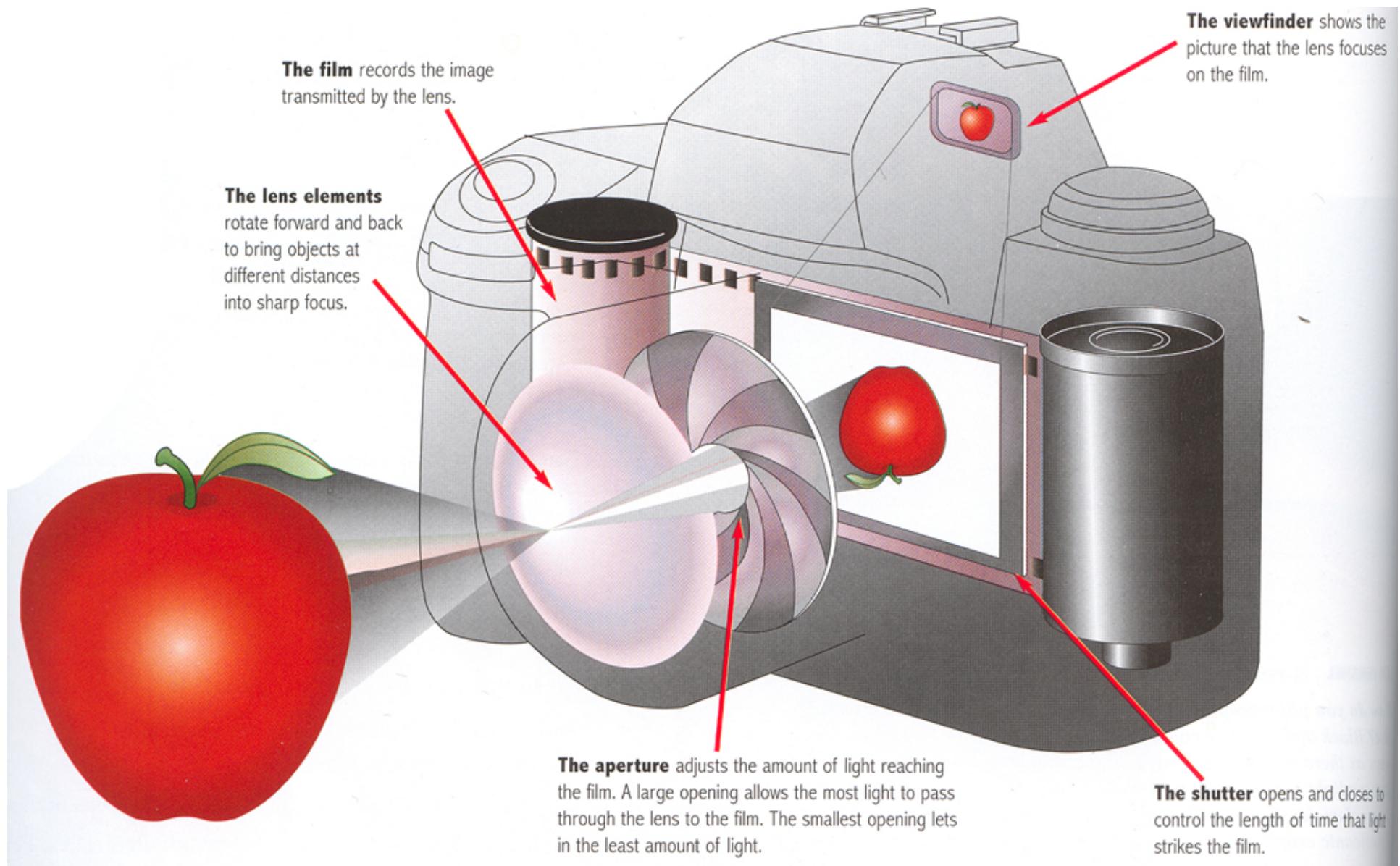


Computational Photography

Week 2, Winter 2009

Instructor: Prof. Ko Nishino

Camera



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

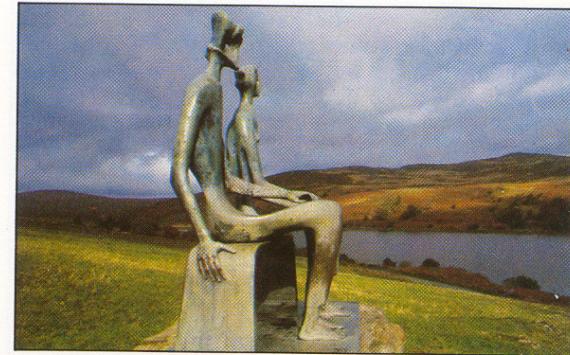
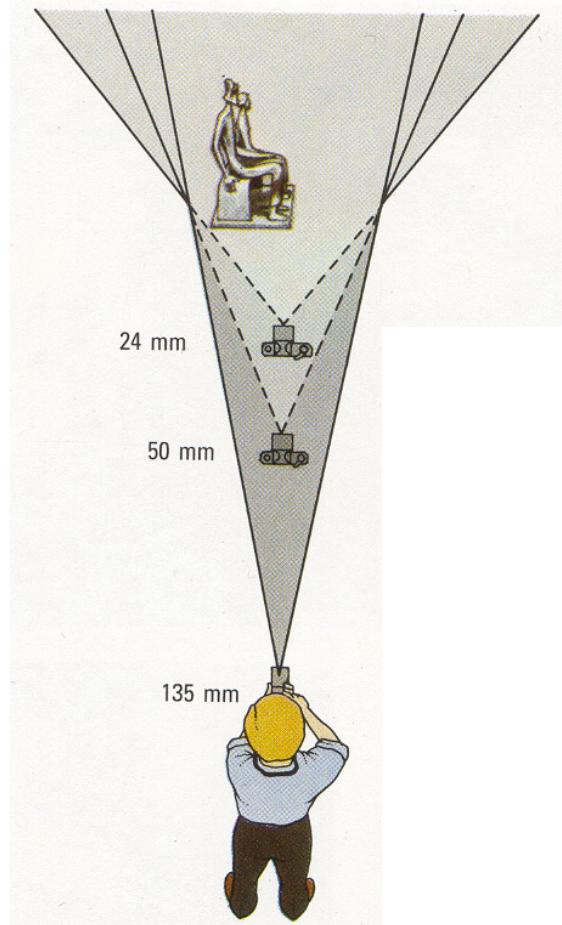


Shutter Speed

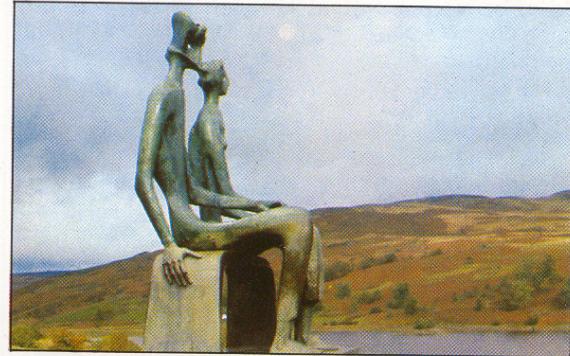
- Controls how long the film/sensor is exposed
- Pretty much linear effect on exposure
- Usually in fraction of a second:
 - 1/30, 1/60, 1/125, 1/250, 1/500
 - Get the pattern ?
- On a normal lens, normal humans can hand-hold down to 1/60
 - In general, the rule of thumb says that the limit is the inverse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

Perspective vs. Viewpoint

- Telephoto makes it easier to select background (a small change in viewpoint is a big change in background).



Grand-angulaire 24 mm



Normal 50 mm



Longue focale 135 mm

Shutter Speed

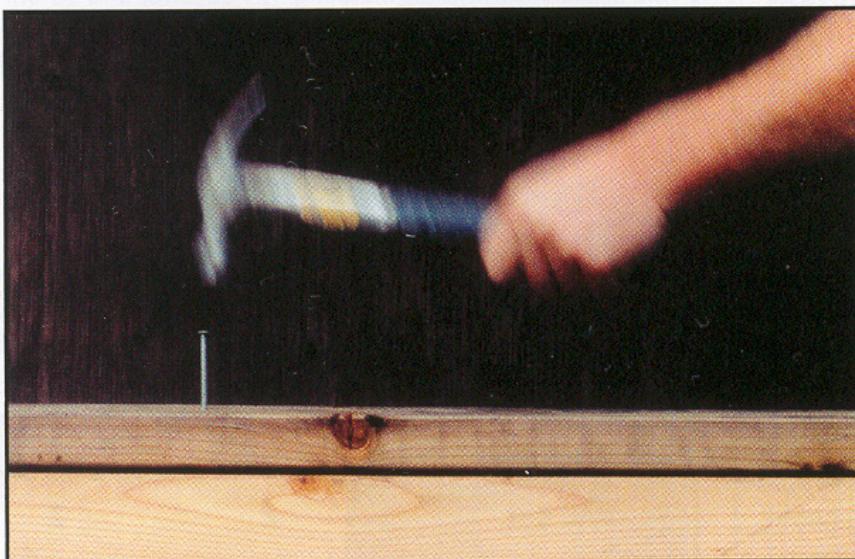
- Controls how long the film/sensor is exposed
- Pretty much linear effect on exposure
- Usually in fraction of a second:
 - 1/30, 1/60, 1/125, 1/250, 1/500
 - Get the pattern ?
- On a normal lens, normal humans can hand-hold down to 1/60
 - In general, the rule of thumb says that the limit is the inverse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

Also depends on the weight of the camera

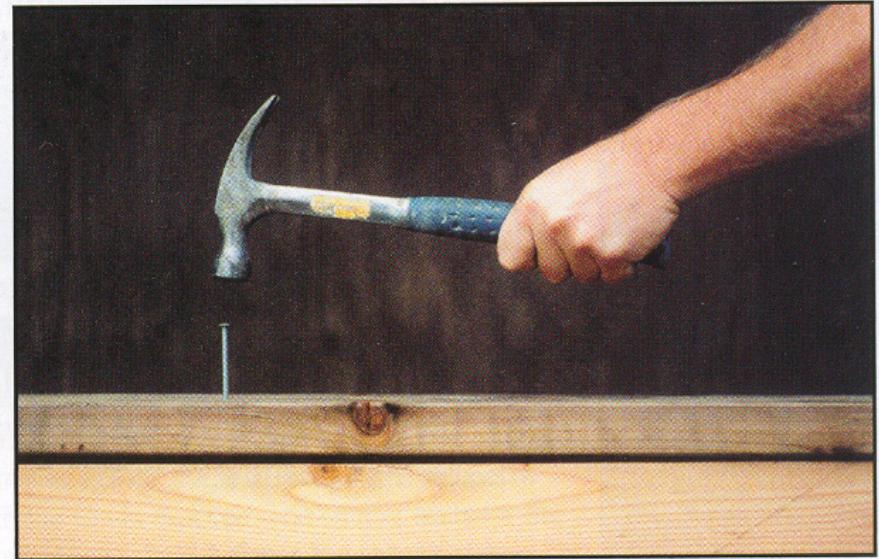
Main Effect of Shutter Speed

■ Motion blur

Slow shutter speed



Fast shutter speed



From Photography, London et al.

Effect of Shutter Speed

■ Freezing motion

Walking people



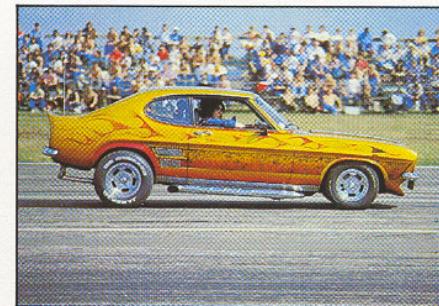
1/125

Running people



1/250

Car



1/500

Fast train



1/1000

Shutter

- Various technologies
- Goal: achieve uniform exposure across image

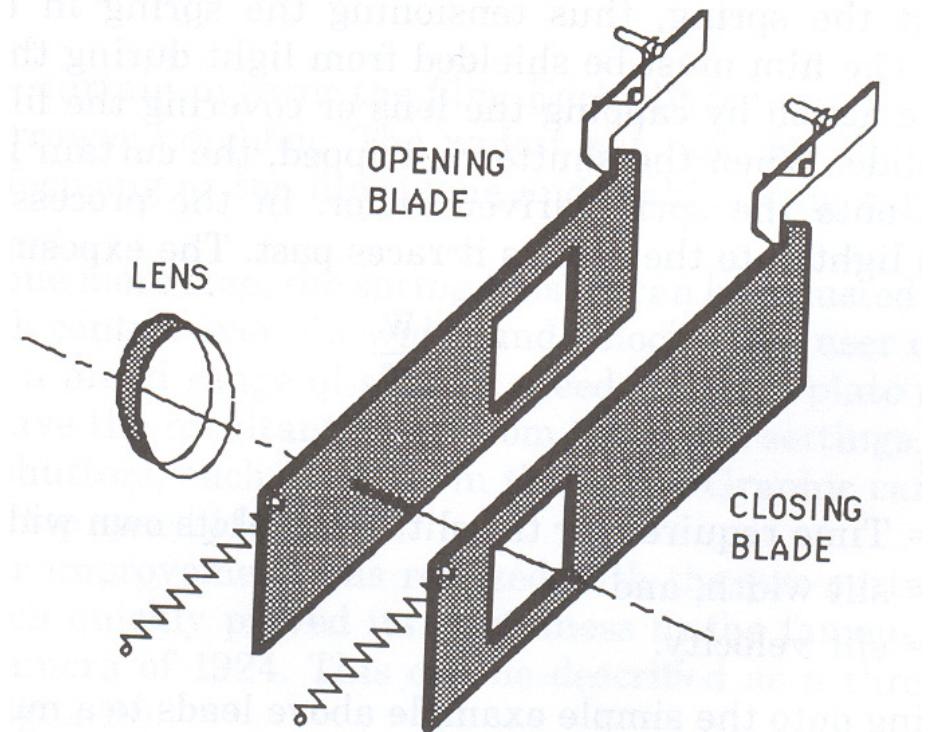


FIG. 2.8 Two-blade guillotine shutter.

Shutter

- Various technologies
- Goal: achieve uniform exposure across image

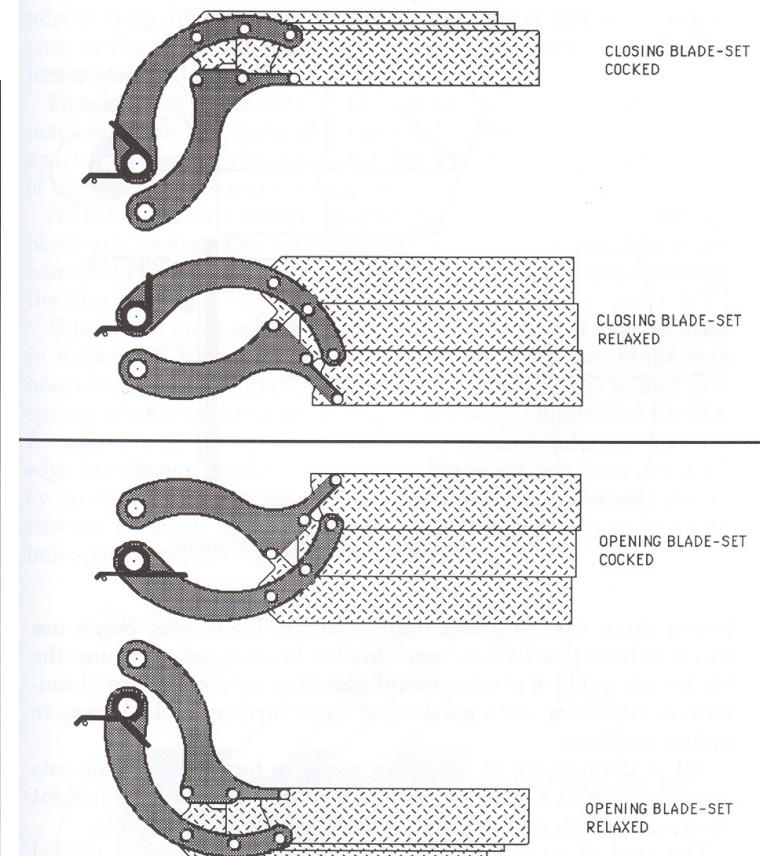
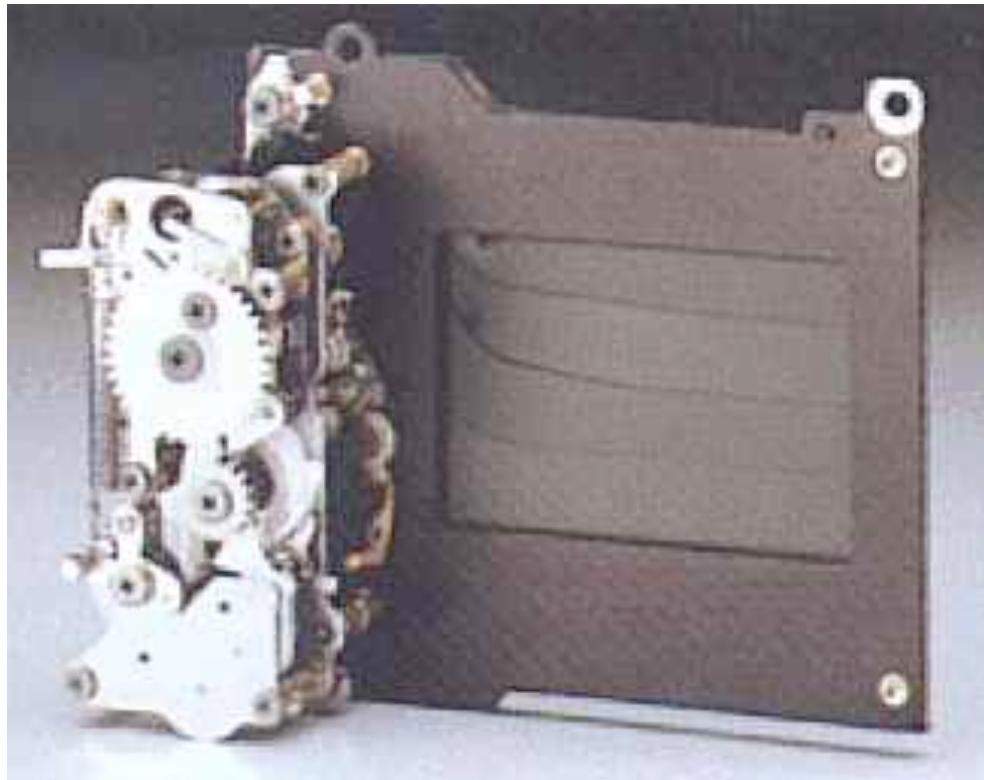


FIG. 2.12 Copal square.

From Camera Technology, Goldberg



Deblurring: Blind Deconvolution

- Estimate motion and deblurred image



Fergus et al.

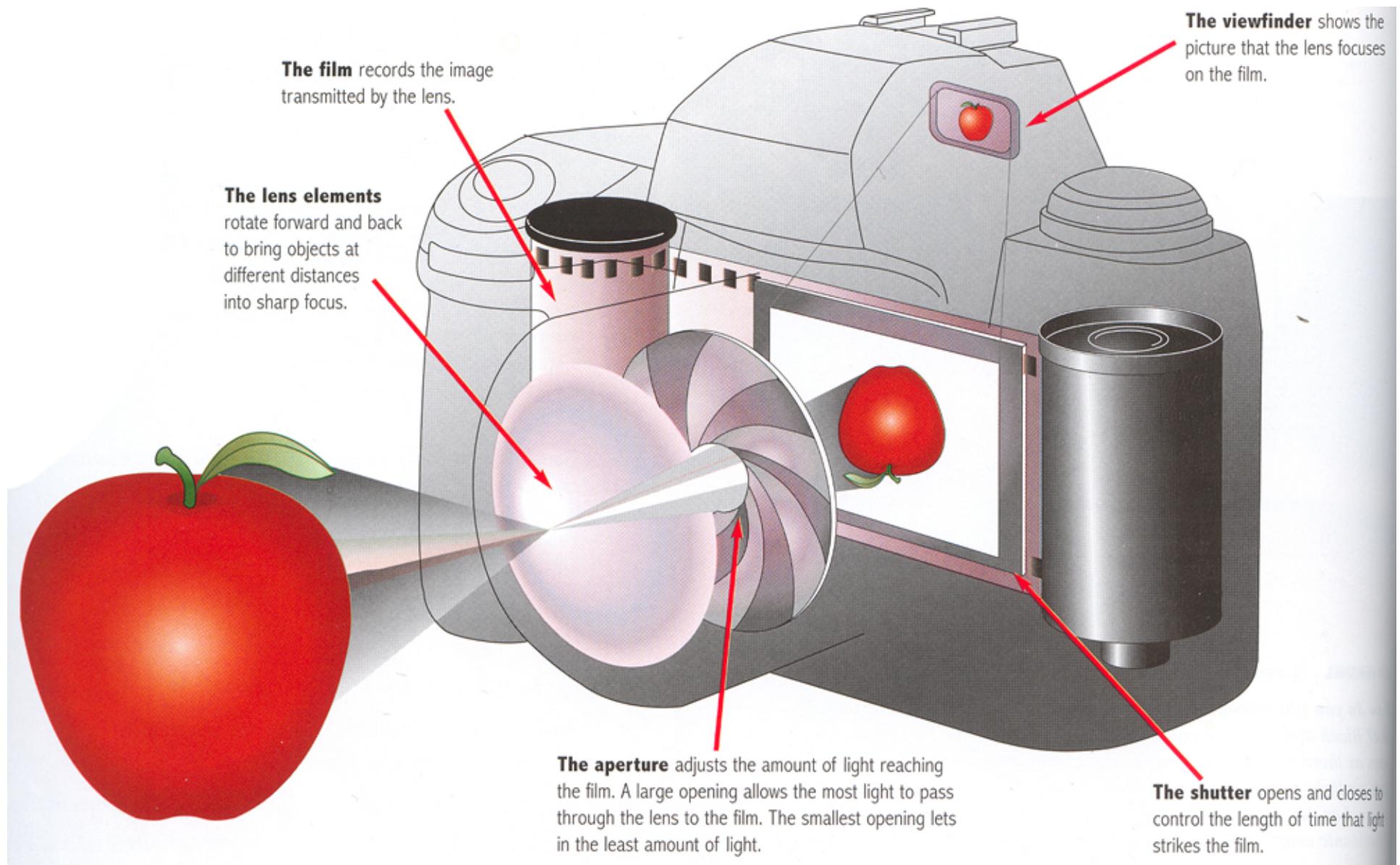
Motion Blur



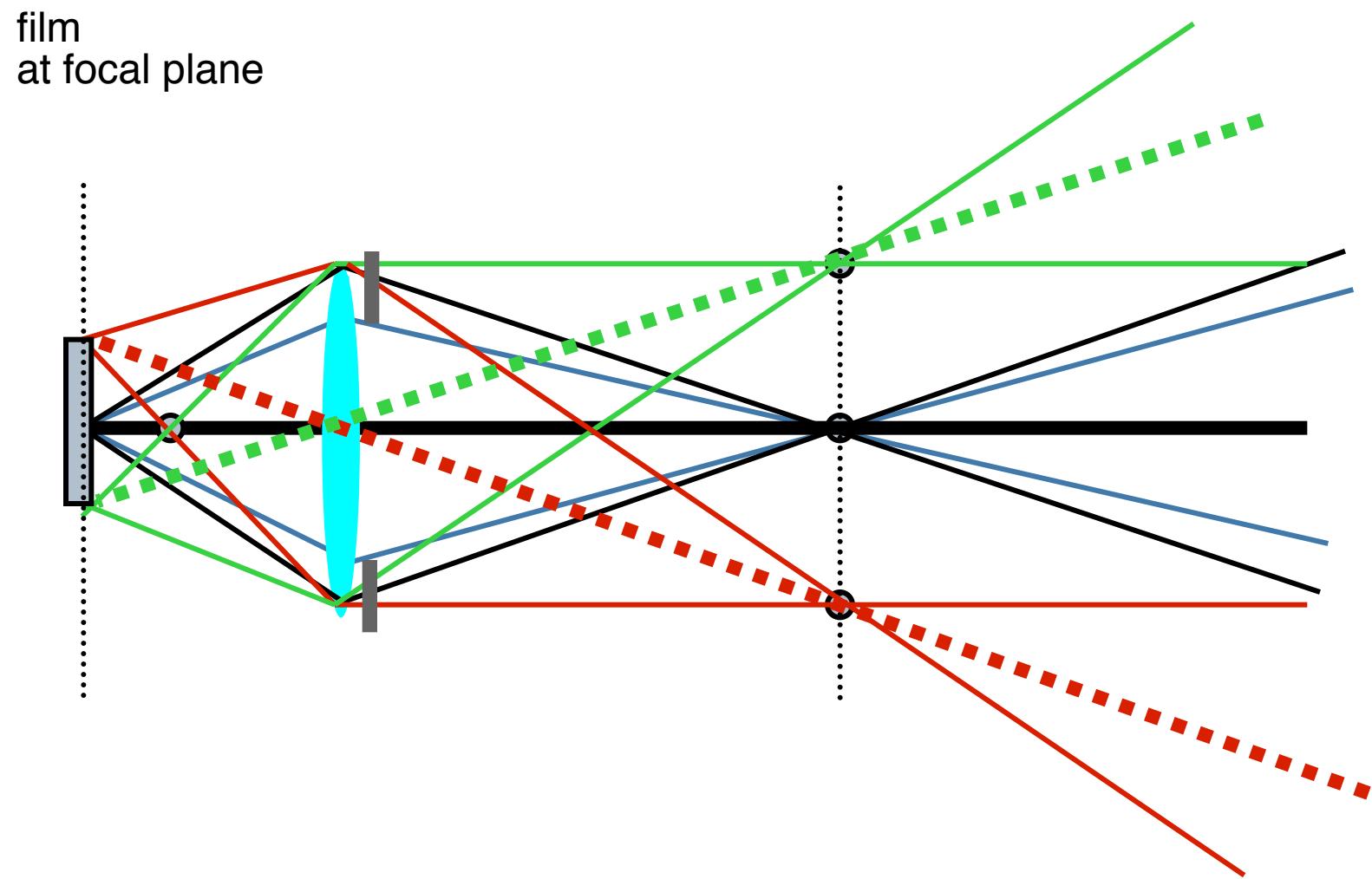
Tripod

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





Aperture

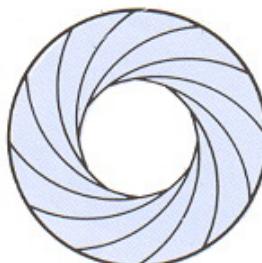


Aperture

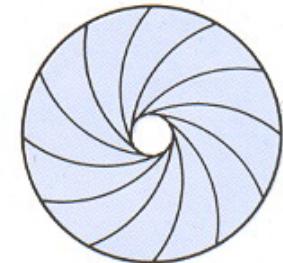
- Diameter of the lens opening (controlled by diaphragm)
- Expressed as a fraction of focal length, in f-number
 - f/2.0 on a 50mm means that the aperture is 25mm
 - f/2.0 on a 100mm means that the aperture is 50mm
- Disconcerting: small f number = big aperture
- What happens to the area of the aperture 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?



Full aperture



Medium aperture

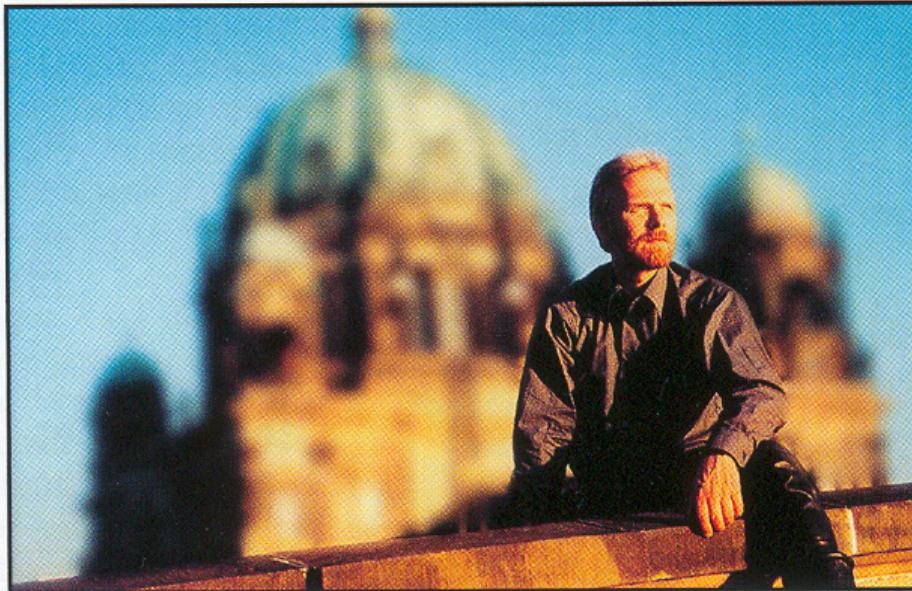


Stopped down

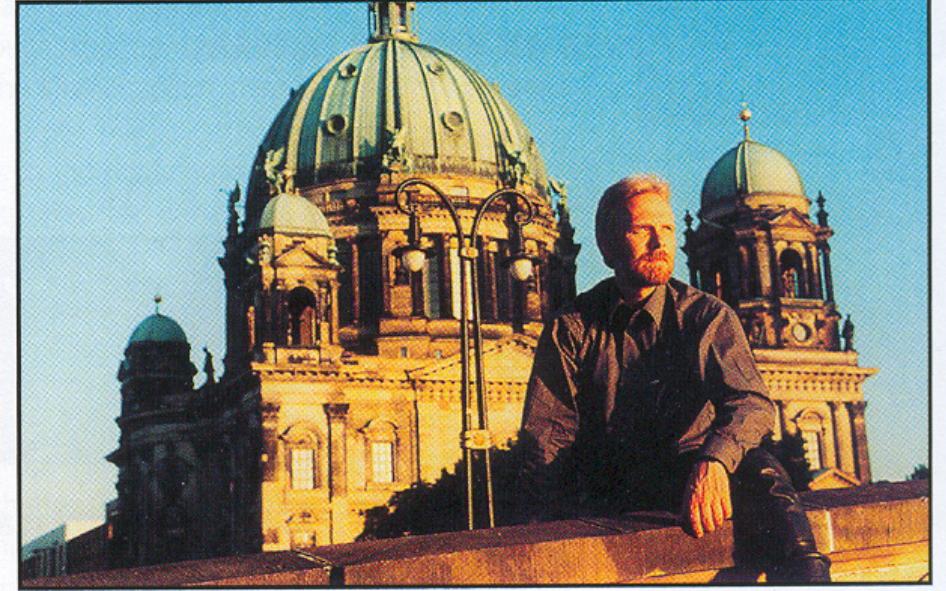
Main Effect of Aperture

■ Depth of field

Large aperture opening

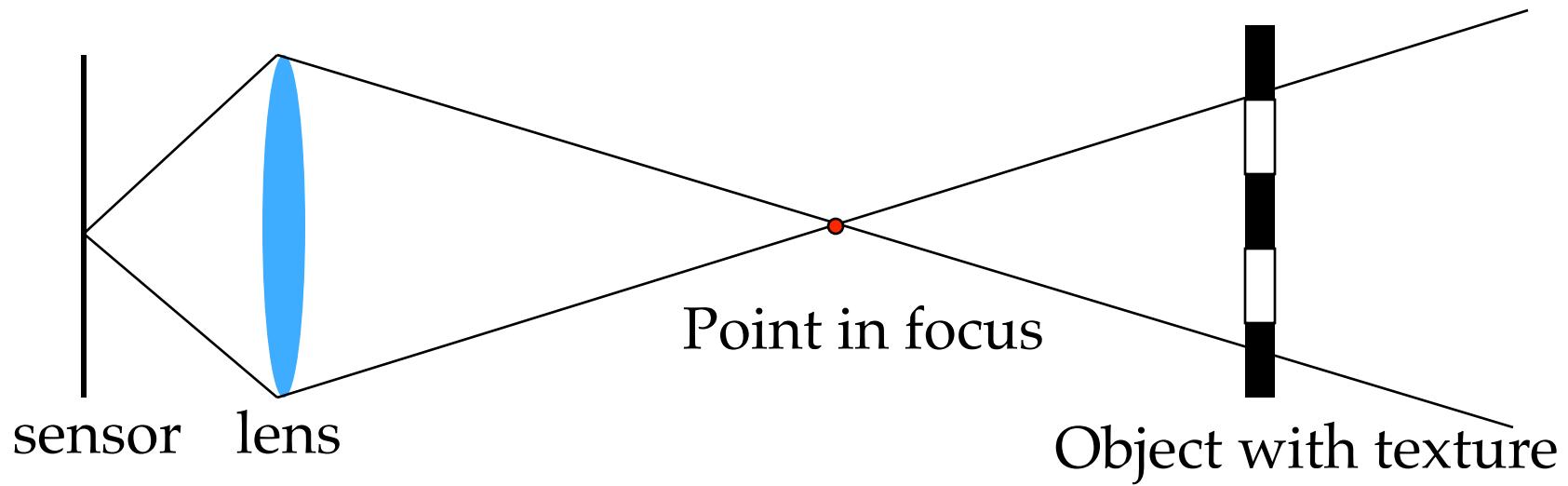


Small aperture opening

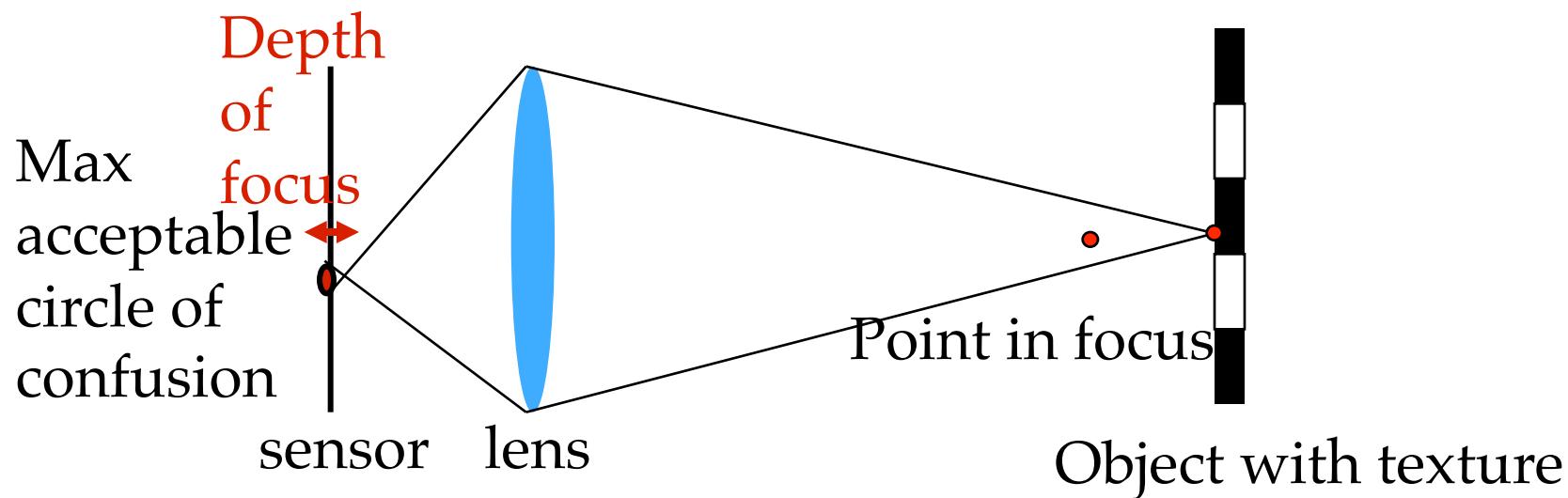
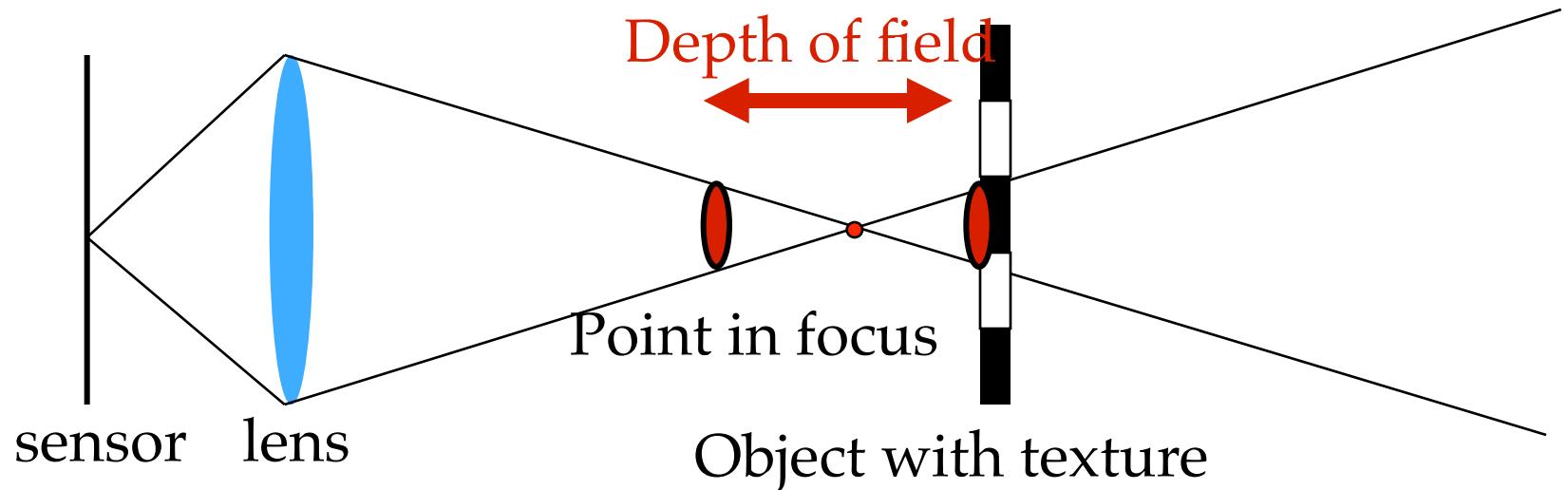


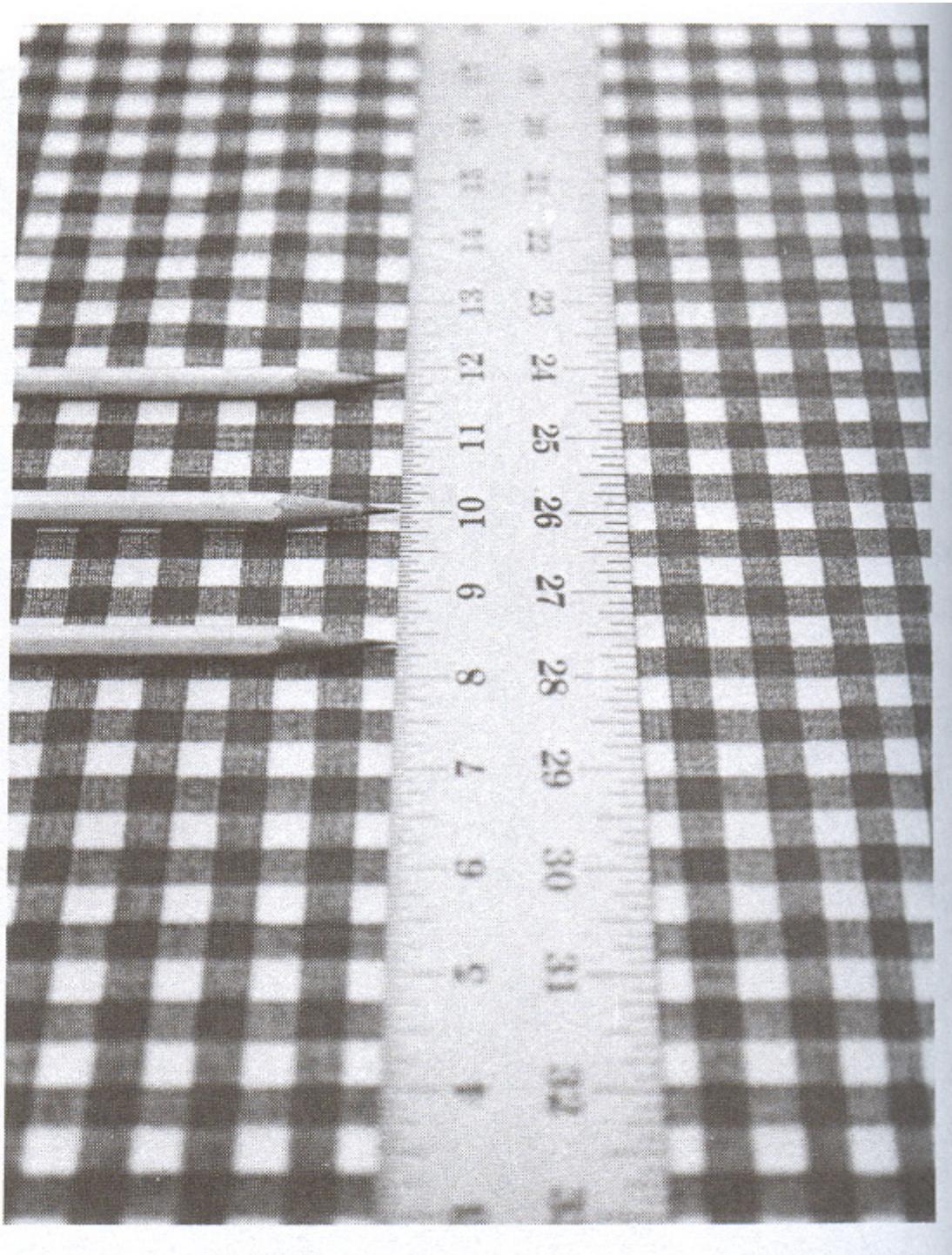
From Photography, London et al.

Depth of Field



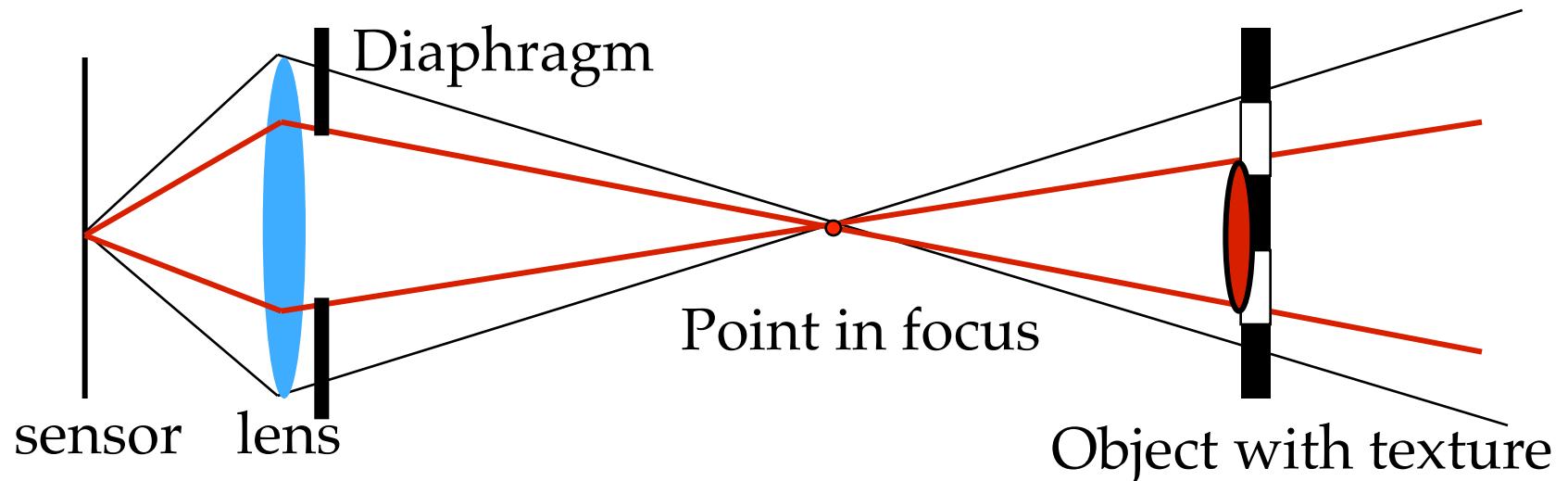
Depth of Field





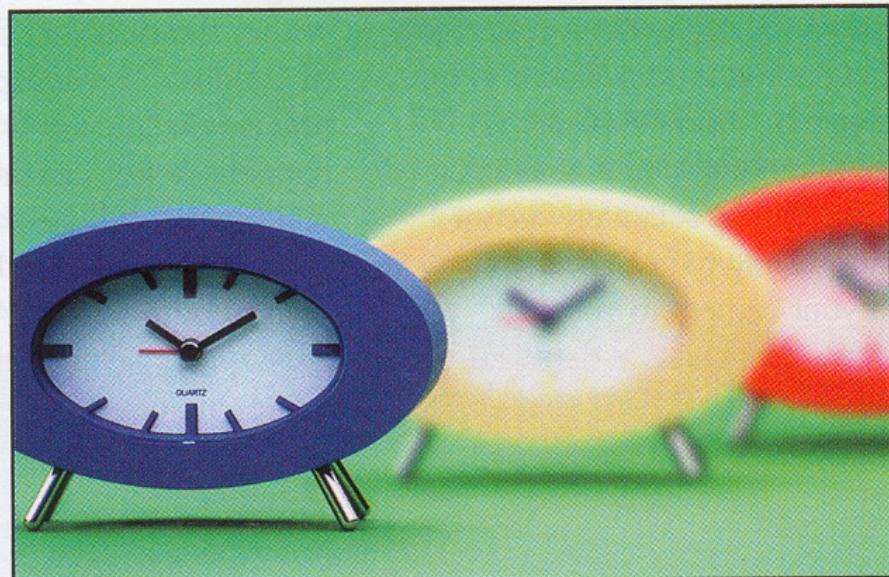
Depth of Field

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



Depth of Field

LESS DEPTH OF FIELD

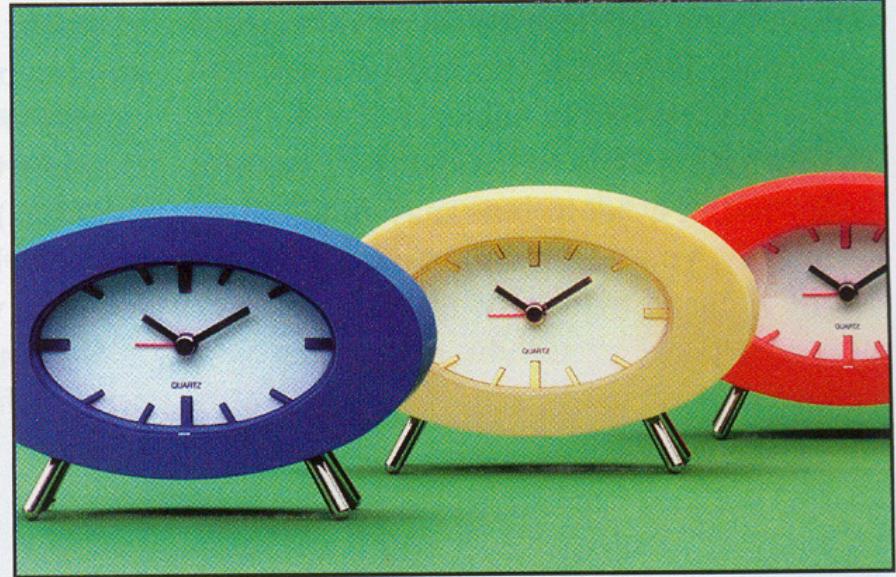


Wider aperture

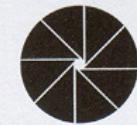


f/2

MORE DEPTH OF FIELD



Smaller aperture

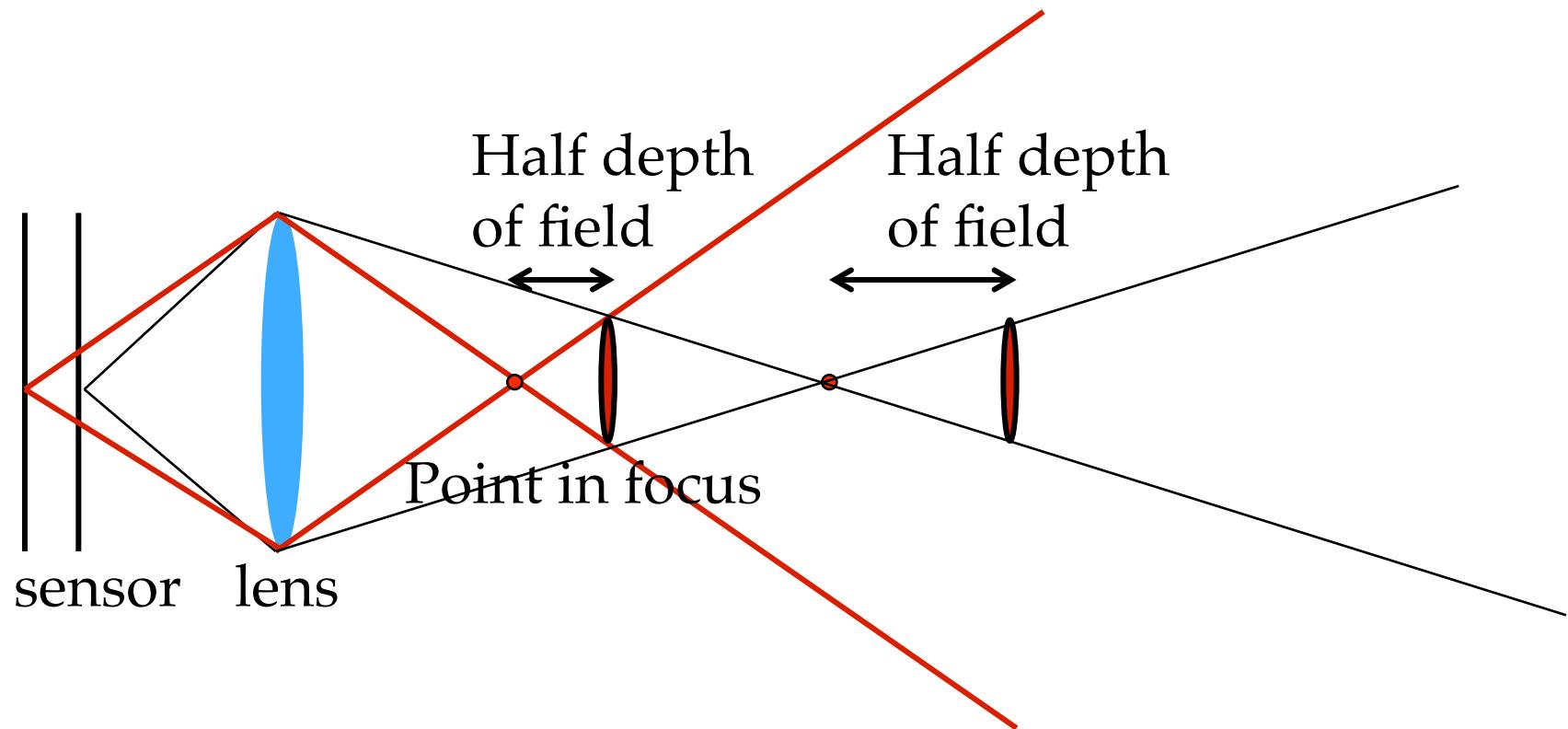


f/16

From Photography, London et al.

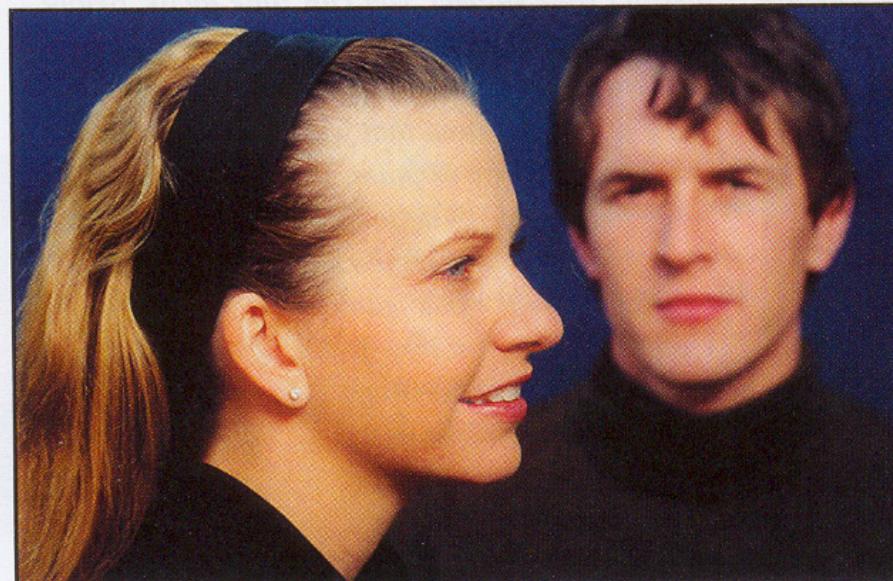
Depth of Field & Focusing Distance

- What happens when we divide focusing distance by two?
 - Similar triangles => divided by two as well

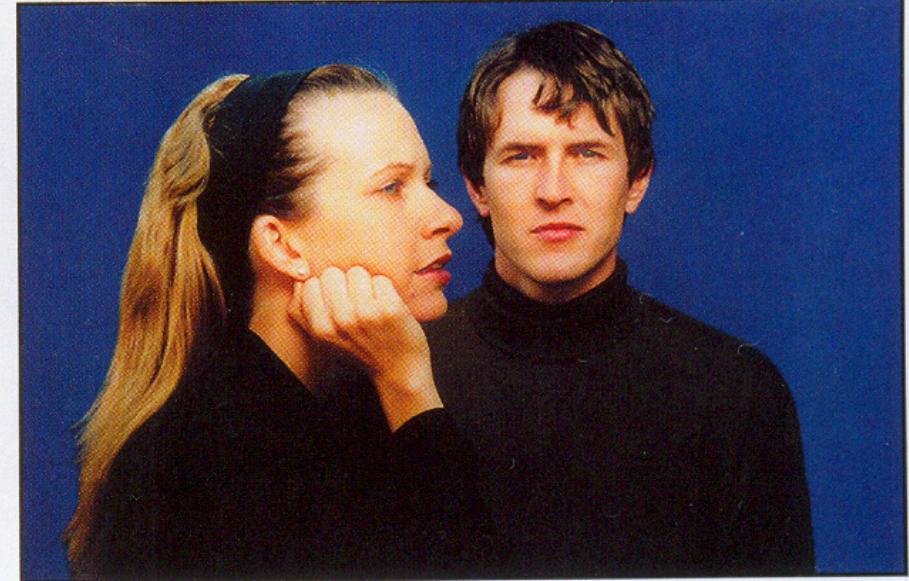


Depth of Field & Focusing Distance

- What happens when we divide focusing distance by two?
 - Similar triangles => divided by two as well



Closer to subject



Farther from subject



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

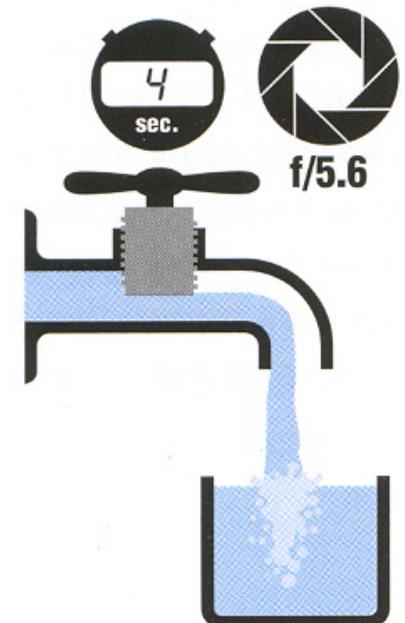
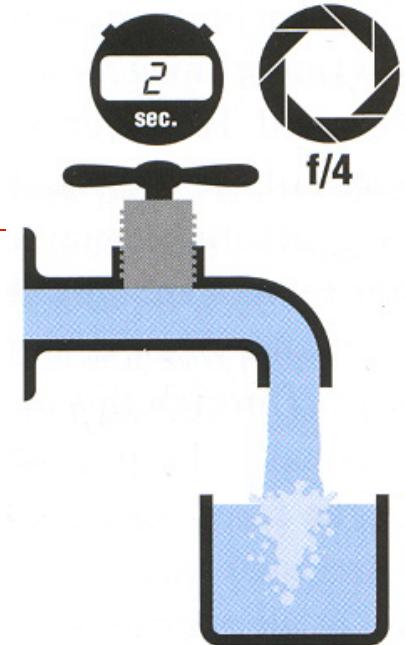
Exposure

- 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*

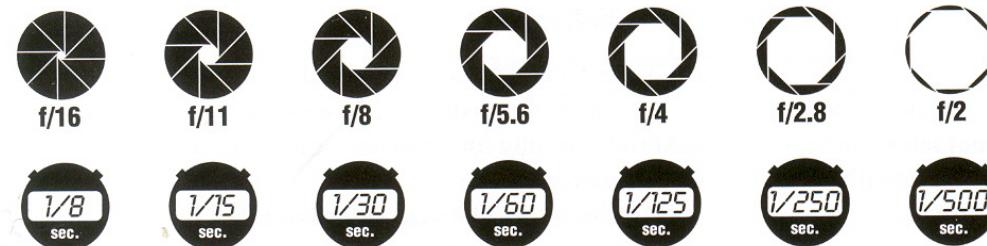
- Hence square root of two progression of f stops vs. power of two progression of shutter speed
- Reciprocity can fail for very long exposures



From Photography, London et al.

Reciprocity

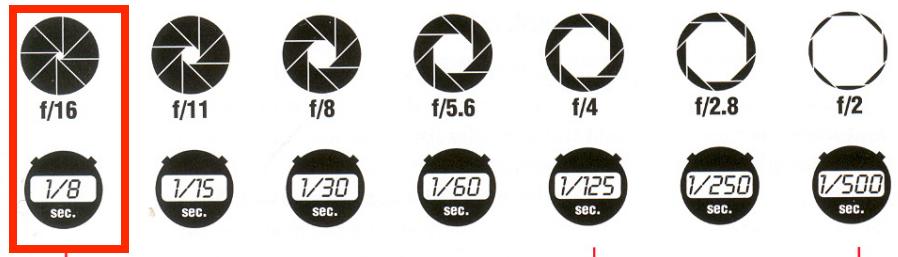
- Assume we know how much light we need
- We have the choice of an infinity of shutter speed/aperture pairs



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



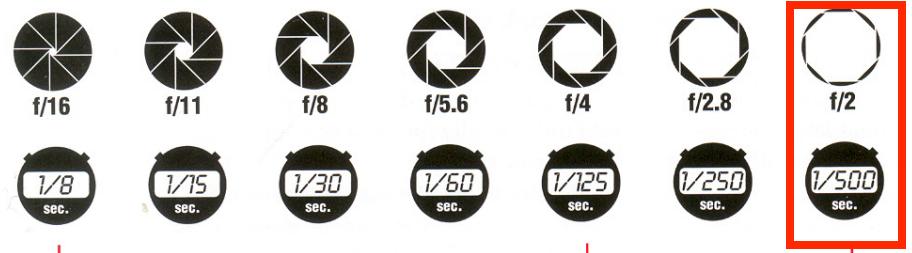
Small aperture (deep depth of field), slow shutter speed (motion blurred). In this scene, a small aperture ($f/16$) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed ($1/8$ sec) was needed; it was too slow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



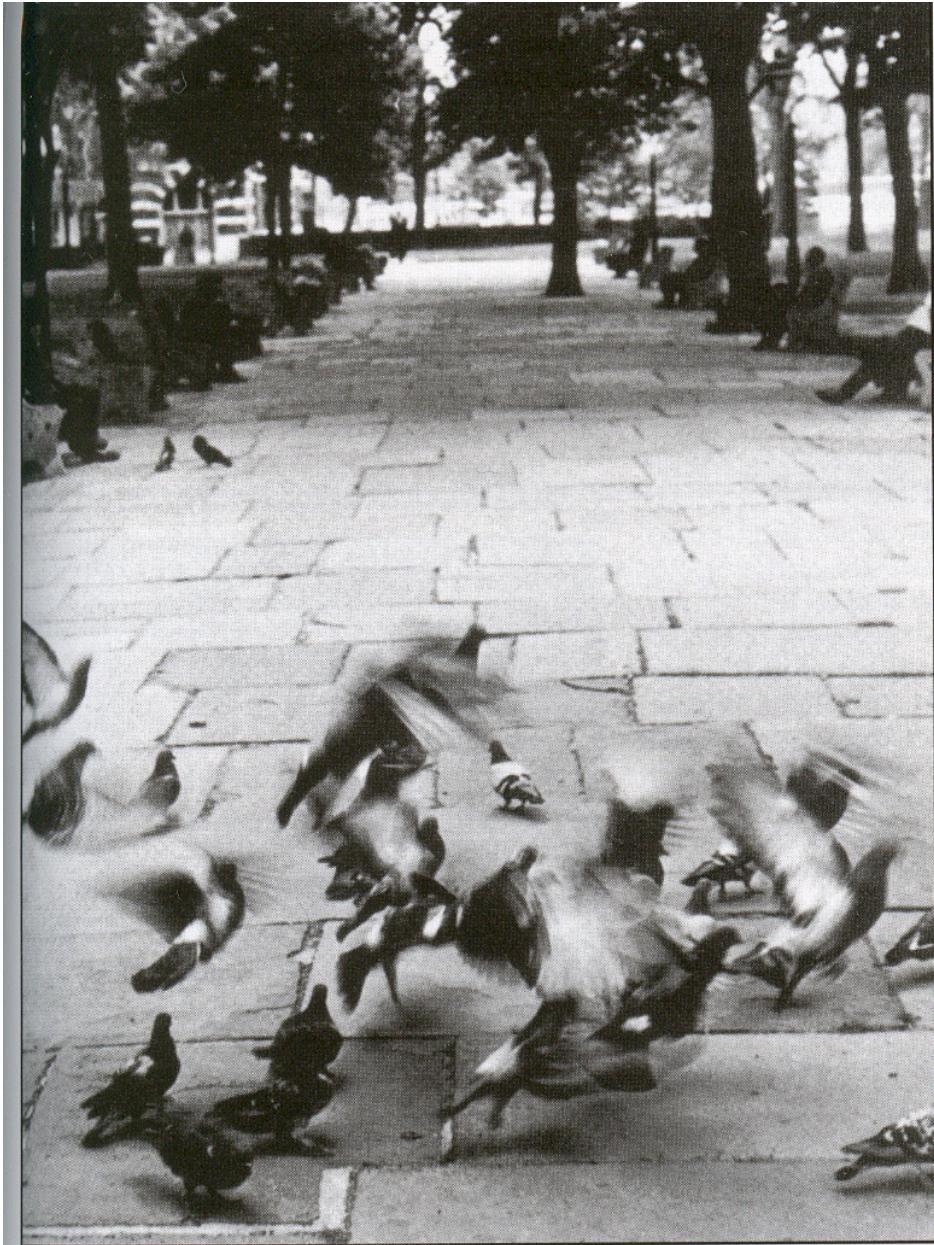
From Photography, London et al.



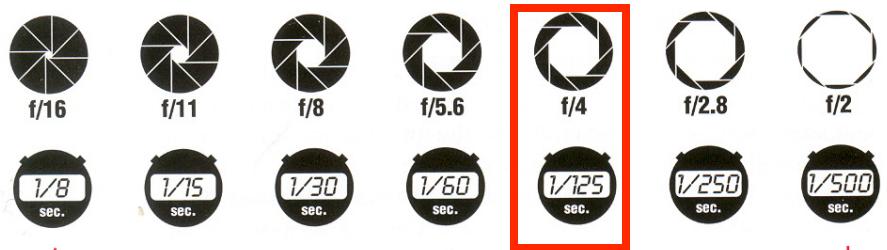
Large aperture (shallow depth of field), fast shutter speed (motion sharp). A fast shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little depth of field that the background is now out of focus.



From Photography, London et al.



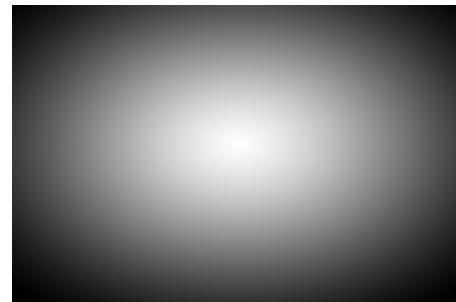
Medium aperture (moderate depth of field), medium shutter speed (some motion sharp). A medium aperture (f/4) and shutter speed (1/125 sec) sacrifice some background detail to produce recognizable images of the birds. But the exposure is still too long to show the motion of the birds' wings sharply.



From Photography, London et al.

Metering

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



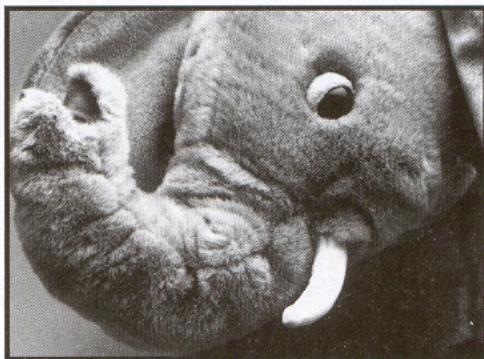
- Assumption? Failure cases?
 - Usually assumes that a scene is 18% gray
 - Problem with dark and bright scenes



White polar bear given exposure suggested by meter



White polar bear given 2 stops more exposure



Gray elephant given exposure suggested by meter



Gray elephant given 2 stops less exposure



Black gorilla given exposure suggested by meter

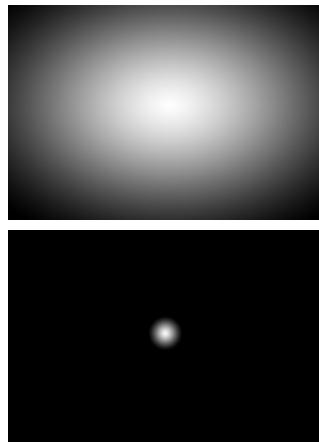


Black gorilla given 2 stops less exposure

From Photography, London et al.

Metering

- Centered average



Choice on Nikon



- Smart metering

- Nikon 3D matrix
- Canon evaluative

Next slide

- Incident

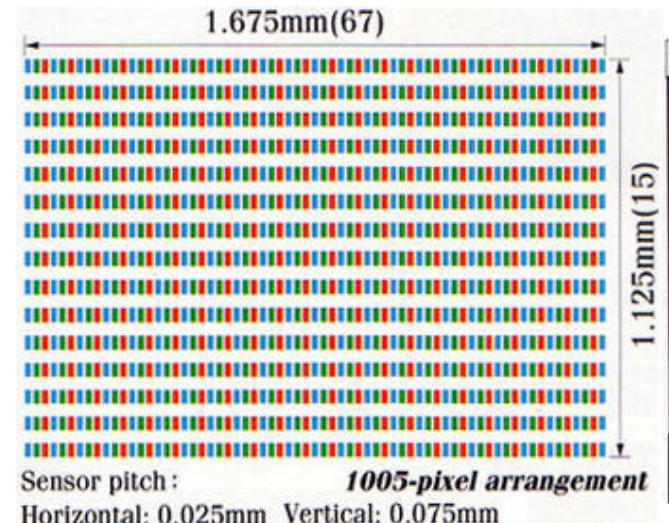
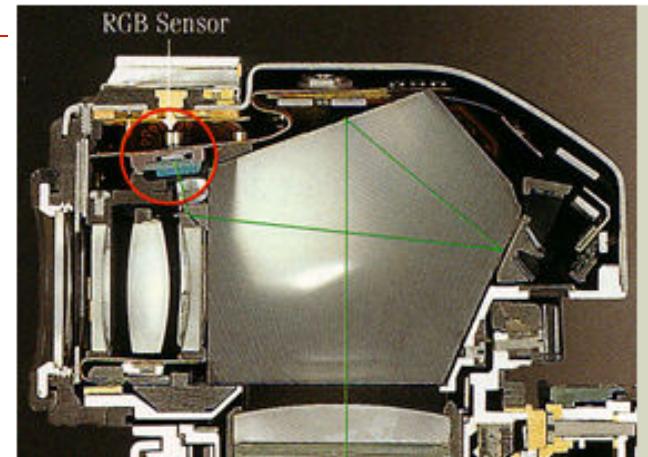
- Measure incoming light



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)

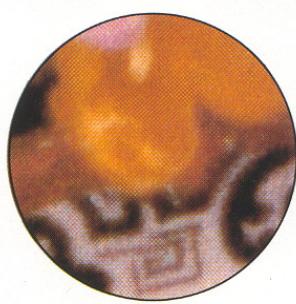
- Third variable for exposure
- Linear effect (200 ISO needs half the light as 100 ISO)
- Film photography: trade sensitivity for grain



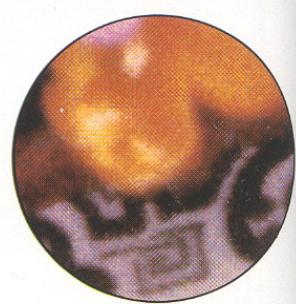
Kodachrome 25 ASA



Ektachrome 64 ASA



Fujichrome 100 ASA



Ektachrome 200 ASA

- Digital photography: trade sensitivity for noise

Nikon D2X ISO 100	Nikon D2X ISO 200	Nikon D2X ISO 400	Nikon D2X ISO 800	Nikon D2X ISO 1600	Nikon D2X ISO 3200

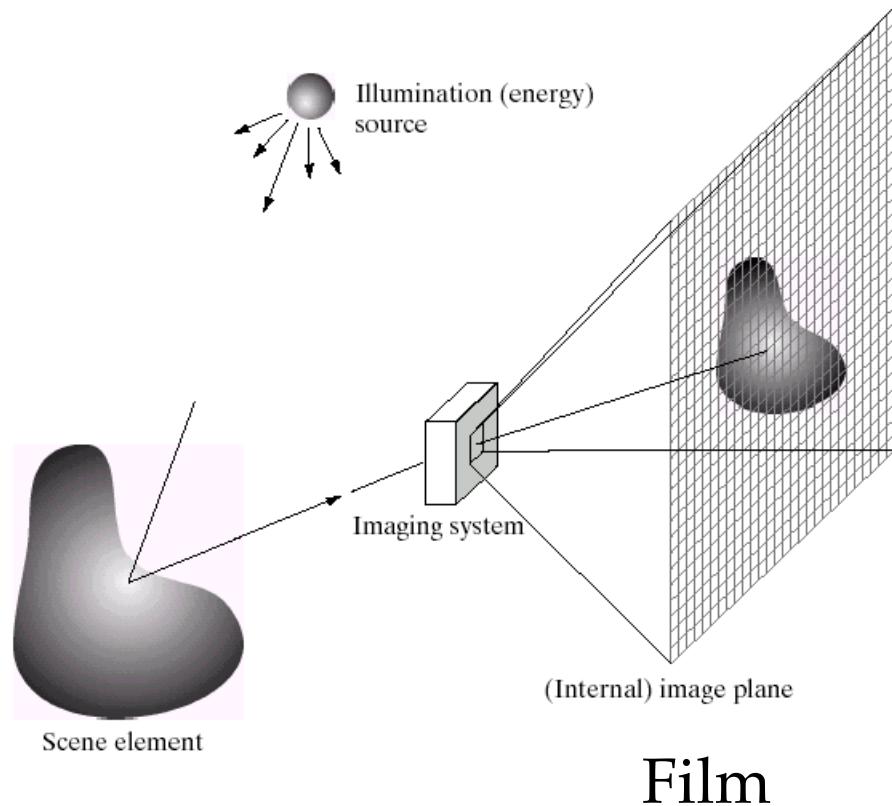
Computational Photography

Week 2, Winter 2009

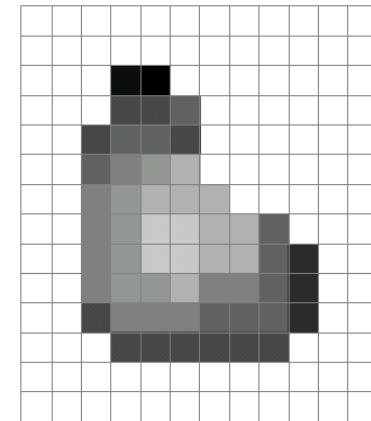
Instructor: Prof. Ko Nishino

Capturing Light

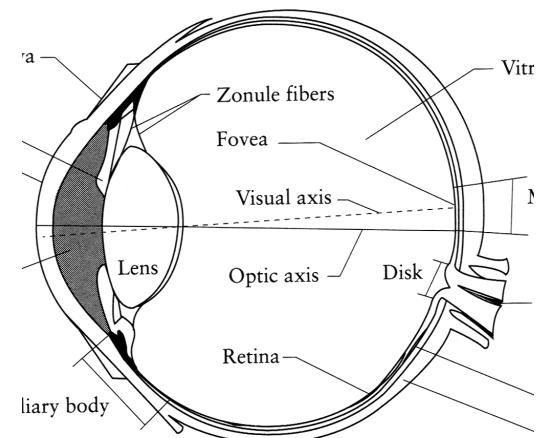
Image Formation



Film



Digital Camera



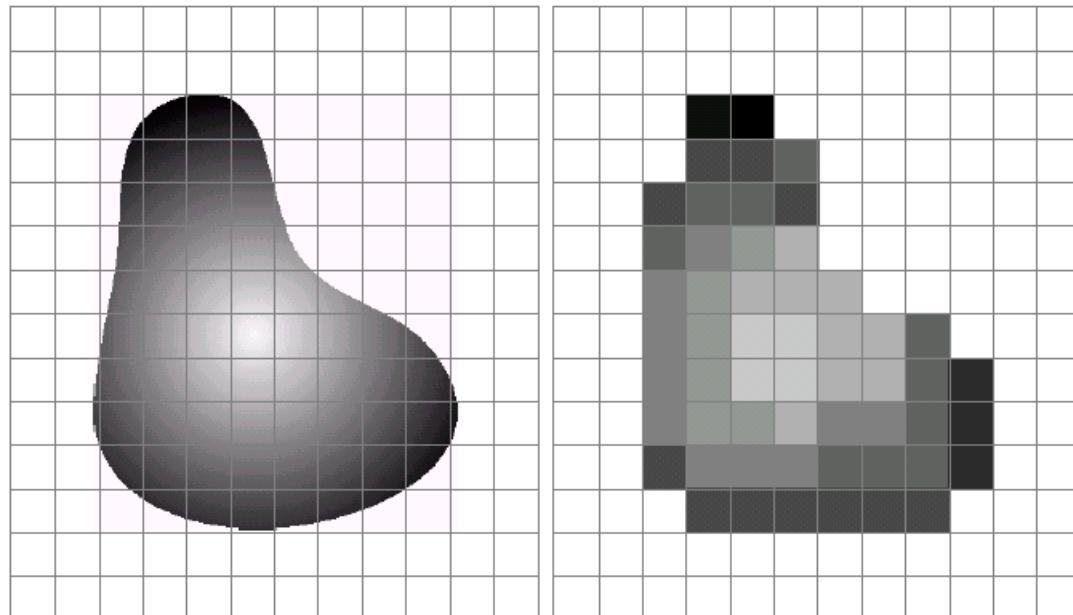
The Eye

Digital Camera



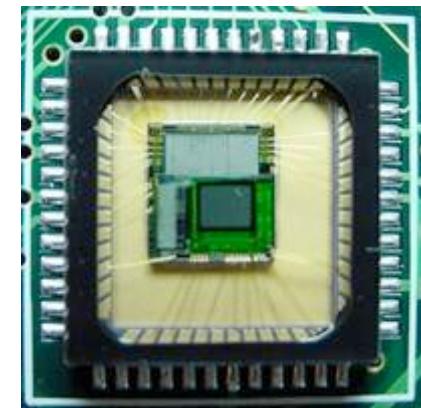
- A digital camera replaces film with a sensor array
 - Each cell in the array is light-sensitive diode that converts photons to electrons
 - Two common types
 - Charge Coupled Device (CCD)
 - CMOS

Sensor Array



a b

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



CMOS sensor

Sampling and Quantization

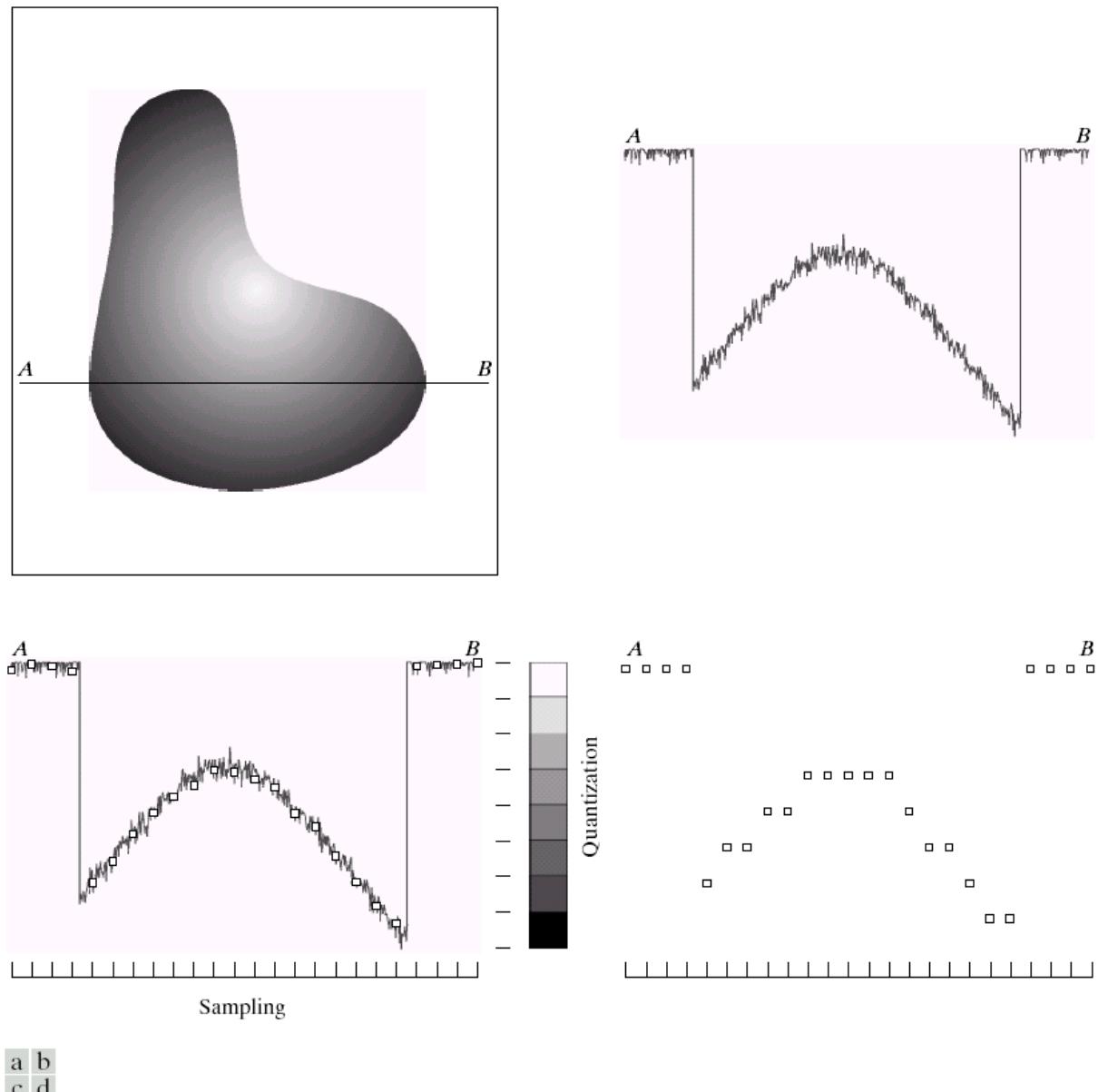
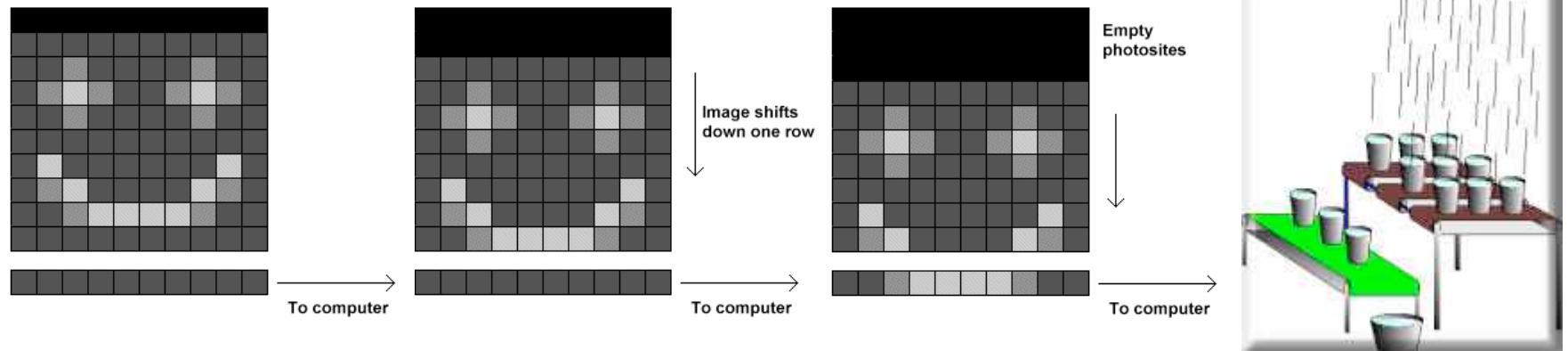


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image.

Sensor Readout

■ CCD

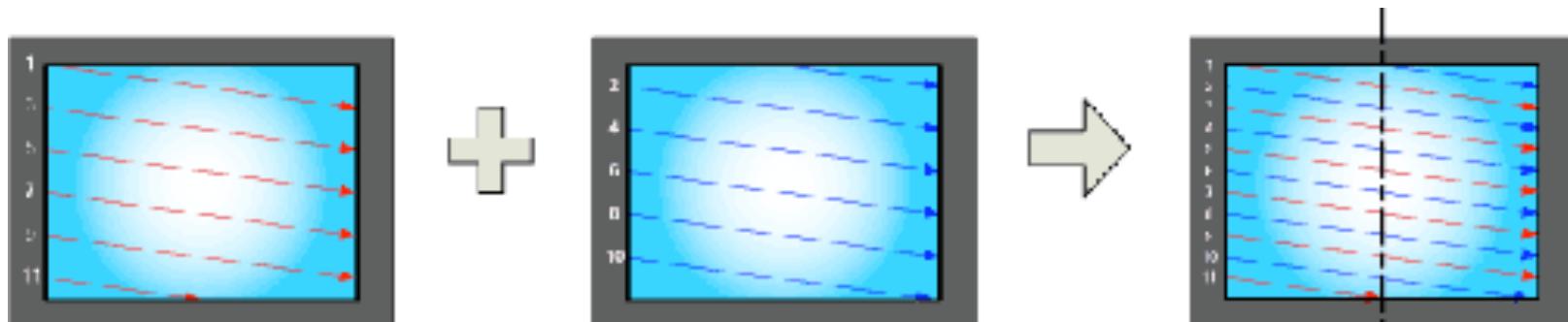


■ CMOS



Images Copyright © 2000 TWI Press, Inc.

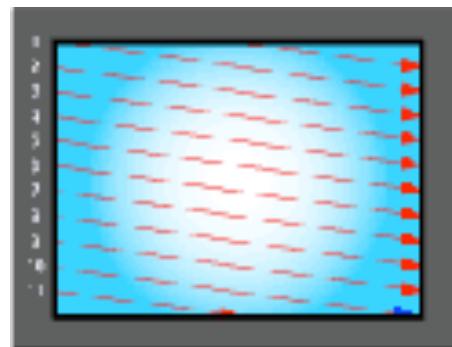
Interlace vs. Progressive Scan



1st field: Odd field

2nd field: Even field

One complete frame
using interlaced scanning



One complete frame
using progressive scanning

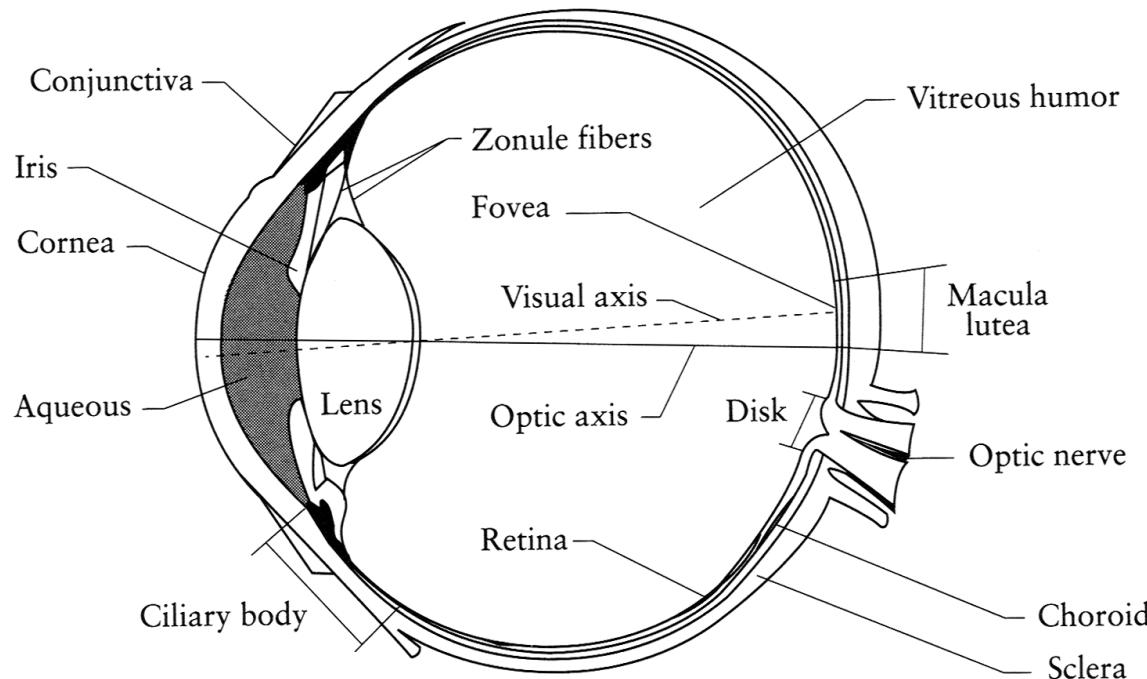
Progressive Scan



Interlace

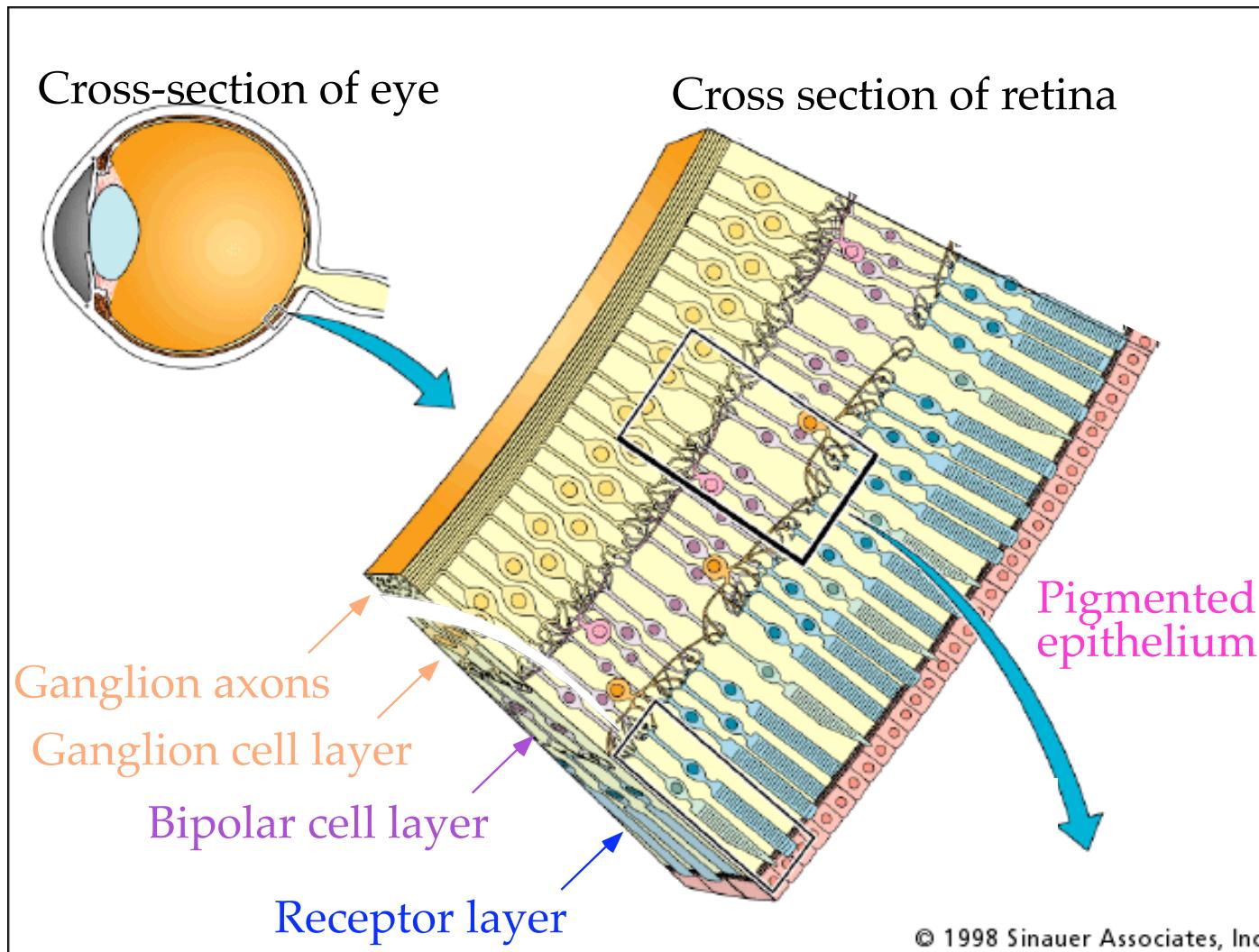


The Eye

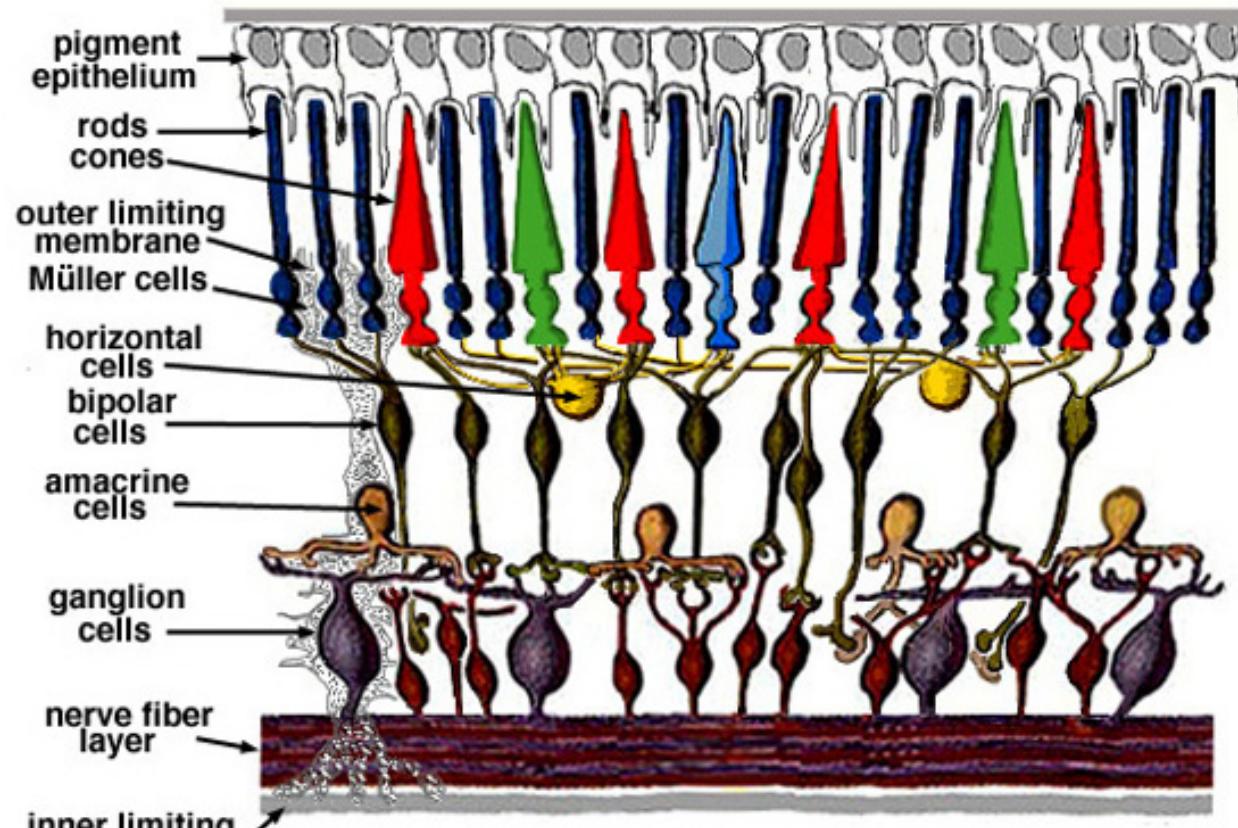


- The human eye is a camera!
 - Iris - colored annulus with radial muscles
 - Pupil - the hole (aperture) whose size is controlled by the iris
 - What's the “film”?
 - photoreceptor cells (rods and cones) in the retina

The Retina

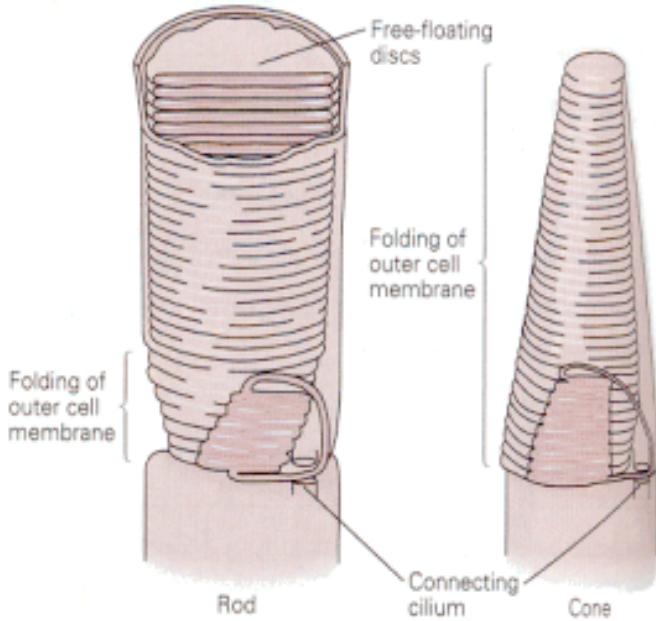


Retina Up-close



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

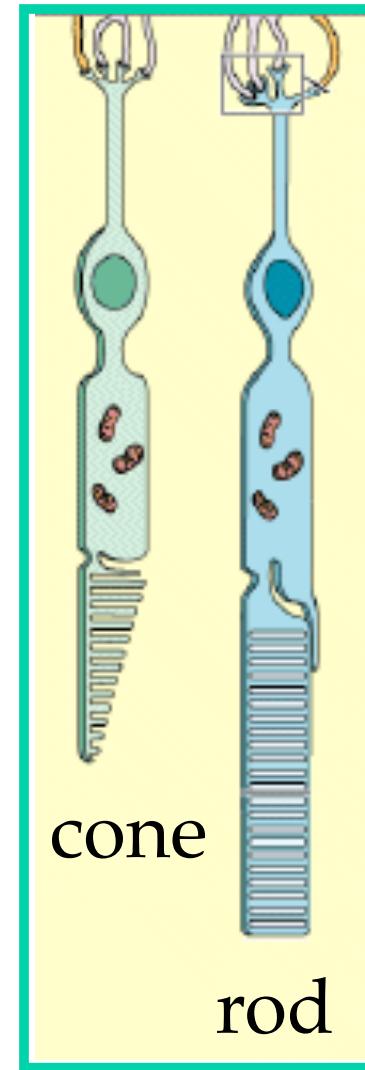
Rods and Cones

Cones

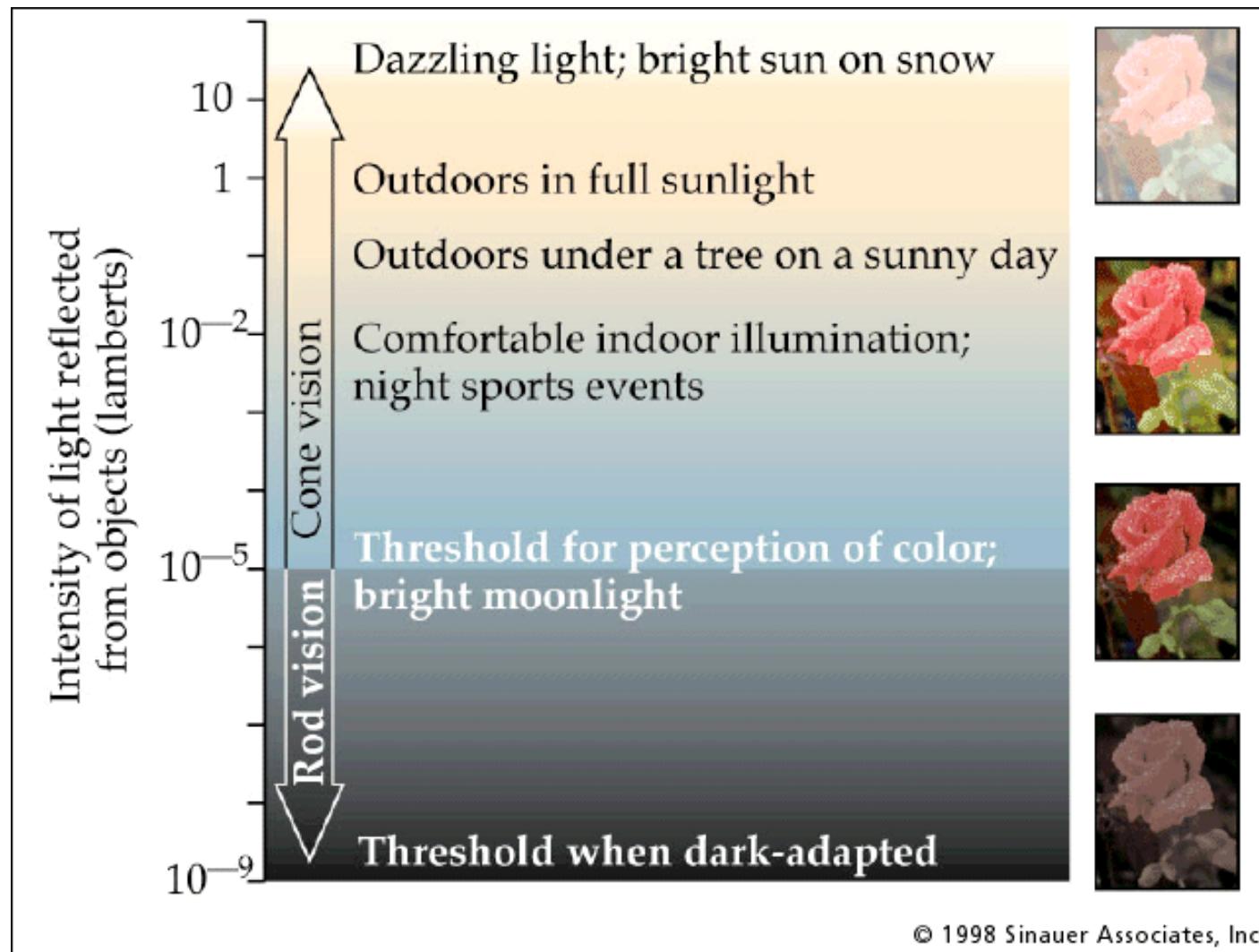
cone-shaped
less sensitive
operate in high light
color vision

Rods

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

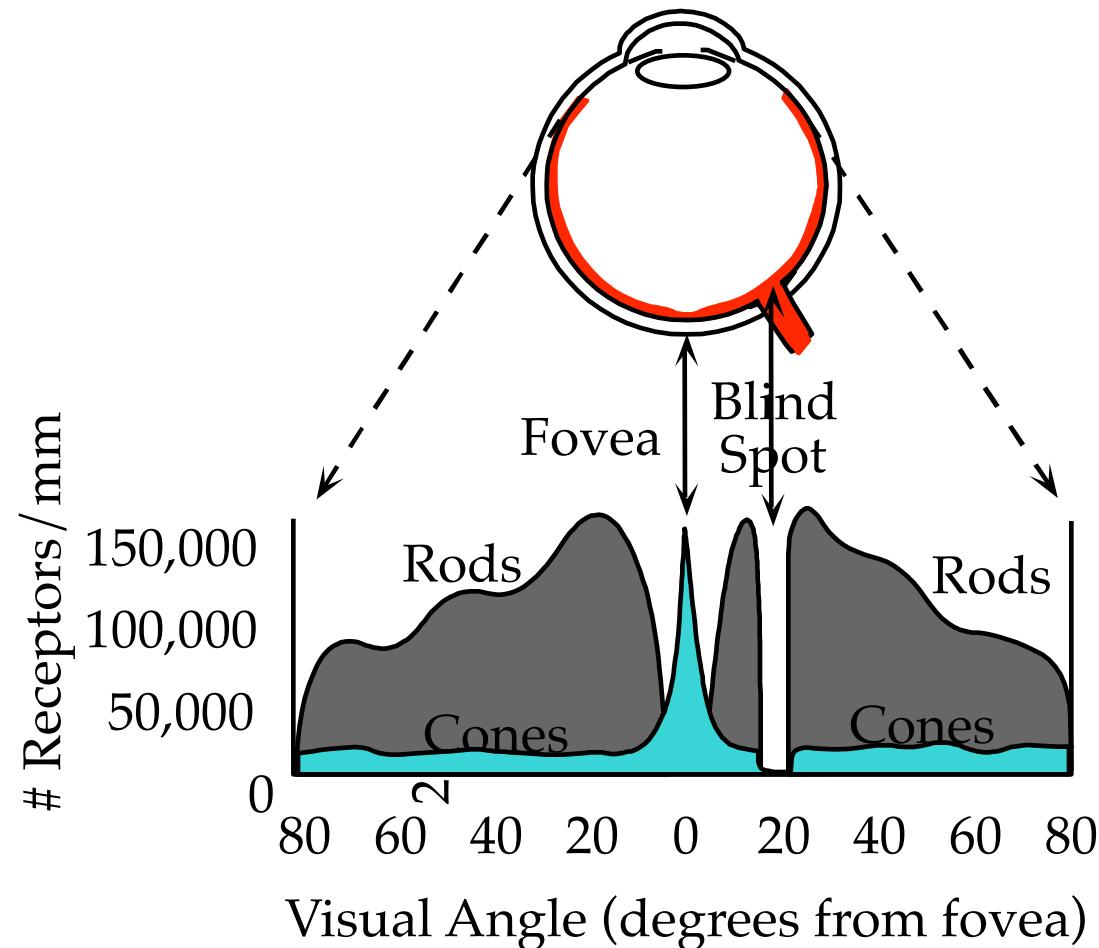


Rod / Cone Sensitivity

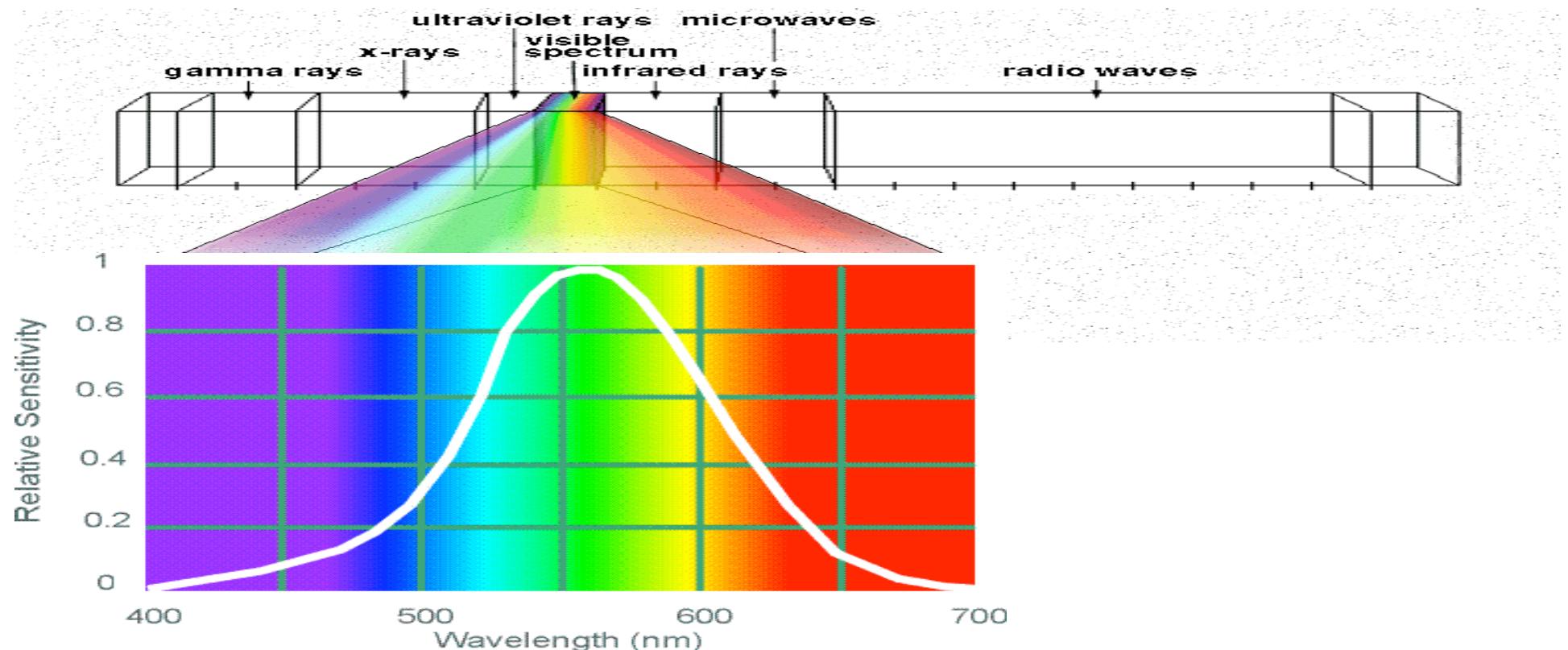


Distribution of Rods and Cones

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



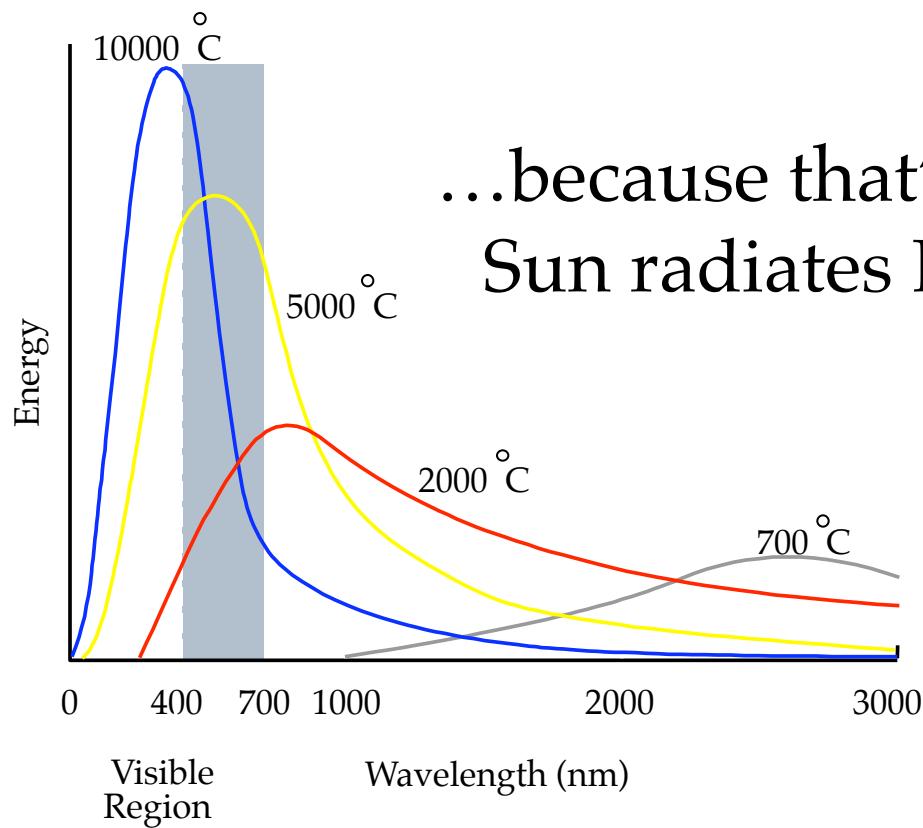
Electromagnetic Spectrum



Human Luminance Sensitivity Function

Visible Light

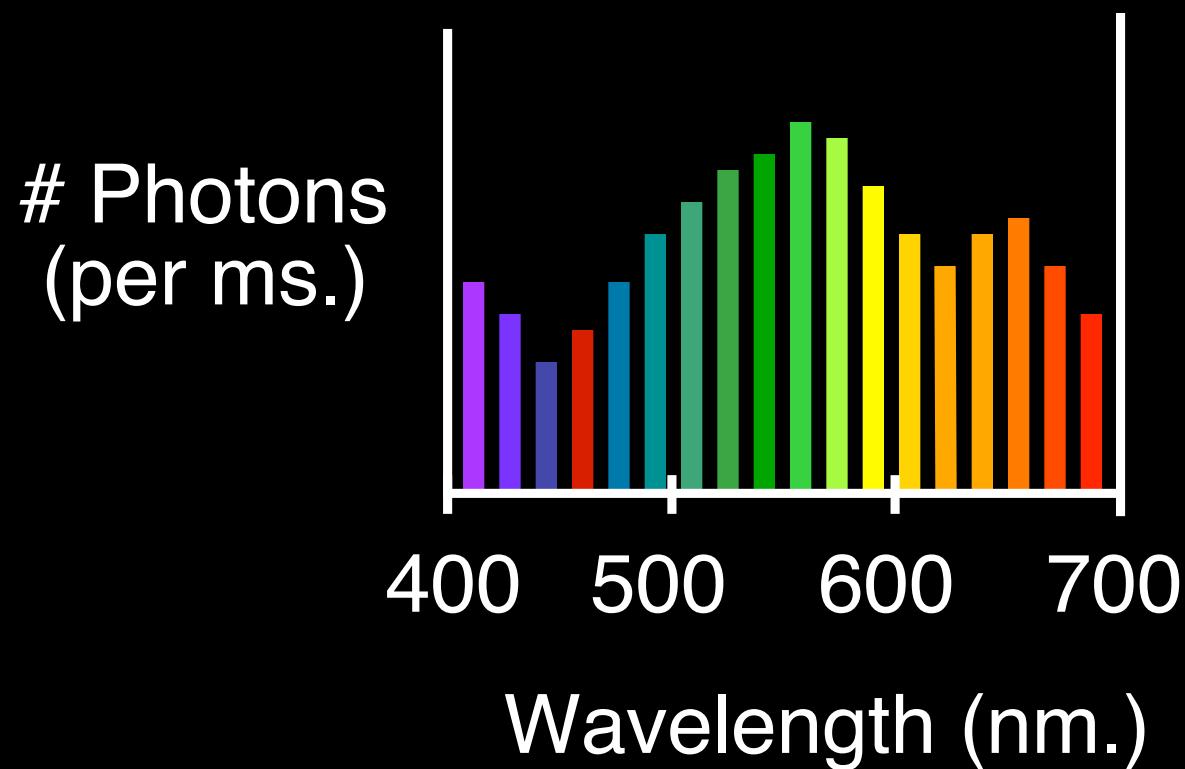
Why do we see light of these wavelengths?



...because that's where the Sun radiates EM energy

The Physics of Light

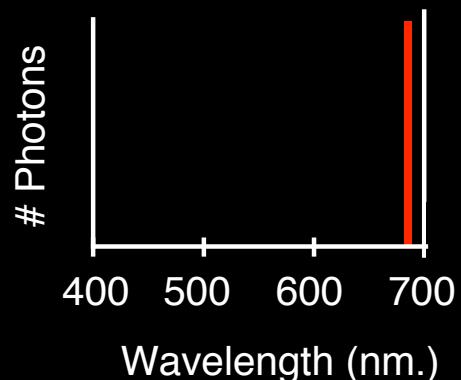
Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.



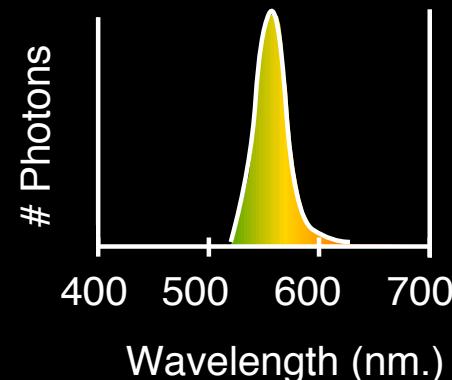
The Physics of Light

Some examples of the spectra of light sources

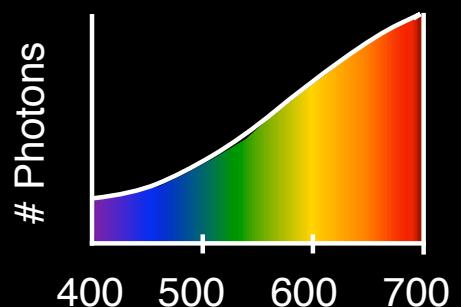
A. Ruby Laser



B. Gallium Phosphide Crystal



C. Tungsten Lightbulb



D. Normal Daylight

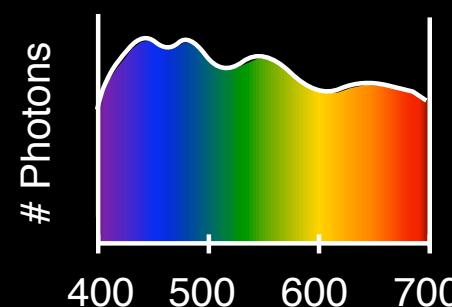


Image Formation

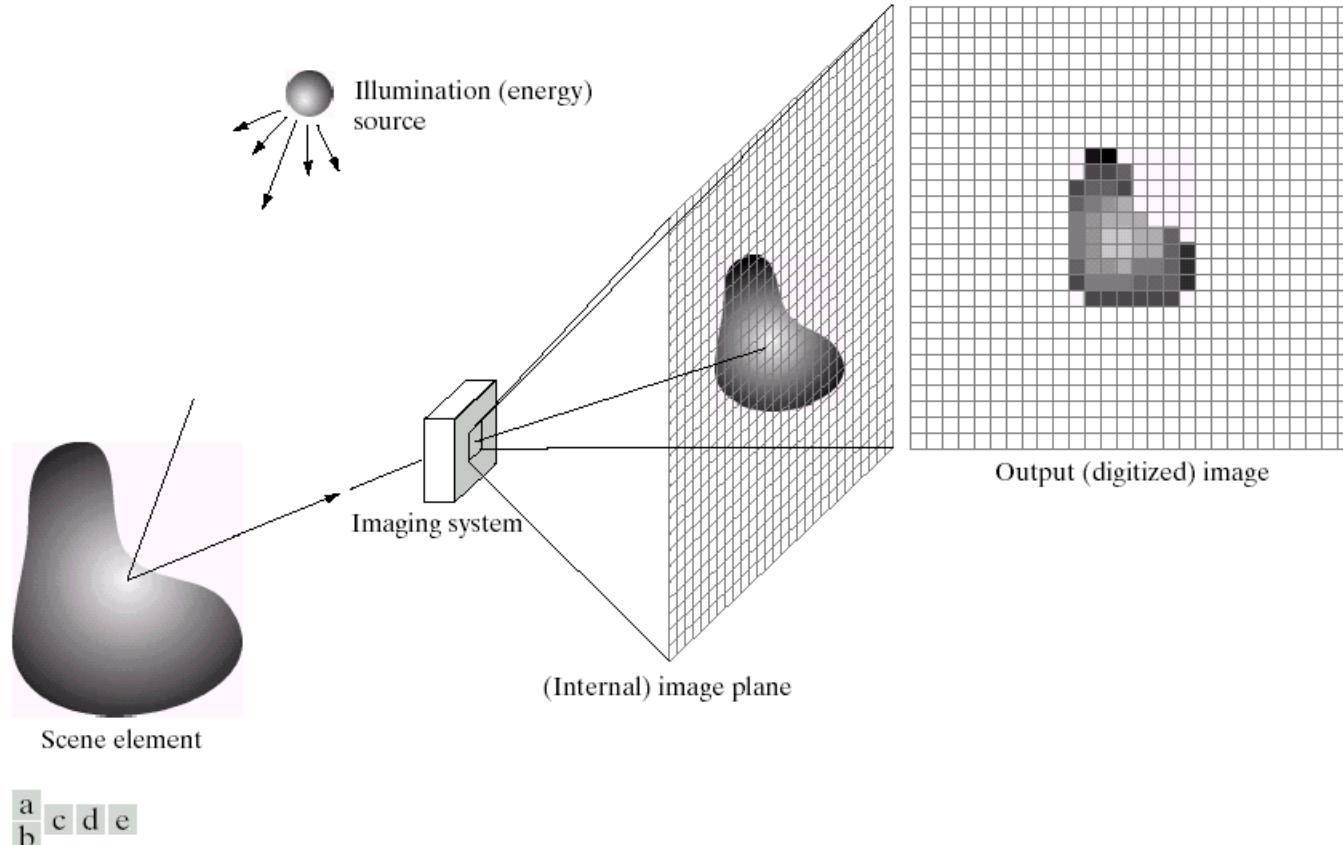


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy (“illumination”) source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

$$f(x,y) = \text{reflectance}(x,y) * \text{illumination}(x,y)$$

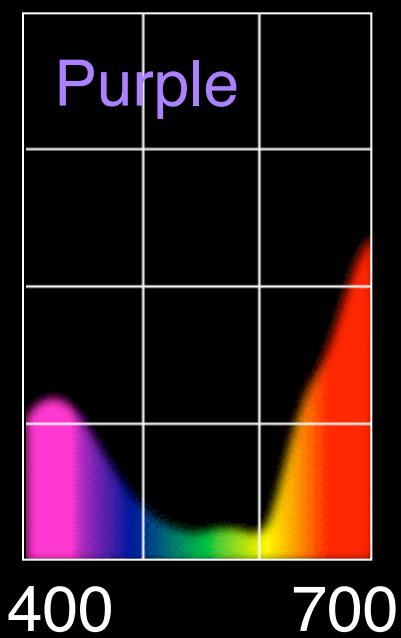
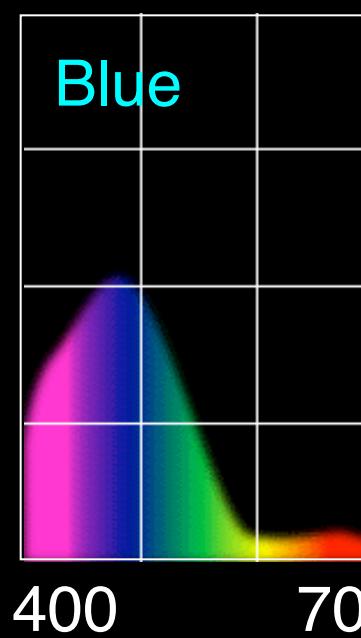
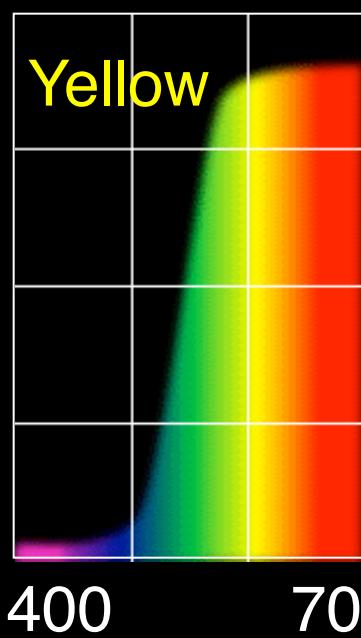
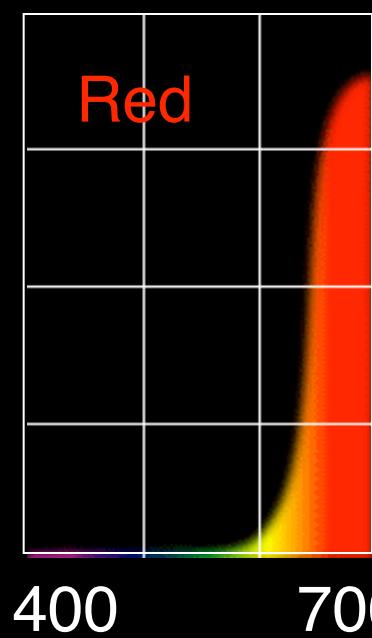
reflectance in $[0,1]$, illumination in $[0,\infty]$

The Physics of Light

Some examples of the reflectance spectra of surfaces

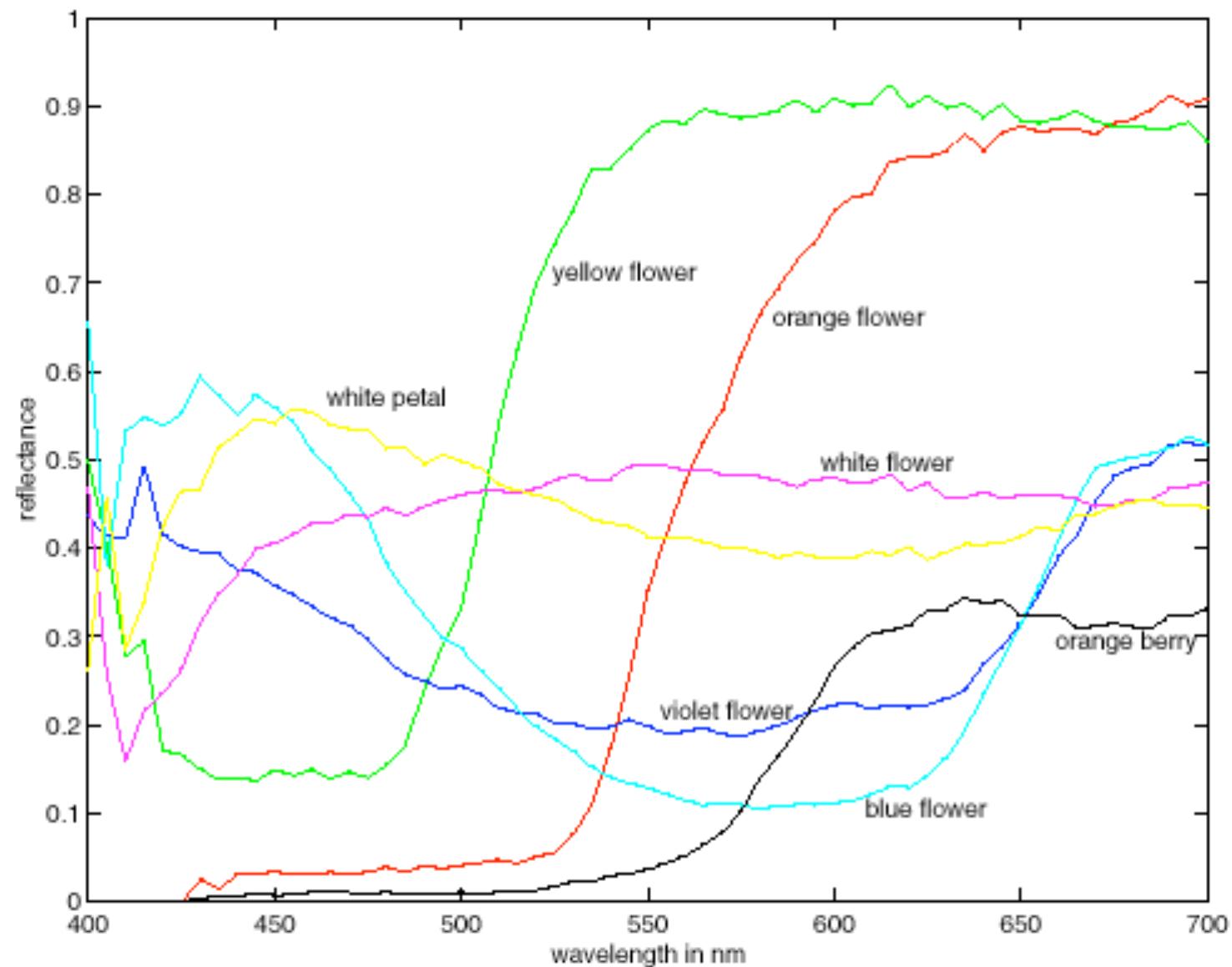


% Photons Reflected



Wavelength (nm)

More Spectra

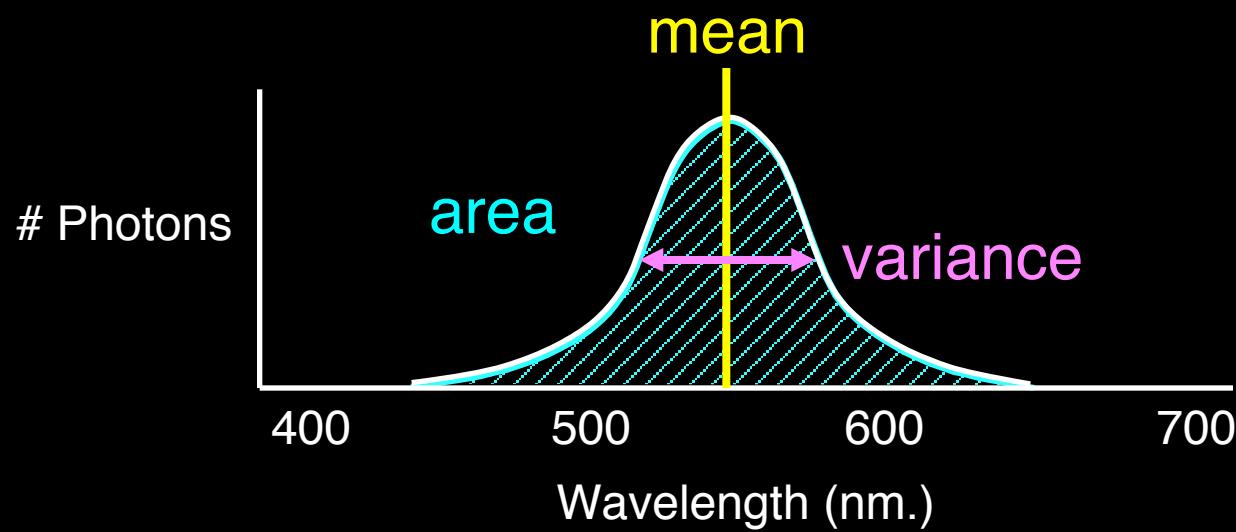


The Psychophysical Correspondence

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

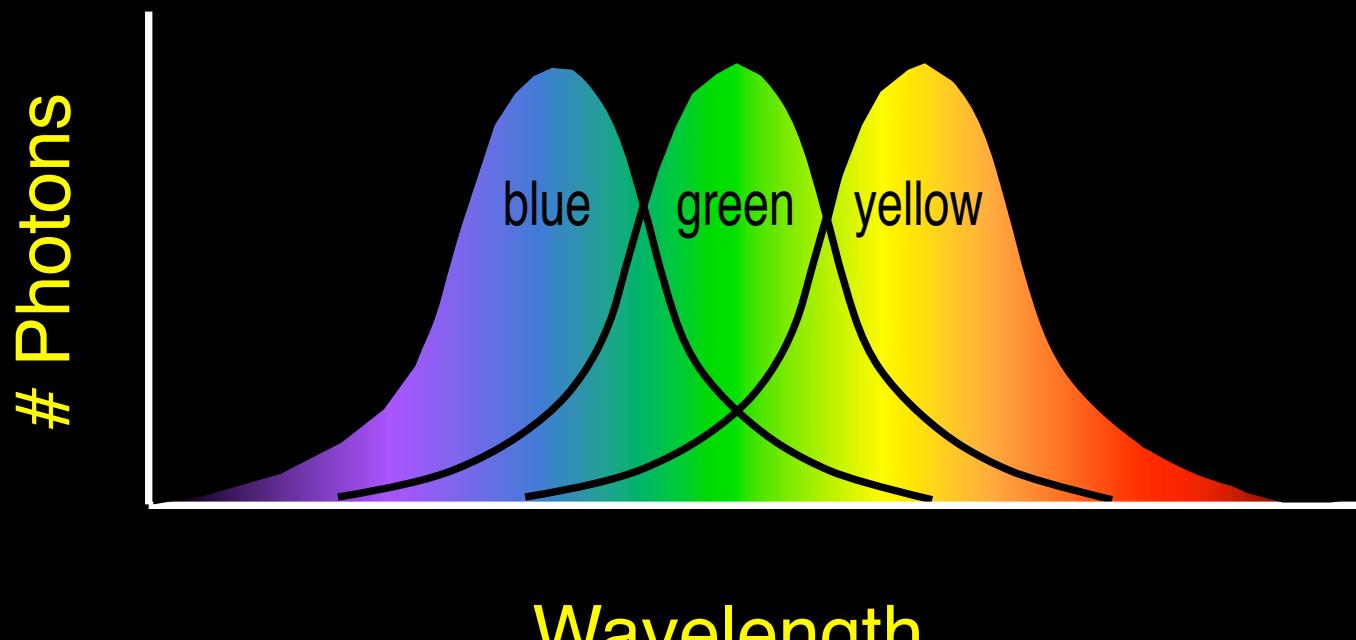
A helpful constraint:

Consider only physical spectra with normal distributions



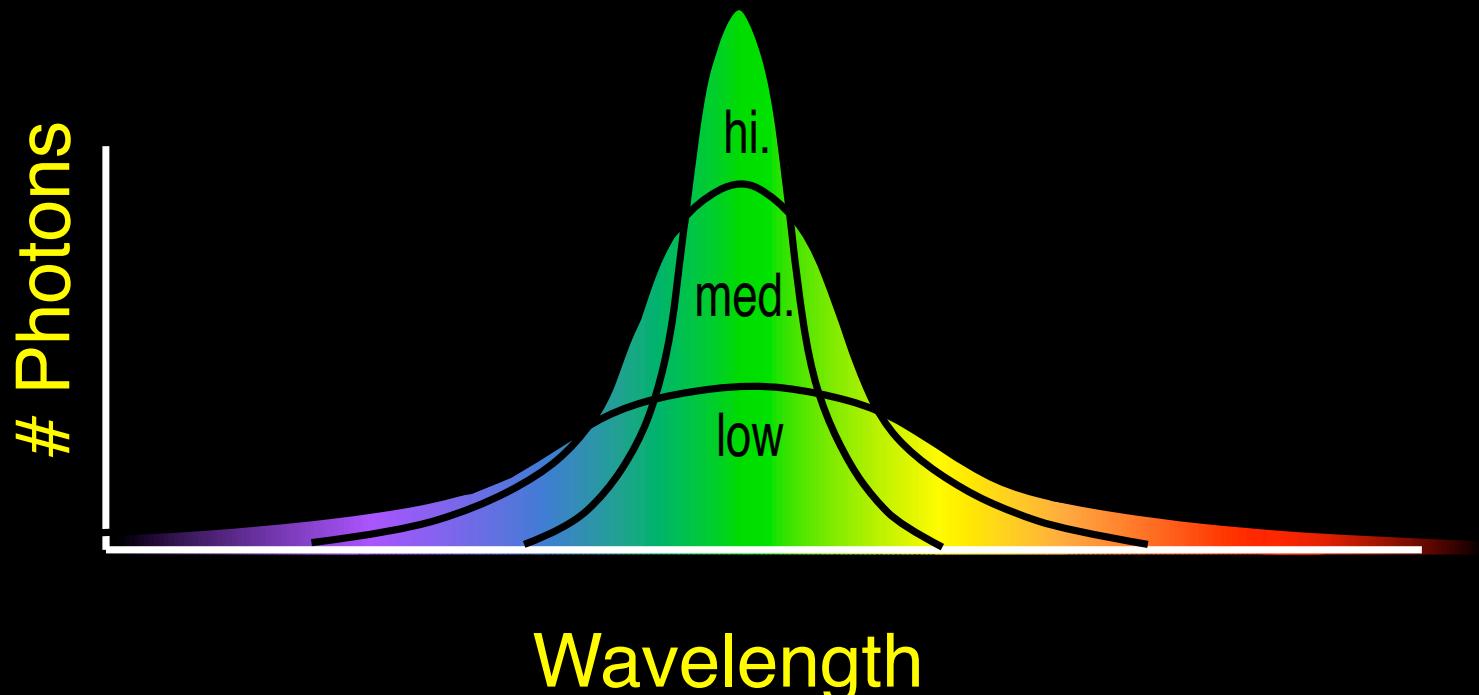
The Psychophysical Correspondence

Mean \longleftrightarrow Hue



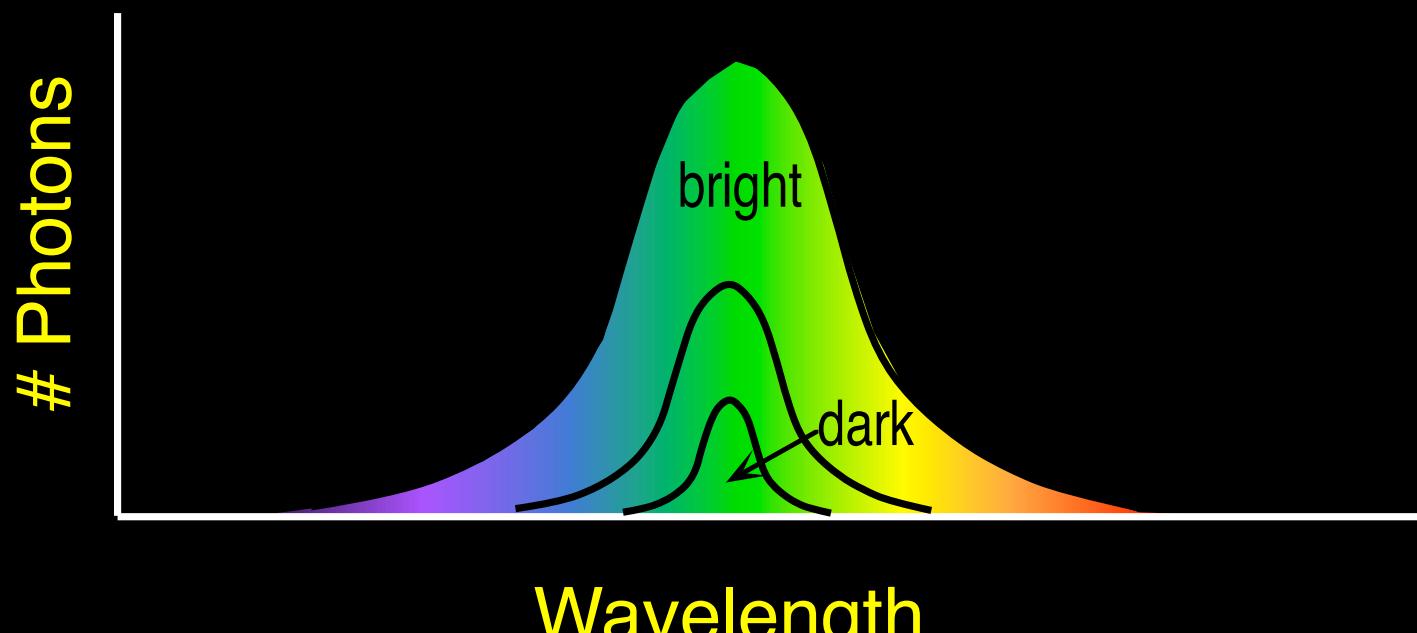
The Psychophysical Correspondence

Variance \longleftrightarrow Saturation

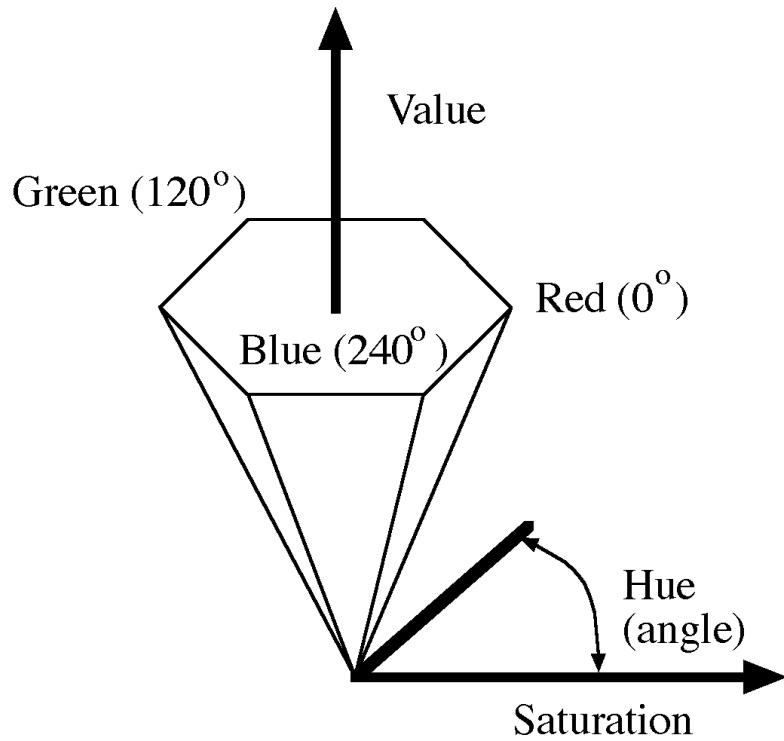
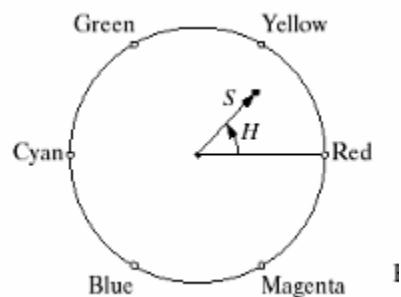
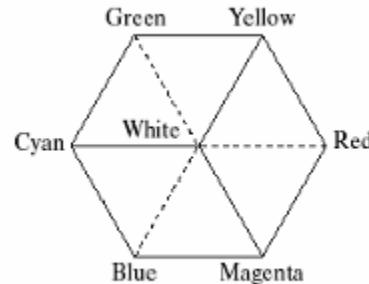


The Psychophysical Correspondence

Area \leftrightarrow Brightness

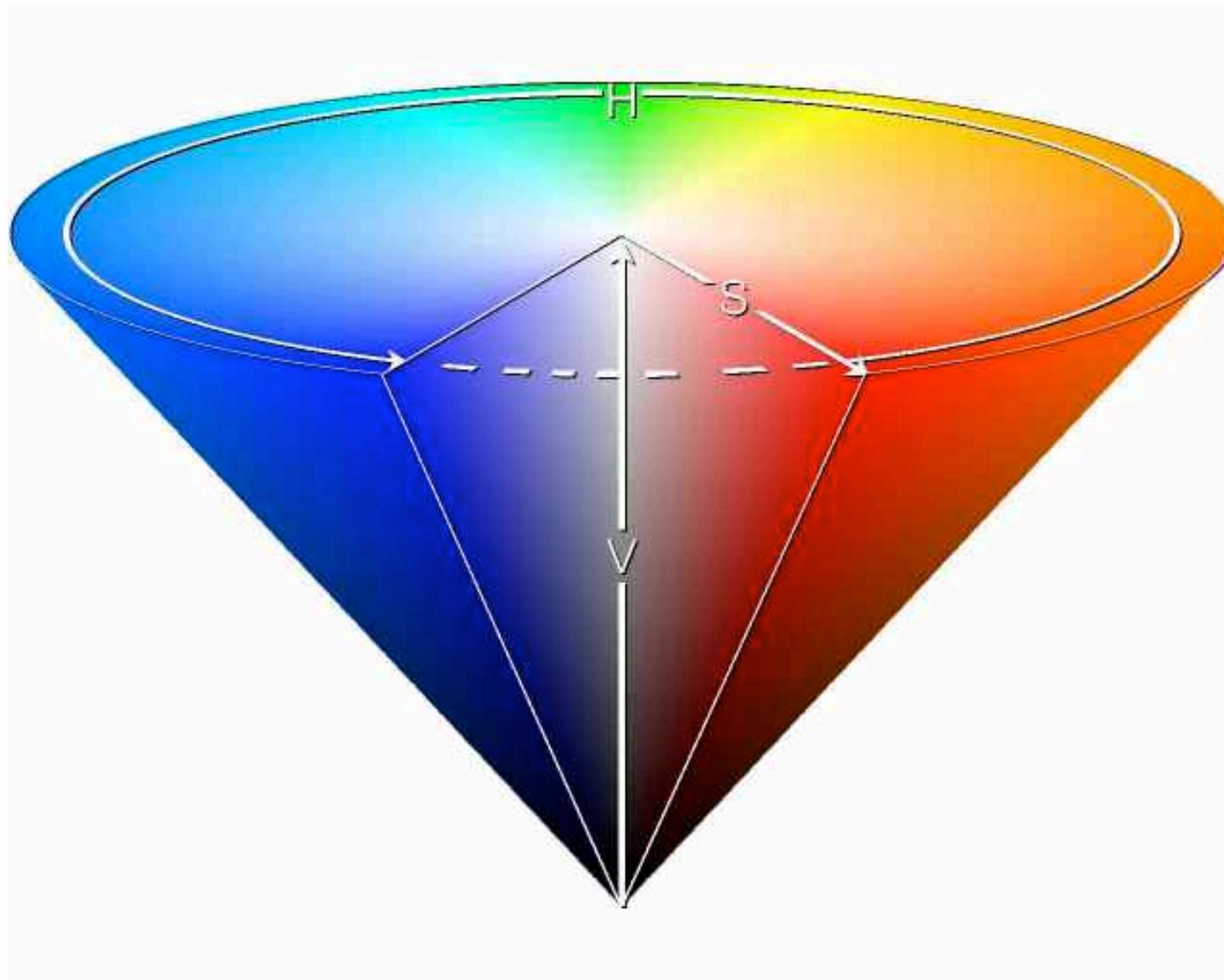


HSV



- Hue, Saturation, Value (Brightness)
 - RGB cube on its vertex
- Decouples the three components
- Use `rgb2HSV()` and `HSV2RGB()` in Matlab

HSV



RGB Color Space

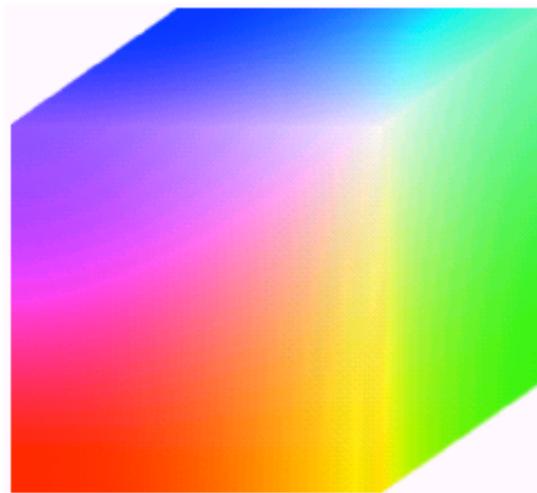
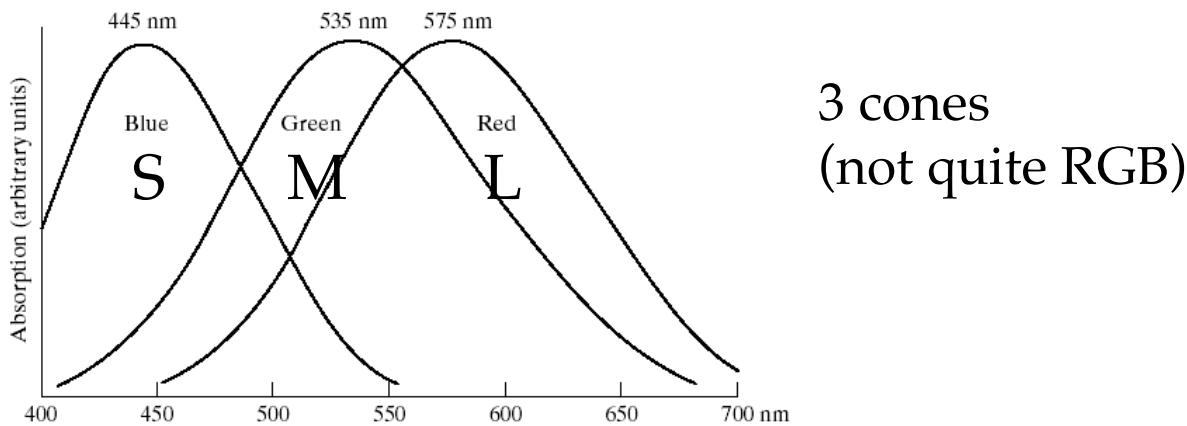


FIGURE 6.8 RGB 24-bit color cube.

- 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:



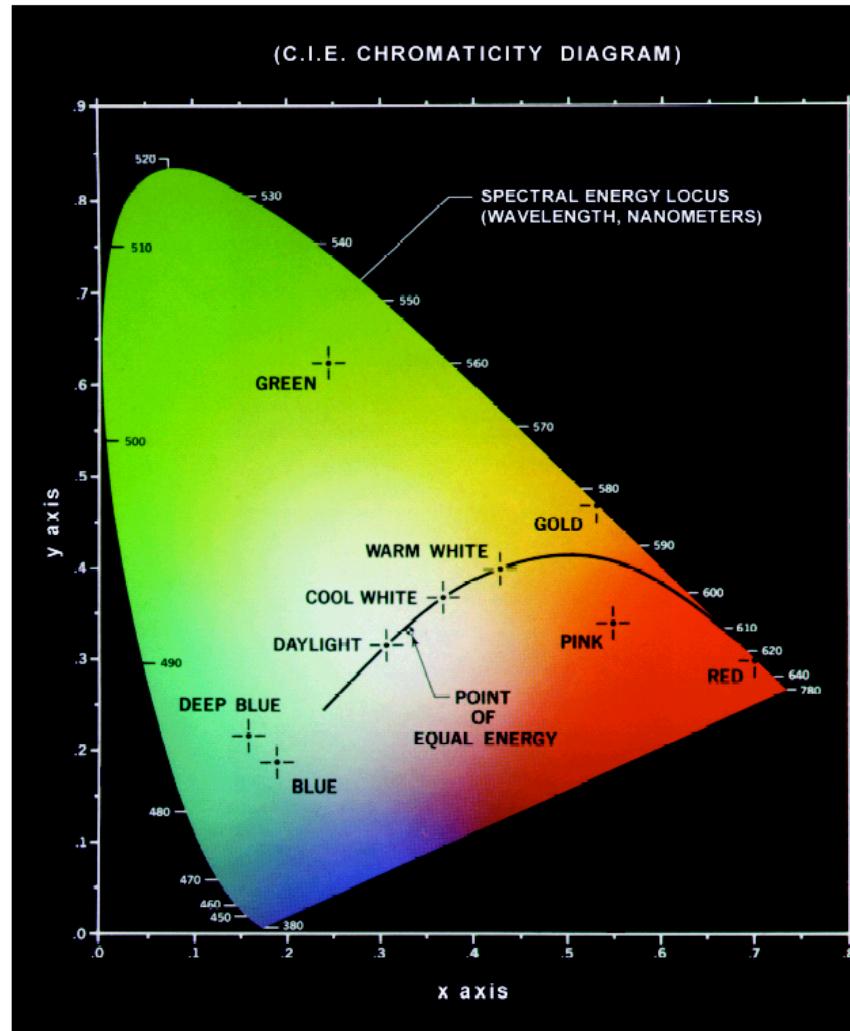
Why is M cone not midway but closer to L?

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
 - Brightness: overall intensity
 - Hue: dominant wavelength
 - Saturation: how much other stuff mixed in with hue
 - Hue + Saturation = Chromaticity
 - $(x,y) = (r/(r+g+b), g/(r+g+b))$

CIE Perceptual Space

Gamut of
Human Vision



Which colors can RGB monitor display?

Monitor and Printer Gamut

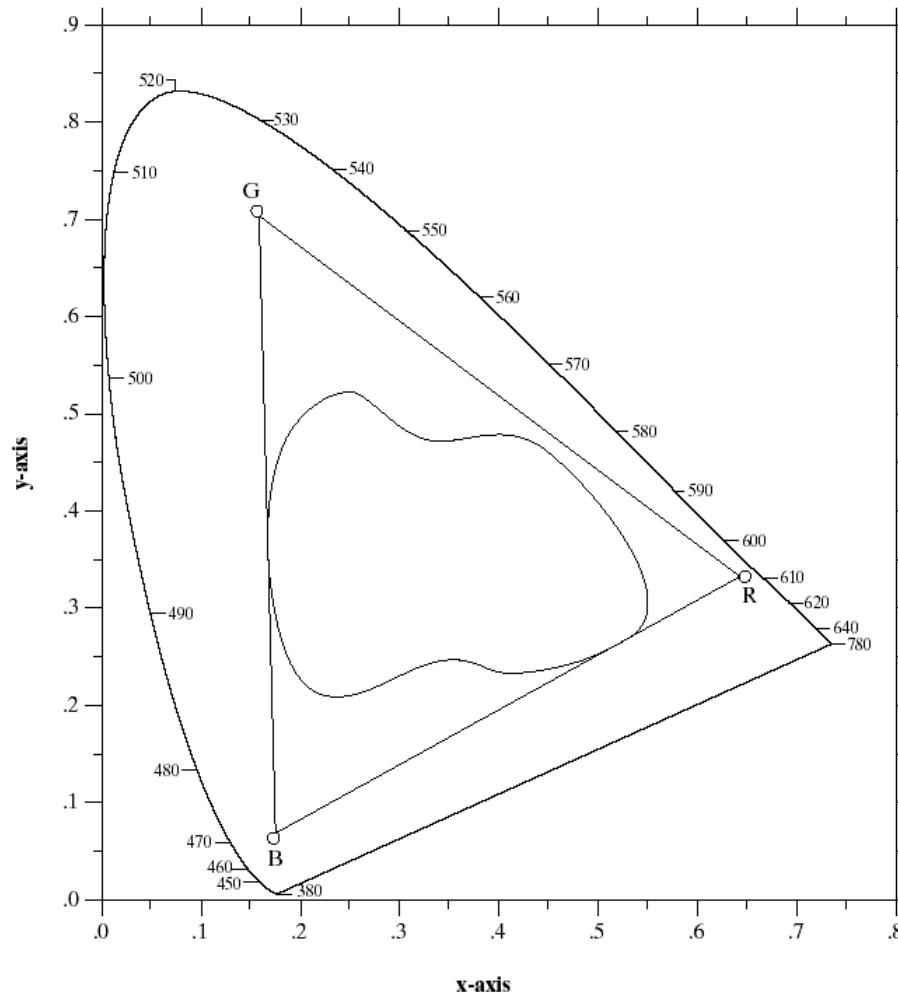


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Additive and Subtractive Color

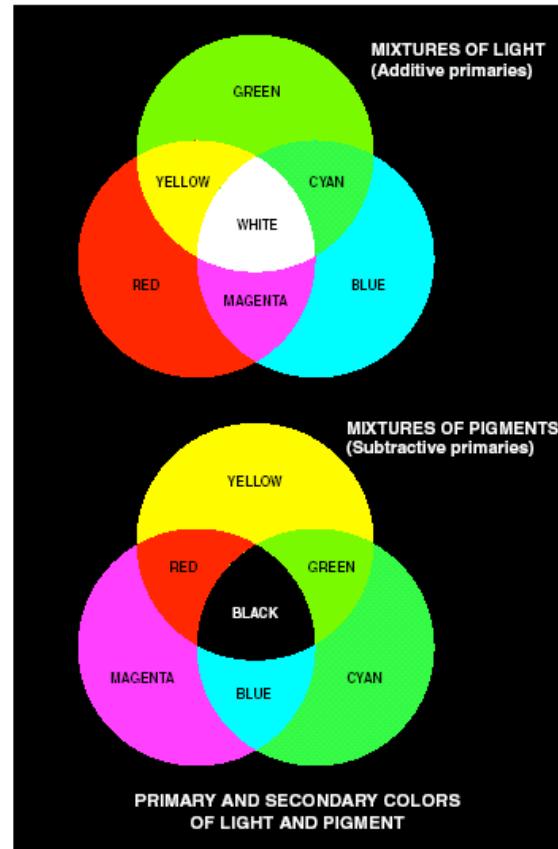
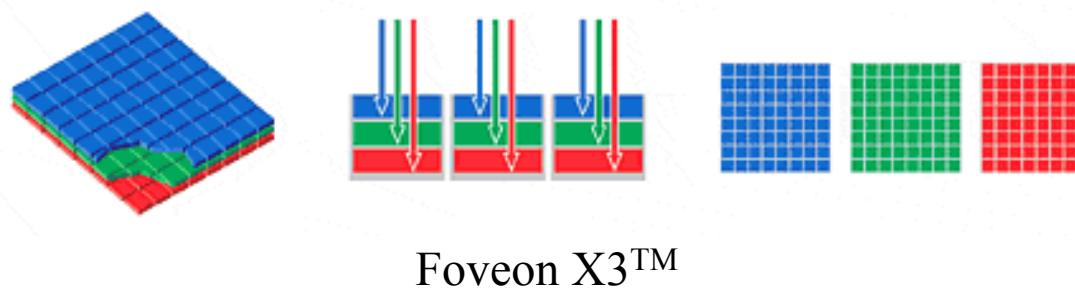
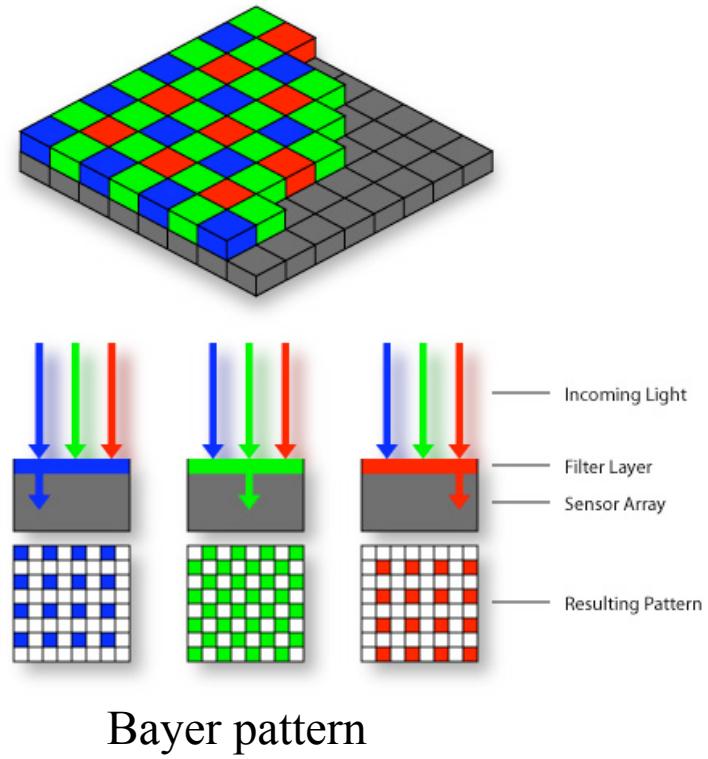
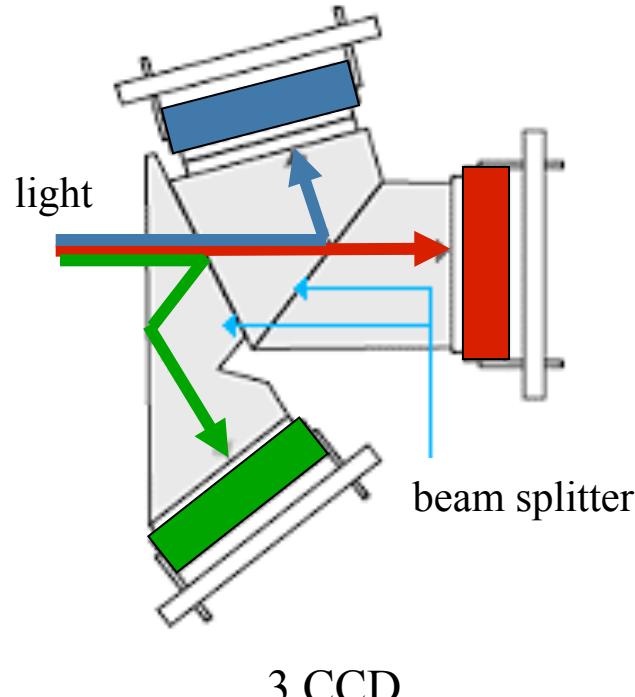
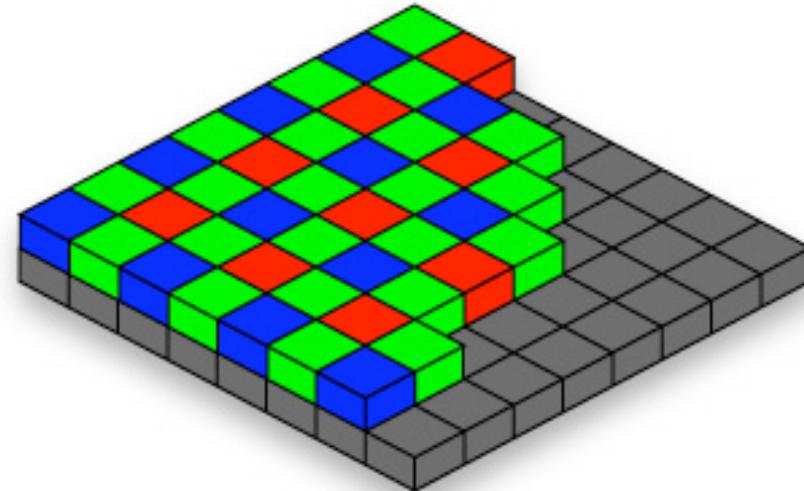
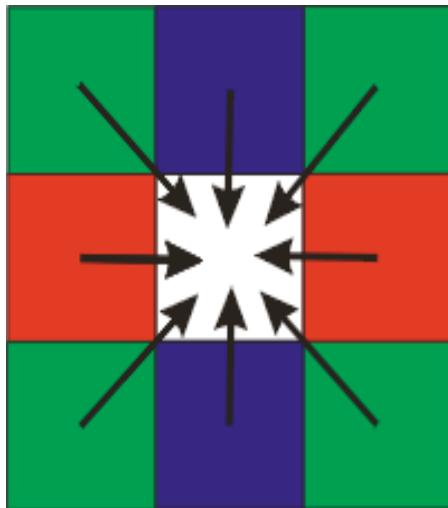


FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Sensing Color



Practical Color Sensing: Bayer Grid



- Estimate RGB at 'G' cells from neighboring values

