# Introduction to Images

## Digital Signal and Image Processing

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(based on notes by Annalisa Barla)

# Outline

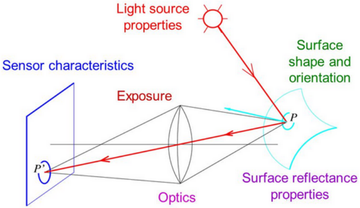
# Digital Image Processing topics

- **Image acquisition**: Camera geometry, optics, digitalization process
- **Representation**: How to represent halftone, grey-scale, color images on the computers?
- **Image Transform**: Pixel domain vs. transform domain, Fourier, (but also Discrete Cosine Transform, Wavelet...)
- **Image processing algorithms:** Contrast enhancement, noise removal, filters
- **Geometic transformations**: similarity, affinity, projective, ...
- **Feature enhancement, feature detection** : Edge and corner detection

# Outline

# Image acquisition

Images cannot exist without light. To produce an image, the scene must be illuminated with one or more light sources.



# Image acquisition

Certain modalities such as fluorescent microscopy, astronomy, MRI and X-ray tomography do not fit this model and the image formation is more complex

# Image observed using different bands

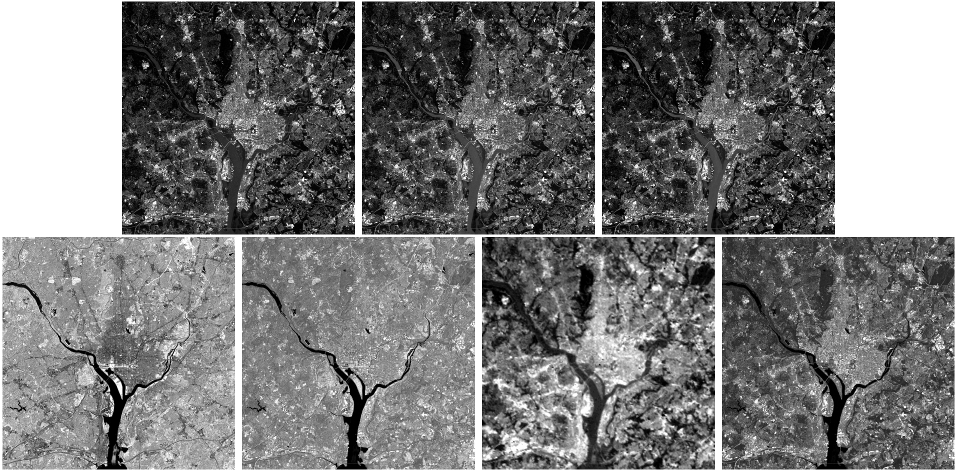
The same scene can be observed acquiring only a specific band of the light.
For instance the same area (Washington D.C.) produces the following images if observed using seven different wavelength bands.
From left to right:

- Visible blue (0.45-0.52 $\mu m$): maximum water penetration
- Visible green (0.52-0.60 $\mu m$): measuring plant vigor
- Visible red (0.63-0.69 $\mu m$): vegetation discrimination
- Near Infrared (0.76-0.90 $\mu m$):biomass mapping
- Thermal Infrared (10.6-12.5 $\mu m$): thermal mapping
- Middle Infraed (2.08-2.35 $\mu m$):Mineal mapping



From: Digital Image Processing 3rd ed. Gonzalez & Woods

# Image observed using different bands



From: Digital Image Processing 3rd ed. Gonzalez & Woods

# Image formation

- **Geometric parameters:** type of projections, position and orientation of the camera, perspective distortion
- **Optical parameters:** lens type, focal length, field of view, aperture
- **Photometric parameters:** type, intensity, direction of illumination; reflectance properties of surfaces, sensors' structure;...
- **Spatial and temporal resolution**
- **Quantization of intensity scale**

# Images

A monochrome image is an array of values. There are two types of discretization involved:

- Spatial sampling (pixels -‘picture elements’)
- Intensity quantization (grey level value).

(0,0)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 84 | 133 | 226 | 212 | 218 | 218 | 222 | 212 | 218 | 222 | 226 | 218 |
| 75 | 156 | 177 | 218 | 212 | 218 | 218 | 218 | 218 | 222 | 218 | 218 |
| 96 | 84 | 133 | 203 | 218 | 218 | 218 | 222 | 212 | 218 | 222 | 218 |
| 123 | 75 | 111 | 156 | 212 | 218 | 212 | 212 | 218 | 218 | 218 | 226 |
| 93 | 75 | 71 | 133 | 185 | 231 | 226 | 226 | 222 | 212 | 218 | 218 |
| 51 | 75 | 75 | 75 | 156 | 206 | 218 | 218 | 218 | 222 | 212 | 222 |
| 44 | 110 | 75 | 65 | 143 | 194 | 231 | 218 | 218 | 218 | 218 | 218 |
| 52 | 123 | 69 | 84 | 60 | 156 | 199 | 231 | 231 | 222 | 226 | 226 |
| 52 | 75 | 84 | 81 | 65 | 69 | 150 | 231 | 231 | 226 | 231 | 231 |
| 36 | 36 | 84 | 93 | 84 | 71 | 156 | 160 | 240 | 240 | 231 | 231 |
| 36 | 40 | 113 | 75 | 69 | 75 | 71 | 133 | 194 | 240 | 240 | 240 |
| 52 | 52 | 105 | 85 | 69 | 75 | 75 | 123 | 111 | 222 | 231 | 231 |
| 69 | 44 | 69 | 93 | 81 | 75 | 75 | 69 | 150 | 177 | 247 | 240 |
| 73 | 44 | 40 | 96 | 101 | 75 | 75 | 75 | 84 | 133 | 231 | 240 |

# Camera pipeline

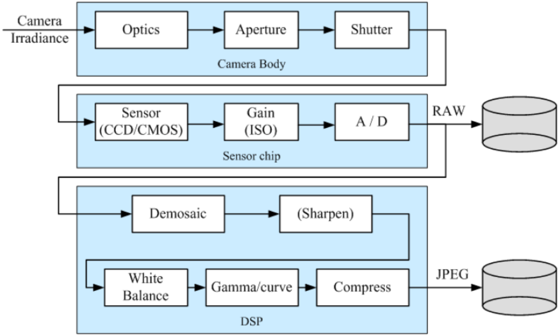



Image sensing pipeline, showing the various sources of noise as well as typical digital post-processing steps.

# Outline

# Digitalization

The digitalization process is formed by two steps

- **Measurement**
- **Conversion** from analog to digital

In the first step the physical quantity to be represented is measured by an appropriate device that converts it into an electrical continuous signal.

In the second step the electrical signal is converted into a digital signal.

# Outline

Digital Image Processing

Image acquisition

Digitalization

Quantization

Representation

Image Processing

Geometric Transformations

# Quantization

| Numer of bits (B) | Depth ($2^B$) i | Max value | Memory occupacy [512x512] uncompressed image |
|---|---|---|---|
| 1 | 2 | 1 | 32 Kb |
| 8 (unsigned char) | 256 | 255 | (512x512x8)bit = 256 Kb |
| 16 (int) | 65536 | 65535 | (512x512x16)bit = 512 Kb |
| 24 (color: 3 int) | ~$16 \times 10^6$ | 255 (per color) | (512x512x8)x3 bit = 768 Kb |
| 32 (long int,float) | $4 \times 10^9$ | $2^{32}$-1 | (512x512x32) bit=1 Mb |

# Quantization

1 bit

8 bit (1 byte)

16 bit (2 byte)

24 bit (true color)

# Outline

# Pixel representation

Let us imagine an image to be digitalized is overlaid with a regular grid:

- This grid is referred to as sampling grid.
- Each element of the grid will contain a portion (region) of the image. The whole portion will be approximated by a unique (average) value.
- A coarse sampling grid produces an image with fewer details.

# The size of an image

- The size of the image is given by the number of pixels composing it.
- The size is conventionally expressed by the number of rows times the number of columns of the image matrix, eg 640 x 480

# Resolution

- Given an image with a fixed size (in pixels), it can be visualized at different sizes (in mm) on various supports (paper, monitor,...)
- The visualization size is controlled by the resolution.
- The resolution depends on the size of the image and the size of the support
- It is measured in dots/cm or, more frequently, dots/inches (dpi).
- The resolution is related on how dense are the elements on the support.

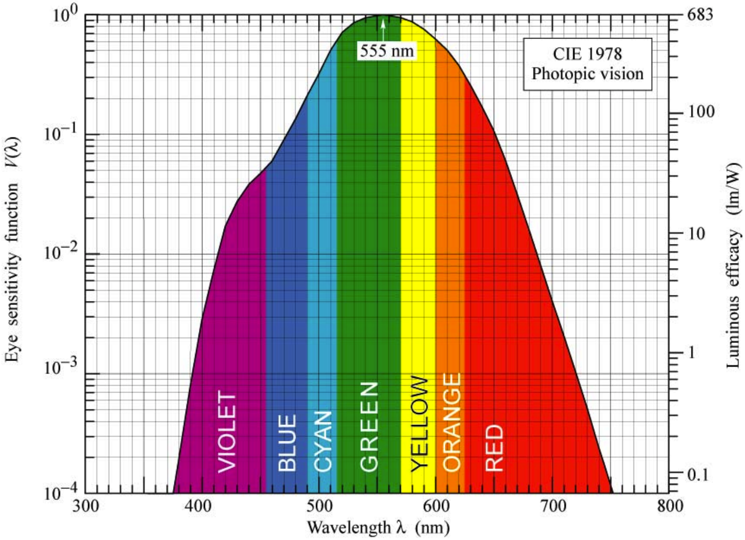
# Grayscale

In photography and computing, a **grayscale** image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information. Images of this sort, are composed exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest.

**Grayscale images** are distinct from one-bit bi-tonal black-and-white images, which in the context of computer imaging are images with only two colors, black and white (also called bilevel or binary images). Grayscale images have many shades of gray in between.

**Grayscale images** are often the result of measuring the intensity of light at each pixel in a single band of the electromagnetic spectrum (e.g. infrared, visible light, ultraviolet, etc.), and in such cases they are monochromatic proper when only a given frequency is captured. But also they can be synthesized from a full color image.

# Human eye spectral sensitivity

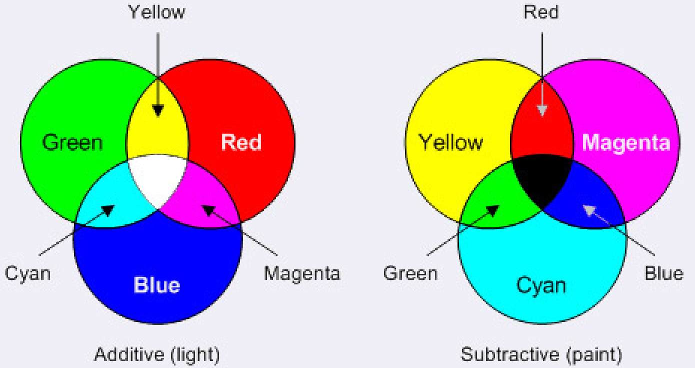


# Color spaces

- **RGB** is short for Red, Green, Blue. It is the color of the light emitted from your computer monitor; when RGB light is combined, the image gets brighter.
  RGB is an **additive color space** and is light-based. You add together Red, Blue, and Green lights/colors to get white. This is how your monitor/tv/projector works.

- **CMYK** is short for Cyan, Magenta, Yellow, Black. These are the inks used in 4-color printing; when the inks are layered on top of each other the image gets darker.
  CMYK is **subtractive** and is pigment-based. You mix together Cyan, Magenta, and Yellow to get black (the K is for Key Black which is used to achieve a deeper/richer black than can be achieved by mixing CMY alone)

# Color space




Additive and subtractive color combinations

# Color space


# Outline

Digital Image Processing

Image acquisition

Digitalization

Quantization

Representation

Image Processing

Geometric Transformations

# Image Histogram

The histogram of a digital image with intensity levels in the range [0,L-1] is a discrete function

$$h(r_k) = n_k \tag{1}$$

where:
$\rightarrow r_k$ is the kth intensity value of the range and
$\rightarrow n_k$ is the number of pixels in the image with intensity $r_k$

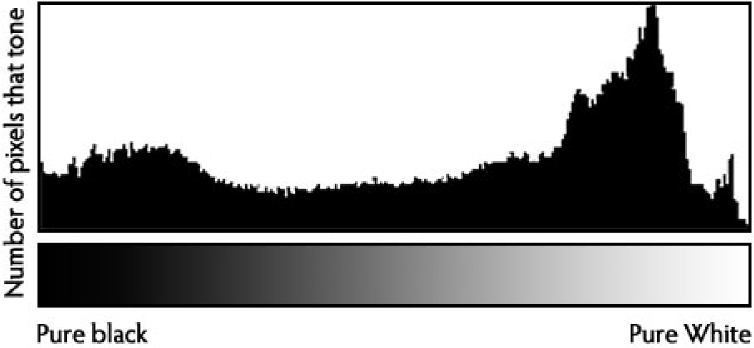
It is common practice to group similar values while computing the histogram.
The range of possible values [0,L-1] can be quantized in bins each of which will group pixels of the image with similar values.

# Image Histogram

- A histogram is a graphical representation of the distribution of data.
- The total area of the histogram is equal to the number of data.
- The correspondence between histogram and image is not unique; different images may have the same histogram.

Images with the same histogram

# Image Histogram

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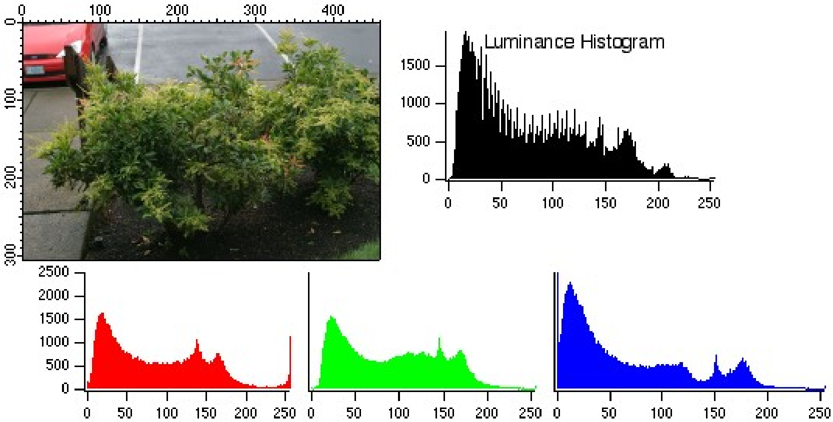
# Image Histogram



# Histogram processing

$$p(r_k) = n_k/NM \qquad (N \times M \text{ is the image size})$$

It can be seen as an estimate of the intensity probability distribution; the area of the normalized histogram is equals to 1.

**Histogram processing algorithms** produce transformations on images through their histograms.

$$s = T(r) \quad 0 \leq r \leq L - 1$$

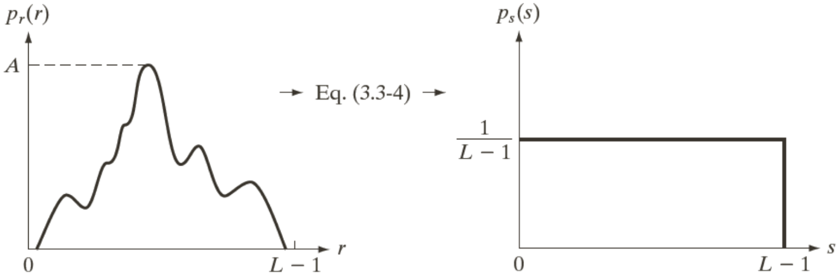
- global transformations: eg equalization
- point wise transformations: eg translation, contrast stretch, ...

# Histogram Equalization

Equalization usually increases the global contrast an image.

Through this adjustment, the intensities can be better distributed on the histogram.
This allows for areas of lower local contrast to gain a higher contrast.

# Histogram Equalization




a b

**FIGURE 3.18** (a) An arbitrary PDF. (b) Result of applying the transformation in Eq. (3.3-4) to all intensity levels, $r$. The resulting intensities, $s$, have a uniform PDF, independently of the form of the PDF of the $r$'s.



From: Digital Image Processing 3rd ed. Gonzalez & Woods

# Histogram Equalization

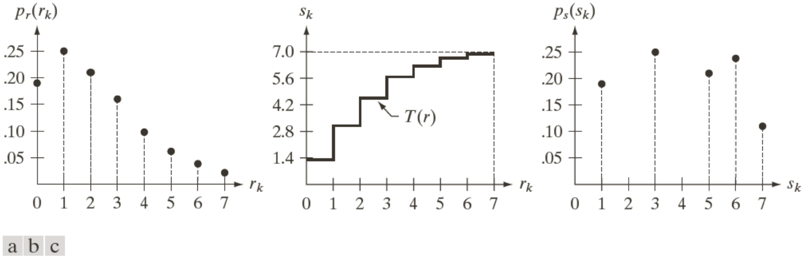
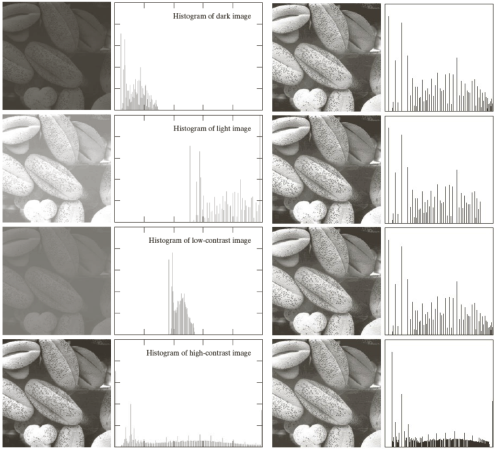



**FIGURE 3.19** Illustration of histogram equalization of a 3-bit (8 intensity levels) image. (a) Original histogram. (b) Transformation function. (c) Equalized histogram.

# Histogram Equalization

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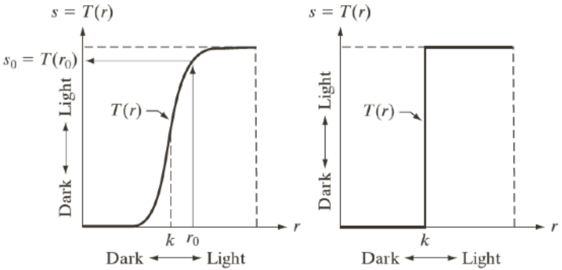
# Point Operators

The simplest kind of image processing transforms are point operators, where each output pixel value depends on only the corresponding input pixel value.

Examples of such operators include brightness and contrast adjustments as well as color correction and transformations.

# Point operators

Intensity transformation are described by a function that define, for each level of the pixel, the new level.
In the following two examples for (a) Contrast stretching and (b) Thresholding.

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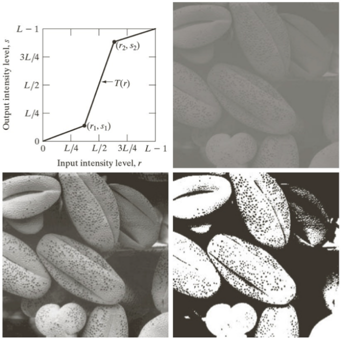
# Pixel intensity transformation




Top-right: Original Image, bottom-left: Contrast stretched image , bottom-right: Threshold image

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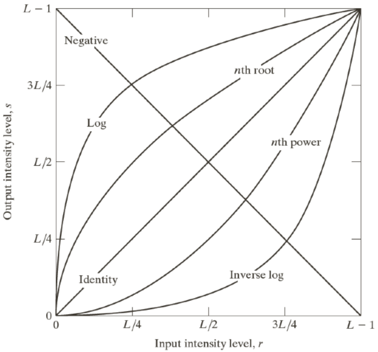
# Pixel intensity transformation




Some basic intensity transformation functions.

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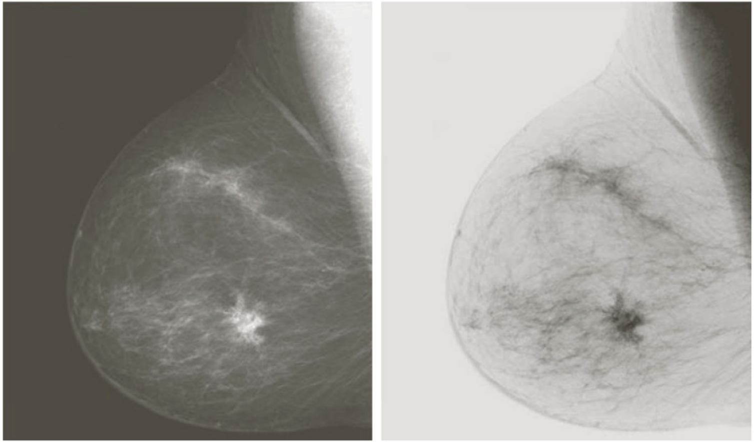
# Negative image



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# Neighbourhood operators

In this class of operators an output pixel is obtained starting from a set of neighbouring pixels in the input image.
The neighbourhood is usually squared (eg $W \times W$ pixels) and its size may vary $W = 3, 5, 11, \ldots$
These operators are often referred as filters. We will meet them again later in the course.

# Outline

# Geometric Transformations

Such transformations modify the position of pixels instead than their value: *transformation of coordinates*
Given a pixel of image $I$ at coordinates $\mathbf{p} = (p_1, p_2)$ the effect of a transformation $\mathbf{H}$ is to move $I(\mathbf{p})$ to $\mathbf{q} = (q_1, q_2)$ that is:

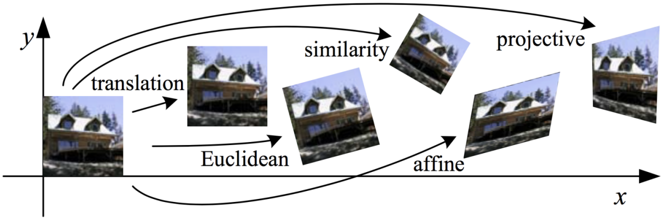
$$\mathbf{q} = \mathbf{H}(\mathbf{p})$$

and the correspo
nding image transformation from the input image $I$ to the output image $J$ is

$$J(\mathbf{q}) = J(\mathbf{H}(\mathbf{p}) = I(\mathbf{p})$$

# Geometric Transformations

Such transformations modify the position of pixels instead than their value: *transformation of coordinates*




R. Szeliski, *Computer Vision: Algorithms and Applications*, Springer, 2010.

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# Geometric Transformations

Such transformations modify the position of pixels instead than their value: *transformation of coordinates*

| **Transformation** | **Matrix** | **Preserves** | **Icon** |
|---|---|---|---|
| translation | $\begin{bmatrix} \boldsymbol{I} \mid \boldsymbol{t} \end{bmatrix}_{2\times 3}$ | orientation | |
| rigid (Euclidean) | $\begin{bmatrix} \boldsymbol{R} \mid \boldsymbol{t} \end{bmatrix}_{2\times 3}$ | lengths | |
| similarity | $\begin{bmatrix} s\boldsymbol{R} \mid \boldsymbol{t} \end{bmatrix}_{2\times 3}$ | angles | |
| affine | $\begin{bmatrix} \boldsymbol{A} \end{bmatrix}_{2\times 3}$ | parallelism | |
| projective | $\begin{bmatrix} \tilde{\boldsymbol{H}} \end{bmatrix}_{3\times 3}$ | straight lines | |

# Geometric Transformations

- Translation $\mathbf{t} = (t_1, t_2)$

$$q_1 = p_1 + t_1$$
$$q_2 = p_2 + t_2$$

- Rotation of an angle $\theta$ (around the origin)

$$q_1 = p_1 \cos\theta + p_2 \sin\theta$$
$$q_2 = -p_1 \sin\theta + p_2 \cos\theta$$

- Scaling

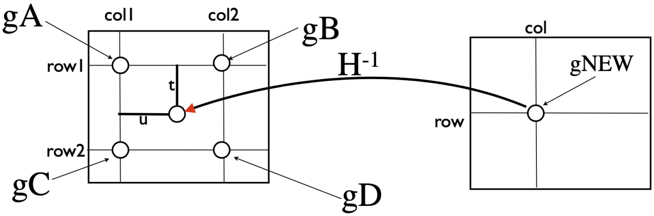
$$q_1 = c \cdot p_1$$
$$q_2 = d \cdot p_2$$

# Geometric Transformations

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

- A spatial transformation of coordinates according to **T**
- An *intensity interpolation* to assign intensity values to the spatially transformed pixels on the discrete grid

# Bilinear interpolation




gNEW = (1-t)(1-u)gA + u(1-t)gB + t(1-u)gC + utgD