Cameras

Digital Visual Effects, Spring 2007

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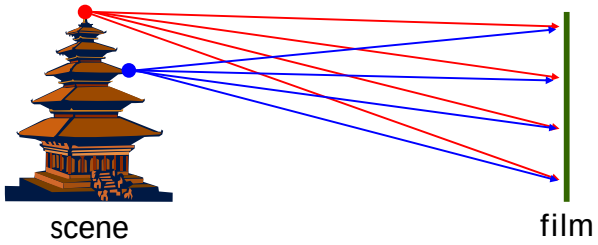
2007/3/6

with slides by Fredo Durand, Brian Curless, Steve Seitz and Alexei Efros

Outline

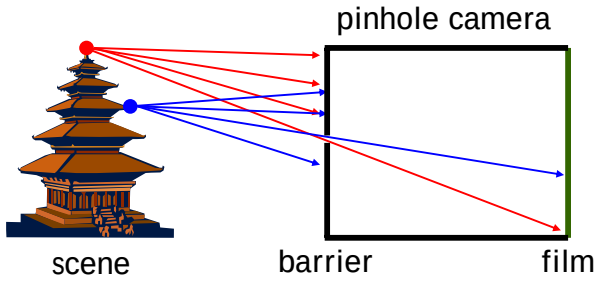
- Pinhole camera
- Film camera
- Digital camera
- Video camera

Camera trial #1



Put a piece of film in front of an object.

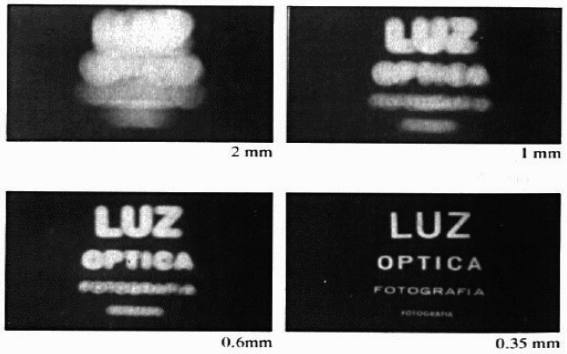
Pinhole camera



Add a barrier to block off most of the rays.

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

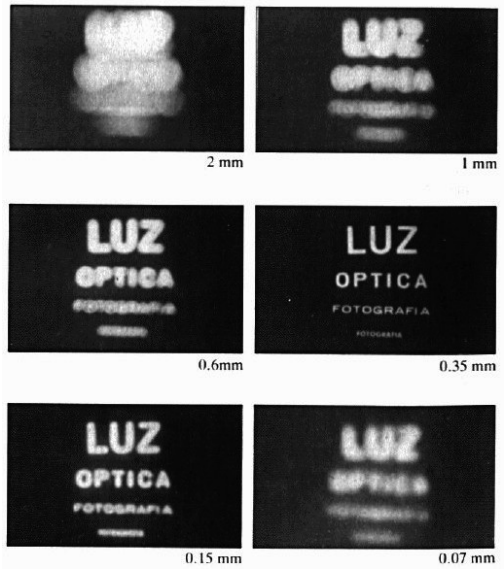
Shrinking the aperture



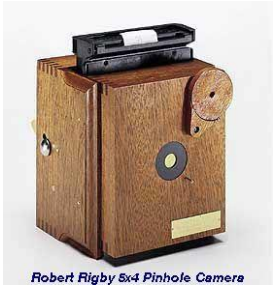
Why not making the aperture as small as possible?

- Less light gets through
- Diffraction effect

Shrinking the aperture

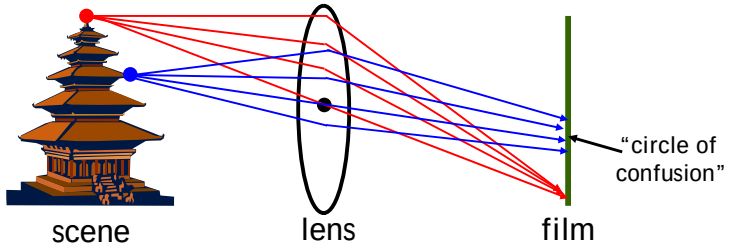


High-end commercial pinhole cameras



$200~$700

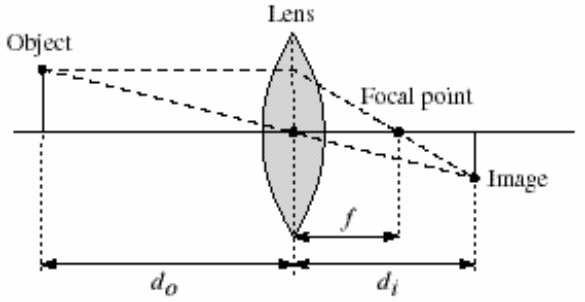
Adding a lens



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

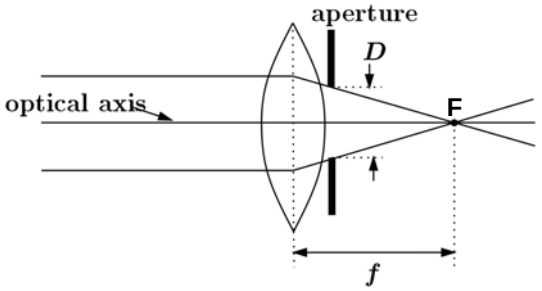
Lenses



Thin lens equation: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$

- Any object point satisfying this equation is in focus
- Thin lens applet: http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html

Exposure = aperture + shutter speed

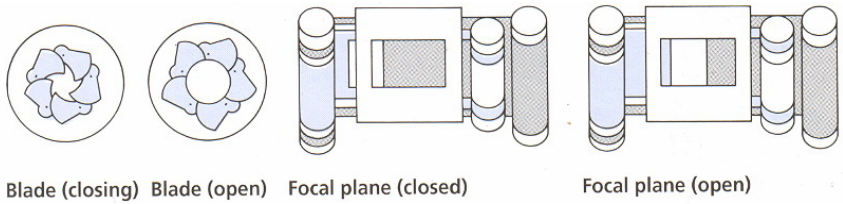


- Aperture of diameter D restricts the range of rays (aperture may be on either side of the lens)
- Shutter speed is the amount of time that light is allowed to pass through the aperture

Exposure

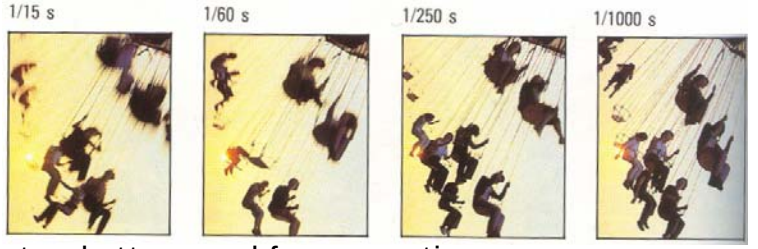
- Two main parameters:
  - Aperture (in f stop)

  - Shutter speed (in fraction of a second)



Effects of shutter speeds

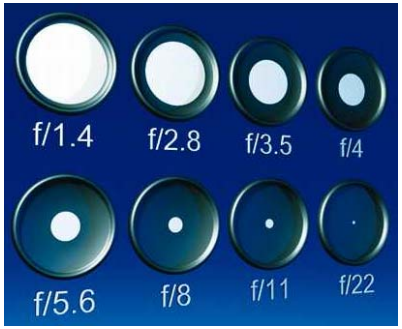
- Slower shutter speed => more light, but more motion blur



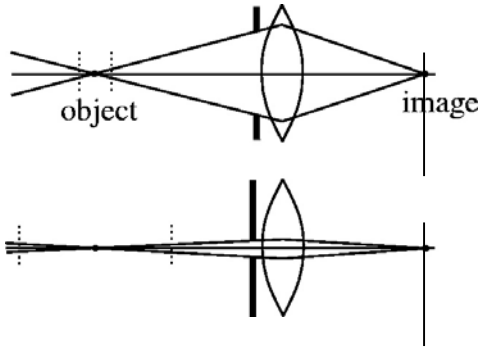
- Faster shutter speed freezes motion

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)



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

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

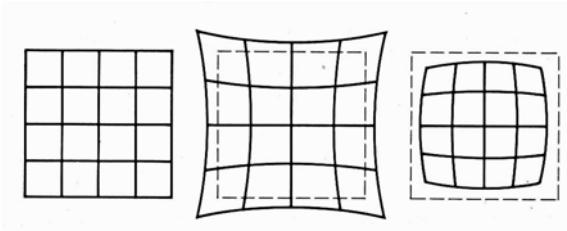
Exposure & metering

- 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

Distortion

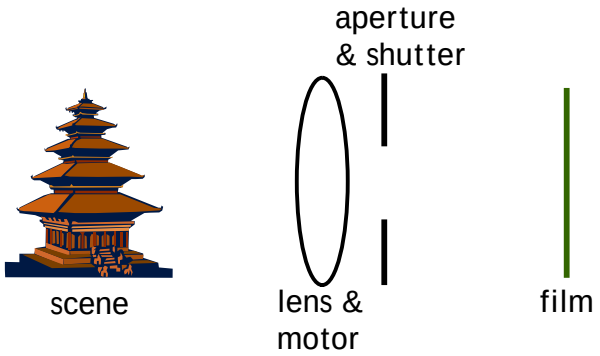


- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens

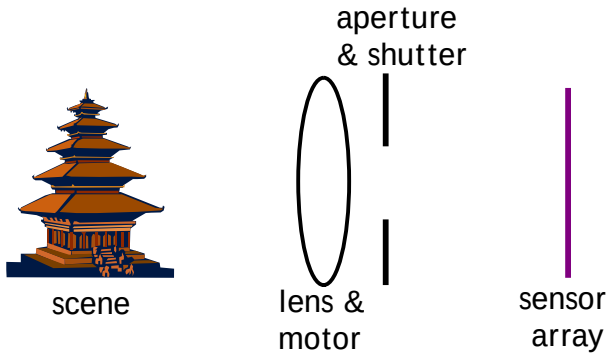
Correcting radial distortion

from Helmut Dersch

Film camera



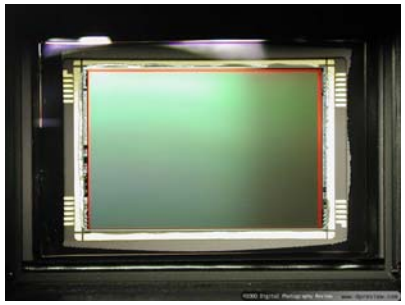
Digital camera



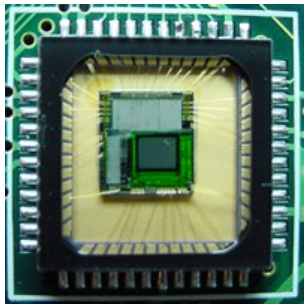
- A digital camera replaces film with a sensor array
- Each cell in the array is a light-sensitive diode that converts photons to electrons

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



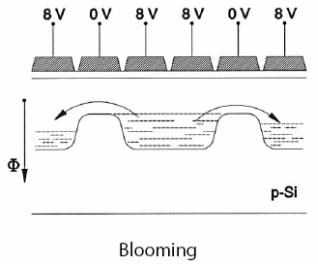
CCD



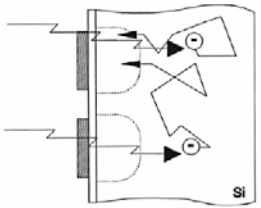
CMOS

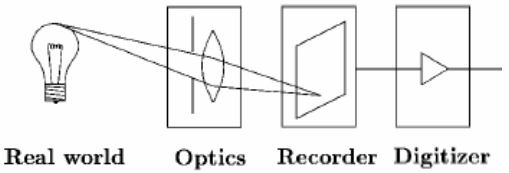
Sensor noise

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



Blooming

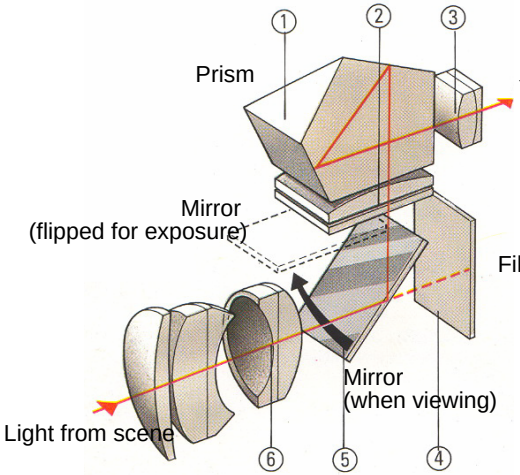


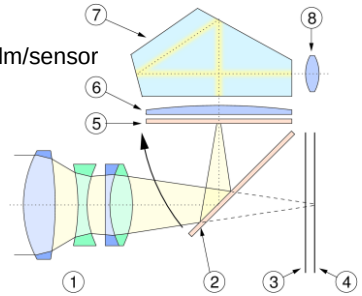


SLR (Single-Lens Reflex)

- 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



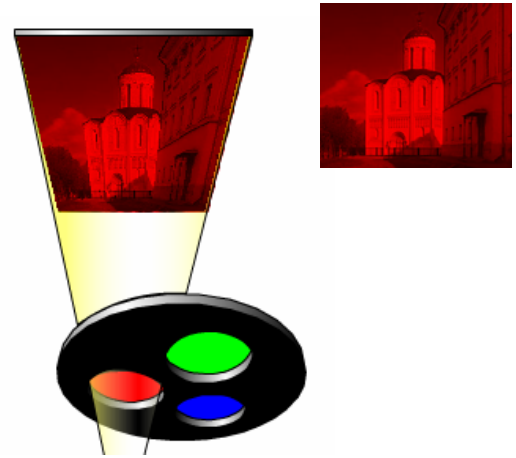


Color

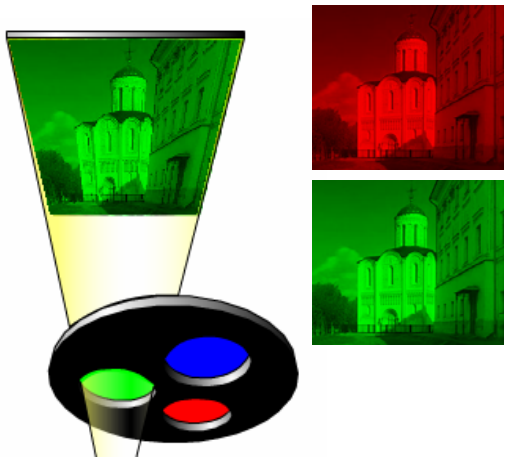
So far, we've only talked about monochrome sensors. Color imaging has been implemented in a number of ways:

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

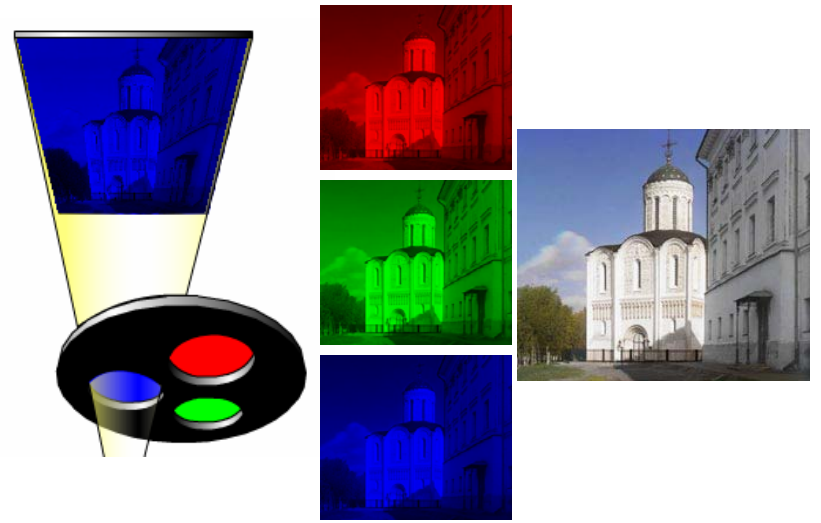
Field sequential



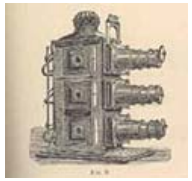
Field sequential



Field sequential



Prokudin-Gorskii (early 1900's)

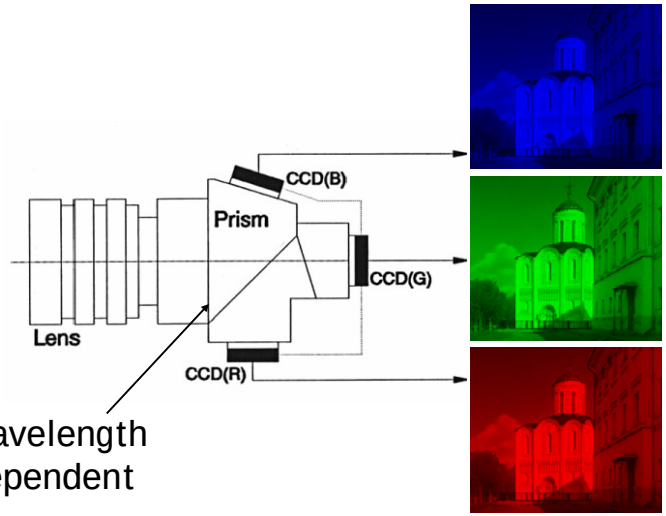


Lantern projector

http://www.loc.gov/exhibits/empire/

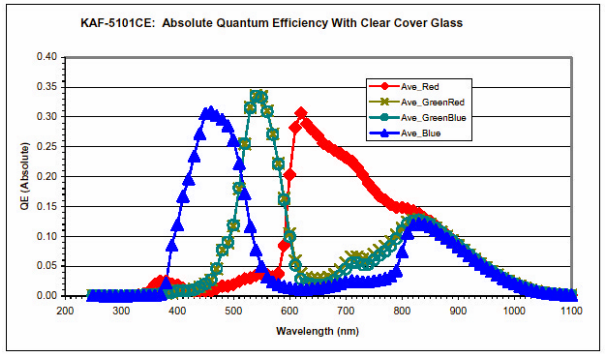
Prokudin-Gorskii (early 1990's)

Multi-chip



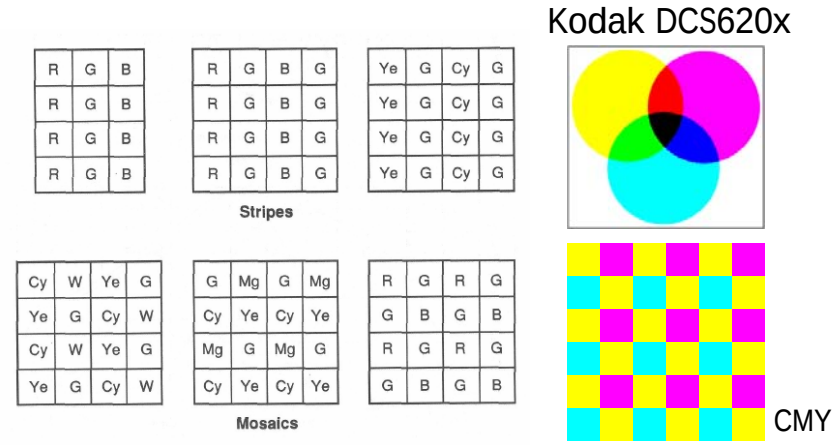
wavelength dependent

Embedded color filters



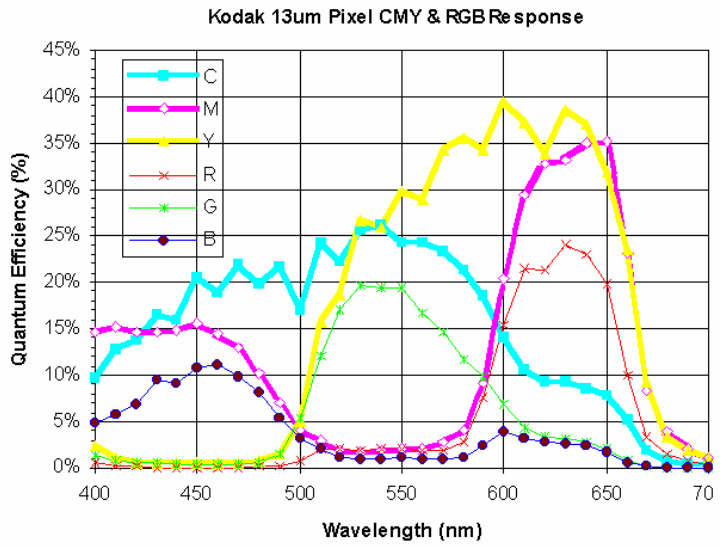
Color filters can be manufactured directly onto the photodetectors.

Color filter array

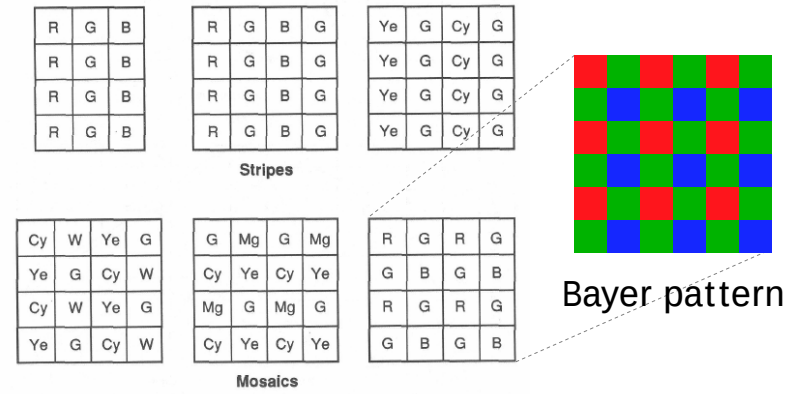


Color filter arrays (CFAs)/color filter mosaics

Why CMY CFA might be better

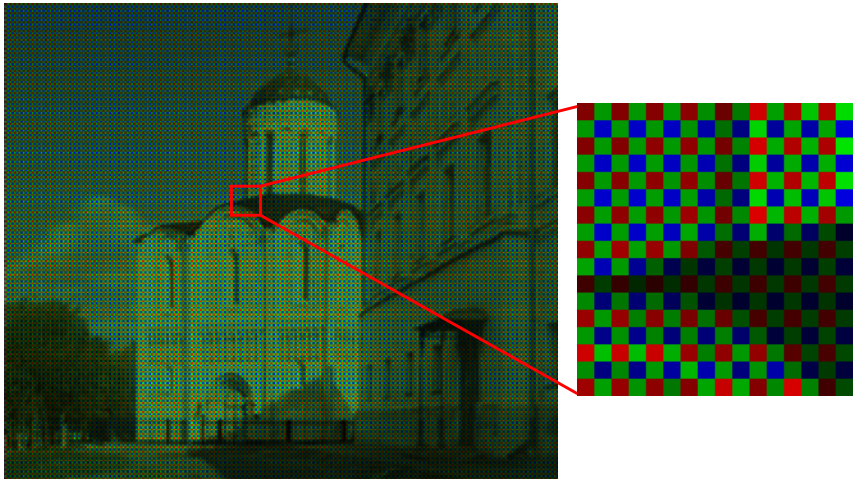


Color filter array

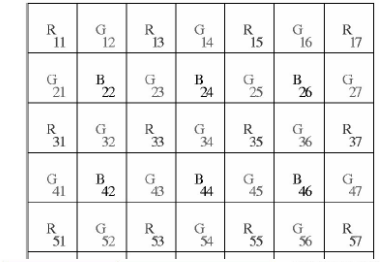


Color filter arrays (CFAs)/color filter mosaics

Bayer's pattern



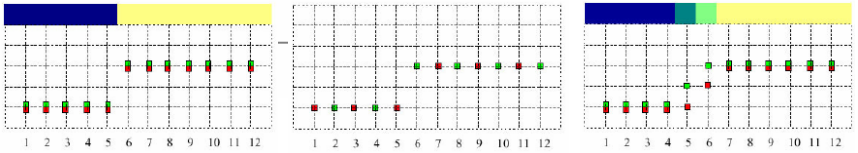
Demosaicking CFA's



bilinear interpolation

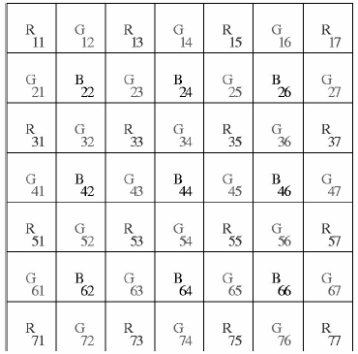
$$G_{44}=(G_{34}+G_{43}+G_{45}+G_{54})/4$$

$$R_{44}=(R_{33}+R_{35}+R_{53}+R_{55})/4$$



original input linear interpolation

Demosaicking CFA's



Constant hue-based interpolation (Cok)

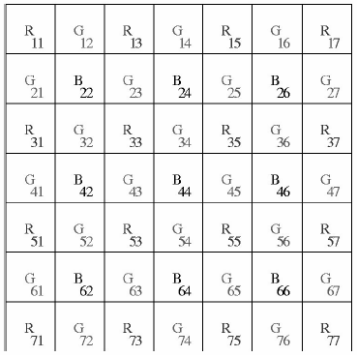
Hue: $(R/G, B/G)$

Interpolate G first

$$R_{44}=\mathbf{G}_{44}\frac{\frac{R_{33}}{\mathbf{G}_{33}}+\frac{R_{35}}{\mathbf{G}_{35}}+\frac{R_{53}}{\mathbf{G}_{53}}+\frac{R_{55}}{\mathbf{G}_{55}}}{4}$$

$$B_{33}=\mathbf{G}_{33}\frac{\frac{B_{22}}{\mathbf{G}_{22}}+\frac{B_{24}}{\mathbf{G}_{24}}+\frac{B_{42}}{\mathbf{G}_{42}}+\frac{B_{44}}{\mathbf{G}_{44}}}{4}$$

Demosaicking CFA's

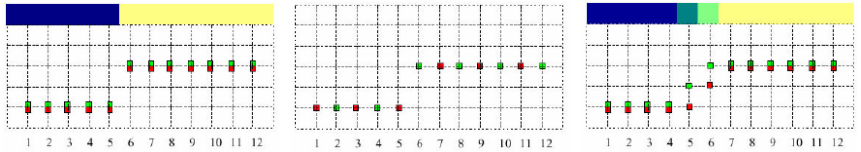


Median-based interpolation (Freeman)

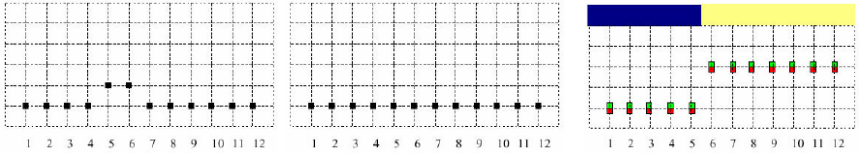
1. Linear interpolation
2. Median filter on color differences

Demosaicking CFA's

Median-based interpolation (Freeman)

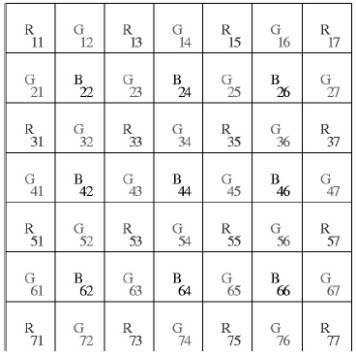


original input linear interpolation



color difference (e.g. G-R) median filter (kernel size 5) Reconstruction (G=R+filtered difference)

Demosaicking CFA's



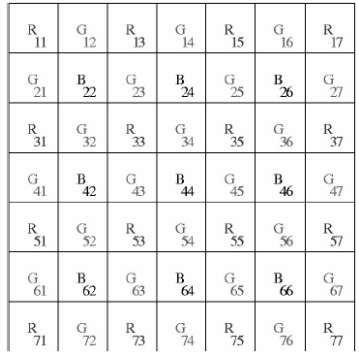
Gradient-based interpolation (LaRoche-Prescott)

1. Interpolation on G

$$\alpha = \text{abs}[(B_{42}+B_{46})/2 - B_{44}]$$
$$\beta = \text{abs}[(B_{24}+B_{64})/2 - B_{44}]$$

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

Demosaicking CFA's



Gradient-based interpolation (LaRoche-Prescott)

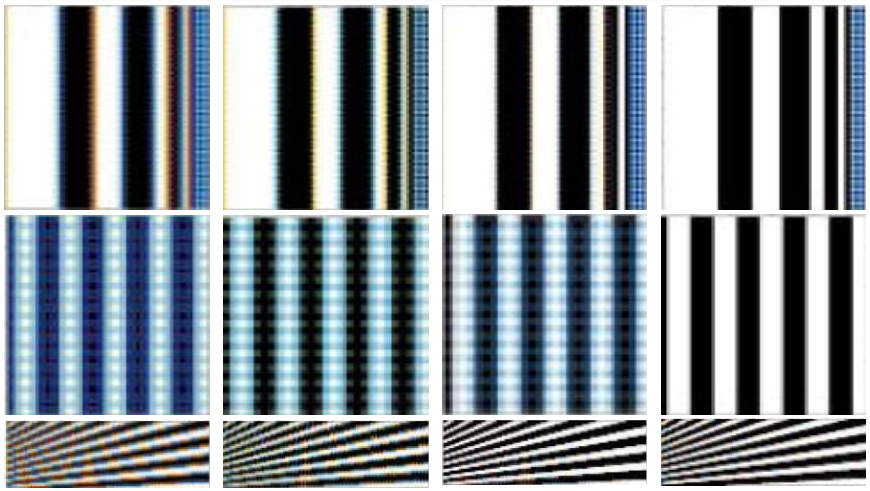
2. Interpolation of color differences

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

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

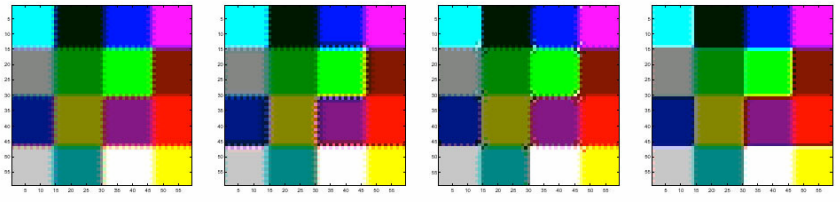
$$R_{44} = \frac{(R_{33}-\mathbf{G}_{33})+(R_{35}-\mathbf{G}_{35})+(R_{53}-\mathbf{G}_{53})+(R_{55}-\mathbf{G}_{55})}{4} + G_{44}.$$

Demosaicking CFA's

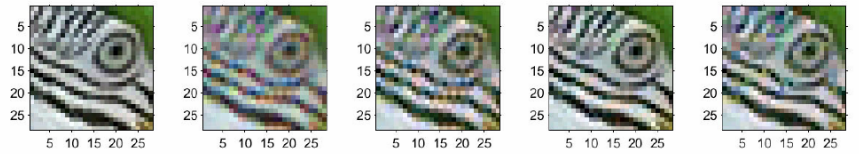


bilinear Cok Freeman LaRoche

Demosaicking CFA's



Bilinear *Cok* *Freeman* *LaRoche*

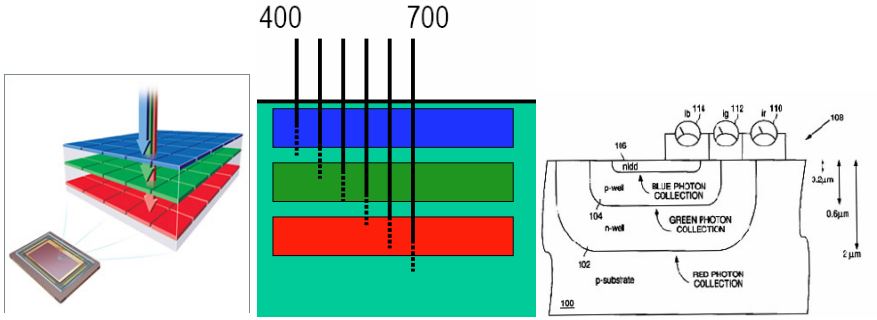


Input *Bilinear* *Cok* *Freeman* *LaRoche*

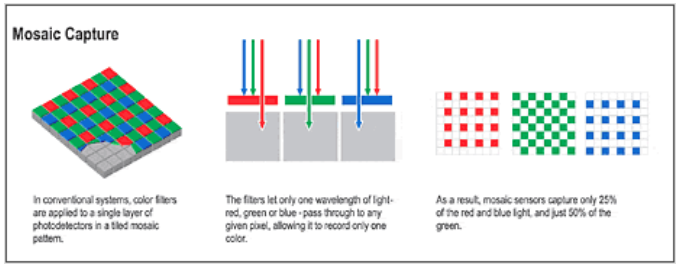
Generally, Freeman's is the best, especially for natural images.

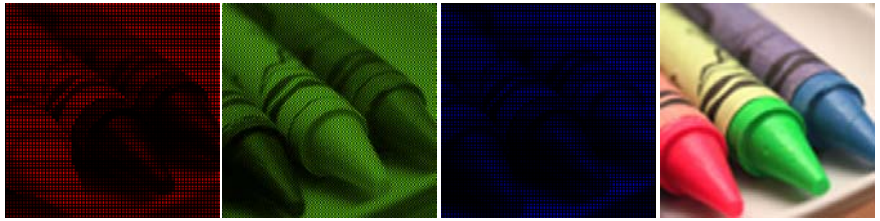
Foveon X3 sensor

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



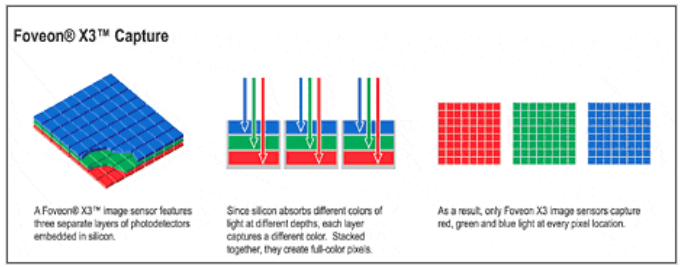
Color filter array

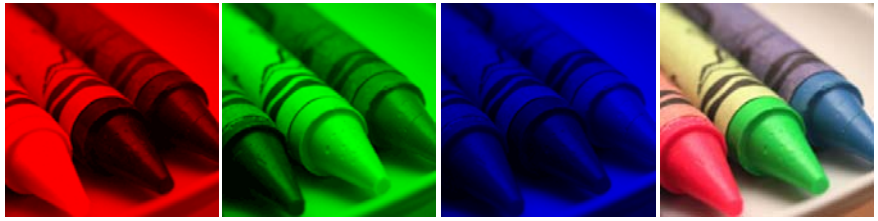




red green blue output

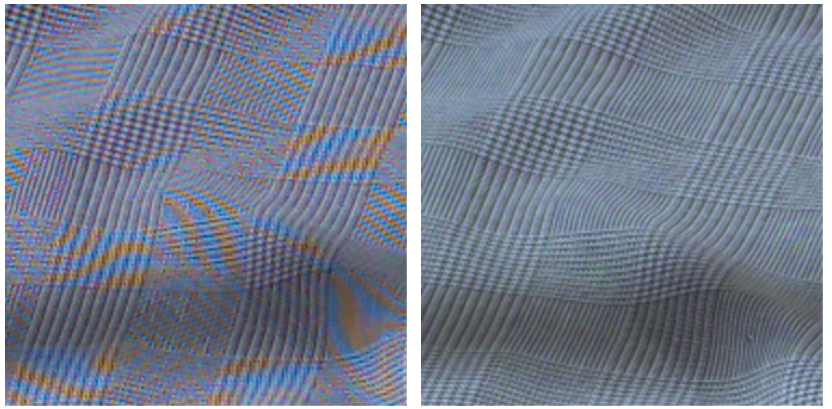
X3 technology





red green blue output

Foveon X3 sensor



Bayer CFA X3 sensor

Cameras with X3

Sigma SD10, SD9

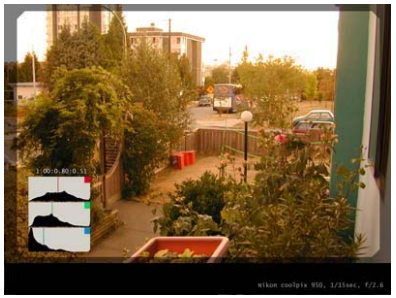
Polaroid X530

Sigma SD9 vs Canon D30

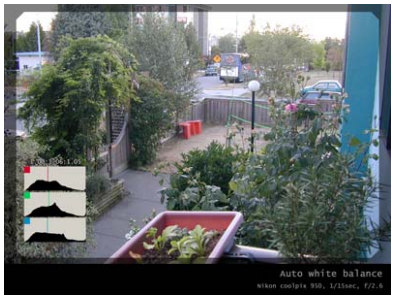
Color processing

- 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

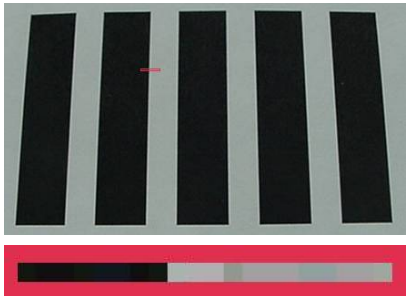
Manual white balance

white balance with the white book

white balance with the red book

Autofocus

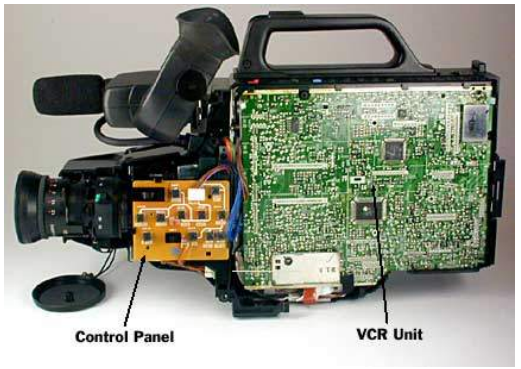
- Active
  - Sonar
  - Infrared
- Passive



Digital camera review website

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

Camcorder



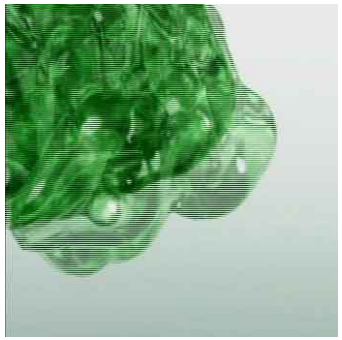
Interlacing

without interlacing

with interlacing

Deinterlacing

blend



weave

Deinterlacing

Discard
(even field only or
odd filed only)

Progressive scan

References

- http://www.howstuffworks.com/digital-camera.htm
- http://electronics.howstuffworks.com/autofocus.htm
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