Computational Photography and Video:

More on Camera, Sensors & Color

Prof. Marc Pollefeys

ETH

inf | Informatik
Computer Science

Today's schedule

- Last week's recap & administrivia
- Metering
- Aberrations
- Sensors
- Color sensing

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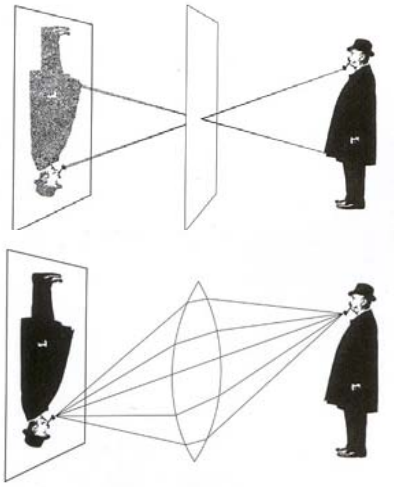
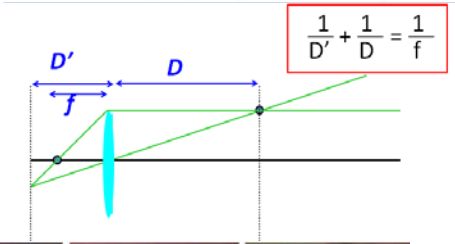
Recap

- 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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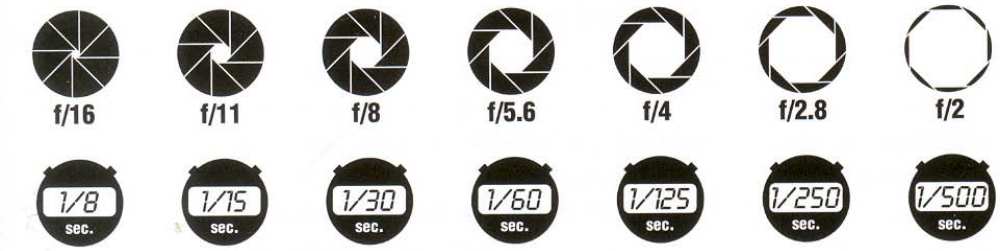
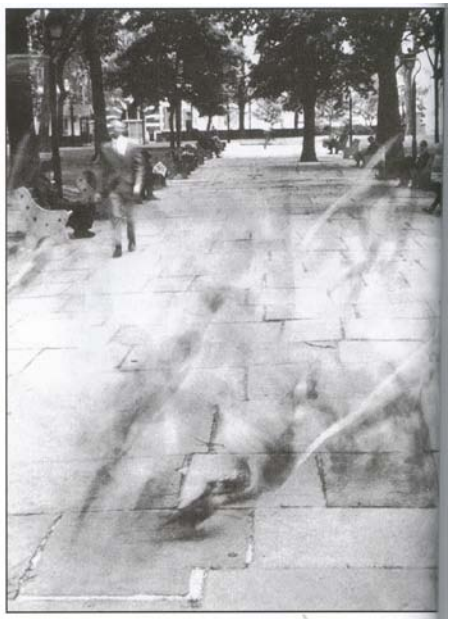
Recap

- Exposure
  - reciprocity





Small aperture (deep depth of field), slow shutter speed (motion blurred). *In the 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.*

Medium aperture (moderate depth of field), medium shutter speed (some motion blur). *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.*

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.*

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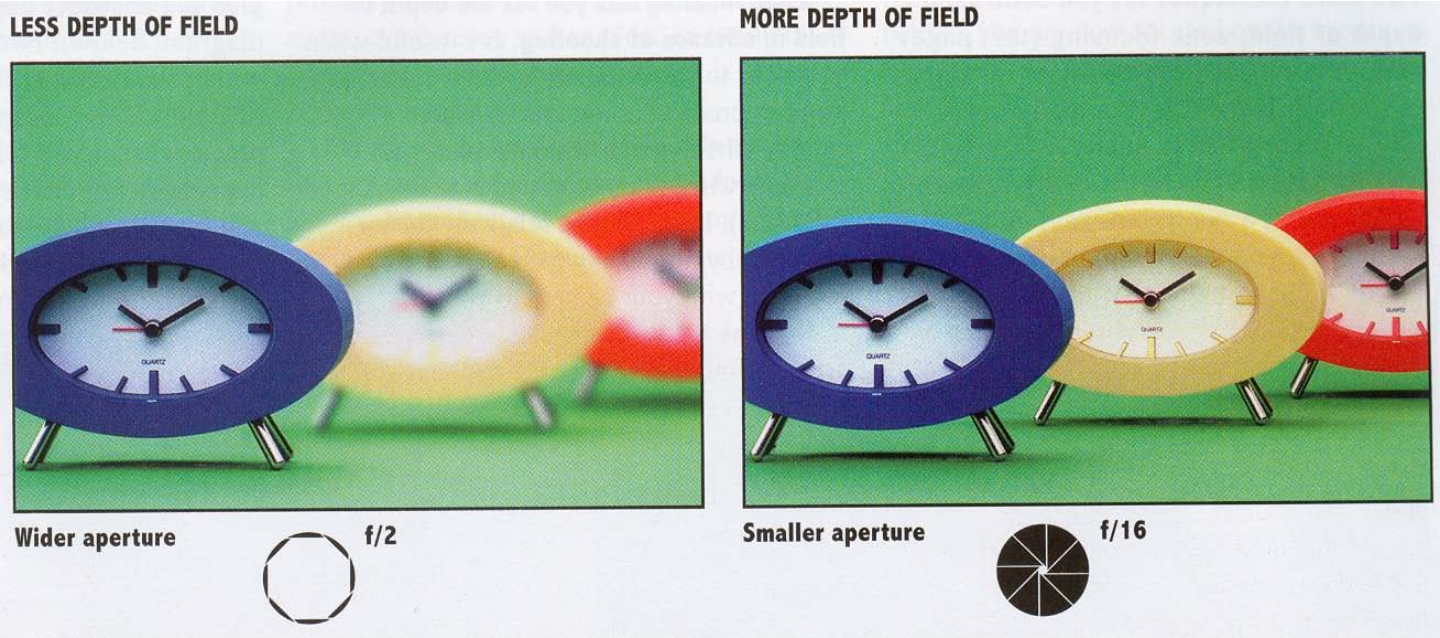
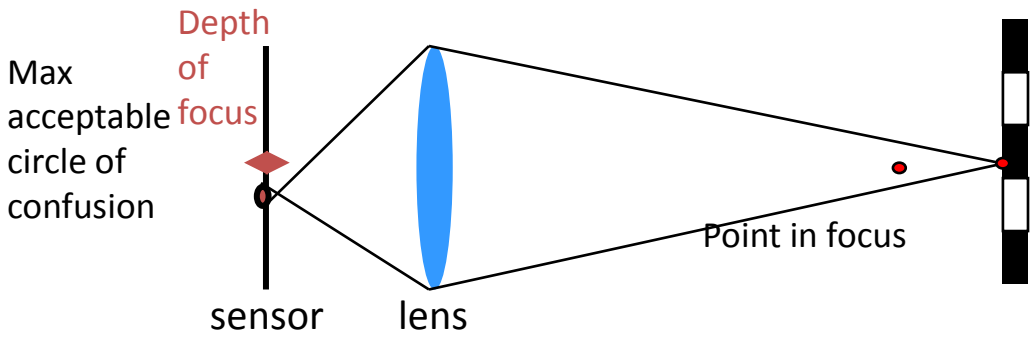
Recap

- Depth-of-field





Schedule	Computational Photography and Video	
24 Feb	Introduction to Computational Photography	
3 Mar	More on Camera,Sensors and Color	Assignment 1
10 Mar	Warping, Mosaics and Morphing	Assignment 2
17 Mar	Blending and compositing	Assignment 3
24 Mar	High-dynamic range	Assignment 4
31 Mar	*TBD*	Project proposals
7 Apr	*Easter holiday – no classes*	
14 Apr	*TBD*	Papers
21 Apr	*TBD*	Papers
28 Apr	*TBD*	Papers
5 May	*TBD*	Project update
12 May	*TBD*	Papers
19 May	*TBD*	Papers
26 May	*TBD*	Papers
2 June	Final project presentation	Final project presentation

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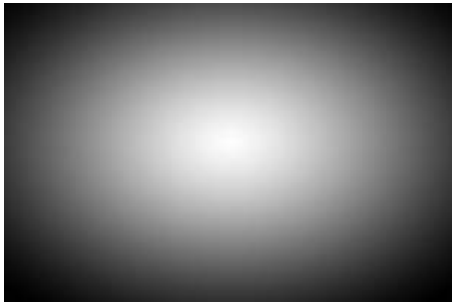
Metering

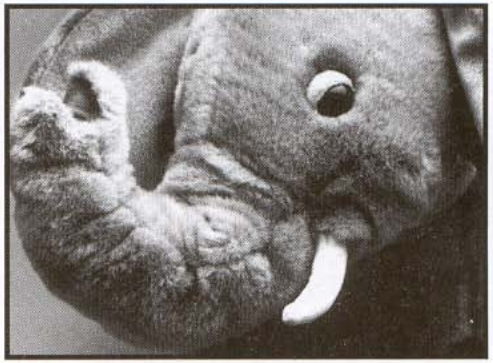
- Photosensitive sensors measure scene luminance
- Usually TTL (through the lens)
- Simple version: center-weighted average



- 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

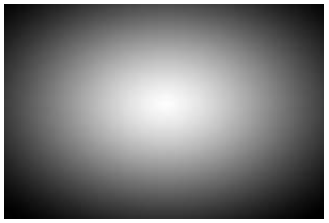
Black gorilla given exposure suggested by meter

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

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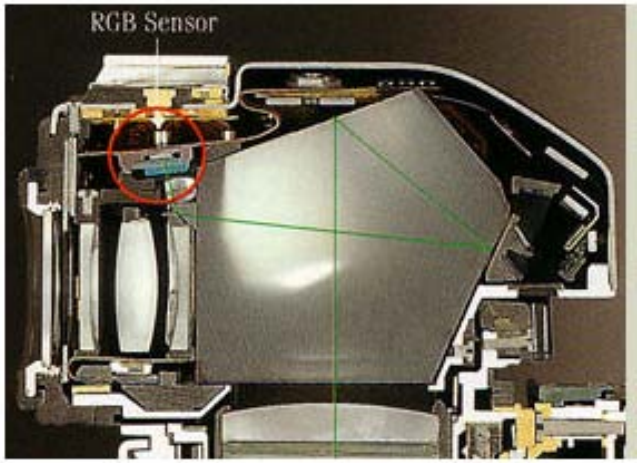
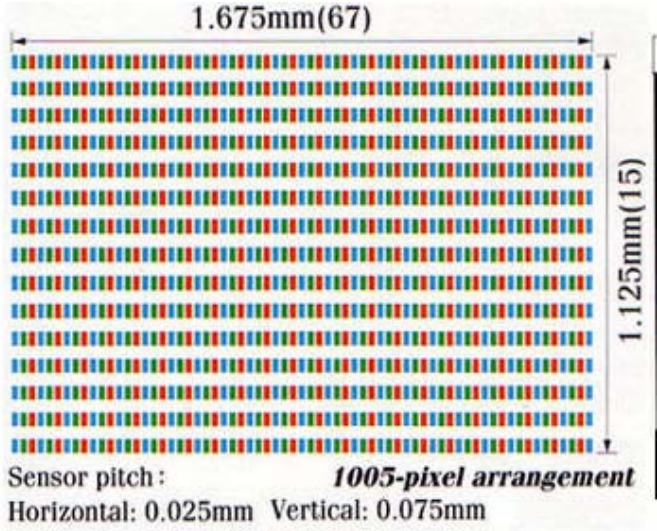
Nikon 3D Color Matrix

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)





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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

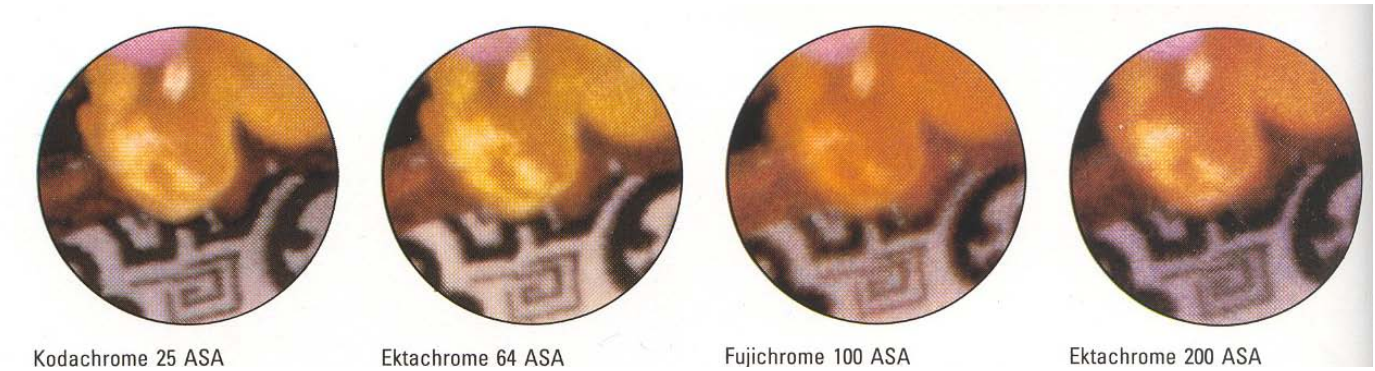
Recap: Metering

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

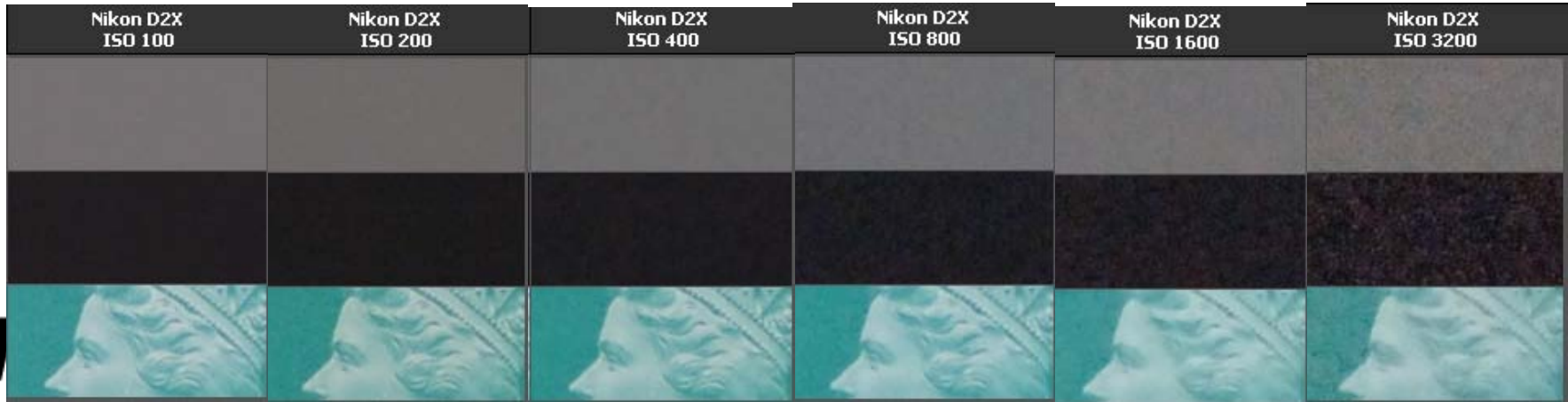
Questions?

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



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Aberrations

- 2 types:

1. geometrical

geometrical : small for paraxial rays

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

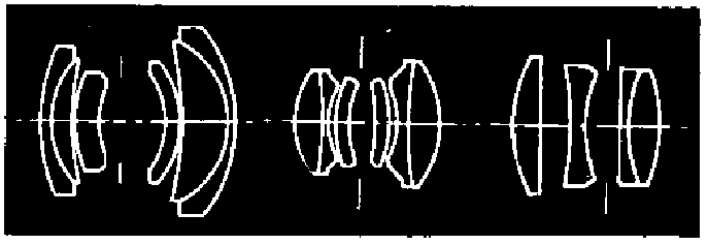
2. chromatic

chromatic : refractive index function of wavelength

Geometric aberrations

- spherical aberration
- astigmatism
- distortion
- coma

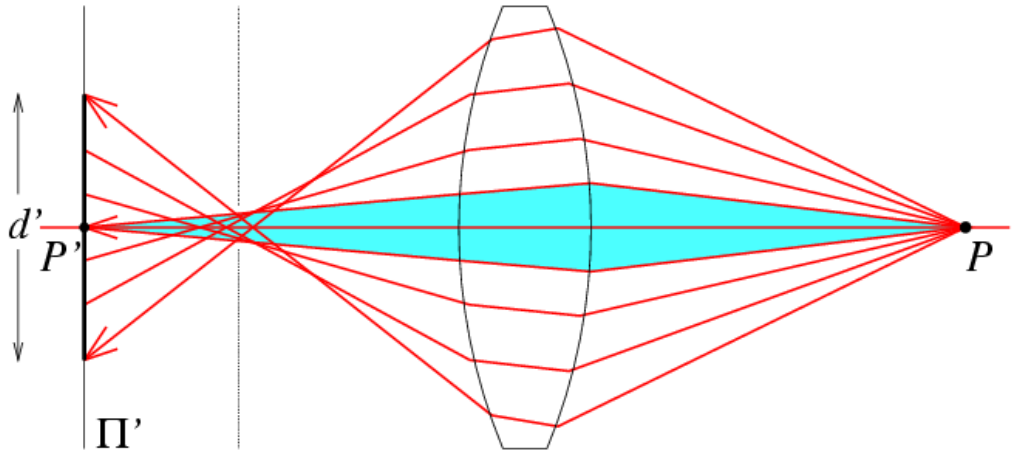
aberrations are reduced by combining lenses



Spherical aberration

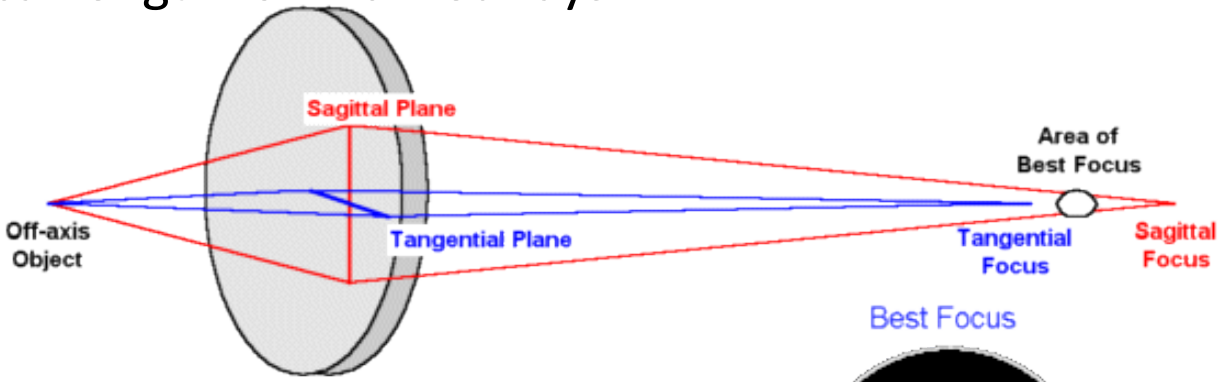
rays parallel to the axis do not converge

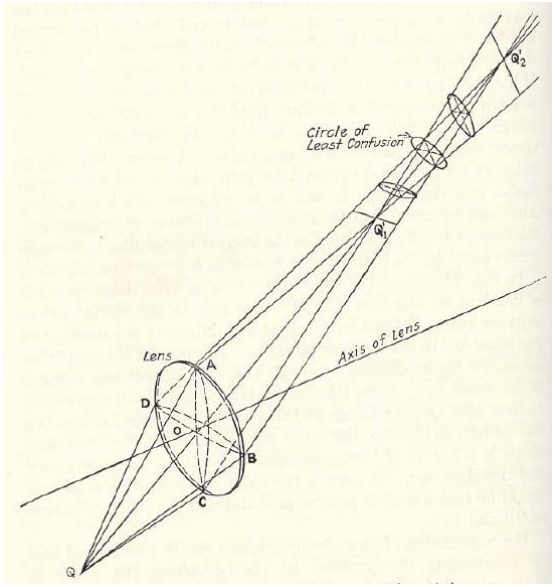
outer portions of the lens yield smaller focal lenghts

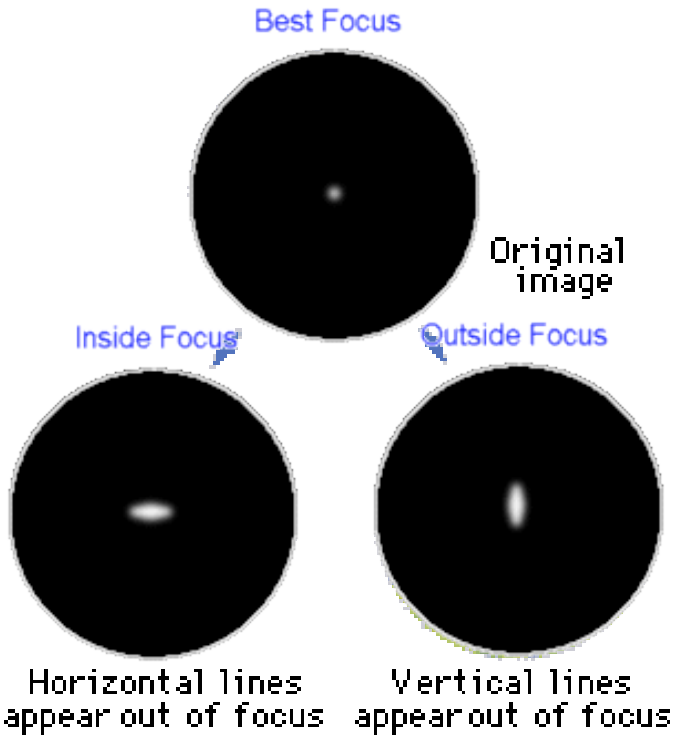


Astigmatism

Different focal length for inclined rays

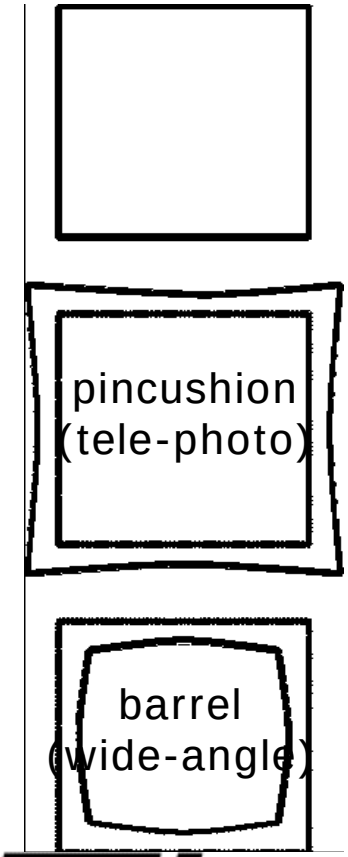


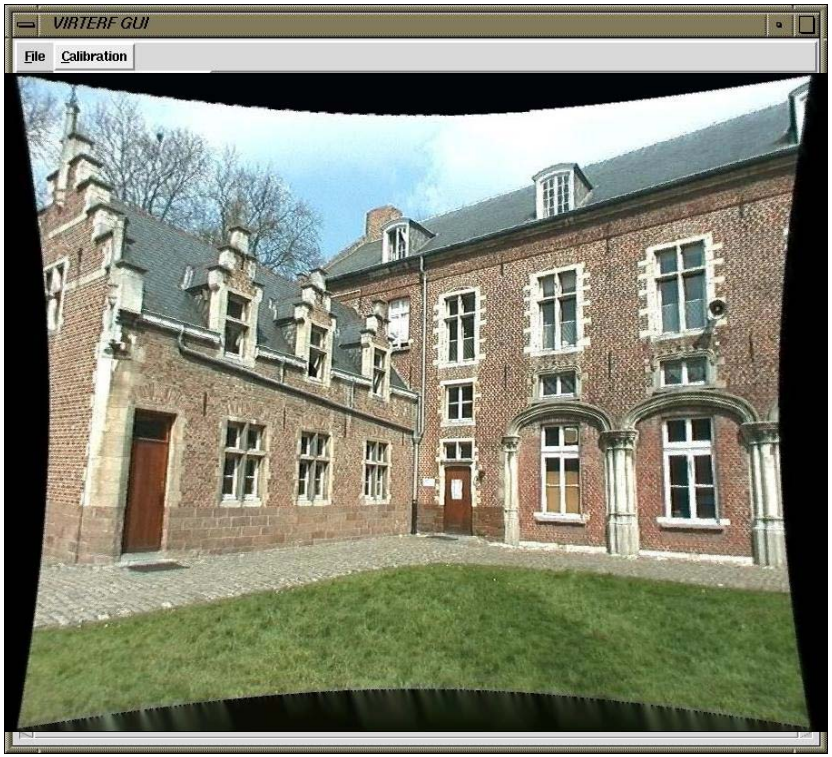




Radial distortion

magnification/focal length different
for different angles of inclination





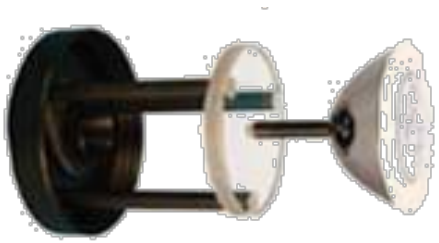
Can be corrected! (if parameters are know)

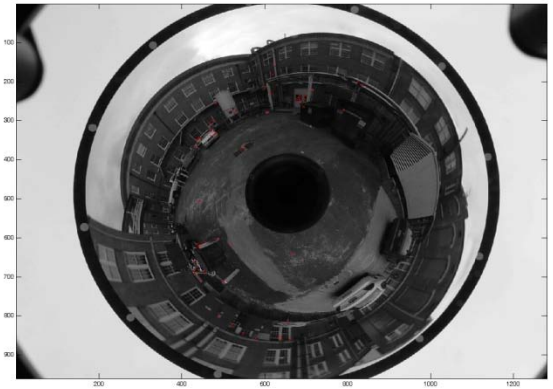
Ultra wide-angle optics

- Sometimes distortion is what you want

Fisheye lens

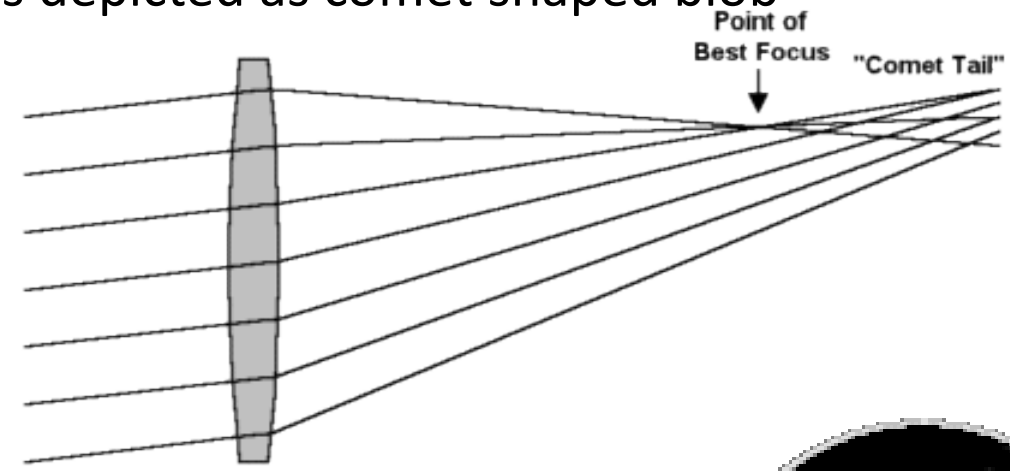
Cata-dioptric system (lens + mirror)

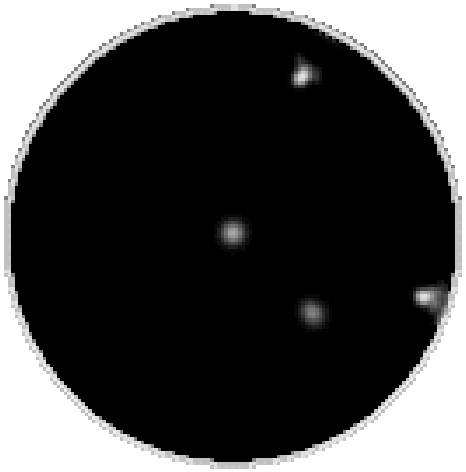




Coma

point off the axis depicted as comet shaped blob





Chromatic aberration

- rays of different wavelengths focused in different planes

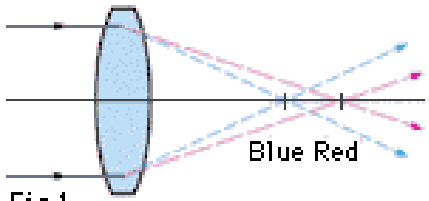


Fig.1
Axial chromatic aberration

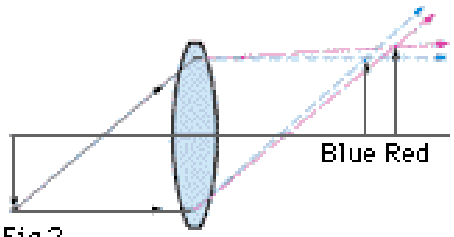
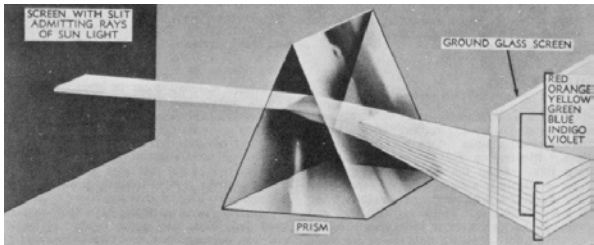


Fig.2
Magnification chromatic aberration


The image is blurred and appears colored at the fringe.

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



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Vignetting

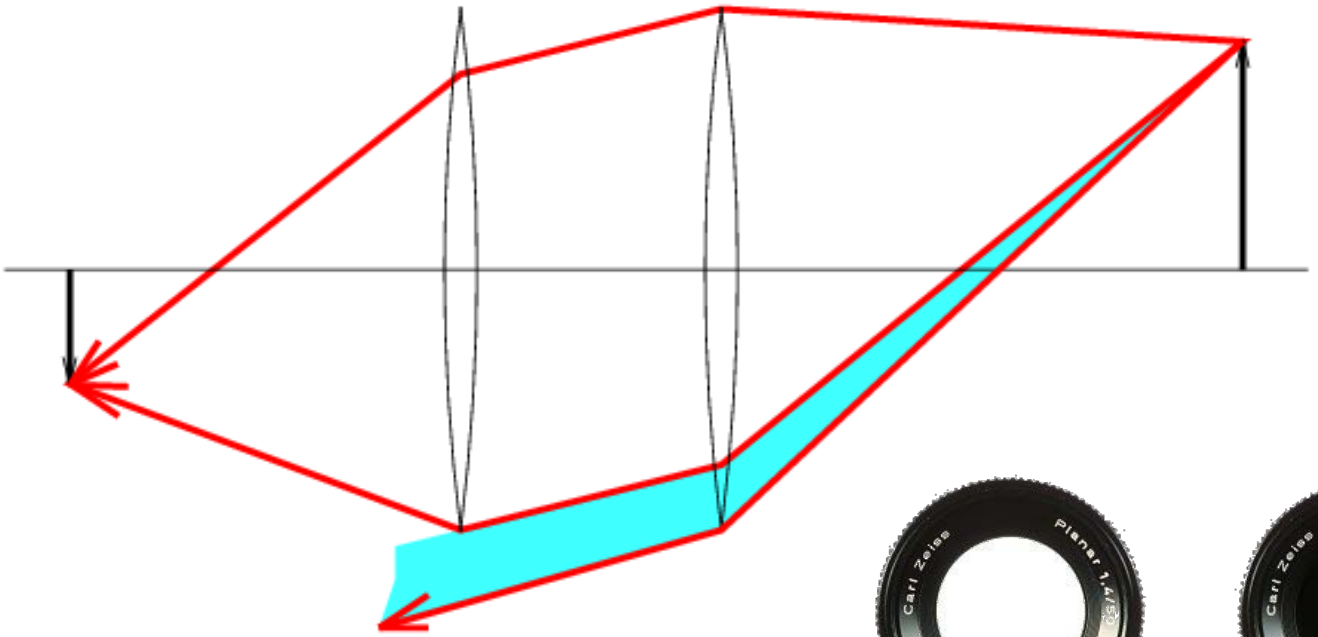


Figure from http://www.vanwalree.com/optics/vignetting.html

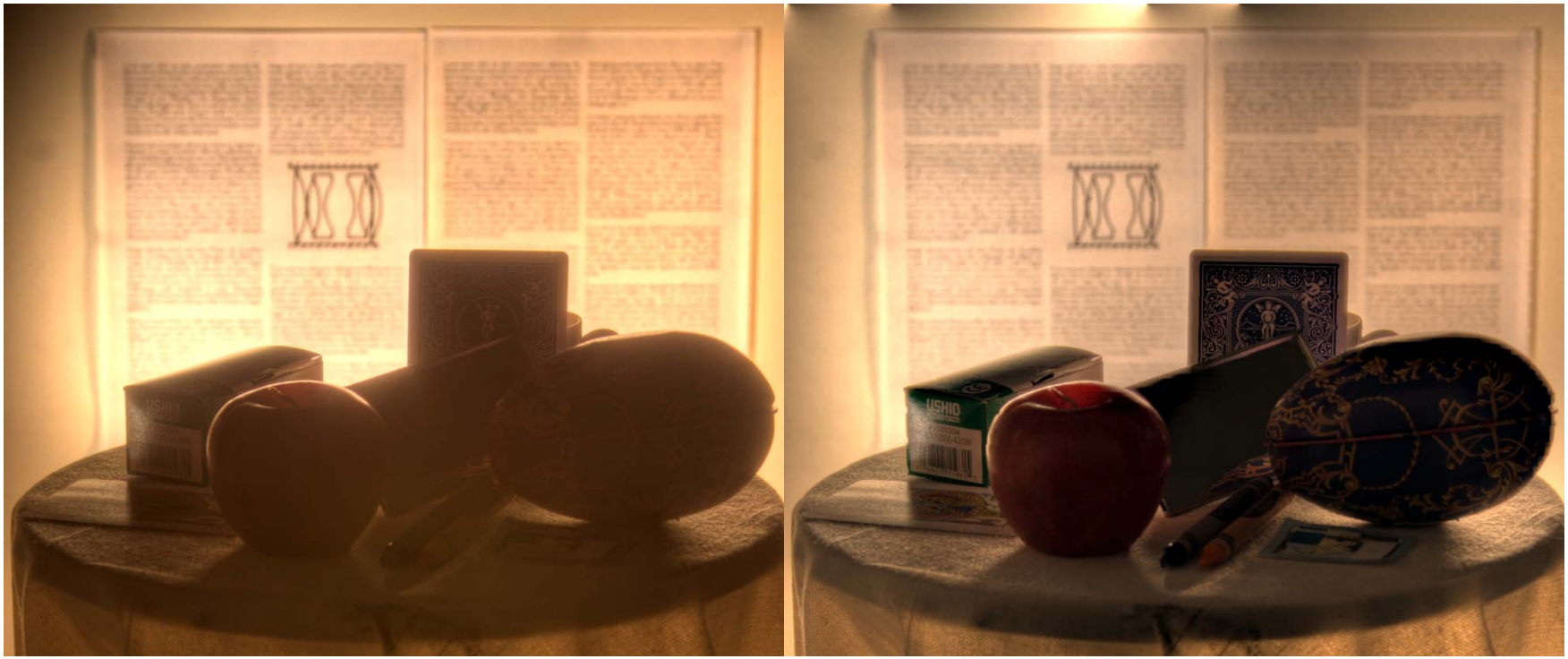
More issues with lenses:

- Lens flare

  Unwanted internal scattering of light in the lens system

class project?

Veiling Glare



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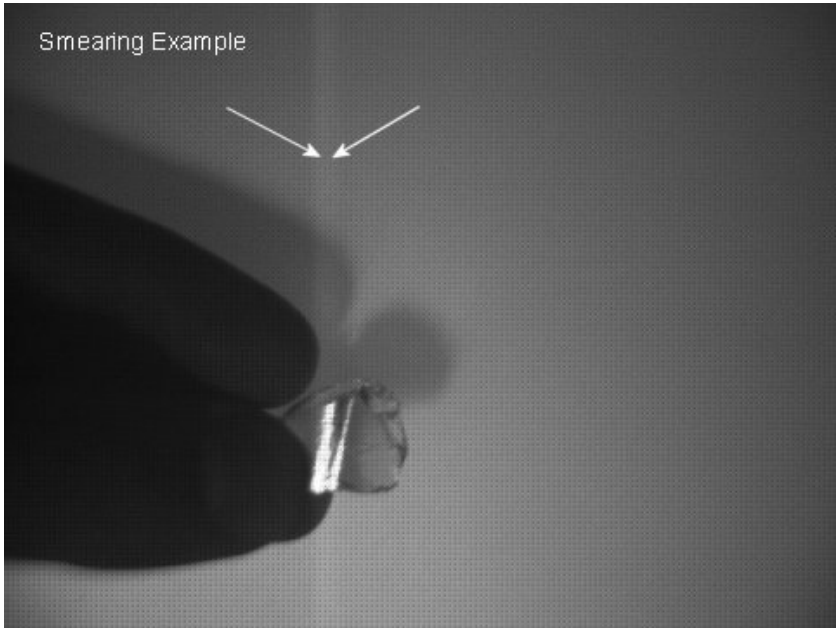
CCD

separate photo sensor at regular positions
no scanning

charge-coupled devices (CCDs)

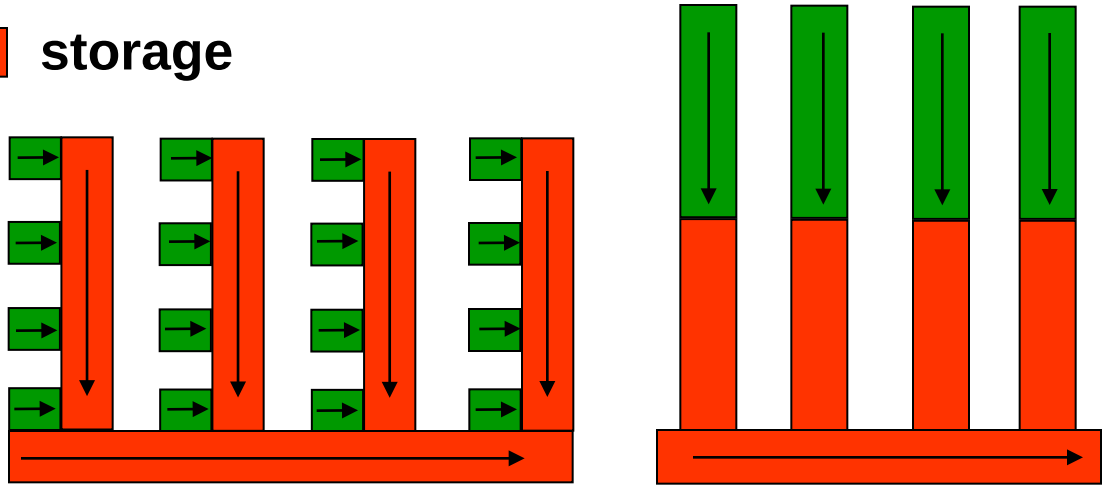
area CCDs and linear CCDs
2 area architectures :
interline transfer and *frame transfer*



PTGREY

photosensitive

storage



CMOS

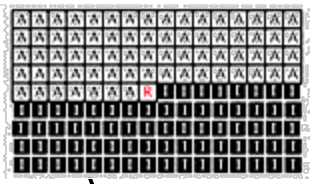
Same sensor elements as CCD

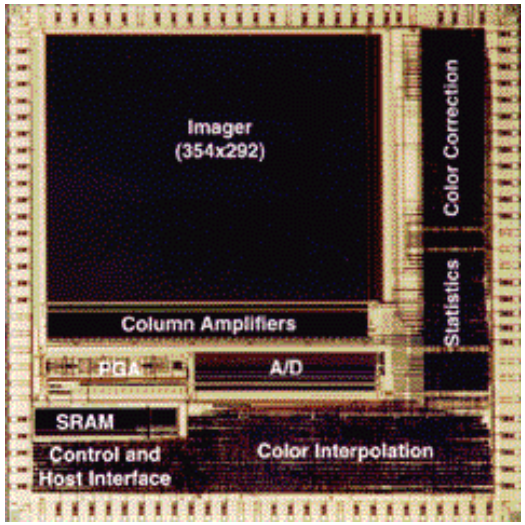
Each photo sensor has its own amplifier

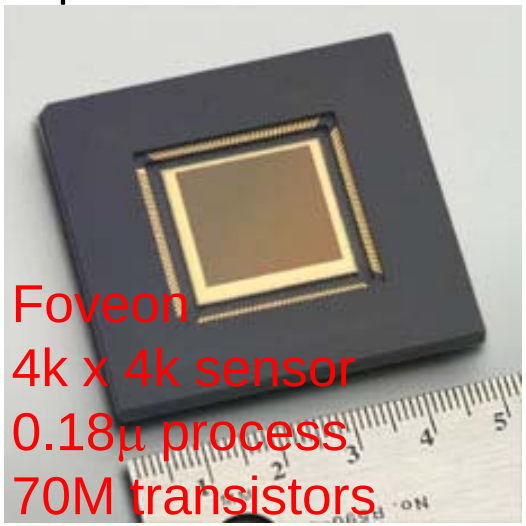
- More noise (reduced by subtracting ‘black’ image)
- Lower sensitivity (lower fill rate)

Uses standard CMOS technology

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







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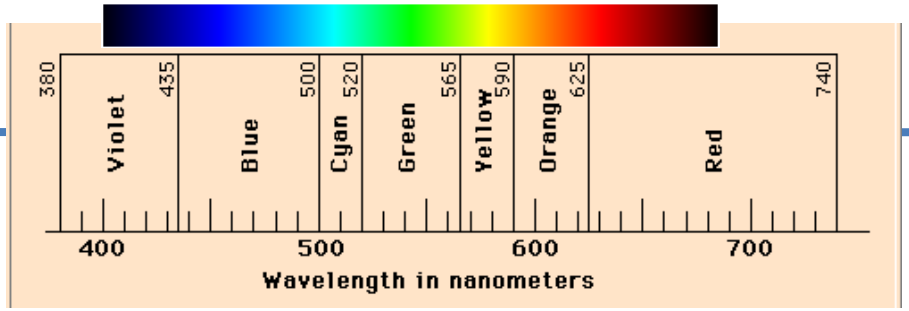
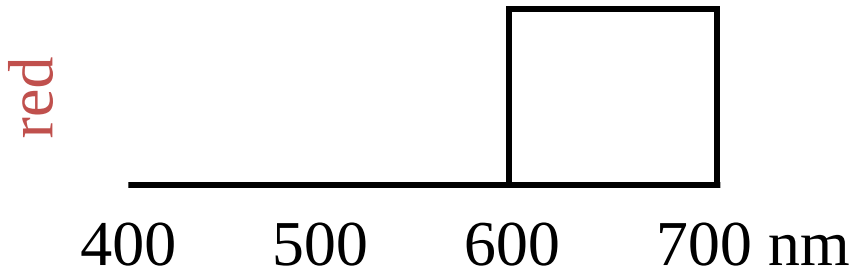
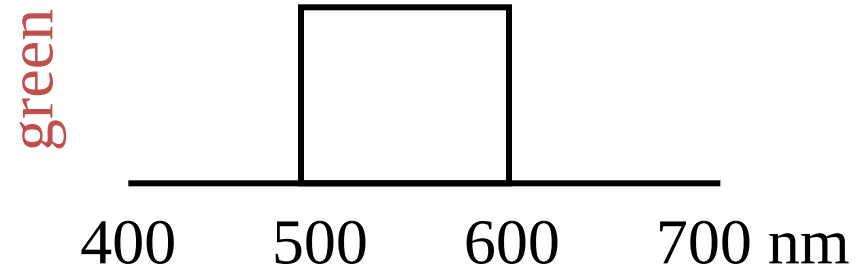
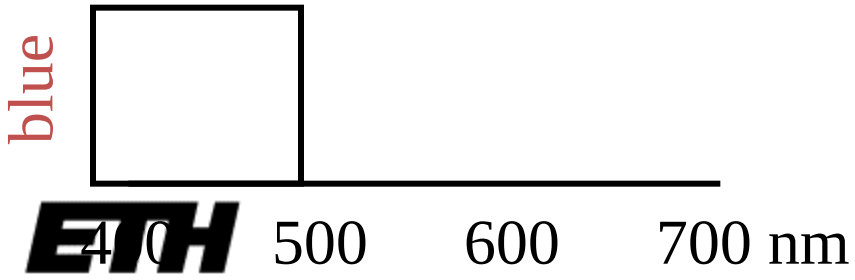
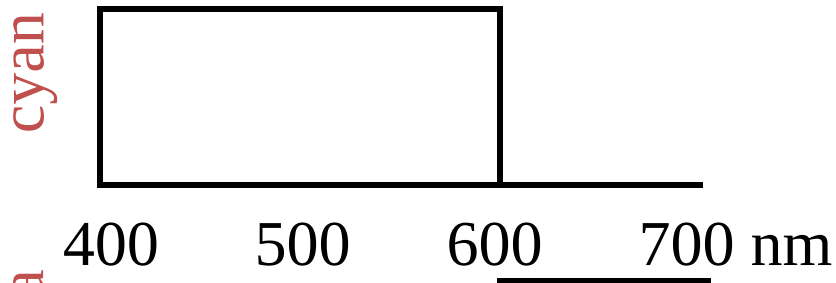
Color names for cartoon spectra

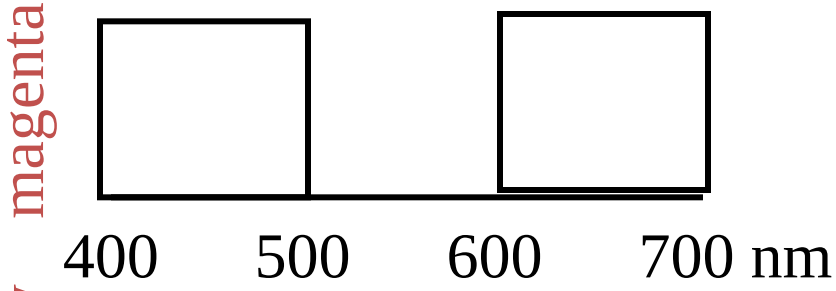


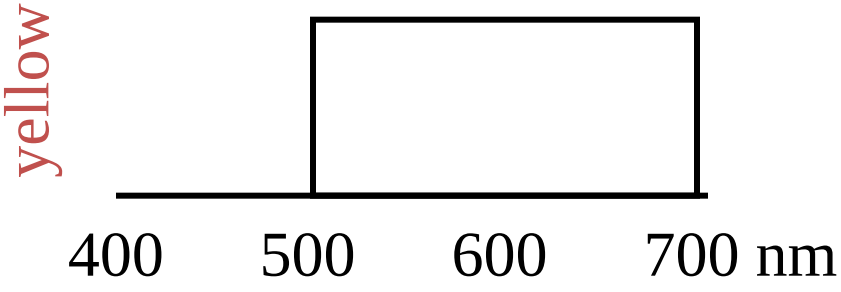












Color cameras

We consider 3 concepts:

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

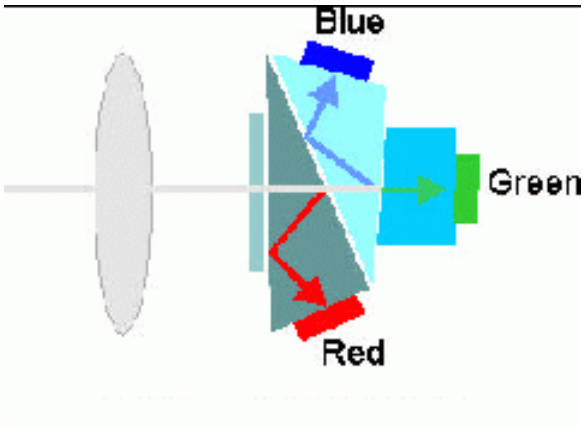
… and X3

Prism color camera

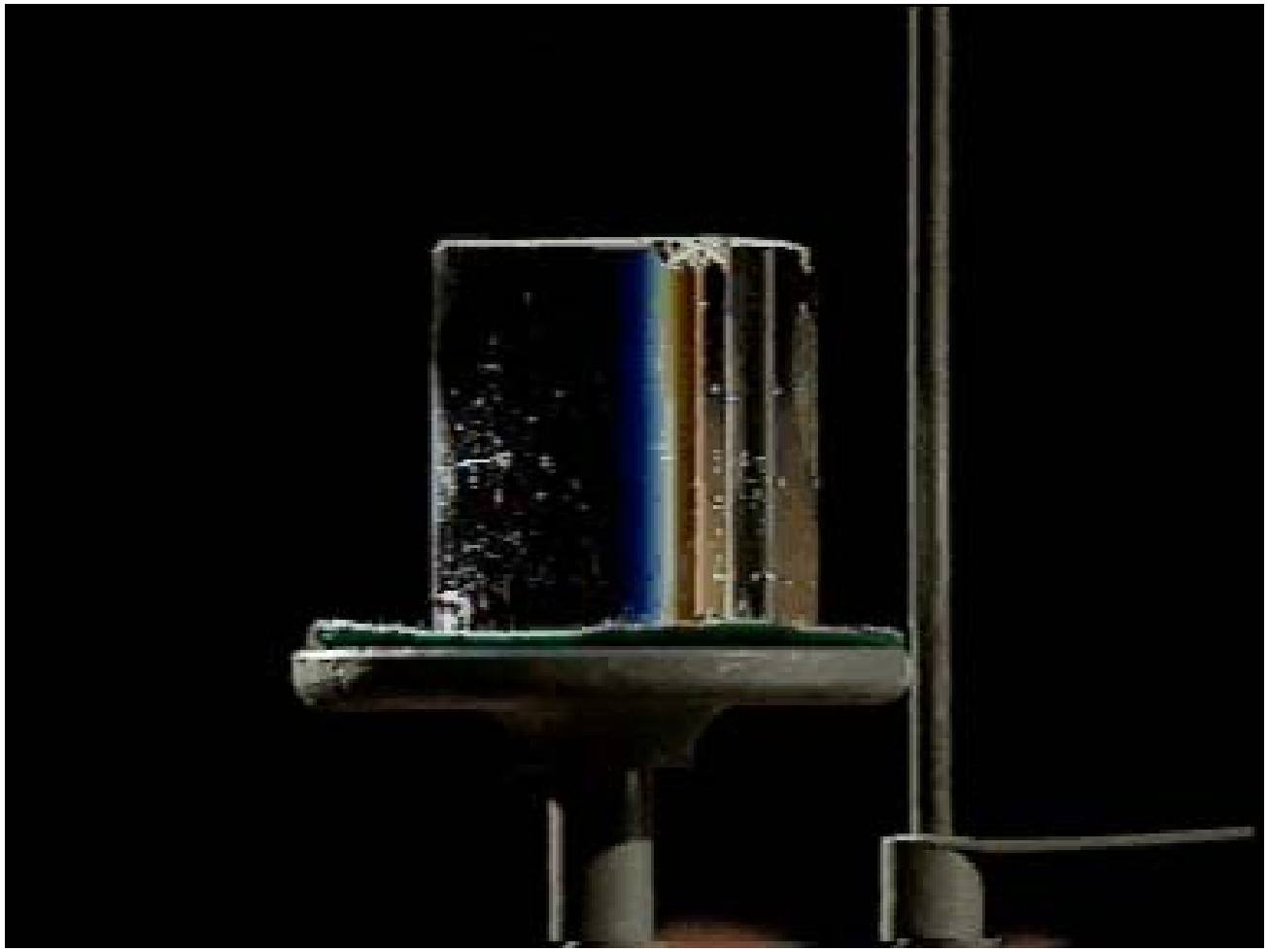
Separate light in 3 beams using dichroic prism

Requires 3 sensors & precise alignment

Good color separation

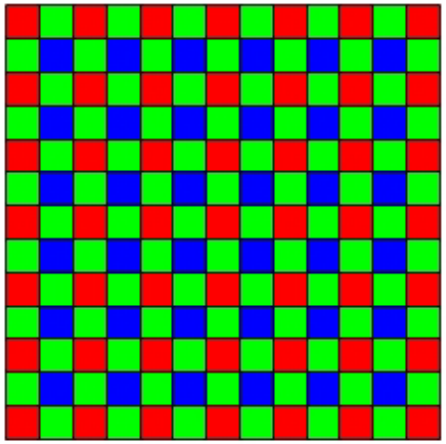


Prism color camera

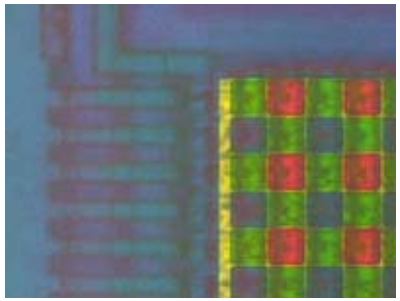


Filter mosaic

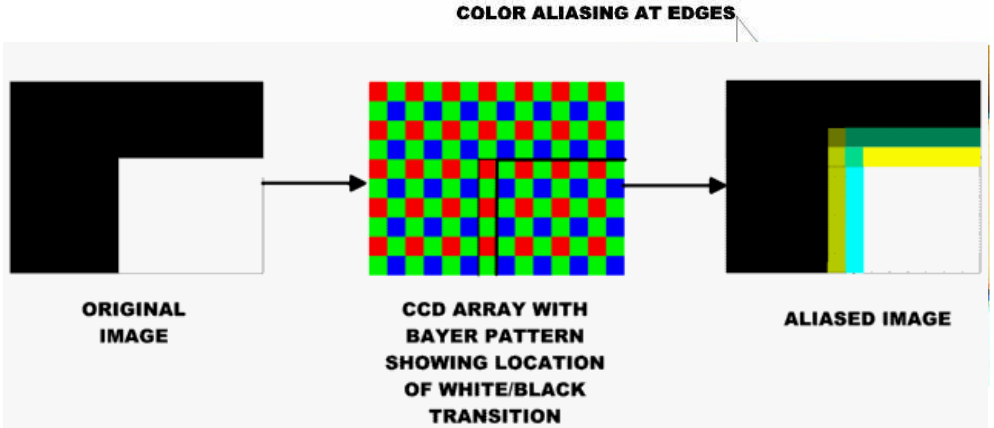
Coat filter directly on sensor



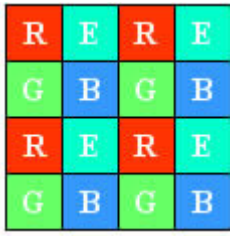
Bayer filter



Demosaicing (obtain full colour & full resolution image)



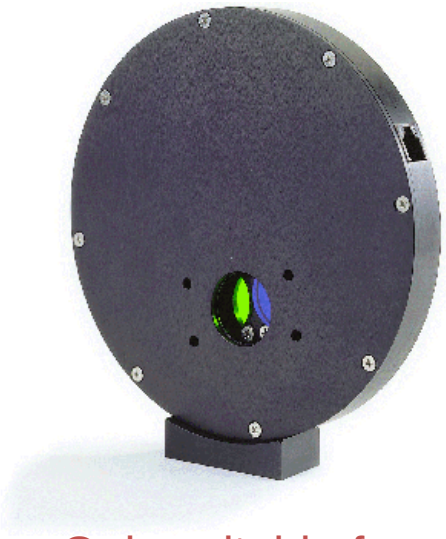
More colors:



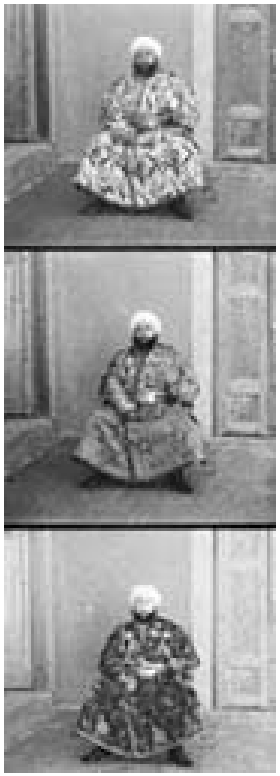
Filter wheel

Rotate multiple filters in front of lens

Allows more than 3 colour bands

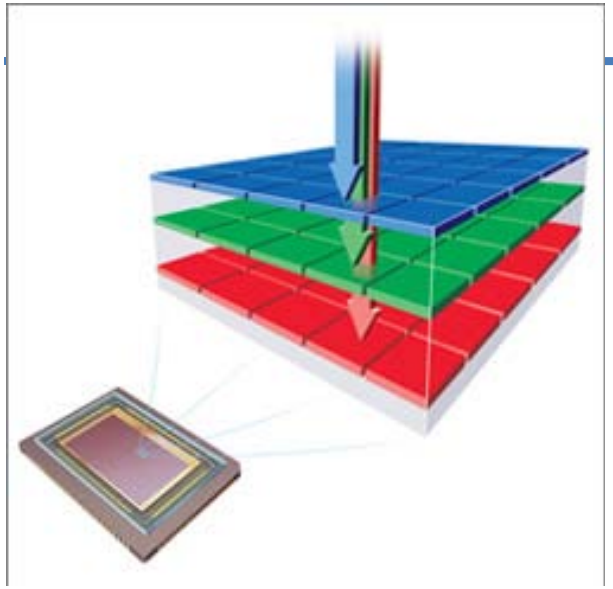


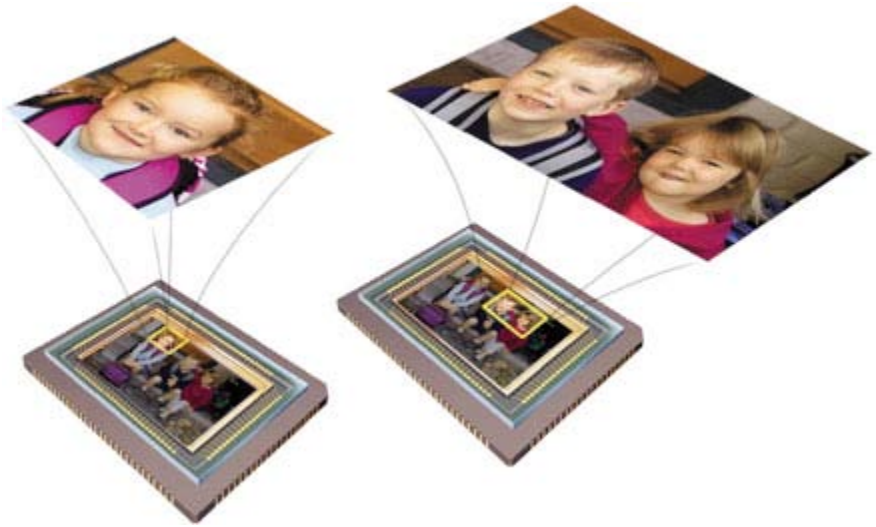
Only suitable for static scenes



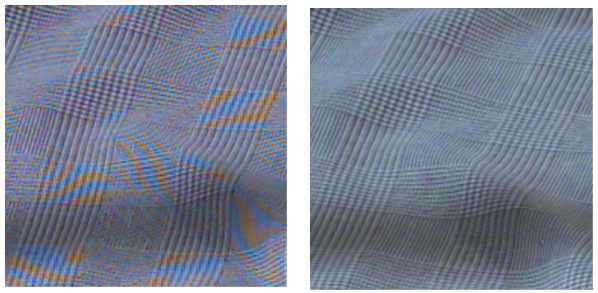
Prokudin-Gorskii

new color CMOS sensor
Foveon's X3

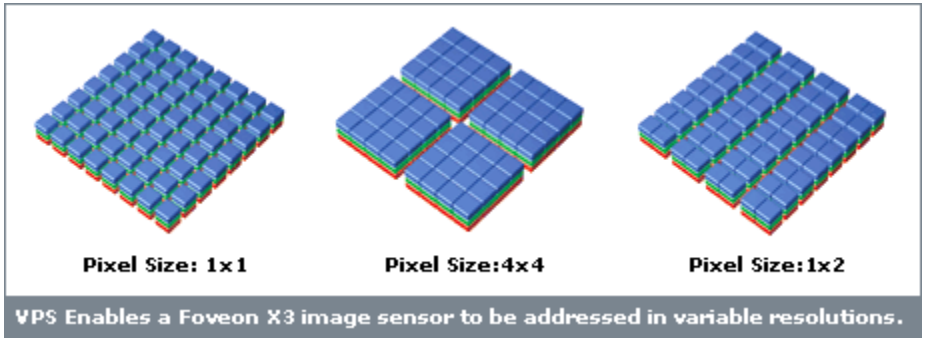




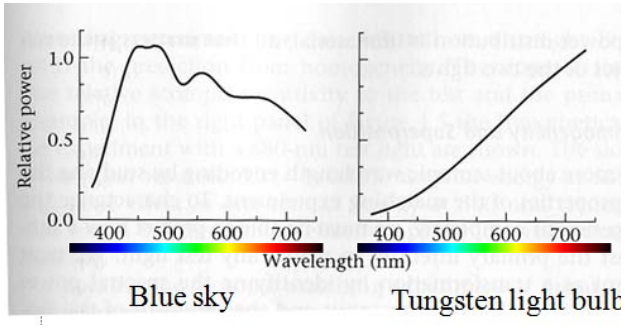
better image quality

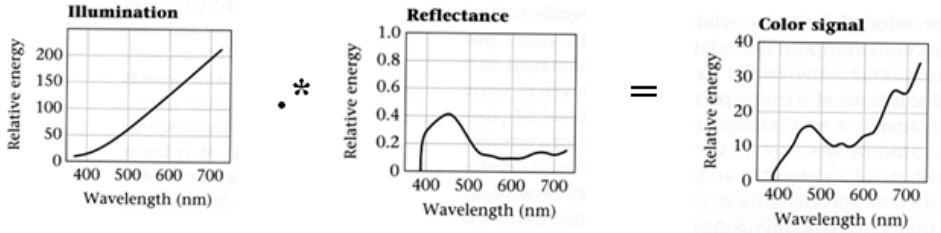


smarter pixels



White balancing





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

Next week

- Warping, morphing and panoramas