Digital Image Processing

- Lecture notes 2024
- **F3i**
- Evaluation : 60% exam 40 % continuous
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- Facebook *image processing F3I*

Image Processing F3I

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+ Add a Butto

Objectives

- Know the different types of digital images
- Manipulate digital images
- Learn basic image operations

Plan

1. General introduction
2. Digitization
3. Digital image
4. Arithmetic and logical operations
5. Study of histograms
6. Thresholding
7. The noise
8. Filtering
9. Edge detection
10. Image segmentation

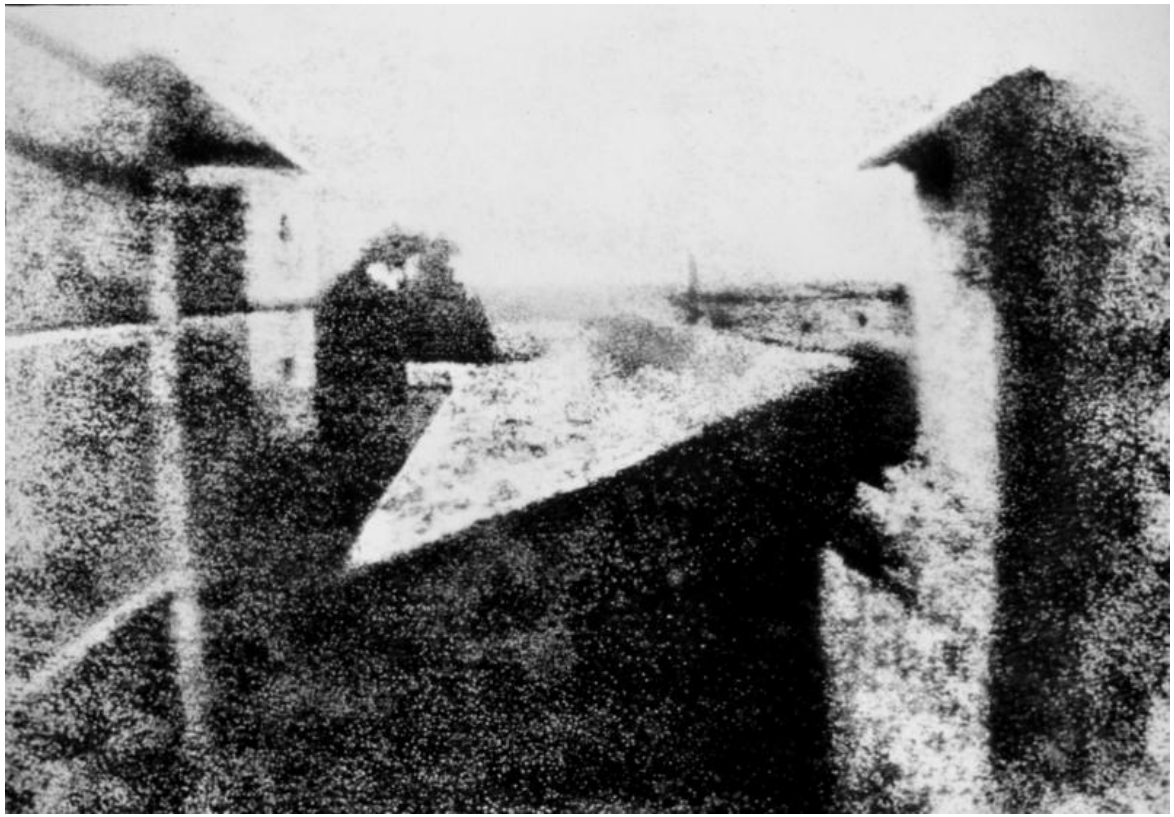
Chapter 1: General introduction

Image

“One picture is worth more than ten thousand words”. Chinese proverb

History

First photograph 1826

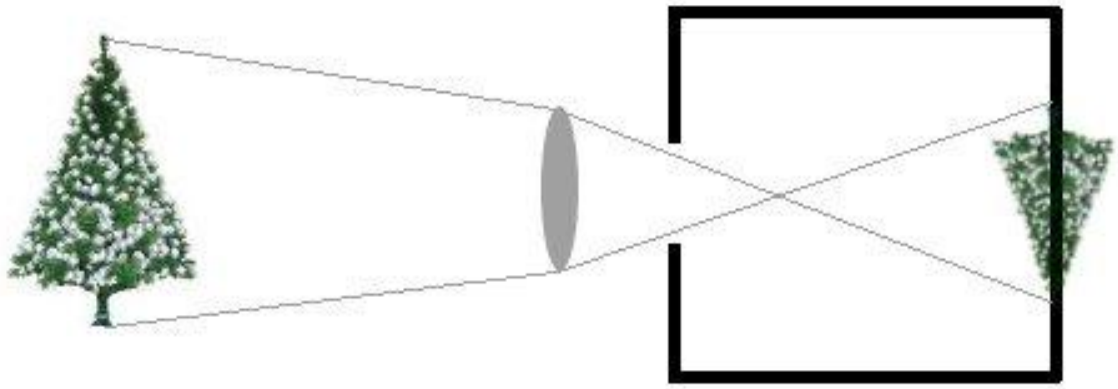


from the window of Nicéphore Niépce's house

Joseph Nicéphore Niépce

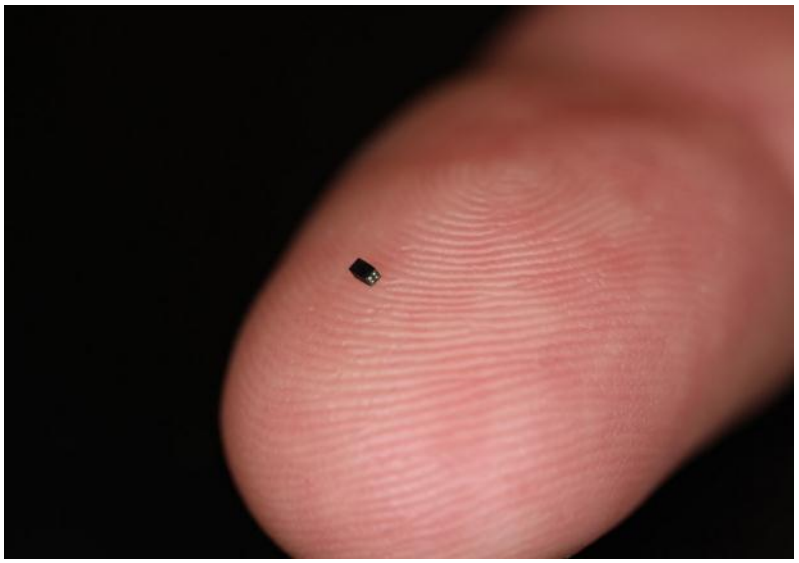
History

Camera obscura principle



- Black box with a hole
- Outside light can only enter through a small hole
- An inverted image forms on the wall opposite the hole (left to right and bottom to top)

History




Camera Lens
TF/SD Card Slot
llpoint Pen
Photo Picture
Video Recorder
Sound Recorder
AVI
USB
Long Hours Battery

Terminology

Image vs Picture vs Photo ?

Examples:

- All **images** of the wedding are in my laptop
- I love taking **photos** of nature
- The painter created the **picture** of Eiffel tower
- The children were drawing **pictures** of their pets.

Terminology

Digital image

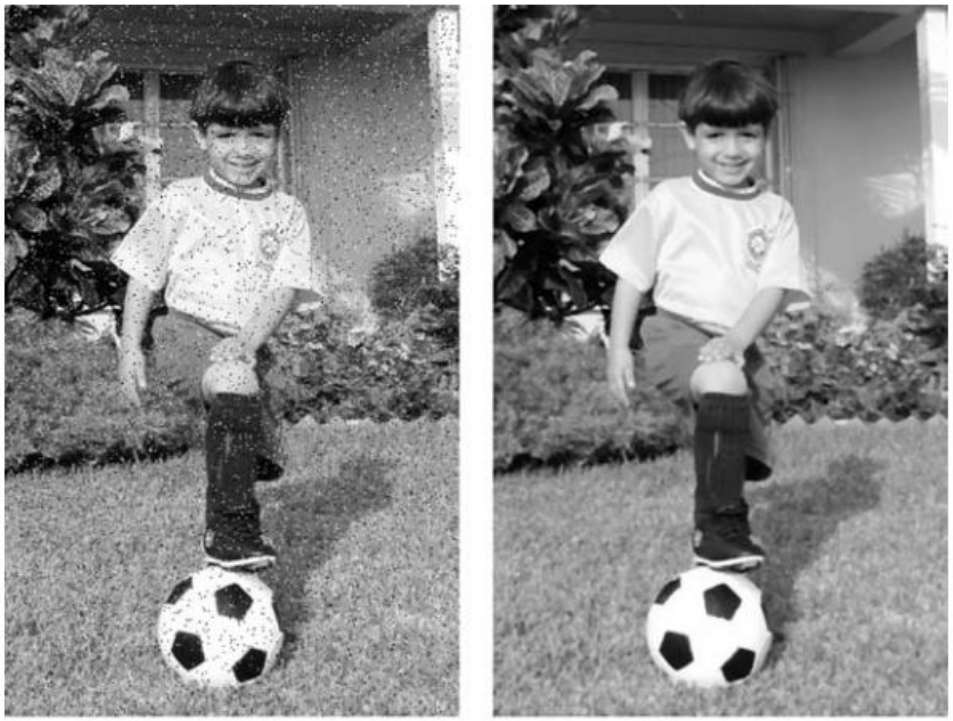
« A digital image consists of a finite number of small spots of color. These spots are called pixels, a contraction of “picture elements”, ….

The image is **stored** (numeric representation) in the form of a matrix where each element consists of single pixel »

Terminology

Digital image processing

"Digital image processing is the use of algorithms and mathematical models to **process** and **analyze** digital images. The goal of digital image processing is to **enhance** the quality of images, **extract** meaningful information from images"



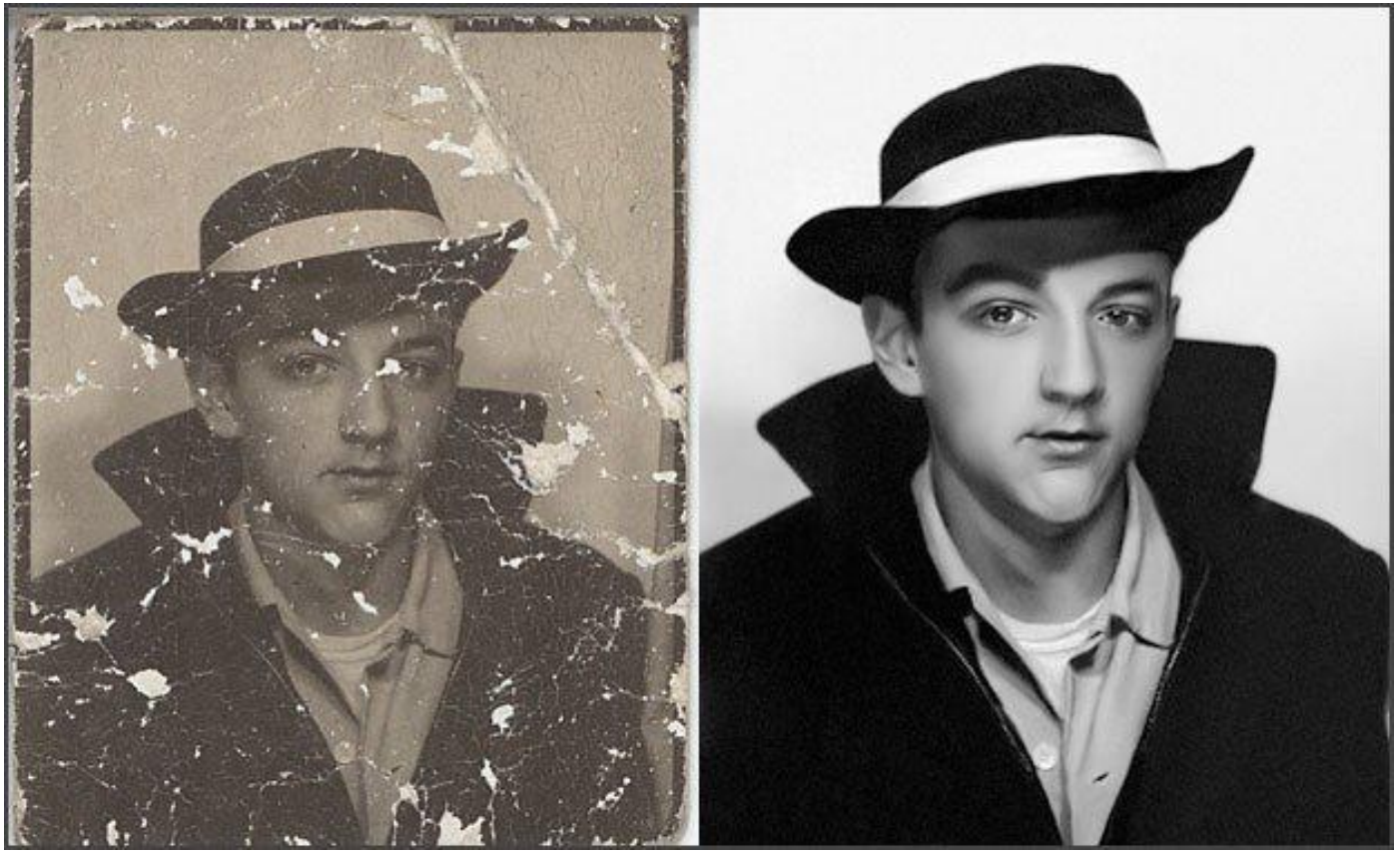
Terminology

Digital image processing

Input: images → **Output**: Enhanced images

Terminology

Image restoration

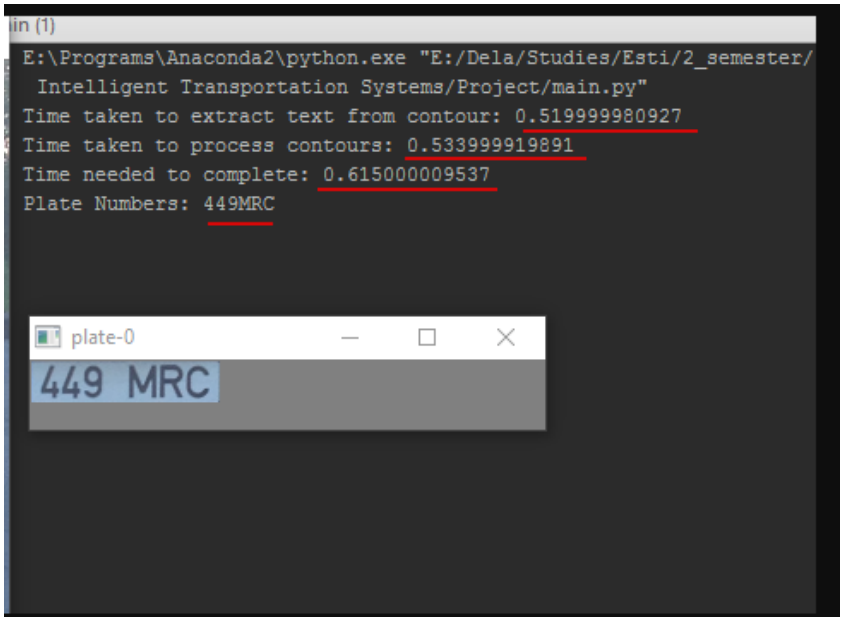


Terminology

Image analysis

The extraction of meaningful information from images

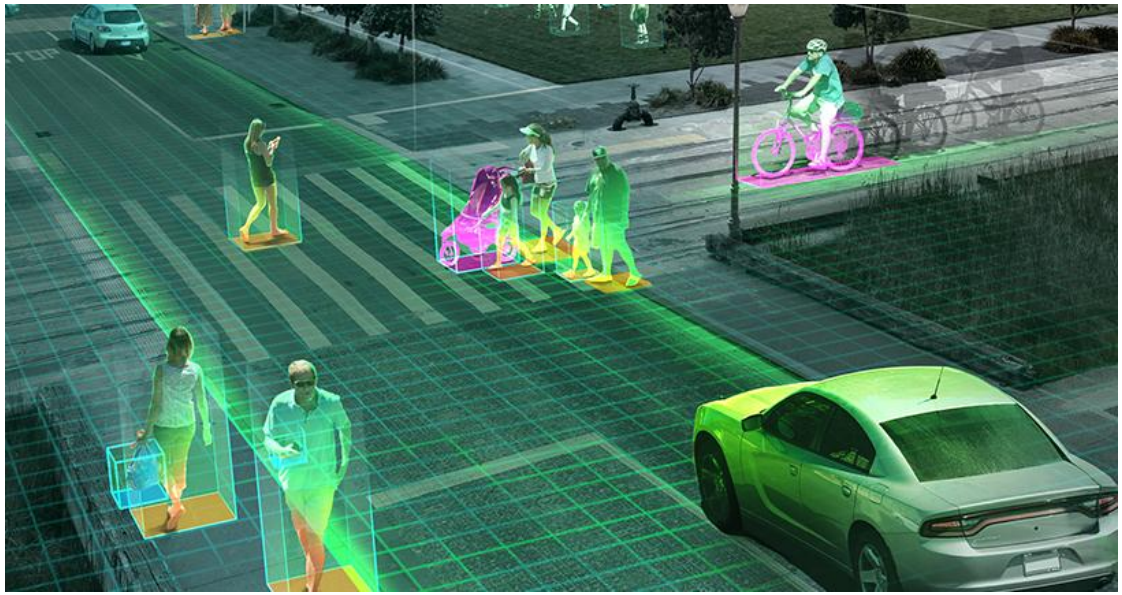
Input: images → **Output**: relevant information



Terminology

Computer vision

“ Subcategory of artificial intelligence (AI) that focuses on building and using digital systems to **process**, **analyze** and **interpret** visual data. The goal of computer vision is to enable computing devices to correctly **identify** an object or person in a digital image and **take appropriate action**”

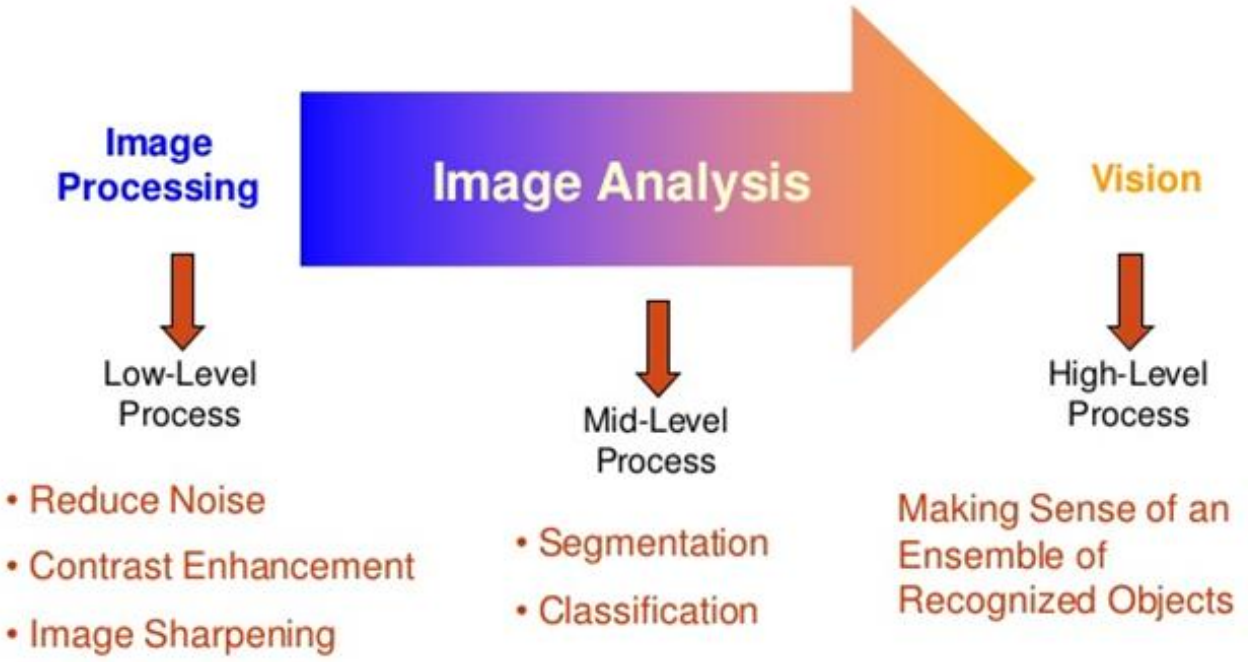


Terminology

Computer vision

"Computer vision is the science of endowing computers or other machines with vision, or the ability to see."

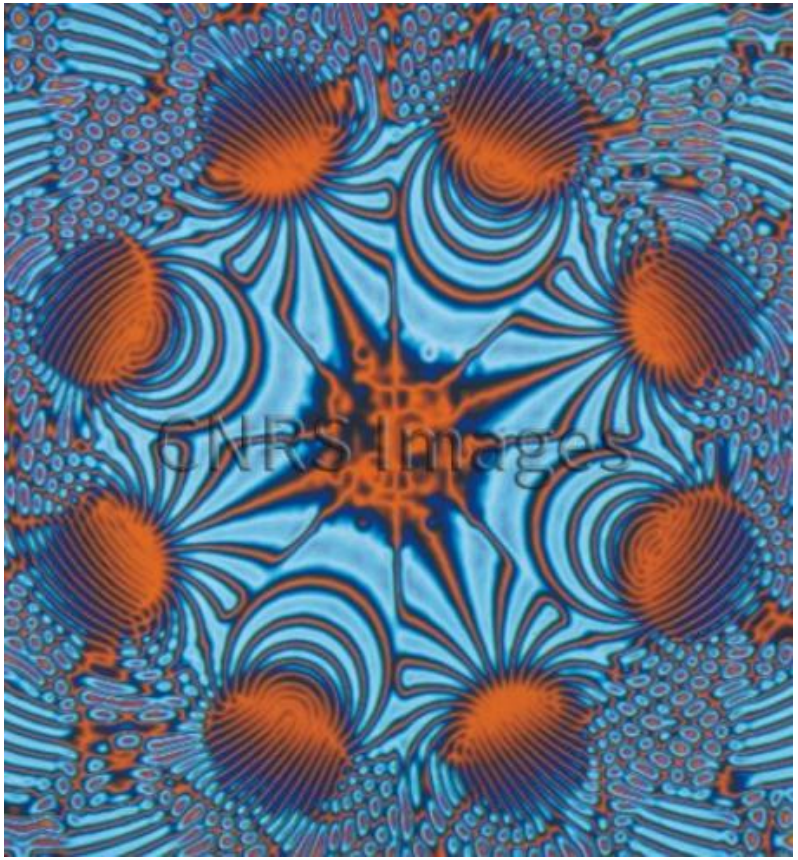
Erik G. Learned-Miller, University of Massachusetts



Terminology

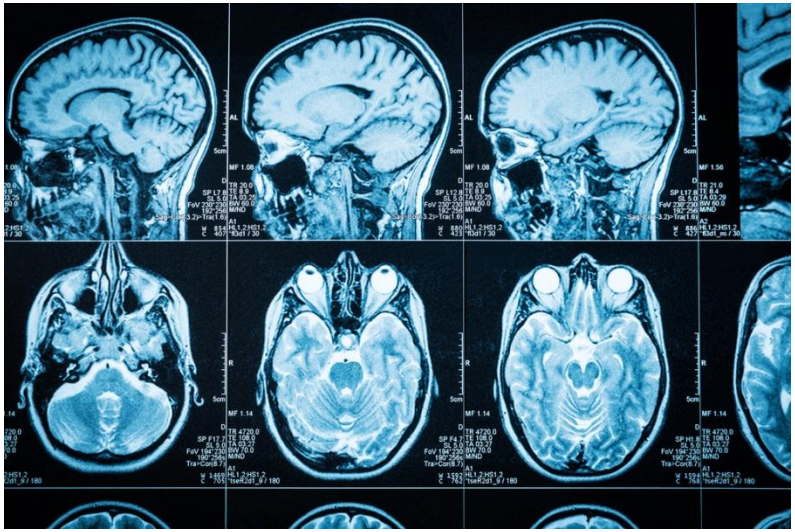
Image synthesis

“ The process of artificially generating(creating) images that contain some particular desired content”



Applications

- Medical imaging
  - Better Diagnosis
  - Eliminate the need for surgery
  - Complicated surgeries (Robot-assisted surgery)….

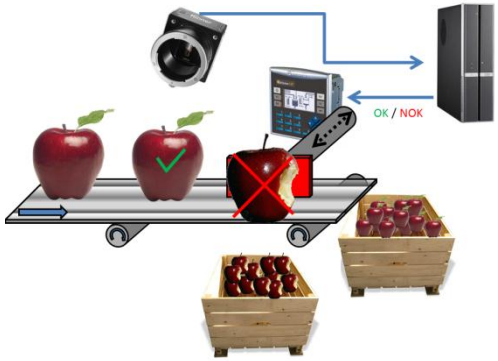


Applications

- Satellite Image Processing
  - Cadastre and Land Records
  - Crime Mapping
  - Global Climate Change
  - Agriculture
  - Forestry…

Applications

- Robotics
  - Games
  - Industrial Vision
  - Automatic sorting system ….

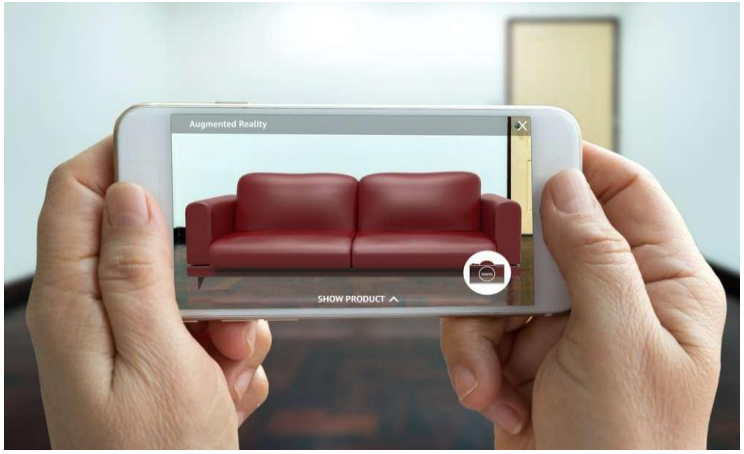


Applications

- Biometrics
  - Fingerprint
  - Iris recognition
  - Facial recognition system…..

Applications

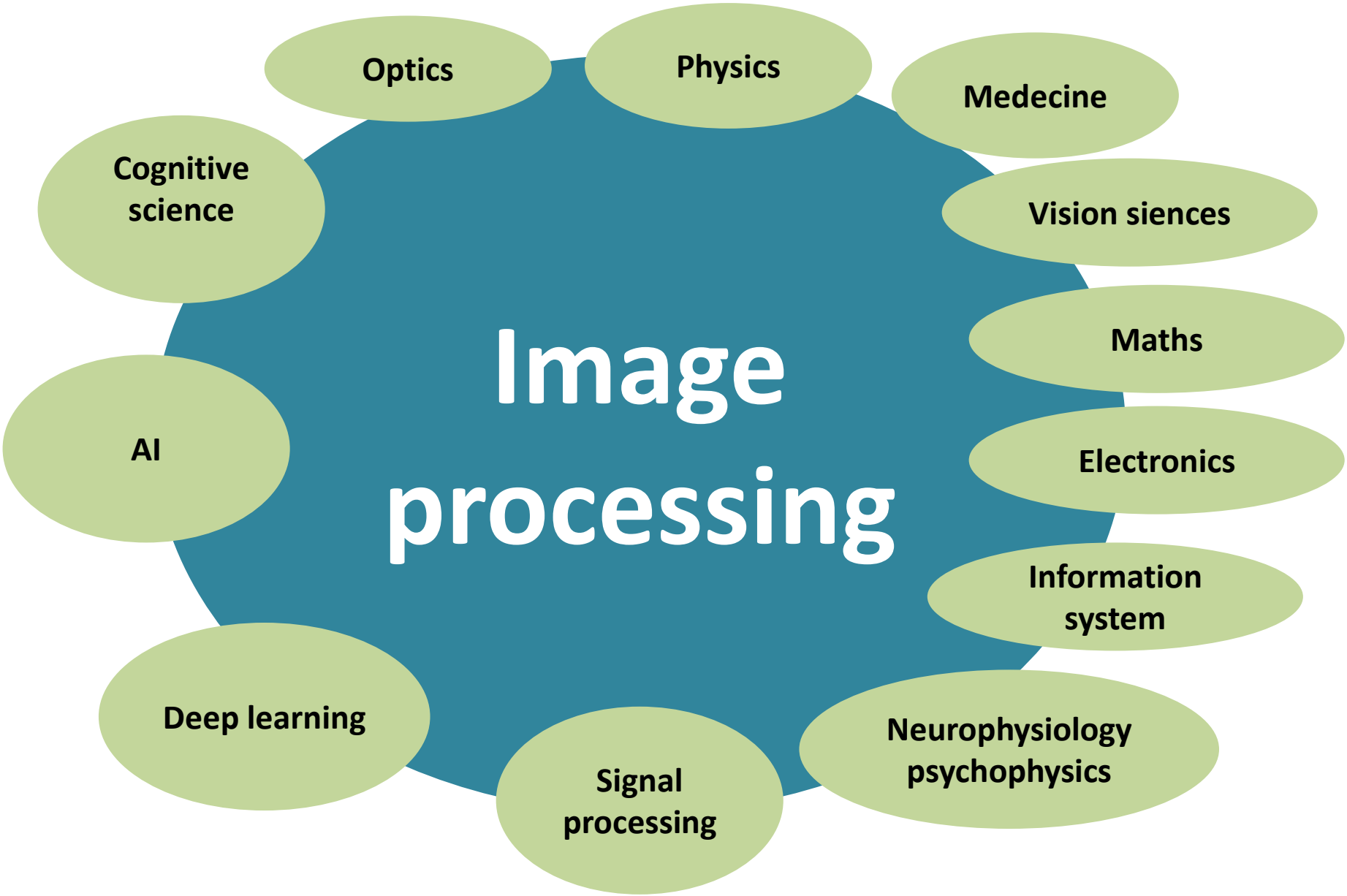
- Virtual reality / Augmented reality/ Gaming



Applications

- Autopilot driving
- Flight simulator
- Target detection
- Remote monitoring

Multidisciplinary



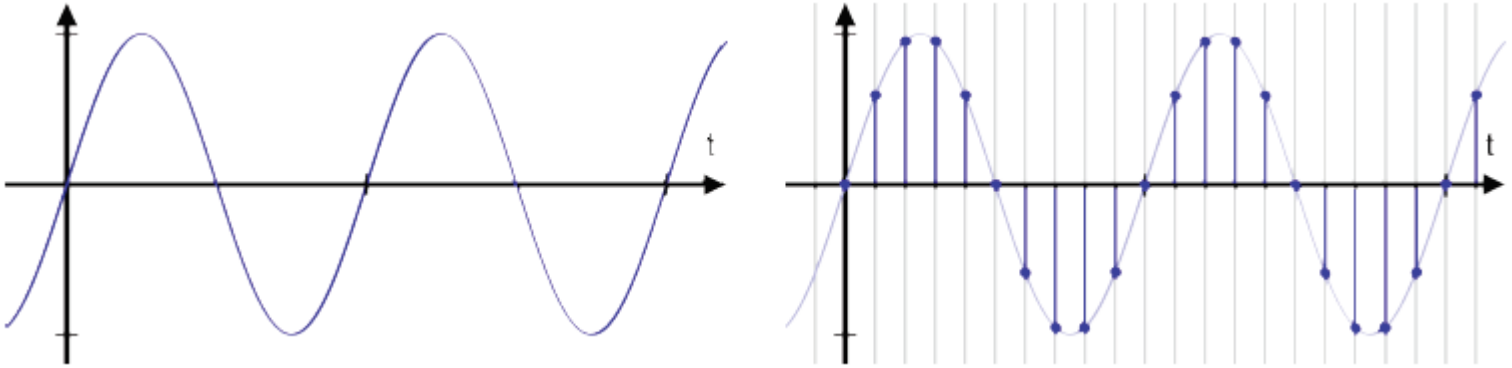
Chapter 2: Digitization

Digitization

Definition

“Is the process of converting an electrical signal, often from a sensor, into a digital signal that a computer can read”

“ Digitization is the operation of converting a real object (**continuous signal**) from the physical world (image, sound, etc.) into a digital format (**discrete signal**) “



Digitization

Definition

There are two steps to digitize an image:

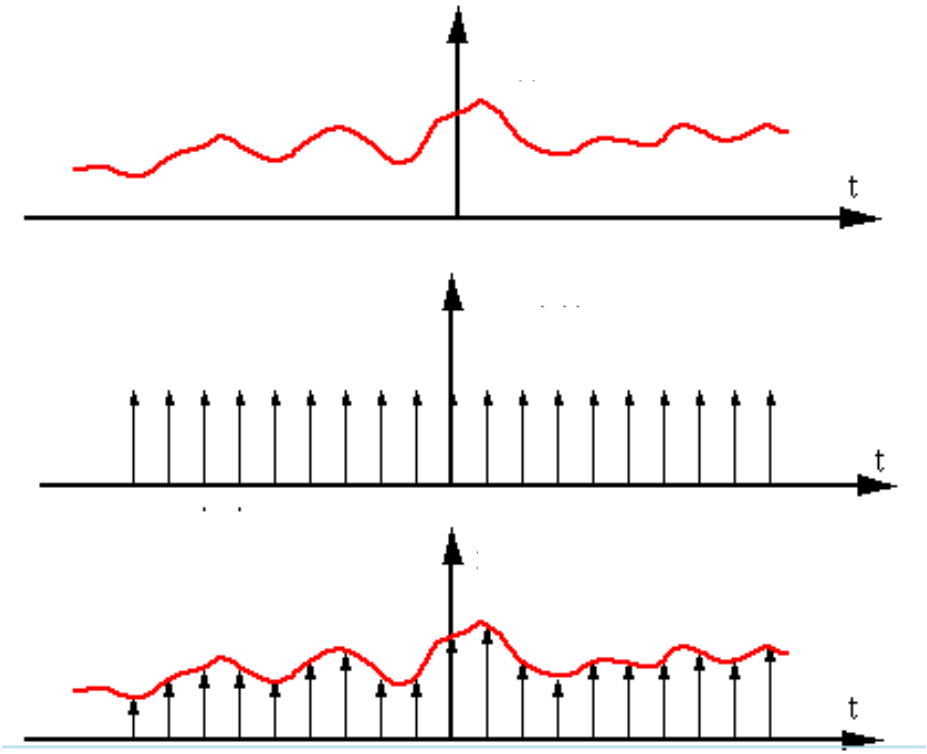
1. **Sampling**
2. **Quantization**

Digitization = Sampling + Quantization

Digitization

Sampling

The process of measuring the instantaneous values of continuous-time signal in a discrete form. It produces a series of discrete values called samples,

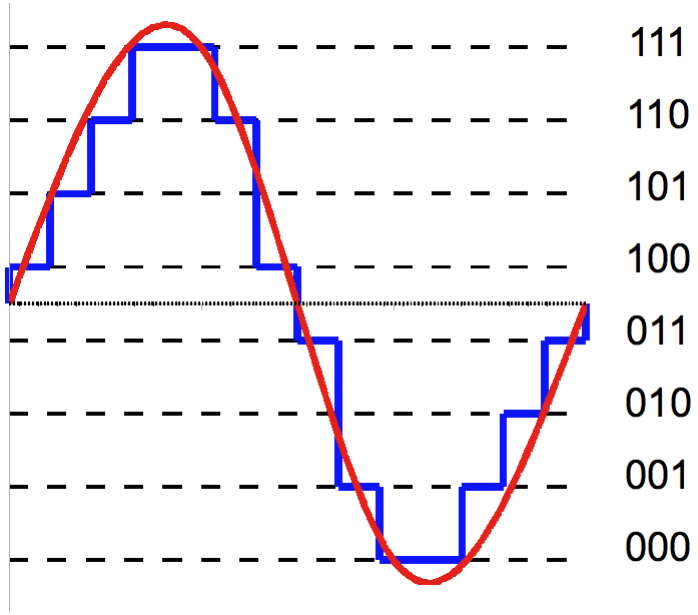


Digitization

Quantization

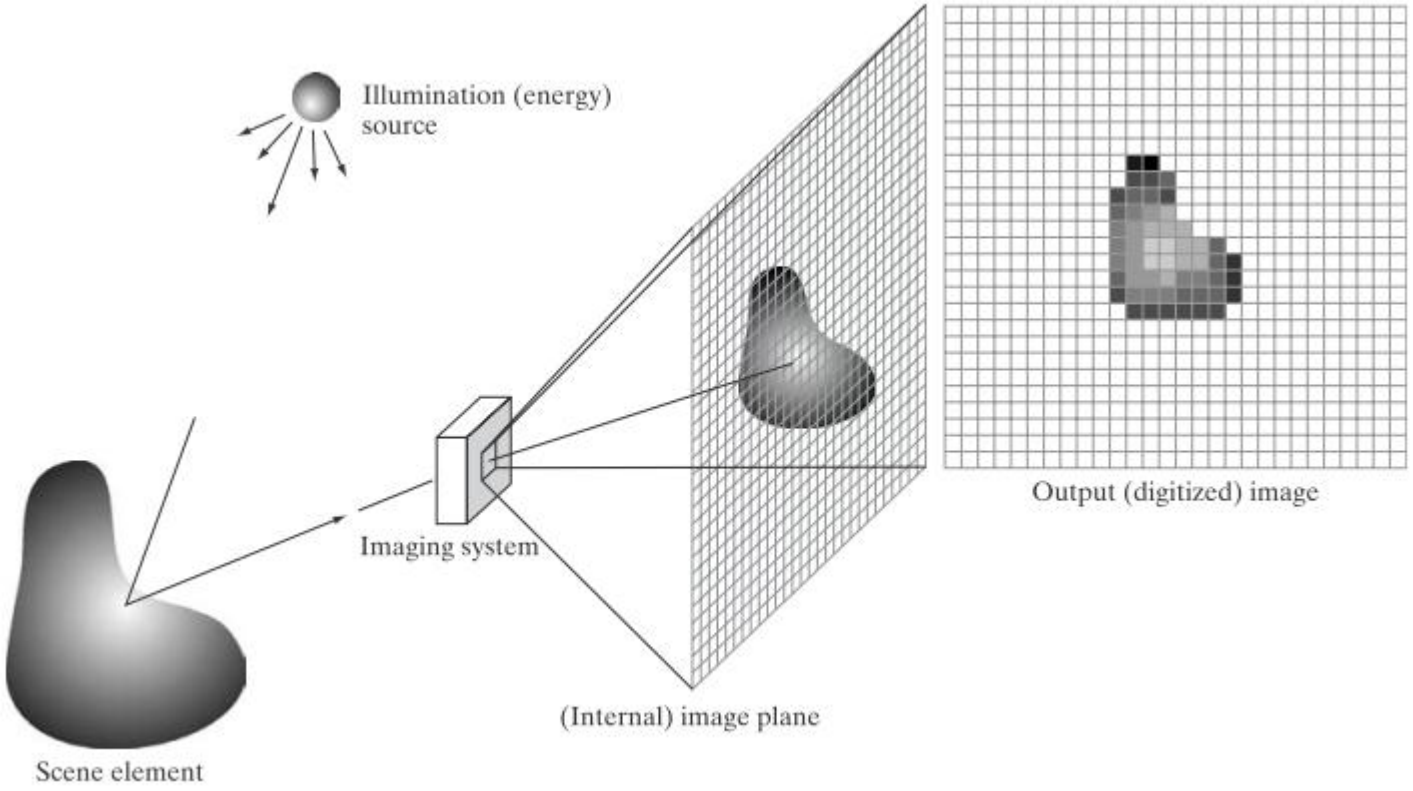
- Quantization consists of assigning a level to any value taken from the signal during sampling

- Each level is coded on **N** bits.
- An **N**-bit converter has $\mathbf{2^N}$ quantization levels.



Numérisation

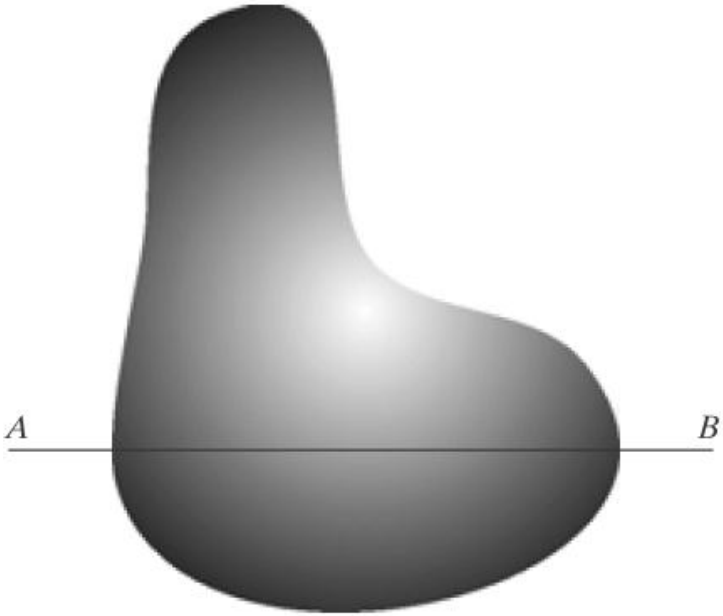
- The image is a **2D** signal (x,y) which represents a **3D** reality (x,y,z)

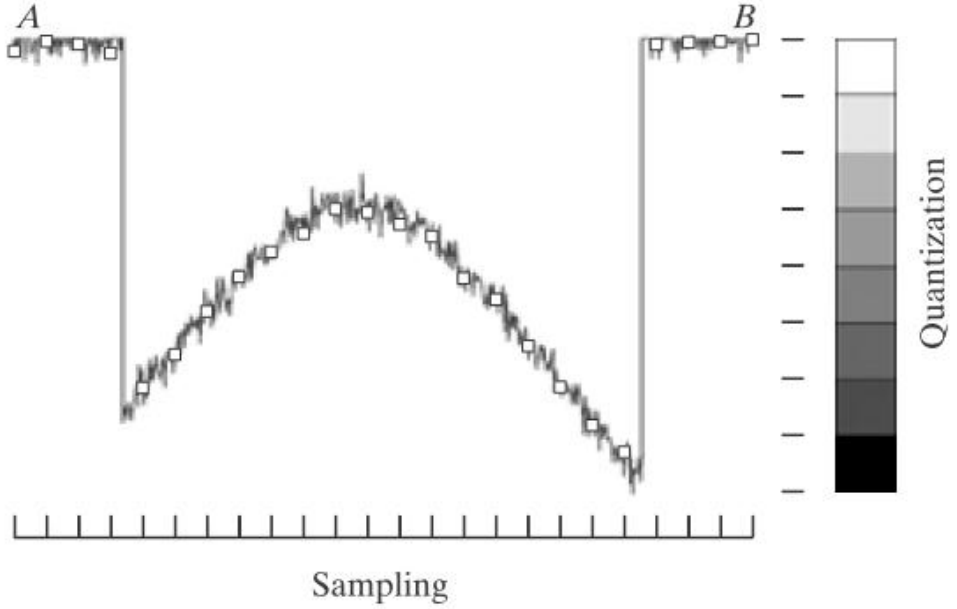


Digitization

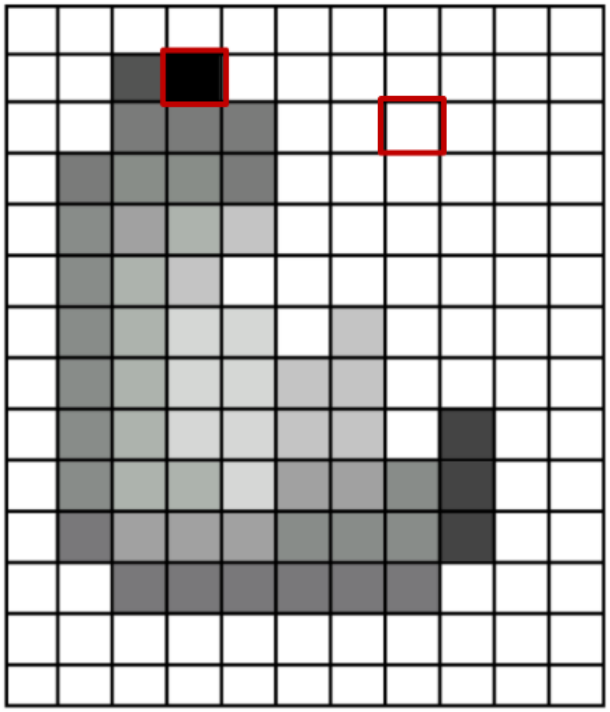
"Digitizing the coordinate values is called **sampling**. Digitizing the amplitude values is called **quantization**".

Example





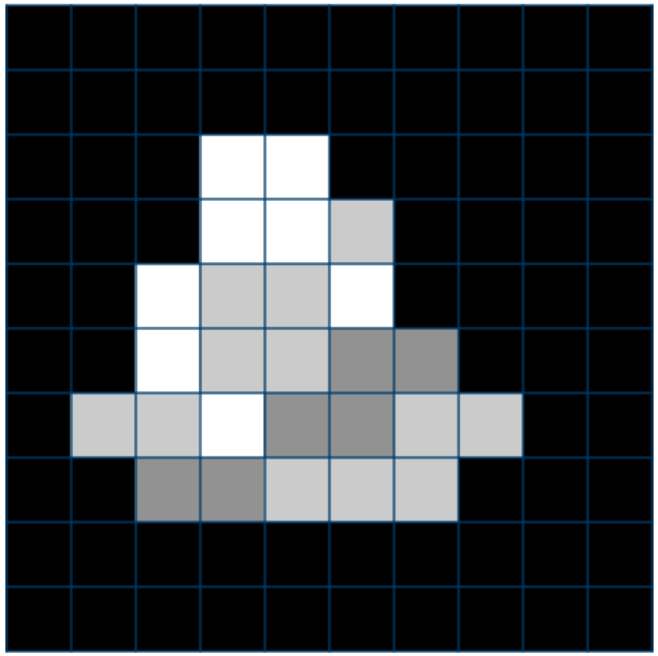
Numérisation



=

255	255	255	255	255	255	255	255	255	255	255
255	255	20	0	255	255	255	255	255	255	255
255	255	75	75	255	255	255	255	255	255	255
255	75	95	95	75	255	255	255	255	255	255
255	96	127	145	175	255	255	255	255	255	255
255	127	145	175	175	175	255	255	255	255	255
255	127	145	200	200	175	175	95	255	255	255
255	127	145	200	200	175	175	95	47	255	255
255	127	145	145	175	127	127	95	47	255	255
255	74	127	127	127	95	95	95	47	255	255
255	255	74	74	74	74	74	74	255	255	255
255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255

Digitization



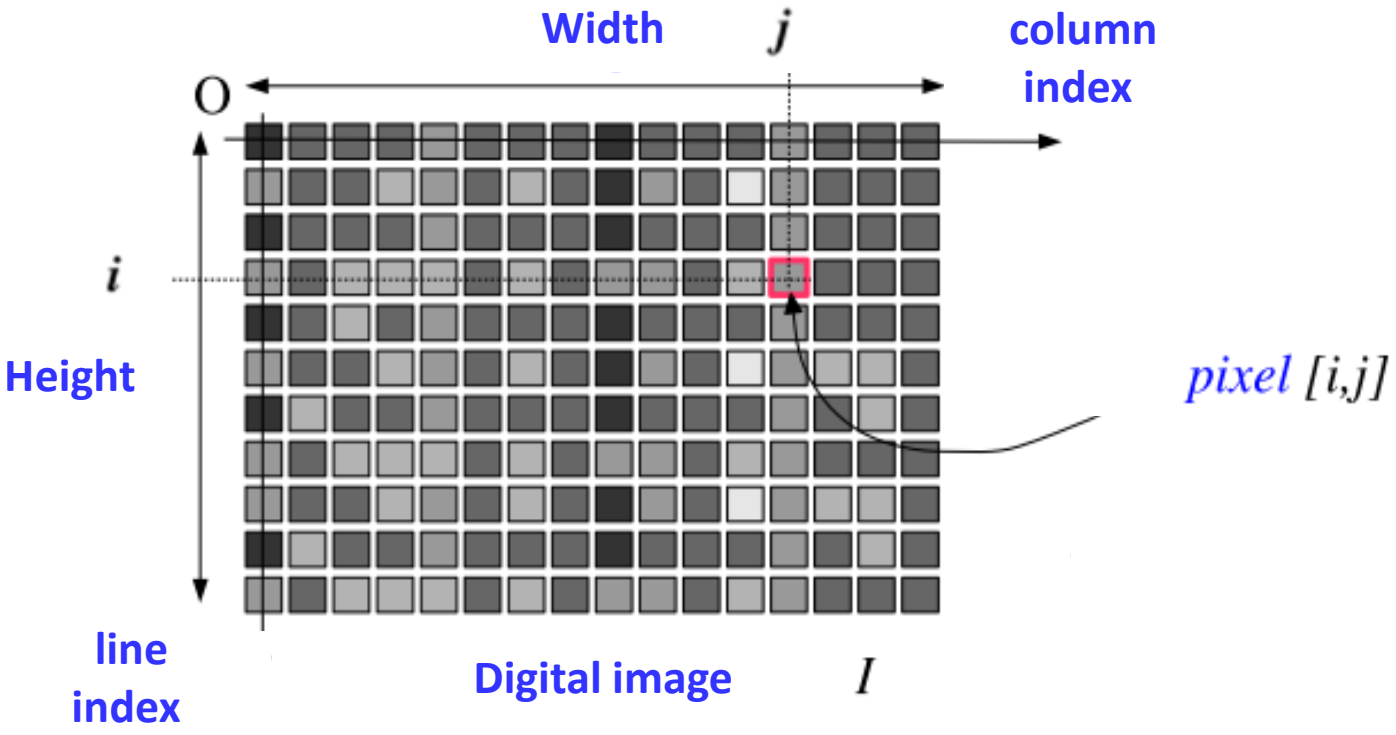
=

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	255	255	0	0	0	0	0
0	0	0	255	255	170	0	0	0	0
0	0	255	170	170	255	0	0	0	0
0	0	255	170	170	85	85	0	0	0
0	170	170	255	85	85	170	170	0	0
0	0	85	85	170	170	170	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Chapter 3: Digital image

Digital image

Bitmap representation (Matrix)

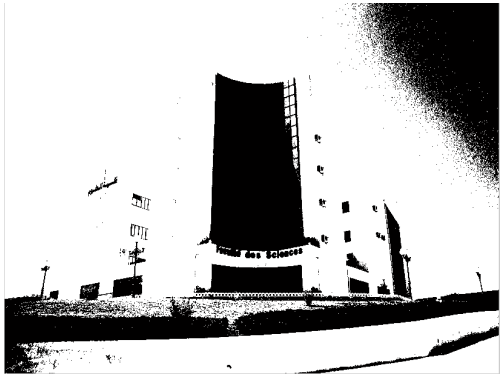


Digital image

Types of digital images

1. **Binary images**
2. **Grayscale images**
3. **Color images**
4. **Indexed Images**

Binary



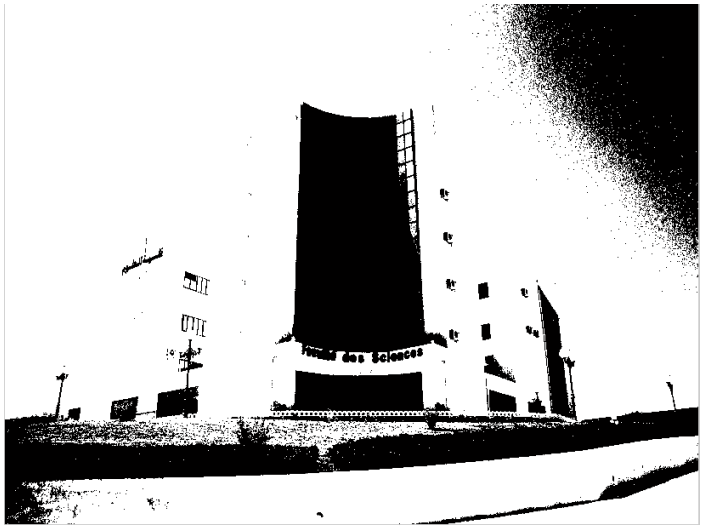
Grayscale

Color

Digital image

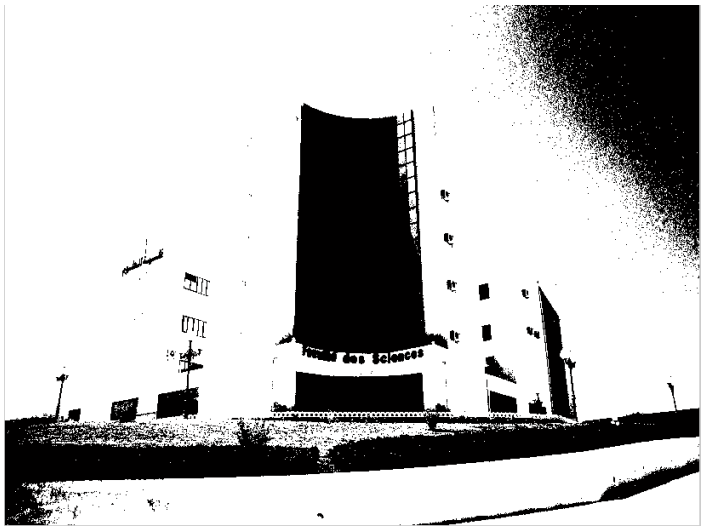
1. Binary images

- Two colors: black (0) and white(1)
- I(x,y) ∈ {0 , 1}
- pixel coded on 1 bit
- Examples: Plan, digital fingerprint, …



1. Binary images

- **Advantages**: easy to acquire / low storage /simple processing….
- **Disadvantages**: limited application….



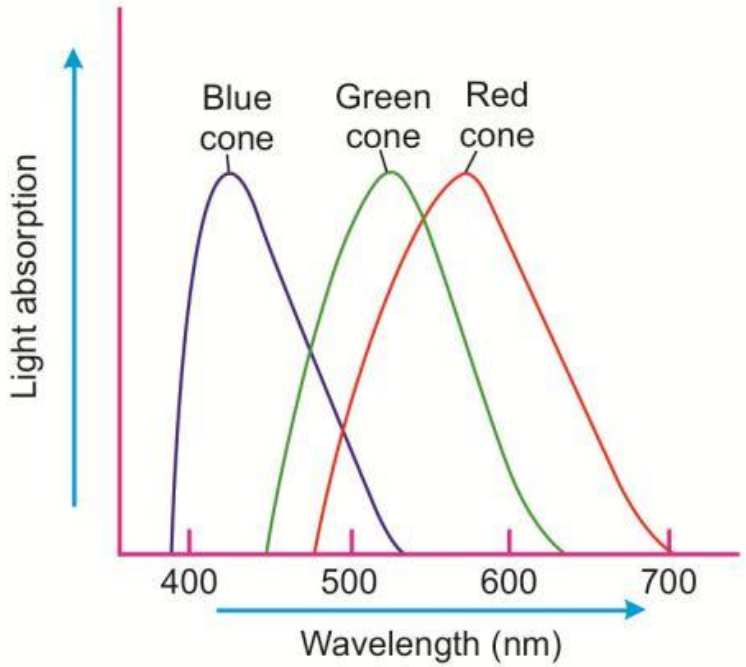
2. Grayscale images

- 256 gray level, $I(x,y) \in \{0 , 255\}$
- pixel coded on 8 bits

. The total number of gray levels is larger than the human visual system requirements (which, in most cases, cannot appreciate any improvements beyond 64 gray levels),

3. Color images

- “The human eye combines 3 primary colors (using the 3 different types of cones) to discern all possible colors”.
- color space (most used) : R G B (Red, Green, Blue)
- Colors are just different light frequencies



3. Color images

- A three-dimensional RGB matrix
- pixel coded on 24 bits (16,777,216 colors)
- $I(x,y, R) \in \{0 , 255\}$, $I(x,y, G) \in \{0 , 255\}$, $I(x,y, B) \in \{0 , 255\}$

Digital image

3. Color images

49	55	56	57	52	53
58	60	60	58	55	57
58	58	54	53	55	56
83	78	72	69	68	69
88	91	91	84	83	82
69	76	83	78	76	75
61	69	73	78	76	76

Red

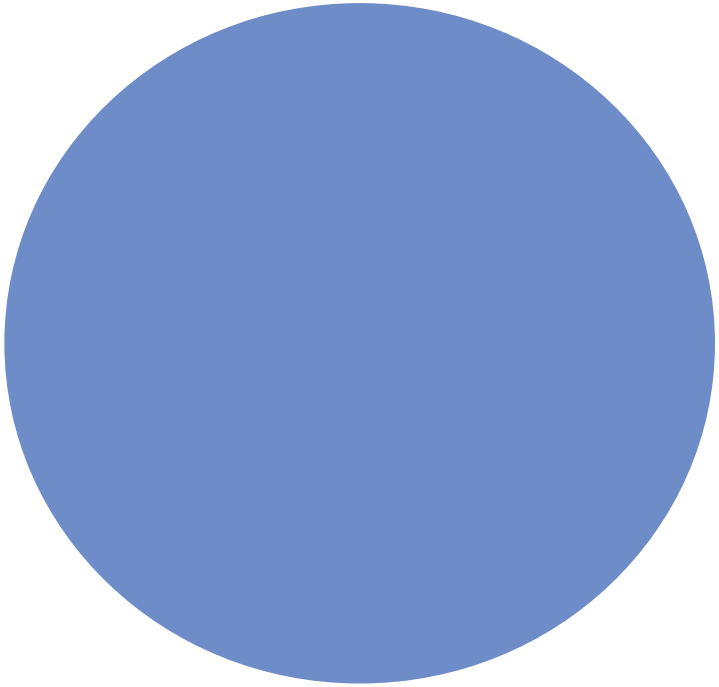
64	76	82	79	78	78
93	93	91	91	86	86
88	82	88	90	88	89
125	119	113	108	111	110
137	136	132	128	126	120
105	108	114	114	118	113
96	103	112	108	111	107

Green

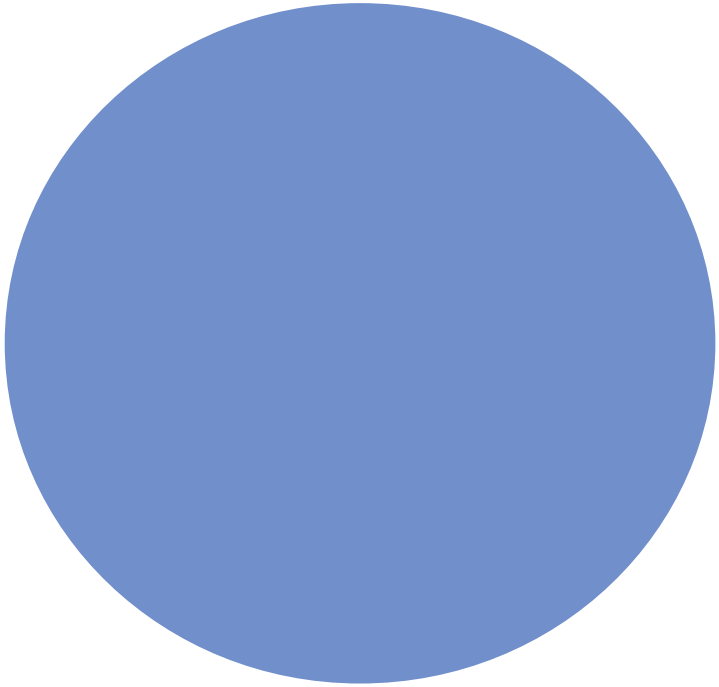
66	80	77	80	87	77
81	93	96	99	86	85
83	83	91	94	92	88
135	128	126	112	107	106
141	129	129	117	115	101
95	99	109	108	112	109
84	93	107	101	105	102

Blue

3. Color images

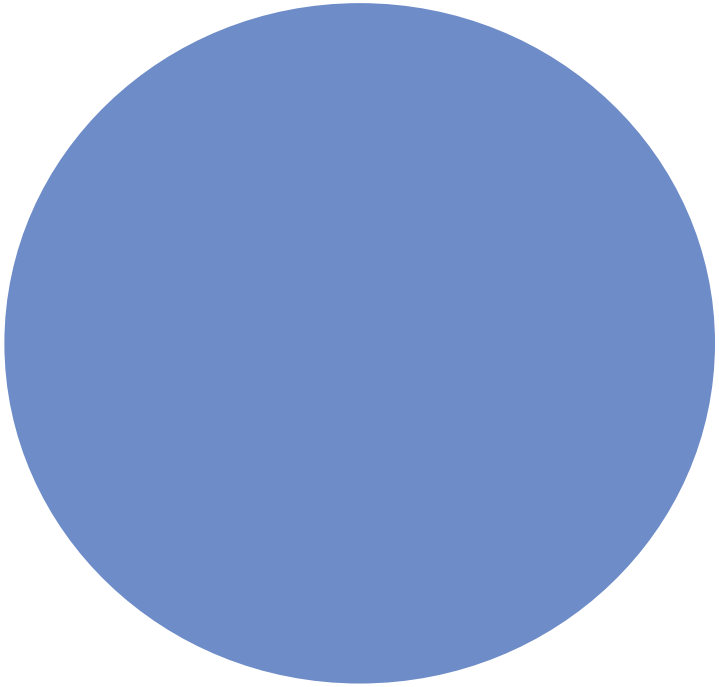


R 110
G 140
B 200

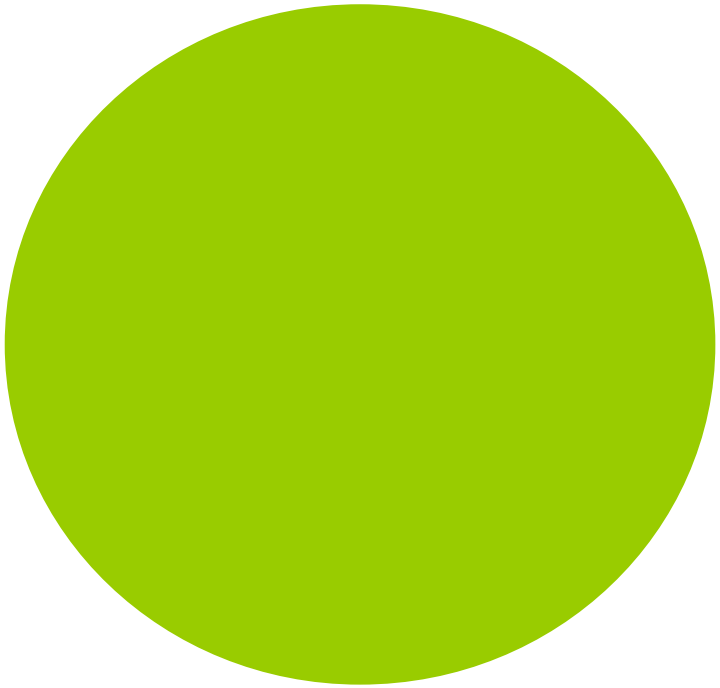


R 113
G 143
B 203

3. Color images



R 110
G 140
B 200

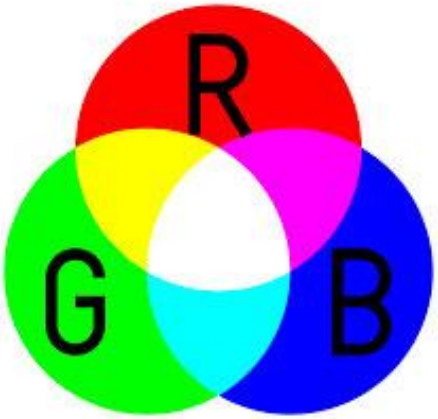


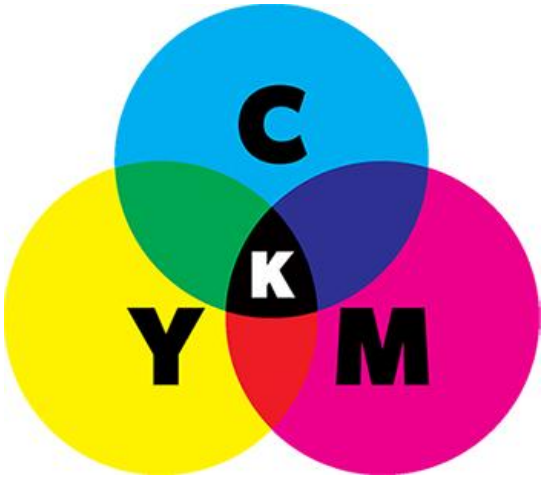
R 153
G 204
B 0

Color spaces

Many color spaces: RGB, HSL, CMYK...

- **RGB** : Red, Green, Blue
- **HSL** : Hue, Saturation, Lightness
- **CMYK**: Cyan, Magenta, Yellow, Black

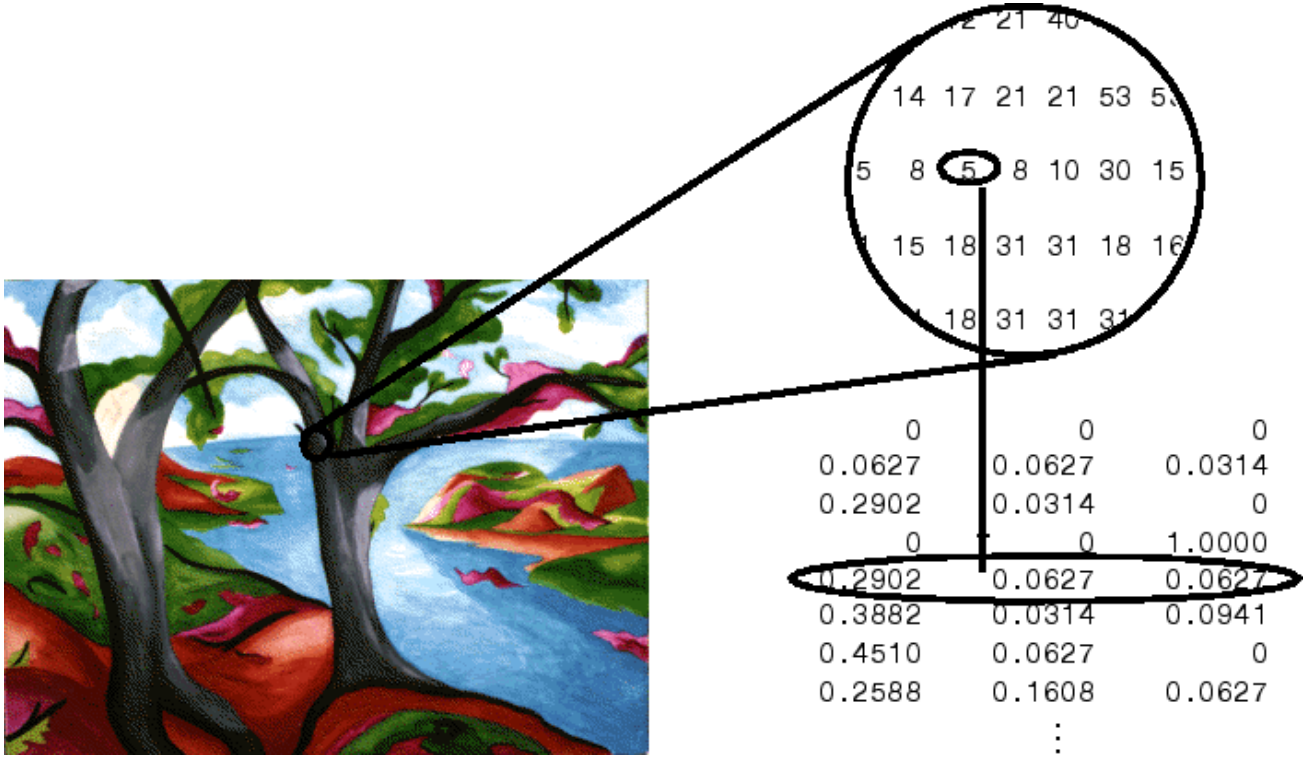




Digital image

4. Indexed image

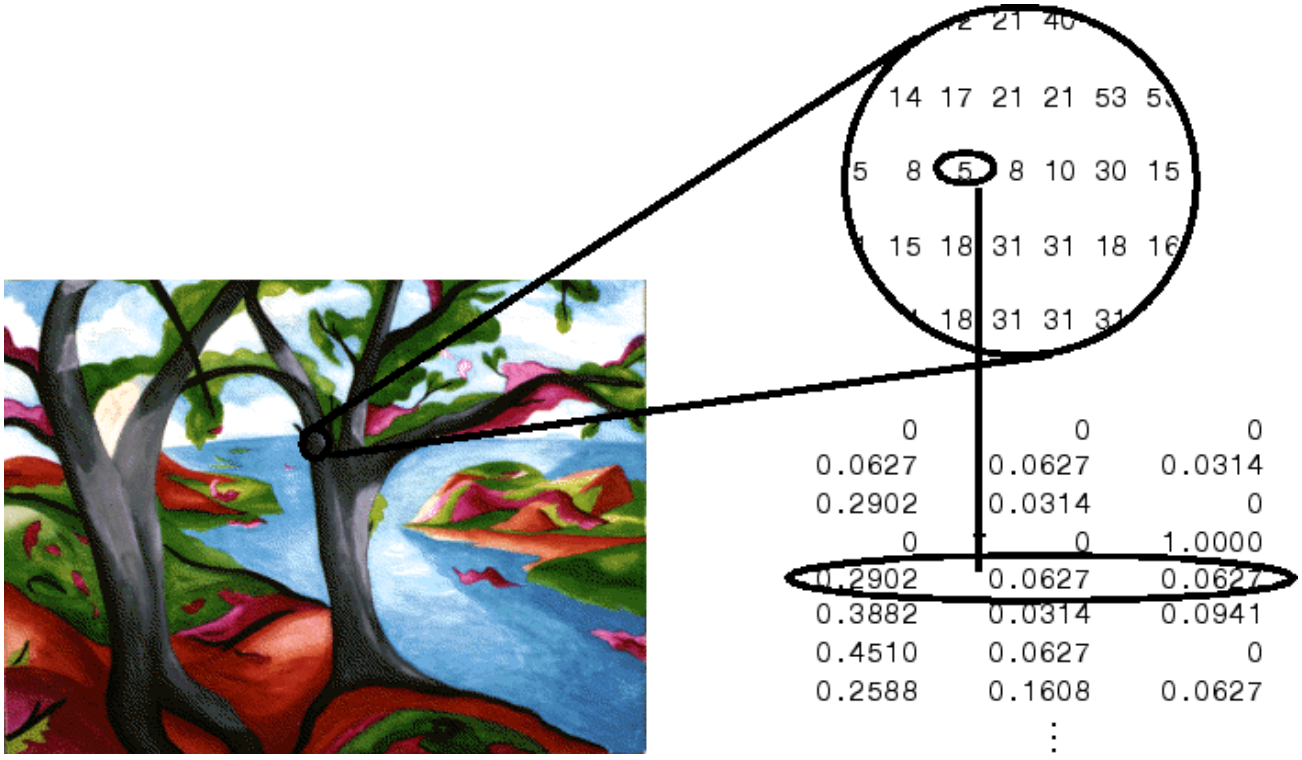
- The color of each pixel is determined by an index value inside an RGB color table (**color map**)
- Each row of the palette matrix = **RGB** value



Digital image

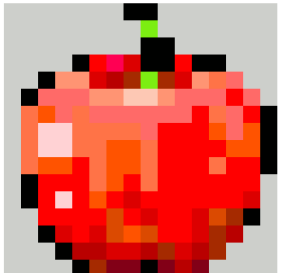
4. Indexed image

- Modifying a value in the color map →modification of the color for all pixels referring to this index.
- **Advantages**: reduce memory space/ transmission time



4. Indexed image (example)

Indexed image 16 colors



```
Palette[ 0]=000 001 000
Palette[ 1]=130 000 023
Palette[ 2]=185 000 000
Palette[ 3]=220 000 000
Palette[ 4]=255 000 000
Palette[ 5]=255 000 083
Palette[ 6]=165 042 000
Palette[ 7]=219 074 001
Palette[ 8]=255 083 000
Palette[ 9]=255 106 104
Palette[10]=255 115 071
Palette[11]=255 148 115
Palette[12]=124 238 018
Palette[13]=205 207 203
Palette[14]=253 200 180
Palette[15]=255 210 212
```

```
13 13 13 13 13 13 13  0  0 13 13 13 13 13 13 13
13 13 13 13 13 13 13 13 12 13 13 13 13 13 13 13
13 13 13 13 13 13 13 13  0  0 13 13 13 13 13 13
13 13 13 13  0  4  5  3  0  0  4  0  0 13 13 13
13 13  0 11 11  3  2  6 12  6  3 11 10  9 13 13
13  0  9  9  9 11 11 14 14 11  9  9  9  4  9 13
13 10  8  9 10  9  9  9  9  9  9  4 10  9  4  0
13 10 15 15 10 10 10 10  9  4  4  4  8  9  8  0
13 10 15 15 10 10  8  8 10  4  4  4  4  8  8  0
13 10  8  8  4 10  8  8 10  4  4  4 10  4  4  0
13  0  4  4  4 10  8  4 10  4  4  4  4  4  4 13
13  0  4 15  4  8  4  3  4  4  4  4  4  4  3 13
13 13  4  4  4  4  7  4  3  4  4  3  7  6  0 13
13 13  0  3  4  3  7  8  7  4  4  3  6  2 13 13
13 13 13  0  2  2  3  3  2  6  3  2  6 13 13 13
13 13 13 13  0  6  1  1  0  1  2  1 13 13 13 13
```

Characteristics of image

1. Size (weight)

Theoretical size = Definition x size necessary to represent a pixel

Real size= Theoretical size + file header

File header **=** meta-informations (height, width, type, date…..)

Characteristics of image

1. Size

- **Binary Image**

Pixel = 1 bit

Example:

- Image 300x400 pixels
- Theoretical size = **300x400**= **120000** bits= **15000** Bytes= **14,64** KB

- **Grayscale images**

Pixel = 8 bits

Example:

- Image 300x400 pixels
- Theoretical size = **300x400x8**= **960000**bits
  = **120000** Bytes= **117,18** KB

Characteristics of image

1. Size

- **Color image**

Pixel = 24 bits

Example:

- Image 300x400 pixels

- Theoretical size = **300x400x24**= **2880000**bits= **360000** Bytes
= **351,56** KB

- **Indexed image (256 colors)**

Example:

- Image 300x400 pixels

- For 256 colors, size of color-map= 256x8x3 bits
= 6144 bits = 768 Bytes.

- Theoretical size = **300x400x8 bits**+ **6144 bits**
= **960000**bits= **120768** Bytes= **117,93** KB

Characteristics of image

Exercise

Let an indexed image (128 colors) of 500x700 pixels.

Calculate the theoretical size en bits.

Characteristics of image

Solution

Color-map (size) = 128x8x3 bits = 3072 bits

theoretical size = 500x700x8 bits+ 3072 bits = 2803072 bits

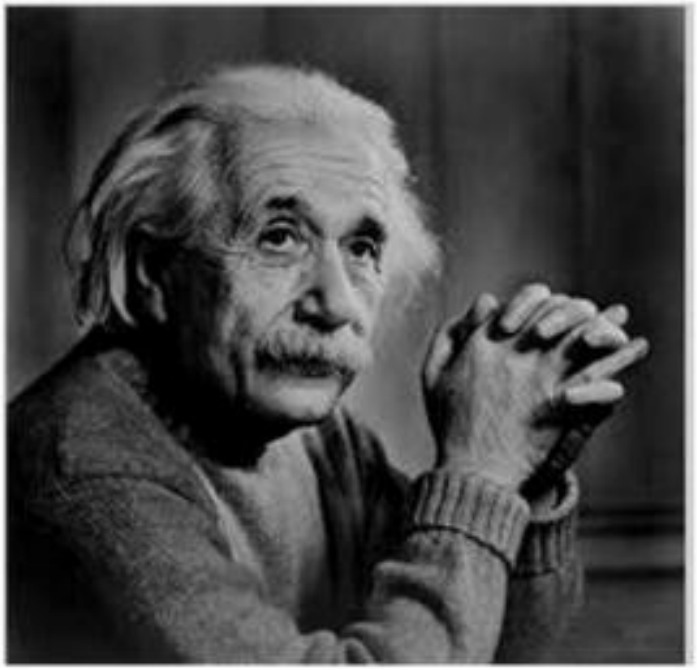
Characteristics of image

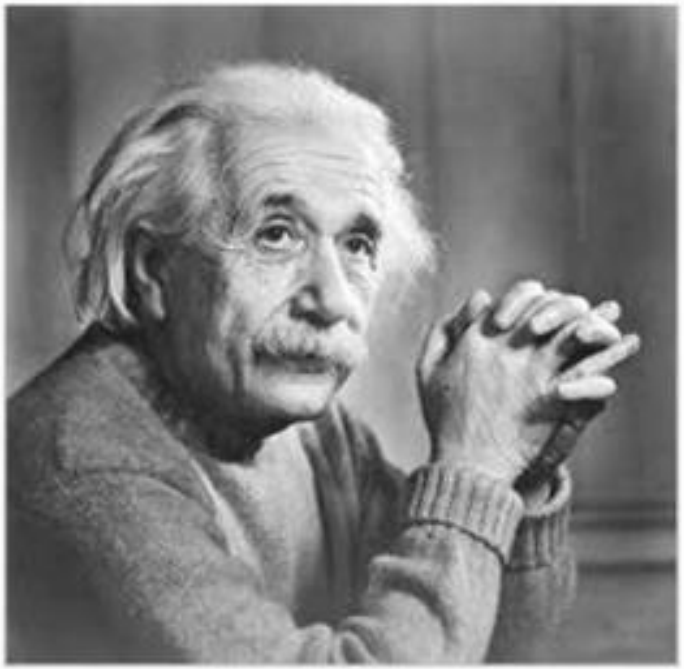
Characteristics of image

2. Luminance

- “ Luminance refers to the absolute amount of light emitted by an object per unit area “.

- A very bright surface →high luminance
- Black surface → zero luminance





Characteristics of image

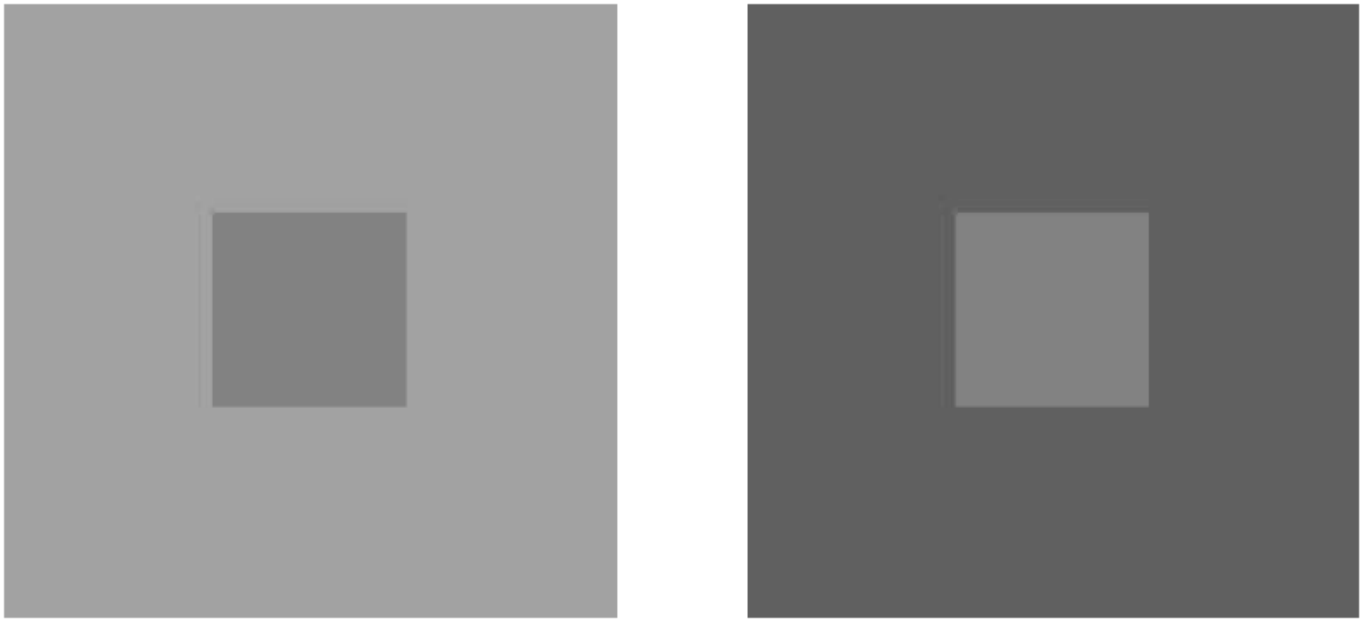
3. Contrast

“Contrast is an important factor in any subjective evaluation of image quality. Contrast is created by the difference in luminance reflected from two adjacent surfaces”

low **high**

Characteristics of image

3. Contrast



A grey square on different backgrounds

Characteristics of image

3. Contrast

- Well contrasted grayscale image = good distribution of gray levels

- Low contrast grayscale image = most pixels having very close gray levels

- Contrast is defined as the ratio $\frac{\max - \min}{\max + \min}$

where **max** and **min** are the maximum and minimum gray levels.

Characteristics of image

4. Resolution

4.1 Spatial resolution

- The density of pixels over the image
- Unit: **pixels per inch (PPI)**

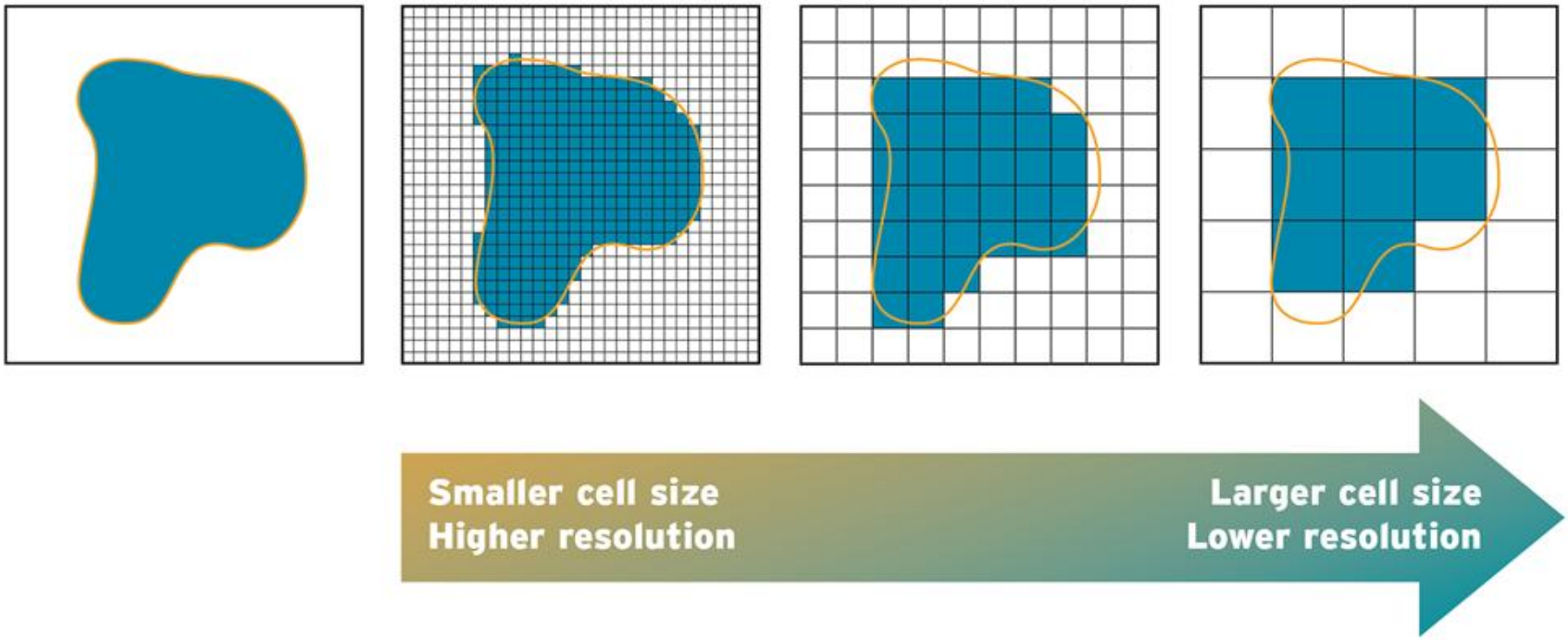
- Greater spatial resolution→ more pixels used to display the image
- Higher resolution → image more clear
  (more detail can be seen: precision)

80 PPI 40 PPI 10 PPI

Characteristics of image

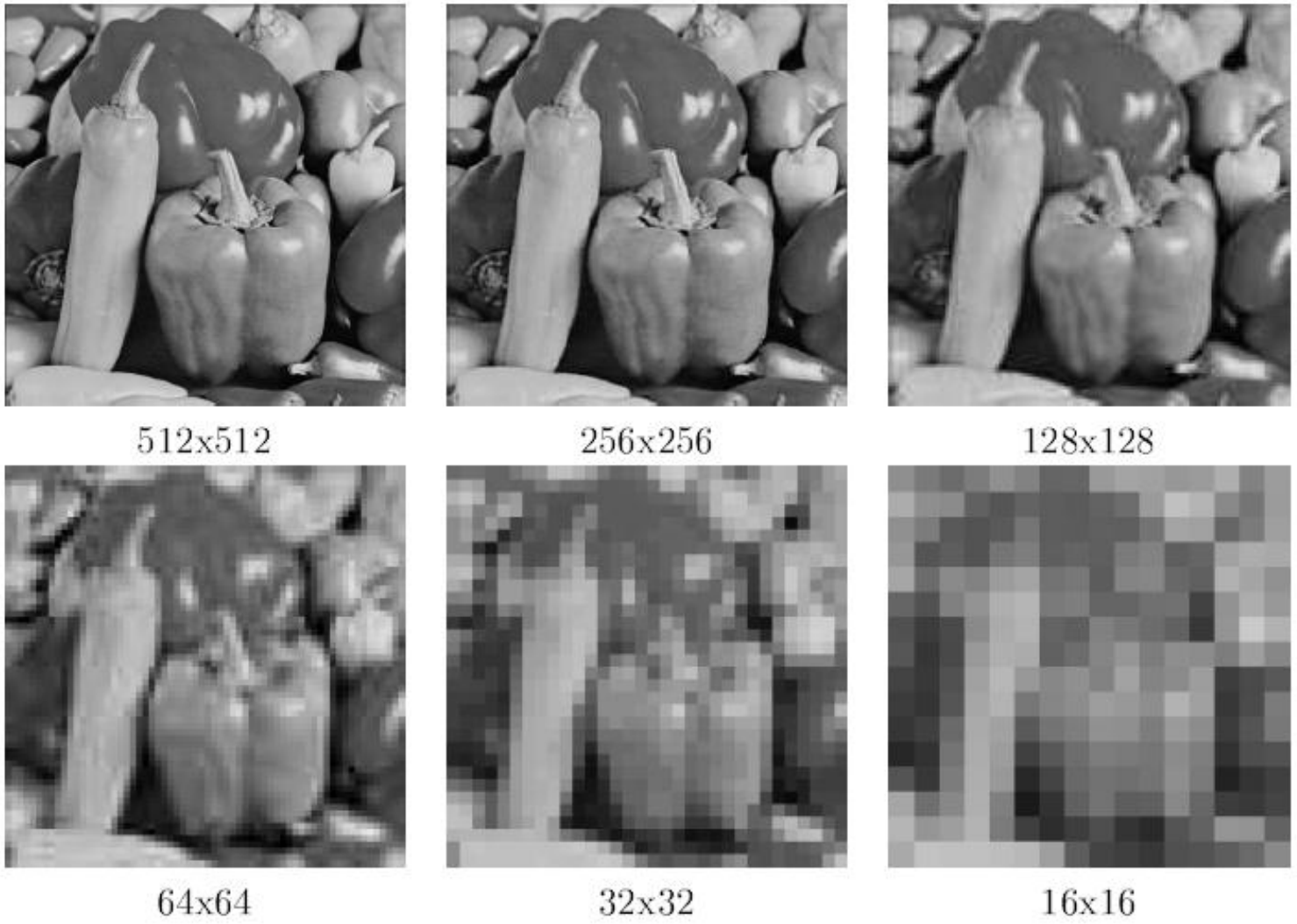
4. Resolution

4.1 Spatial resolution



https://www.jbarisk.com/news-blogs/dem-spatial-resolution-what-does-this-mean-for-flood-modellers/

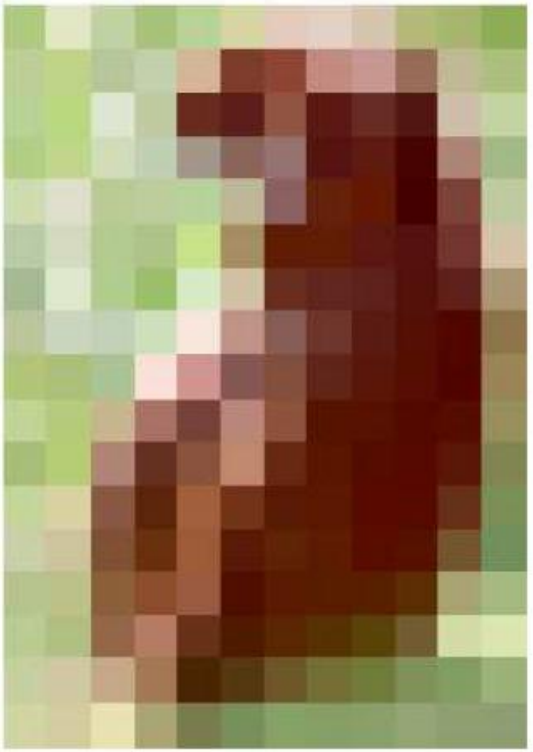
Characteristics of image



Characteristics of image

200 X 278

50 X 70



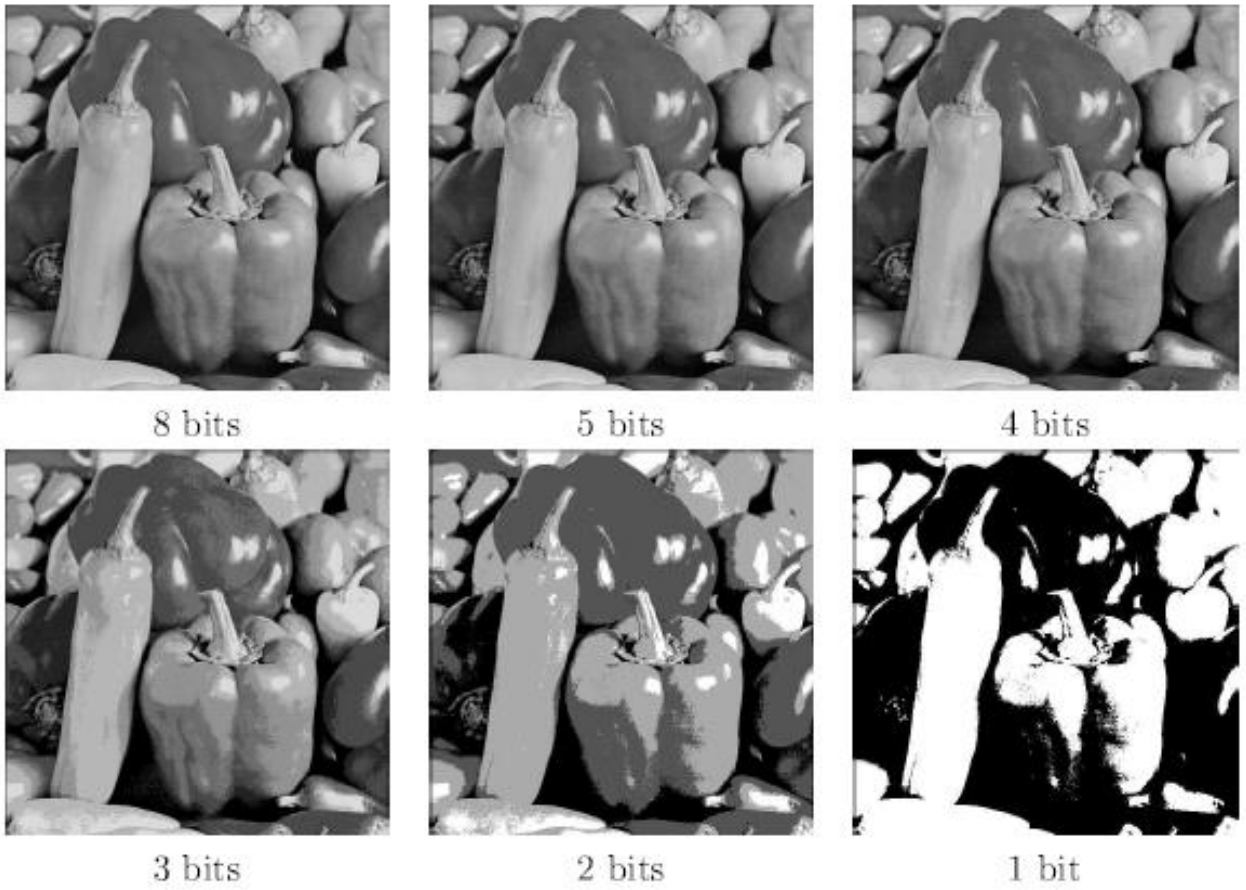
12 X 18

Characteristics of image

4. Resolution

4.1 Tonal resolution

- The number of bits used to represent a pixel (number of colors)



Characteristics of image

4. Resolution

4.1 Tonal resolution

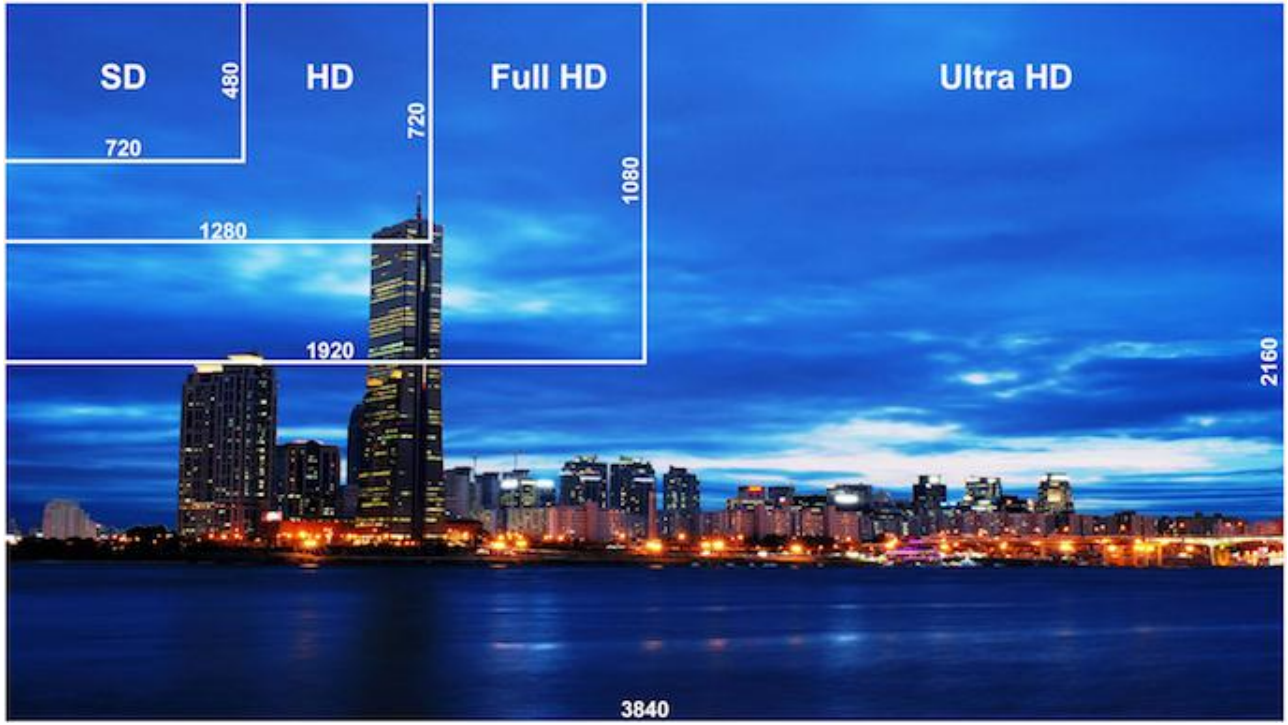
4 bits

8bits

24 bits

Characteristics of image

- Resolution of a screen is the number of pixels that can display



Characteristics of image

Resolution	Measurements (In pixels)	Pixel count
8k (Ultra HD)	7,680 × 4,320	33,177,600
4k (Ultra HD)	3,840 × 2,160	8,294,400
1080p (Full HD)	1,920 × 1,080	2,073,600
720p (HD)	1,280 × 720	921,600
480p (SD)	640 × 480	307,000

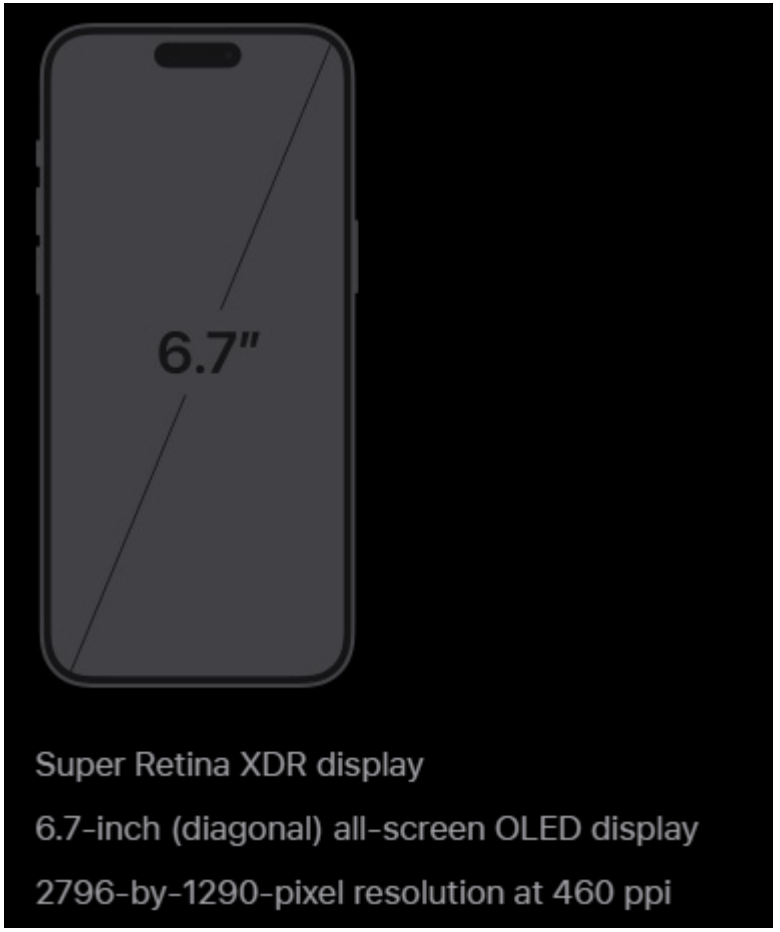
Characteristics of image

15360 × 8640=
132.7 megapixels

Chinese manufacturer BOE (2023)

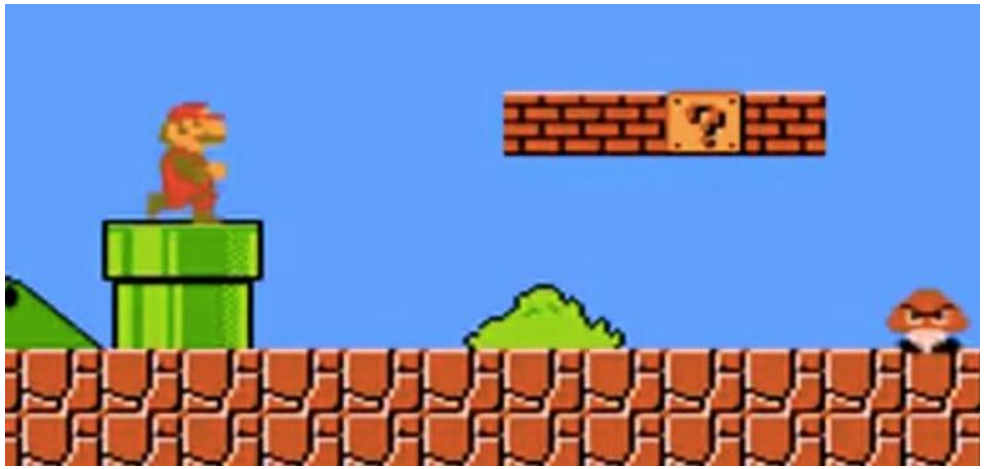
Characteristics of image

iPhone 15 Pro Max



Characteristics of image

Resolution problem!



“Mario was given his cap …….. A red cap was added because programmers found it difficult to create the hair movement that would occur when the character jumped”

Characteristics of image

Size= definition/ spatial resolution

- For example, with a resolution of **200 ppi** and a definition of **1280x1024**
- We obtain an image of **6.4x5.12** inches = 16x13 cm.

Characteristics of image

Exam 2022

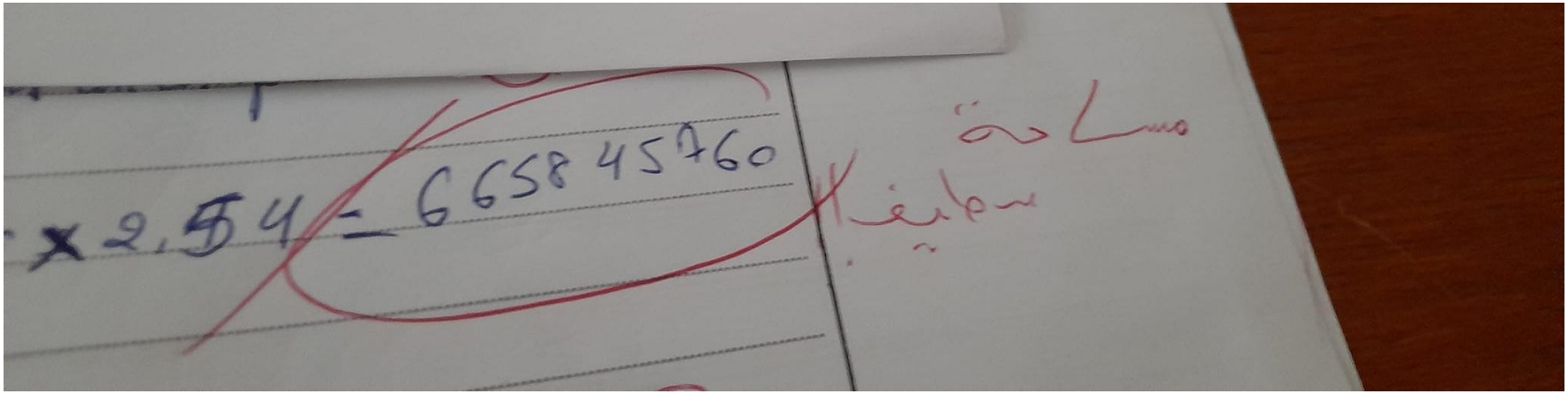


Image formats

Two image formats:

1. **bitmap**
2. **Vector**

Image formats

1. **Bitmap images (raster)**

The image is a matrix of pixels.

more zoom in → more the pixels become apparent
(blurry or distorted)

Image formats

2. Vector images

- “A vector image is an image created using mathematical formulas to represent the image”.
- Describing elementary geometric shapes (square, circle, ellipse, curve, etc.)
- It can be scaled to any size without losing quality.

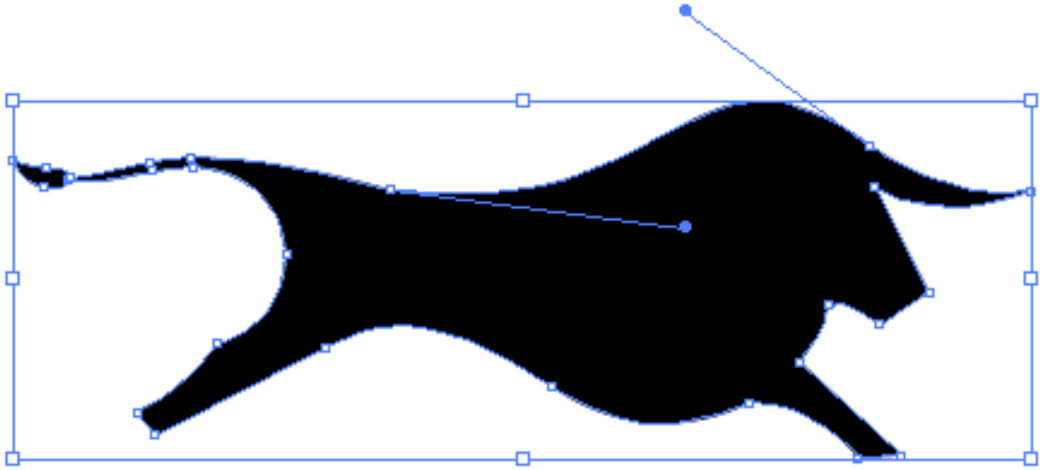


Image formats

2. Vector images

- Each shape has a number of attributes such as:

  the color, the thickness of the line, coordinates....

- Used when graphics are required in different scales, with the highest quality: geometric designs, logos, icons, pictograms, technical illustrations, product illustrations, fonts and the creation of layouts

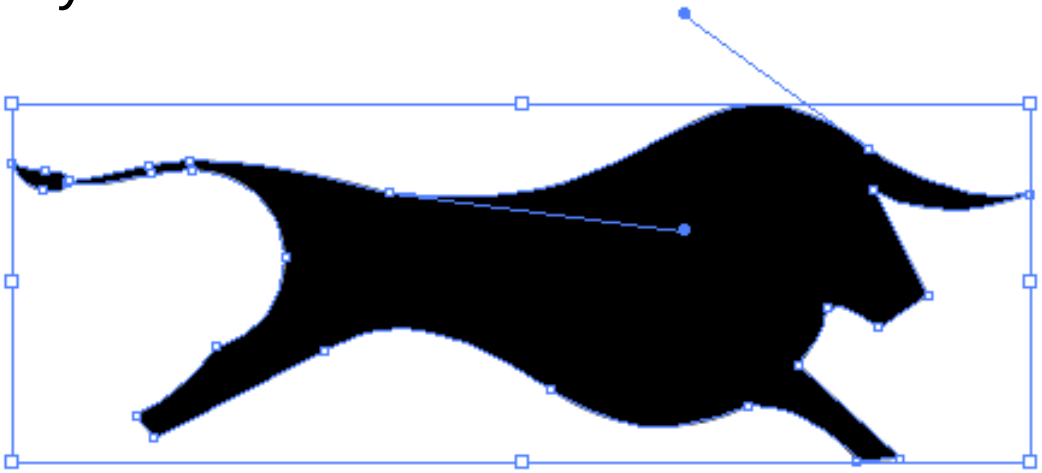
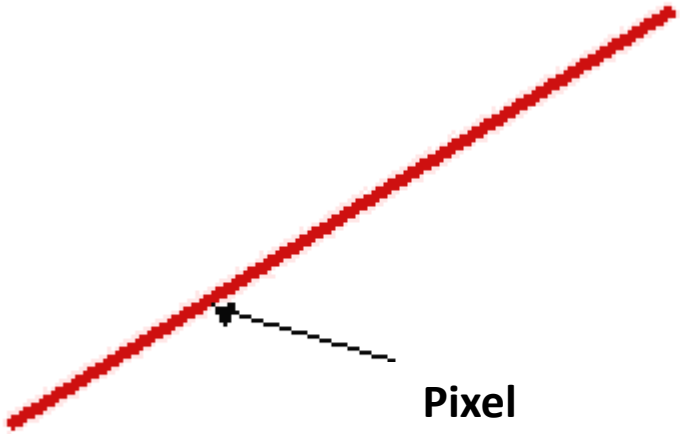


Image formats

bitmap

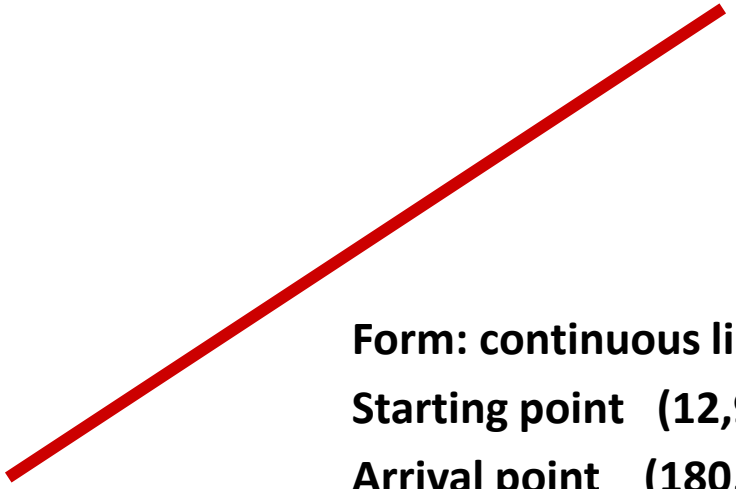


Pixel

Position in matrix 80, 43

Color RGB= 255,0,0 (red)

vector



Form: continuous line

Starting point (12,98)

Arrival point (180, 276)

Thickness : 4 mm

Color RGB= 255,0,0 (red)

Image formats

bitmap

Vector

Image formats

- **Bitmap images**

Advantages

- Well suited to complex images (photography): realism
- Richness in details and colour gradations
- More accessible and shareable (widespread use):

  Web, camera, social media…..
- Each pixel can be edited and adjusted individually

Disadvantages

- Pixelation problem → Zoom in (blurred contours and details)
- Higher quality → larger file size

Image formats

- **Vector images**

Advantages

- Resizable without loss of quality

- Well adapted to geometric transformations (change of scale, rotation, translation, etc.)→ Easy to edit

- Smaller file size

Image formats

Images vectorielles

Disadvantages

- Not suitable for complex images (photos)
- Format compatibility problem
- Vectorization of bitmap images → loss of details

Standard formats

Bitmap formats

- **BMP (Bitmap)**
- **TIF or TIFF (Tagged Image File Format)**
- **PNG (Portable Network Graphics)**
- **JPG (JPEG) (Joint Photographic Experts Group)**
- **GIF (Graphics Interchange Format)**
- **Other formats:**

PSD (PhotoShop Document),
HEIF (High Efficiency Image File Format)
Avif
WebP (Google)….

Standard Formats

Formats Vectoriels standards

- **WMF (Windows Metafile Format)**
- **SVG (Scalable Vector Graphics)**
- **PS (PostScipt), EPSF (Encapsulated PostScript File)**
- **AI (Adobe Illustrator)**
- **PDF (Portable Document Format)**
- **DWG (DraWinG) AutoCAD drawing**
- **….**