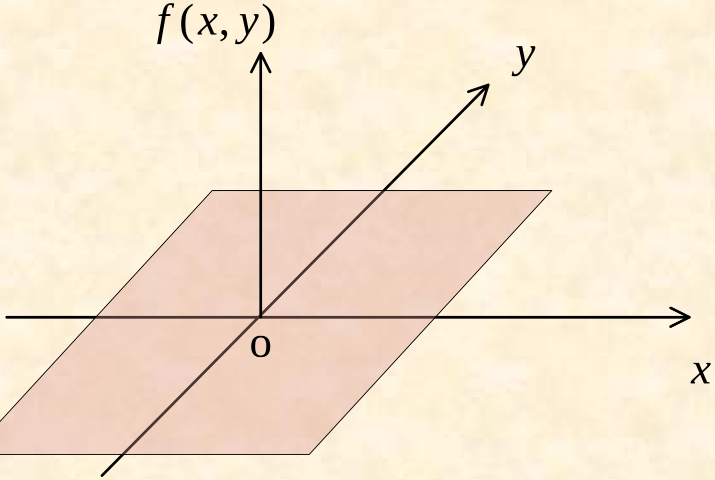
EE3206

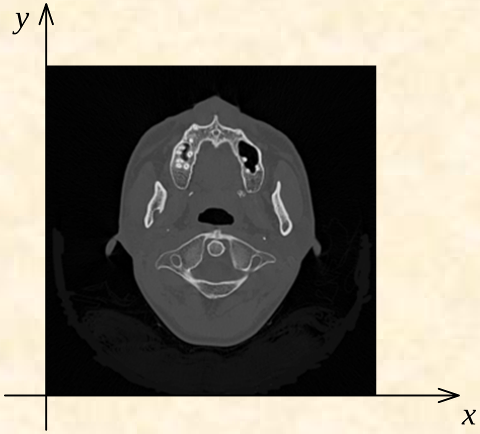
INTRO TO COMPUTER VISION AND IMAGE PROCESSING

I - INTRODUCTION

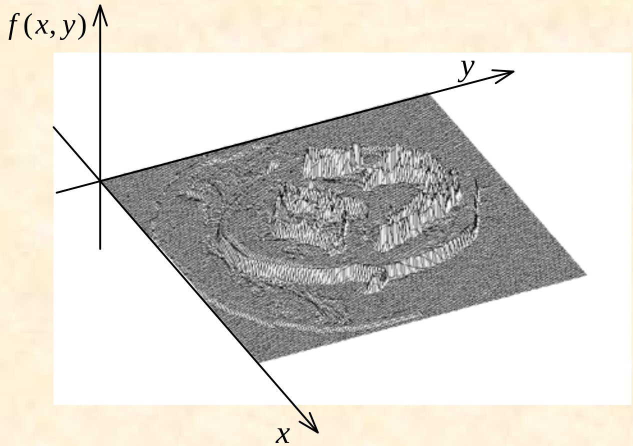
What is an image?

An image is a two-dimensional function $f(x,y)$, where
- x and y are spatial coordinates
- the amplitude of f at a point (x,y) gives the intensity or gray level of the image at that point.

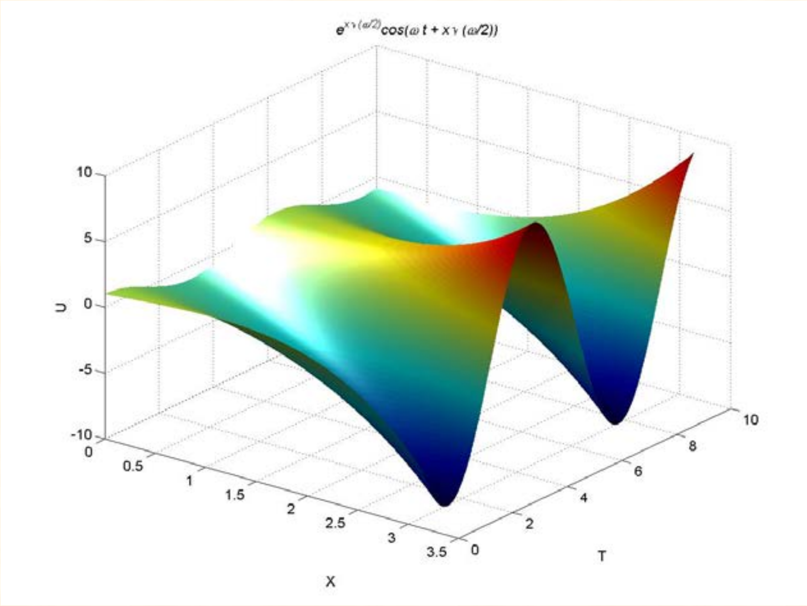




y
x



$f(x,y)$
y
x



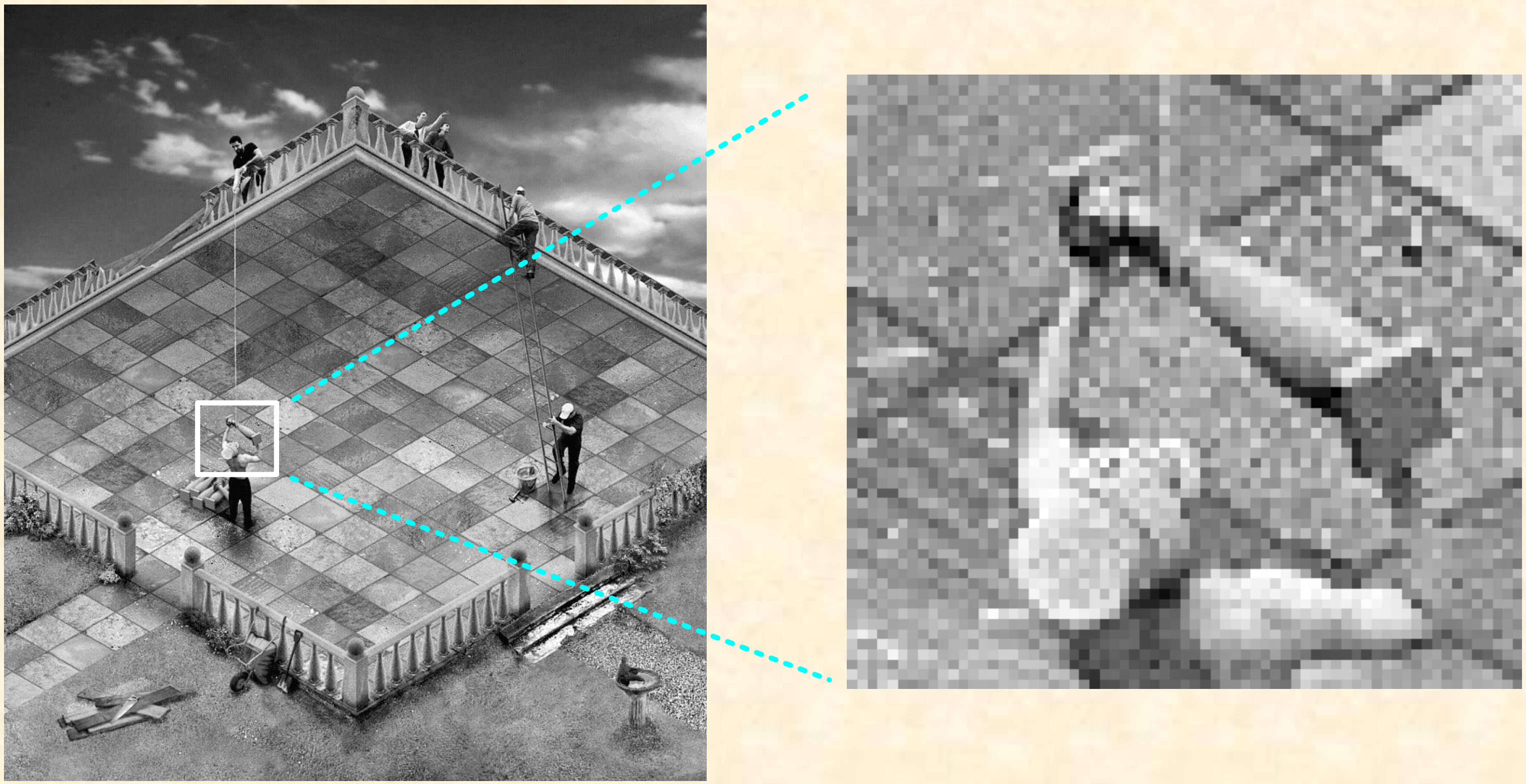
$e^{x\gamma(\omega/2)}\cos(\omega t + x\gamma(\omega/2))$
10
5
0
-5
-10
U
0
0.5
1
1.5
2
2.5
3
3.5
X
0
2
4
6
8
10
T

When x, y, and the amplitude values of f are finite, discrete quantities, we call the image a digital image.

y →, x ↓

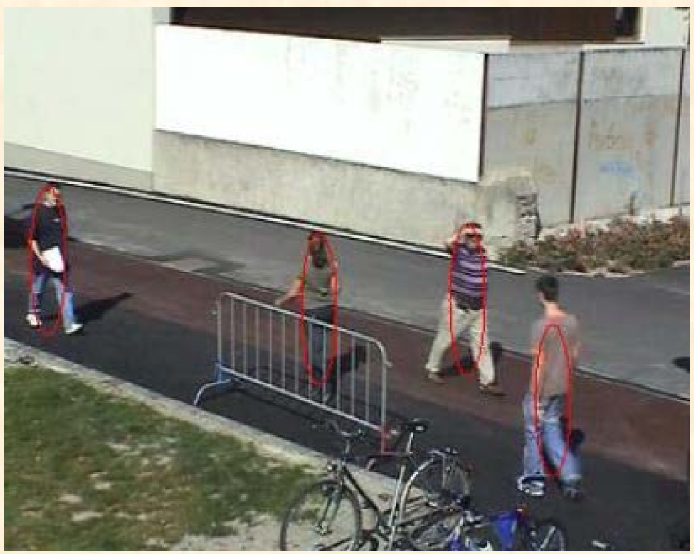
x \ y	0	1	2	3	4	5	6	7
0	0	0	0	0	0	0	0	0
1	0	0	16	15	56	3	53	6
2	0	0	26	48	55	66	54	23
3	0	0	36	33	8	54	68	56
4	0	0	28	42	23	56	65	84
5	0	0	27	44	33	31	53	8
6	0	0	53	23	34	43	44	8
7	0	0	76	34	34	33	43	4

$f(4,2) = 28$

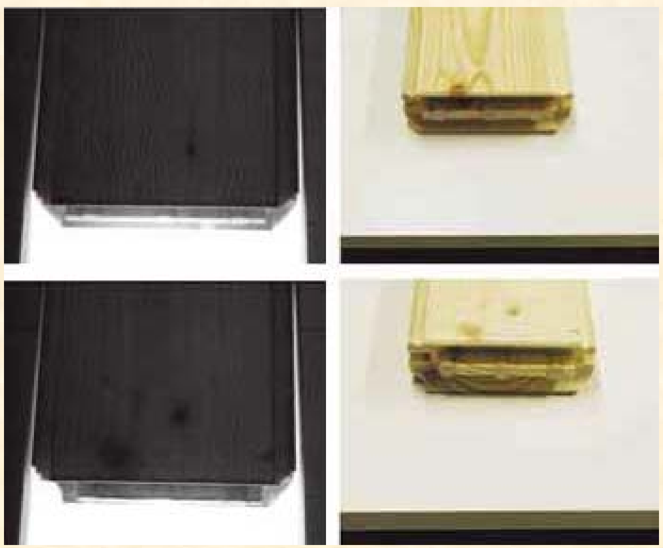


What is computer vision and image processing?

Computer vision is the process of extracting, characterizing and interpreting information from images of a 2-D or 3-D scene, e.g., tracking people/vehicles, face recognition and product inspection.

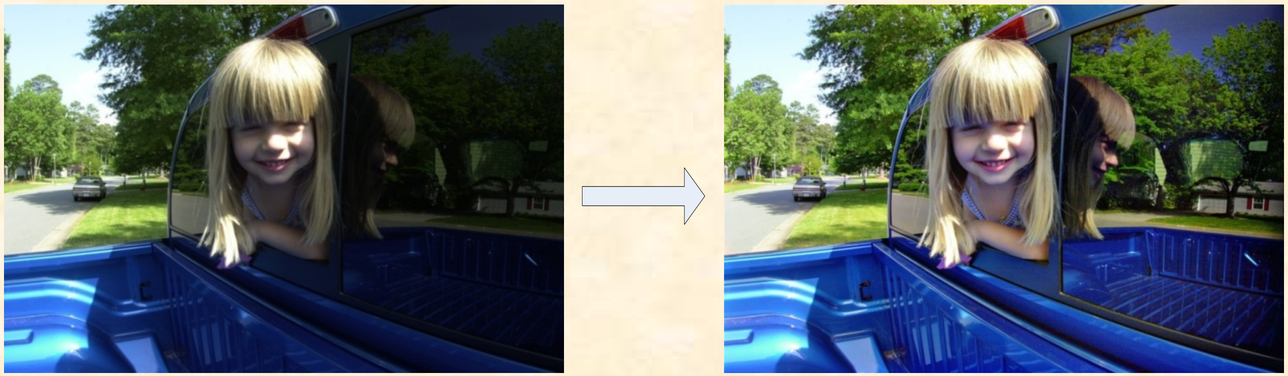


People tracking



Product inspection

Image processing is concerned with the operations for the manipulation of image data, e.g., image enhancement, noise reduction and image compression.



Improving visual quality

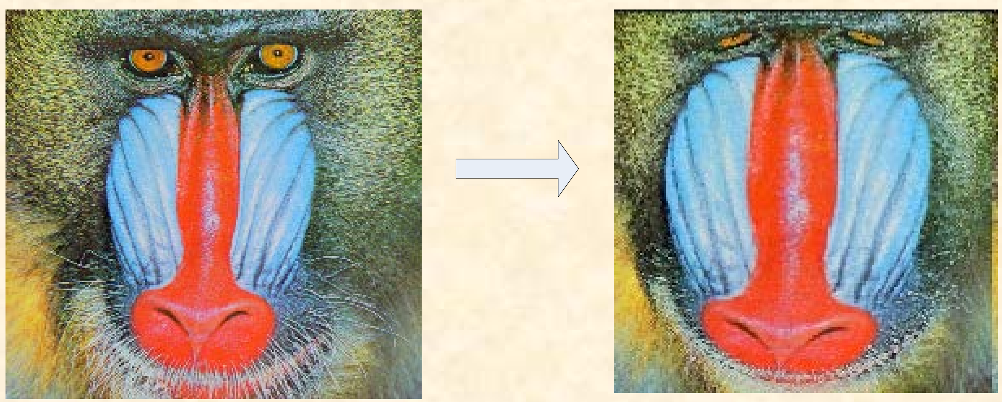
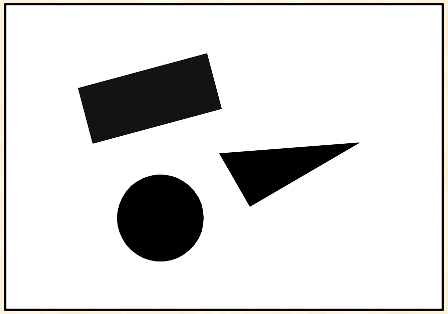
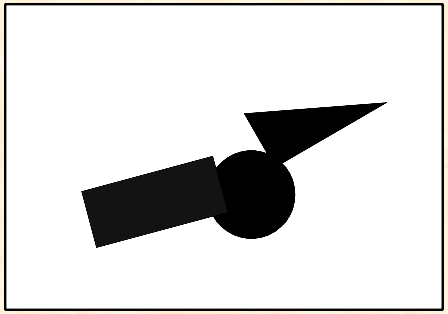


Image warping

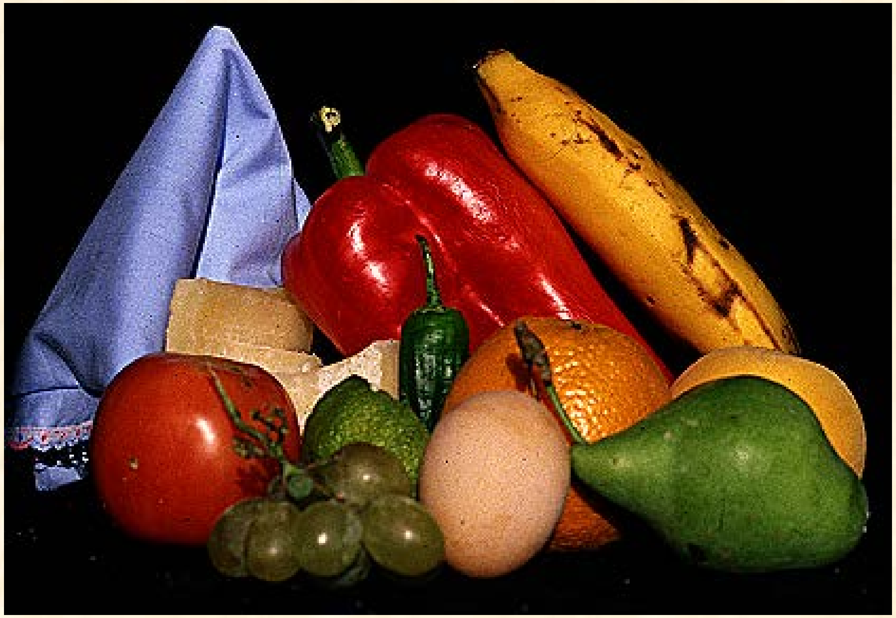
An example of a problem in computer vision is to recognise the objects in a scene:

Distinct objects





Overlapping objects



Complex scene

Consider a vision system that aims to identify the planar objects in a scene. The knowledge database contains information about the problem domain. It guides the operation of each processing module and controls the interaction between modules.

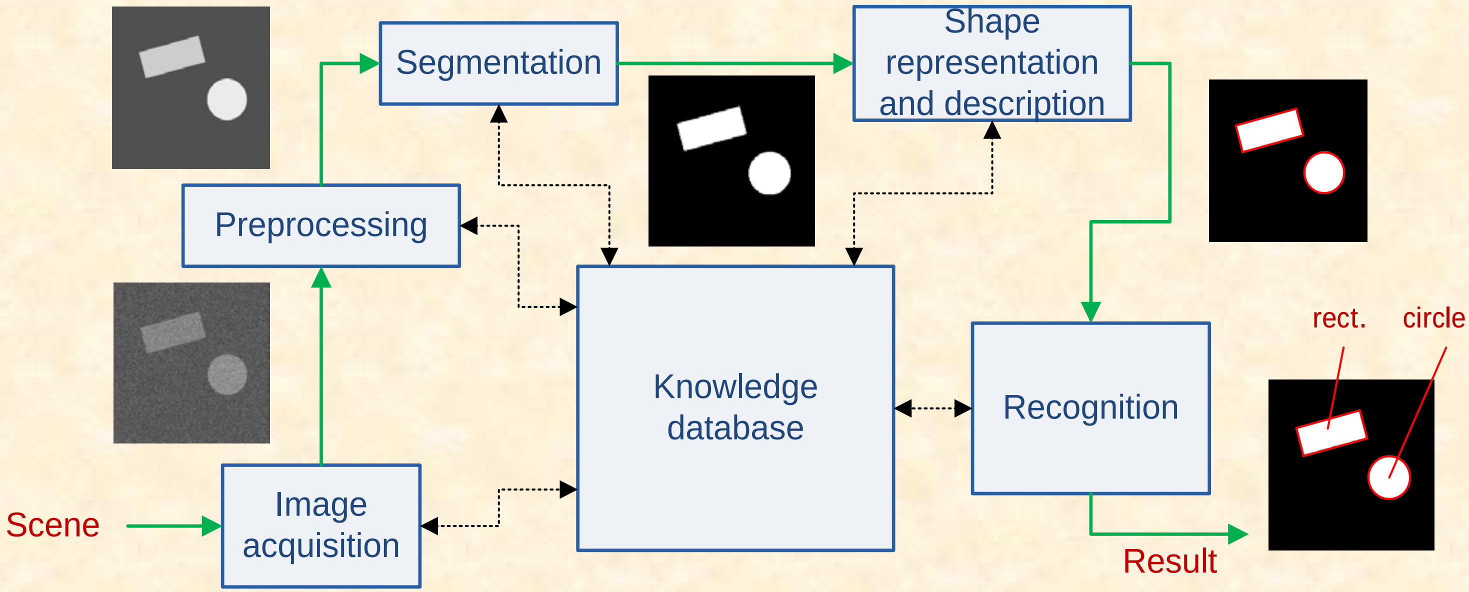


Image acquisition: obtaining a digital image with an image sensor.

Preprocessing: improving the image quality, e.g., removing image noise.

Segmentation: partitioning of the image into regions of interest.

Representation: representing the regions by boundary or internal characteristics.

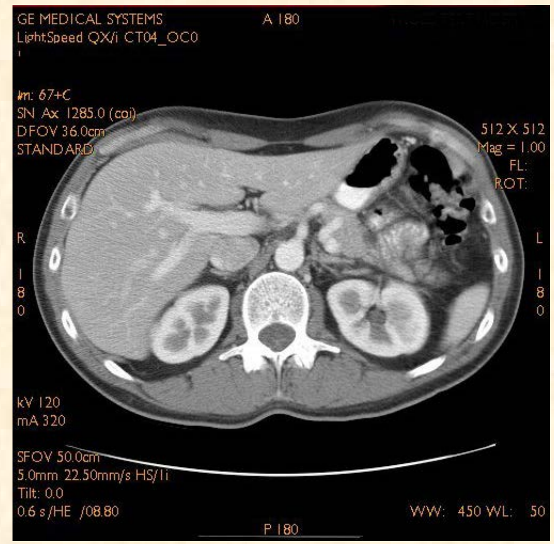
Description: extracting/measuring features that quantitatively describe classes of objects.

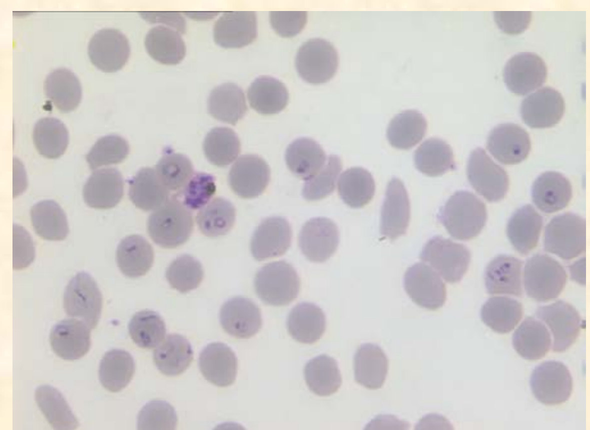
Recognition: assigning a label to an object based on the information provided by the descriptors.

EXAMPLES OF APPLICATIONS

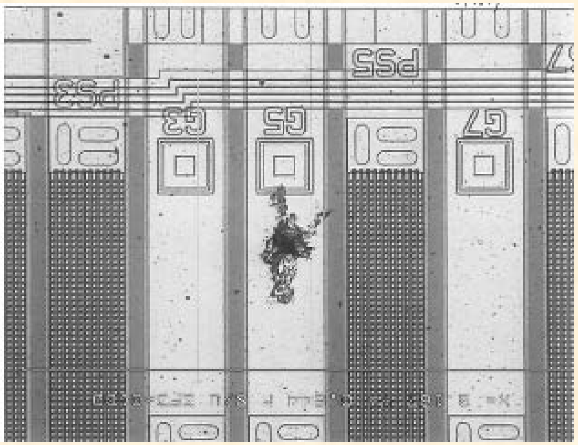
Character recognition: Mail sorting, label reading, bank-cheque processing, document processing, car number plate recognition

Medical imaging: Computed tomography imaging, blood cell count, tumour detection from X-rays.

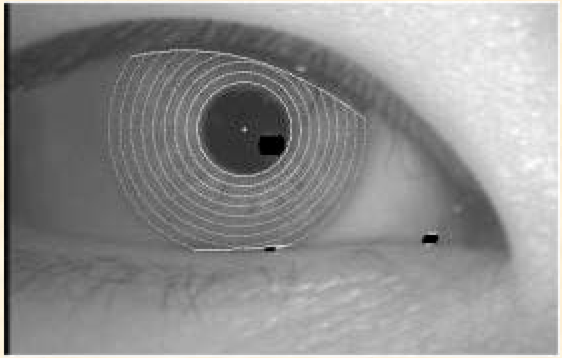


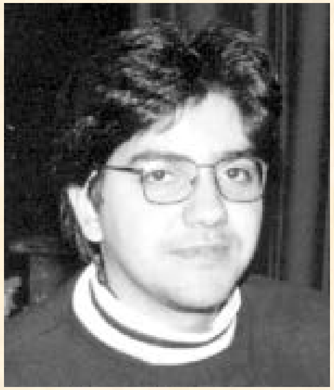


Industrial automation: Parts identification on assembly lines, inspection for defects.

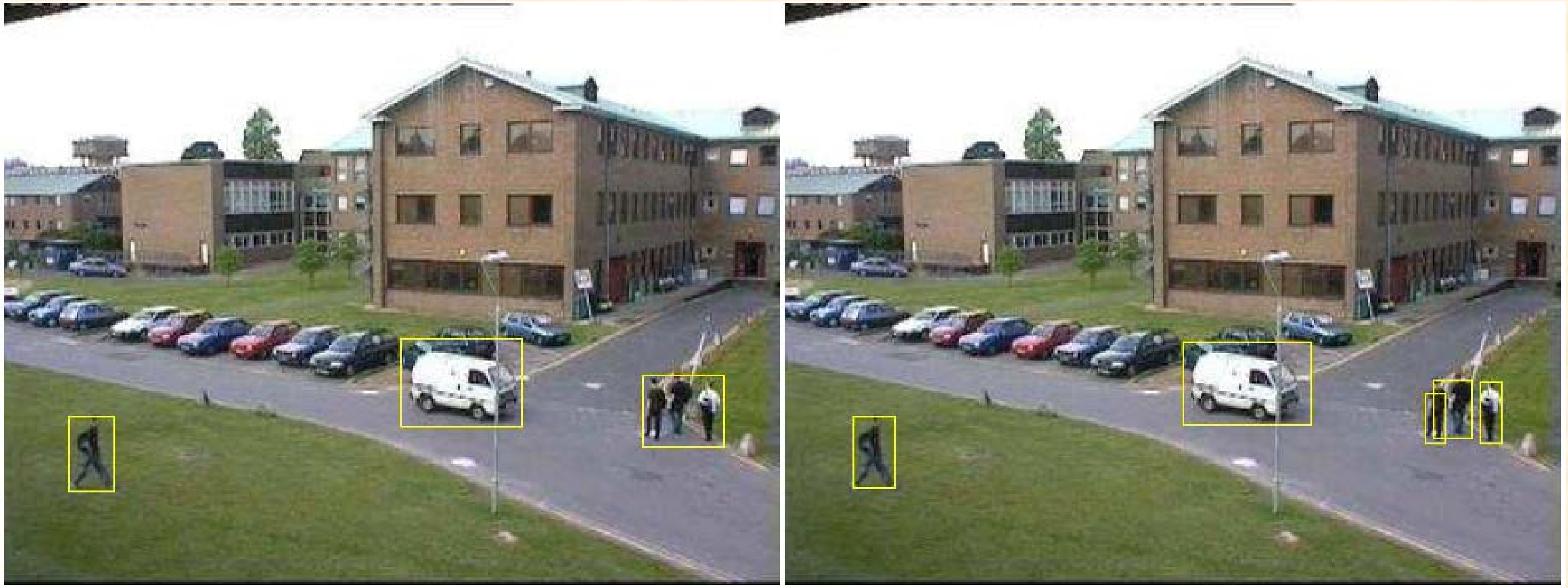


Biometrics: Human identification, finger-print matching, face recognition.

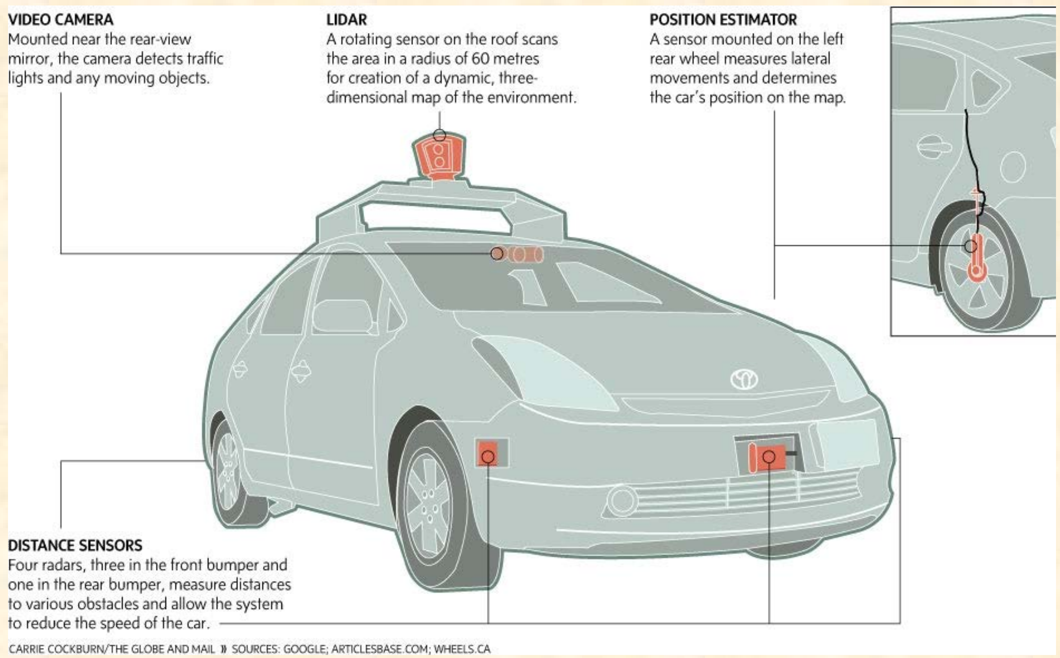




Surveillance:

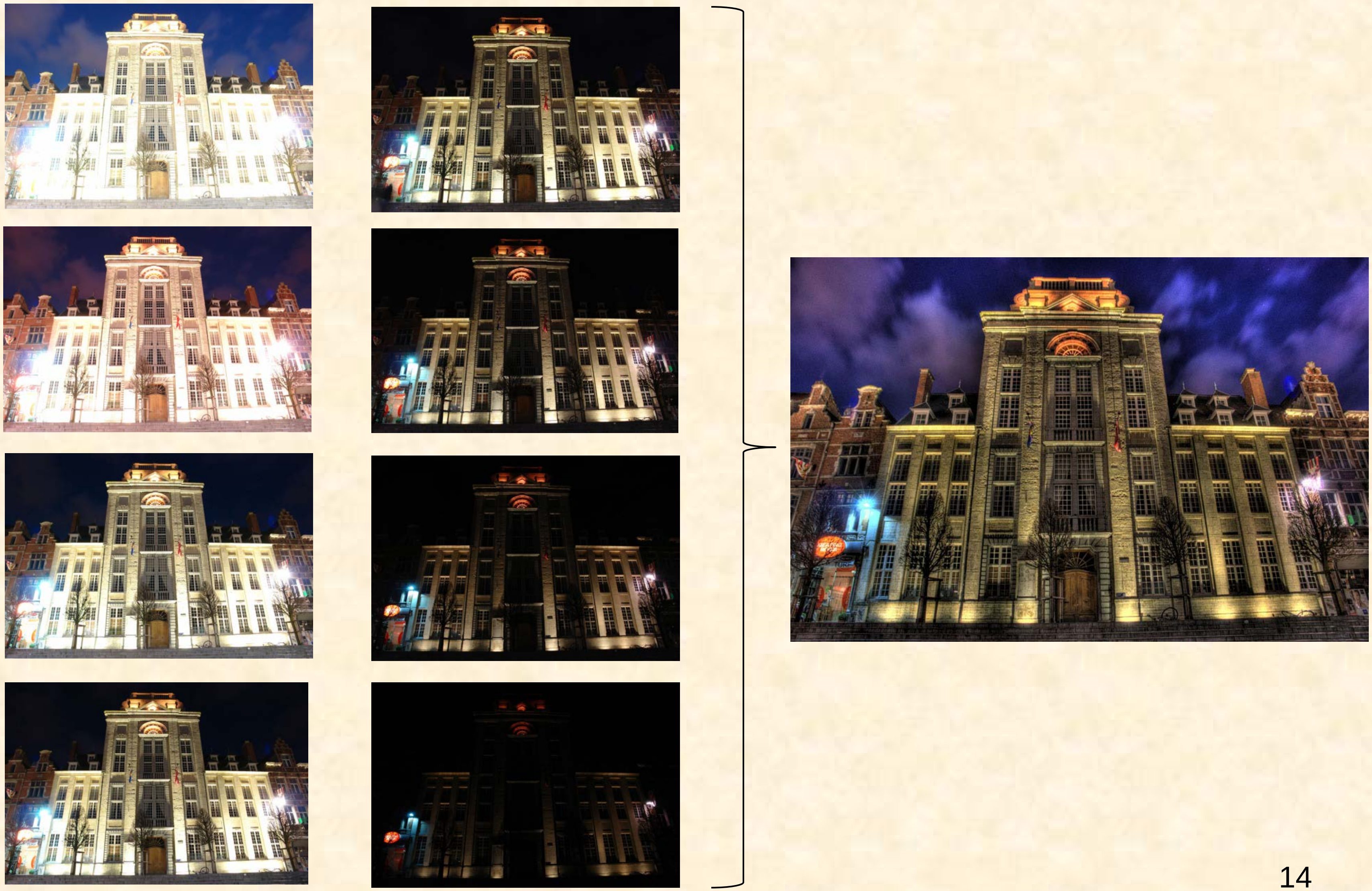


Robotics: Recognition and interpretation of objects in a scene, motion control and execution through visual feedback, picking objects in a bin, autonomous guided vehicle

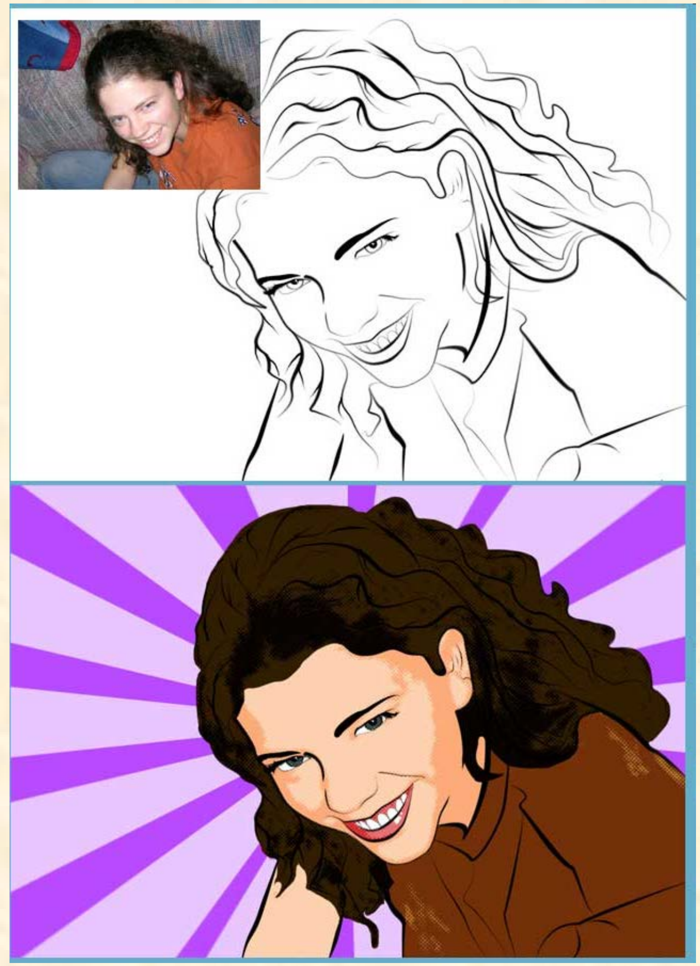


Google driverless car

Photography: High dynamic range (HDR) imaging



Graphics: Special effects



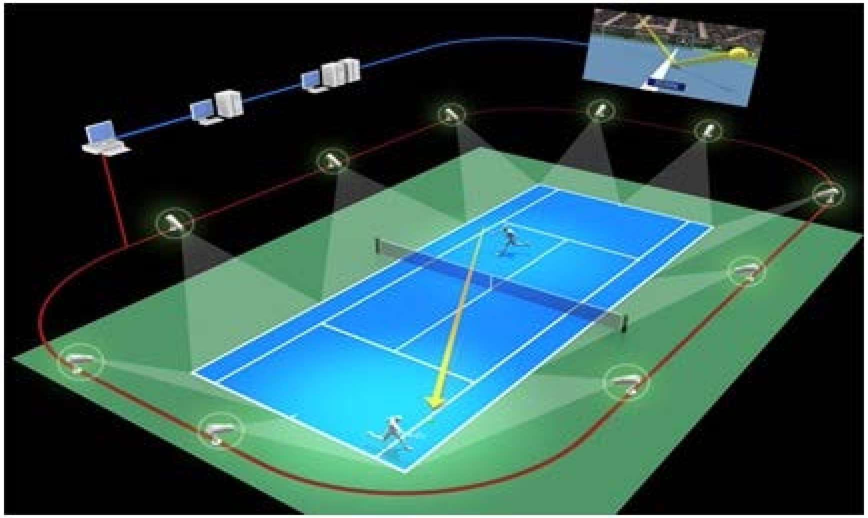
Multimedia: Video conferencing, image and video compression

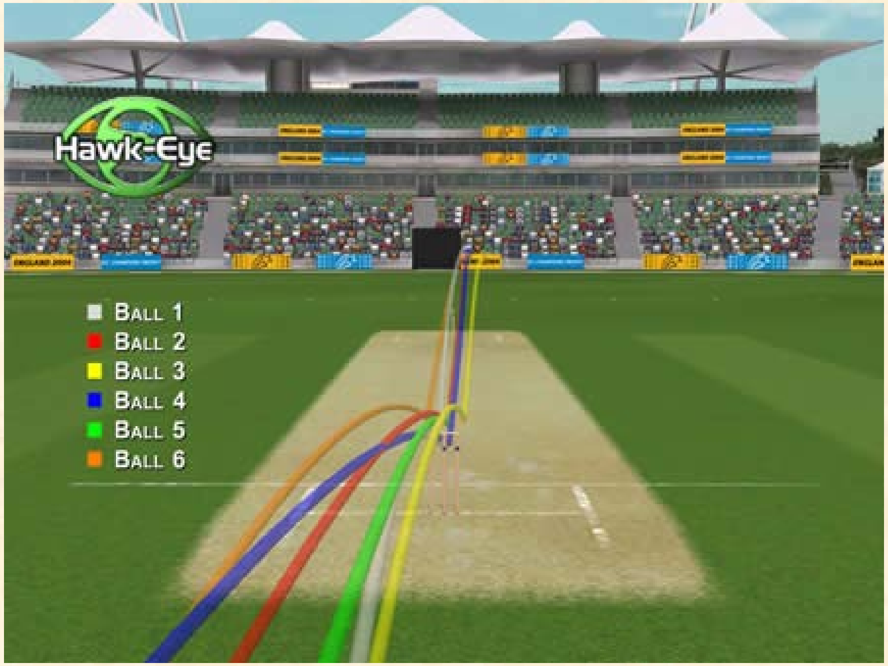
1,543,200 bytes

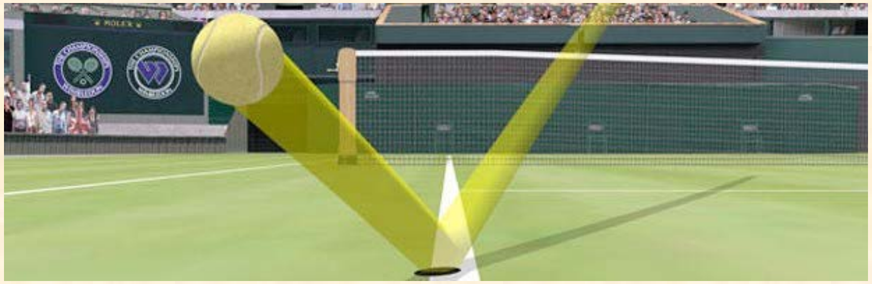
30,120 bytes

Slight distortion

Sports



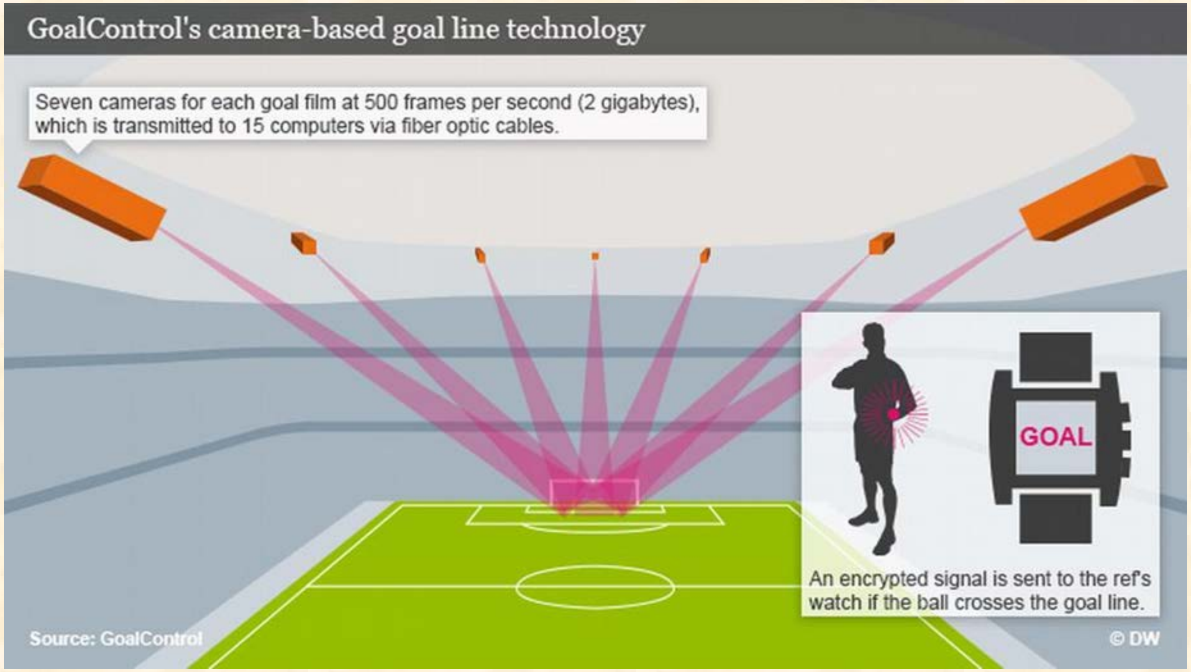




Hawk-Eye

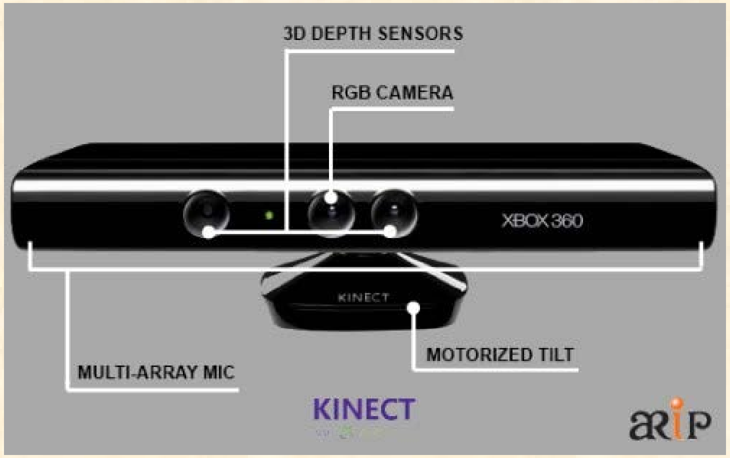
Sports

BBC 38:12 GER 2-1 ENG

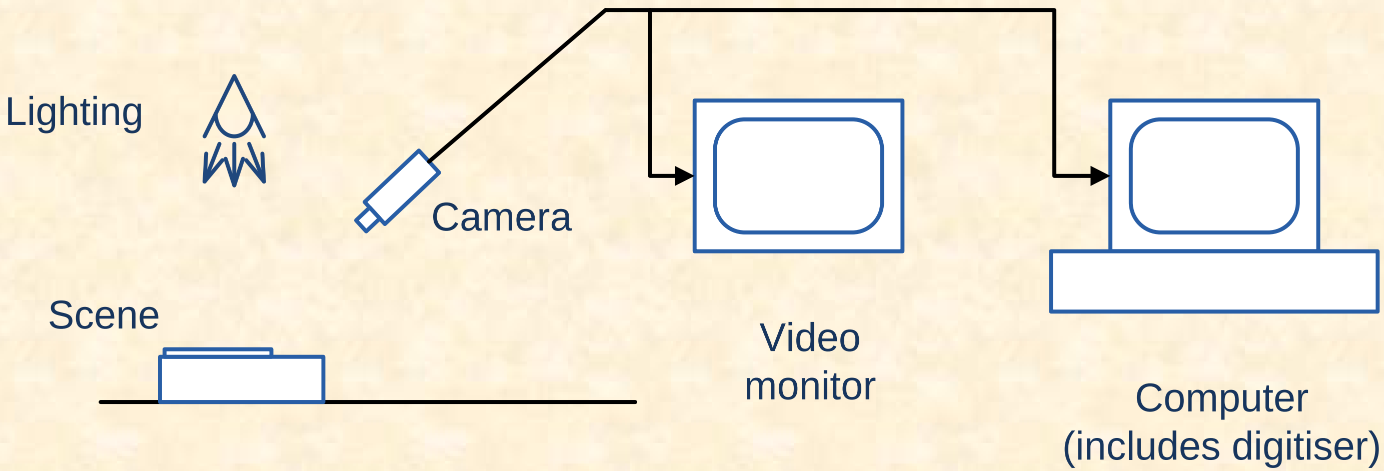


GoalControl's camera-based goal line technology
Seven cameras for each goal film at 500 frames per second (2 gigabytes), which is transmitted to 15 computers via fiber optic cables.
GOAL
An encrypted signal is sent to the ref's watch if the ball crosses the goal line.
Source: GoalControl
© DW

Kinect


3D DEPTH SENSORS
RGB CAMERA
XBOX 360
KINECT
MULTI-ARRAY MIC
MOTORIZED TILT
KINECT

ELEMENTS OF VISION SYSTEMS



<u>Image Acquisition</u>
- sensor (e.g., video camera)
- digitiser (e.g., frame grabber)
- lighting

<u>Processing</u>
- computer
- dedicated hardware

<u>Storage</u>
- hard disk
- optical disk
- digital video tape

<u>Display</u>
- video monitor
- film
- printer

A SIMPLE IMAGE FORMATION MODEL

An image *is* a 2D light-intensity function, $f(x,y)$, where the value of f at spatial coordinates (x,y) gives the intensity (or brightness) of the image at that point.

The image function may be approximated by:

$$f(x, y) = i(x,y)\, r(x,y)$$

where

$i(x,y)$ = illumination component, $0 < i(x,y) < \infty$

$r(x,y)$ = reflectance component, $0 < r(x,y) < 1$

- $i(x, y)$ is determined by the light source
- $r(x, y)$ is determined by the characteristics of the objects in a scene

$$f(x, y) = i(x, y)\, r(x, y)$$

Some Examples

Illumination:
- 100,000 lux on a clear day
- < 10,000 lux on a cloudy day
- 0.1 lux on a clear evening under full moon (on surface of earth)
- 1,000 lux in the office

The lux is a measure of illuminance (the luminous flux per unit area.)

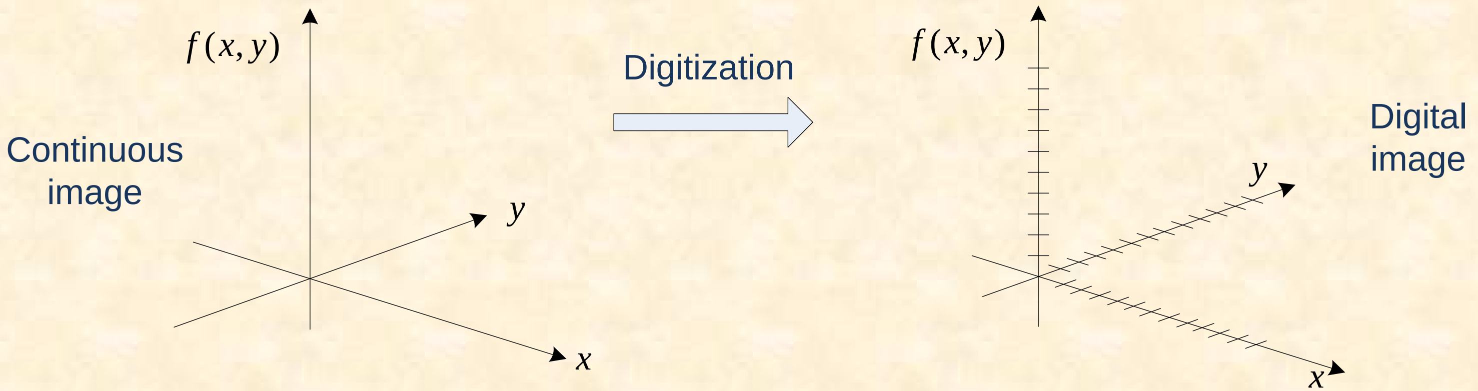
Reflectance:
- 0.01 for black velvet
- 0.65 for stainless steel
- 0.80 for flat-white wall paint
- 0.90 for silver-plated metal
- 0.93 for snow

SAMPLING AND QUANTIZATION

In order for a computer to process an image, the image must be digitized spatially and in amplitude.

• *Image sampling:* digitization of the spatial coordinates (*x,y*).

• *Gray-level quantization:* digitization of amplitude.



$$\begin{array}{ccc} & N \text{ columns} & \\ f(x,y) \approx & \begin{pmatrix} f(0,0) & \dots & f(0,N-1) \\ \vdots & \ddots & \vdots \\ f(M-1,0) & \cdots & f(m-1,n-1) \end{pmatrix} & M \text{ rows} \end{array}$$

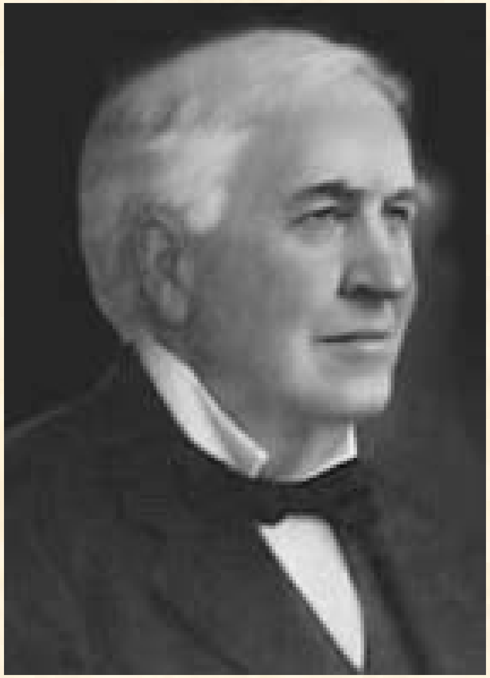
Continuous image function

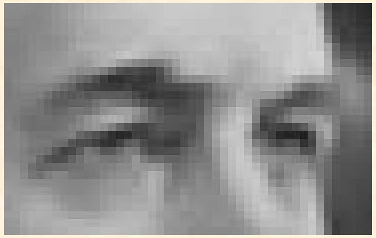
Digital image

The continuous image function (LHS) is approximated by a digital representation, the $M \times N$ array on the RHS. Each element of the array is referred to as an image element, picture element or pixel. The equation implies that the *x* axis points downwards and the *y* axis points to the right. Note that this is not the only convention.

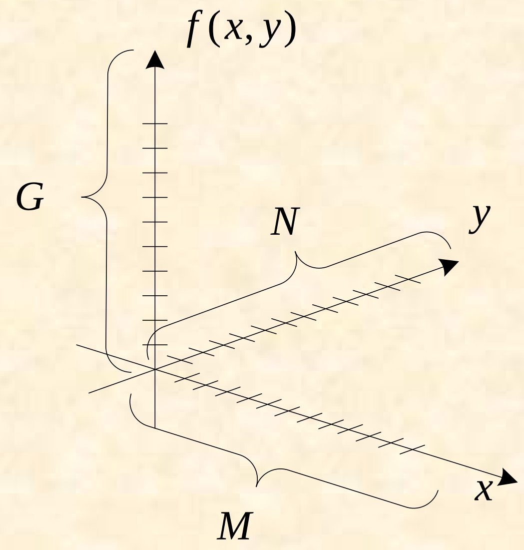
The *brightness* of a monochrome image *f* at coordinates (x,y) is called the gray level (z_k) of the image at that point, where z_k is an integer in the range $[0,L-1]$ where 0 is black and L-1 is white.

Digital images:





The resolution (the degree of discernible detail) of an image depends on
- the number of samples ($M \times N$), and
- the number of gray levels (G).



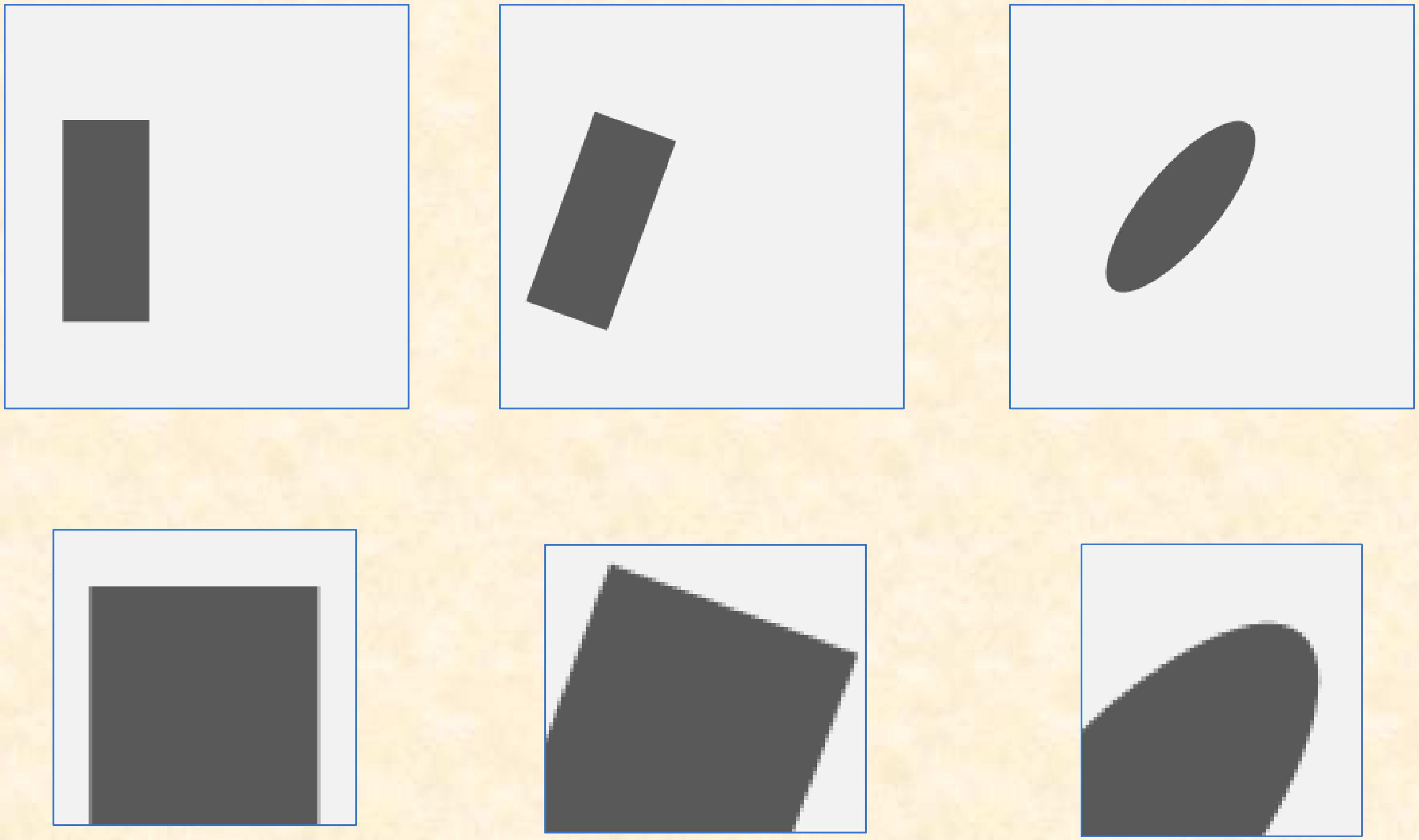
The larger these parameters, the closer the digitized array approximates the original image, but storage and processing requirements increase as a function of M, N, and G.

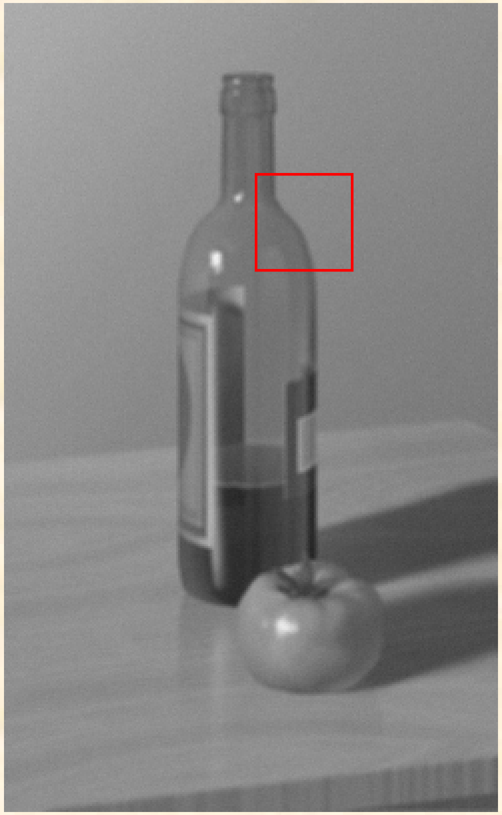
If a pixel is stored in a byte (G = 256), as is usually the case for monochrome images, the number of bytes required for storage is $M \times N$.

The number of samples and gray levels required for a faithful reproduction of an original image depends on the image. When processing or analysing a digital image, there should be sufficient resolution so that acceptable results are obtained.

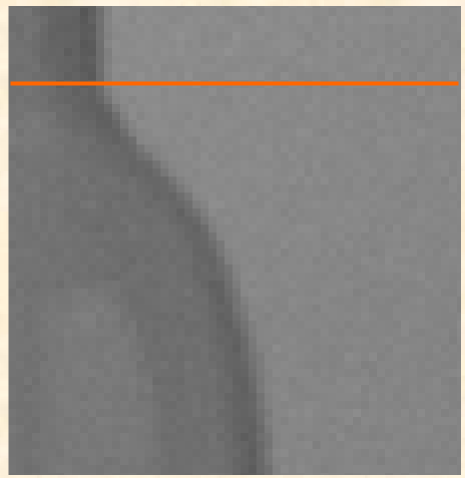
Insufficient spatial resolution → checkerboard effect (pixellation)

Sampling effects

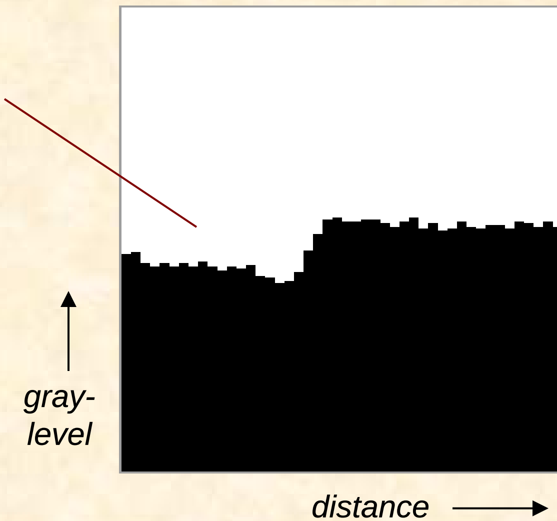




Image



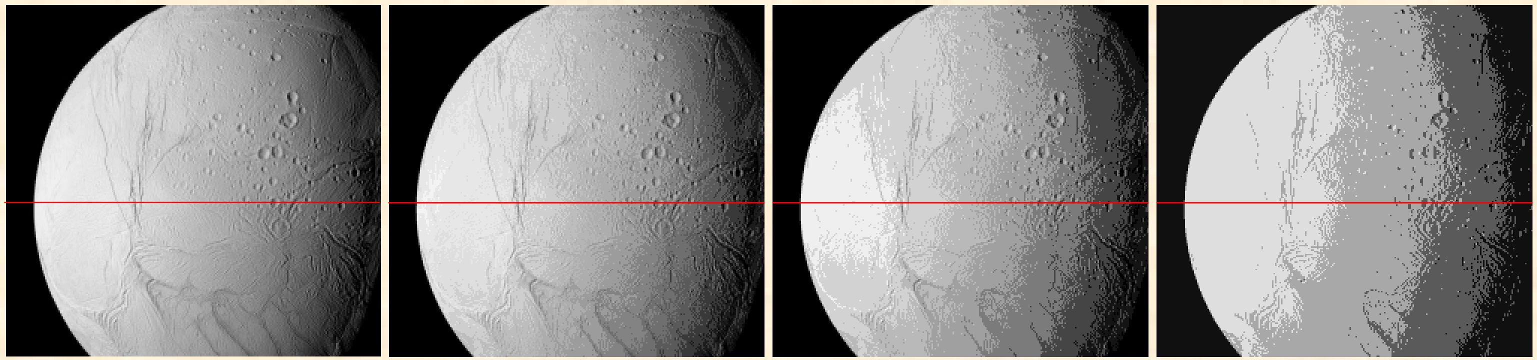
Magnified portion



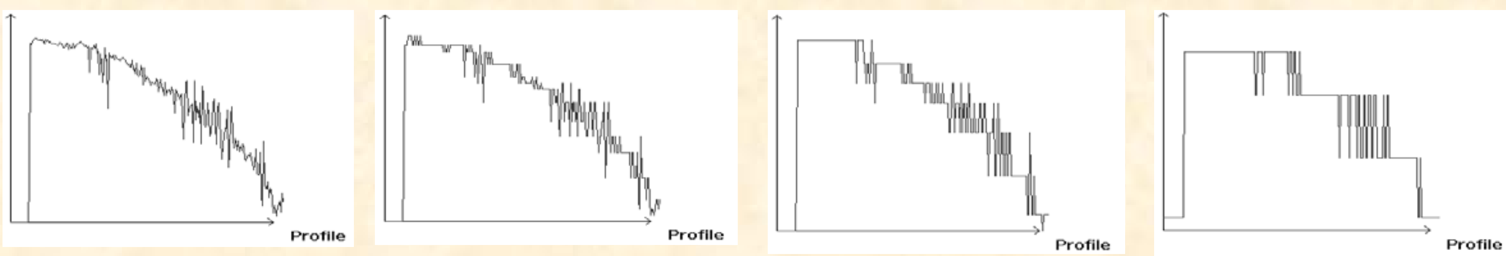
Gray-level profile
or
scan line

Insufficient gray-level resolution → false contouring

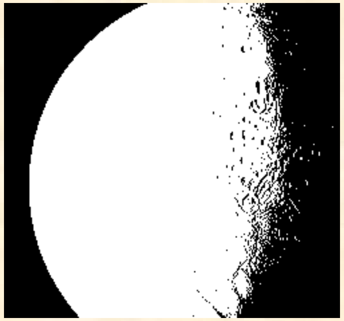
Good gray-level resolution requires $G \geq 256$



8 bits 4 bits 3 bits 2 bits



Binary images: two brightness levels (logical 0 and 1)



36435 colours

256 colours

BASIC RELATIONSHIPS BETWEEN PIXELS

Neighbours of a Pixel

	a	b	c	
	d	p	e	
	f	g	h	

4-neighbours of p: $N_4(p) = \{b, d, e, g\}$

Diagonal neighbours of p: $N_D(p) = \{a, c, f, h\}$

8-neighbours of p: $N_8(p) = N_4(p) \cup N_D(p) = \{a, b, c, d, e, f, g, h\}$

Connectivity

The concept of connectivity is used in establishing boundaries of objects and connected components in an image.

To establish whether two pixels are connected, we must determine if they satisfy two criteria:

- they are *adjacent* in some sense (e.g., if they are 4-neighbours or 8-neighbours)
- their gray levels satisfy a specified *criterion of similarity* (e.g., if they lie within a range).

55	0	0	0	0	0
0	0	0	53	99	56
0	0	0	0	0	0
0	0	53	54	0	0
0	51	0	0	0	0
0	56	0	0	0	0

Let V be the set of gray-level values used to define the *similarity criterion*. For example,

$$V = \{1\} \quad \text{(binary image)} \;\; \text{or } V = \{51, 52, \ldots, 60\} \quad \text{(gray-level image)}$$

Two types of connectivity are commonly used:

- 4-*connectivity*. Two pixels p and q with values from V are 4-connected if q is in the set $N_4(p)$, i.e., p and q are 4-neighbours
- 8-*connectivity*. Two pixels p and q with values from V are 8-connected if q is in the set $N_8(p)$, i.e., i.e., p and q are 8-neighbours

$$\begin{array}{ccccc} 1 & \cdots & 1 & & 0 \\ & & \vdots & & \\ 0 & & 1 & & 0 \\ & & \vdots & & \\ 0 & & 1 & & 0 \end{array} \qquad\qquad \begin{array}{ccccc} 1 & \cdots & 1 & & 0 \\ & \ddots & \vdots & & \\ 0 & & 1 & & 0 \\ & & \vdots & & \\ 0 & & 1 & & 0 \end{array}$$

4-connectivity   *8-connectivity*

Example

$$V = \{7,8,9\}$$

0	2	1	1	2	0	7
1	0	8	8	9	1	7
0	0	9	0	1	0	1
1	8	7	1	1	2	1
9	0	1	1	1	0	1

0	2	1	1	2	0	7
1	0	8	8	9	1	7
0	0	9	0	1	0	1
1	8	7	1	1	2	1
9	0	1	1	2	0	1

0	2	1	1	2	0	7
1	0	8	8	9	1	7
0	0	9	0	1	0	1
1	8	7	1	1	2	1
9	0	1	1	2	0	1

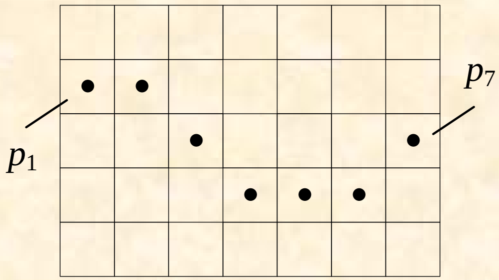
4-connectivity

0	2	1	1	2	0	7
1	0	8	8	9	1	7
0	0	9	0	1	0	1
1	8	7	1	1	2	1
9	0	1	1	2	0	1

8-connectivity

A *path* from pixel p_1 with coordinates (x_1, y_1) to pixel p_n with coordinates (x_n, y_n) is a sequence of distinct pixels with coordinates

$$(x_1, y_1), (x_2, y_2), (x_3, y_3), \ldots\ldots, (x_n, y_n)$$



where

(x_i, y_i) is connected to (x_{i-1}, y_{i-1}), $1 \le i \le n$

We can define 4- or 8-paths, depending on the type of connectivity specified.

0	0	1	0	0	0	0
1	0	0	0	0	0	0
1	1	1	0	1	0	1
1	0	1	0	1	1	1
0	0	1	1	1	0	1

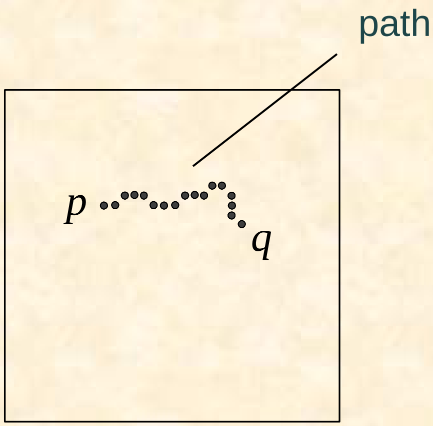
4-path

0	0	1	0	0	0	0
1	0	0	0	0	0	0
1	1	1	0	1	0	1
1	0	1	0	1	1	1
0	0	1	1	1	0	1

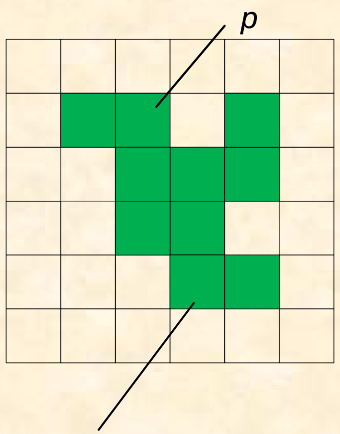
8-path

Connected components:

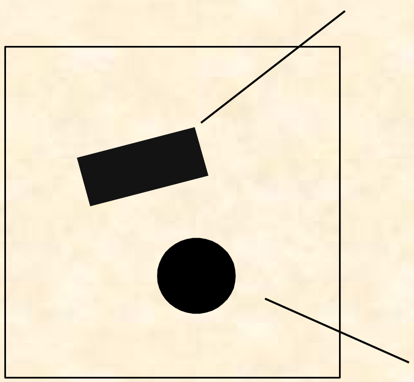
- Pixels p and q are connected if there is a path from p to q.
- The set of pixels that are connected to p is called a *connected component*. Hence, any two pixels of a connected component are connected to each other, and distinct connected components are disjoint.



p is connected to *q*



connected component
(all 'green' pixels)



Distance Measures

Euclidean distance:

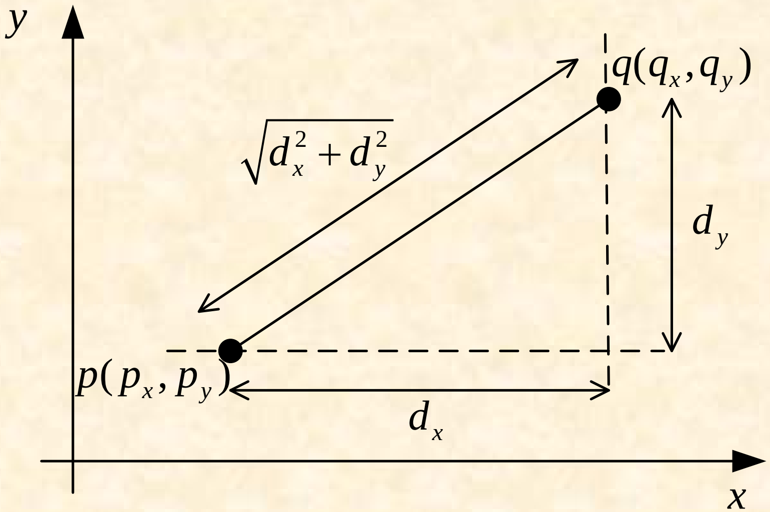
$$D_e(p,q) \triangleq (d_x^2 + d_y^2)^{1/2} = [(q_x - p_x)^2 + (q_y - p_y)^2]^{1/2}$$

D_4 distance (city-block distance):

$$D_4(p,q) \triangleq |d_x| + |d_y| = |q_x - p_x| + |q_y - p_y|$$

D_8 distance (chessboard distance):

$$D_8(p,q) \triangleq \max\left(|d_x|, |d_y|\right) = \max\left(|q_x - p_x|, |q_y - p_y|\right)$$



Arithmetic/Logic Operations

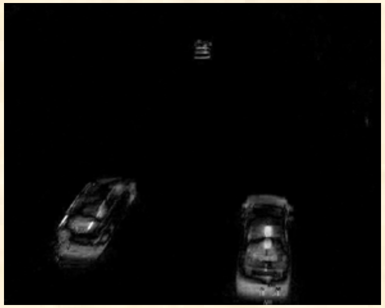
Arithmetic operations between two pixels p (value z_p) and q (value z_q) are

$$\text{Addition: } z_p + z_q$$
$$\text{Subtraction: } z_p - z_q$$
$$\text{Multiplication: } z_p \times z_q$$
$$\text{Division: } z_p \div z_q$$

Often, one of the pixels is a constant operand, as in the multiplication of an image by a constant.

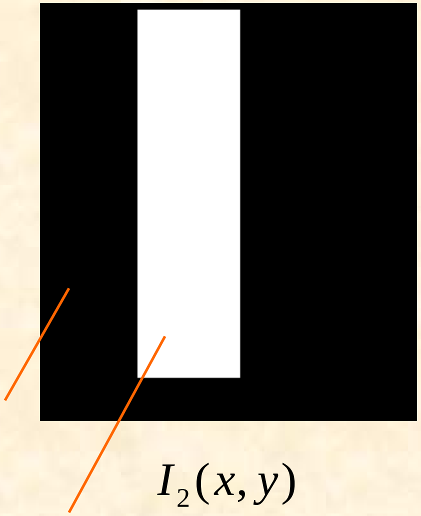
$I_1(x,y)$

$I_2(x,y)$



$I_3(x,y) = \left| I_1(x,y) - I_2(x,y) \right|$

$I_1(x,y)$



0

255

$I_2(x,y)$

$I_3(x,y) = I_1(x,y) \times I_2(x,y)$

rescaled to [0,255]

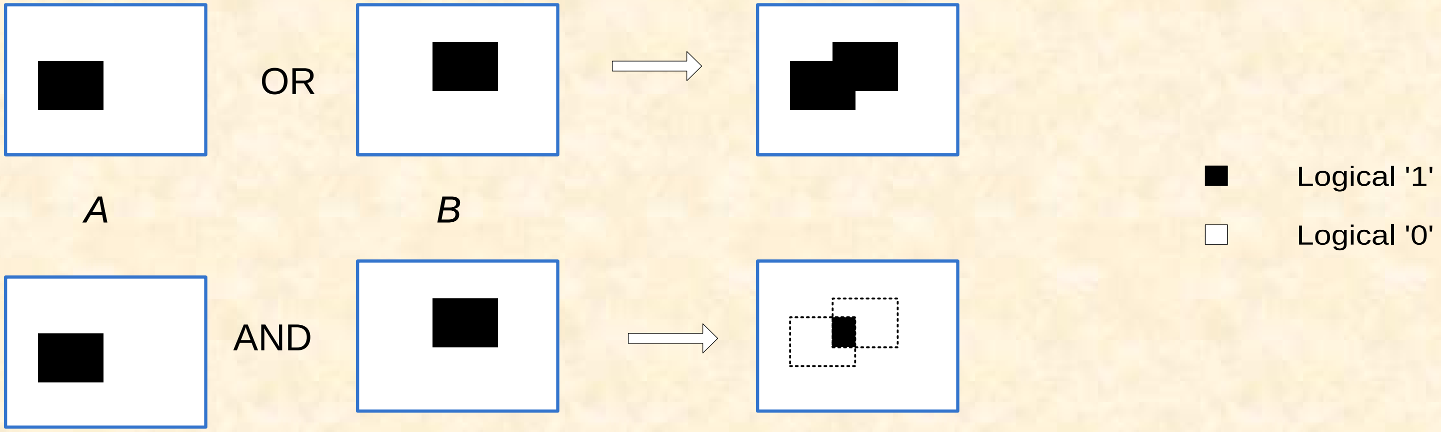
Logic operations are applicable only to binary images. With logical values z_p and z_q:

$$\text{AND: } z_p \bullet z_q$$

$$\text{OR : } z_p + z_q$$

$$\text{COMPLEMENT : } \bar{z}_p$$

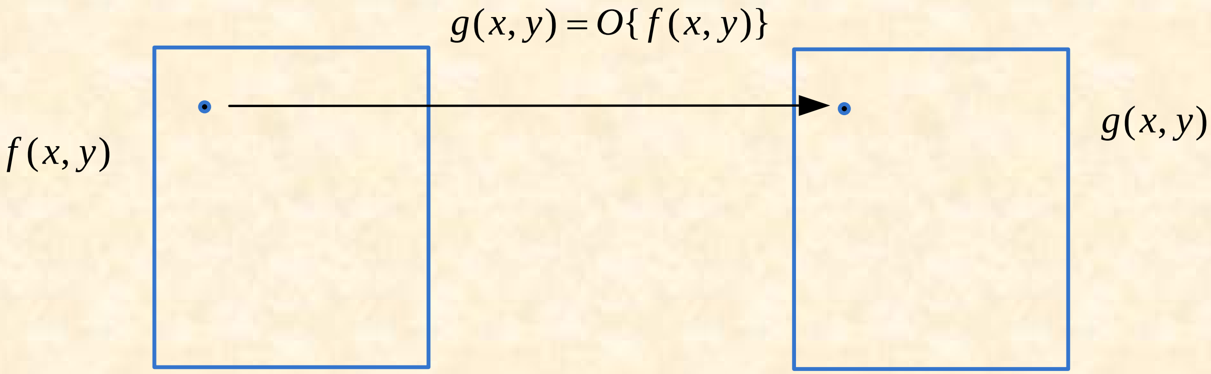
Logic operations are basic tools in binary image processing where they are used for tasks such as feature detection and shape analysis.



Arithmetic and logical operations are used in basically two ways: point operations and neighbourhood operations.

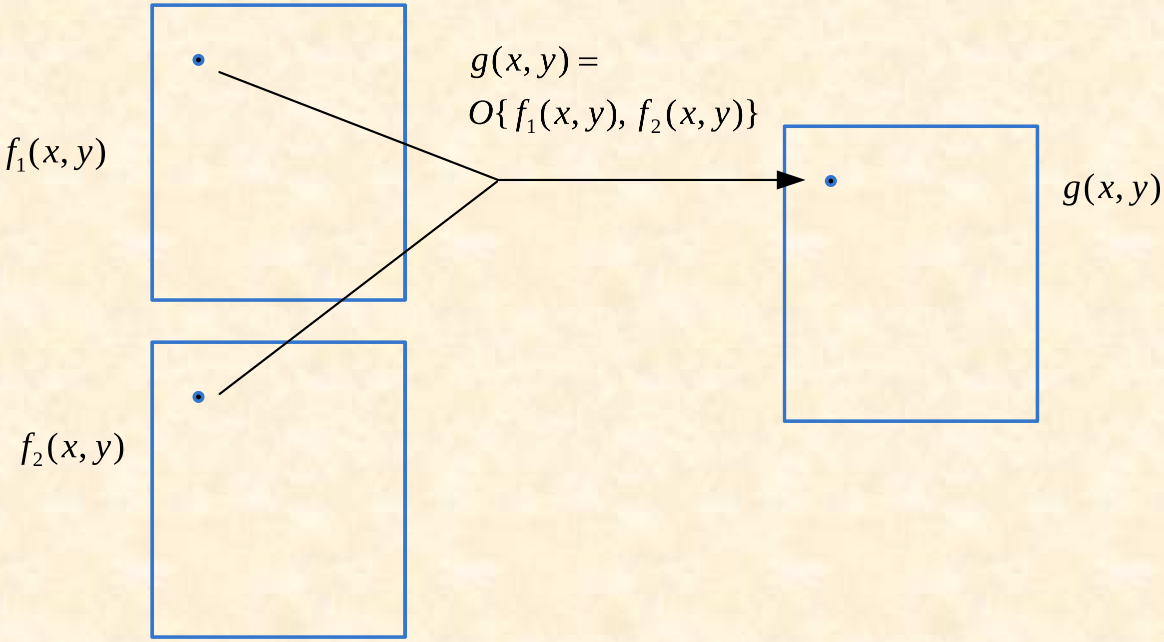
Point operations:

Point operations modify the gray values at individual pixels depending only on the gray value. The input may be one or more images. Examples are gray-level transformation or addition of two images.



Example:

$$g(x,y)=0.5f(x,y)+20$$



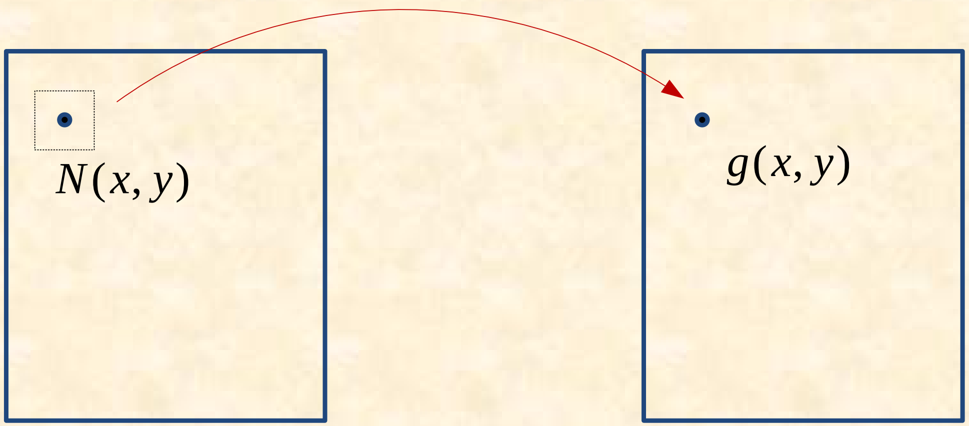
Example:

$$g(x,y) = f_1(x,y) + f_2(x,y) - 20$$

Neighbourhood operations:

Neighbourhood operations combine the values of the pixels in a neighbourhood to yield the output value. This requires the definition of appropriate masks (template, window, or filter). Mask sizes vary, e.g., 3×3, 3×1, 5×5.

$$g(x, y) = O\{N(x, y)\}$$



3x3 nbhd in image

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

3x3 window, mask values/coefficients w_i

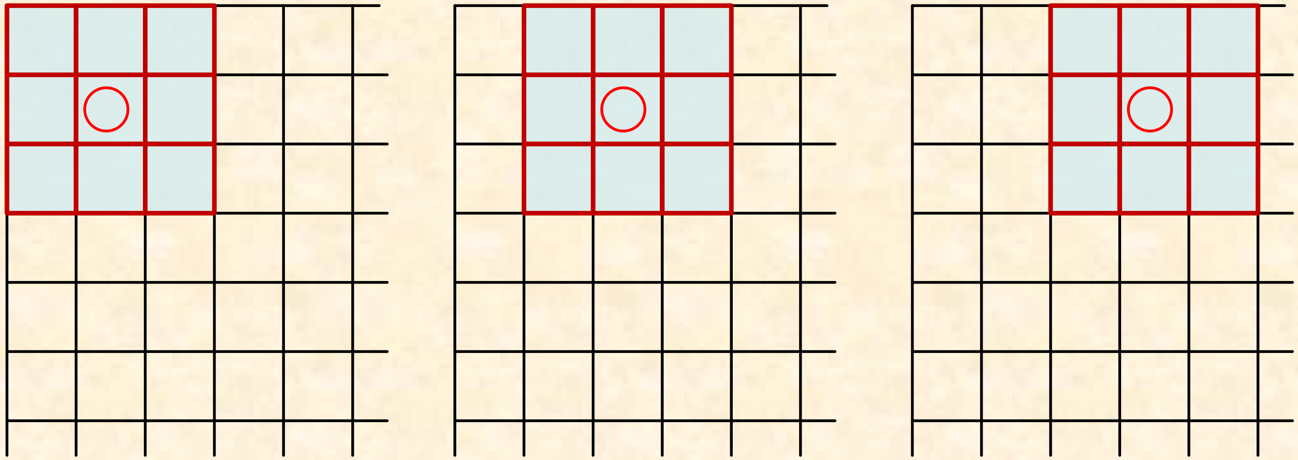
The value of the center pixel is replaced by a new value z_{new}:

$$z_{new} = w_1 z_1 + w_2 z_2 + w_3 z_3 + w_4 z_4 + w_5 z_5 + w_6 z_6 + w_7 z_7 + w_8 z_8 + w_9 z_9$$

If we set $w_i = 1/9$,

$$z_{new} = \frac{1}{9}(z_1 + z_2 + z_3 + z_4 + z_5 + z_6 + z_7 + z_8 + z_9)$$

which is the average value of the pixels in the 3×3 neigbourhood.



The mask is moved across the image, column by column, row by row.

Many useful image processing functions can be obtained by neighbourhood operations, e.g., noise reduction, edge detection and image enhancement.

Example

Input image
8 x 6

0	0	0	0	0	0
0	0	0	20	50	10
0	0	20	25	50	10
0	20	25	40	50	10
0	25	40	40	50	10
0	35	100	100	100	10
0	50	50	50	50	10
0	0	0	0	0	0

Mask
3 x 3

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

Output image
6 x 4

	2	7	18	18	
	7	17	31	29	
	14	26	38	32	
	27	47	61	46	
	33	54	64	47	
	26	43	50	36	

Note: For a 3x3 mask, the outermost rows and columns are lost.

GRAY-LEVEL HISTOGRAM

The histogram plot shows the number of pixels at each gray level, i.e., number of pixels *vs* gray level.

For a digital image with intensity levels in the range [0, $L-1$], it is the discrete function

$$h(r_k) = n_k, \qquad k = 0, 1, 2, \ldots, L-1$$

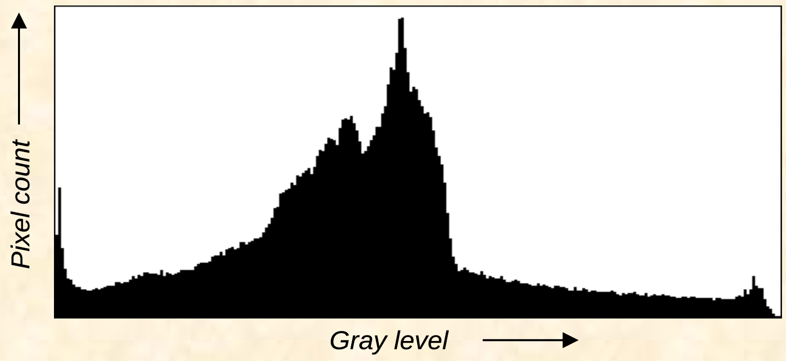
where n_k is the number of pixels with intensity r_k.

The number of pixels may be normalized by the total number of pixels in the image, N, to give

$$p(r_k) = n_k / N$$

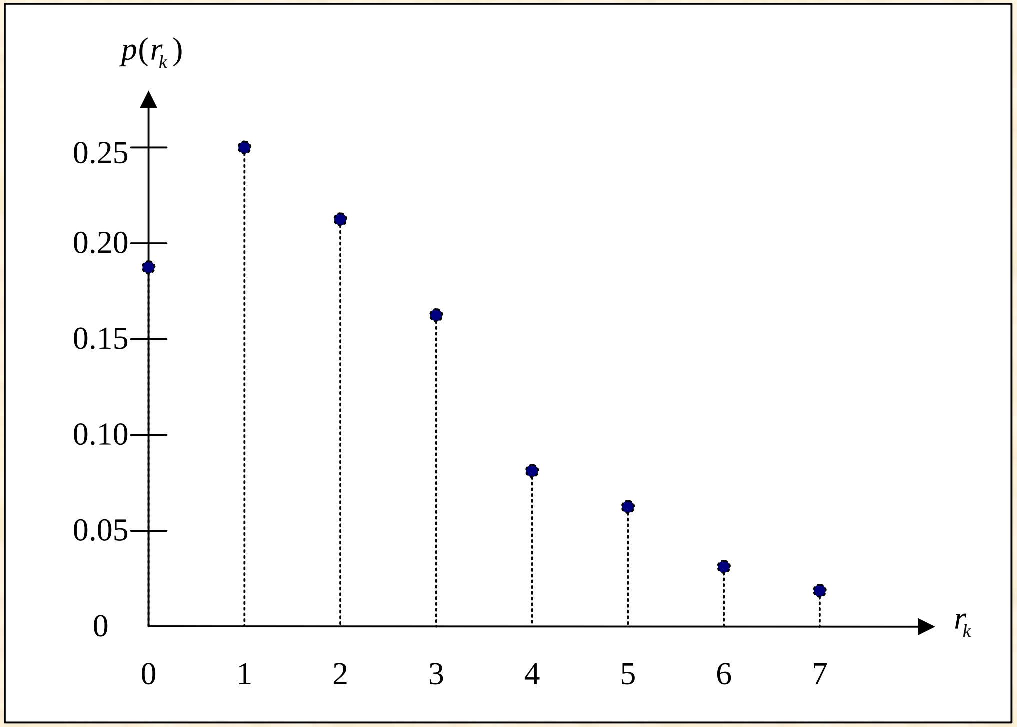
Note that:

$$\sum_{k=0}^{L-1} p(r_k) = 1$$



Example

r_k	$h(r_k) = n_k$	$p(r_k) = n_k/N$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02



How do we describe a histogram quantitatively? We can use statistical measures.

The mean is defined as

$$m = \sum_{k=0}^{L-1} r_k \, p(r_k)$$

mean is the average intensity.

The *n*th moment of r_k about the mean is defined as

$$\mu_n = \sum_{k=0}^{L-1} (r_k - m)^n \, p(r_k)$$

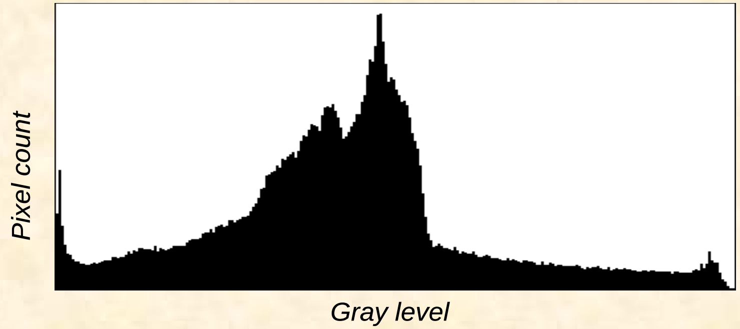
Zeroth moment μ_0 is always 1; first moment μ_1 is always 0.
Second moment μ_2 is also known as the variance, denoted by σ^2.

For the previous histogram

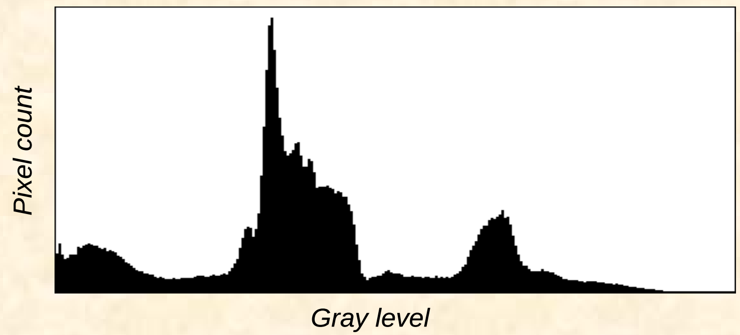
variance is a measure of image contrast

$$m = 2.09, \quad \mu_2 = 3.00, \quad \mu_3 = 4.26, \quad \mu_3 = 28.1$$

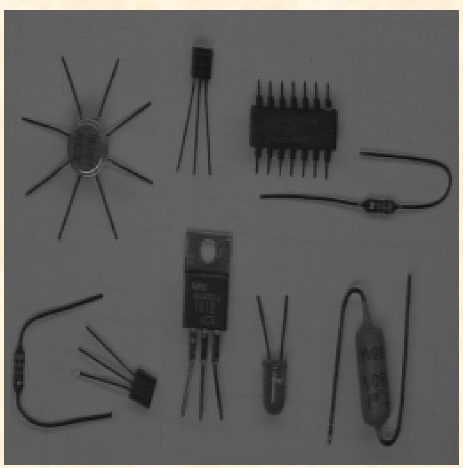
From its gray-level histogram, some characteristics of an image may be discerned, e.g., its contrast and overall intensity.

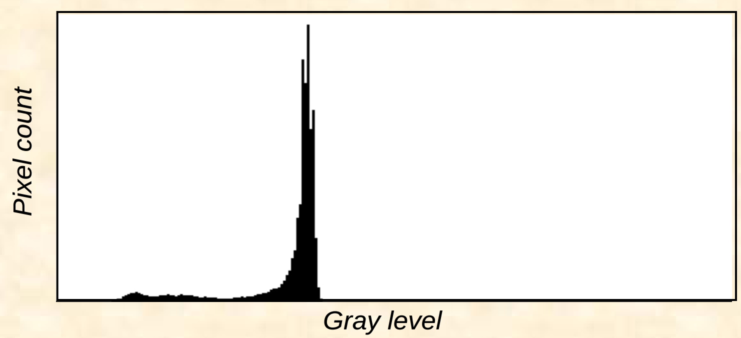


$m = 109; \quad \sigma = 48$



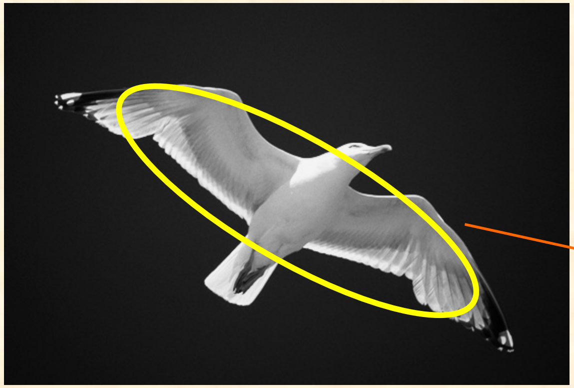
$m = 98; \quad \sigma = 48$

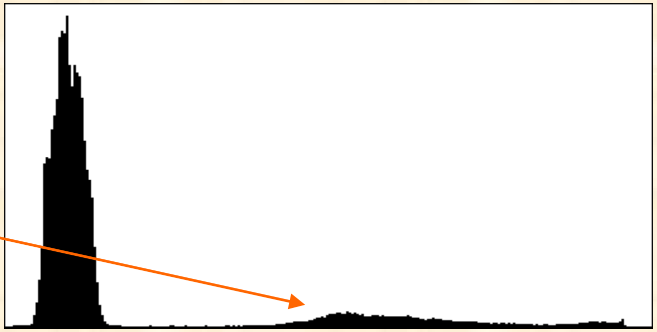


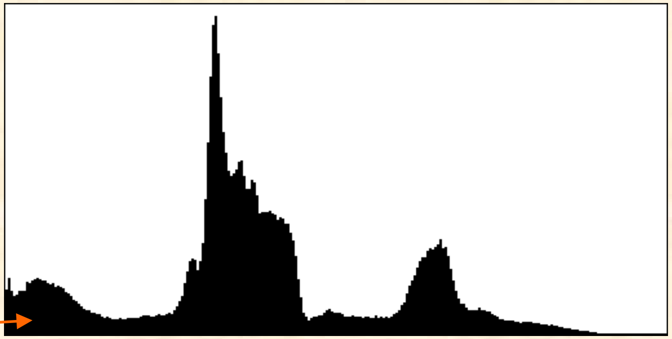


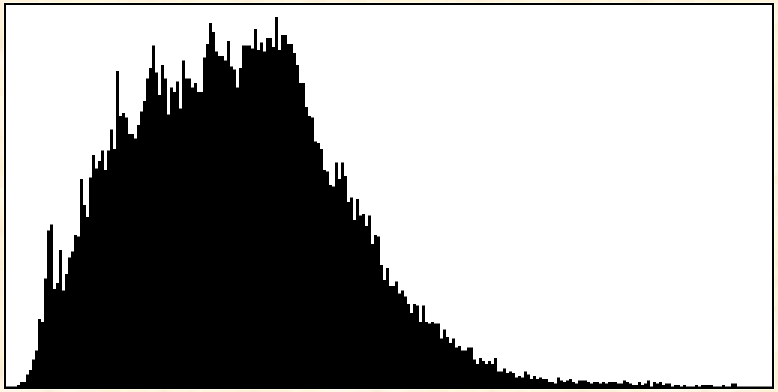
$m = 86; \quad \sigma = 18$

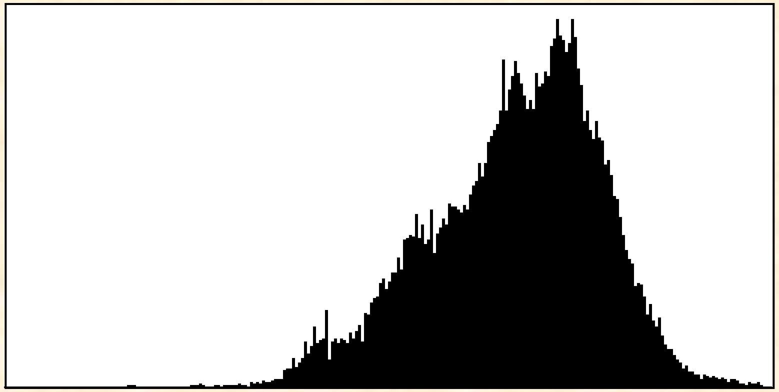
It may be possible to relate a histogram mode to its corresponding image region.

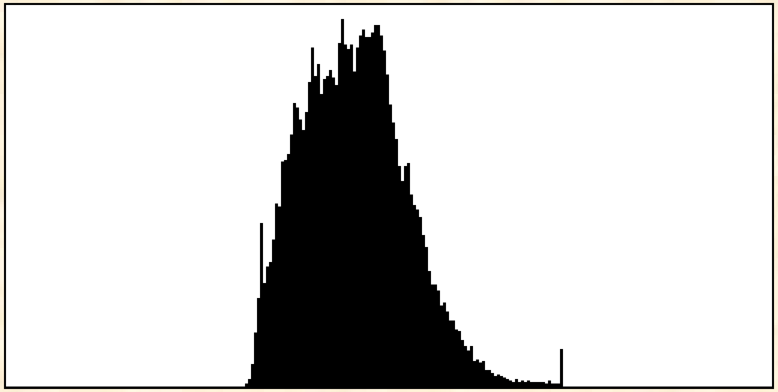




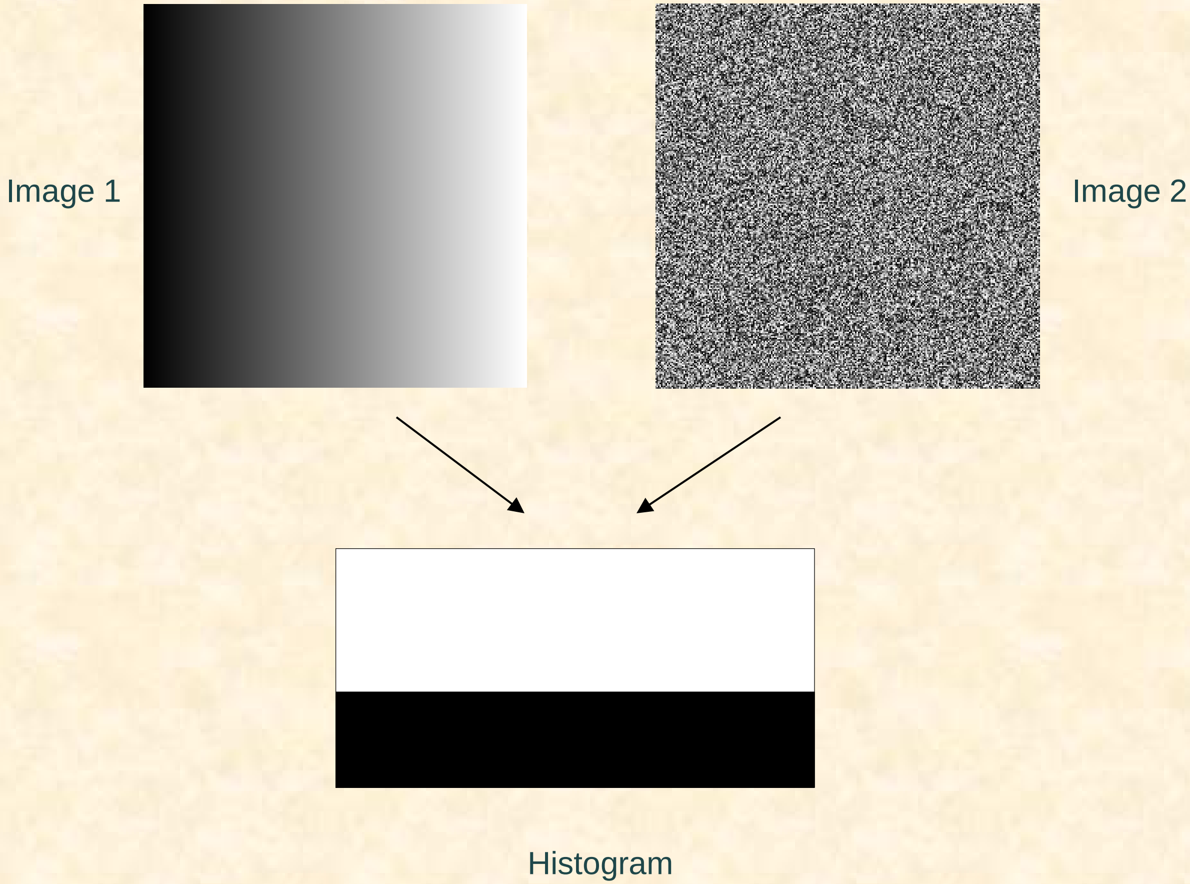




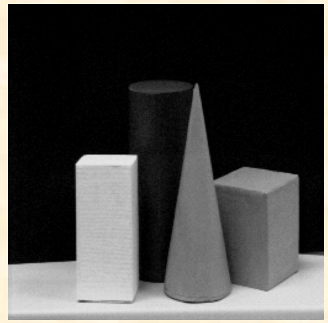


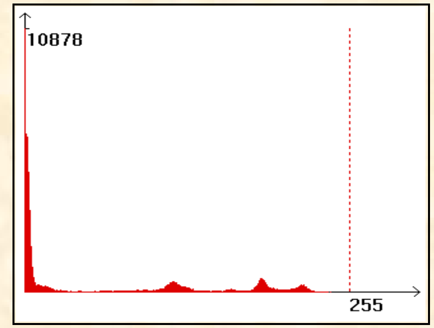
The histogram provides a global view of the gray-level distribution; thus two images with the same or similar histogram may be markedly different in appearance.



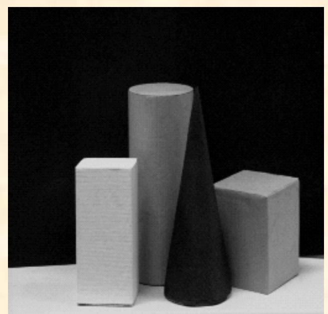
For colour images, each pixel has three components: red, green and blue. Thus, for a colour image, we have three histograms, one for each of the three components.

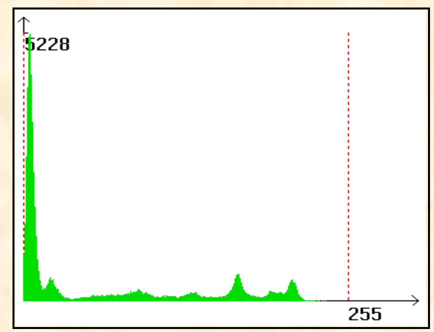
Red





Green





Blue