# VC 12/13 – T2
# Image Formation

Mestrado em Ciência de Computadores

Mestrado Integrado em Engenharia de Redes e Sistemas Informáticos

***Miguel Tavares Coimbra***

U. PORTO FC

# Outline

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

**Acknowledgements: Most of this course is based on the excellent courses offered by Prof. Shree Nayar at Columbia University, USA and by Prof. Srinivasa Narasimhan at CMU, USA. Please acknowledge the original source when reusing these slides for academic purposes.**

# Topic: Computer Vision?

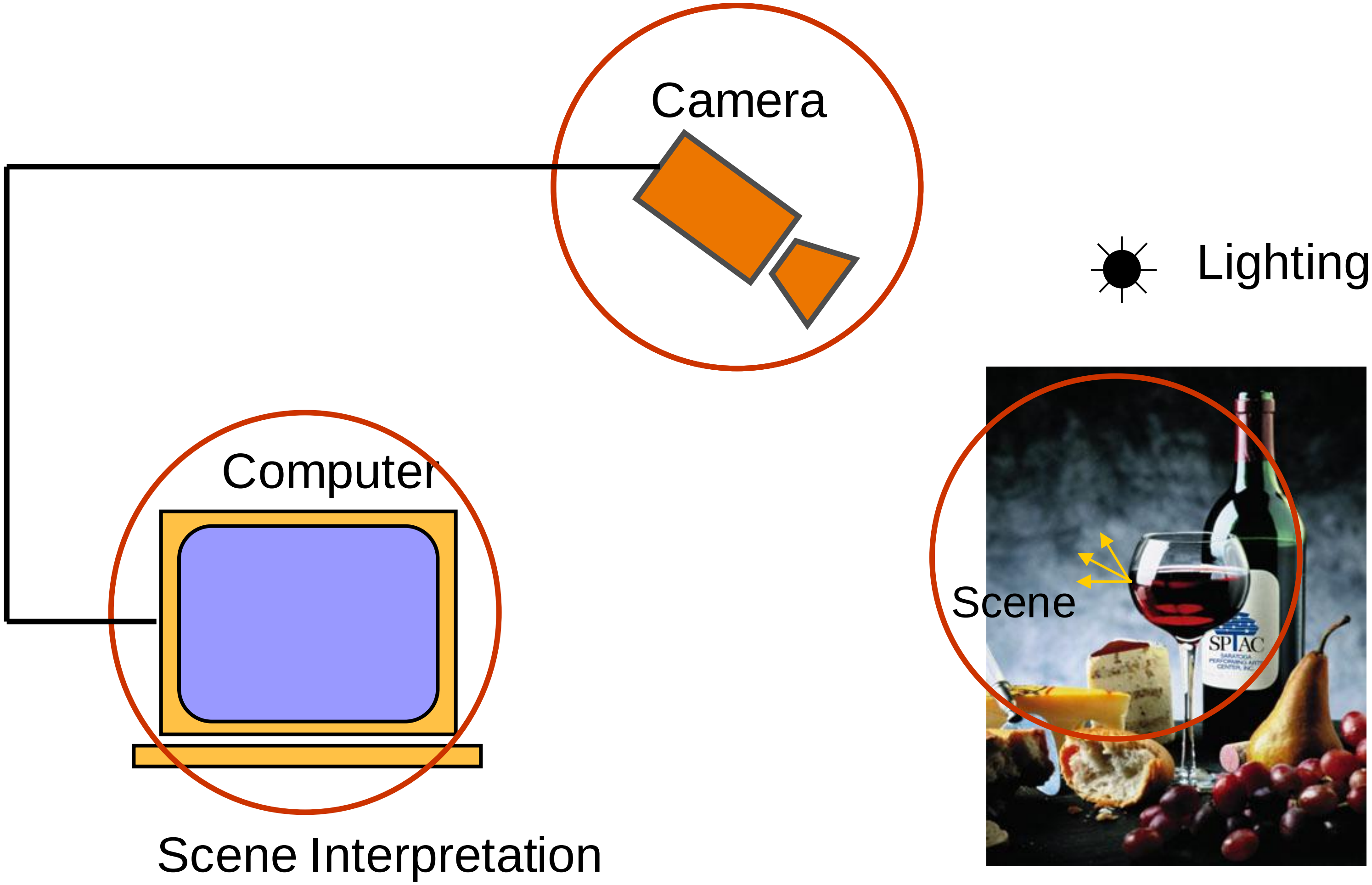
- ‘Computer Vision’?
- The Human Visual System
- Image Capturing Systems

# 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

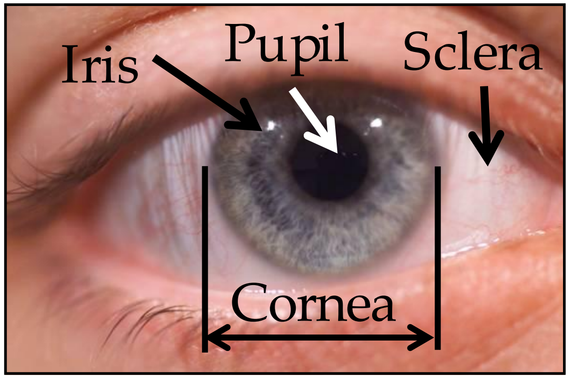
# Components of a Computer Vision System

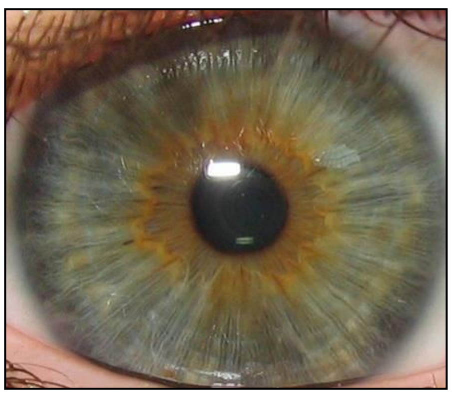


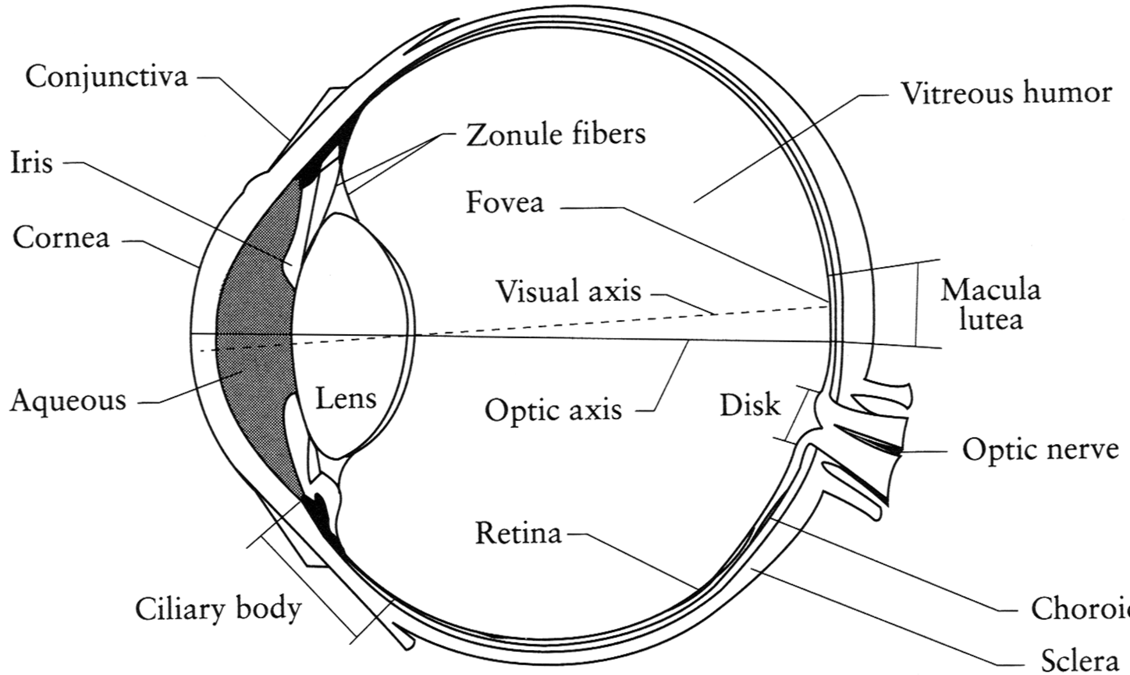
# Topic: The Human Visual System

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

# Our Eyes



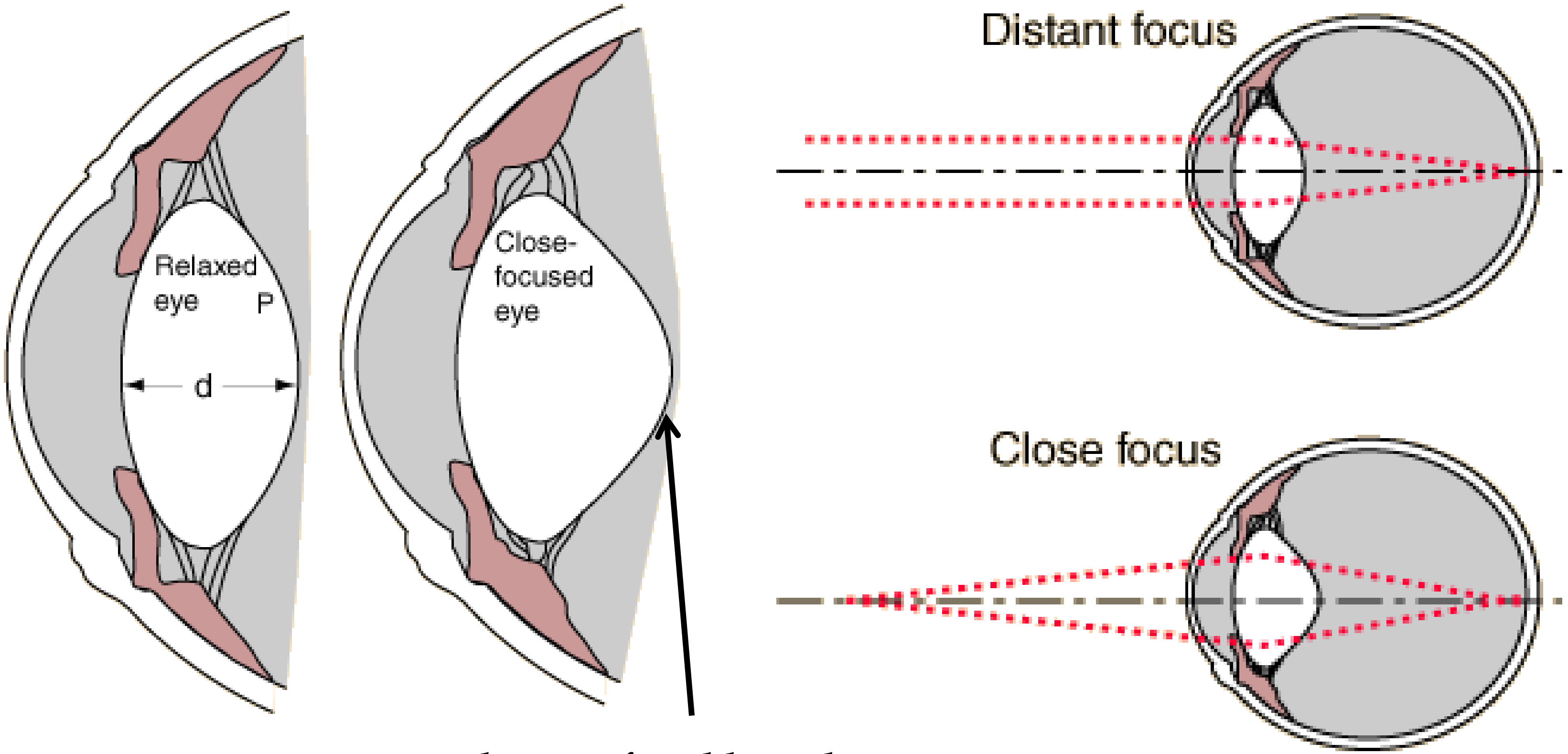






-Iris is the diaphragm that changes the aperture (pupil)

-Retina is the sensor where the fovea has the highest resolution

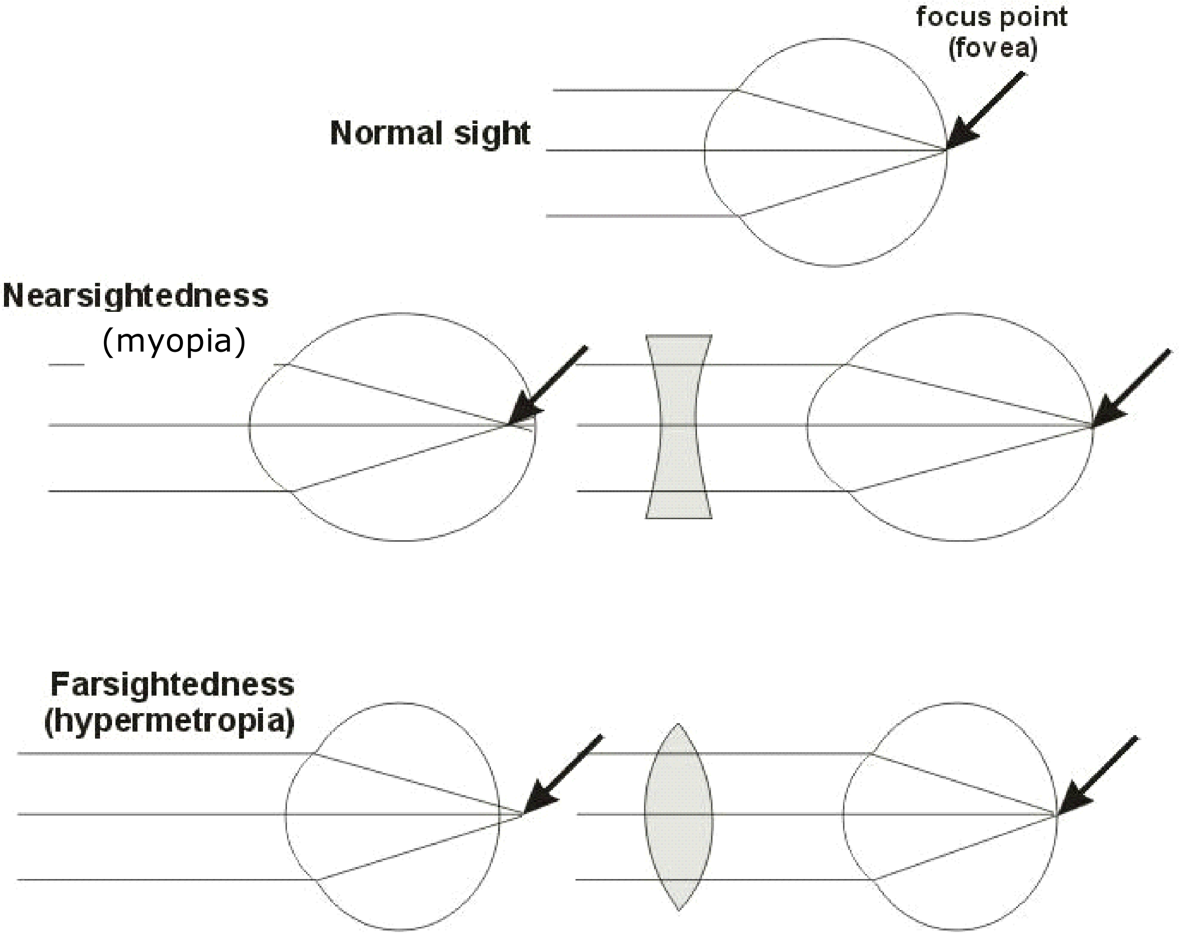
# Focusing



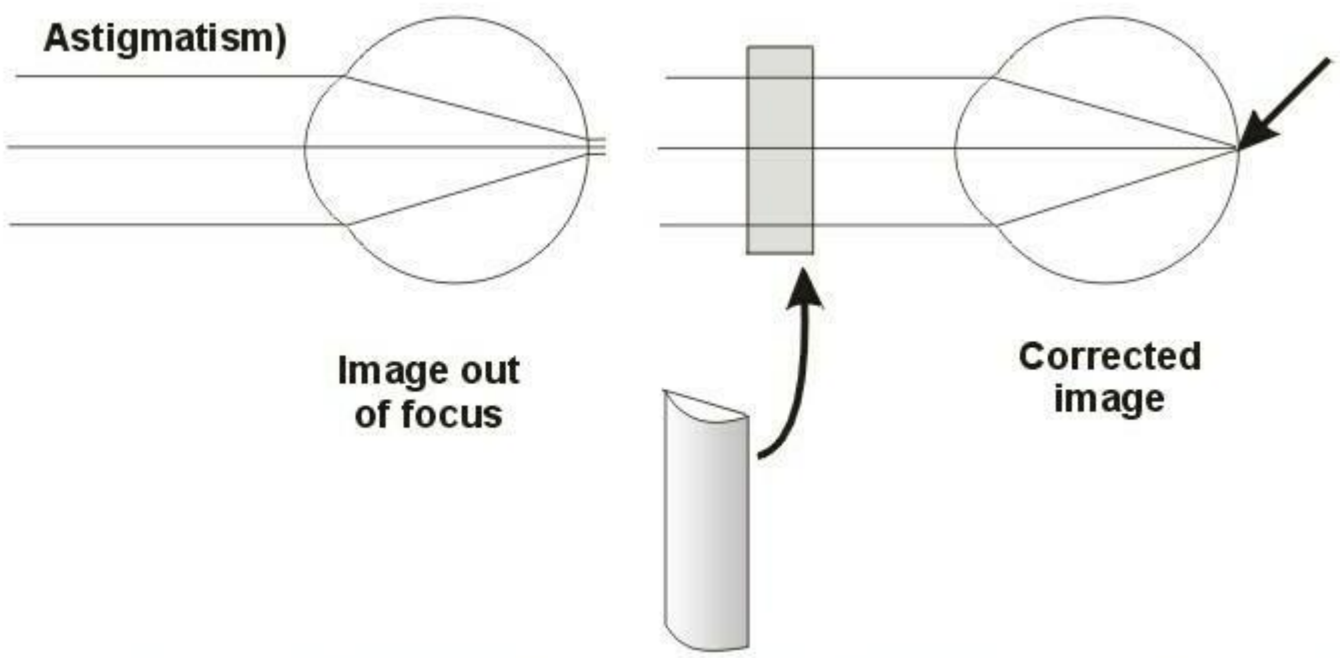

shorter focal length

Changes the focal length of the lens

# Myopia and Hyperopia



# Astigmatism



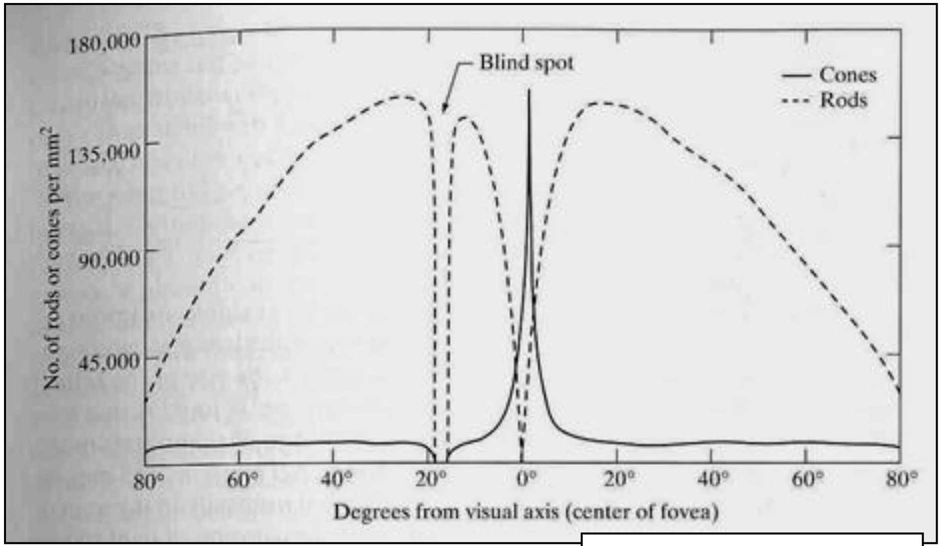

The cornea is distorted causing images to be un-focused on the retina.

# 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



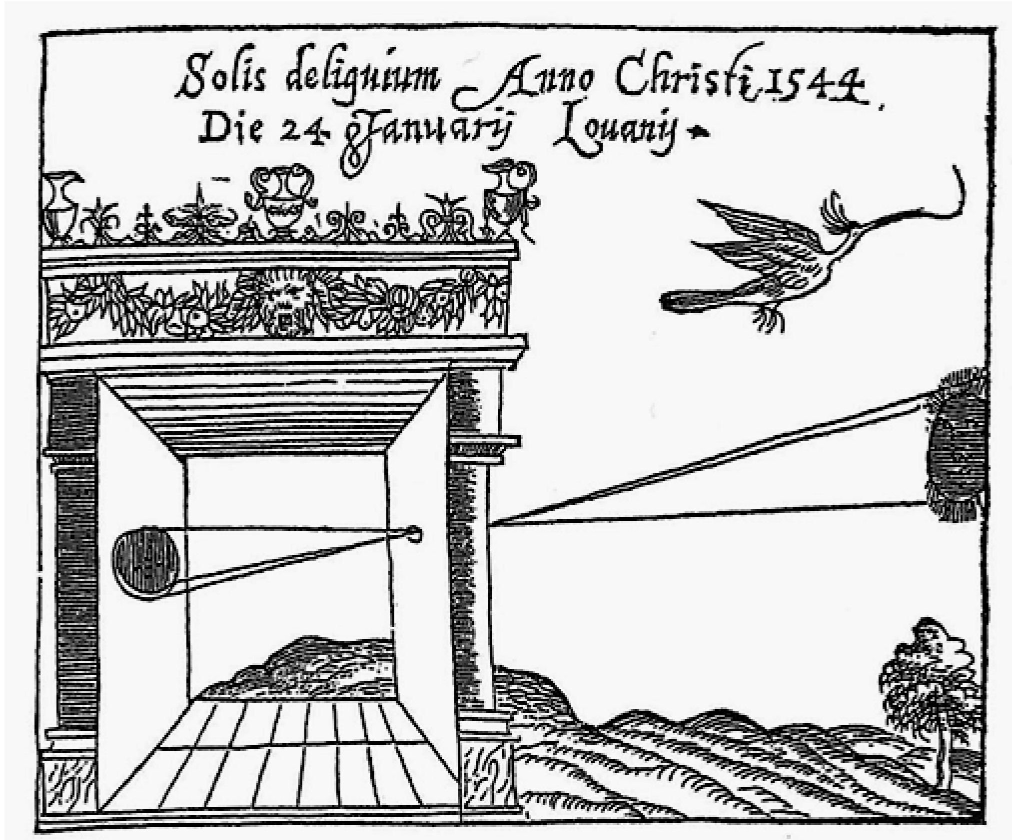

Gonzalez & Woods

We only see colour in the center of our retina!

# Topic: Image Capturing Systems

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

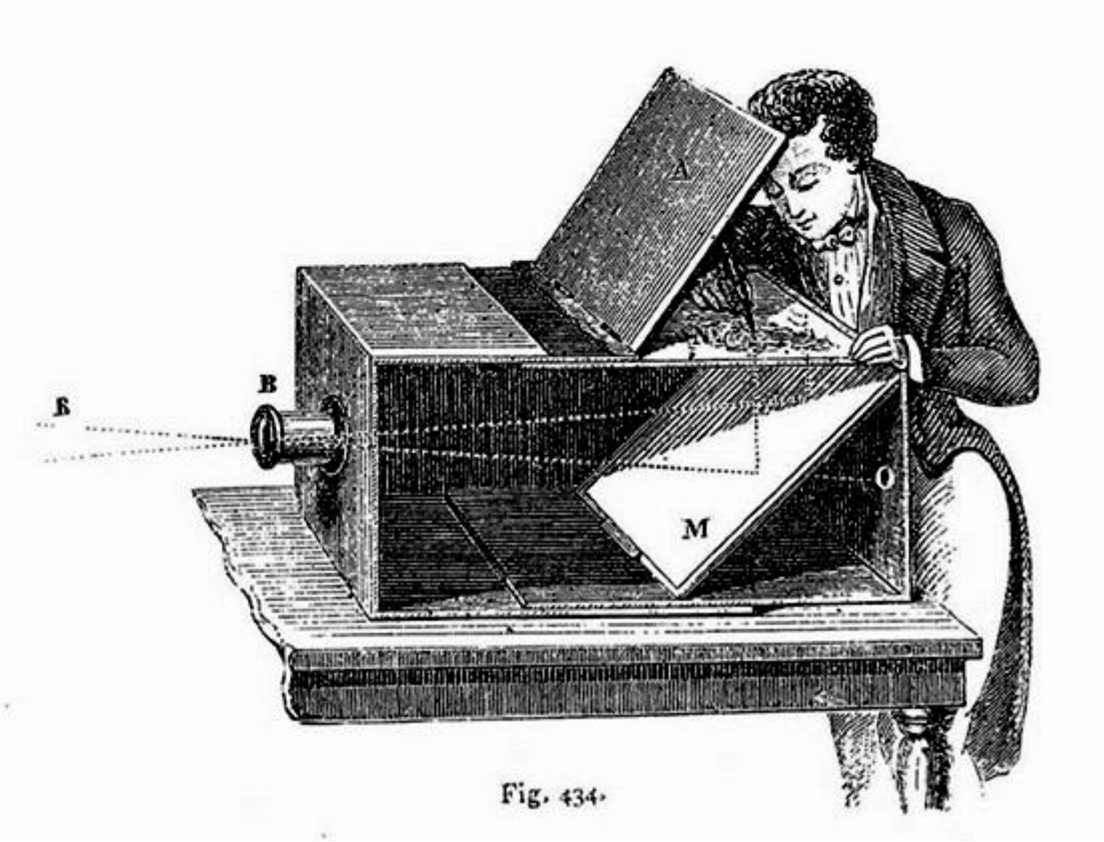
# A Brief History of Images




1544

*Camera Obscura*, Gemma Frisius, 1544

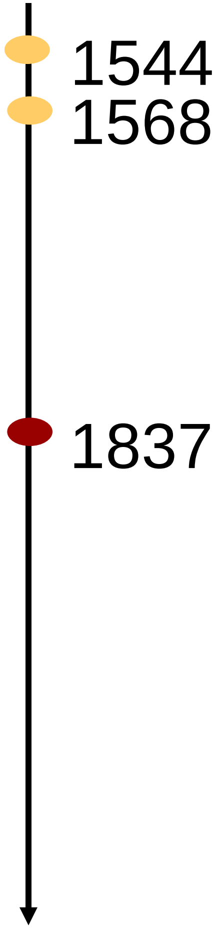
# A Brief History of Images



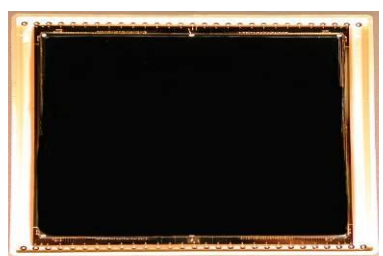

Lens Based Camera Obscura, 1568

# A Brief History of Images

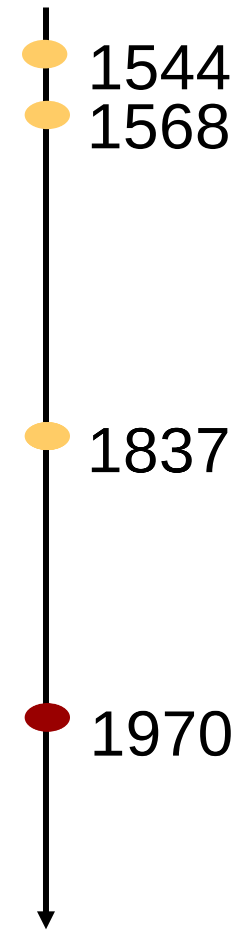
Still Life, Louis Jaques Mande Daguerre, 1837



# A Brief History of Images



Silicon Image Detector, 1970

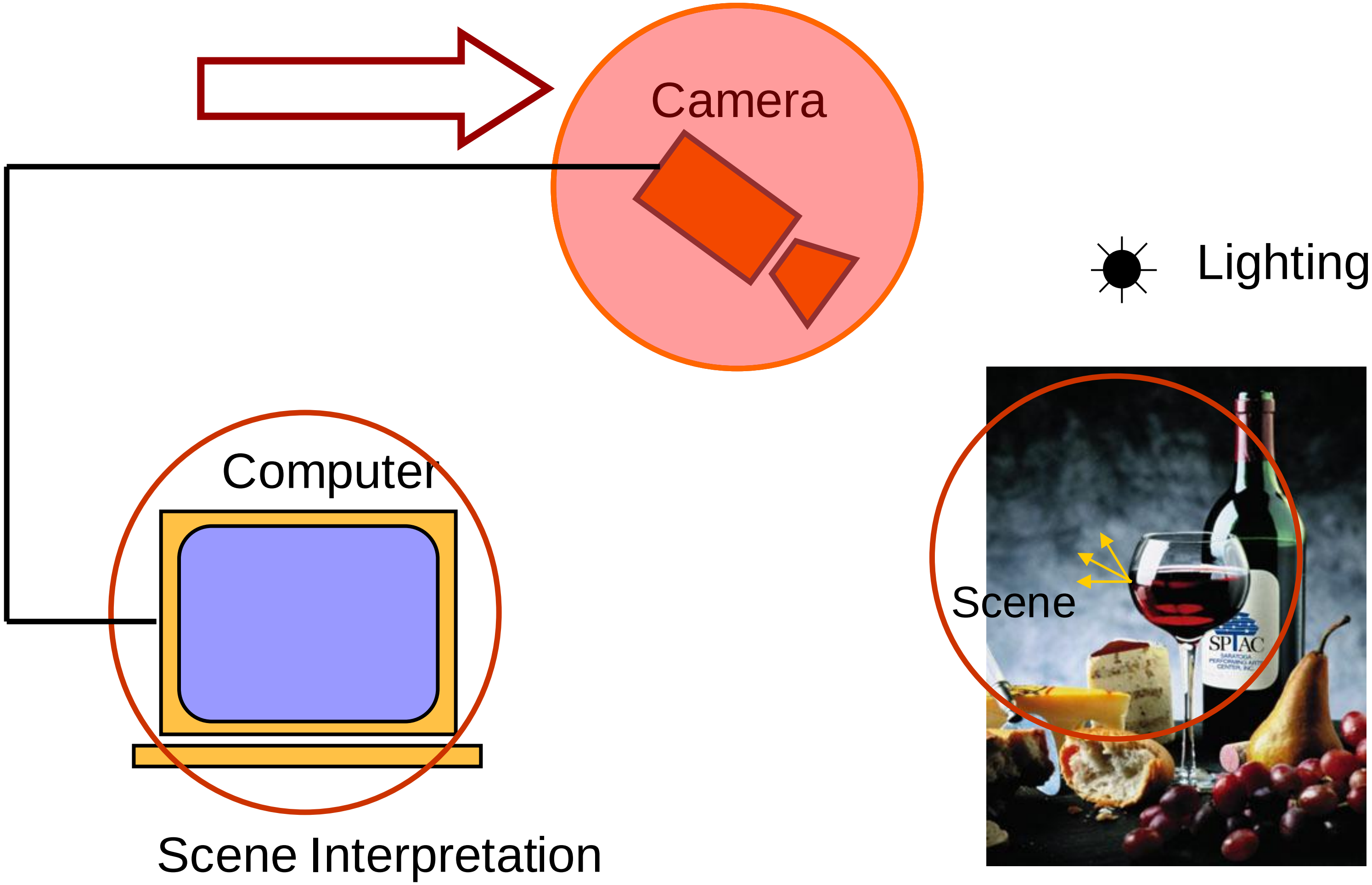



# A Brief History of Images

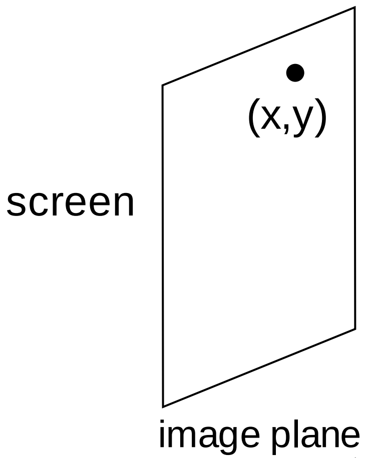

Digital Cameras

1544
1568
1837
1970
1995

# Components of a Computer Vision System



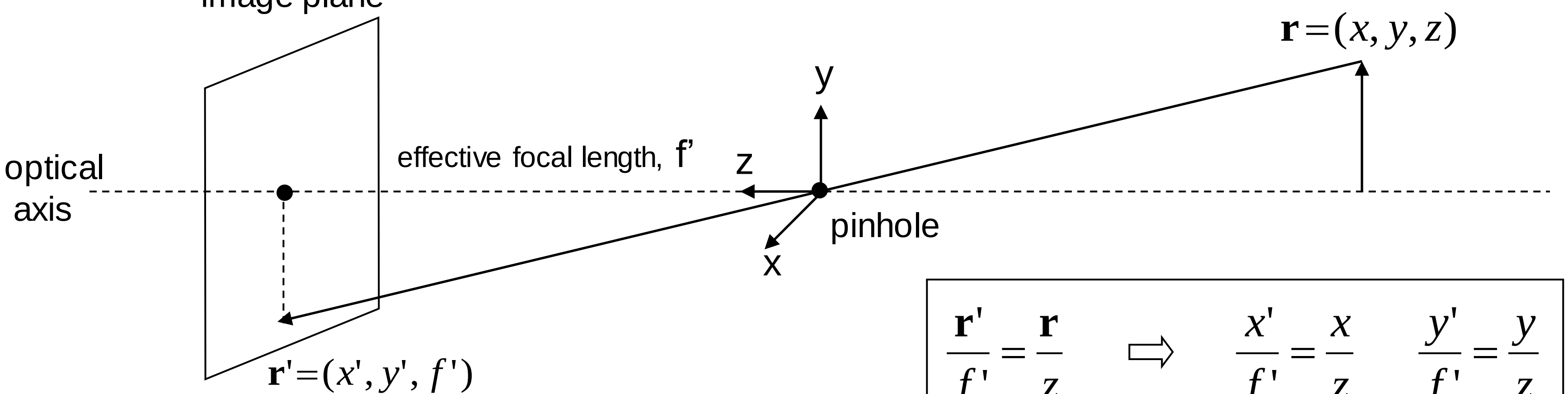
# Pinhole and the Perspective Projection




scene

Is an image being formed on the screen?

YES! But, not a “clear” one.

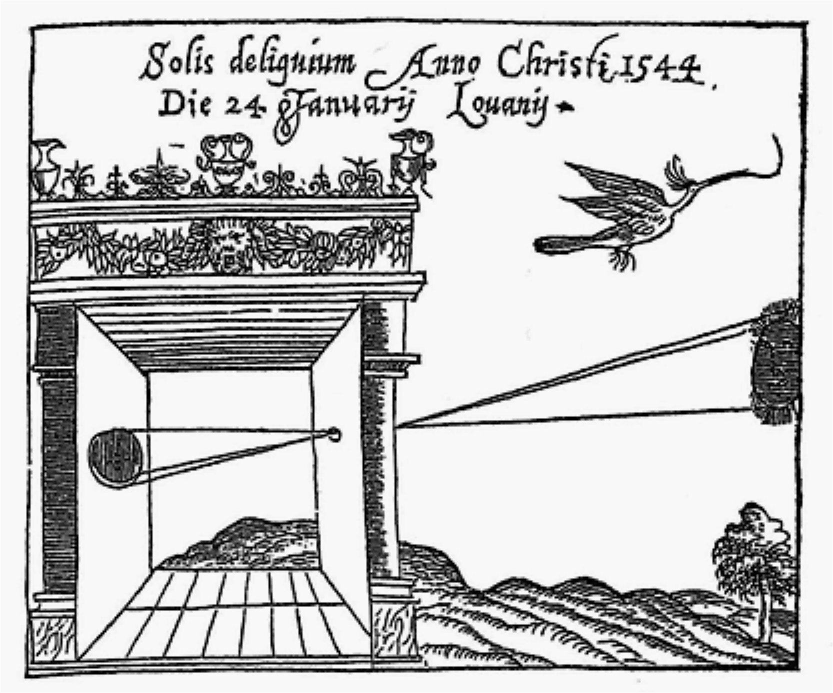



$$\frac{\mathbf{r}'}{f'} = \frac{\mathbf{r}}{z} \quad \Rightarrow \quad \frac{x'}{f'} = \frac{x}{z} \qquad \frac{y'}{f'} = \frac{y}{z}$$

# 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.



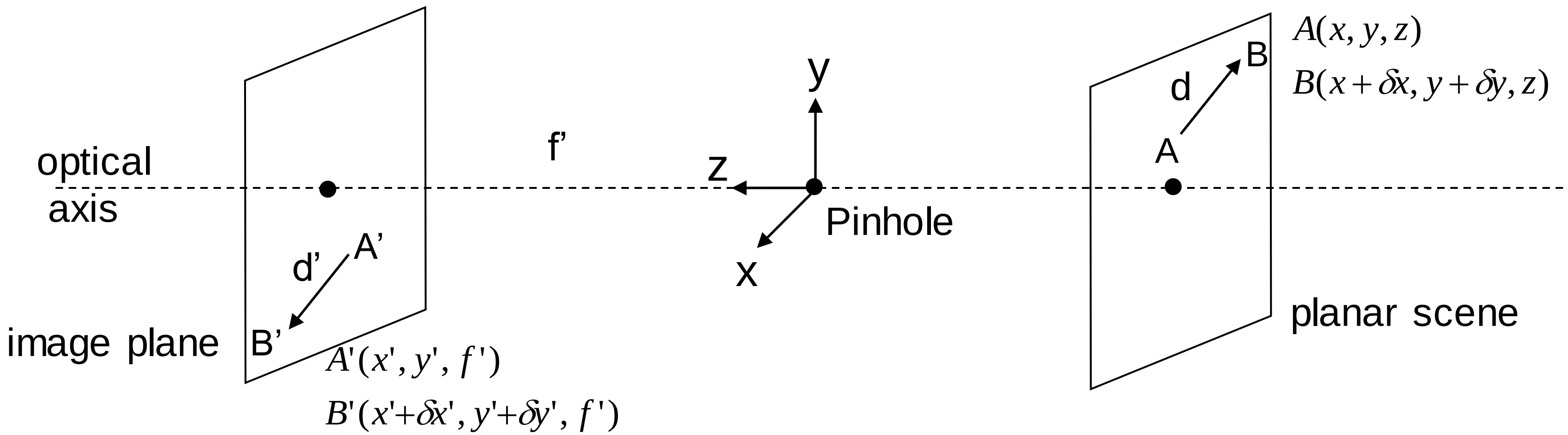
# Pinhole Photography

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

Image Size inversely proportional to Distance

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

# Magnification




From perspective projection:

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

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

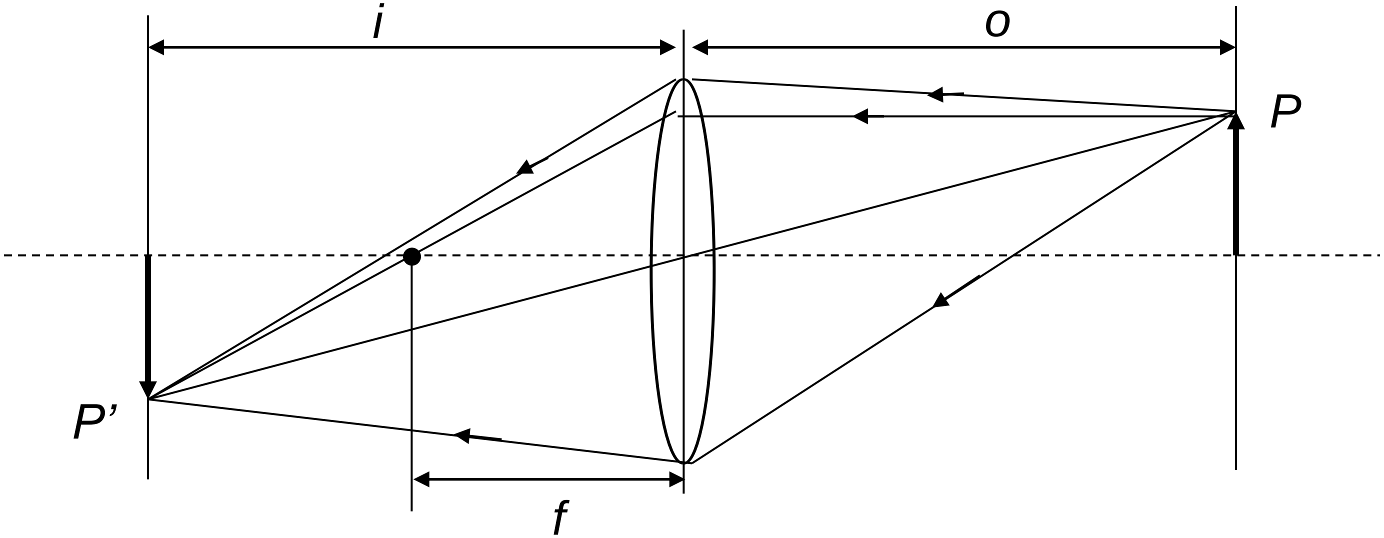
Magnification:

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

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

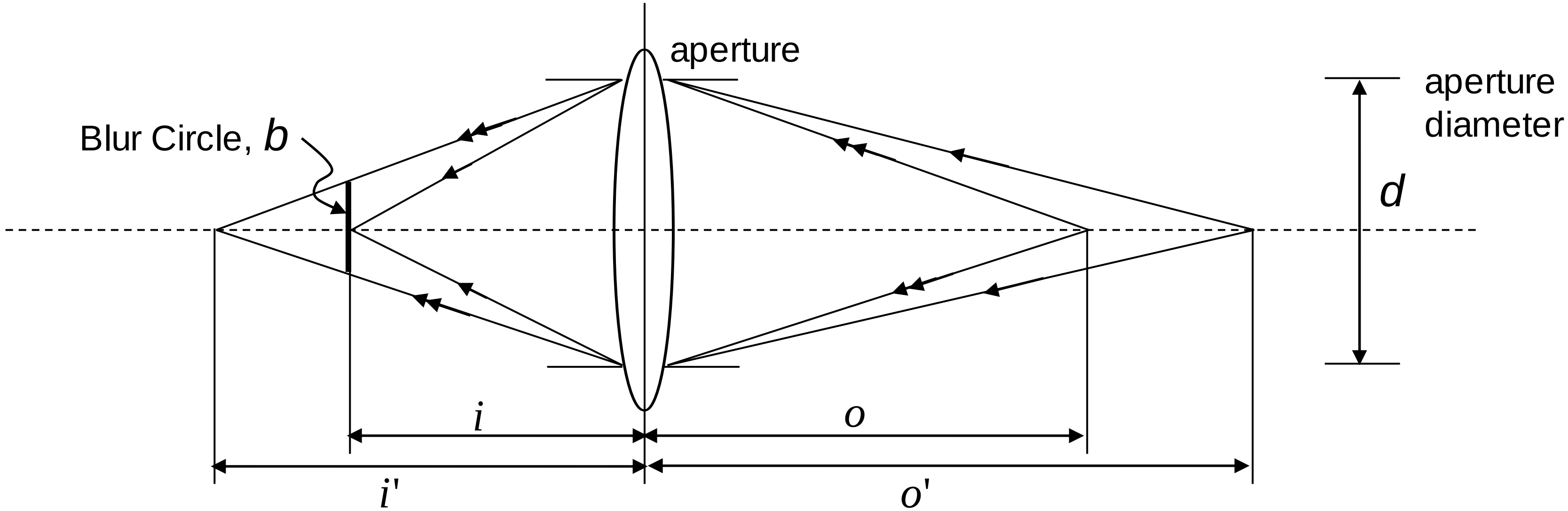
# Image Formation using Lenses

- 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.

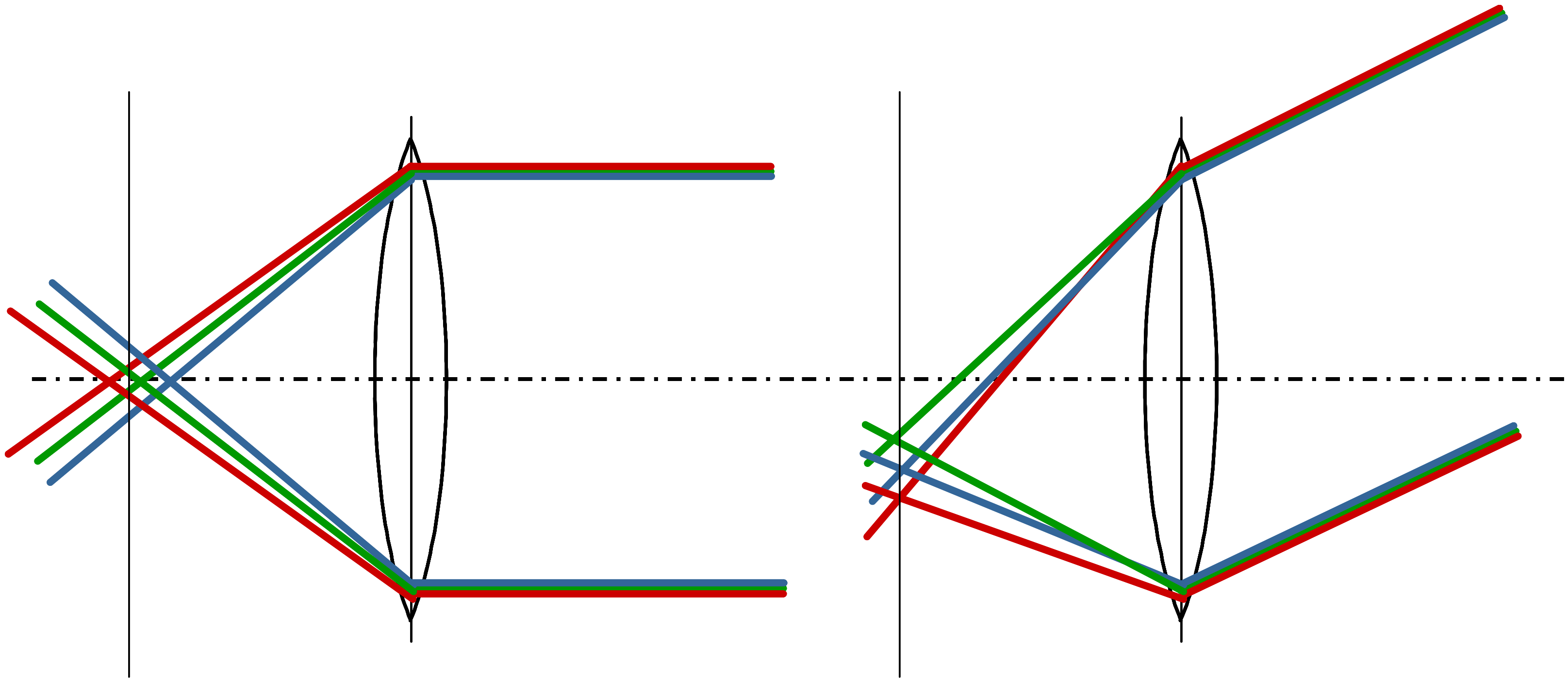
# Depth of Field

- 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

# Chromatic Aberration



longitudinal chromatic aberration (axial)

transverse chromatic aberration (lateral)

# Image Sensors

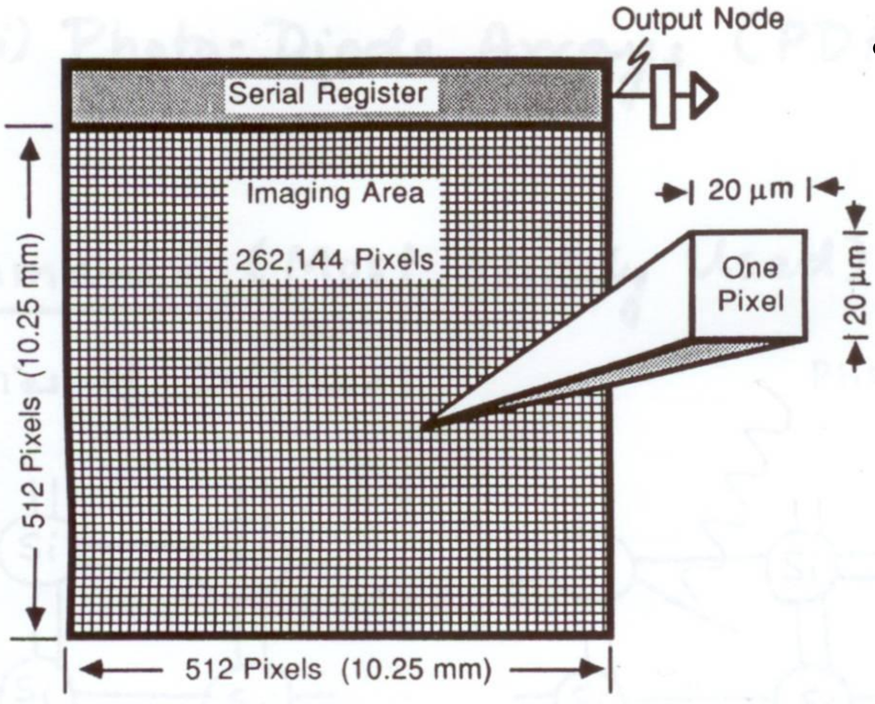
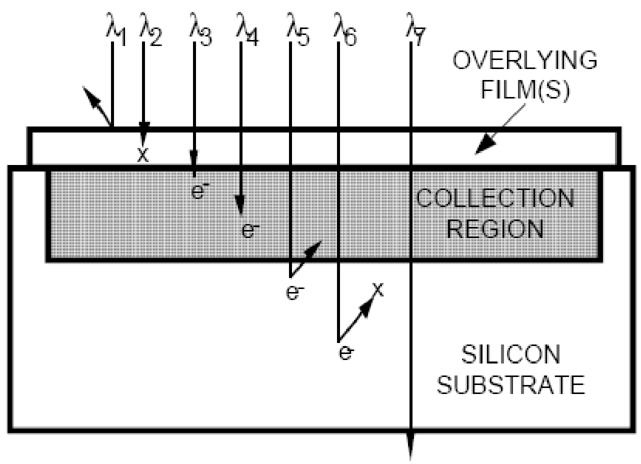


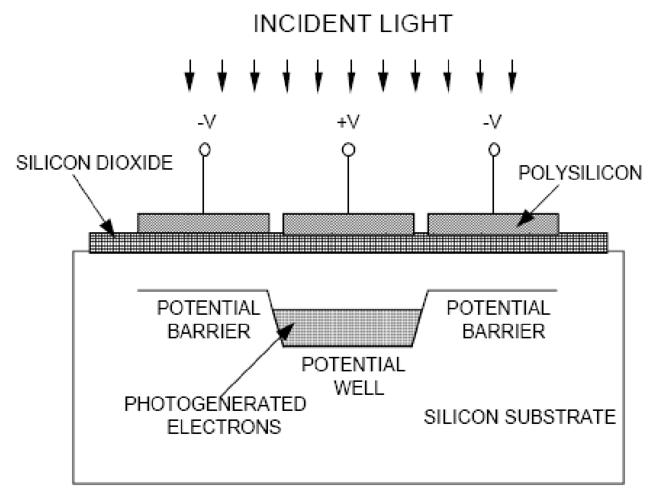

FIG. 4. Typical 512 × 512 CCD.

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

# Image Sensors

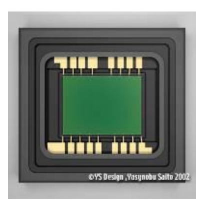
- Convert light into an electric charge



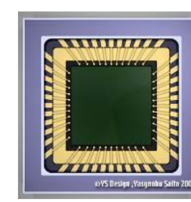

CCD (charge coupled device)

Higher dynamic range
High uniformity
Lower noise



CMOS (complementary metal Oxide semiconductor)

Lower voltage
Higher speed
Lower system complexity

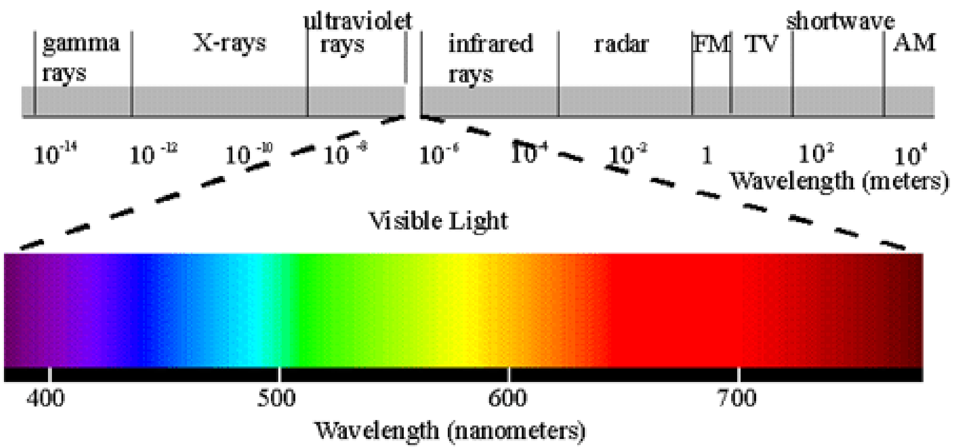


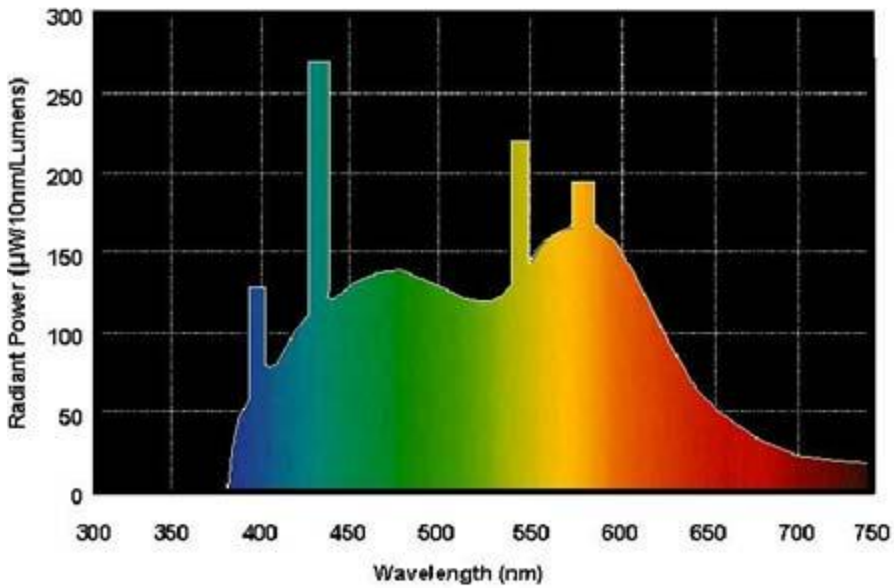
# CCD Performance Characteristics

- Linearity Principle: Incoming photon flux vs. Output Signal
  - Sometimes cameras are made non-linear on purpose.
  - Calibration must be done (using reflectance charts)---covered later
- Dark Current Noise: Non-zero output signal when incoming light is zero
- Sensitivity: Minimum detectable signal produced by camera

# Sensing Brightness

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



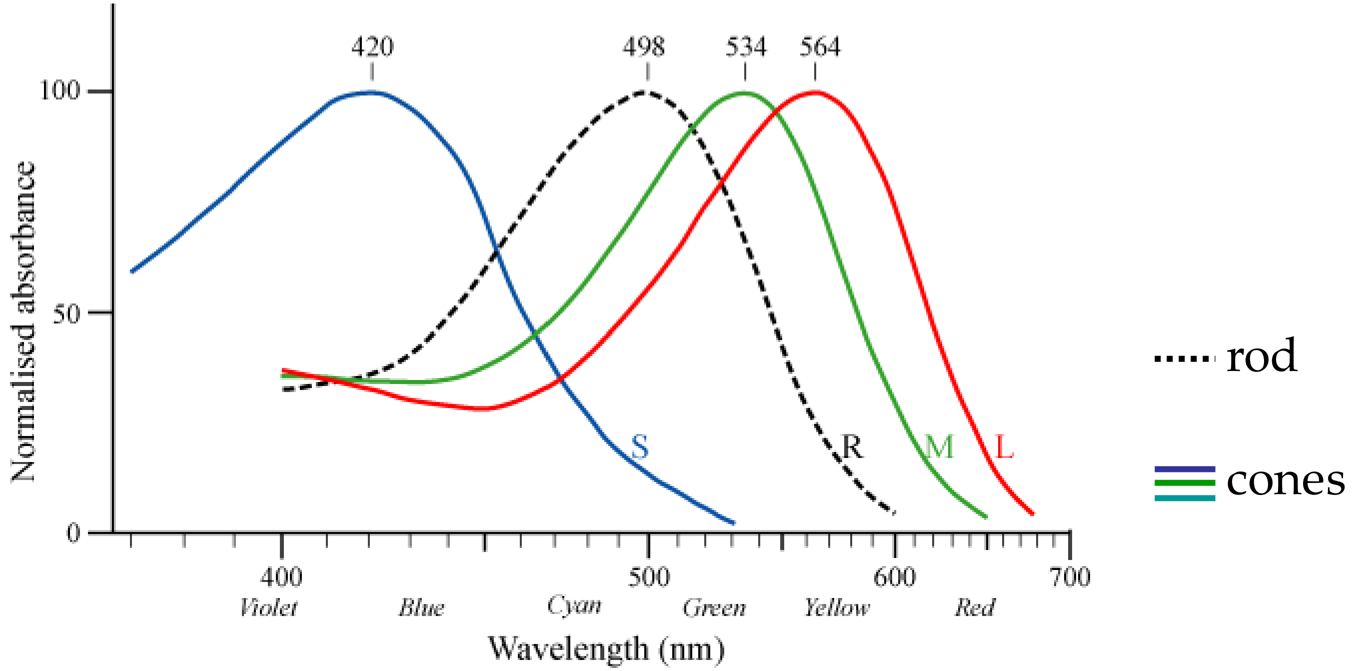




So the pixel intensity becomes

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

# How do we sense colour?

- Do we have infinite number of filters?

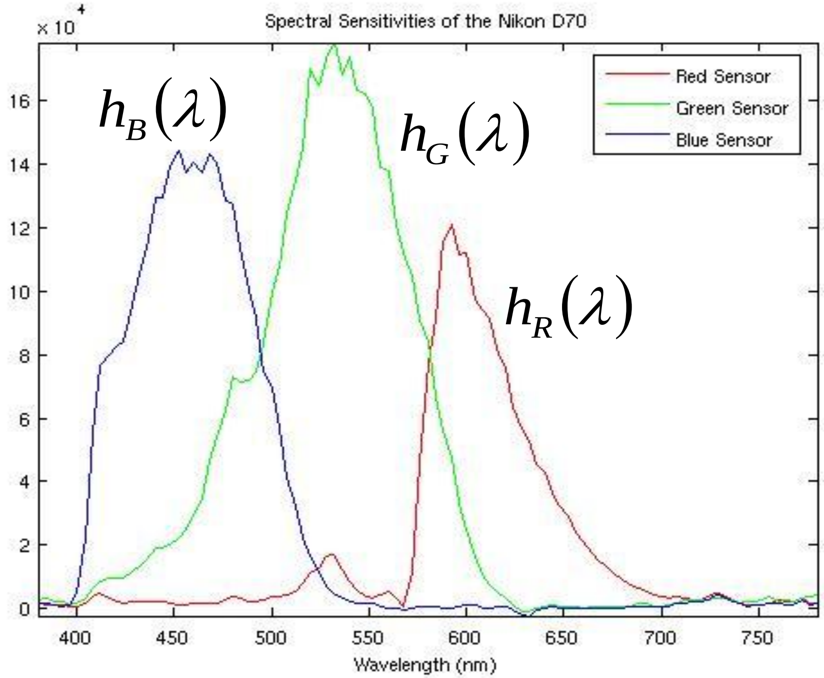



Three filters of different spectral responses

# Sensing Colour

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

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

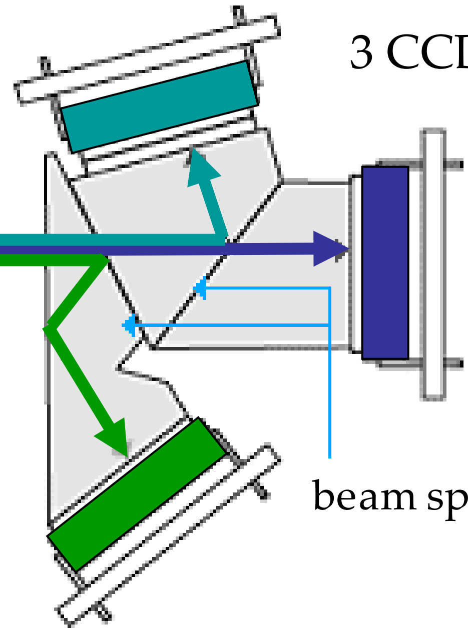


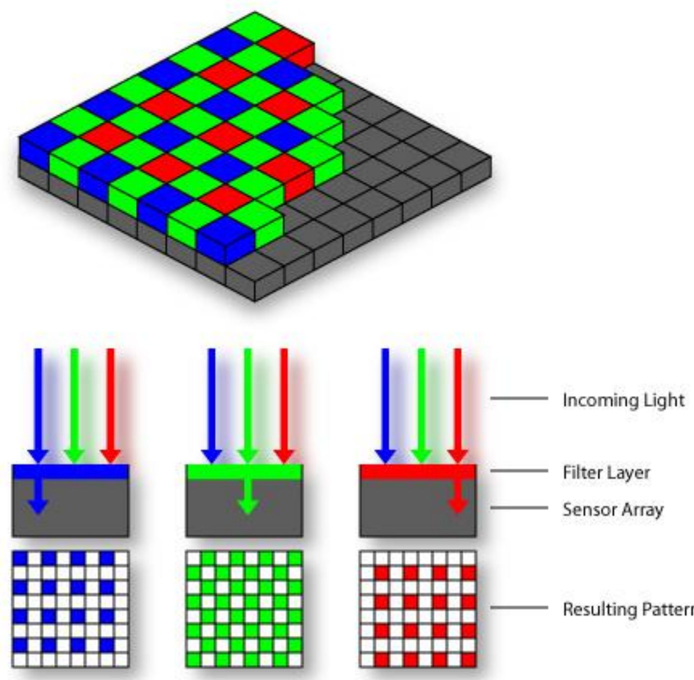

$$I_R = k \int_{-\infty}^{\infty} h_R(\lambda) p(\lambda) d\lambda$$

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

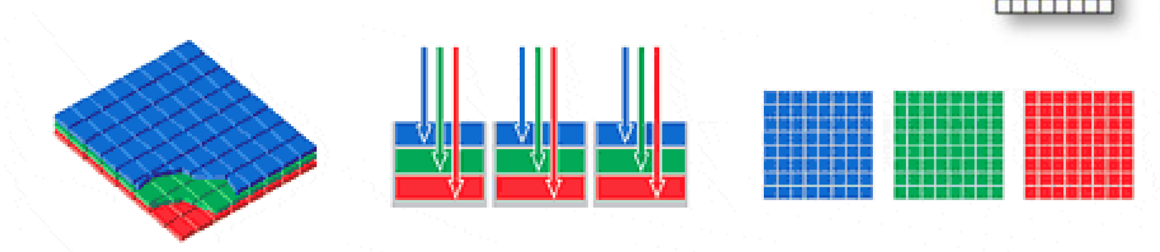
$$I_B = k \int_{-\infty}^{\infty} h_B(\lambda) p(\lambda) d\lambda$$

# Sensing Colour




Bayer pattern



Foveon X3$^{TM}$

# Resources

- J.C. Russ – Chapters 1 and 2
- L. Shapiro, and G. Stockman – Chapter 1
- “Color Vision: One of Nature's Wonders” in http://www.diycalculator.com/sp-cvision.shtml