Computer Vision – TP1
Image Formation

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Outline

- 'Computer Vision'?
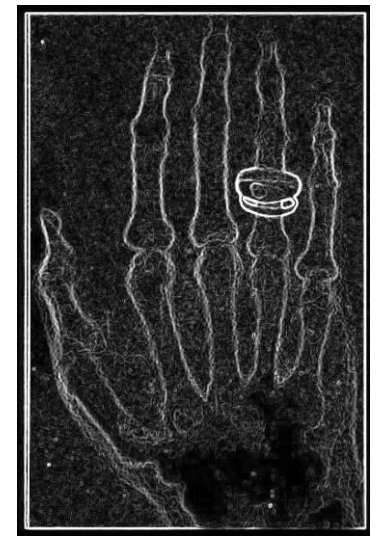- The Human Visual System
- Image Capturing Systems

Topic: Computer Vision?

- 'Computer Vision'?
- The Human Visual System
- Image Capturing Systems

Computer Vision

"The goal of Computer Vision is to make useful decisions about real physical objects and scenes based on sensed images",

Shapiro and Stockman, "Computer Vision", 2001

Fast Growing Field

- Technological evolution
  -> Deep neural networks
- Growing relevance to business contexts

- Consequences
  - Niche area -> Area of general interest
  - Change in programmatic content
  - Continuous education contexts
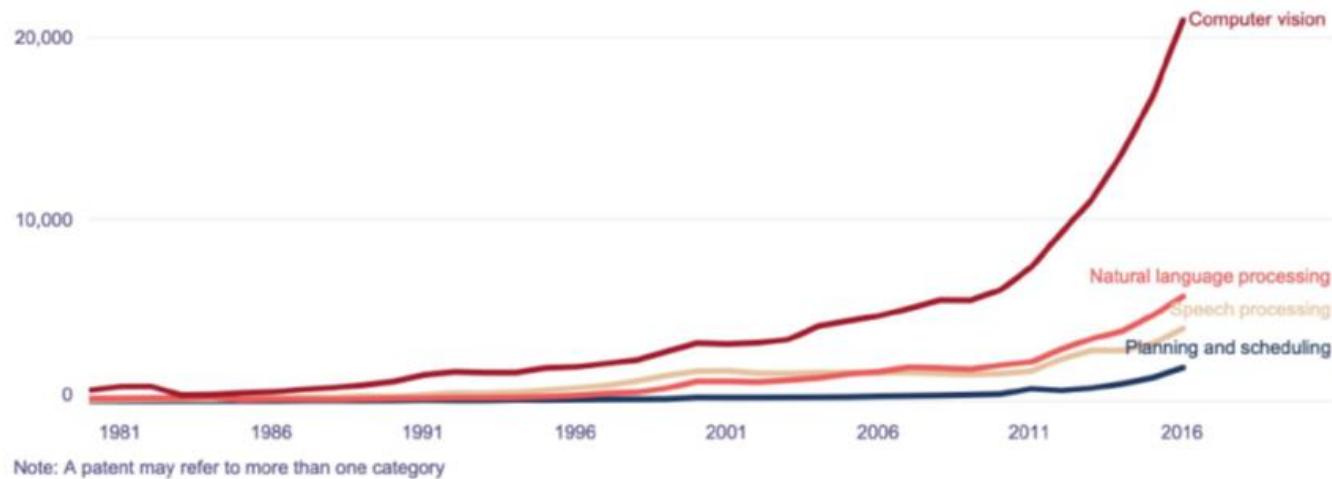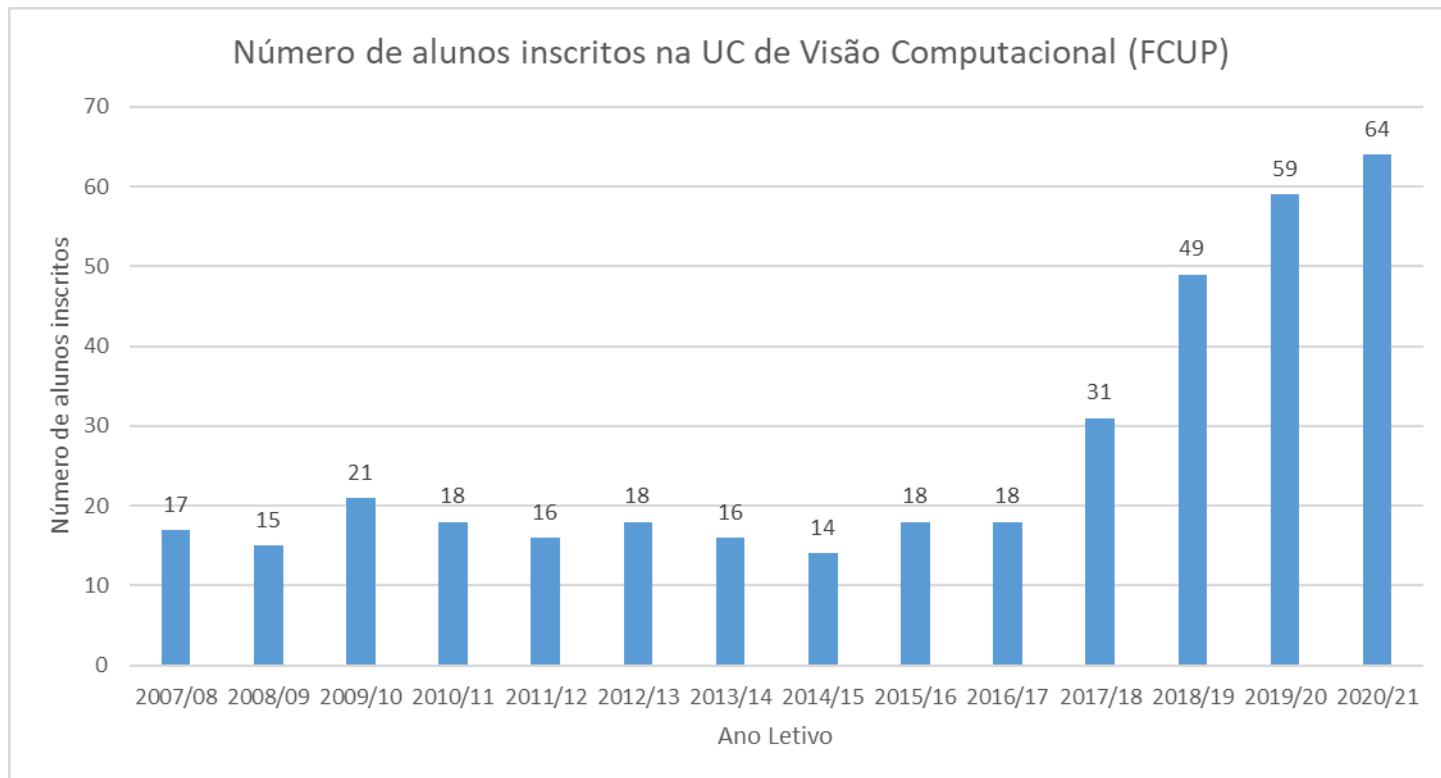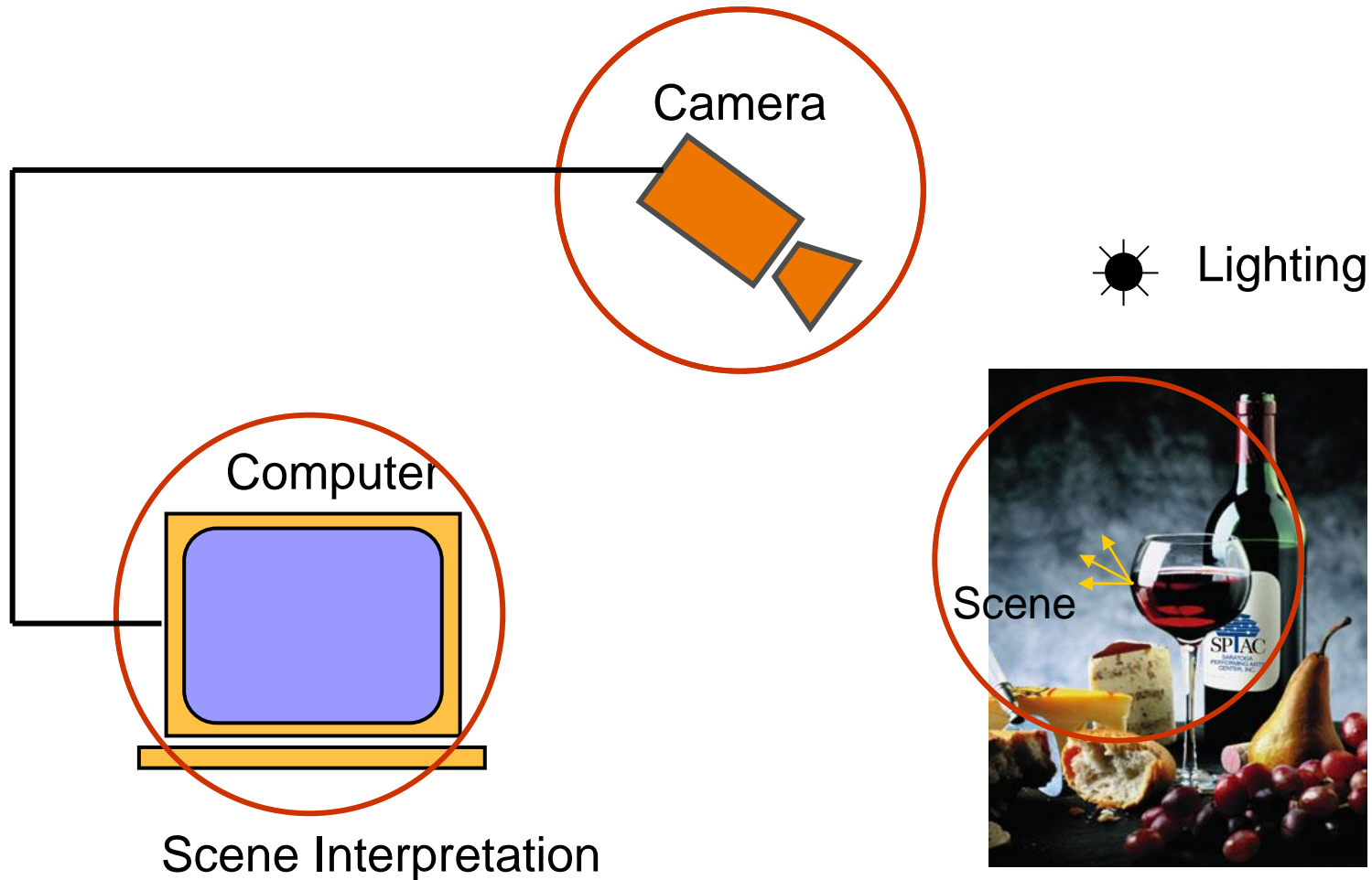

Figure 1 - Patents per year in Artificial Intelligence (WIPO, 2019)

VC Students @ FCUP

Número de alunos inscritos na UC de Visão Computacional (FCUP)

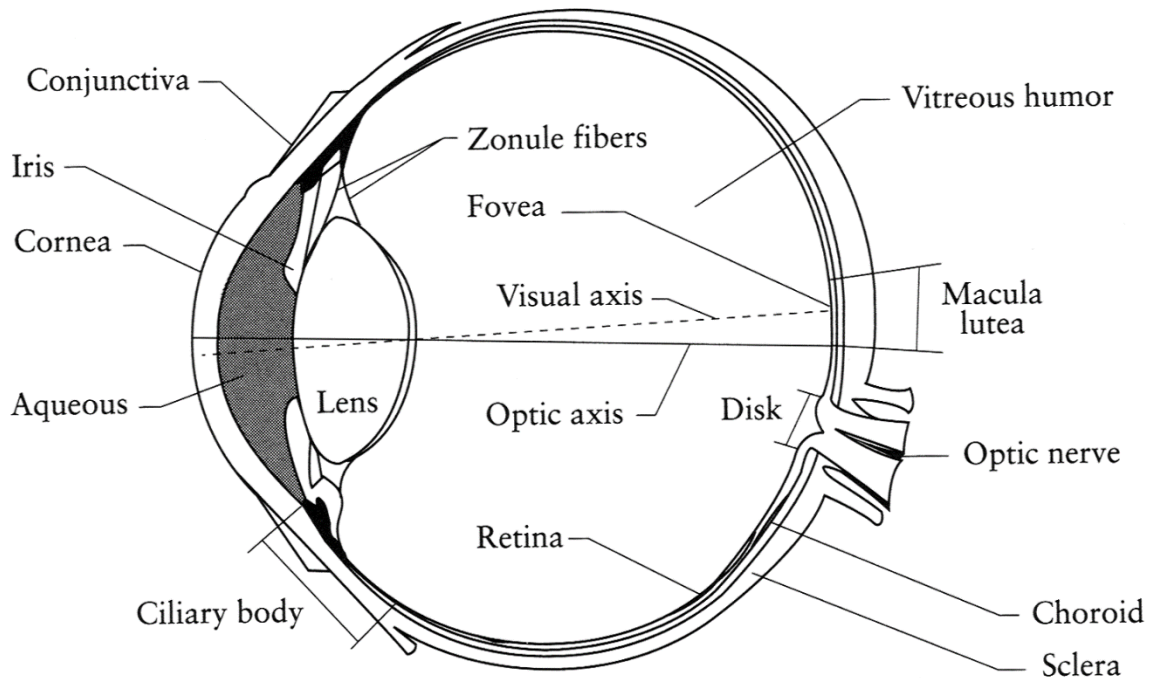# Components of a Computer Vision System

Camera

Lighting

Computer

Scene

Scene Interpretation
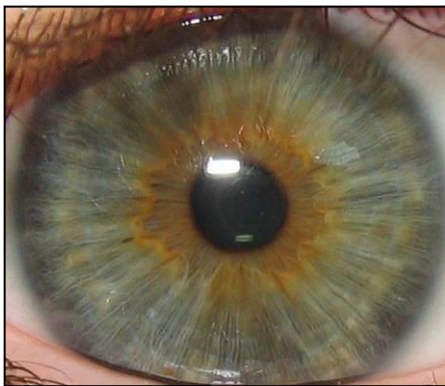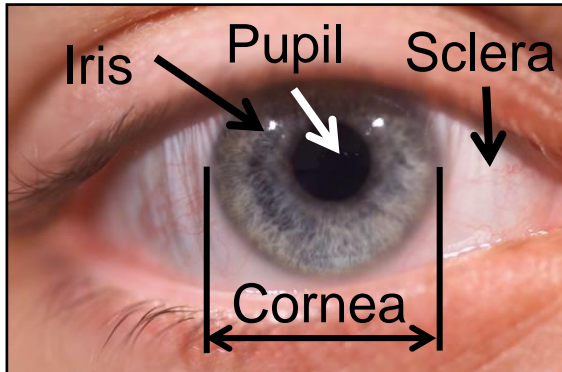
Topic: The Human Visual System

- 'Computer Vision'?
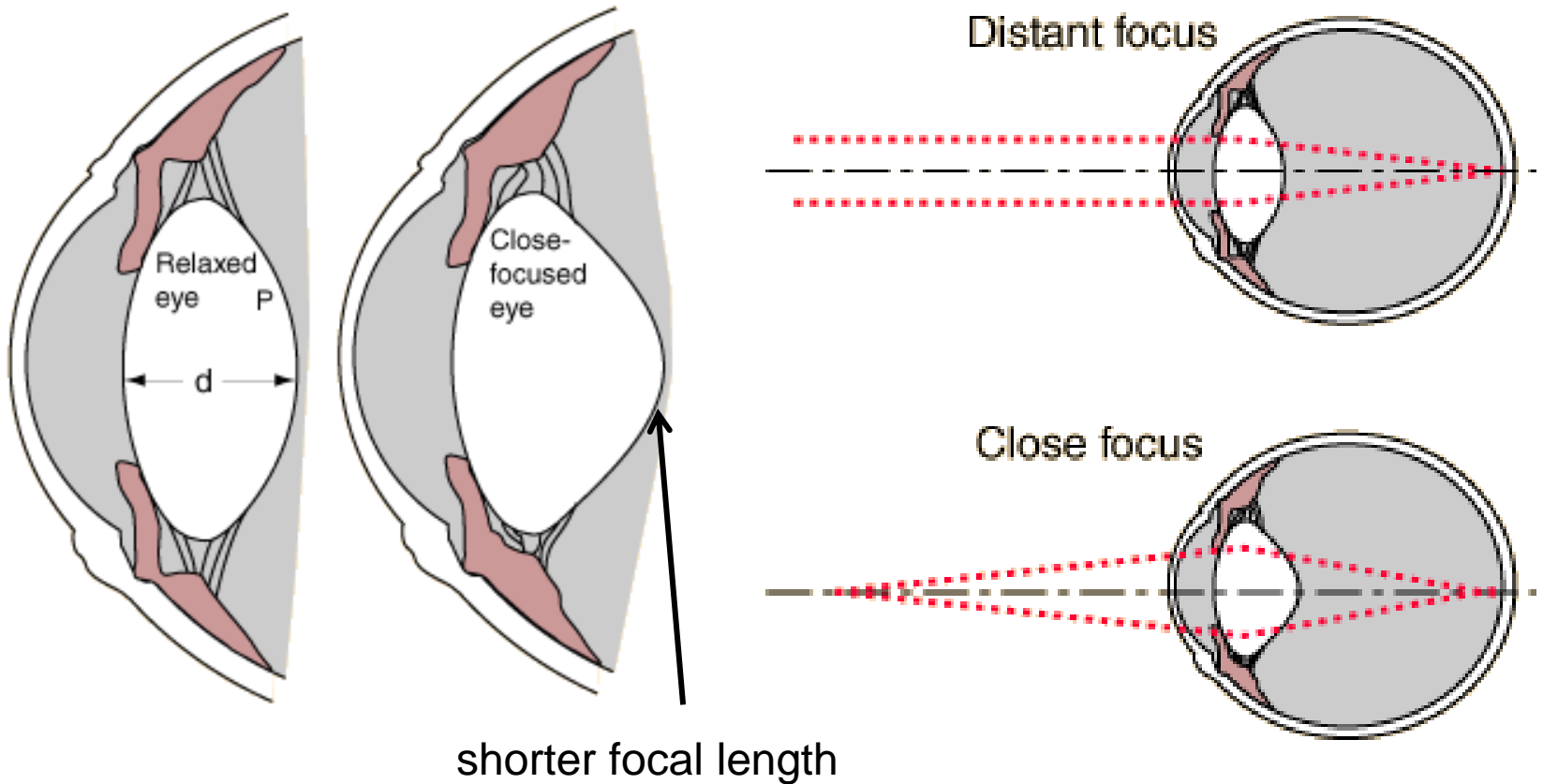- The Human Visual System
- Image Capturing Systems

Our Eyes

Iris is the diaphragm that changes the aperture (pupil)
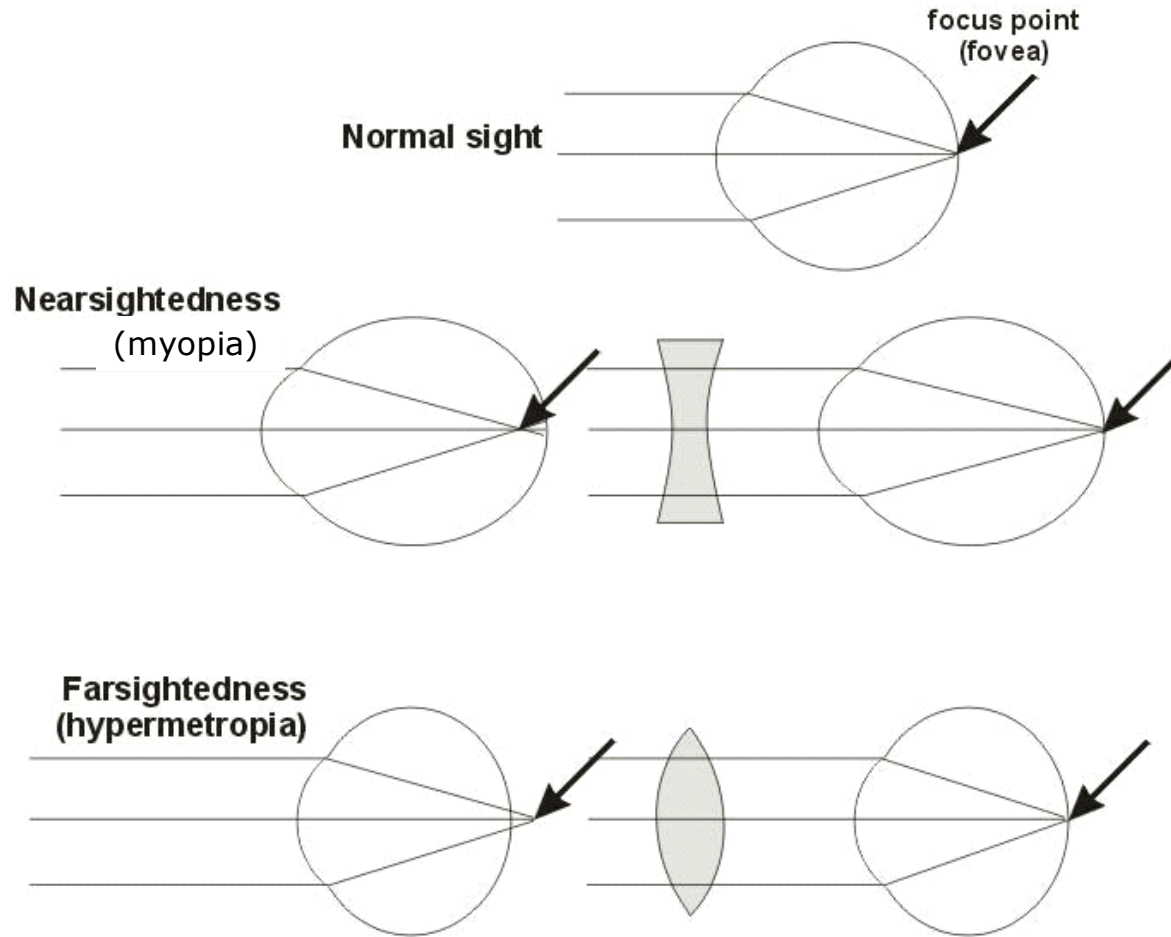
Retina is the sensor where the fovea has the highest resolution

Focusing

shorter focal length

Changes the focal length of the lens

Myopia and Hyperopia

focus point (fovea)

Normal sight

Nearsightedness (myopia)

Farsightedness (hypermetropia)
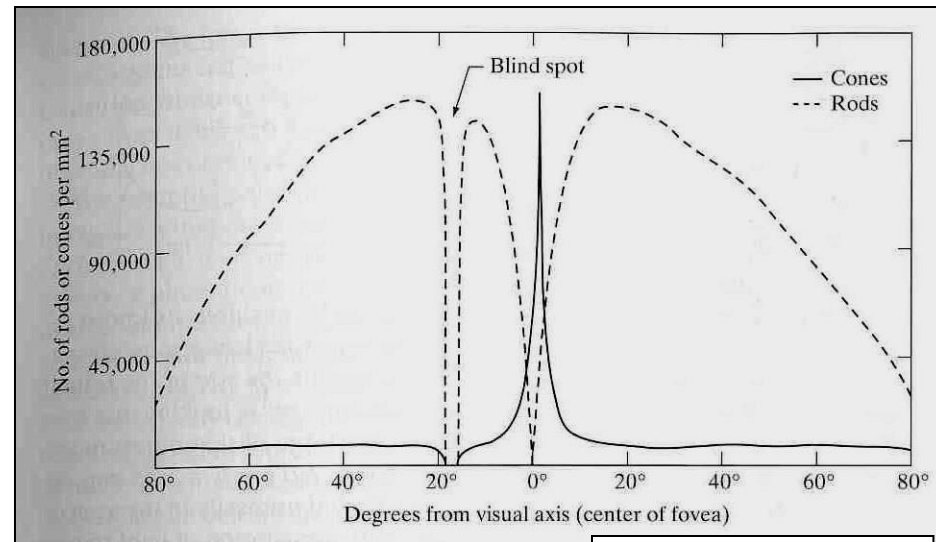
Blind Spot in the Eye

●   **+**

Close your right eye and look directly at the "+"

Colour

- Our retina has:
  - **Cones** – Measure the frequency of light (colour)
    - 6 to 7 millions
    - High-definition
    - Need high luminosity
  - **Rods** – Measure the intensity of light (luminance)
    - 75 to 150 millions
    - Low-definition
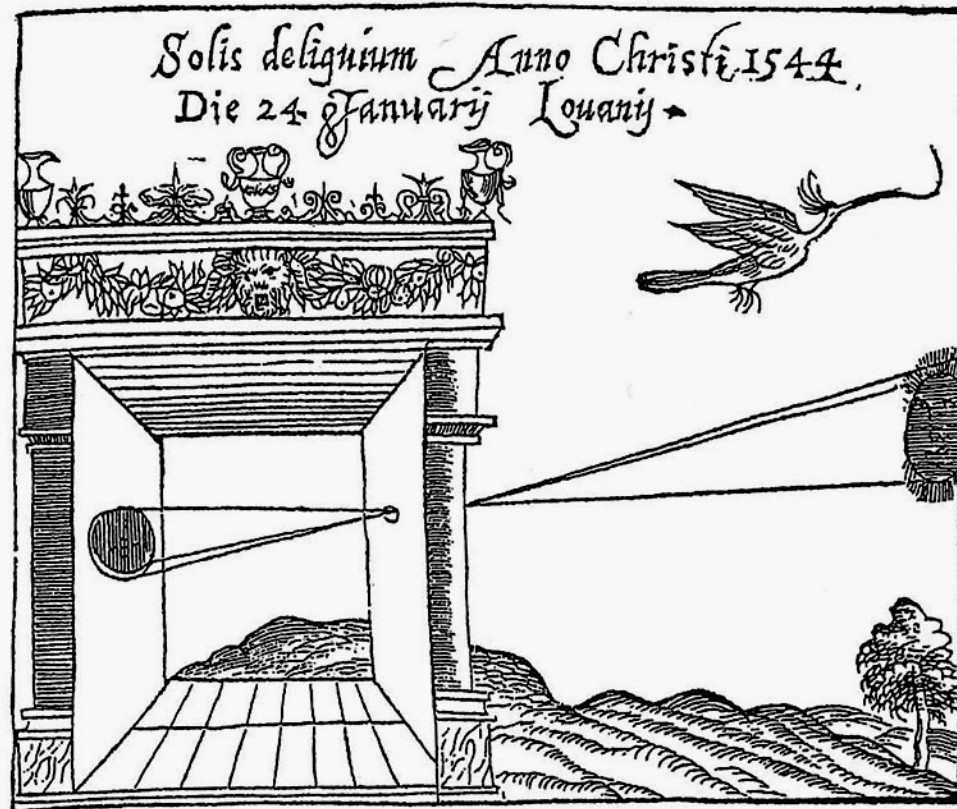   - Function with low luminosity

Gonzalez & Woods

We only see colour in the centre of our retina!

Topic: Image Capturing Systems

- 'Computer Vision'?
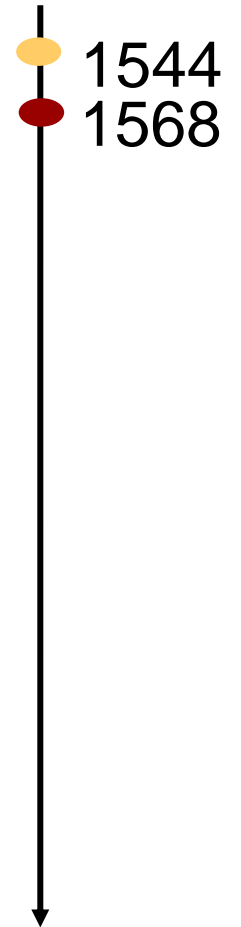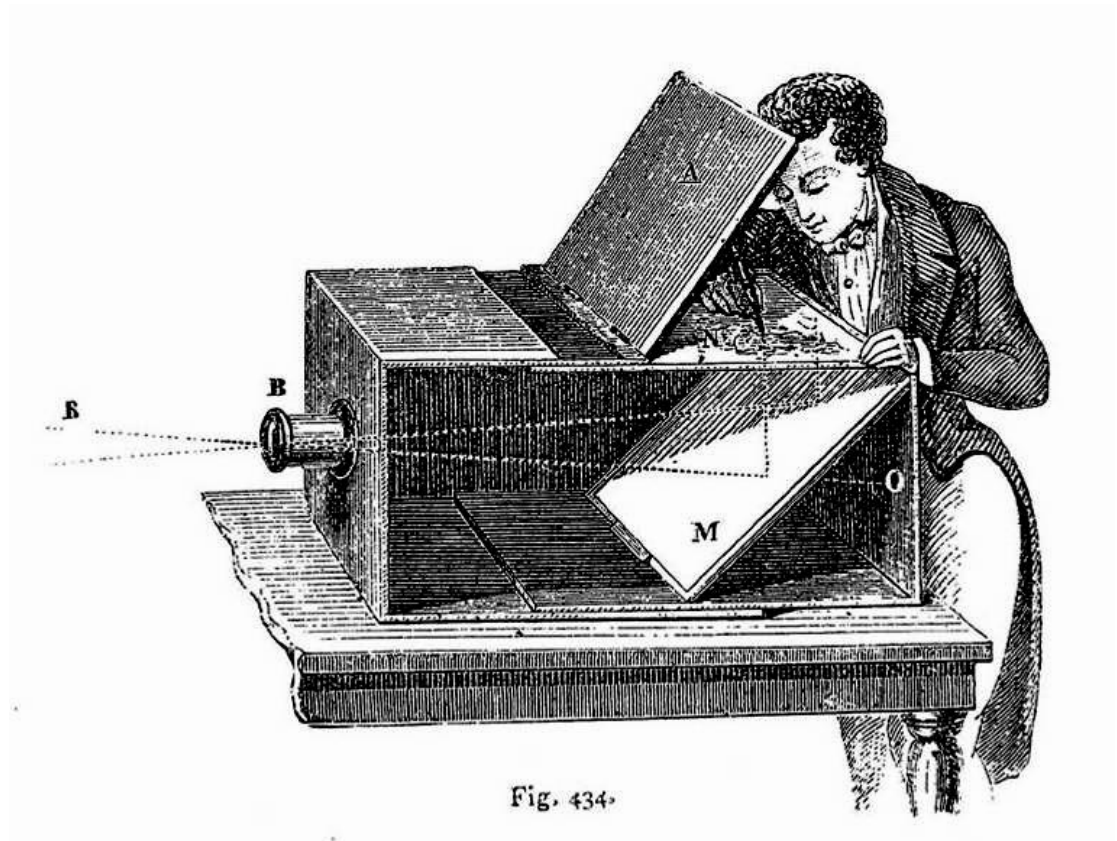- The Human Visual System
- Image Capturing Systems

A Brief History of Images

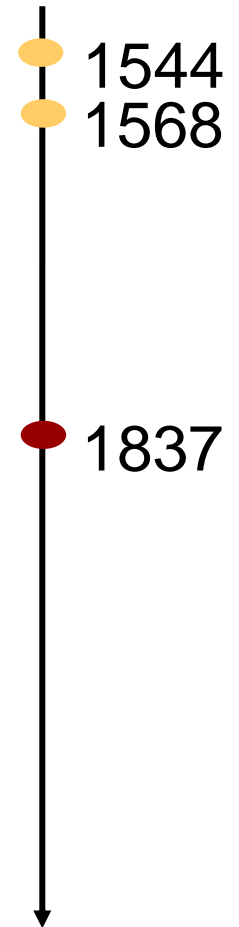*Camera Obscura*, Gemma Frisius, 1544

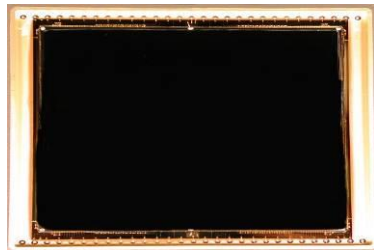# A Brief History of Images

Lens Based Camera Obscura, 1568
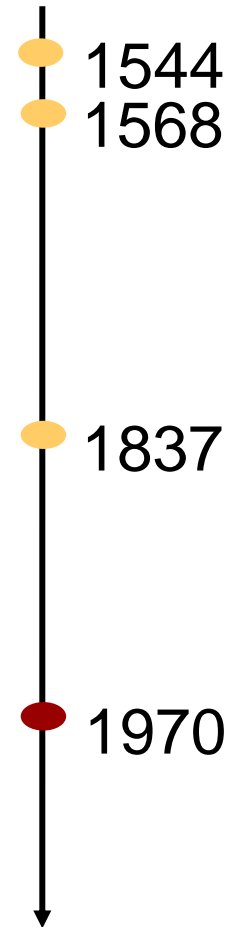
1544
1568

A Brief History of Images

1544

1568

1837

Still Life, Louis Jaques Mande Daguerre, 1837

U.PORTO

A Brief History of Images

Silicon Image Detector, 1970

1544
1568

1837

1970

A Brief History of Images

Digital Cameras

1544
1568

1837

1970
1995

Components of a Computer Vision System

Camera

Lighting

Computer

Scene

Scene Interpretation
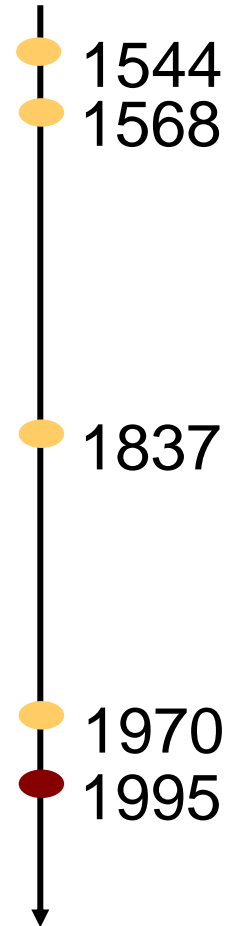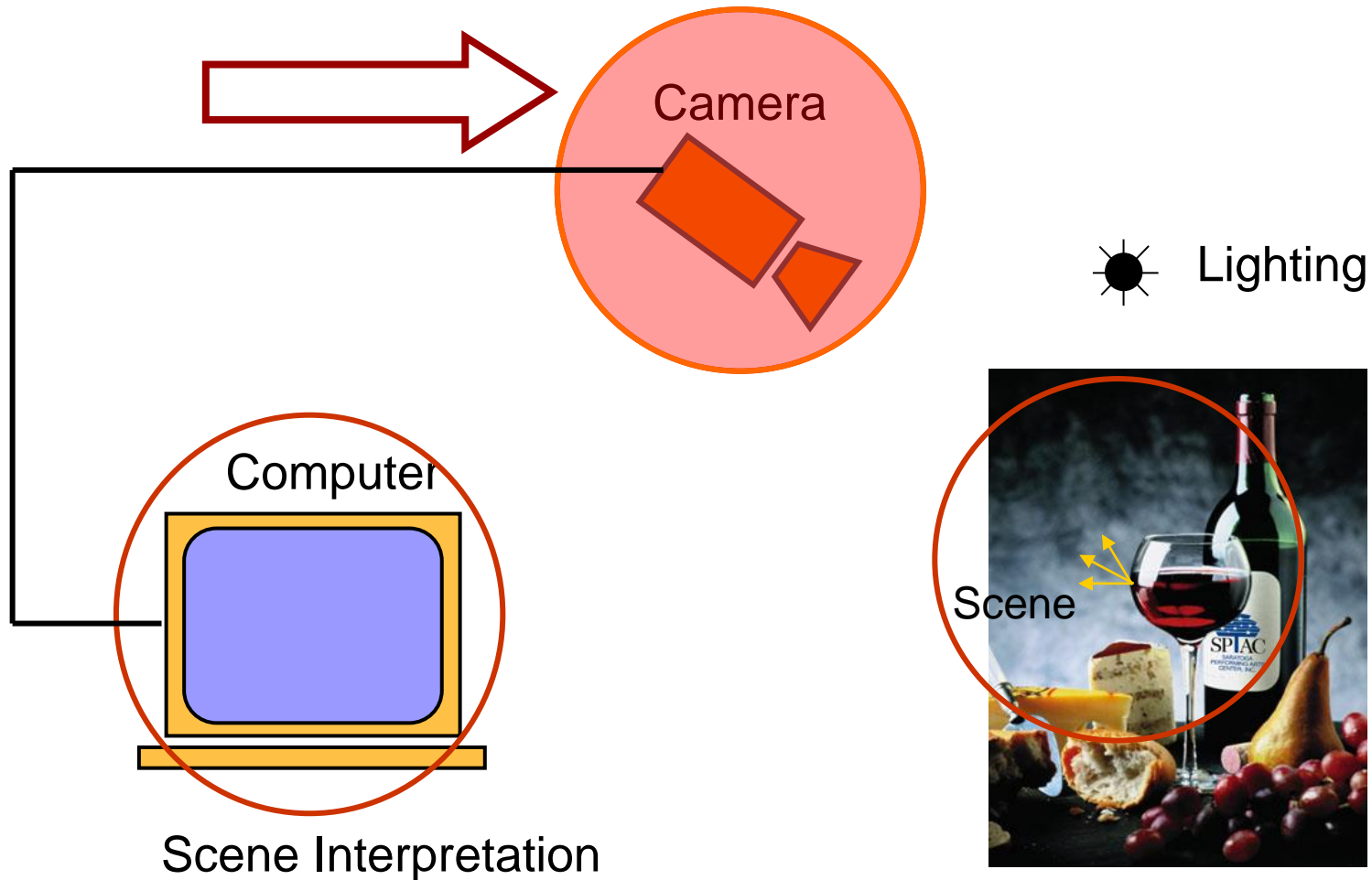
Pinhole and the Perspective Projection

(x,y)

screen

image plane

scene

Is an image being formed on the screen?

YES!   But, not a "clear" one.

$\mathbf{r} = (x, y, z)$

y

effective focal length, $\mathbf{f'}$

z

optical axis

pinhole

x

$\mathbf{r'} = (x', y', f')$

$$\frac{\mathbf{r'}}{f'} = \frac{\mathbf{r}}{z} \quad \Rightarrow \quad \frac{x'}{f'} = \frac{x}{z} \qquad \frac{y'}{f'} = \frac{y}{z}$$

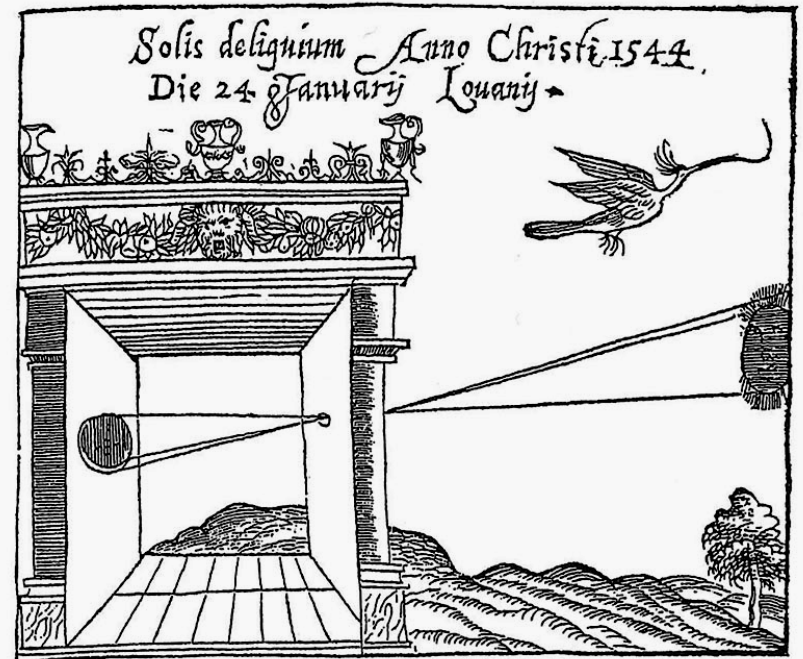U.PORTO FC
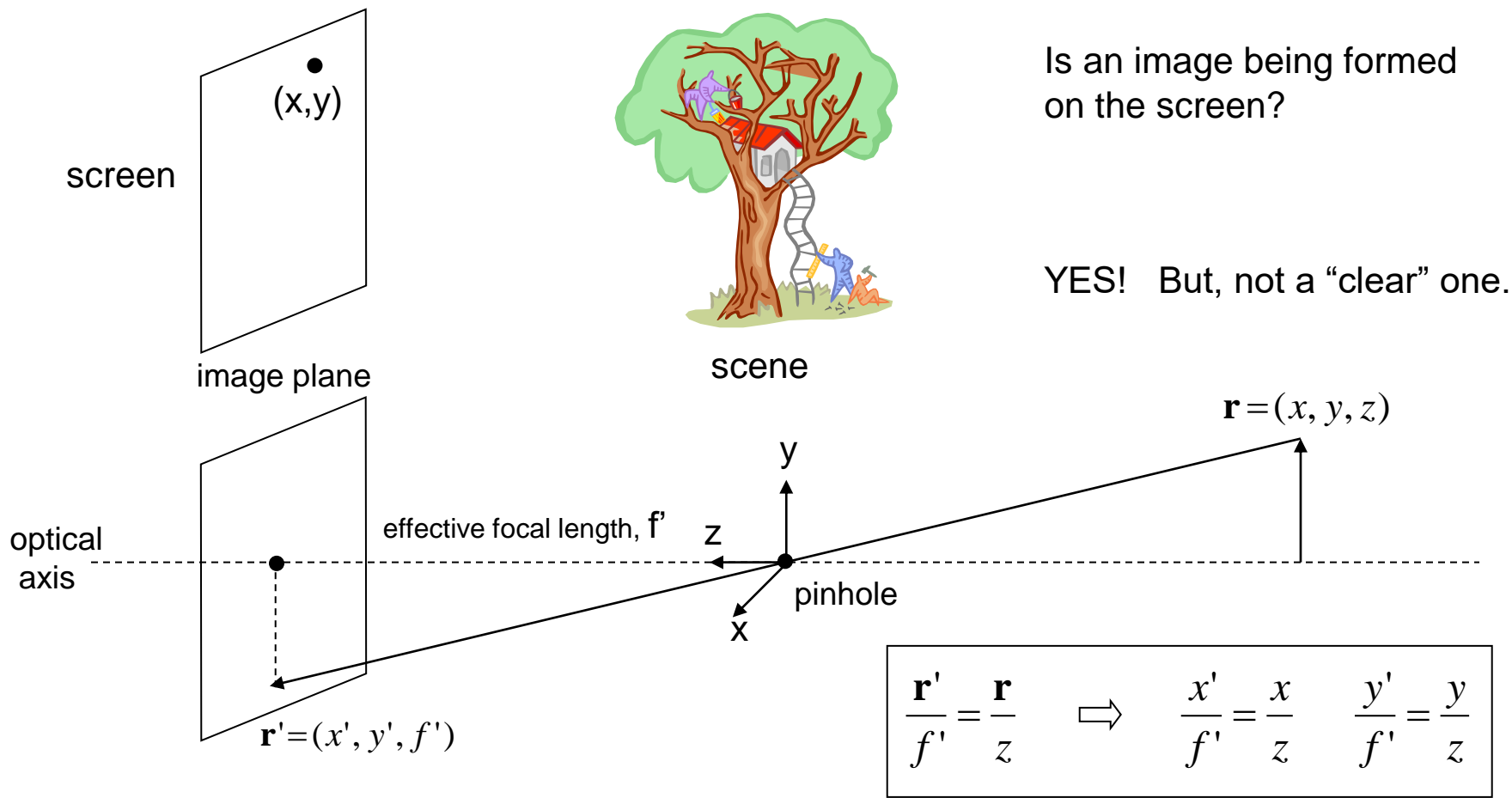
Pinhole Camera

• Basically a pinhole camera is a box, with a tiny hole at one end and film or photographic paper at the other.

• Mathematically: out of all the light rays in the world, choose the set of light rays passing through a point and projecting onto a plane.
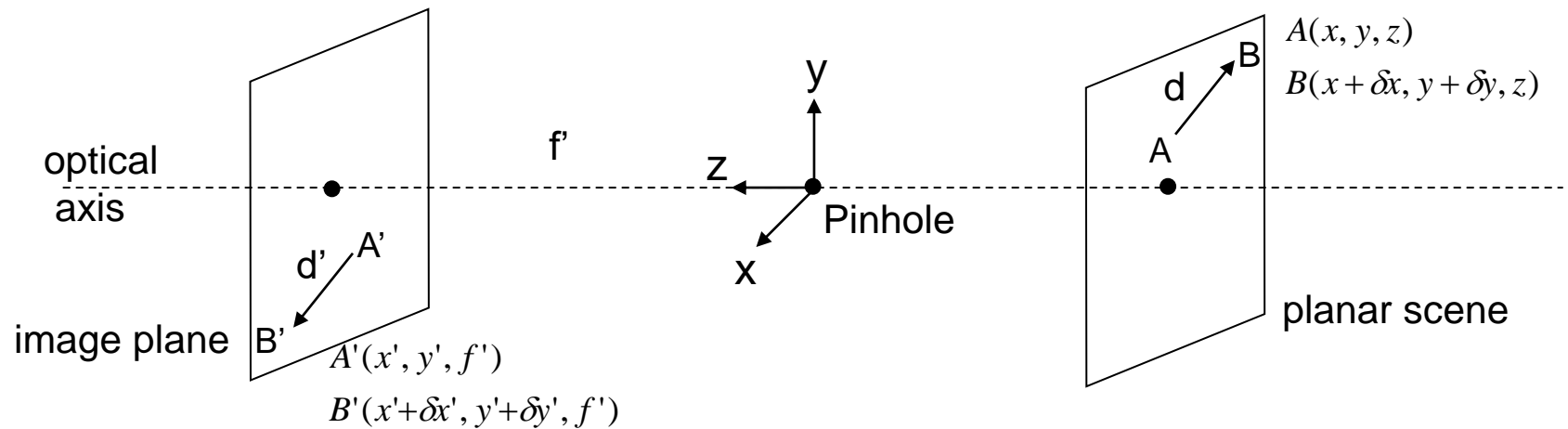
Pinhole Photography

©Charlotte Murray Untitled, 4" x 5" pinhole photograph, 1992

Image Size inversely proportional to Distance

Reading: http://www.pinholeresource.com/

Magnification

From perspective projection:

$$\frac{x'}{f'} = \frac{x}{z} \qquad \frac{y'}{f'} = \frac{y}{z}$$

$$\frac{x'+\delta x'}{f'} = \frac{x+\delta x}{z} \qquad \frac{y'+\delta y'}{f'} = \frac{y+\delta y}{z}$$

Magnification:
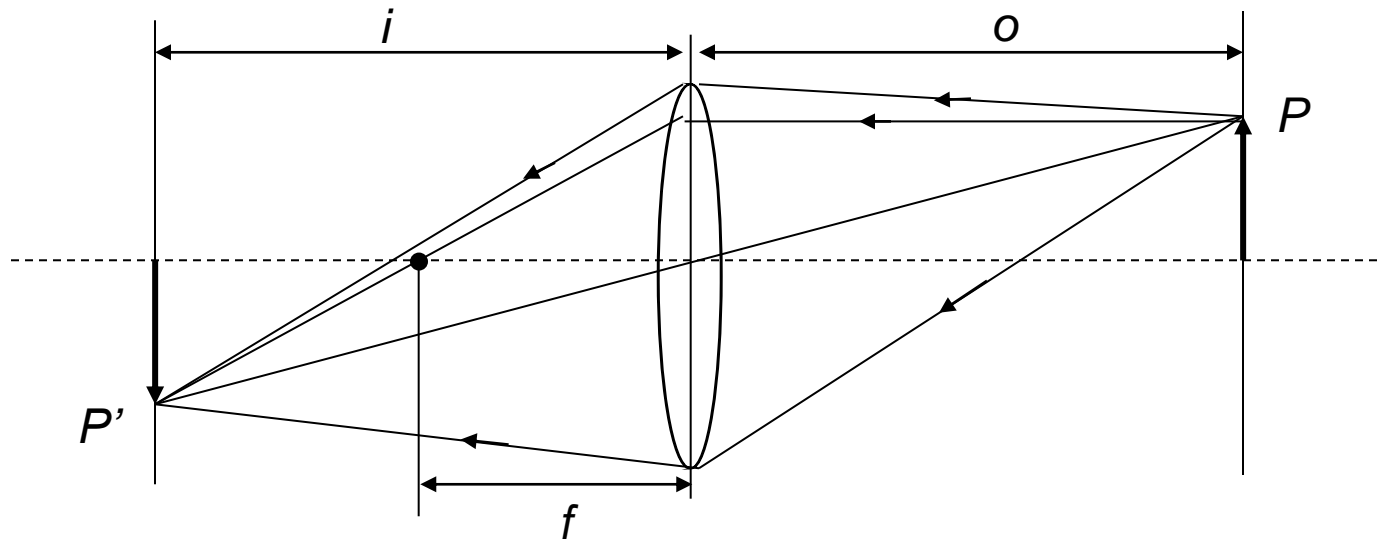
$$m = \frac{d'}{d} = \frac{\sqrt{(\delta x')^2 + (\delta y')^2}}{\sqrt{(\delta x)^2 + (\delta y)^2}} = \frac{f'}{z}$$
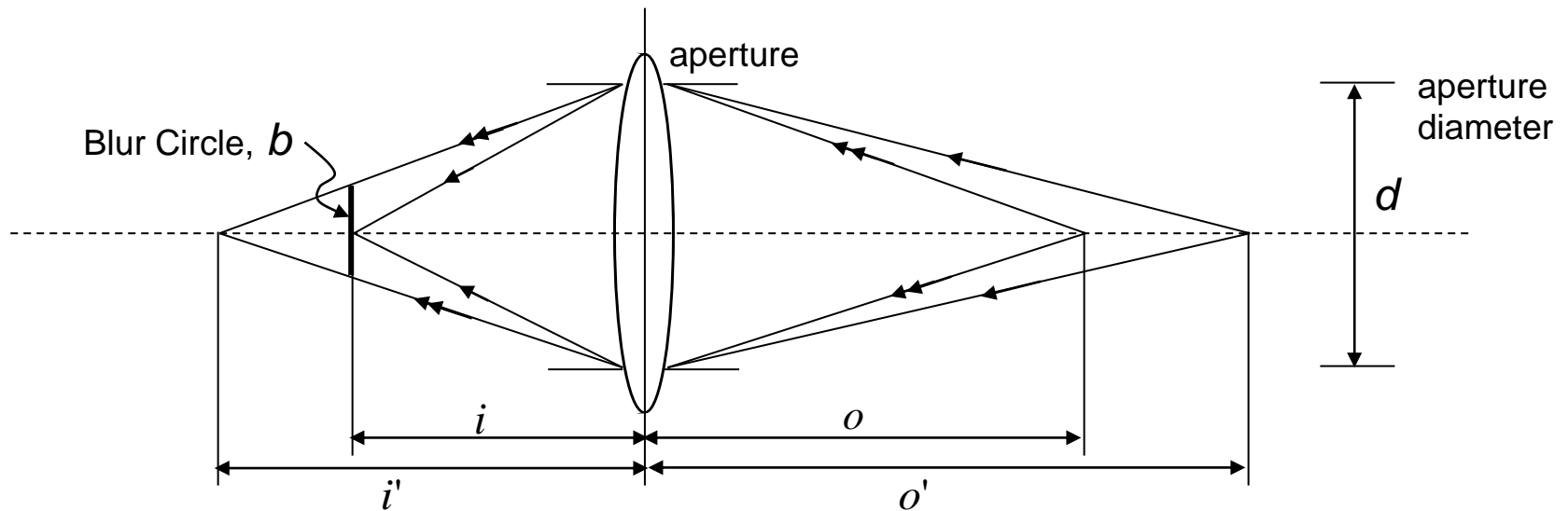
$$\frac{Area_{image}}{Area_{scene}} = m^2$$

Image Formation using Lenses

- Lenses are used to avoid problems with pinholes.

- Ideal Lens: Same projection as pinhole but gathers more light!

- Gaussian Thin Lens Formula: $\dfrac{1}{i} + \dfrac{1}{o} = \dfrac{1}{f}$

- f is the focal length of the lens – determines the lens's ability to refract light

Focus and Defocus

- Gaussian Law:

$$\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$$

$$\frac{1}{i'} + \frac{1}{o'} = \frac{1}{f}$$

$$\Longrightarrow \qquad (i'-i) = \frac{f}{(o'-f)}\frac{f}{(o-f)}(o-o')$$

- In theory, only one scene plane is in focus

Depth of Field

- Range of object distances over which image is <u>sufficiently well</u> focused

- Range for which *blur circle* is less than the resolution of the sensor
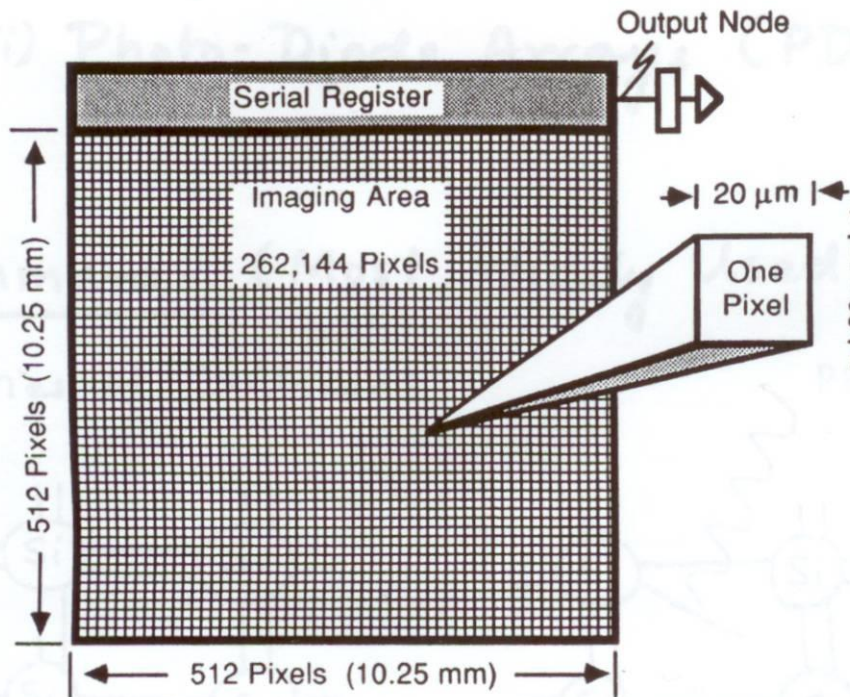

http://images.dpchallenge.com/images_portfolio/27920/print_preview/116336.jpg
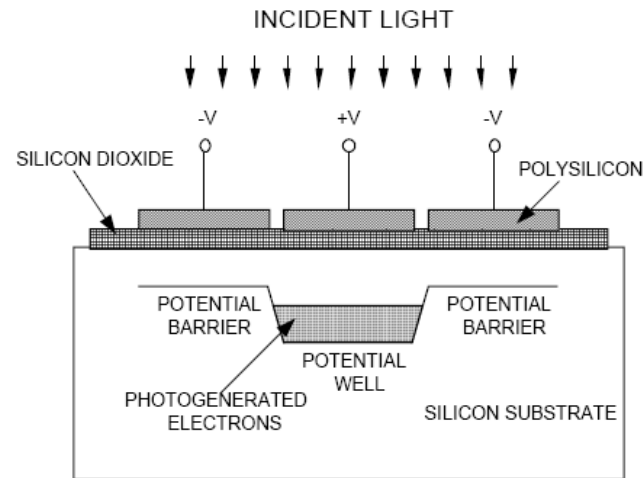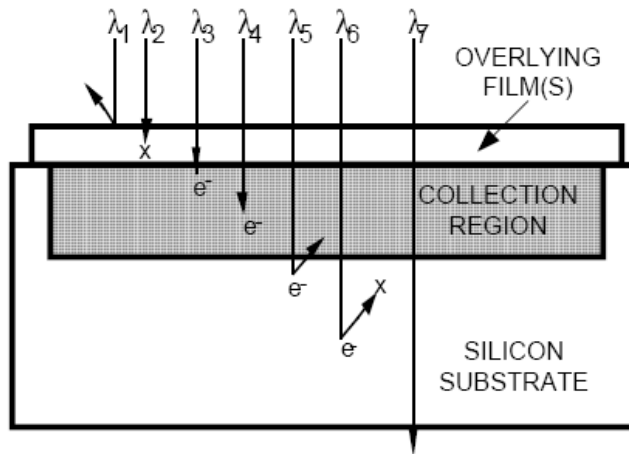
Image Sensors

FIG. 4. Typical 512 × 512 CCD.

- Considerations

  - Speed

  - Resolution

  - Signal / Noise Ratio

  - Cost

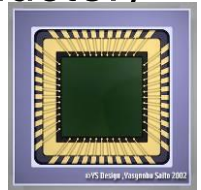# Image Sensors

- ## Convert light into an electric charge

CCD (charge coupled device)
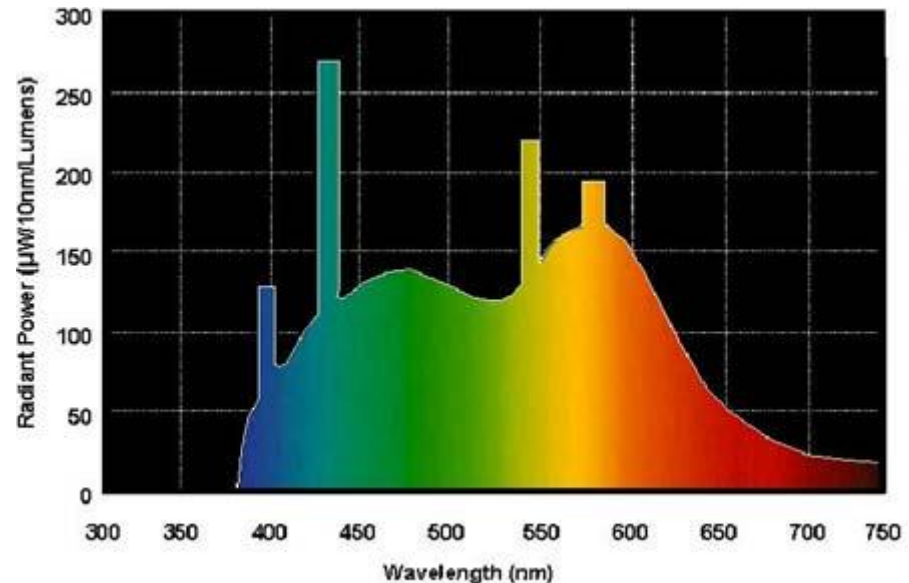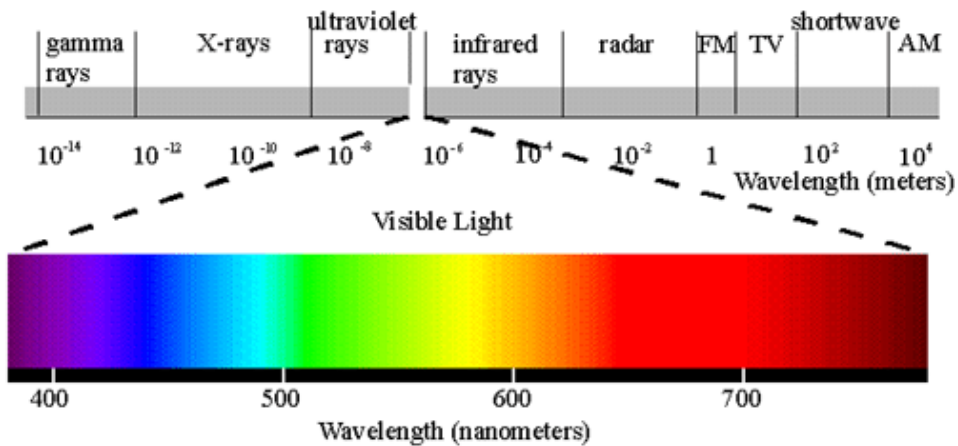
Higher dynamic range

High uniformity

Lower noise
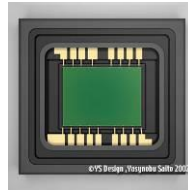
CMOS (complementary metal
Oxide semiconductor)

Lower voltage

Higher speed

Lower system complexity

Sensing Brightness

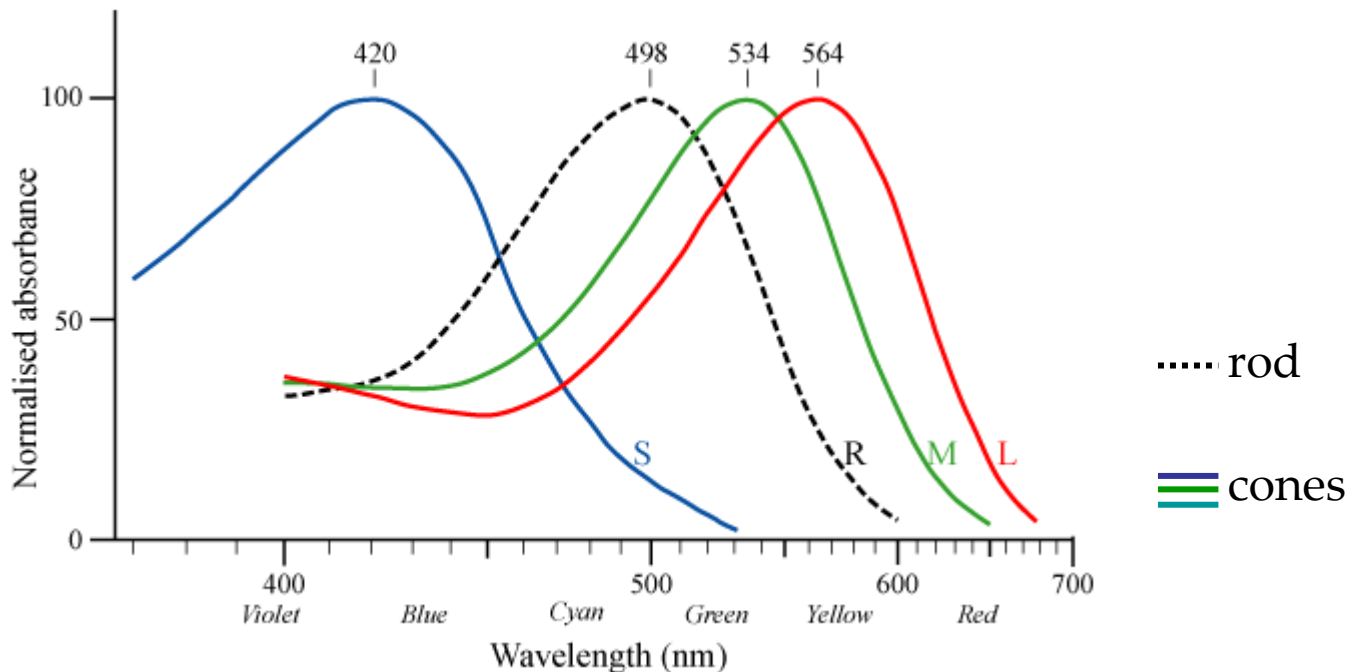Incoming light has a **spectral distribution** $p(\lambda)$

So the pixel intensity becomes

$$I = k \int_{-\infty}^{\infty} q(\lambda) p(\lambda) d\lambda$$

How do we sense colour?
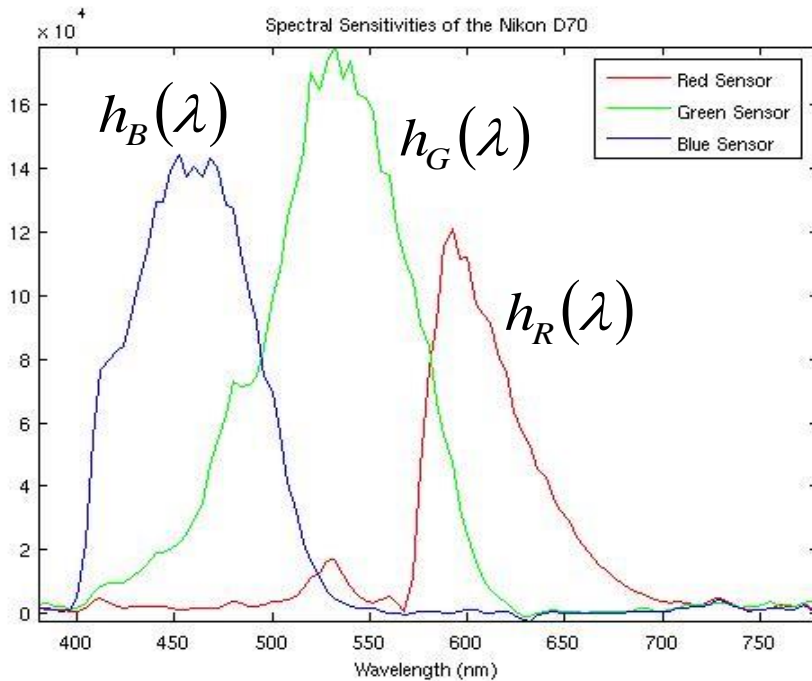
- ## Do we have infinite number of filters?

Three filters of different spectral responses

Sensing Colour

- ## Tristimulus (trichromatic) values (I_R, I_G, I_B)

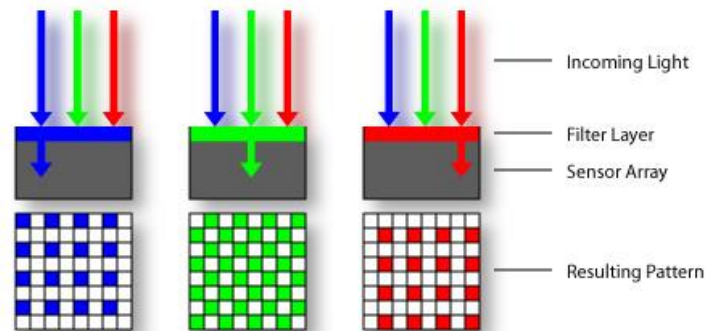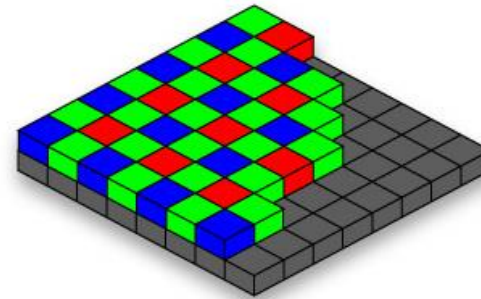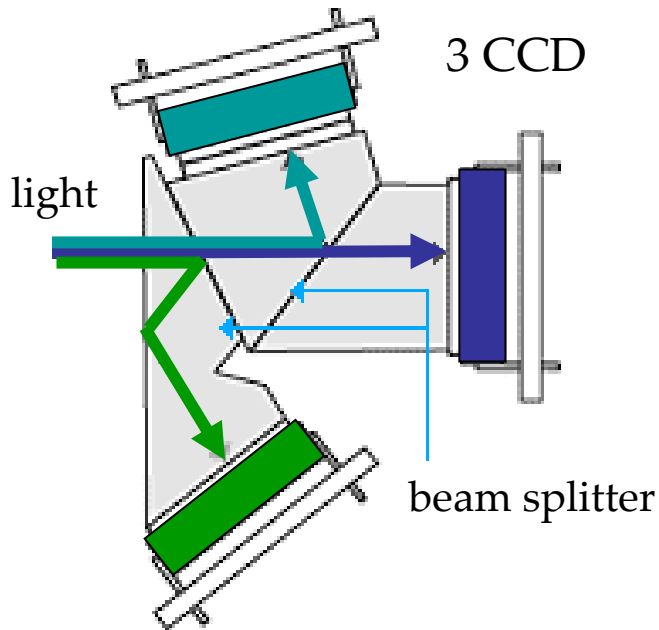Camera's spectral response functions: $h_R(\lambda), h_G(\lambda), h_B(\lambda)$

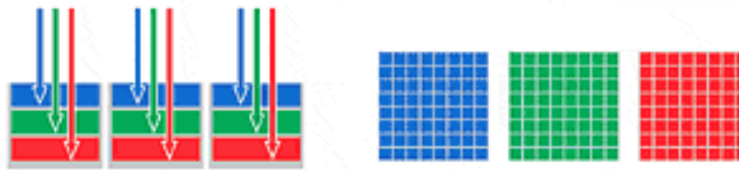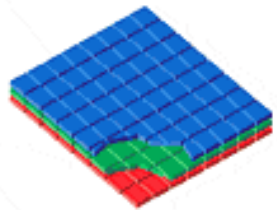$$I_R = k \int_{-\infty}^{\infty} h_R(\lambda) p(\lambda) d\lambda$$

$$I_G = k \int_{-\infty}^{\infty} h_G(\lambda) p(\lambda) d\lambda$$

$$I_B = k \int_{-\infty}^{\infty} h_B(\lambda) p(\lambda) d\lambda$$

Sensing Colour

3 CCD

light

beam splitter

Bayer pattern

Foveon X3™

U. PORTO FC

Resources

- Szeliski, "Computer Vision: Algorithms and Applications", Springer, 2011
  - Chapter 1 – "Introduction"
  - Chapter 2 – "Image Formation"