# Computer Vision – TP1
# Image Formation

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# Outline

- ‘Computer Vision’?
- The Human Visual System
- Image Capturing Systems

# Topic: Computer Vision?

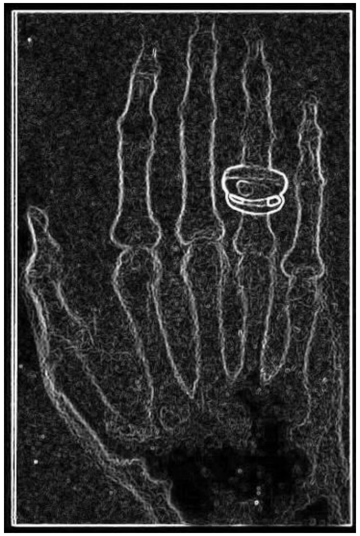
- ‘Computer Vision’?
- The Human Visual System
- Image Capturing Systems

# Computer Vision

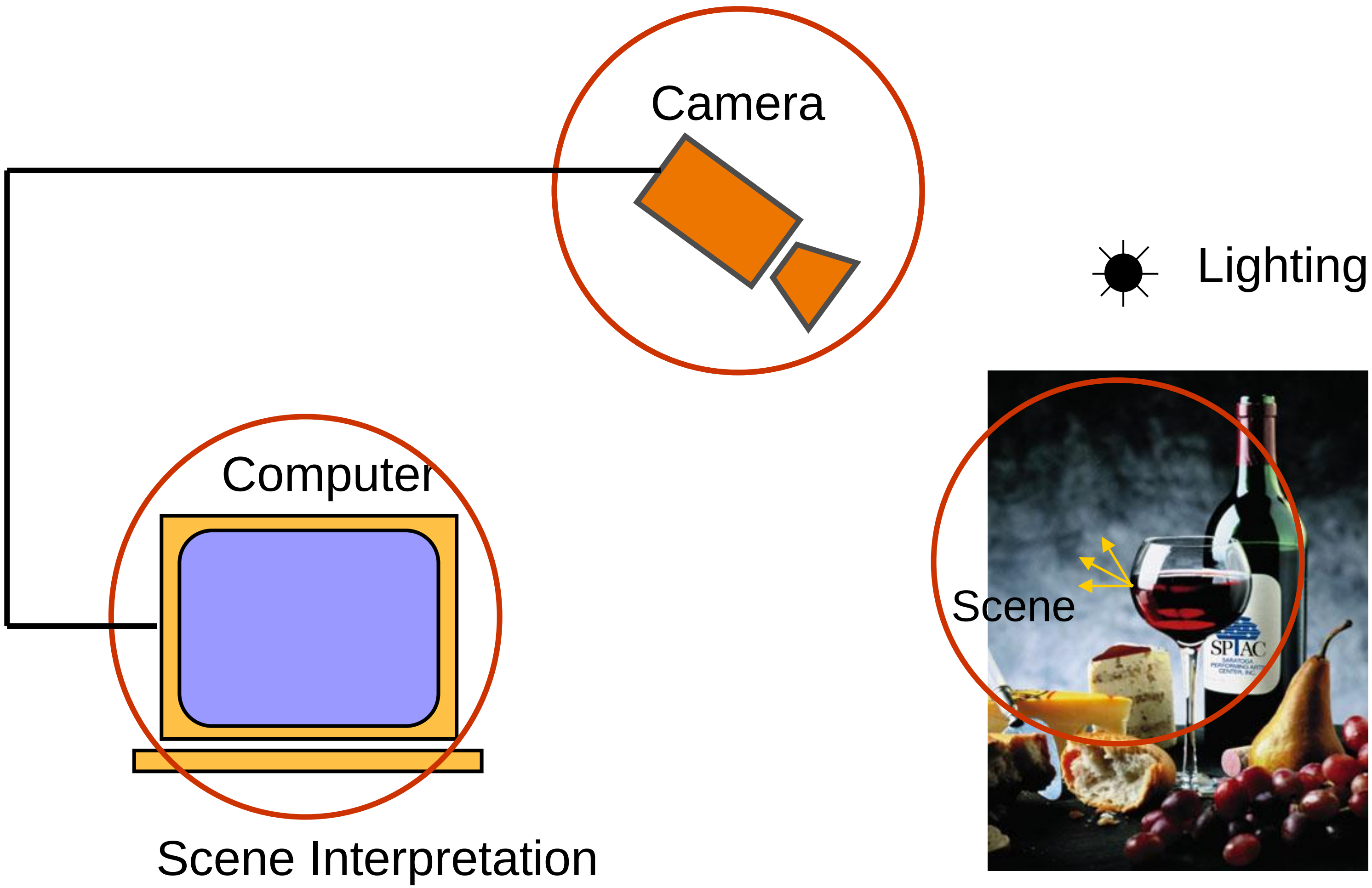
"The goal of Computer Vision is to make useful decisions about real physical objects and scenes based on sensed images",

Shapiro and Stockman, "Computer Vision", 2001





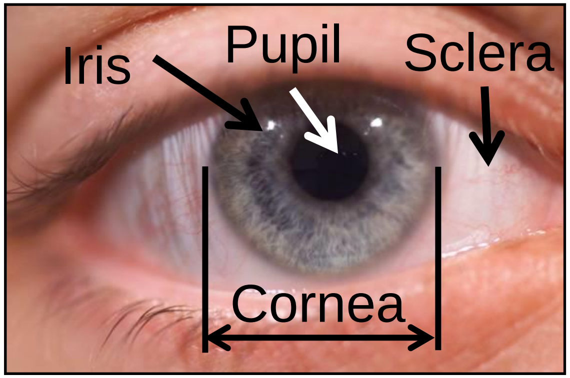
# Components of a Computer Vision System

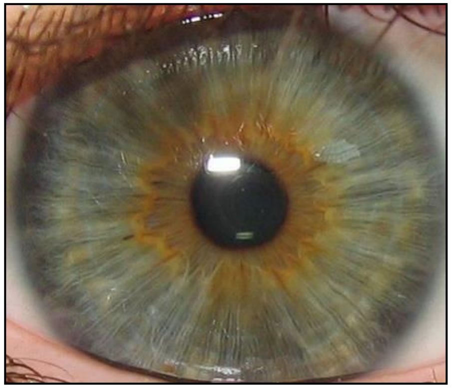


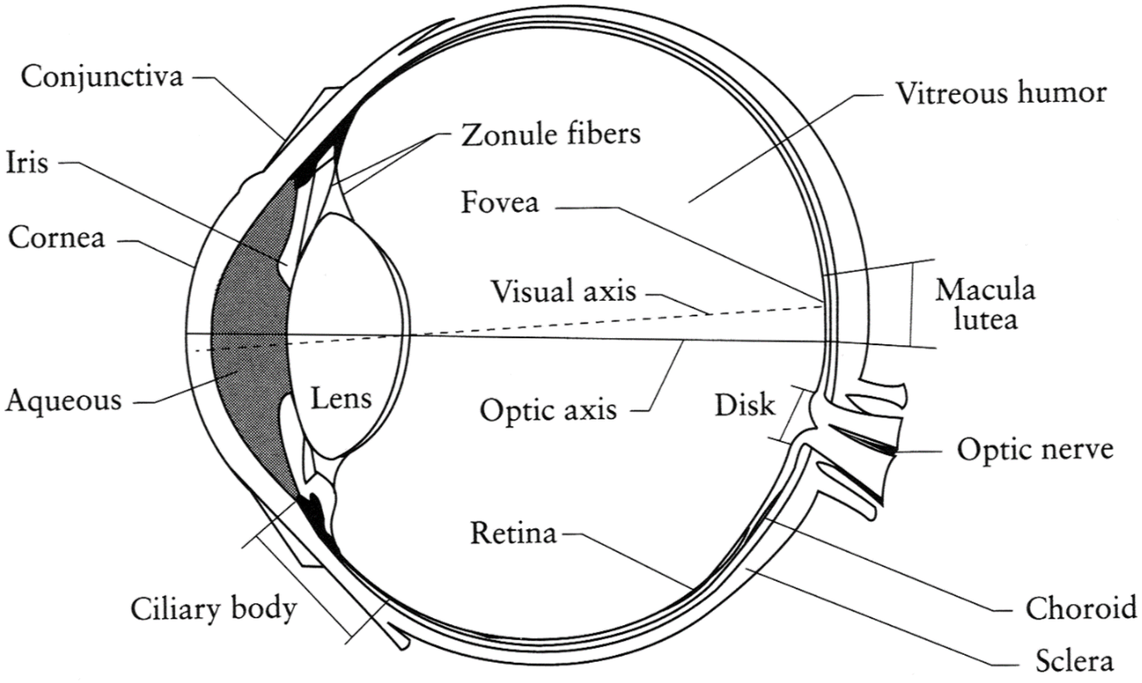
# Topic: The Human Visual System

- ‘Computer Vision’?
- The Human Visual System
- Image Capturing Systems

# Our Eyes



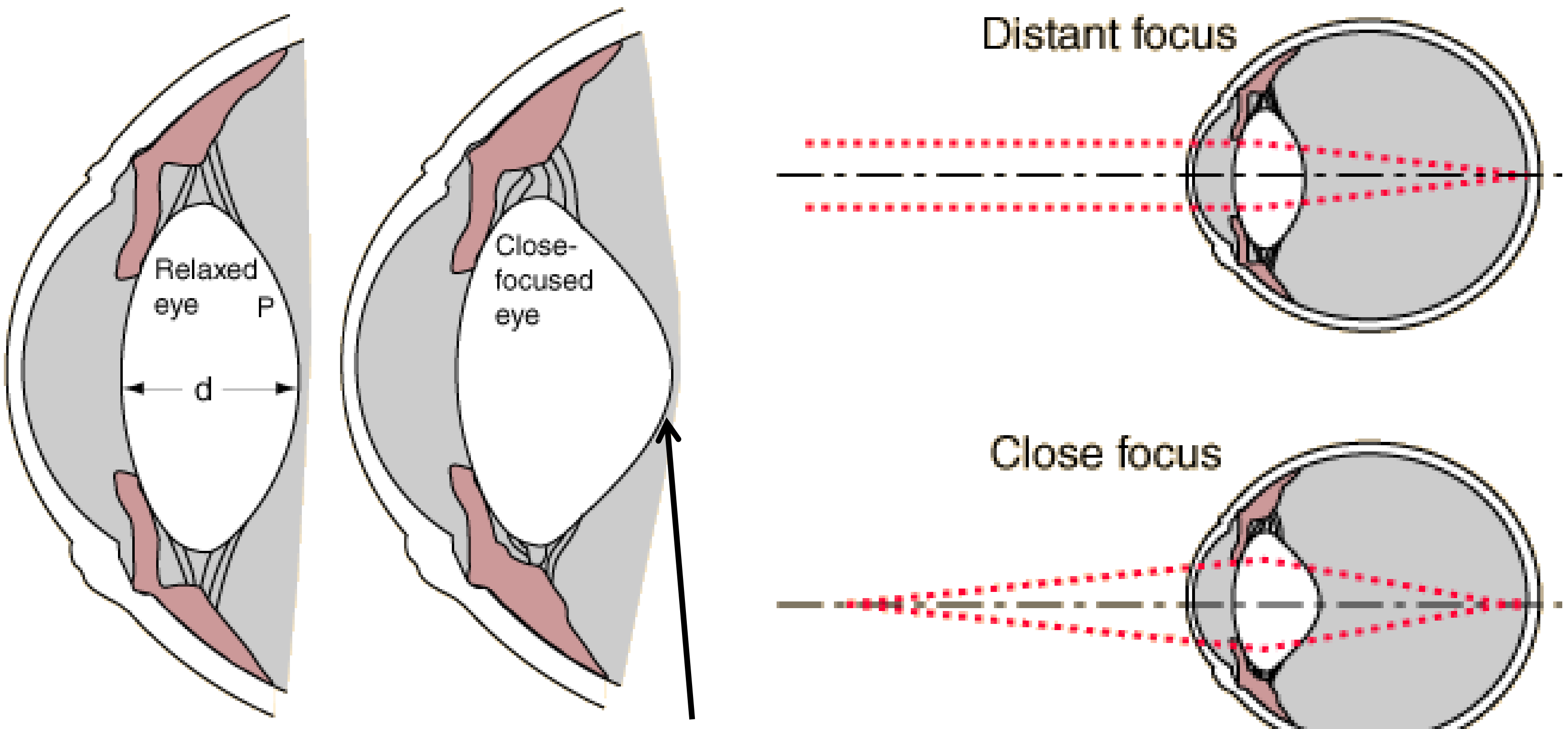






Iris is the diaphragm that changes the aperture (pupil)

Retina is the sensor where the fovea has the highest resolution

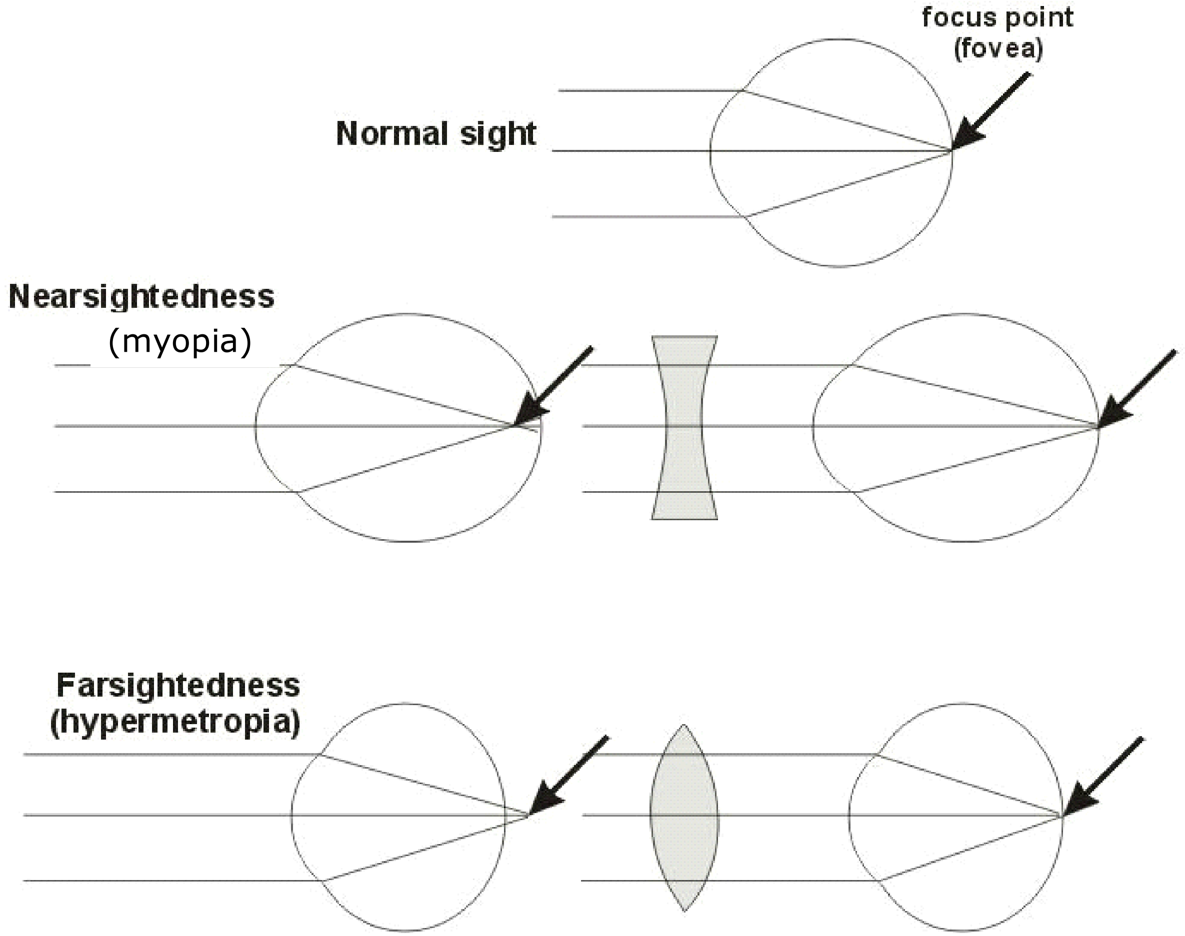
# Focusing




shorter focal length

Changes the focal length of the lens

# Myopia and Hyperopia

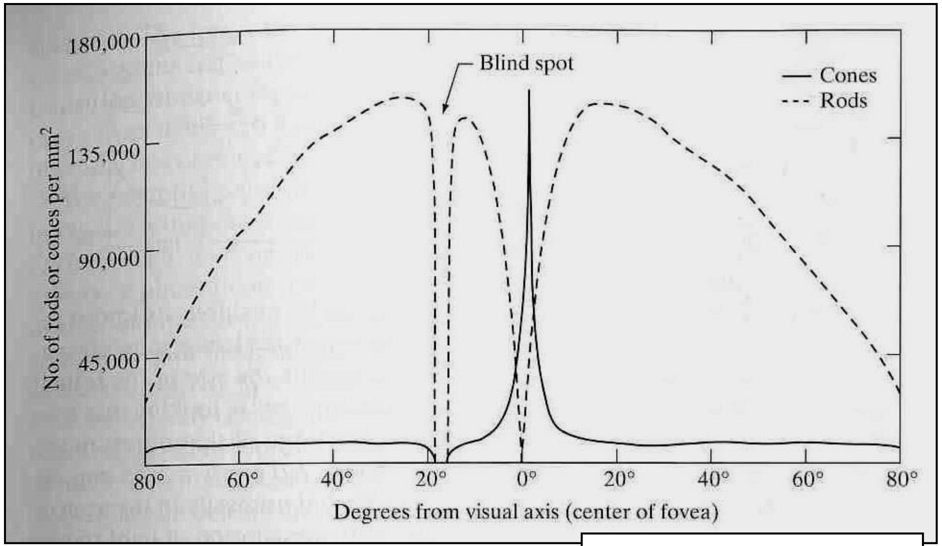


# Blind Spot in the Eye

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



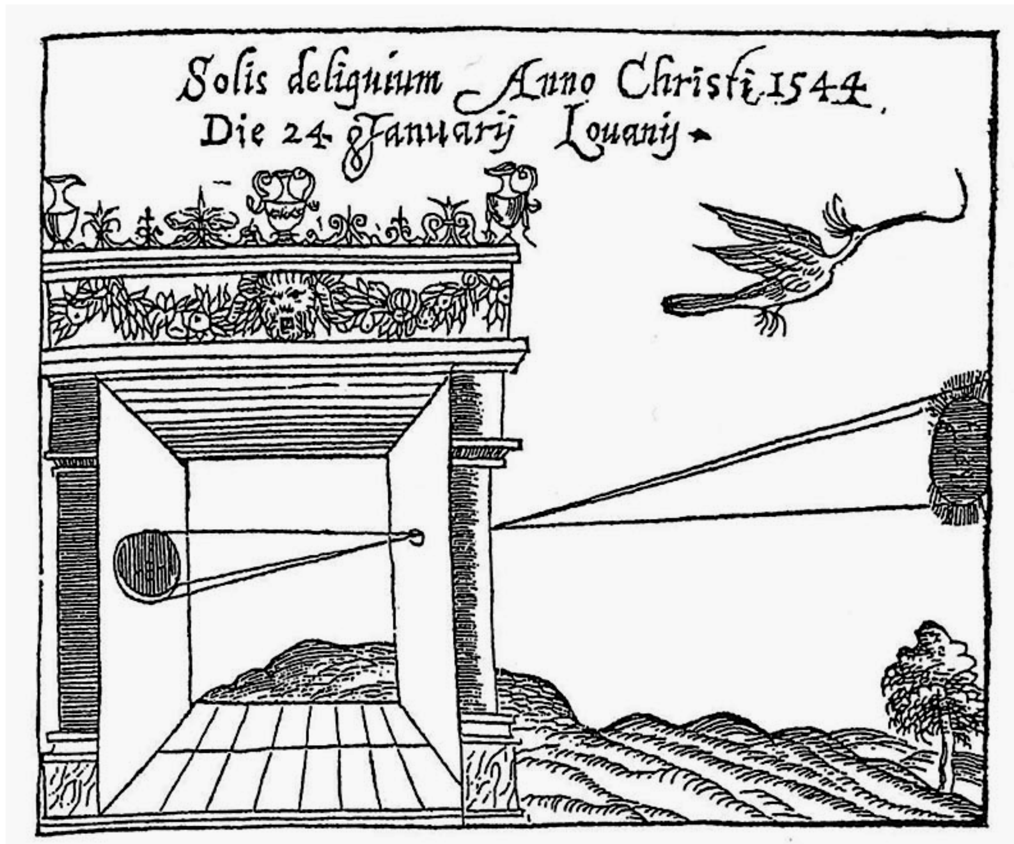

Gonzalez & Woods

We only see colour in the centre of our retina!

# Topic: Image Capturing Systems

- ‘Computer Vision’?
- The Human Visual System
- Image Capturing Systems

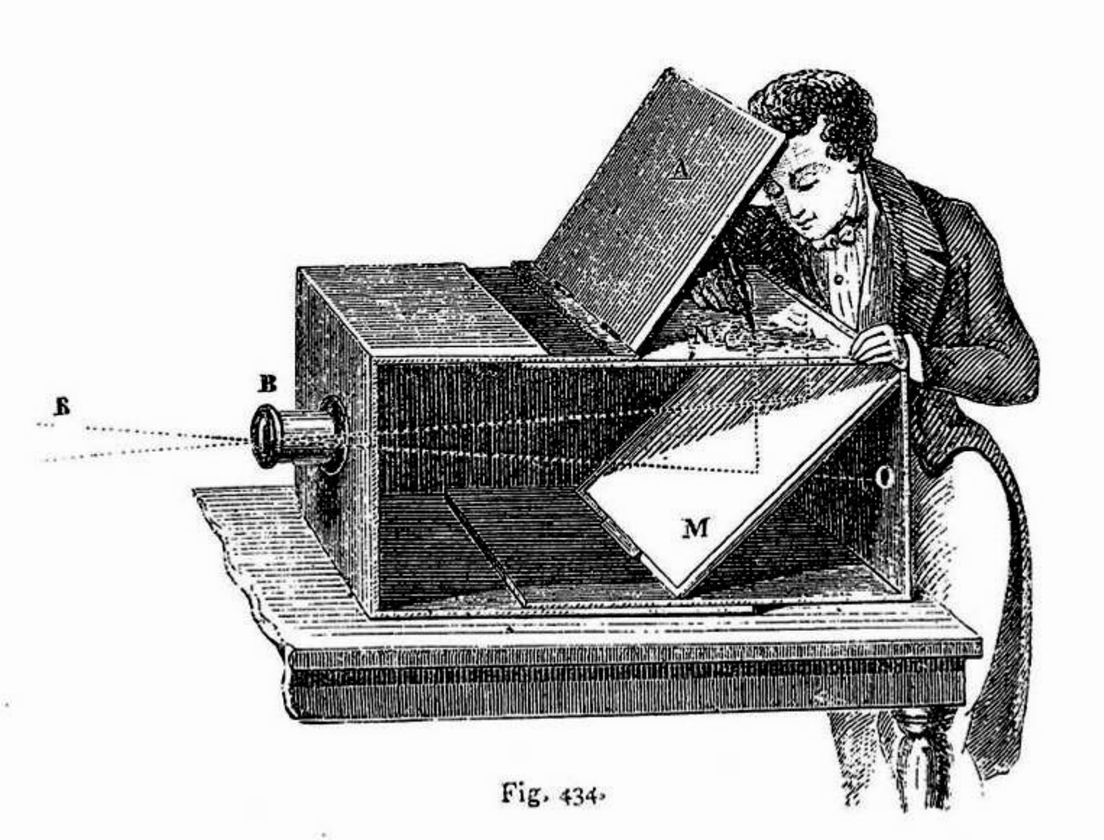
# A Brief History of Images




*Camera Obscura*, Gemma Frisius, 1544

1544

# A Brief History of Images

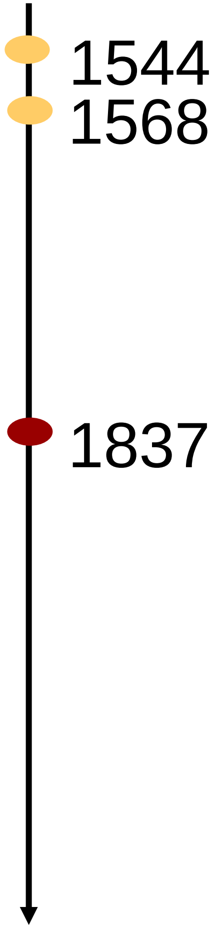




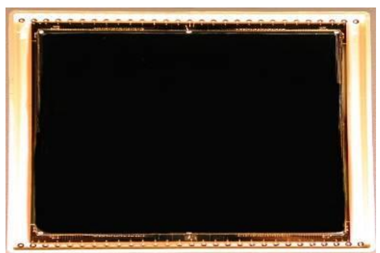
Lens Based Camera Obscura, 1568

# A Brief History of Images

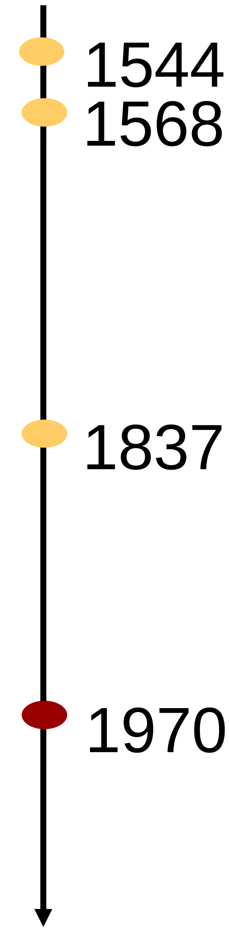
*Still Life*, Louis Jaques Mande Daguerre, 1837



# A Brief History of Images

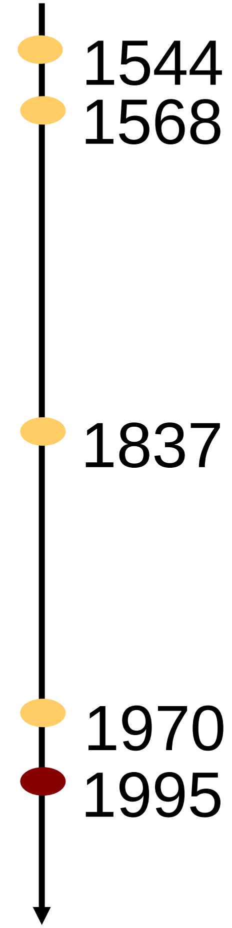


Silicon Image Detector,  1970

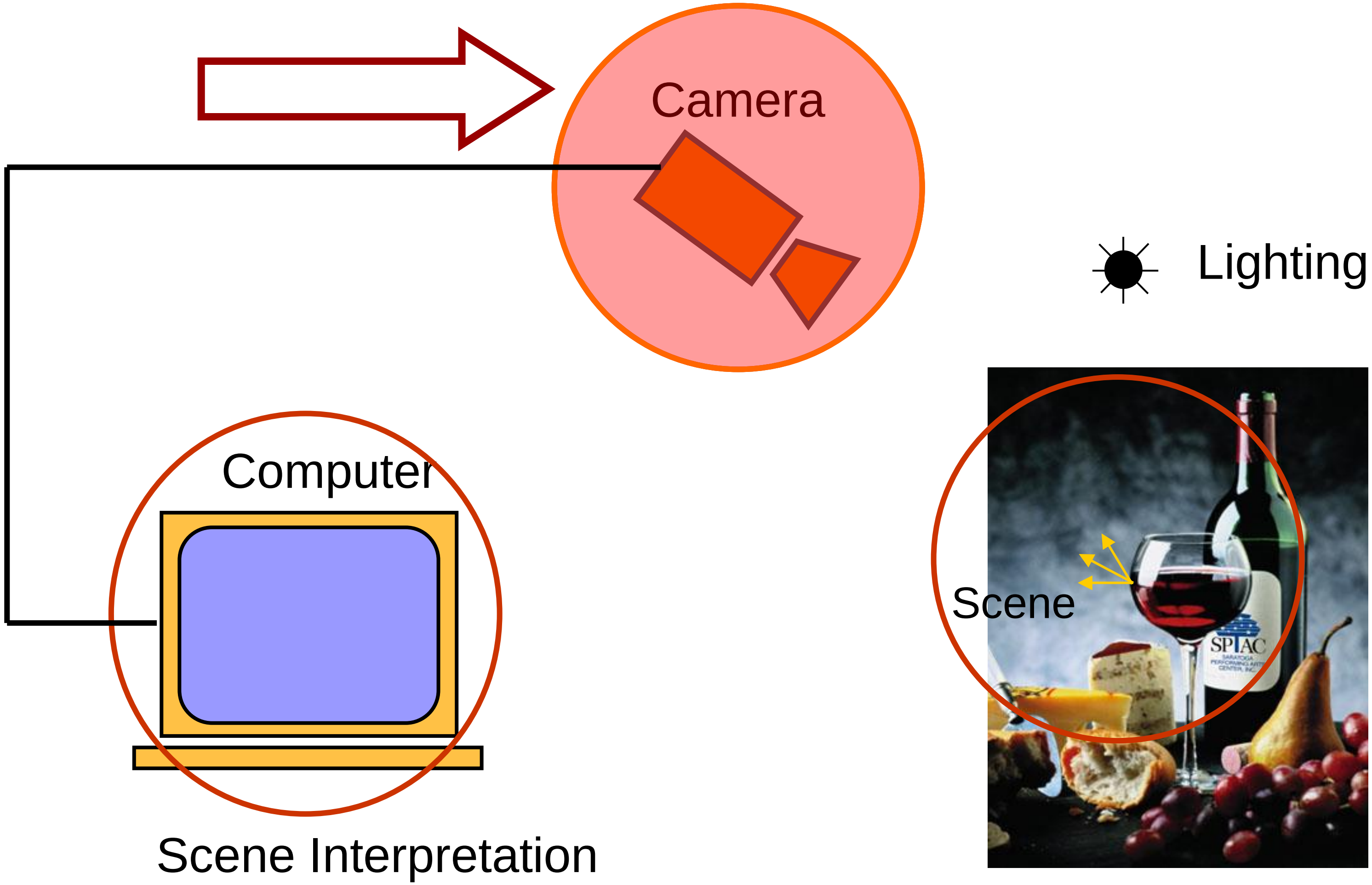



# A Brief History of Images

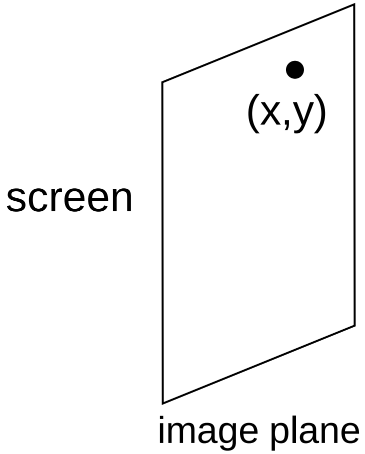

Digital Cameras



# Components of a Computer Vision System



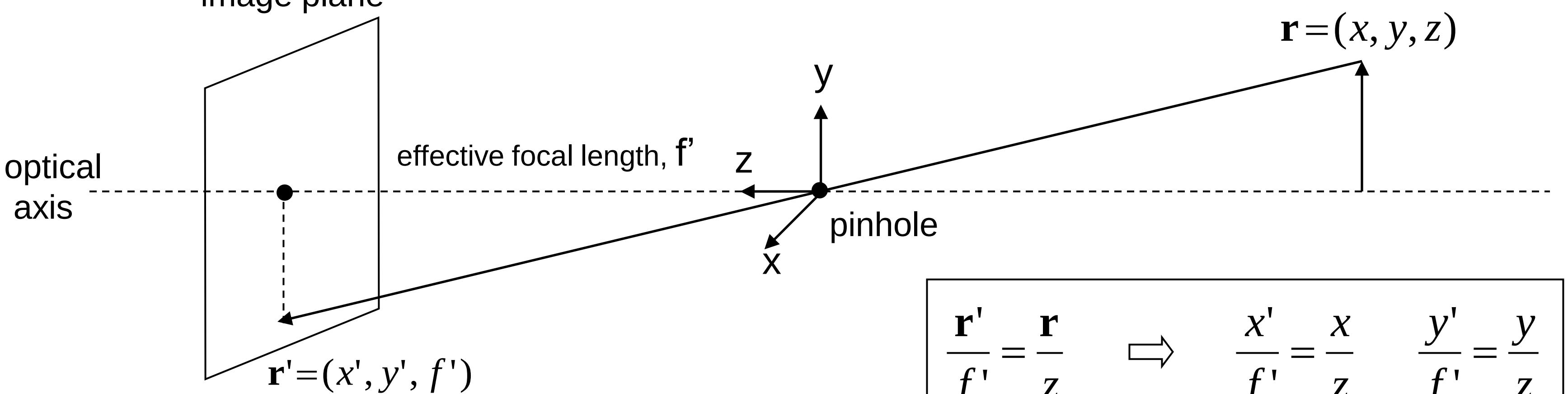
# Pinhole and the Perspective Projection




scene

Is an image being formed on the screen?

YES! But, not a “clear” one.

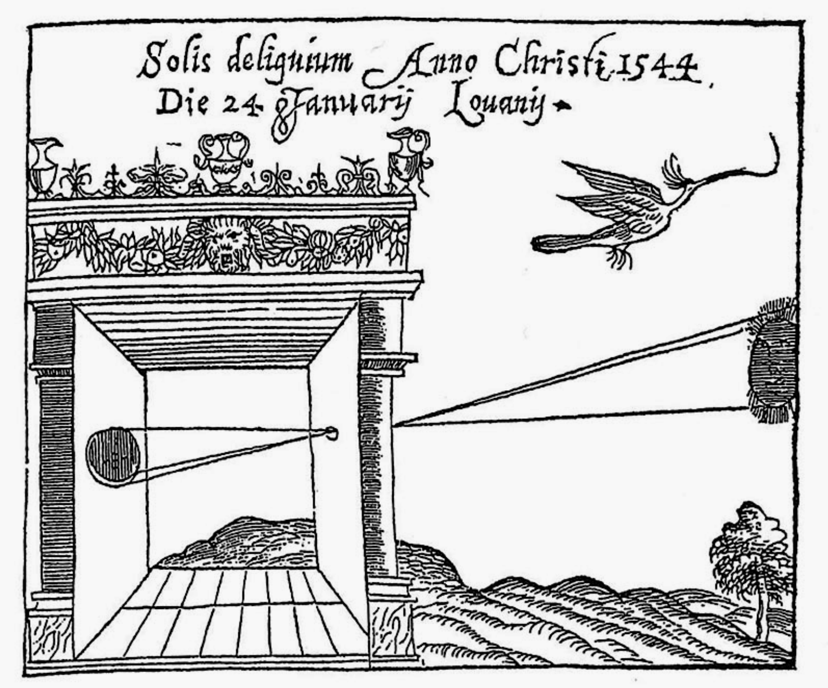



$$\frac{\mathbf{r}'}{f'} = \frac{\mathbf{r}}{z} \quad \Rightarrow \quad \frac{x'}{f'} = \frac{x}{z} \qquad \frac{y'}{f'} = \frac{y}{z}$$

# 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.



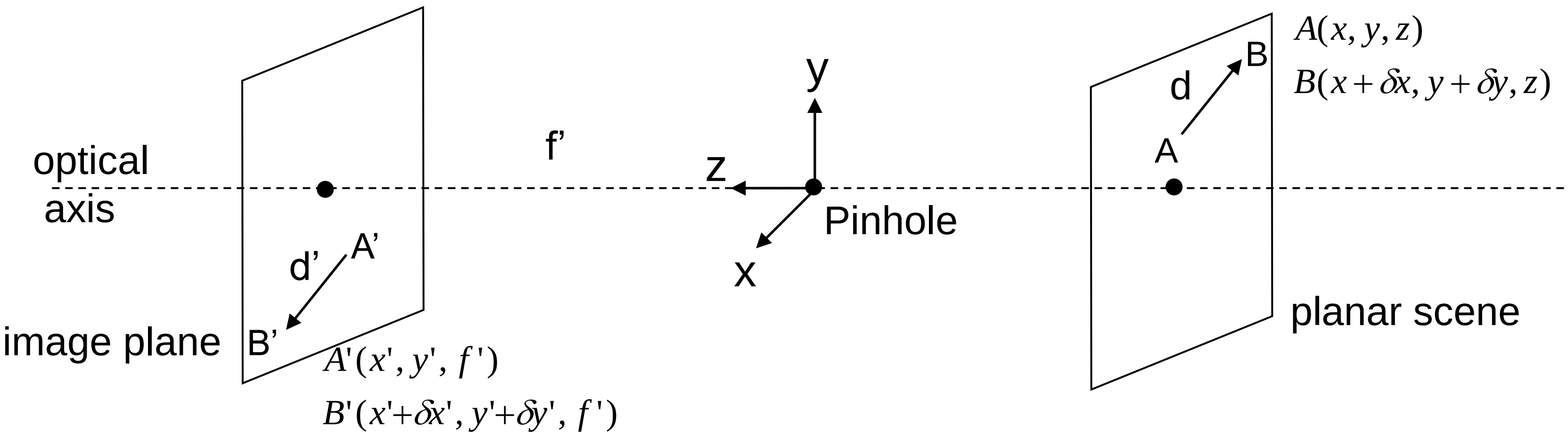
# Pinhole Photography

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

Image Size inversely proportional to Distance

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

# Magnification




From perspective projection:

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

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

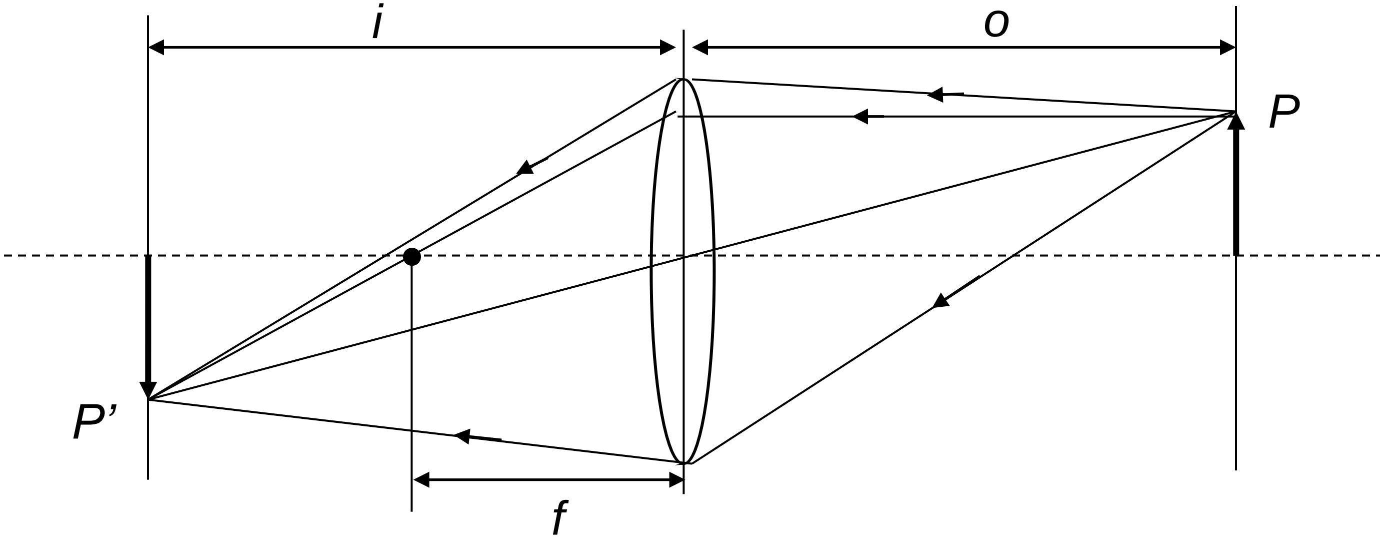
Magnification:

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

$$\frac{Area_{image}}{Area_{scene}} = m^2$$

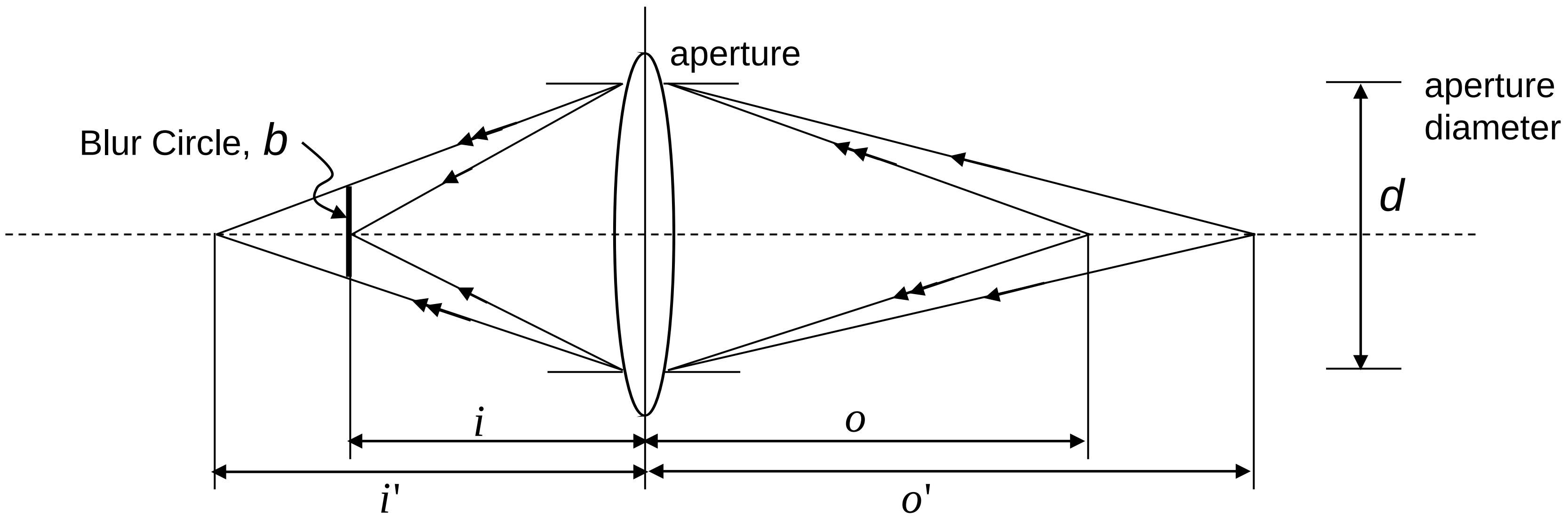
# Image Formation using Lenses

- Lenses are used to avoid problems with pinholes.
- Ideal Lens: Same projection as pinhole but gathers more light!




- Gaussian Thin Lens Formula: $$\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$$
- *f* is the focal length of the lens – determines the lens's ability to refract light

# Focus and Defocus




- Gaussian Law:

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

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

$$\Rightarrow \quad (i' - i) = \frac{f}{(o' - f)} \frac{f}{(o - f)} (o - o')$$

- 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

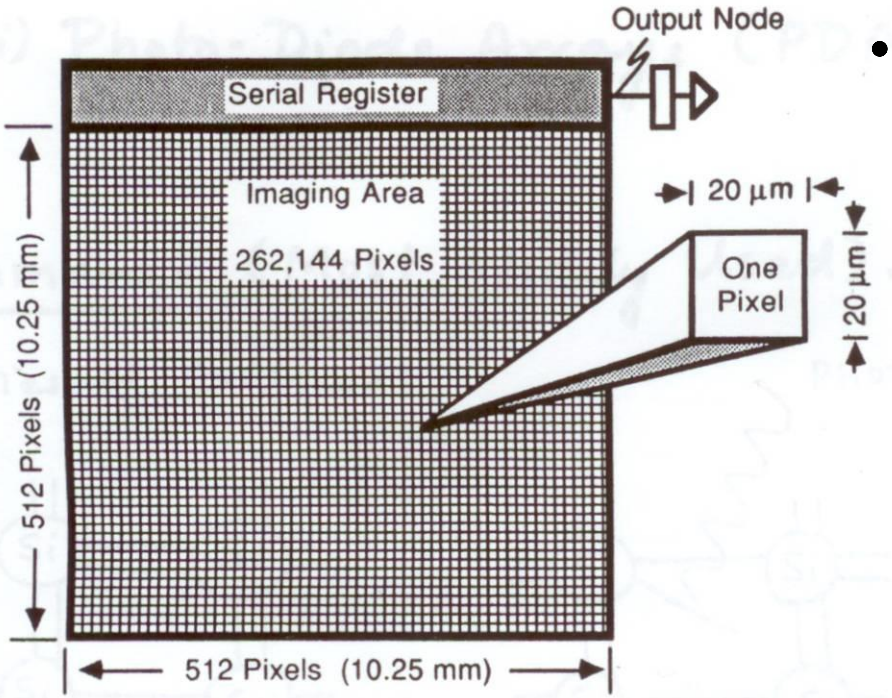
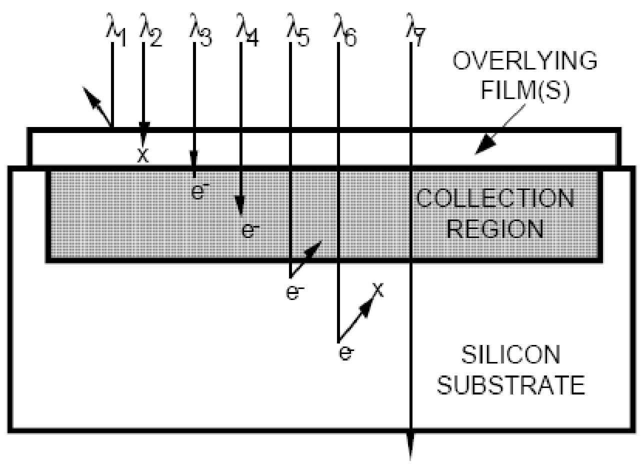


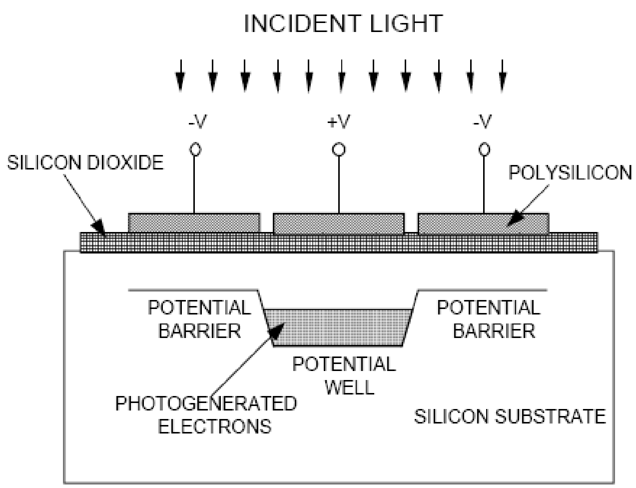

FIG. 4. Typical 512 × 512 CCD.

- Considerations
  - Speed
  - Resolution
  - Signal / Noise Ratio
  - Cost

# Image Sensors

- Convert light into an electric charge



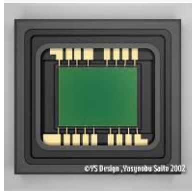




CCD (charge coupled device)

Higher dynamic range

High uniformity

Lower noise

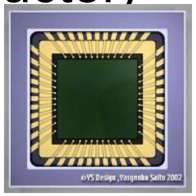


CMOS (complementary metal Oxide semiconductor)

Lower voltage

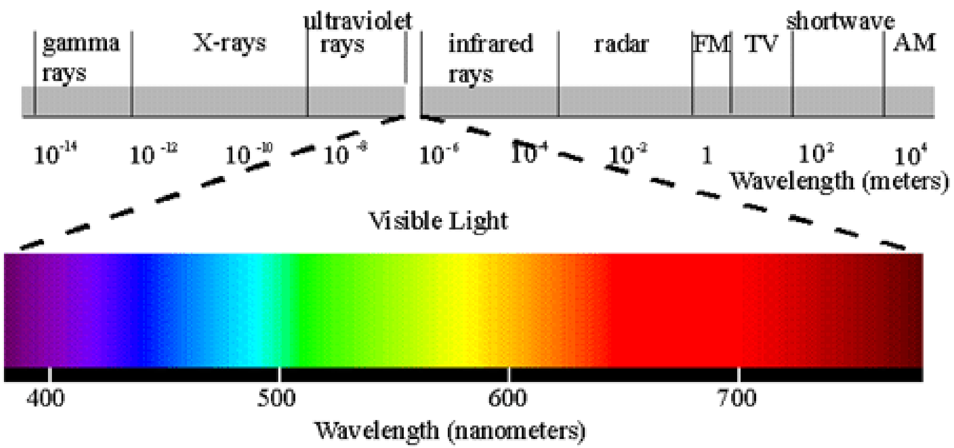
Higher speed

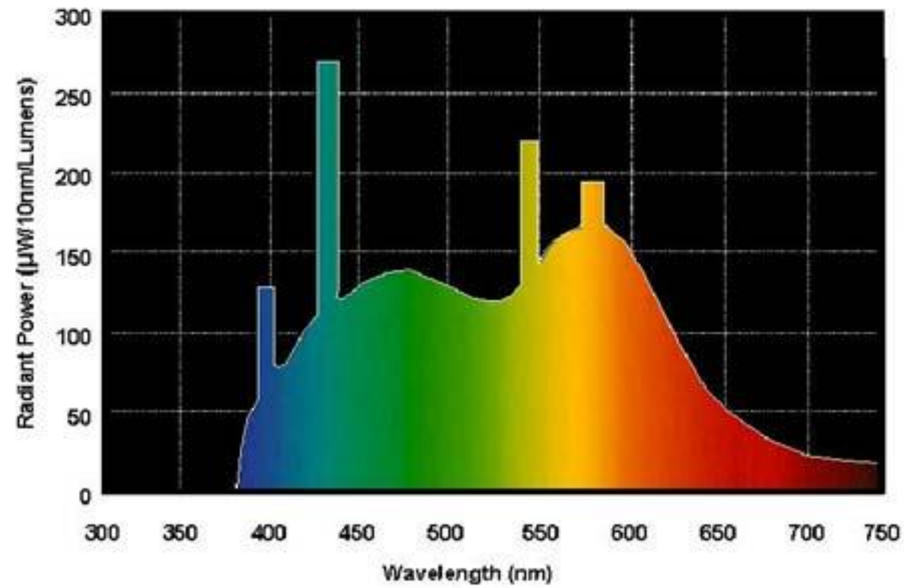
Lower system complexity



# Sensing Brightness

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



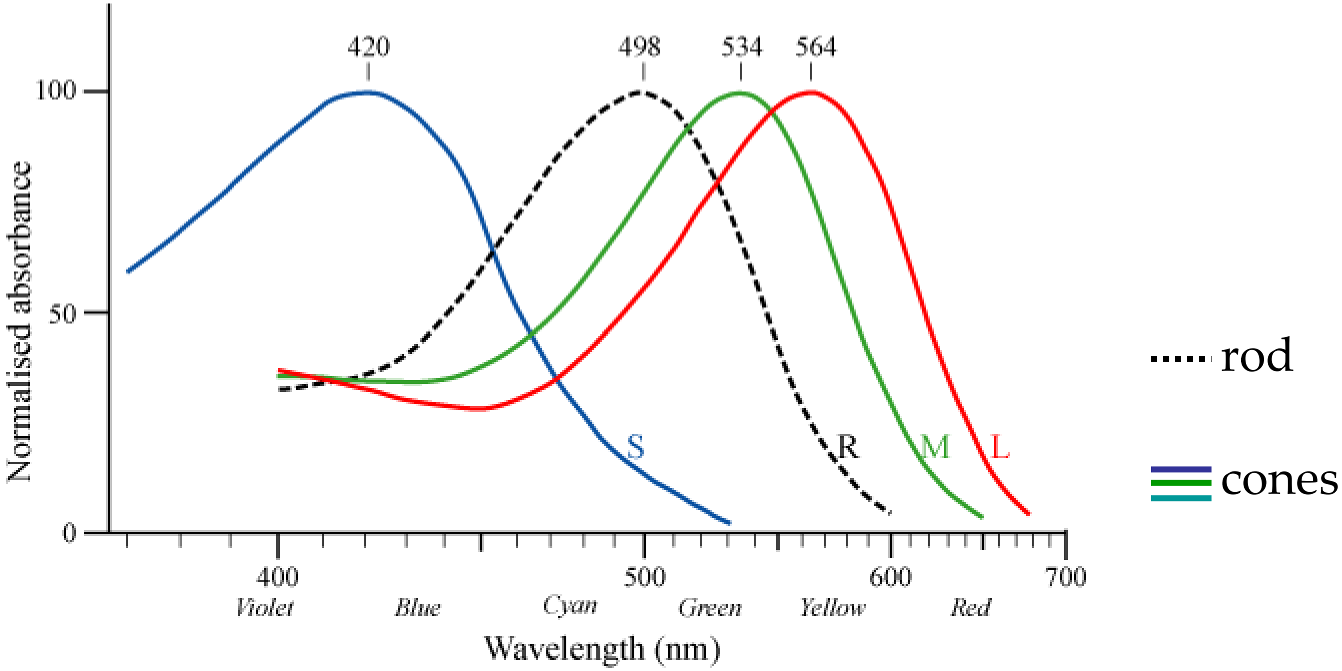




So the pixel intensity becomes

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

# How do we sense colour?

- Do we have infinite number of filters?

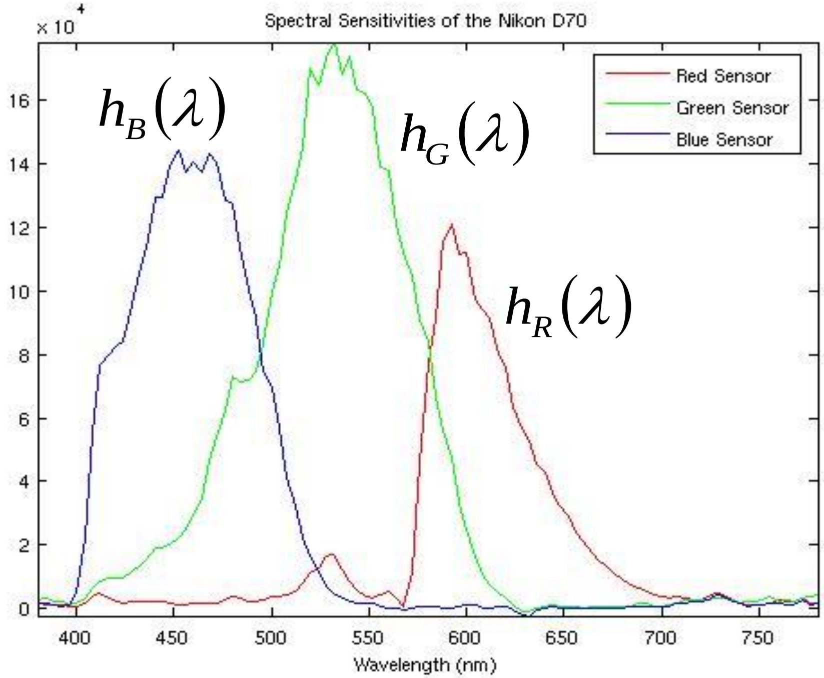



Three filters of different spectral responses

# Sensing Colour

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

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

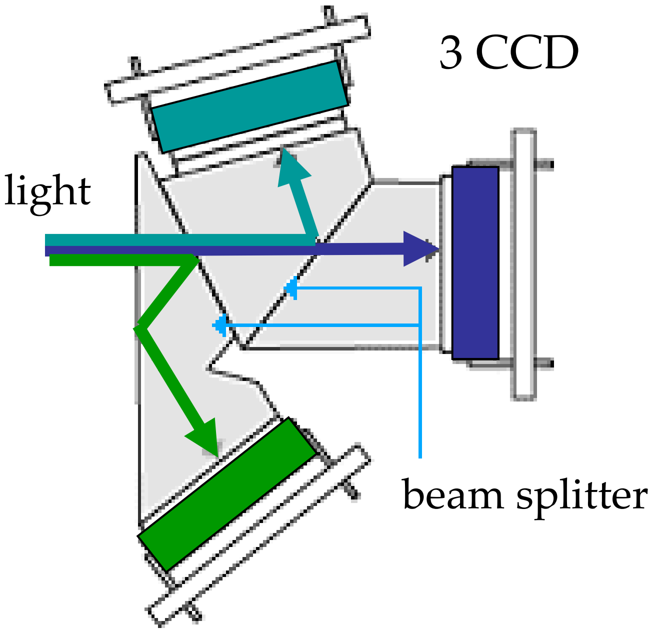


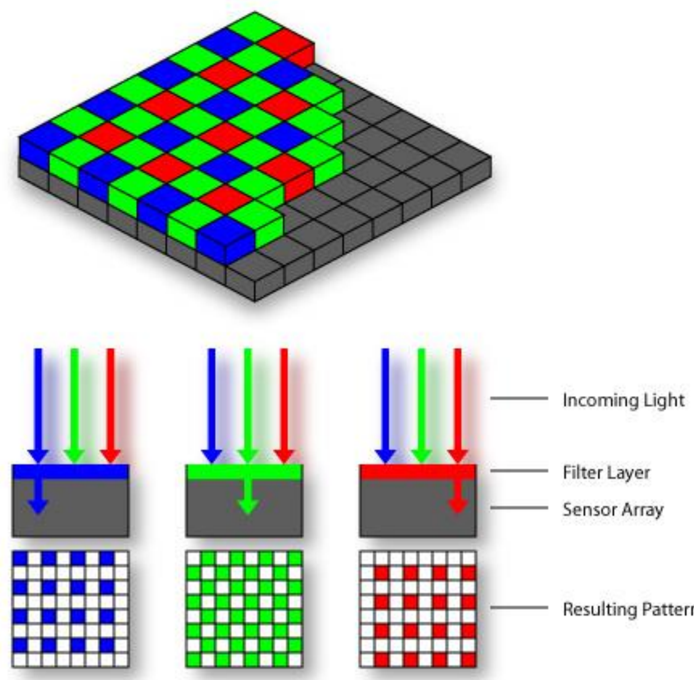

$$I_R = k \int_{-\infty}^{\infty} h_R(\lambda) p(\lambda) d\lambda$$

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

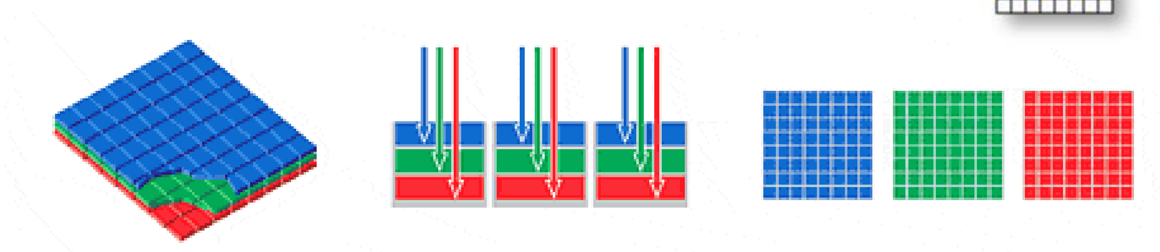
$$I_B = k \int_{-\infty}^{\infty} h_B(\lambda) p(\lambda) d\lambda$$

# Sensing Colour




Bayer pattern



Foveon X3$^{TM}$

# Resources

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