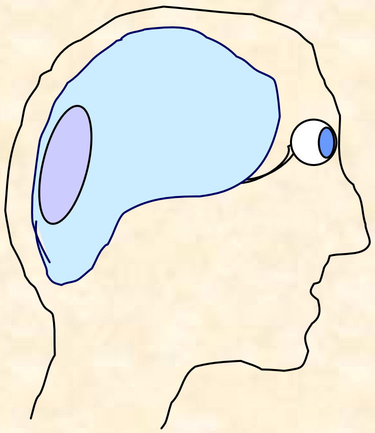
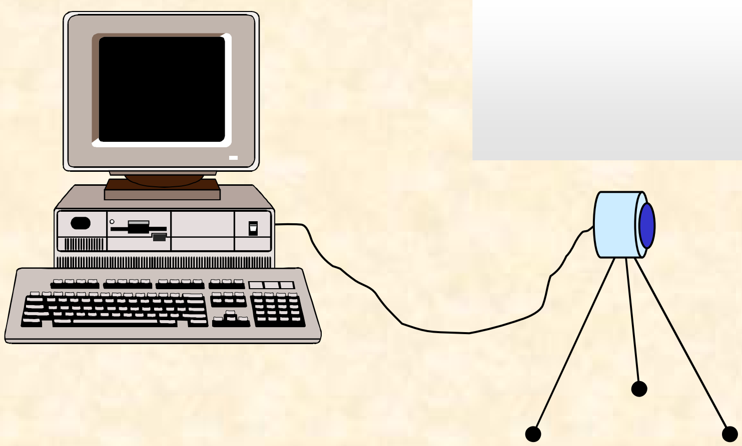


Visual perception basics



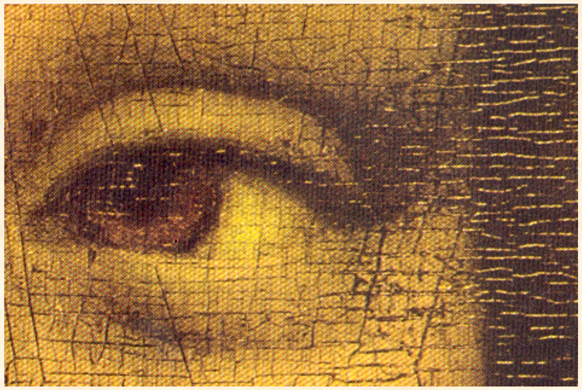
P. Strumiłło

Light perception by humans

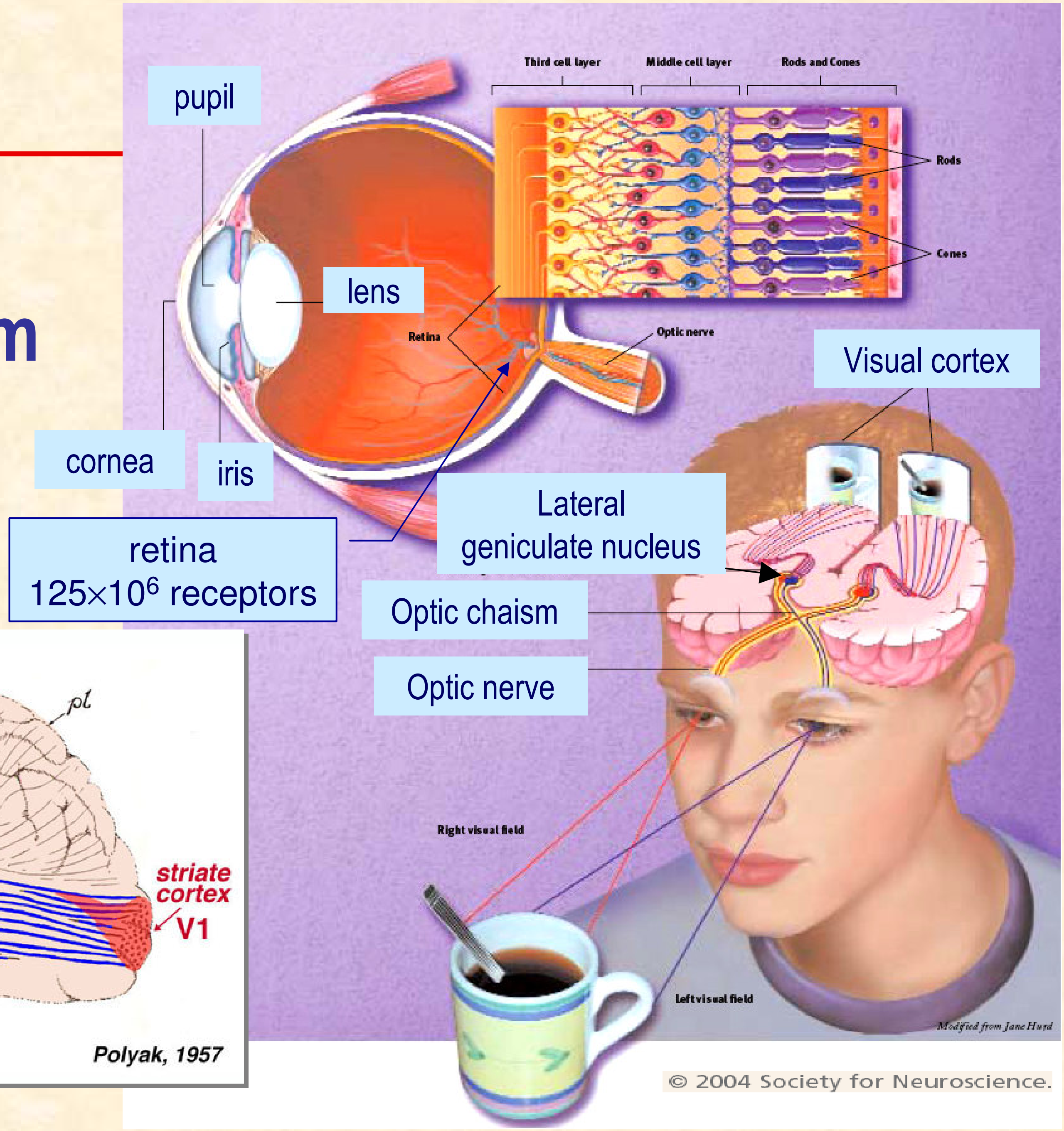
Humans perceive approx. **90%** of information about the environment by means of visual system.

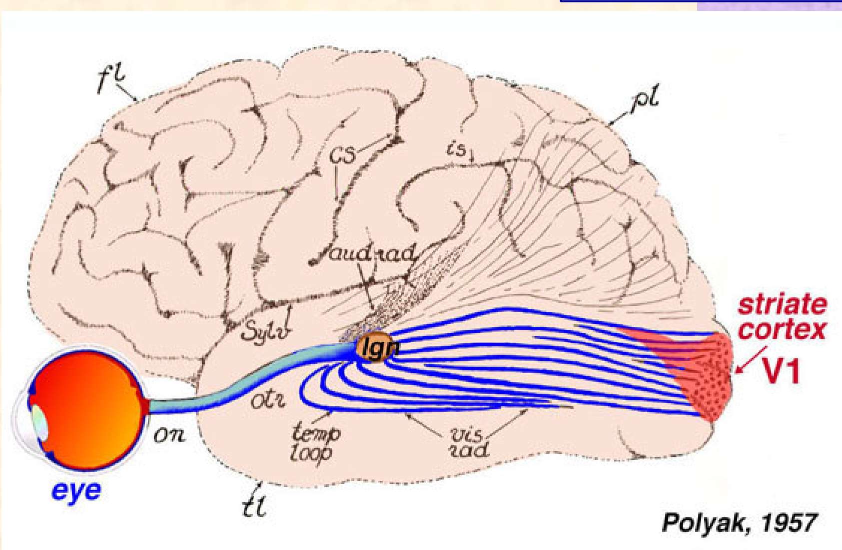
Efficiency of the human visual system is characterised by a number of features:

- visual aquity - the ability to resolve image details (θ=1'=1°/60=pi/10800);
- the ability to discriminate between brightness levels (contrast sensitivity);
- colour perception;
- brightness adaptation;



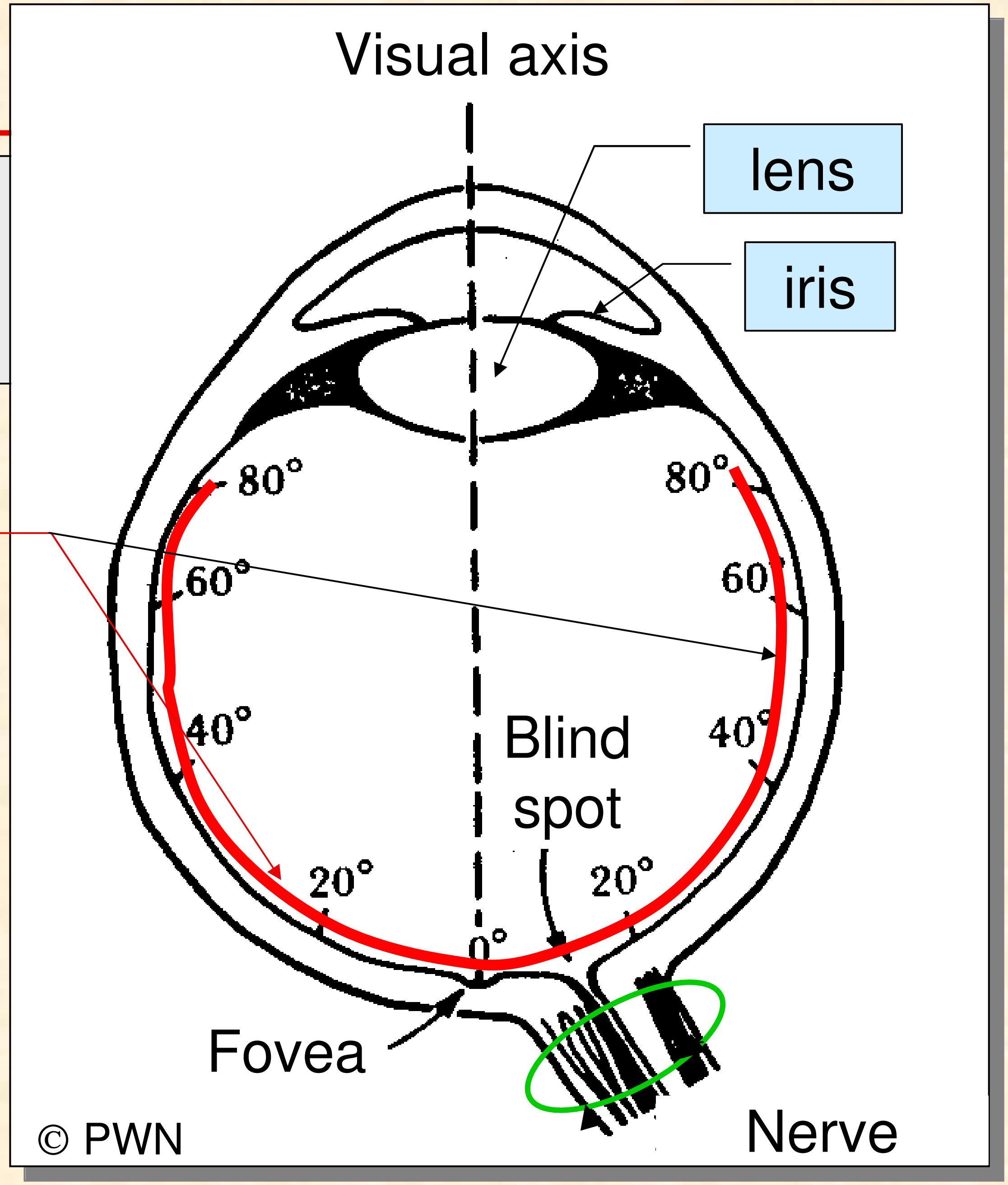
Human visual system



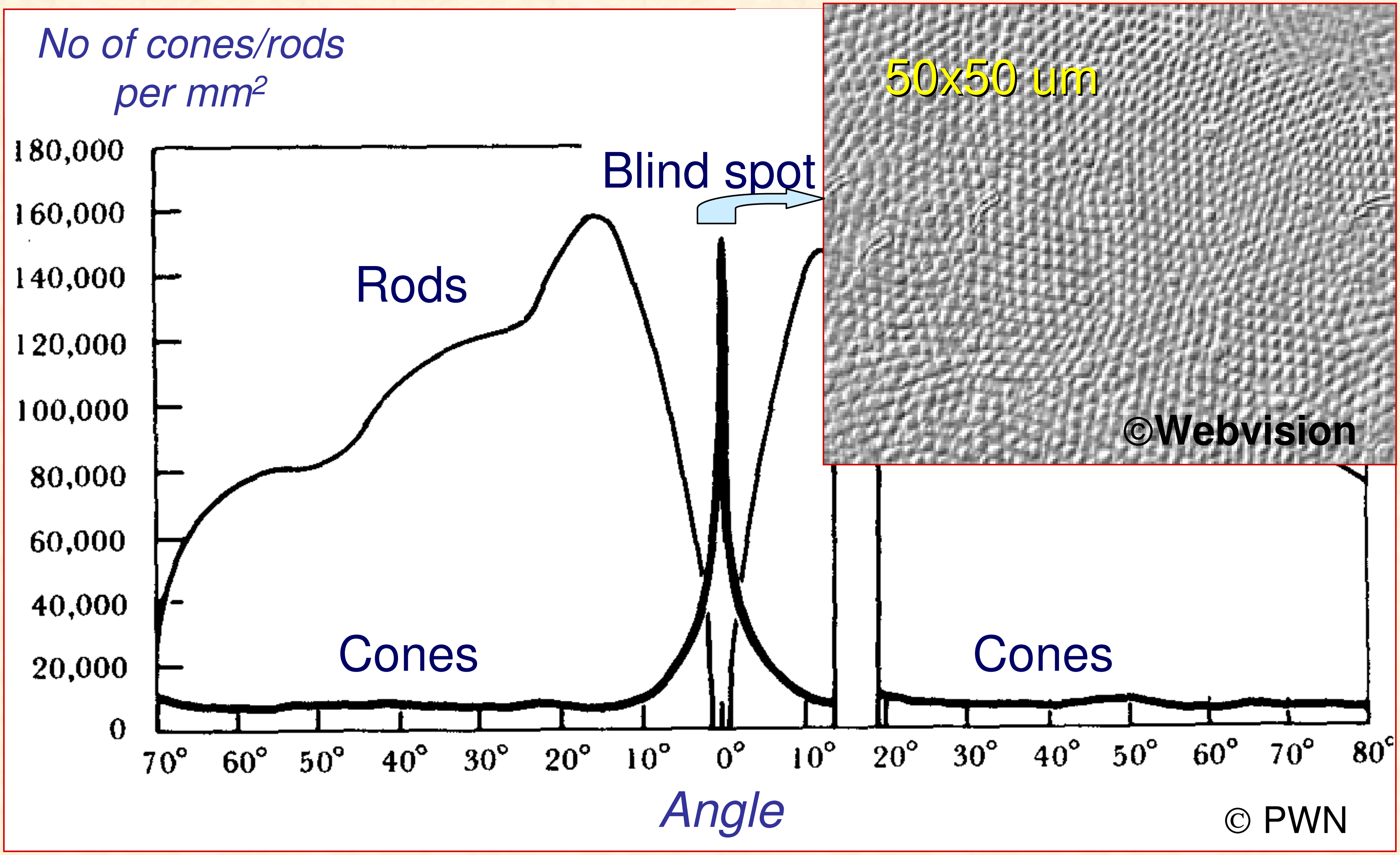


Structure of the human eye

retina
125×10^6
receptors

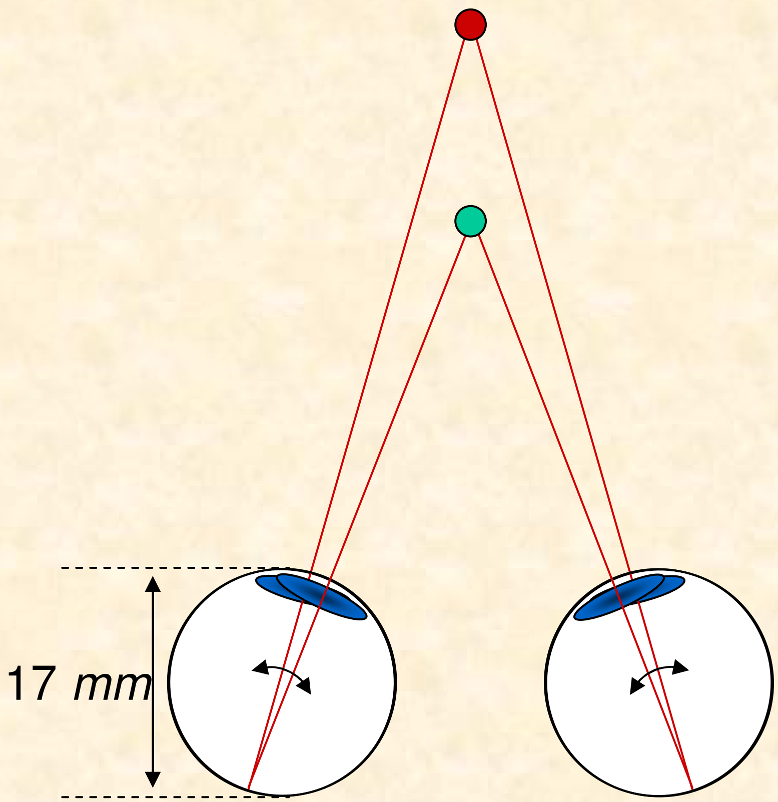


Distribution of rods and cones in the retina

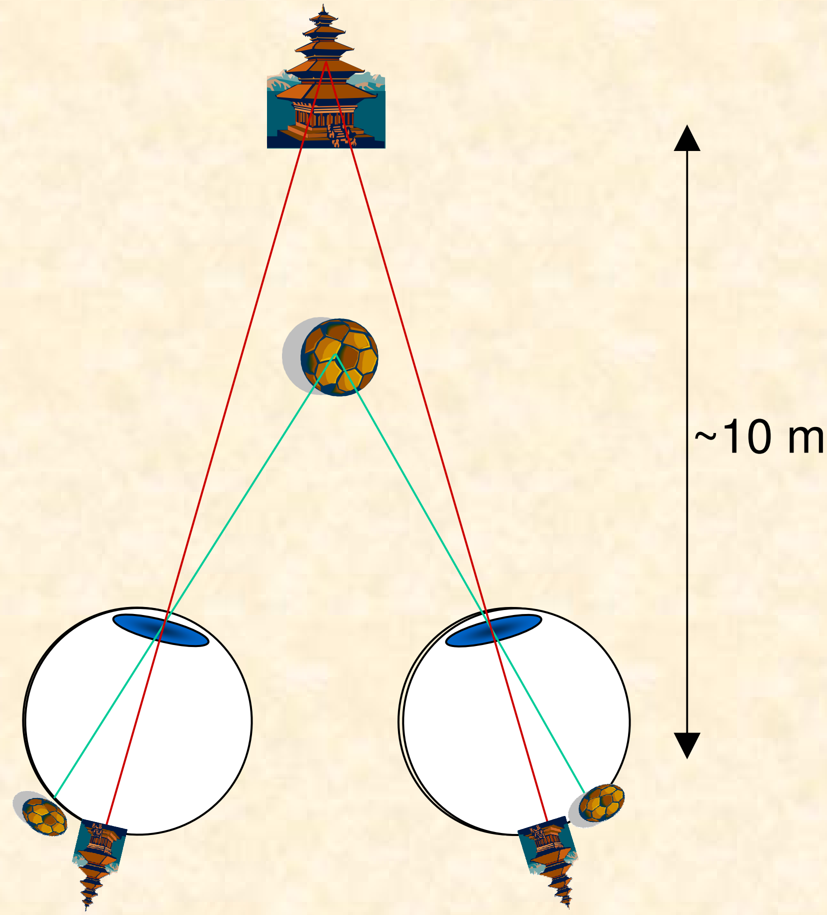


Binocular vision

Perception of depth (distance)

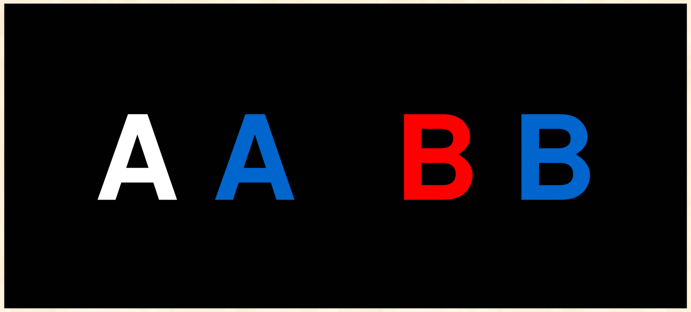


Eye convergence angle

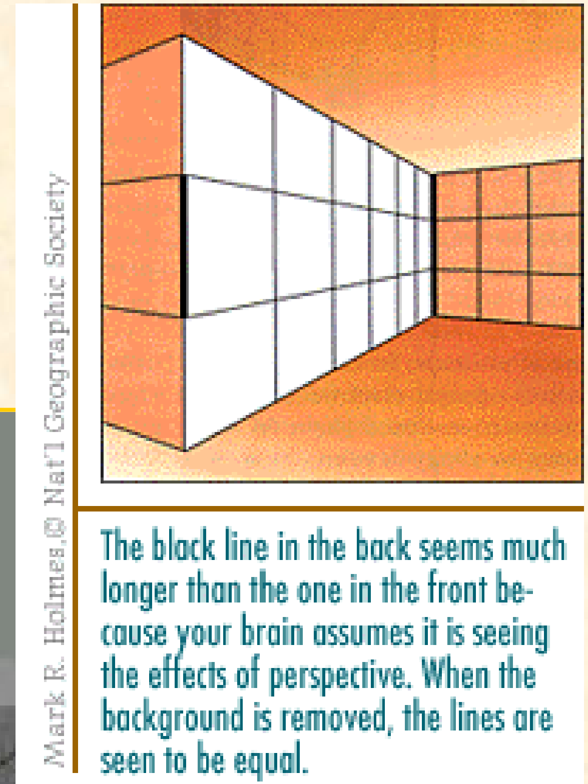


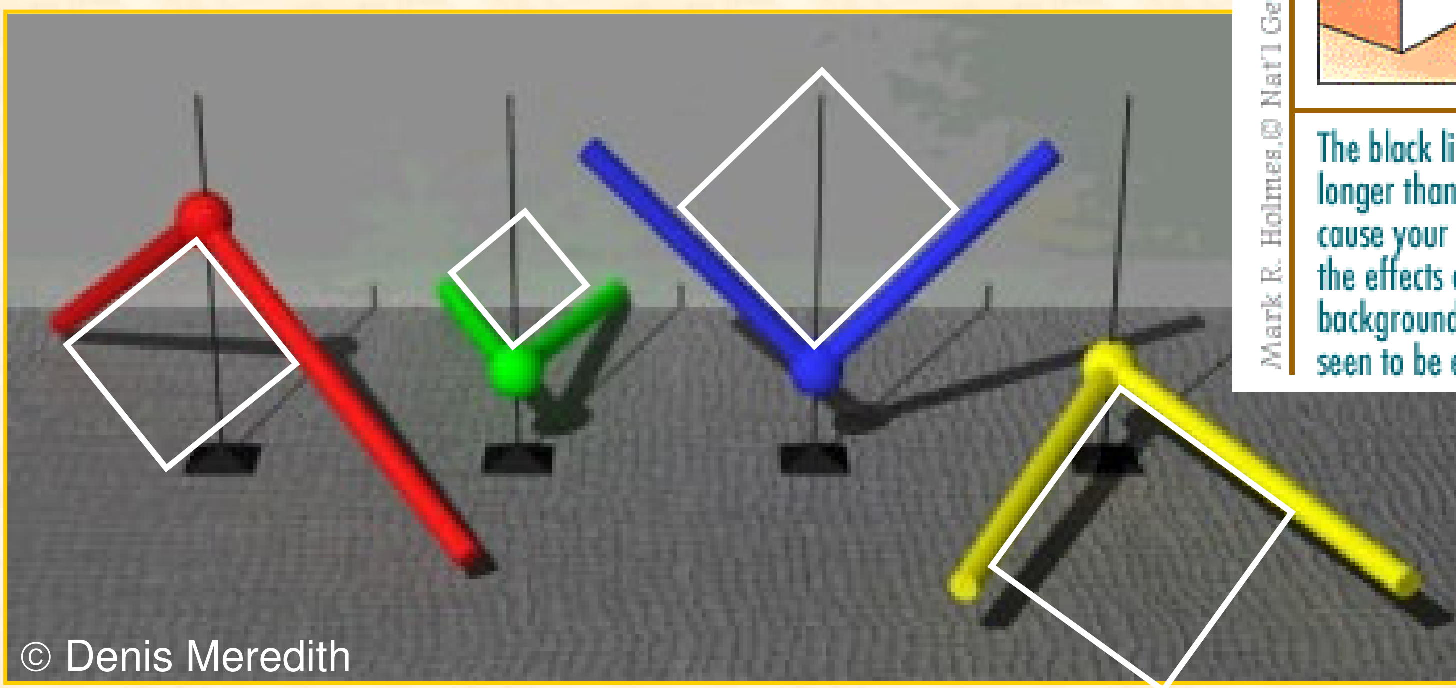
Disparity in binocular vision

Depth and perspective perception

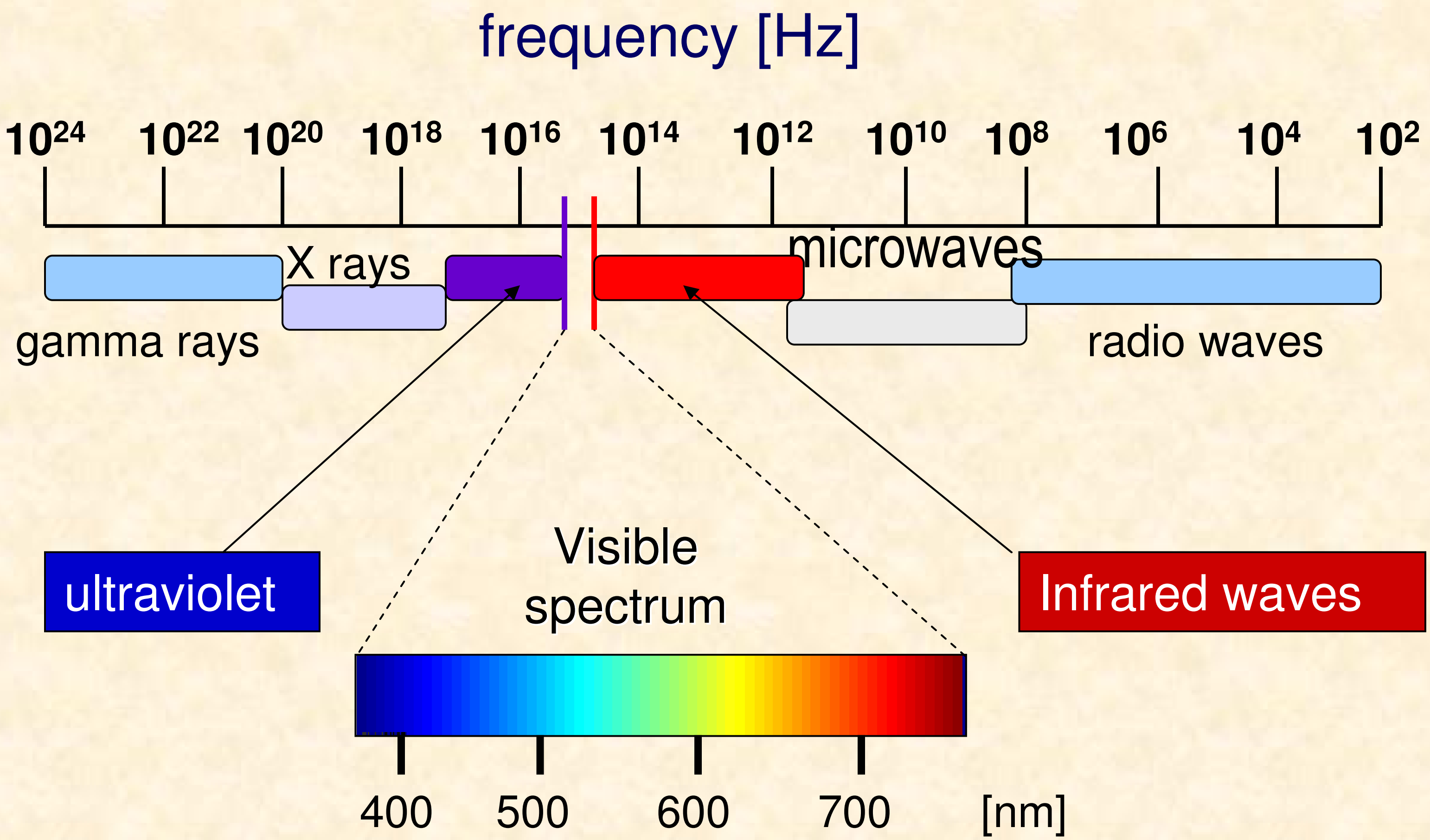


The role of colours in depth perception



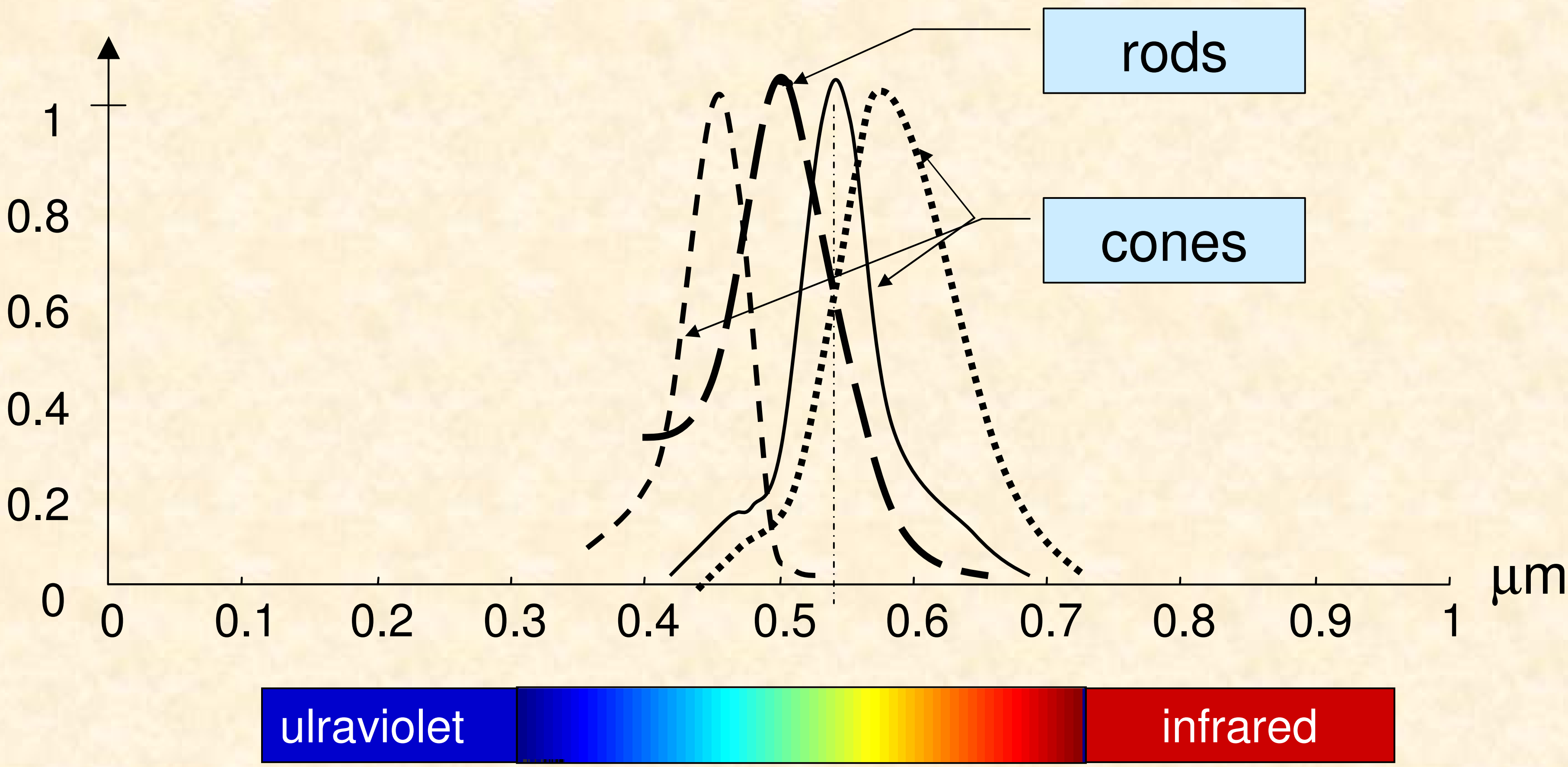


Electromagnetic spectrum



 P. Strumiłło

Spectral sensitivity characteristic of the human eye

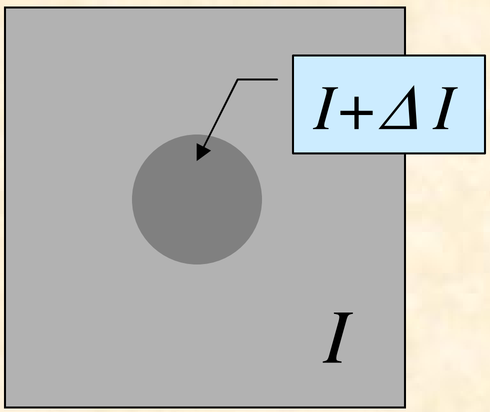


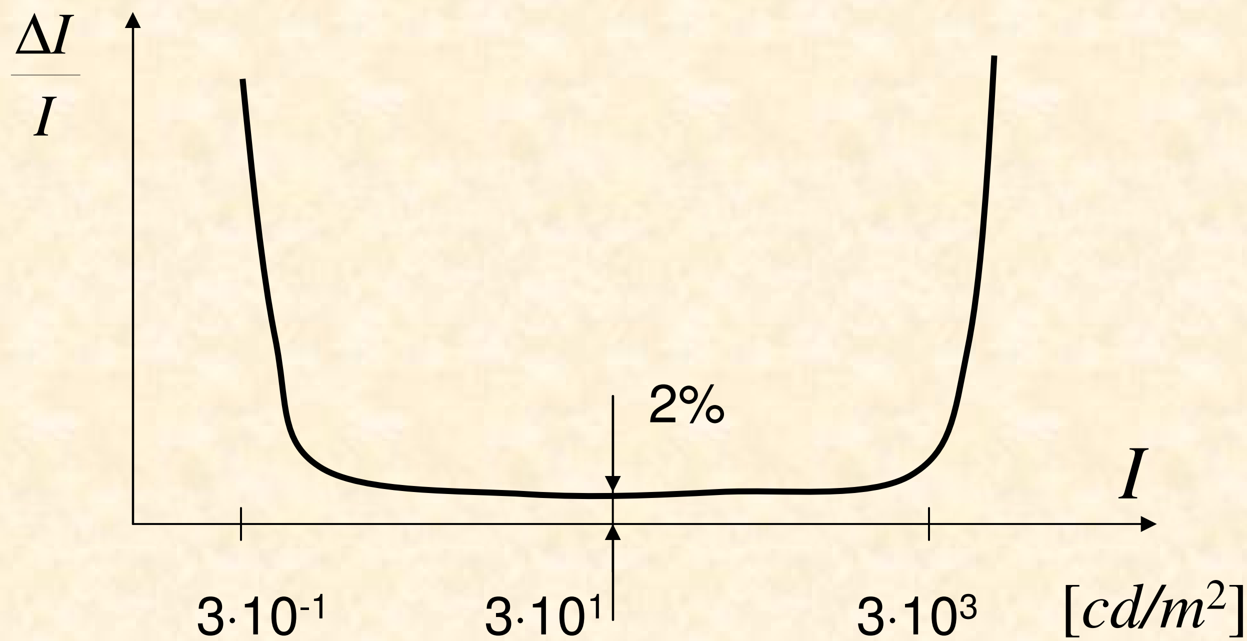
Visual perception

Subjective brightness sensation assumes a logarithmic characteristic.

Human eye can percieve brightness in the range of 10^{10}.

Contrast sensitivity (Weber fraction)

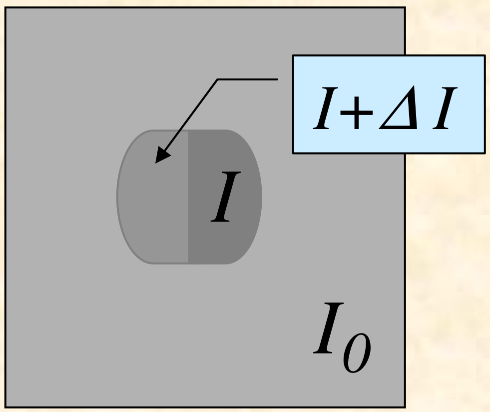


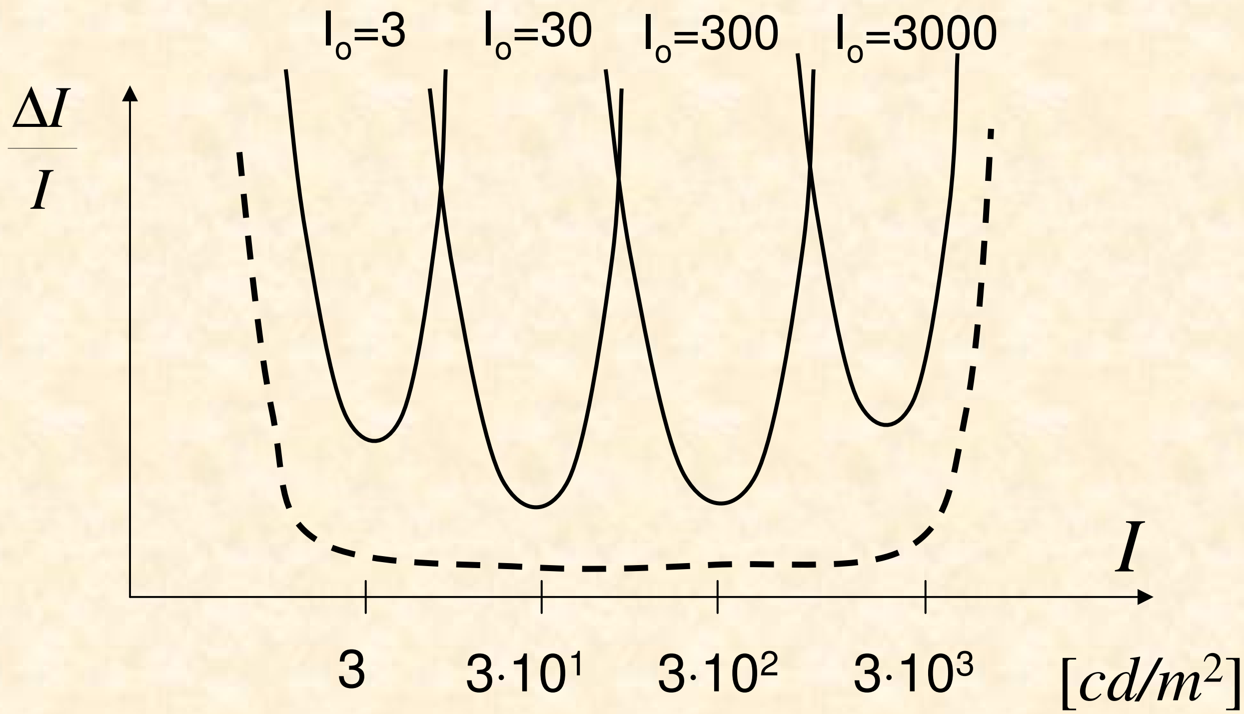


The ratio $\frac{\Delta I}{I}$ is termed the Weber fraction.

It reflects contrast sensitivity characteristc of the human eye.

Contrast sensitivity (Weber fraction)





The eye achieves maximum sensitivity for:

$$I+\Delta I \approx I_0$$

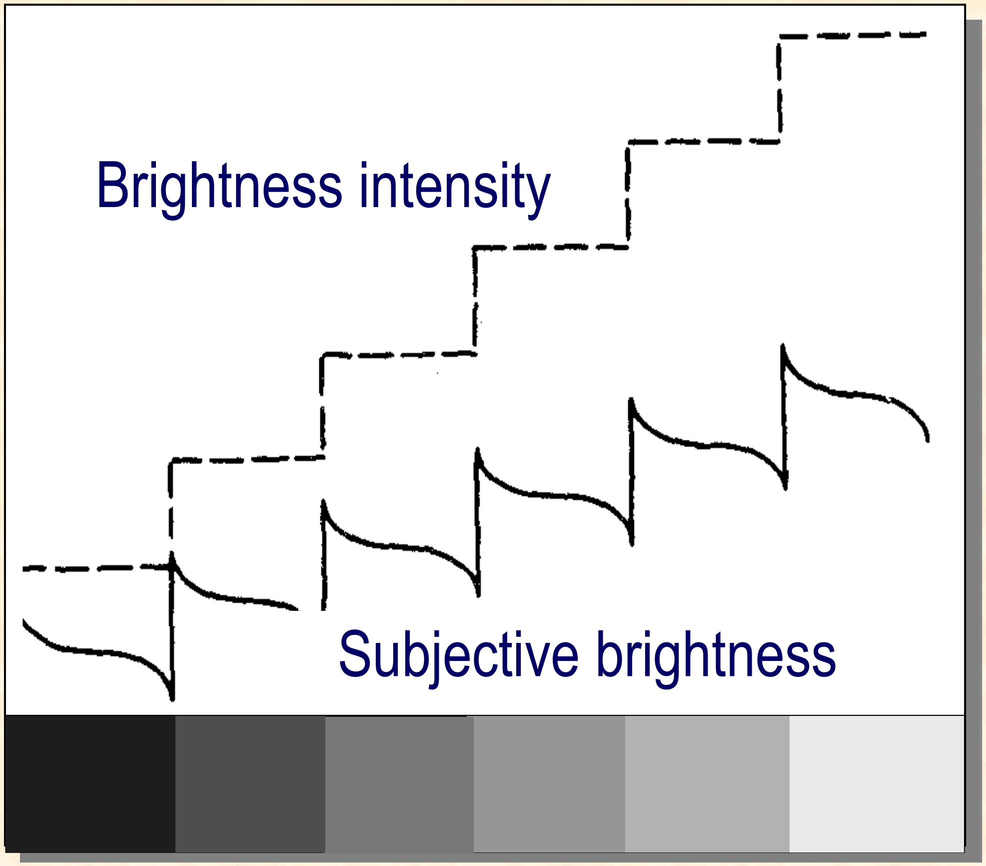
P. Strumiłło

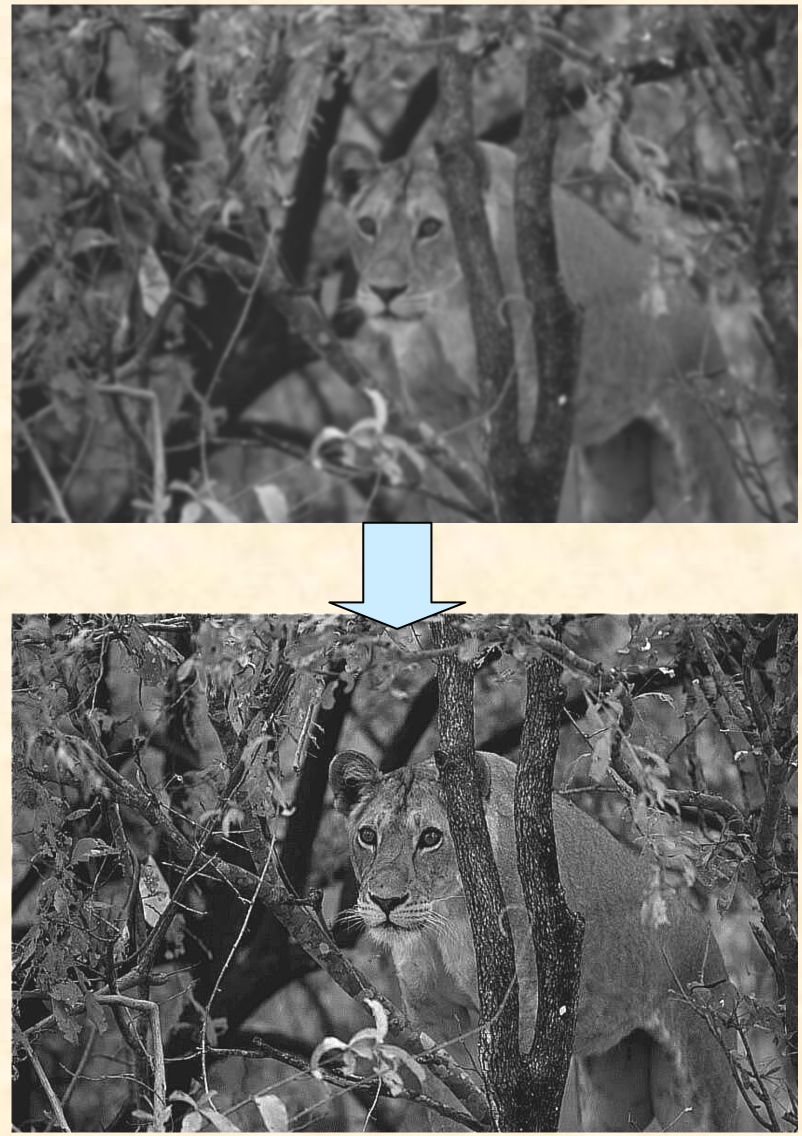
Image coded using 16 gray levels

© MIT

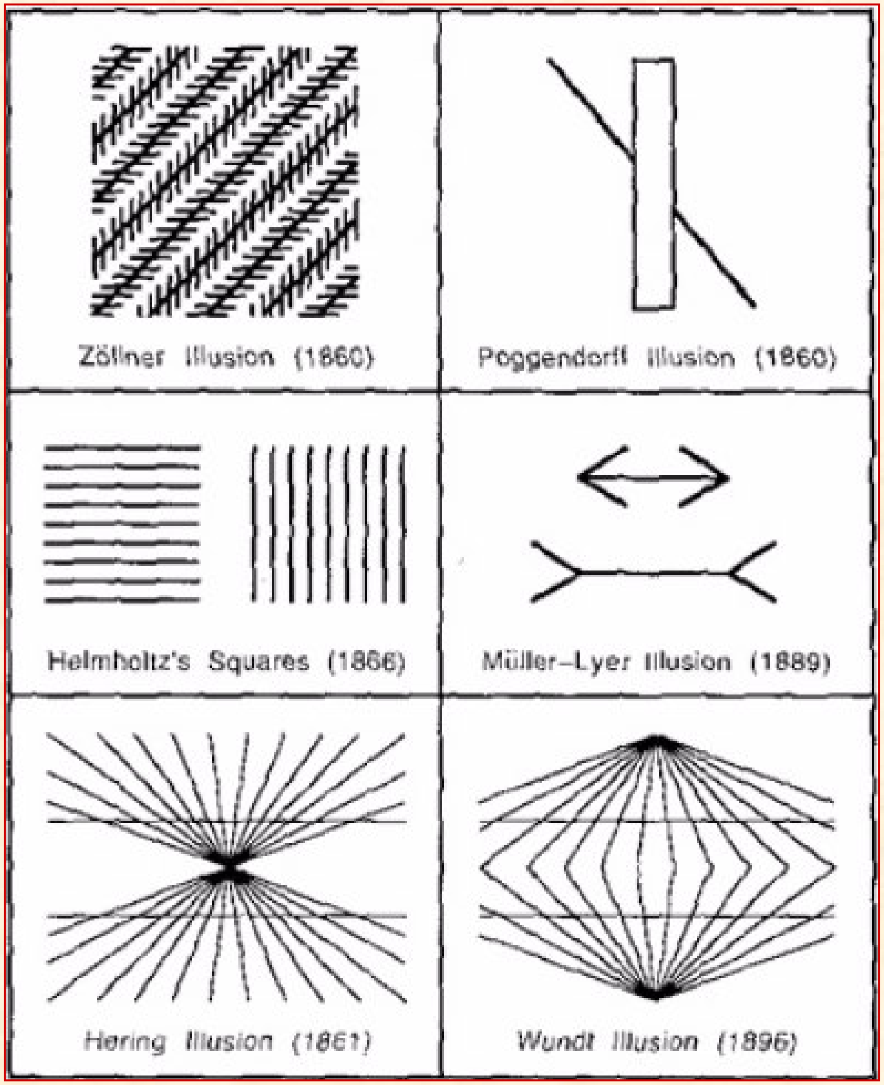
4 bits/pixel

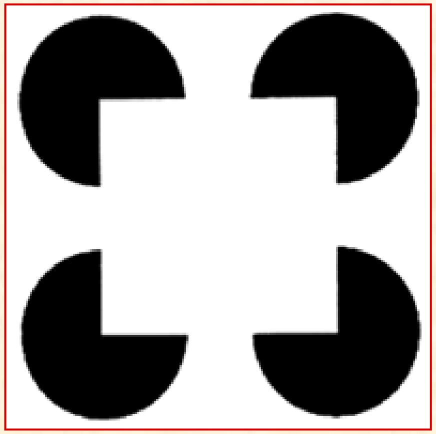
Mach bands





Visual illusions



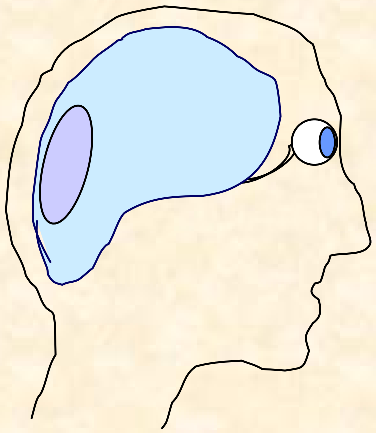


Pattern pre-coding

„Thatcher illusion" - Thompson (1980)

Pattern pre-coding

„Thatcher illusion" - Thompson (1980)



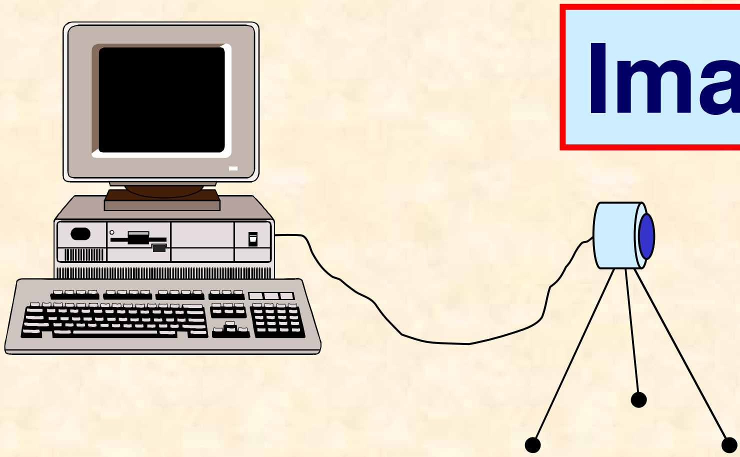
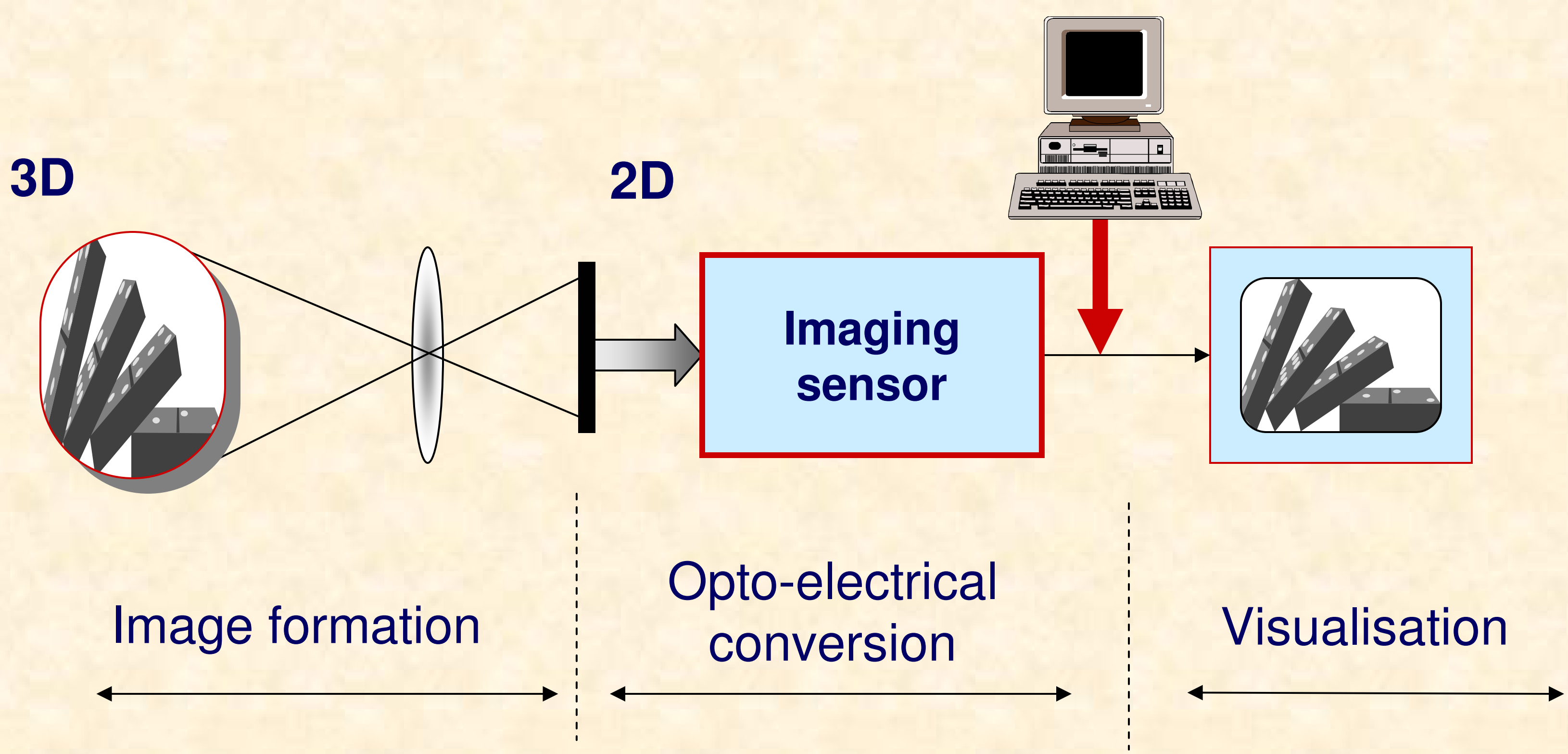


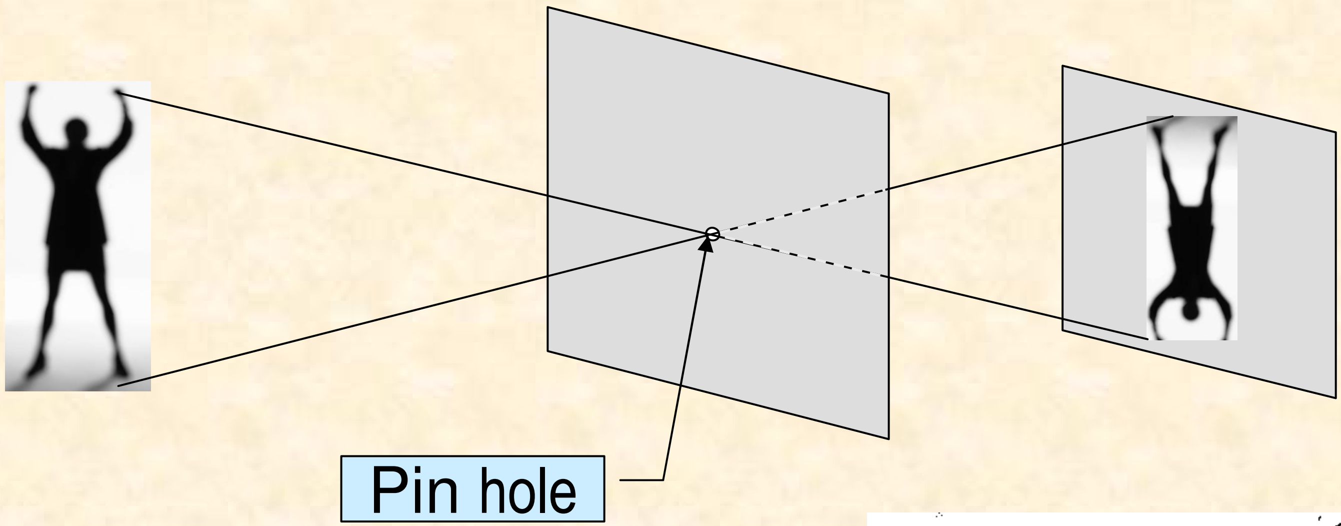
Image aquisition system

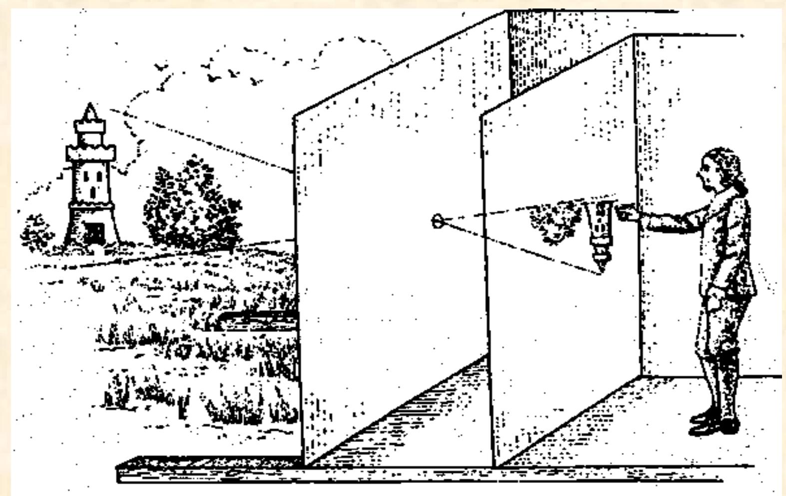
Visual path of the image processing system

Visual path – a set optical and electronic elements converting radiant energy into an electrical signal and imaging it using display devices.



The pinhole camera (camera obscura)

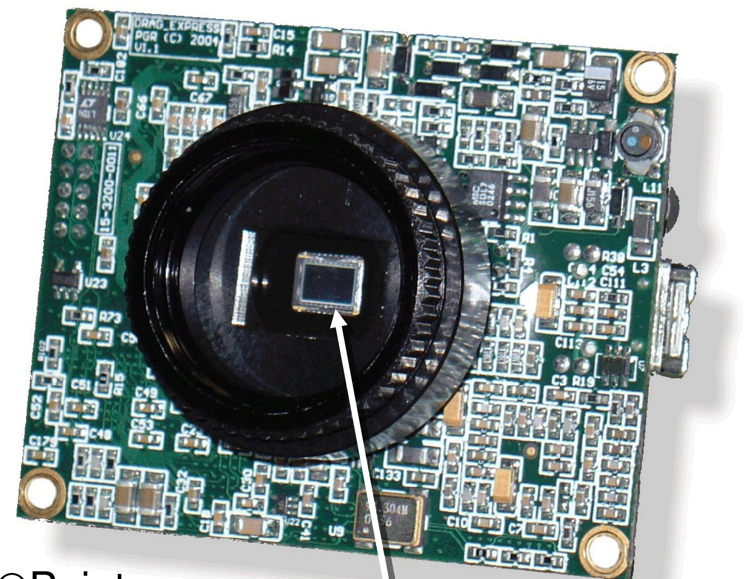




Pros and cons:

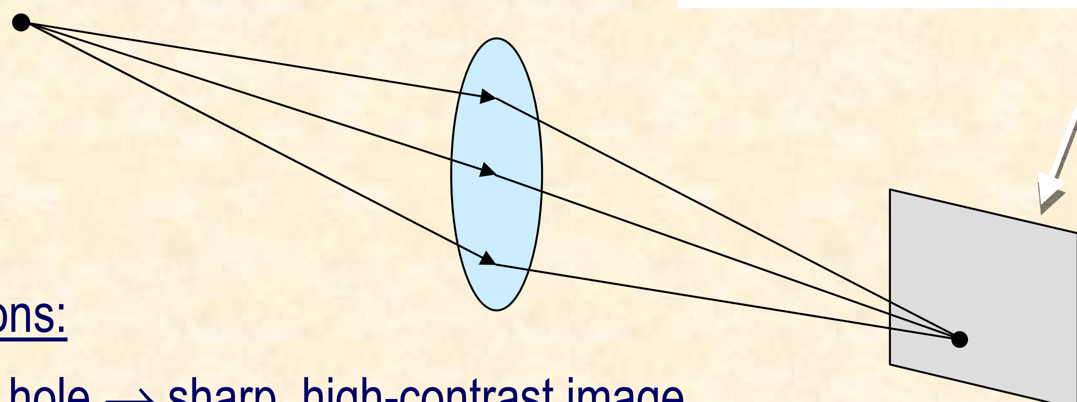
- small hole $\rightarrow$ little light goes in
- large hole $\rightarrow$ image blurring

Cameras today



®Pointgrey

CCD sensor



Pros and cons:

- large hole → sharp, high-contrast image
- geometric distortions

Image formation model

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

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

$$0 < r(x,y) < 1$$

reflectance coefficient at (x,y)

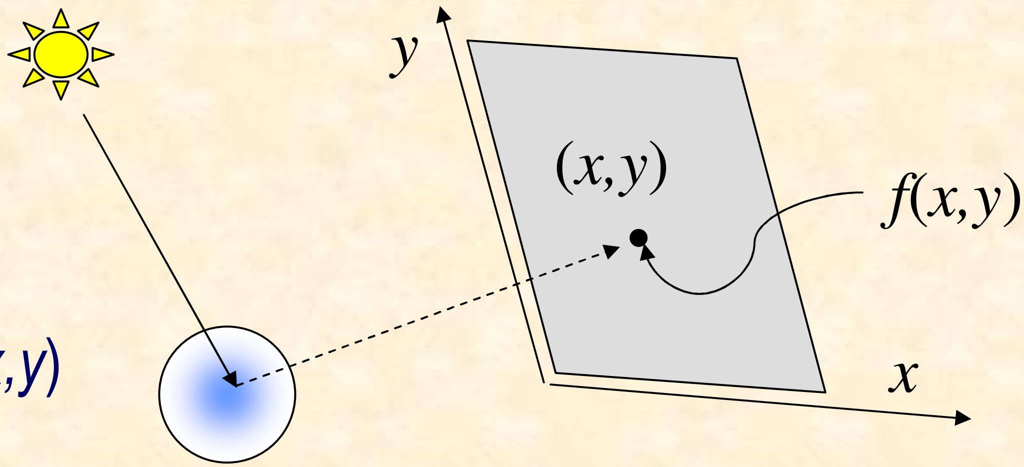


Image – a 2-D light intensity function $f(x,y) >= 0$ reflecting light energy distribution

illumination: sunny day ~ 5000 cd/m^2, cloudy day ~ 1000 cd/m^2, full moon ~ 0.001 cd/m^2,

Reflectance coeff.: black velvet - 0.01, white wall - 0.8, snow - 0.93.

P. Strumiłło

Image formation model

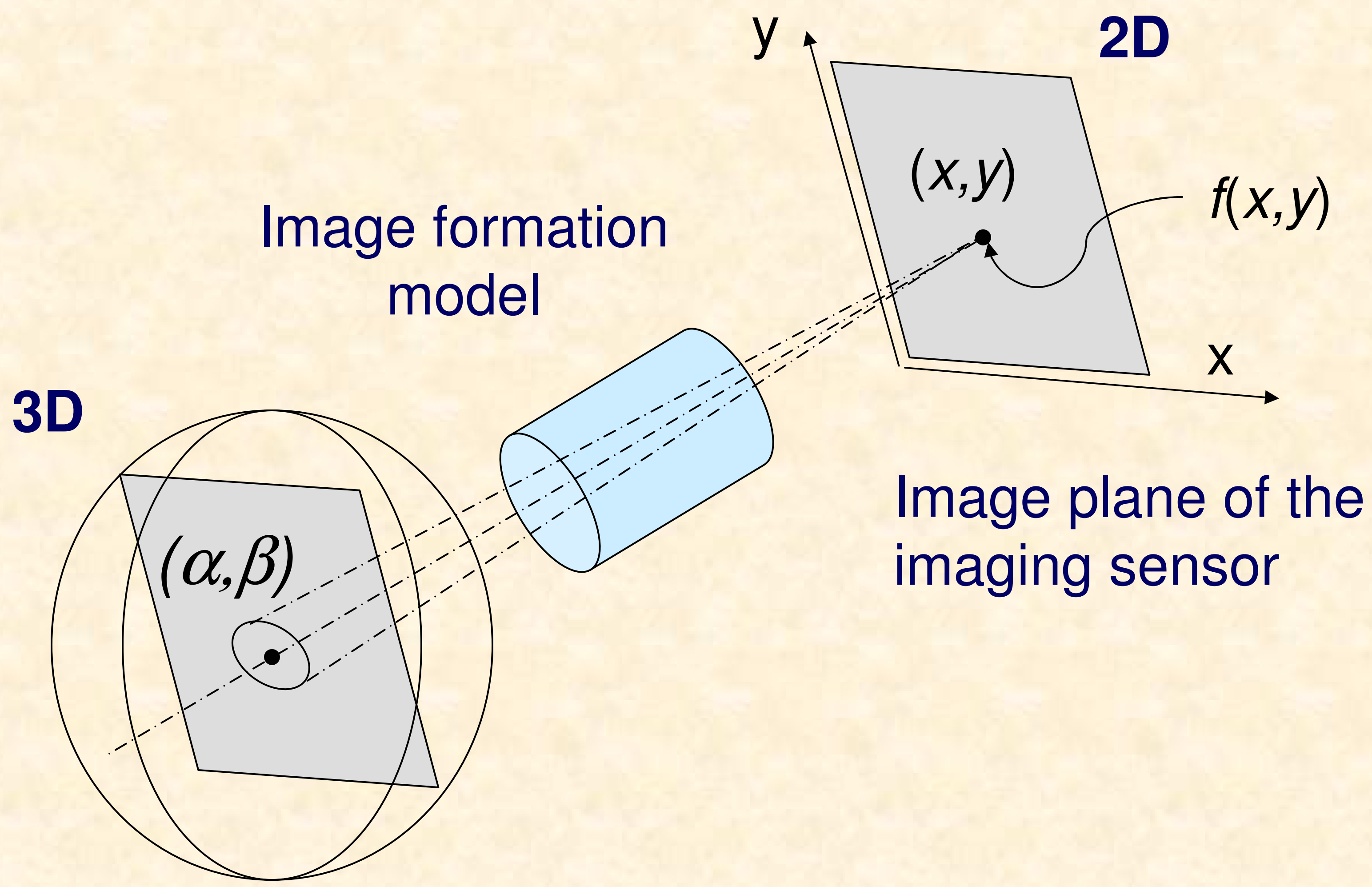


Image formation model

For a linear process of energy accumulation in the image sensor plane:

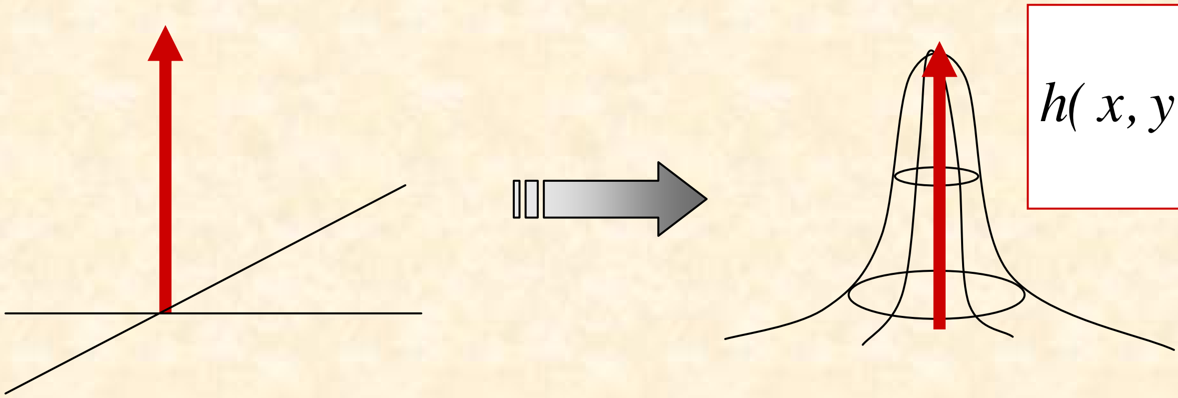
$$f(x,y) = \iint_{-\infty}^{\infty} f(\alpha,\beta)\, h(x,y,\alpha,\beta)\, d\alpha\, d\beta$$

$h(.)$ – is the impulse response of the system; in optical systems it is termed *the* ***point spread function*** of a system

Image formation model

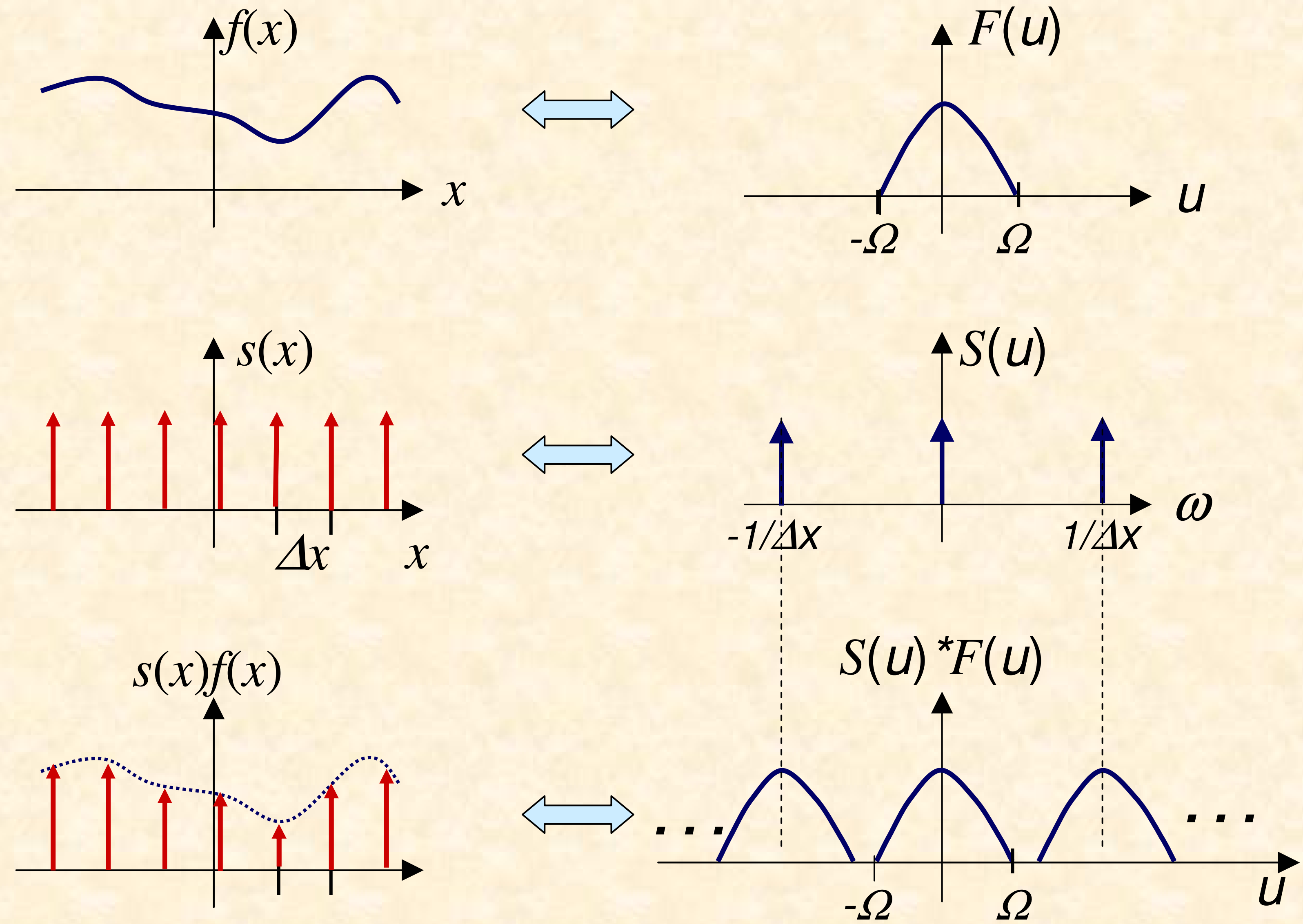
If the **point spread function** is shift invariant, then the image formation model is given by a convolution integral:

$$f(x,y)=\int_{-\infty}^{\infty}\int f(\alpha,\beta)\,h(x-\alpha,y-\beta)\,d\alpha\,d\beta$$



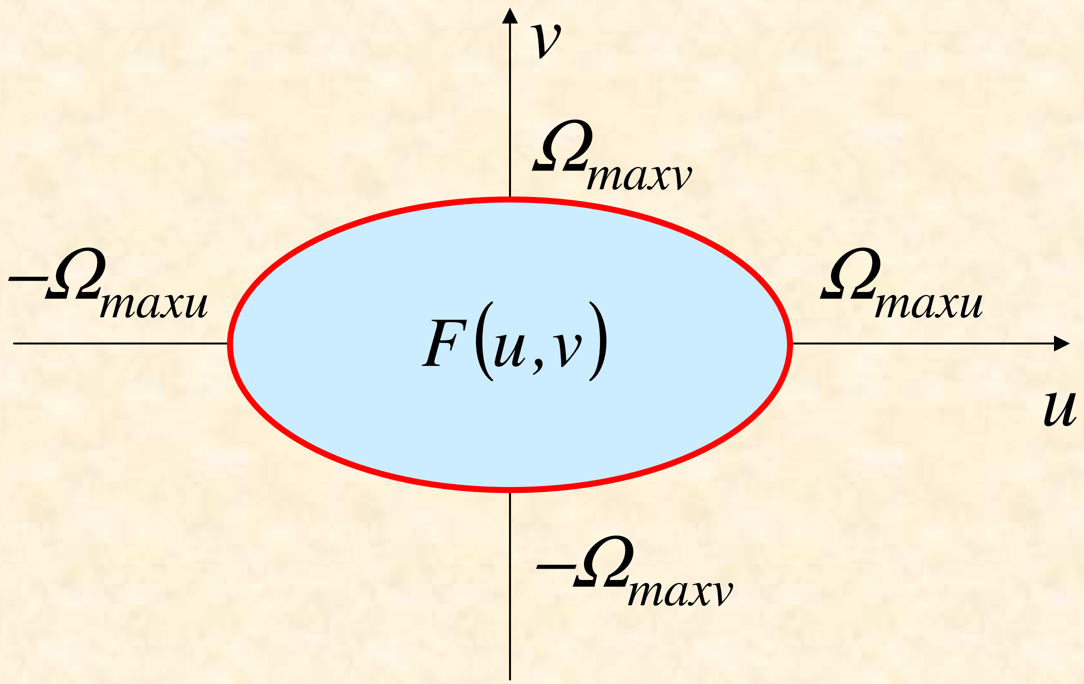
$$h(x,y)=exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)$$

Sampling of 1-D signals



Sampling of 2-D signals

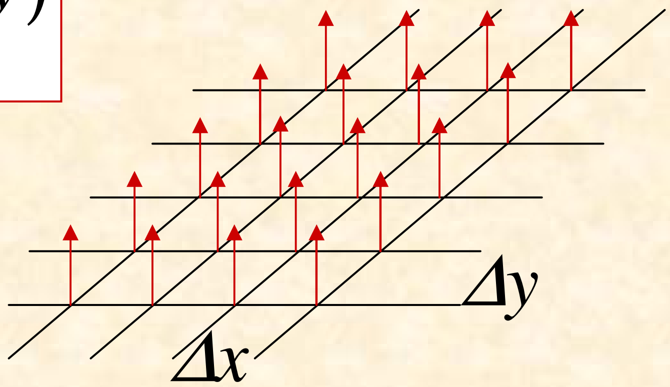
Assume the source image (analog image) features a limited Fourier bandwidth



Sampling of 2-D signals

Image sampling function:

$$S(x,y)=\sum_{i=0}^{M-1}\sum_{k=0}^{N-1}\delta(x-i\Delta x, y-k\Delta y)$$



and a sampled image:

$$f_s(x,y)=f(x,y)S(x,y)=$$
$$=\sum_{i=0}^{M-1}\sum_{k=0}^{N-1}f(i\Delta x,k\Delta y)\delta(x-i\Delta x, y-k\Delta y)$$

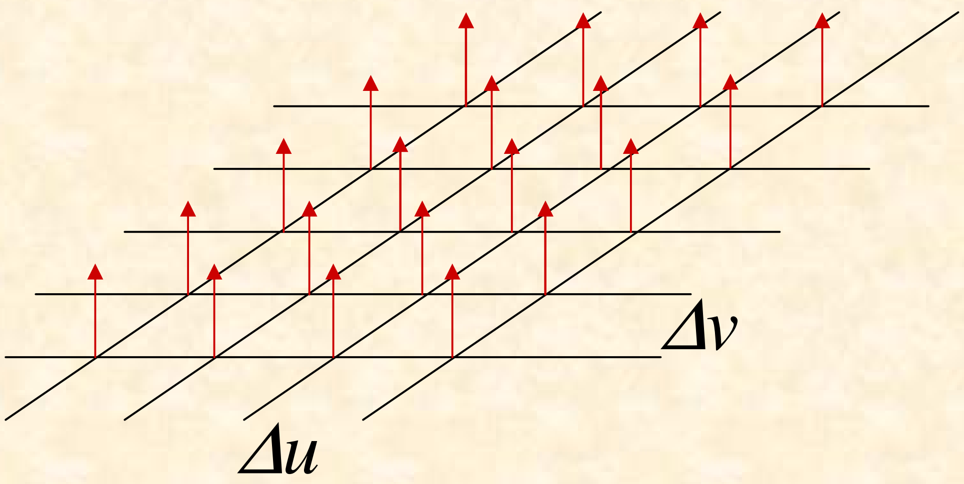
Sampling of 2-D signals

Fourier spectrum of the sampled image:

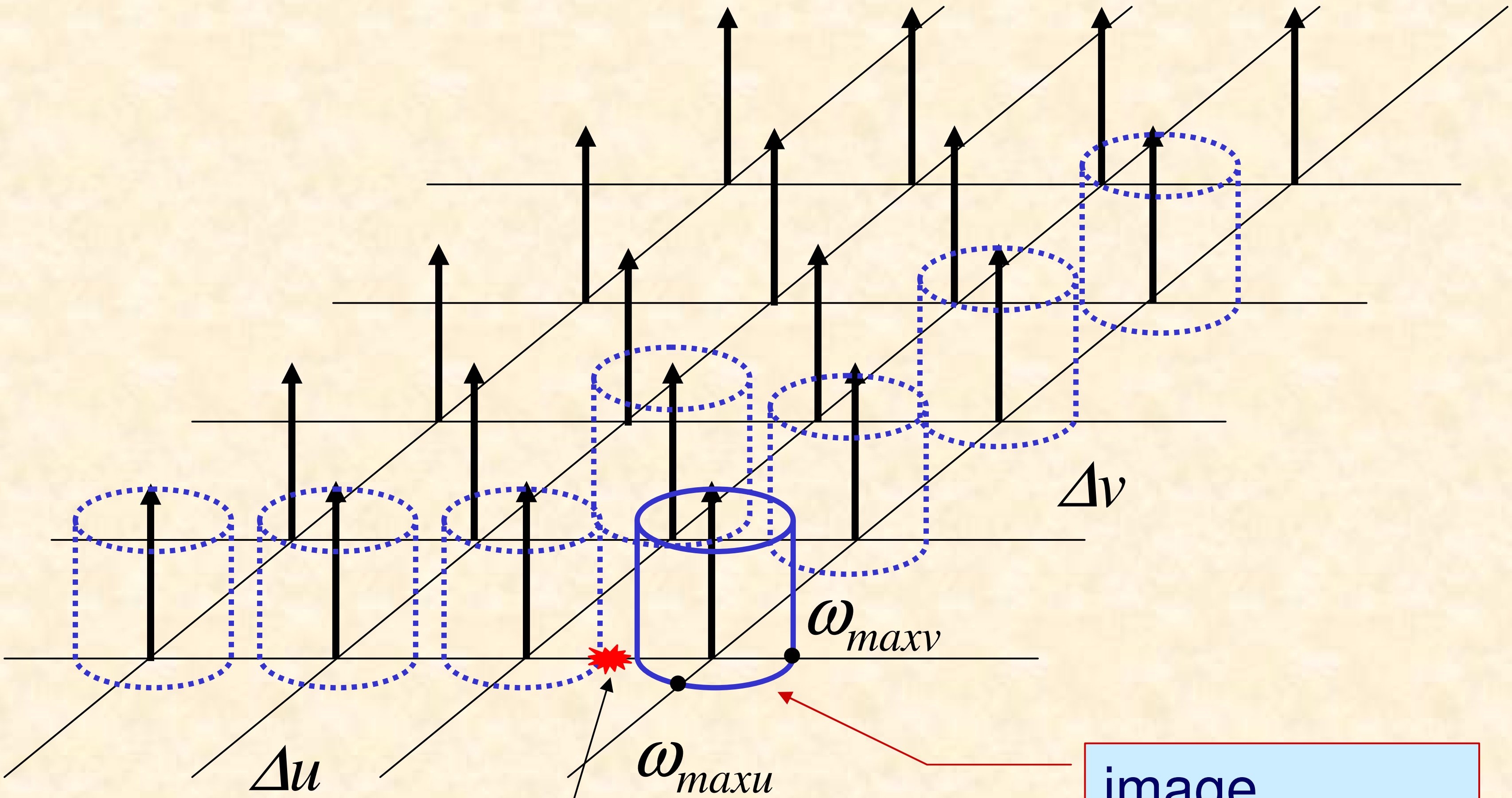
$$F_s(u,v) = \frac{1}{NM} \sum_{i=0}^{M-1} \sum_{k=0}^{N-1} F(u - i\Delta u, v - k\Delta v)$$

where:

$$\Delta u = \frac{1}{\Delta x}, \quad \Delta v = \frac{1}{\Delta y}$$

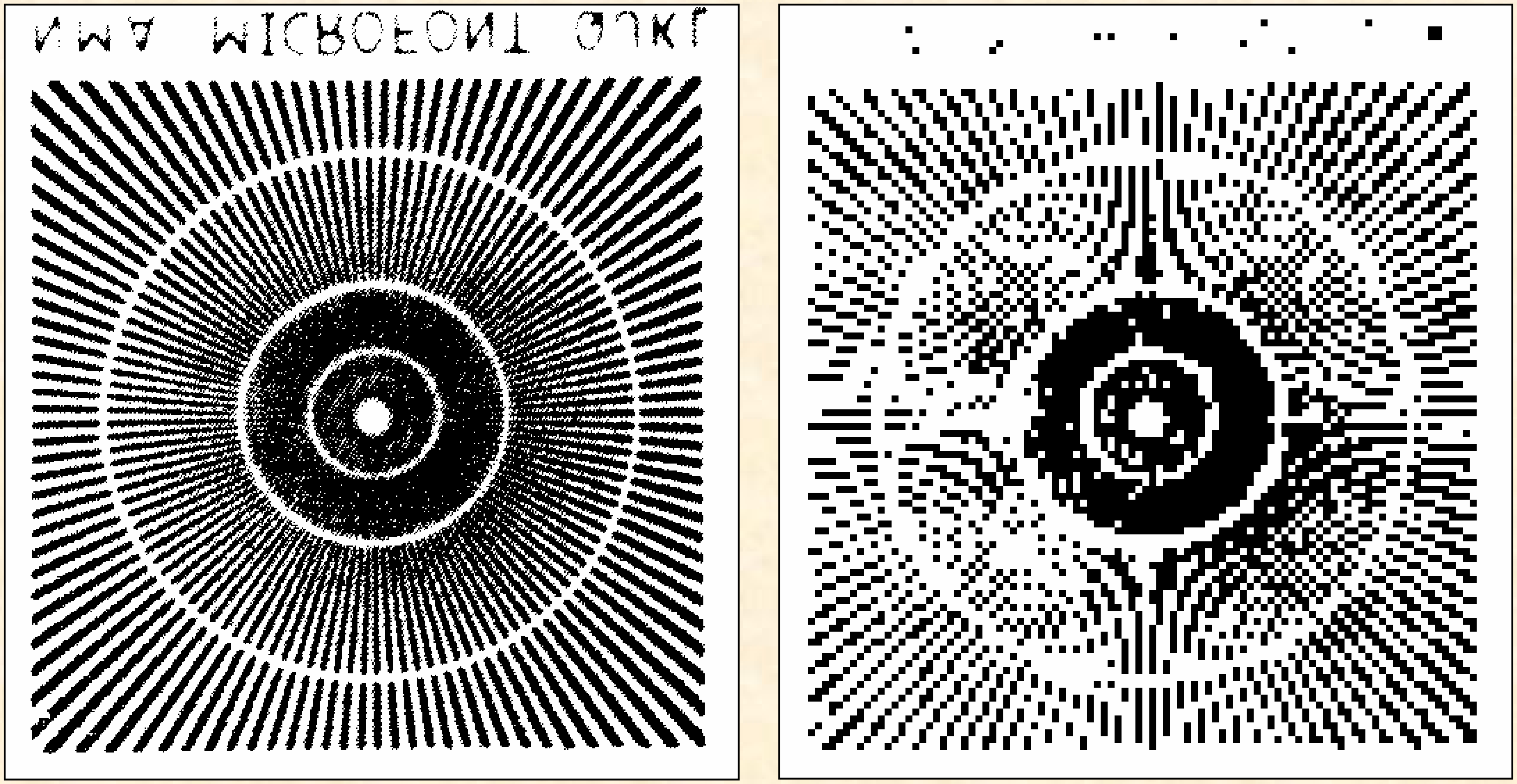


Sampling of 2-D signals



$$\Omega_{max} < \frac{\Delta u}{2} = \frac{1}{2\Delta x}$$

Aliasing distortion - example



Scanned images:

500 dpi

100 dpi
(*dots per inch*)

Image acquisition

Image acquisition is the process of converting light energy radiating from image scene points into an electrical signal (suitable for storing or transmission).

Image acquisition devices:

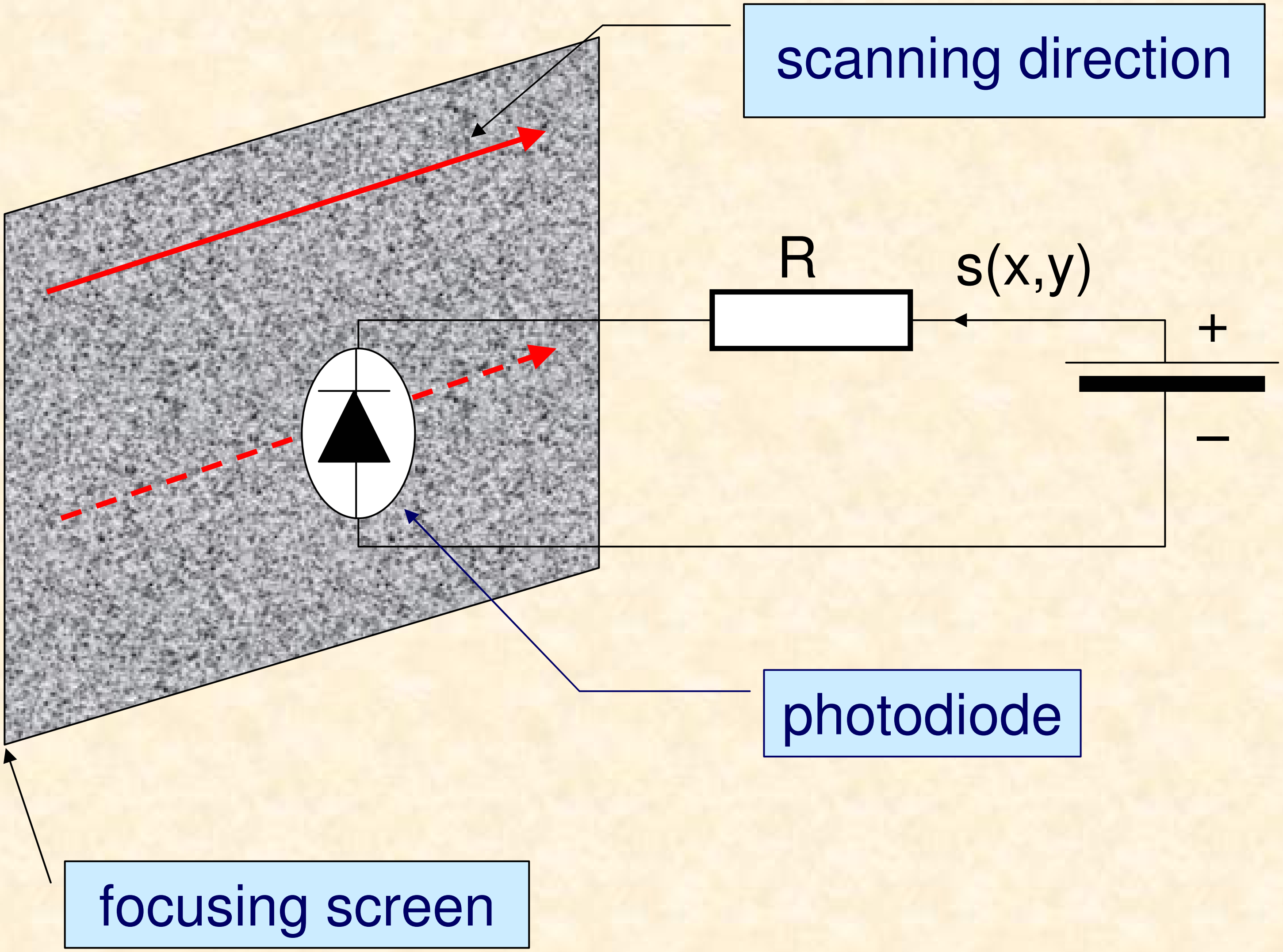
- **CCD camera**
- **Video camera**
- **Scanner**
- **Digitizer**

Image acquisition

There are two basic schemes for converting optical images into electrical signals:

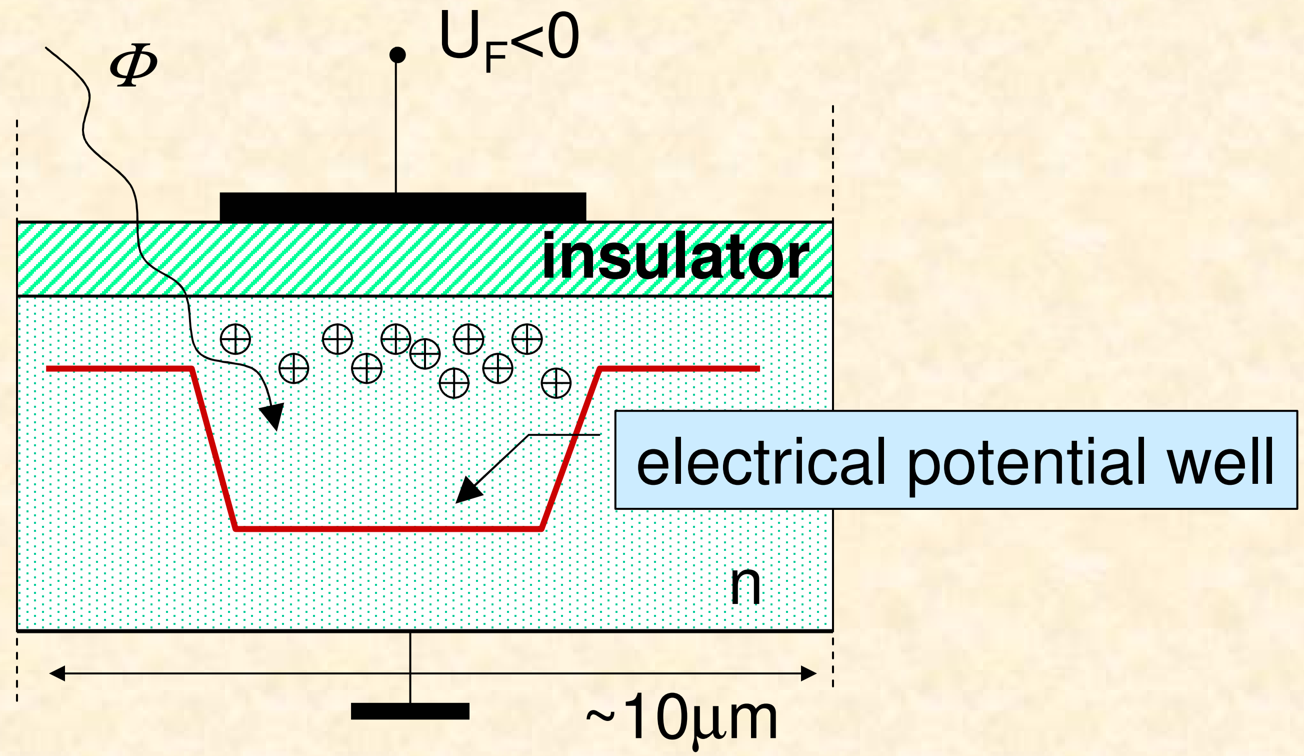
- **without accumulation of photo-charges** (eg. optical scanner),
- **with accumulation of photo-charges** (np. vidicon, CCD array)

Imaging sensor (no photo-charges)



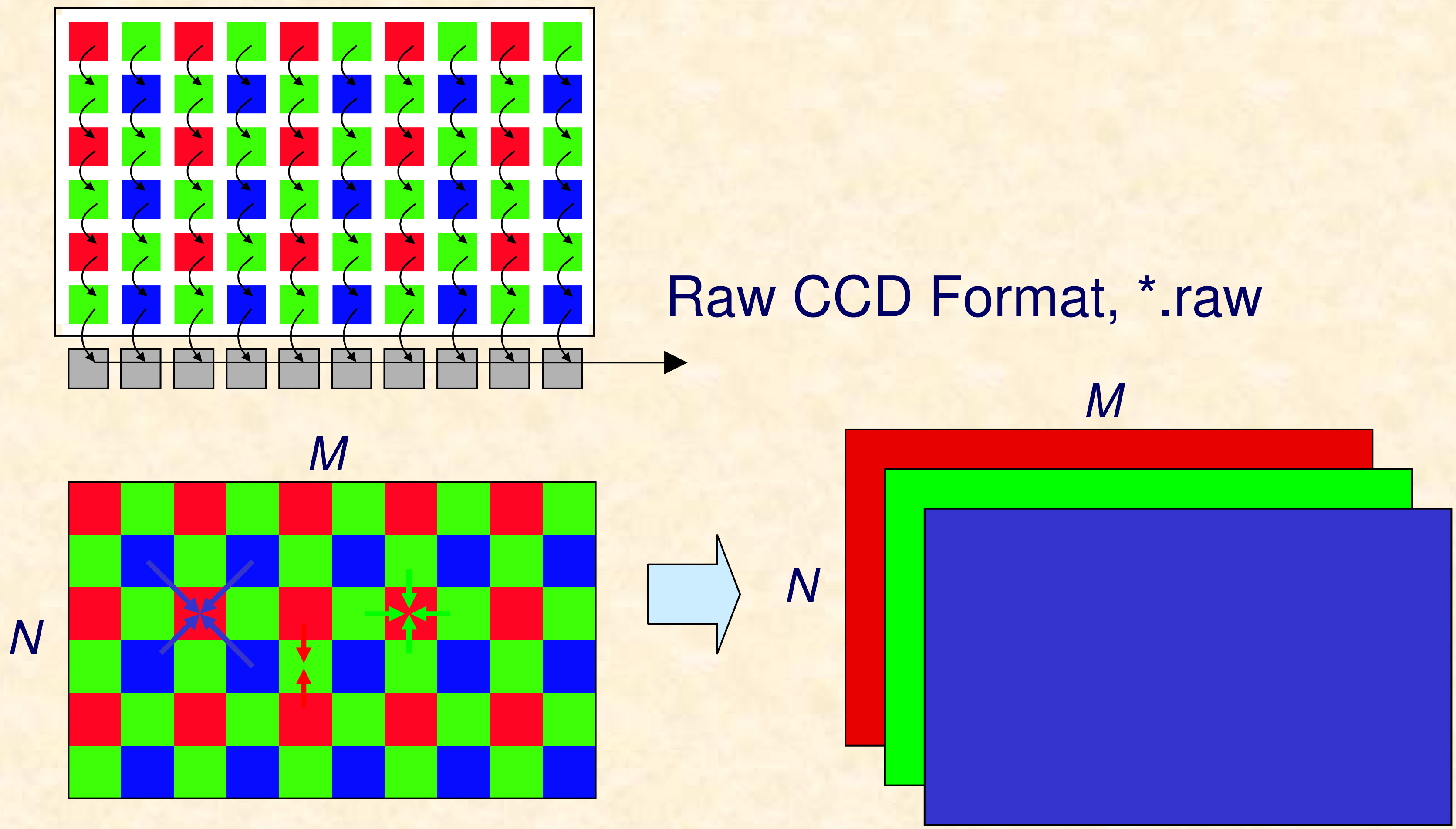
CCD array (accumulation of photo-charges)

Image formation is based on the internal photo-electric phenomenon



Capacitor cell

The Bayer matrix



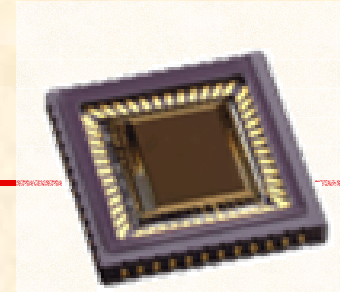
Calculate RGB image by interpolating colour components
from the Bayer matrix

Pixim – Digital Pixel System (DPS)

A/D converter for each pixel
(no charge couplings)

Single A/D converter

CMOS image sensors

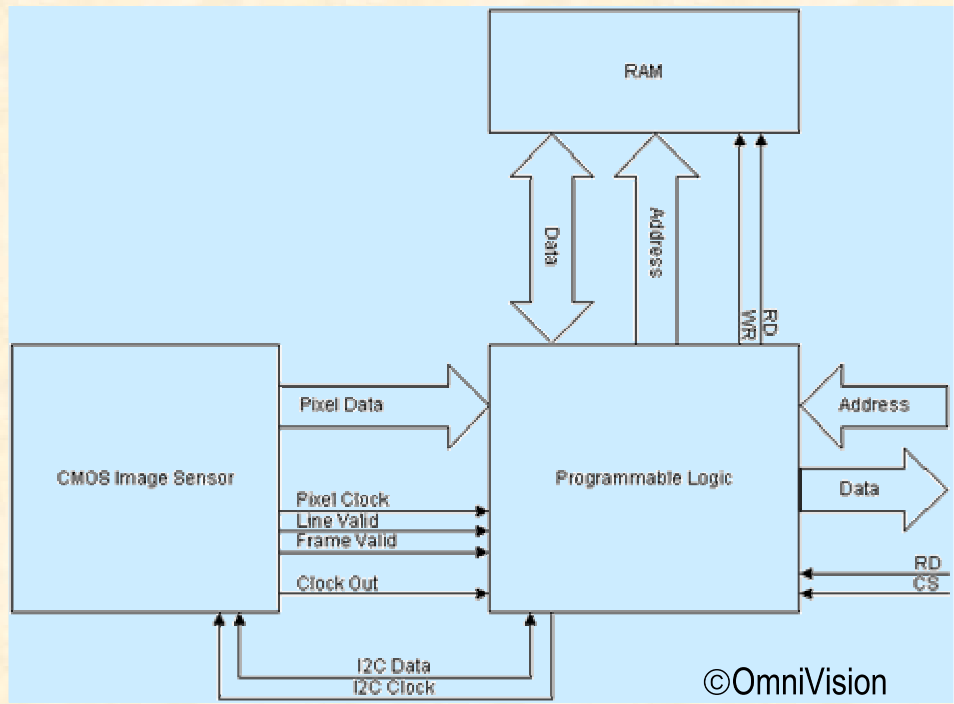


Pros:

- cheap technology (used for fabricating memory and CPU modules),
- low power consumption (100 times!)
- random access to pixel regions (block image processing)
- no „charge leaking” typical for CCD technology
- on-chip analog-to-digital conversion and signal processing

Cons:

- more susceptible to noise than CCD
- lower light sensitivity due to many transistors used for a single pixel

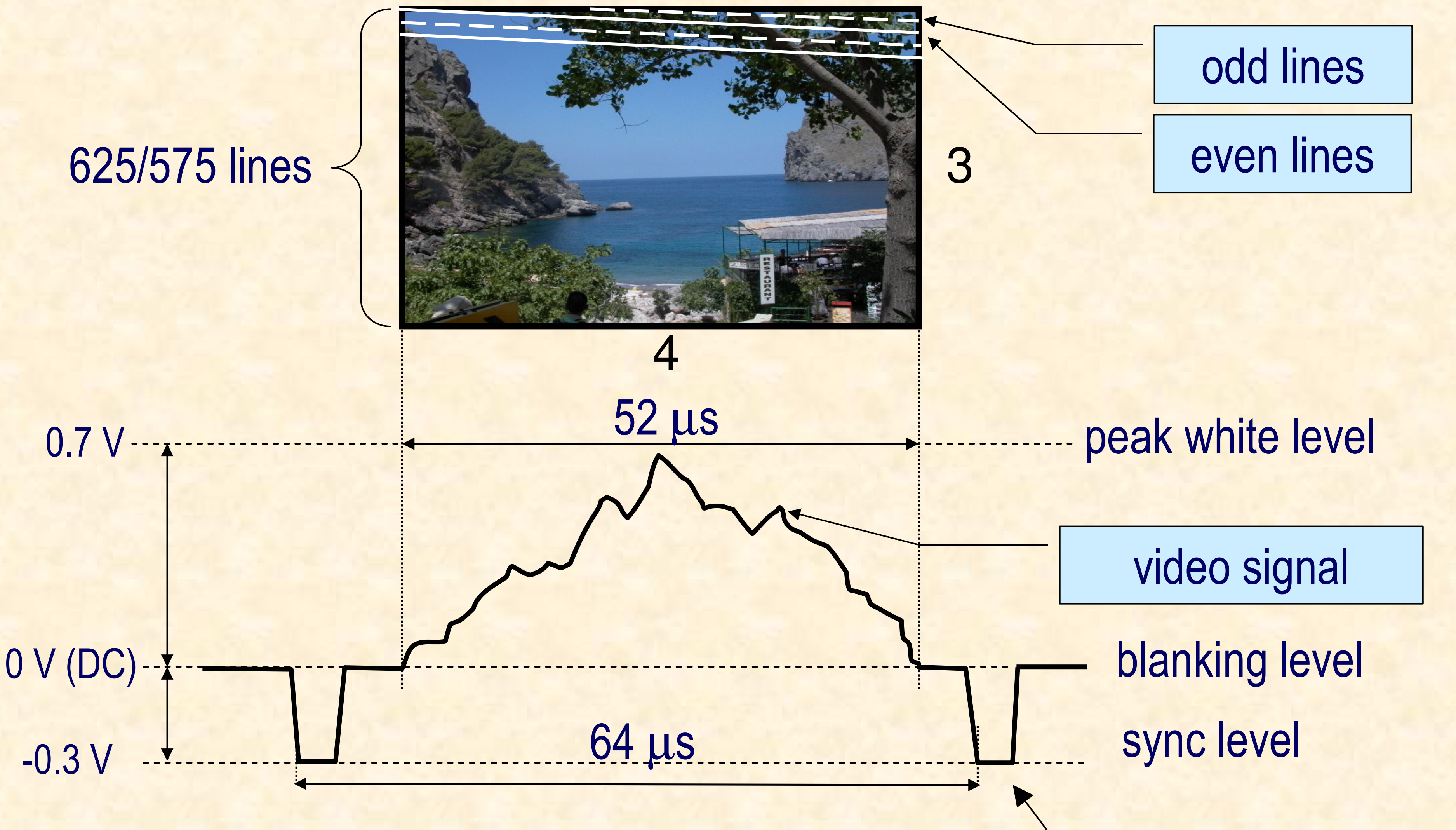


Monochrome TV standards

- European **CCIR** standard: (625 (**575**) lines, line display time 64us, 50 half-images per sec., 1Vpp, 75Ω, signal
- American **RS170** standard: (525 (**484**) lines, line display time 63,5 us, 60 half-images per sec.,1.4 Vpp, 75Ω signal
- American **RS-343** standard": (875 lines, 60 half-images, dedicated to CCTV, scientific applications,…)

***C**omité **C**onsultatif **I**nternational des **R**adiocommunication*

TV CCIR standard



Composite video signal

COHU® CCD camera

Specification Highlights

Imager:
1/2" interline transfer CCD
Picture Elements:
RS-170A: 768 (H) x 494 (V);
CCIR: 752 (H) x 582 (V)
Pixel Cell Size:
RS-170A: 8.4 µm (H) x 9.8 µm (V);
CCIR: 8.6 µm (H) x 8.3 µm (V)

Resolution:
RS-170A: 580 horizontal TVL, 350 vertical TVL; CCIR: 560 horizontal TVL,
450 vertical TVL
Synchronization:
Crystal/H&V/Asynchronous, standard
Shutter: 1/60 to 1/10,000
AGC: 20 dB
Integration: 2 - 16 Fields
Sensitivity:
Full video, No AGC: 0.65 lux; 80% video, AGC on: 0.04 lux; 30% video, AGC on: 0.008 lux
S/N Ratio (Gamma 1, gain 0 dB): 55 dB

CCD image sensor characteristics

- small size,
- robust to mechanical vibrations (70 G),
- no geometrical distortions,
- low supply voltage (12 V, 1.4W),
- SNR ~70 dB,
- linear (gamma coefficient),
- no intra-frame photo-charge accumulation,
- high resolution,
- reliable
- cheap

Image frame grabber

Matrox Cronos*Plus*

Video capture board for PCI captures from **NTSC, PAL, RS-170** and **CCIR** video sources,
connect up to 4 CVBS or 1 Y/C trigger input,
7 TTL auxiliary I/Os,
32-bit/33MHz PCI-bus master

Matrox ®

Software is sold separately, includes e.g., **Matrox ® Imaging Library** for Microsoft® Windows®