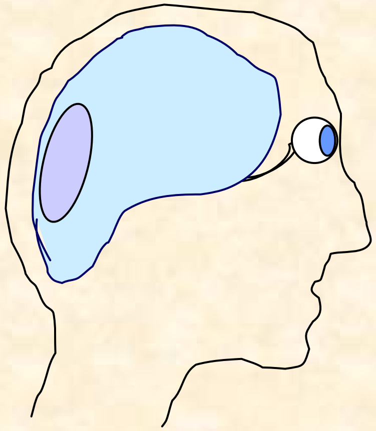
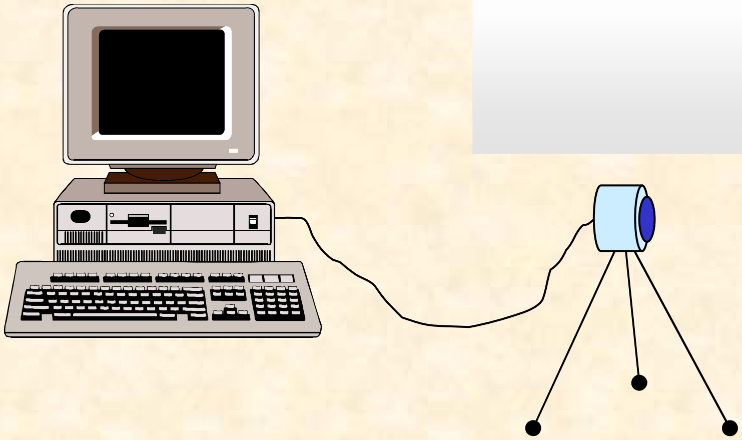


Visual perception basics

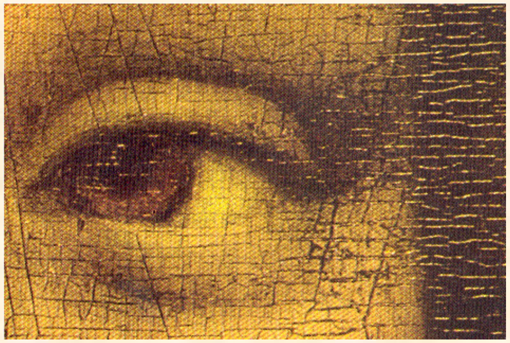


Light perception by humans

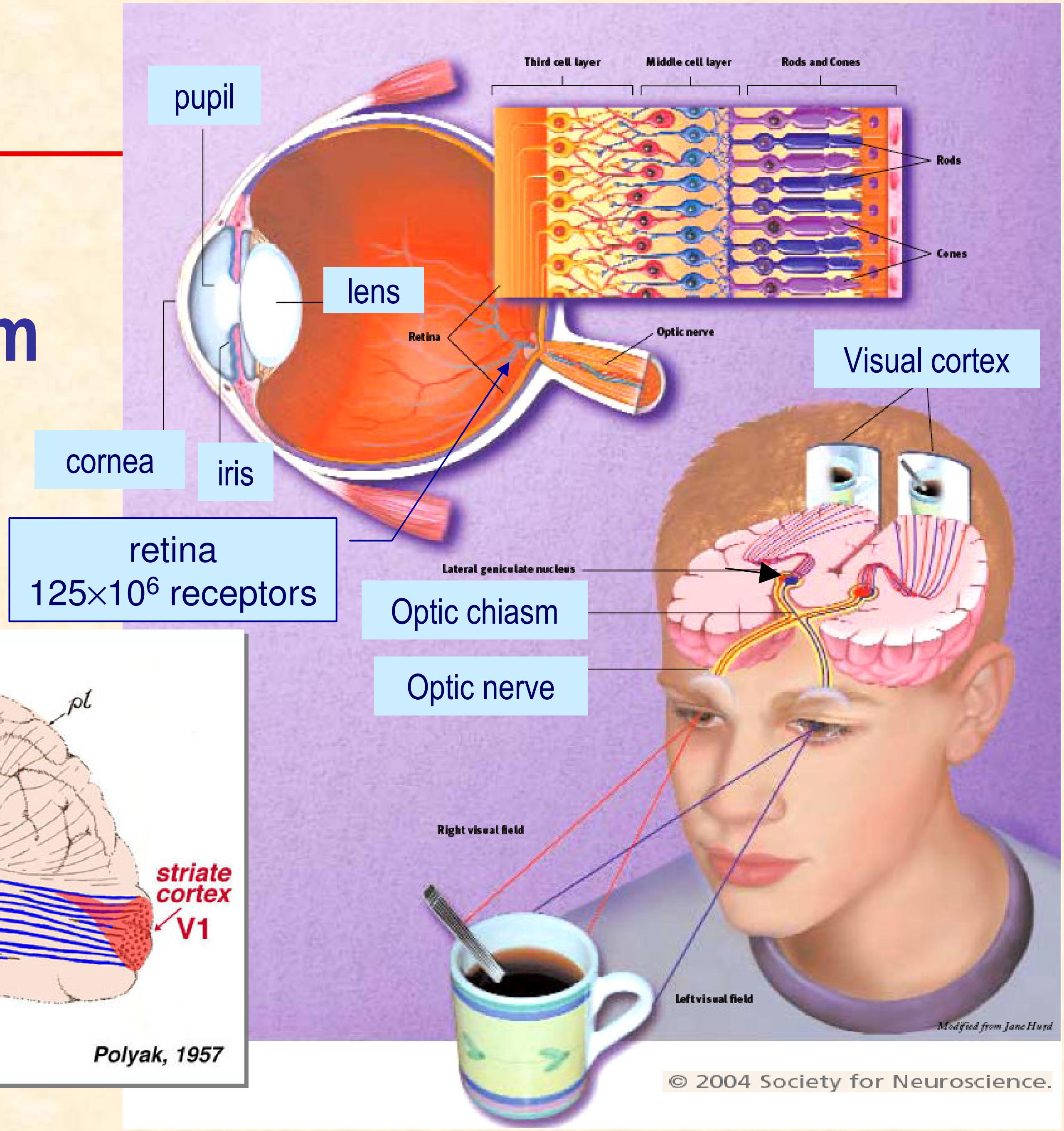
Humans perceive approx. **90%** of information about the environment by means of visual system.

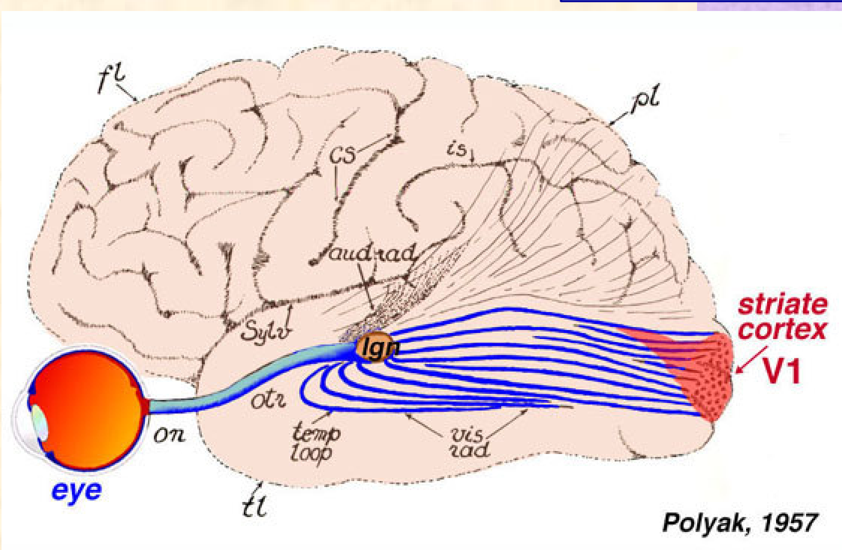
Efficiency of the human visual system is characterised by a number of features:

- 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;



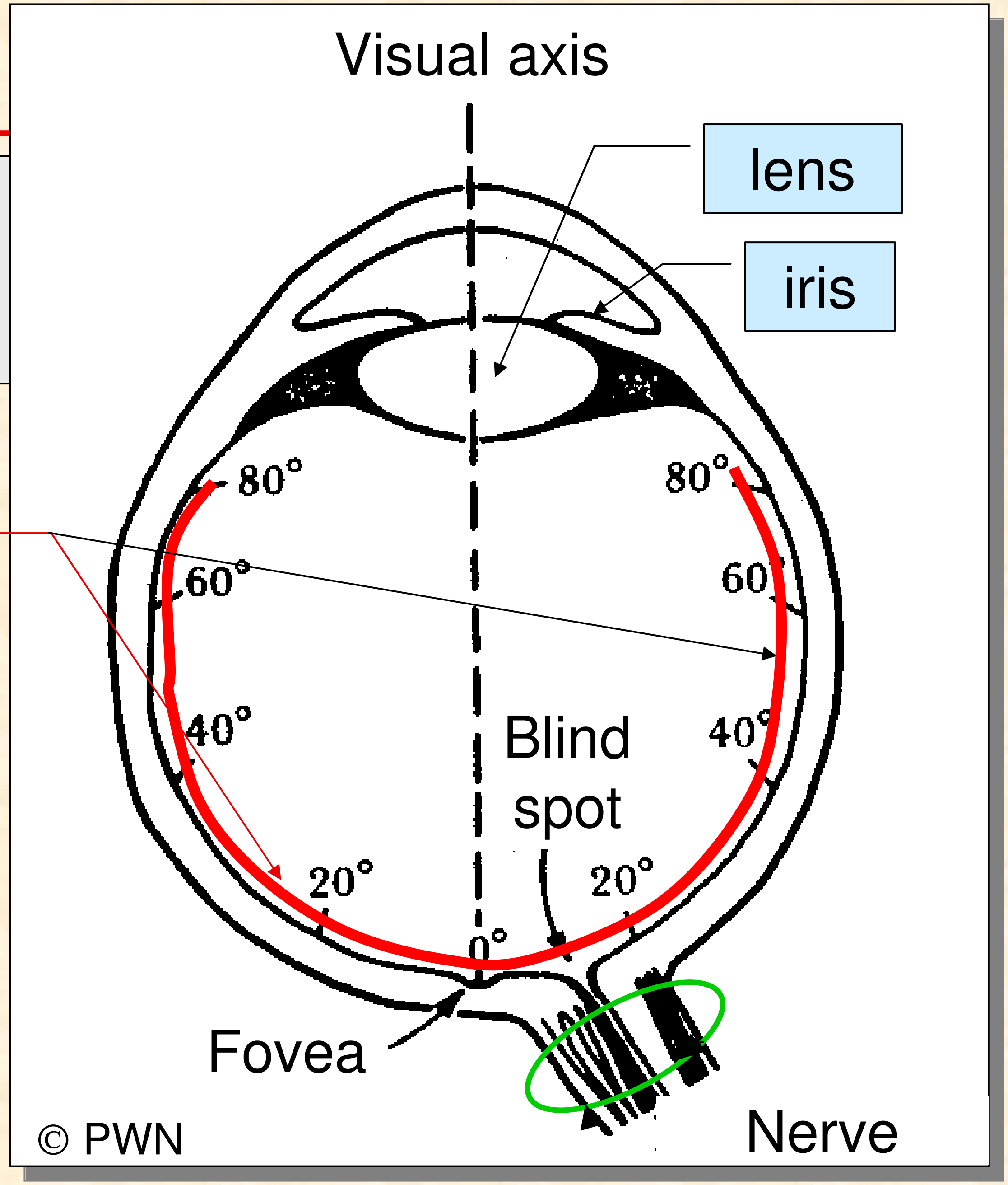
Human visual system



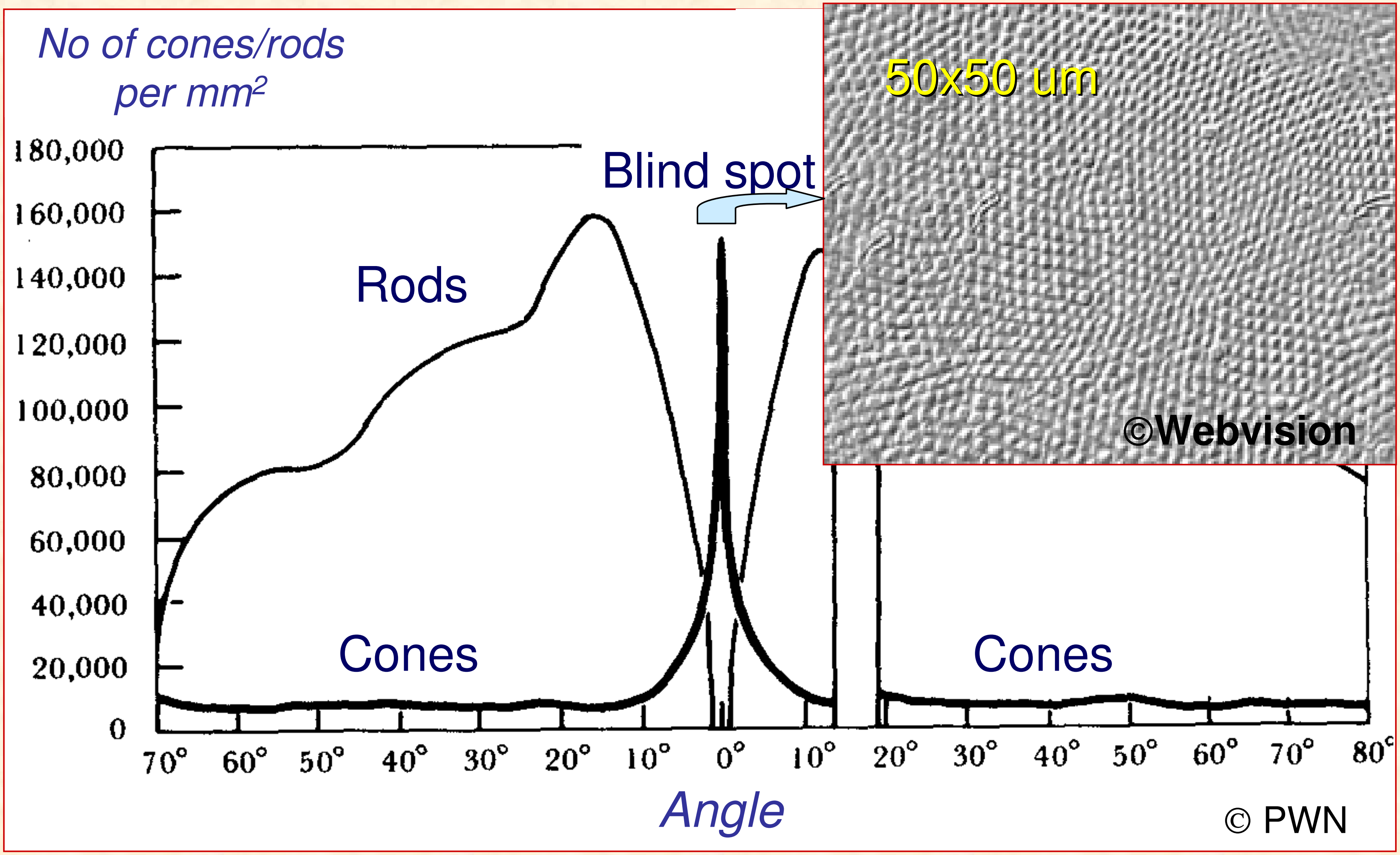


Structure of the human eye

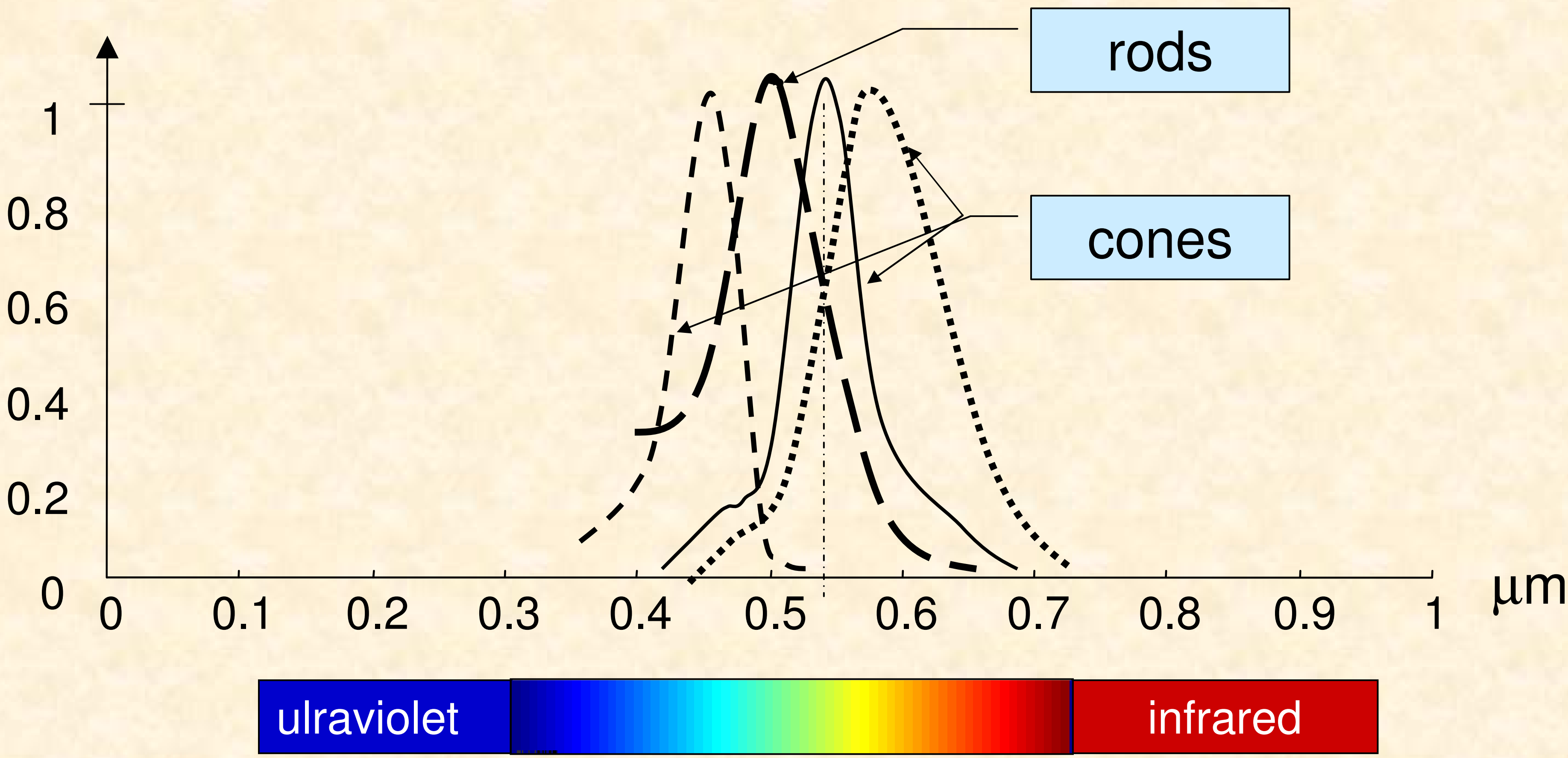
retina
125×10⁶
receptors



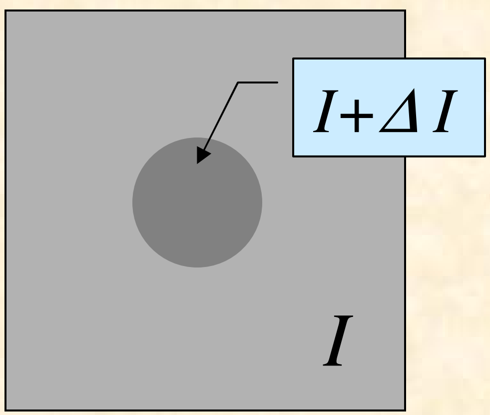
Distribution of rods and cones in the retina

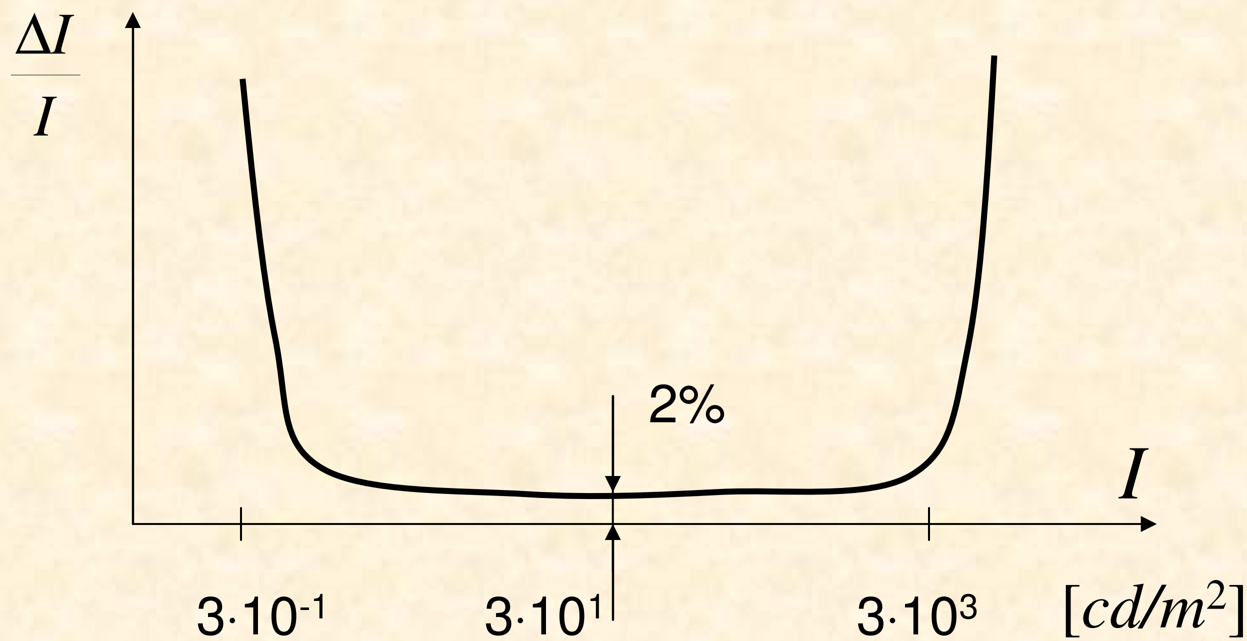


Spectral sensitivity characteristic of the human eye



Contrast sensitivity (Weber fraction)





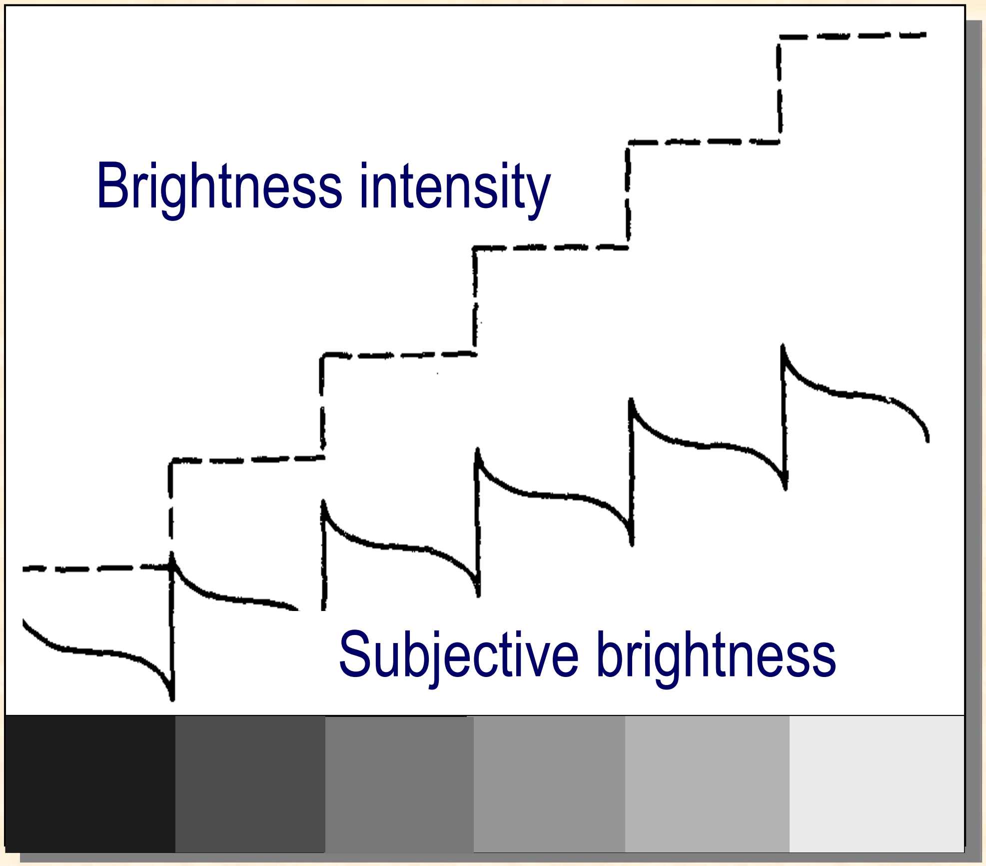
The ratio $\frac{\Delta I}{I}$ is termed the Weber fraction.

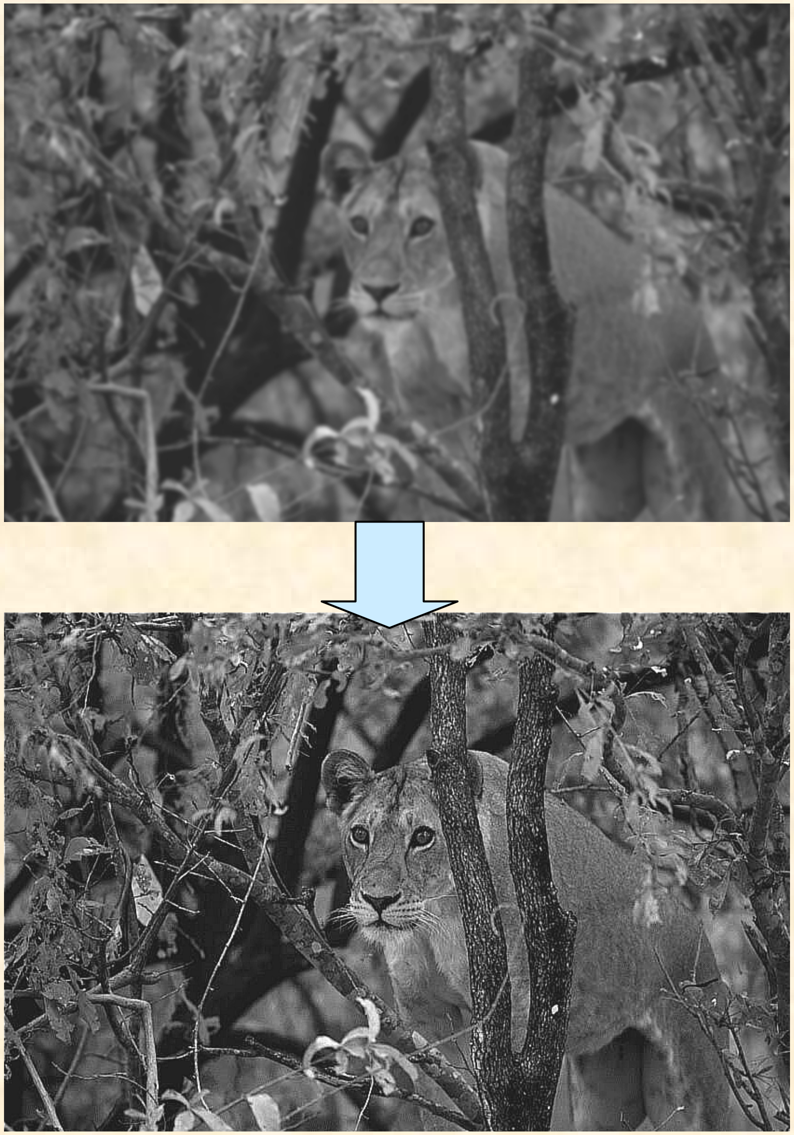
It reflects contrast sensitivity characteristc of the human eye.

Image coded using 16 gray levels

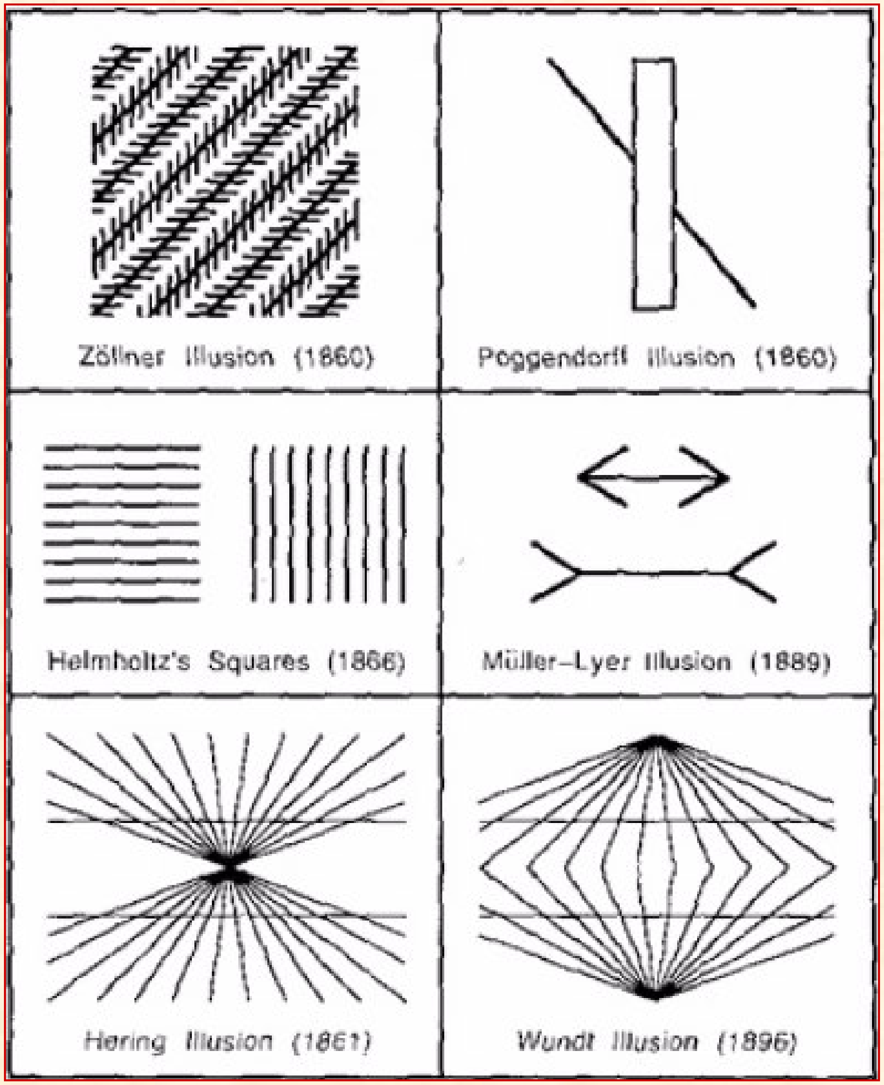
4 bits/pixel

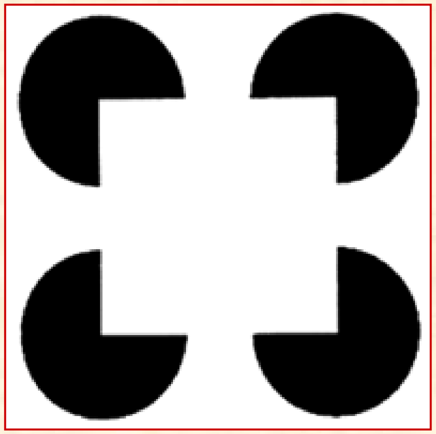
Mach bands





Visual illusions





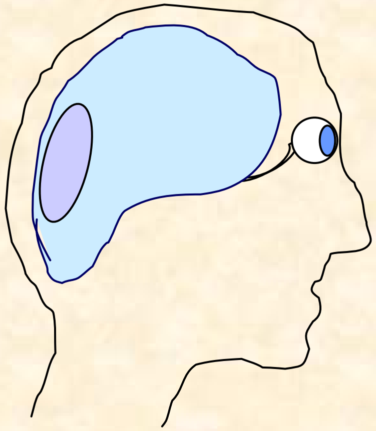
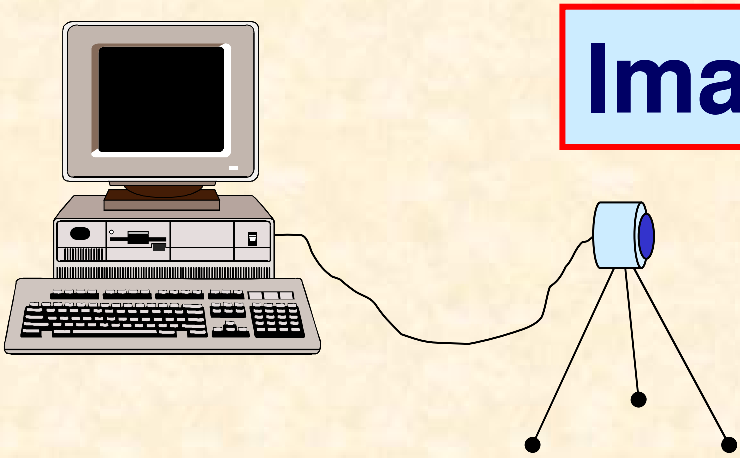


Image aquisition system



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.

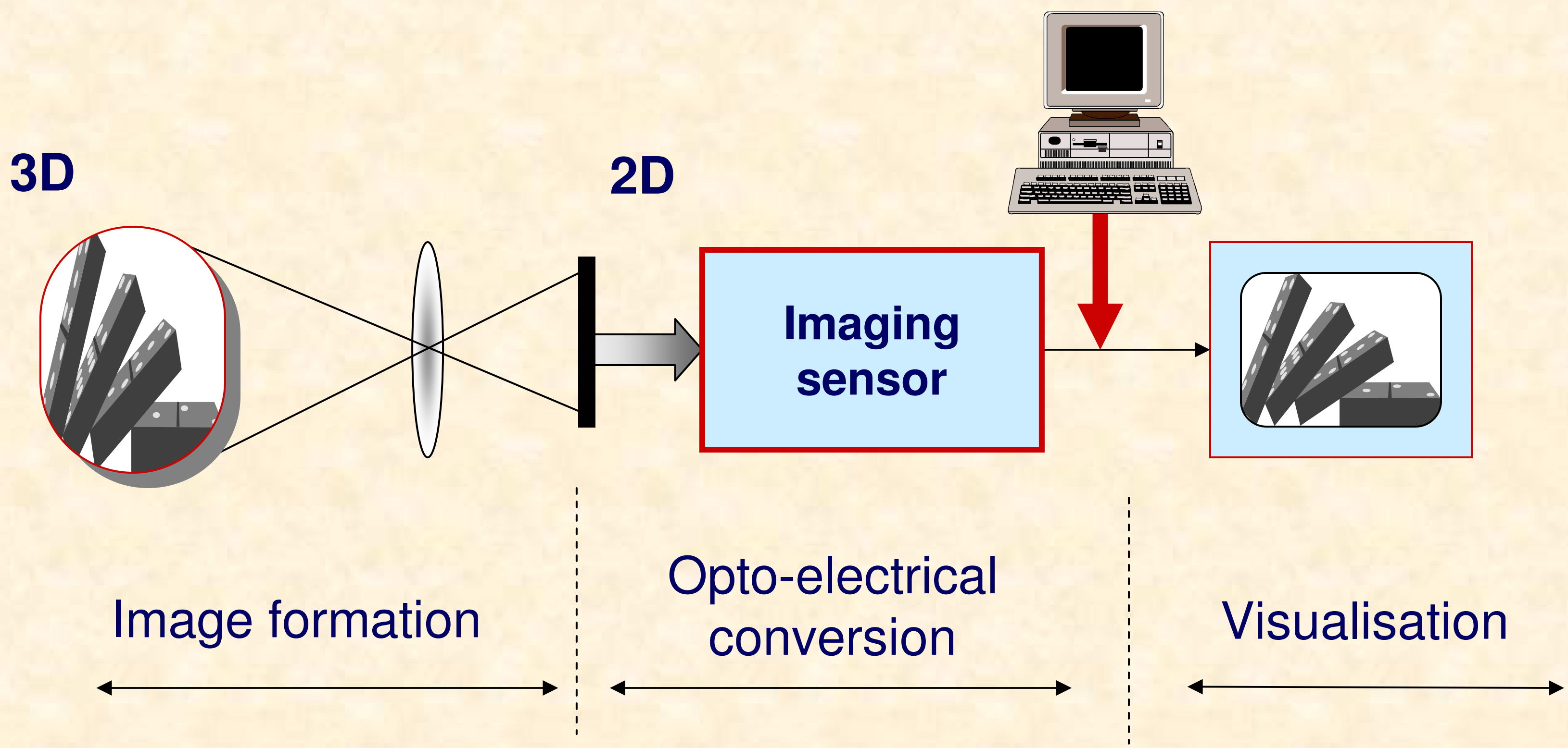


Image formation model

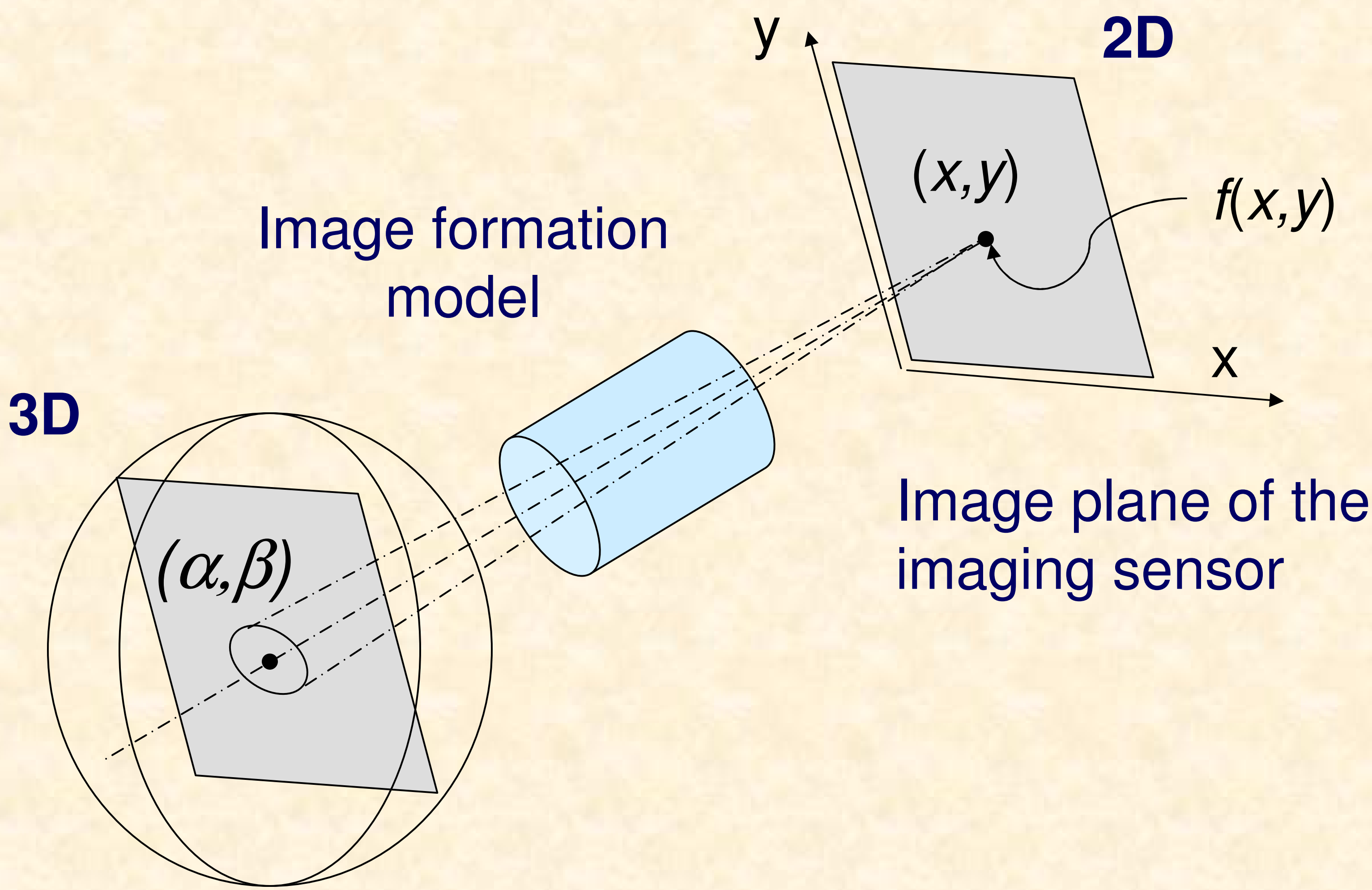


Image formation model

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

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

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

reflectance coefficient at (*x*,*y*)

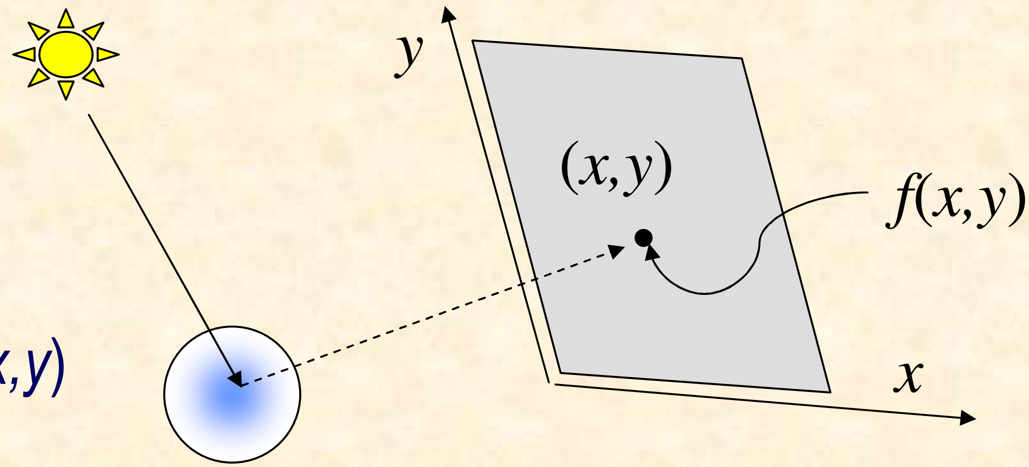


Image – a 2-D light intensity function *f*(*x*,*y*)>=0 reflecting light energy distribution

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.

Image formation model

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

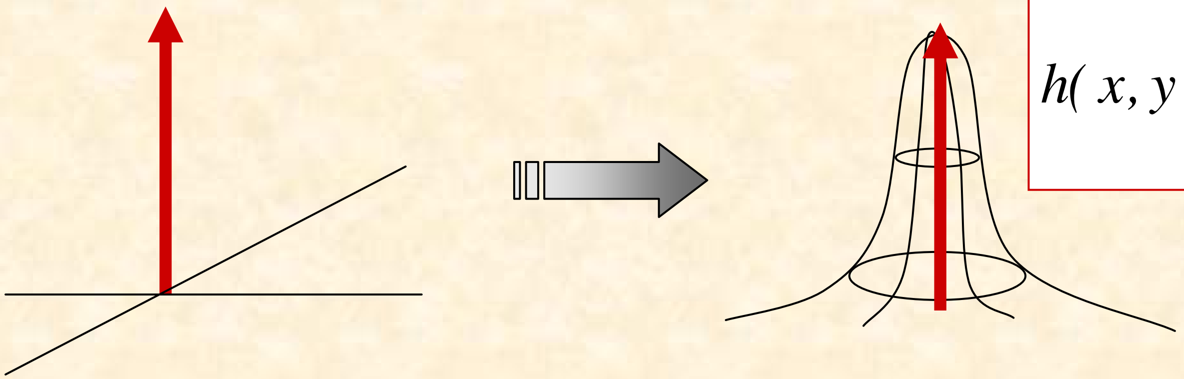
$$f(x,y)=\int_{-\infty}^{\infty}\int f(\alpha,\beta)h(x,y,\alpha,\beta)\,d\alpha\,d\beta$$

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

Image formation model

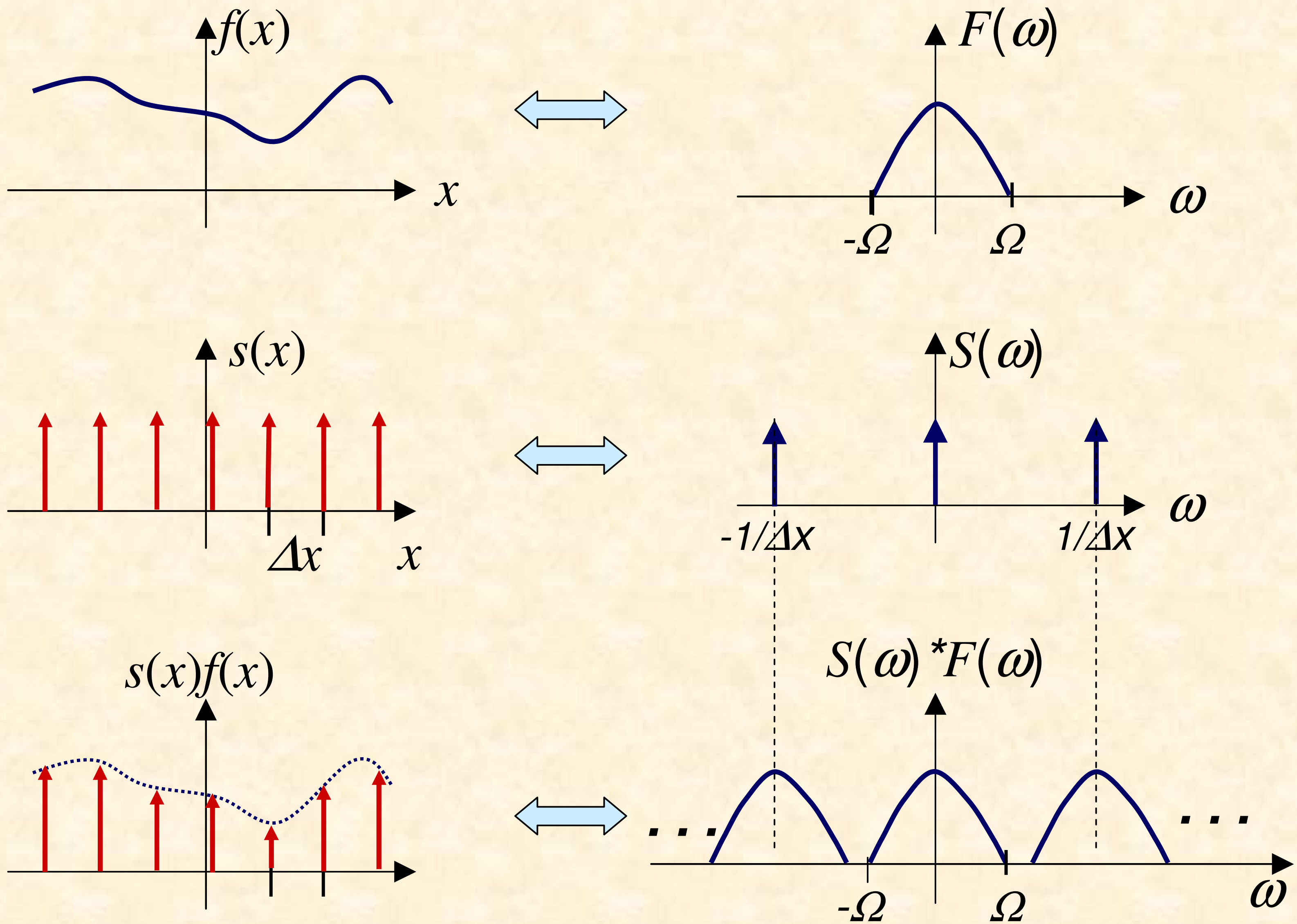
If the **point spread function** is shift invariant, then the image formation model is given by a convolution integral:

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



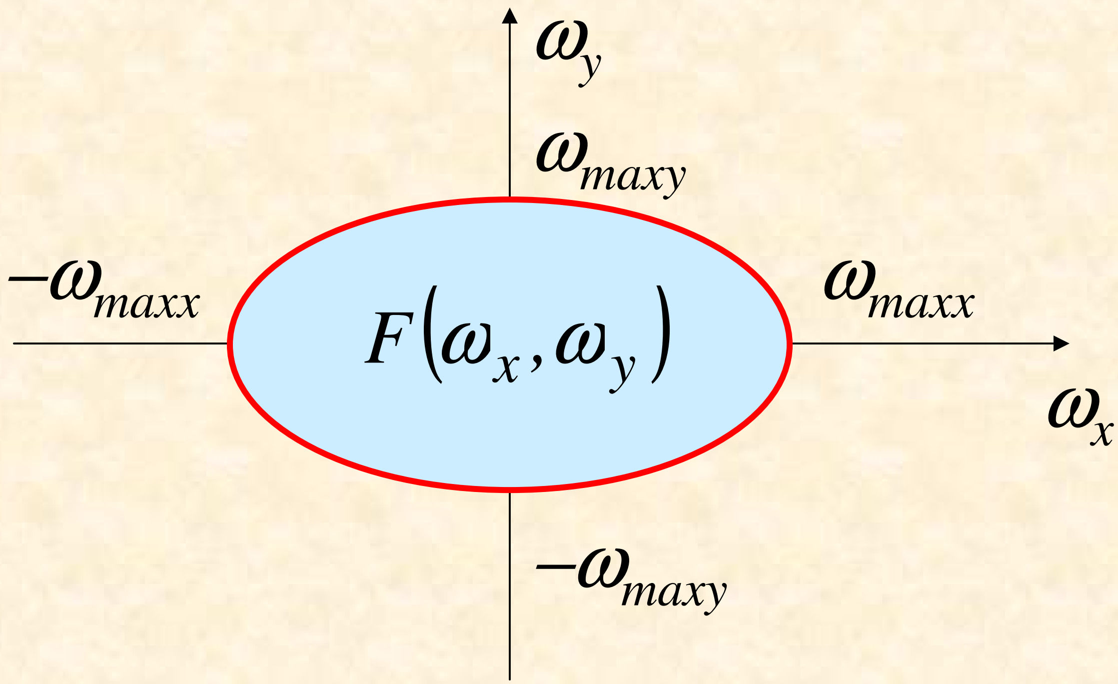
$$h(x,y)=exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)$$

Sampling of 1-D signals



Sampling of 2-D signals

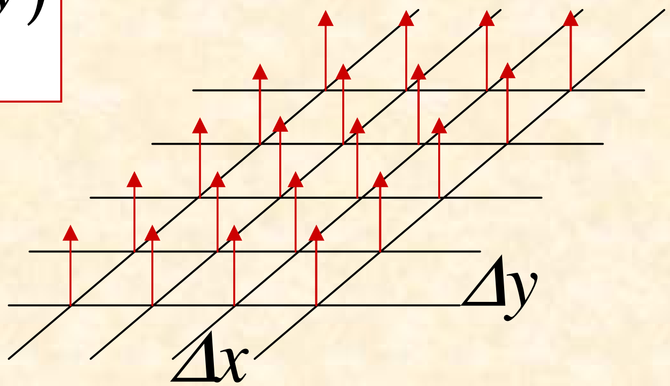
Assume the source image (analog image) features a limited Fourier bandwidth



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:

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

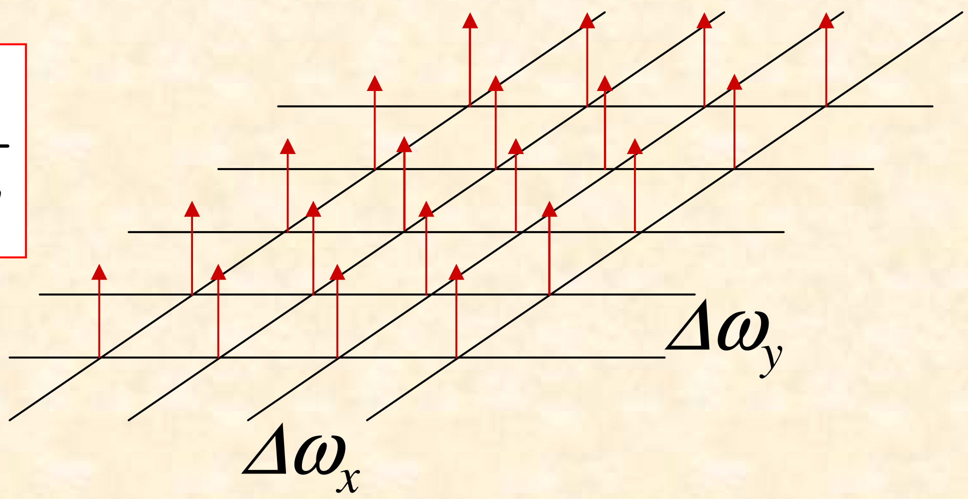
Sampling of 2-D signals

Fourier spectrum of the sampled image:

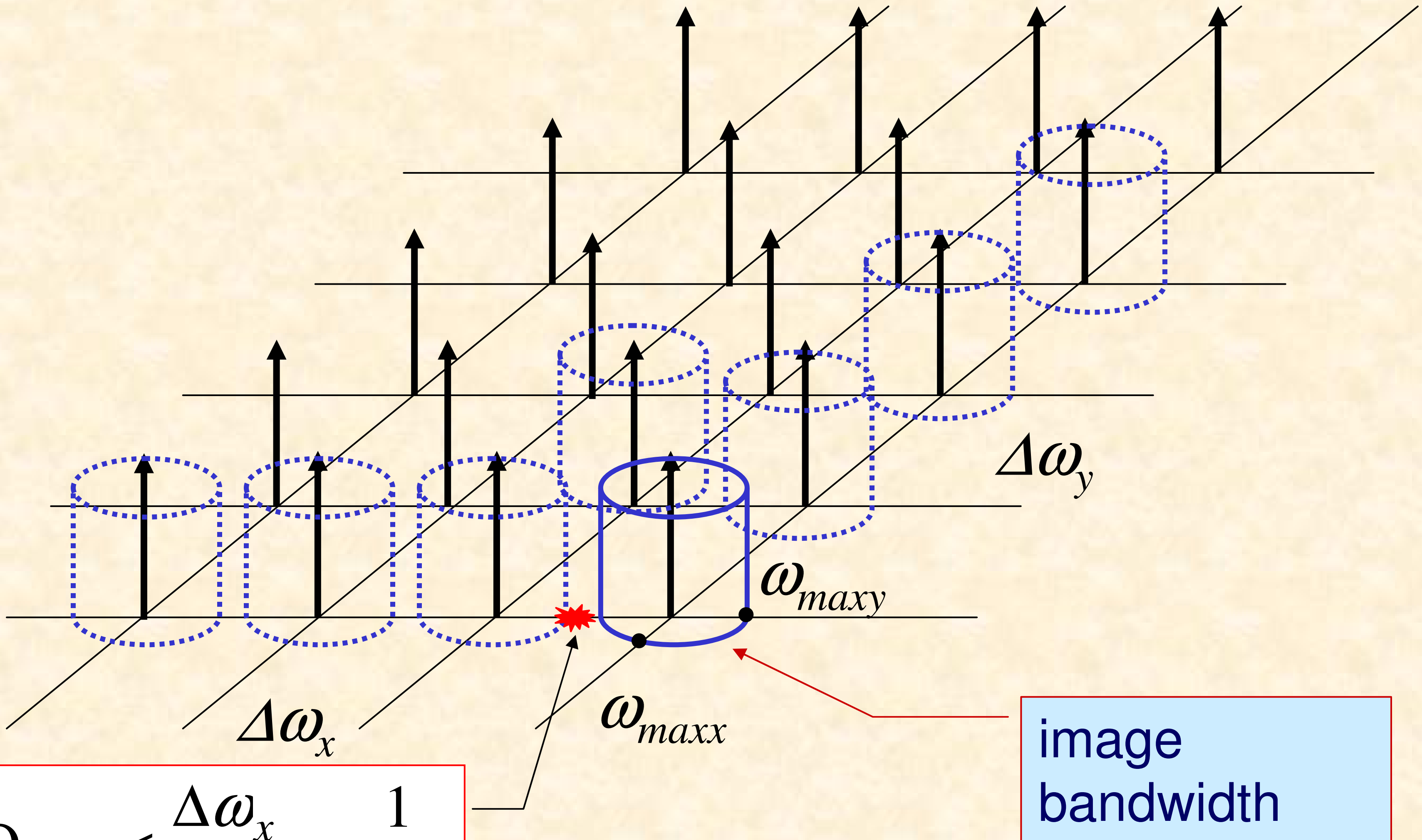
$$F_s(\omega_x, \omega_y) = \frac{1}{\Delta x \Delta y} \sum_{i=0}^{M-1} \sum_{k=0}^{N-1} F(\omega_x - i\Delta\omega_x, \omega_y - k\Delta\omega_y)$$

where:

$$\Delta\omega_x = \frac{1}{\Delta x}, \quad \Delta\omega_y = \frac{1}{\Delta y}$$

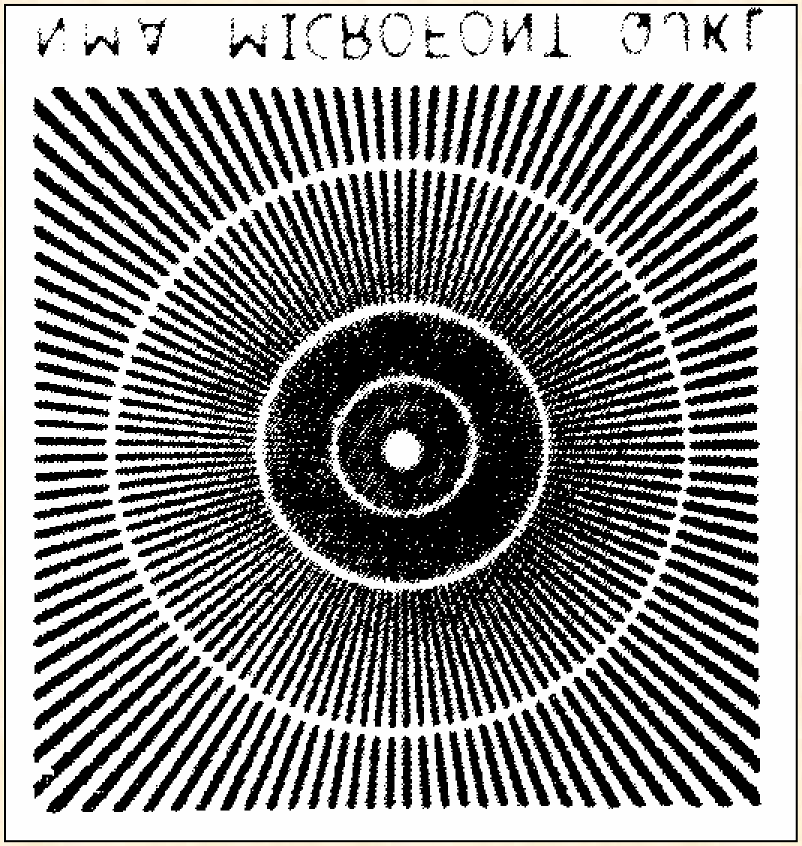


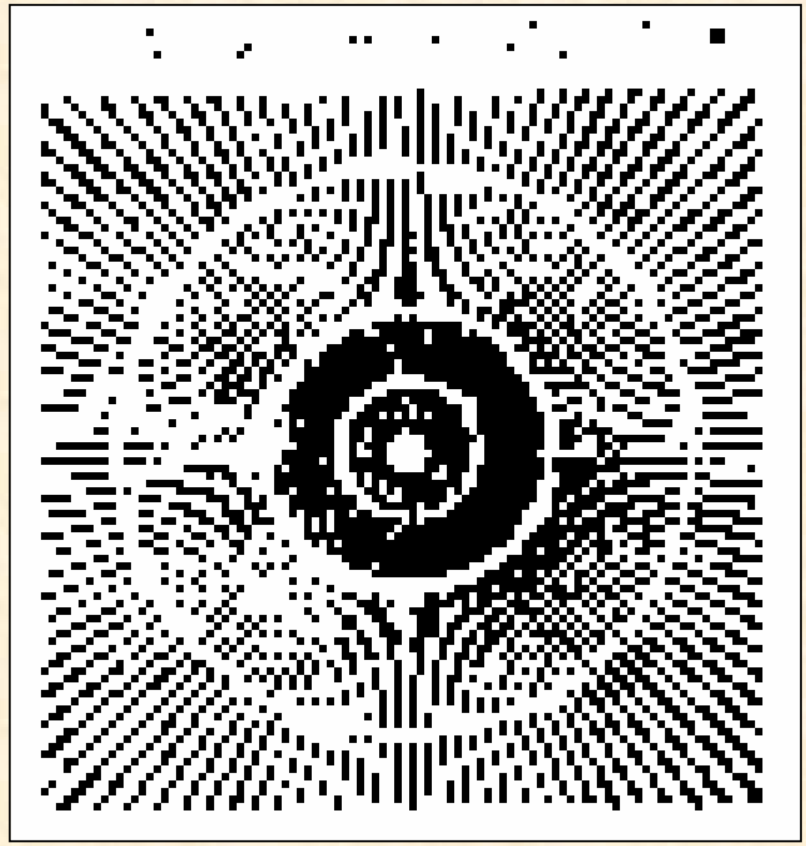
Sampling of 2-D signals



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

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:

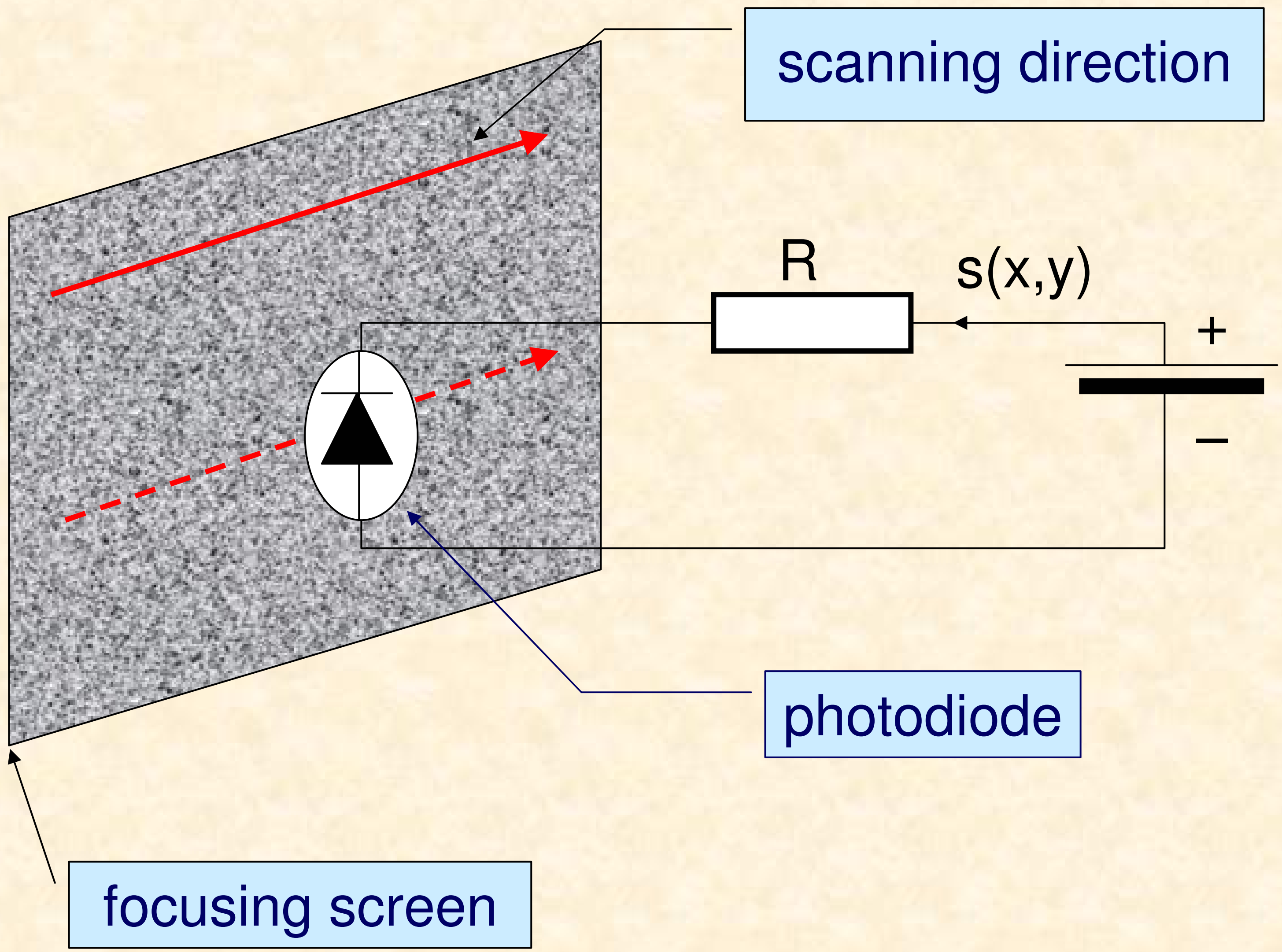
- **CCD camera**
- **Video camera**
- **Scanner**
- **Digitizer**

Image acquisition

There are two basic schems of converting optical images into electrical signals:

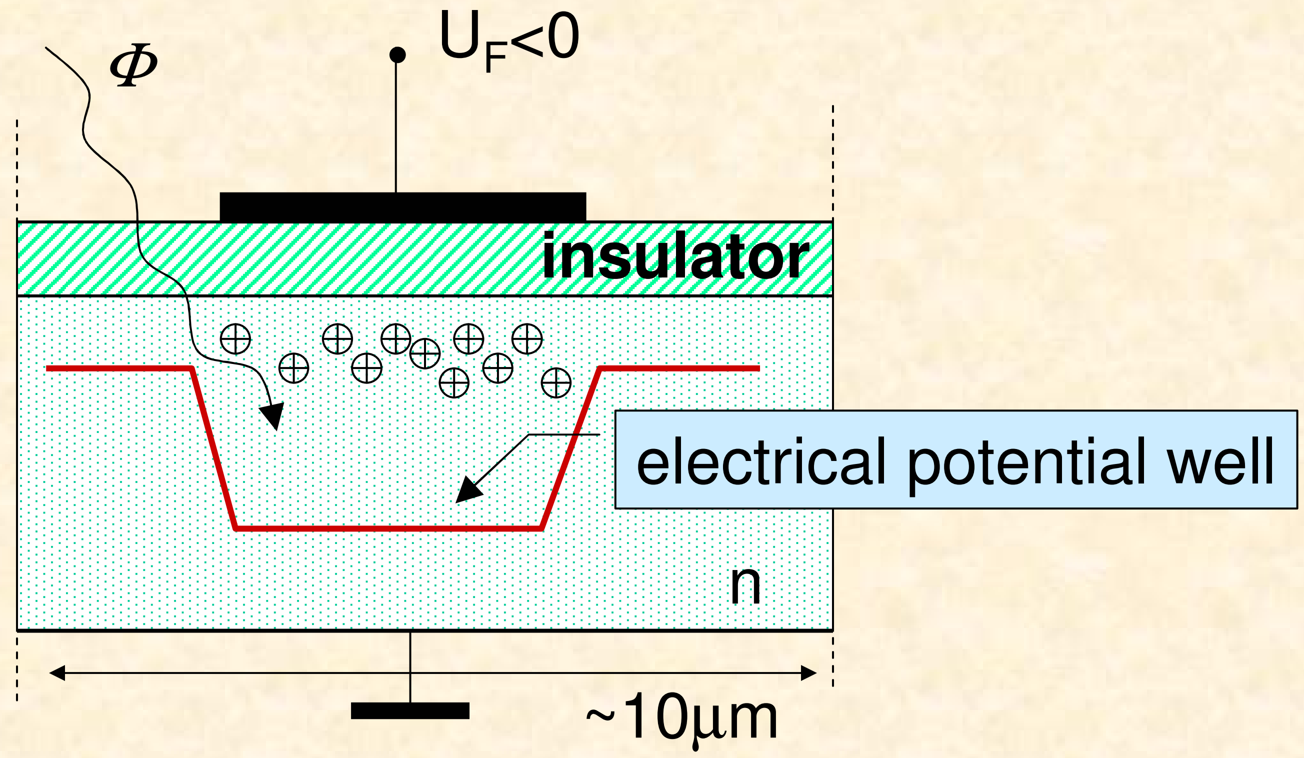
- **without accumulation of photo-charges** (eg. optical scanner),
- **with accumulation of photo-charges** (np. vidicon, CCD array)

Imaging sensor (no photo-charges)



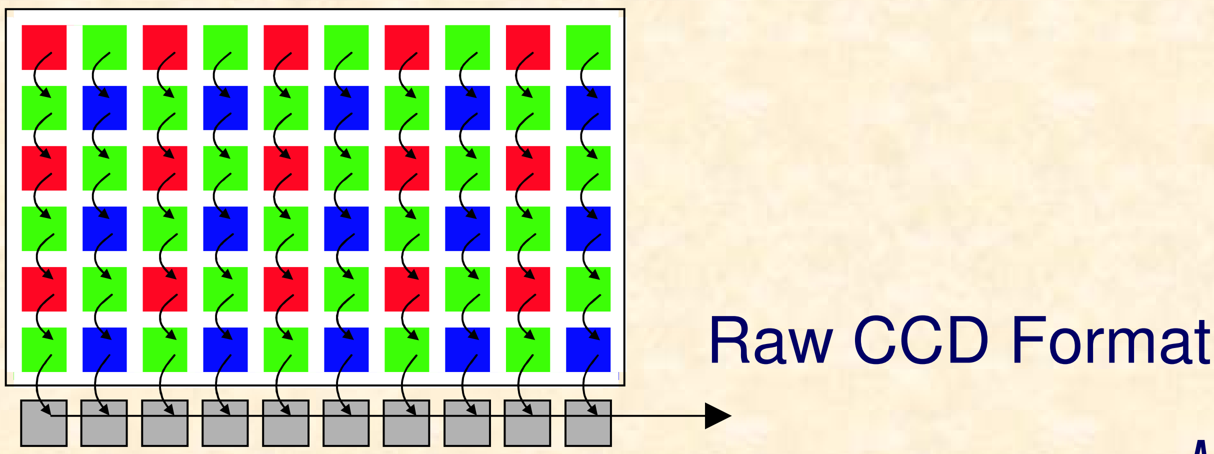
CCD array (accumulation of photo-charges)

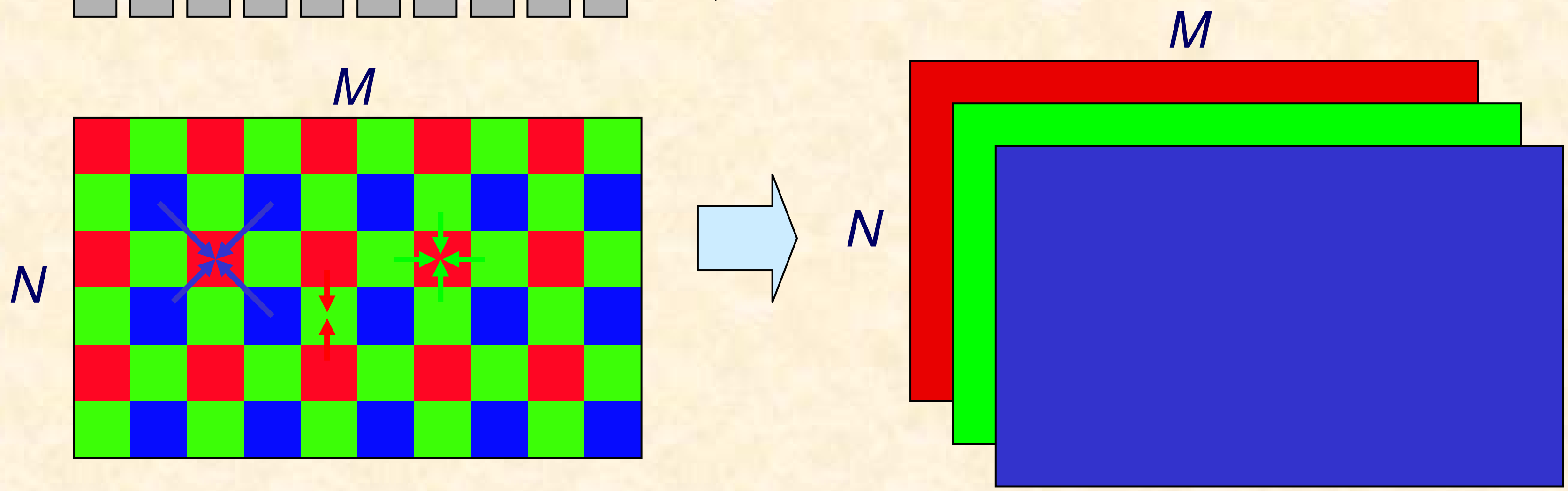
Image formation is based on the internal photo-electric phenomenon



Capacitor cell

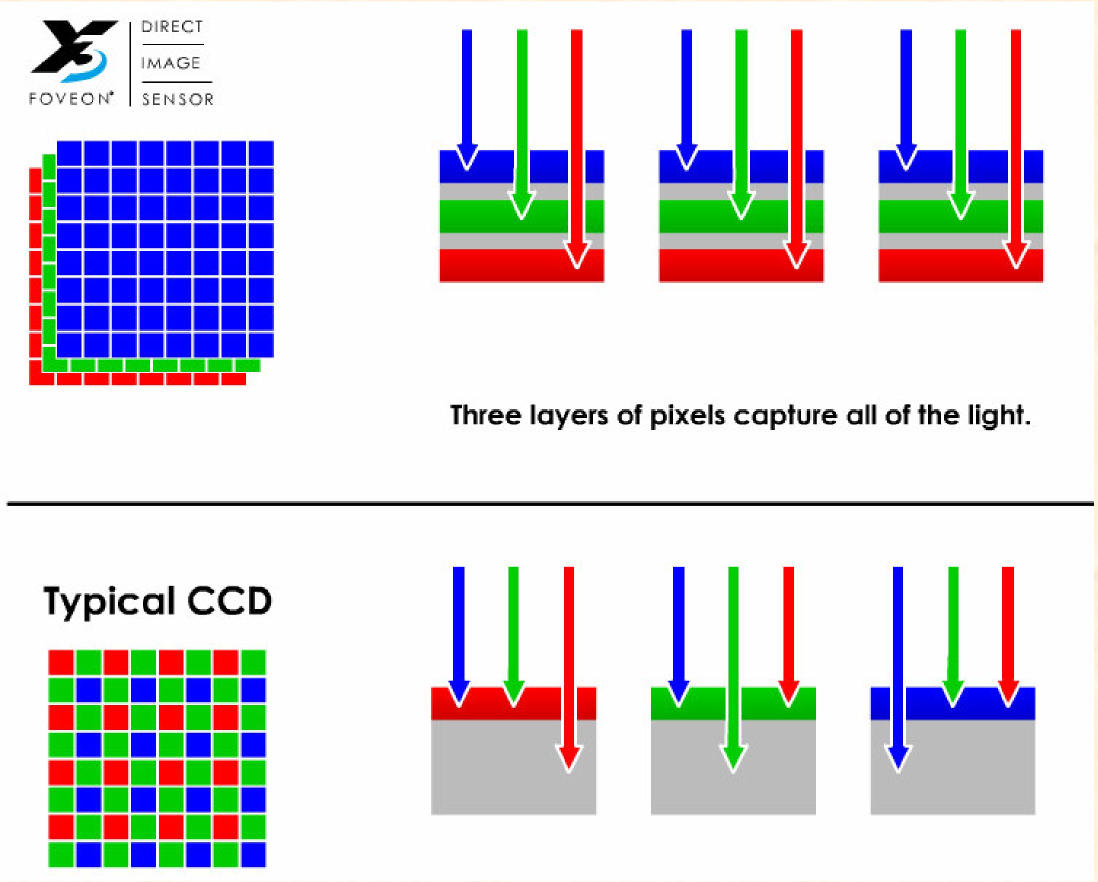
The Bayer matrix

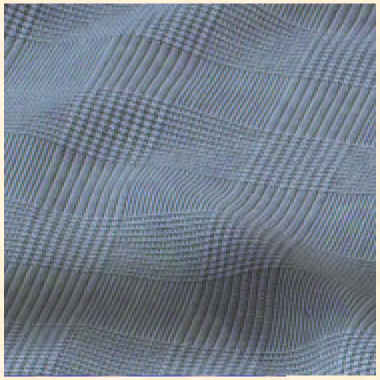


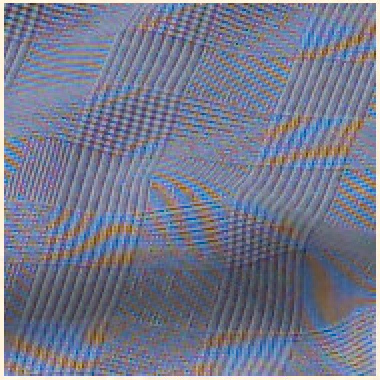


Calculate RGB image by interpolating colour components from the Bayer matrix

FOVEON matrix







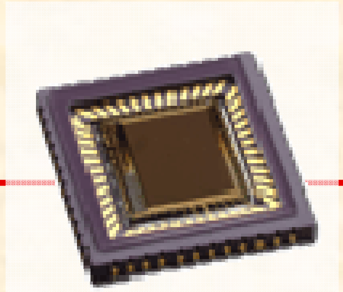
www.foveon.com

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 susceptibel to noise than CCD
- lower light sensitivity due to many transistors used for single pixel