Image fundamentals

Computer Vision Crash Course

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What you will learn

What is a digital image

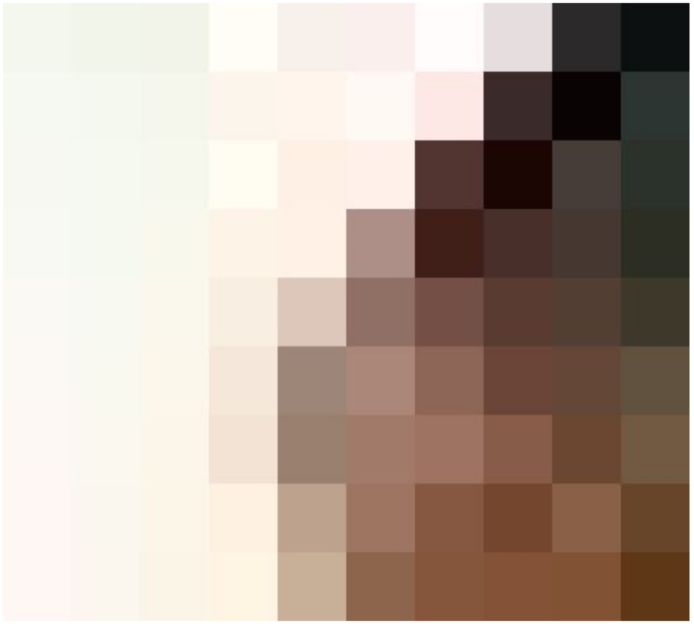
Spatial coherence and adjacency

Histograms

Operations on images

Digital Images

Breaking the ice...



Digital images

Breaking the ice...

Raster images have a regular pattern

Because of this regularity they are usually modelled as **matrices** of elements

An element is referred to as a ***pixel*** (*pic*ture *el*ement)

Digital images

Pixel Content

It depends on the image type

- Pictorial digital images (photos): intensity, color
- Range images: Depth information
- Medical images: Radiations absorbance level
- Termal images: Heat
- ....

Digital Images

Size: number of pixels composing the image
Convention: rows x columns

Matrices of numbers

							COLUMN					
	98	103	102	110	118	118	119	119	118	118	109	88
	98	105	101	110	118	118	119	118	116	113	105	84
	92	98	96	109	116	121	130	130	142	141	151	145
	95	98	98	104	110	112	124	127	148	147	157	159
	95	98	98	104	110	112	124	127	148	147	157	159
	103	104	107	111	116	121	128	128	137	135	146	169
	101	106	106	110	116	119	128	128	134	133	145	166
	99	109	106	118	127	131	143	145	154	153	155	168
	102	110	110	121	131	136	148	148	157	157	160	169
ROW	102	110	111	124	136	140	153	154	164	165	167	174
	105	113	112	124	130	135	147	147	159	159	167	175
	104	113	112	125	134	137	144	147	161	161	169	177
	102	110	108	122	131	131	140	140	149	150	157	168
	103	109	109	121	128	131	139	140	149	148	156	167
	101	106	103	116	127	133	144	143	148	148	149	159
	84	94	91	103	113	118	132	134	145	146	146	149
	85	92	91	103	114	119	134	135	146	145	146	149
	70	82	81	91	97	100	112	115	131	130	139	142
	70	82	81	91	97	100	114	115	131	132	139	142
	77	76	76	82	89	89	100	101	115	113	127	135
	111	85	84	79	81	81	90	90	102	100	111	125
	107	86	88	79	79	79	88	88	100	101	110	126

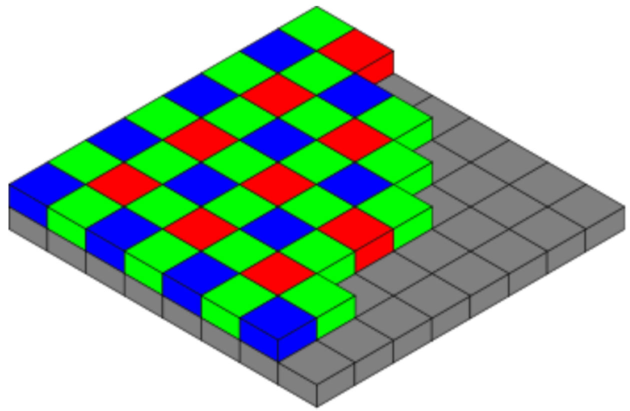
Digital Images

Two important observations

- The exact relationship of a digital image to the physical world is determined by the ***acquisition process***
- Any information contained in images (shape, measurements, objects identities) is computed starting from 2D numerical arrays.

Digital Images

Color



From the sensor we receive a stream of data which is then organized in ordered data structures.

A color image is usually acquired by using 3 filters sensitive to red green and blue. we obtain 3 monochrome images which are then combined in a single image

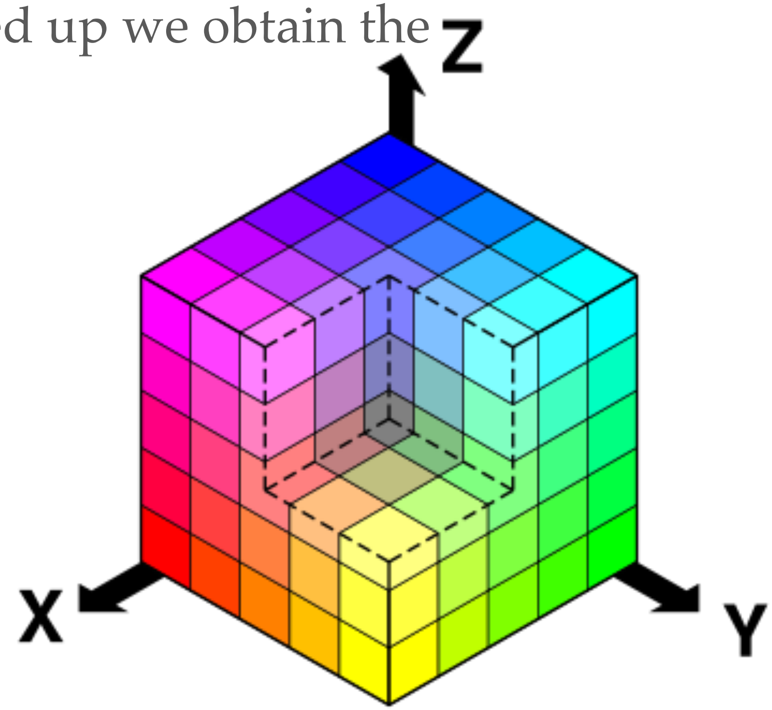
Here we refer to ***color RGB images*** where each pixel is described by a triplet (R,G,B)

a standard 24-bit image (also called *full color)* associates 1 byte per pixel to each color field (overall 3 bytes per pixel)

RGB

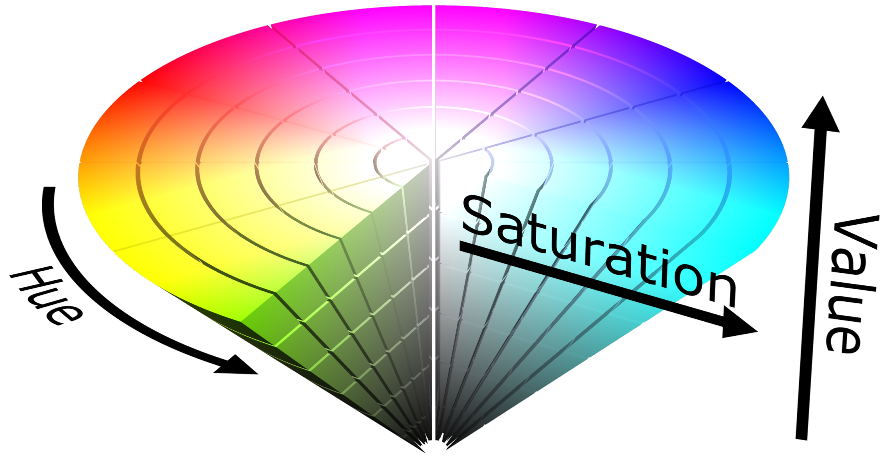
- It is based on 3 primary monochrome colors:
  - R red(wavelength λ=700nm)
  - G green(λ=546.1nm)
  - B blue(λ=435.8nm)

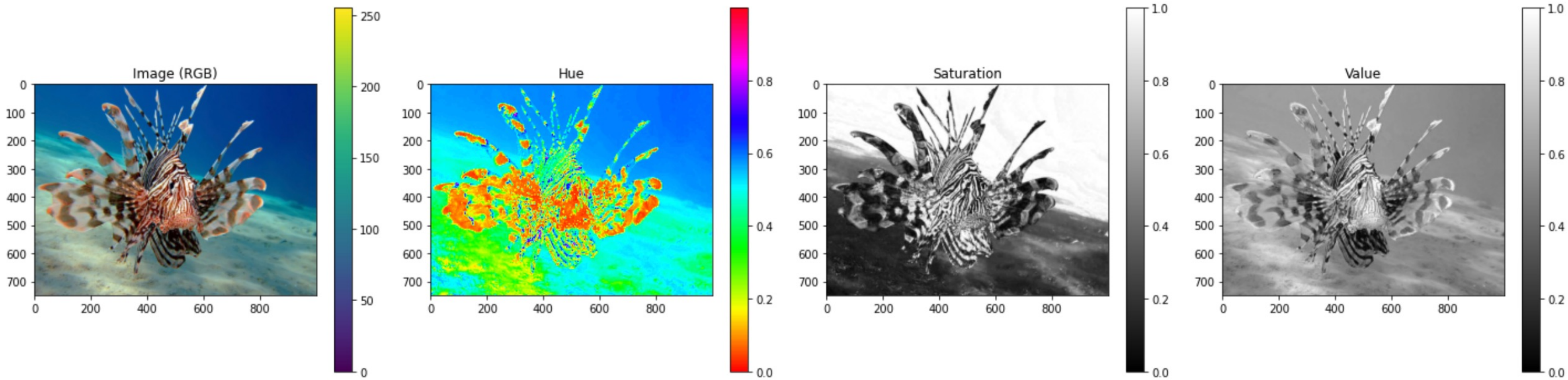
- *Most* visible spectrum may be represented by blending red, green and blue lights in different proportions and intensities.
- If a maximum quantity of primary colors is summed up we obtain the white
  - RGB is an additive model



Perceptive color spaces

- RGB has been designed to model color for specific devices
- It does not consider our perception of color
- Other spaces are the result of studies in human perception
- An example is the HSV color space
  - H = hue
  - S = saturation
  - V = value



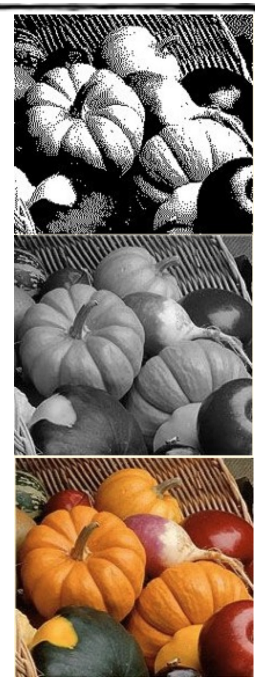


Dynamic Range

- Total number of distinctive values occurring in the image

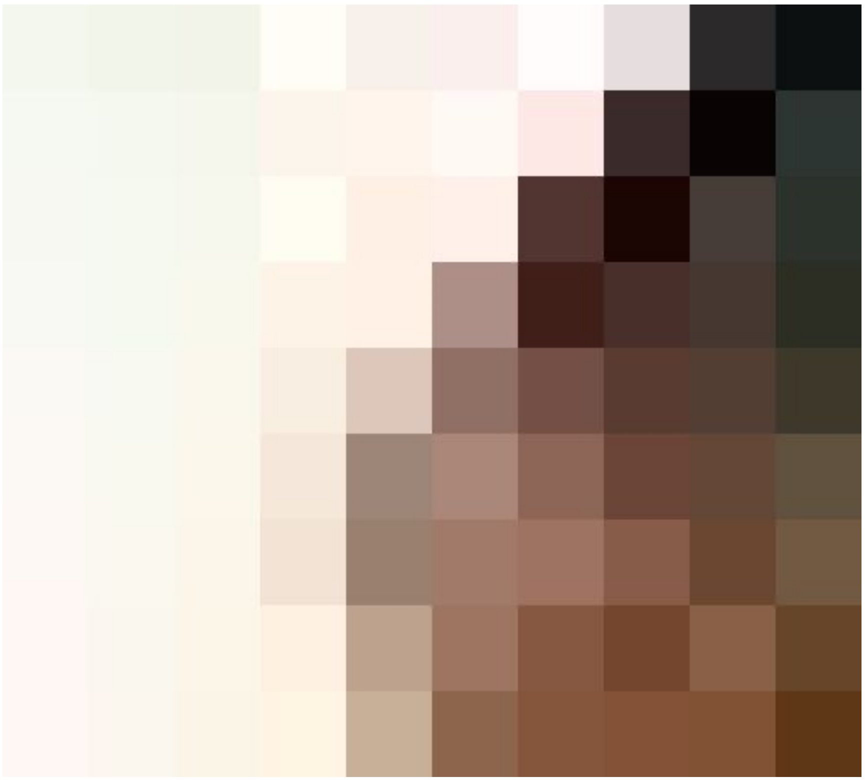
  - it is limited by the number of bit per pixel we may want to use
  - it is also limited by the physical dynamic range of the sensor

- to represent black-white images 1 bit is sufficient
- gray level images: usually associate a byte to a pixel 2^8=256 gray levels
- color images: usually 1 byte per channel (“millions of color”)

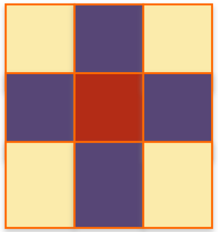


Spatial Coherence

- Neighbouring pixels usually carry similar information



Relationships between pixels



A pixel *p* at coordinates *(i,j)* has four horizontal and vertical neighbors at coordinates *(i-1,j) (i+1,j) (i,j-1) (i,j+1)*

This set is called ***4-neighborhood*** $N_4(p)$

The pixel also has four diagonal neighbors: *(i-1,j-1) (i+1,j-1) (i+1,j-1) (i+1,j+1)*

The 8 points together form a ***8-neighborhood*** $N_8(p)$

Adjacency and connectivity

- Two pixels *p* and *q* are **4-adjacent** if *q is in* $N_4(p)$

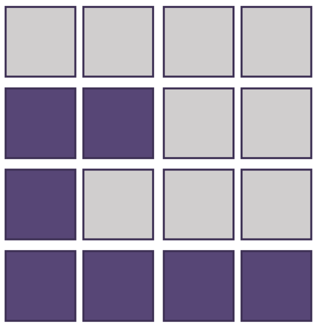
- Usually adjacency is associated to pixel similarity. Therefore we may say that two pixel are 4-adjacent if the definition of above holds and the two pixels have "coherent" values

- A **path** between a pixel $p=(i,j)$ and $q=(s,t)$ is a sequence
  $(a_0,b_0)\ (a_1,b_1)\ \ldots\ (a_n,b_n)$
  where $(a_0,b_0)=(i,j)$ and $(a_n,b_n)=(s,t)$ and (a_i,b_i) and (a_{i+1},b_{i+1}) are adjacent for each i

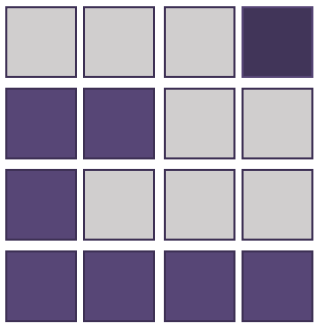
ADJACENCY AND CONNECTIVITY

- Let S represent a subset of pixels in an image. Two pixels p and q are said to be ***connected*** in S it there exists a path between them consisting entirely of pixels in S.

- For any pixel p in S the set of pixels connected to p in S is called a ***connected component*** of S.



CONNECTED COMPONENT



NON CONNECTED

Another way to look at the image content

Histograms

An image histogram is a representation of the values distribution of an image

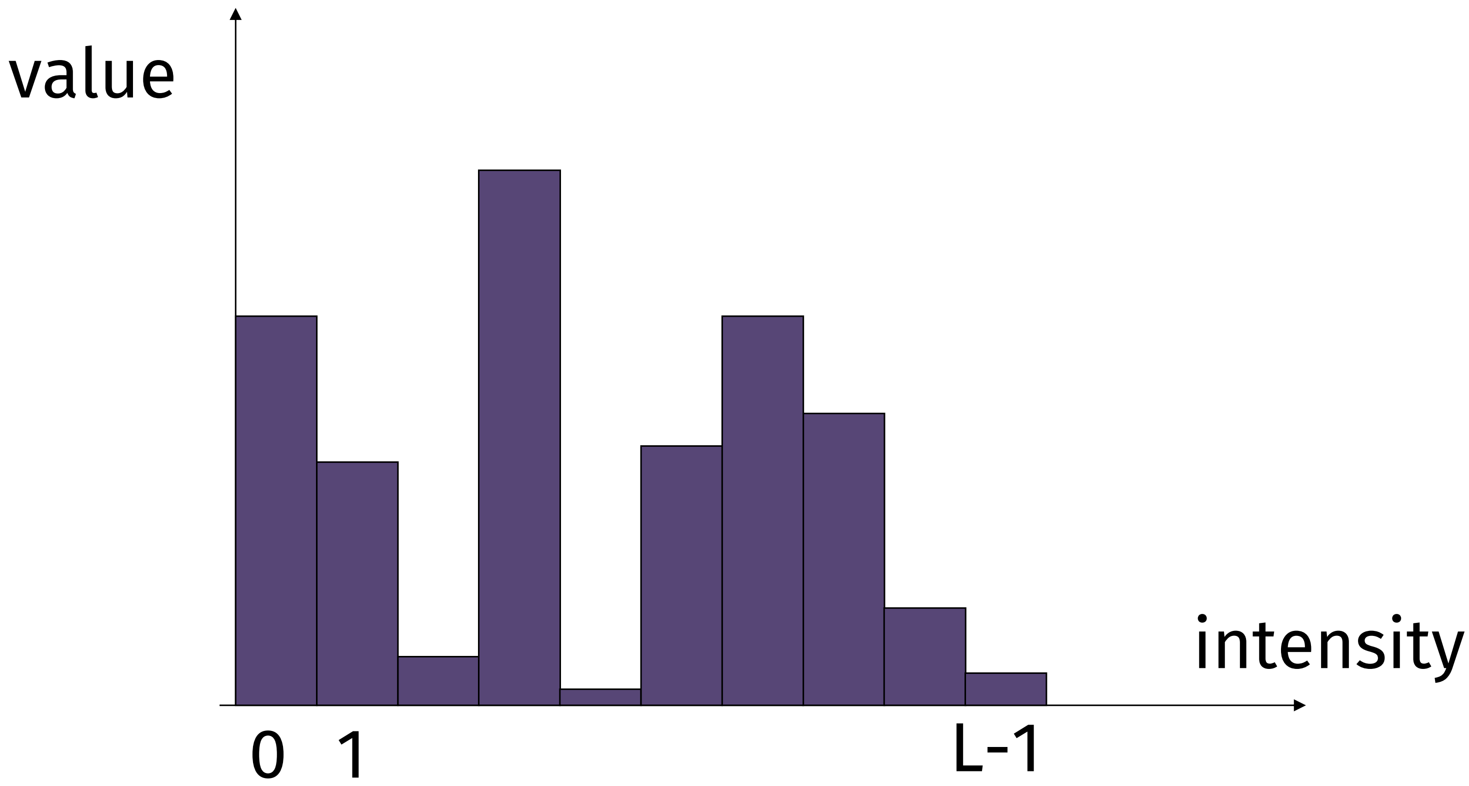
The histogram of a digital image with intensity values in the range [0,L-1] is a discrete function $h(r_k)=n_k$

where

- r_k is the k*th* intensity value of the range
- n_k is the number of pixels in the image with intensity r_k

Another way to look at the image content

Histograms

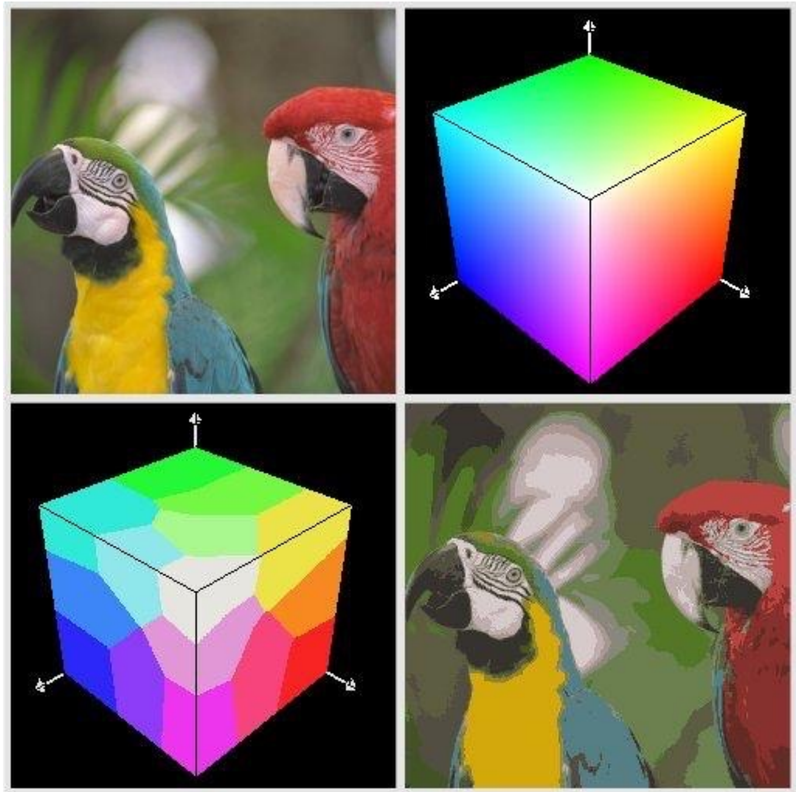


HISTOGRAMS: BINS

It is common practice to group similar values while computing the histogram

The range of possible values [0,L-1] can be quantized in *bins* each of which will group pixels of the image with similar values.

Histogram bins & image quantization



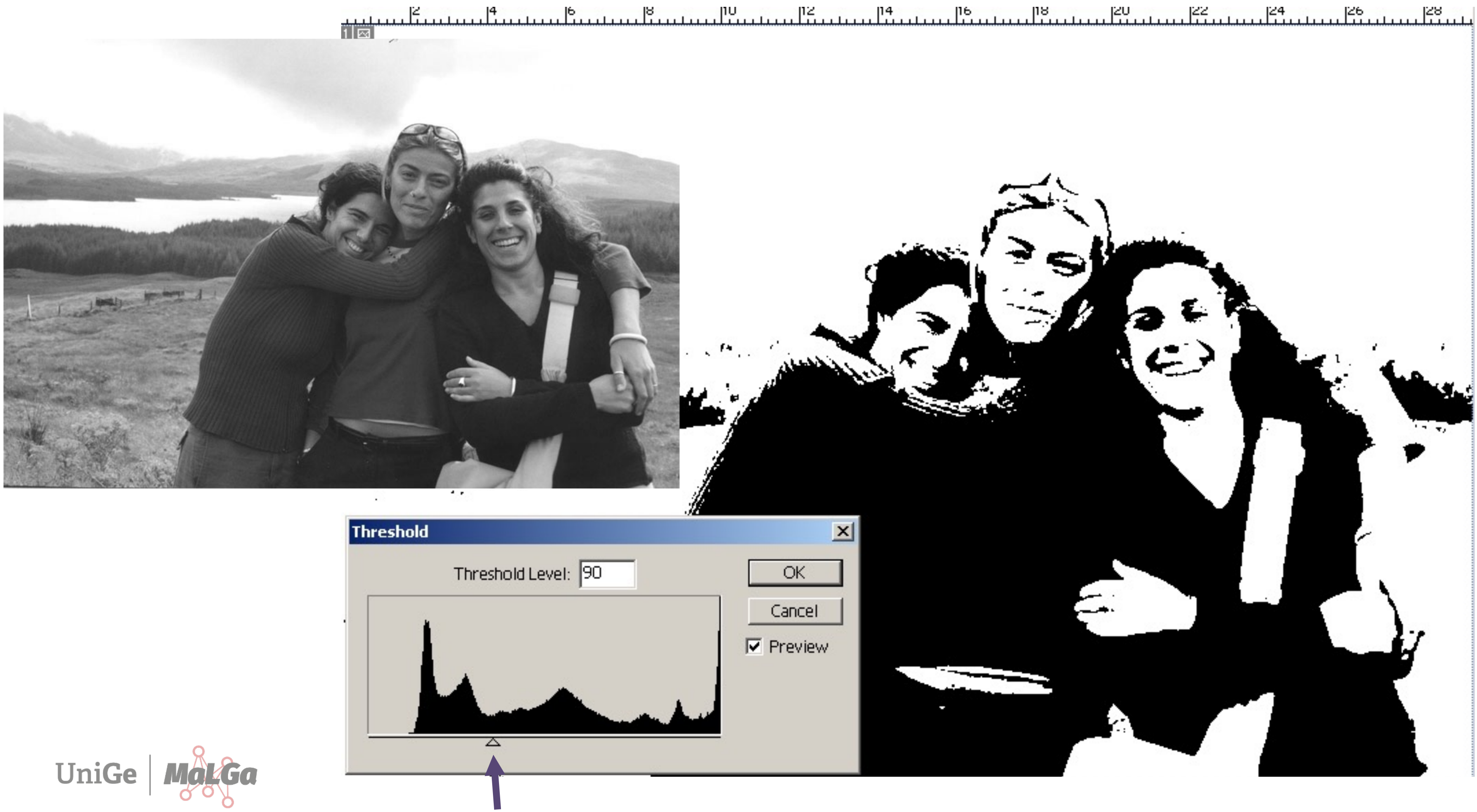
Histogram: information loss

The corresponding histograms are identical!

Operations on pixel values (with an effect on histograms)

Thresholding

$$J(i,j) = \begin{cases} 0 & \text{if} \quad I(i,j) < T \\ 1 & \text{otherwise} \end{cases}$$



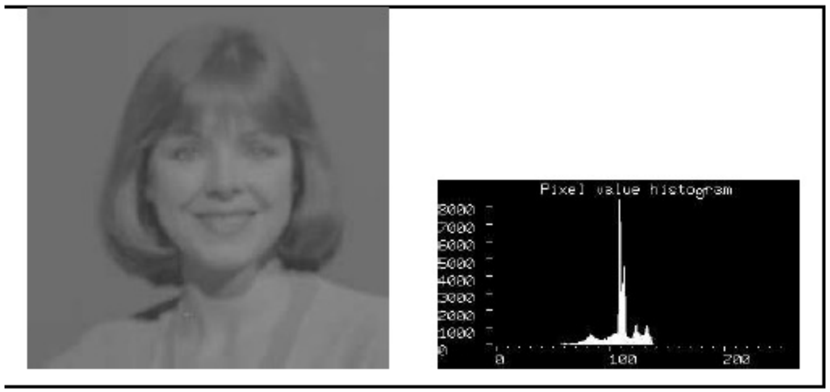
Operations on pixel values (with an effect on histograms)

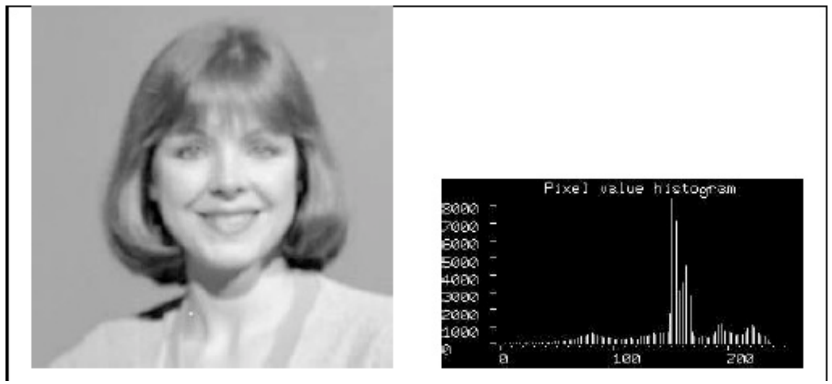
Contrast Stretch

Contrast stretch is a simple linear operation that produces an expansion of the image histogram

We choose the range of values of output image J, for instance [0,L-1].

$$J(i,j) = \frac{I(i,j) - min_I}{max_I - min_I}(L-1)$$





Operations on images

Operations on pixels

- They produce changes in pixels content
- Alter corresponding histograms

Geometrical transformations:

- They modify the position of pixels instead than their value
- Do not alter histograms

Geometric spatial transformations

Each point $\mathbf{p} = (x, y)$ of an input image is mapped to a point $\mathbf{q} = (u, v)$ of the output image, through the effect of a geometric transformation *T*

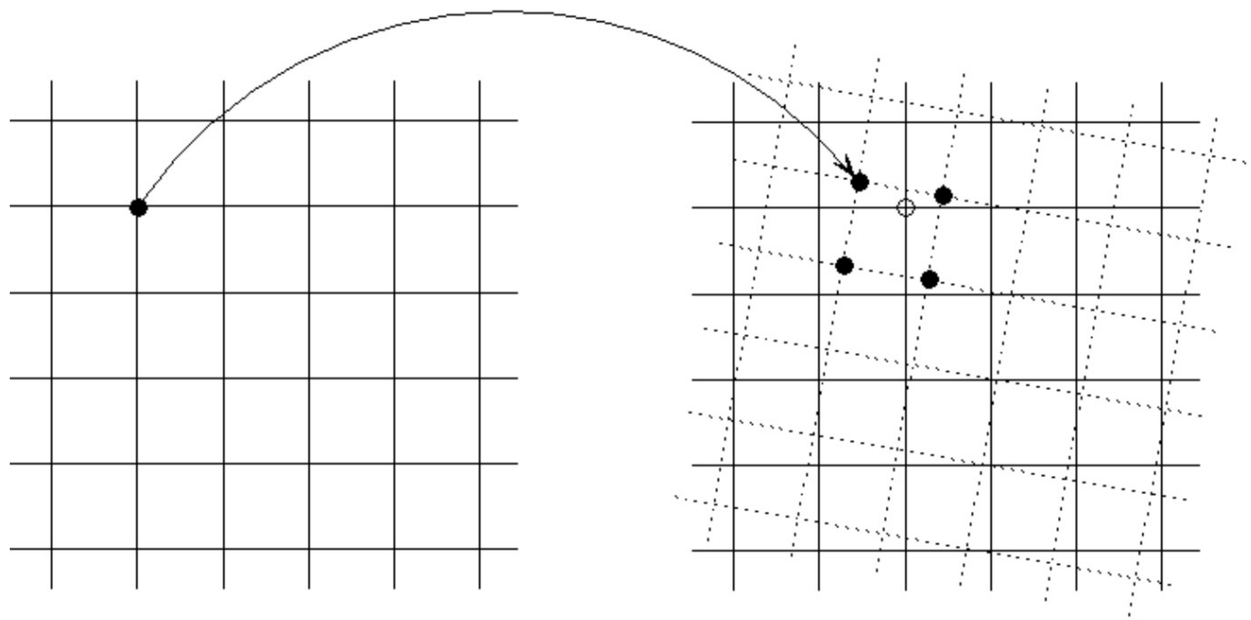
$$\mathbf{q} = T(\mathbf{p})$$

$$I_{out}(\mathbf{q}) = I_{in}(\mathbf{p})$$

Geometric spatial transformations

In ***digital*** image processing they consist of two steps

- A spatial transformation of coordinates from $\boldsymbol{p}$ to $\boldsymbol{q}$ according to T
- *Intensity interpolation* to assign intensity values to the spatially transformed pixels



Geometric transformation examples

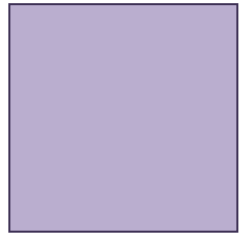


Image in-plane rotation

$$u = x\cos\theta + y\sin\theta$$
$$v = -x\sin\theta + y\cos\theta$$

$$T = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

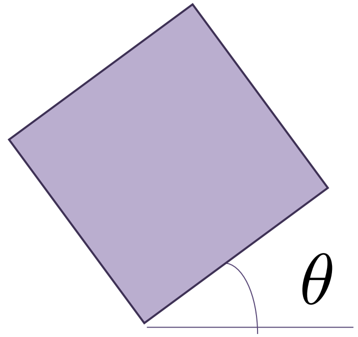
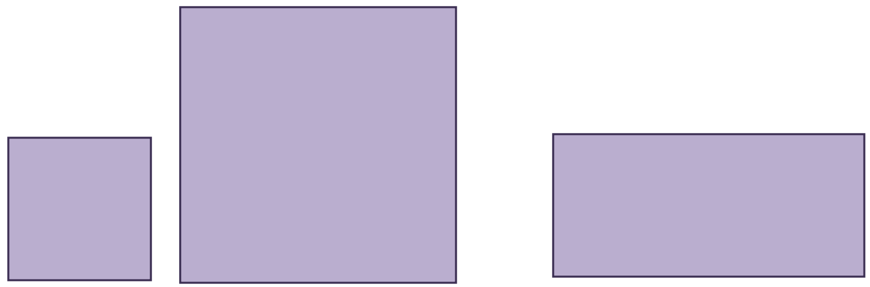


Image scaling

$$u = s_1 x$$
$$v = s_2 y$$

$$T = \begin{bmatrix} s_1 & 0 \\ 0 & s_2 \end{bmatrix}$$

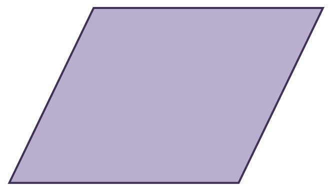


$s_1 = s_2$ $\qquad$ $s_1 \neq s_2$

Affine transformation

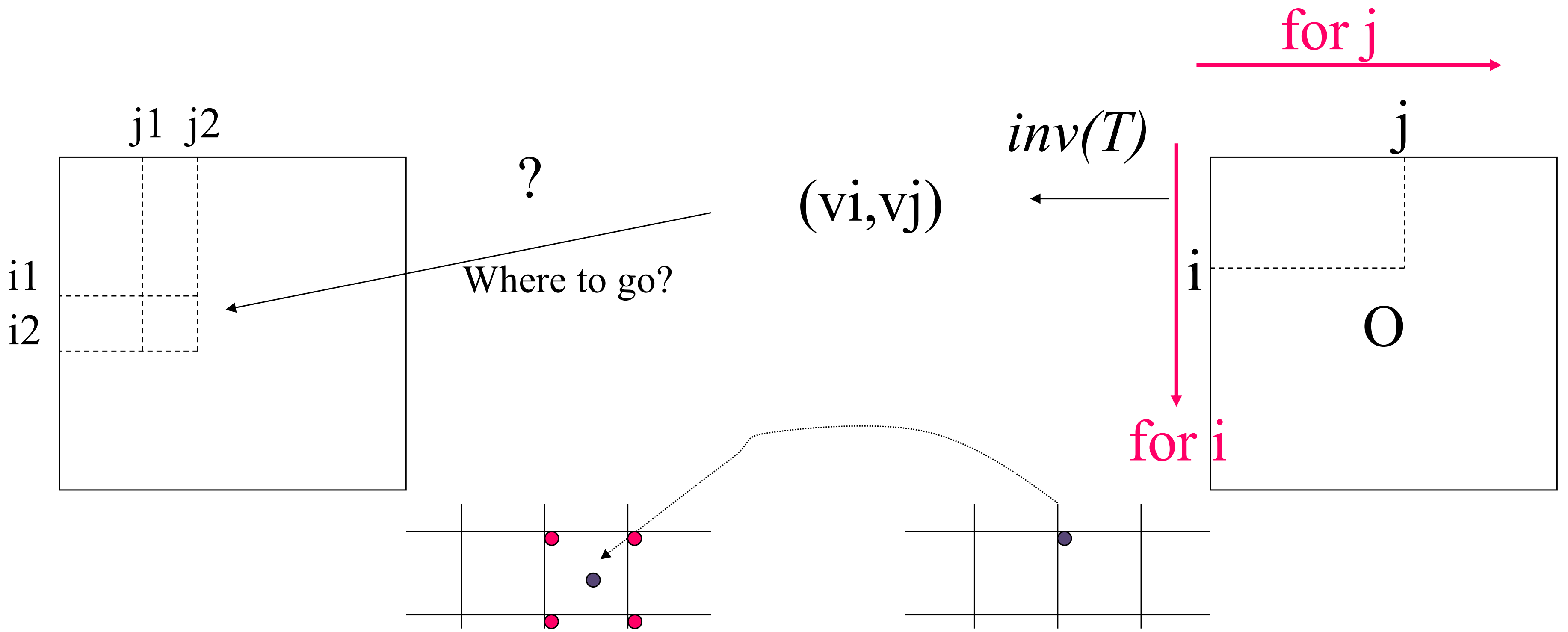
$$u = ax + by + c$$
$$v = dy + ey + f$$

$$\mathbf{q} = A\mathbf{p} + \mathbf{t}$$



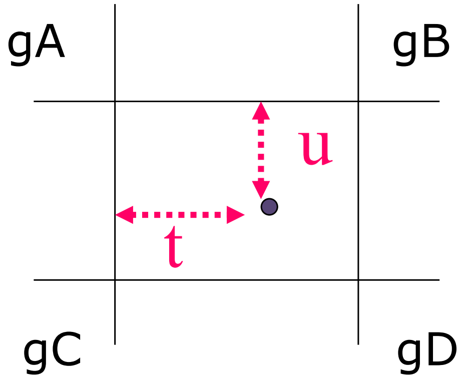
Interpolation with an inverse mapping

We start from the output image to have the guarantee that all pixels are filled



Interpolation with an inverse mapping

There are different interpolation methods, here we see the *bilinear interpolation*



g_new = (1-t)(1-u)gA + (1-t)u gB+
+ u (1-t) gC + u t gD

t = vi – i1
u= vj – j1

$$0 \leq u, t \leq 1$$

UniGe

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