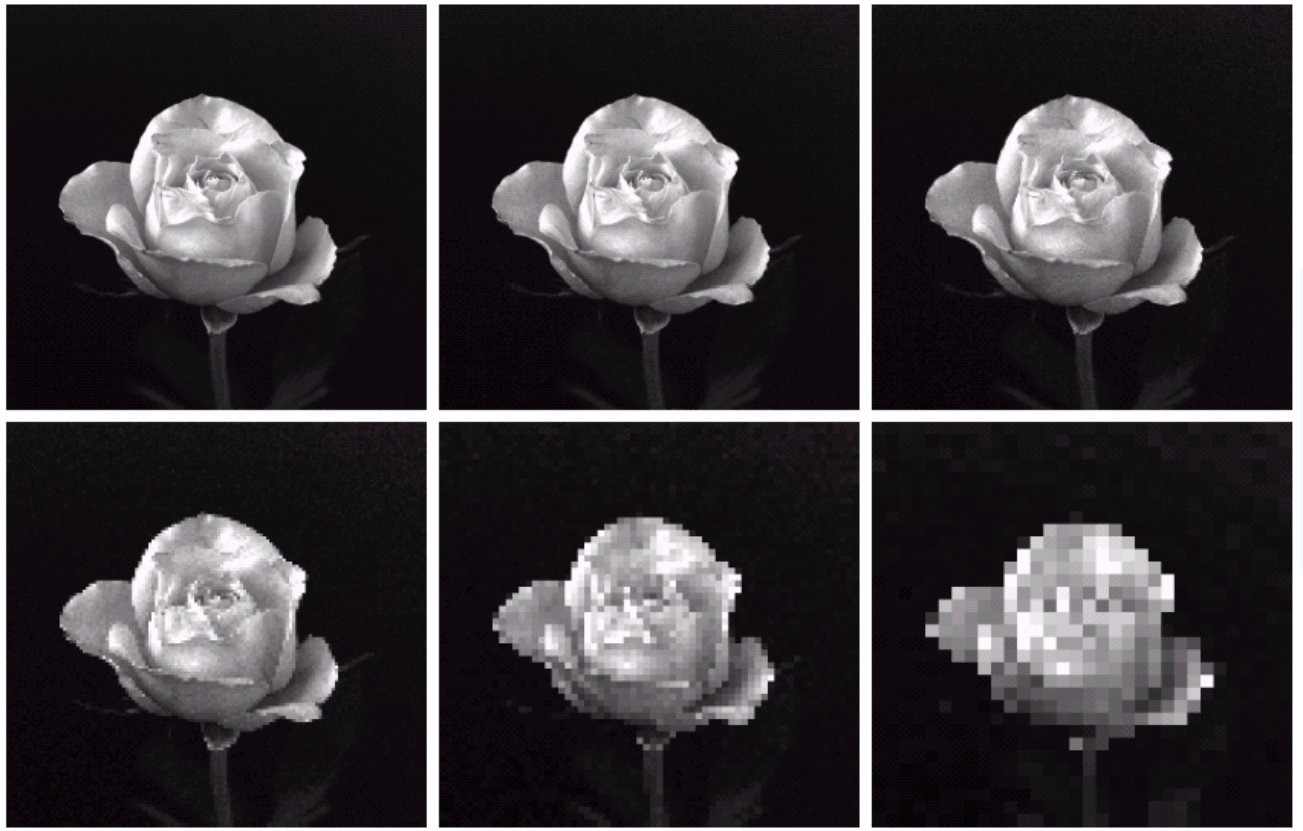
Effect of Spatial Resolution Downsampling



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Effect of Spatial Resolution
Upsampling (duplication):

Upsampling (duplication): basically expanding an image, and filling in "gaps" in rows and columns of the original image. For example, say we want to increase the width and height of an image by a factor of 4. We could simply "repeat/redraw" each row and column of the original image 4 times.



a b c
d e f

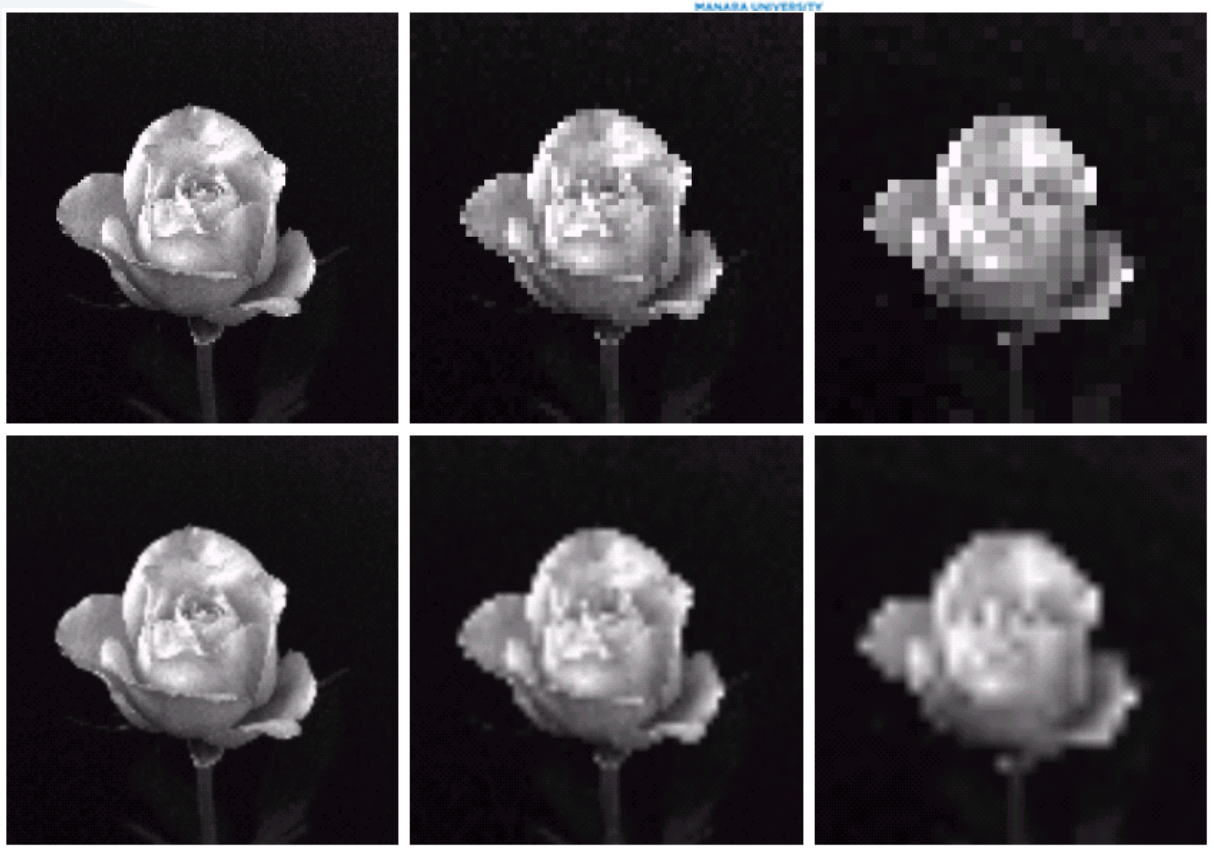
FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

A problem with this approach is that it only works when we want to increase the image dimensions by an integral factor (ie: 2, 4, 10), as it cannot deal with the case of image scaling by a fractional number (2.5, 10/3, etc).

Effect of Spatial Resolution
Upsampling (interpolation):

Can we increase spatial resolution by interpolation ?

Down sampling is an irreversible process.



a b c
d e f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

I - Nearest Neighbour Interpolation

II – Bilinear Interpolation

III - Bicubic Spline Interpolation

IV - Generalized Bicubic Interpolation

خلاصة

- دقة الصورة هي وحدة قياس لأصغر جزء في الصورة يمكن تمييزه بالعين. تصبح معالم الصورة اوضح تبعا لـ:

1. حجم الصور ويحدد مباشرة من عدد الأسطر M وعدد الأعمدة N للمصفوفة الممثلة للصورة وبالتالي عدد البكسلات في الصورة وهو **لا يعطي معلومات دقيقة عن الدقة المكانية** ولا يحدد وضوحها لوحده.
2. Spatial resolution الدقة المكانية: كلما كانت البكسلات متقاربة كانت الدقة أعلى. تحدد الدقة المكانية للصورة بعدد العناصر المميزة في واحدة القياس وتقاس بمقاييس مختلفة حسب التطبيق:

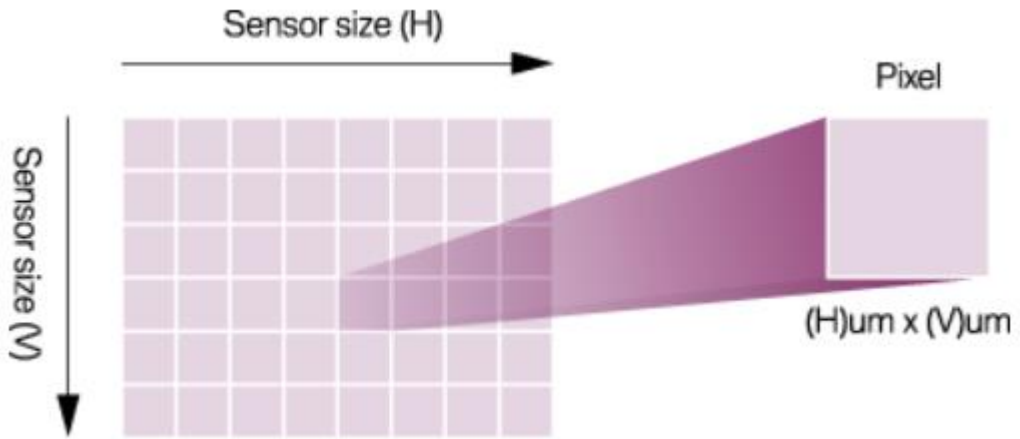
- Dot per inch (dpi): monitors
- Lines per inch (lpi): laser printers
- Pixels per inch (ppi): tablets, Mobile- phones
- Pixel per Km: sattelite images
- Samples per inch (spi): scanners

Spatial resolution: pixel size AND number of pixels

3. دقة الشدة الضوئية: عدد القيم أو السويات اللونية الممكنة في الصورة (عمق البت)، كلما كانت اكثر كان لها قدرة اعلى على زيادة الدقة.

Pixel Size

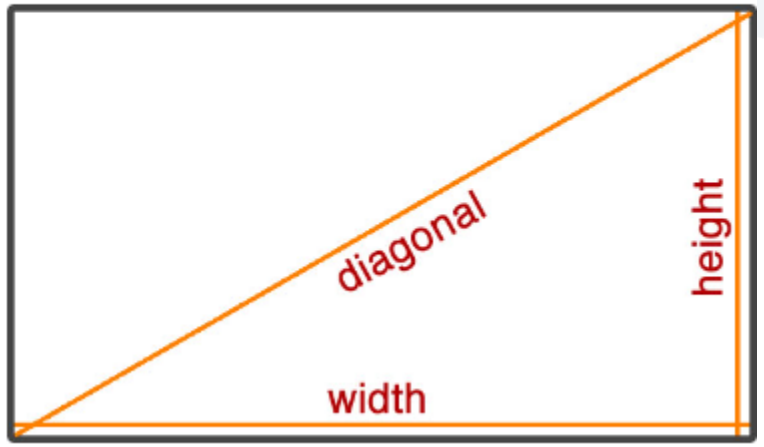
- **Sensor size is the size of the sensor inside a camera>**
- **Pixel size is the size of image sensor that compose image sensor.**
- Pixel size: 4.4µm x 4.4µm
  Effective Pixel amount : 1600 x 1200
  Sensor size (H) ＝ 0.0044 x 1200 ＝ 5.28mm
  Sensor size (V) ＝ 0.0044 x 1600 ＝ 7.04mm
  Sensor size ＝ 7.04 x 5.28mm



Digital camera image sensors consist of a large number of tiny sensors that collect photons. The photodiode then converts the photons into an electrical charge. Each pixel associates with a single photodiode.

Calculate PPI

$$\text{diagonal} = \sqrt{\text{width}^2 + \text{height}^2}$$



$$\text{PPI} = \frac{\text{diagonal in pixels}}{\text{diagonal in inches}}$$

- A screen that is 1920 pixels wide by 1080 pixels high
- The diagonal is 10 inches= 25.4cm=254mm

$diagonal_{pixels} = \sqrt{(1920^2 + 1080^2)}$

$diagonal_{pixels} = \sqrt{(3686400 + 1166400)}$

$diagonal_{pixels} = \sqrt{4852800}$

$diagonal_{pixels} = 2202.91$ pixels

$PPI = diagonal_{pixels} / diagonal_{inches}$

$PPI = 2202.91 / 10$

$PPI = 220.29$ pixels

- So there are 220.29 pixels in a 1 inch line on the display (about 220.29/25.4=8.6 pixels per mm).
- $220.29^2 = 48528$ pixels per square inch
- So there are 48528 pixels in an area of the screen that is 1 inch wide by one inch high
- Screen length= 1920/220.29=8.71 inch=221.38 mm
- Screen width=1080/220.29=4.9 inch = 124.5 mm

How to Calculate the diagonal dot pitch

Diagonal dot pitch is the diagonal distance from the center of one pixel to the center of the next.

Dot pitch is calculated from the diagonal length in inches and pixels then converted from inches per pixel to millimeters per pixel but normally only expressed in millimeters (mm).

$$\mathrm{PPI} = \frac{\text{diagonal in pixels}}{\text{diagonal in inches}}$$

$$\text{dot pitch} = \frac{\text{diagonal in inches}}{\text{diagonal in pixels}} \times \frac{25.4\ \text{mm}}{\text{inch}}$$

If a screen diagonal is 15.4 inches and has 3396 pixels. Dot pitch = (15.4/3396) × 25.4 ≈ 0.1152 mm.

Example

Pixel total	1000 x 1000 Pixel [1 Mpx]
Picture size	254 x 254 mm
dpi / ppi	100 dpi
Color depth	8 Bit - MSX2 computer
Disk space	1 MB
Pitch	254 µm
Pixel size	64516 µm²

10inch*10inch

NOTE:1mm = 1000/254=4 pixels

Diagonal in pixels = $\sqrt{1000^2 + 1000^2} = 1414.2\ pixels$

Diagonal in inch = $\sqrt{10^2 + 10^2} = 14.142\ inch$

$PPI = diagonal_{pixels} / diagonal_{inches}$

PPI =1414.2/14.142=100 pixel per inch
=100/25.4=4 pixel per mm

PITCH=(1/PPI)*25.4 =(1/100)*25.4=0.254mm

Does smartphone having same camera sensor have different image quality?

There are several factors that can affect the quality of an image taken with a camera, even if they have the same number of pixels. Some of these factors include:

1. The resolution of the camera in megapixels.
2. The quality of the lens.
3. The sensor size AND The sensor technology used in the camera
4. the image processing software and algorithms used.
5. and the overall design and engineering of the camera.
6. lighting conditions: It's basically your camera's sensitivity to light. The higher the ISO sensitivity, the less light required to take a high-quality image. This is an important factor in determining your balance of settings in low or high light scenarios.
7. Additionally, external factors such as:, movement, and subject matter can also play a role in the quality of the final image.
8. **Resolution 2880*2160 Aperture F1.7 Focal length:4.2mm Flash ISO Exposure time:1/50s**

Resolution: How Much Is Enough?

The word “suitable” is subjective: depending on “subject”.

The picture on the right is fine for counting the number of cars, but not for reading the number plate

Low detail image

Lena image

Medium detail image

Cameraman image

High detail image

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