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Digital Image Processing

Digital Image Fundamentals

Département Génie Electrique
5GE - TdSi

Summary

Digital Image Fundamentals

- Visual perception
- Light
- Image Sensing and Acquisition
- Image Sampling and Acquisition
- Basic relationships between pixels
- Linear and nonLinear operations

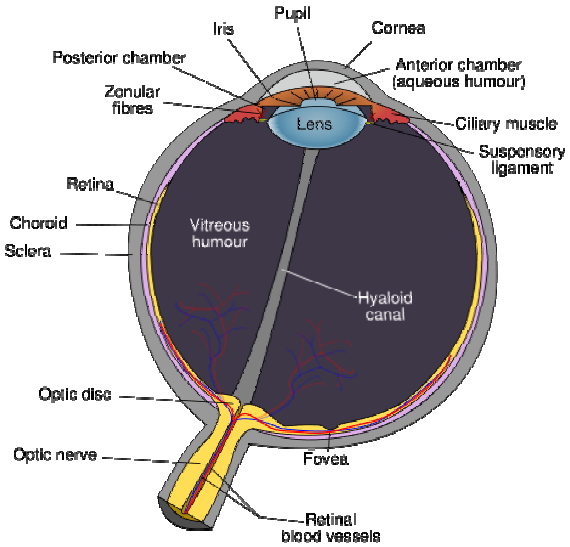
→ Books :

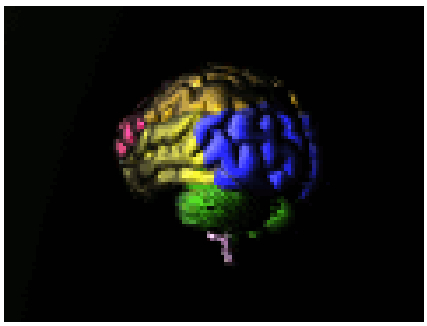
Digital Image Processing, Gonzales, *Prentice Hall (3Ed.)*
Digital Image Processing, Jahne, Springer (6Ed.)

Visual perception

- Human visual perception

Eyes + Brain



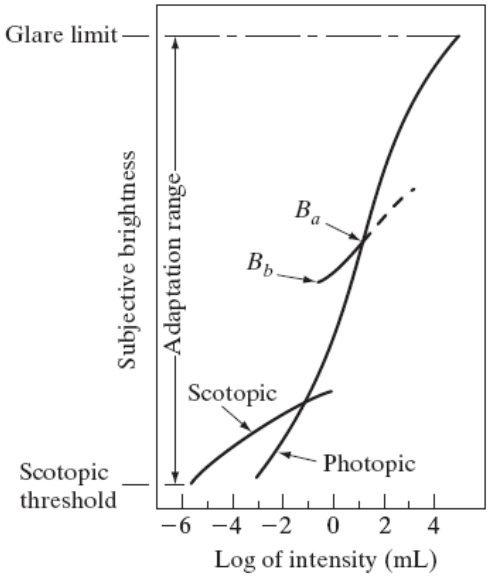


Visual perception

- Brightness adaptation and discrimination
  - Digital images are displayed as a discrete set of intensities

➔Range of light intensity levels to which the human visual system can adapt?

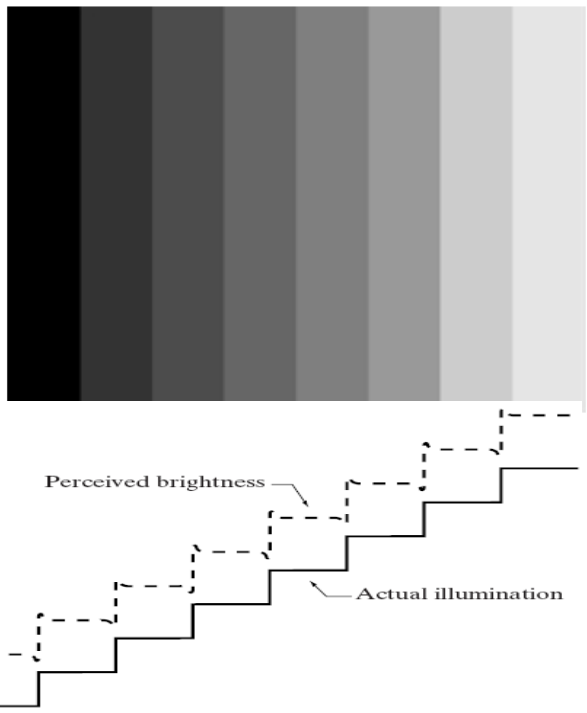
Enormous: on the order of 10^{10}



Scotopic vision is the monochromatic vision of the eye in low light
Photopic vision is the vision of the eye under well-lit conditions. In humans and many animals, photopic vision allows color perception, mediated by cone cells.

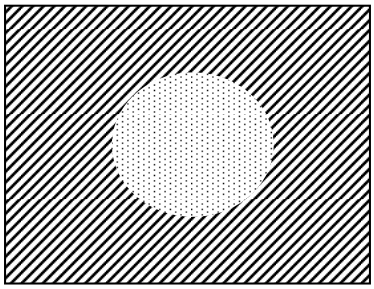
Visual perception

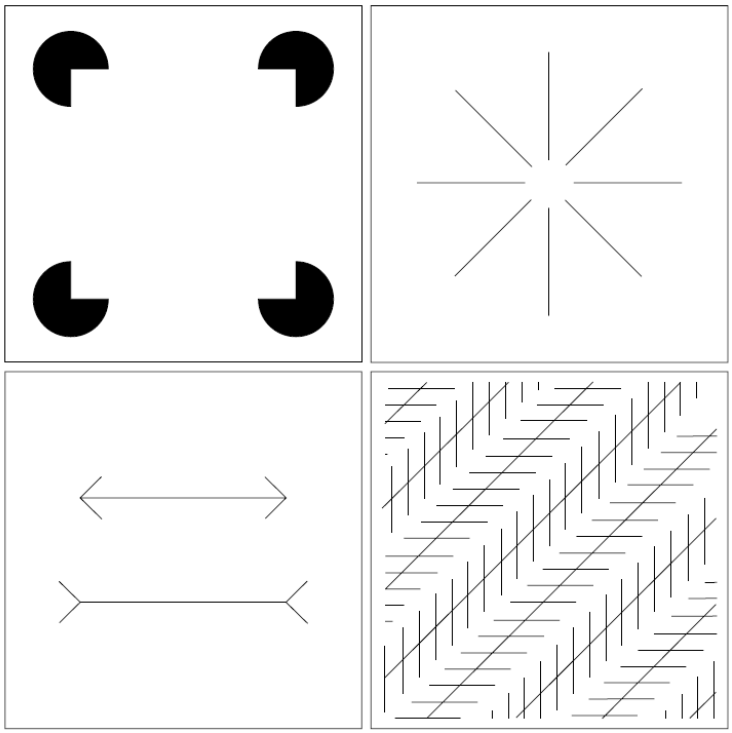
- Brightness adaptation & discrimination



Visual perception

- Other examples of human perception phenomena: optical illusions





Light and electromagnetic spectrum

- A ‘light’ (illumination) source is needed to generate an image. The elements of the ‘scene’ should reflect or absorb the energy of that source (or be that source)
- Imaging is based predominantly on energy radiated by electromagnetic waves
- Other methods for image generation exist
  - Sound reflected on objects (ultrasound image)
  - Electron beams (microscopy)
  - Synthetic images (graphics and visualization)
  - Mechanic sensors
  - …

- Electromagnetic spectrum

Wavelength (*m*)

$$\lambda = \frac{c}{f}$$

Photon energy (*eV, J*)

$$E = \frac{hc}{\lambda}$$

$$E = hf$$

frequency

Where:

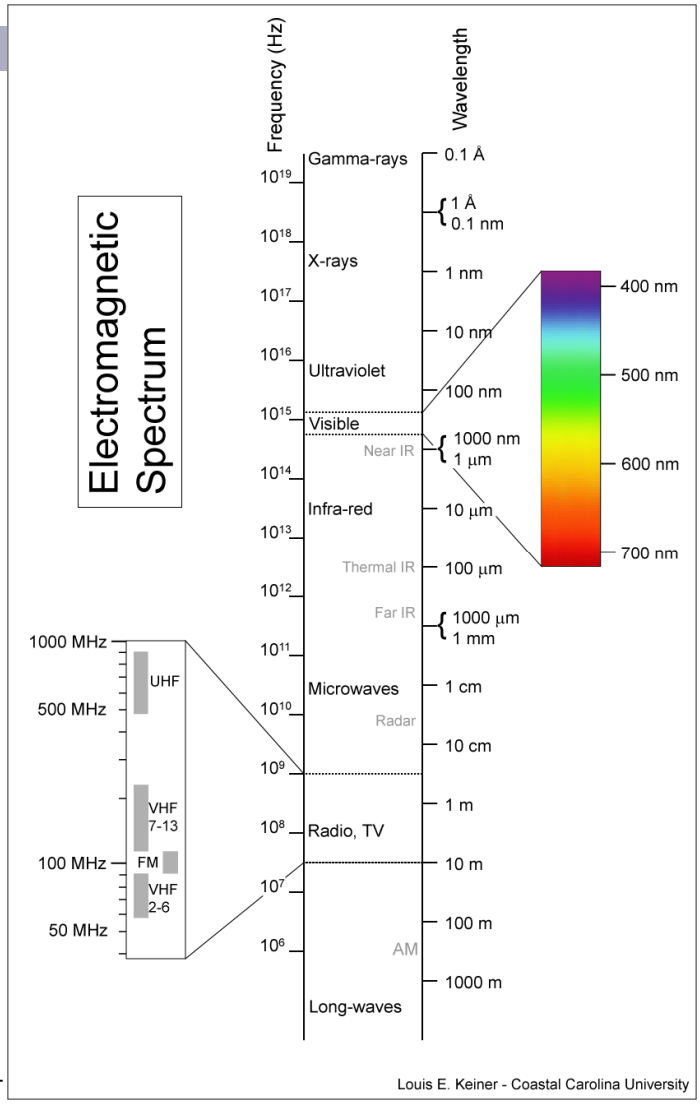
c is the speed of light

h is the Planck's constant

$$c = 299792.458\, m/s$$

$$h = 6.626069 \cdot 10^{-34}\, J \cdot s$$

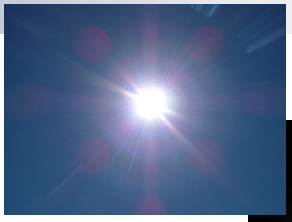
$$\approx 4.13567 meV / Hz$$



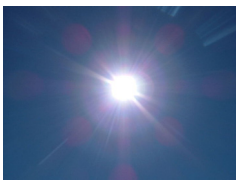
Light sources

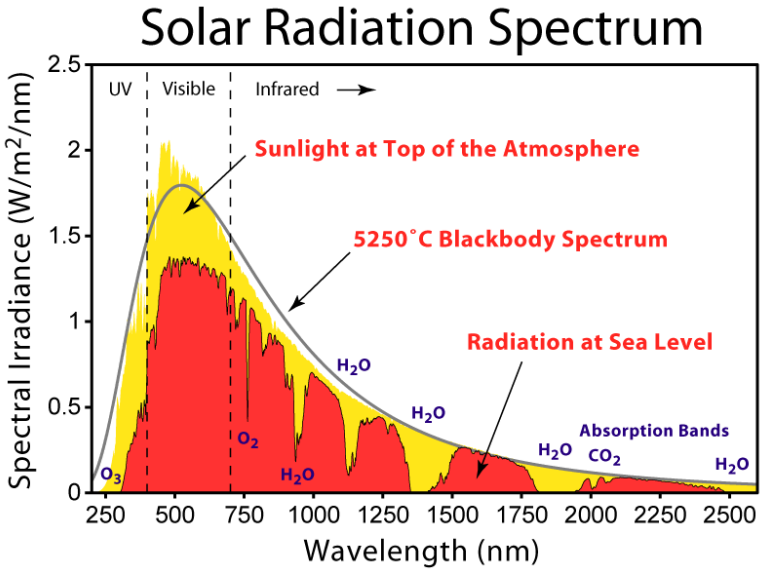
- *Monochromatic (or achromatic) light*
  - Light that is void of color
- *Chromatic (color) light*
  - Light that spans the electromagnetic energy spectrum (from 0.43 to 0.79 μm)
- Basic quantities used to describe the quality of sources
  - **Radiance** (in Watts): total amount of energy that flows the light source
  - **Luminance** (in lumens, lm): gives a measure of the amount of energy that an observer perceives from a light source
  - **Brightness** (measurable ??): subjective descriptor of light perception (one of the key factors in describing color sensation)

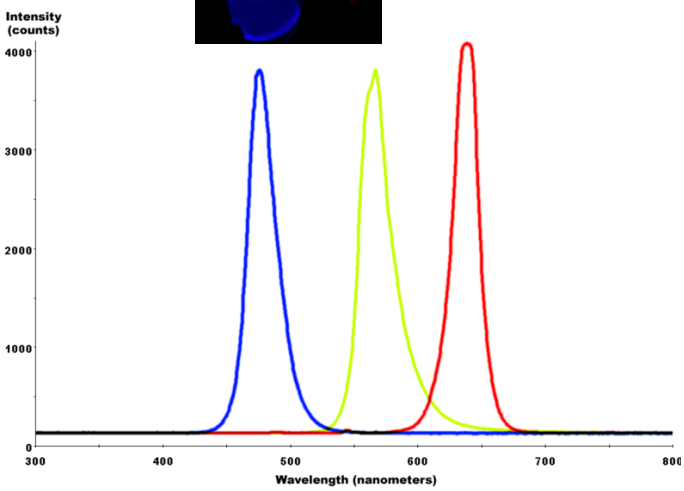
Light sources

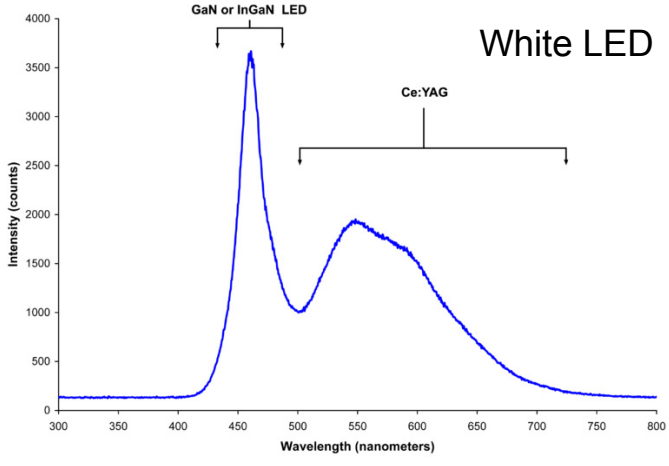


- Quality of these sources?
  - Sun
  - Candle
  - Conventional incandescent light bulbs
  - Fluorescent lamp
  - Light-Emitting Diode (LED)
  - Laser
  - Xenon flash lamp

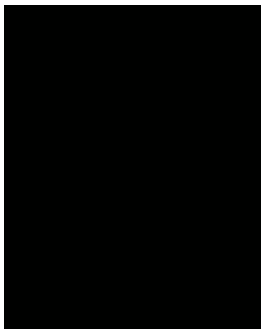








- Flashes can be used for capturing quickly moving objects

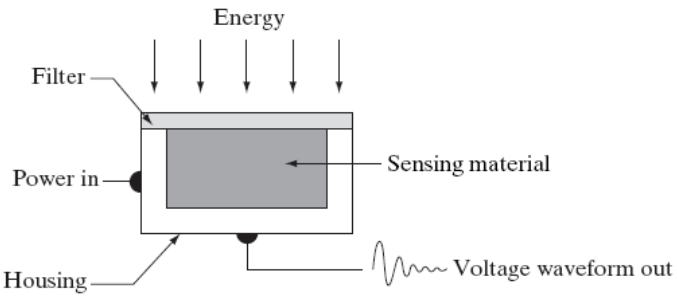


Xenon flash

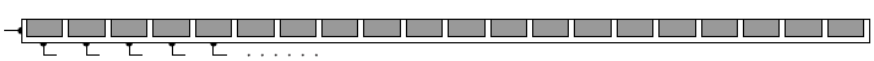
Running water "frozen" by flash

Image Sensing and Acquisition

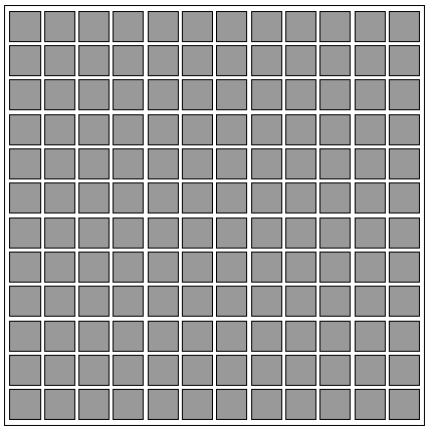
- Sensor arrangements used to transform illumination energy into digital images



Single imaging sensor



Line sensor



Array sensor

Image Sensing and Acquisition

- Image acquisition (single and line sensors)

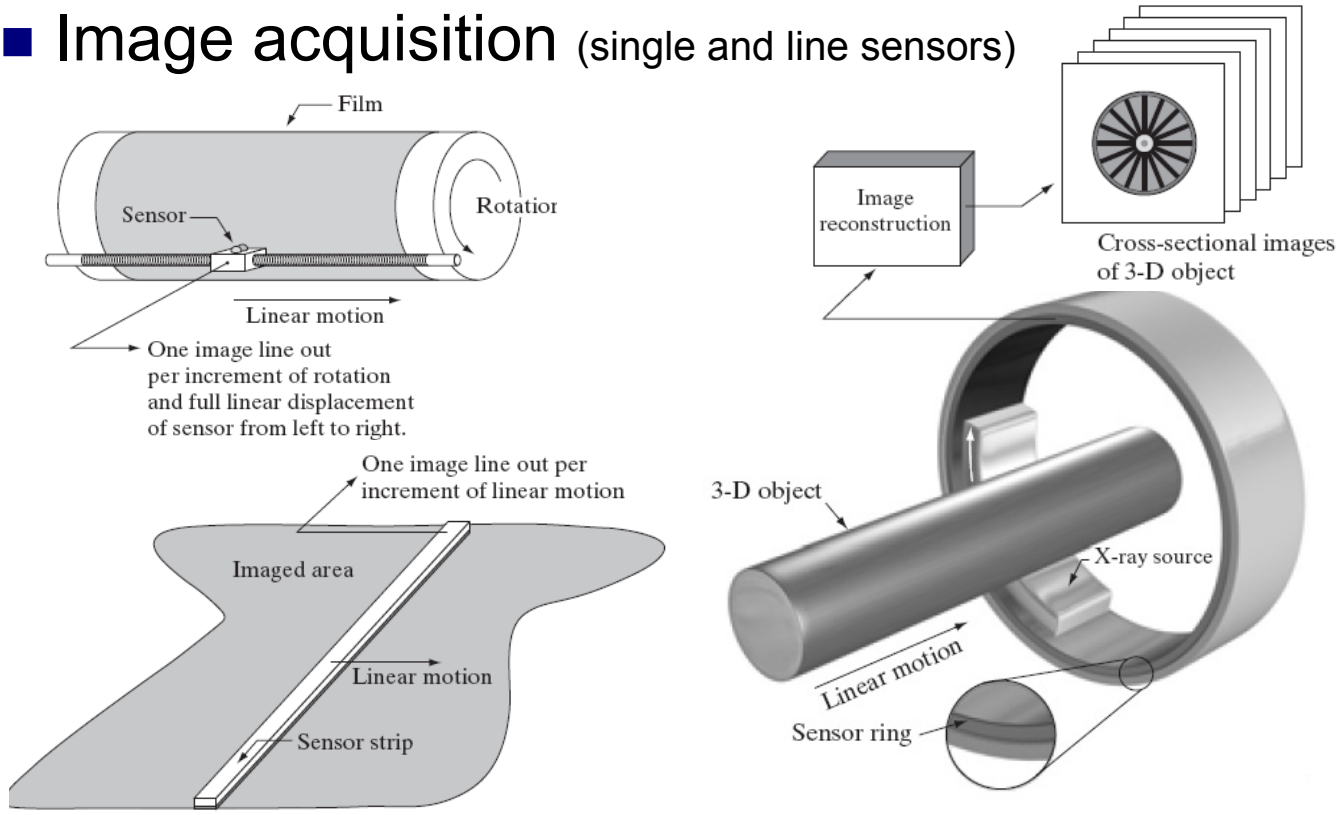


Image Sensing and Acquisition

- Image acquisition (array sensor)

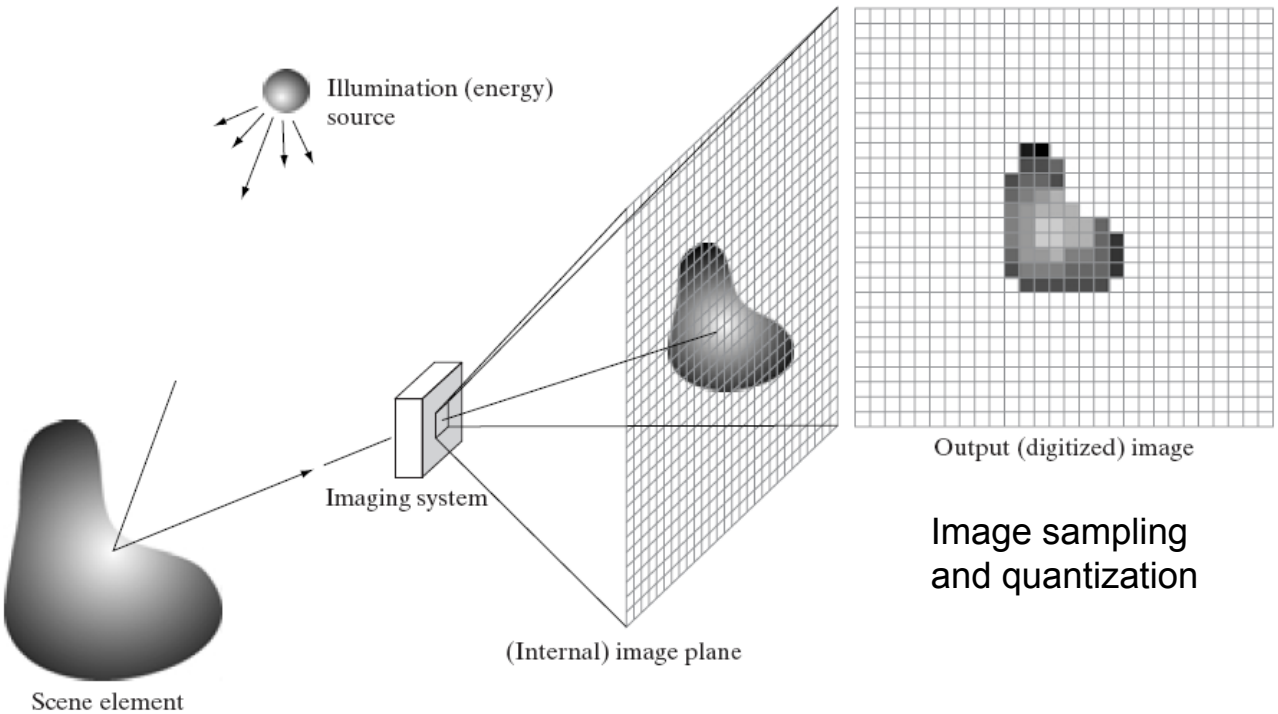
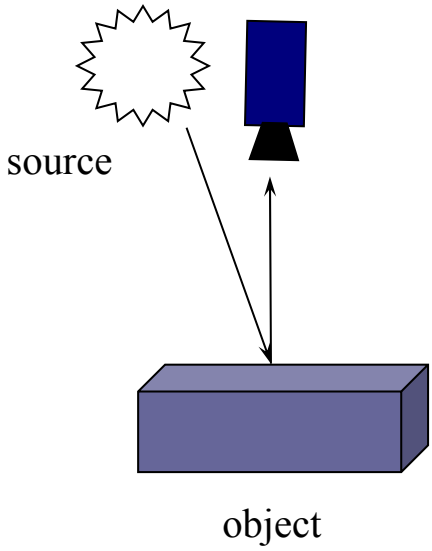


Image sampling
and quantization

Image Sensing and Acquisition

- Image acquisition
  - camera, object and source positions



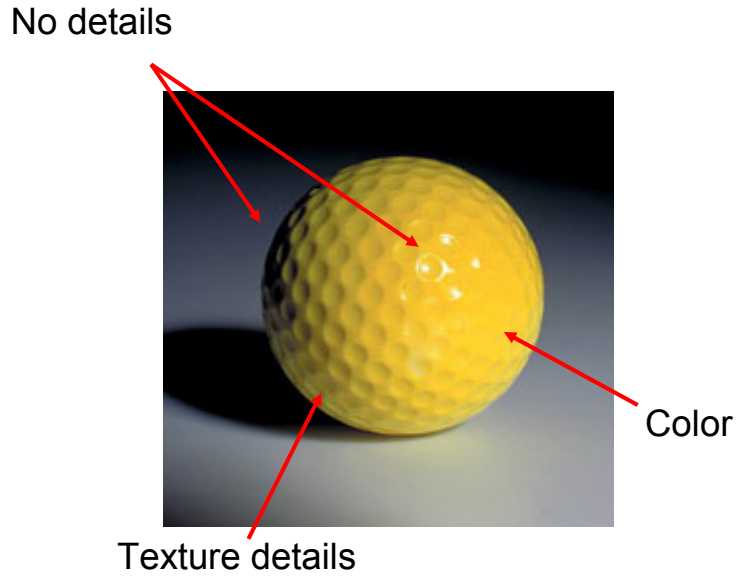


Image Sensing and Acquisition

- Image acquisition
  - camera, object and source positions

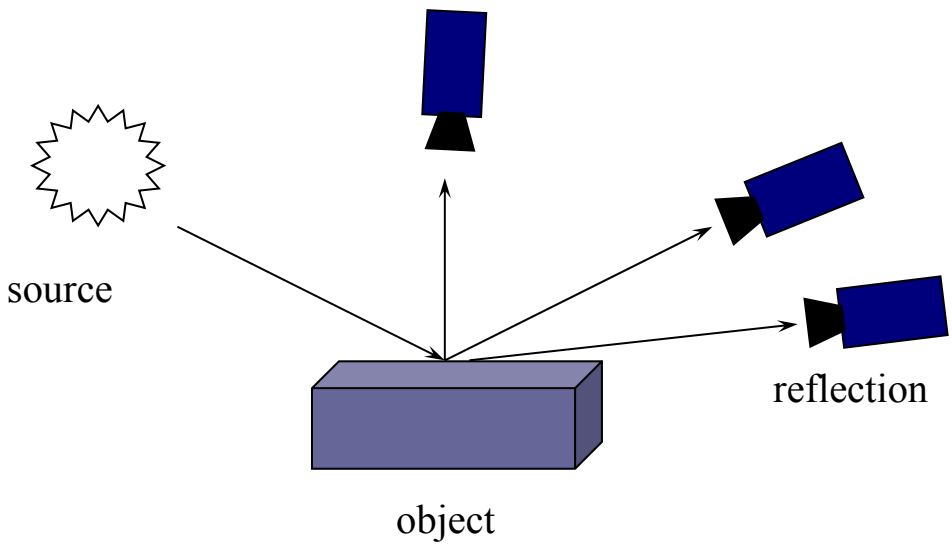
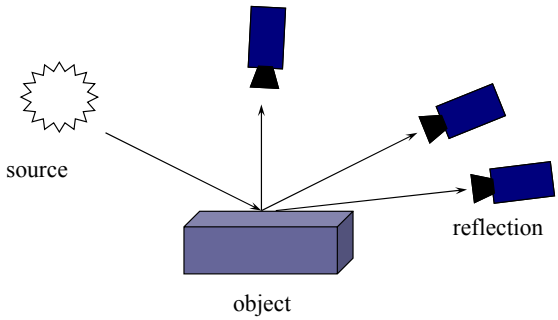


Image Sensing and Acquisition

- Image acquisition:
  - camera, object and source positions



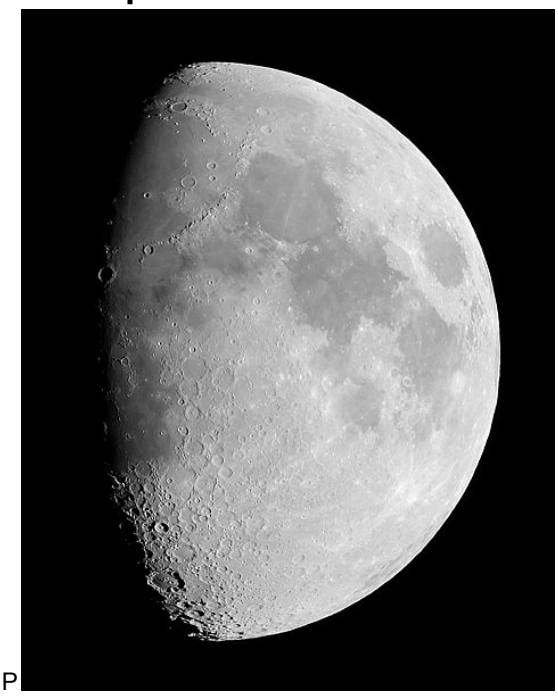


Image Sensing and Acquisition

- Image acquisition: contre-jour (or backlighting)

Transmission: X, PET

  - This effect usually
    - Hides details,
    - Causes a stronger contrast between light and dark,
    - Creates silhouettes,
    - Emphasizes lines and shapes.

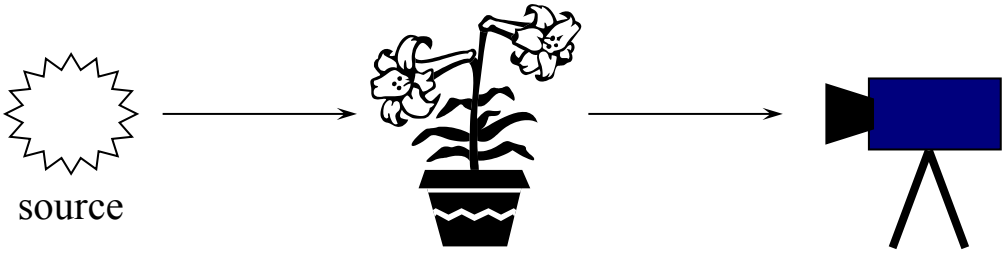
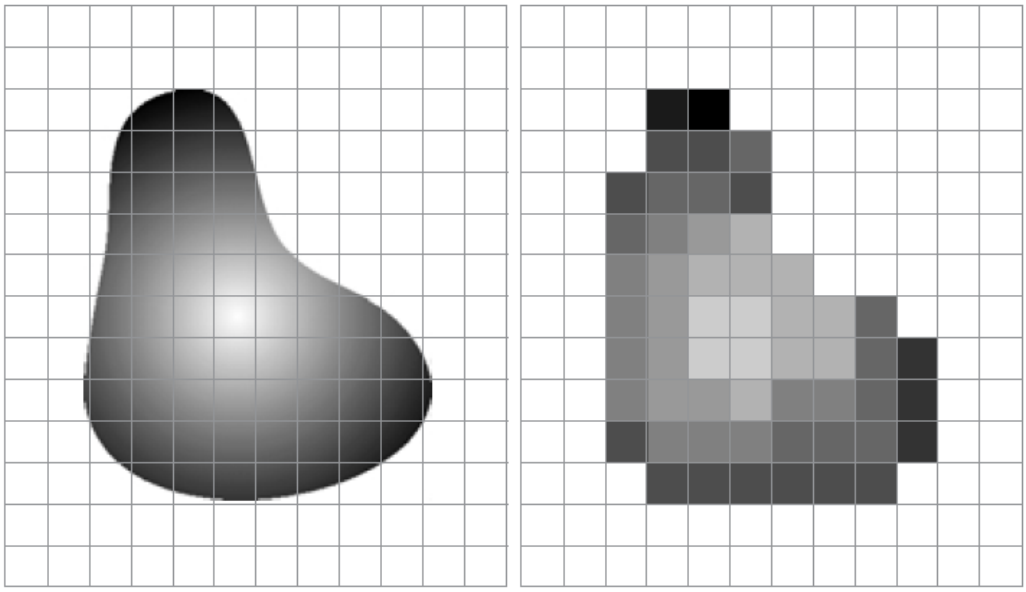


Image Sampling and Quantization

- Digitization : sampling and quantization



Continuous image projected on an array sensor

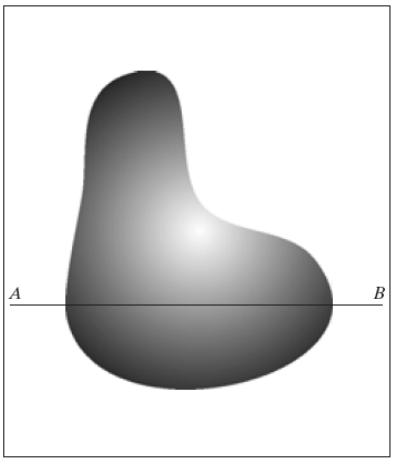
Result of image sampling and quantization

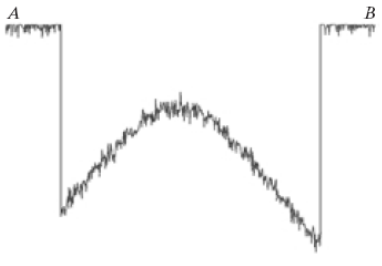
Image Sampling and Quantization

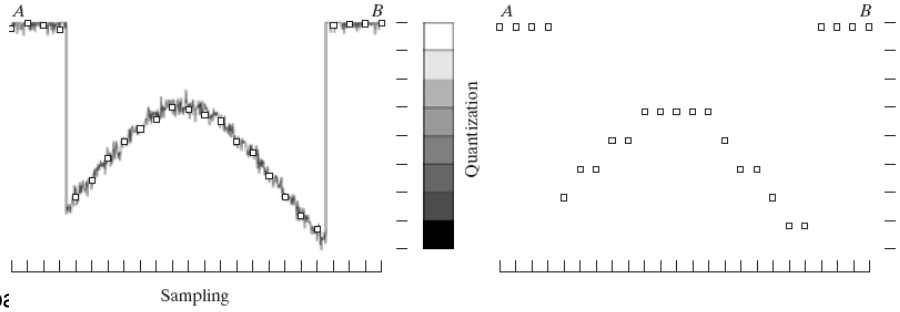
- Definitions

Sampling:
Digitizing the coordinate values (spatial resolution)

Quantization:
Digitizing the amplitude values (intensity levels)







Quantization

→ Number of intensity levels typically is an integer power of two (often 256 : 1 Byte = 8bits per pixel), the discrete levels are equally spaced

- Effects of reducing the number of intensity levels

8 bits (256 levels)

4 bits (16 levels)

2 bits (4 levels)

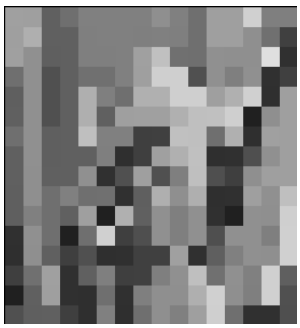
- false contours appear
- quantification noise
- visible (eyes) effect under 6/7 bits
- quantification for the display : 8bits

Sampling

- Effects of reducing spatial resolution

256 x 256 pixels

64 x 64 pixels



16 x 16 pixels

- ugly contours (by steps)
- blur effect
- Details are less precise / detectable
- Resolution loose

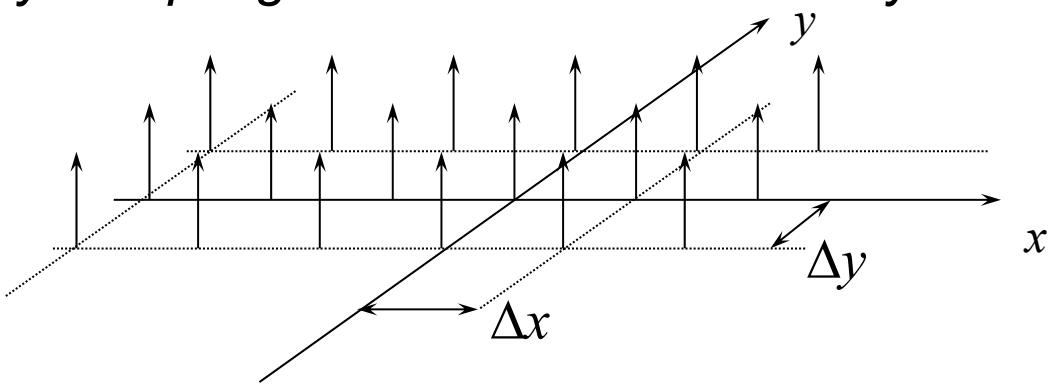
Sampling

- Sampling of function *f(x,y)*

$$f_e(x,y) = f(x,y).\Sigma_i \Sigma_j \delta(x - i\,\Delta x , y - j\,\Delta y)$$

Δx *sampling distance in direction of x*

Δy *sampling distance in direction of y*



$\Sigma_i \Sigma_j \delta(x - i\,\Delta x , y - j\,\Delta y)$: 2D Dirac comb

→ Δx *and* Δy *limits ?*

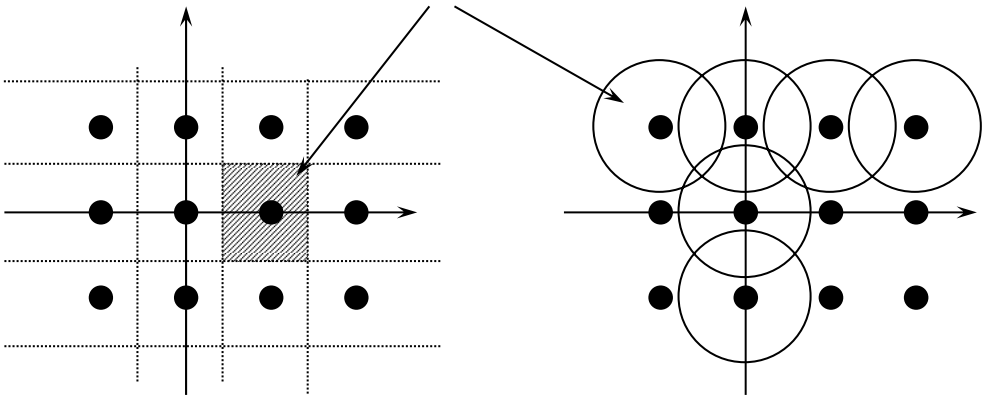
Sampling

$$f_e(x,y) = \sum_i \sum_j \tilde{f}(i\Delta x, j\Delta y)\delta(x - i\Delta x, y - j\Delta y)$$

- The dirac weight of $\tilde{f}(i\Delta x, j\Delta y)$ is:
  - The value of *f(x,y)* at $x = i\,\Delta x$ and $y = j\,\Delta y$
  - The 'mean' value of *f(x,y)* around $(i\,\Delta x , j\,\Delta y)$

f(x,y) is weighted by h and integrated over R

$$\tilde{f}(i\Delta x, i\Delta y) = \int_R f(x,y)h(i\Delta x - x, j\Delta y - y)dxdy$$



i.e: CCD Camera

i.e.: video camera tube or pickup tube

Sampling

- Sampling distances limits
  - Sampling leads to a reduction in resolution,
    - structures of about the scale of the sampling distance and finer will be lost
  - Sampling theorem
    - We will obtain a periodic structure correctly only if we take at least two samples per wavelength
    - Else : Moiré effect (‘*aliasing*’ for 1D signal)

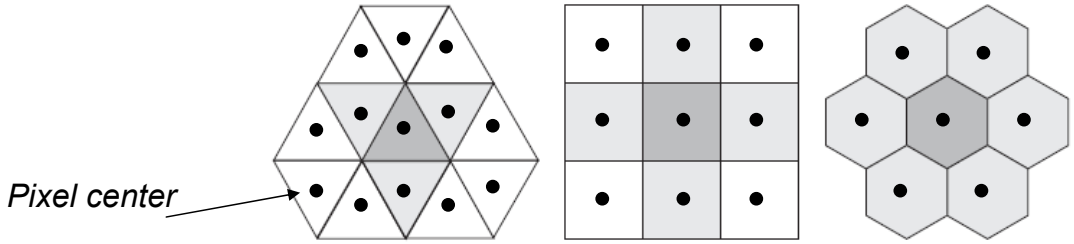
Sampling distances: *Moiré effect*

Properly sampled image of brick wall.

Spatial aliasing in the form of a Moiré pattern

Image representation

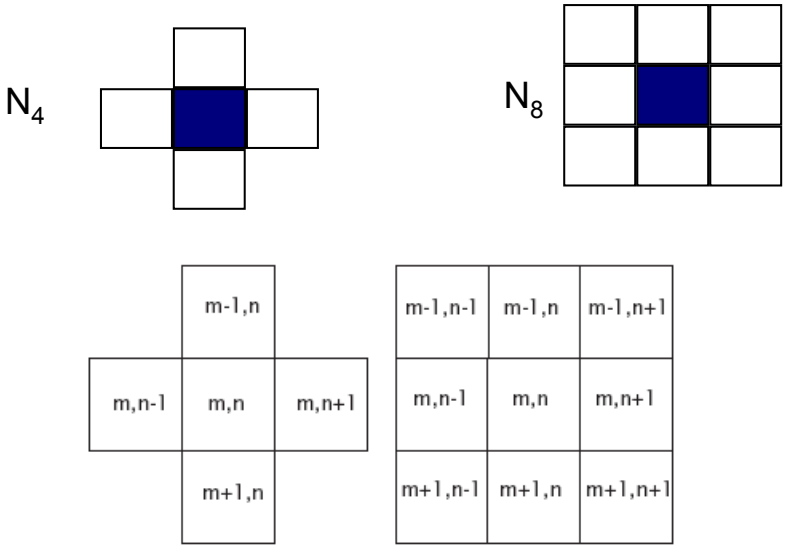
- A rectangular grid is only the simplest geometry for a digital image ($\Delta x = \Delta y$)
- Other geometrical arrangements of the pixels and geometric forms of the elementary cells are possible



*The three possible regular grids in 2-D: **left** triangular grid, **center** square grid, **right** hexagonal grid*

Basic relationships between pixels

- Neighborhoods
  - 4- and 8- neighbors of a pixel

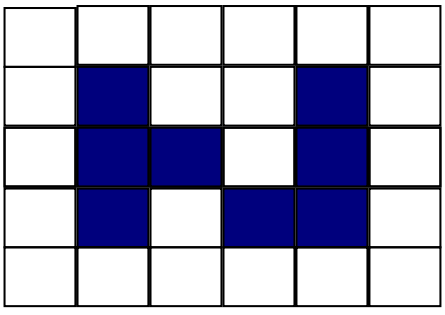


Basic relationships between pixels

- Adjacency
  - Two pixels p and q are ***4-adjacent*** if q is in the set $N_4(p)$
  - Two pixels p and q are ***8-adjacent*** if q is in the set $N_8(p)$
- Connectivity
  - A (digital) ***path*** from pixel p to pixel q is a sequence of distinct pixels where the next pixels is adjacent to the previous one
  - Let S represent a subset of pixels in an image. Two pixels p and q are said to be ***connected*** in S if there exists a ***path*** between them consisting entirely of pixels in S

Basic relationships between pixels

- Region
  - Let R be a subset of pixels in an image. We call R a region of the image if R is a connected set
  - Regions that are not adjacent are said to be *disjoint*



Two regions if 4-adjecency is used

One region if 8-adjecency is used

Basic relationships between pixels

- Boundaries
  - The boundary (or border, or contour) of a region R is the set of points that are adjacent to points in the complement of R (*the background*)
  - Or… the border of a region is the set of pixels in the region that have at least one 'background' neighbor

Basic relationships between pixels

- Distances between to pixels $f[i,j]$ et $f'[k,l]$

• Euclidian Distance $d_e(f,f') = \sqrt{(i-k)^2\Delta x^2 + (j-l)^2\Delta y^2}$

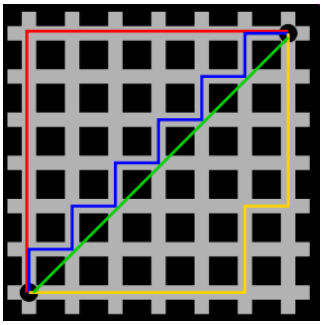
• *City-Block* distance $d_c(f,f') = |i-k|\Delta x + |j-l|\Delta y$

Taxicab, Manhattan distance, D_4 distance

• Chessboard distance $d_b(f,f') = \max(|i-k|\Delta x, |j-l|\Delta y)$

D_8 distance

• …



Euclidian vs City block distances

3	2	2	2	2	2
3	2	1	1	1	2
3	2	1	**X**	1	2
3	2	1	1	1	2
3	2	2	2	2	2
3	3	3	3	3	3

Chessboard distance

Linear and nonLinear operations

- Important classification of an image-processing method
  - Is it a linear or a a nonlinear method ?
- Let H be a general operator

$$H[f(x,y)] = g(x,y)$$

- H is said to be a ***linear operator*** if

$$H[a_i f_i(x,y) + a_j f_j(x,y)] = a_i H[f_i(x,y)] + a_j H[f_j(x,y)]$$
$$= a_i g_i(x,y) + a_j g_j(x,y)$$

➔ Tools: vector-matrix, PDE, set, *and related operators (+,*, convolution)…*