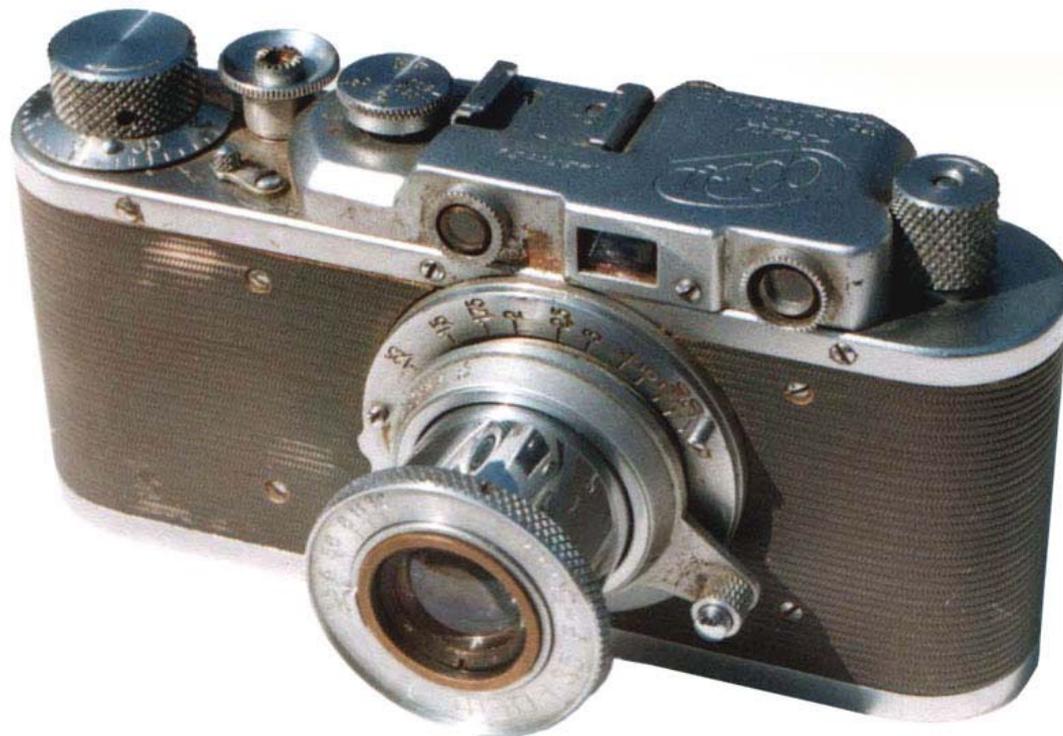


CS6670: Computer Vision

Noah Snavely

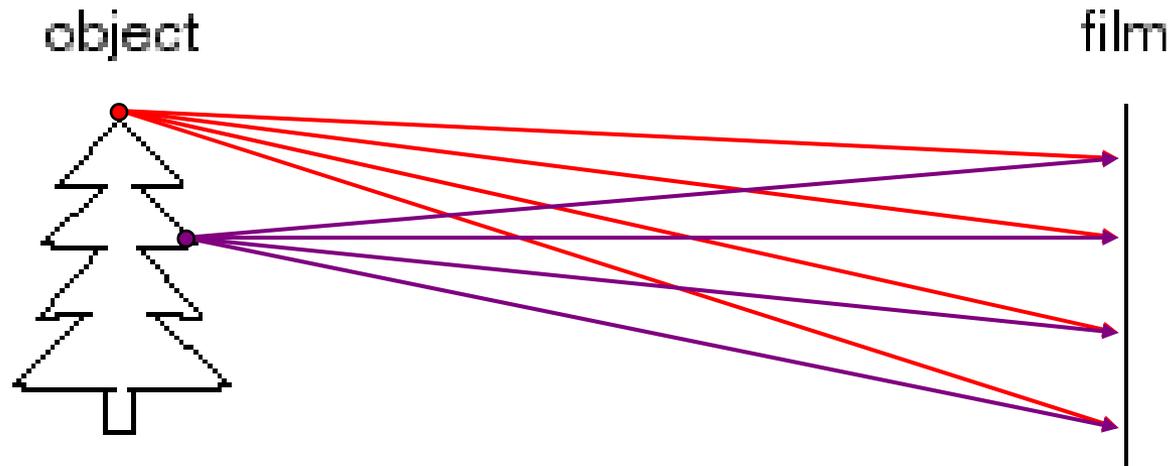
Lecture 4a: Cameras



Reading

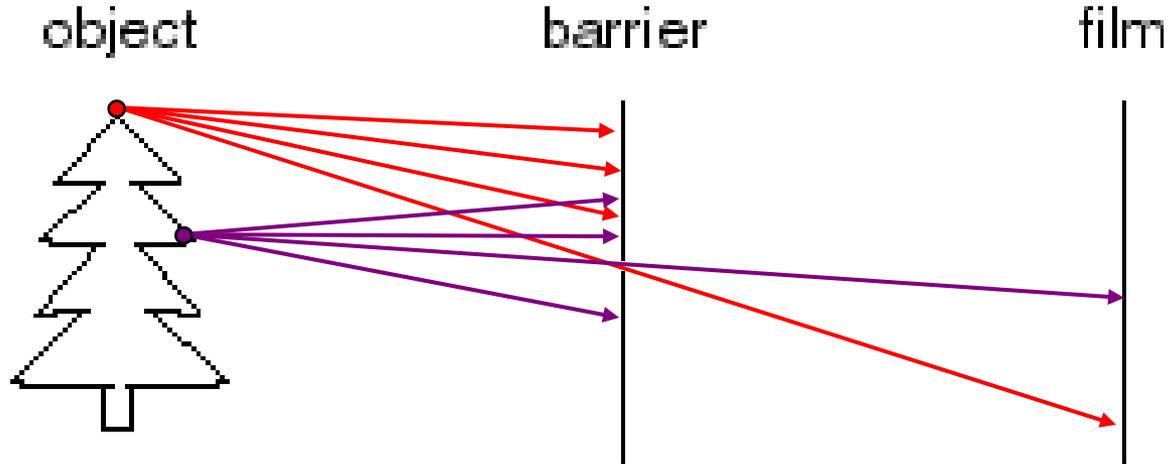
- Szeliski chapter 2.2.3, 2.3

Image formation



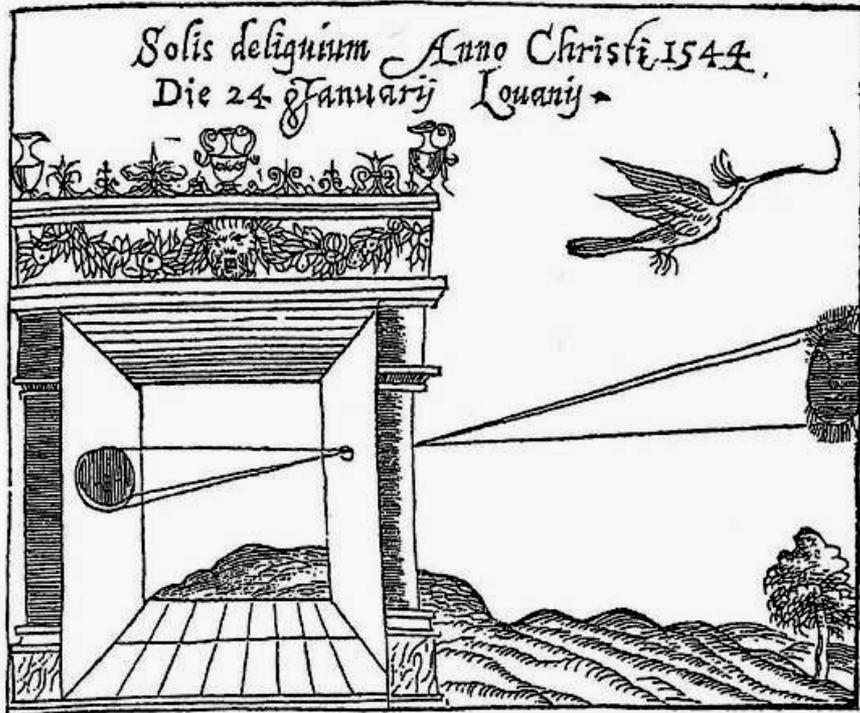
- Let's design a camera
 - Idea 1: put a piece of film in front of an object
 - Do we get a reasonable image?

Pinhole camera



- Add a barrier to block off most of the rays
 - This reduces blurring
 - The opening known as the **aperture**
 - How does this transform the image?

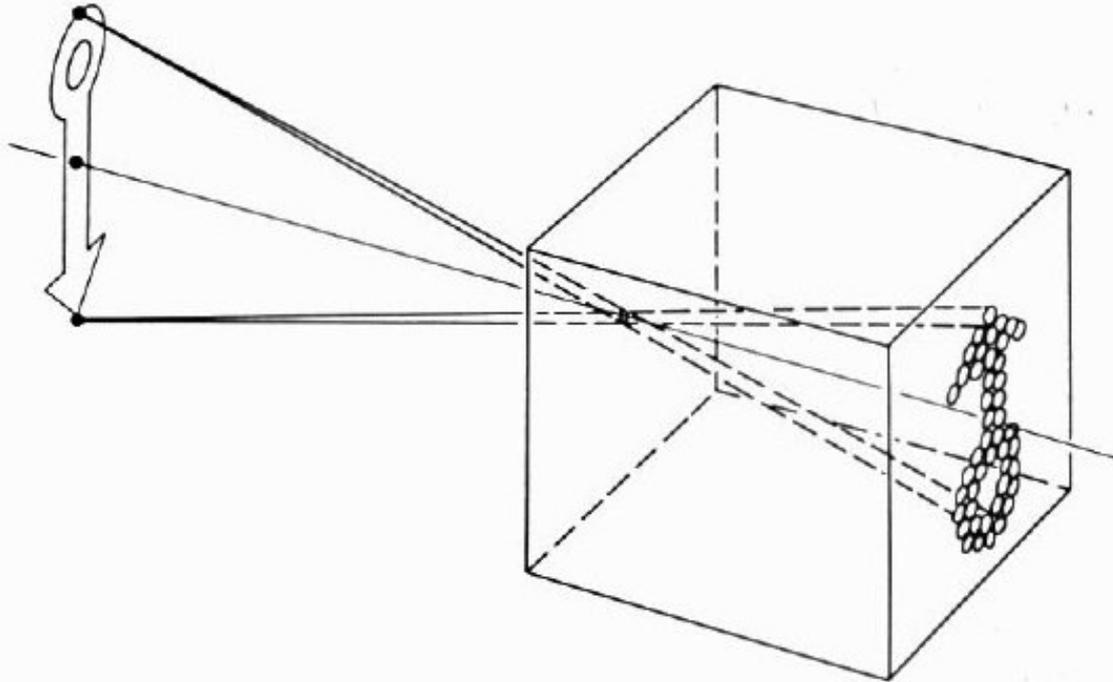
Camera Obscura



Gemma Frisius, 1558

- Basic principle known to Mozi (470-390 BC), Aristotle (384-322 BC)
- Drawing aid for artists: described by Leonardo da Vinci (1452-1519)

Camera Obscura

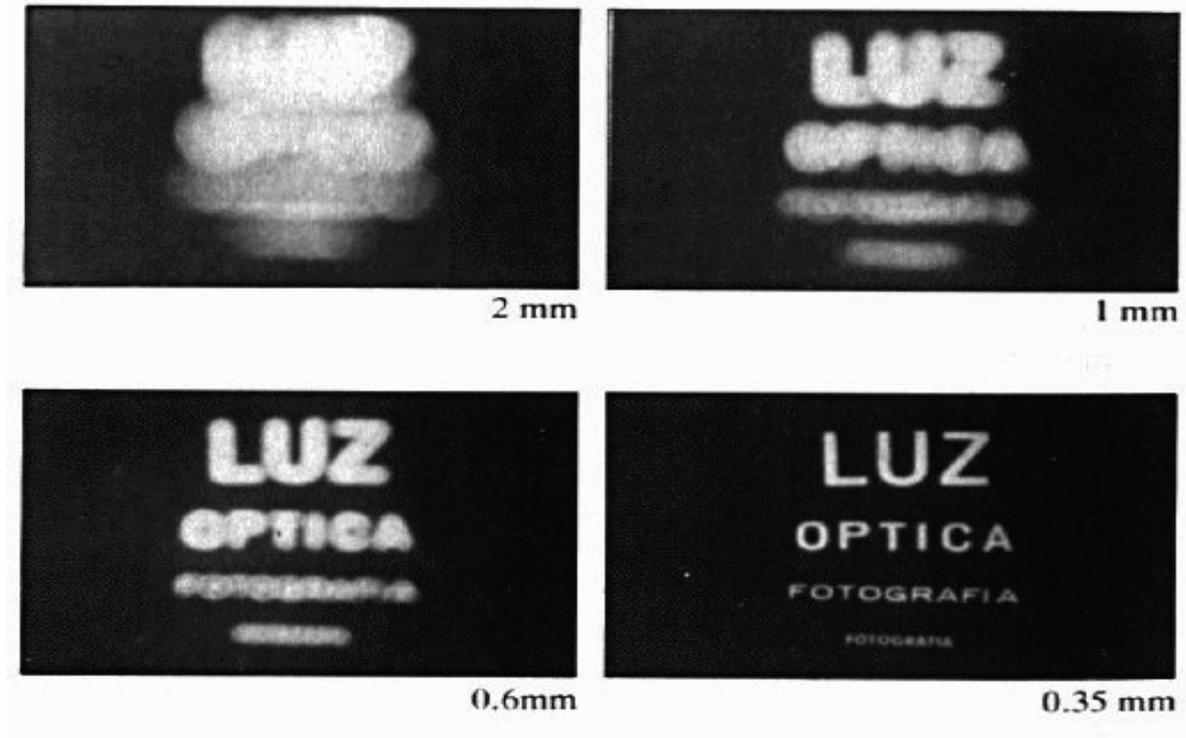


Home-made pinhole camera



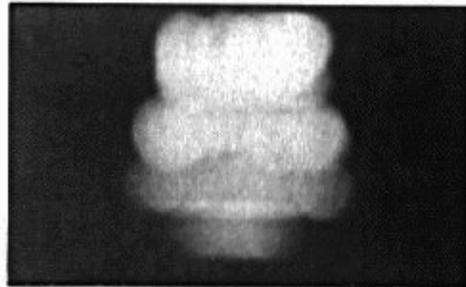
Why so blurry?

Shrinking the aperture

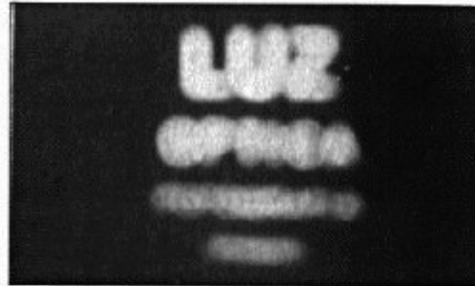


- Why not make the aperture as small as possible?
 - Less light gets through
 - *Diffraction* effects...

Shrinking the aperture



2 mm



1 mm



0.6mm



0.35 mm

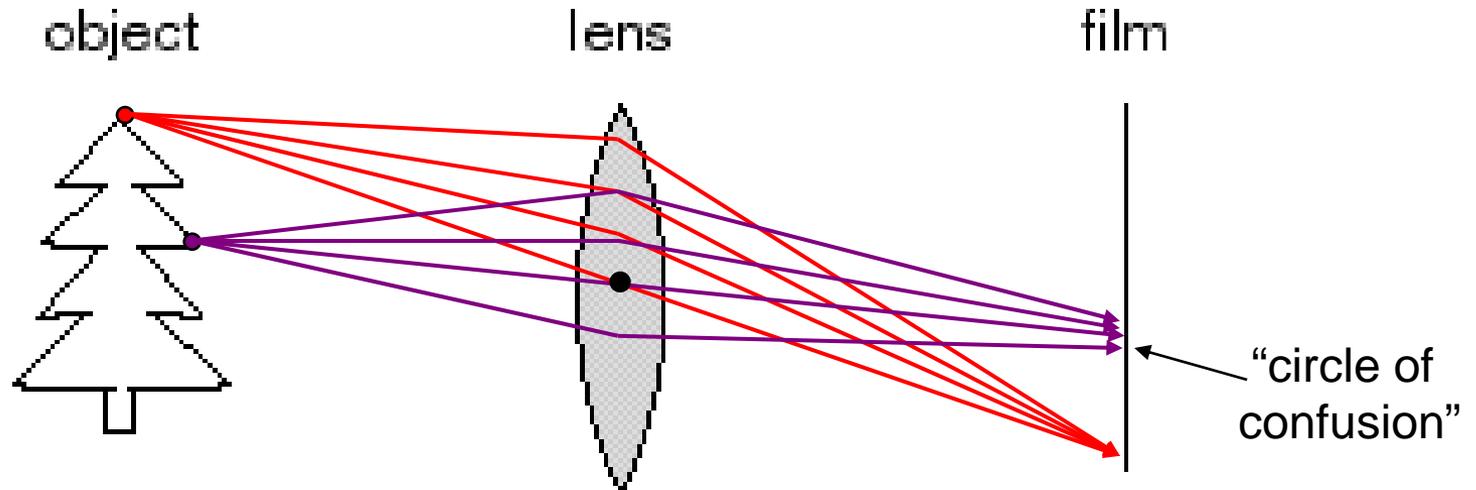


0.15 mm



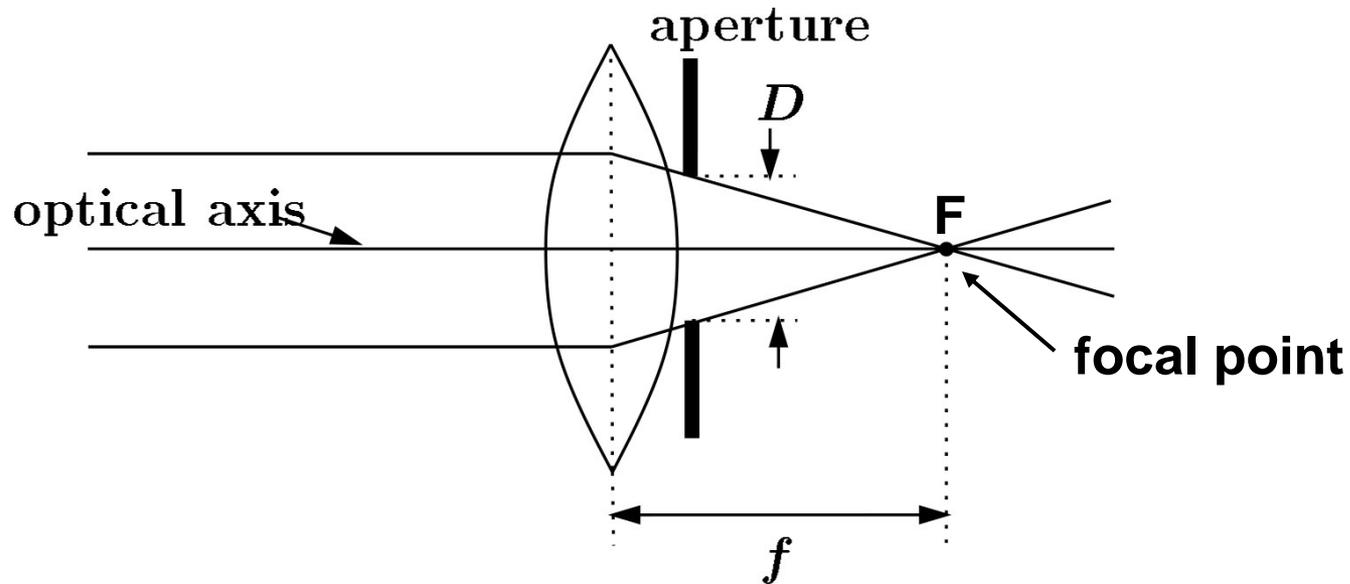
0.07 mm

Adding a lens



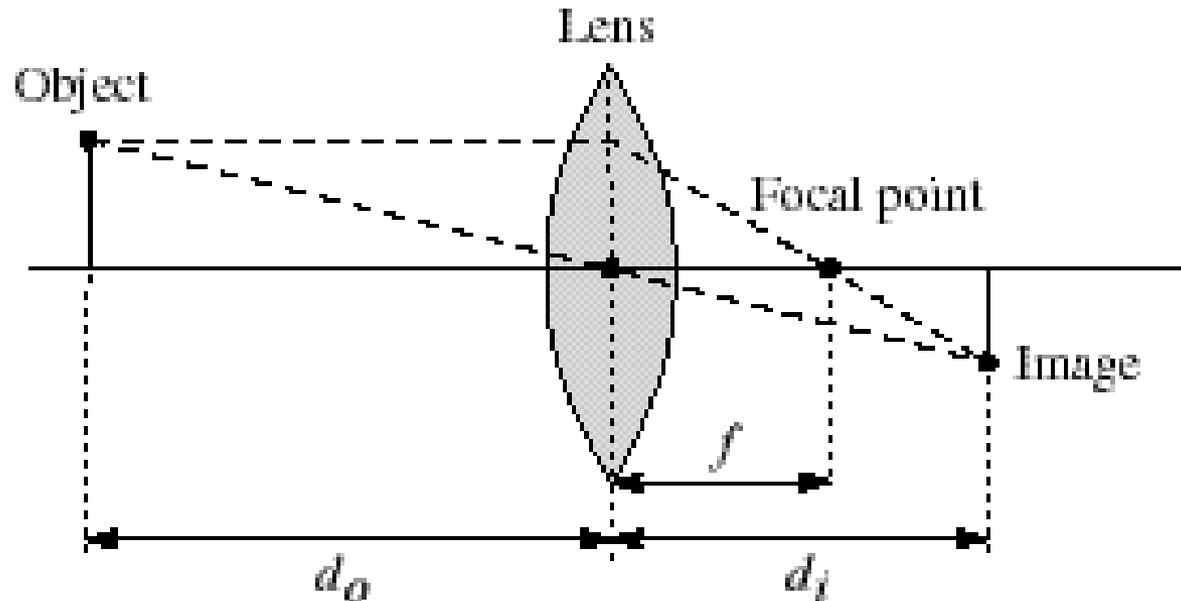
- A lens focuses light onto the film
 - There is a specific distance at which objects are “in focus”
 - other points project to a “circle of confusion” in the image
 - Changing the shape of the lens changes this distance

Lenses



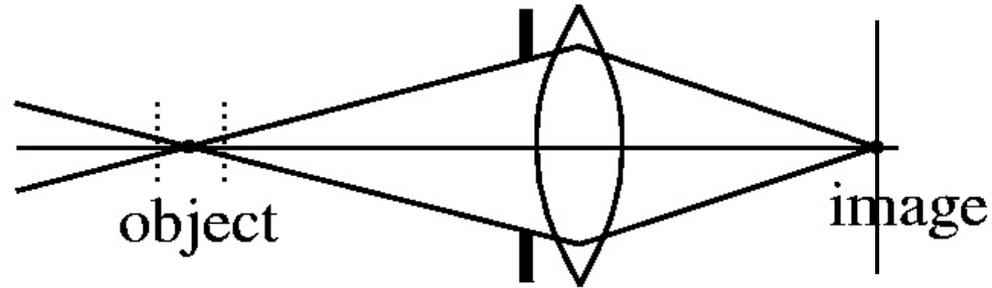
- A lens focuses parallel rays onto a single focal point
 - focal point at a distance f beyond the plane of the lens (the *focal length*)
 - f is a function of the shape and index of refraction of the lens
 - Aperture restricts the range of rays
 - aperture may be on either side of the lens
 - Lenses are typically spherical (easier to produce)

Thin lenses

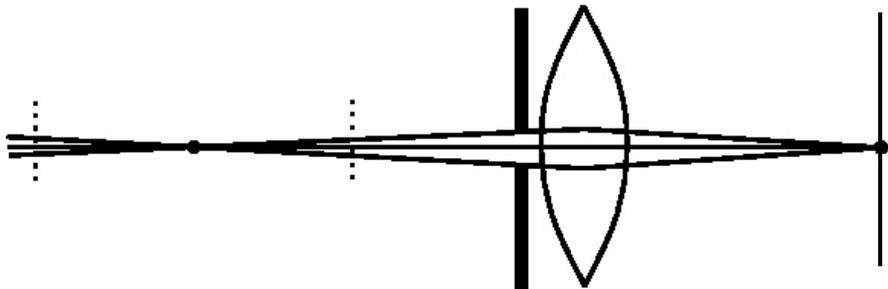


- Thin lens equation:
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$
 - Any object point satisfying this equation is in focus
 - What is the shape of the focus region?
 - How can we change the focus region?
 - Thin lens applet: http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html (by Fu-Kwun Hwang)

Depth of Field



$f/5.6$

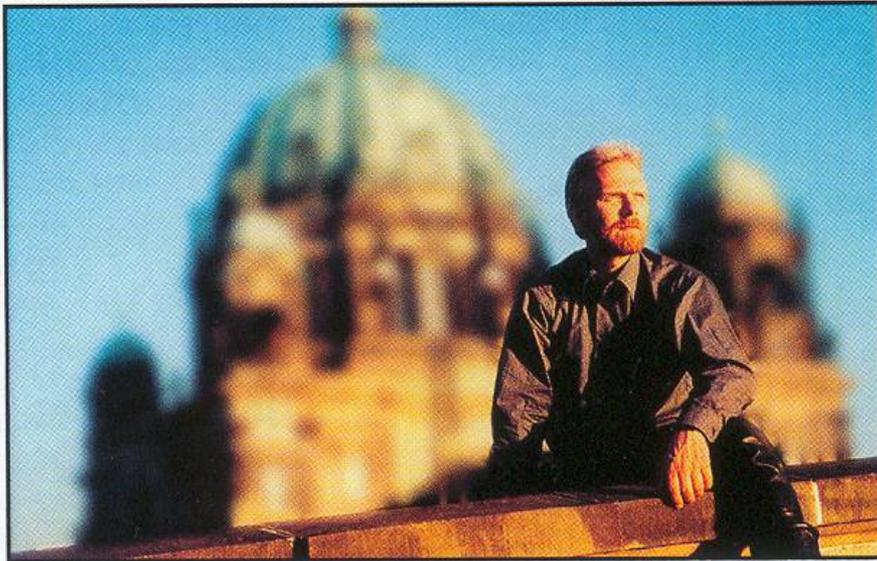


$f/32$

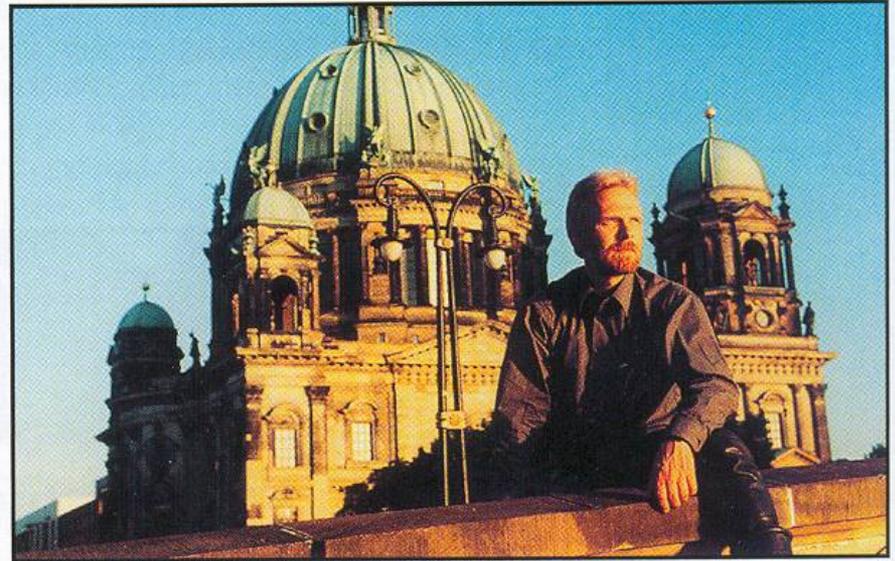
- Changing the aperture size affects depth of field
 - A smaller aperture increases the range in which the object is approximately in focus

Depth of Field

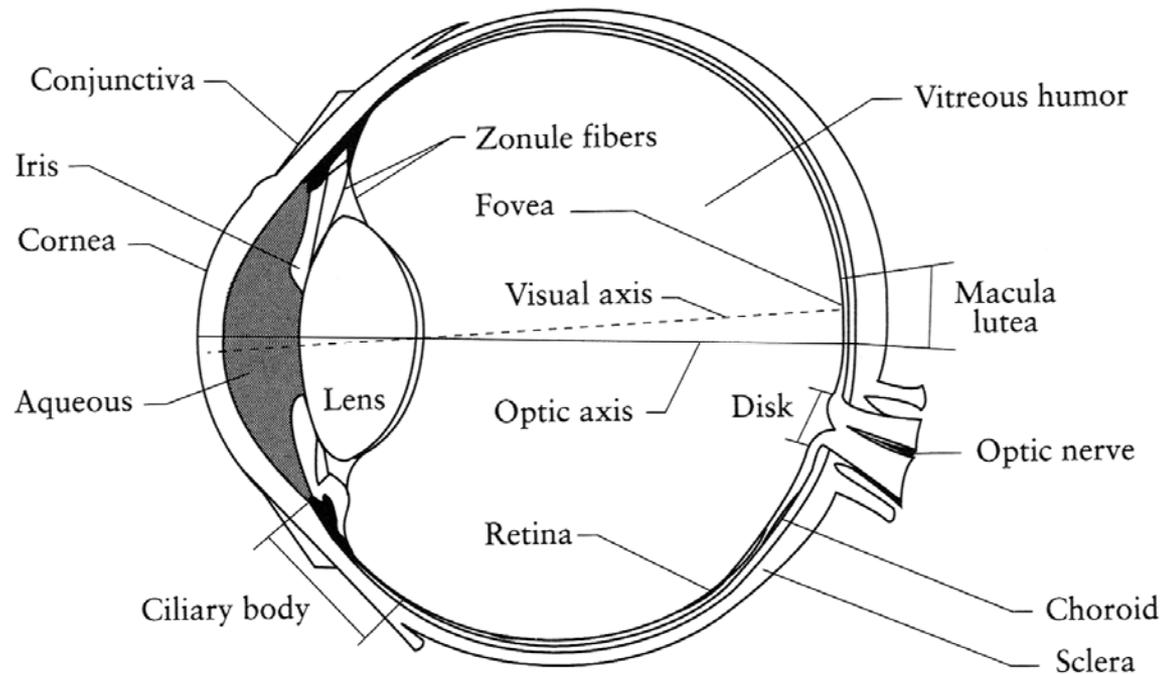
Large aperture opening



Small aperture opening



The eye

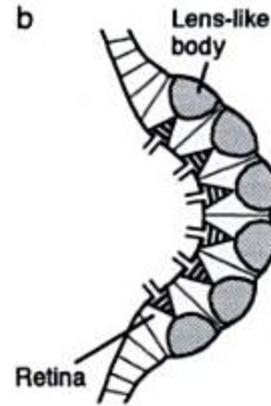
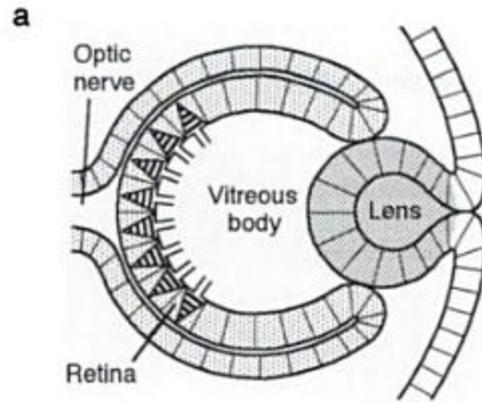
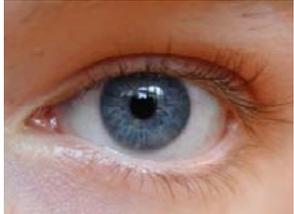


- The human eye is a camera
 - **Iris** - colored annulus with radial muscles
 - **Pupil** - the hole (aperture) whose size is controlled by the iris
 - What's the "film"?
 - photoreceptor cells (rods and cones) in the **retina**

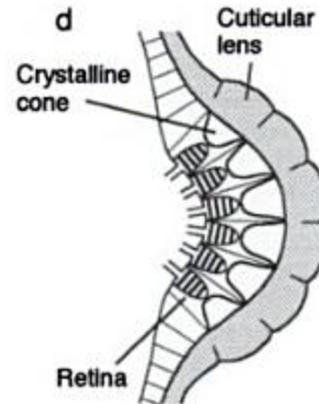
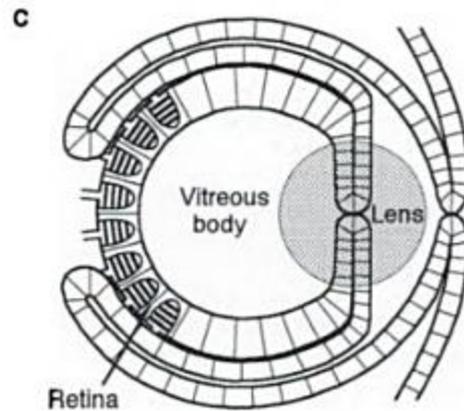
Eyes in nature: eyespots to pinhole camera



Eyes in nature



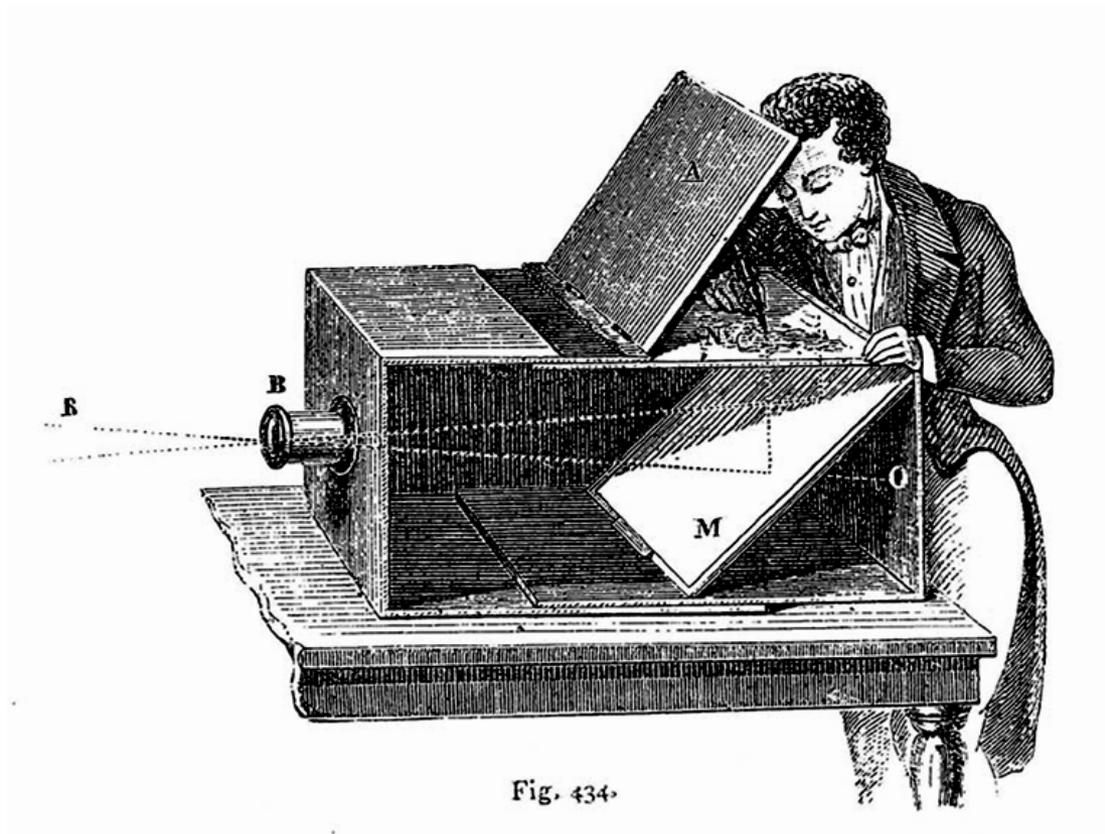
(polychaete fan worm)



 Ciliary photoreceptor cell

 Microvillar photoreceptor cell

Before Film was invented



Lens Based Camera Obscura, 1568

Film camera



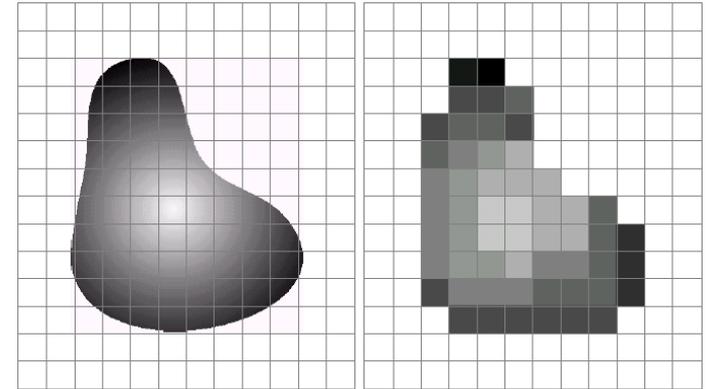
Still Life, Louis Jaques Mande Daguerre, 1837

Silicon Image Detector



Silicon Image Detector, 1970

Digital camera



a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

- A digital camera replaces film with a sensor array
 - Each cell in the array is a **Charge Coupled Device**
 - light-sensitive diode that converts photons to electrons
 - other variants exist: CMOS is becoming more popular
 - <http://electronics.howstuffworks.com/digital-camera.htm>

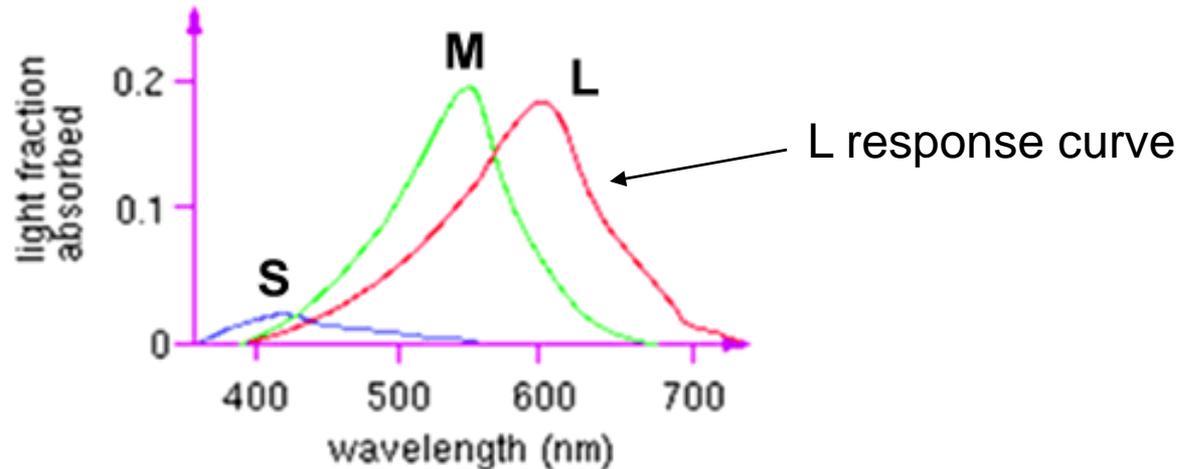
Color

- So far, we've talked about grayscale images
- What about color?
- Most digital images are comprised of three color channels – red, green, and blue – which combine to create most of the colors we can see



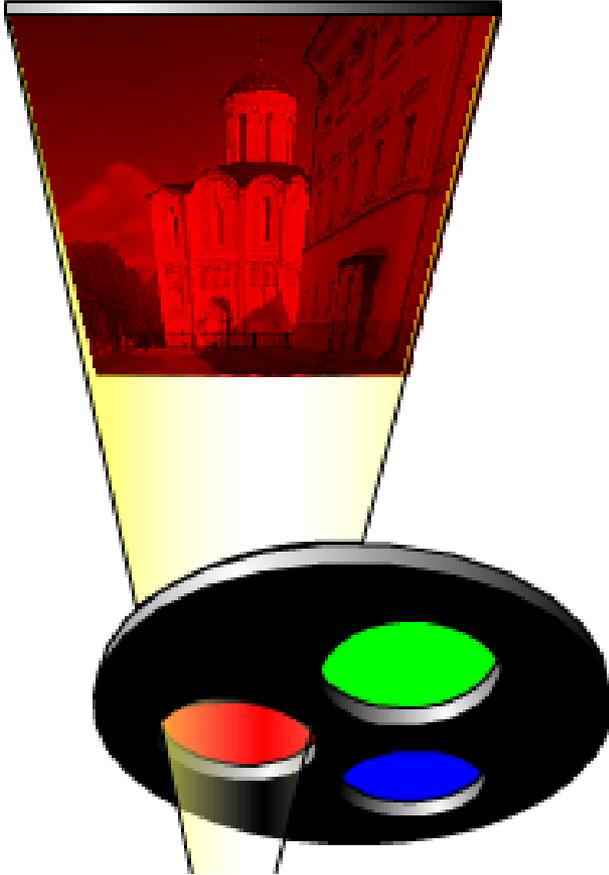
- Why are there three?

Color perception

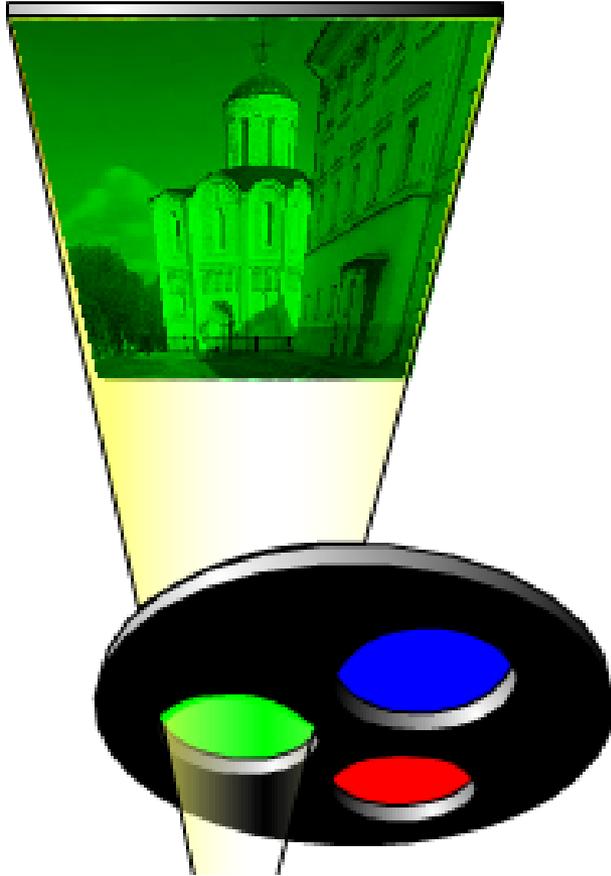


- Three types of cones
 - Each is sensitive in a different region of the spectrum
 - but regions overlap
 - Short (S) corresponds to blue
 - Medium (M) corresponds to green
 - Long (L) corresponds to red
 - Different sensitivities: we are more sensitive to green than red
 - varies from person to person (and with age)
 - Colorblindness—deficiency in at least one type of cone

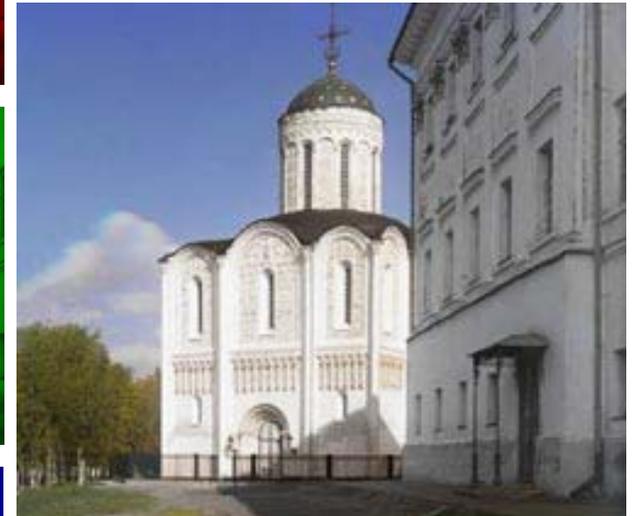
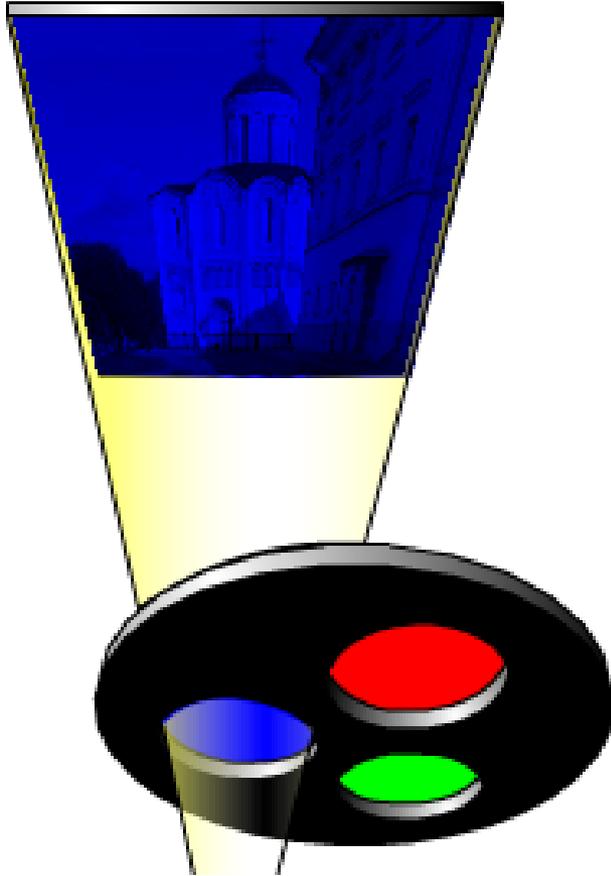
Field sequential



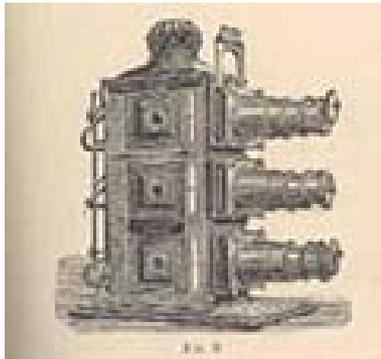
Field sequential



Field sequential



Prokudin-Gorskii (early 1900's)



Lantern projector



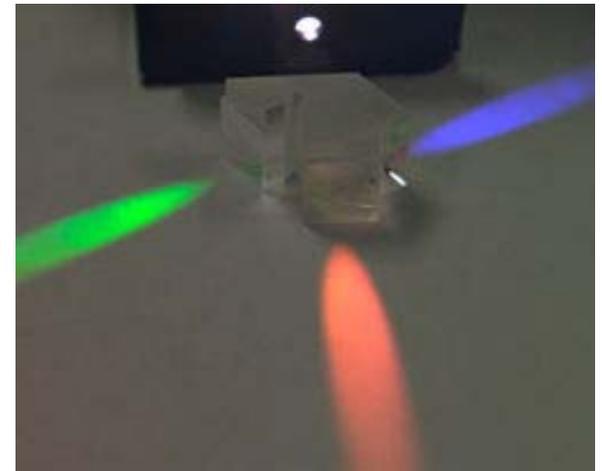
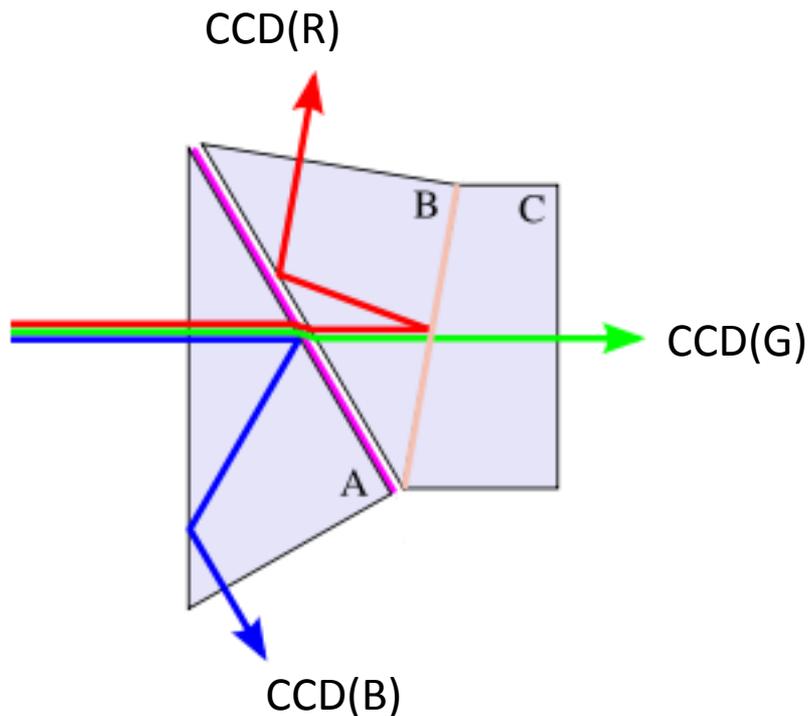
<http://www.loc.gov/exhibits/empire/>

Prokudin-Gorskii (early 1990's)



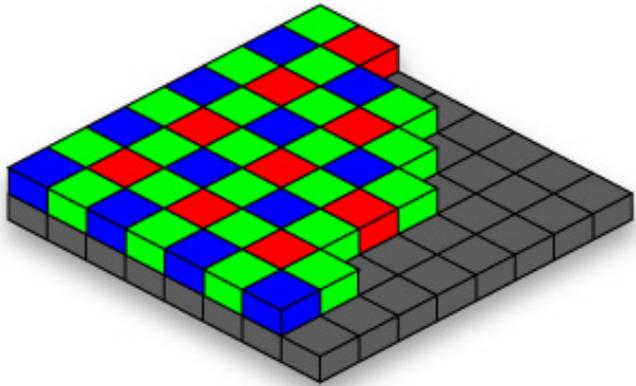
Color sensing in camera: Prism

- Requires three chips and precise alignment
- More expensive

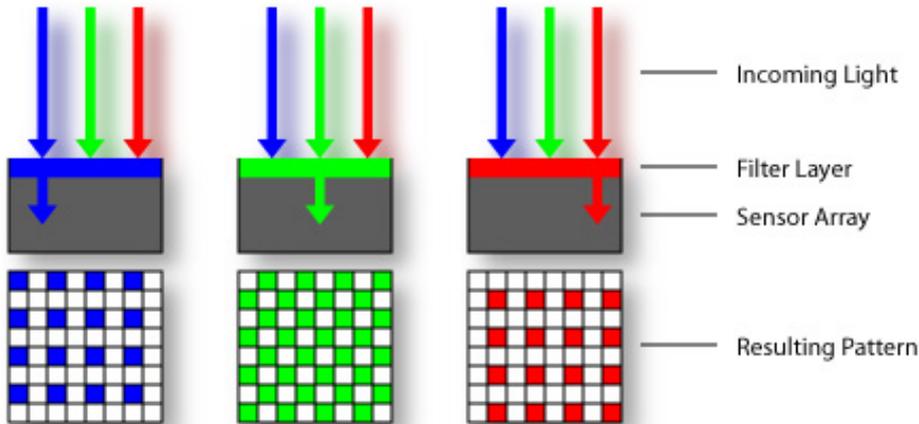
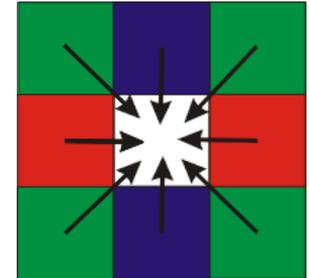


Color filter array

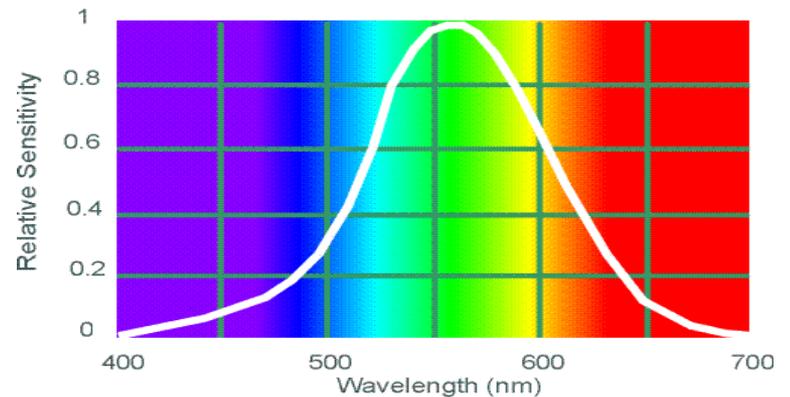
Bayer grid



Estimate missing components from neighboring values (demosaicing)

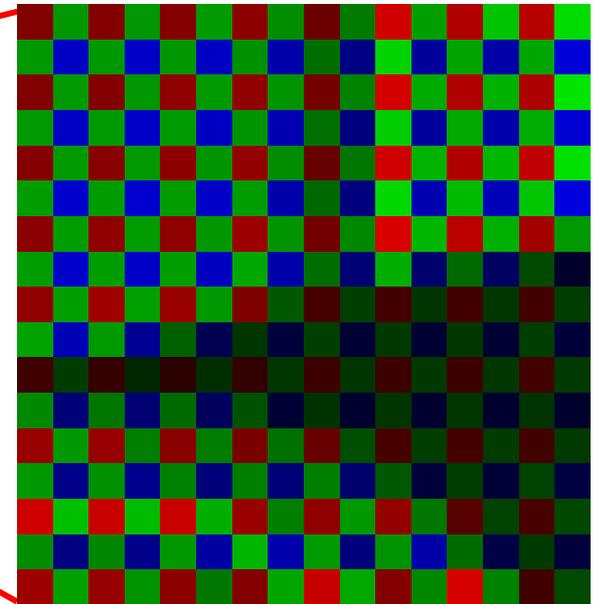


Why more green?



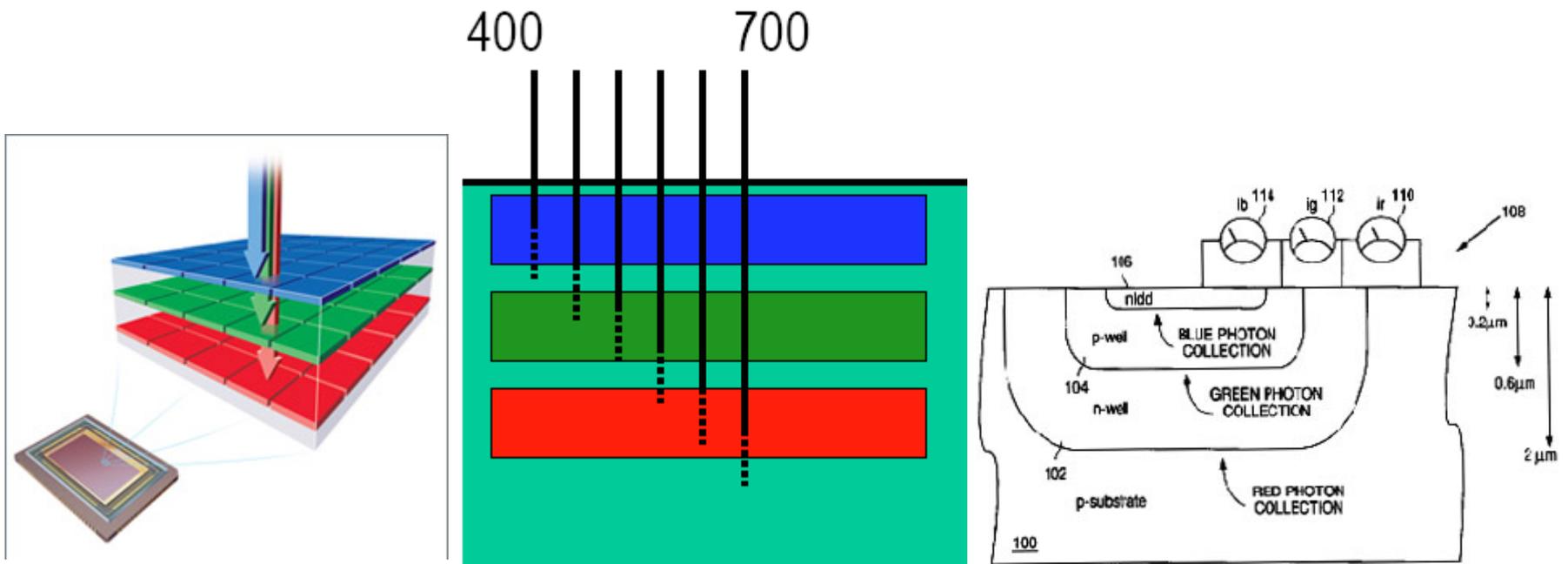
Human Luminance Sensitivity Function

Bayer's pattern

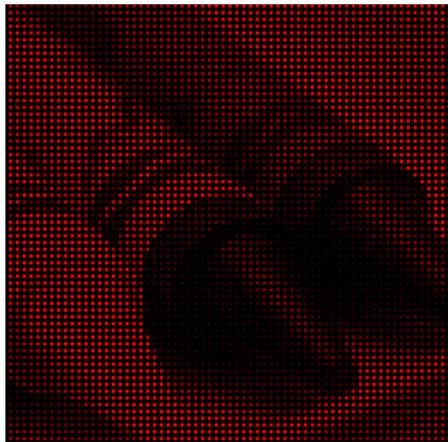
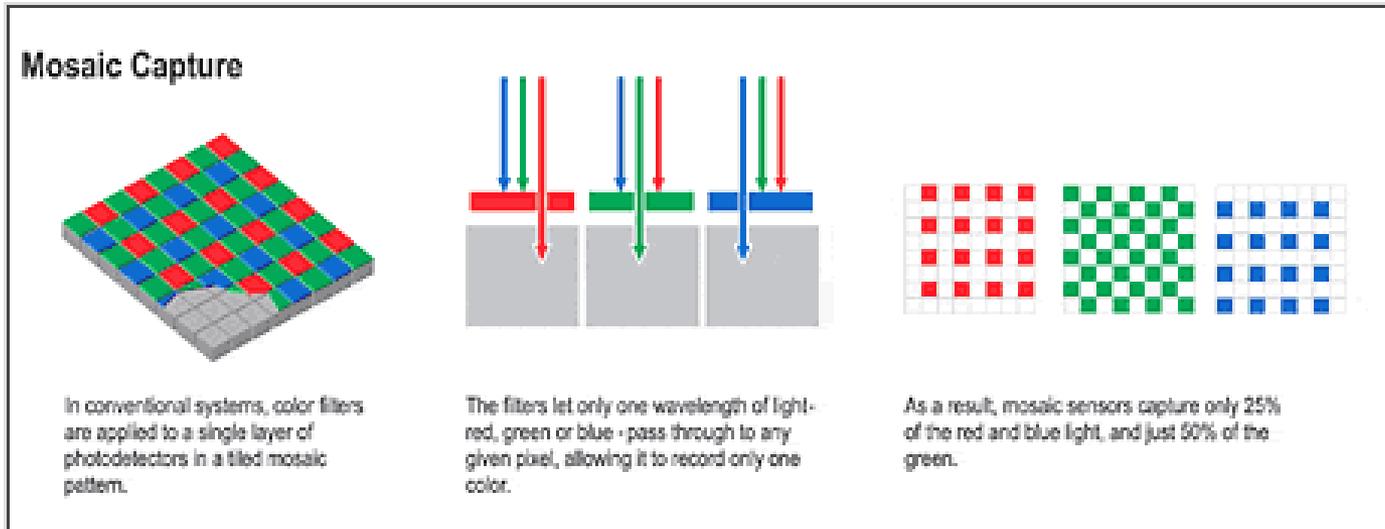


Foveon X3 sensor

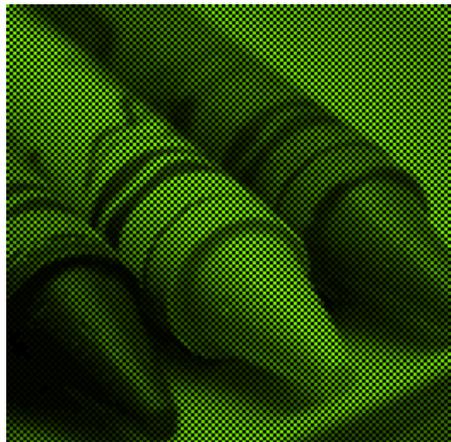
- Light penetrates to different depths for different wavelengths
- Multilayer CMOS sensor gets 3 different spectral sensitivities



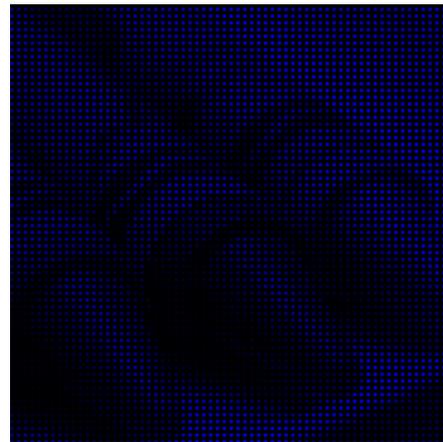
Color filter array



red



green

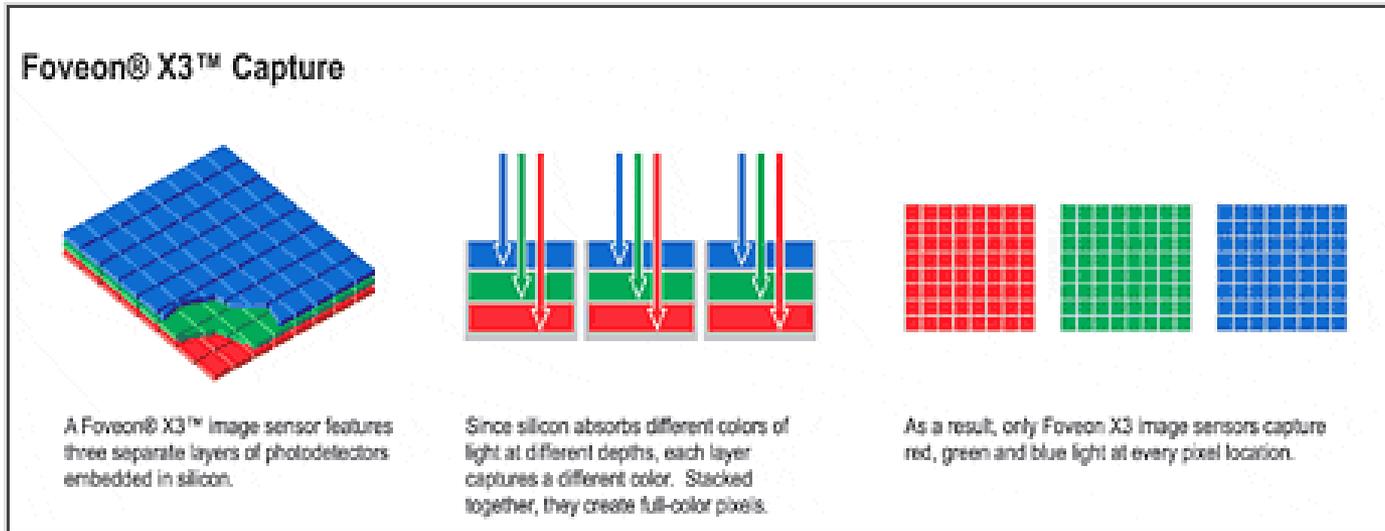


blue



output

X3 technology



red



green

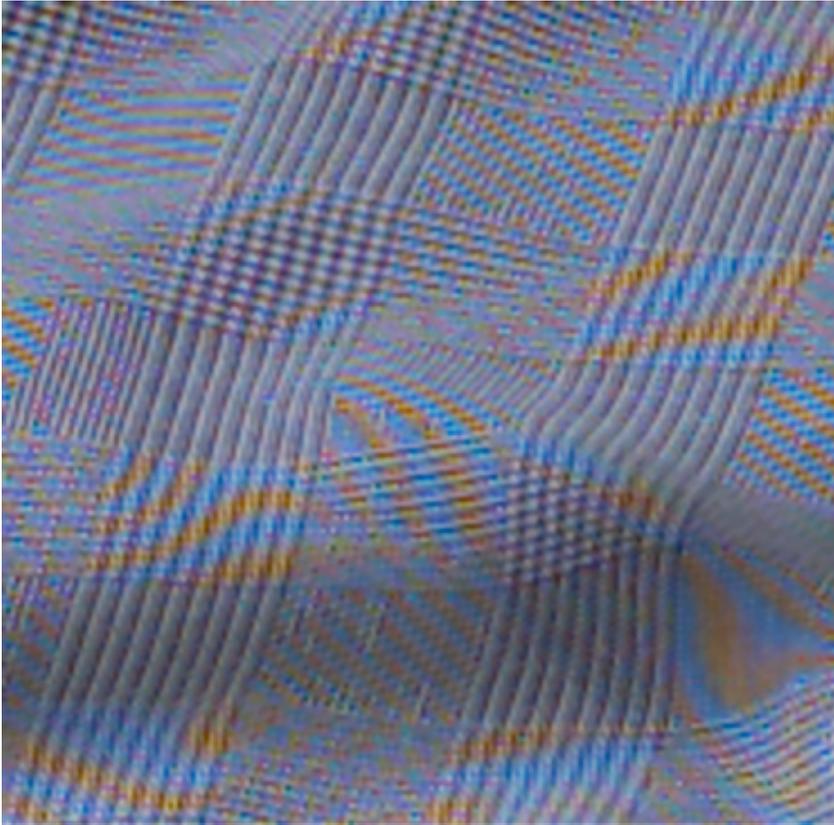


blue

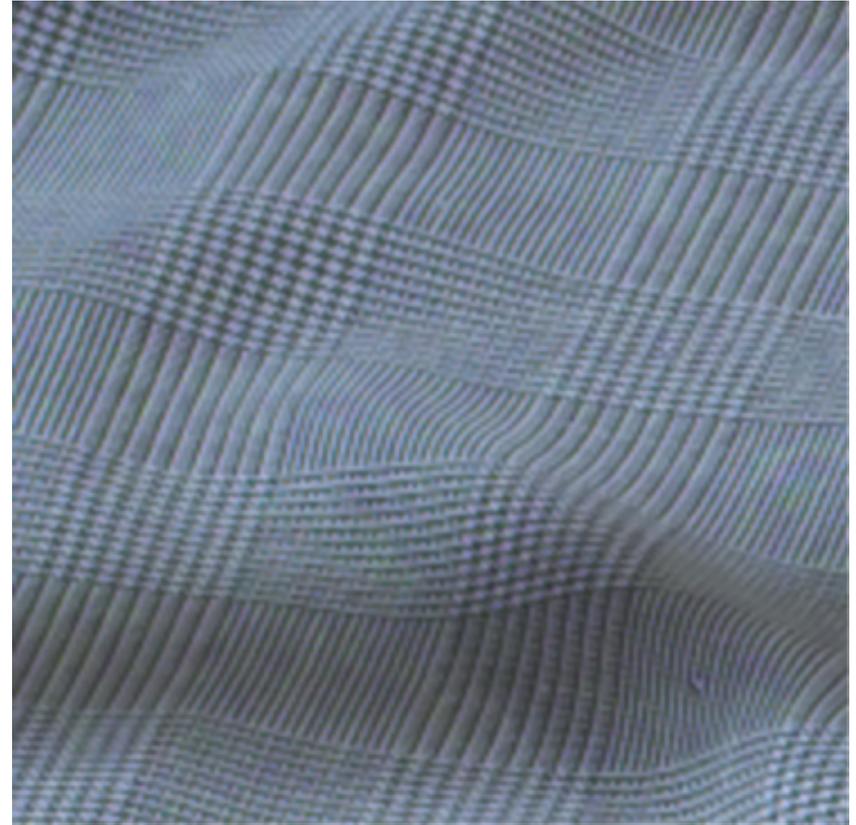


output

Foveon X3 sensor



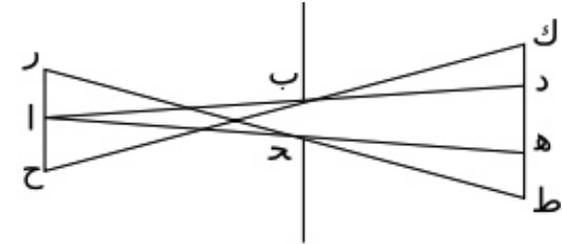
Bayer CFA



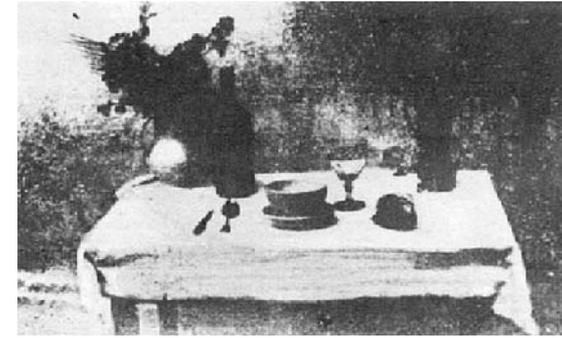
X3 sensor

Historical context

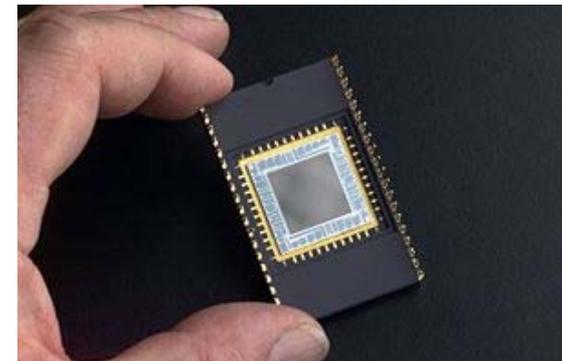
- **Pinhole model:** Mozi (470-390 BC), Aristotle (384-322 BC)
- **Principles of optics (including lenses):** Alhacen (965-1039)
- **Camera obscura:** Leonardo da Vinci (1452-1519), Johann Zahn (1631-1707)
- **First photo:** Joseph Nicephore Niepce (1822)
- **Daguerréotypes** (1839)
- **Photographic film** (Eastman, 1889)
- **Cinema** (Lumière Brothers, 1895)
- **Color Photography** (Lumière Brothers, 1908)
- **Television** (Baird, Farnsworth, Zworykin, 1920s)
- **First consumer camera with CCD:** Sony Mavica (1981)
- **First fully digital camera:** Kodak DCS100 (1990)



Alhacen's notes



Niepce, "La Table Servie," 1822



CCD chip