Computational Photography and Video:

More on Camera, Sensors & Color

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ETH

inf | Informatik Computer Science

Today's schedule

- Last week's recap & administrivia
- Exposure & Depth-of-field
- Aberrations
- Sensors
- Color sensing

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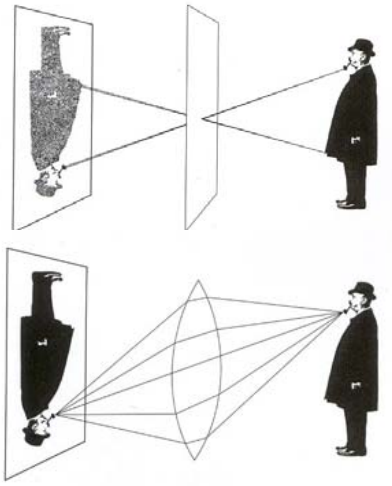
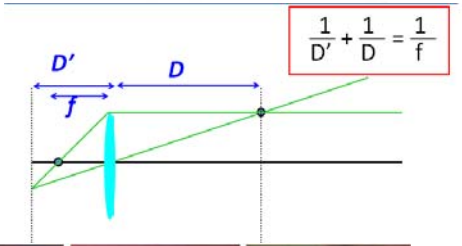
Recap

- 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





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Schedule	Computational Photography and Video	
20 Feb	Introduction to Computational Photography	
27 Feb	More on Cameras, Sensors and Color	Assignment 1: Color
5 Mar	Warping, morphing and panoramas	Assignment 2: Alignment
12 Mar	Image pyramids, Graphcuts	Assignment 3: Blending
19 Mar	Dynamic Range, HDR imaging, tone mapping	Assignment 4: HDR
26 Mar	*Easter holiday – no classes*	
2 Apr	TBD	Project proposals
9 Apr	TBD	Papers
16 Apr	TBD	Papers
23 Apr	TBD	Papers
30 Apr	TBD	Project update
7 May	TBD	Papers
14 May	TBD	Papers
21 May	TBD	Papers
28 May	TBD	Final project presentation

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Exercises

Starting next week, 2 options

- Thursday, 11-12 (status-quo)
- Wednesday 16-17 (1h break)

- Conflicts?
- Preferences?

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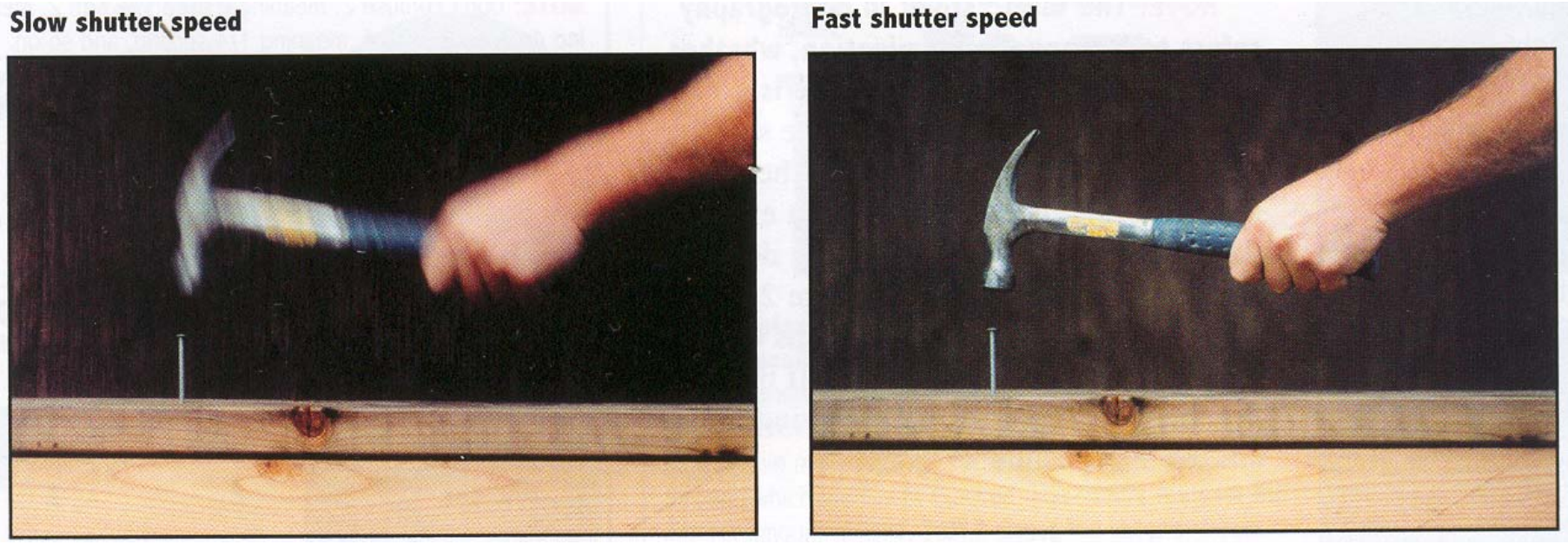
Exposure

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

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

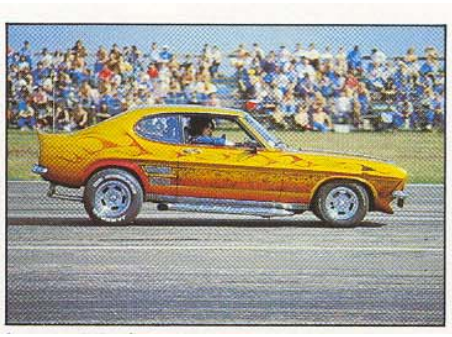
Main effect of shutter speed



From Photography, London et al.

Effect of shutter speed

- Freezing motion

Walking people	Running people	Car	Fast train
			
1/125	1/250	1/500	1/1000

Shutter

- Various technologies

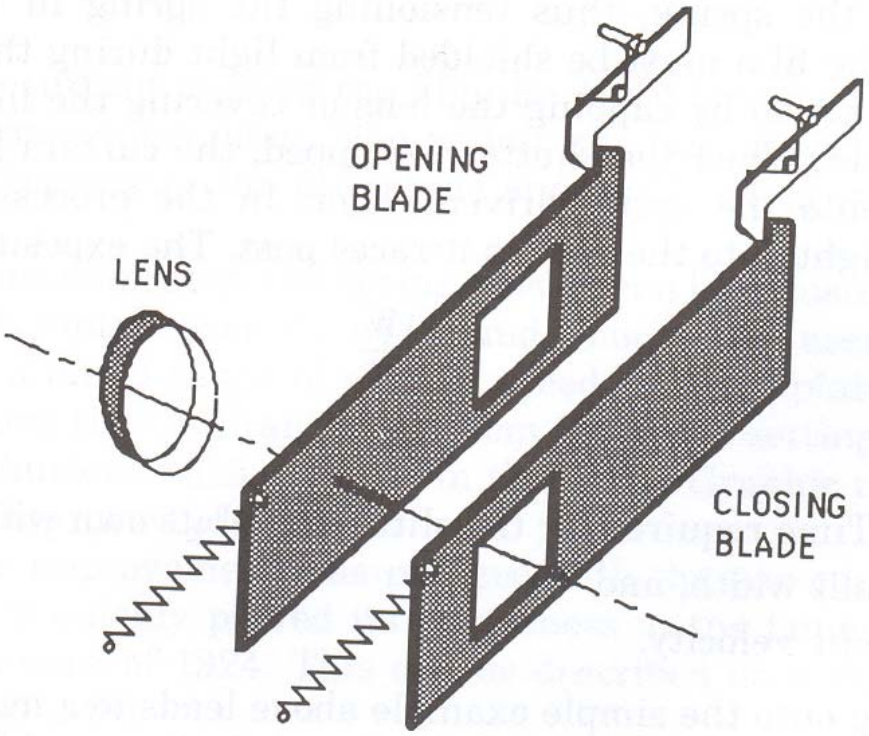


FIG. 2.8 Two-blade guillotine shutter.

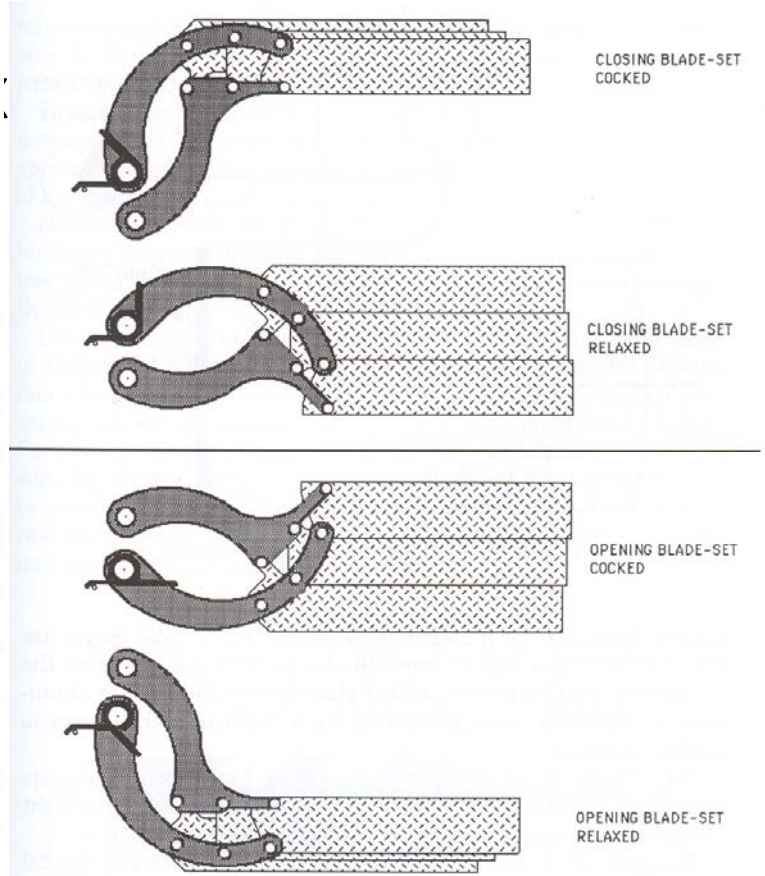
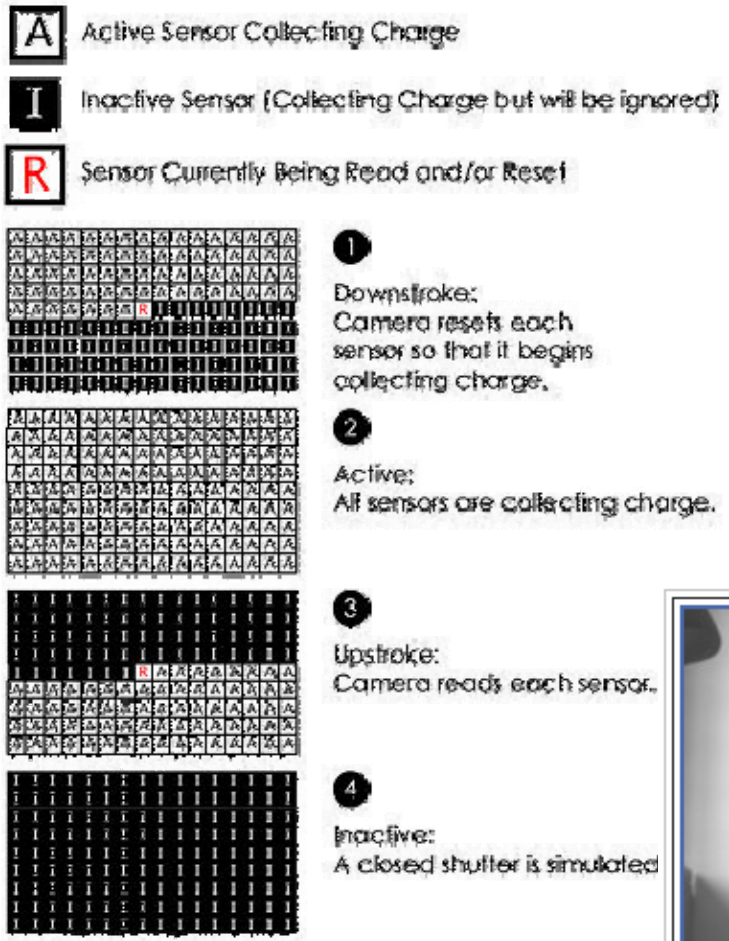


FIG. 2.12 Copal square.

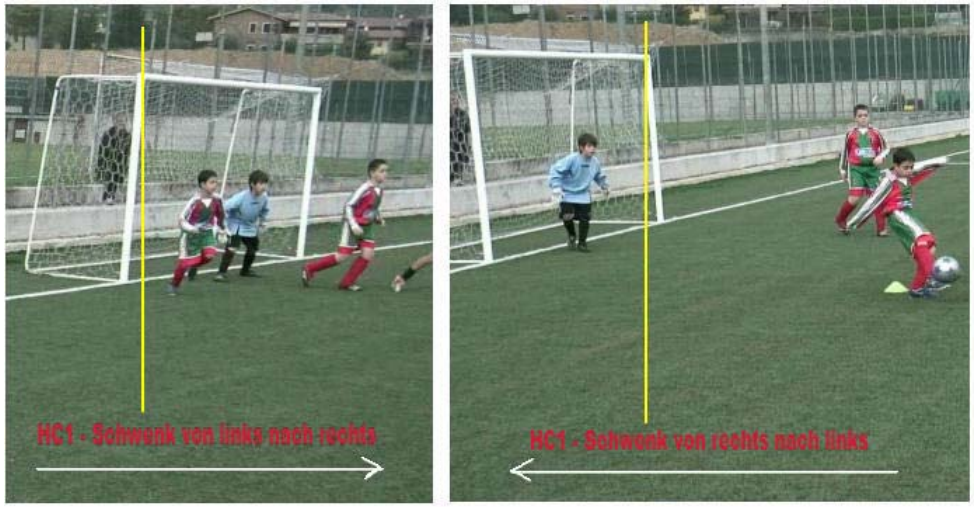
From Camera Technology, Goldberg

Figure 6–6. Jacques Henri Lartigue, *Grand Prix of the Automobile Club of France, 1912.* This classic photograph provides an exaggerated example of the distortion that can be caused by a focal-plane shutter. The oval shape of the automobile tire is caused by the motion of the car between the time the bottom of the tire was exposed and the top. (Remember–the image is upside-down on the negative.) The same principle caused the leaning appearance of the spectators. Lartigue turned the camera to follow the automobile (panning), and thus the image of the spectators moved at the film plane during the exposure. (Courtesy International Museum of Photography at George Eastman House.)

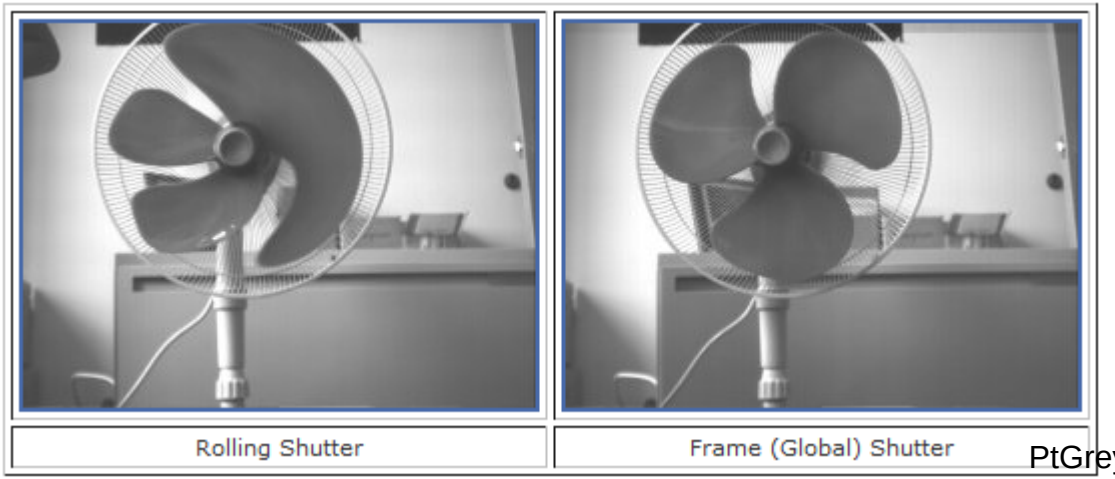
Electronic rolling shutter



From redhax.com



http://dvxuser.com/jason/CMOS-CCD/



PtGrey

Flash synch speed?

- Fastest shutter speed for which the shutter opens completely at some instant.
- For faster speeds, it opens and closes at the same time and exposes a slit.
- Modern high-speed flash synch uses multiple flash bursts

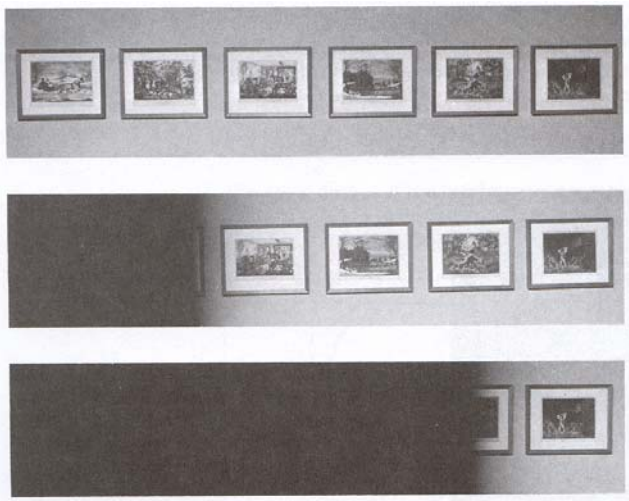
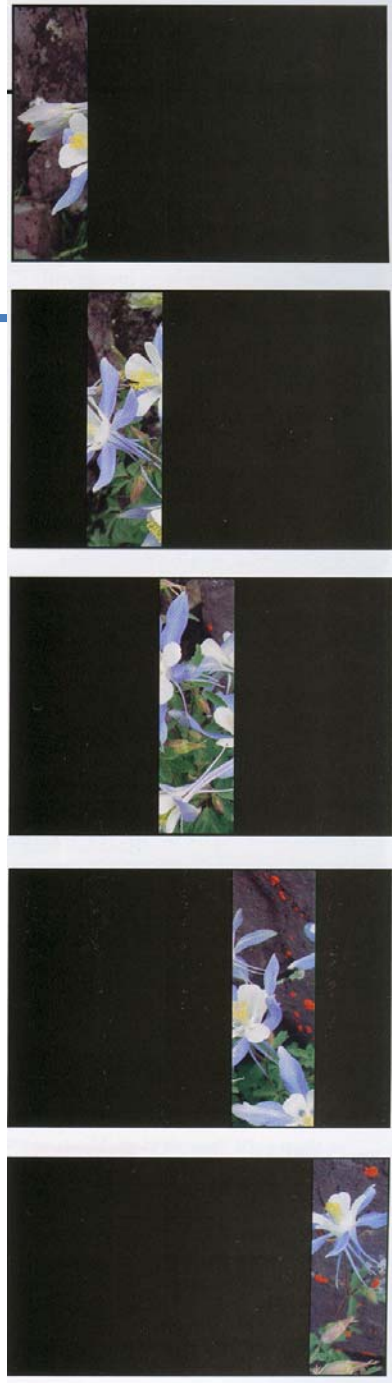


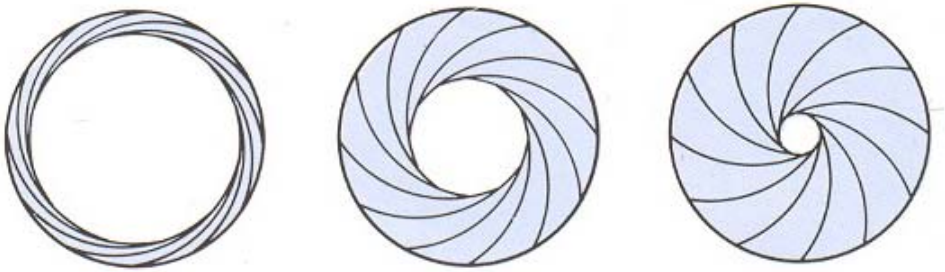
Figure 2–16 Electronic-flash illumination used with a focal-plane-shutter at shutter speeds of 1/60, 1/125, and 1/250 second (top to bottom). At the higher speeds the second curtain begins to cover the film before the first curtain has completely uncovered it. The highest shutter speeds that can be used with electronic flash have increased dramatically with newer single-lens-reflex cameras and flash units.



From Photography, London et al.

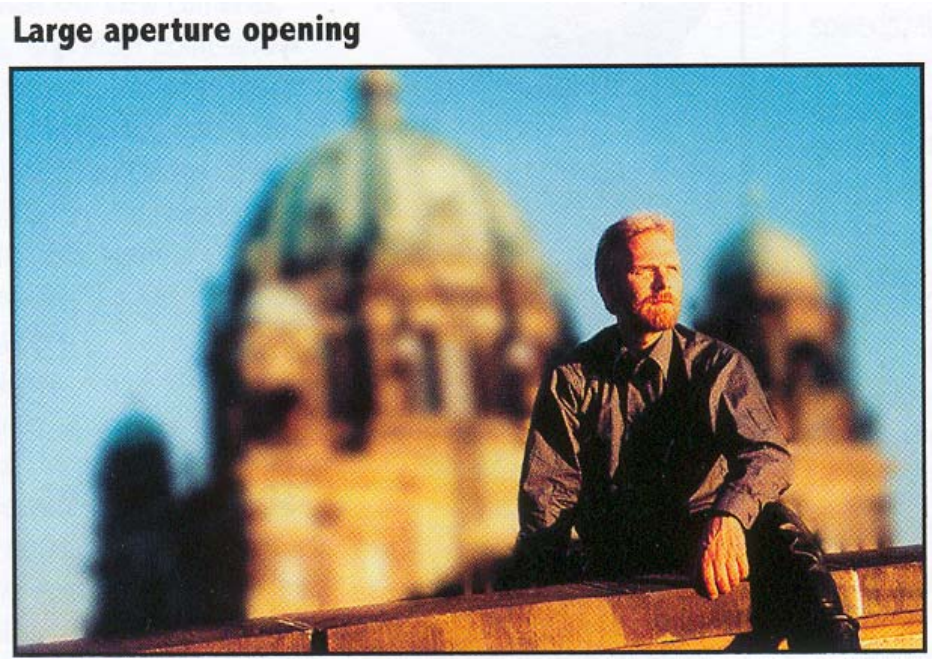
Aperture

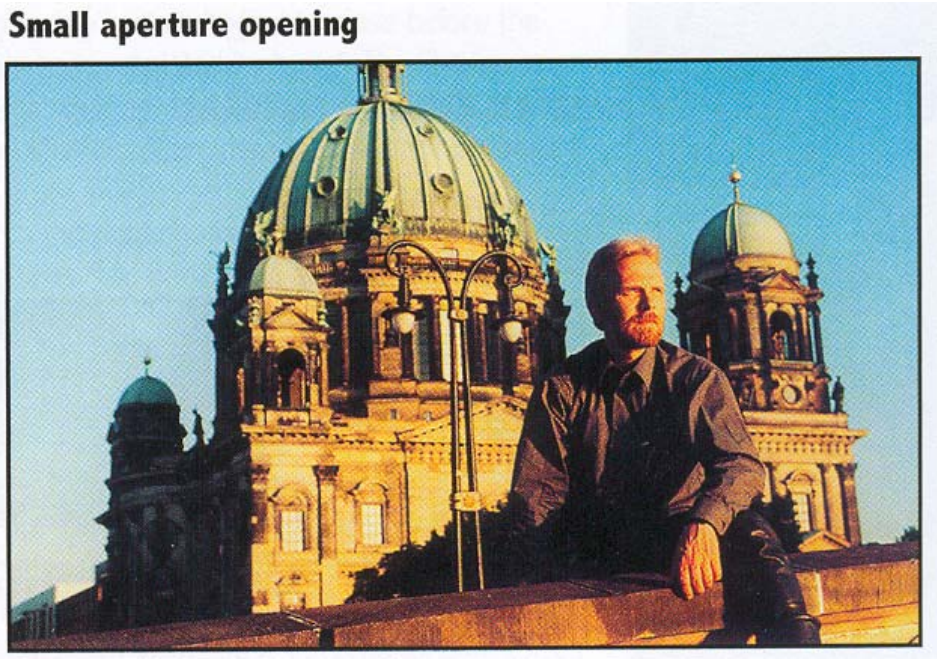
- Diameter of the lens opening (controlled by diaphragm)
- Expressed as a fraction of focal length, in f-number
  - f/2.0 on a 50mm means that the aperture is 25mm
  - f/2.0 on a 100mm means that the aperture is 50mm
- Disconcerting: small f number = big aperture
- What happens to the area of the aperture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



Main effect of aperture

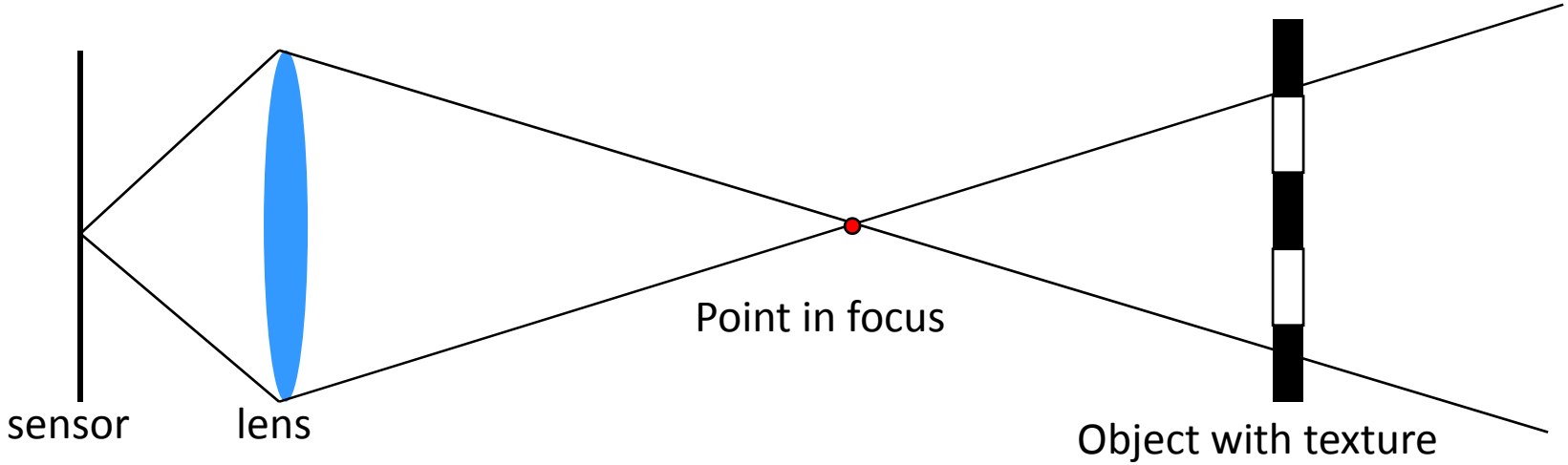
- Depth of field





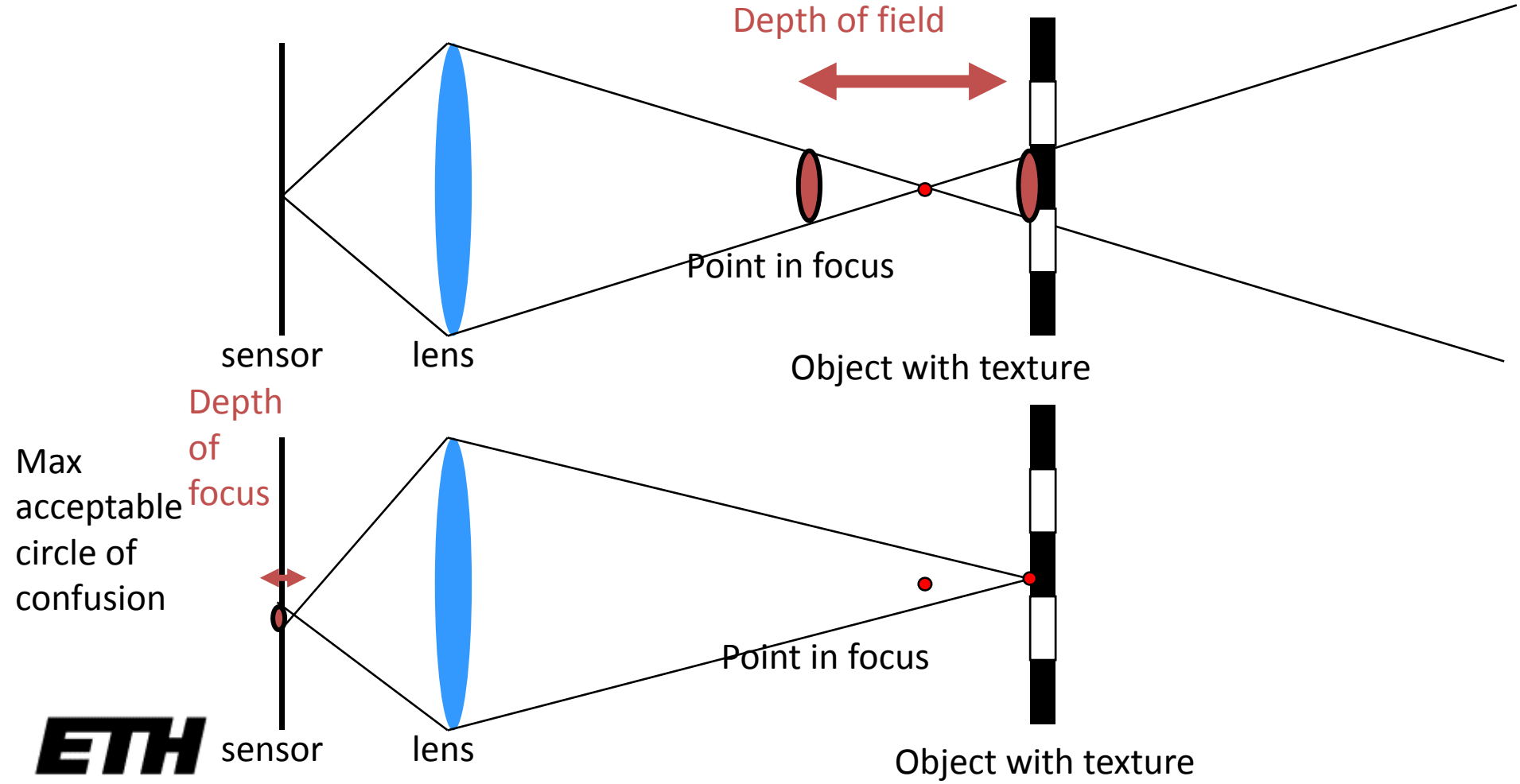
From Photography, London et al.

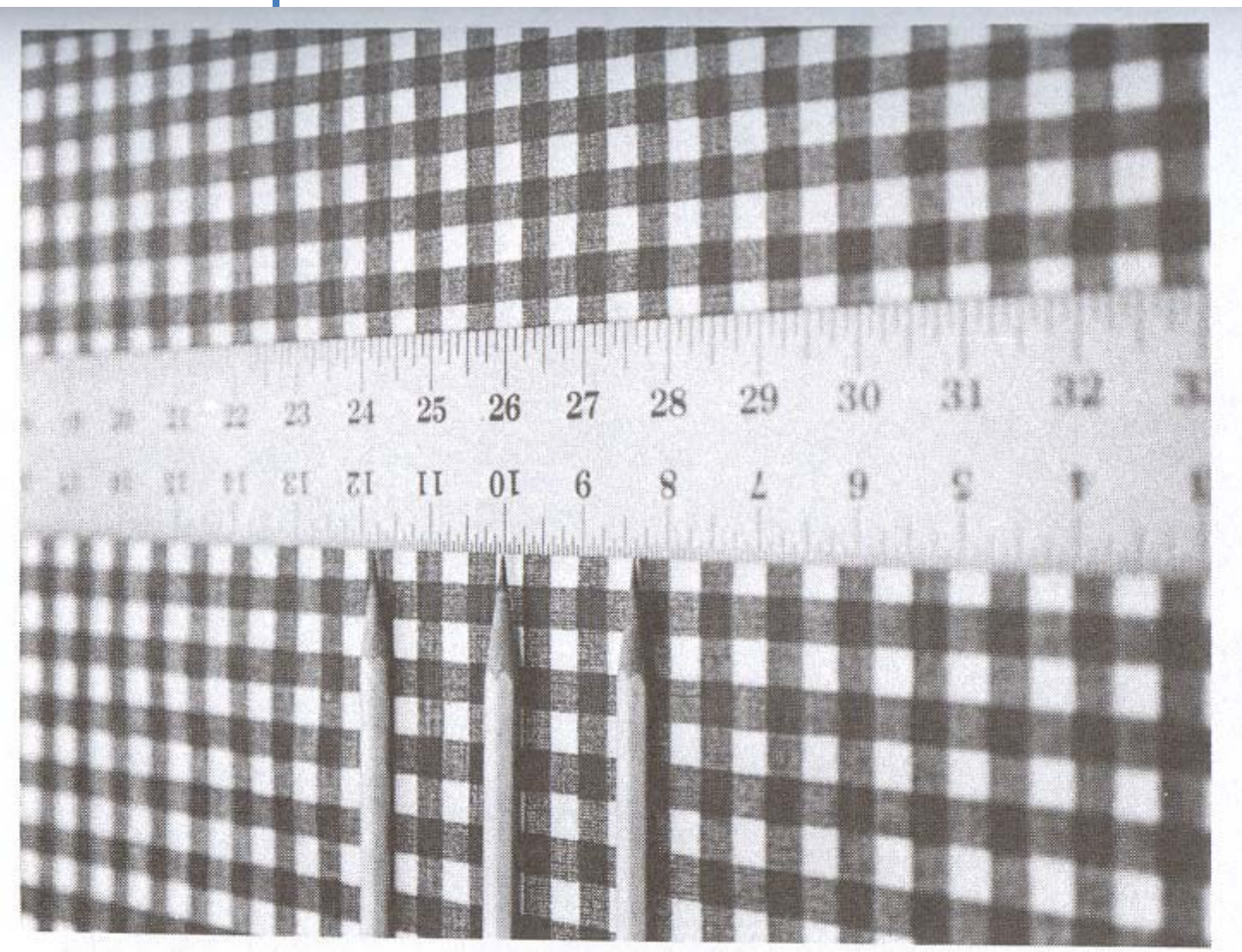
Depth of field



Depth of field

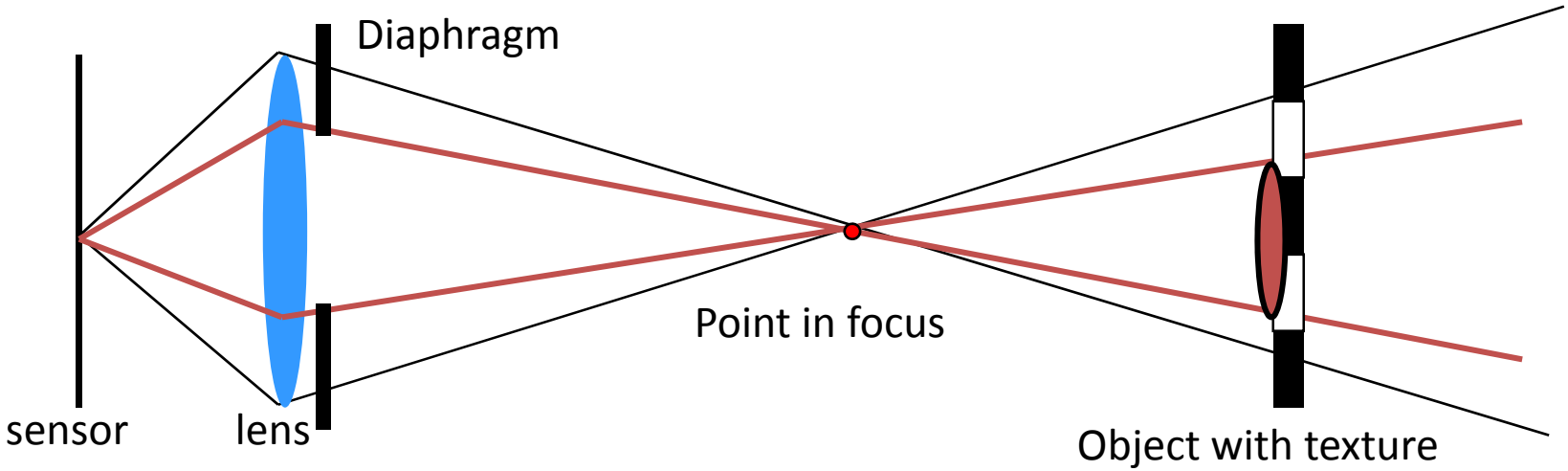
- We allow for some tolerance



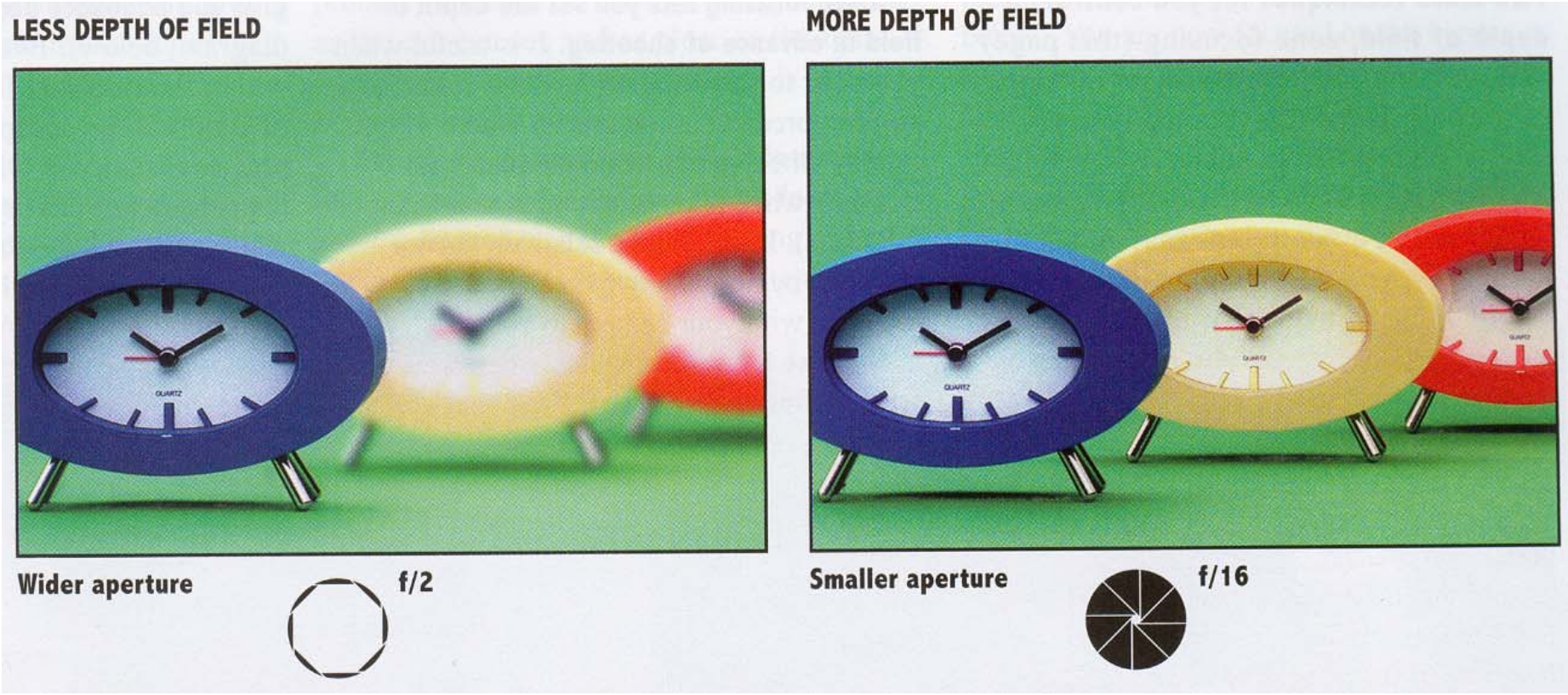

23 24 25 26 27 28 29 30 31 32
13 12 11 10 6 8 7 9 5 4

Depth of field

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



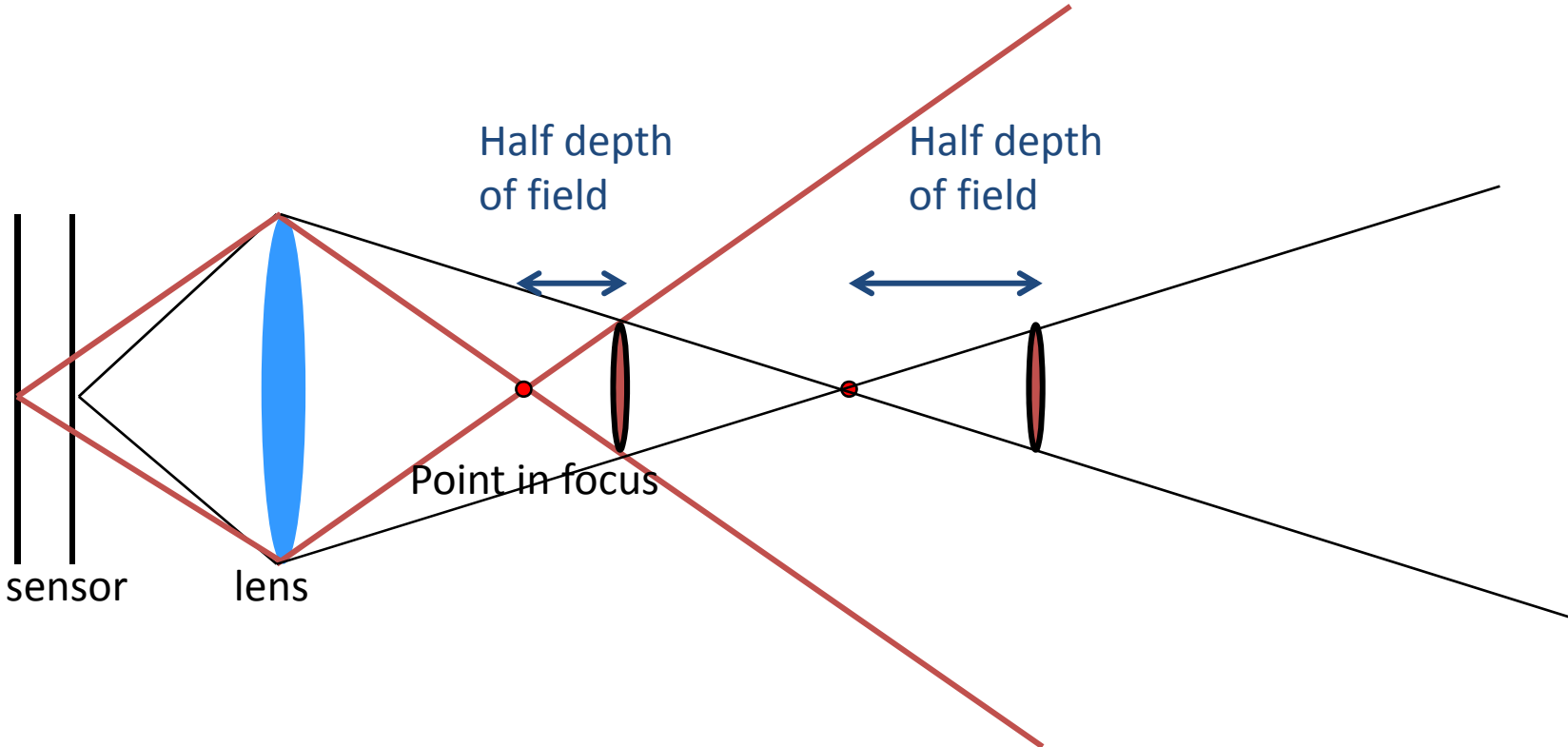
Depth of field



From Photography, London et al.

Depth of field & focusing distance

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



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Depth of field & focusing distance

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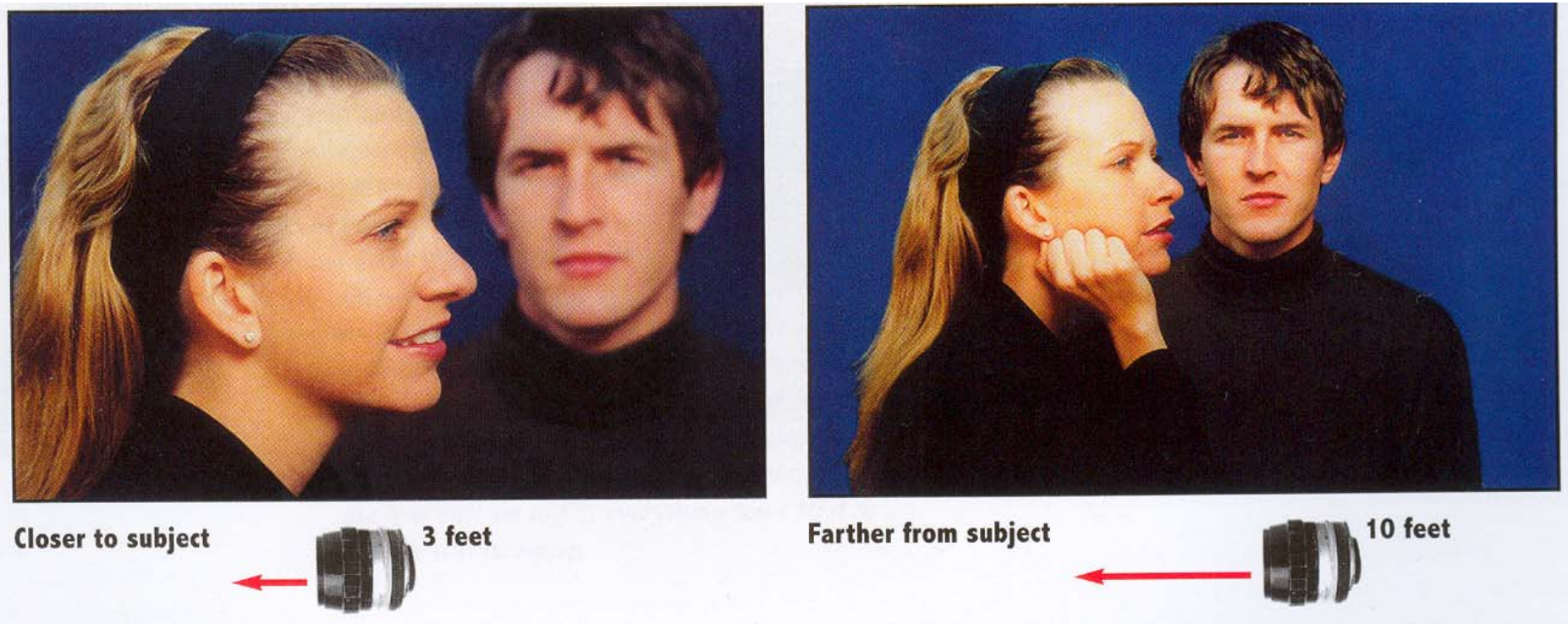


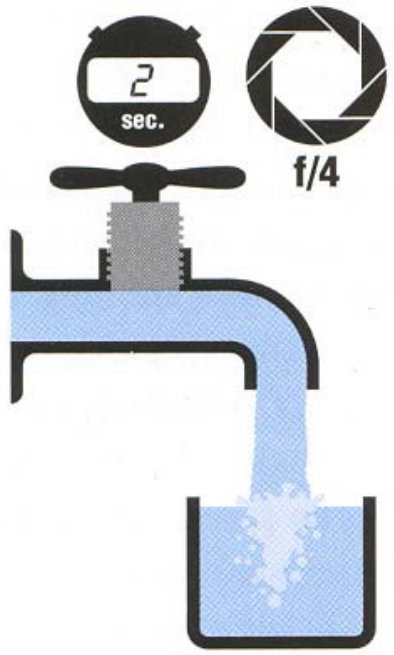
From Photography, London et al.

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

Questions?

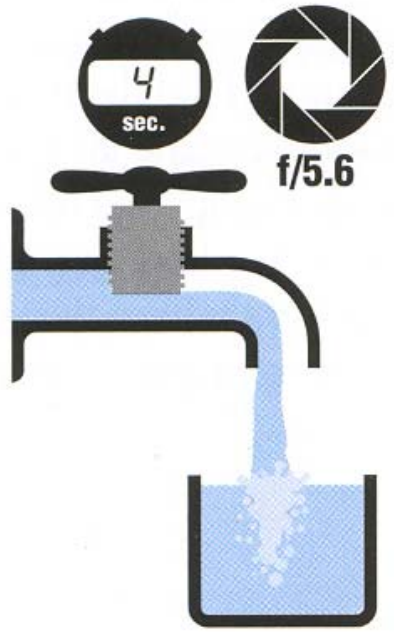
Exposure



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

  The same exposure is obtained wit an exposure twice as long and an aperture *area* half as big

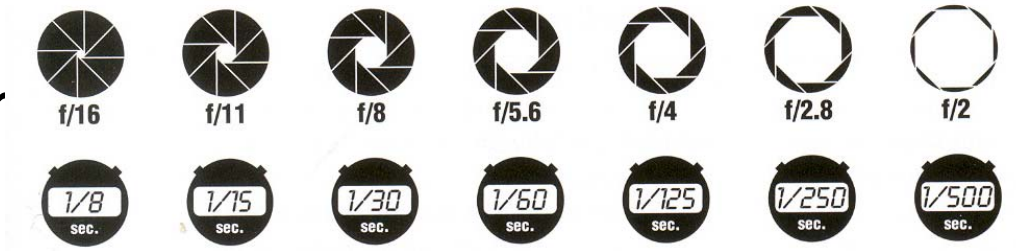
  - Hence square root of two progression of f stops vs. power of two progression of shutter speed
  - Reciprocity can fail for very long exposures



From Photography, London et al.

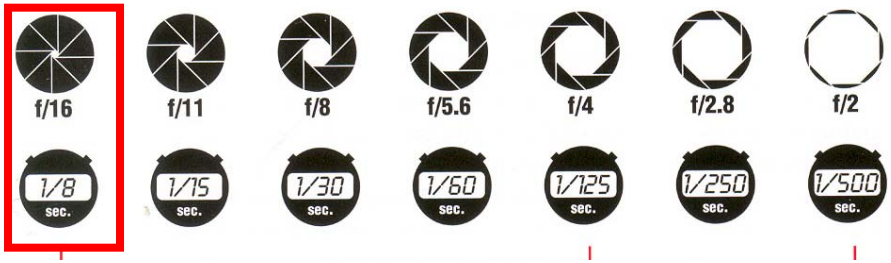
Reciprocity

- Assume we know how much light we need
- We have the choice between speed/aperture pairs

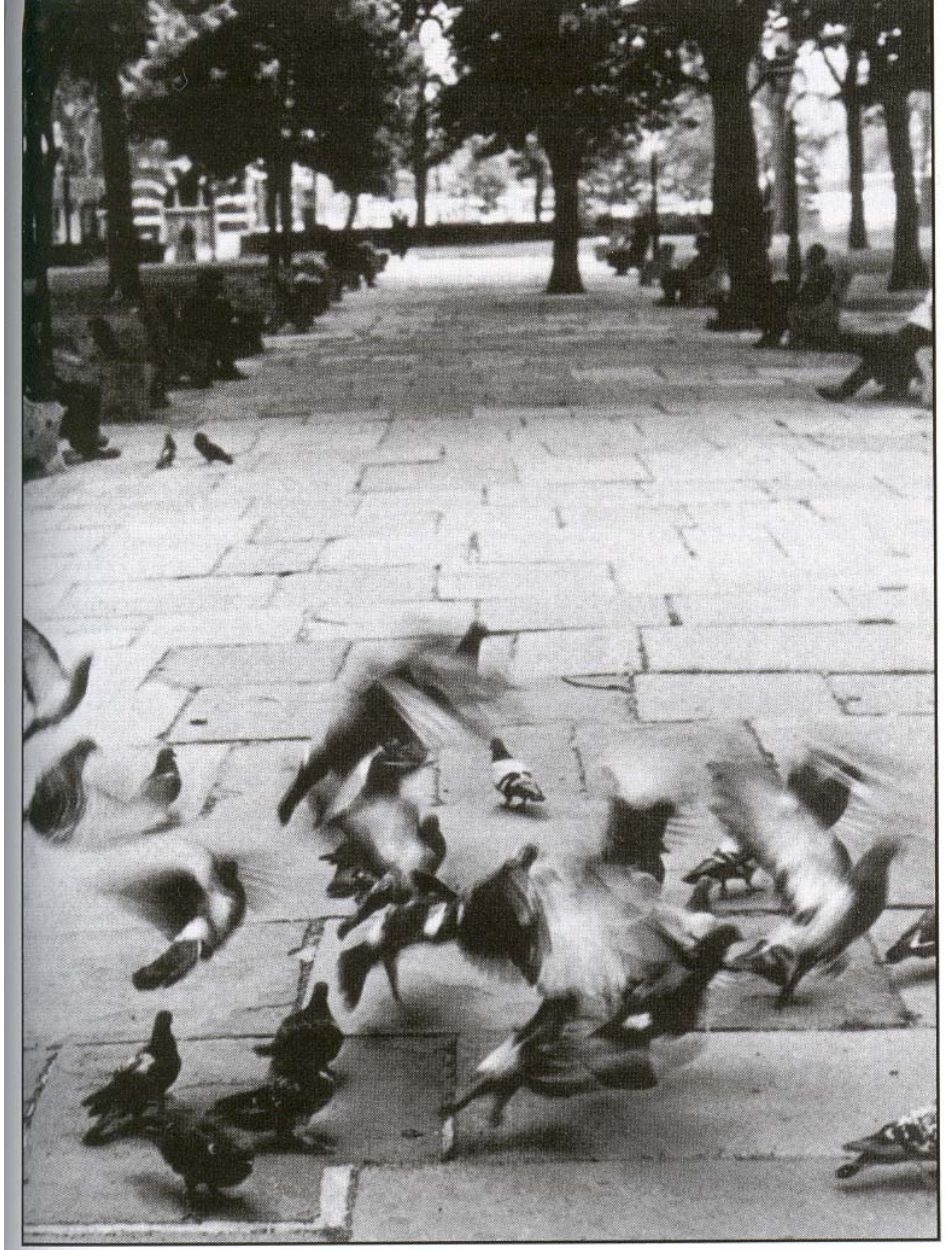


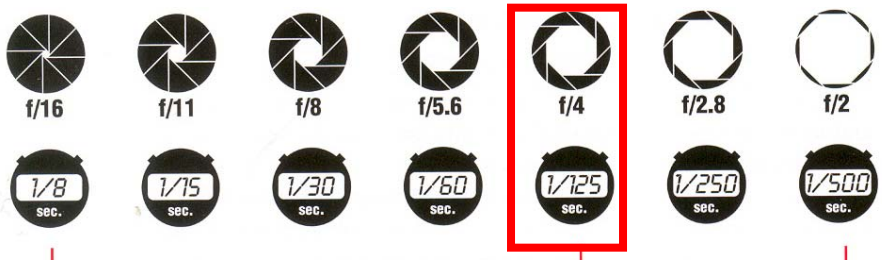
- What will guide our choice of a shutter speed?
  - Freeze motion vs. motion blur, camera shake
- What will guide our choice of an aperture?
  - Depth of field, diffraction limit
- Often we must compromise
  - Open more to enable faster speed (but shallow DoF)

Small aperture (deep depth of field), slow shutter speed (motion blurred). *In th 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 shar It also meant that a tripod had to be used to hold the camera steady.*



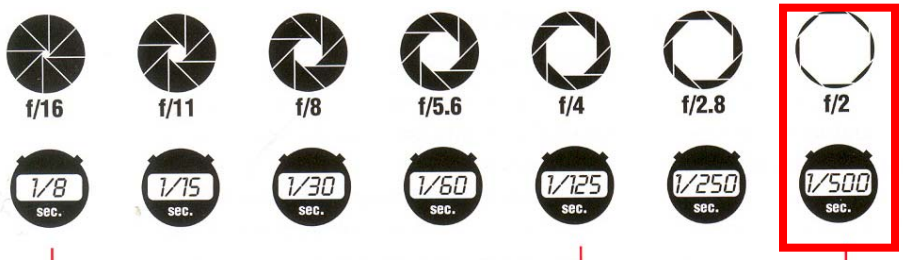
From Photography, London et al.





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.



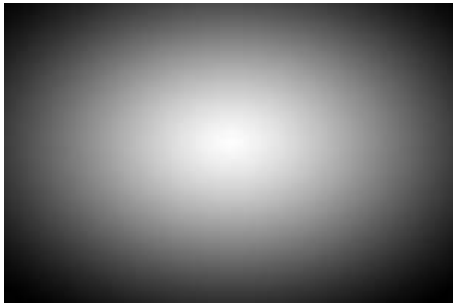
Large aperture (shallow depth of field), fast shutter speed (motion sharp). *A fa*
shutter speed (1/500 sec) stops the motion of the pigeons so completely that the
flapping wings are frozen. But the wide aperture (f/2) needed gives so little dept
of field that the background is now out of focus.

From Photography, London et al.

Questions?

Metering

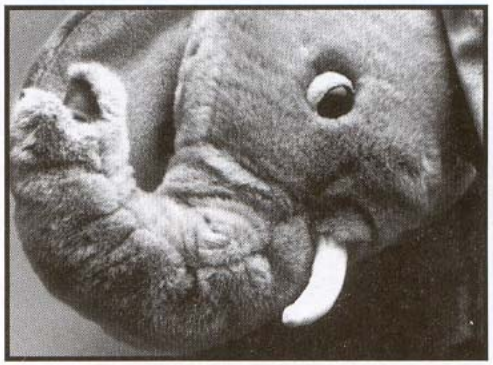
- Photosensitive sensors measure scene luminance
- Usually TTL (through the lens)
- Simple version: center-weighted average



- 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

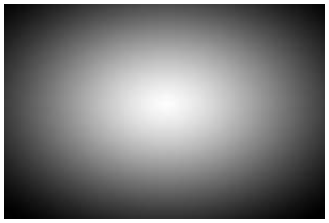
Black gorilla given exposure suggested by meter

Black gorilla given 2 stops less exposure

From Photography, London et al.

Metering

- Centered average
- Spot
- Smart metering
  - Nikon 3D matrix
  - Canon evaluative
- Incident
  - Measure incoming light



Next slide

Choice on Nikon

http://www.mir.com.my//

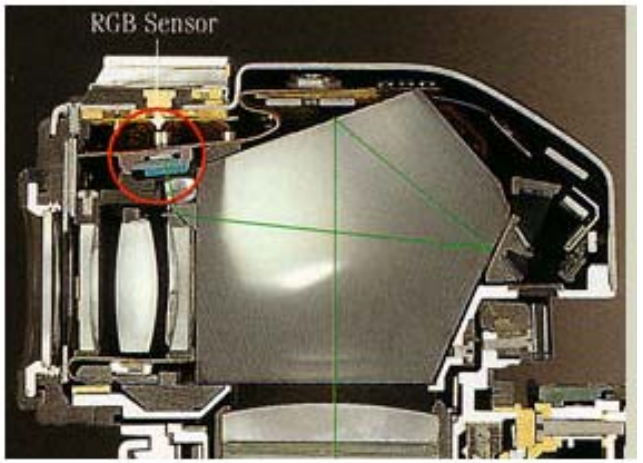
From the luminous landscape

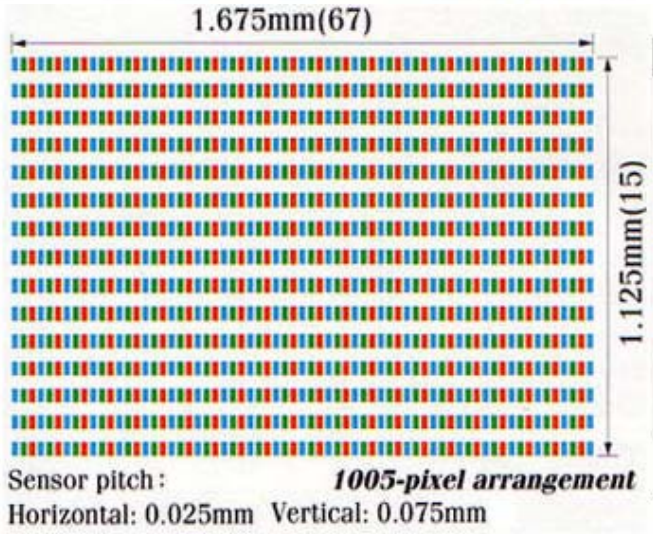
ETH

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
  - 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

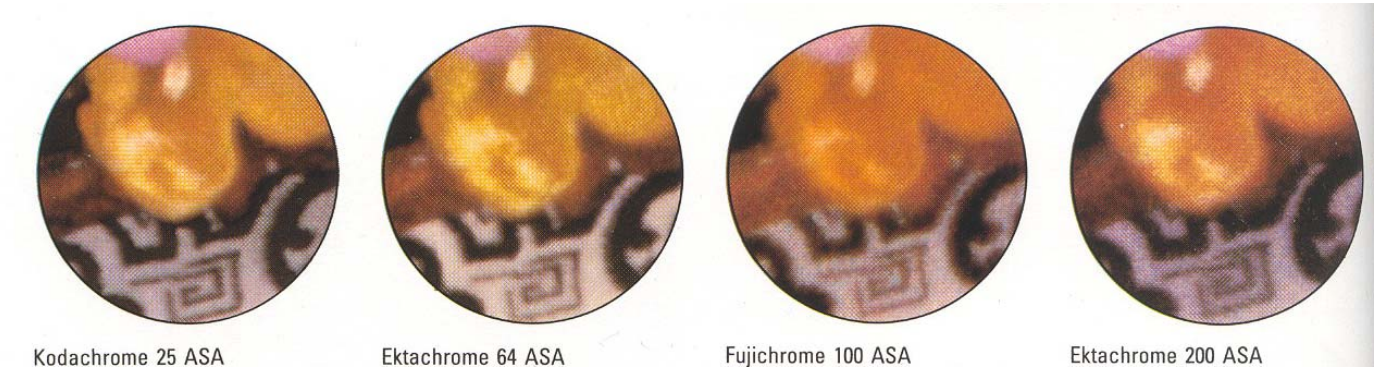
Recap: Metering

- Measure scene brightness
- Some advanced modes that take multiple sources of information
- Still an open problem

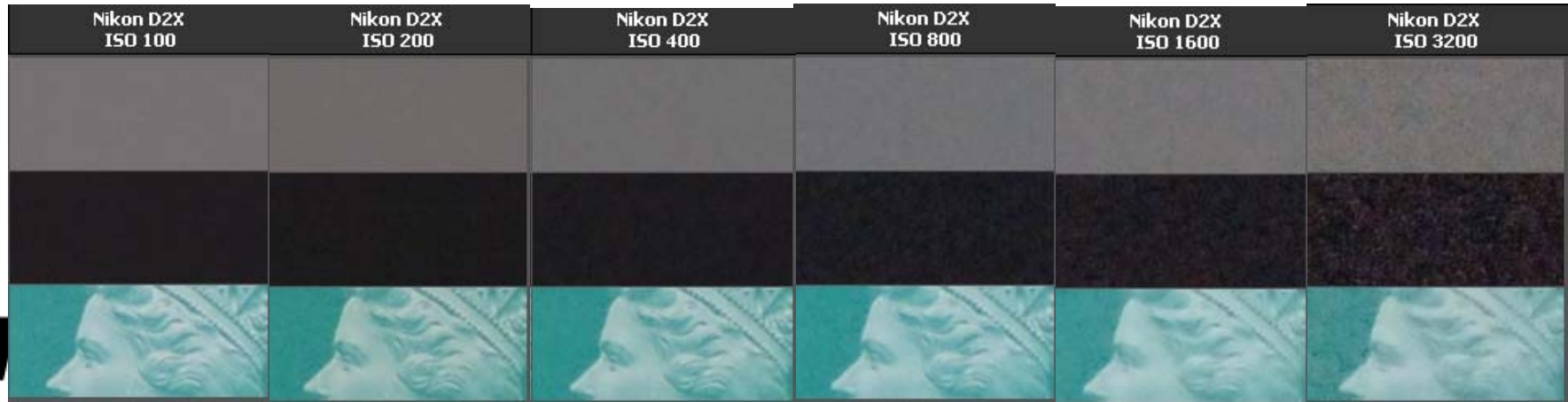
Questions?

Sensitivity (ISO)

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



- From dpreview.com



Today's schedule

- Last week's recap & administrivia
- Exposure & Depth-of-field
- Aberrations
- Sensors
- Color sensing

Aberrations

- 2 types:

1. geometrical

geometrical : small for paraxial rays

study through 3rd order optics $\sin(\theta) \approx \theta - \frac{\theta^3}{6}$

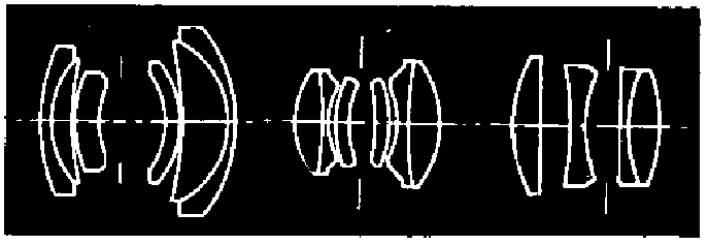
2. chromatic

chromatic : refractive index function of wavelength

Geometric aberrations

- spherical aberration
- astigmatism
- distortion
- coma

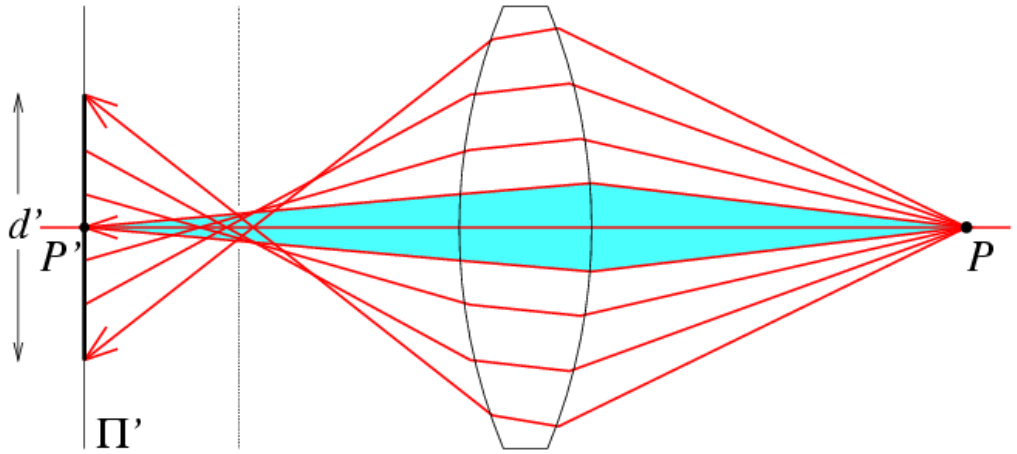
aberrations are reduced by combining lenses



Spherical aberration

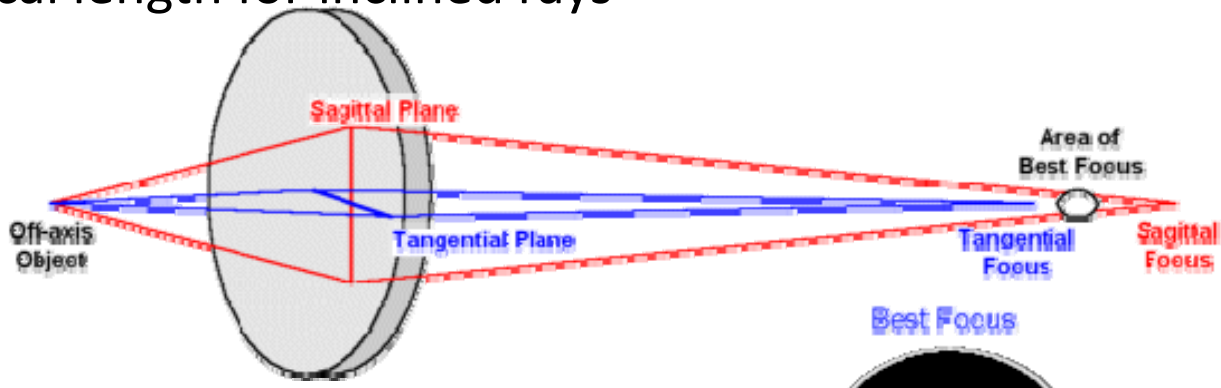
rays parallel to the axis do not converge

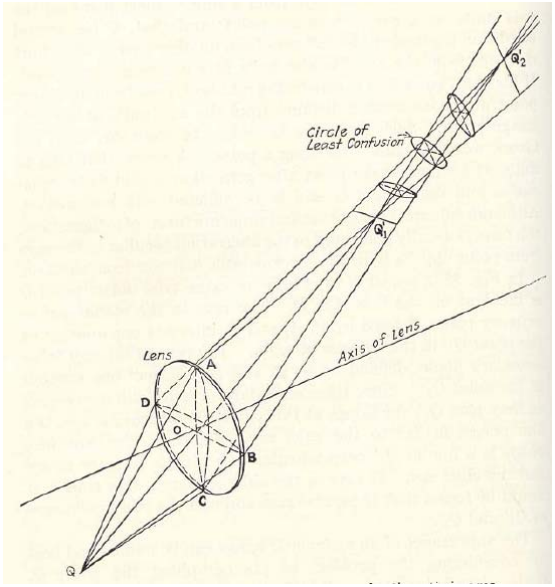
outer portions of the lens yield smaller focal lenghts

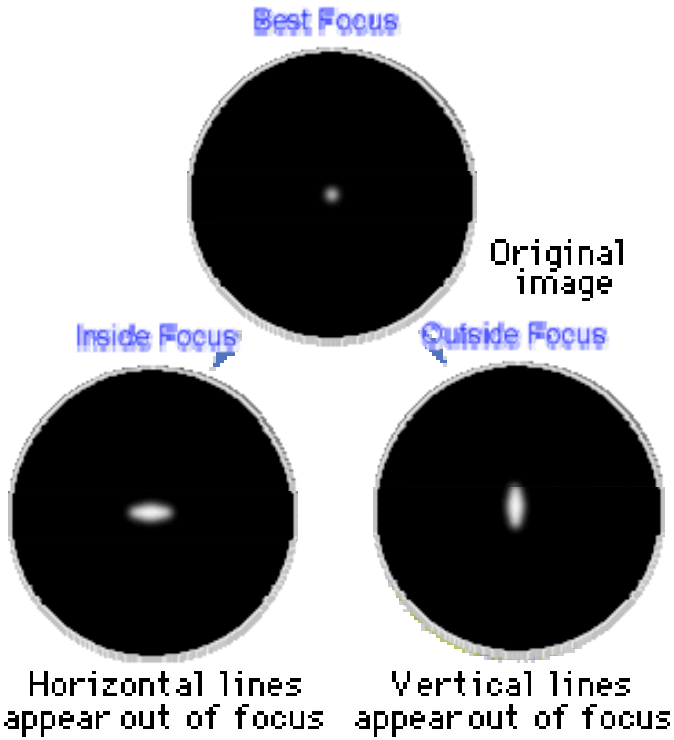


Astigmatism

Different focal length for inclined rays

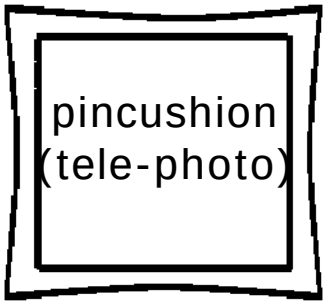


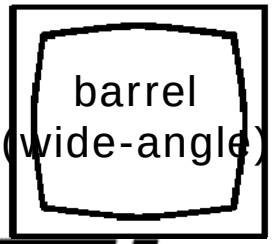


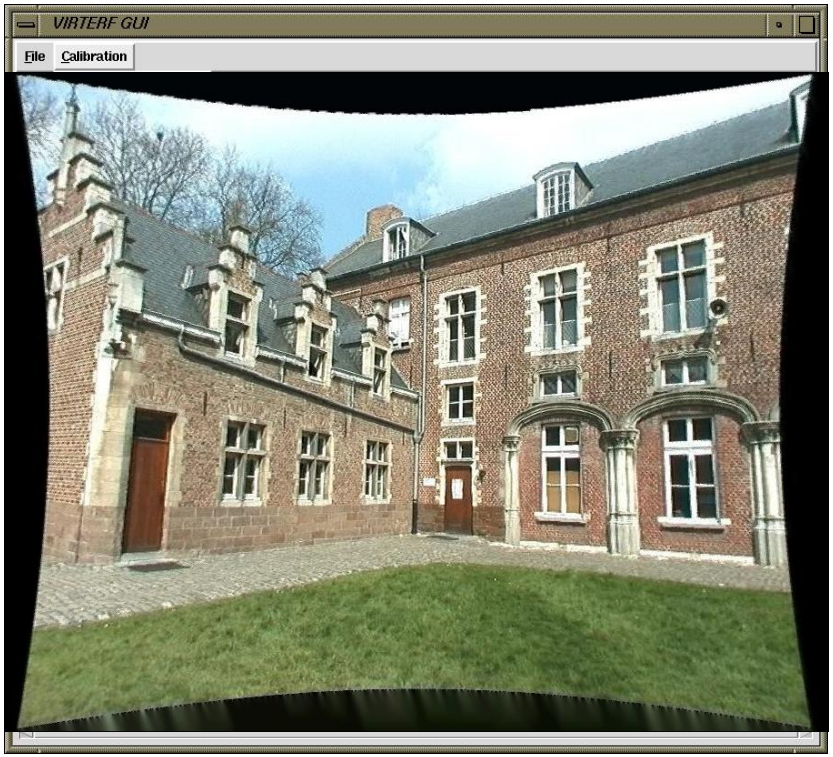


Radial distortion

magnification/focal length different
for different angles of inclination







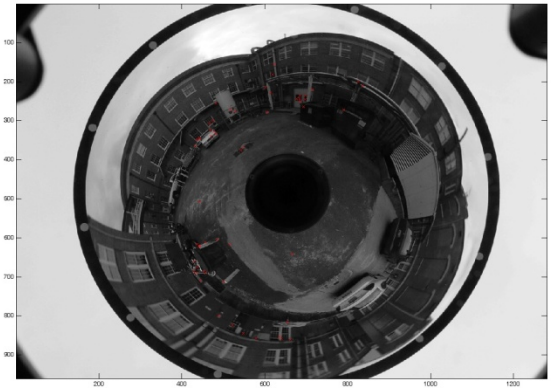
Can be corrected! (if parameters are know)

Ultra wide-angle optics

- Sometimes distortion is what you want

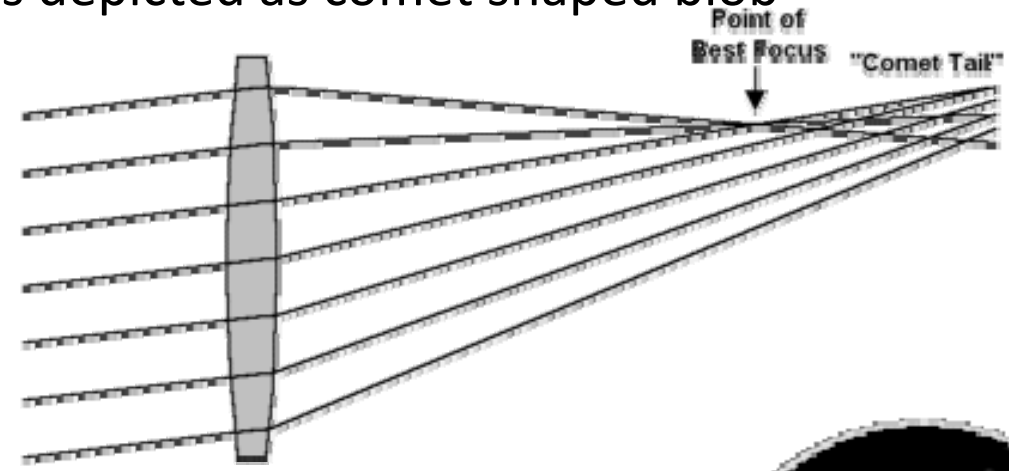
Fisheye lens

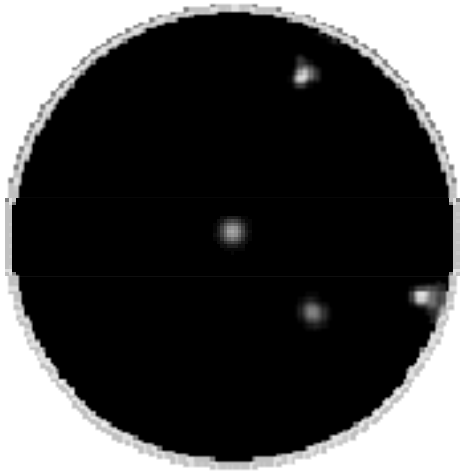
Cata-dioptric system (lens + mirror)



Coma

point off the axis depicted as comet shaped blob





Chromatic aberration

- rays of different wavelengths focused in different planes

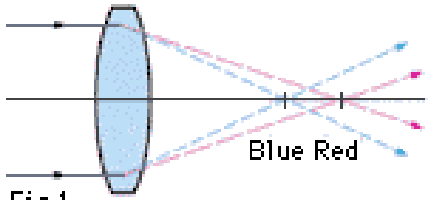


Fig.1
Axial chromatic aberration

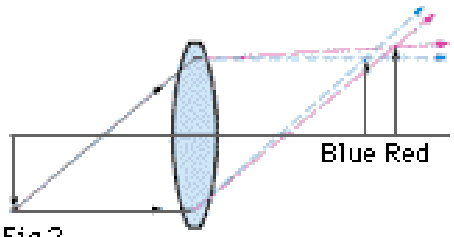
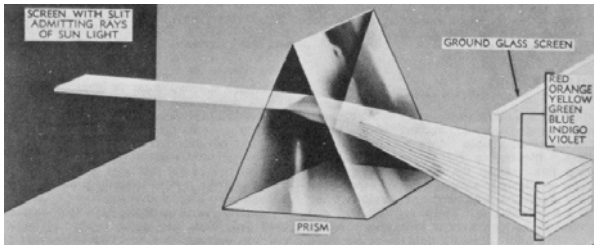


Fig.2
Magnification chromatic aberration


The image is blurred and appears colored at the fringe.

- cannot be removed completely
- sometimes achromatization is achieved for more than 2 wavelengths



Vignetting

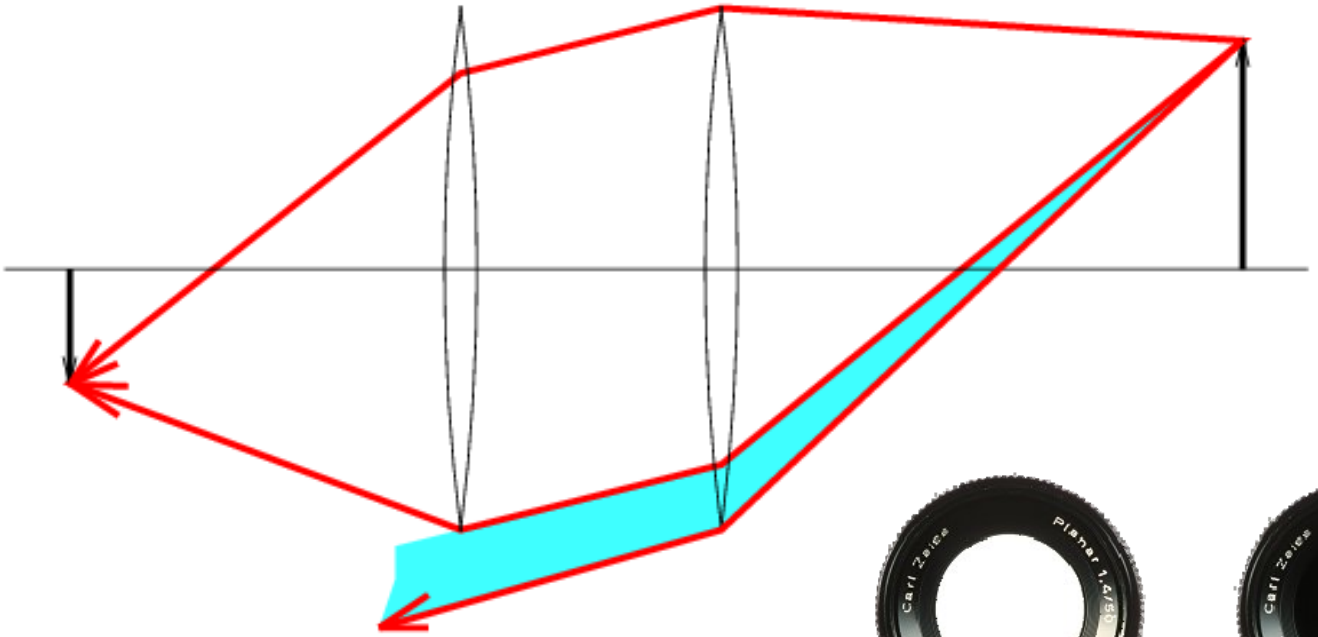


Figure from http://www.vanwalree.com/optics/vignetting.html

More issues with lenses:

- Lens flare

  Unwanted internal scattering of light in the lens system

class project?

Today's schedule

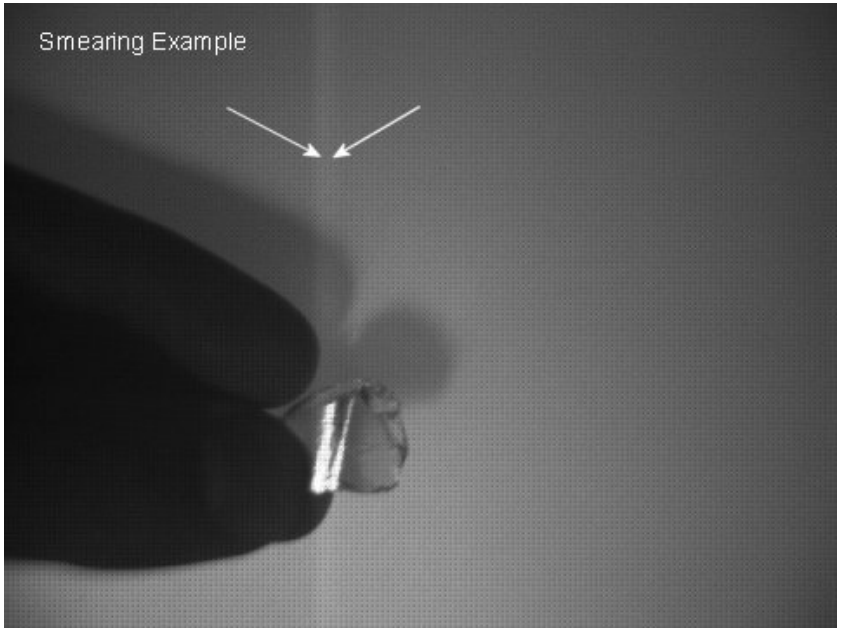
- Last week's recap & administrivia
- Exposure & Depth-of-field
- Aberrations
- Sensors
- Color sensing

CCD

separate photo sensor at regular positions
no scanning

charge-coupled devices (CCDs)

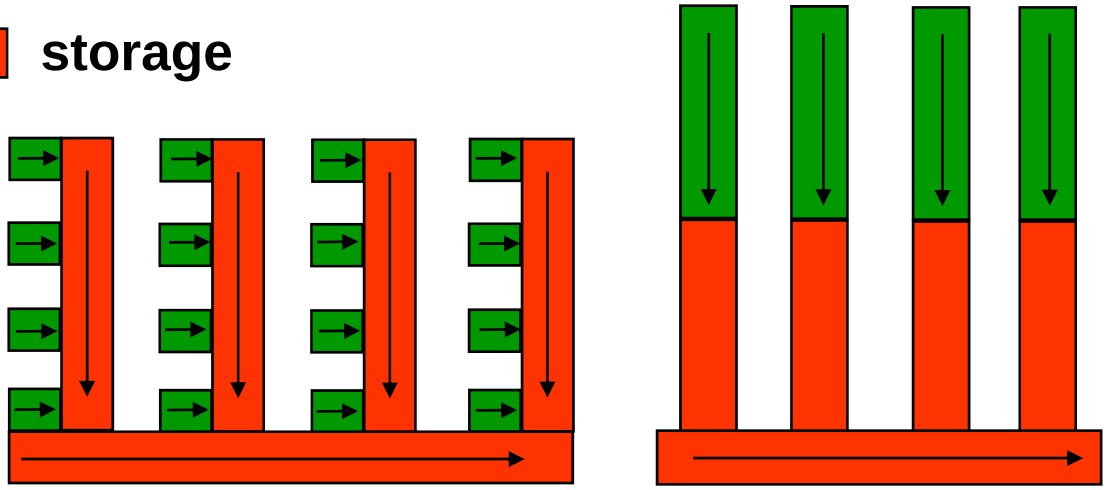
area CCDs and linear CCDs
2 area architectures :
interline transfer and *frame transfer*



PTGREY

photosensitive

storage



CMOS

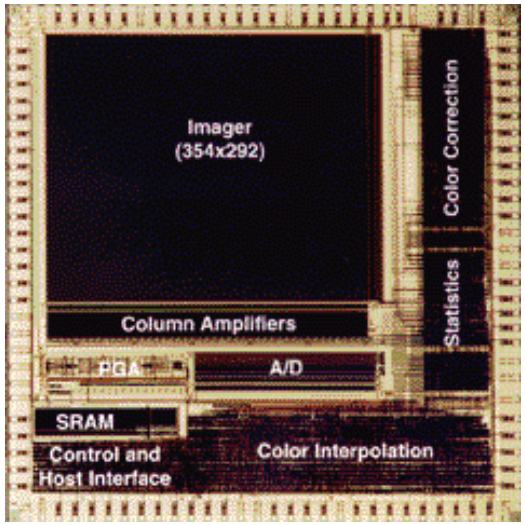
Same sensor elements as CCD

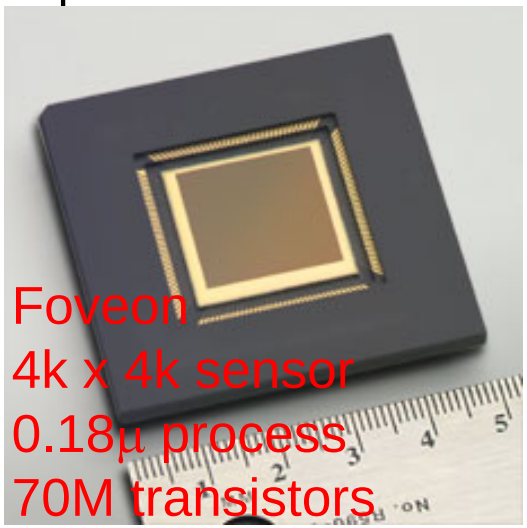
Each photo sensor has its own amplifier

- More noise (reduced by subtracting ‘black’ image)
- Lower sensitivity (lower fill rate)

Uses standard CMOS technology

- Allows to put other components on chip ‘Smart’ pixels

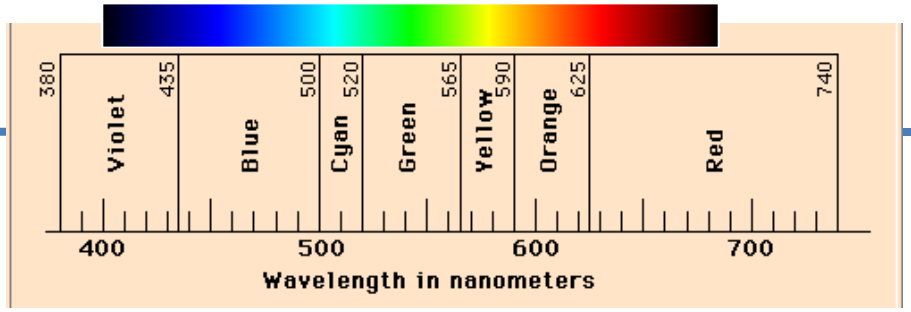


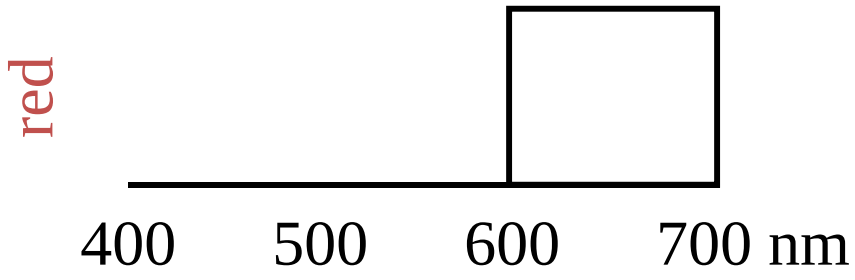


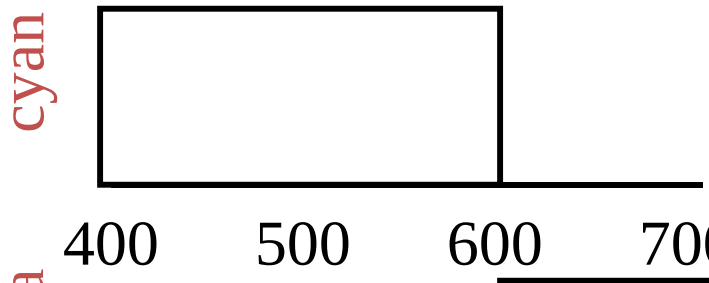
Today's schedule

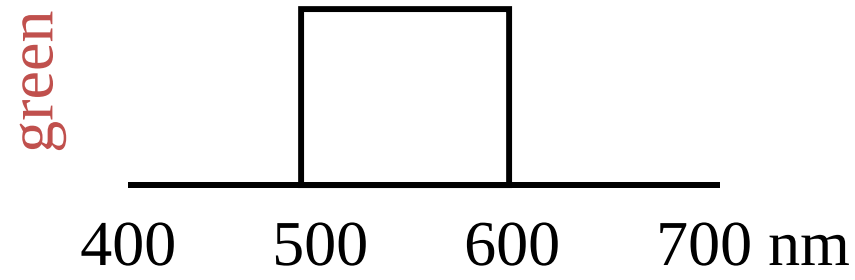
- Last week's recap & administrivia
- Exposure & Depth-of-field
- Aberrations
- Sensors
- Color sensing

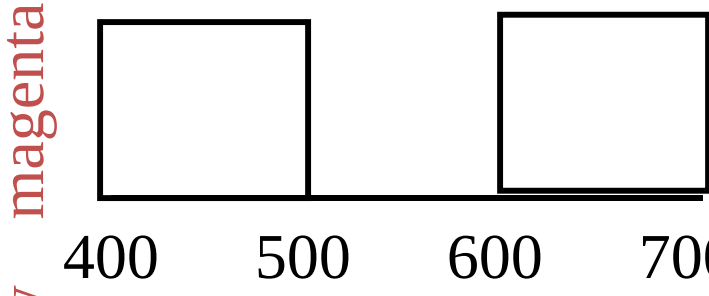
Color names for cartoon spectra

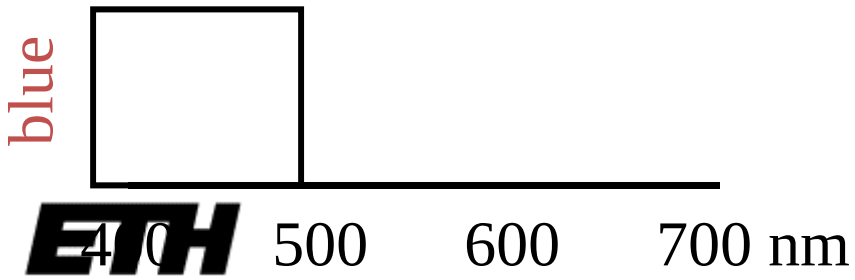


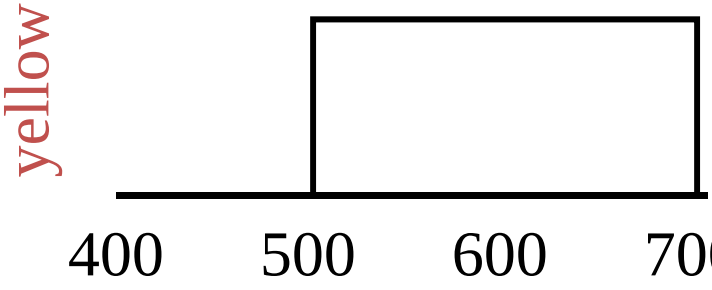












Color cameras

We consider 3 concepts:

1. Prism (with 3 sensors)
2. Filter mosaic
3. Filter wheel

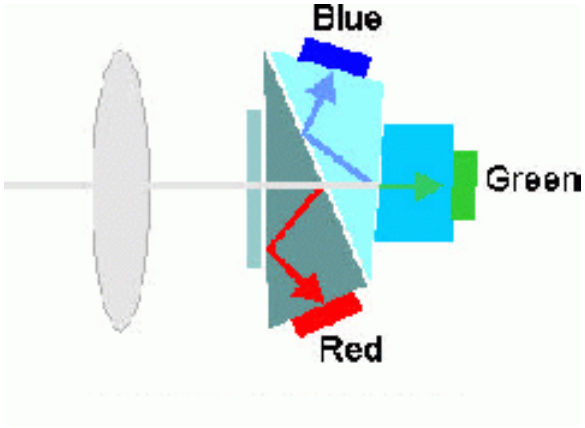
… and X3

Prism color camera

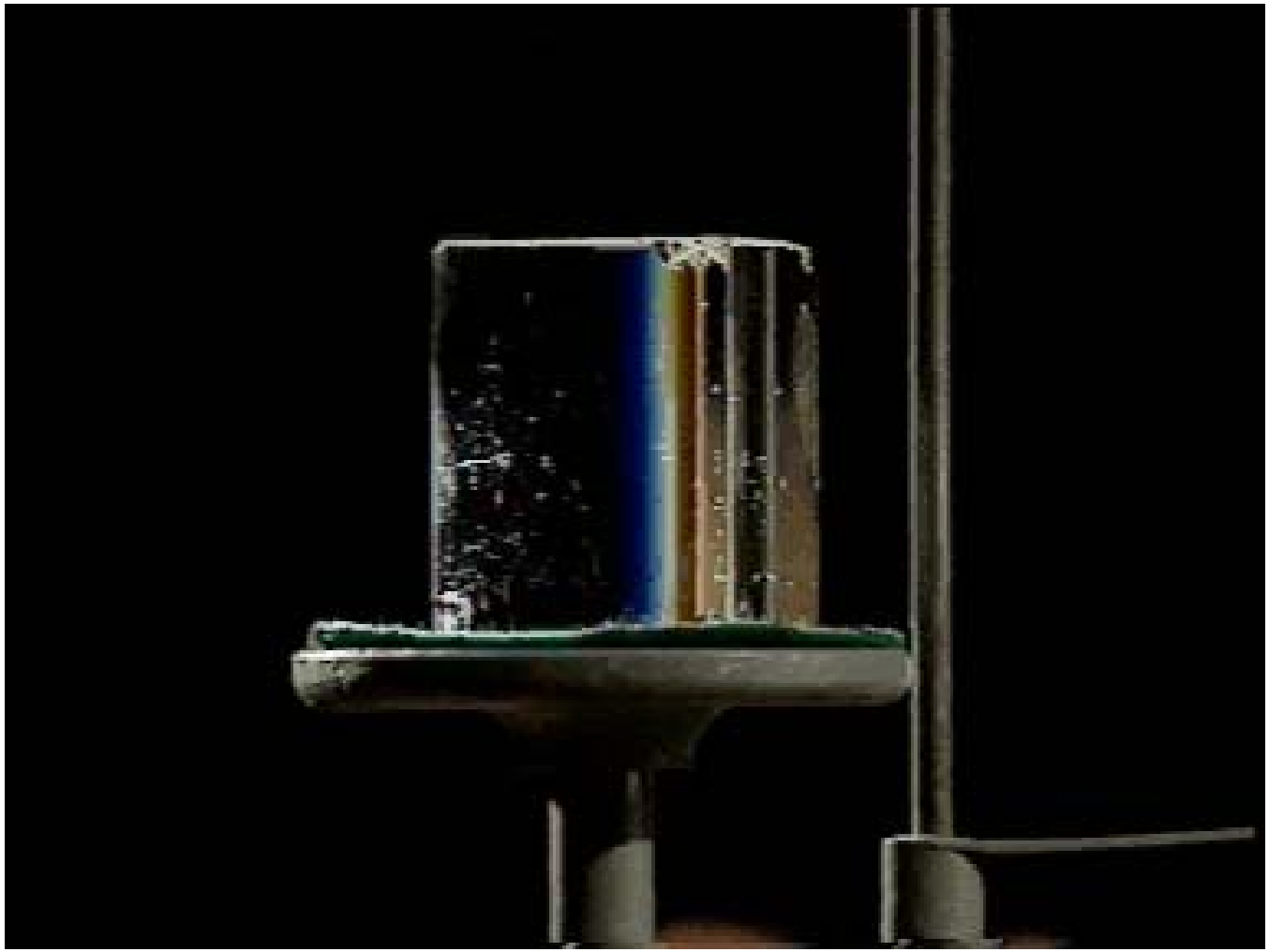
Separate light in 3 beams using dichroic prism

Requires 3 sensors & precise alignment

Good color separation

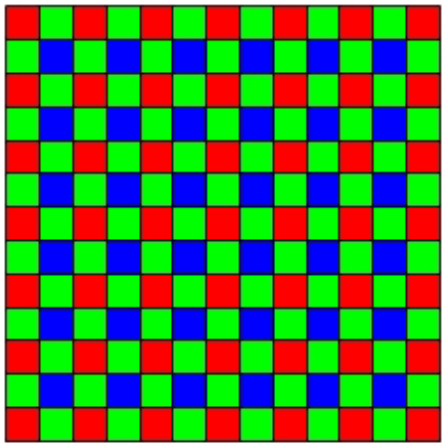


Prism color camera

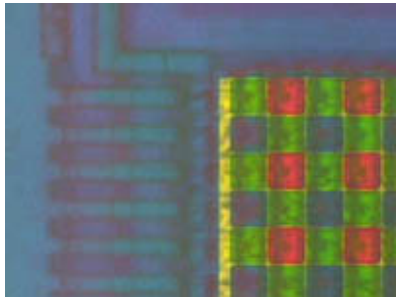


Filter mosaic

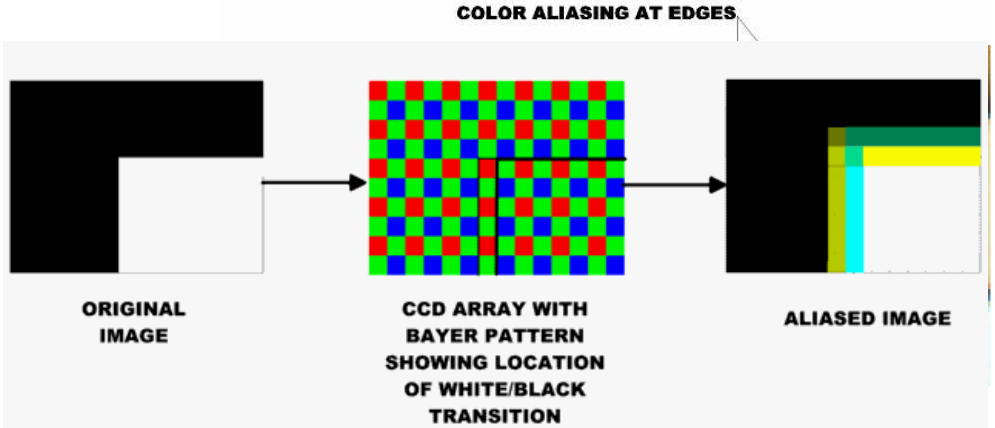
Coat filter directly on sensor



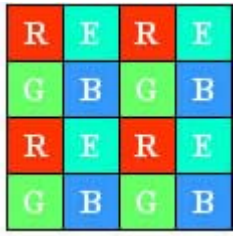
Bayer filter



Demosaicing (obtain full colour & full resolution image)



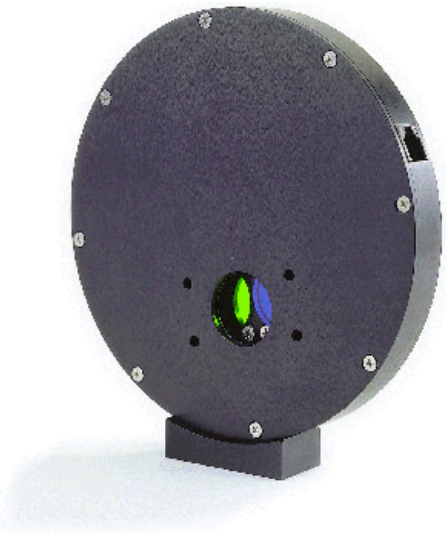
More colors:



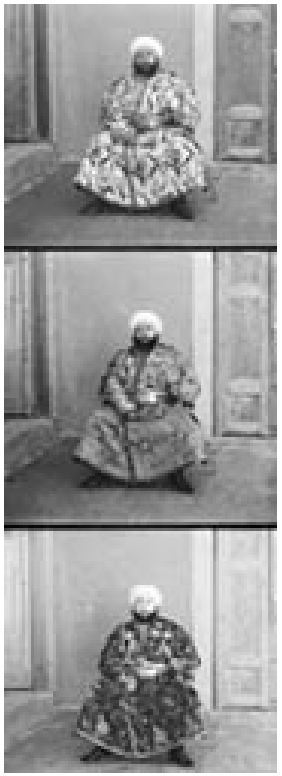
Filter wheel

Rotate multiple filters in front of lens

Allows more than 3 colour bands

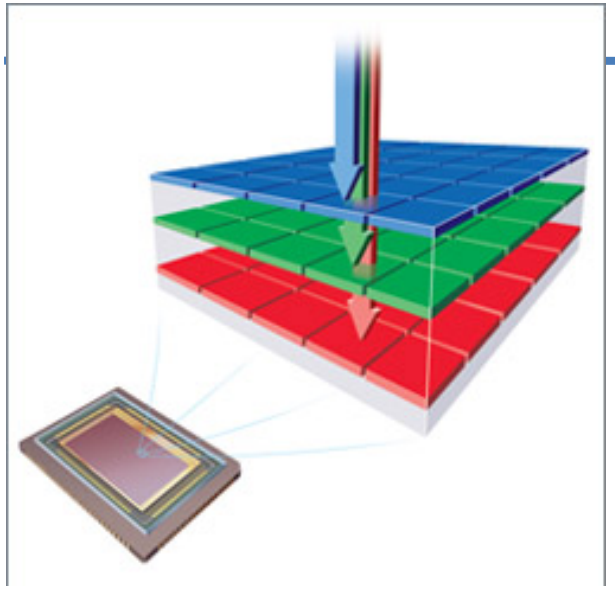


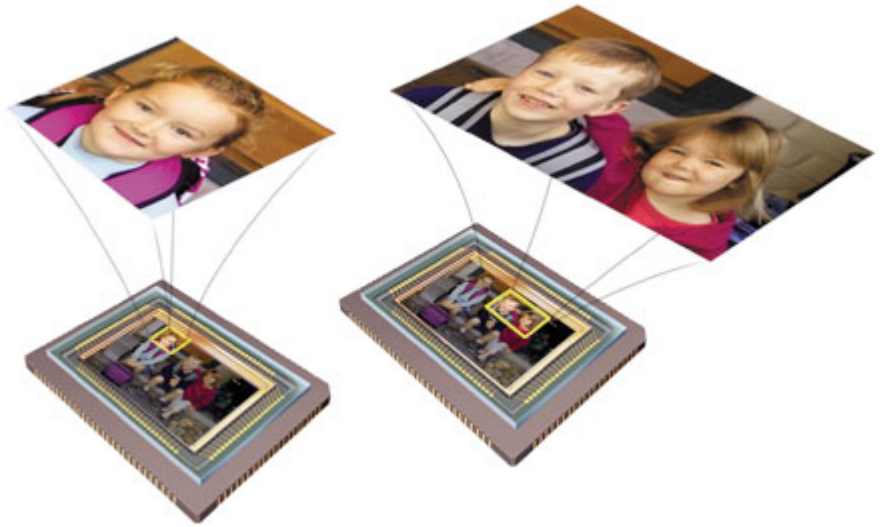
Only suitable for static scenes



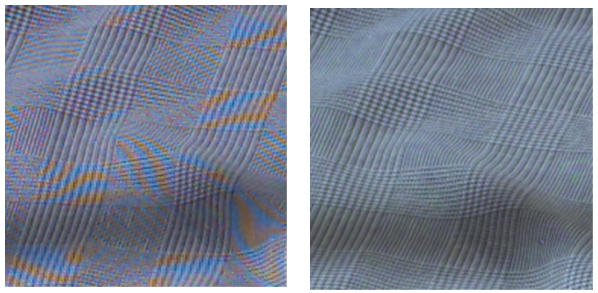
Prokudin-Gorskii

new color CMOS sensor
Foveon's X3

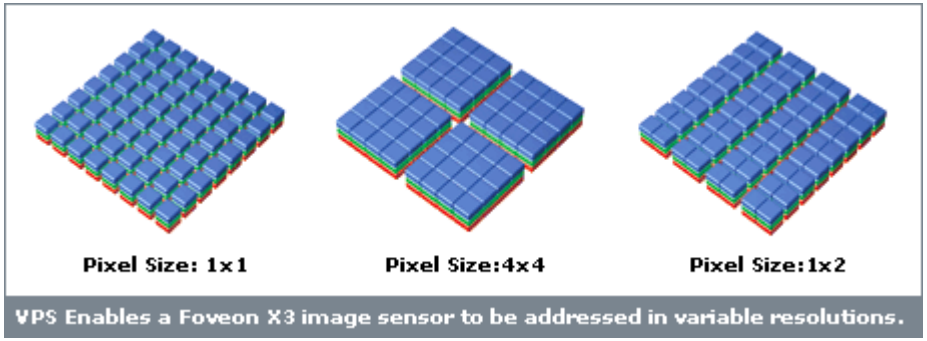




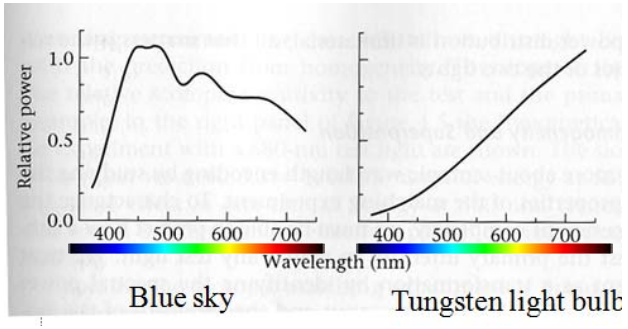
better image quality

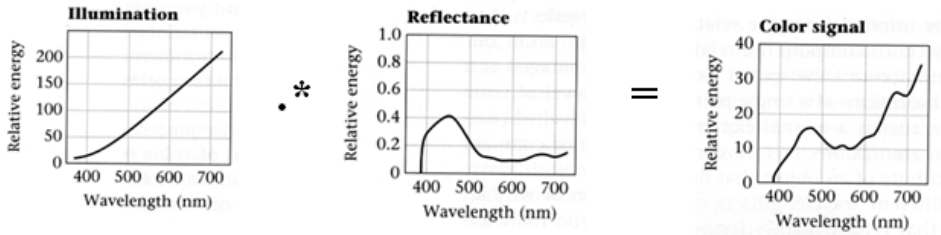


smarter pixels



White balancing





Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Next week

- Warping, morphing and panoramas