CS559: Computer Graphics

Lecture 2: Image Formation in Eyes and Cameras

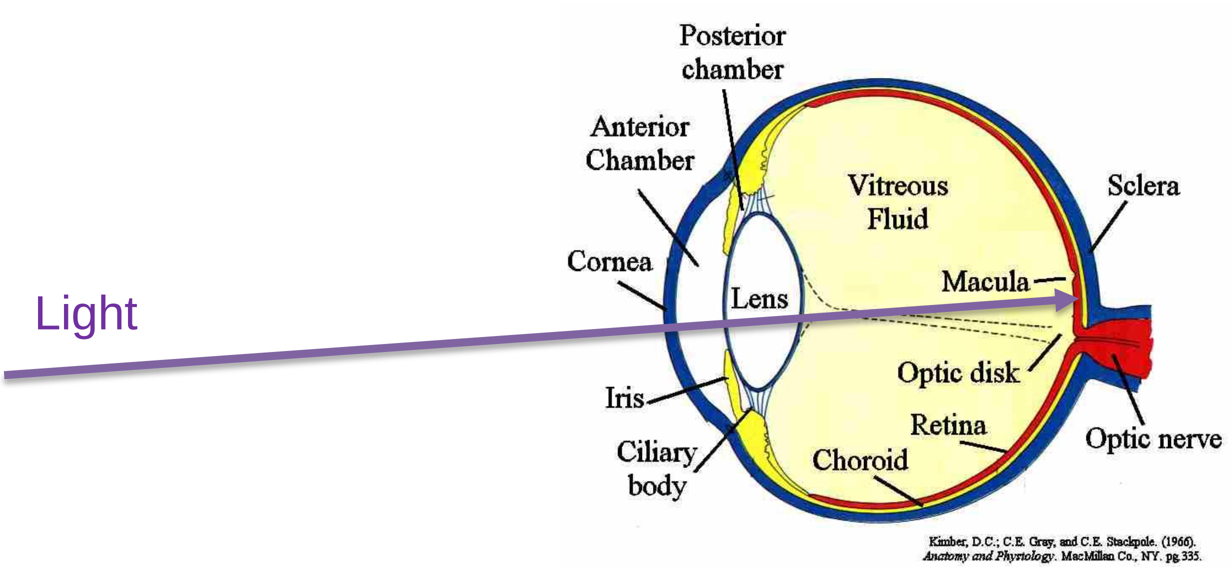
Li Zhang

Spring 2008

Today

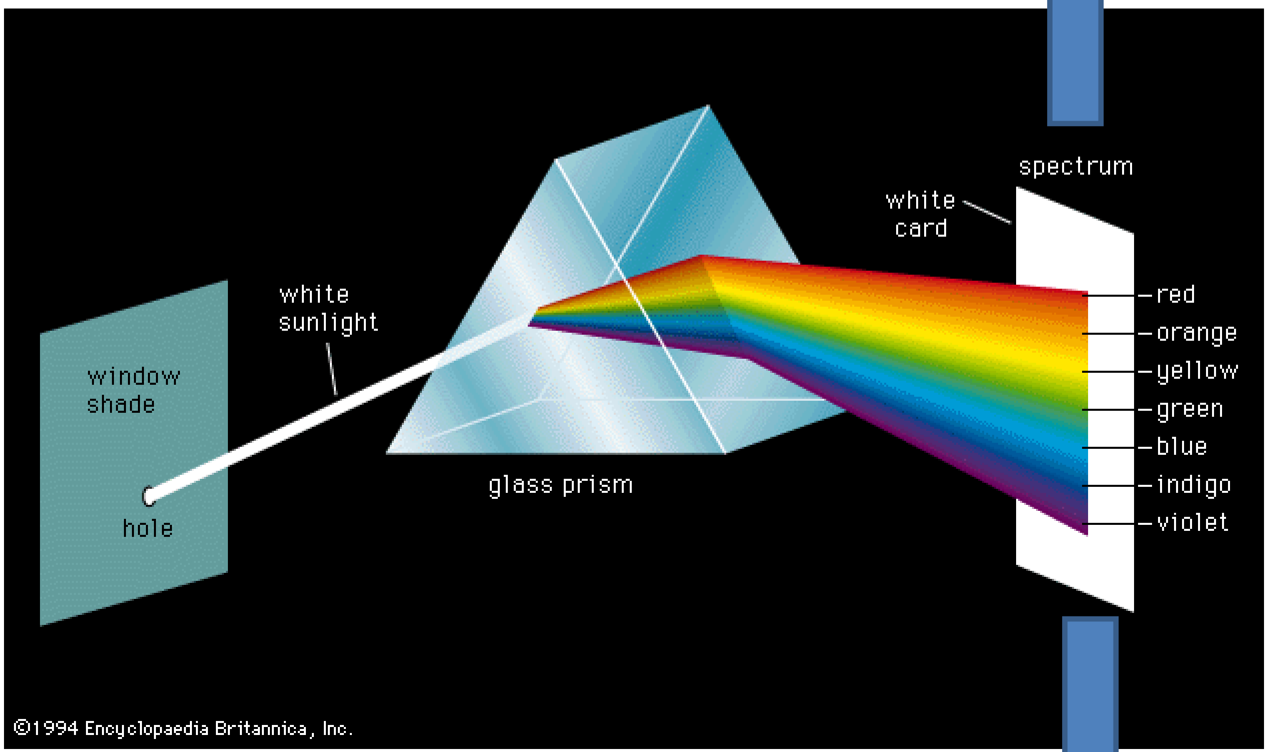
- Eyes
- Cameras

Why can we see?



Visible Light and Beyond

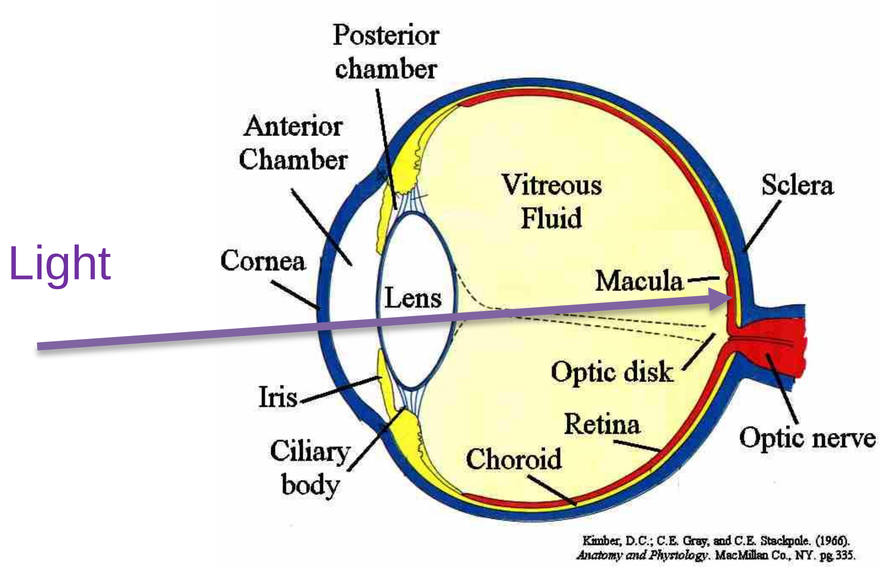
Infrared, e.g. radio wave
longer wavelength

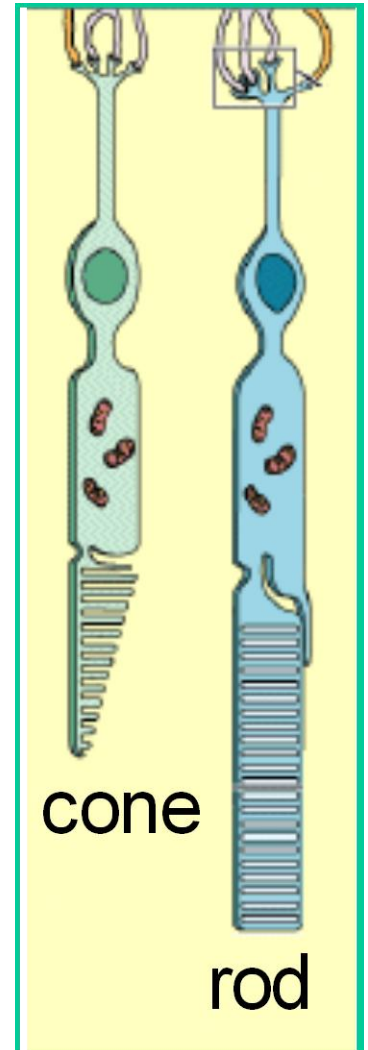


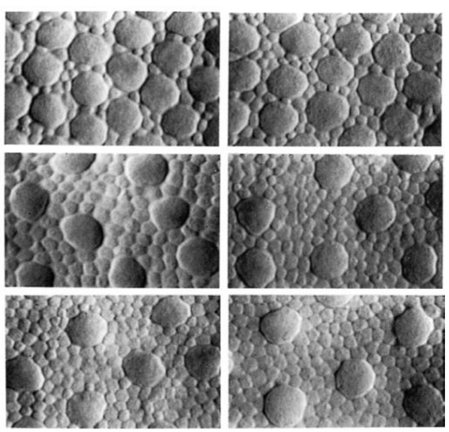
Newton’s prism experiment, 1666.

shorter wavelength
Ultraviolet, e.g. X ray

Cones and Rods

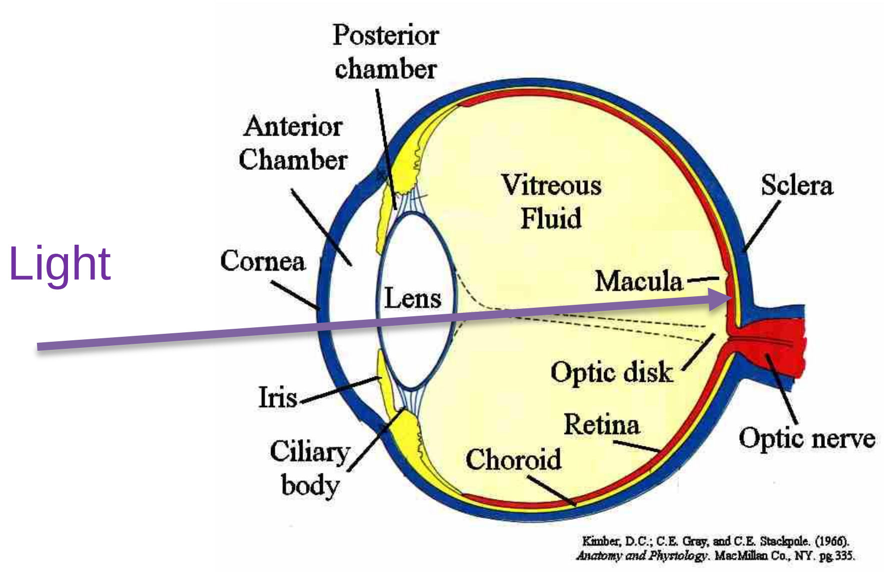




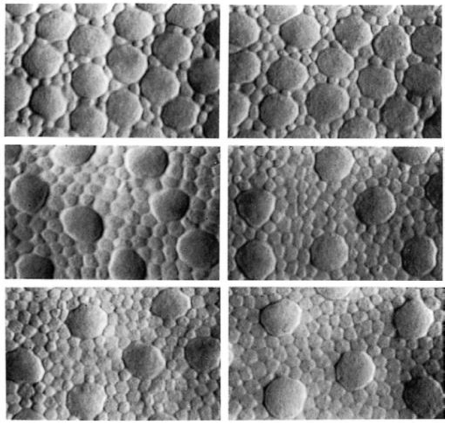


Photomicrographs at increasing distances from the fovea. The large cells are cones; the small ones are rods.

Color Vision



Rods
- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision

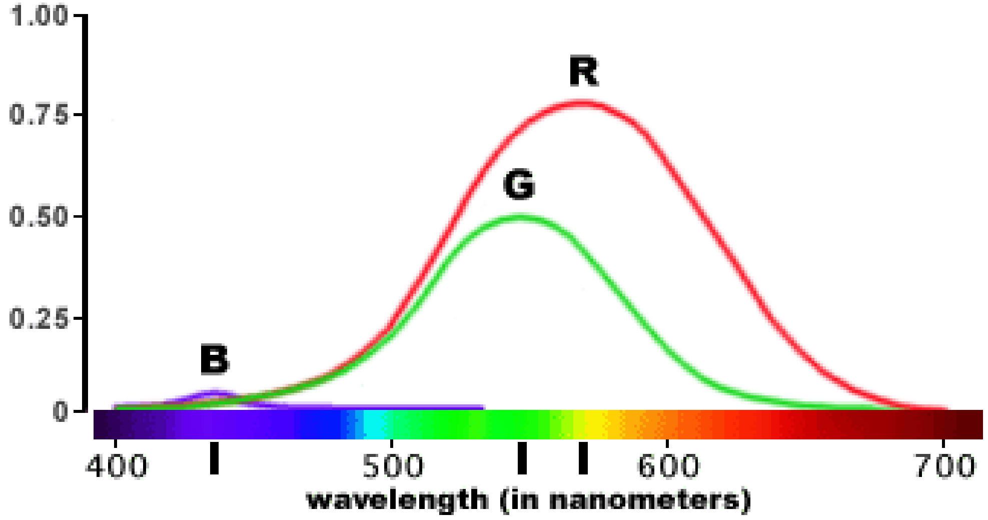


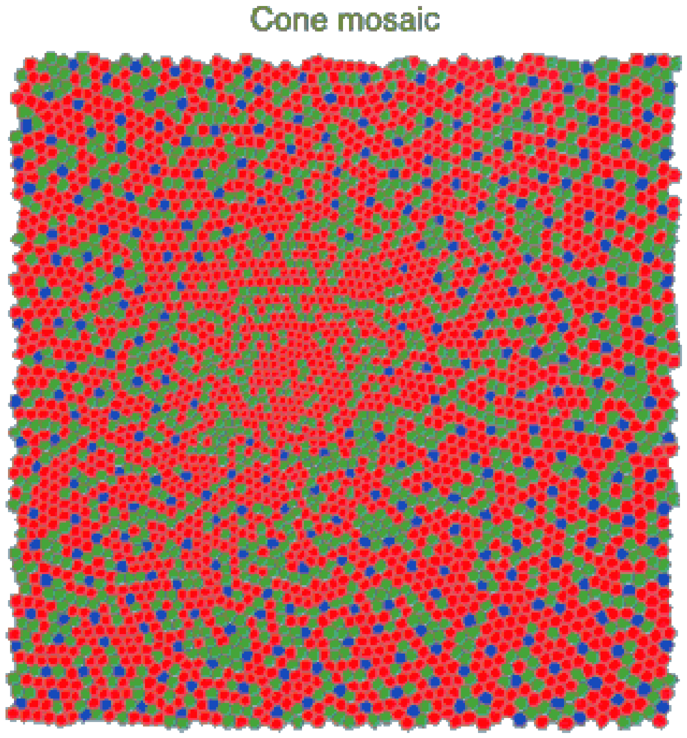
Photomicrographs at increasing distances from the fovea. The large cells are cones; the small ones are rods.

Cones
- cone-shaped
- less sensitive
- operate in high light
- color vision

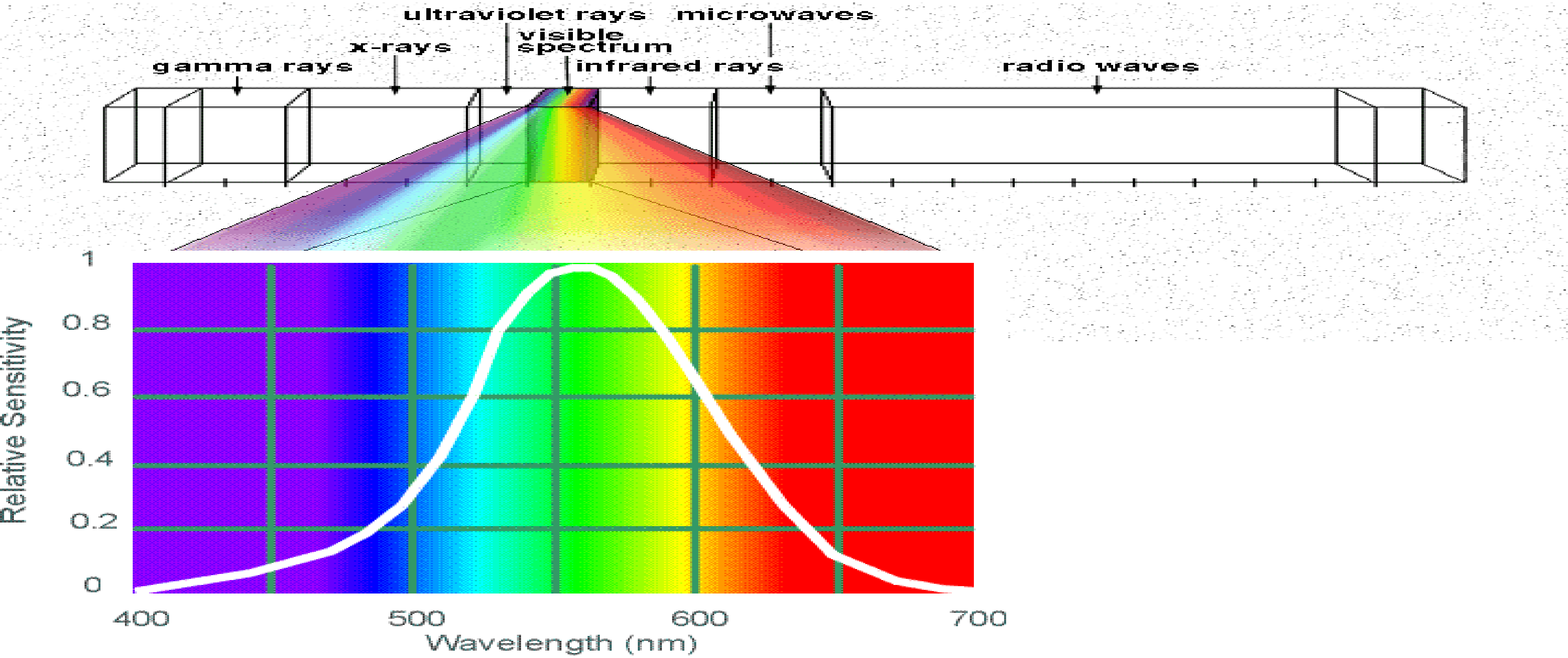
Color Vision

Three kinds of cones:





Electromagnetic Spectrum

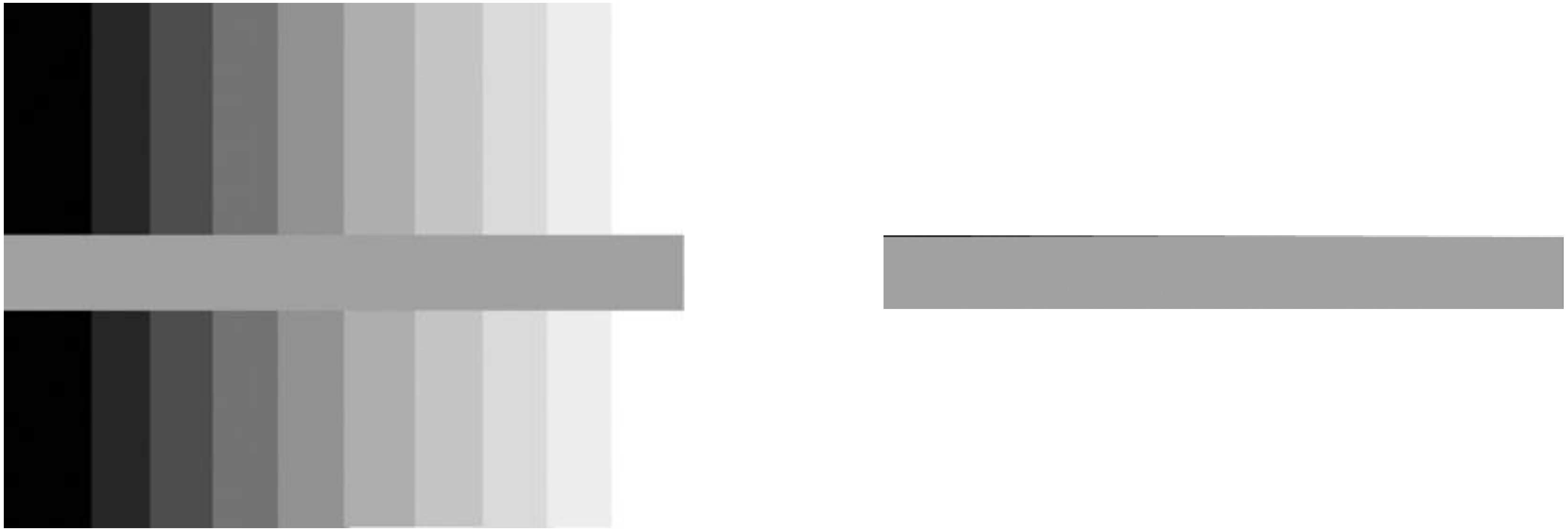


Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm

Lightness contrast

- Also know as
  - Simultaneous contrast
  - Color contrast (for colors)

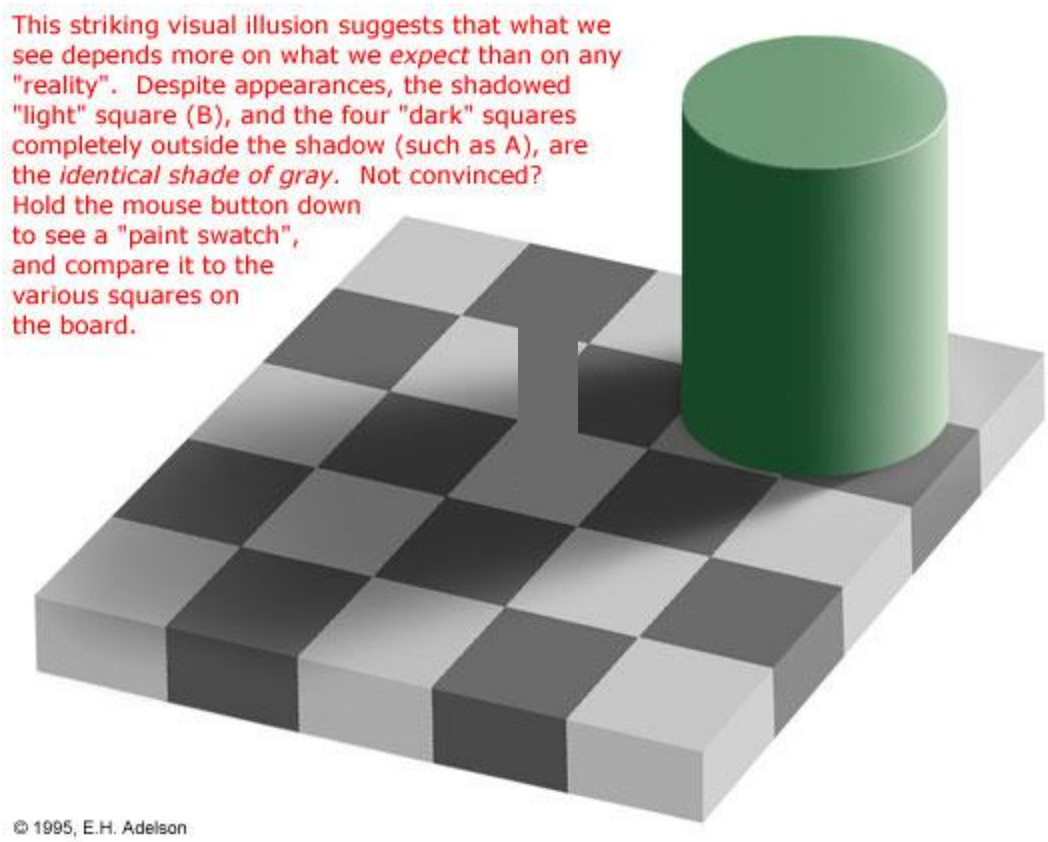


Why is it important?

- This phenomenon helps us maintain a consistent mental image of the world, under dramatic changes in illumination.

But, It causes Illusion as well

- http://www.michaelbach.de/ot/lum_white-illusion/index.html

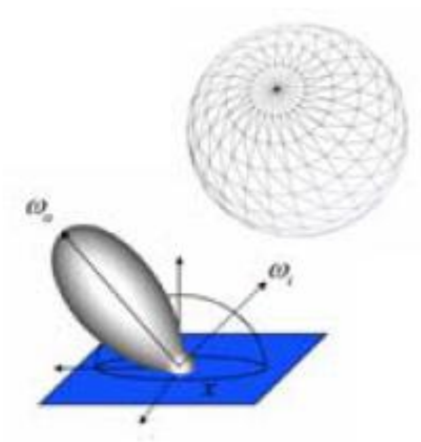


Noise

- Noise can be thought as randomness added to the signal
- The eyes are relatively insensitive to noise.

Vision vs. Graphics

Computer Graphics



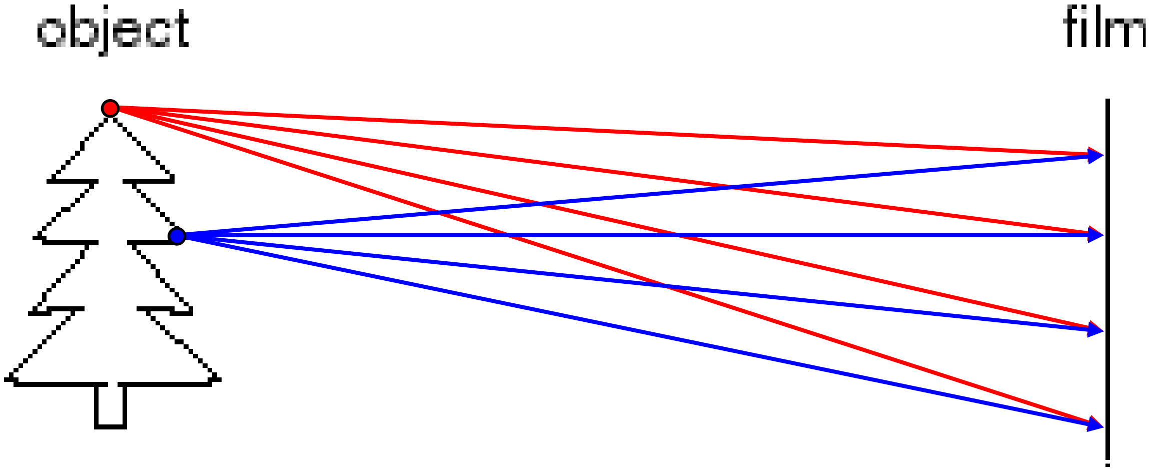
Modelling

Simulation &
Rendering

Image

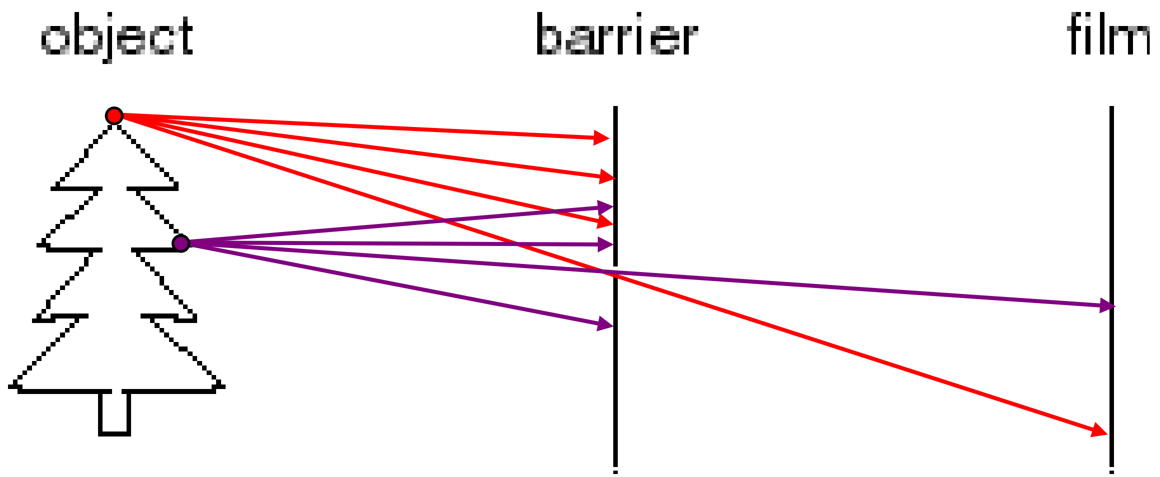
Computer Vision

Image Capture



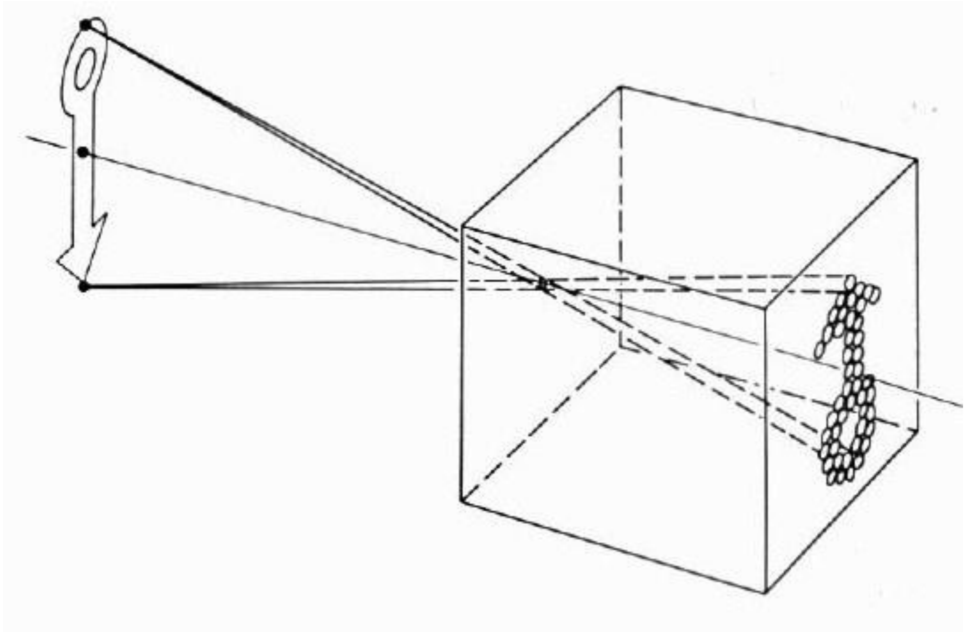
- Let's design a camera
  - Idea 1: put a piece of film in front of an object
  - Do we get a reasonable image?

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?

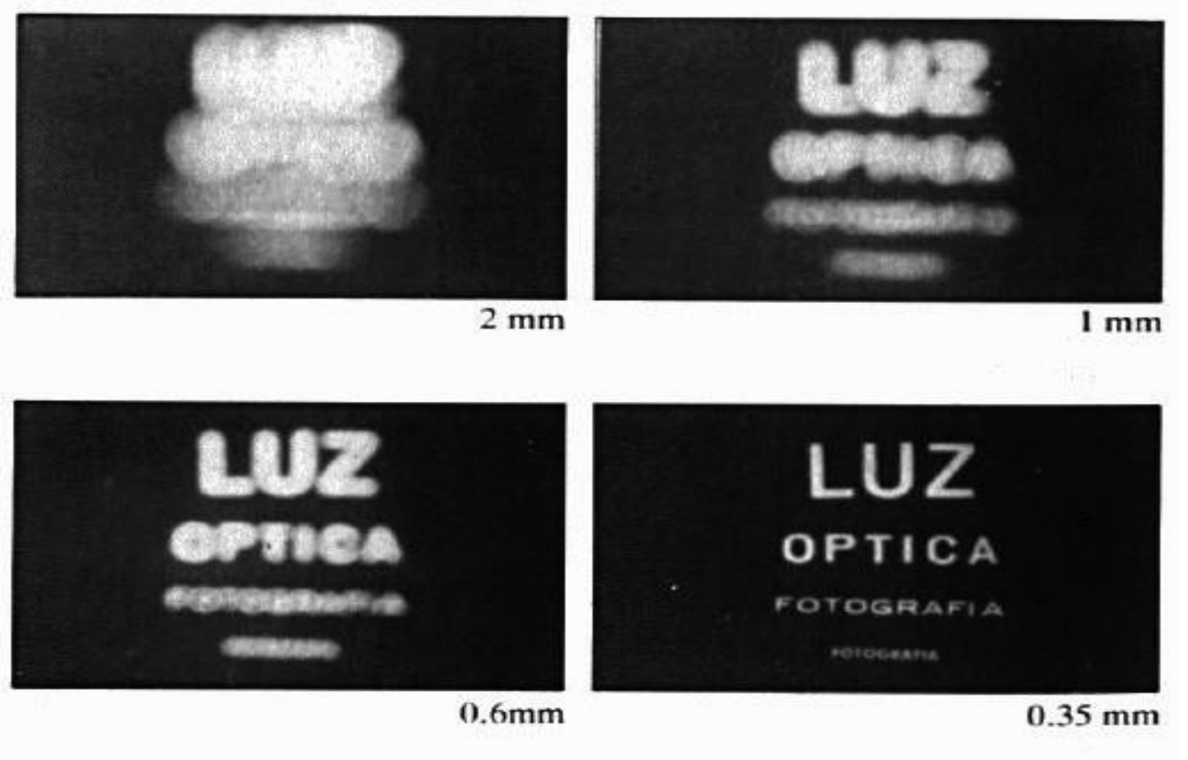
Camera Obscura



- The first camera
  - 5^{th} B.C. Aristotle, Mozi (Chinese: 墨子)
  - How does the aperture size affect the image?

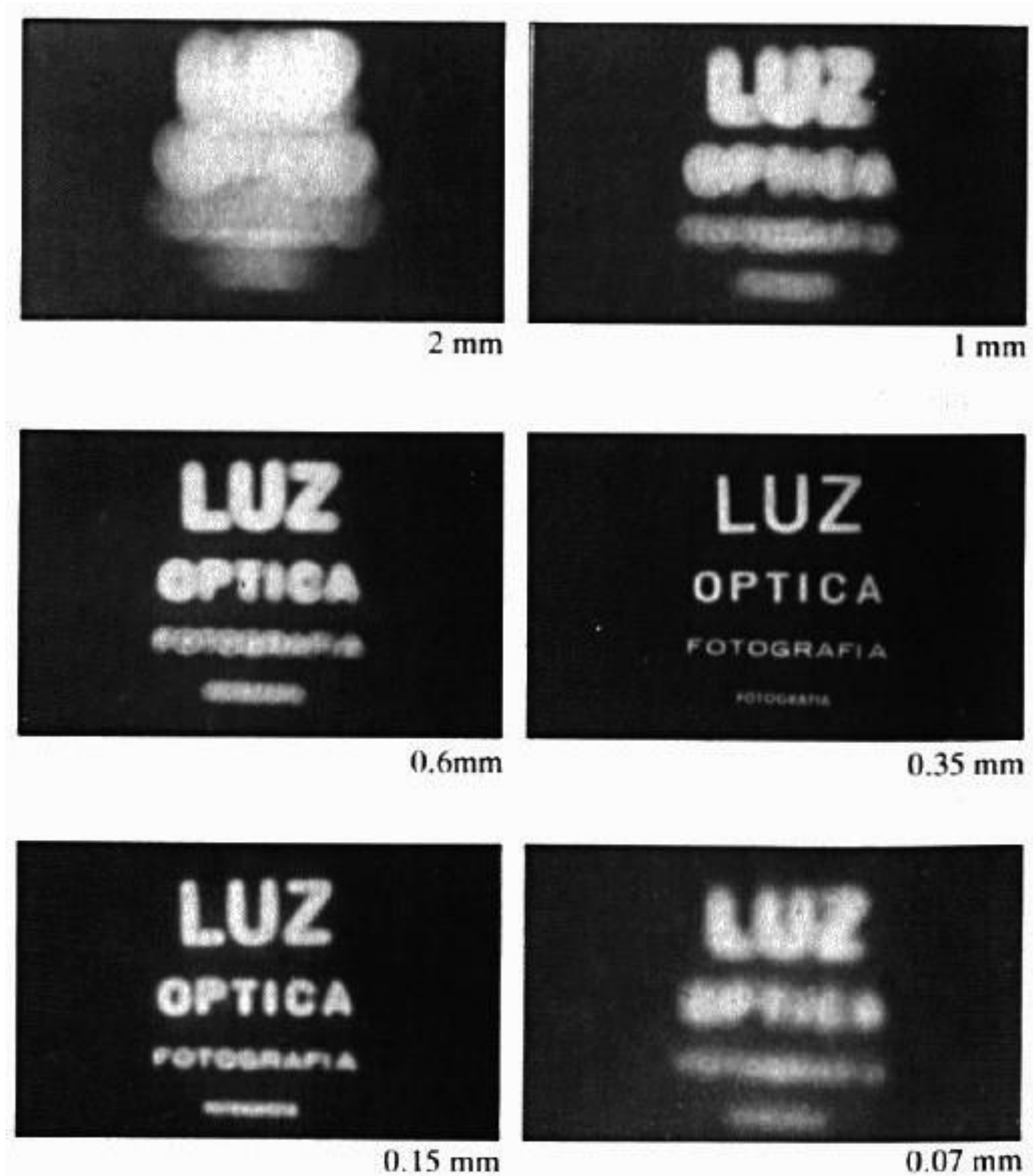
http://en.wikipedia.org/wiki/Pinhole_camera

Shrinking the aperture



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

Shrinking the aperture



Shrinking the aperture

Sharpest image is obtained when:

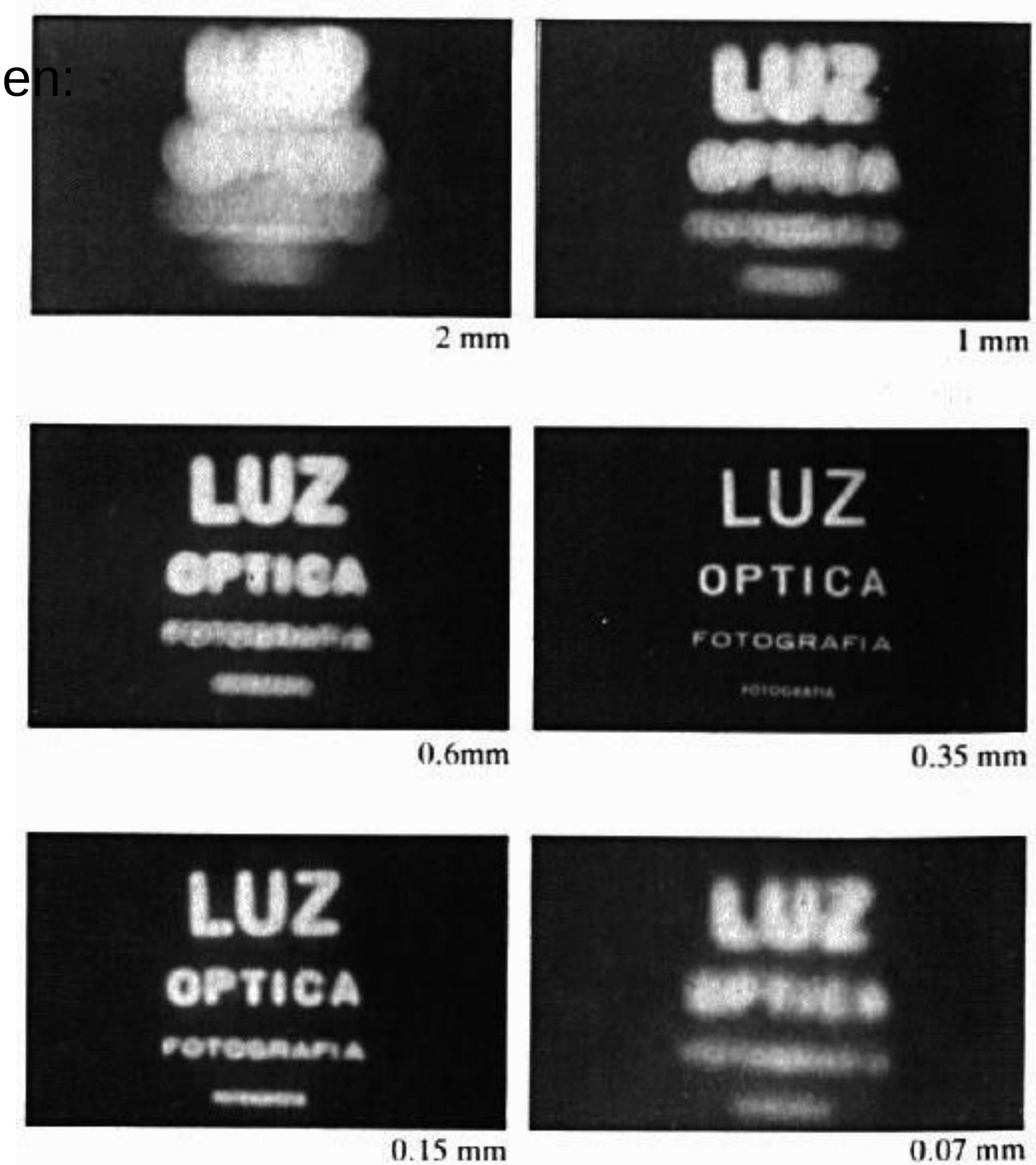
$$d = 2\sqrt{f\lambda}$$

d is diameter,
f is distance from hole to film
λ is the wavelength of light,
all given in metres.

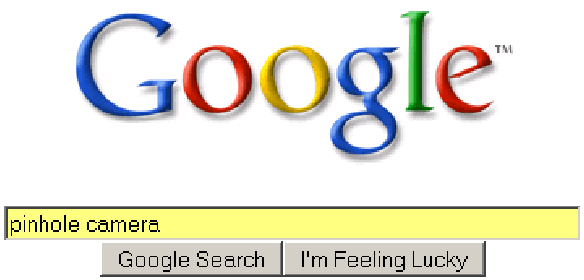
Example: If *f* = *50mm,*

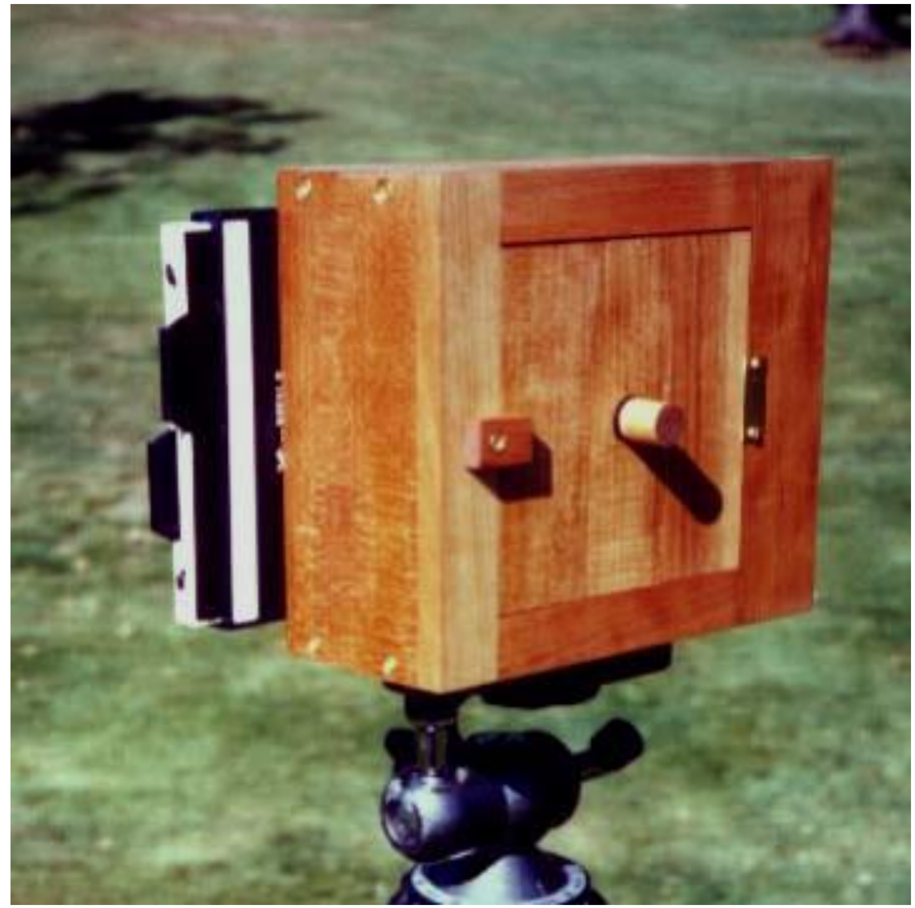
λ = *600nm* (red),

d = *0.36mm*



Pinhole cameras are popular





Jerry Vincent's Pinhole Camera

Impressive Images

Jerry Vincent's Pinhole Photos

What's wrong with Pinhole Cameras?

- Low incoming light => Long exposure time => Tripod

KODAK Film or Paper	Bright Sun	Cloudy Bright
TRI-X Pan	1 or 2 seconds	4 to 8 seconds
T-MAX 100 Film	2 to 4 seconds	8 to 16 seconds
KODABROMIDE Paper, F2	2 minutes	8 minutes

http://www.kodak.com/global/en/consumer/education/lessonPlans/pinholeCamera/pinholeCanBox.shtml

What's wrong with Pinhole Cameras

People are ghosted

What’s wrong with Pinhole Cameras

People become ghosts!

Pinhole Camera Recap

- Pinhole size (aperture) must be “very small” to obtain a clear image.

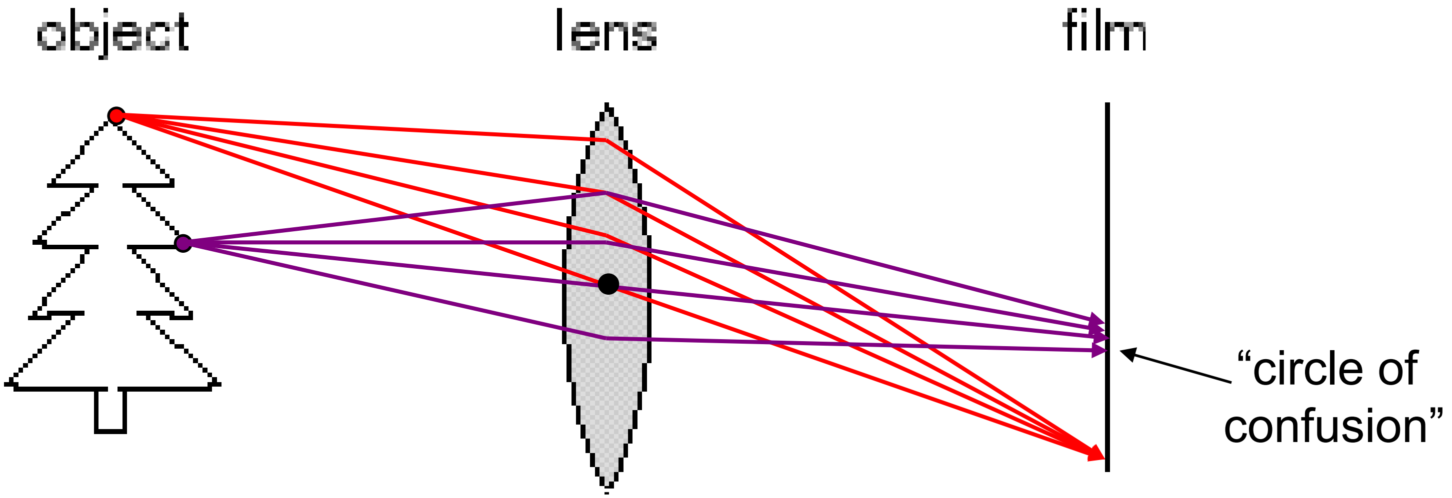
- However, as pinhole size is made smaller, less light is received by image plane.

- If pinhole is comparable to wavelength of incoming light, ***DIFFRACTION*** effects blur the image!

- Require long exposure time

What's the solution?

- Lens

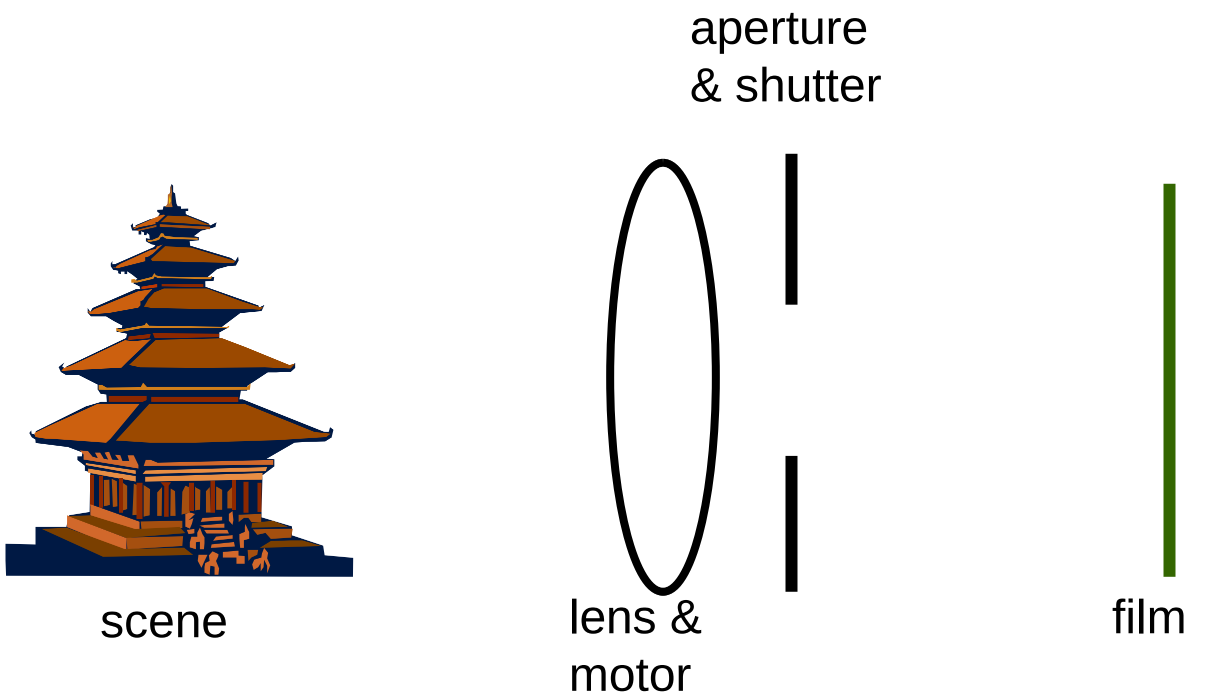


- A lens focuses light onto the film
  - There is a specific distance at which objects are "in focus"
    - other points project to a "circle of confusion" in the image
  - Changing the shape of the lens changes this distance

Demo!

– http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html (by Fu-Kwun Hwang)

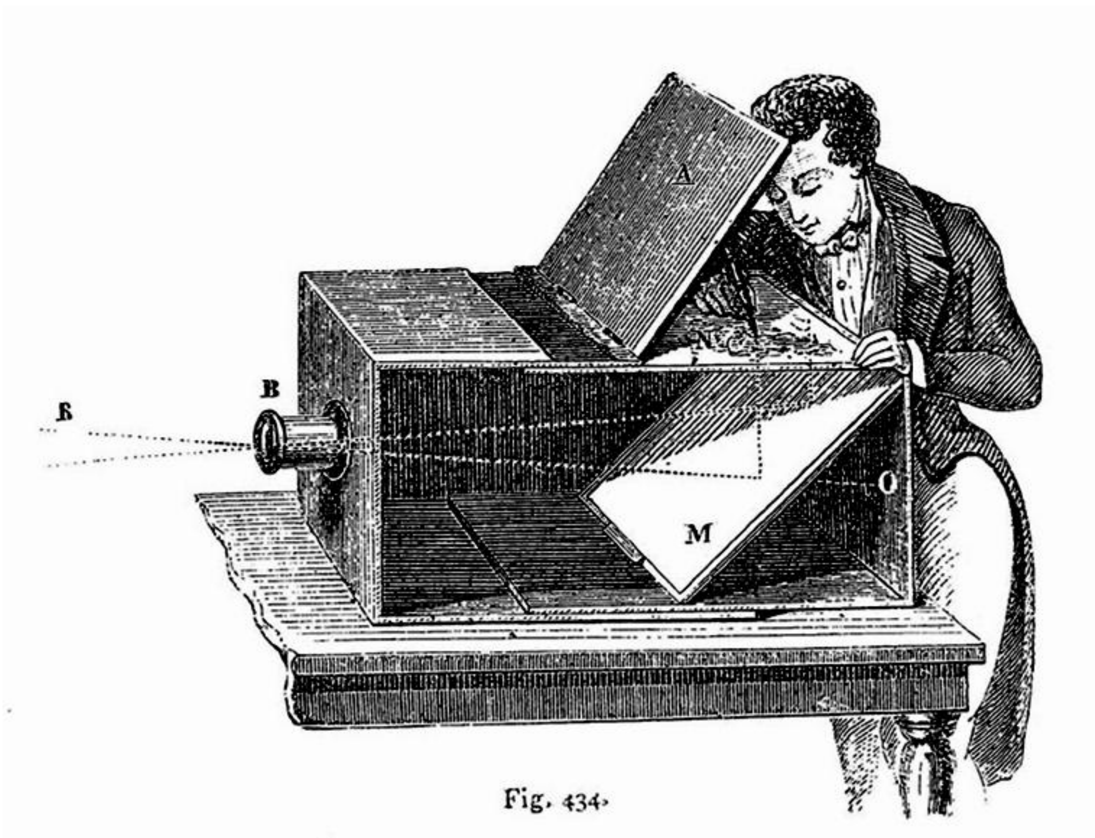
Film camera



Film camera

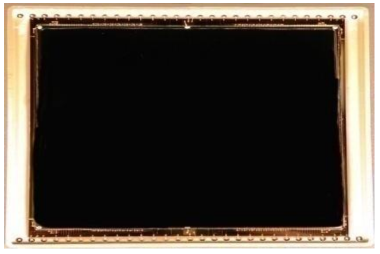
Still Life, Louis Jaques Mande Daguerre, 1837

Before Film was invented



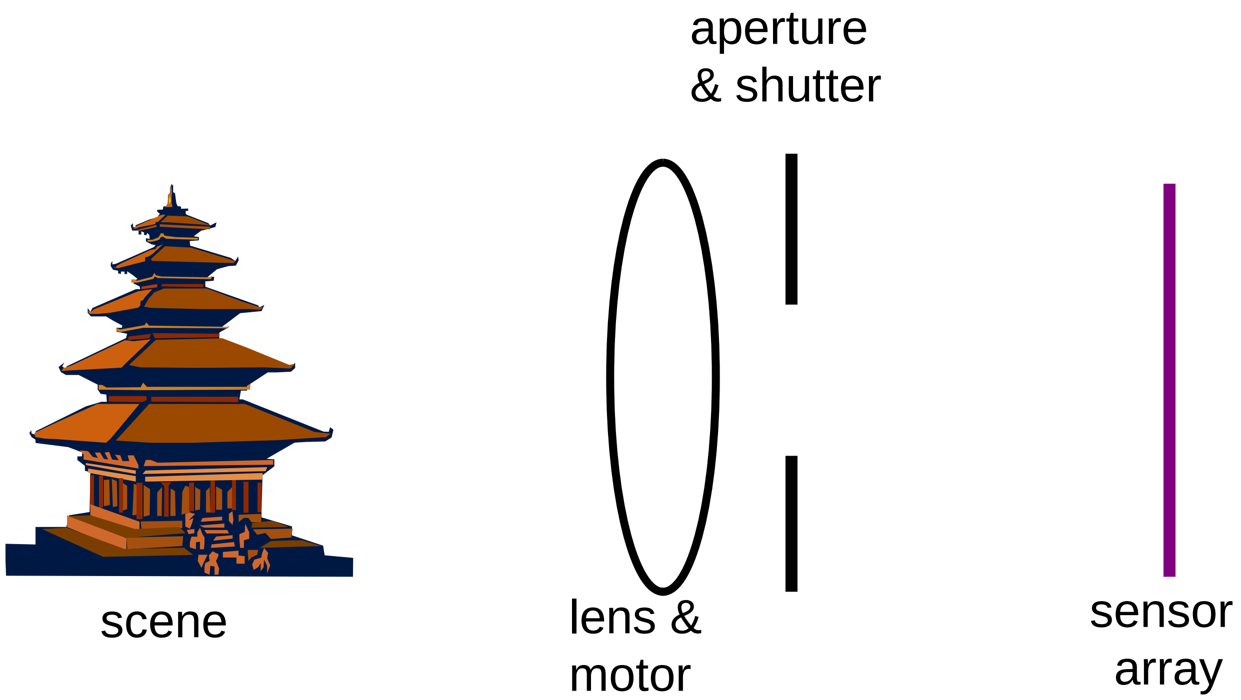
Lens Based Camera Obscura, 1568

Silicon Image Detector



Silicon Image Detector, 1970

Digital camera



- A digital camera replaces film with a sensor array
- Each cell in the array is a light-sensitive diode that converts photons to electrons

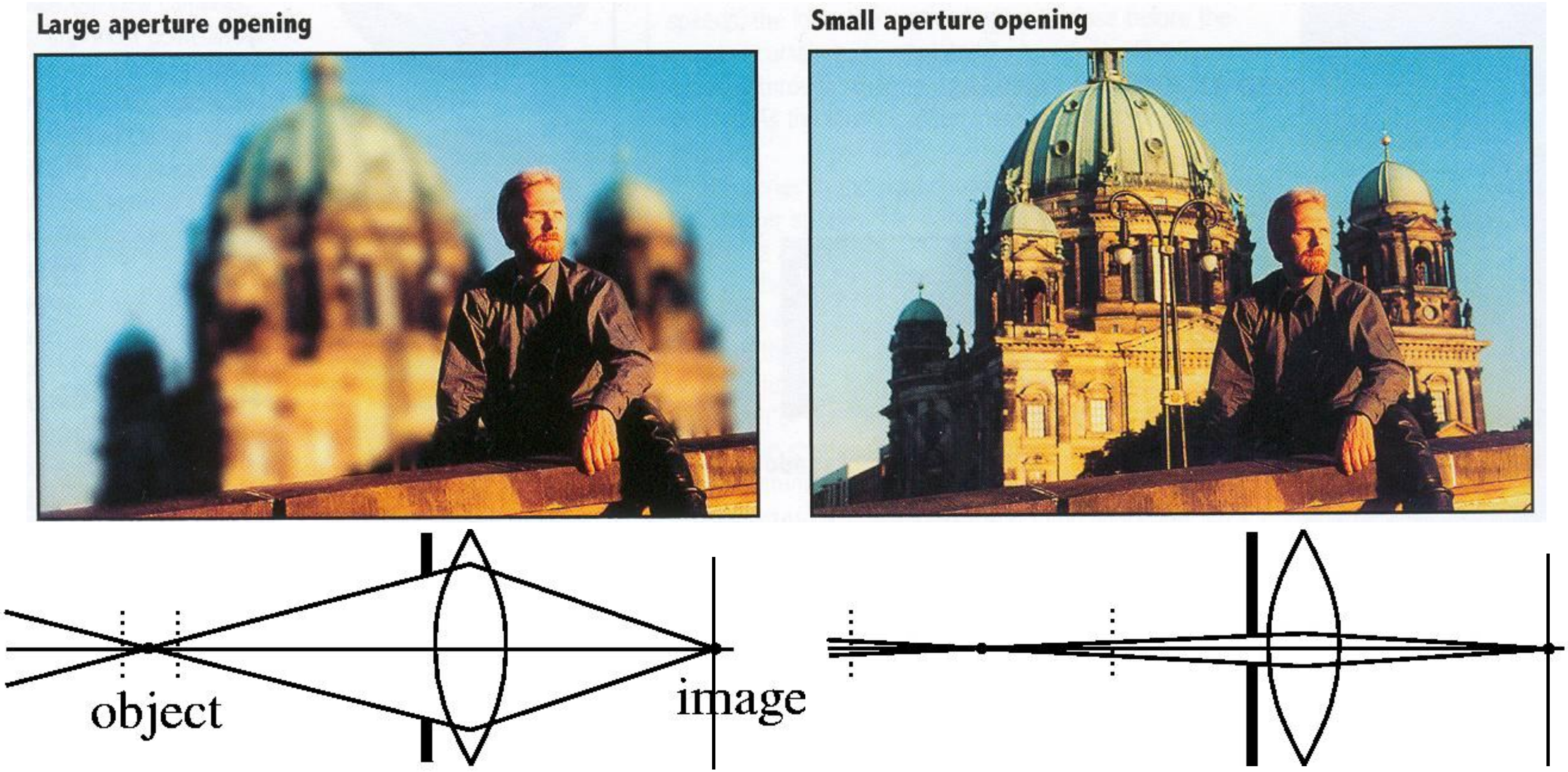
SLR (Single-Lens Reflex)

- Reflex (R in SLR) means that we see through the same lens used to take the image.
- Not the case for compact cameras

Exposure

- Two main parameters:
  - Aperture (in f stop)
  - shutter speed (in fraction of a second)

Depth of Field

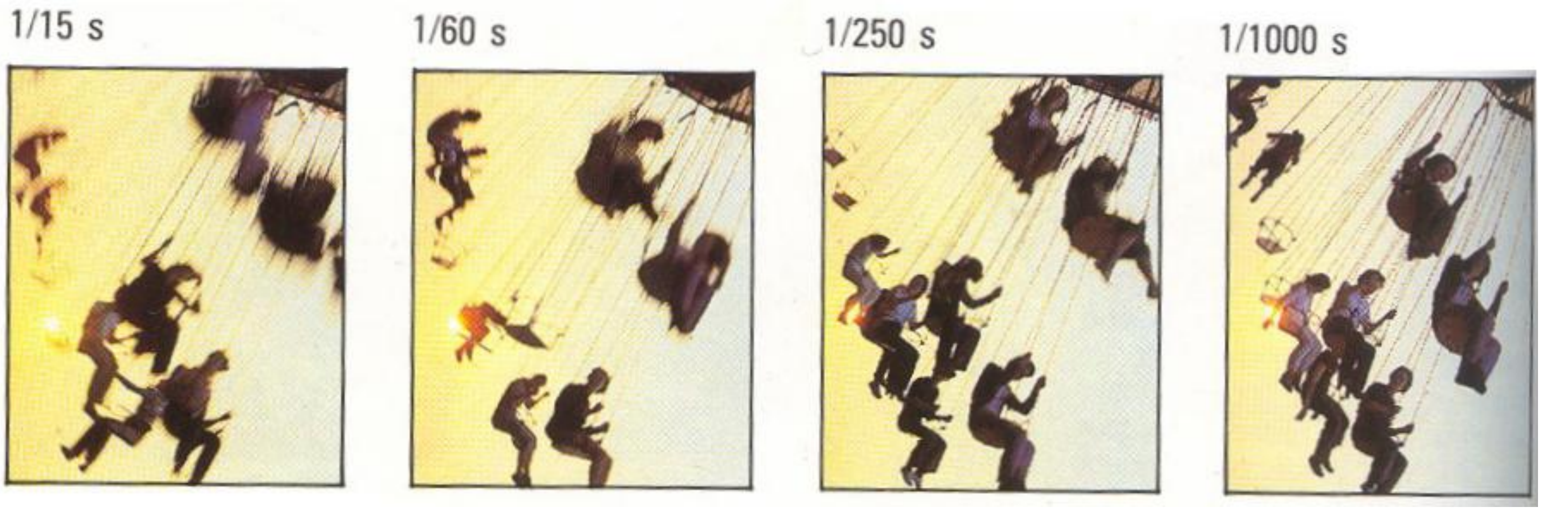


Changing the aperture size affects depth of field. A smaller aperture increases the range in which the object is approximately in focus

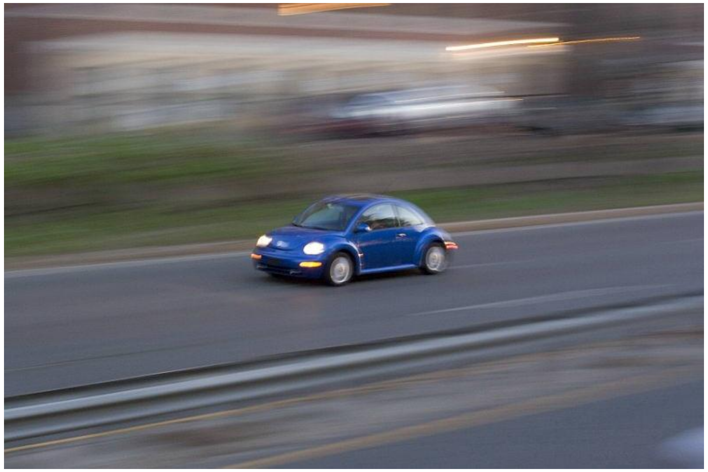
See http://www.photonhead.com/simcam/

Effects of shutter speeds

- Slower shutter speed => more light, but more motion blur



- Faster shutter speed freezes motion

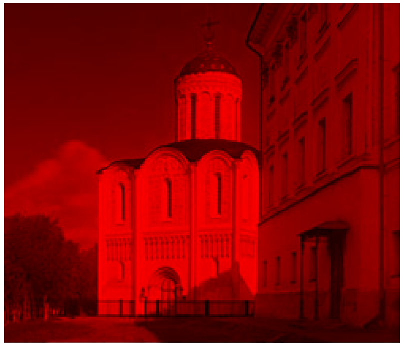


Color

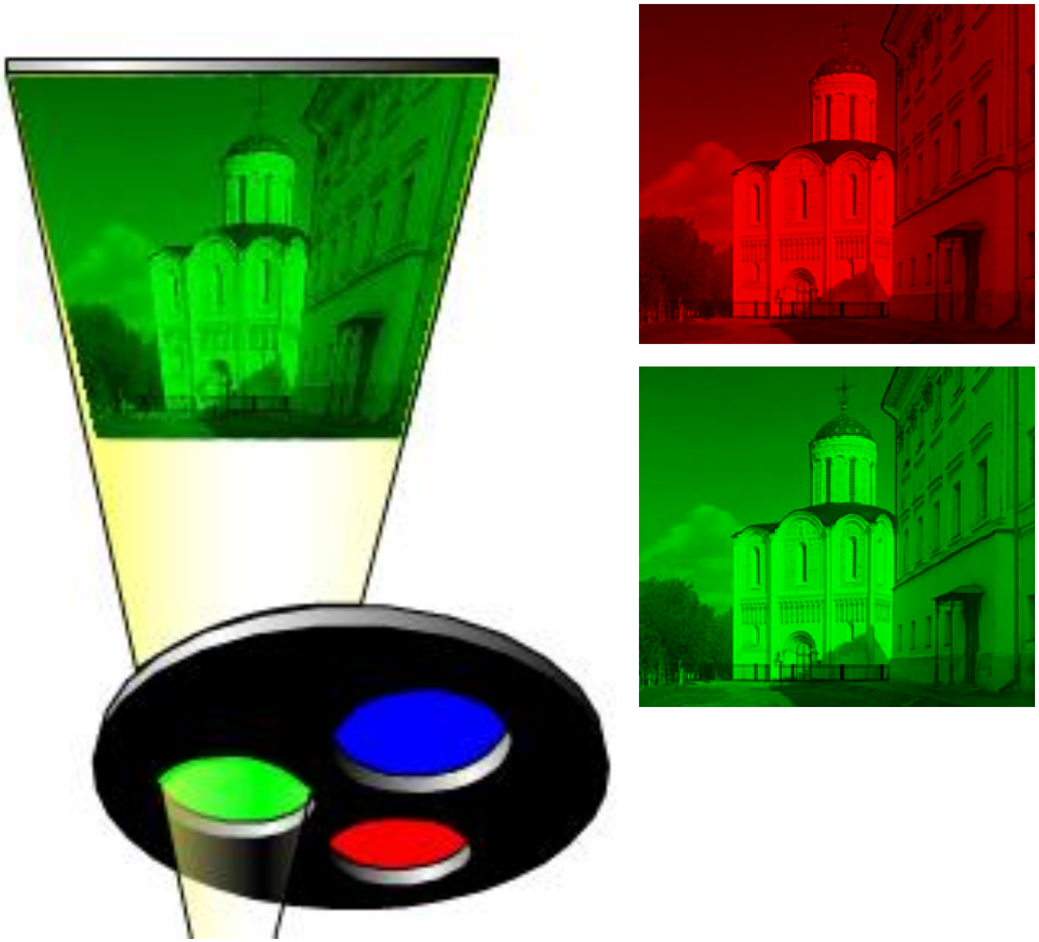
So far, we’ve only talked about monochrome sensors. Color imaging has been implemented in a number of ways:

- Field sequential
- Multi-chip
- Color filter array
- X3 sensor

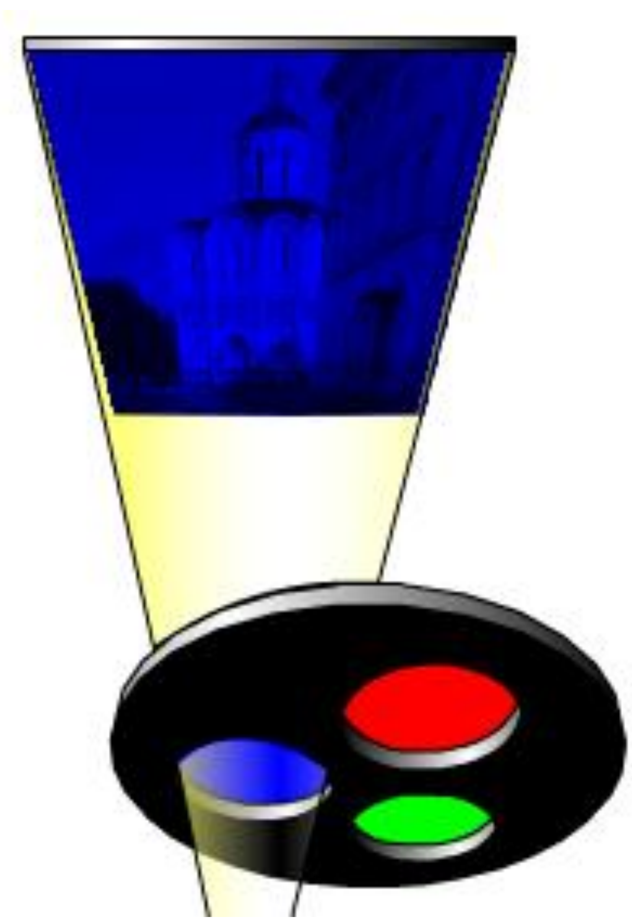
Field sequential

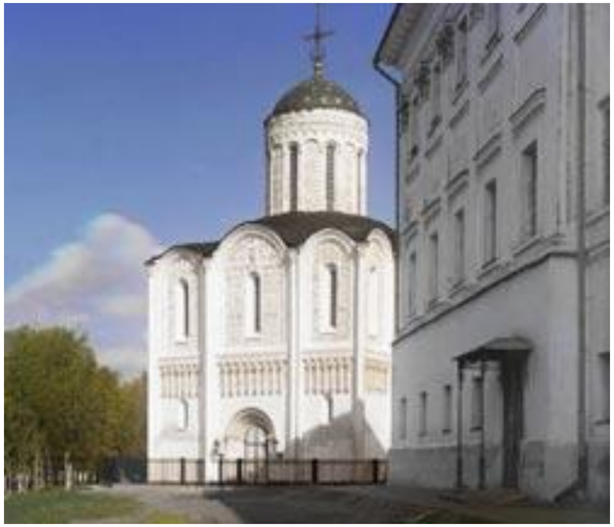


Field sequential

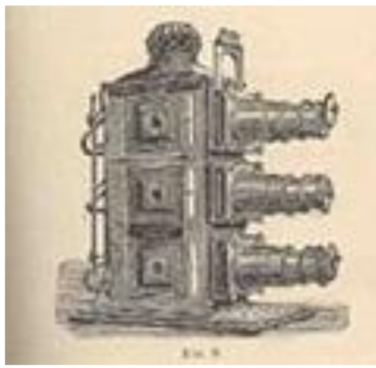


Field sequential





Prokudin-Gorskii (early 1900’s)

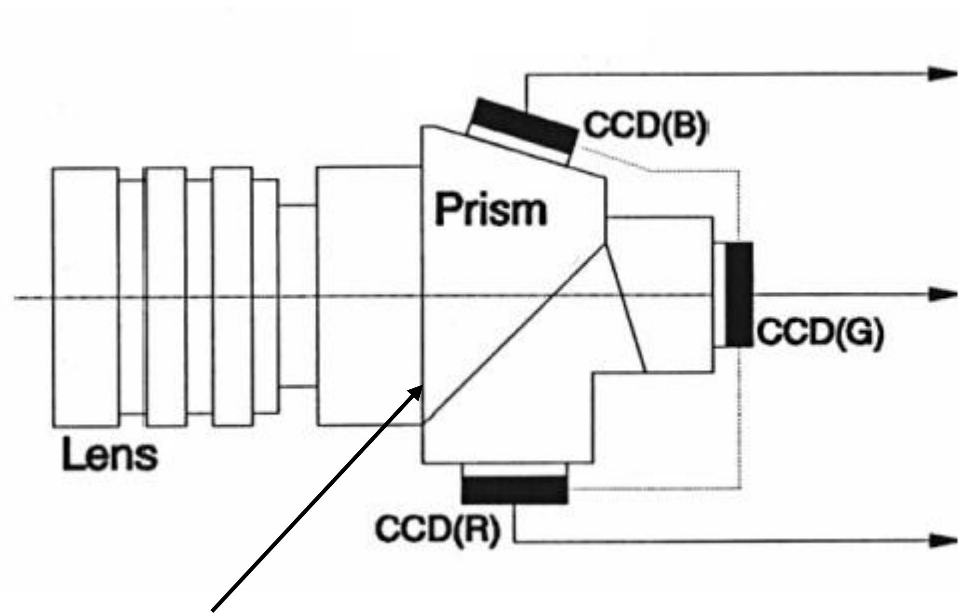


Lantern projector

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

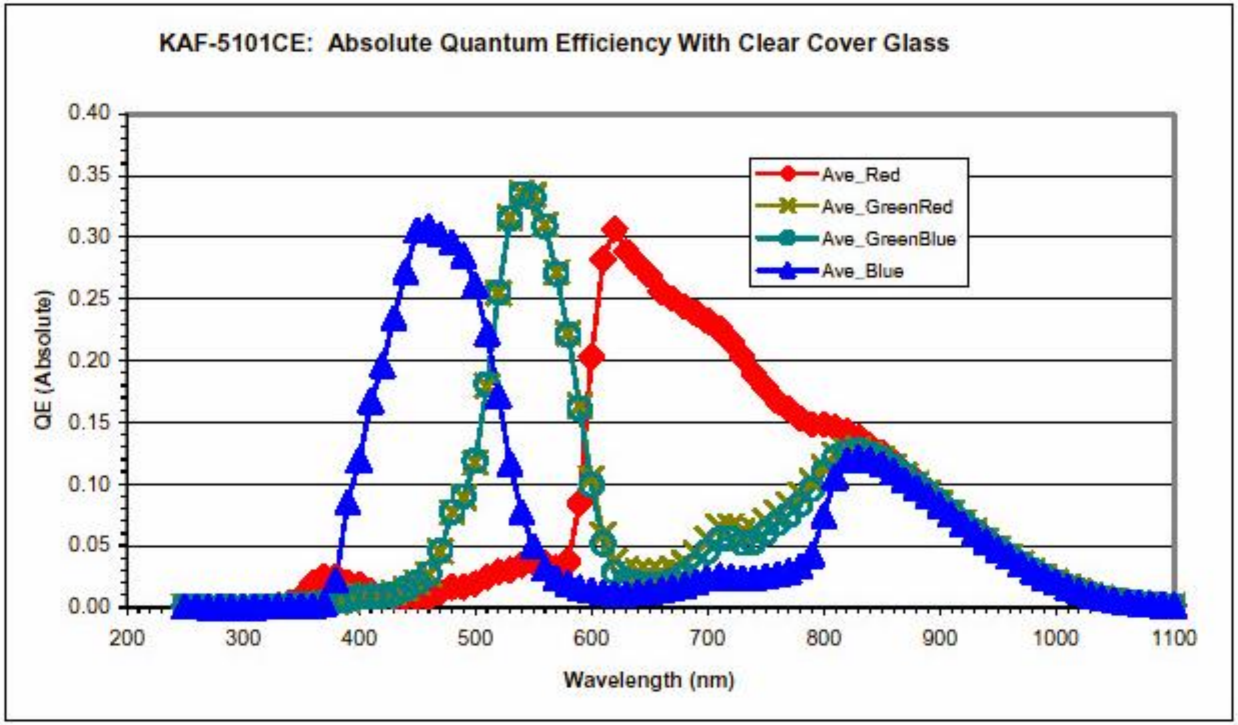
Prokudin-Gorskii (early 1990's)

Multi-chip



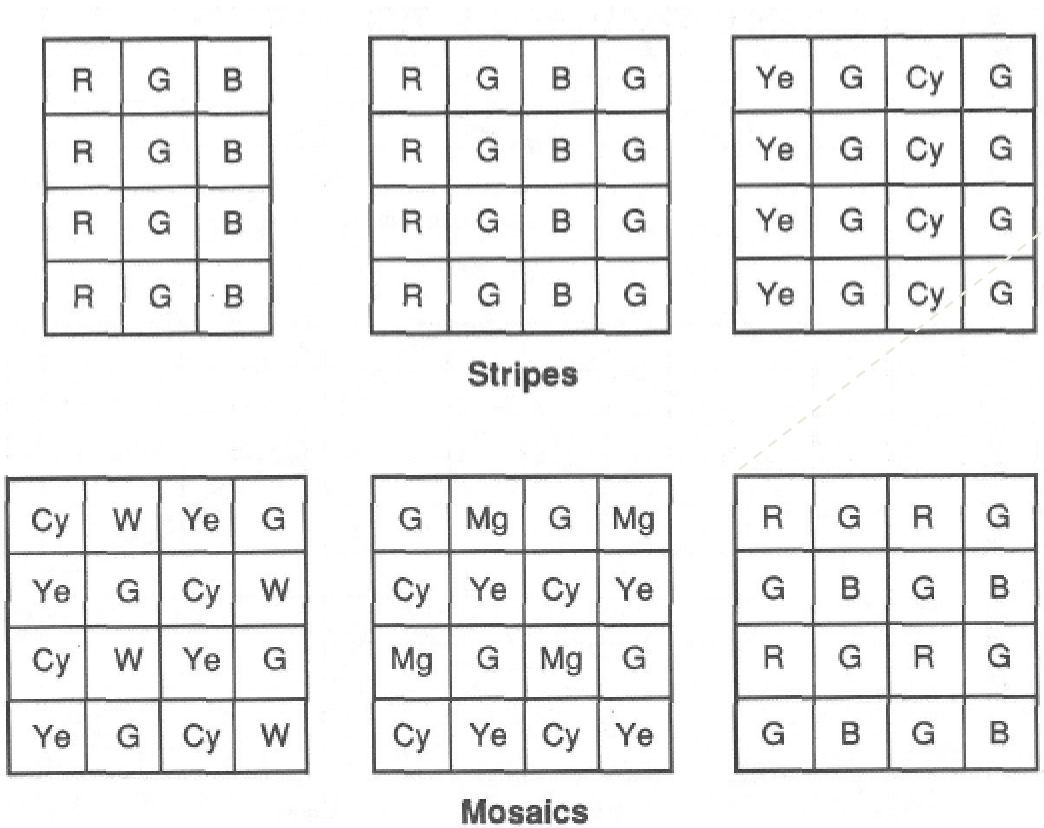
wavelength
dependent

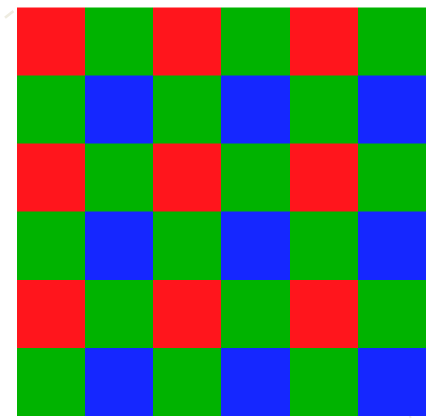
Embedded color filters



Color filters can be manufactured directly onto the photodetectors.

Color filter array

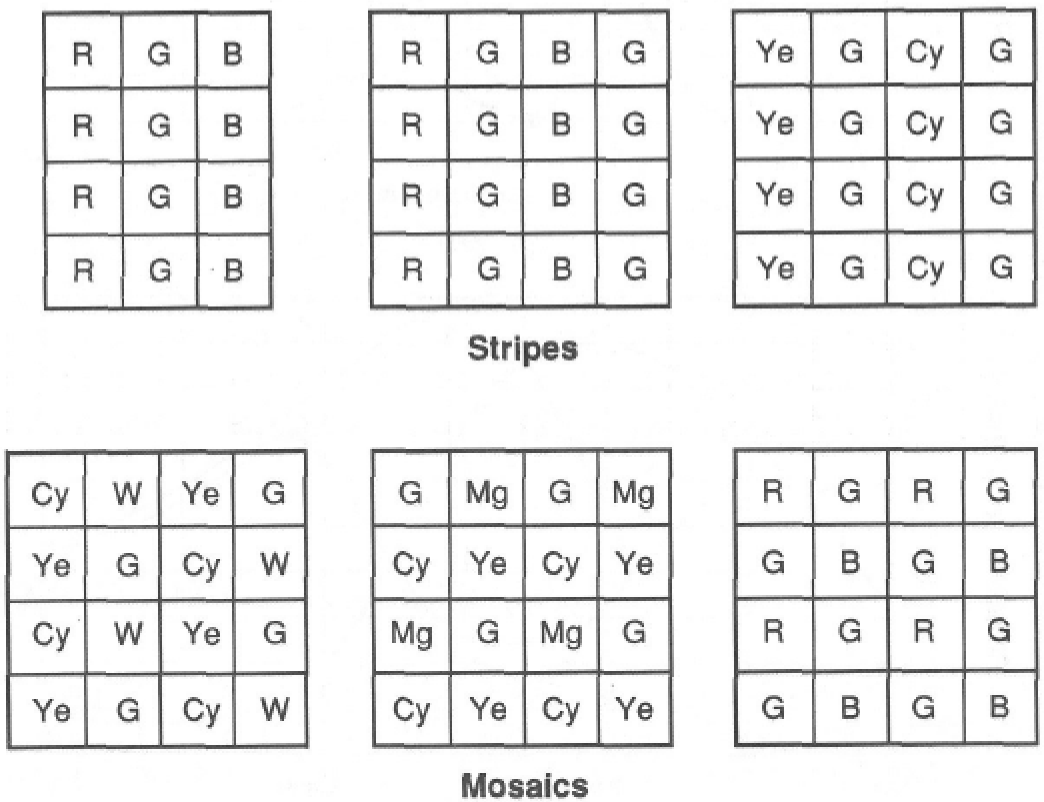




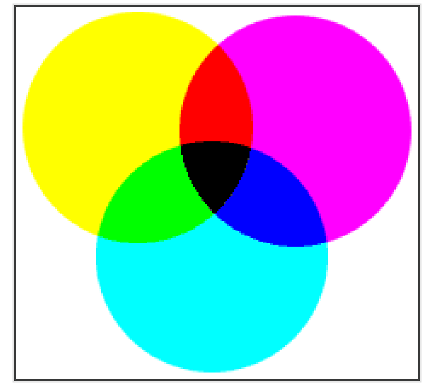
Bayer pattern

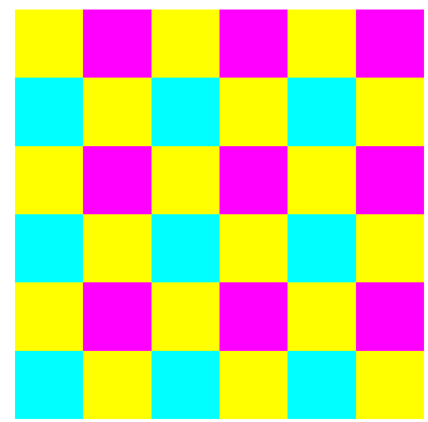
Color filter arrays (CFAs)/color filter mosaics

Color filter array



Kodak DCS620x

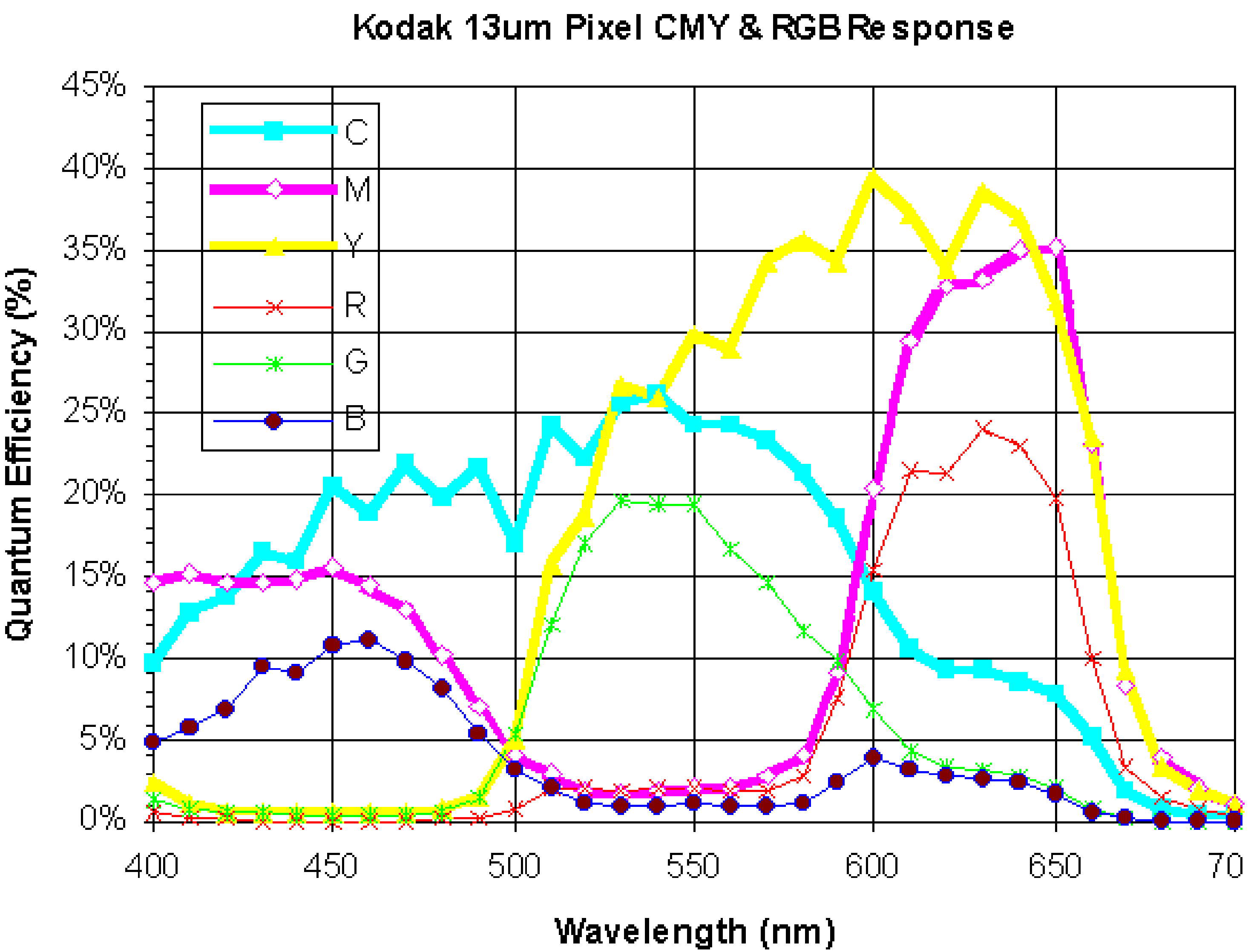




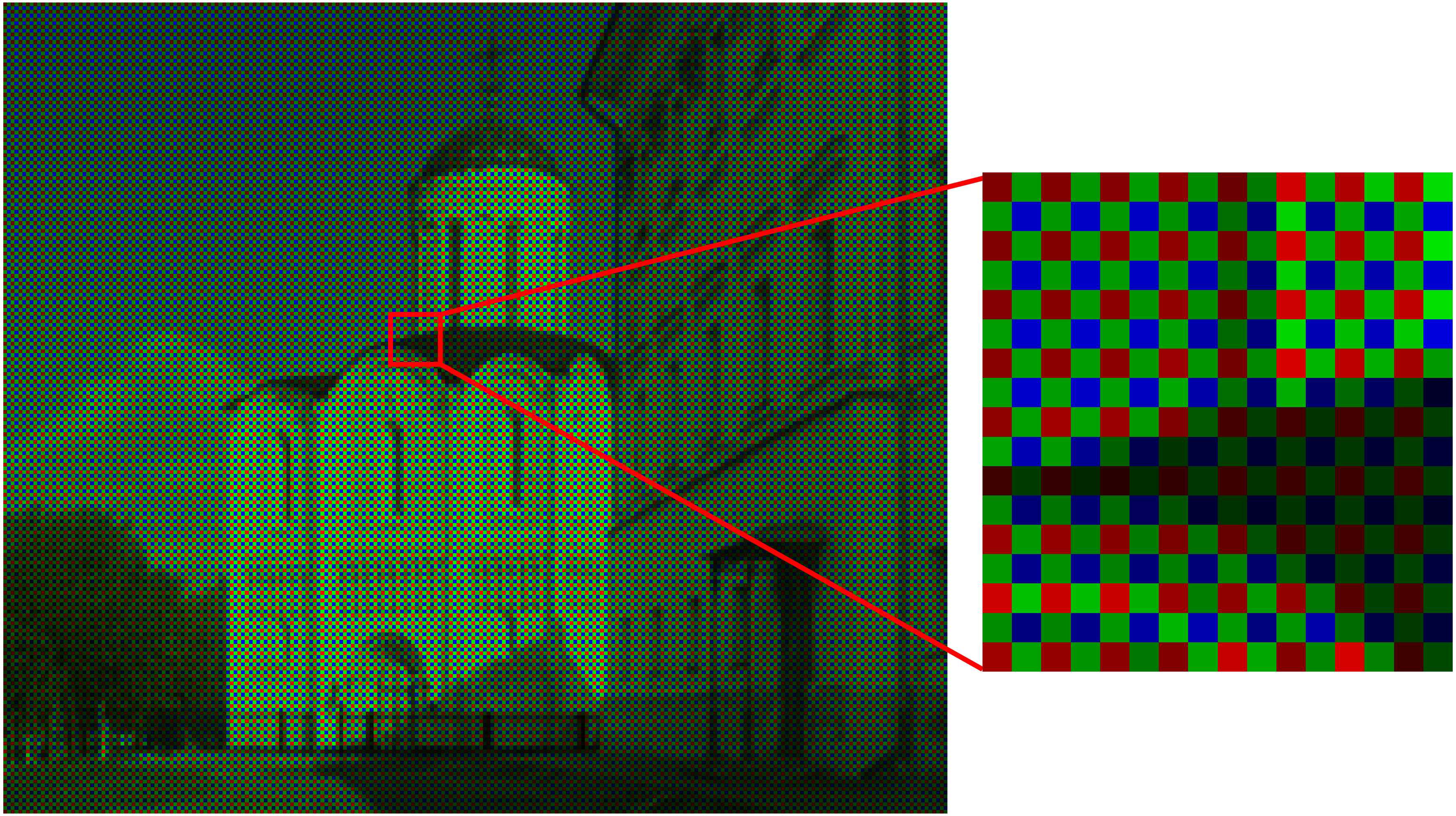
CMY

Color filter arrays (CFAs)/color filter mosaics

Why CMY CFA might be better

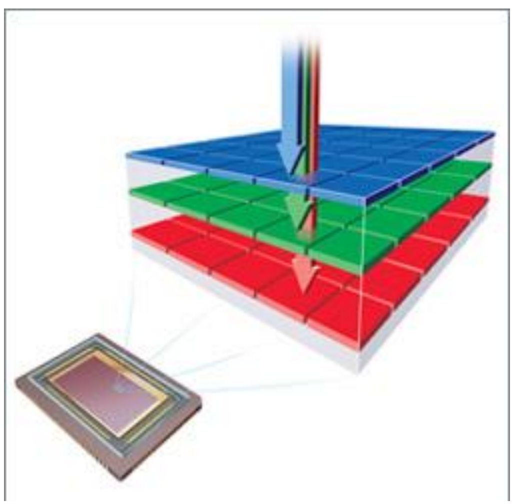


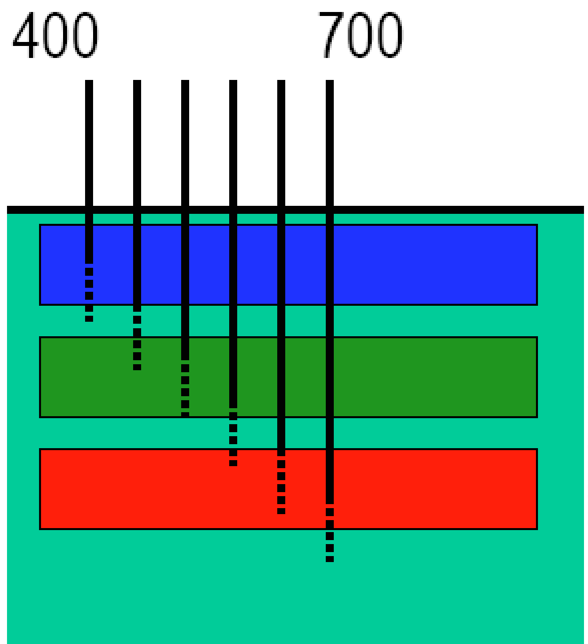
Bayer's pattern

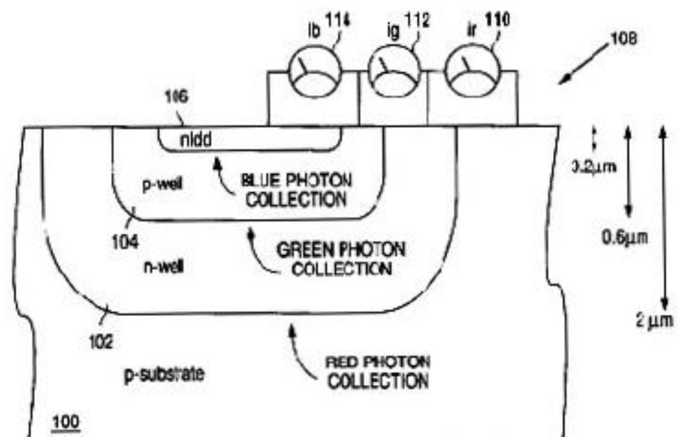


Foveon X3 sensor

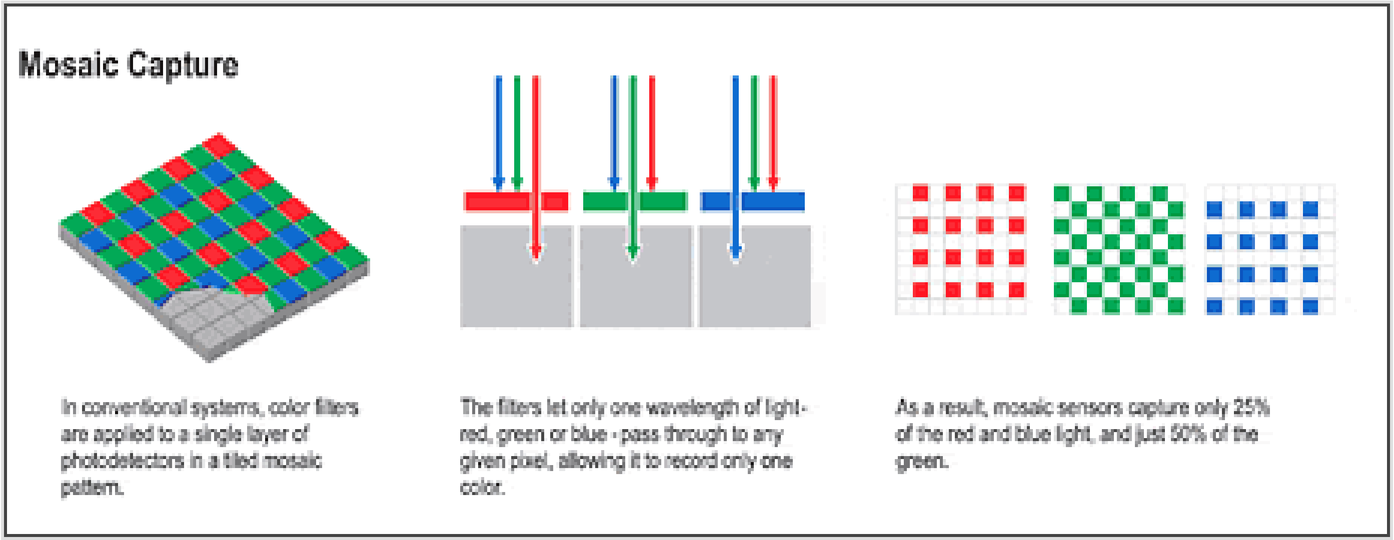
- light penetrates to different depths for different wavelengths
- multilayer CMOS sensor gets 3 different spectral sensitivities

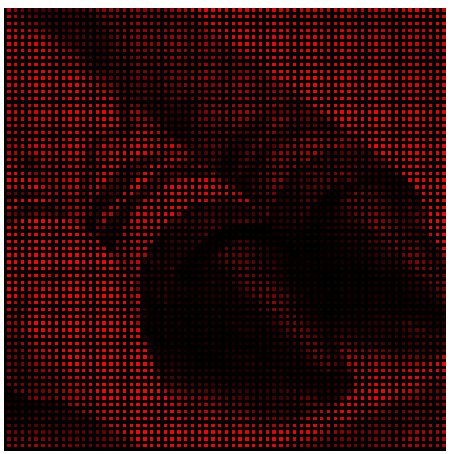


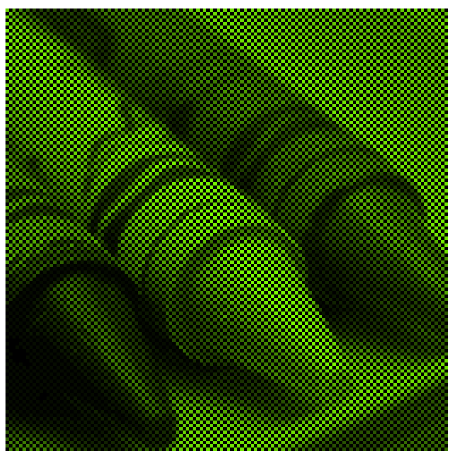


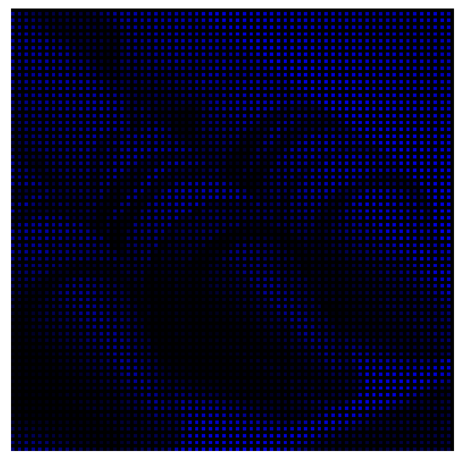


Color filter array



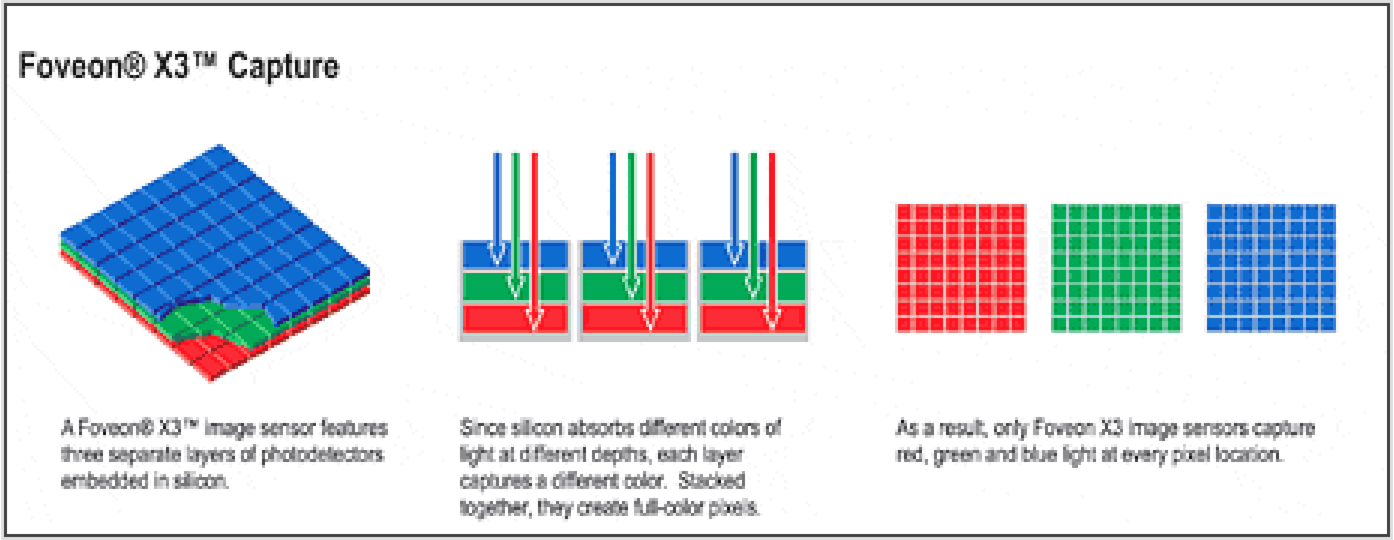

red

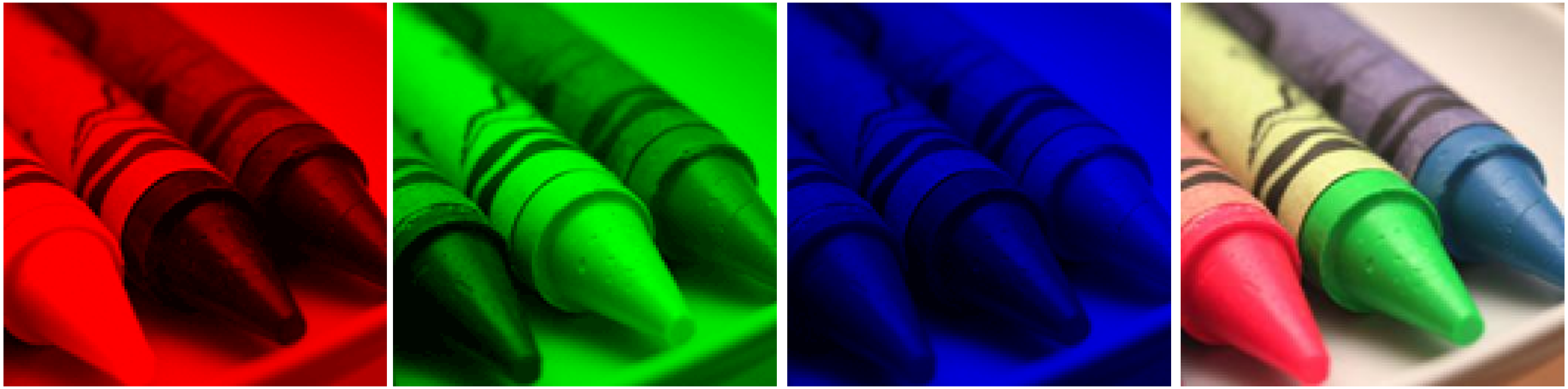

green


blue


output

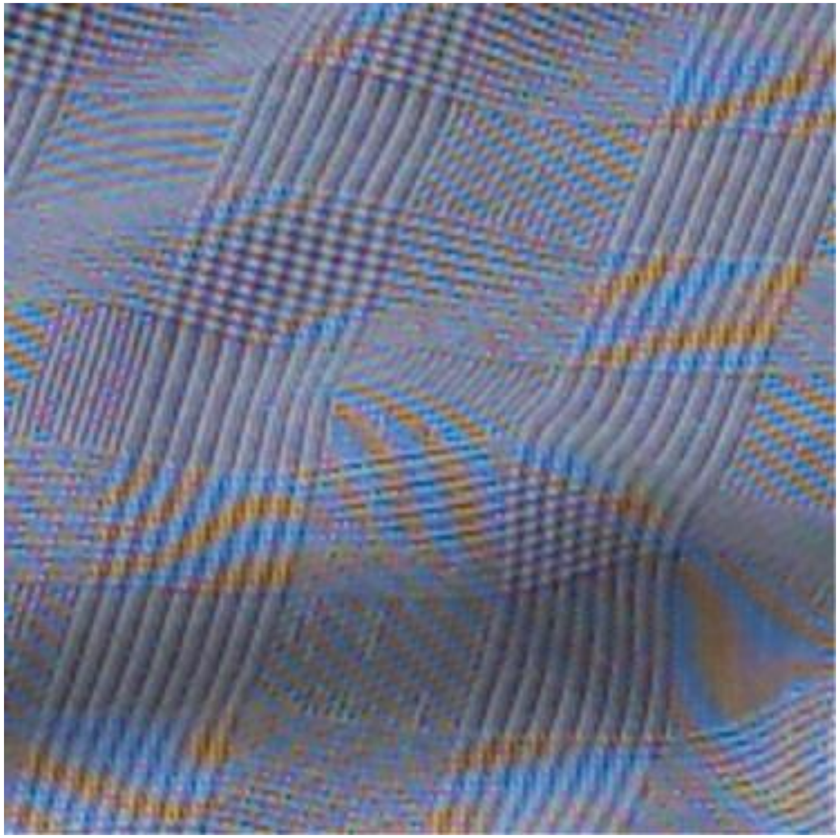
X3 technology



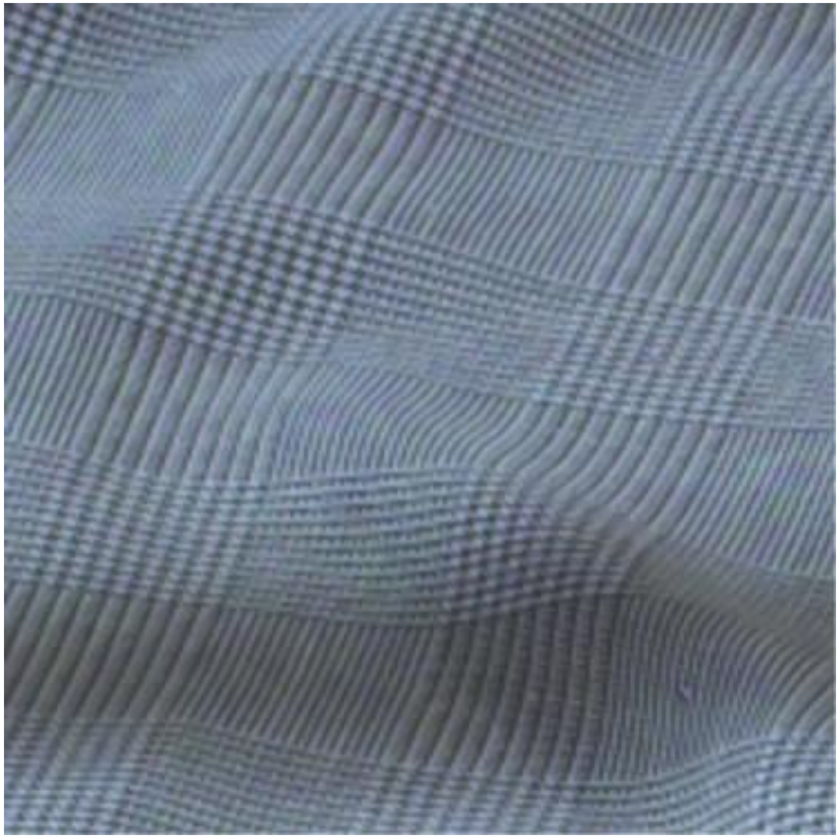


red green blue output

Foveon X3 sensor



Bayer CFA



X3 sensor

Cameras with X3

Sigma SD10, SD9

Polaroid X530

Sigma SD9 vs Canon D30