Cameras

Digital Visual Effects, Spring 2009
Yung-Yu Chuang
2009/2/26

Announcements

- Do subscribe the mailing list
- Assignment #1 announced on 3/4 (due on 3/24 midnight)
- It is for warming up and considered easier; it is suggested that you implement at least one bonus (MTB/tone mapping/other HDR construction)
- You have a total of 10 days of delay without penalty for assignments; after that, -1 point per day applies in your final grade until reaching zero for each project.

scene
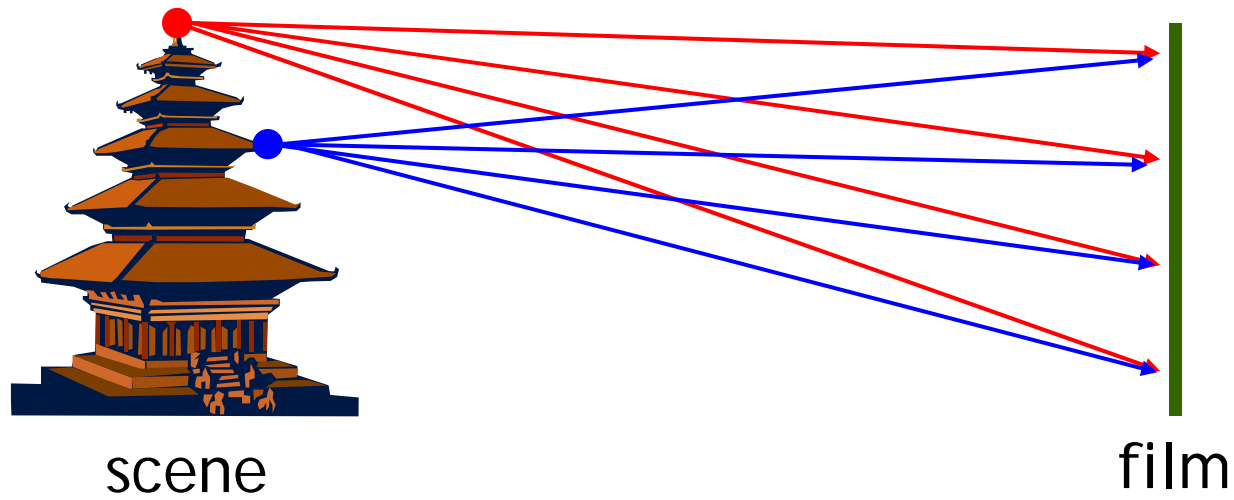
film

Put a piece of film in front of an object.

Pinhole camera

pinhole camera

scene   barrier   film
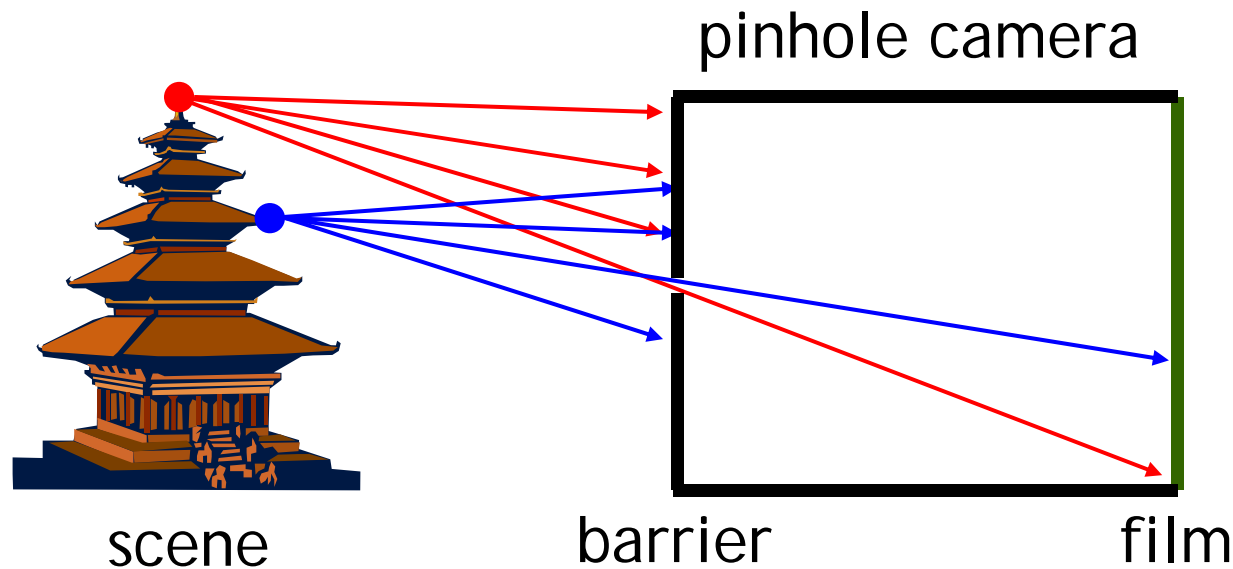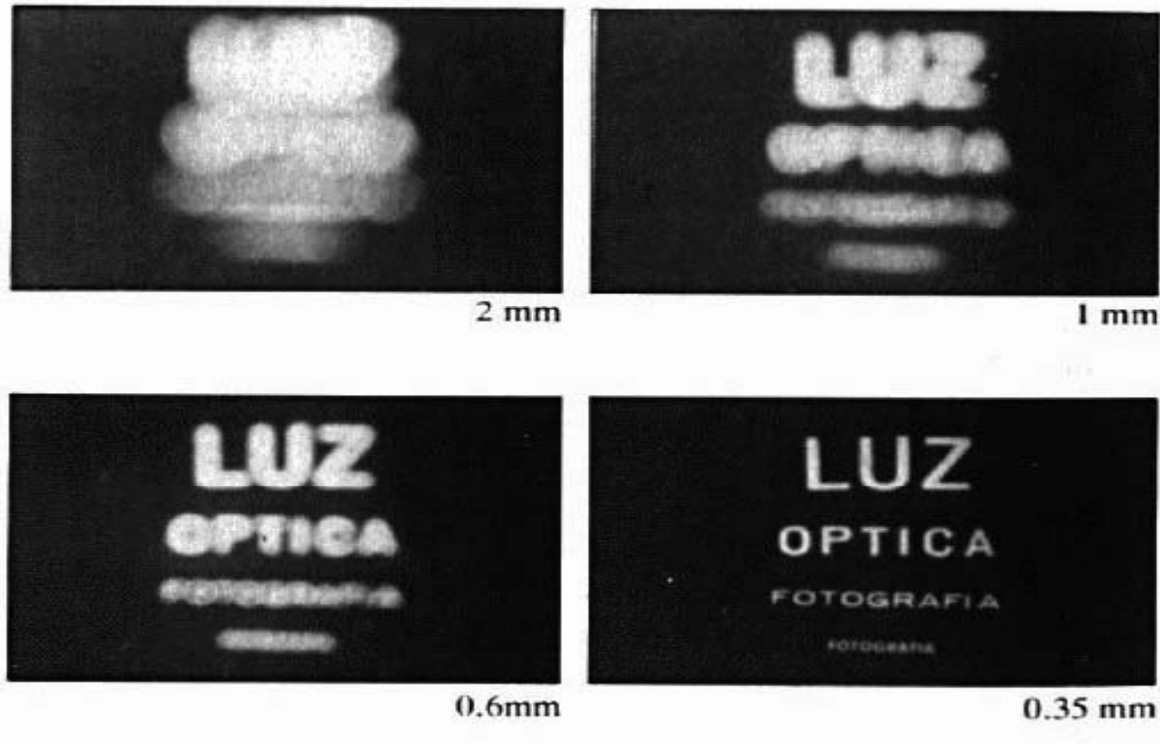
Add a barrier to block off most of the rays.

- It reduces blurring
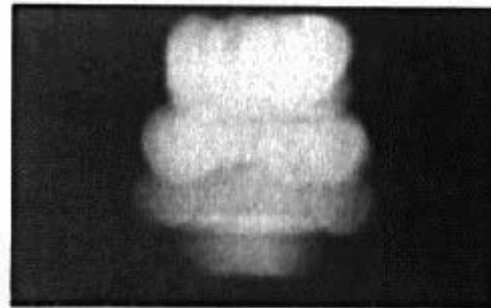- The pinhole is known as the aperture
- The image is inverted
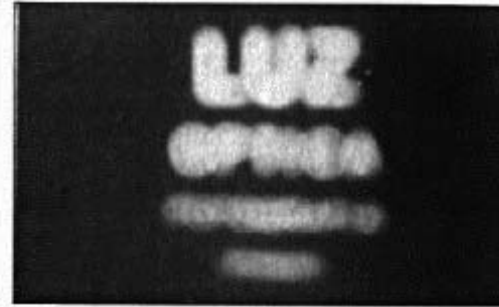
Shrinking the aperture

Why not making the aperture as small as possible?
- Less light gets through
- Diffraction effect

Shrinking the aperture

High-end commercial pinhole cameras
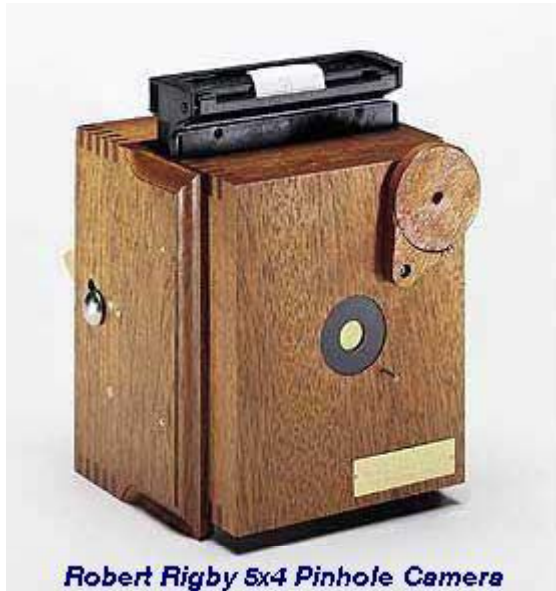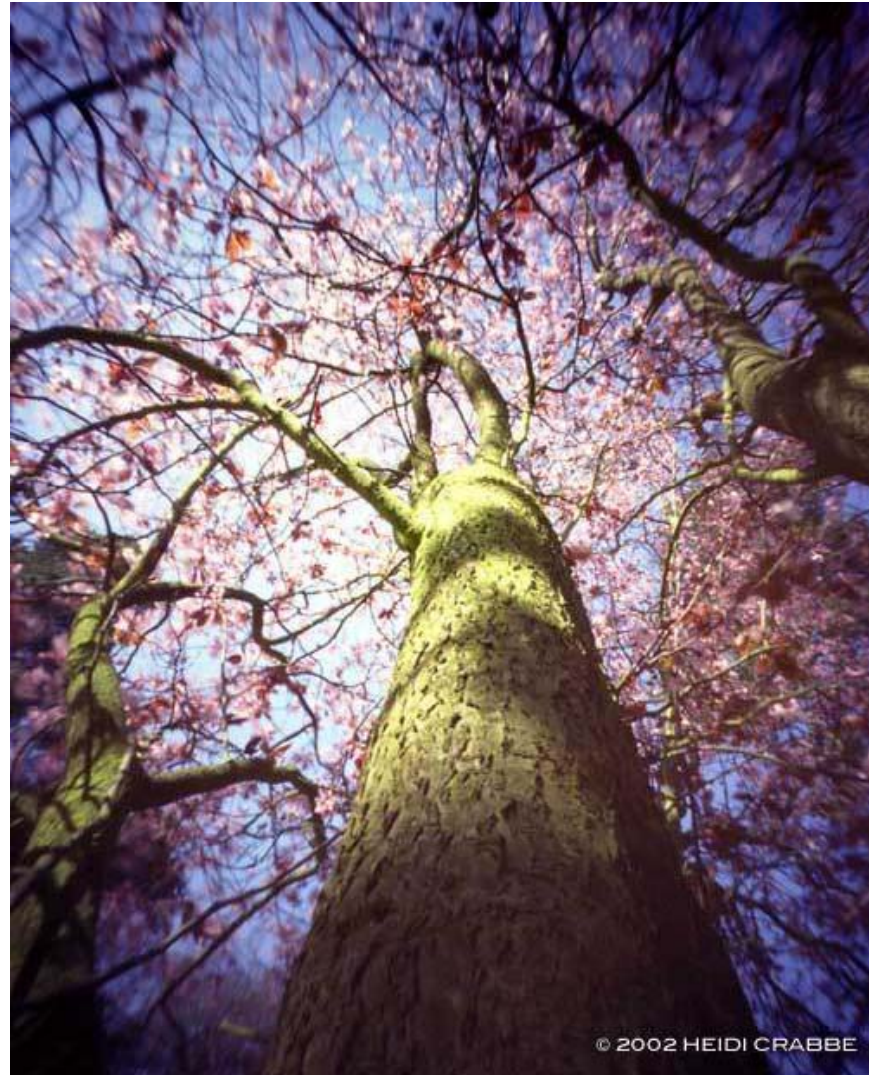
Robert Rigby 5x4 Pinhole Camera

$200~$700

© 2002 HEIDI CRABBE

Adding a lens

scene   lens   film

"circle of confusion"
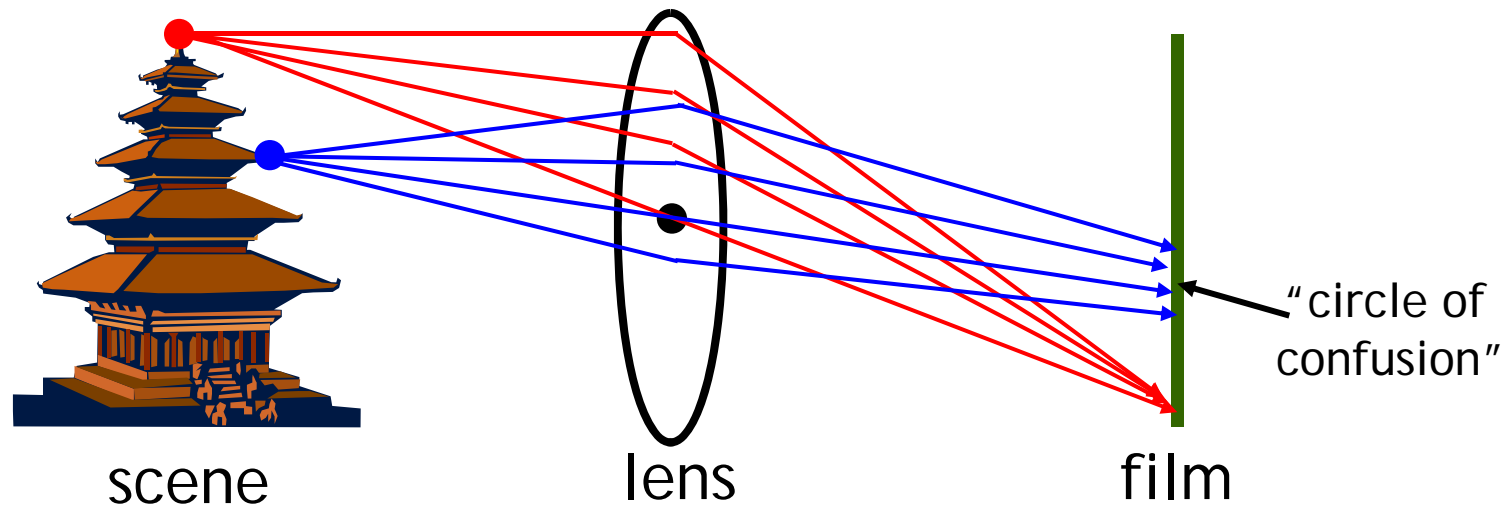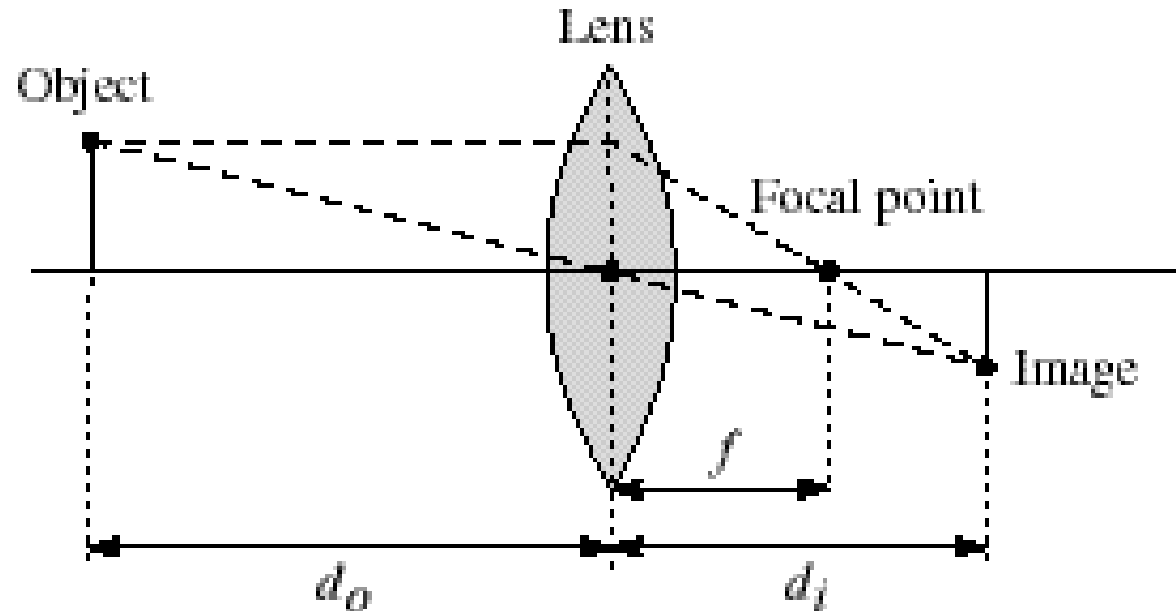
A lens focuses light onto the film

- There is a specific distance at which objects are "in focus"
- other points project to a "circle of confusion" in the image
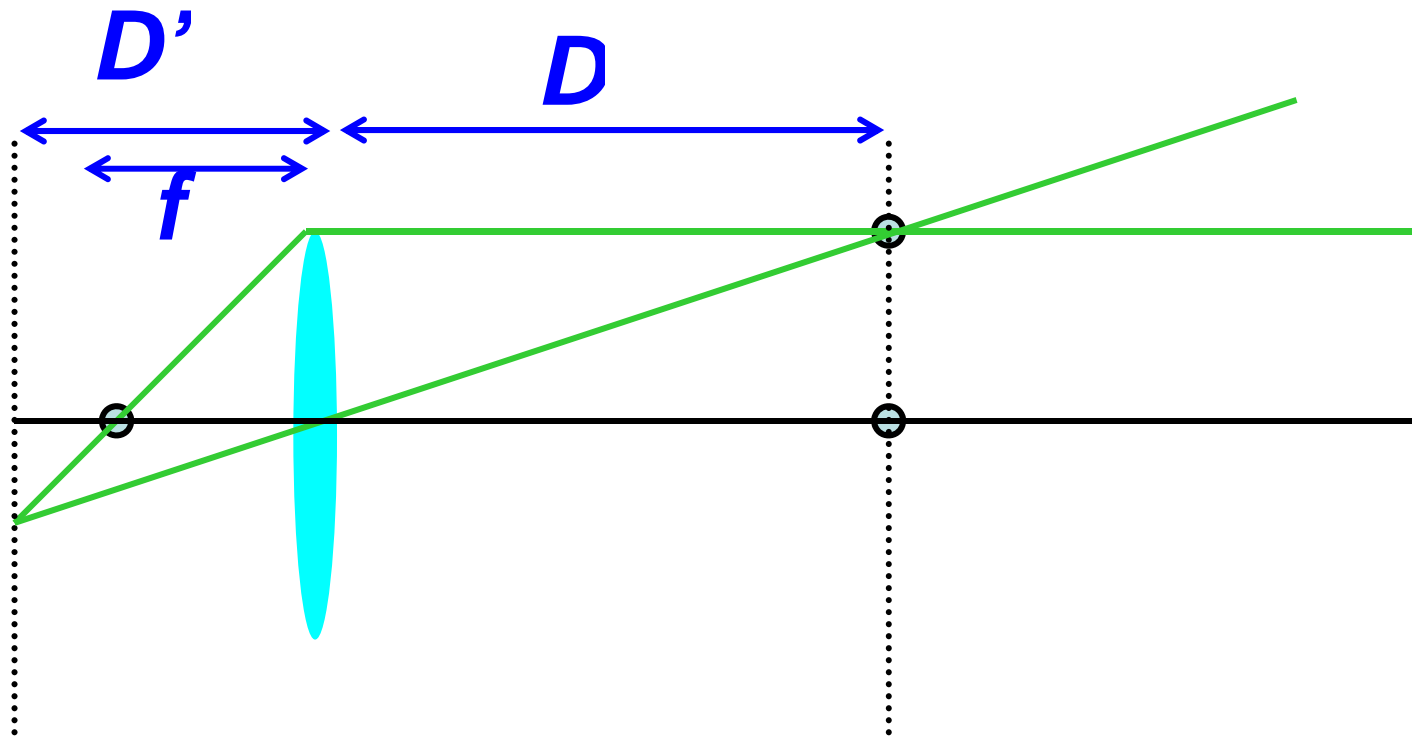
Lenses

Thin lens equation: $\dfrac{1}{d_o} + \dfrac{1}{d_i} = \dfrac{1}{f}$
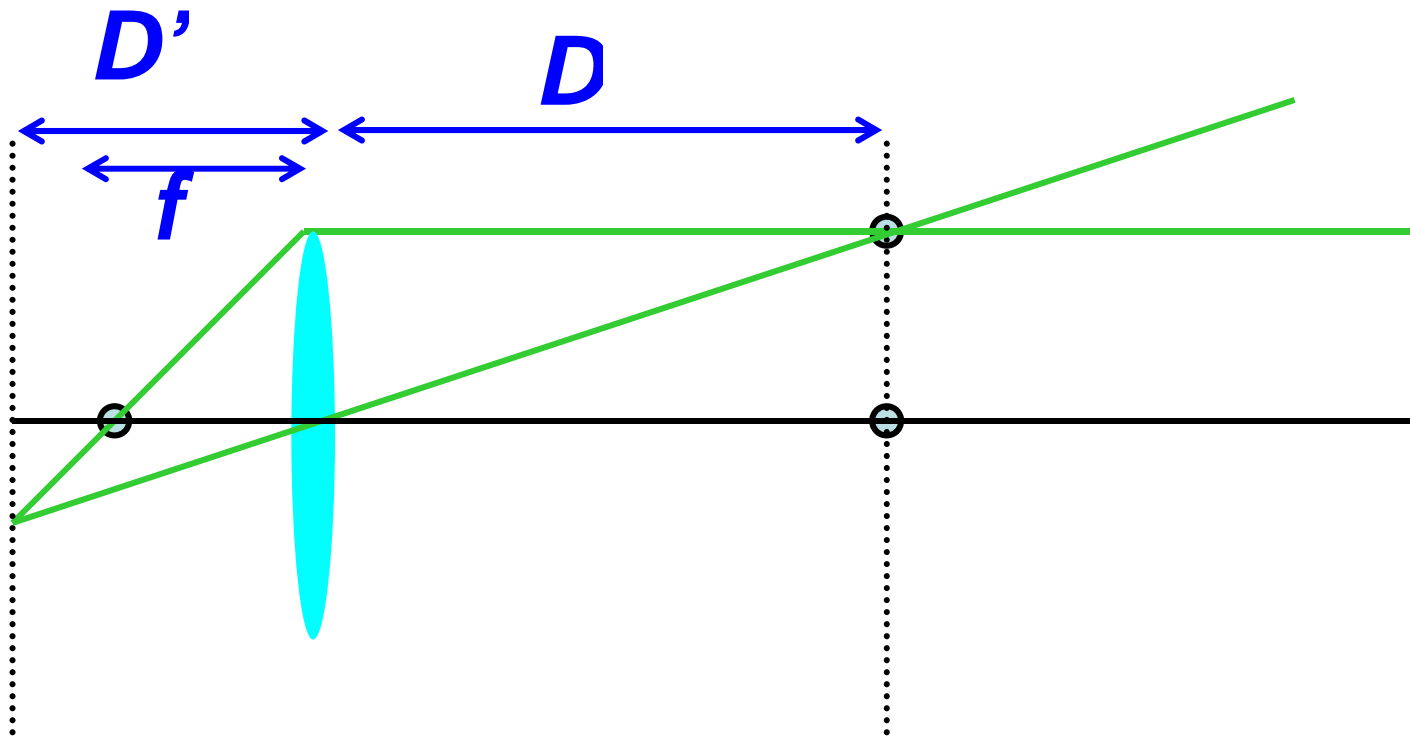
- Any object point satisfying this equation is in focus
- Thin lens applet:
  http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html

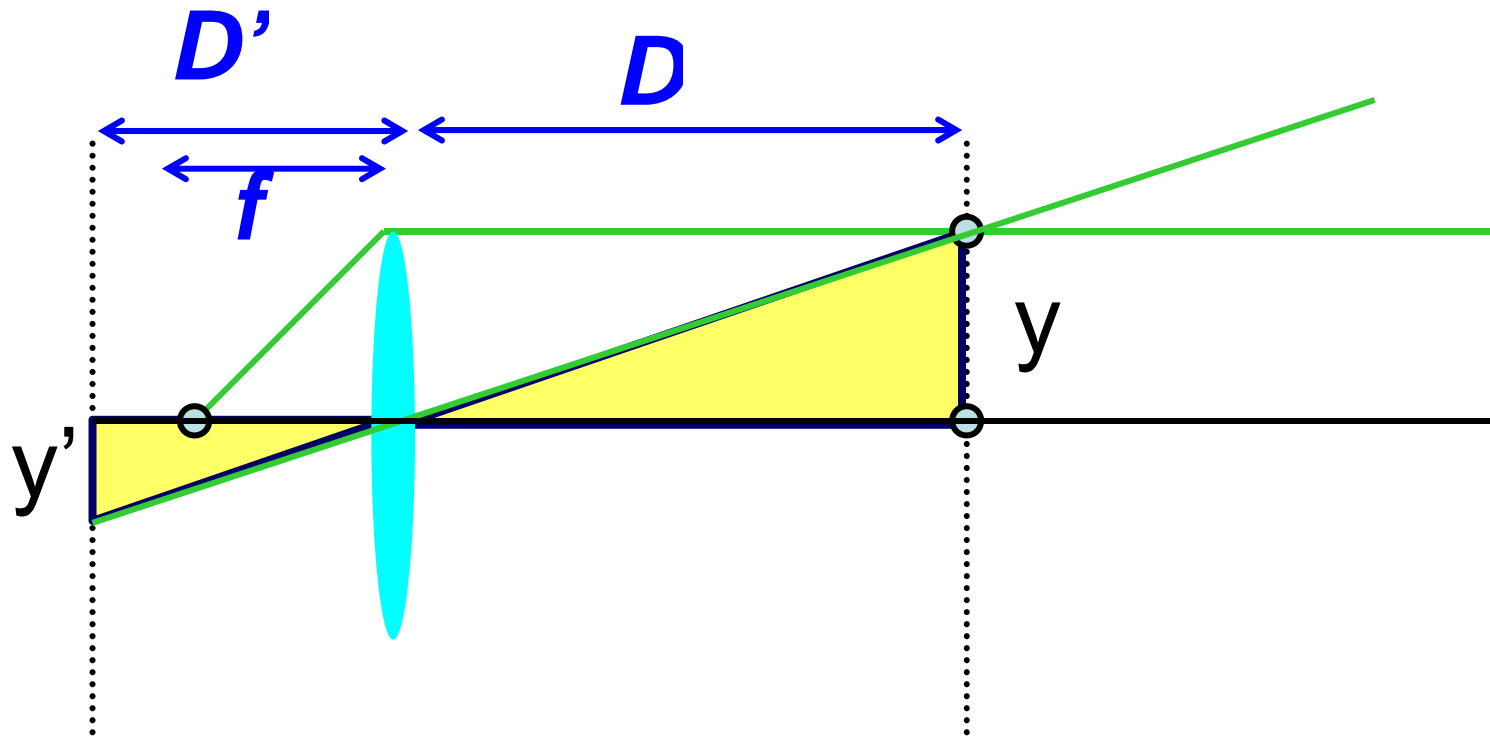# Thin lens formula

Thin lens formula

Similar triangles everywhere!

Frédo Durand's slide

Thin lens formula

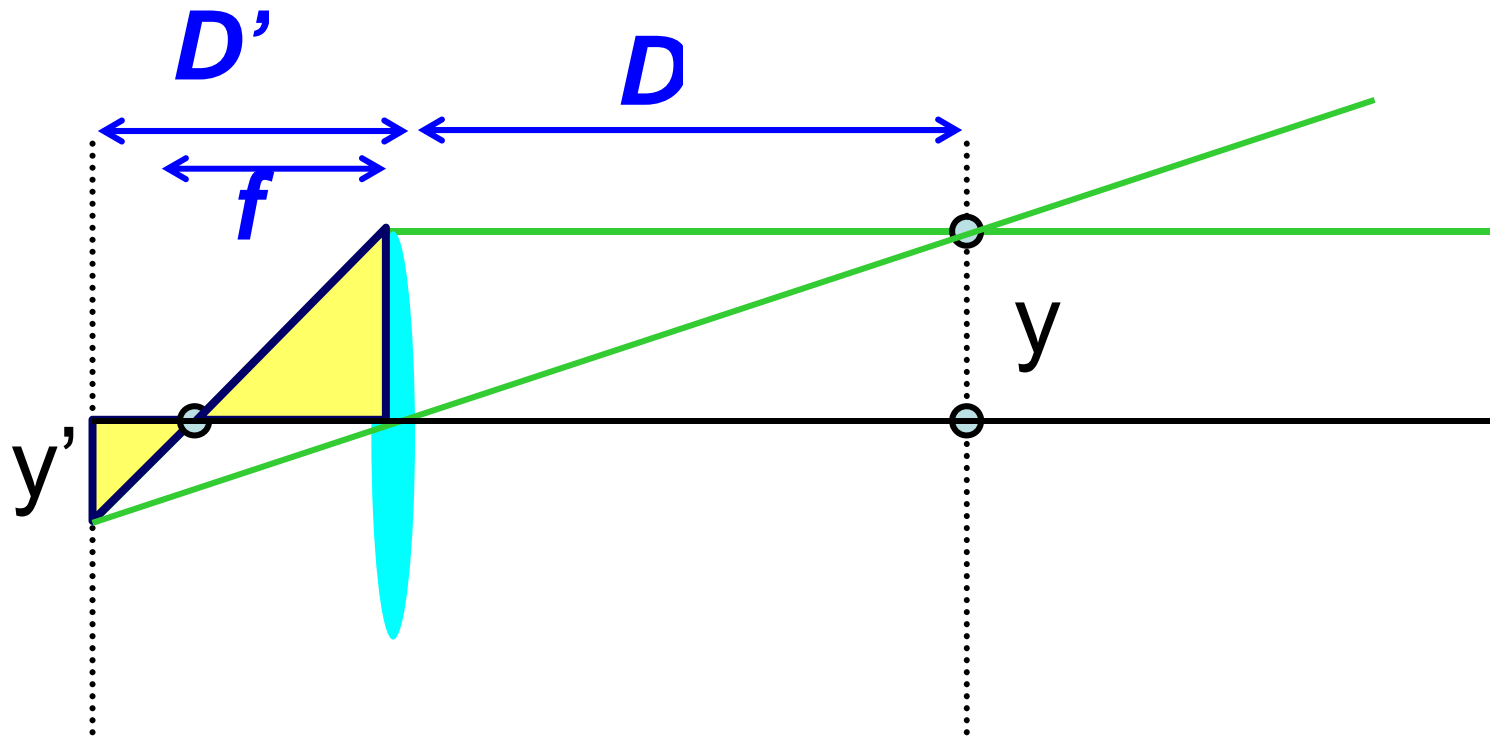Similar triangles everywhere!

$$y'/y = D'/D$$

Thin lens formula

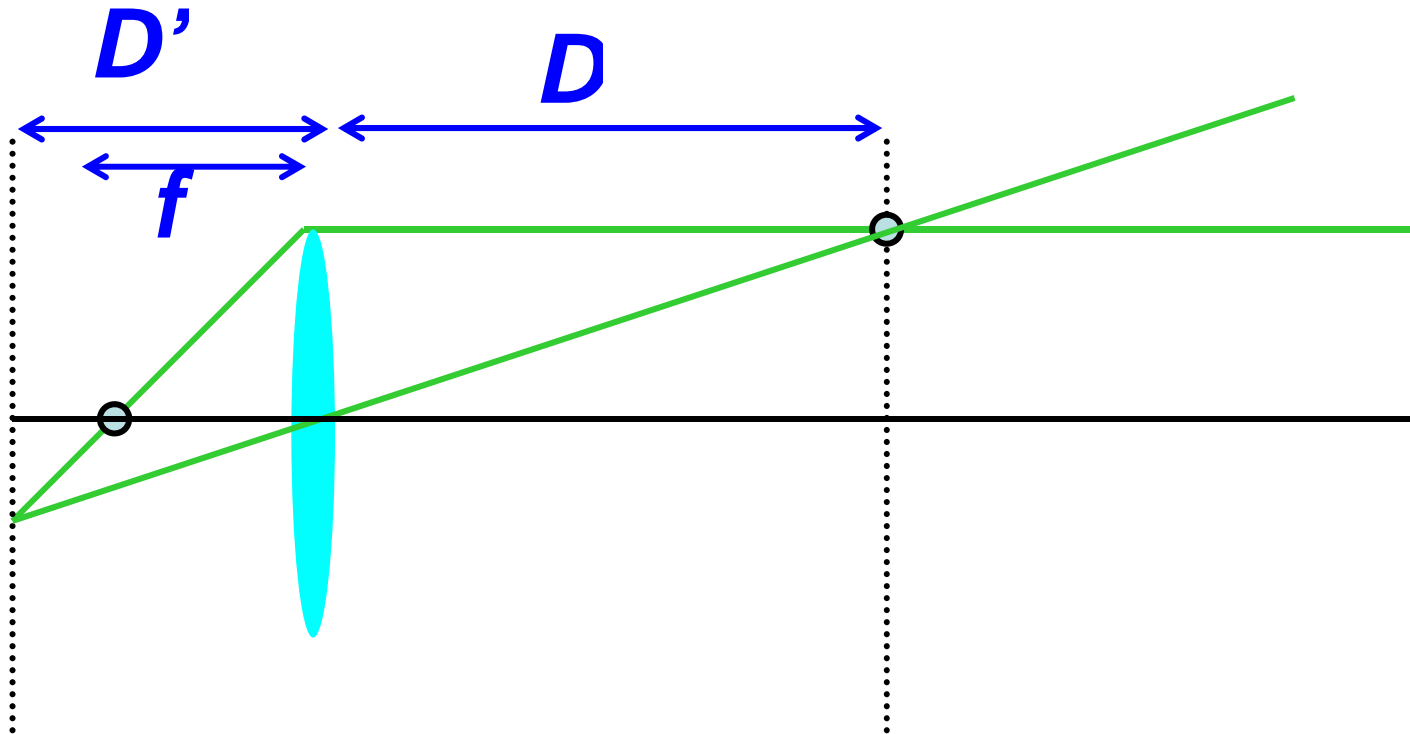Similar triangles everywhere!

$$y'/y = D'/D$$

$$y'/y = (D'-f)/D$$

Thin lens formula

$$\frac{1}{D'} + \frac{1}{D} = \frac{1}{f}$$

The focal length f determines the lens's ability to bend (refract) light. It is a function of the shape and index of refraction of the lens.
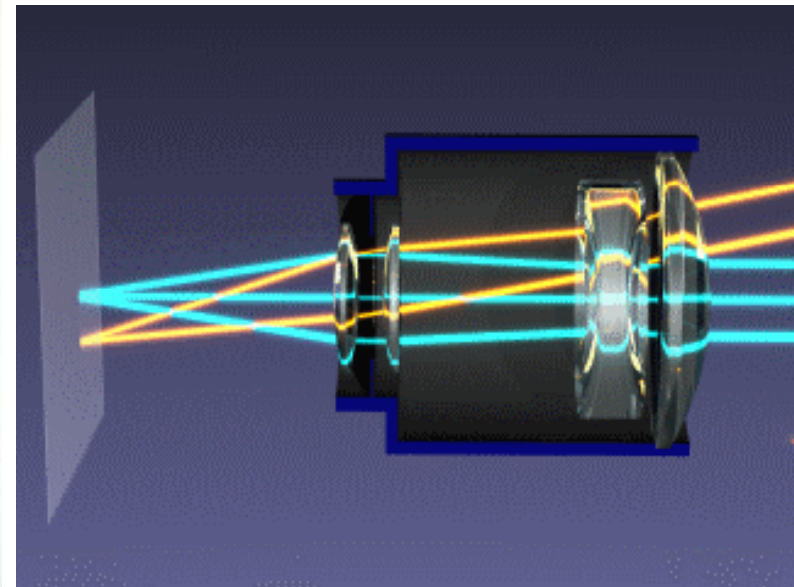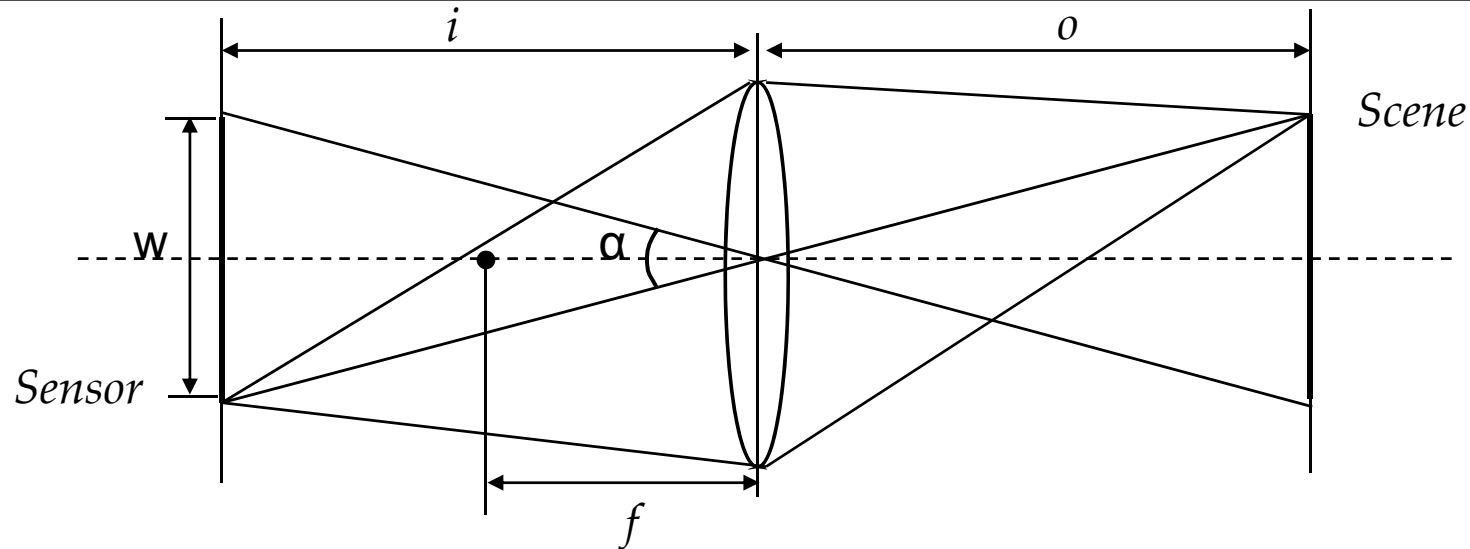
Zoom lens

200mm

28mm

Nikkor 28-200mm zoom lens.

simplified zoom lens in operation

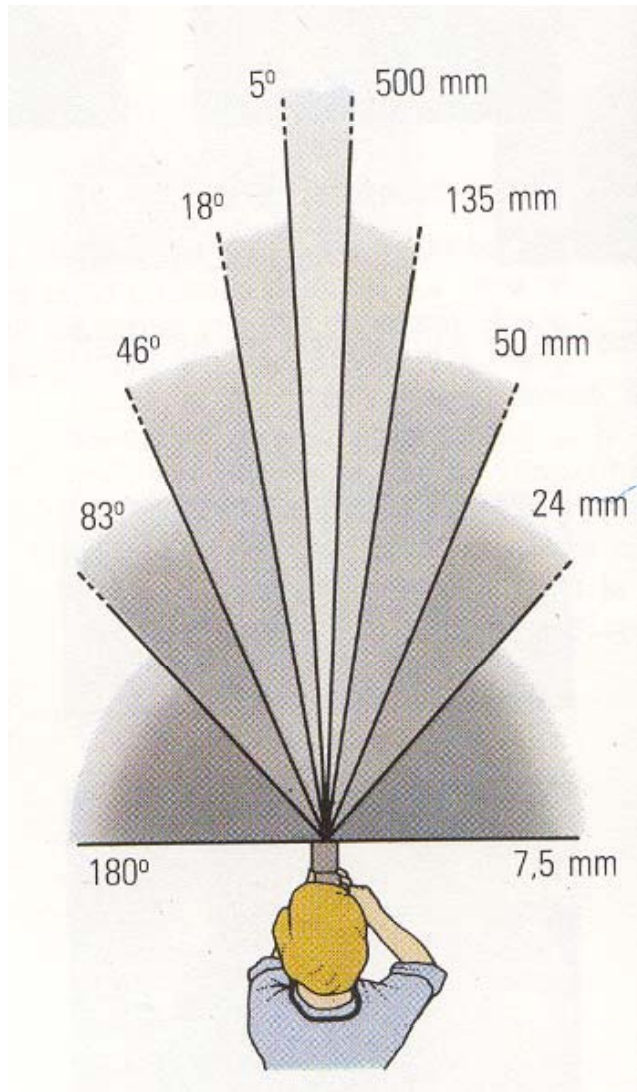From wikipedia

Field of view vs focal length

Gaussian Lens Formula:

$$\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$$

Field of View: $\alpha = 2\arctan(w/(2i))$ $\approx 2\arctan(w/(2f))$

Example: w = 30mm, f = 50mm => $\alpha \approx 33.4°$

Slides from Li Zhang
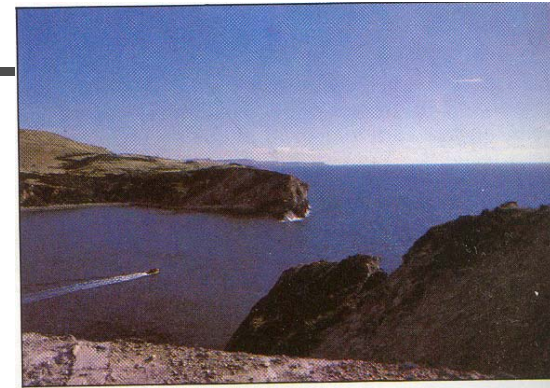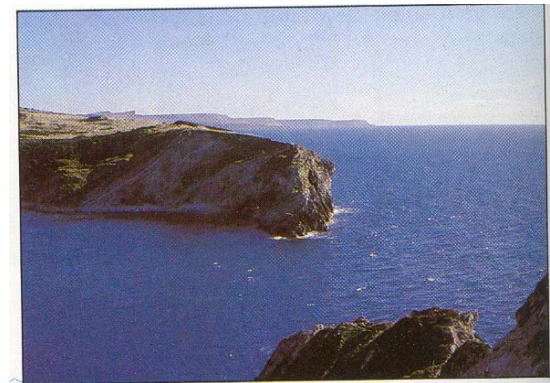
Focal length in practice
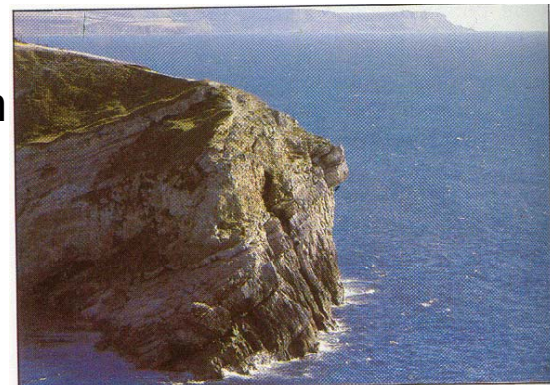
Focal length in practice

wide angle   standard   telephoto

Distortion

No distortion   Pin cushion   Barrel
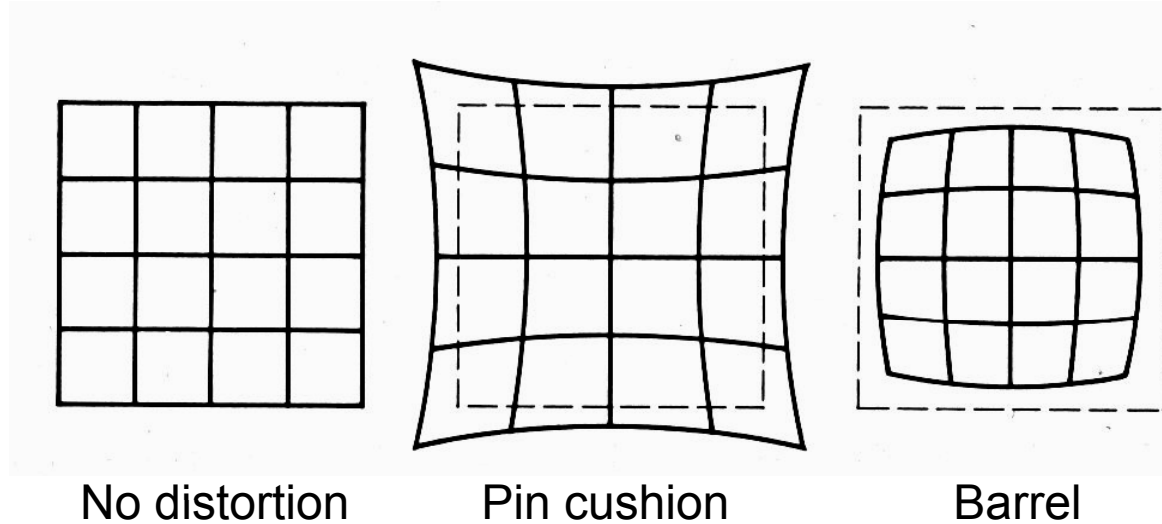
- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens

Correcting radial distortion

from Helmut Dersch

Vignetting

Vignetting

$$L_3 \quad L_2 \quad L_1$$

B

A

more light from A than B !

Vignetting

Vignetting

L_3 L_2 L_1 B

A

more light from A than B !
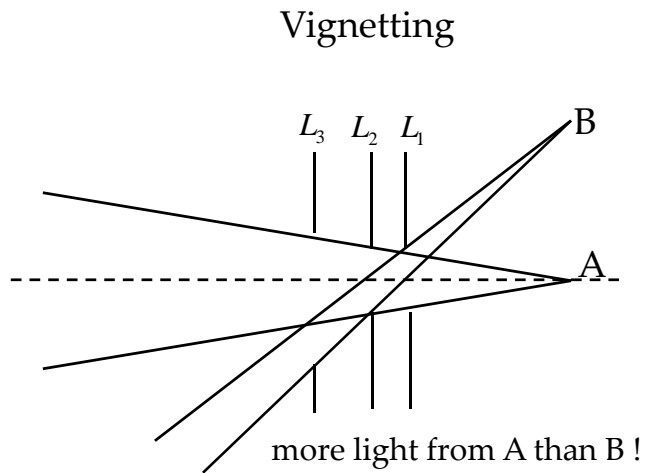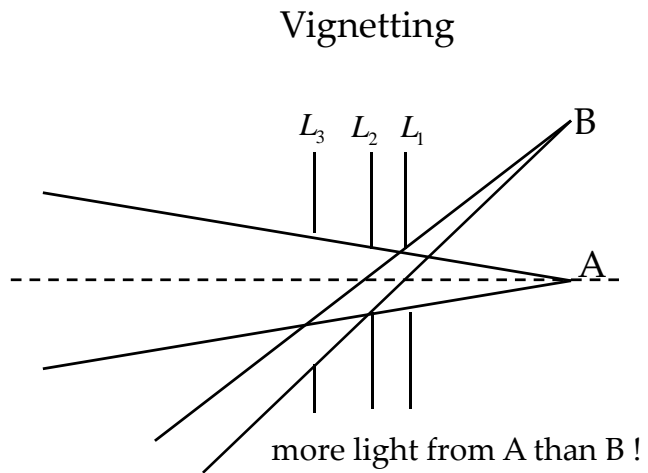
original   corrected

Goldman & Seitz ICCV 2005

Slides from Li Zhang

Chromatic Aberation
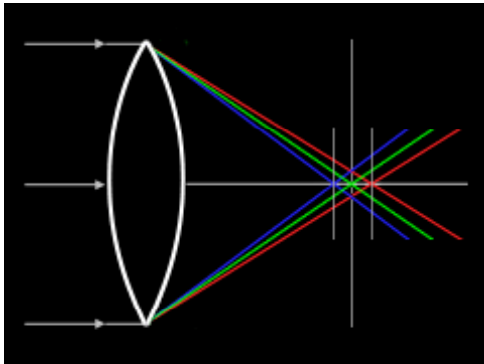
Lens has different refractive indices
for different wavelengths.
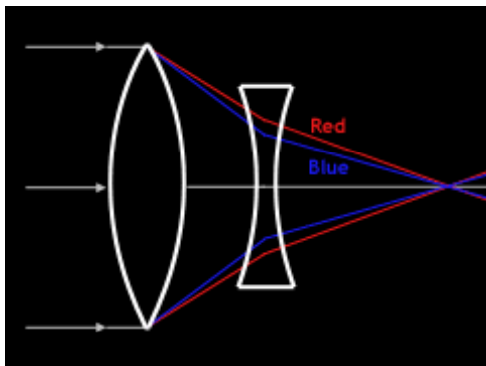
Special lens systems using two or more pieces
of glass with different refractive indexes can
reduce or eliminate this problem.

http://www.dpreview.com/learn/?/Glossary/Optical/chromatic_aberration_0
1.htm

Slides from Li Zhang

Exposure = aperture + shutter speed
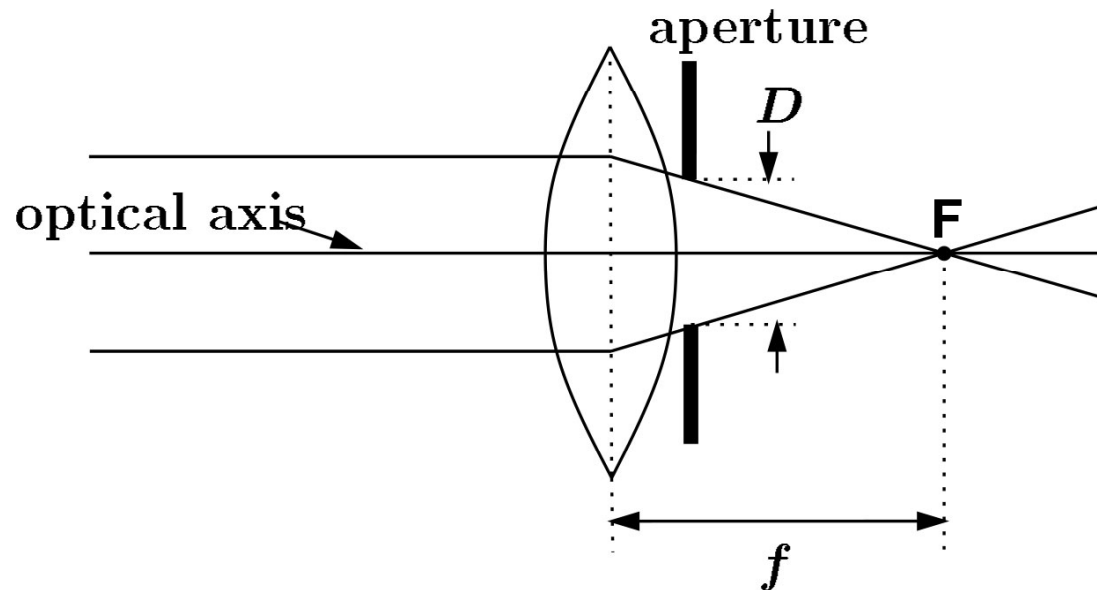
- Aperture of diameter D restricts the range of rays (aperture may be on either side of the lens)
- Shutter speed is the amount of time that light is allowed to pass through the aperture

Exposure

- Two main parameters:
  - Aperture (in f stop)

Full aperture　　Medium aperture　　Stopped down
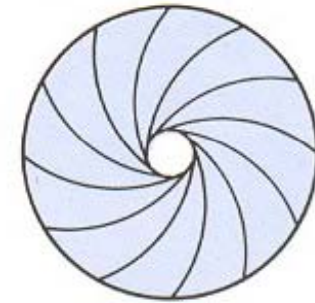
  - Shutter speed (in fraction of a second)
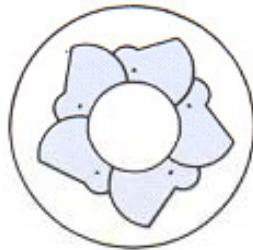
Blade (closing)　Blade (open)　Focal plane (closed)　　Focal plane (open)
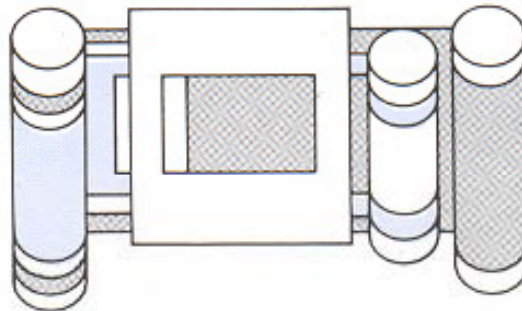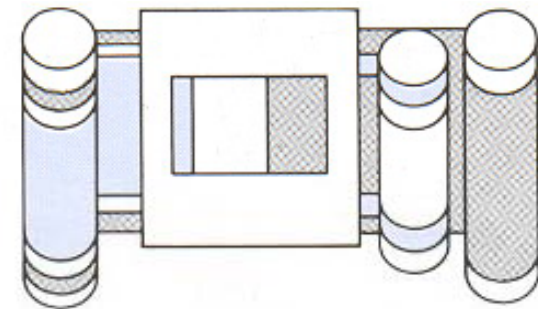
Effects of shutter speeds

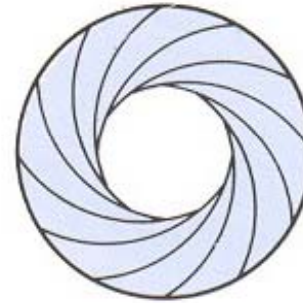- Slower shutter speed => more light, but more motion blur

Slow shutter speed   Fast shutter speed

From Photography, London et al.
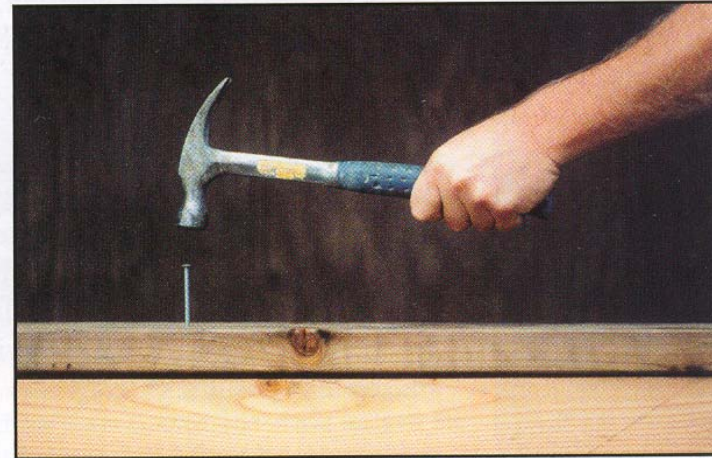
- Faster shutter speed freezes motion

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

DigiVFX

Aperture

- Aperture is the diameter of the lens opening, usually specified by f-stop, f/D, a fraction of the focal length.
  - f/2.0 on a 50mm means that the aperture is 25mm
  - f/2.0 on a 100mm means that the aperture is 50mm

- When a change in f-stop occurs, the light is either doubled or cut in half.

- Lower f-stop, more light (larger lens opening)

- Higher f-stop, less light (smaller lens opening)

f/1.4   f/2.8   f/3.5   f/4

f/5.6   f/8   f/11   f/22
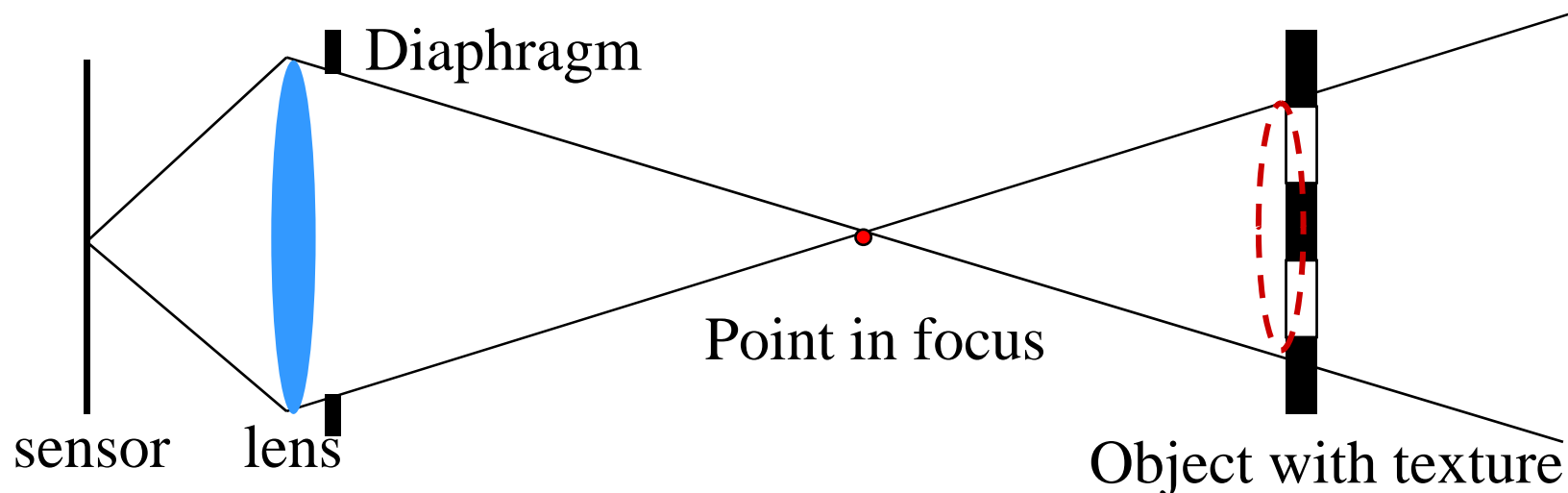
Depth of field

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

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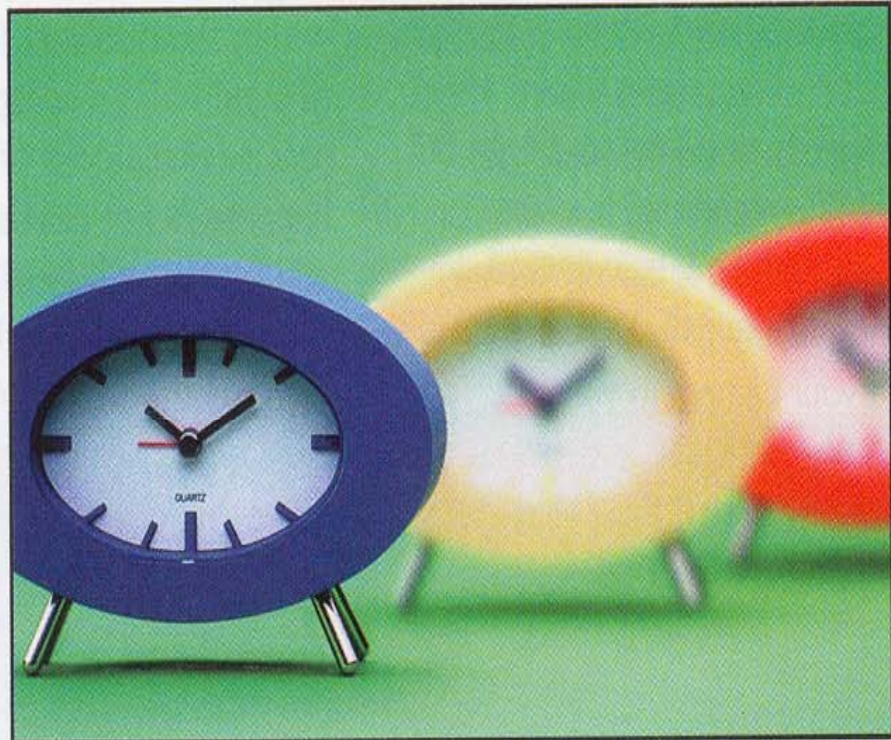
Changing the aperture size affects depth of field.
A smaller aperture increases the range in which
the object is approximately in focus

Diaphragm

Point in focus

sensor   lens

Object with texture

Depth of field

From Photography, London et al.

Exposure

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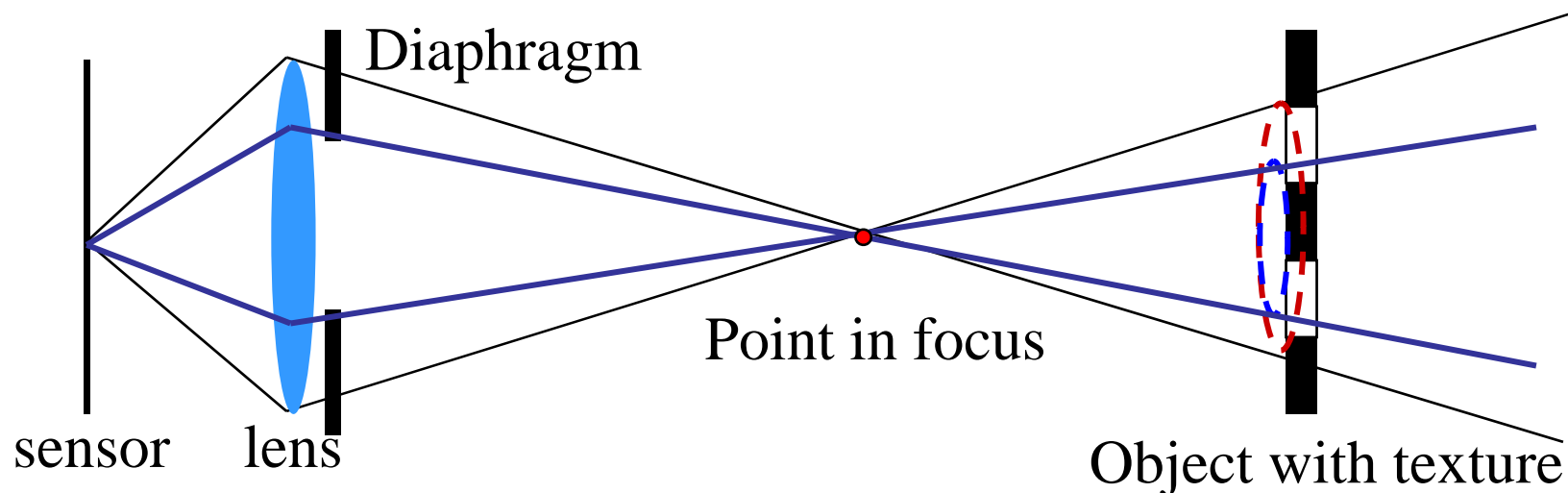 - Aperture (in f stop)
  - Shutter speed (in fraction of a second)
- Reciprocity

  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

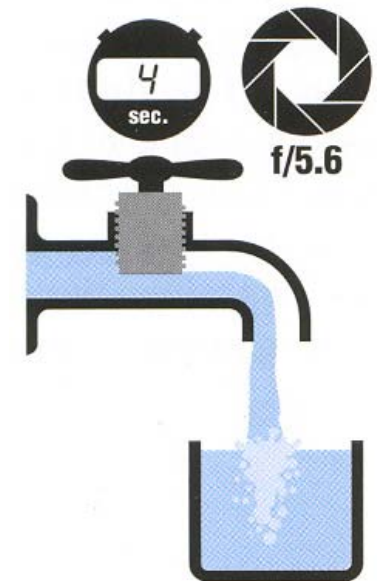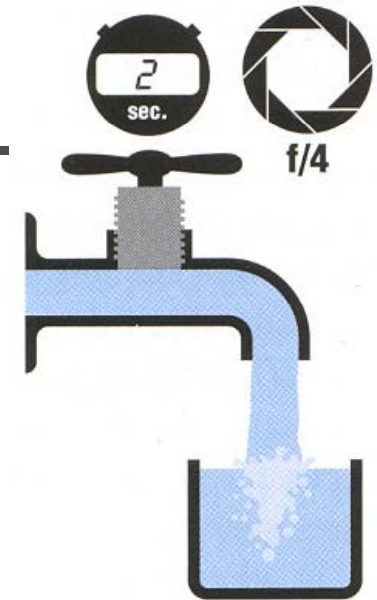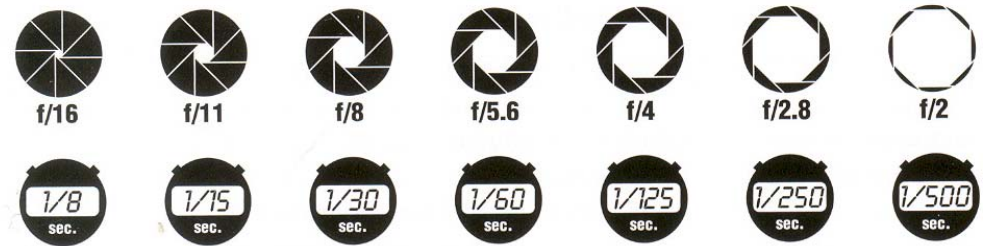- Assume we know how much light we need
- We have the choice of an infinity of shutter speed/aperture pairs

f/16 f/11 f/8 f/5.6 f/4 f/2.8 f/2

1/8 sec. 1/15 sec. 1/30 sec. 1/60 sec. 1/125 sec. 1/250 sec. 1/500 sec.

- 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)

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, photographers sets the shutter speed and the camera deduces the aperture

- In Program mode, the camera decides both exposure and shutter speed (middle value more or less)

- In Manual mode, 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

Sensitivity (ISO)

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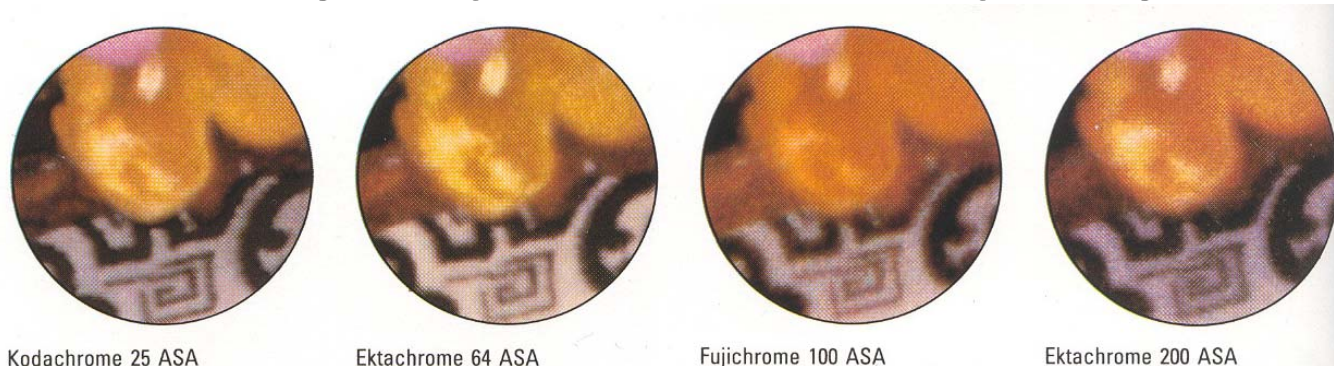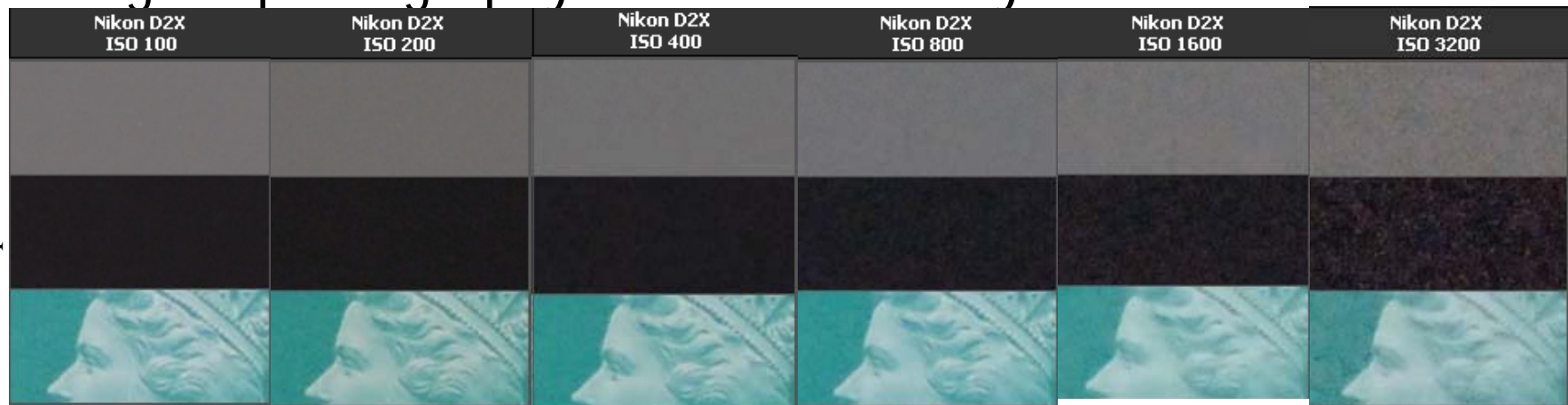

Kodachrome 25 ASA   Ektachrome 64 ASA   Fujichrome 100 ASA   Ektachrome 200 ASA

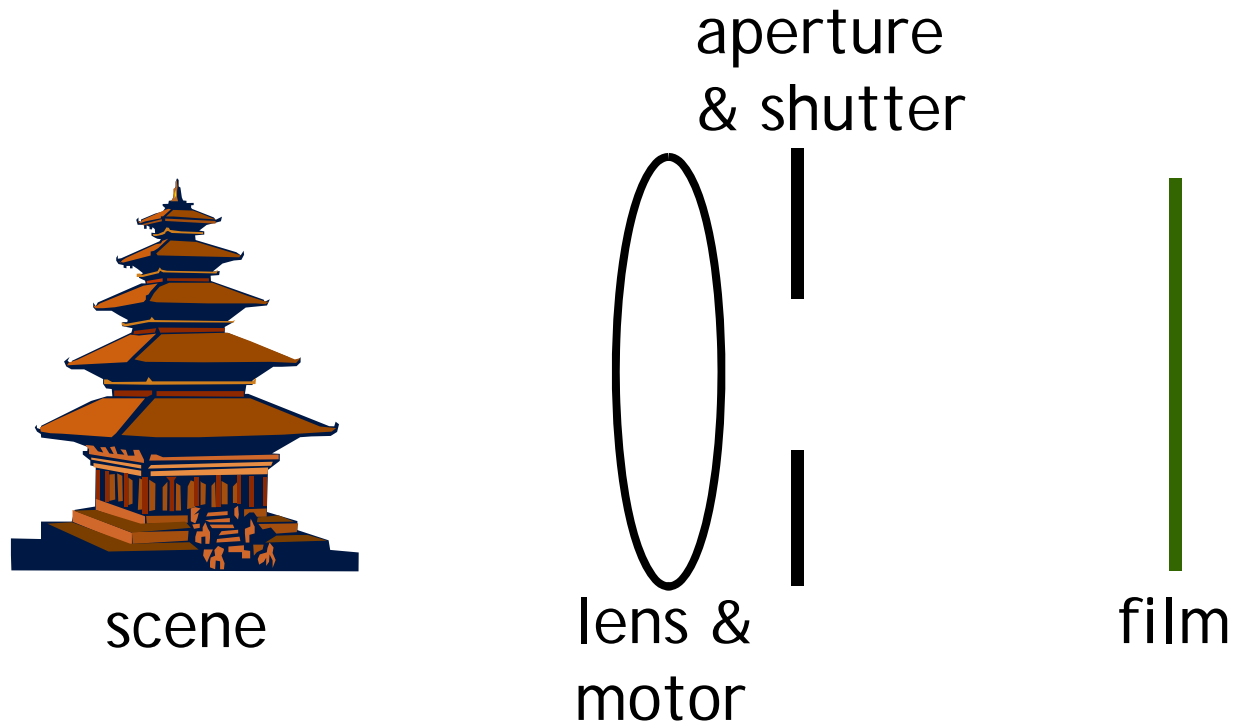- Digital photography: trade sensitivity for noise

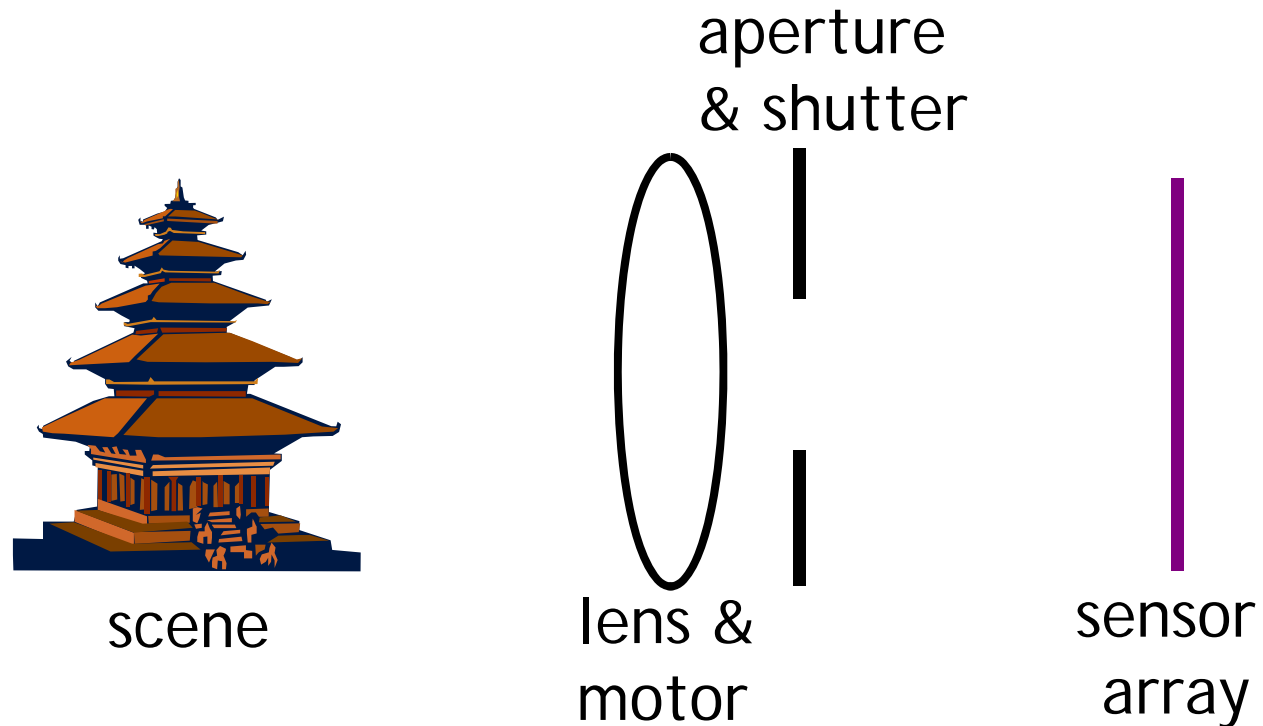From dpreview.com

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

Demo

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

Film camera

aperture
& shutter

scene

lens &
motor

film
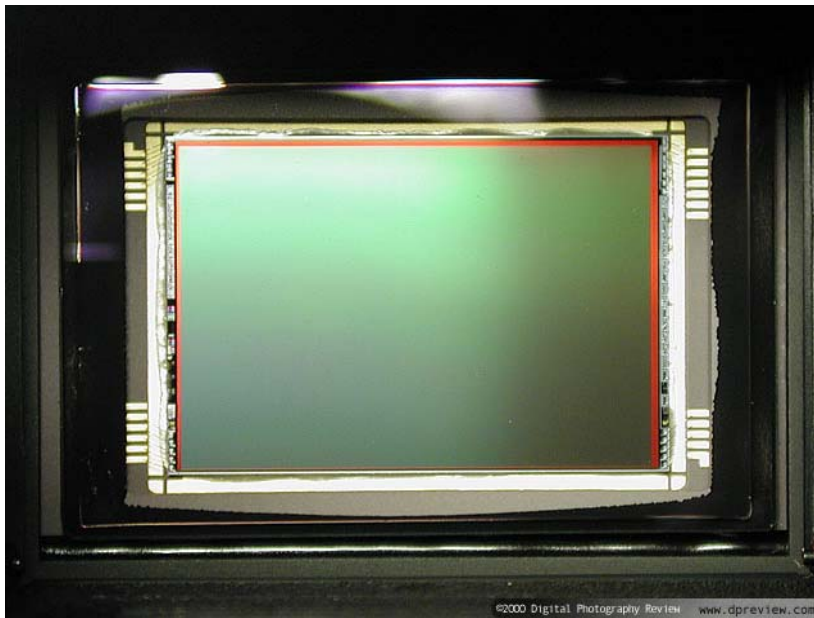
Digital camera

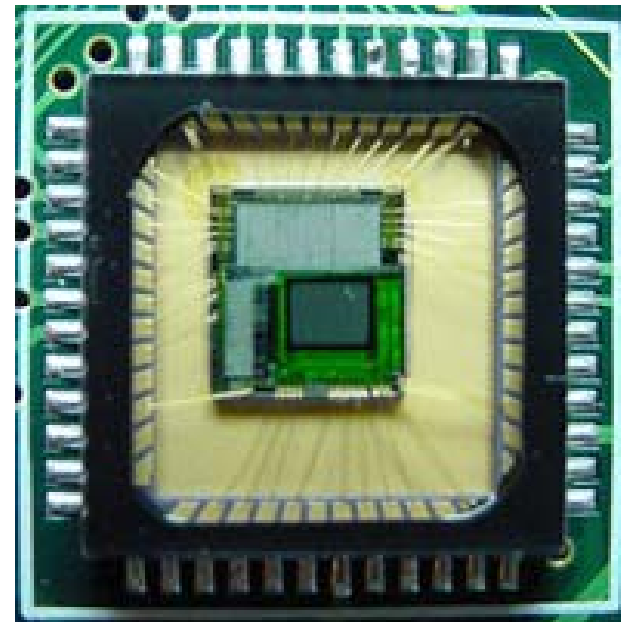aperture & shutter

scene

lens & motor

sensor array

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

CCD v.s. CMOS

- CCD is less susceptible to noise (special process, higher fill factor)
- CMOS is more flexible, less expensive (standard process), less power consumption
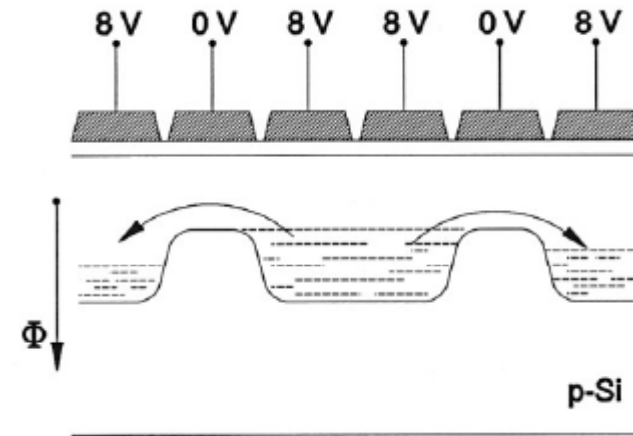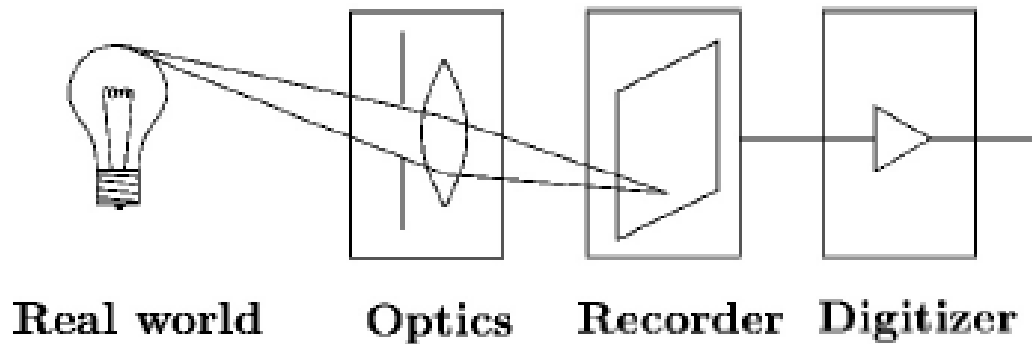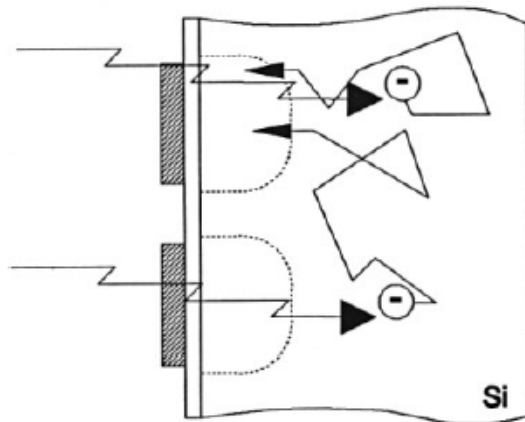

CCD

CMOS

Sensor noise

- Blooming
- Diffusion
- Dark current
- Photon shot noise
- Amplifier readout noise

Blooming

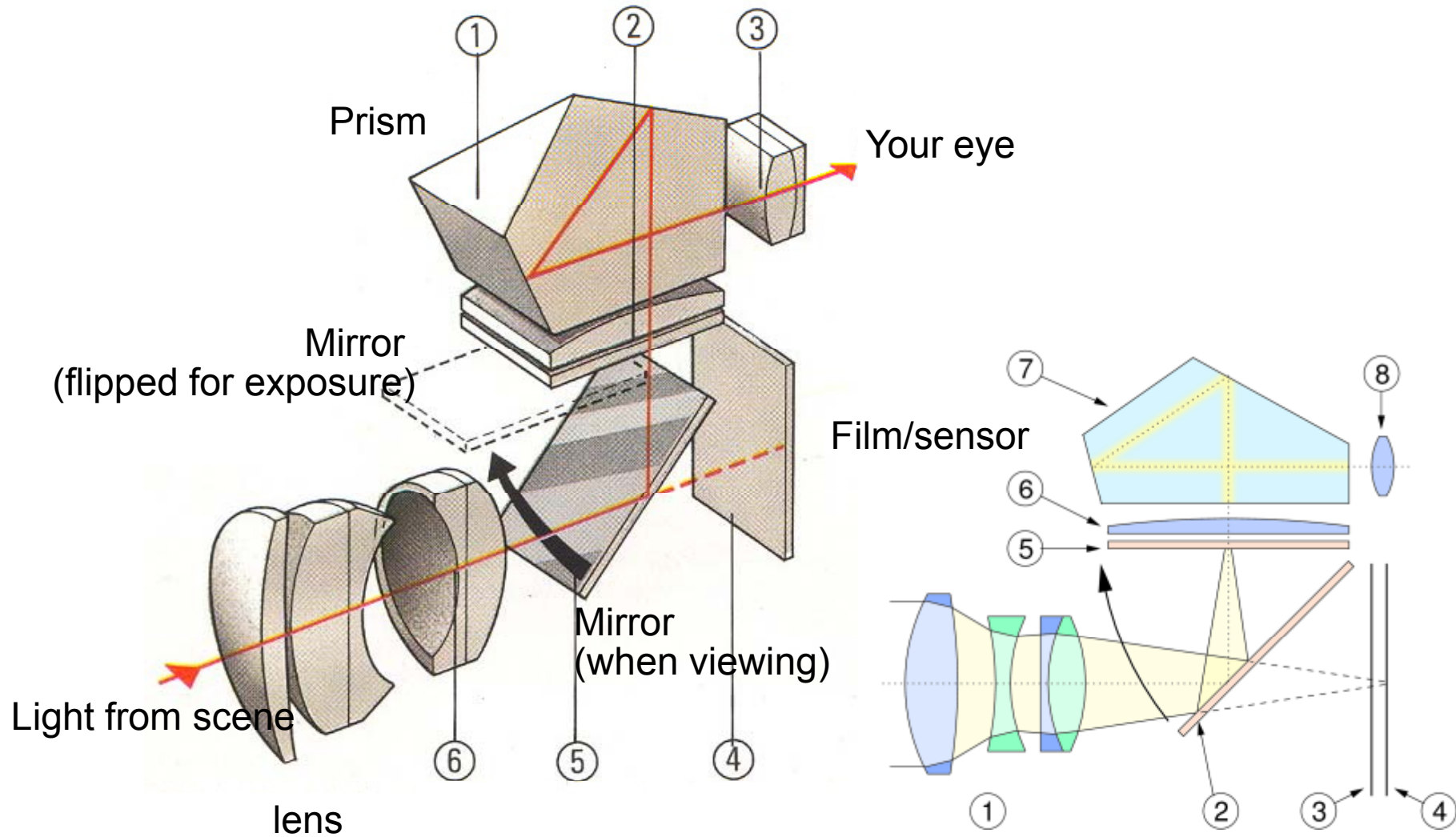Real world   Optics   Recorder   Digitizer

SLR (Single-Lens Reflex)

- Reflex (R in SLR) means that we see through the same lens used to take the image.

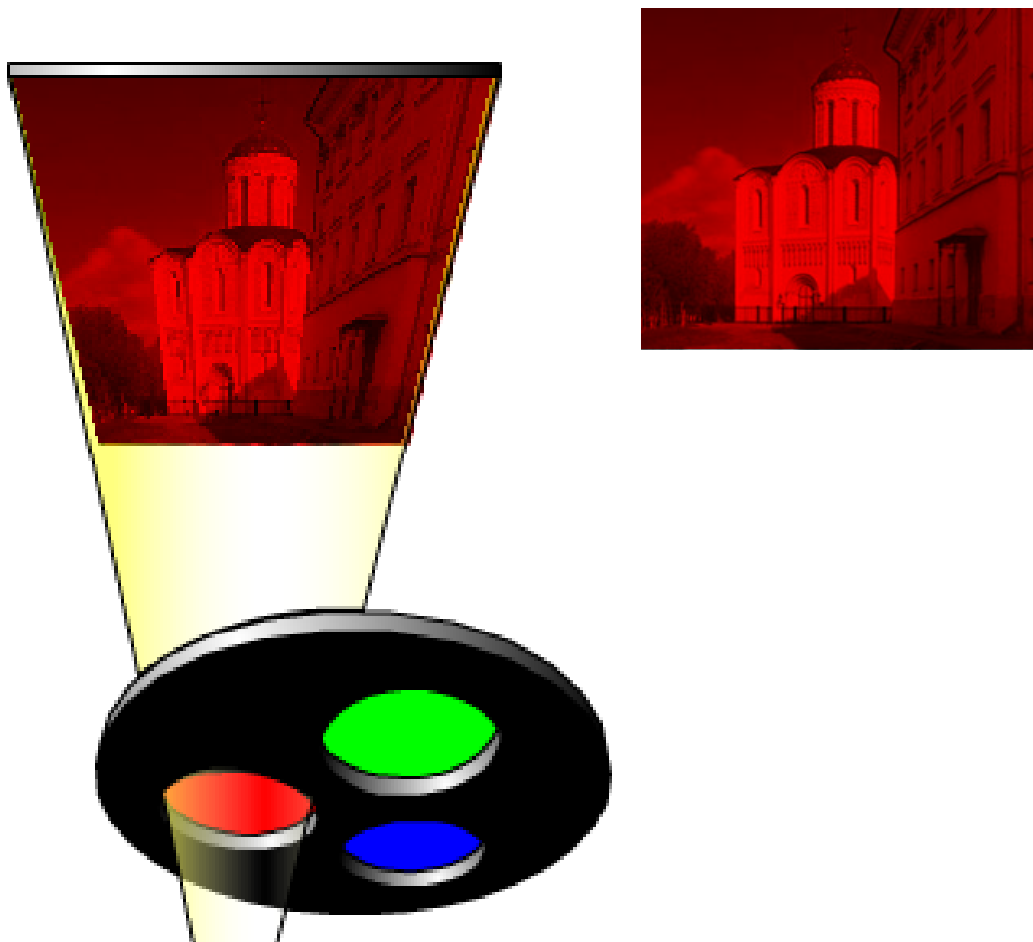- Not the case for compact cameras
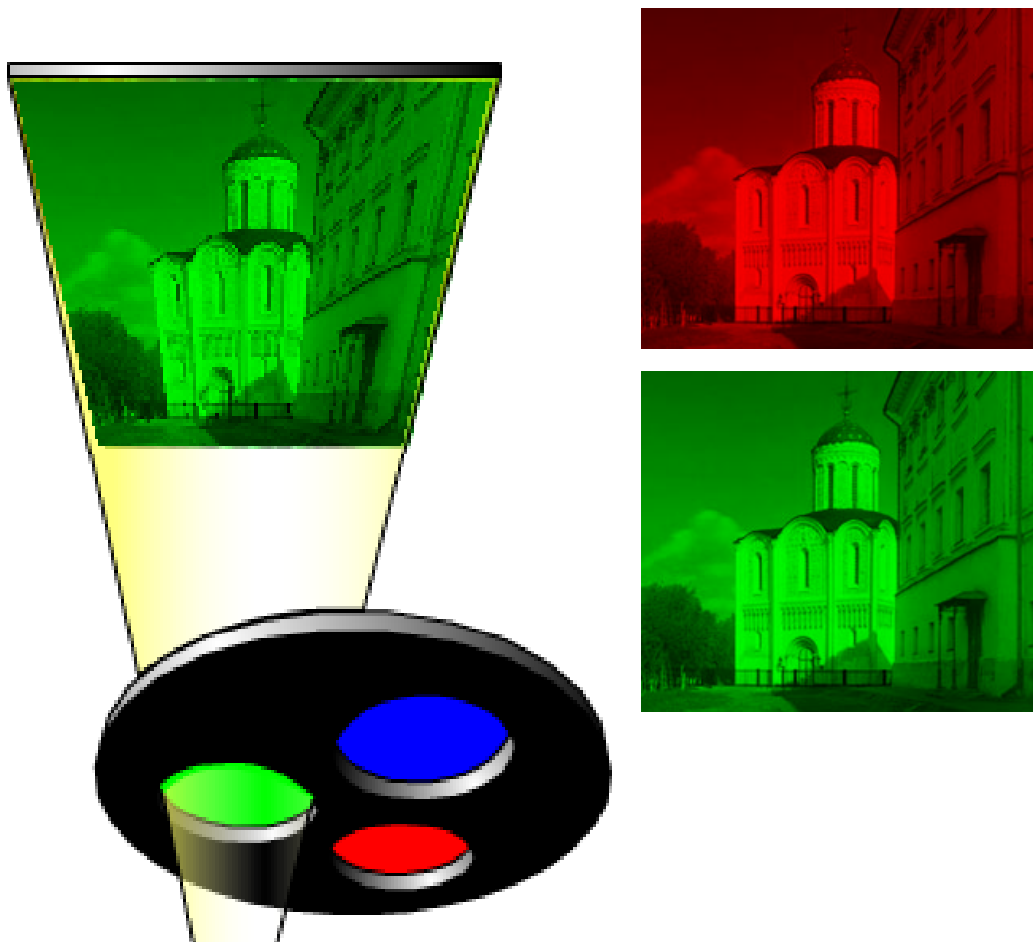
SLR view finder

Color

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

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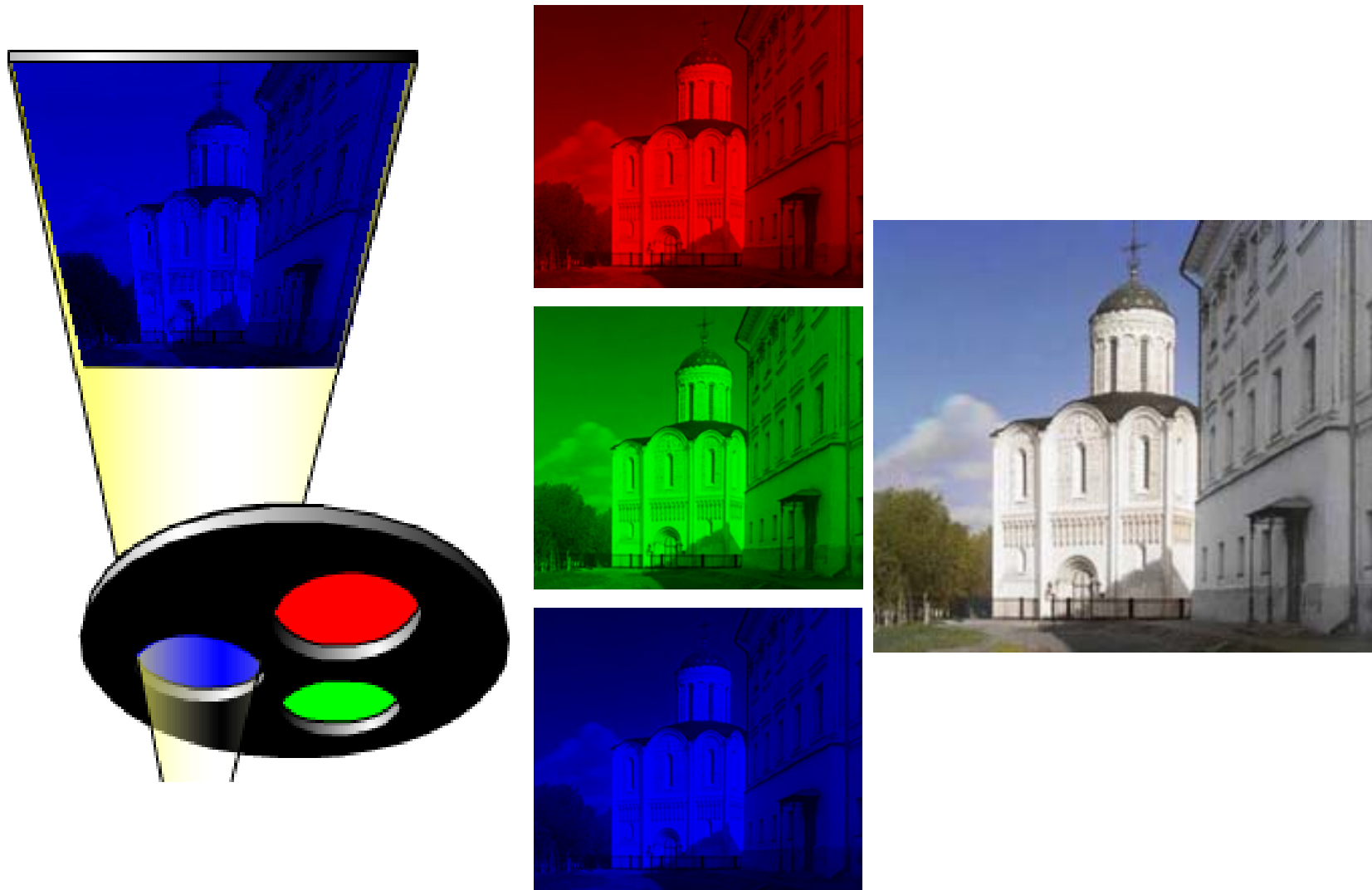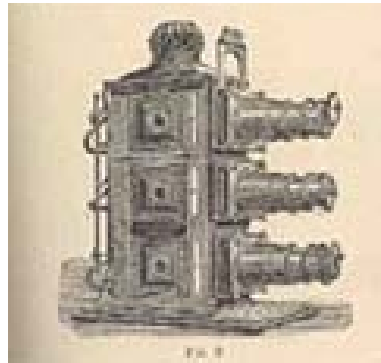- Color filter array
- X3 sensor

Field sequential

Field sequential

Field sequential

Prokudin-Gorskii (early 1900's)

Lantern projector

http://www.loc.gov/exhibits/empire/
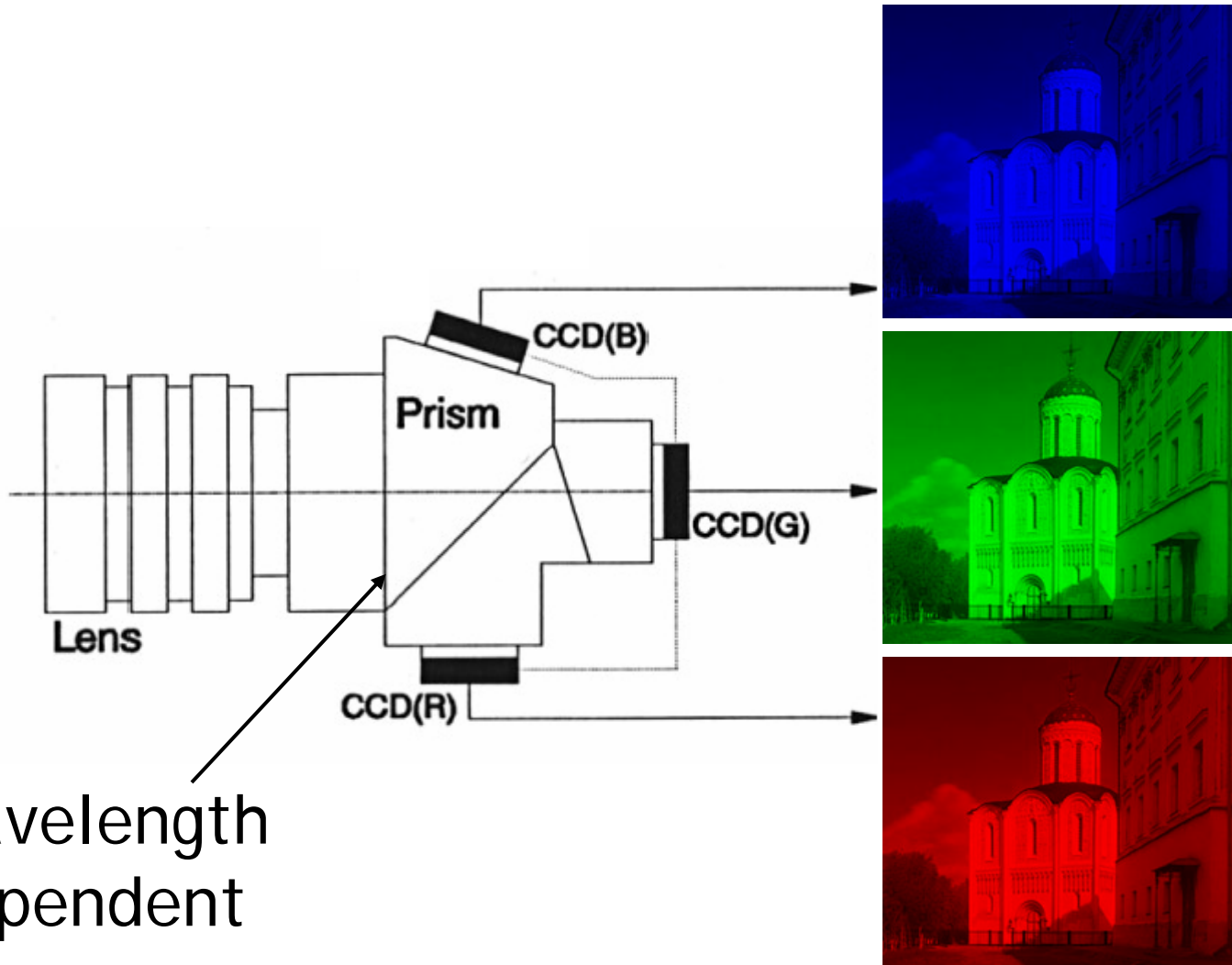
Prokudin-Gorskii (early 1990's)

Multi-chip

wavelength
dependent

Embedded color filters

KAF-5101CE: Absolute Quantum Efficiency With Clear Cover Glass
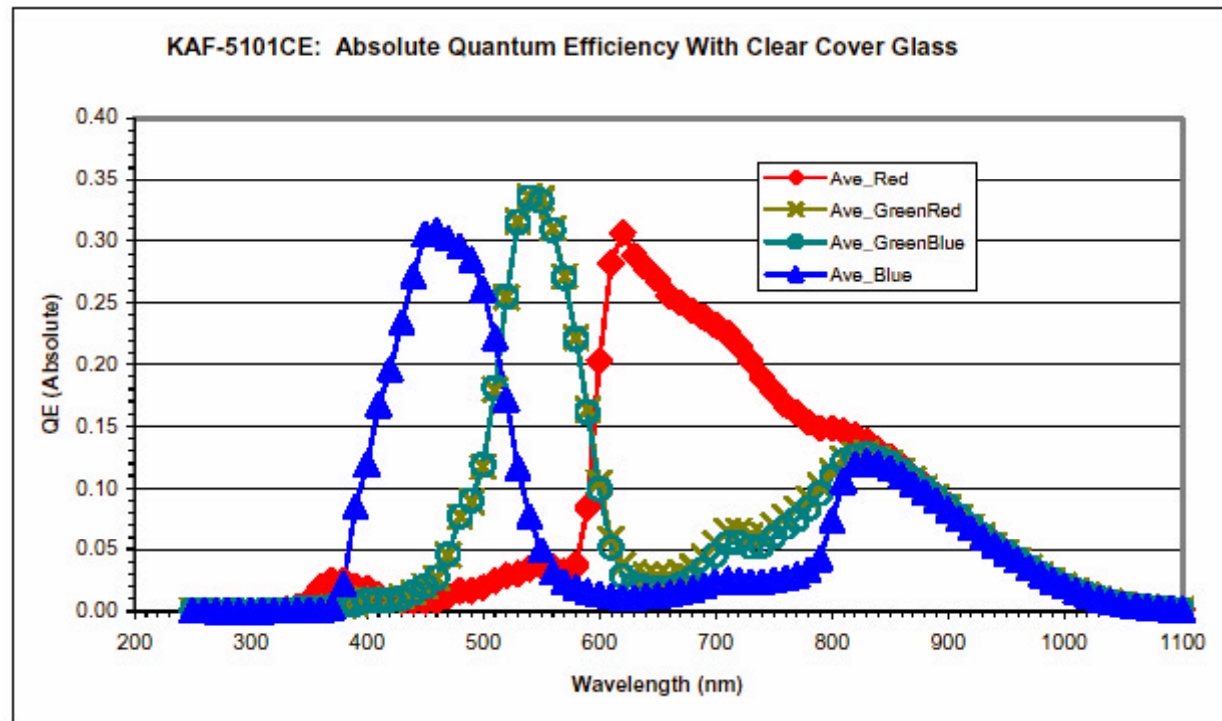
Color filters can be manufactured directly onto the photodetectors.

Color filter array

Kodak DCS620x
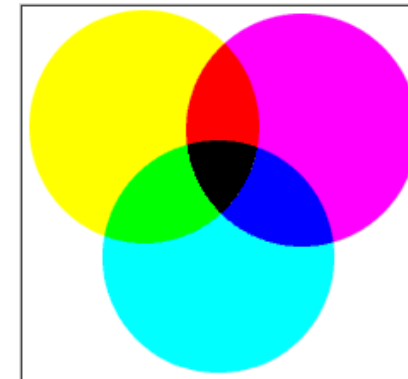
CMY

Color filter arrays (CFAs)/color filter mosaics

Why CMY CFA might be better

Kodak 13um Pixel CMY & RGB Response

Color filter array

Stripes
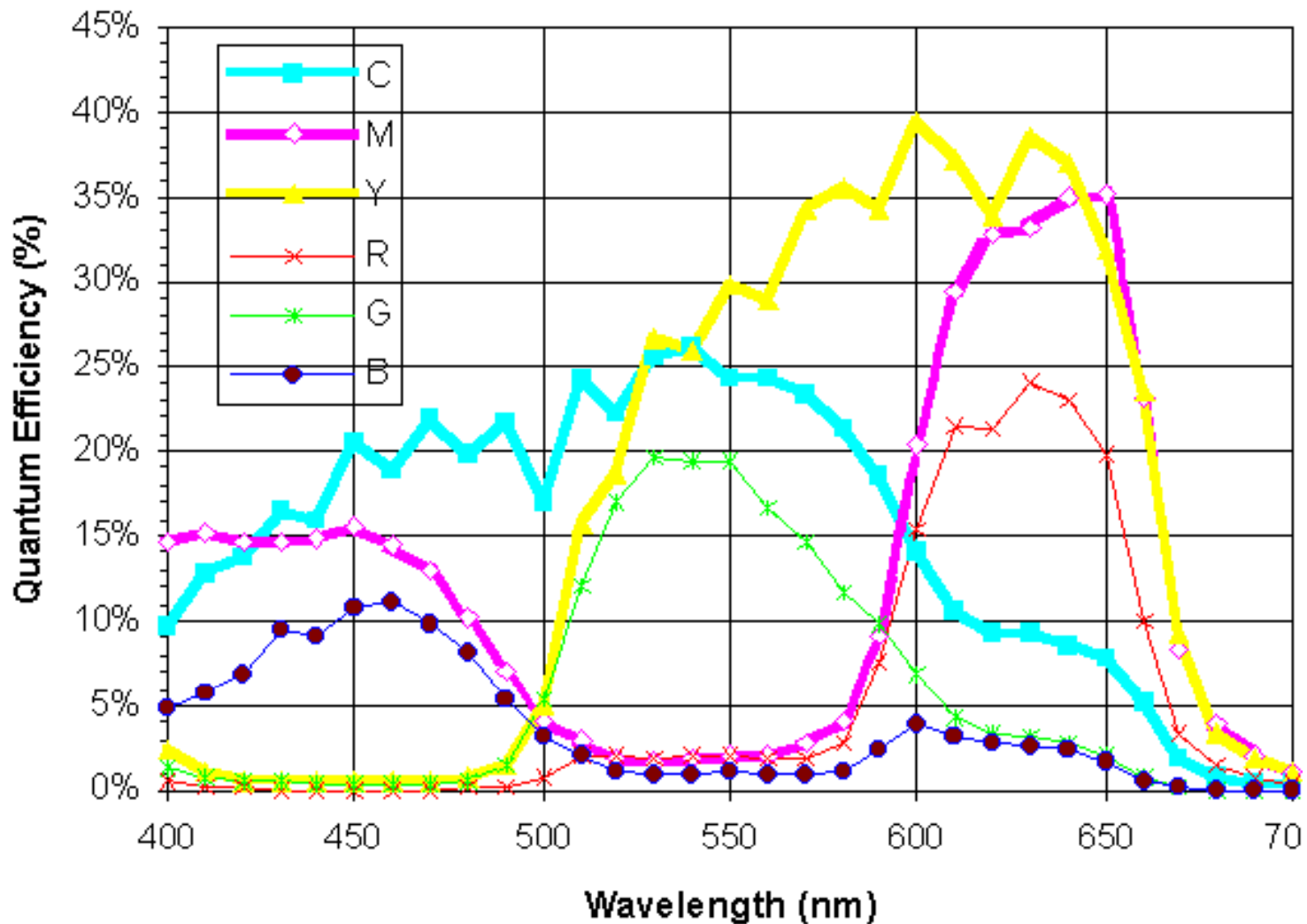
Mosaics
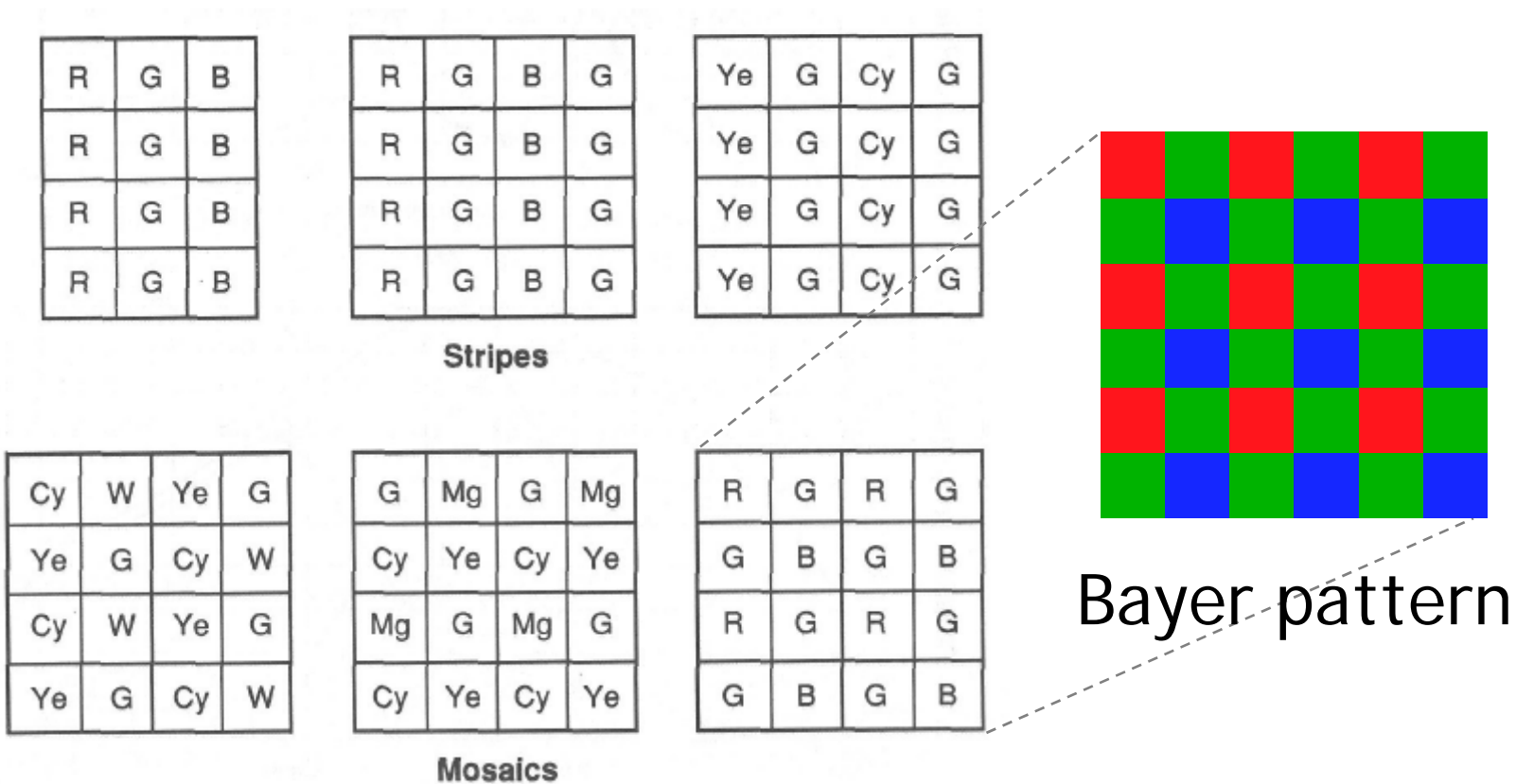
Bayer pattern

Color filter arrays (CFAs)/color filter mosaics

Bayer's pattern

Demosaicking CFA's

bilinear interpolation

$$G_{44} = (G_{34} + G_{43} + G_{45} + G_{54})/4$$

$$R_{44} = (R_{33} + R_{35} + R_{53} + R_{55})/4$$
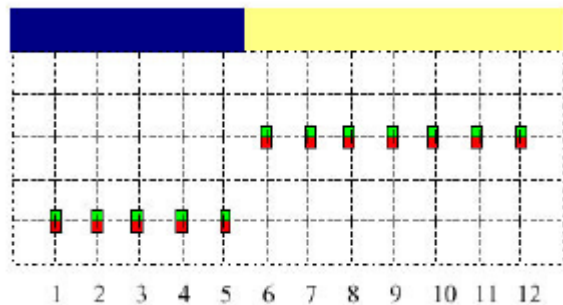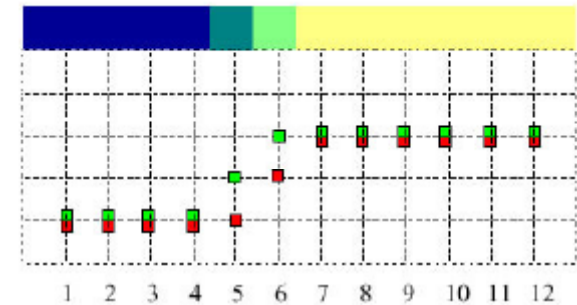
original   input   linear interpolation

Demosaicking CFA's

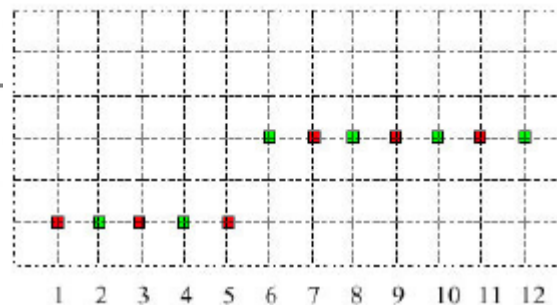|						
R_{11}	G_{12}	R_{13}	G_{14}	R_{15}	G_{16}	R_{17}
G_{21}	B_{22}	G_{23}	B_{24}	G_{25}	B_{26}	G_{27}
R_{31}	G_{32}	R_{33}	G_{34}	R_{35}	G_{36}	R_{37}
G_{41}	B_{42}	G_{43}	B_{44}	G_{45}	B_{46}	G_{47}
R_{51}	G_{52}	R_{53}	G_{54}	R_{55}	G_{56}	R_{57}
G_{61}	B_{62}	G_{63}	B_{64}	G_{65}	B_{66}	G_{67}
R_{71}	G_{72}	R_{73}	G_{74}	R_{75}	G_{76}	R_{77}

Constant hue-based interpolation (Cok)

Hue: $(R/G, B/G)$

Interpolate G first

$$R_{44} = G_{44} \frac{\dfrac{R_{33}}{G_{33}} + \dfrac{R_{35}}{G_{35}} + \dfrac{R_{53}}{G_{53}} + \dfrac{R_{55}}{G_{55}}}{4}$$

$$B_{33} = G_{33} \frac{\dfrac{B_{22}}{G_{22}} + \dfrac{B_{24}}{G_{24}} + \dfrac{B_{42}}{G_{42}} + \dfrac{B_{44}}{G_{44}}}{4}$$

Demosaicking CFA's

Median-based interpolation (Freeman)

1. Linear interpolation
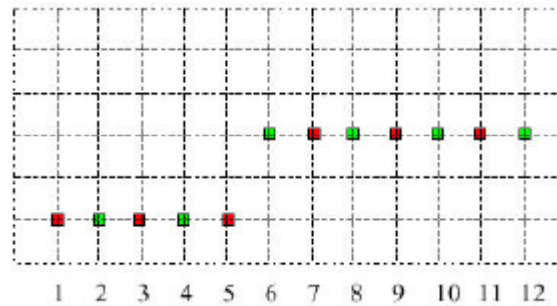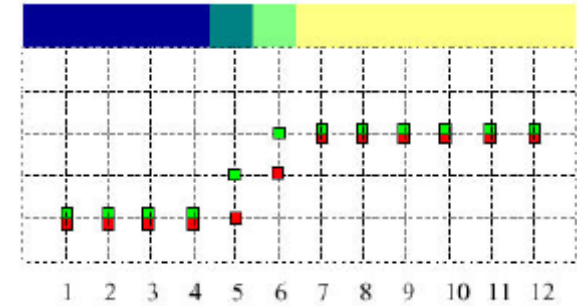2. Median filter on color differences

Demosaicking CFA's
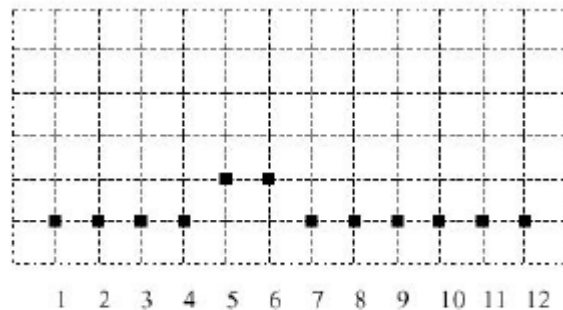
Median-based interpolation (Freeman)
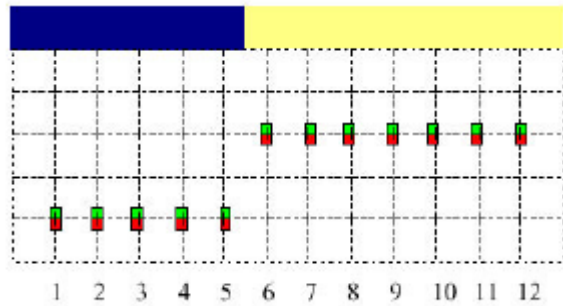
original
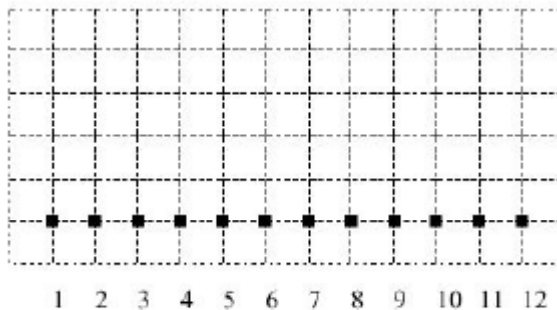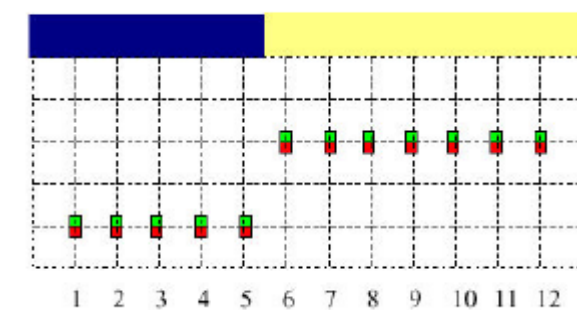
input

linear interpolation

color difference
(e.g. G-R)

median filter
(kernel size 5)

Reconstruction
(G=R+filtered
difference)

Demosaicking CFA's

R 11	G 12	R 13	G 14	R 15	G 16	R 17
G 21	B 22	G 23	B 24	G 25	B 26	G 27
R 31	G 32	R 33	G 34	R 35	G 36	R 37
G 41	B 42	G 43	B 44	G 45	B 46	G 47
R 51	G 52	R 53	G 54	R 55	G 56	R 57
G 61	B 62	G 63	B 64	G 65	B 66	G 67
R 71	G 72	R 73	G 74	R 75	G 76	R 77

Gradient-based interpolation (LaRoche-Prescott)

1. Interpolation on G

$$\alpha = \mathrm{abs}[(B_{42} + B_{46})/2 - B_{44}]$$

$$\beta = \mathrm{abs}[(B_{24} + B_{64})/2 - B_{44}]$$

$$\mathbf{G}_{44} = \begin{cases} \dfrac{G_{43} + G_{45}}{2} & \text{if } \alpha < \beta \\[2mm] \dfrac{G_{34} + G_{54}}{2} & \text{if } \alpha > \beta. \\[2mm] \dfrac{G_{43} + G_{45} + G_{34} + G_{54}}{4} & \text{if } \alpha = \beta \end{cases}$$

Demosaicking CFA's

| R 11 | G 12 | R 13 | G 14 | R 15 | G 16 | R 17 |
| B 22 | G 23 | B 24 | G 25 | B 26 | G 27 |

(the grid)

R 11	G 12	R 13	G 14	R 15	G 16	R 17
G 21	B 22	G 23	B 24	G 25	B 26	G 27
R 31	G 32	R 33	G 34	R 35	G 36	R 37
G 41	B 42	G 43	B 44	G 45	B 46	G 47
R 51	G 52	R 53	G 54	R 55	G 56	R 57
G 61	B 62	G 63	B 64	G 65	B 66	G 67
R 71	G 72	R 73	G 74	R 75	G 76	R 77

Gradient-based interpolation (LaRoche-Prescott)

2. Interpolation of color differences

$$R_{34} = \frac{(R_{33} - \mathbf{G}_{33}) + (R_{35} - \mathbf{G}_{35})}{2} + G_{34} ,$$

$$R_{43} = \frac{(R_{33} - \mathbf{G}_{33}) + (R_{53} - \mathbf{G}_{53})}{2} + G_{43} ,$$

$$R_{44} = \frac{(R_{33} - \mathbf{G}_{33}) + (R_{35} - \mathbf{G}_{35}) + (R_{53} - \mathbf{G}_{53}) + (R_{55} - \mathbf{G}_{55})}{4} + G_{44} .$$

Demosaicking CFA's
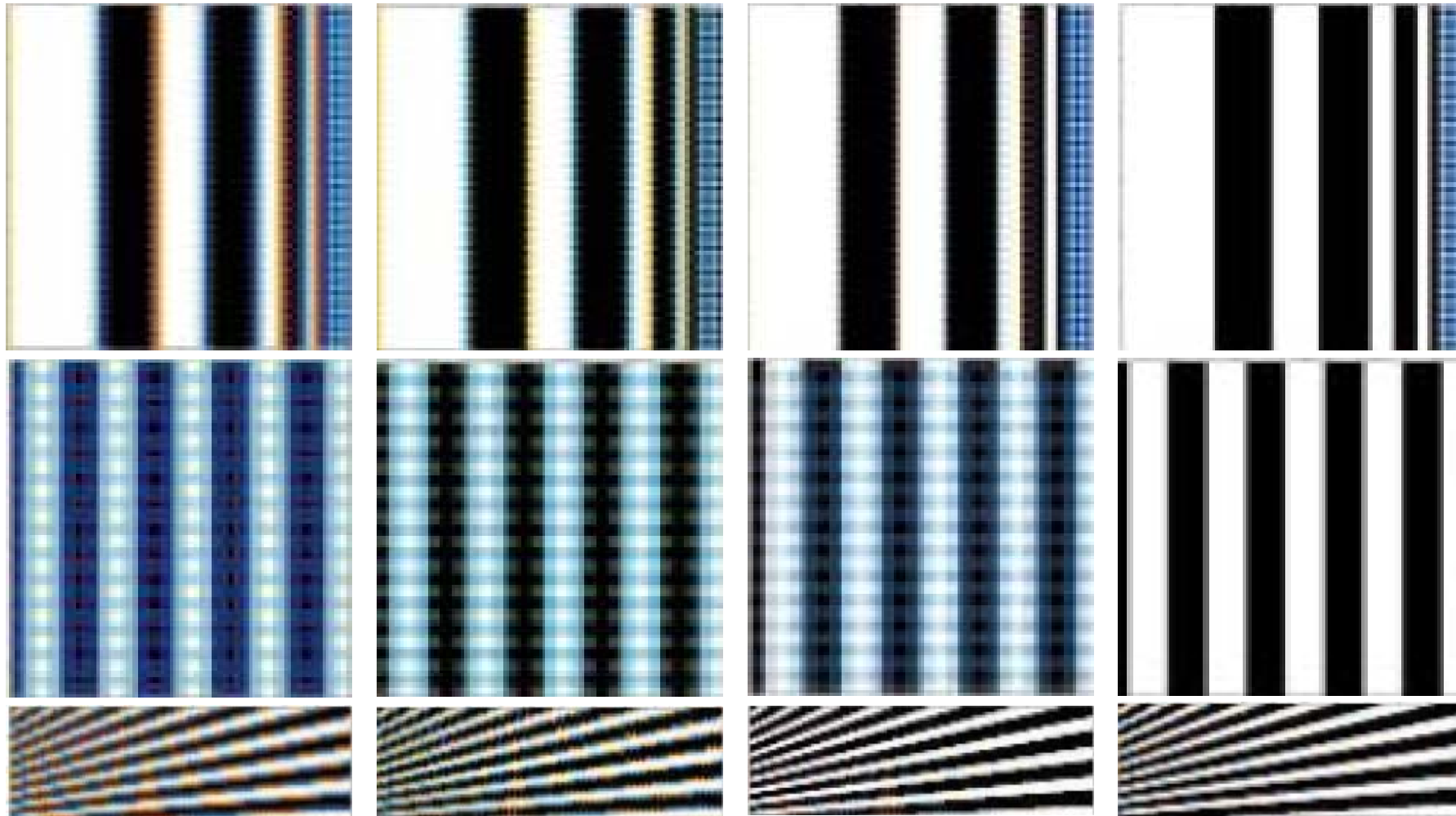
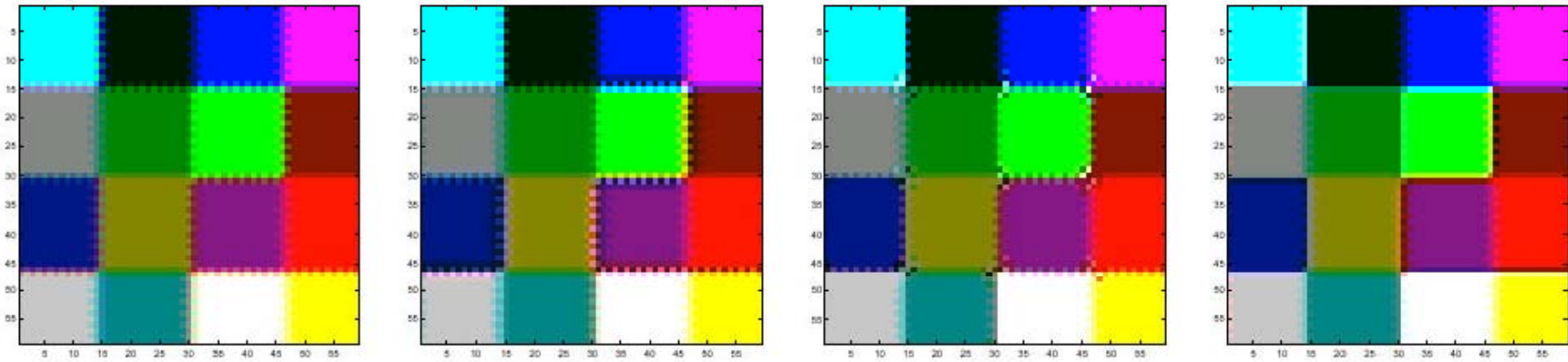bilinear   Cok   Freeman   LaRoche

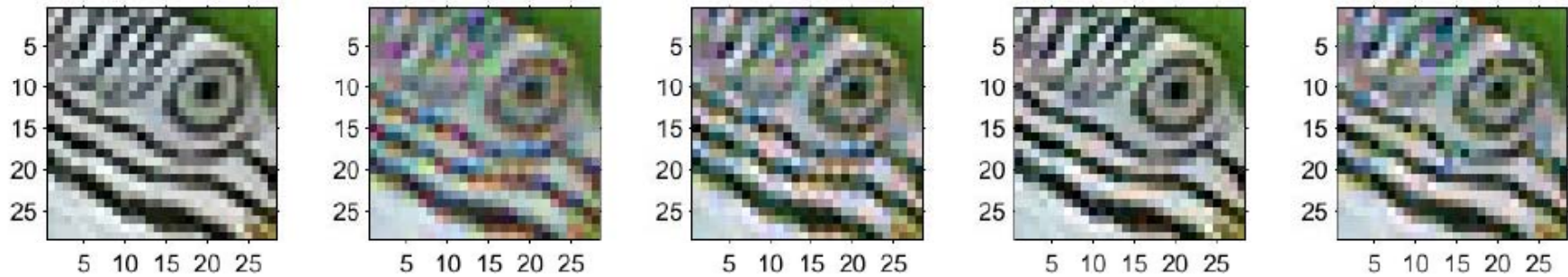# Demosaicking CFA's

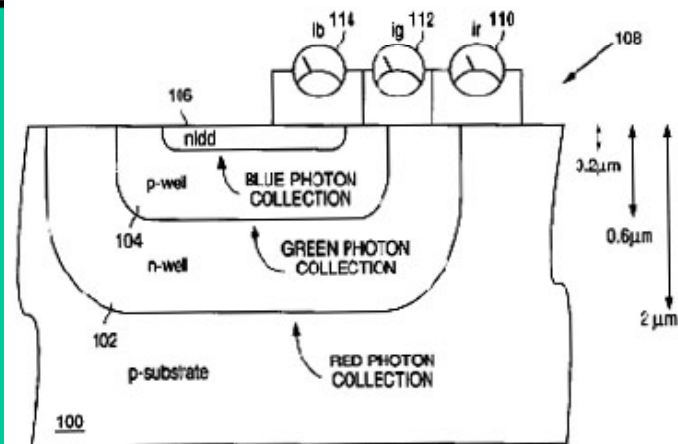Bilinear   Cok   Freeman   LaRoche
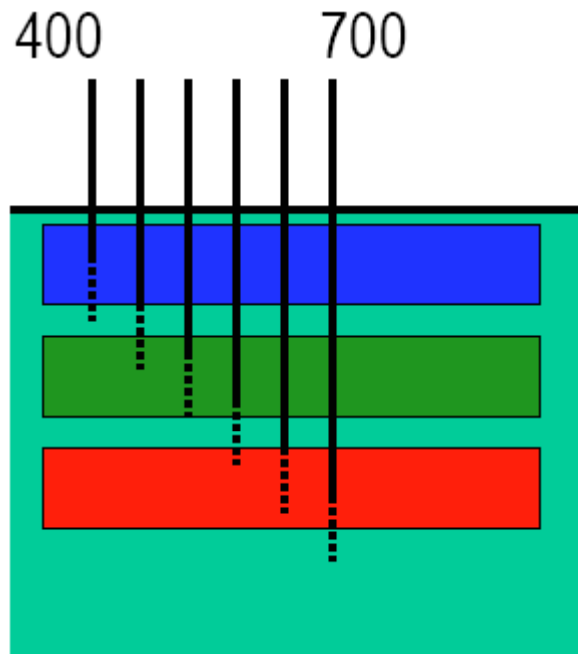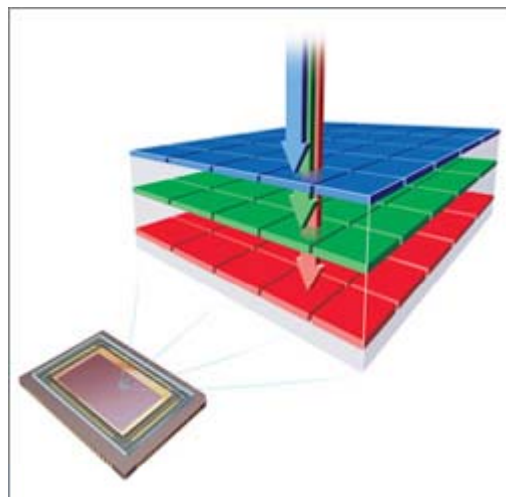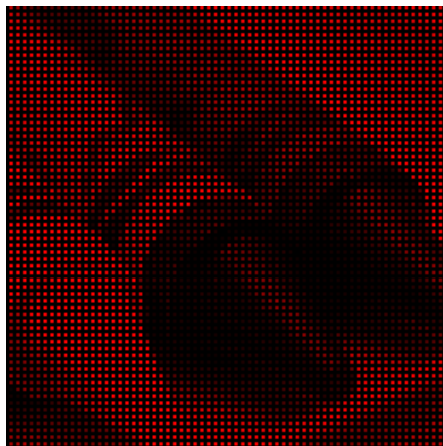
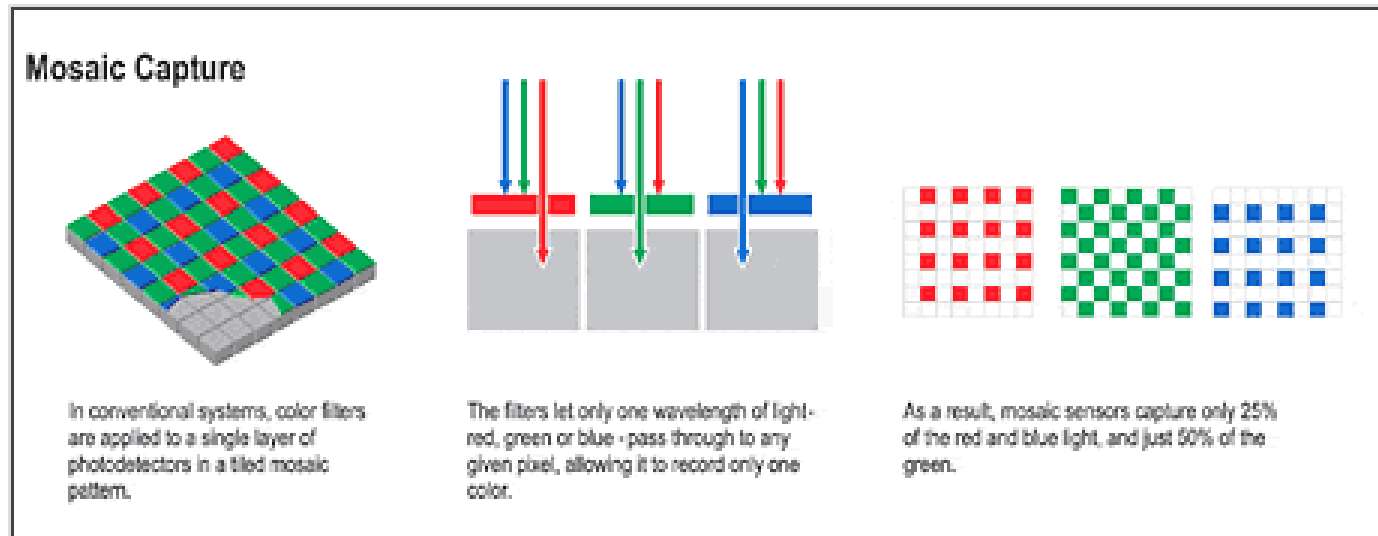Input   Bilinear   Cok   Freeman   LaRoche

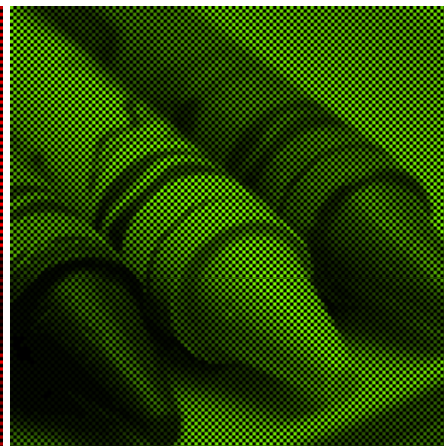Generally, Freeman's is the best, especially for natural images.

Foveon X3 sensor

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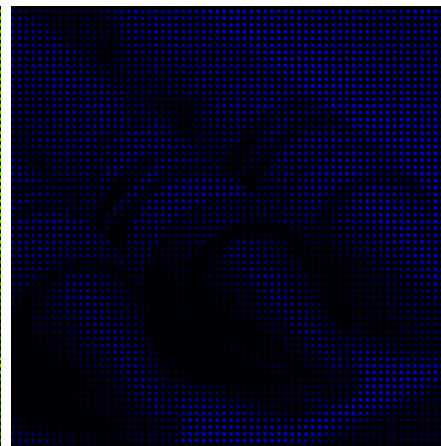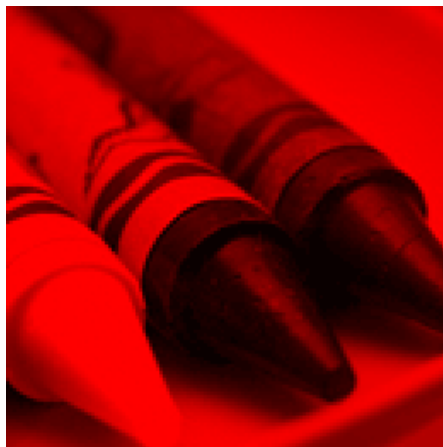- multilayer CMOS sensor gets 3 different spectral sensitivities

Color filter array

Mosaic Capture

In conventional systems, color filters are applied to a single layer of photodetectors in a tiled mosaic pattern.

The filters let only one wavelength of light - red, green or blue - pass through to any given pixel, allowing it to record only one color.

As a result, mosaic sensors capture only 25% of the red and blue light, and just 50% of the green.

red   green   blue   output

X3 technology

Foveon® X3™ Capture

A Foveon® X3™ image sensor features three separate layers of photodetectors embedded in silicon.

Since silicon absorbs different colors of light at different depths, each layer captures a different color. Stacked together, they create full-color pixels.

As a result, only Foveon X3 image sensors capture red, green and blue light at every pixel location.
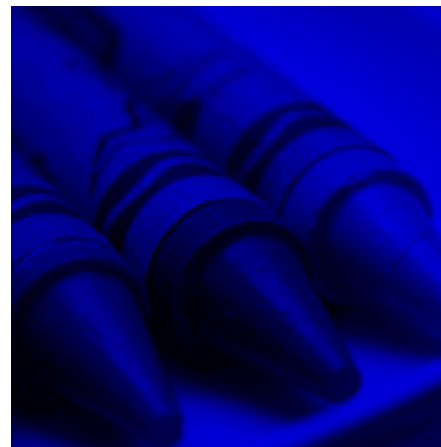
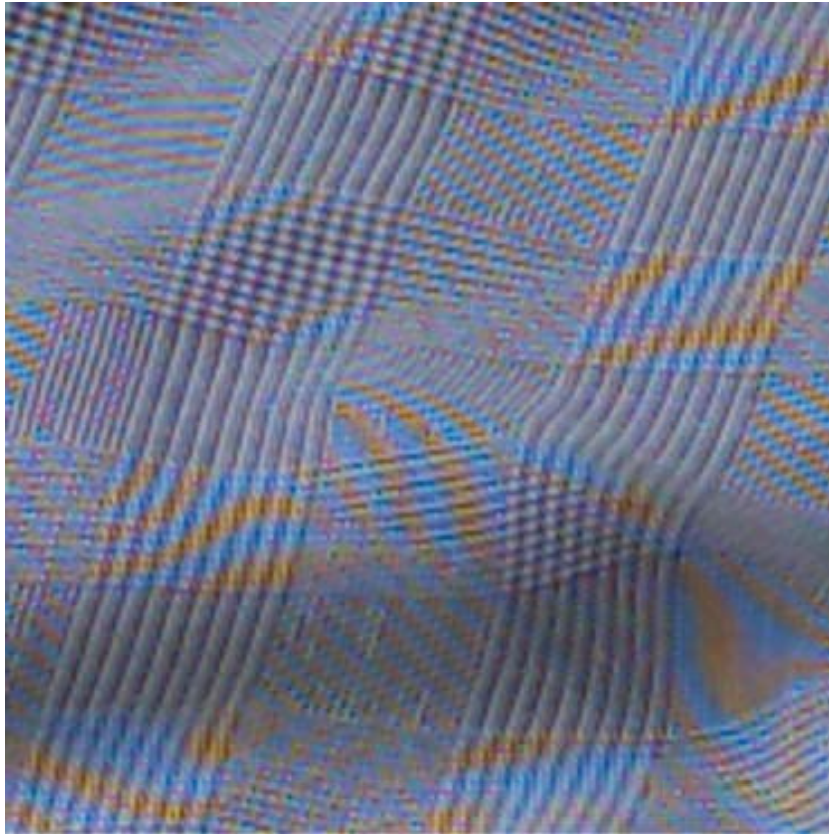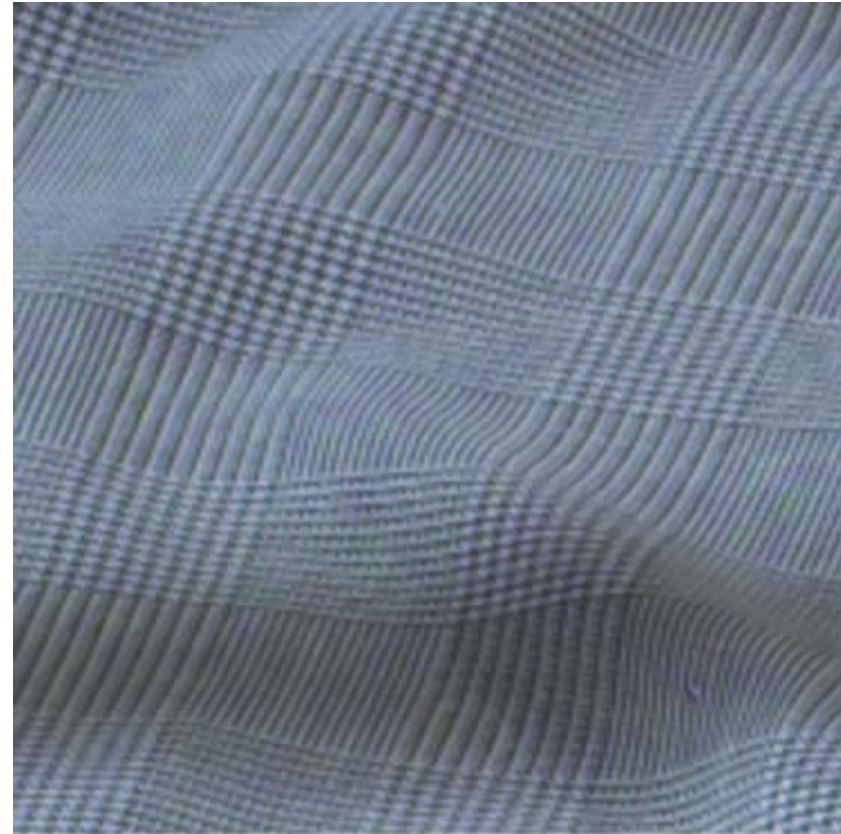red   green   blue   output

Foveon X3 sensor

Bayer CFA

X3 sensor

Cameras with X3
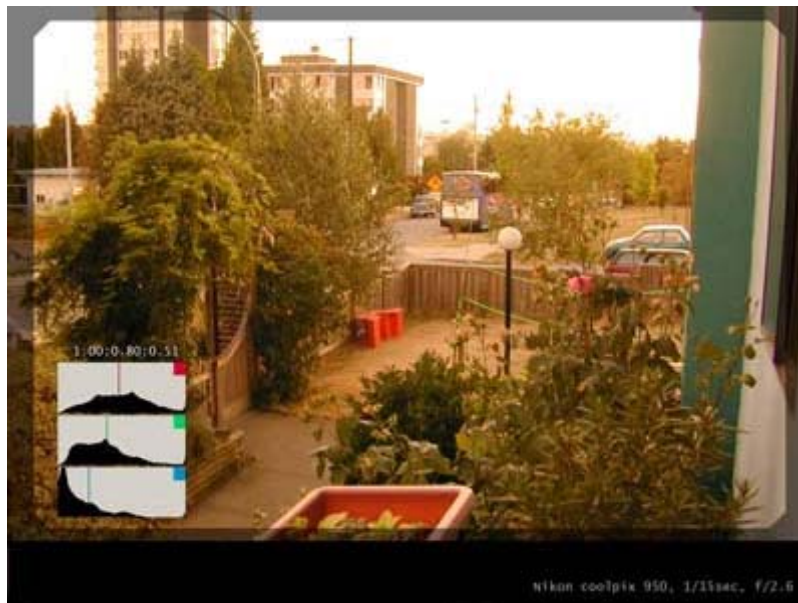

Sigma SD10, SD9

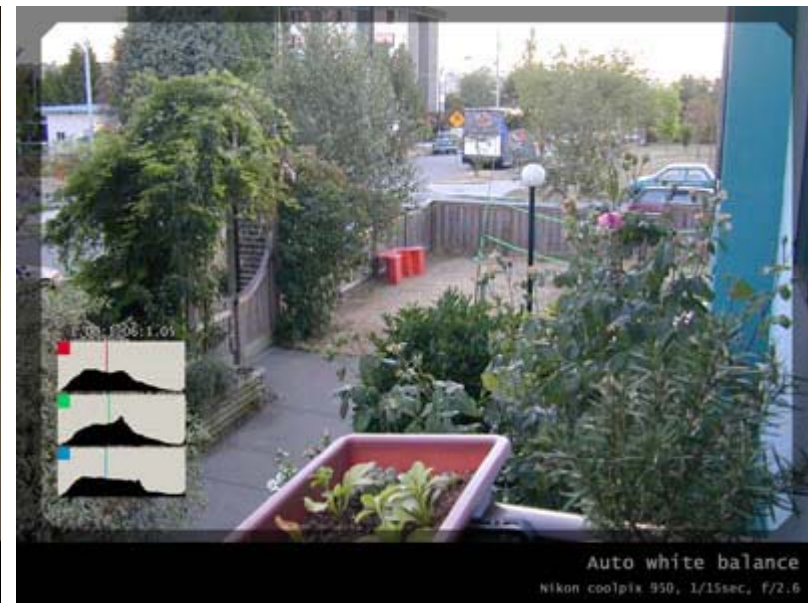**Polaroid X530**

Sigma SD9 vs Canon D30

Color processing

- After color values are recorded, more color processing usually happens:

    - White balance

    - Non-linearity to approximate film response or match TV monitor gamma

White Balance

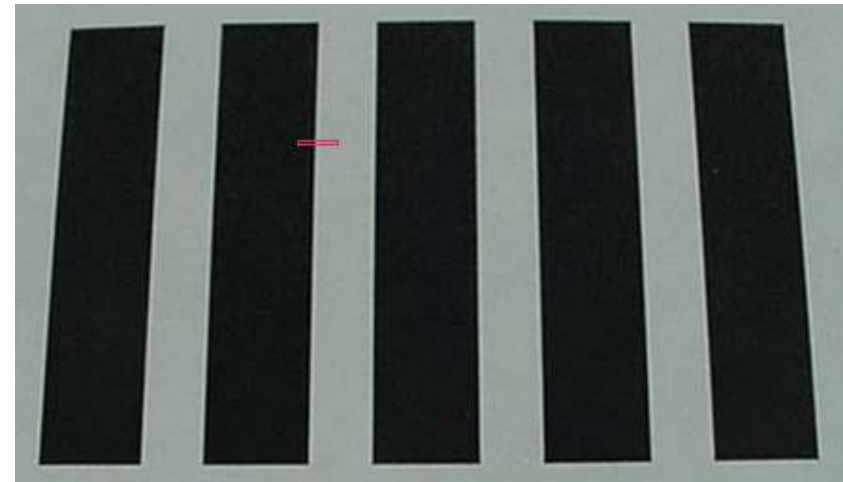warmer +3   automatic white balance
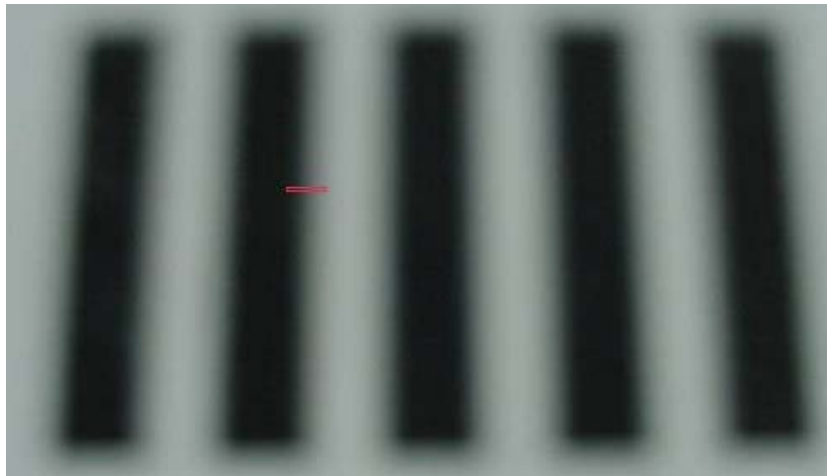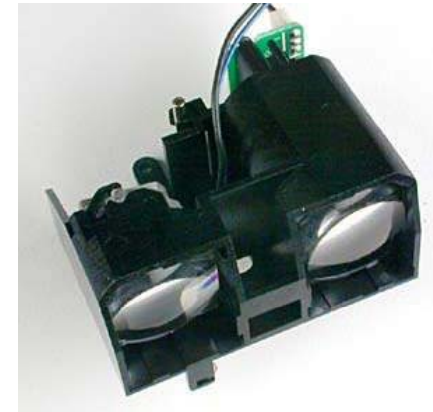
Manual white balance

white balance with
the white book

white balance with
the red book

Autofocus
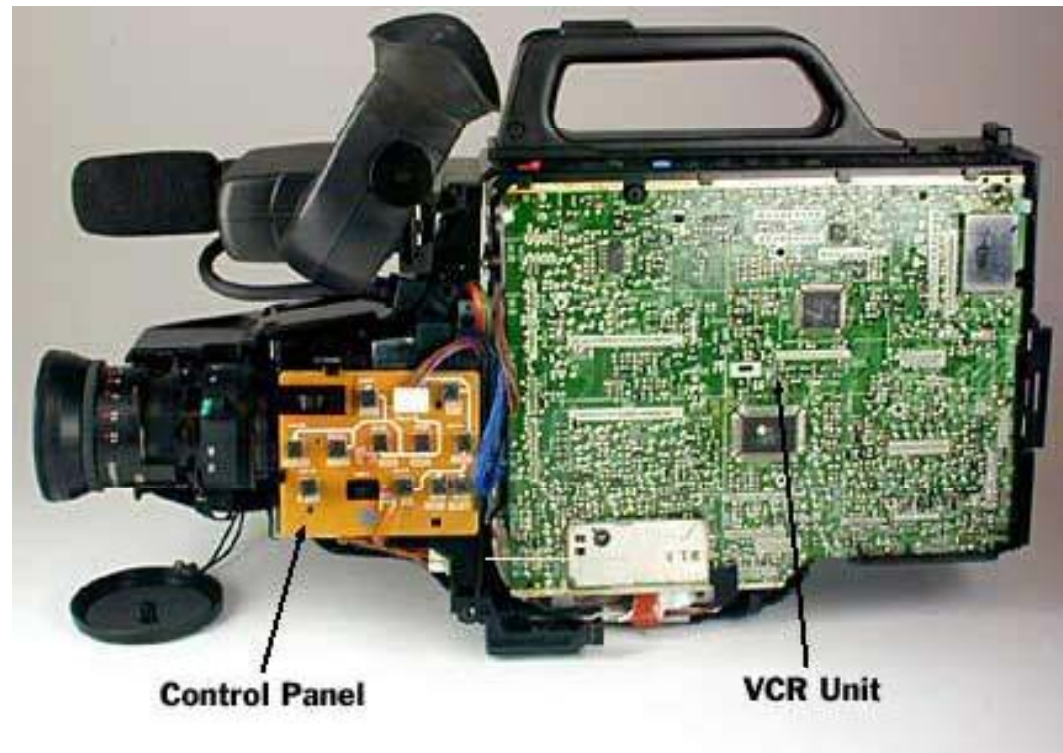
- Active
  - Sonar
  - Infrared
- Passive

Digital camera review website

- A cool video of digital camera illustration
- http://www.dpreview.com/

Camcorder

Control Panel

VCR Unit

Interlacing

without interlacing   with interlacing
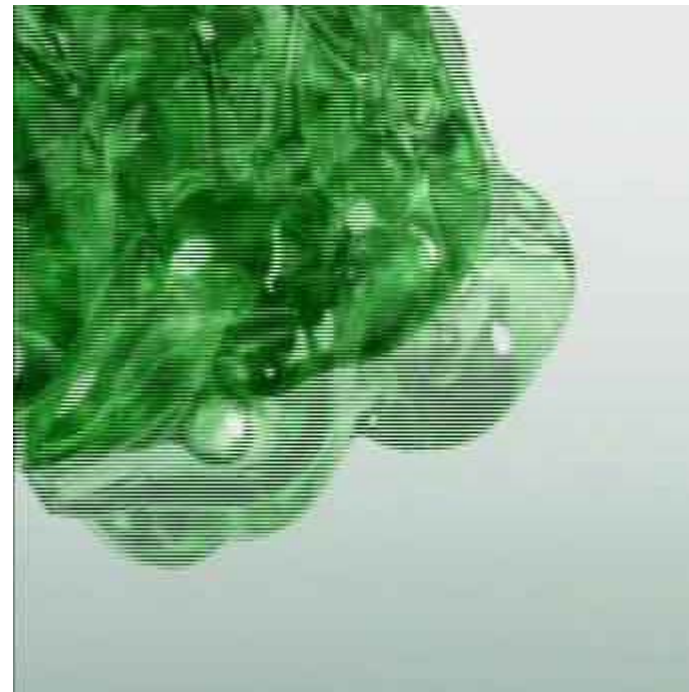
Deinterlacing

blend   weave

Deinterlacing

Discard
(even field only or
odd filed only)

Progressive scan

Hard cases

References

DigiVFX

- http://www.howstuffworks.com/digital-camera.htm
- http://electronics.howstuffworks.com/autofocus.htm
- Ramanath, Snyder, Bilbro, and Sander. Demosaicking Methods for Bayer Color Arrays, Journal of Electronic Imaging, 11(3), pp306-315.
- Rajeev Ramanath, Wesley E. Snyder, Youngjun Yoo, Mark S. Drew, Color Image Processing Pipeline in Digital Still Cameras, IEEE Signal Processing Magazine Special Issue on Color Image Processing, vol. 22, no. 1, pp. 34-43, 2005.
- http://www.worldatwar.org/photos/whitebalance/index.mhtml
- http://www.100fps.com/