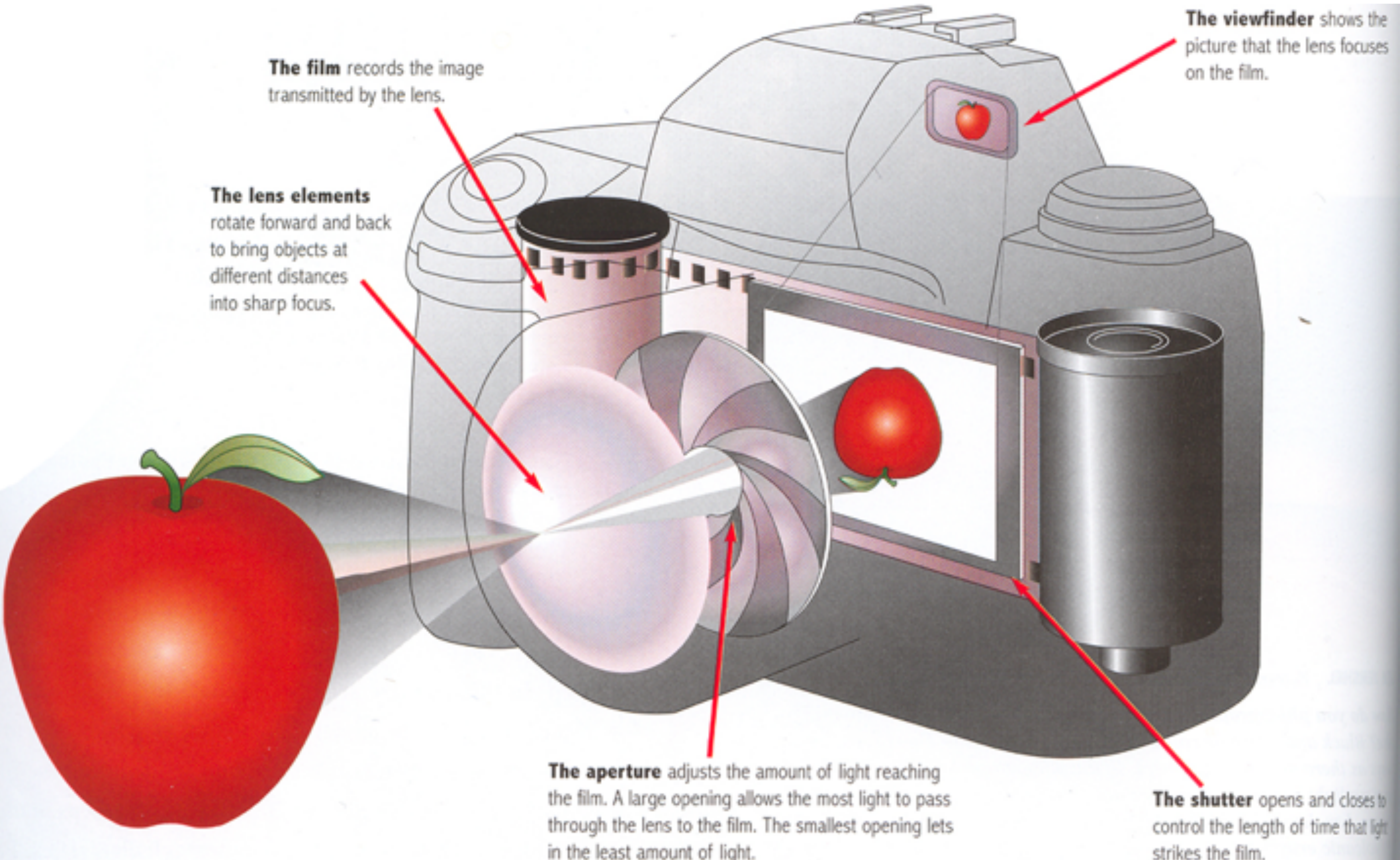
Computational Photography

Week 2

Instructor: Lou Kratz

Camera



The film records the image transmitted by the lens.
The viewfinder shows the picture that the lens focuses on the film.
The lens elements rotate forward and back to bring objects at different distances into sharp focus.
The aperture adjusts the amount of light reaching the film. A large opening allows the most light to pass through the lens to the film. The smallest opening lets in the least amount of light.
The shutter opens and closes
control the length of time that
strikes the film.

Recap

- Pinhole is the simplest model of image formation
- Lenses gather more light
  - But get only one plane focused
  - Focus by moving sensor/film
  - Cannot focus infinitely close
- Focal length determines field of view
  - From wide angle to telephoto
  - Depends on sensor size

Exposure

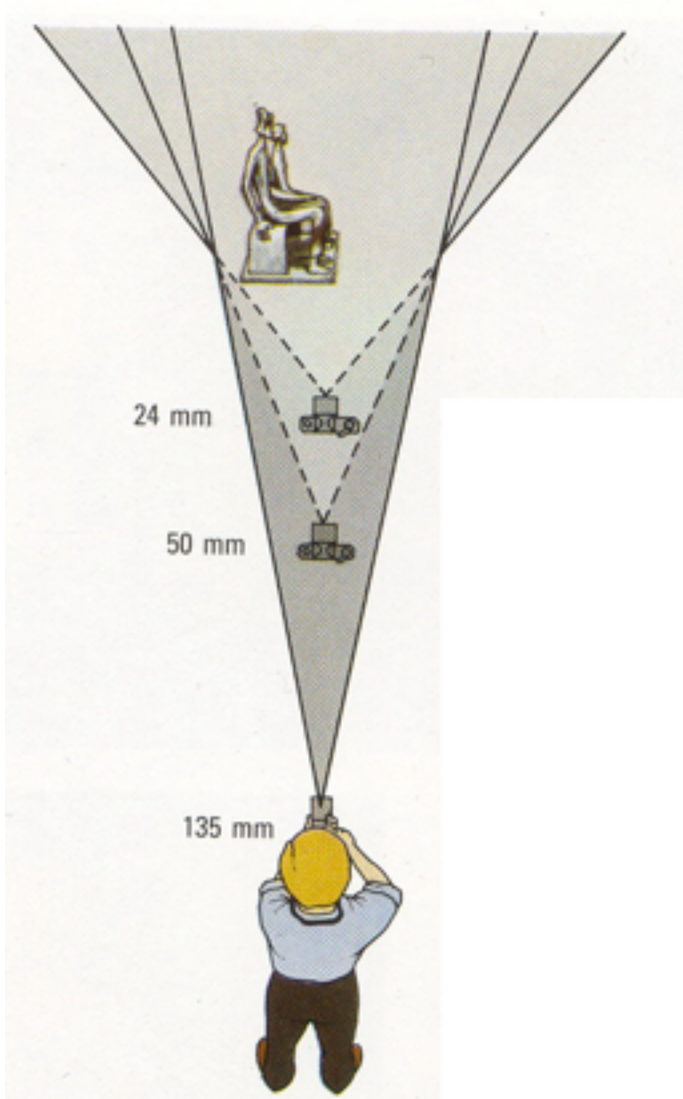
- Get the right amount of light to sensor/film
- Two main parameters:
  - Shutter speed
  - Aperture (area of lens)

Shutter

Shutter Speed

- Controls how long the film/sensor is exposed
- Pretty much linear effect on exposure
- Usually in fraction of a second:
  - 1/30, 1/60, 1/125, 1/250, 1/500
  - Get the pattern ?
- On a normal lens, normal humans can hand-hold down to 1/60
  - In general, the rule of thumb says that the limit is the inverse of focal length, e.g. 1/500 for a 500mm

Why it depends on the focal length



Grand-angulaire 24 mm

Normal 50 mm

Longue focale 135 mm

Shutter Speed

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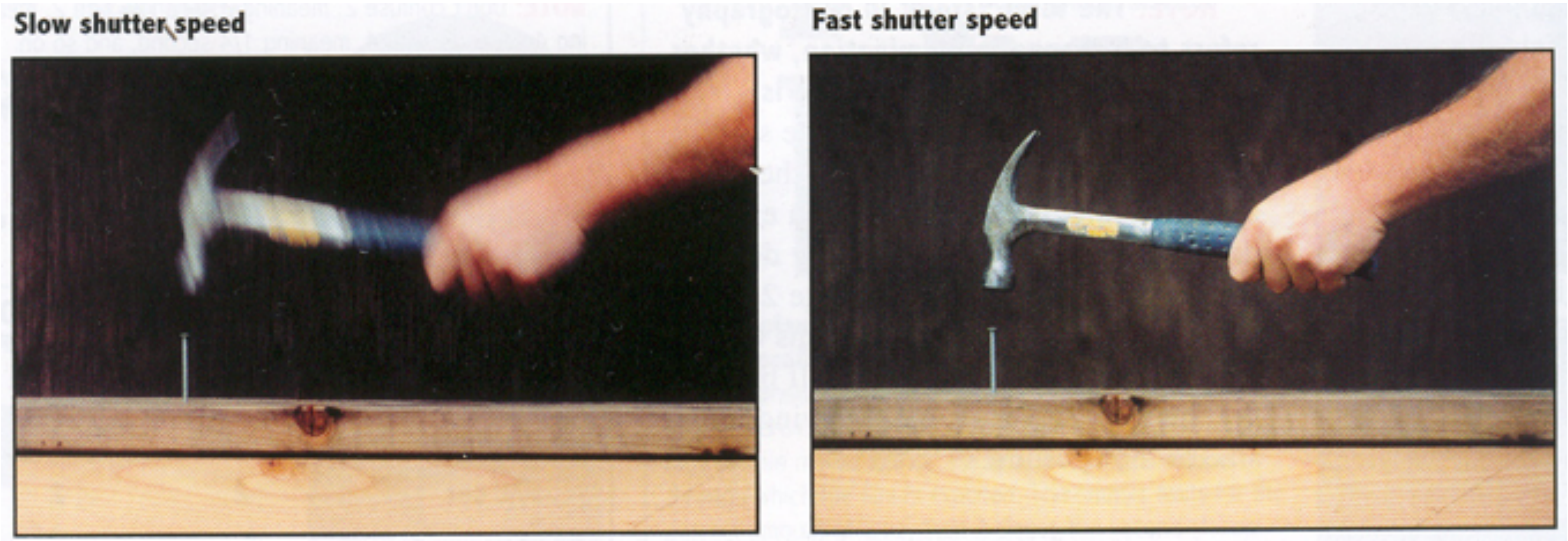
Also depends on the weight of the camera

Main Effect of Shutter Speed

- Motion blur



From Photography, London et al.

Effect of Shutter Speed

- Freezing motion

Walking people

1/125

Running people

1/250

Car

1/500

Fast train

1/1000

https://youtu.be/qW7NcMqMoVY?t=213

Shutter

- Various technologies
- Goal: achieve uniform exposure across image

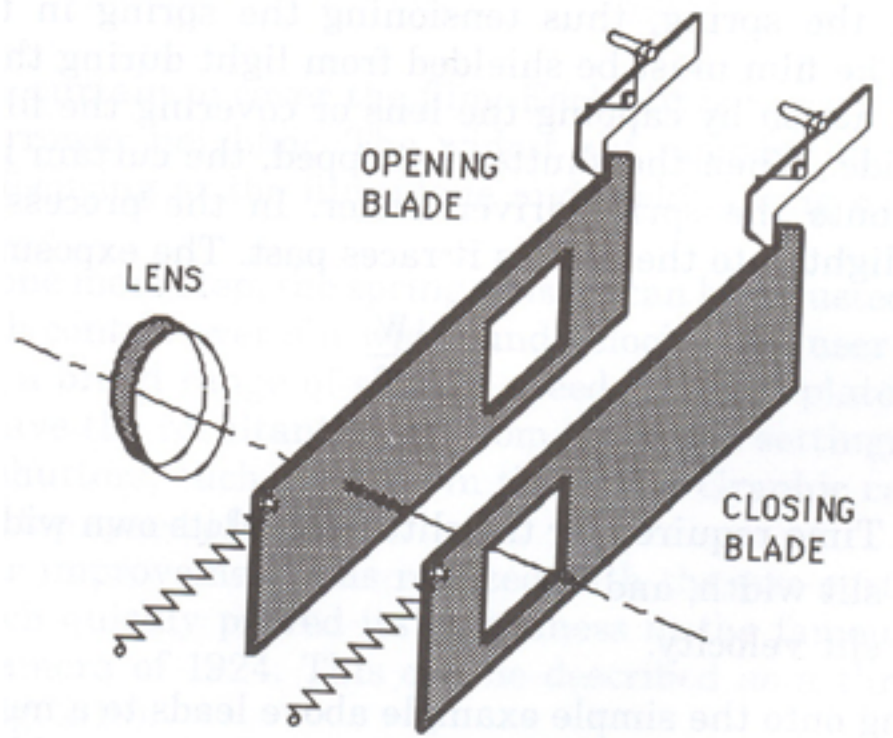
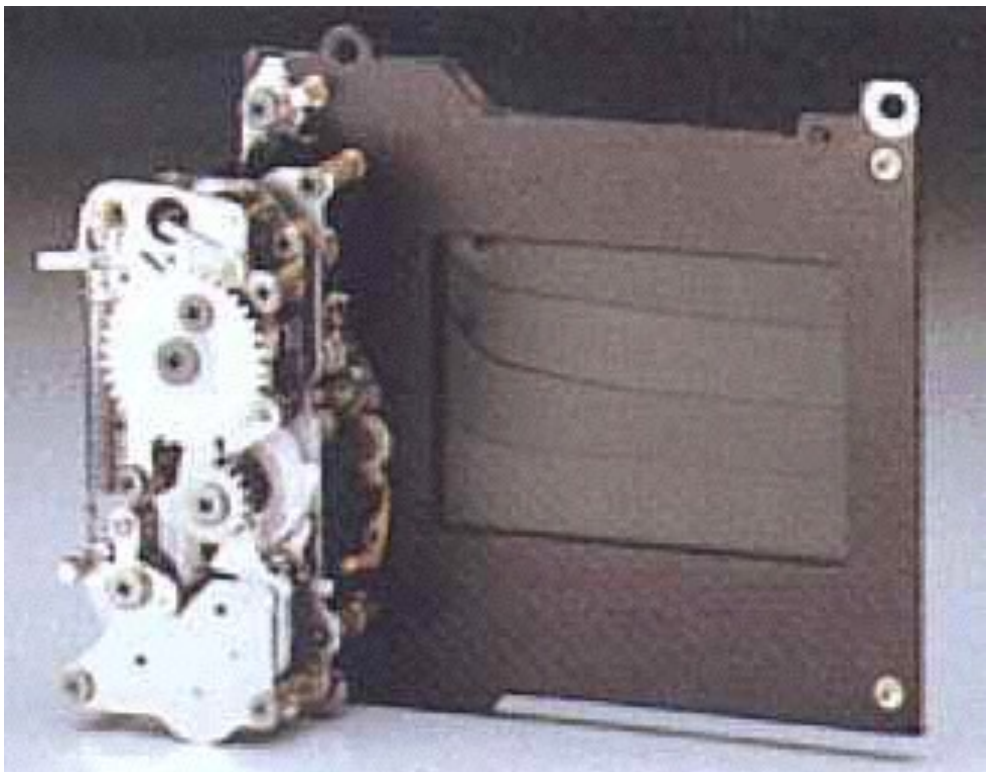


FIG. 2.8 Two-blade guillotine shutter.

Shutter

- Various technologies
- Goal: achieve uniform exposure across image



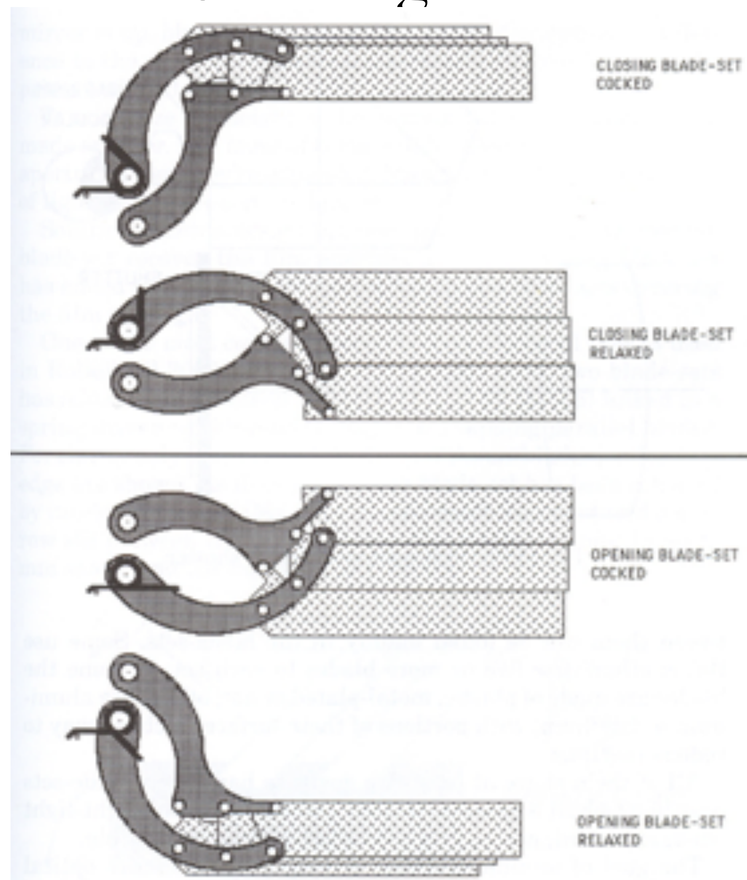


FIG. 2.12 Copal square.

From Camera Technology, Goldberg


6

Deblurring: Blind Deconvolution

- Estimate motion and deblurred image

Fergus et al.

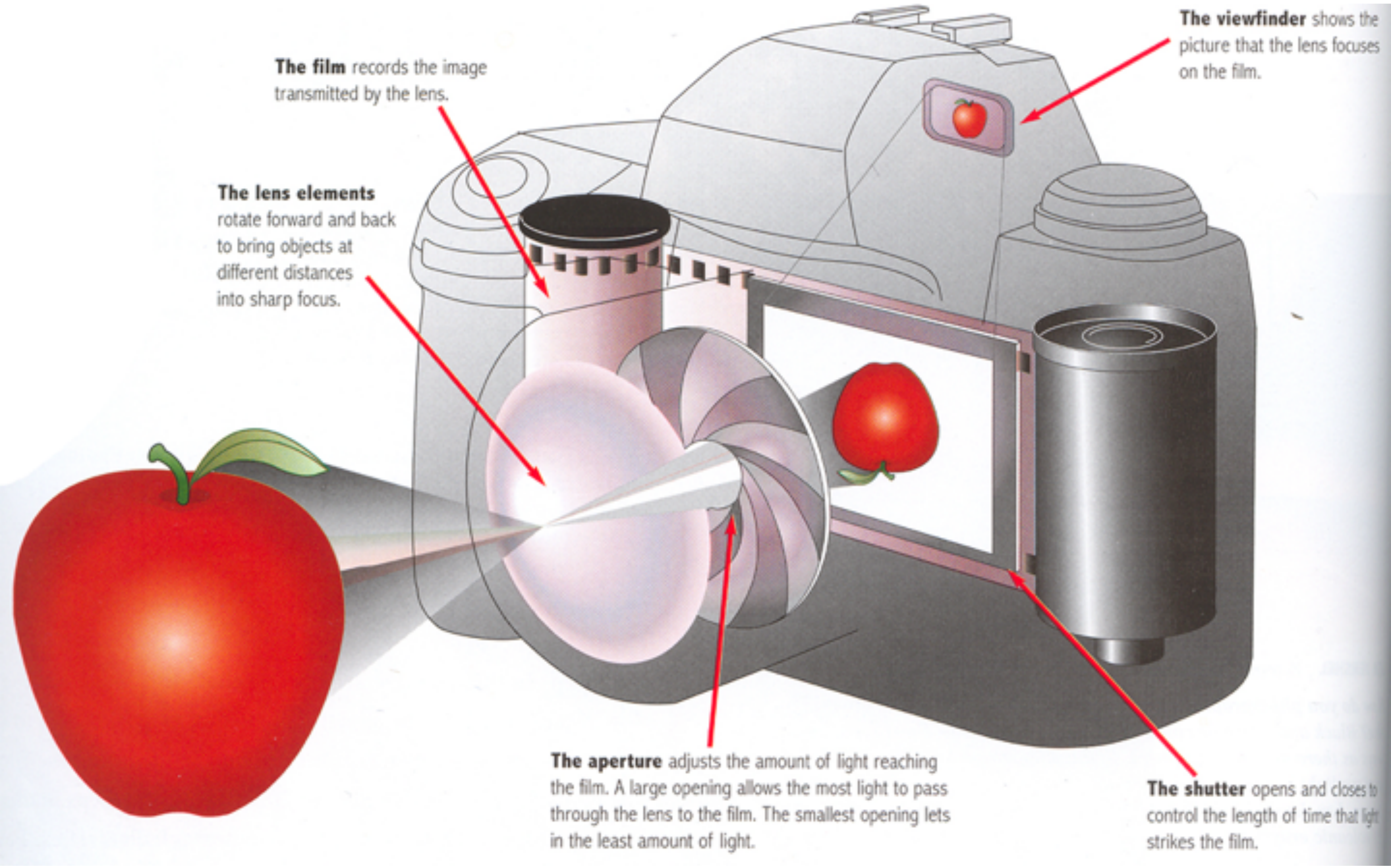
Motion Blur

Tripod

- Use a tripod! It will always enhance sharpness
  - Avoid camera shake

Exposure

- Get the right amount of light to sensor/film
- Two main parameters:
  - Shutter speed
  - **Aperture (area of lens)**



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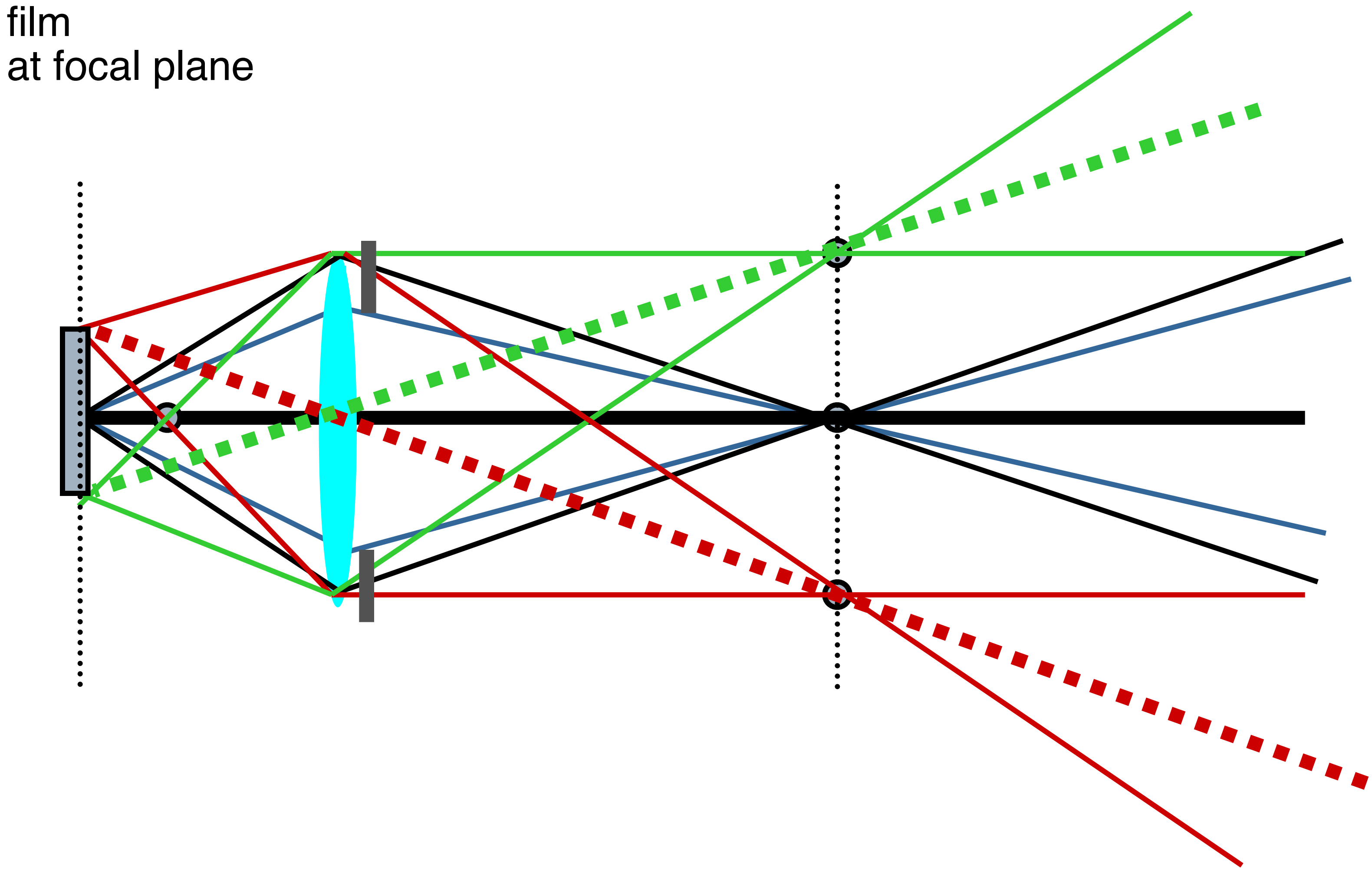
Aperture

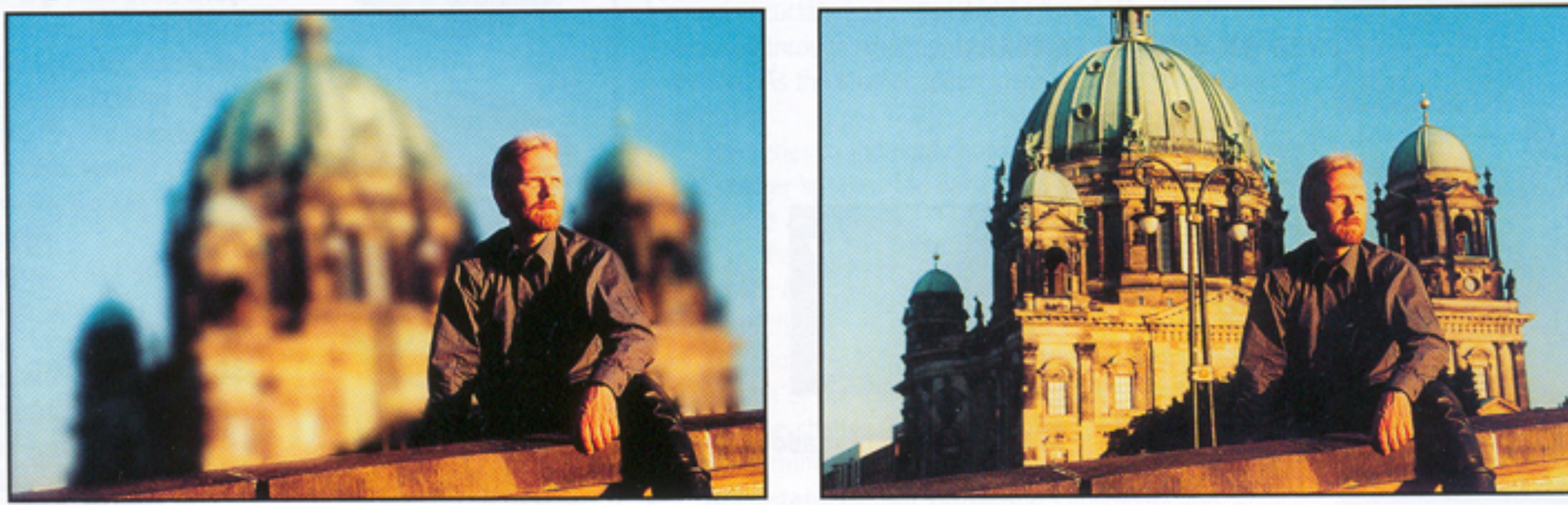


Aperture

- Diameter of the lens opening (controlled by diaphragm)
- Expressed as a fraction of focal length, in f-number
  - f/2.0 on a 50mm means that the aperture's diameter is 25mm
  - f/2.0 on a 100mm means that the aperture is 50mm
- Disconcerting: small f number = big aperture
- What happens to the area of the aperture when going from f/2.0 to f/4.0?
- Typical f numbers are
  f/2.0, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32
  - See the pattern?

Main Effect of Aperture

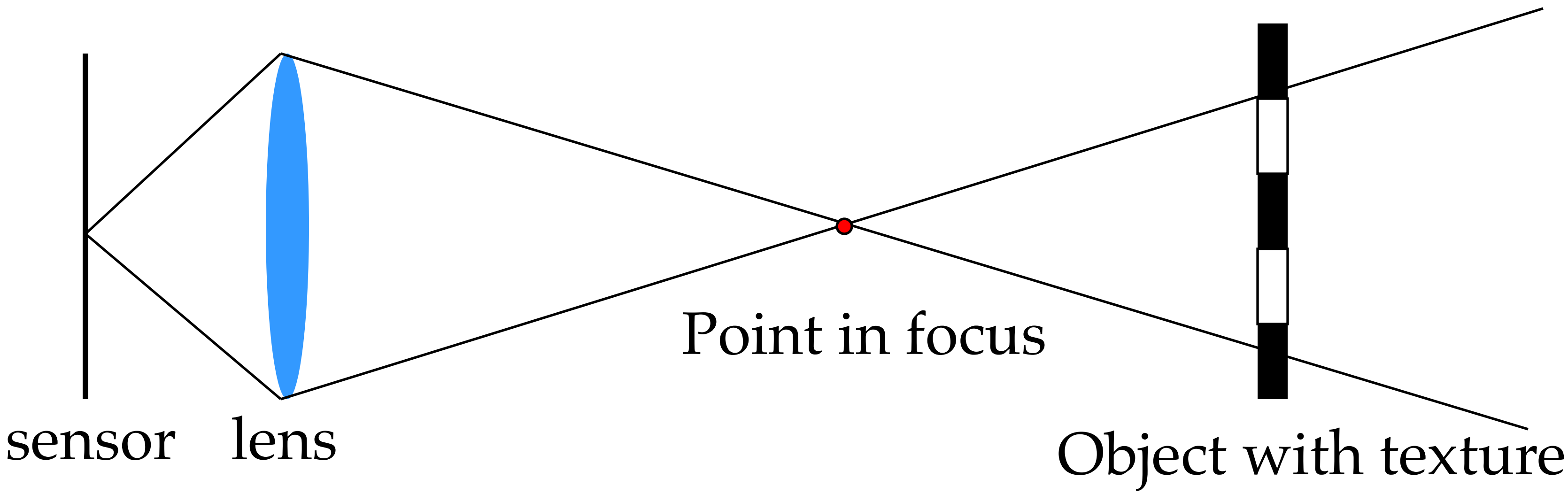
- Depth of field



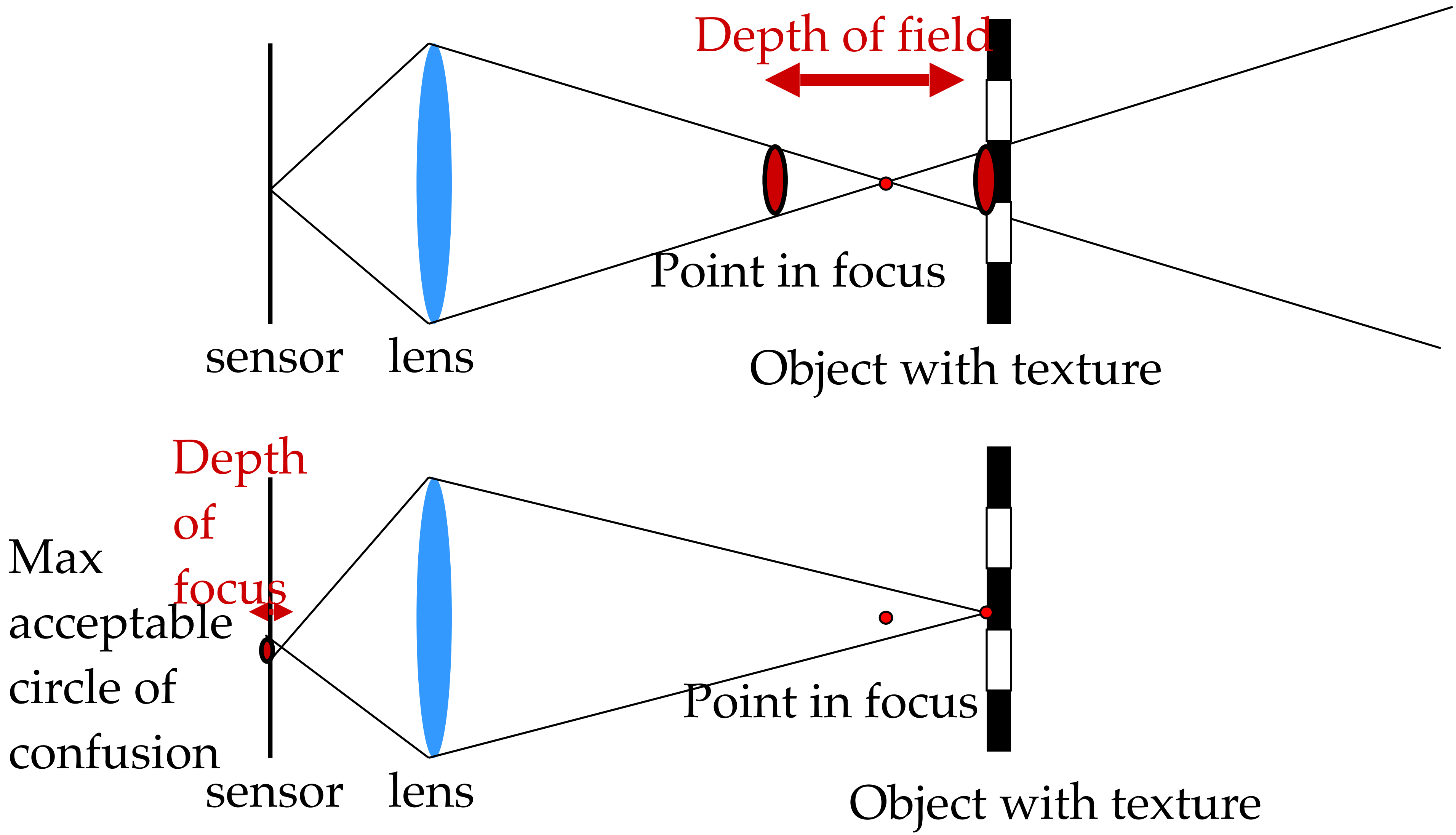
Large aperture opening   Small aperture opening

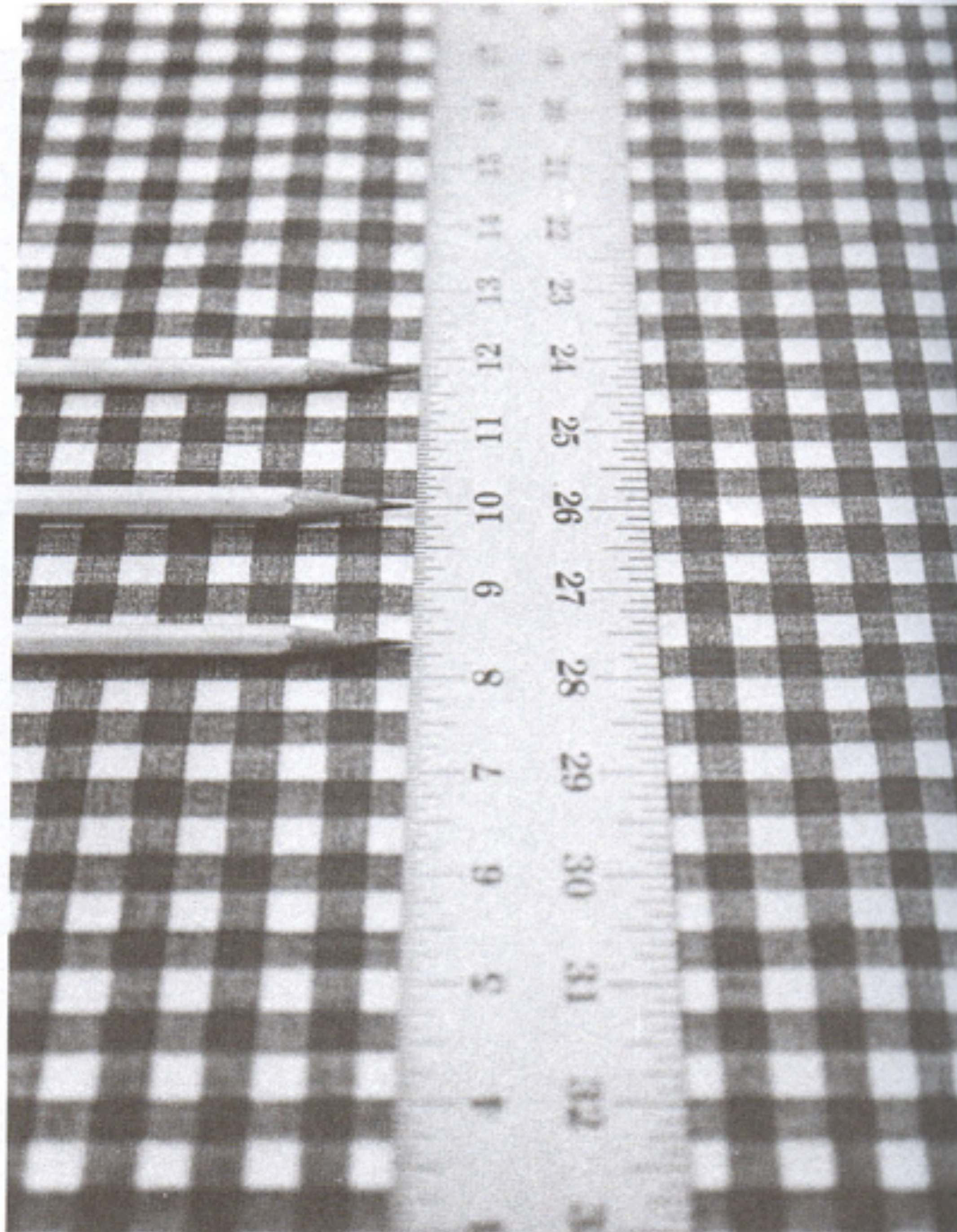
From Photography, London et al.

Depth of Field



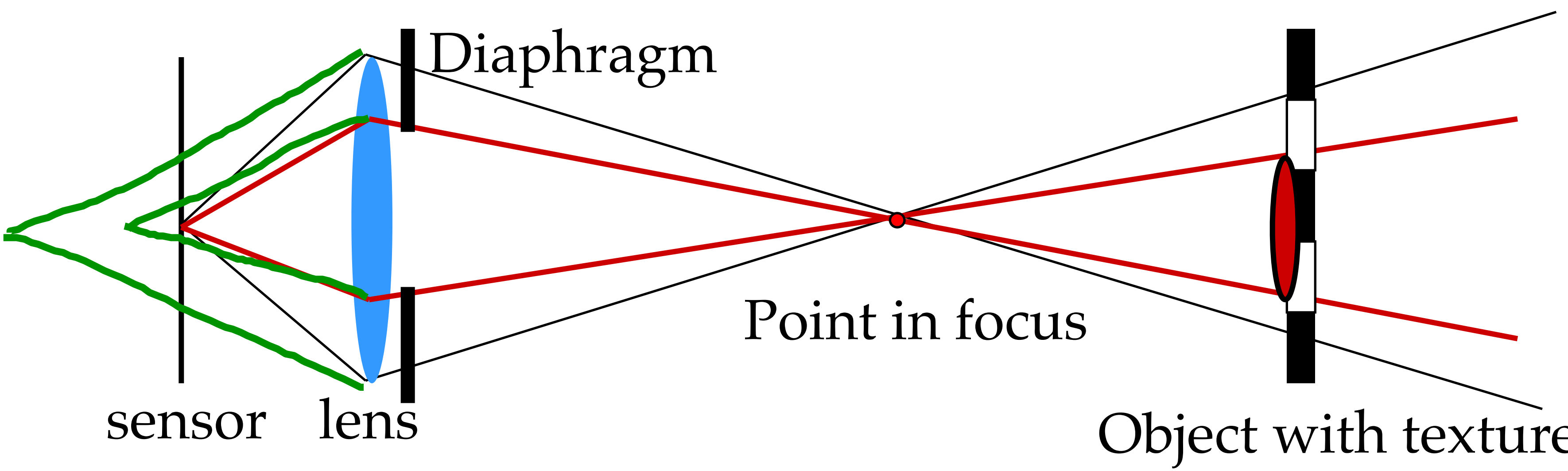
Depth of Field



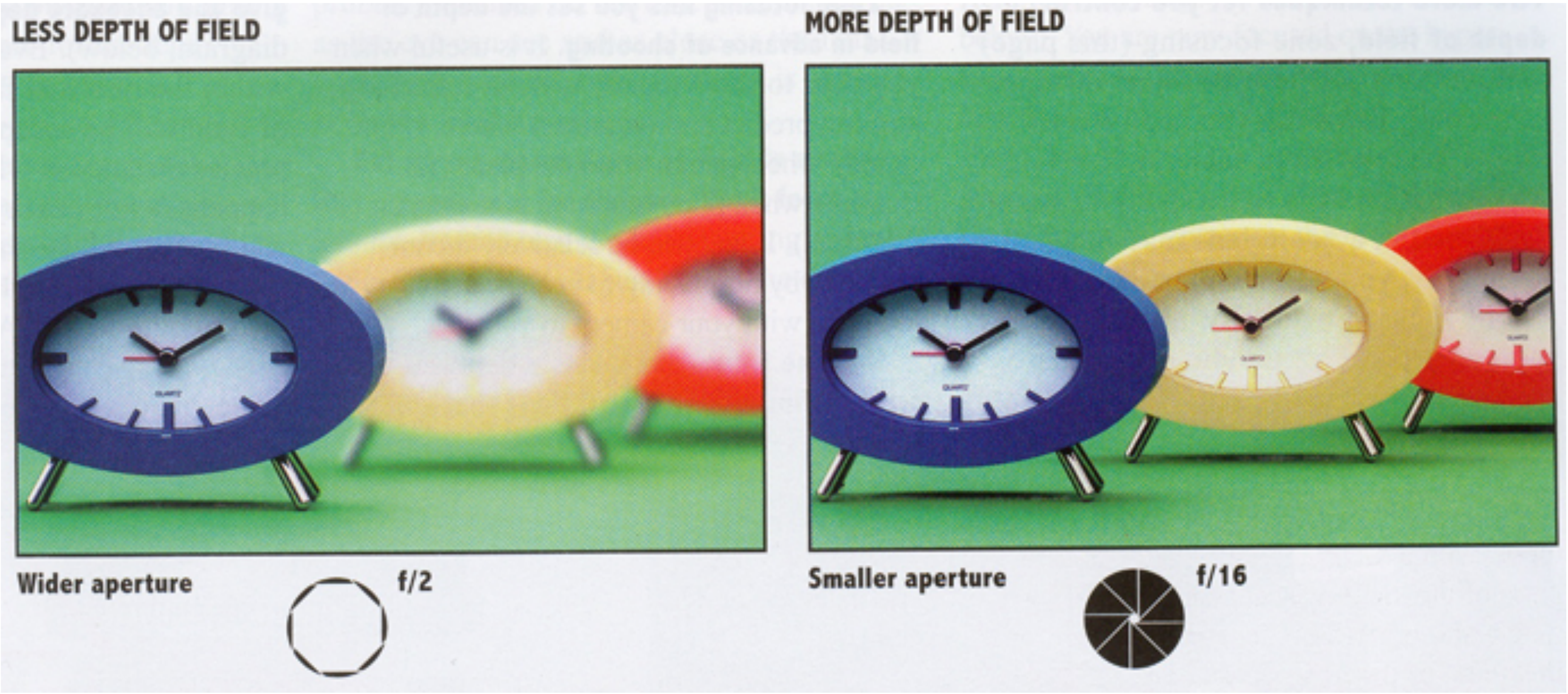


Depth of Field

- What happens when we close the aperture by two stop?
  - Aperture diameter is divided by two
  - Depth of field is doubled



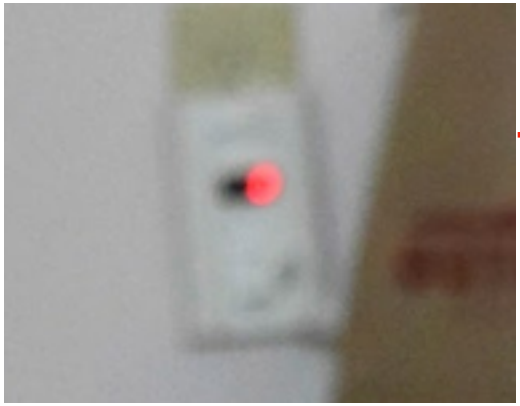
Depth of Field



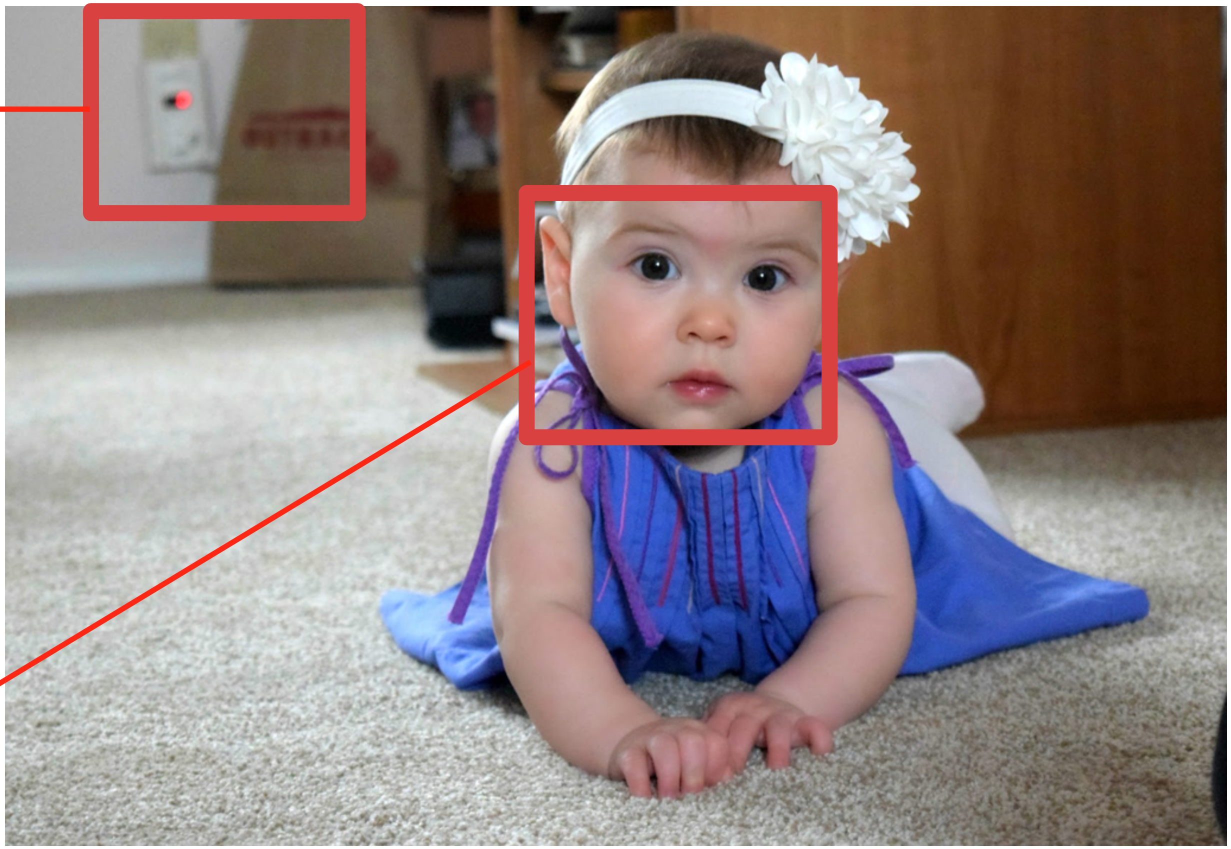
From Photography, London et al.

Artistic Effects

Background: Blurred

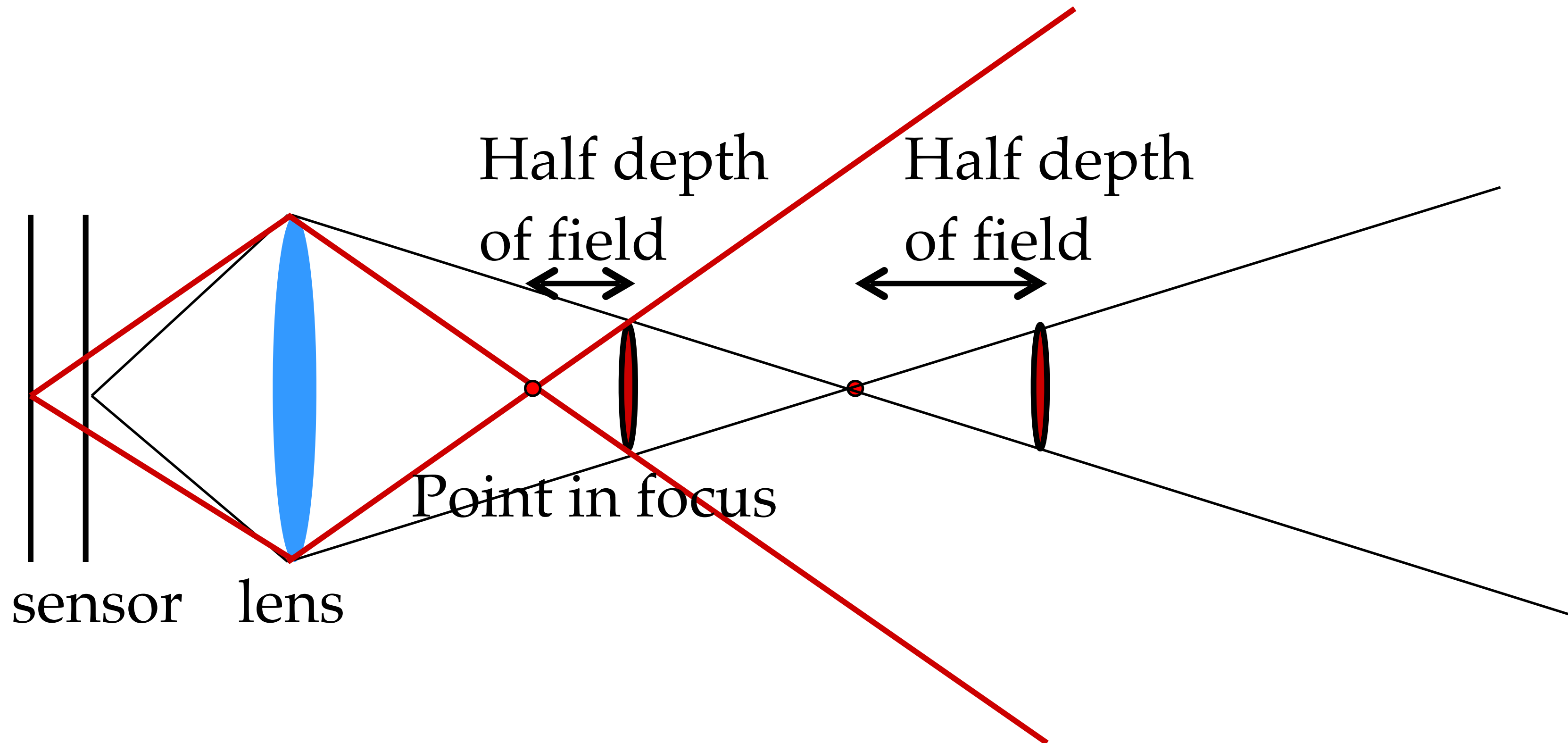


Subject: In Focus



Depth of Field & Focusing Distance

- What happens when we focus closer?
  - Depth of field decreases



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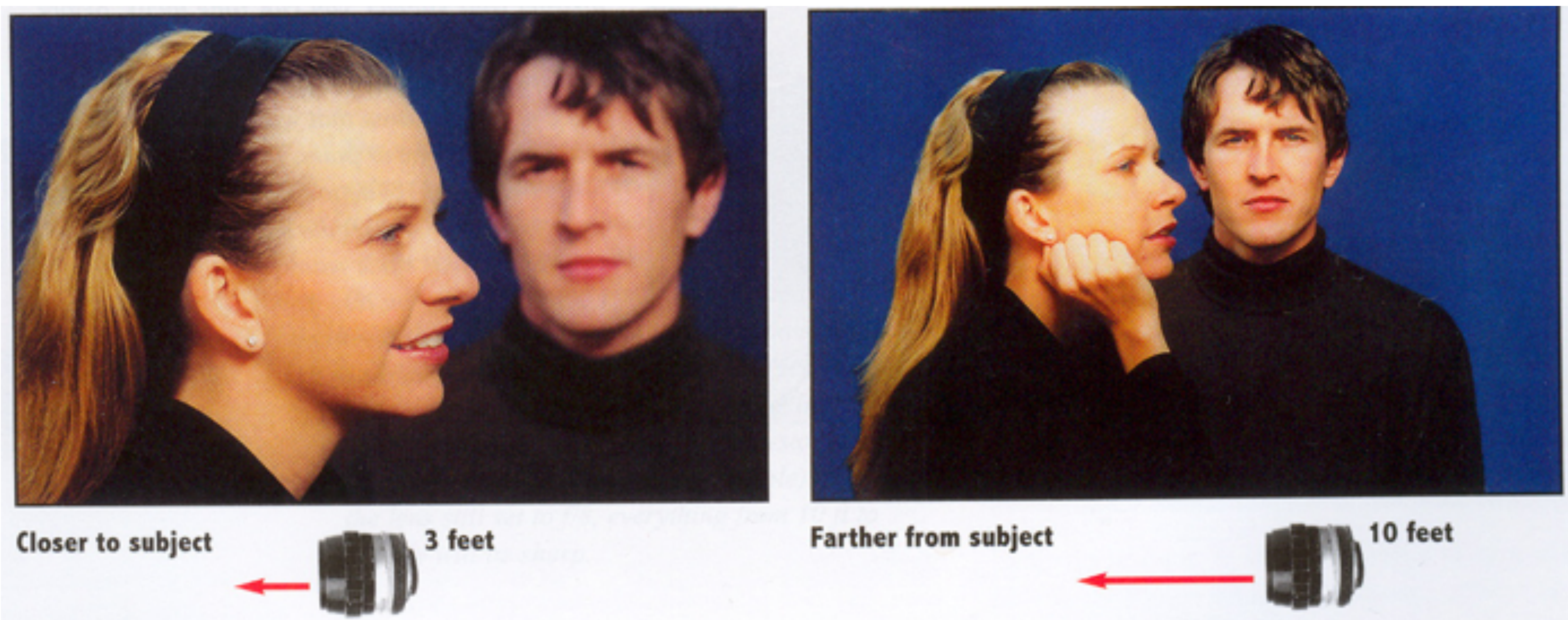


From Photography, London et al.

SLR Viewfinder & Aperture

- By default, an SLR always shows you the biggest aperture
- Brighter image
- Shallow depth of field help judge focus
- Depth of field preview button:
  - Stops down to the aperture you have chosen
  - Darker image
  - Larger depth of field

Exposure

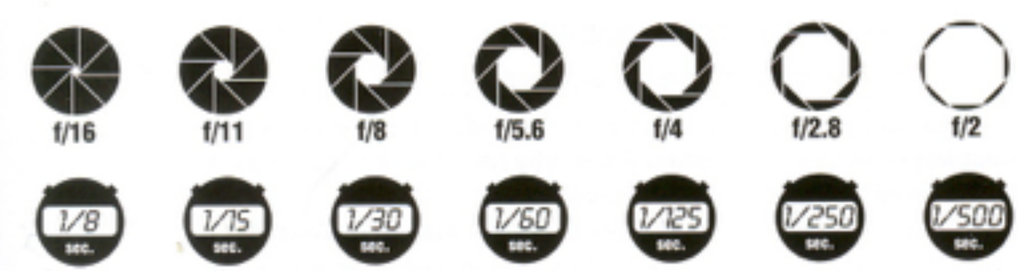
- Two main parameters:
  - Aperture (in f stop)
  - Shutter speed (in fraction of a second)
- Reciprocity

  The same exposure is obtained with an exposure twice as long and an aperture *area* half as big
  - Hence square root of two progression of f stops vs. power of two progression of shutter speed
  - Reciprocity can fail for very long exposures

From Photography, London et al.

Reciprocity

- Assume we know how much light we need
- We have the choice of an infinity of shutter speed/aperture pairs



- What will guide our choice of a shutter speed?
  - Freeze motion vs. motion blur, camera shake
- What will guide our choice of an aperture?
  - Brightness, depth of field
- Often we must compromise
  - Open more to enable faster speed (but shallow DoF)

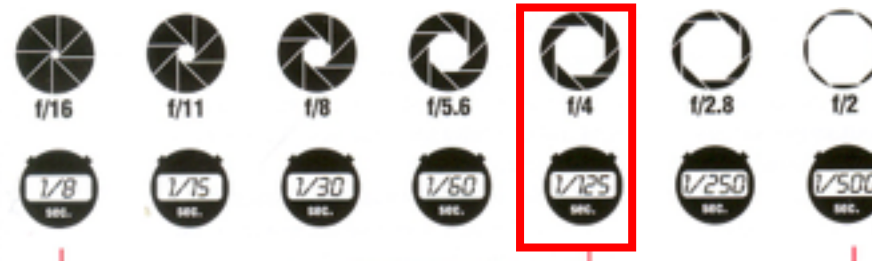
Small aperture (deep depth of field), slow shutter speed (motion blurred). *scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to show moving pigeons sharply. It also meant that a tripod had to be used to hold the camera steady.*

From Photography, London et al.

Large aperture (shallow depth of field), fast shutter speed (motion sharp). *A fa shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little dept of field that the background is now out of focus.*

From Photography, London et al.

Medium aperture (moderate depth of field), medium shutter speed (some motion sharp). A medium aperture (f/4) and shutter speed (1/125 sec) sacrifice some background detail to produce recognizable images of the birds. But the exposure is still too long to show the motion of the birds' wings sharply.



From Photography, London et al.

Metering

- Photosensitive sensors measure scene luminance
- Usually TTL (through the lens)
- Simple version: center-weighted average

- Assumption? Failure cases?
  - Usually assumes that a scene is 18% gray
  - Problem with dark and bright scenes

White polar bear given exposure suggested by meter

White polar bear given 2 stops more exposure

Gray elephant given exposure suggested by meter

Black gorilla given exposure suggested by meter

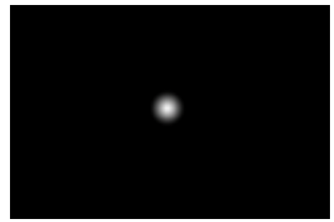
Black gorilla given 2 stops less exposure

From Photography, London et al.

Metering

- Centered average

- Spot



- Smart metering
  - Nikon 3D matrix
  - Canon evaluative

Next slide

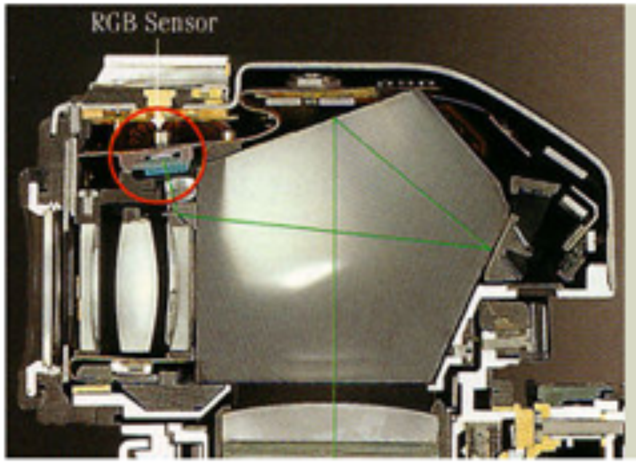
Choice on Nikon

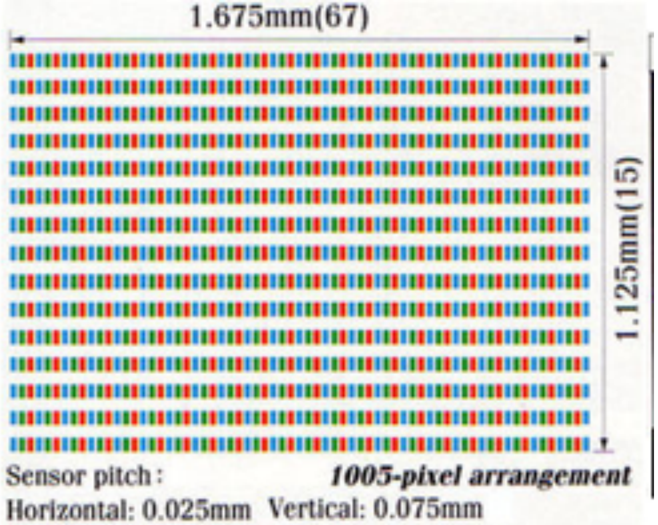
- Incident
  - Measure incoming light

Nikon 3D Color Matrix

http://www.mir.com.my/rb/photography/hardwares/classics/NikonF5/metering/

- Learning from database of 30,000 photos
- Multiple captors (segments)
- Exposure depends on
  - Brightness from each segments
  - Color
  - Contrast
  - Distance
  - Focus (where is the subject)





Exposure & Metering

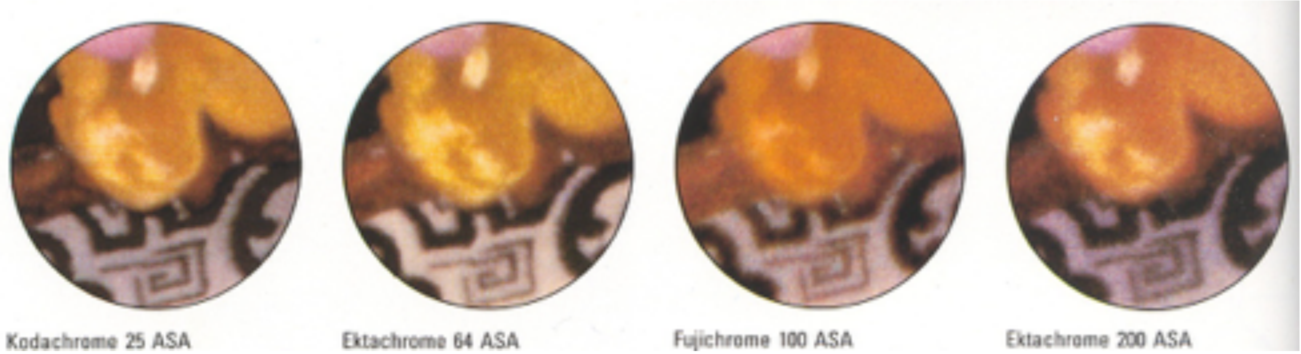
- The camera metering system measures how bright the scene is
- In Aperture priority mode, the photographer sets the aperture, the camera sets the shutter speed
- In Shutter-speed priority mode, the photographers sets the shutter speed and the camera deduces the aperture
  - In both cases, reciprocity is exploited
- In Program mode, the camera decides both exposure and shutter speed (middle value more or less)
- In Manual, the user decides everything (but can get feedback)

Pros and Cons of Various Modes

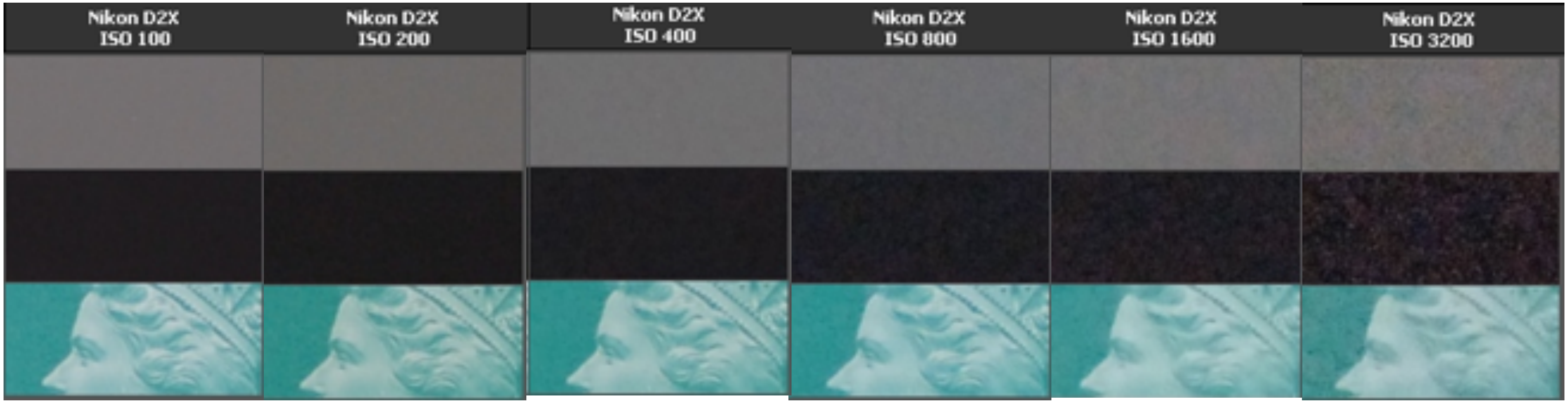
- Aperture priority (useful for most cases)
  - Direct depth of field control
  - Cons: can require impossible shutter speed (e.g. with f/1.4 for a bright scene)
- Shutter speed priority
  - Direct motion blur control
  - Cons: can require impossible aperture (e.g. when requesting a 1/1000 speed for a dark scene)
    - Note that aperture is somewhat more restricted
- Program
  - Almost no control, but no need for neurons
- Manual
  - Full control, but takes more time and thinking

Sensitivity (ISO)

- Third variable for exposure
- Linear effect (200 ISO needs half the light as 100 ISO)
- Film photography: trade sensitivity for grain



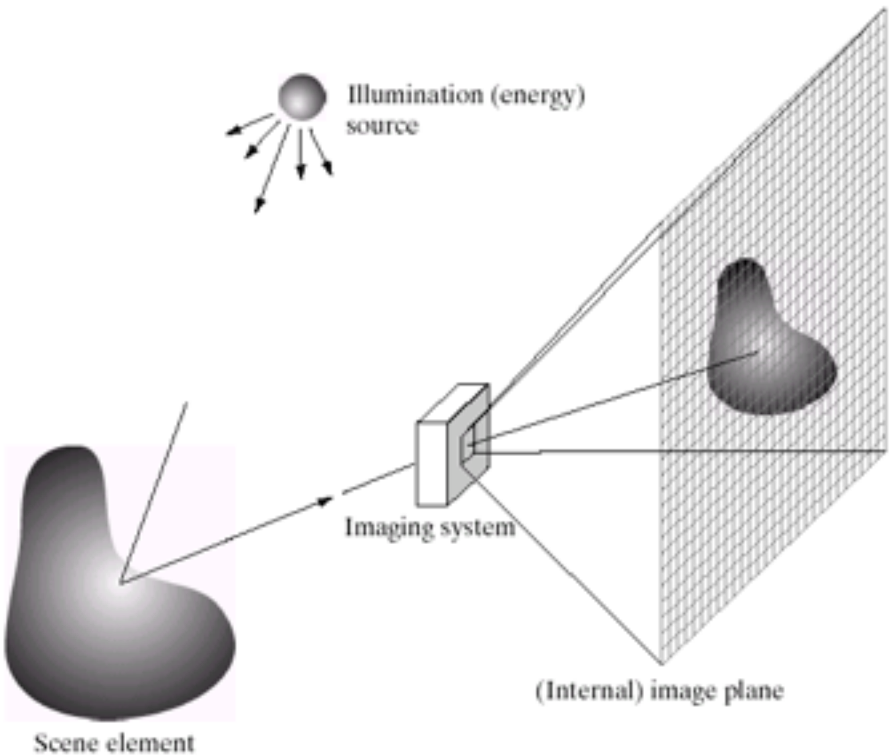
- Digital photography: trade sensitivity for noise



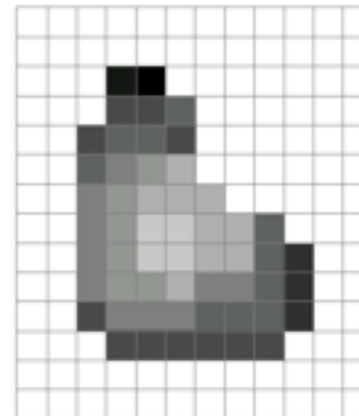
From dpreview.com

Capturing Light

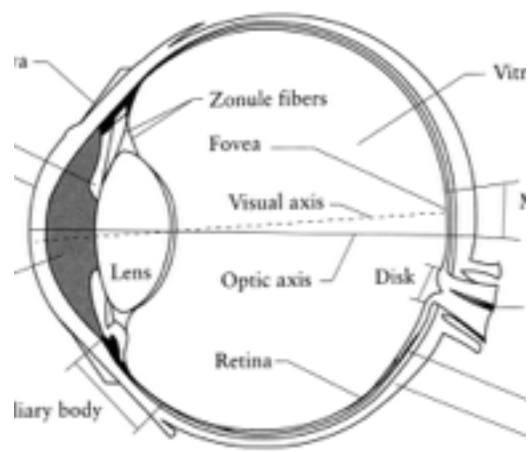
Image Formation



Film



Digital Camera



The Eye

Digital Camera

- A digital camera replaces film with a sensor array
  - Each cell in the array is light-sensitive diode that converts photons to electrons
  - Two common types
    - Charge Coupled Device (CCD)
    - CMOS

Sensor Array

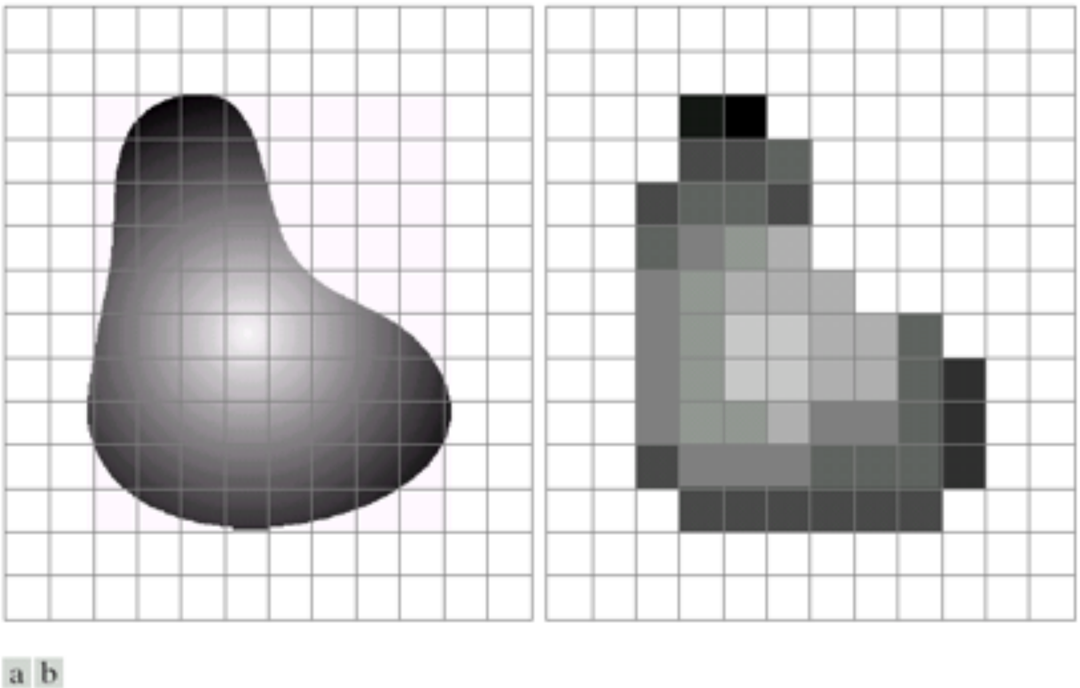
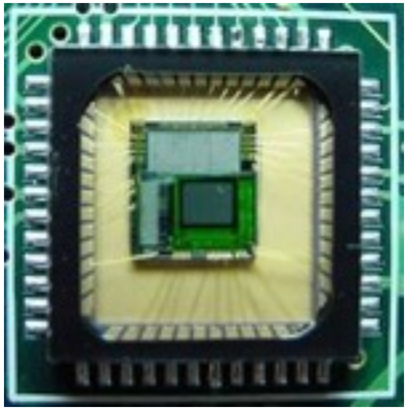
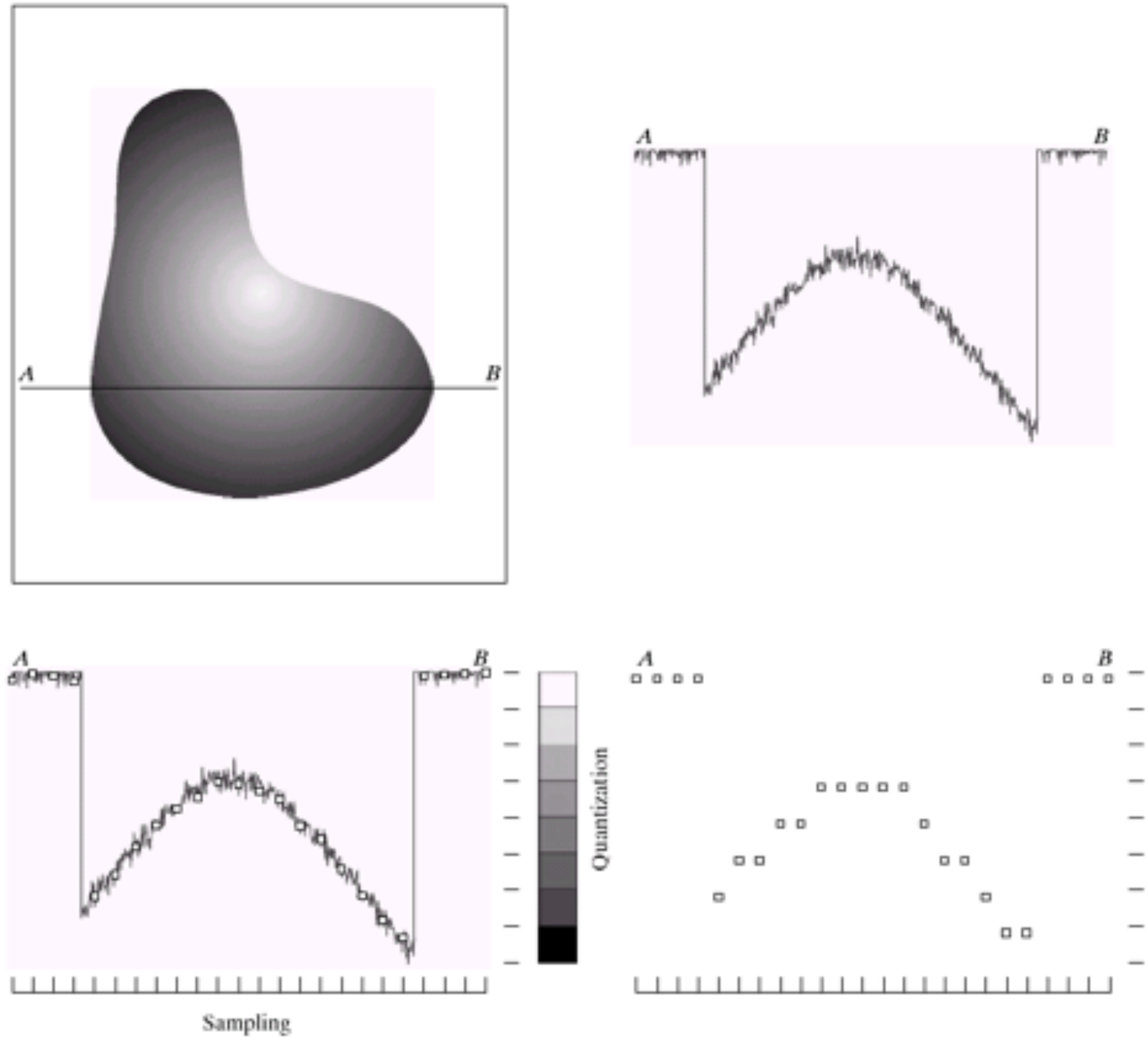


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



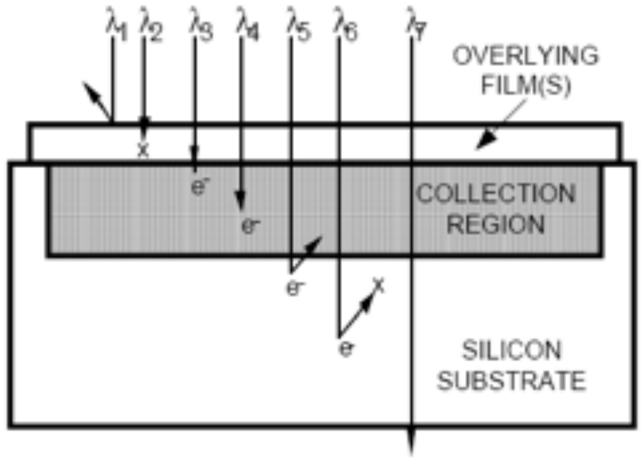
CMOS sensor

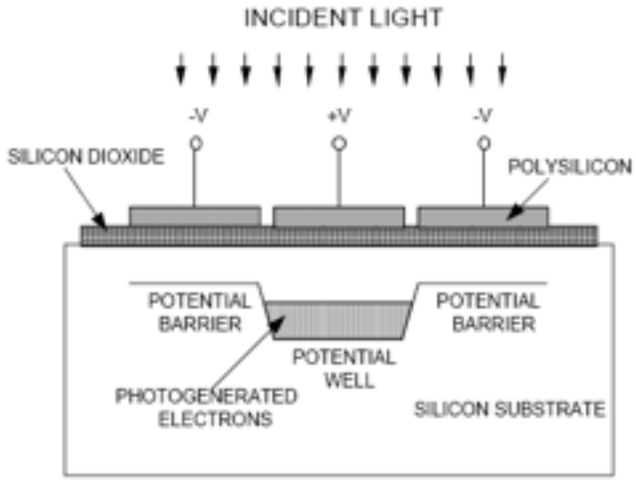
Sampling and Quantization



Sensors

- Convert light into electric charge



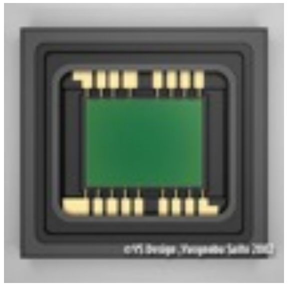


- CCD (charge coupled device)

Higher dynamic range

High uniformity

Lower noise



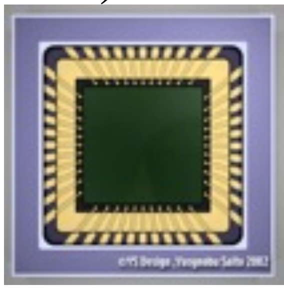
- CMOS (complementary metal Oxide semiconductor)

Higher speed

Lower system complexity

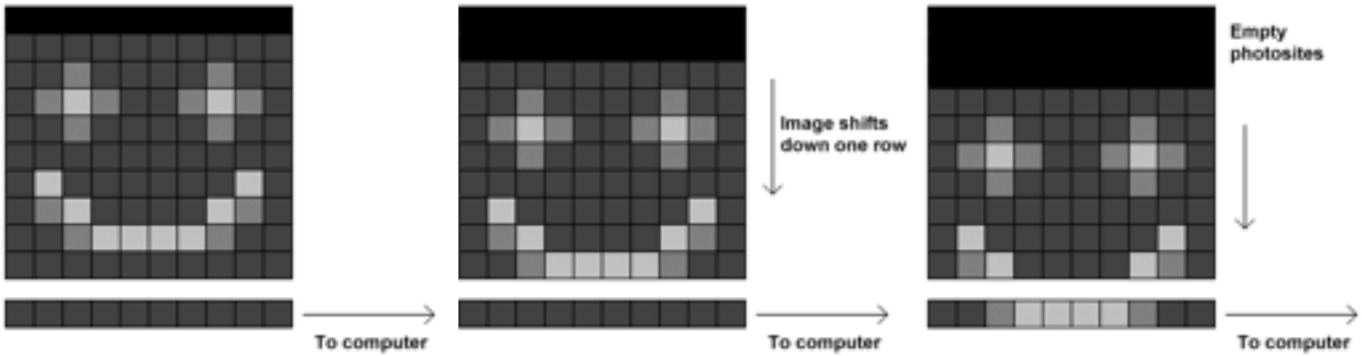
(cheaper to manufacture)

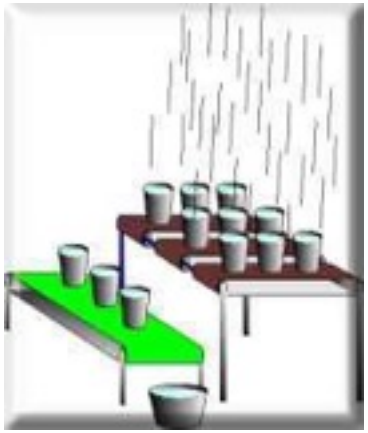
Lower power consumption



Sensor Readout

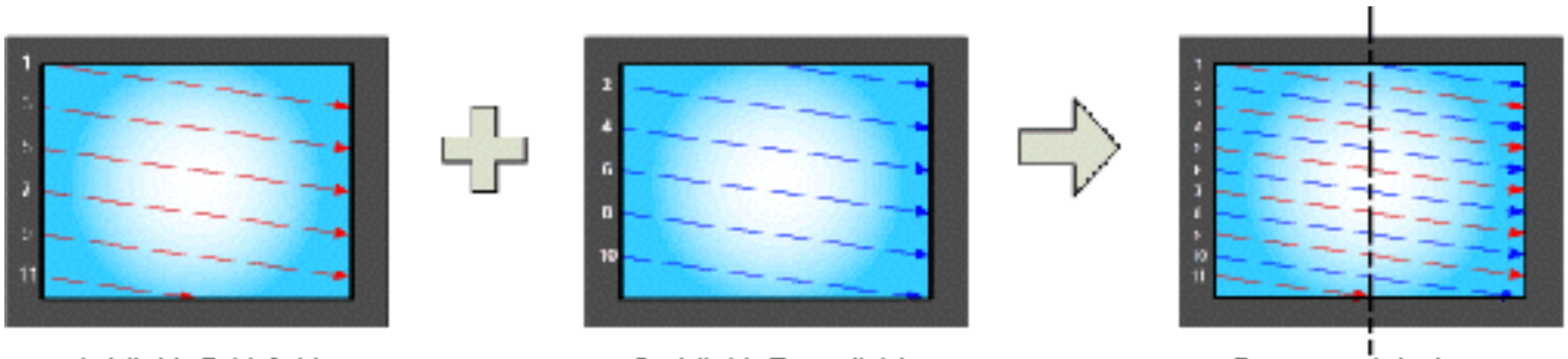
- CCD





- CMOS

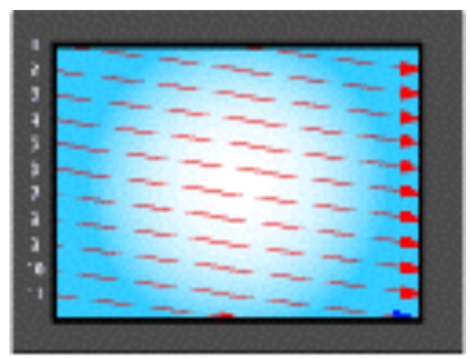
Interlace vs. Progressive Scan



1st field: Odd field

2nd field: Even field

One complete frame
using interlaced scanning



One complete frame
using progressive scanning

Progressive Scan

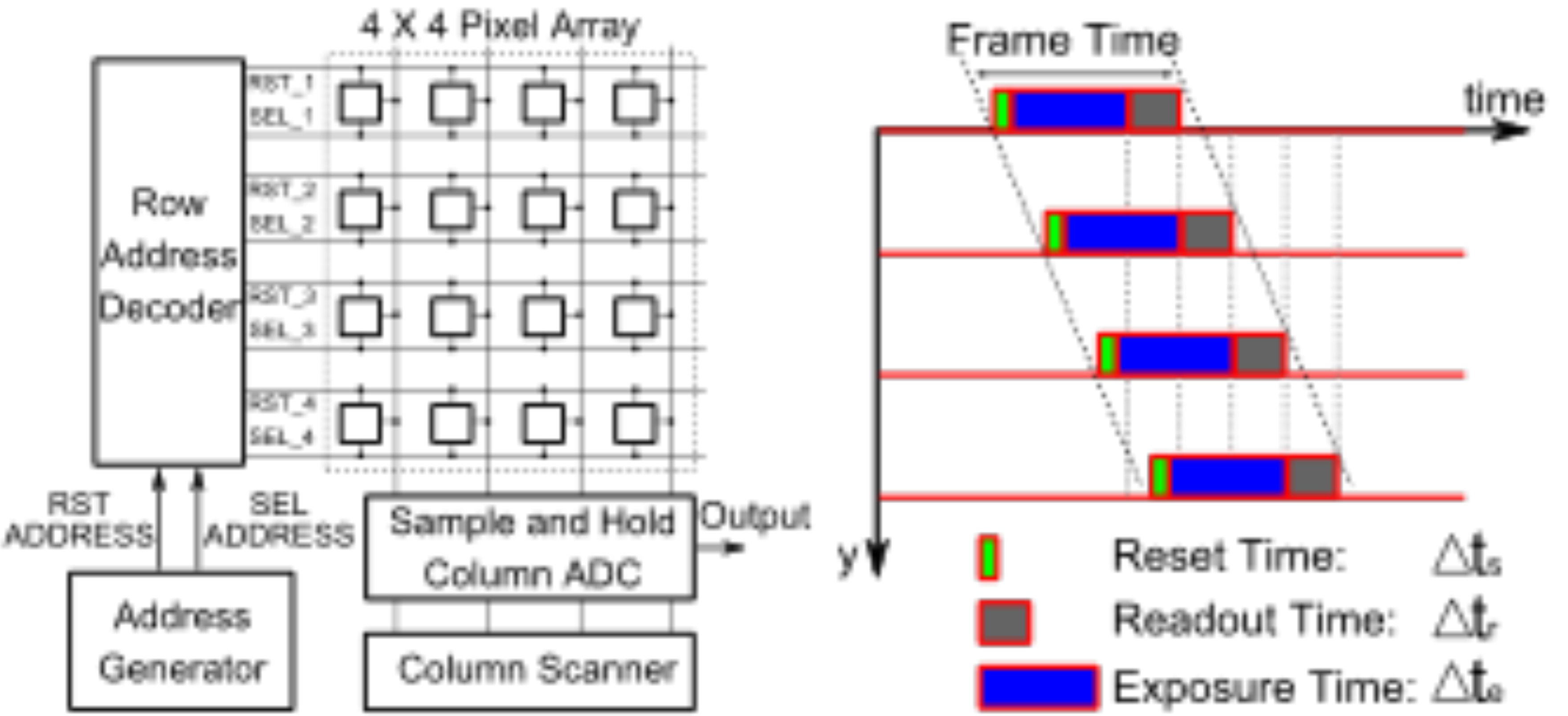
Interlace

Interlace

Rolling Shutter

- Read out each row sequentially
- No explicit shutter; controlled sequential exposure
- CMOS
- CCD ≠ Rolling Shutter
- Introduces distortion for object moving faster than buffering limit

Rolling Shutter



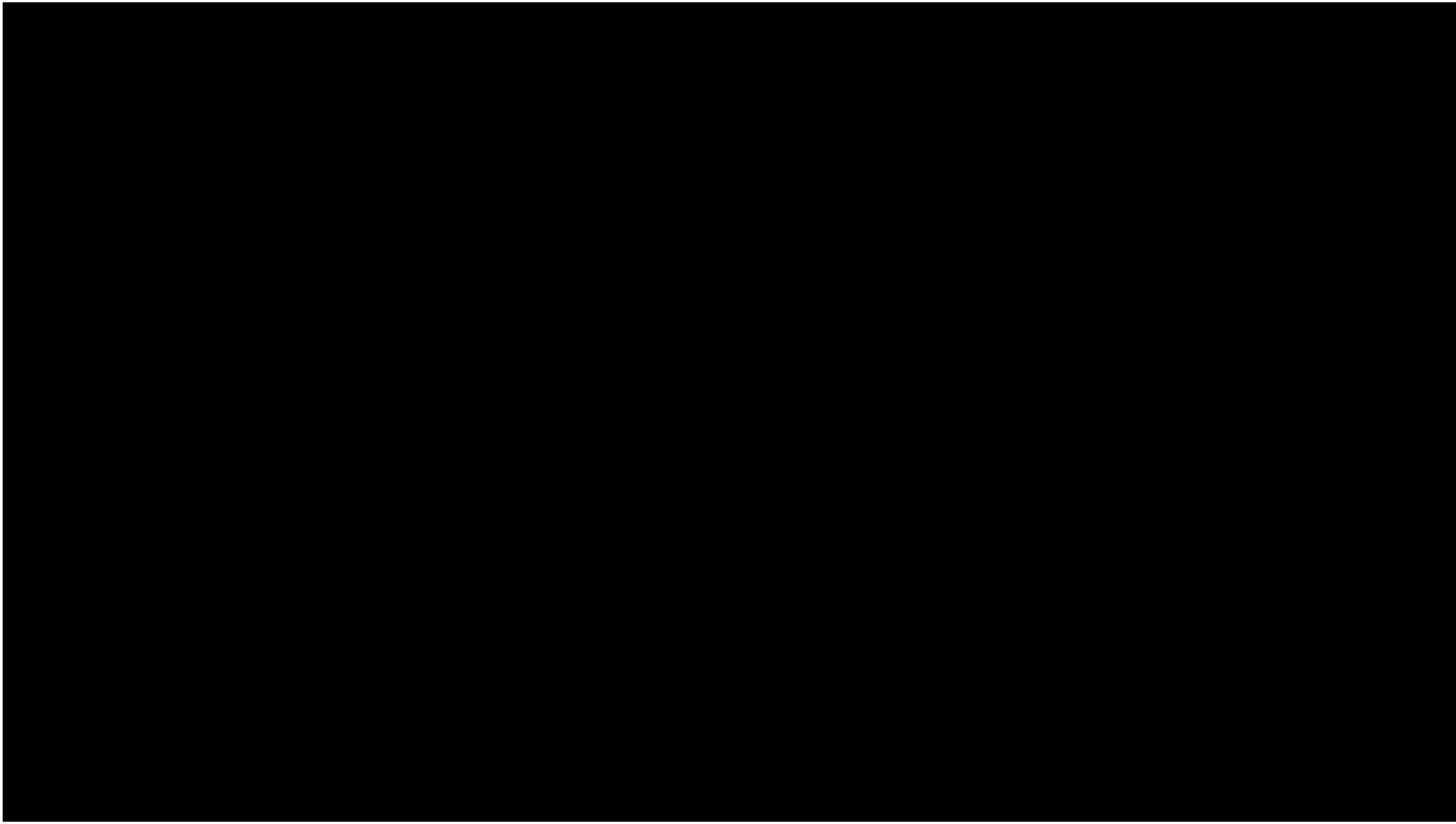
(a) CMOS image sensor architecture (b) Timing for rolling shutter

Figure by Jinwei Gu

Rolling Shutter Distortion

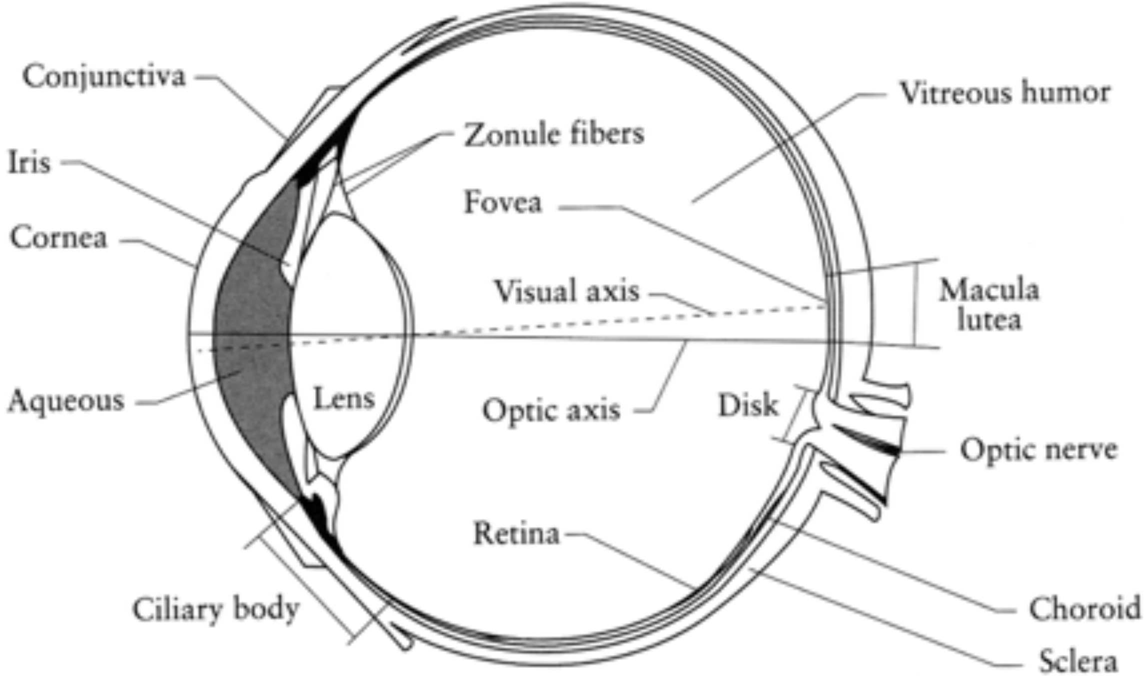
Rolling shutter effect

Rectifying Rolling Shutter Video from Hand-Held Devices



https://www.youtube.com/watch?v=t0DIxIMwkRo

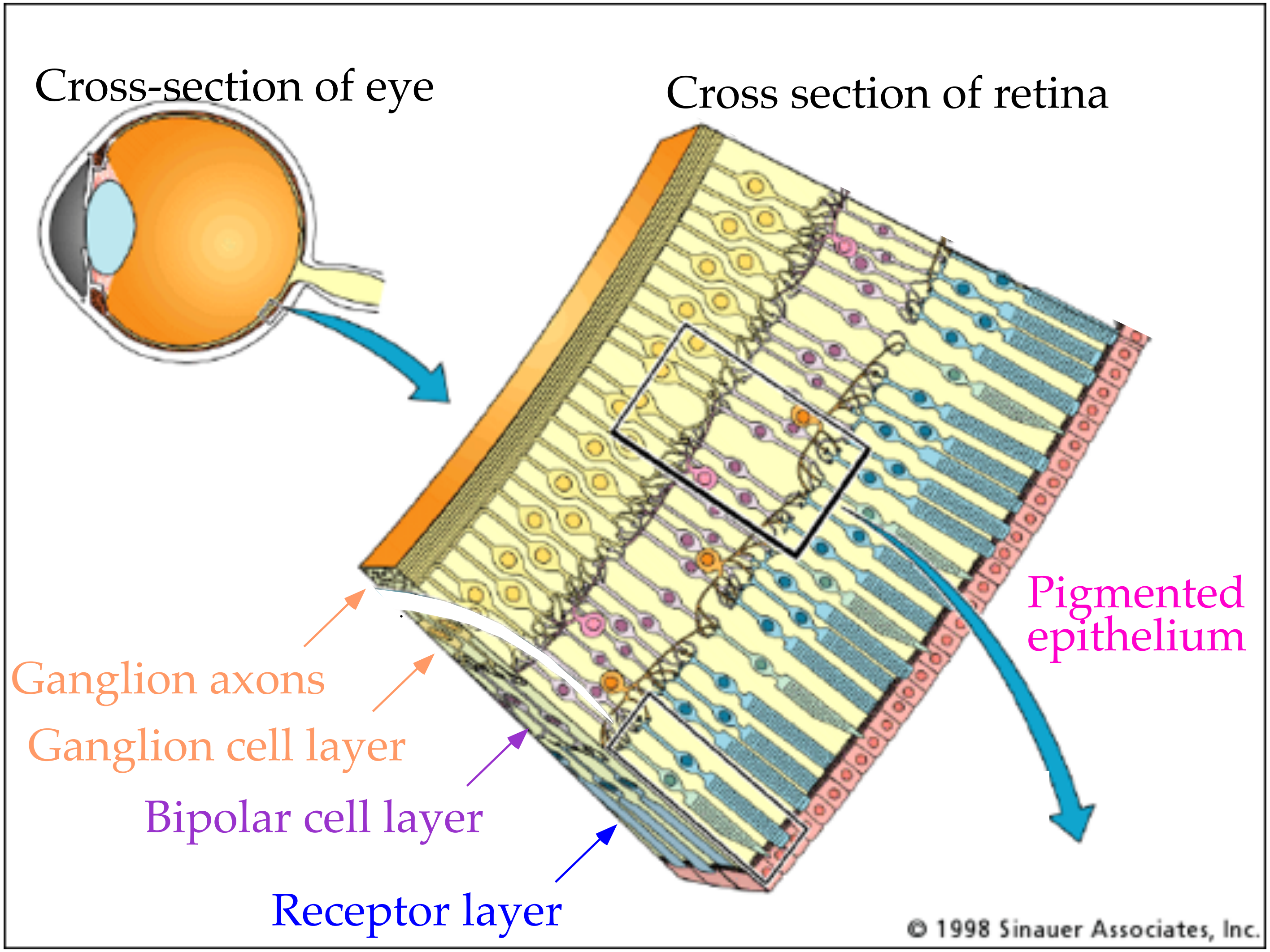
The Eye



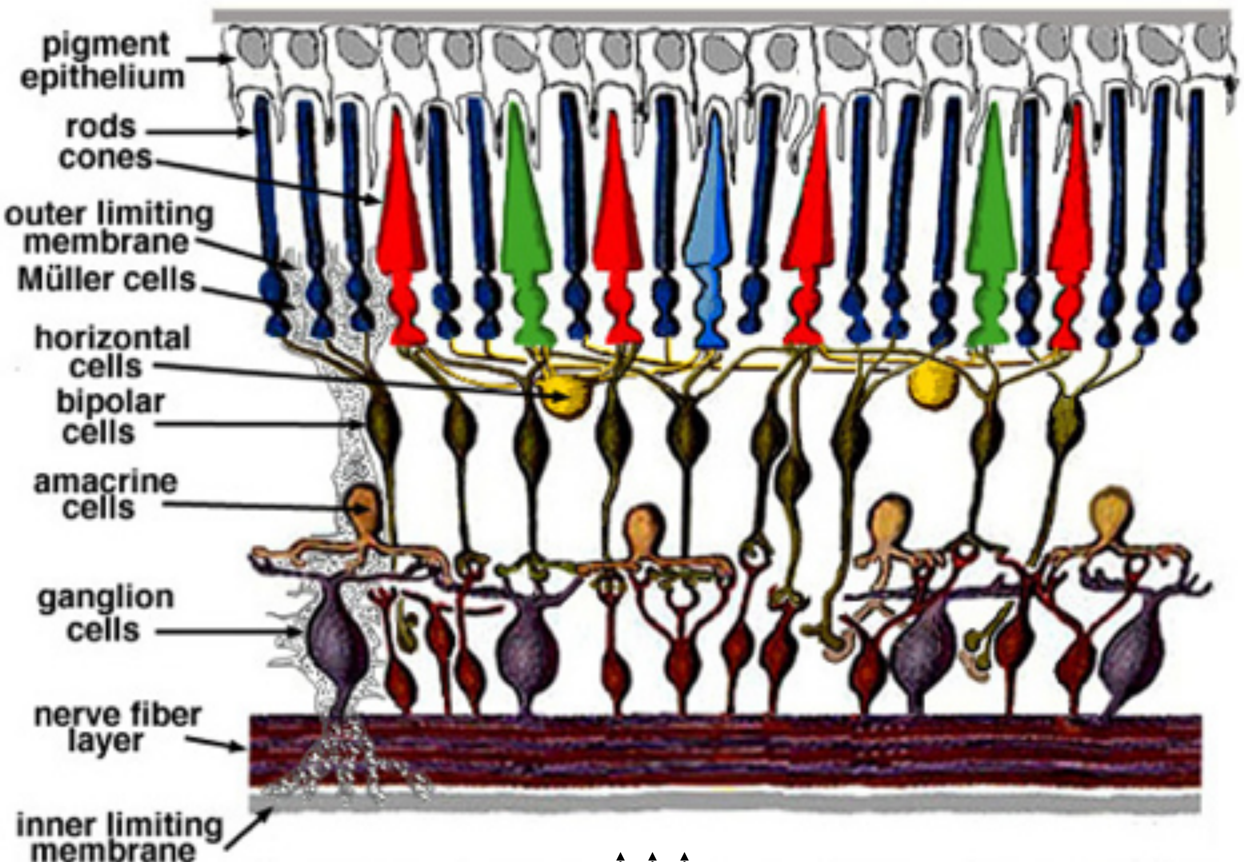
- The human eye is a camera!
  - **Iris** - colored annulus with radial muscles
  - **Pupil** - the hole (aperture) whose size is controlled by the iris
  - What's the "film"?

  - photoreceptor cells (rods and cones) in the **retina**

The Retina

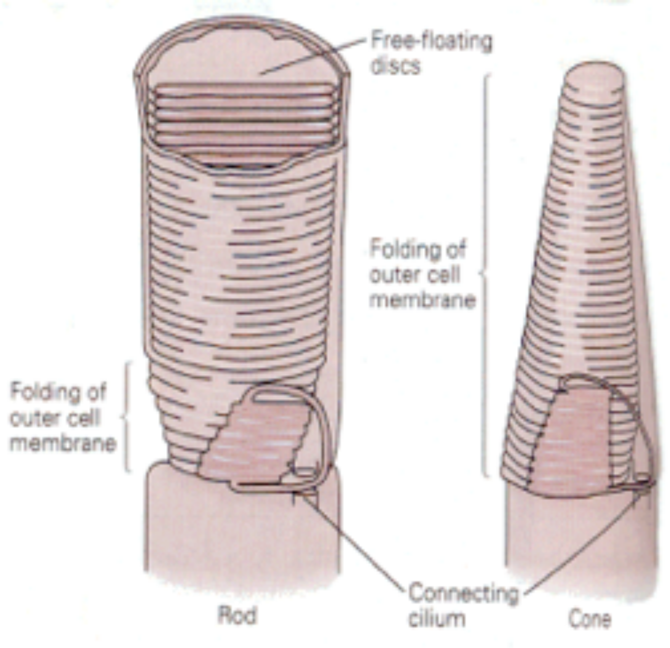

Cross-section of eye
Cross section of retina
Pigmented epithelium
Ganglion axons
Ganglion cell layer
Bipolar cell layer
Receptor layer
© 1998 Sinauer Associates, Inc.

Retina Up-close



Light

Rods and Cones



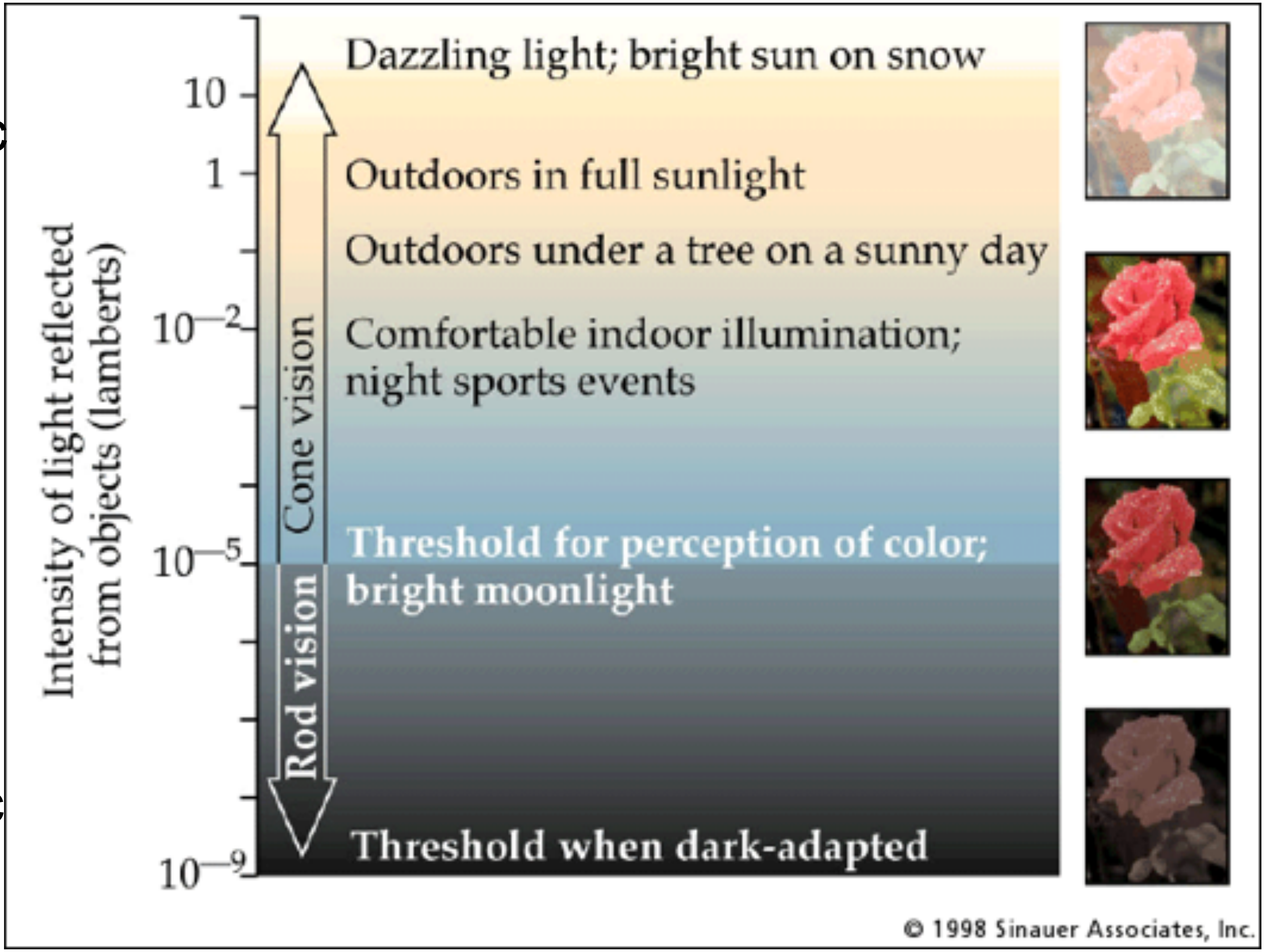
Rods	**Cones**
Achromatic: one type of pigment	Chromatic: three types of pigment
Slow response (long integration time)	Fast response (short integration time)
High amplification High sensitivity	Less amplification Lower absolute sensitivity
Low acuity	High acuity

Rod / Cone Sensitivity

Photopic

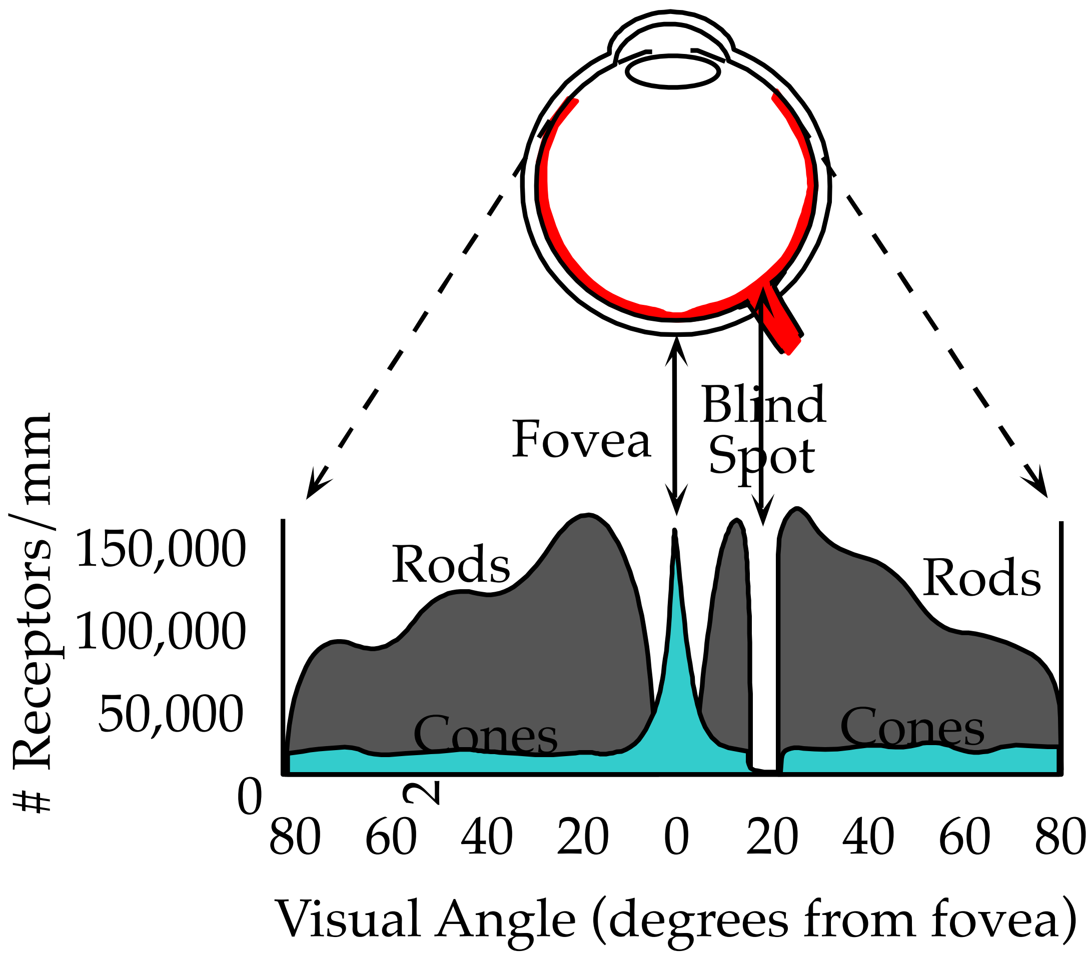
Mesopic

Scotopic



Distribution of Rods and Cones

Night Sky: why are there more stars off-center?

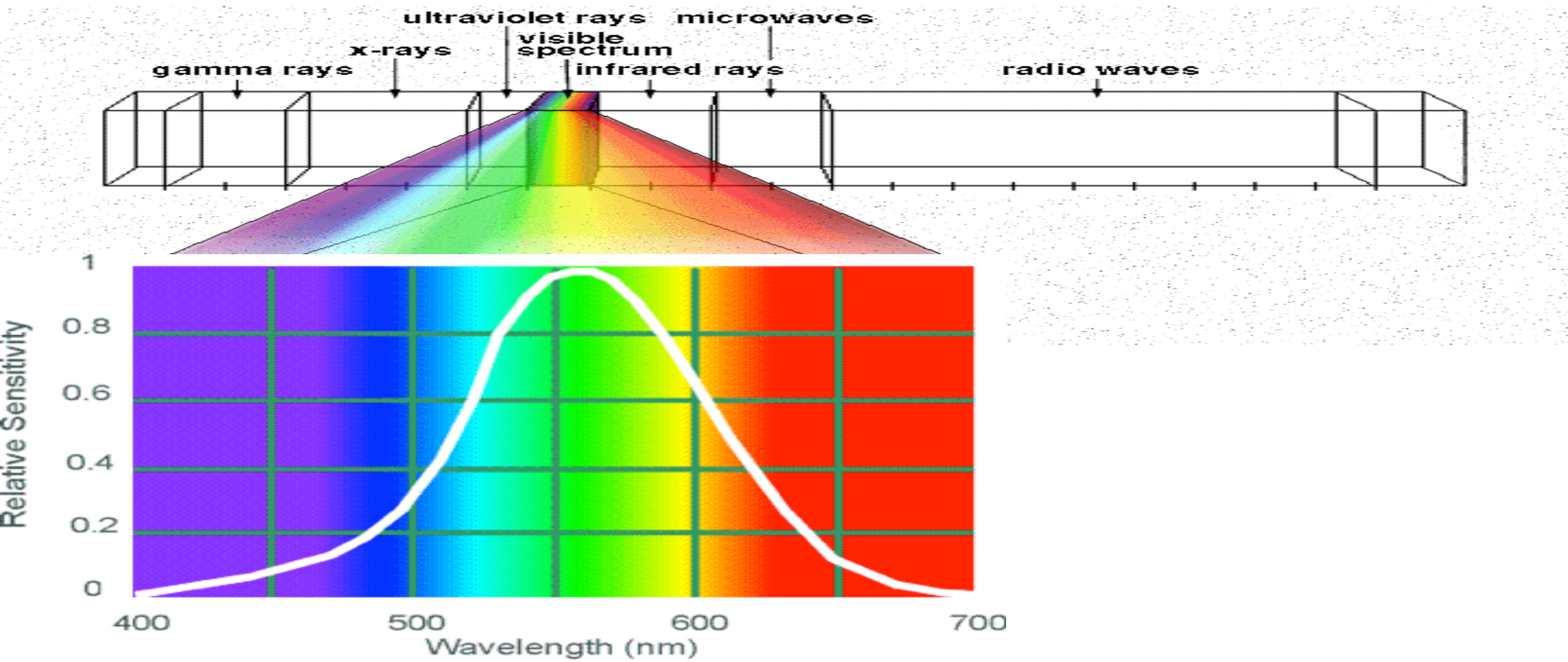


Blind Spot

http://io9.gizmodo.com/5804116/why-every-human-has-a-blind-spot---and-how-to-find-yours

Color

Electromagnetic Spectrum

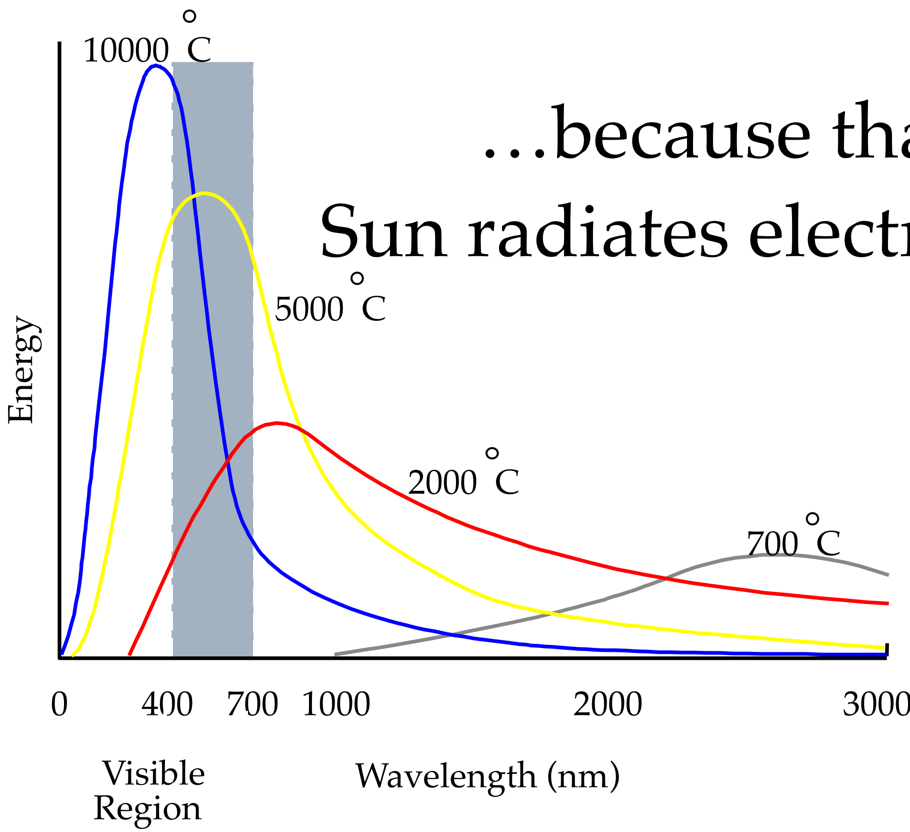


Human Luminance Sensitivity Function

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

Visible Light

Why do we see light of these wavelengths?

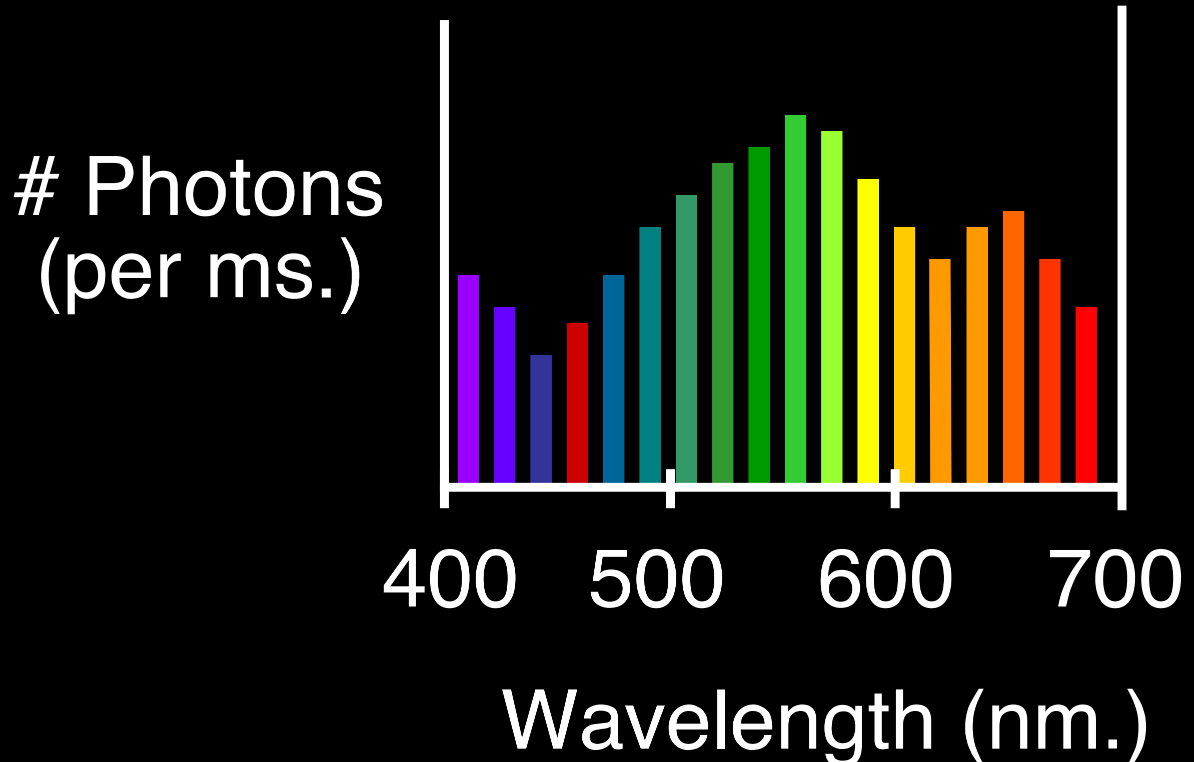


…because that's where the Sun radiates electromagnetic energy

Color curves are of blackbody radiator (e.g., 2000 degs=candle light)

The Physics of Light

Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.



The Physics of Light

Some examples of the spectra of light sources

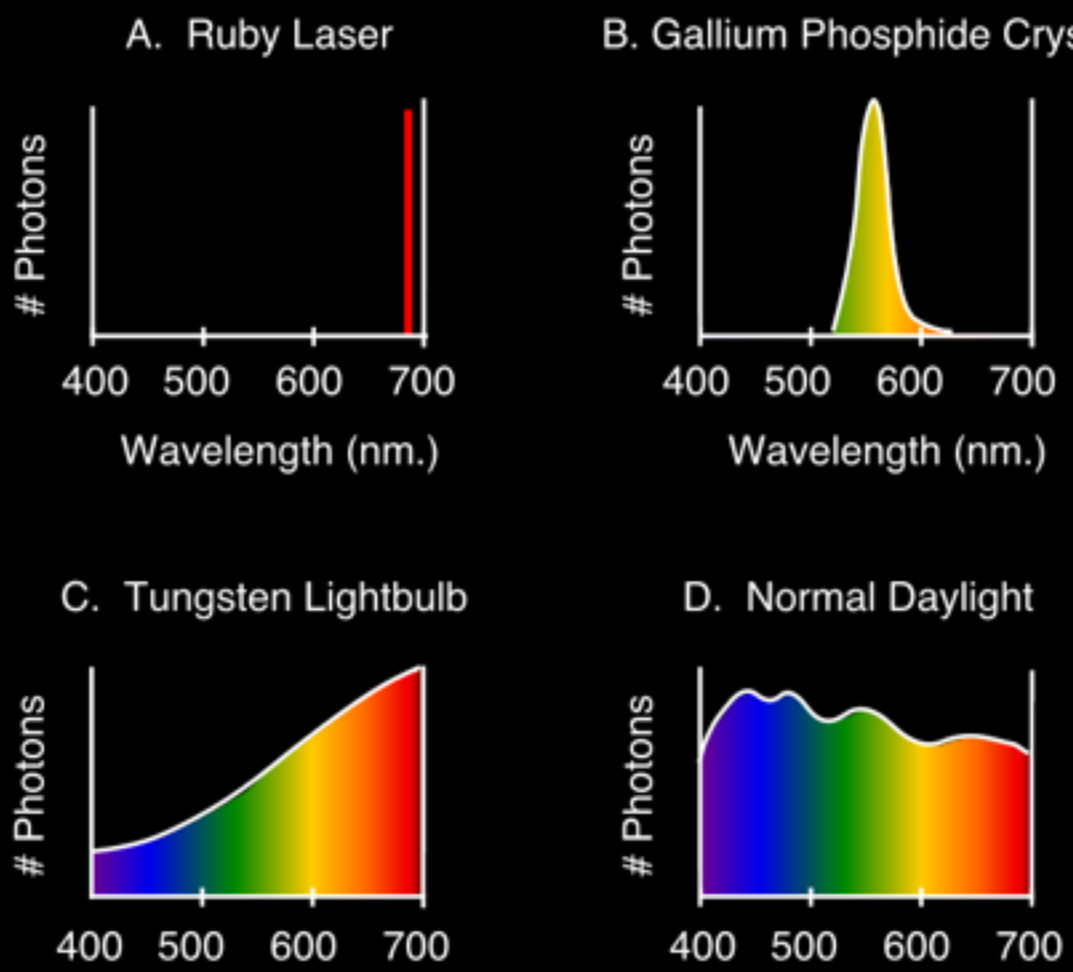


Image Formation

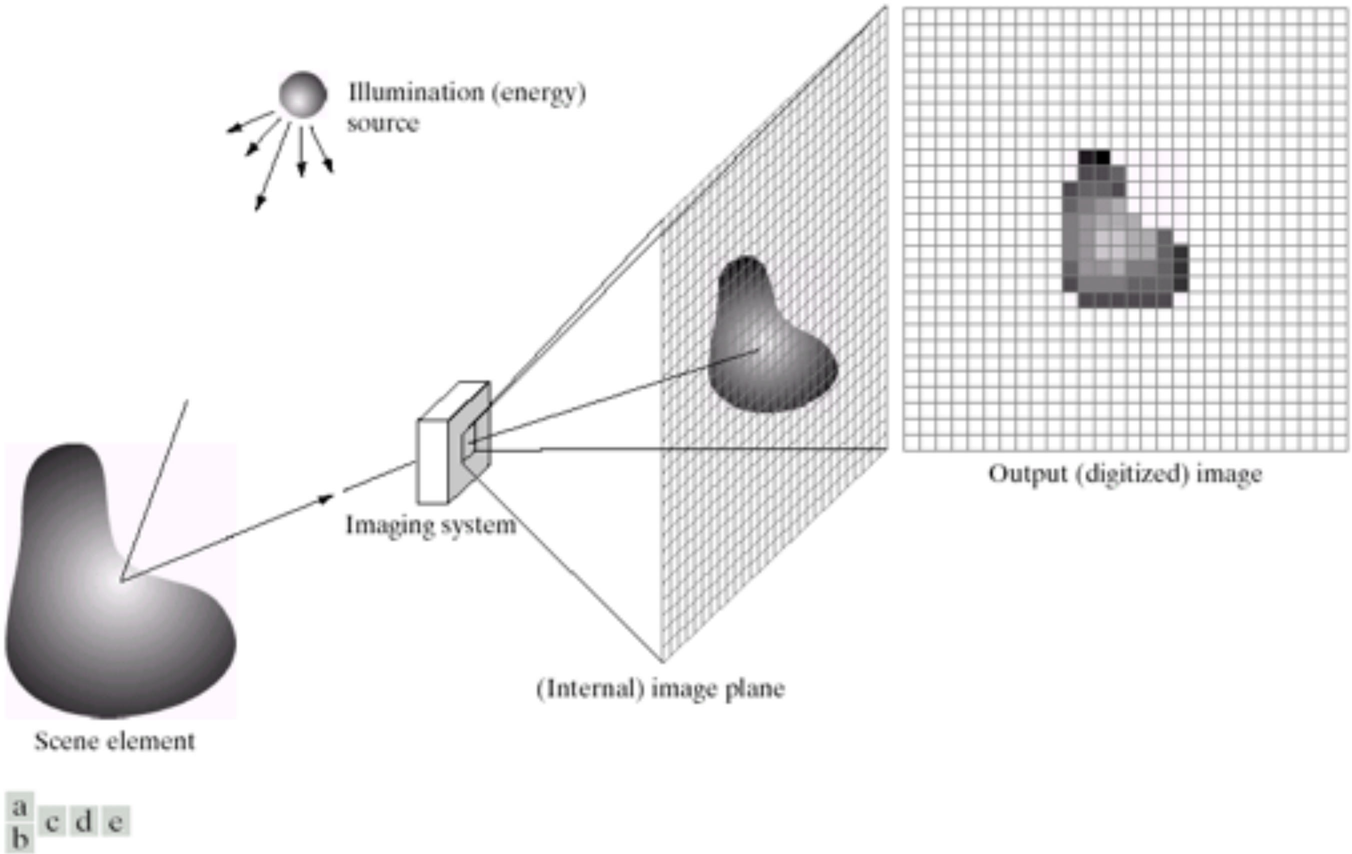


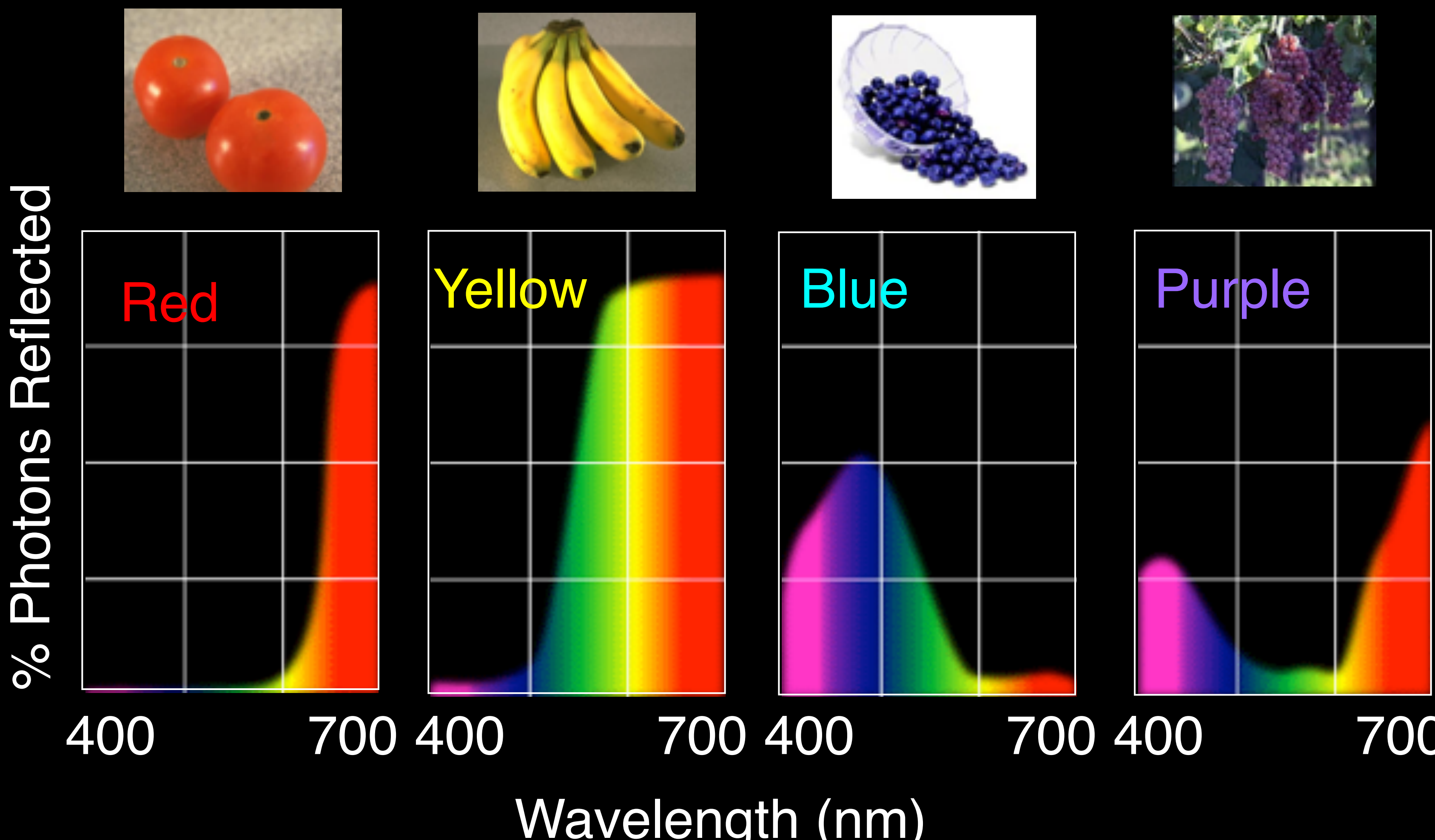
FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

*f(x,y) = reflectance(x,y) * illumination(x,y)*

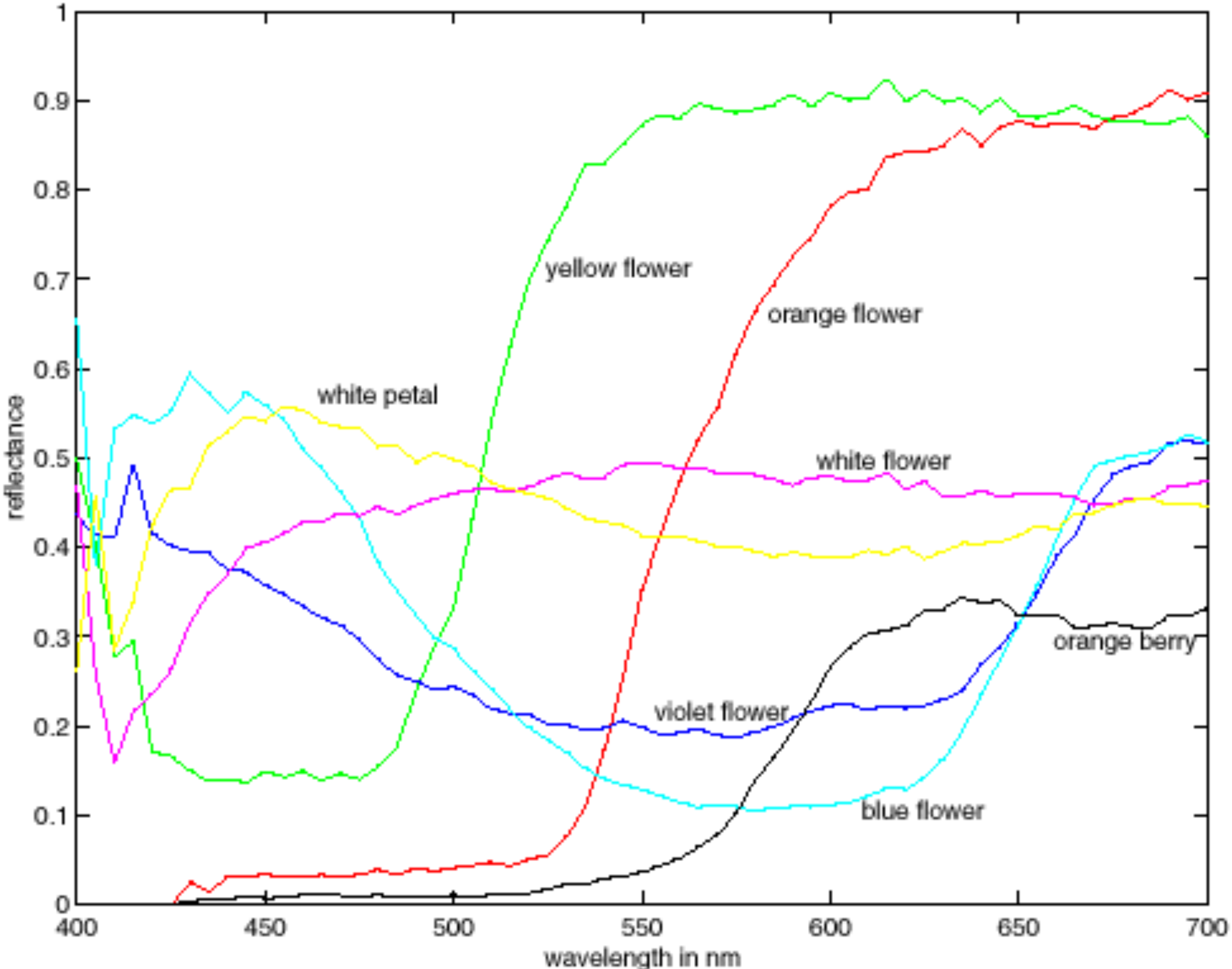
reflectance in [0,1], illumination in [0,inf]

The Physics of Light

Some examples of the reflectance spectra of surfaces



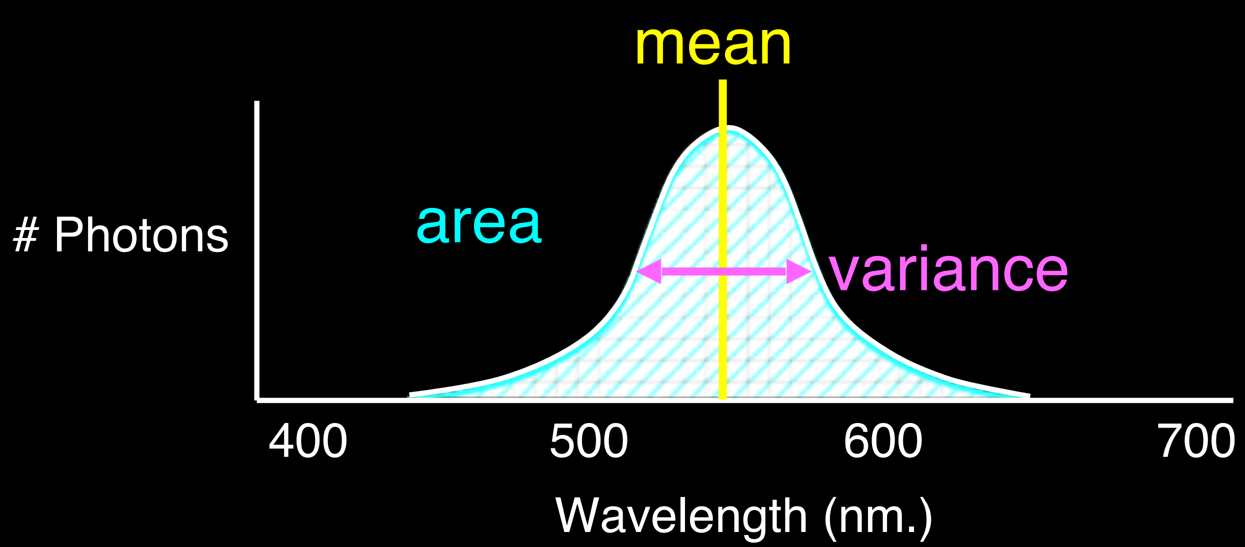
More Spectra



The Psychophysical Correspondence

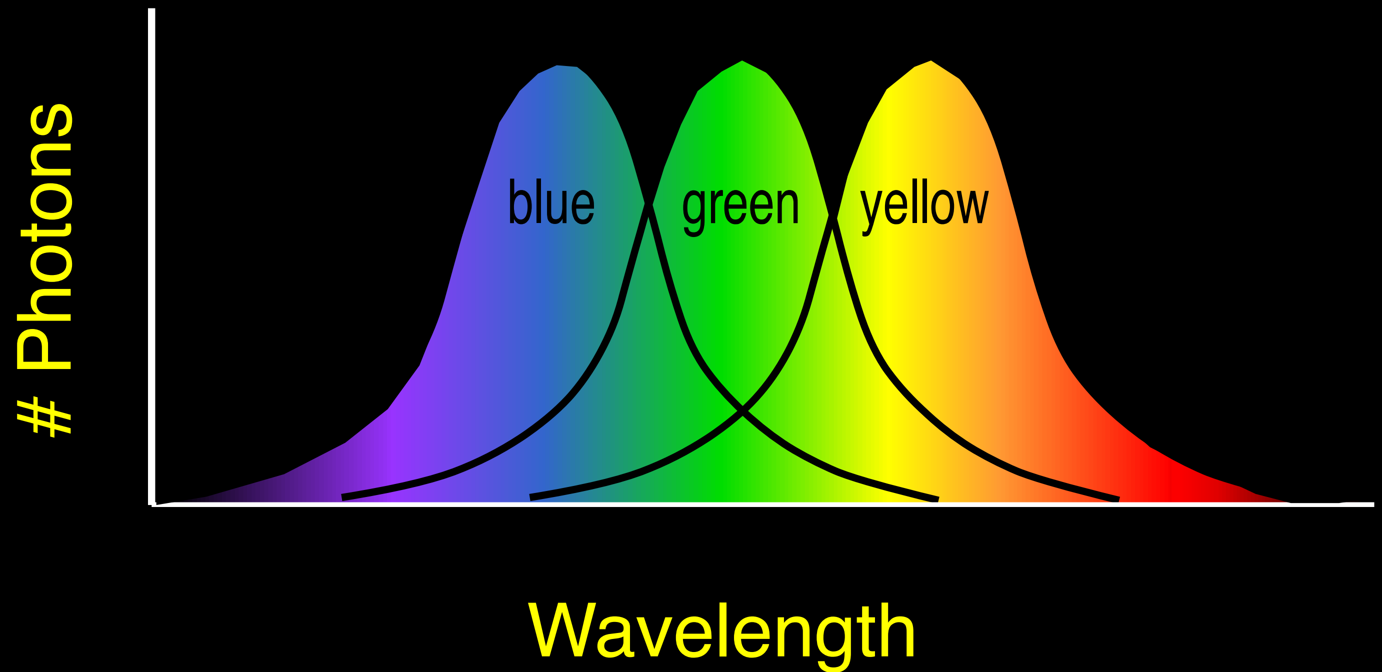
There is no simple functional description for the perceived color of all lights under all viewing conditions, but ......

A helpful constraint:
Consider only physical spectra with normal distributions



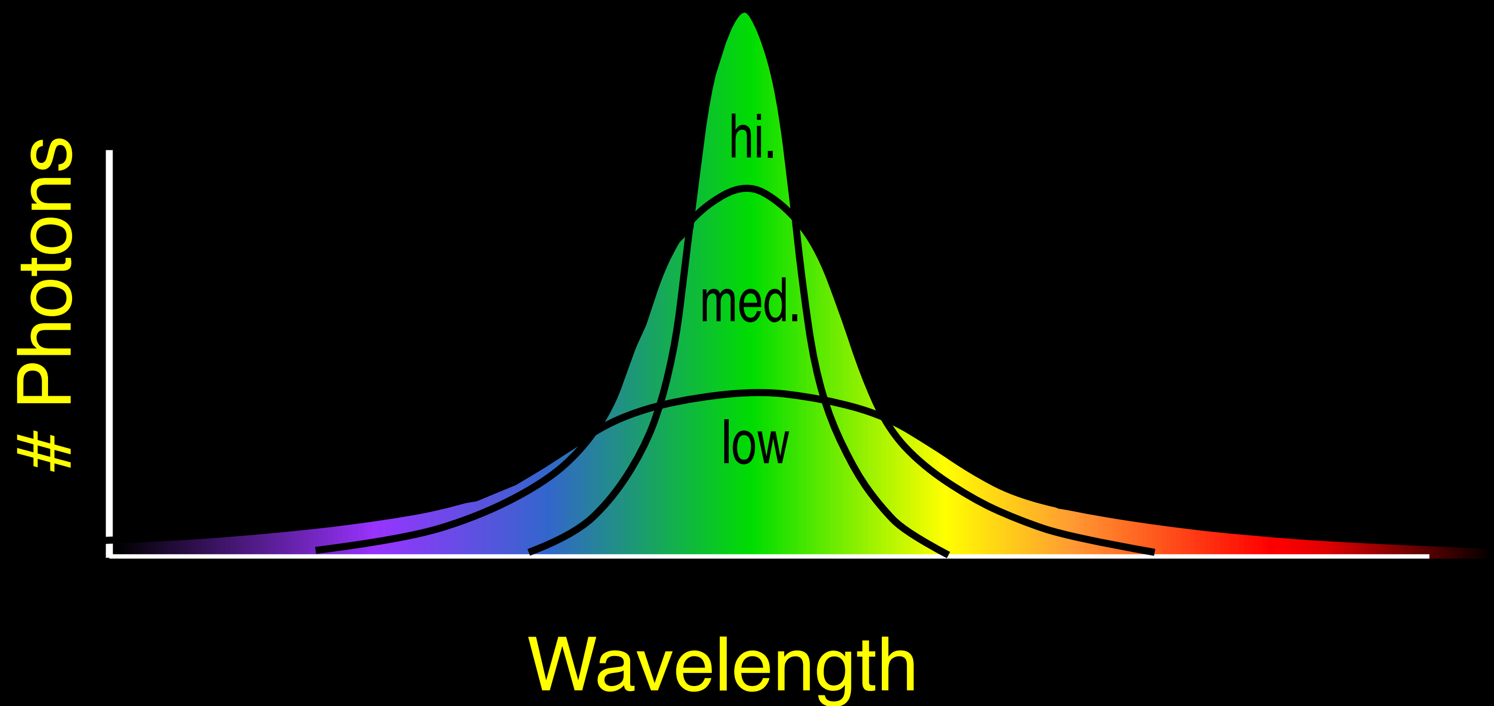
The Psychophysical Correspondence

Mean ⟷ Hue



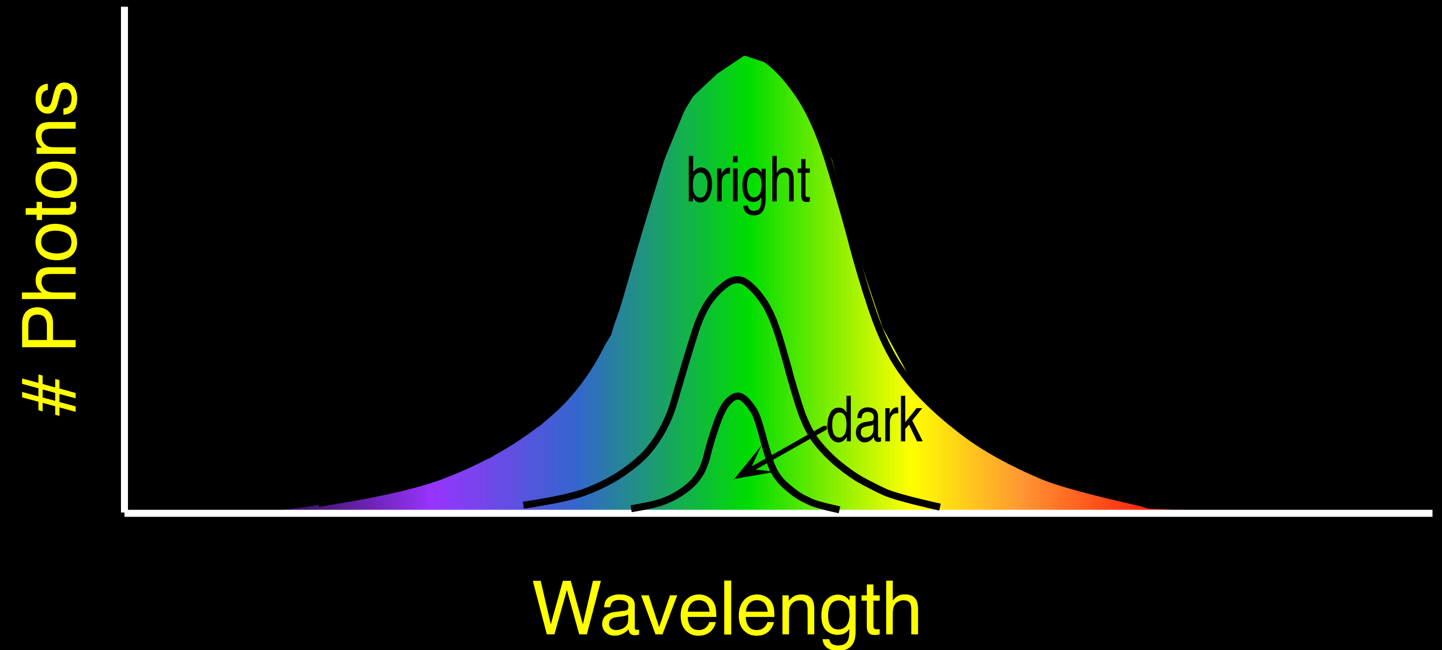
The Psychophysical Correspondence

Variance (1/Variatnce) ⟷ Saturation

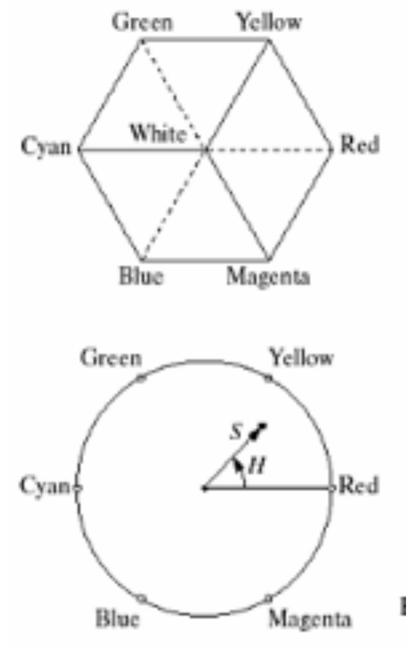


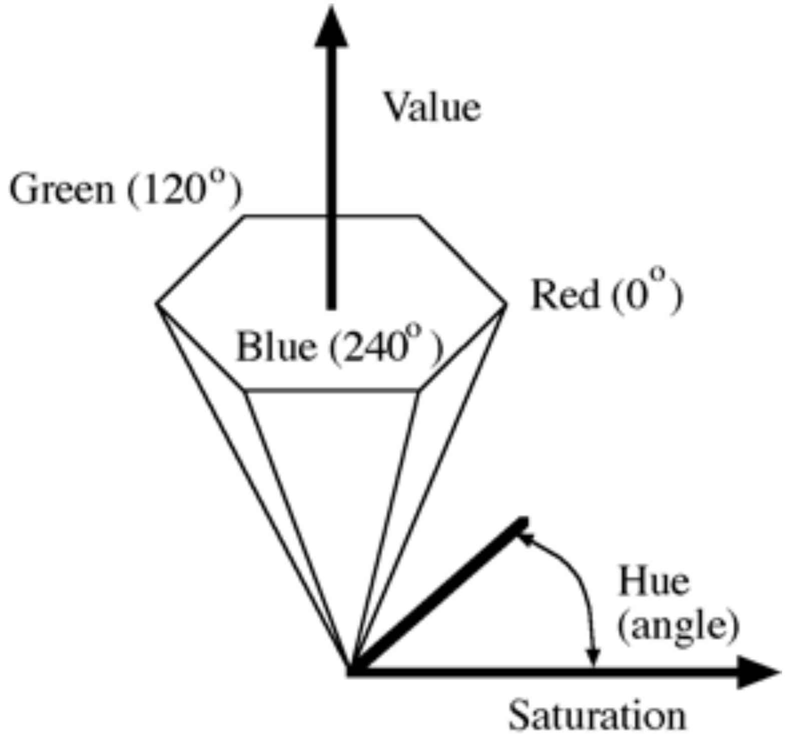
The Psychophysical Correspondence

Area ⟷ Brightness (Value)



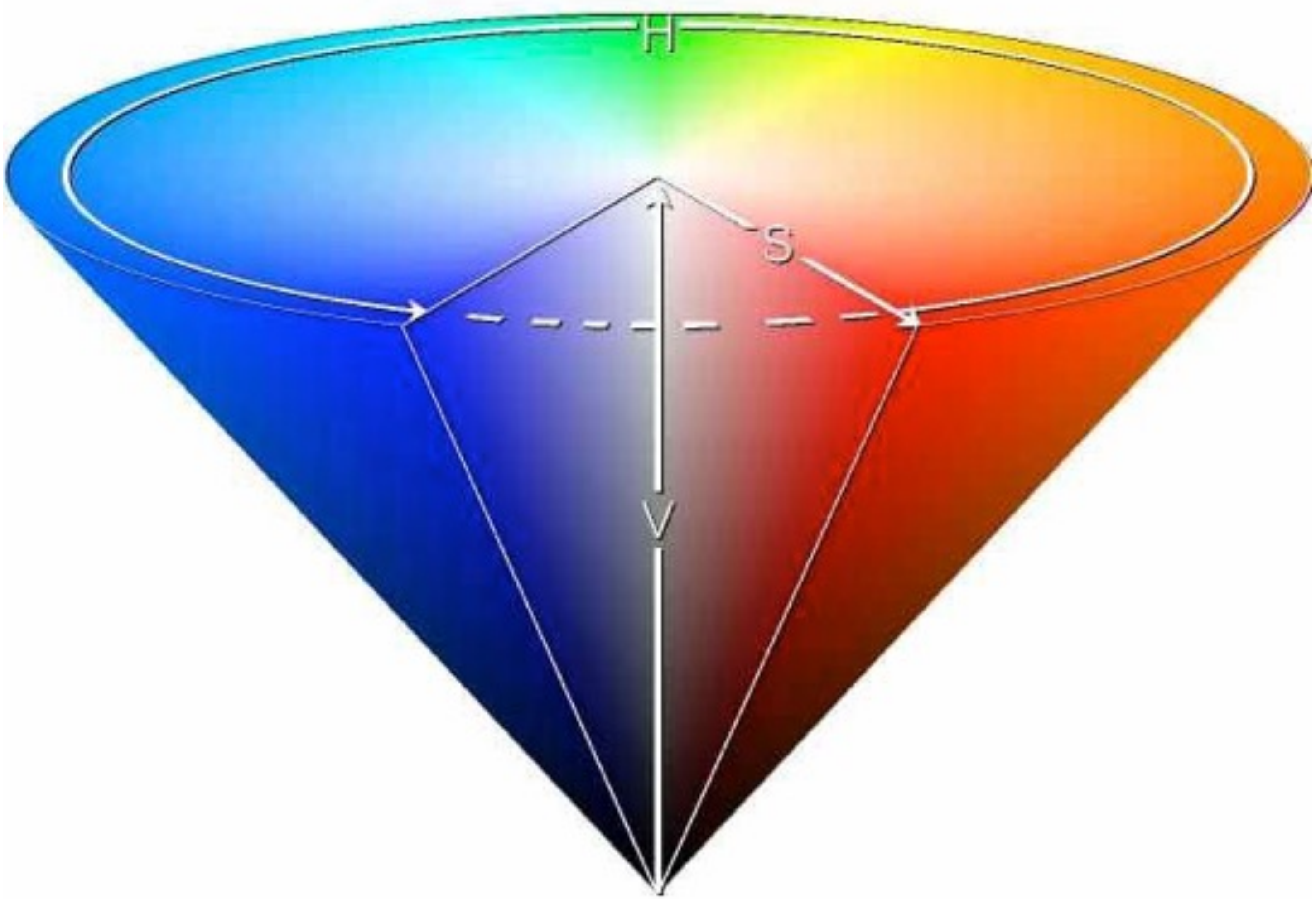
HSV





- Hue, Saturation, Value (Brightness)
  - RGB cube on its vertex
- Decouples the three components

HSV



RGB Color Space

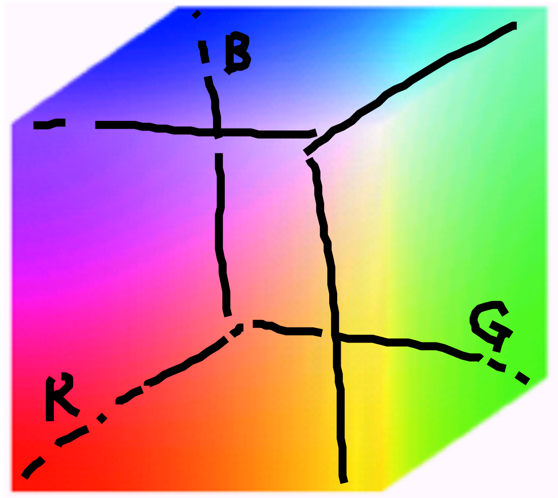
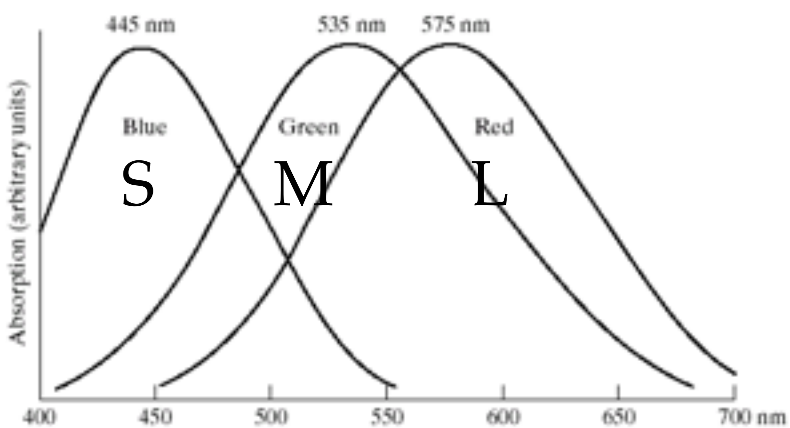


FIGURE 6.8 RGB 24-bit color cube.

- RGB cube
  - Easy for devices
  - But not perceptual
  - Where do the grays live?

Why 3?

- How should one represent spectral reflectance?
  - Distribution of light at various wavelengths (a histogram)
- Then why do we represent color with a single R,G,B triplet?
- No physical reason…
- …but psychophysical:



3 cones
(not quite RGB)

Why is M cone not midway but closer to L?

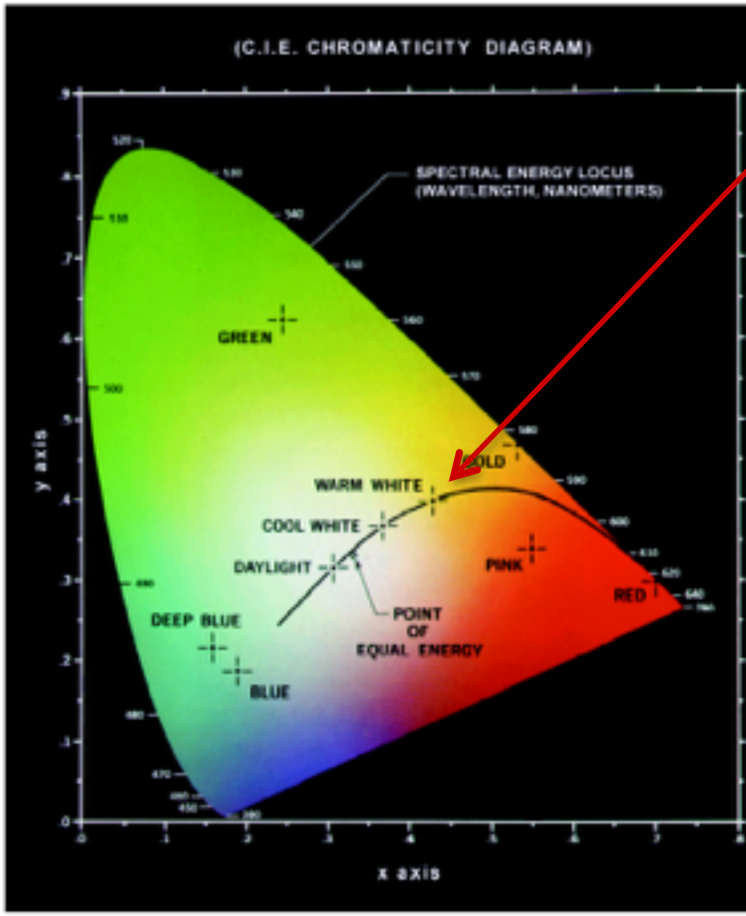
It’s all in your head

- So, color is psychological
  - Most people have the same cones, but there are some people who don’t – the sky might not look blue to them (although they will call it “blue” nonetheless)
  - But many people (mostly men) are colorblind, missing 1,2 or 3 cones
  - Primary colors (R,G,B) related to cones, not physics
- Describing Color
  - HSV
  - RGB
  - Hue + Saturation = Chromaticity
    - $(x,y) = (r/(r+g+b), g/(r+g+b))$
  - Etc.

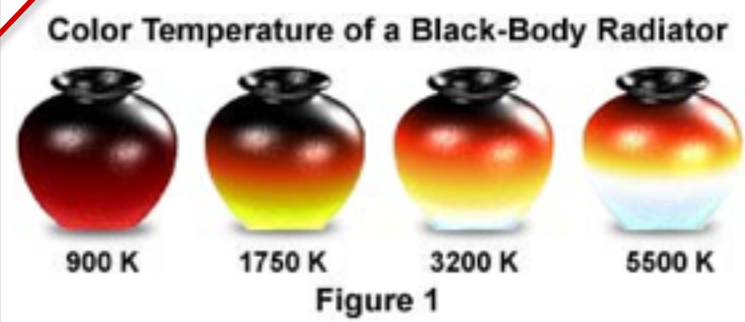
CIE Perceptual Space

Gamut of Human Vision

FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)



Planckian locus



Which colors can RGB monitor display?

Monitor and Printer Gamut

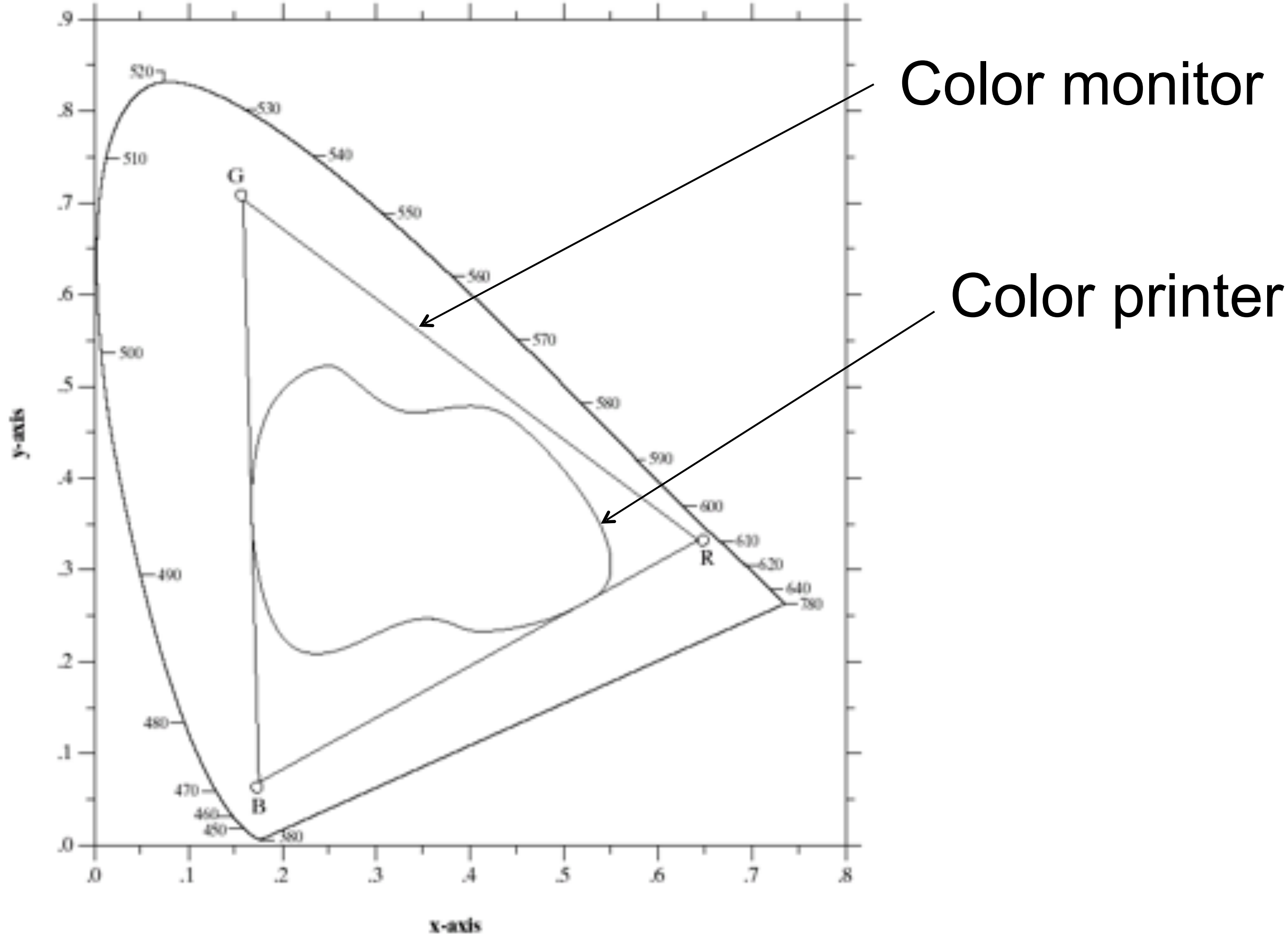
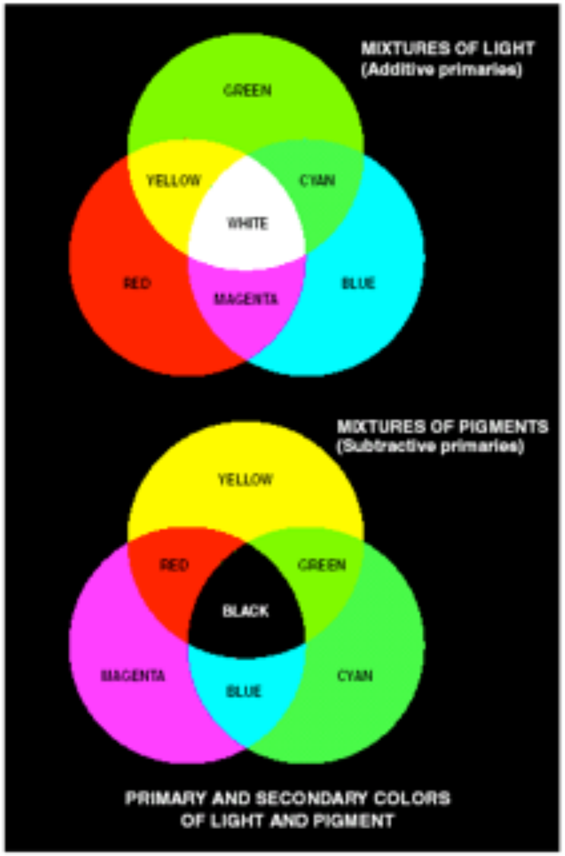


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

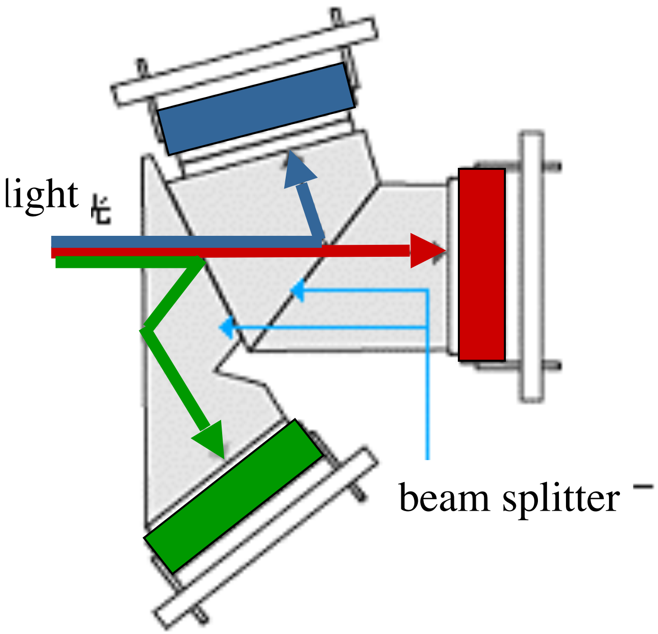
Additive and Subtractive Color



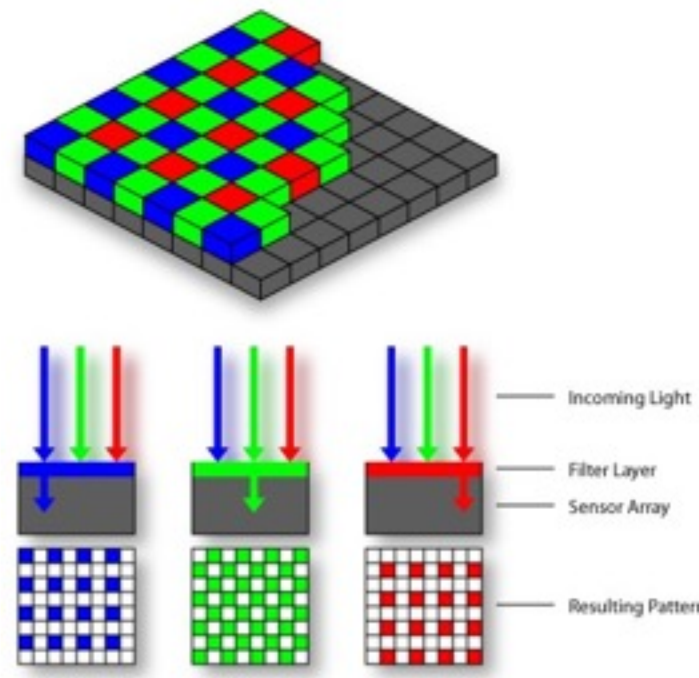
a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

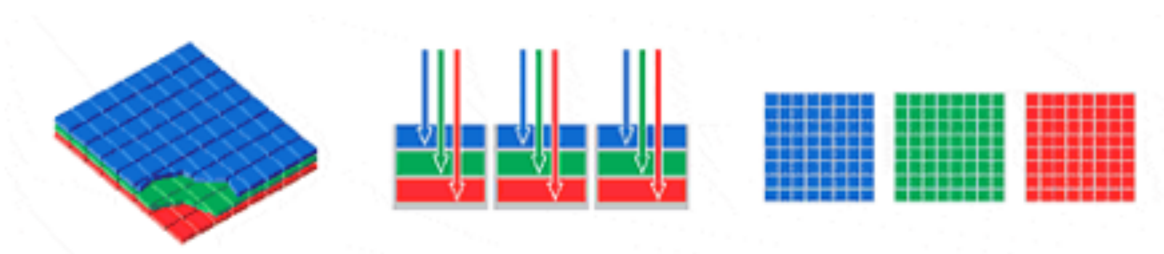
Sensing Color



3 CCD

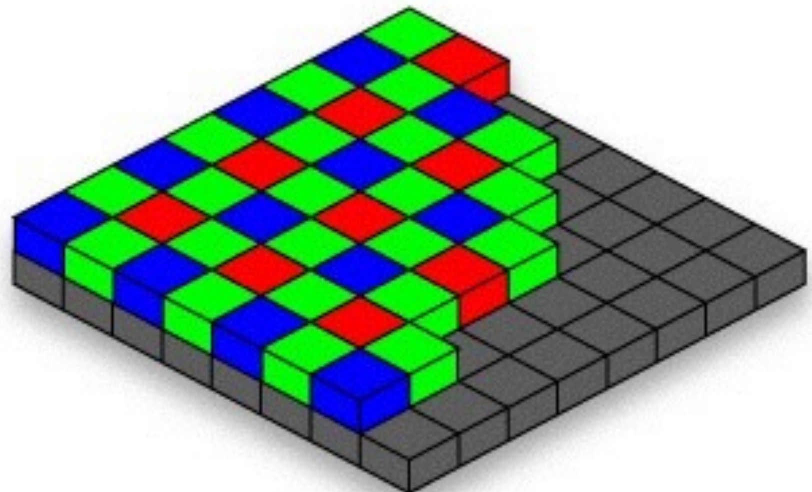


Bayer pattern



Foveon X3™

Practical Color Sensing: Bayer Grid



- Estimate RGB
  at ‘G’ cells from
  neighboring values