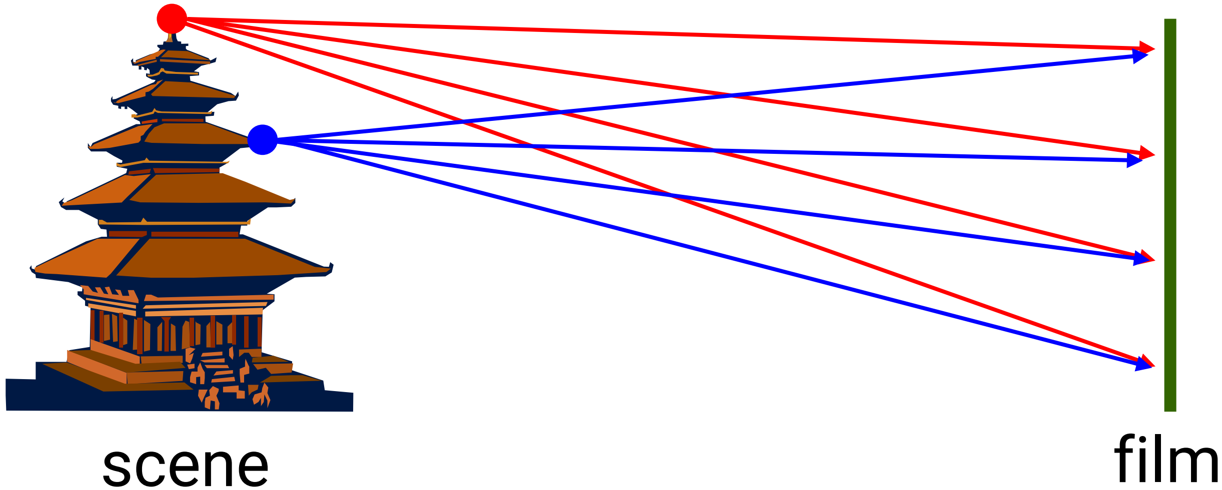
Camera

Multimedia Techniques & Applications

Yu-Ting Wu

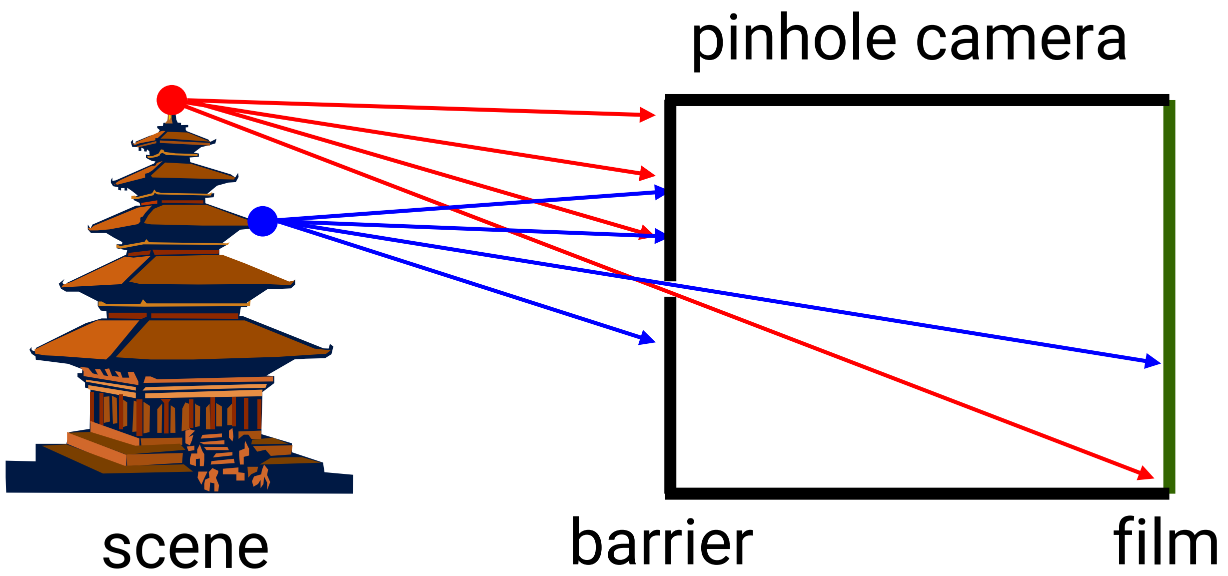
(this slides are borrowed from Prof. Yung-Yu Chuang)

Camera Trial



Put a piece of film in front of an object

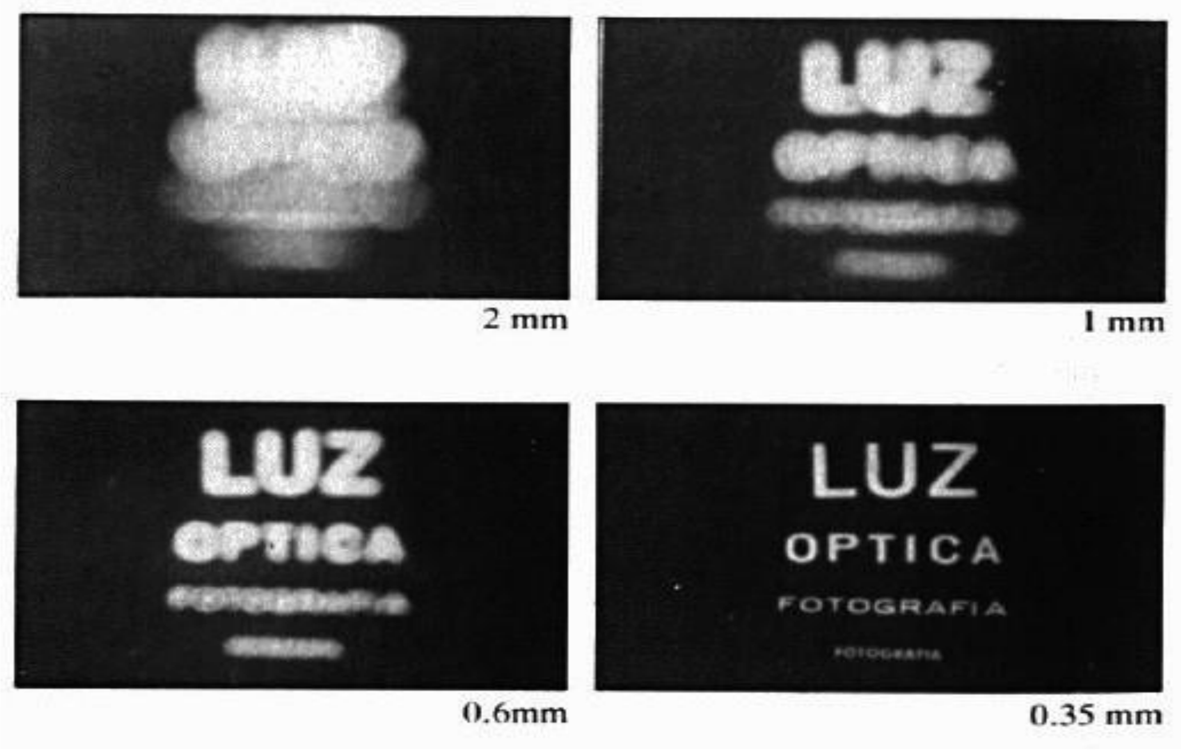
Pinhole Camera



Add a barrier to block off most of the rays

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

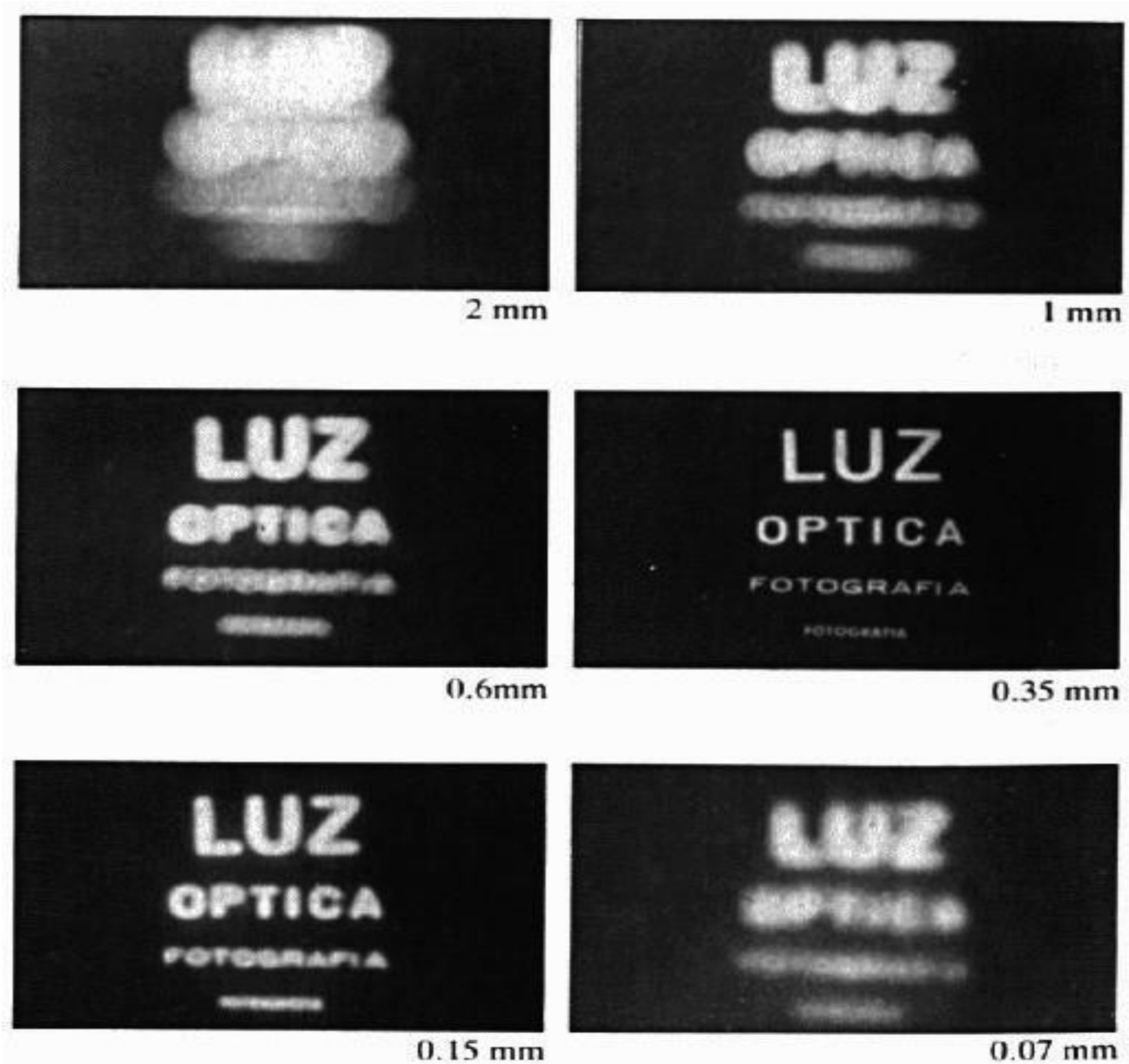
Shrinking the Aperture



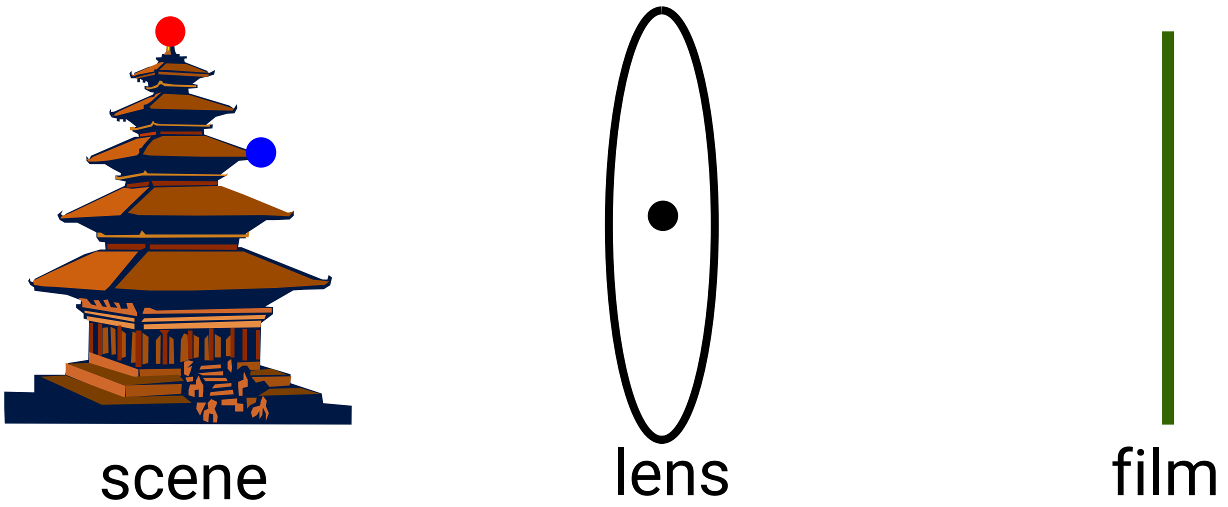
Why not making the aperture as small as possible?

- Less light gets through
- Diffraction effect

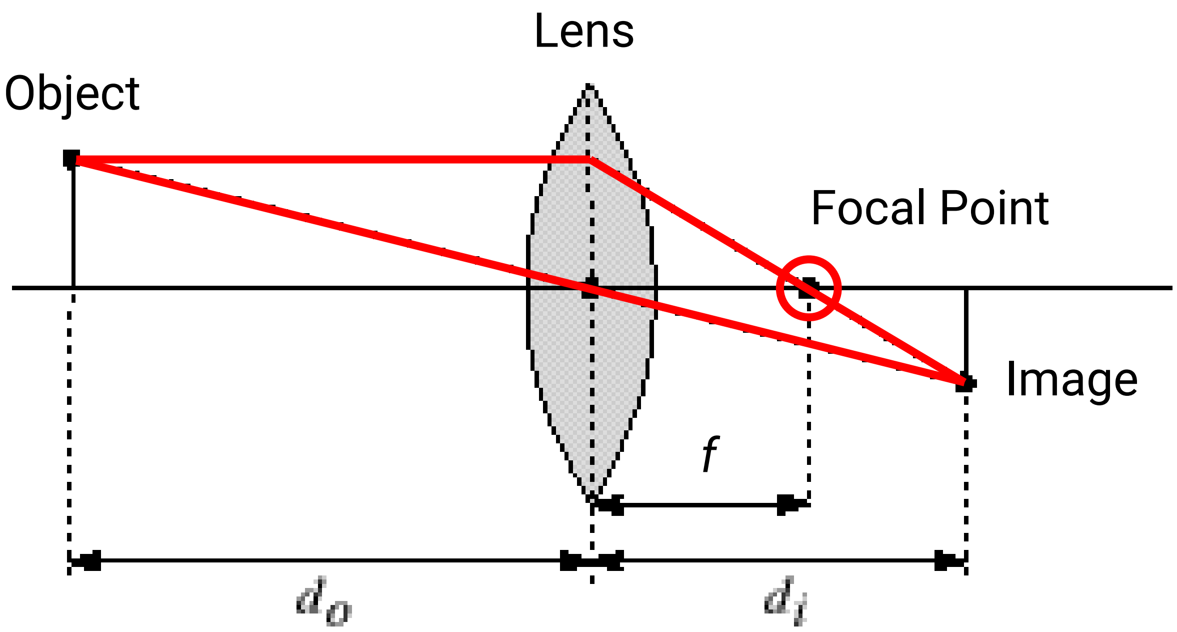
Shrinking the Aperture



Adding a Lens



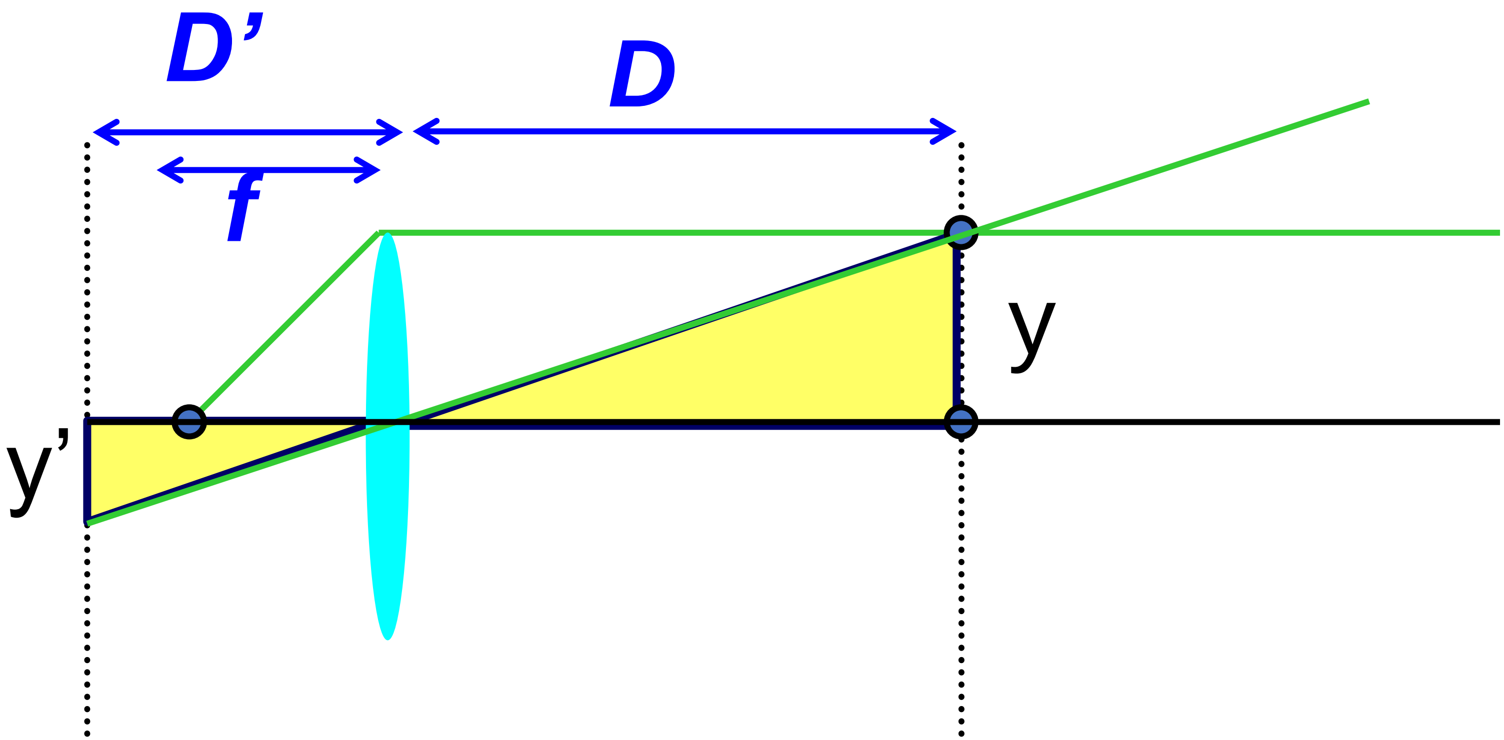
Lenses



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

Thin Lens Formula

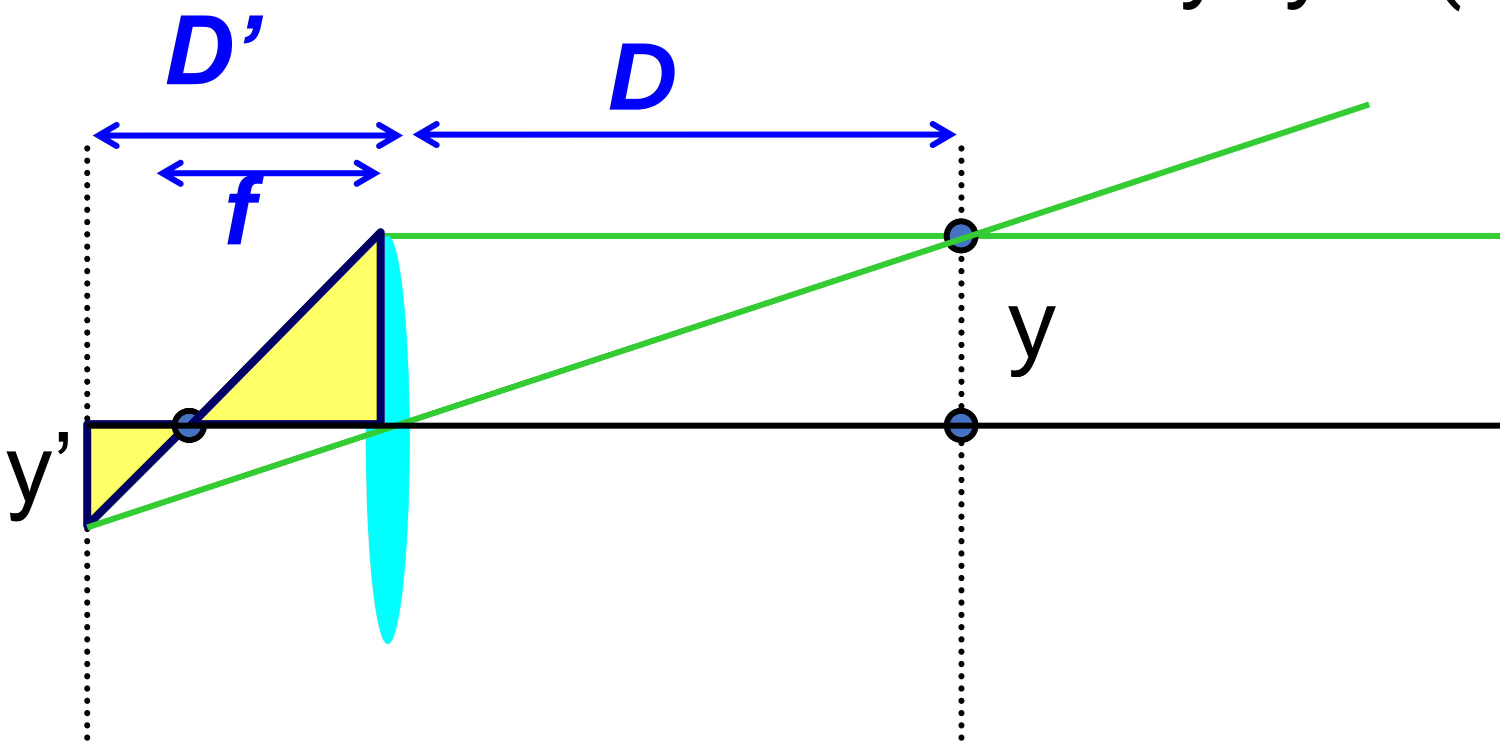
$$y'/y = D'/D$$



Thin Lens Formula (cont.)

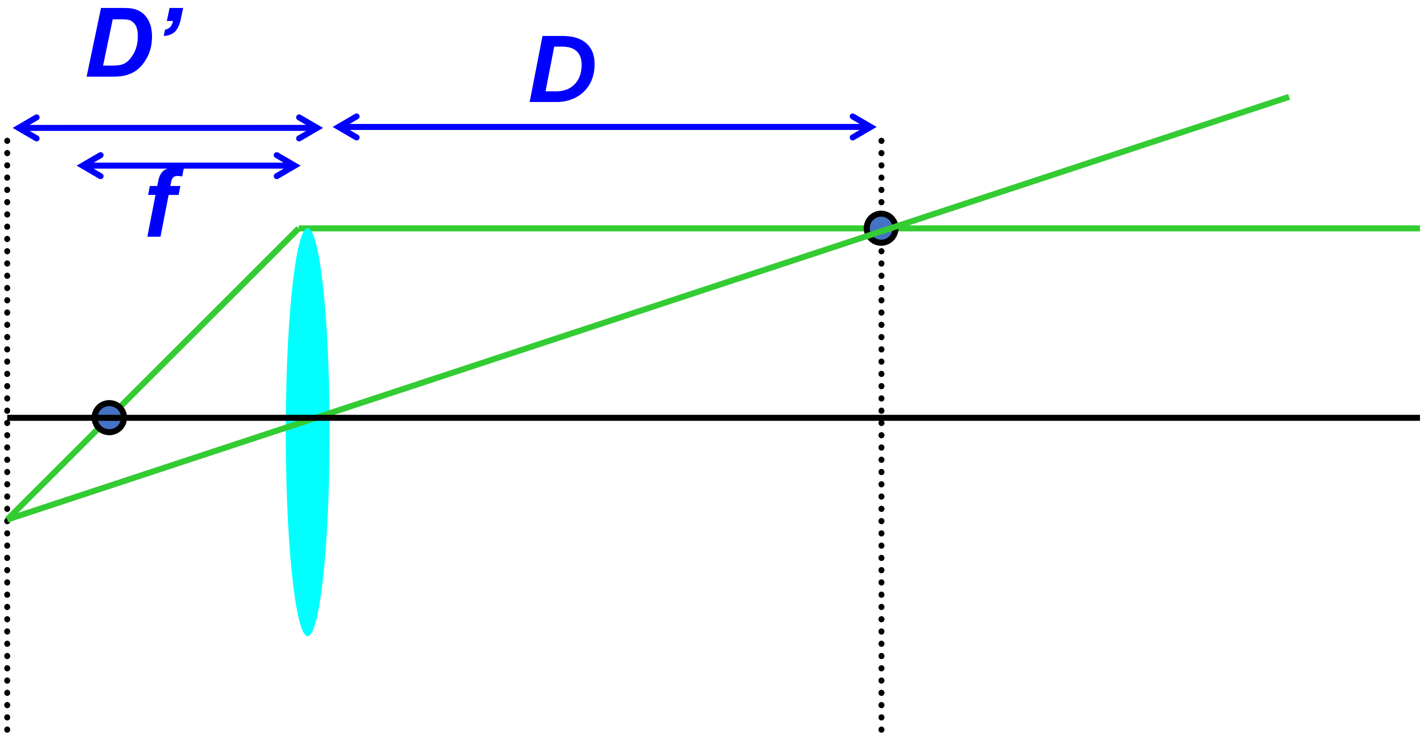
$$y'/y = D'/D$$

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

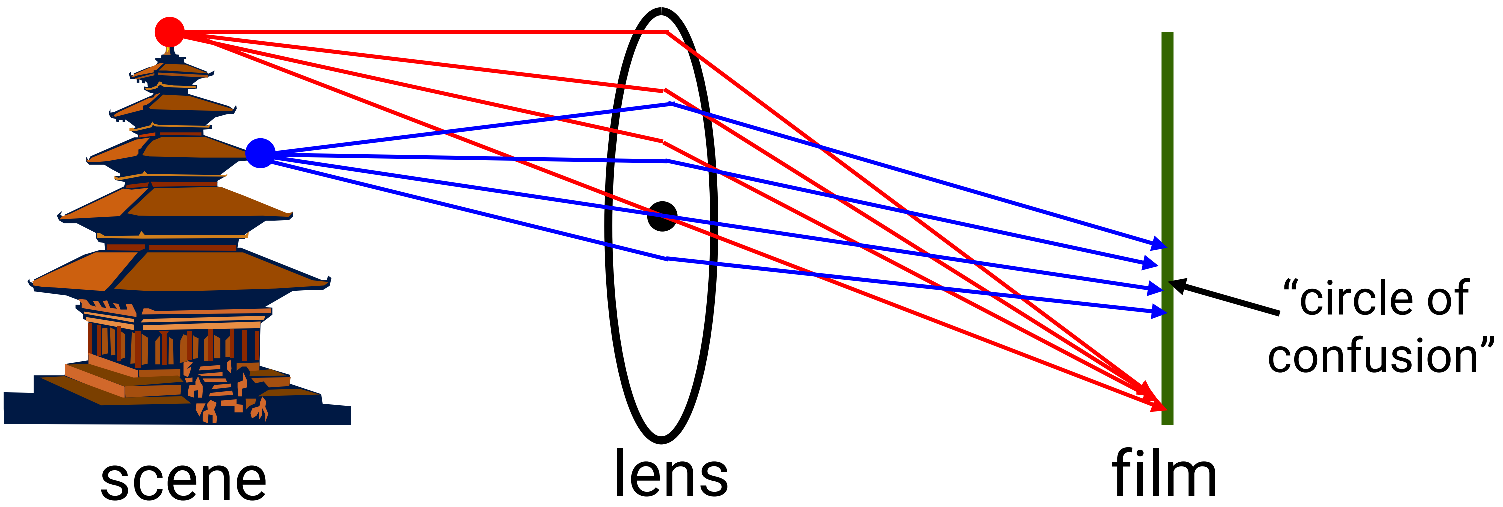


Thin Lens Formula (cont.)

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



Adding a Lens (cont.)

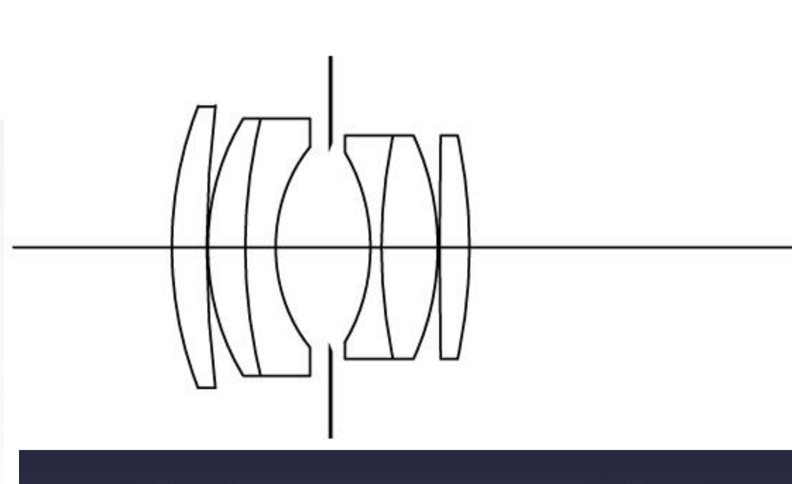


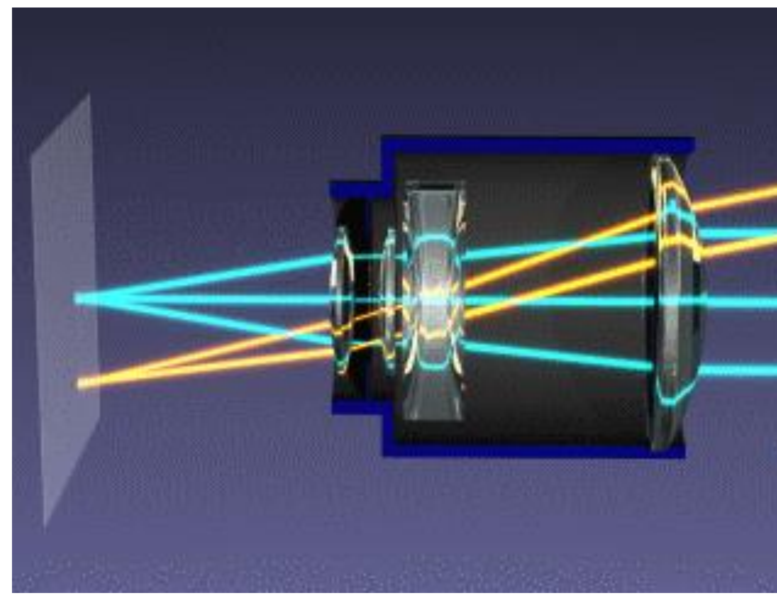
A lens focuses light onto the film

- There is a specific distance at which objects are “in focus”
- Other points project to a “circle of confusion” in the image

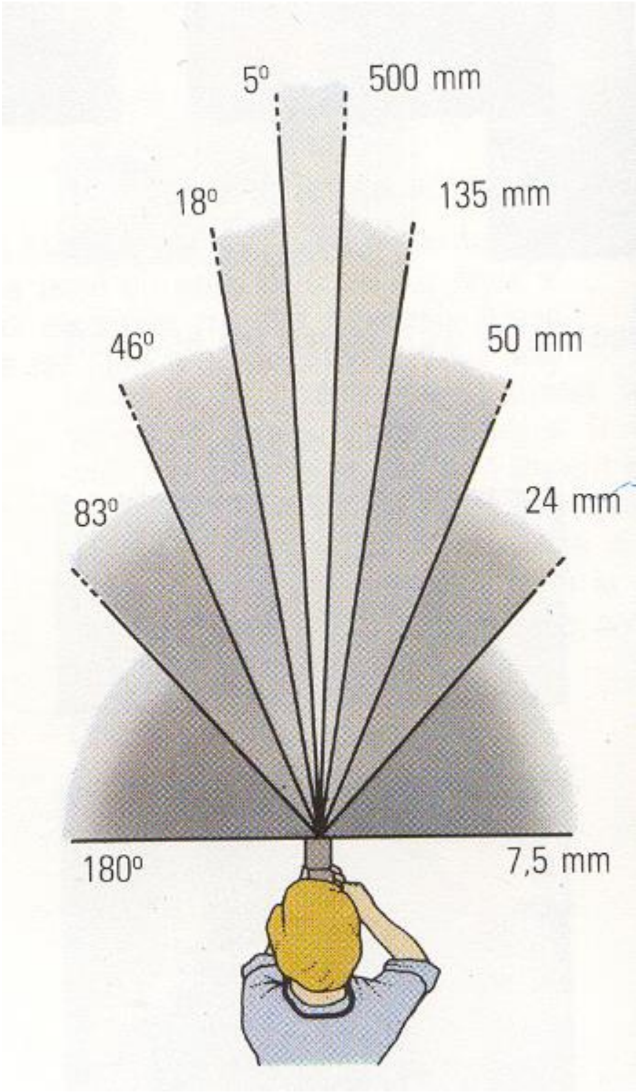
Zoom Lens

Nikon 28-200mm zoom lens.

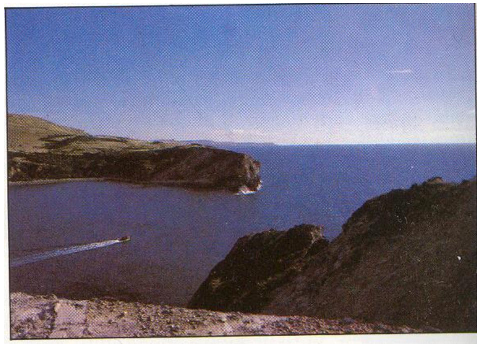




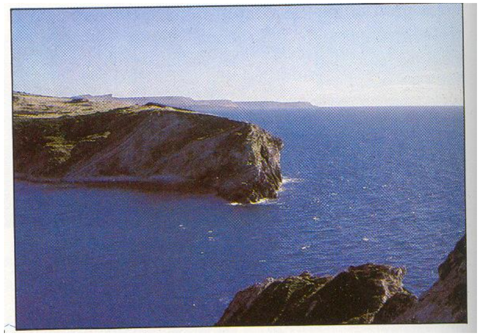
Focal Length in Practice



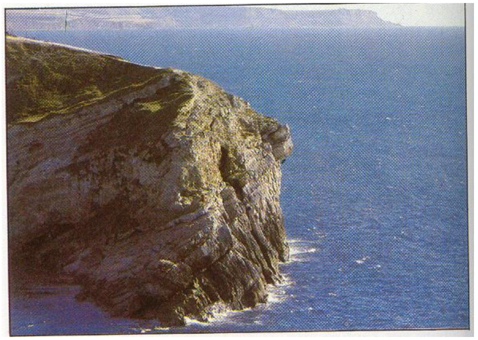
24mm



50mm

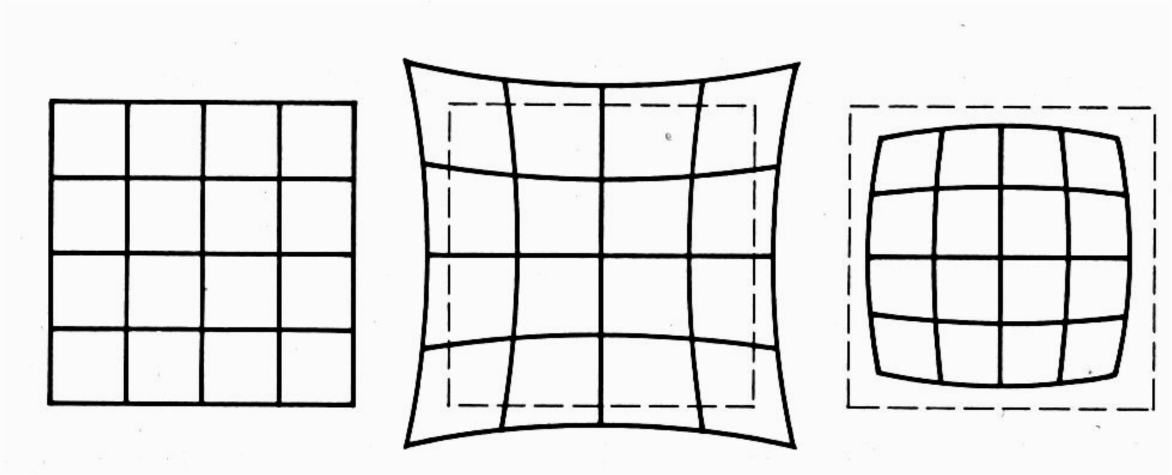


135mm



Problems with Lens

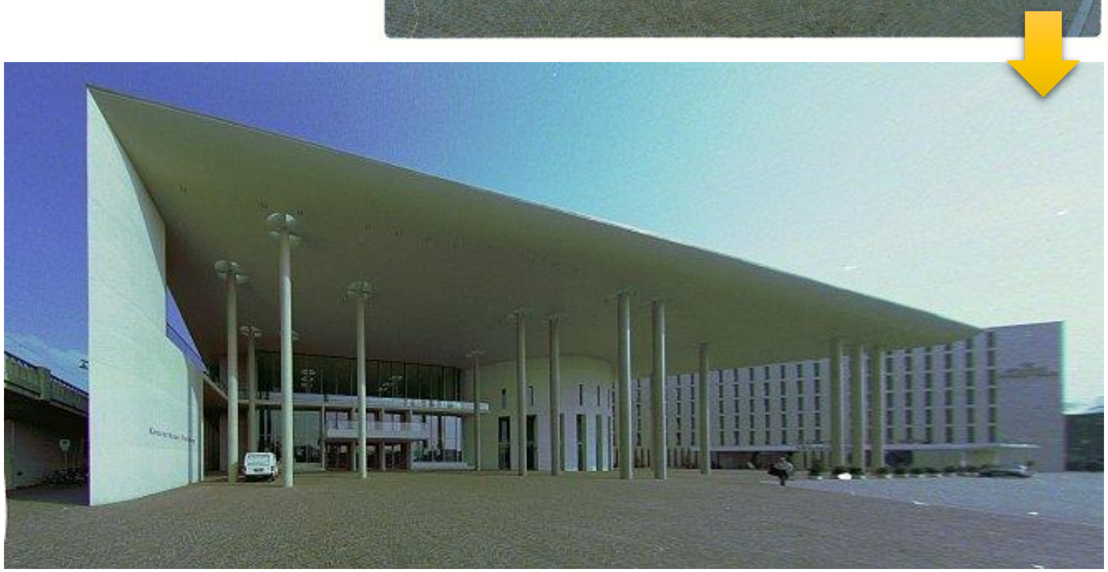
- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviation are most noticeable for rays that pass through the edge of the lens



no distortion pin cushion barrel

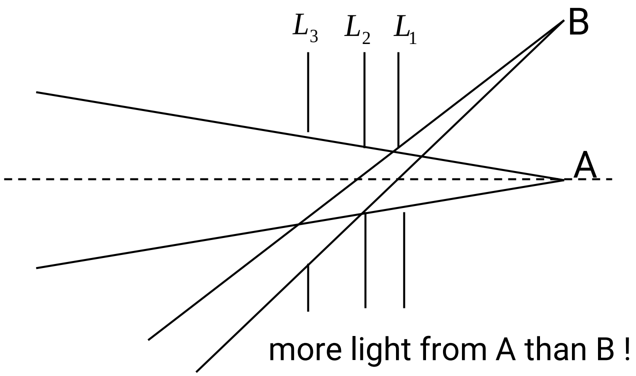
Problems with Lens (cont.)

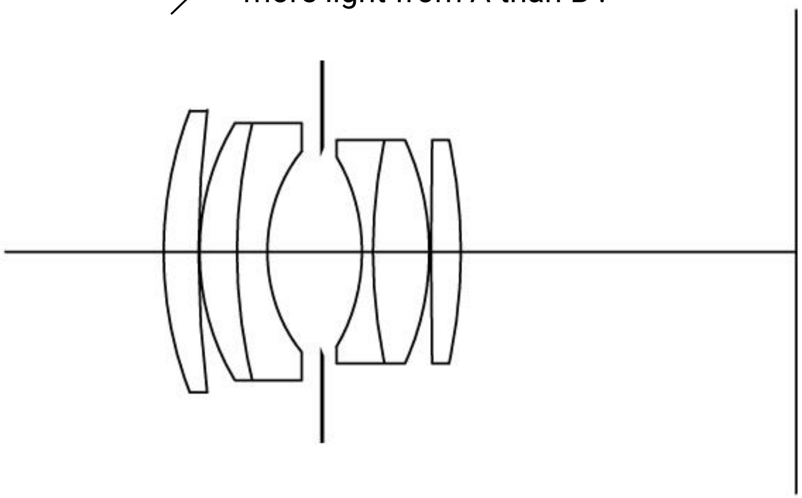
- Correcting radial distortion



Problems with Lens (cont.)

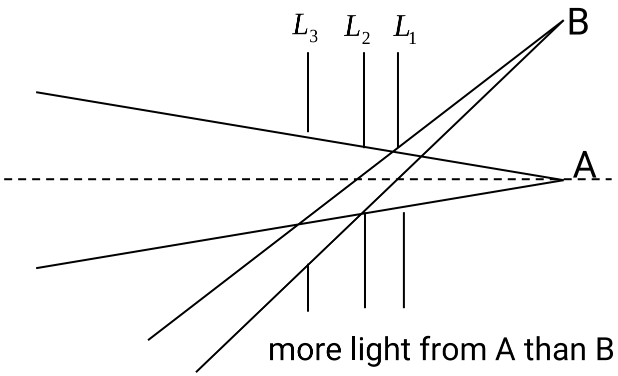
- Vignetting

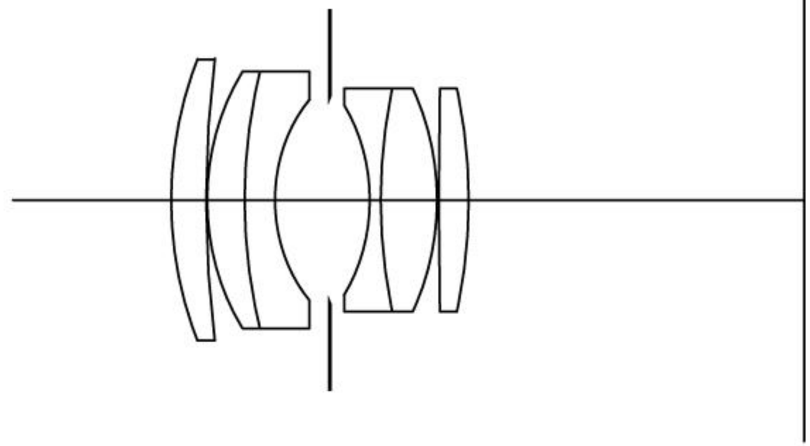




Problems with Lens (cont.)

- Vignetting

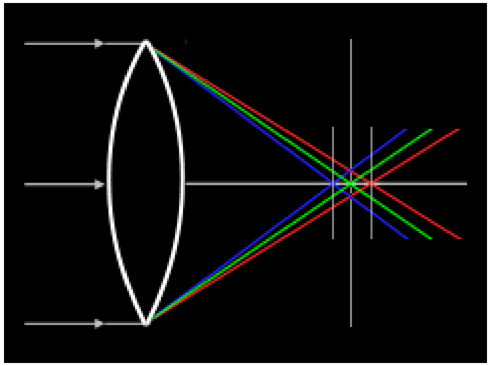




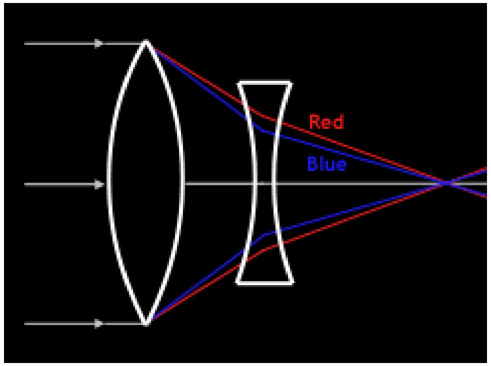
original corrected

Goldman & Chen, ICCV 2005

Chromatic Aberration



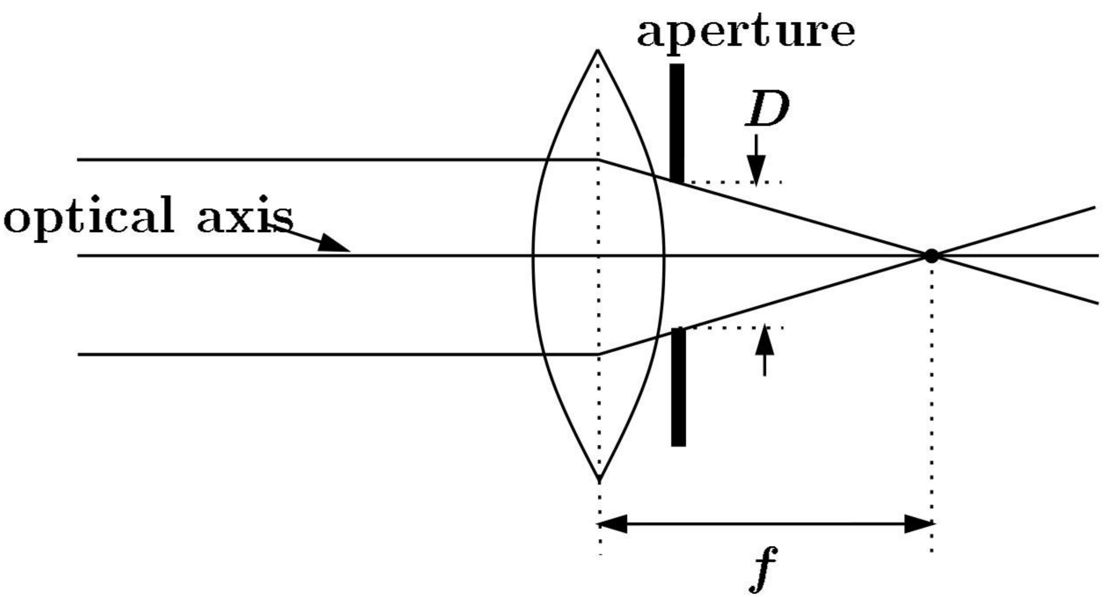
Lens has different refractive indices for different wavelengths.



Special lens systems using two or more pieces of glass with different refractive indexes can reduce or eliminate this problem.

Exposure

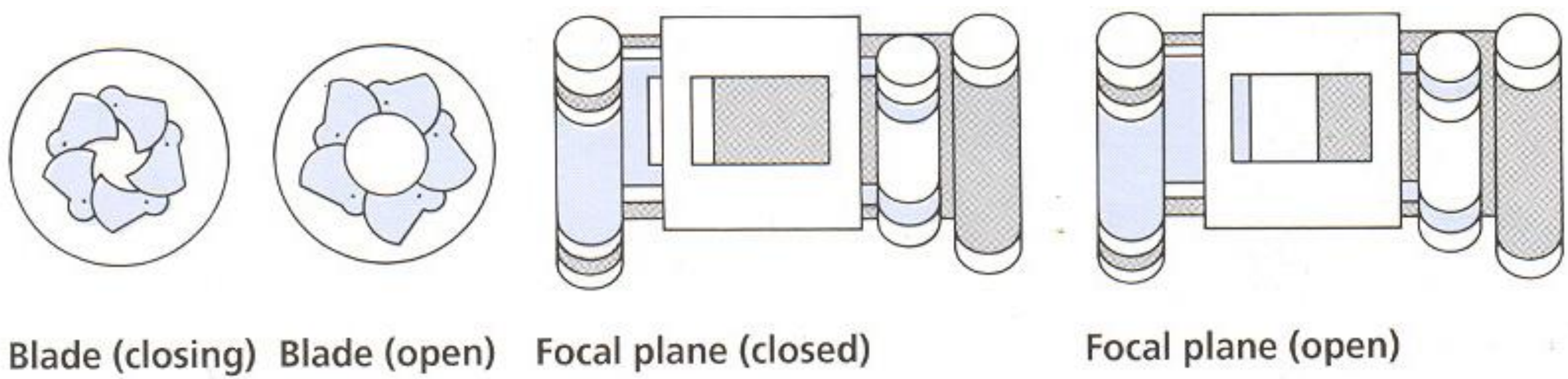
- **Exposure = aperture + shutter speed**
  - **Aperture** of diameter D restricts the range of rays (aperture may be on either side of the lens)
  - **Shutter speed** is the amount of time that light is allowed to pass through the aperture



Exposure (cont.)

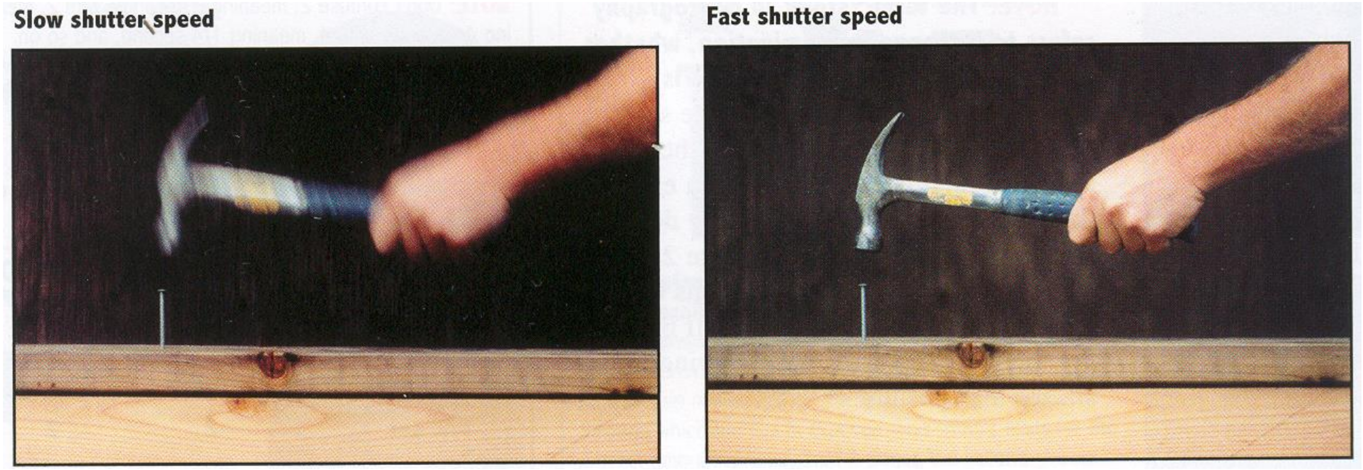
- Aperture (in f stop)

- Shutter speed (in fraction of a second)

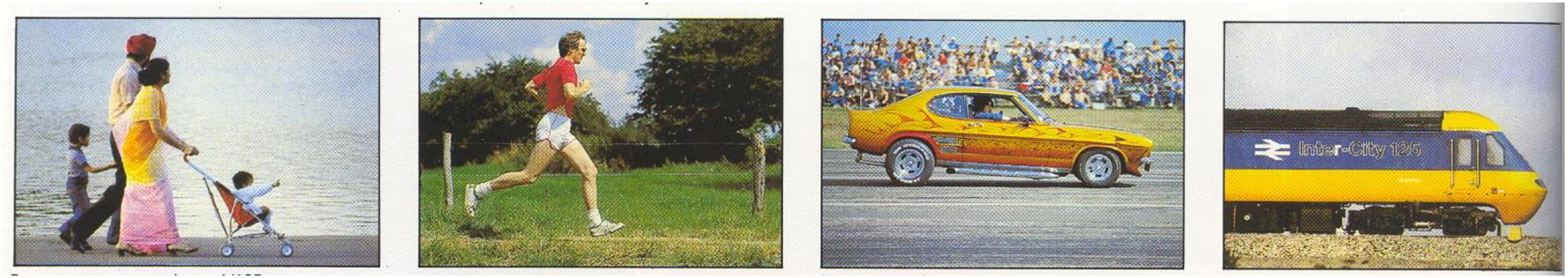


Effect of Shutter Speeds

- Slow shutter speed ➔ more light, but more motion blur



- Faster shutter speed freezes motion



1/125 1/250 1/500 1/1000

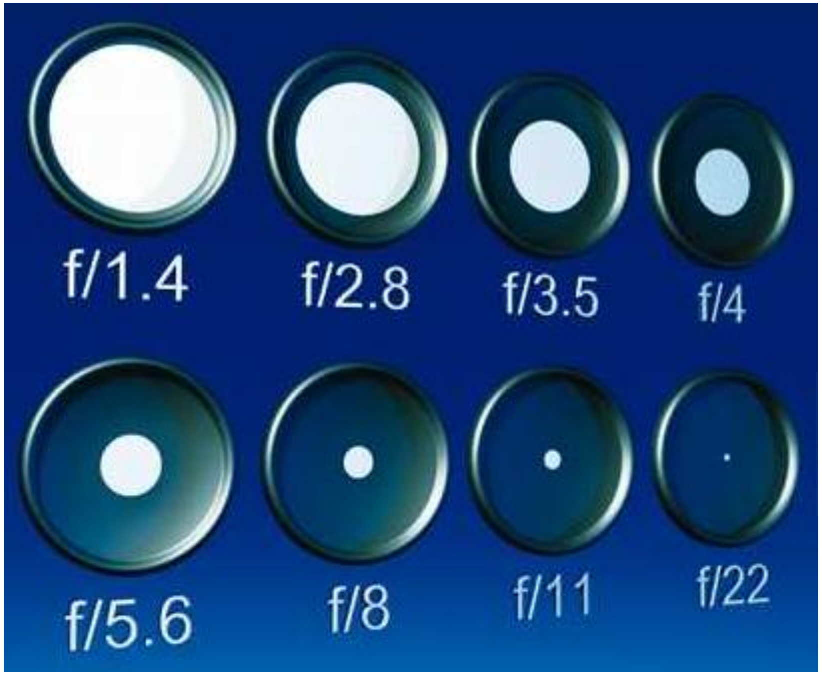
Effect of Shutter Speeds (cont.)

- Light trail

Aperture

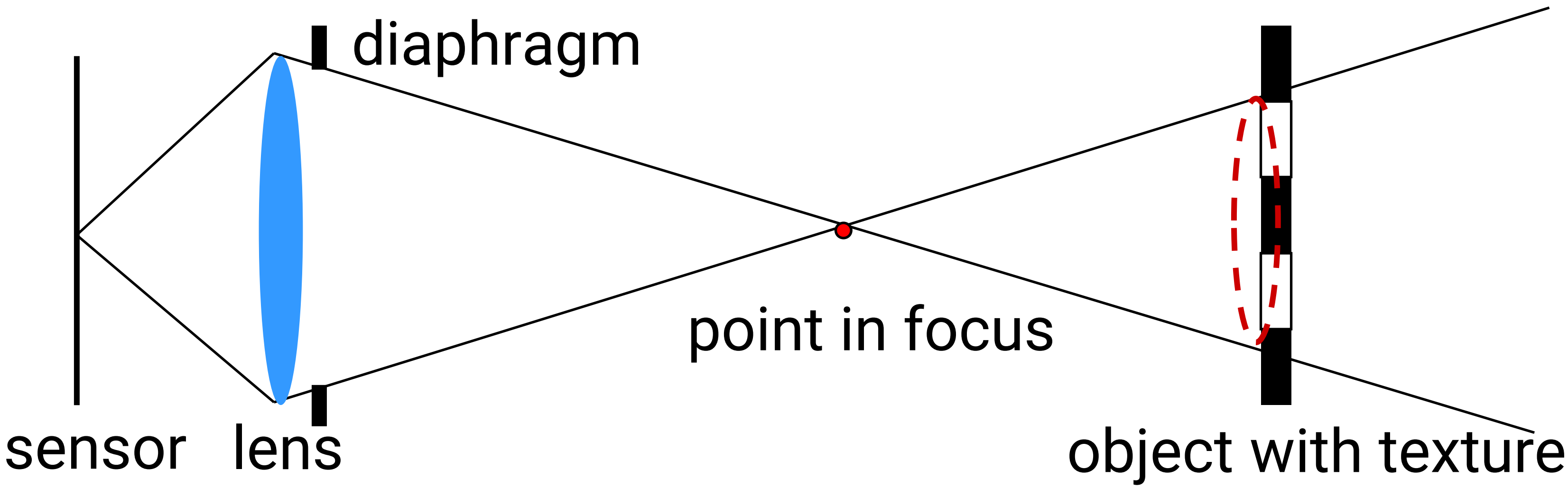
- Aperture is the diameter of the lens opening, usually specified by f-stop, f/D, a fraction of the focal length

- 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)



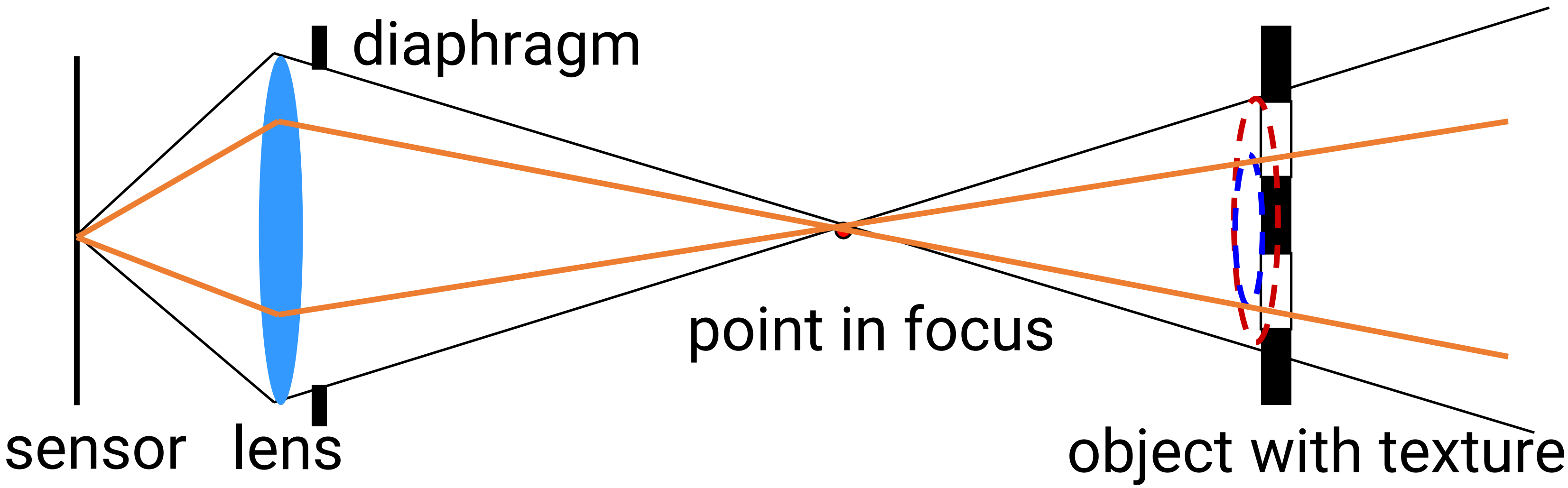
Depth of Field

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



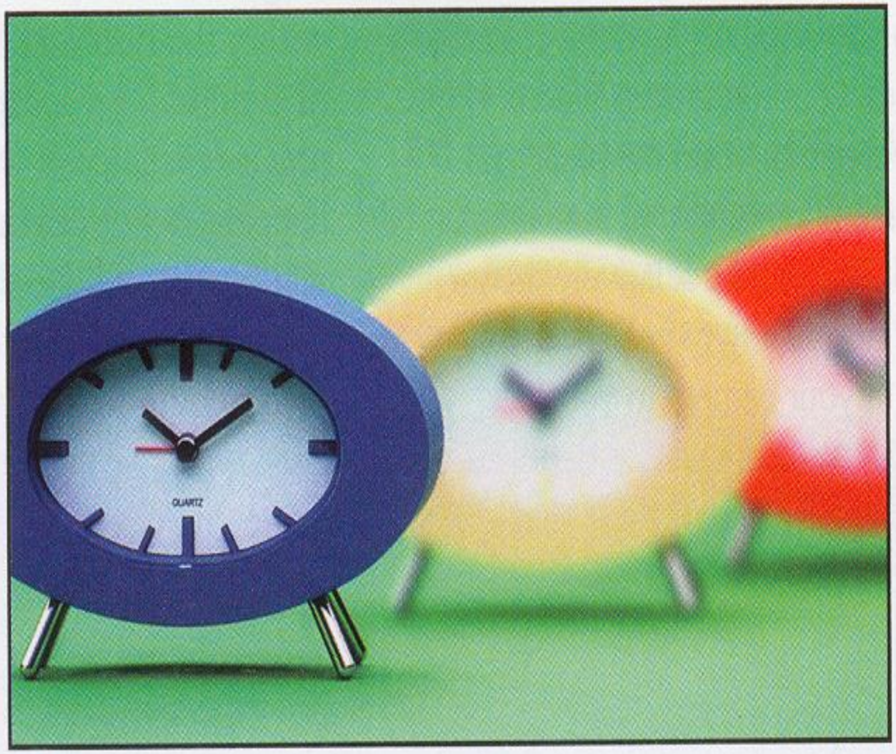
Depth of Field (cont.)

- 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 (cont.)

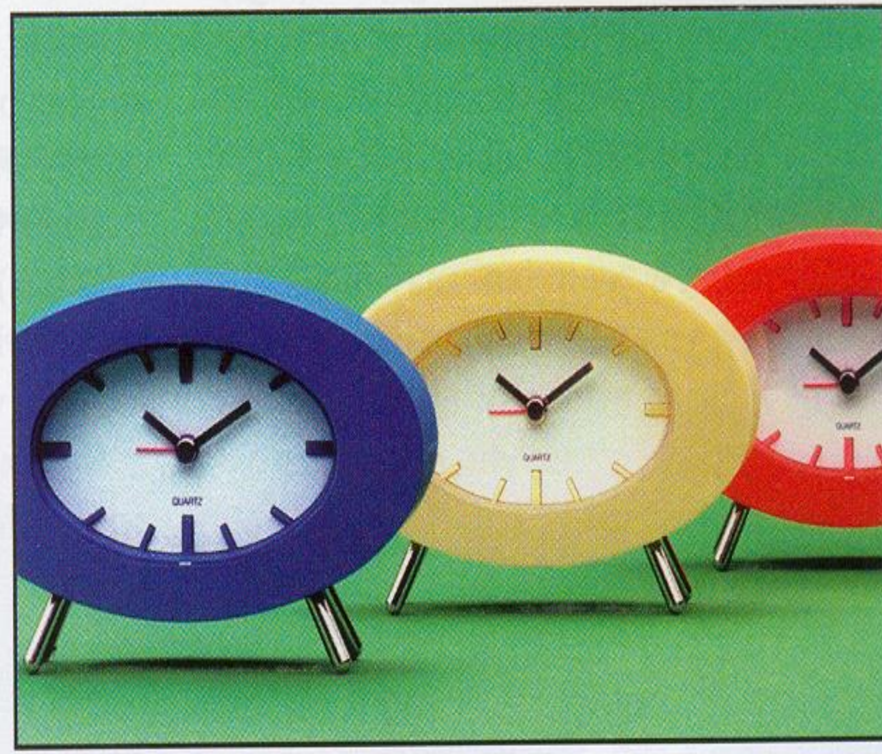
LESS DEPTH OF FIELD



Wider aperture

f/2

MORE DEPTH OF FIELD

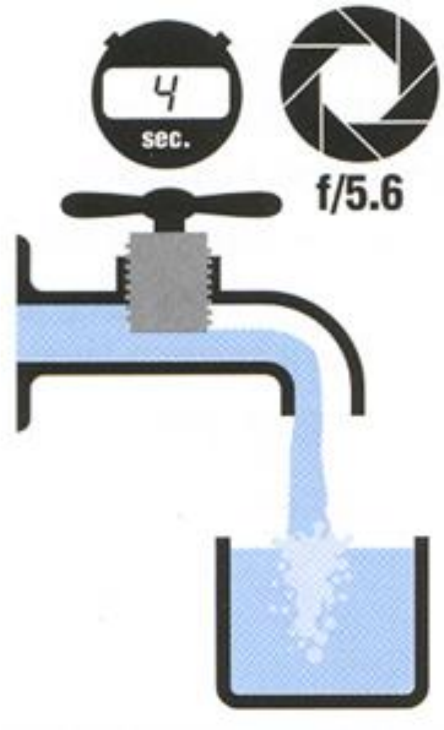


Smaller aperture

f/16

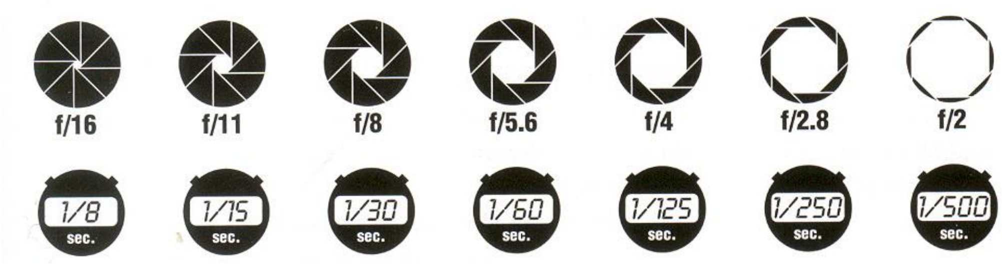
Aperture and Shutter Speed

- The same exposure is obtained with an exposure twice as long and an aperture area half as big



Aperture and Shutter Speed (cont.)

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



- What will guide our choice of a shutter speed?
  - Freeze motion vs. motion blur, camera shake
- What will guide our choice of an aperture?
  - Depth of field, diffraction limit

Exposure and Metering

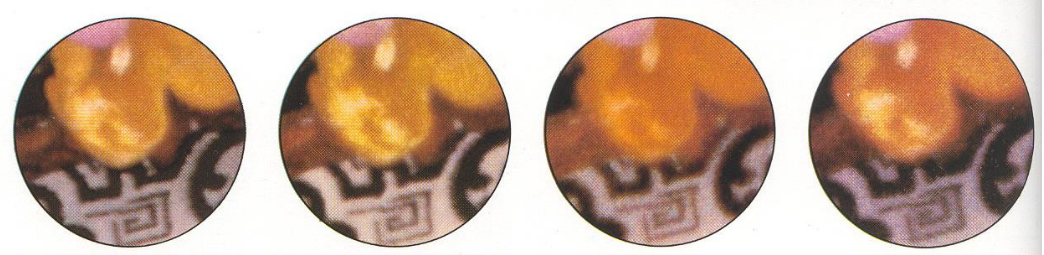
- The camera metering system measures how bright the scene is
- In **aperture priority** mode, the photographer sets the aperture, the camera sets the shutter speed
- In **shutter-speed** priority mode, photographers sets the shutter speed and the camera deduces the aperture
- In **program mode**, the camera decides both exposure and shutter speed (middle value more or less)
- In **manual mode**, the user decides everything (but can get feedback)

Exposure and Metering (cont.)

- **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)
- **Program**
  - Almost no control, but no need for neurons
- **Manual**
  - Full control, but takes more time and thinking

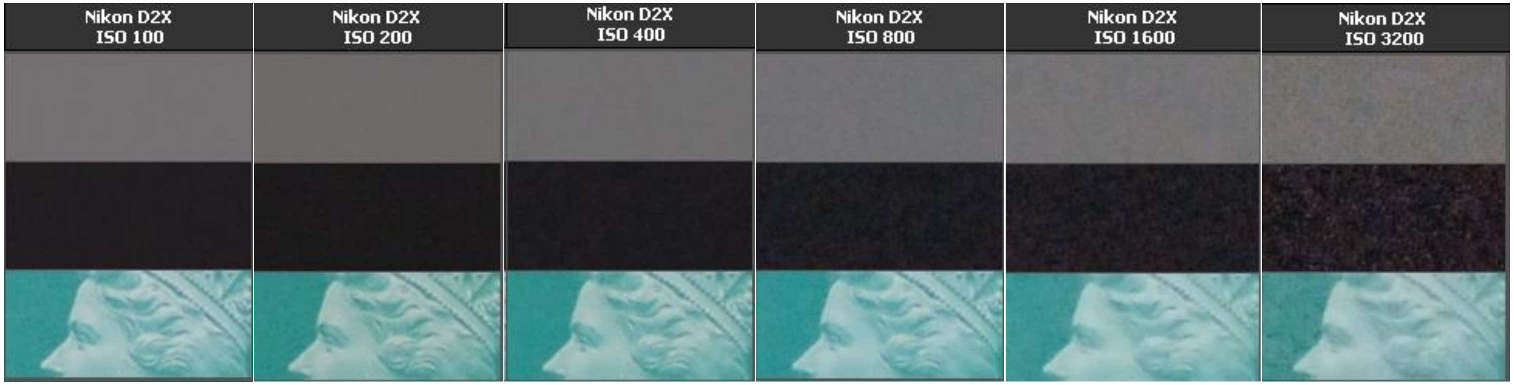
Sensitivity

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

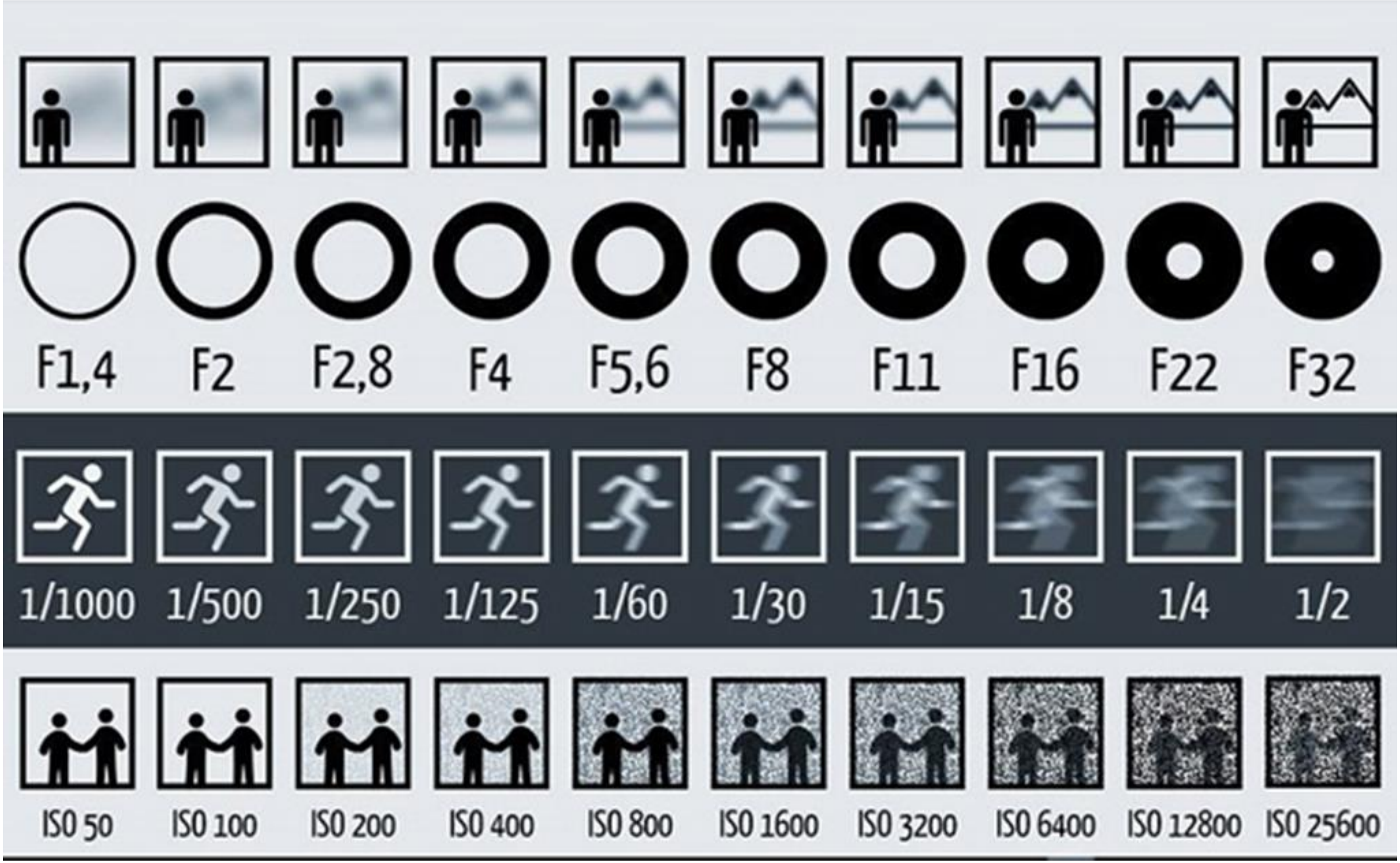


Kodachrome 25 ASA — Ektachrome 64 ASA — Fujichrome 100 ASA — Ektachrome 200 ASA

- Digital photography: trade sensitivity for noise

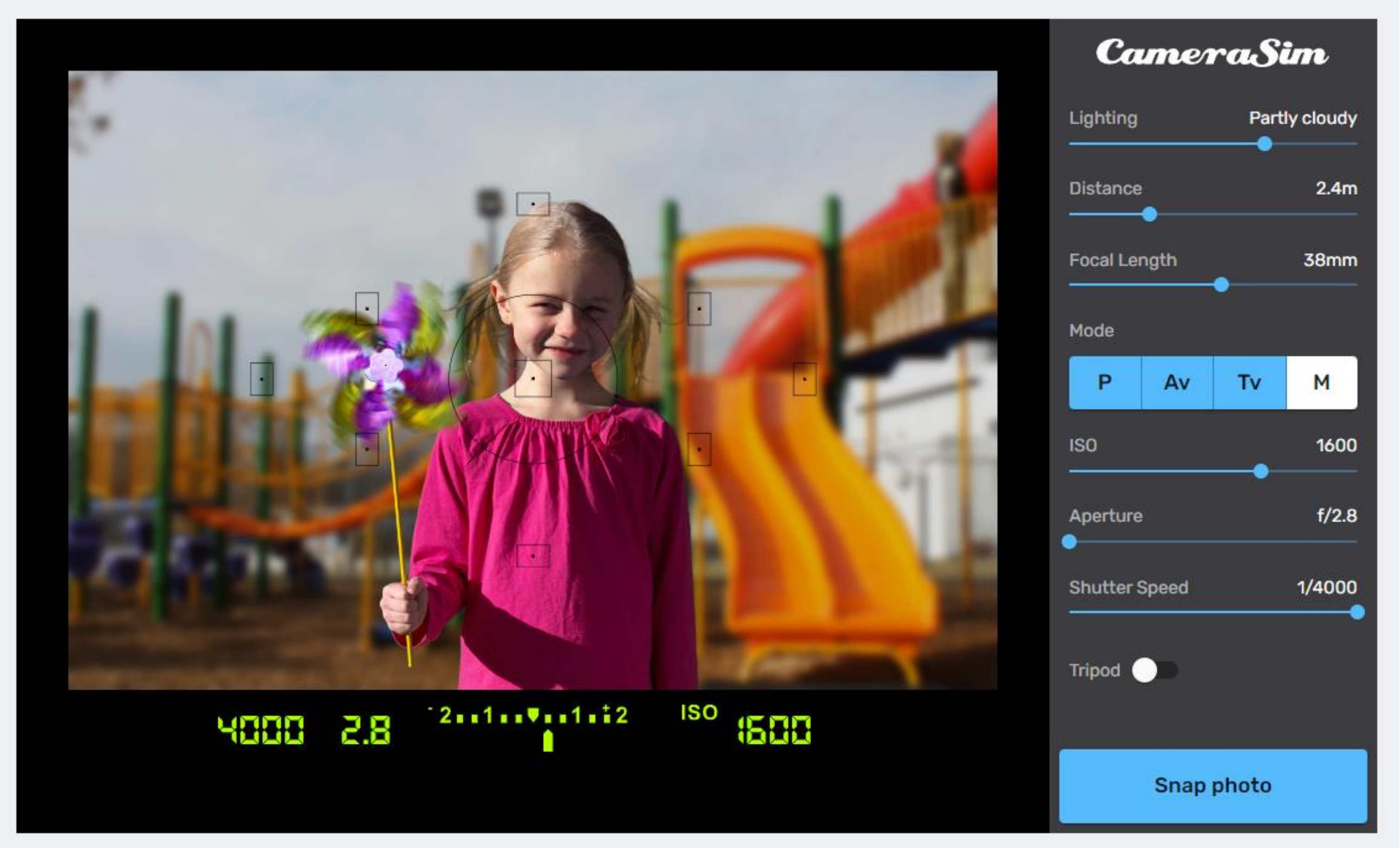


Shutter Speed, Aperture, and Sensitivity

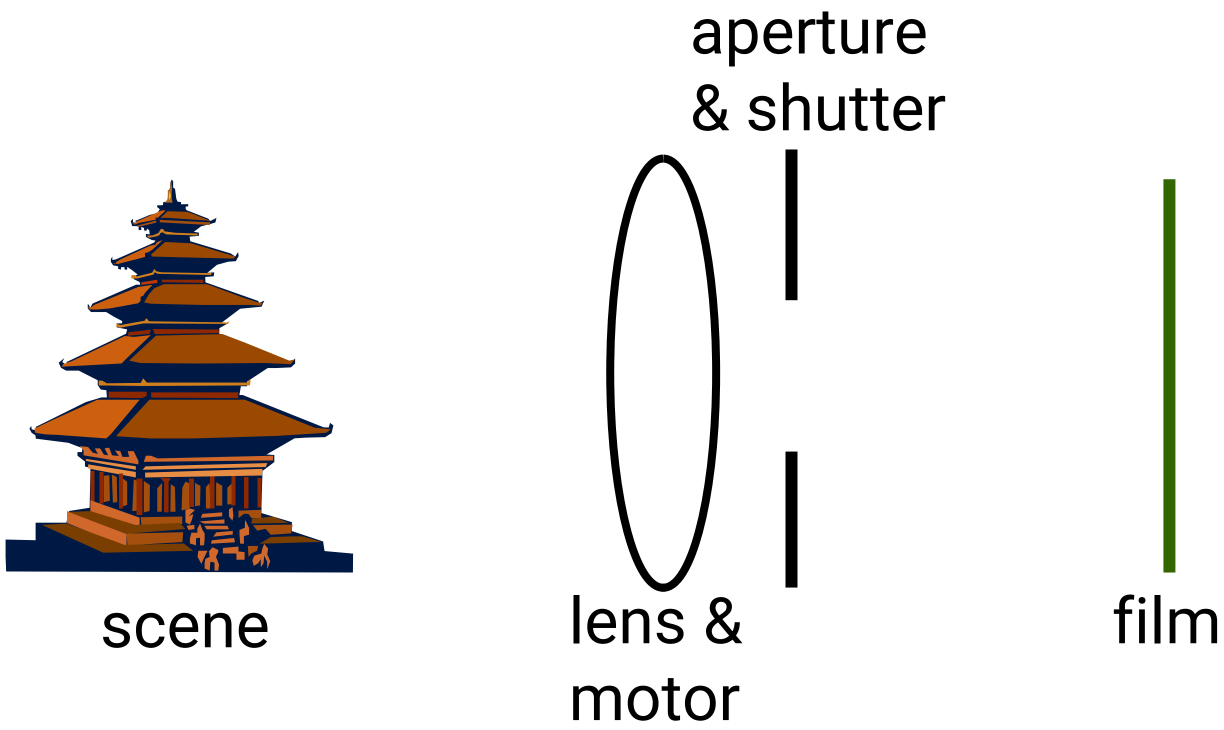


Demo

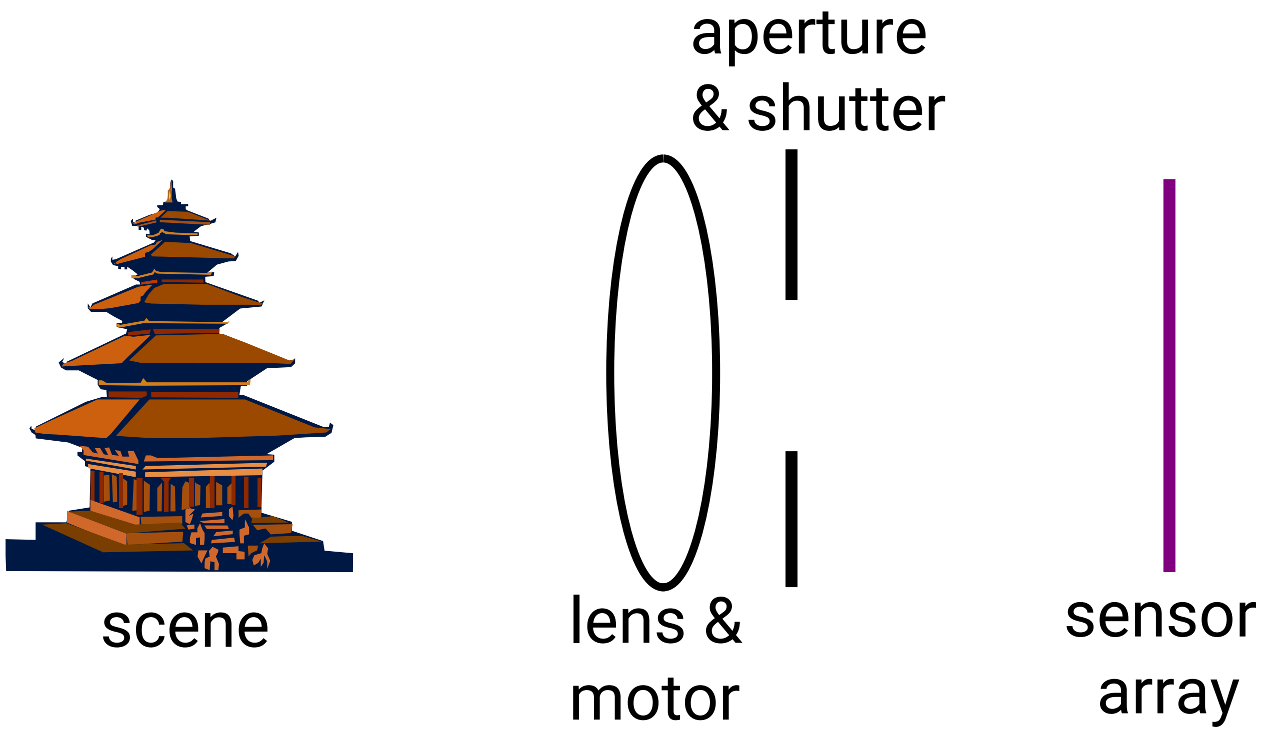
- https://camerasim.com/camerasim-free-web-app/



Film Camera



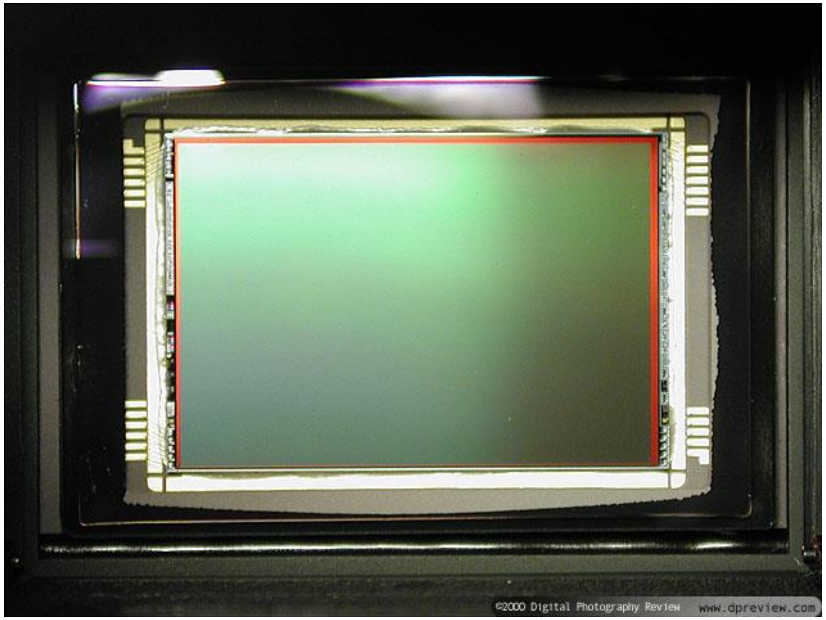
Digital Camera



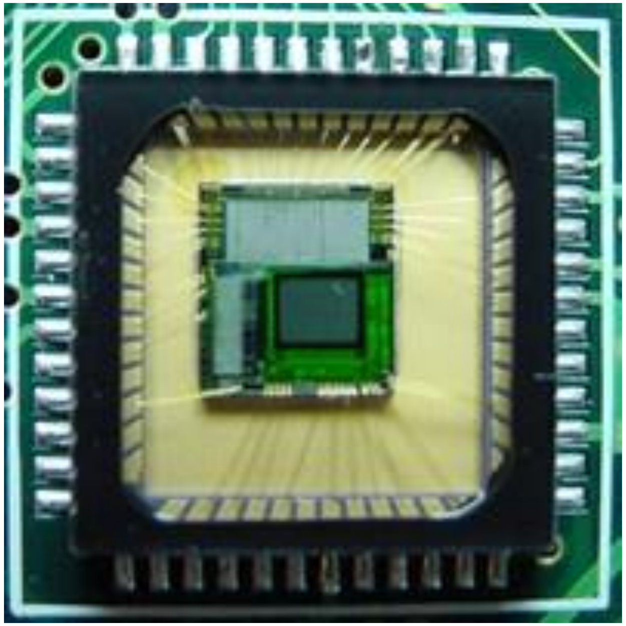
- A digital camera replaces film with a sensor array
- Each cell in the array is a light-sensitive diode that converts photons to electrons

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

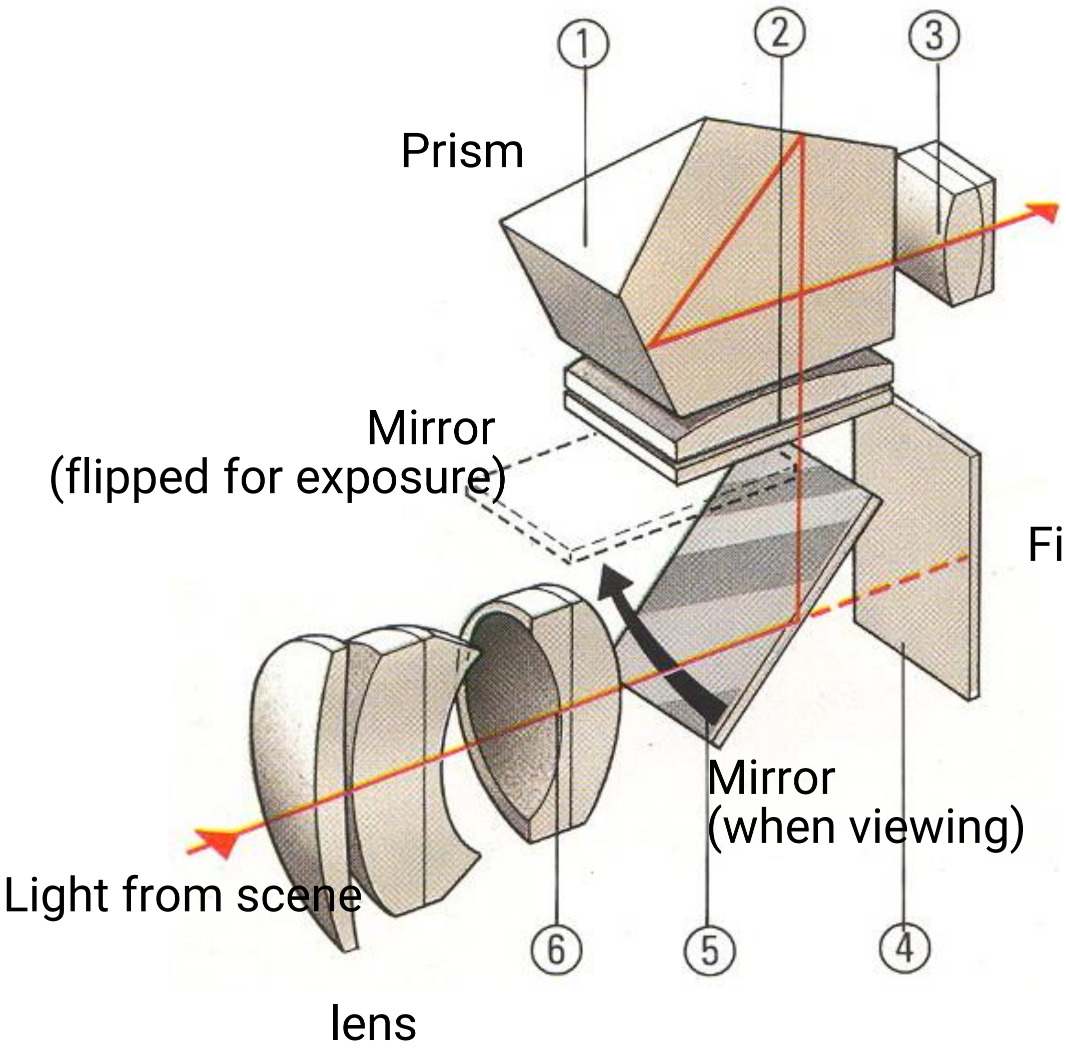


CMOS

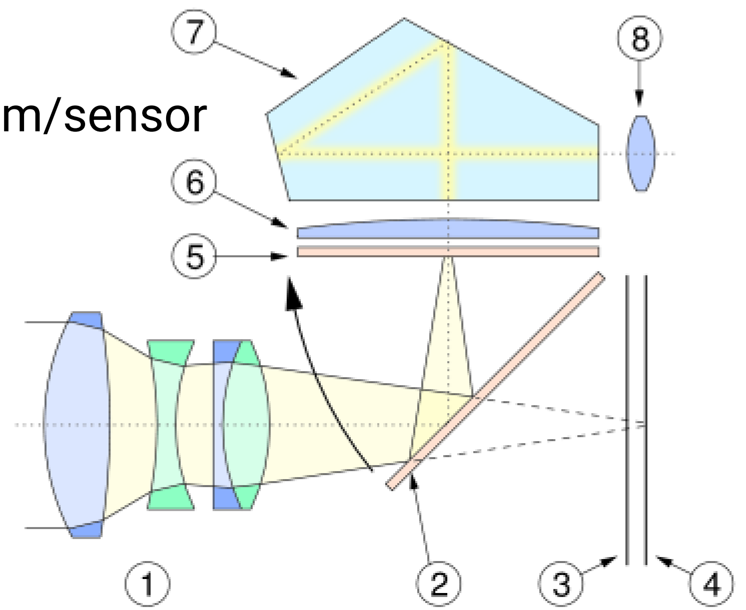
SLR (Single-Lens Reflex)

- 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



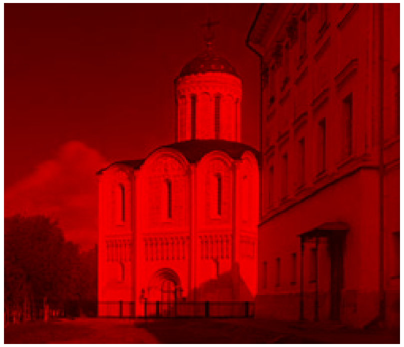
Film/sensor



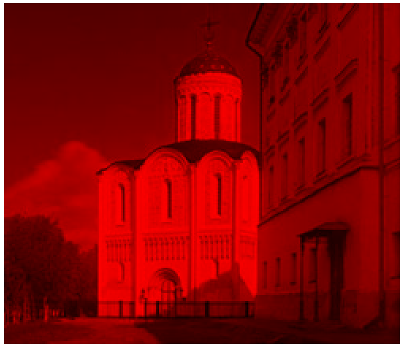
Color

- 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

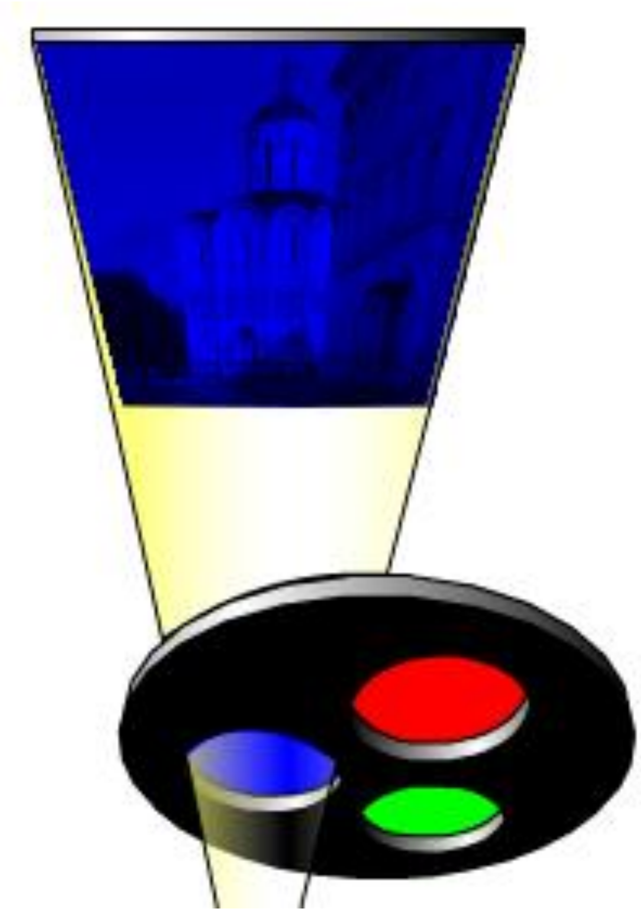
Field Sequential



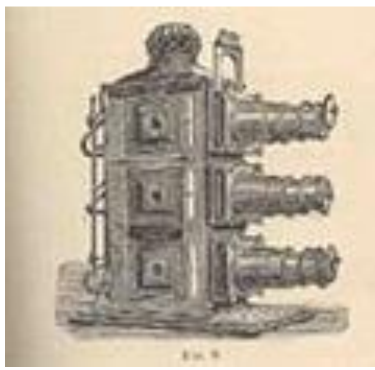
Field Sequential (cont.)



Field Sequential (cont.)



Prokudin-Gorskii (early 1900’s)

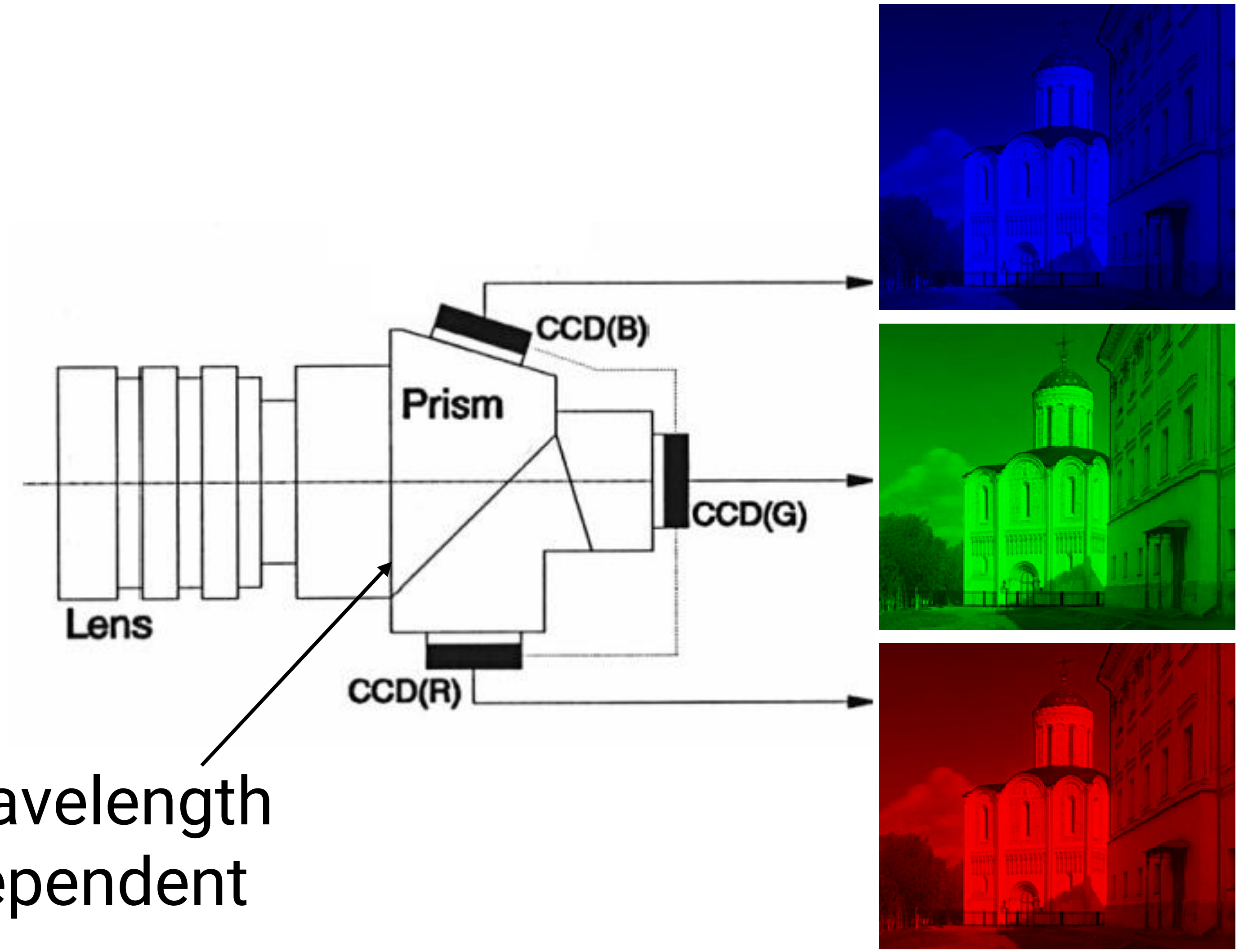


lantern projector

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

Prokudin-Gorskii (early 1900's)

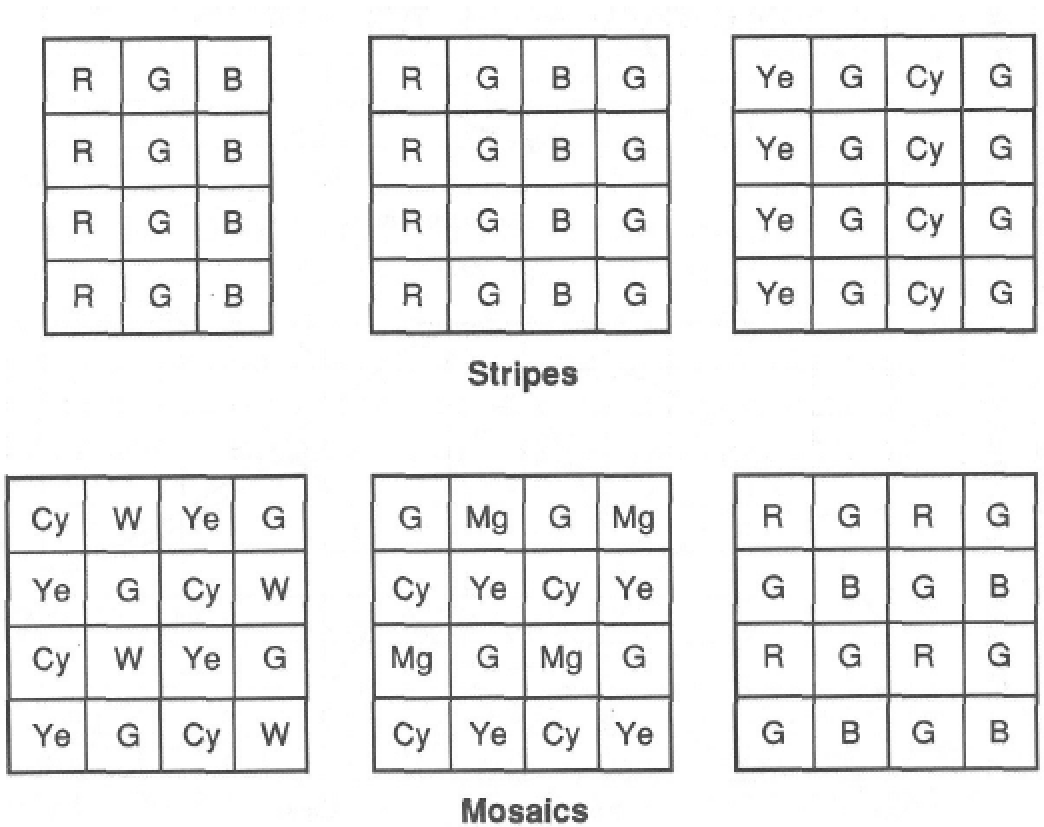
Multi-chip



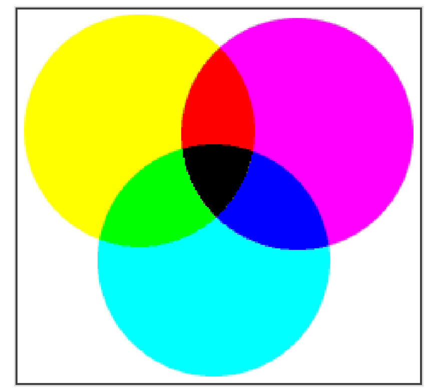
wavelength dependent

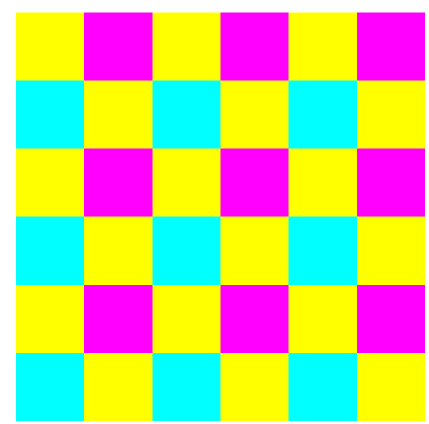
Color Filter Array

- Color filter arrays (CFAs) / color filter mosaics



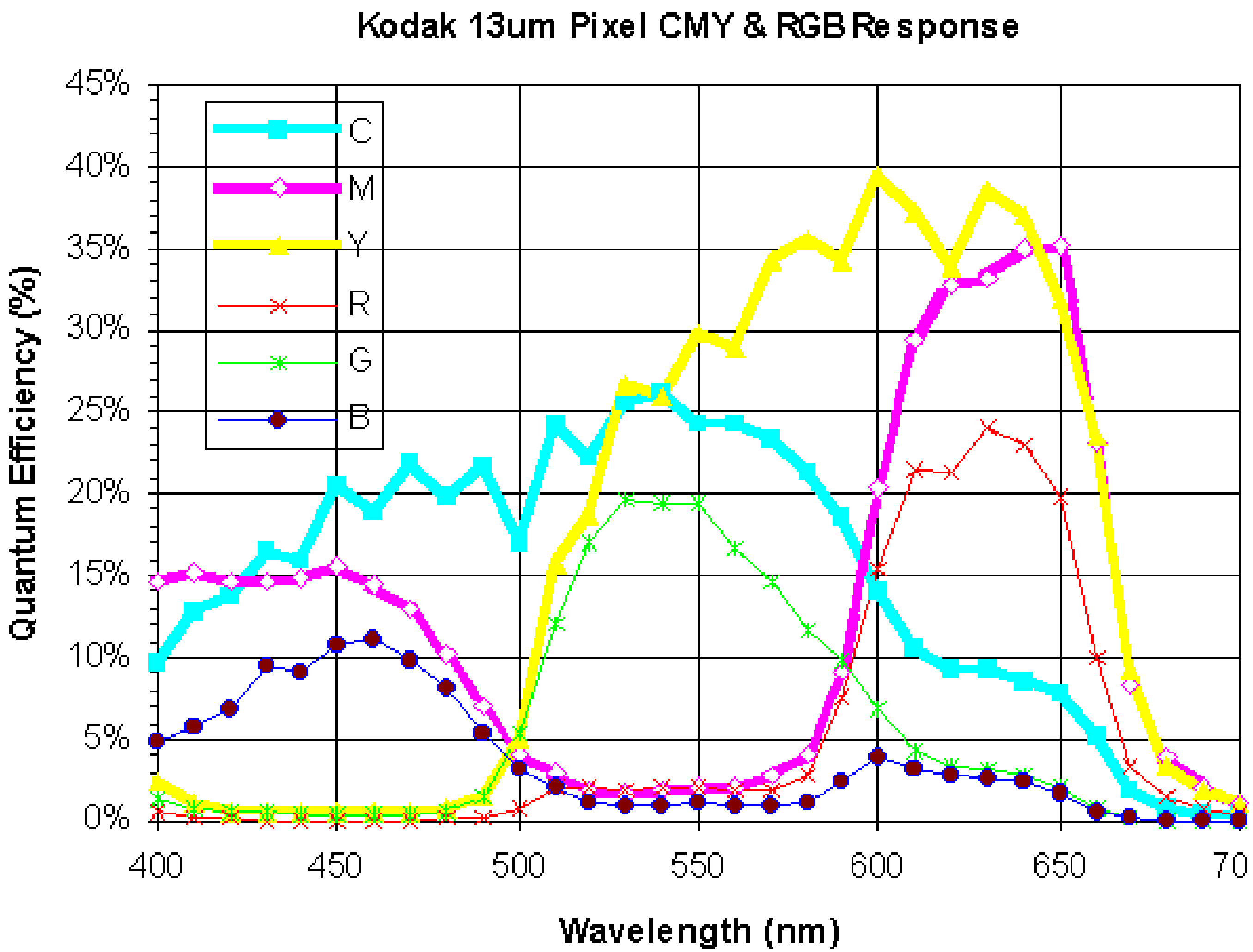
Kodak DCS620x





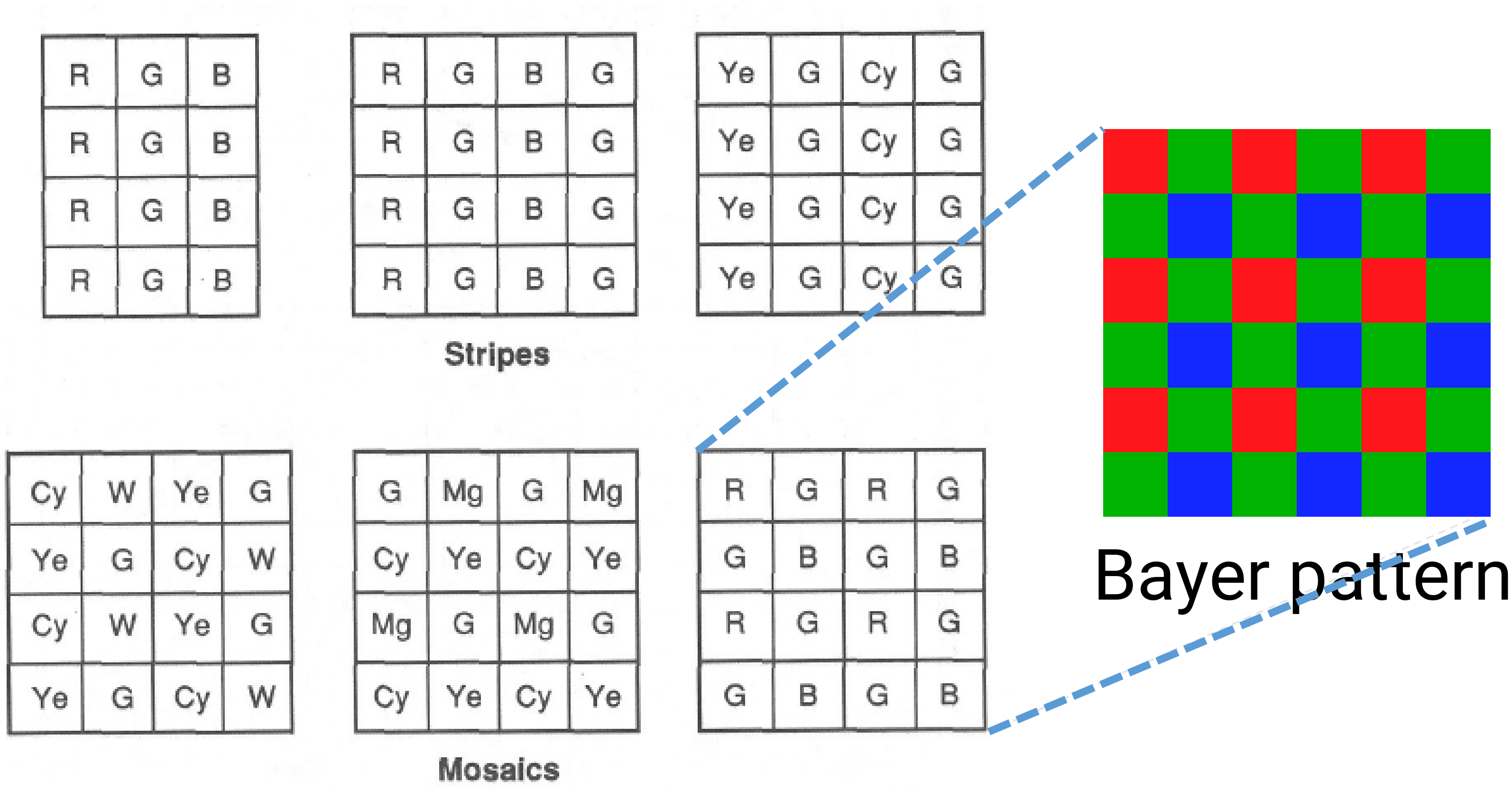
CMY

CMY v.s. RGB CFA

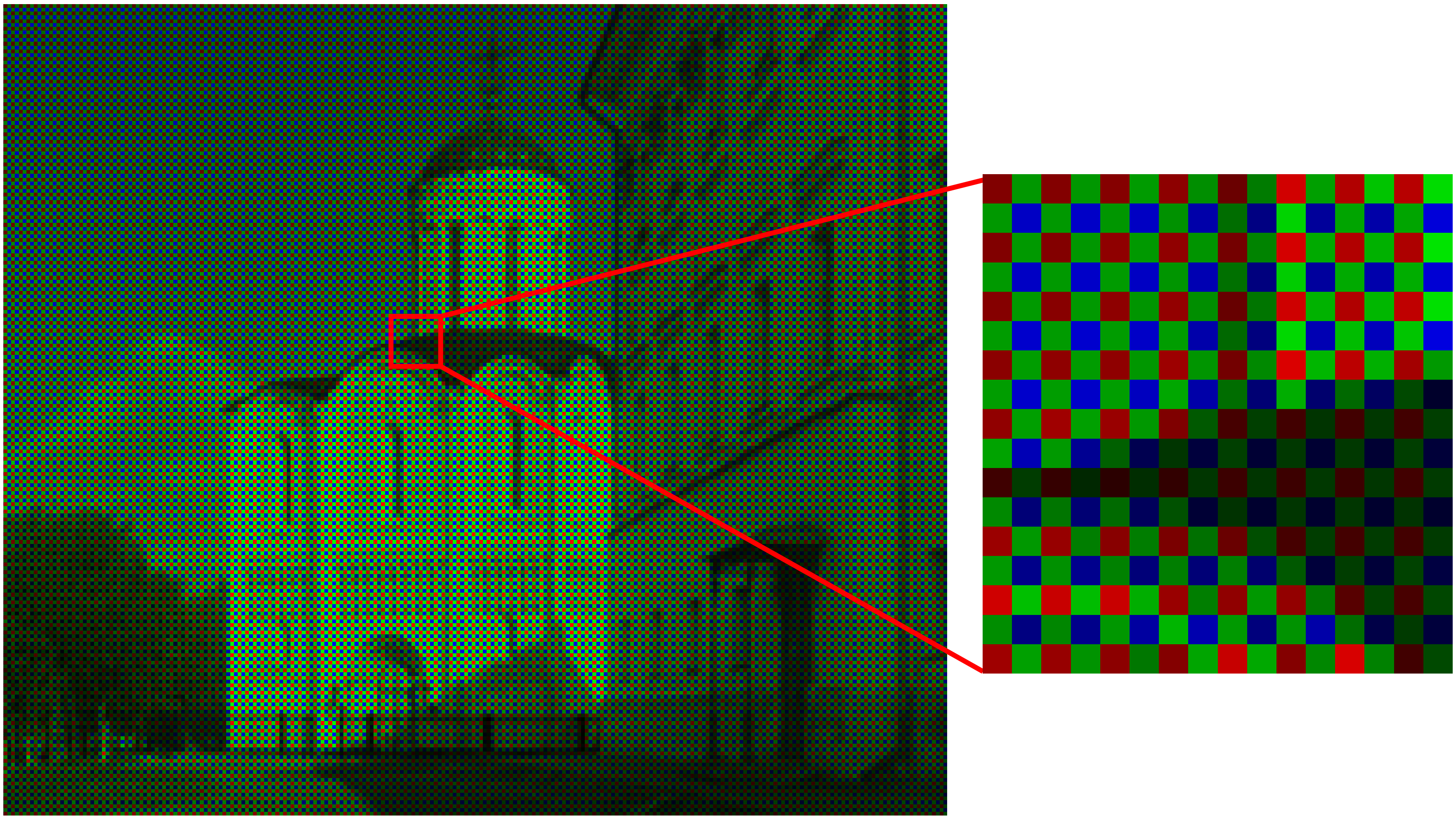


Color Filter Array (cont.)

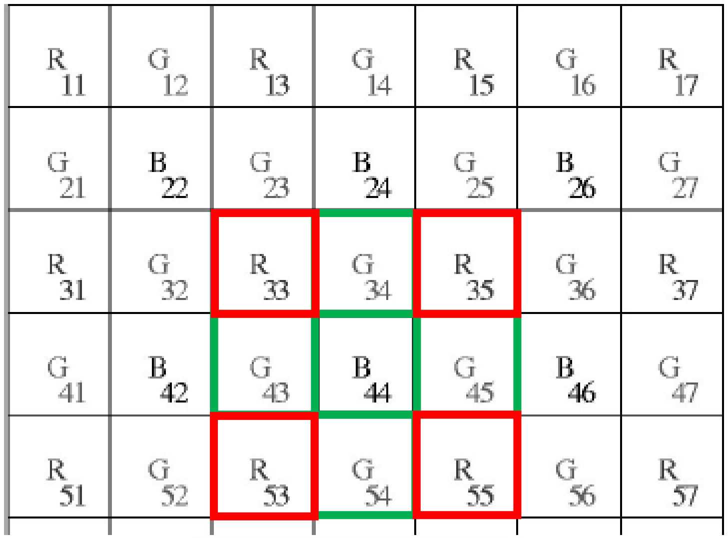
- Color filter arrays (CFAs) / color filter mosaics



Bayer’s Pattern



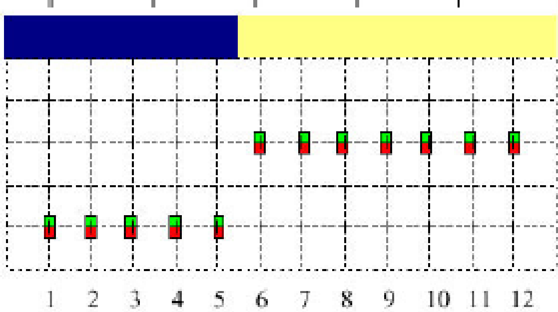
Demosaicking CFA



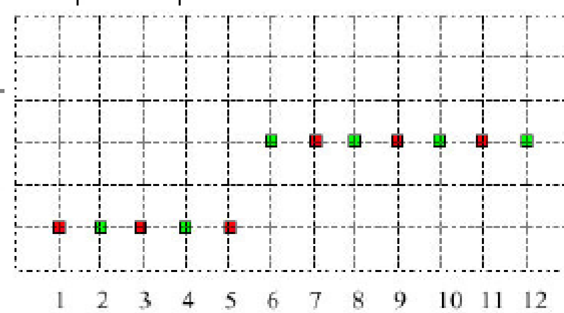
bilinear interpolation

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

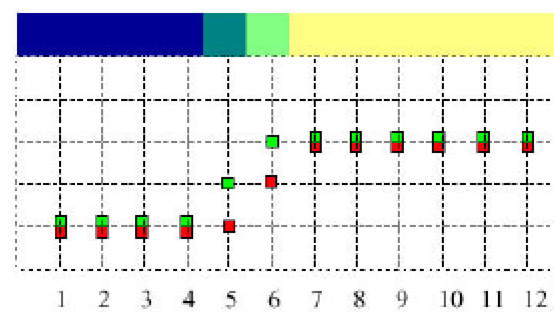
$$R_{44}=(R_{33}+R_{35}+R_{53}+R_{55})/4$$



original

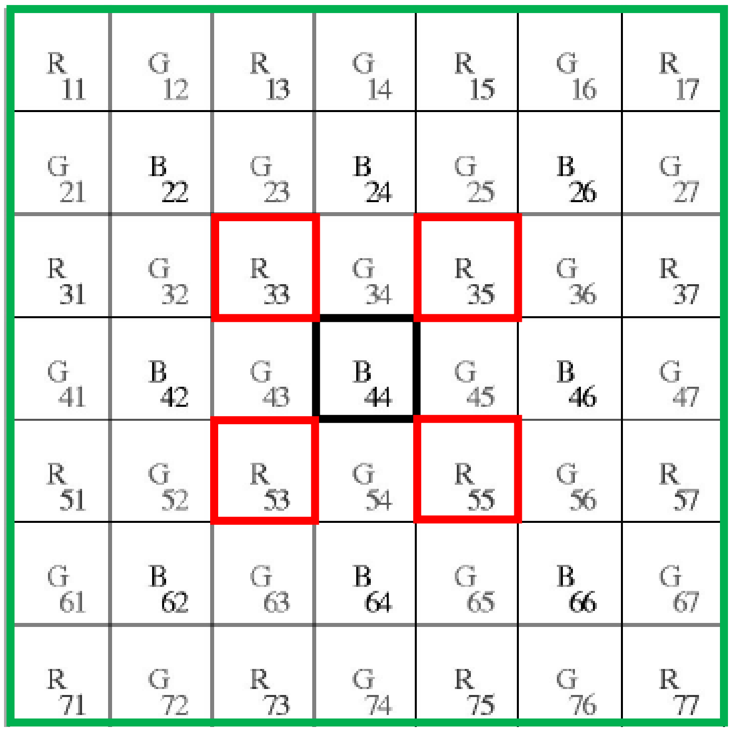


input



linear interpolation

Demosaicking CFA (cont.)



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 (cont.)

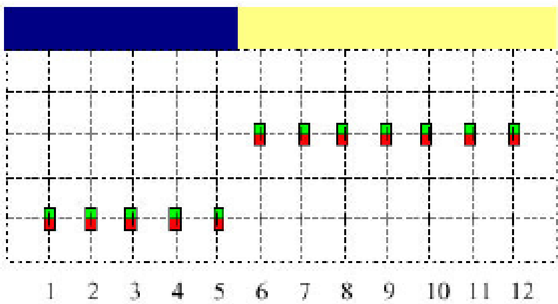
R 11	G 12	R 13	G 14	R 15	G 16	R 17
G 21	B 22	G 23	B 24	G 25	B 26	G 27
R 31	G 32	R 33	G 34	R 35	G 36	R 37
G 41	B 42	G 43	B 44	G 45	B 46	G 47
R 51	G 52	R 53	G 54	R 55	G 56	R 57
G 61	B 62	G 63	B 64	G 65	B 66	G 67
R 71	G 72	R 73	G 74	R 75	G 76	R 77

Median-based interpolation (Freeman)

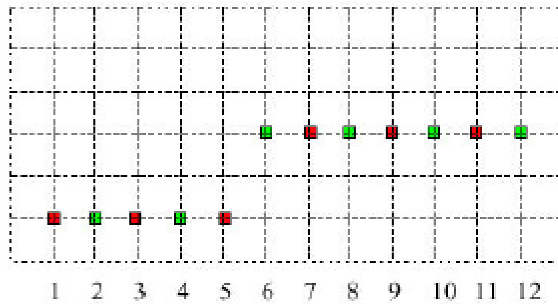
1. Linear interpolation
2. Median filter on color differences

Demosaicking CFA (cont.)

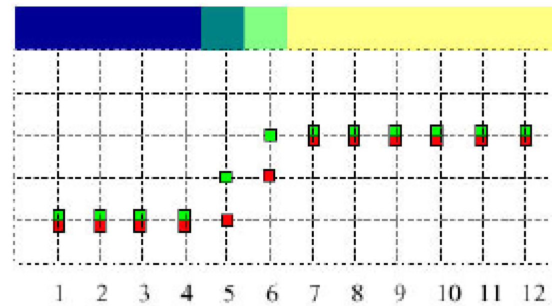
- Median-based interpolation (Freeman)



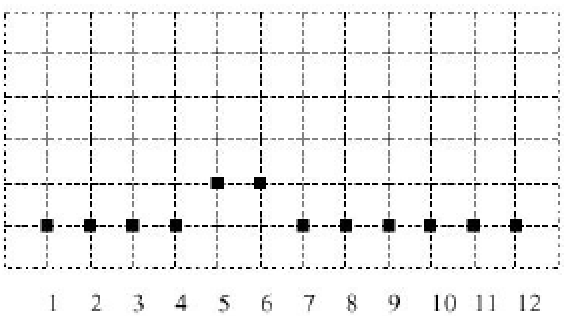
original



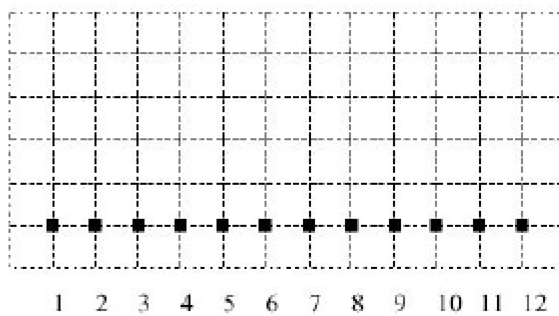
input



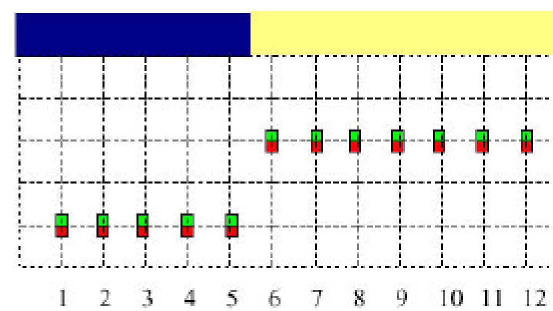
linear interpolation



color difference
(e.g. G-R)

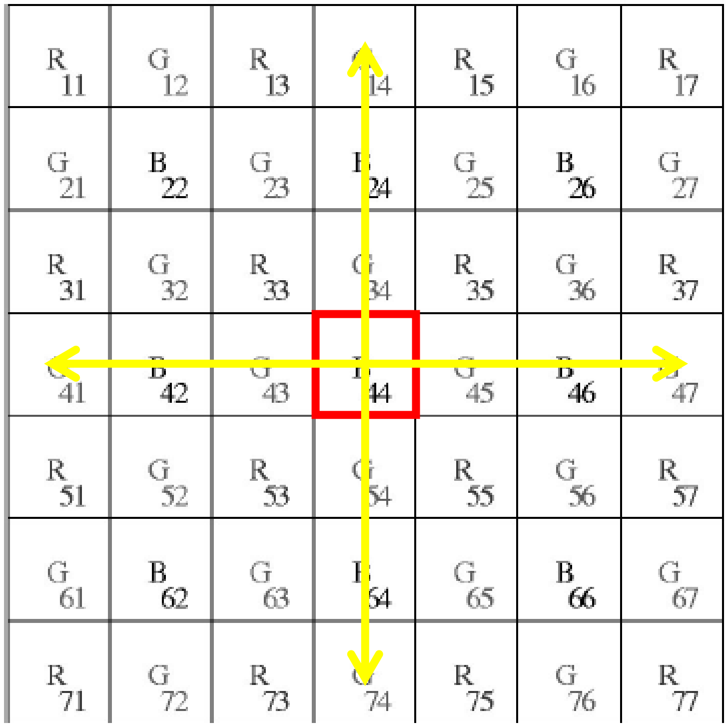


median filter
(kernel size 5)



reconstruction
(G=R+filtered difference)

Demosaicking CFA (cont.)



Gradient-based interpolation (LaRoche-Prescott)

1. Interpolation on G

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

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

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

Demosaicking CFA (cont.)

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

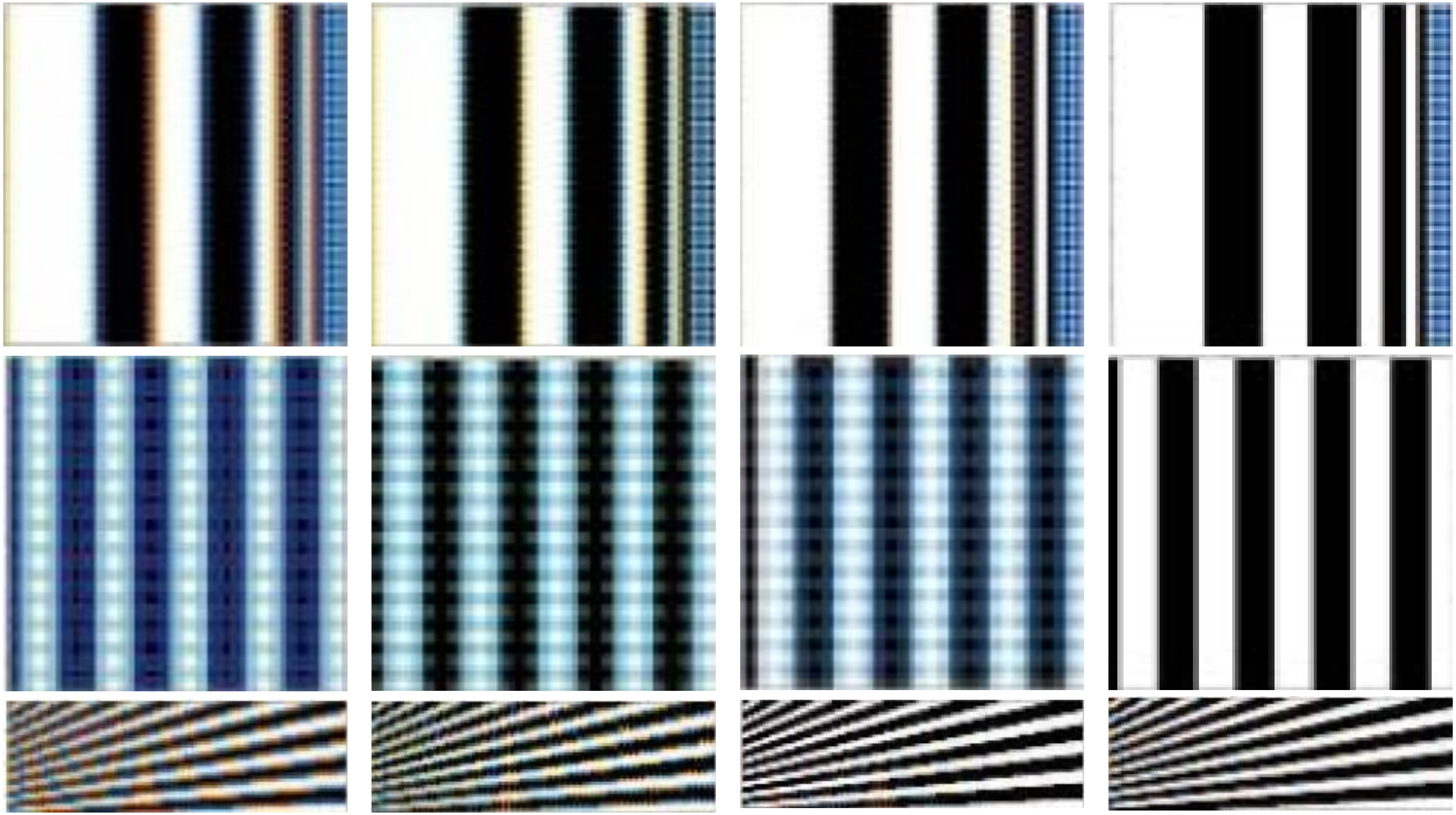
$$R_{34}=\frac{(R_{33}-\mathbf{G}_{33})+(R_{35}-\mathbf{G}_{35})}{2}+G_{34},$$

$$R_{43}=\frac{(R_{33}-\mathbf{G}_{33})+(R_{35}-\mathbf{G}_{35})}{2}+G_{43},$$

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

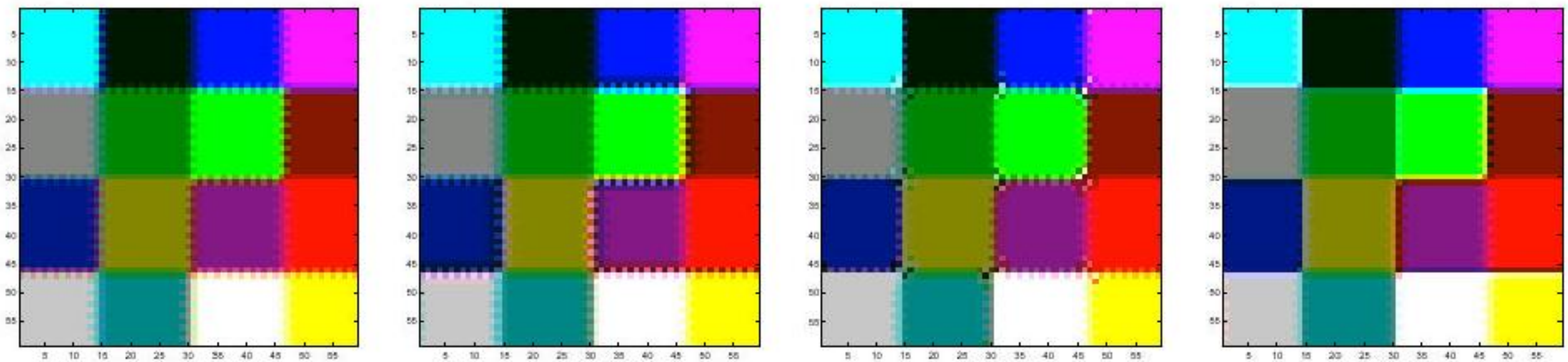
$$+G_{44}.$$

Demosaicking CFA (cont.)

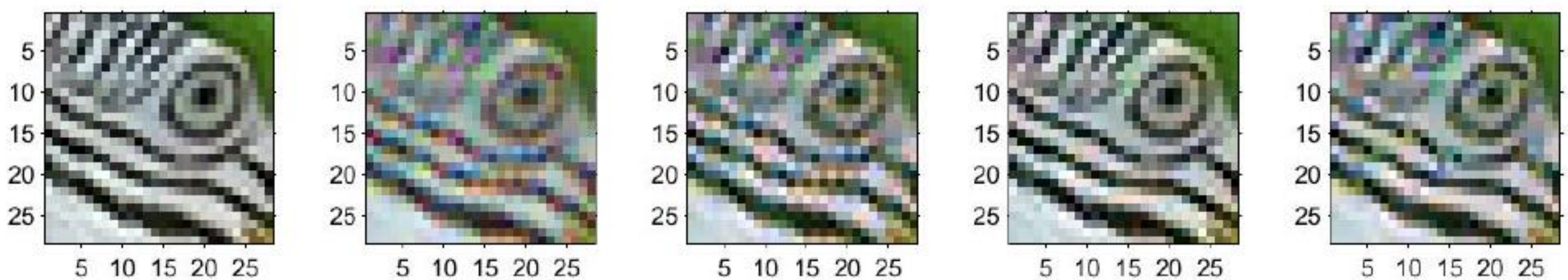


bilinear | Cok | Freeman | LaRoche

Demosaicking CFA (cont.)



Bilinear *Cok* *Freeman* *LaRoche*

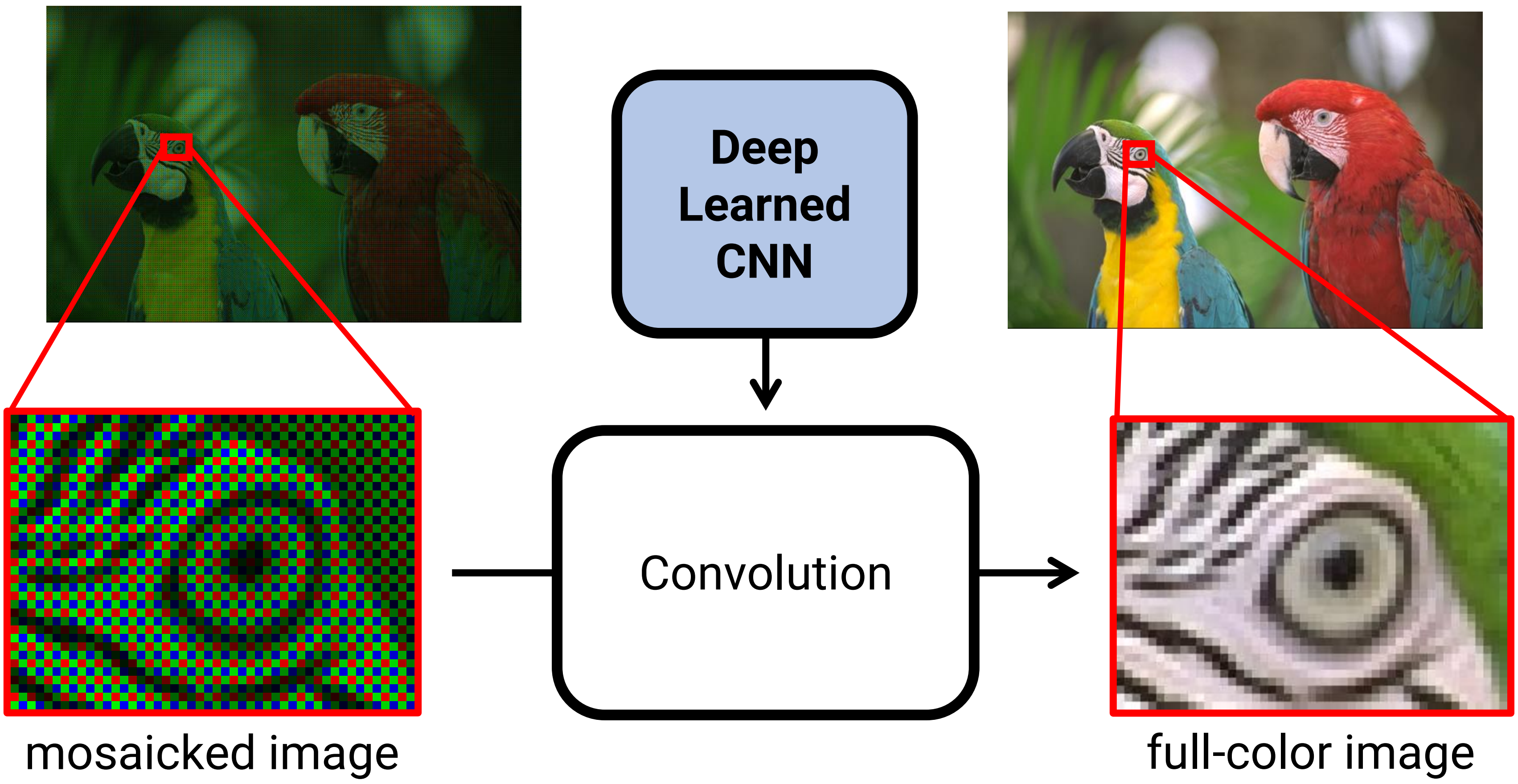


Input *Bilinear* *Cok* *Freeman* *LaRoche*

Generally, Freeman’s is the best, especially for natural images

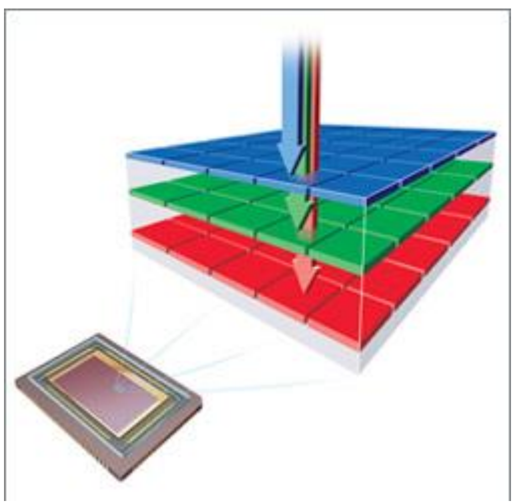
Demosaicking CFA (cont.)

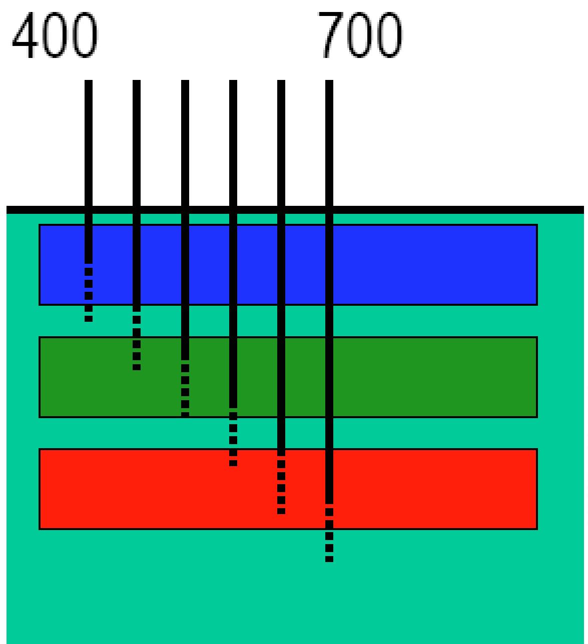
- Deep learning approach

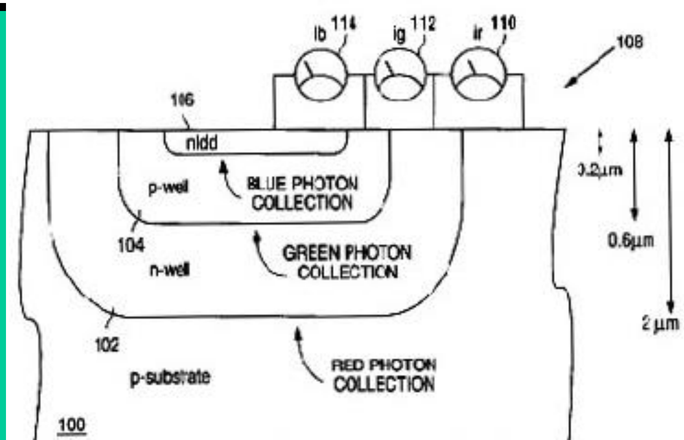


Foveon X3 sensor

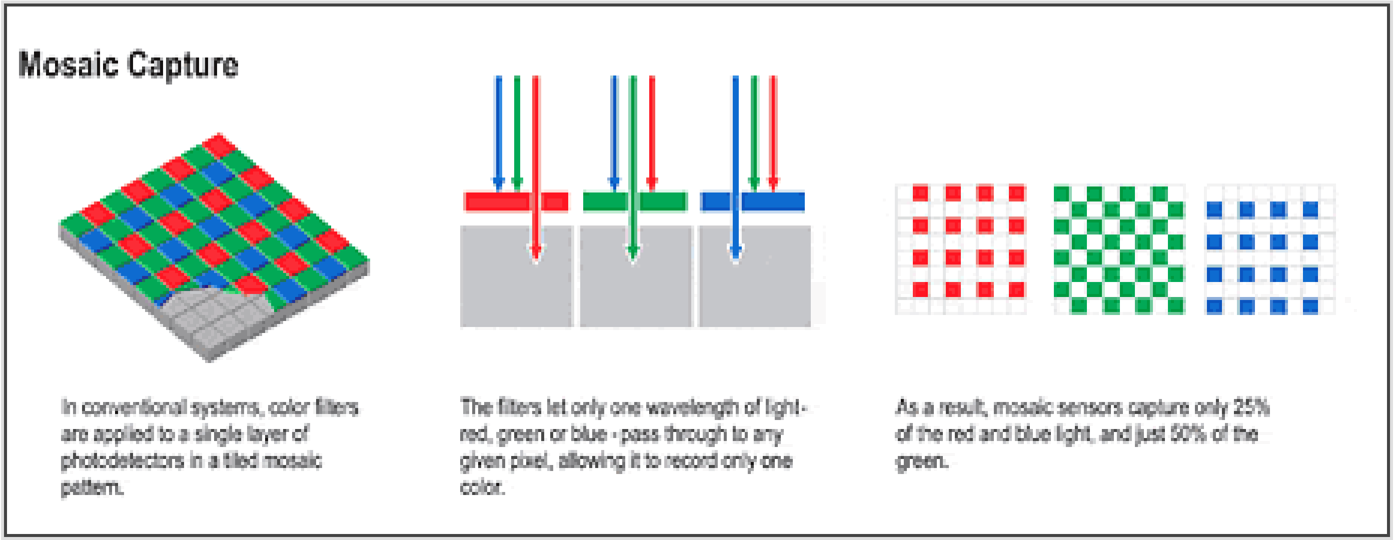
- light penetrates to different depths for different wavelengths
- Multilayer CMOS sensor gets 3 different spectral sensitivities

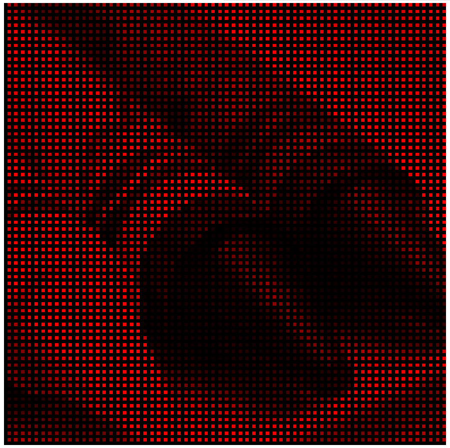


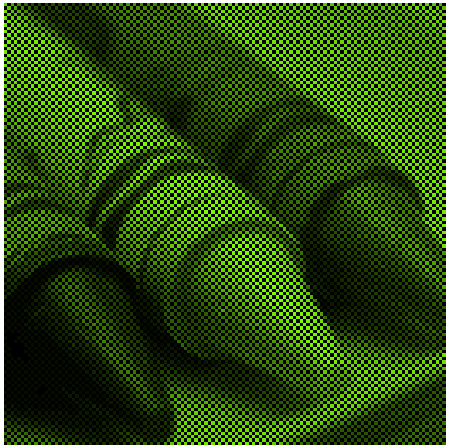


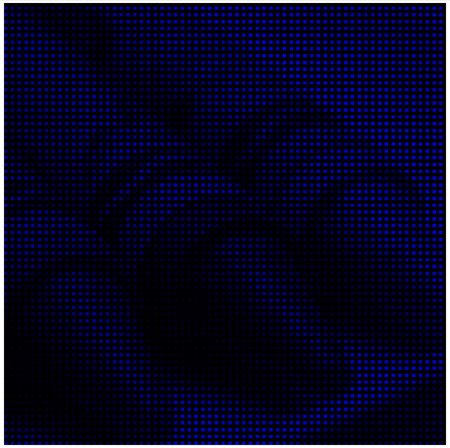


X3 Technology



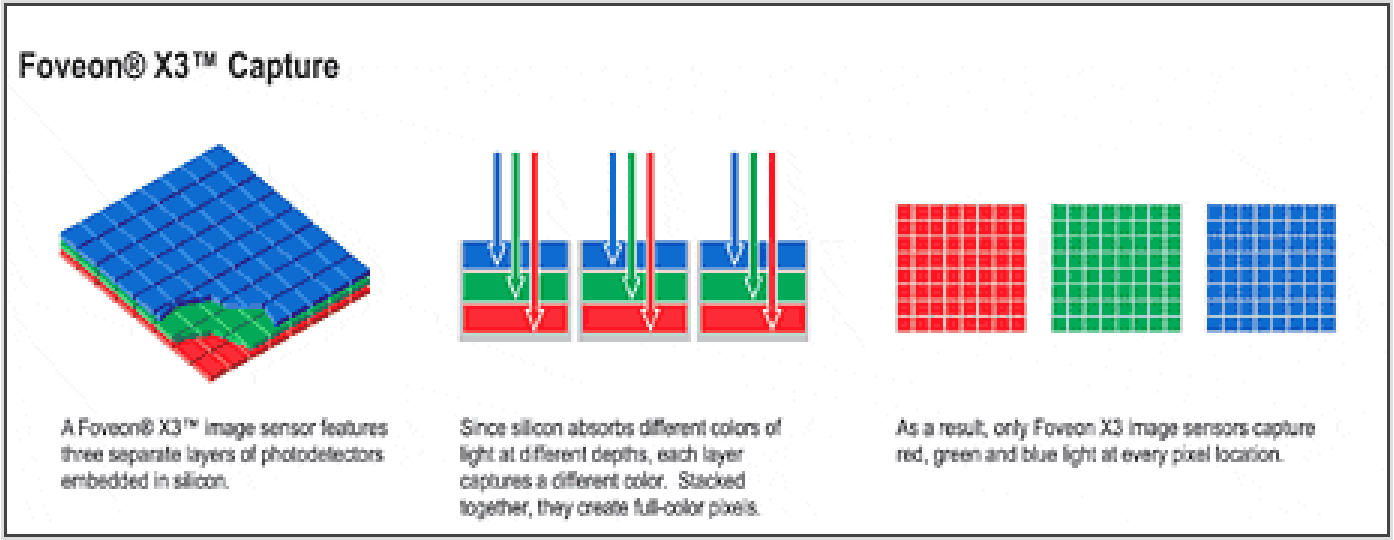

red

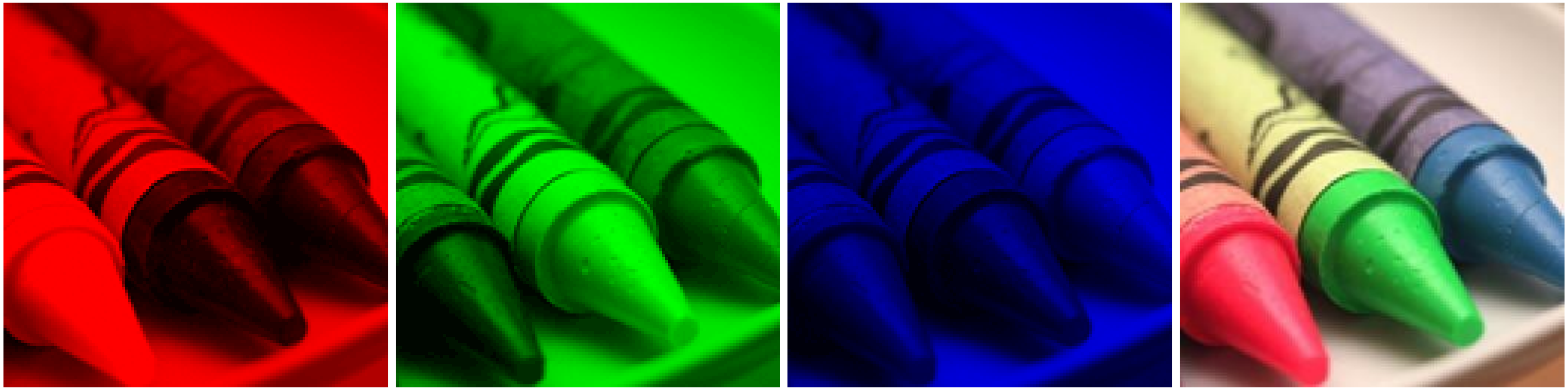

green


blue


output

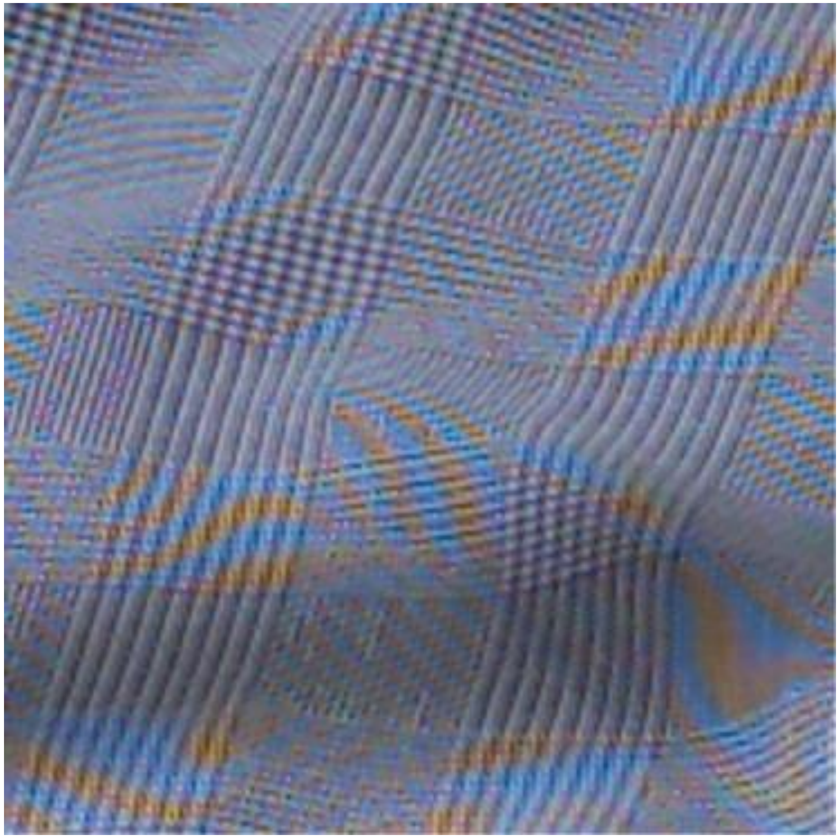
Color Filter Array



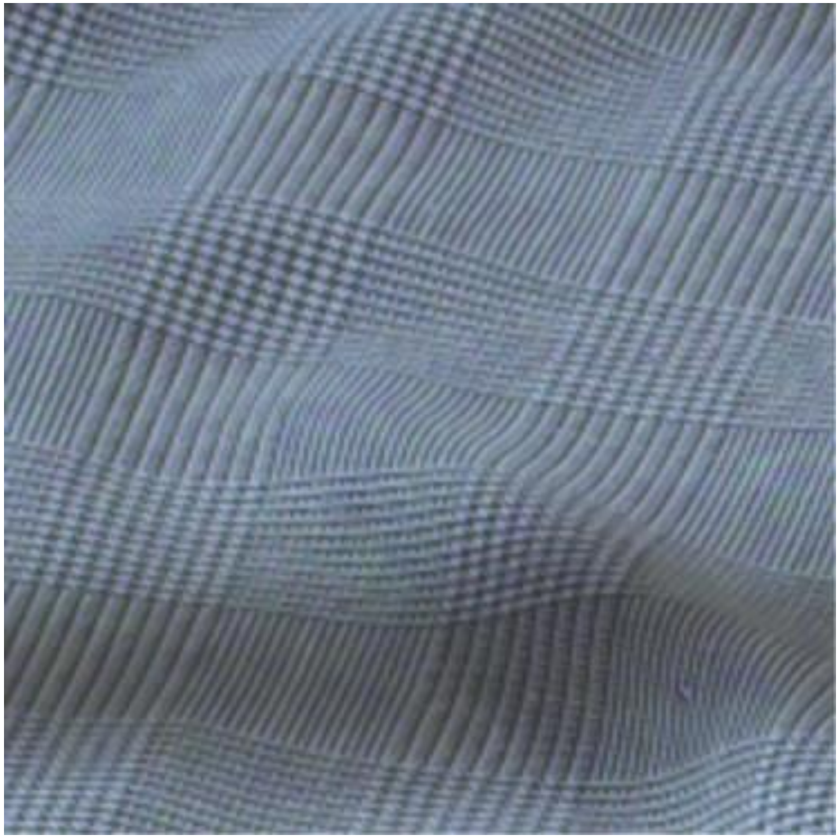


red green blue output

Foveon X3 sensor



Bayer CFA



X3 sensor

Camera with X3

Sigma SD10, SD9

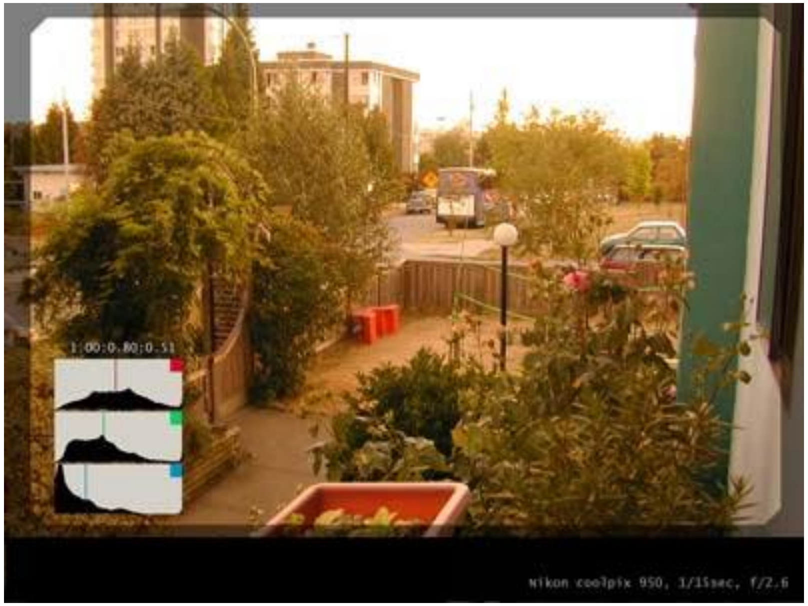
Polaroid X530

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

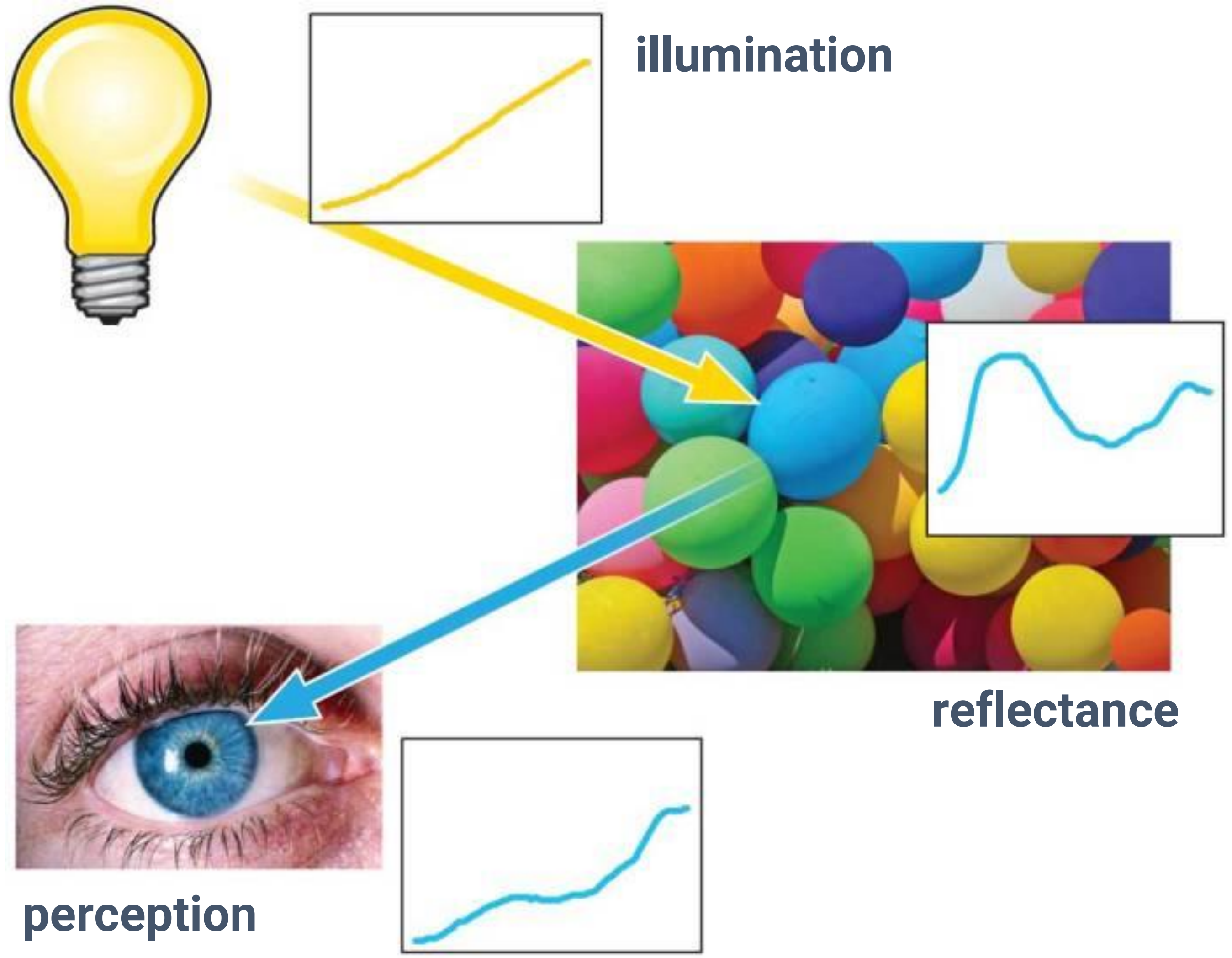
White Balance



warmer +3

automatic white balance

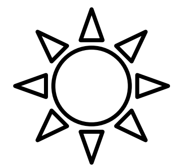
White Balance (cont.)

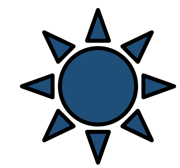


Color Constancy

What color is the dress?

Color Constancy (cont.)

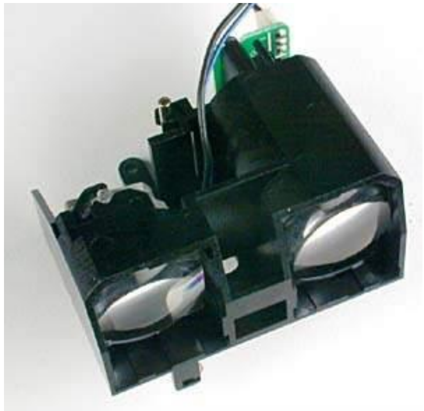


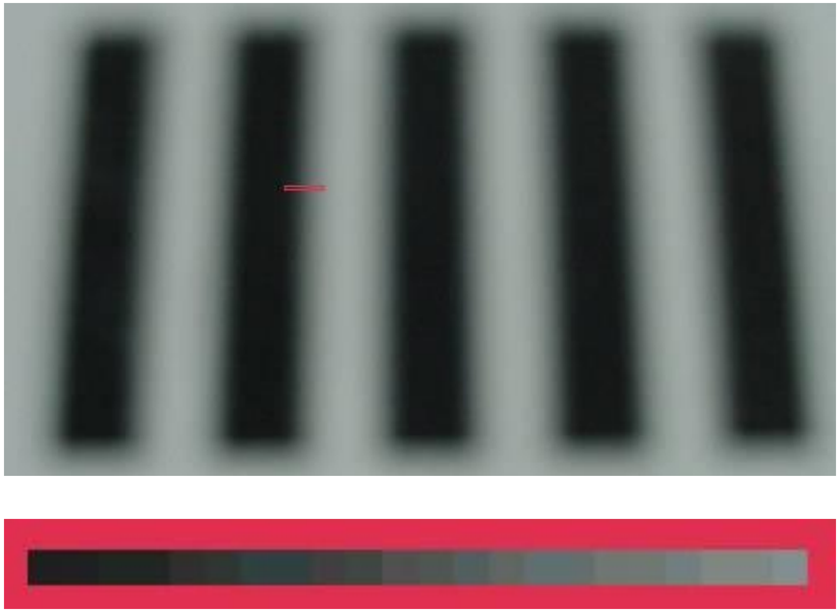


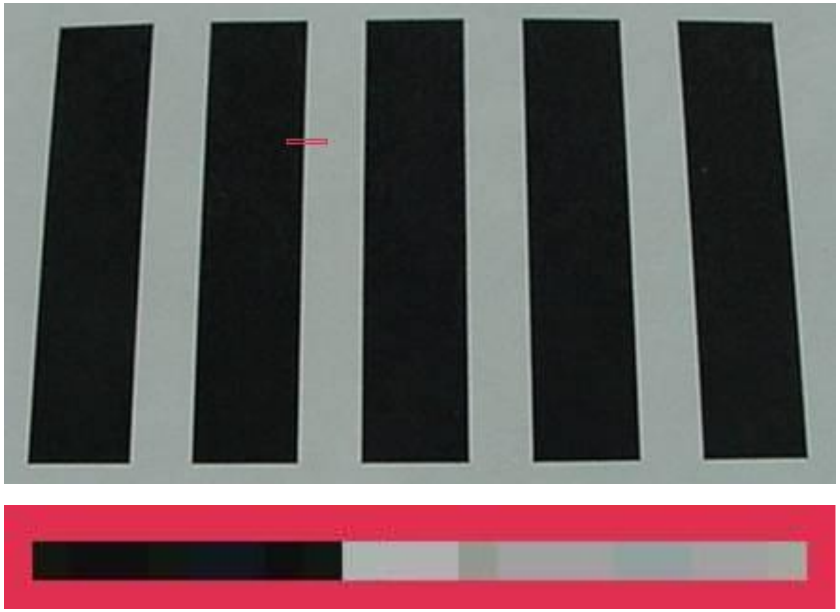
Human Vision is Complex

Autofocus

- Active
  - Sonar
  - Infrared
- Passive



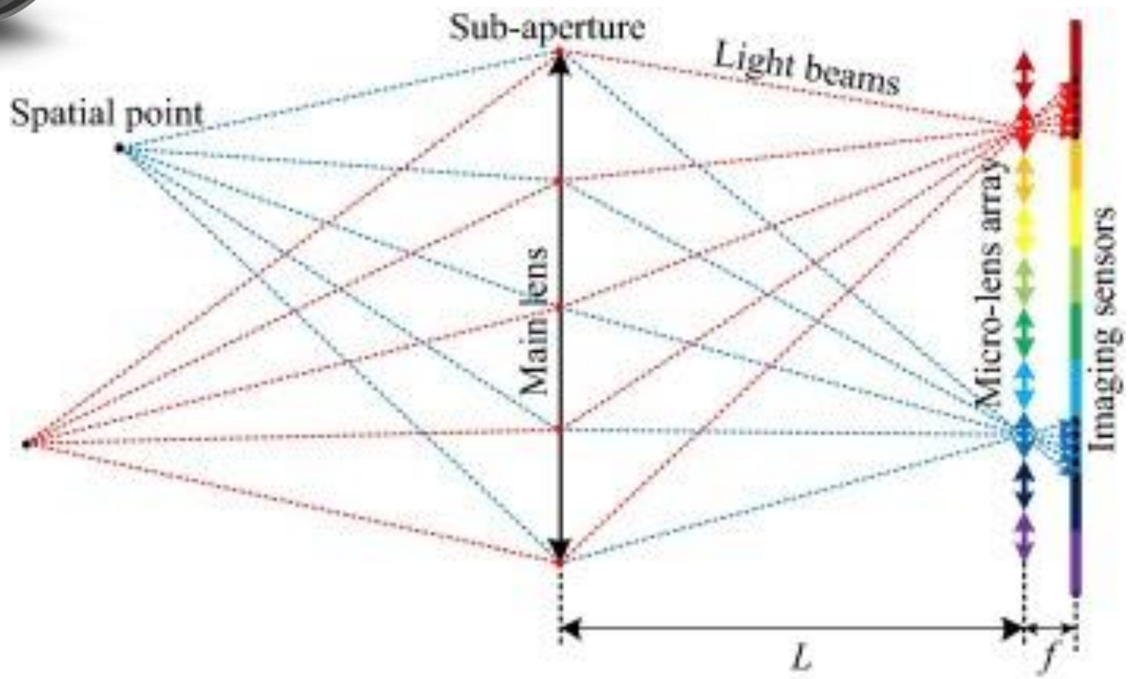




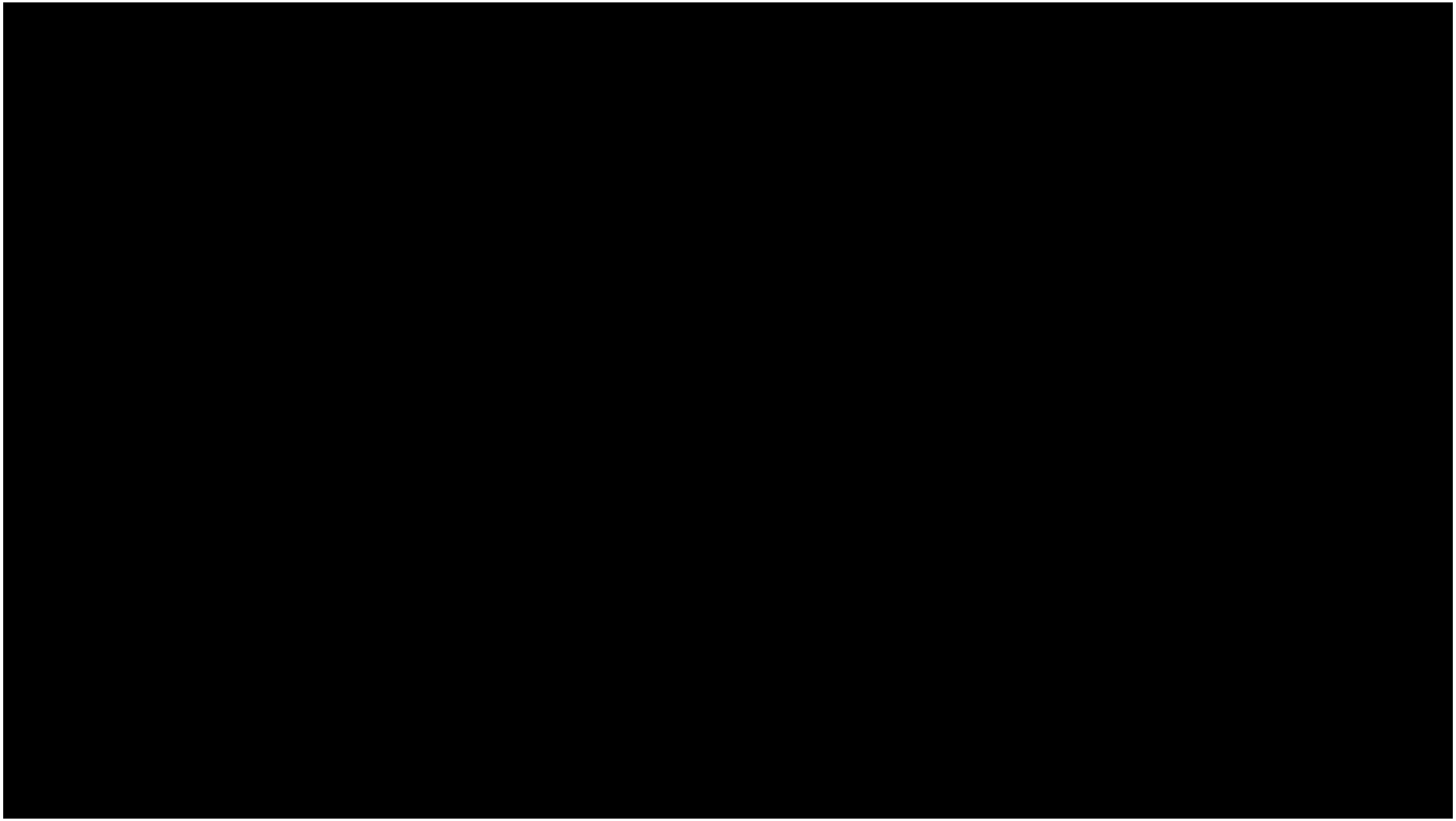
Computational Cameras

Light-field Camera

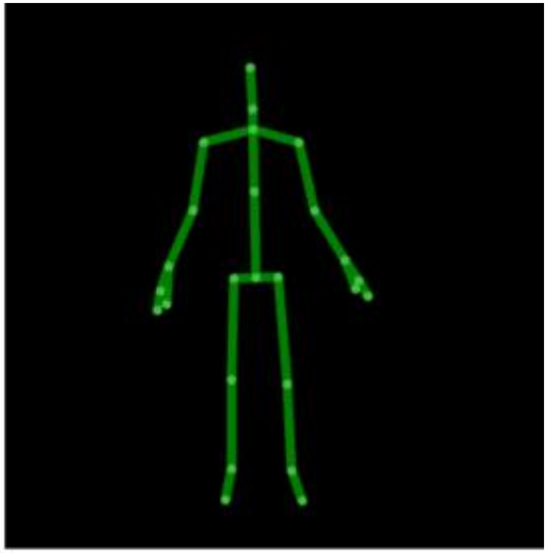
Lytro Illum



Light-field Camera (cont.)



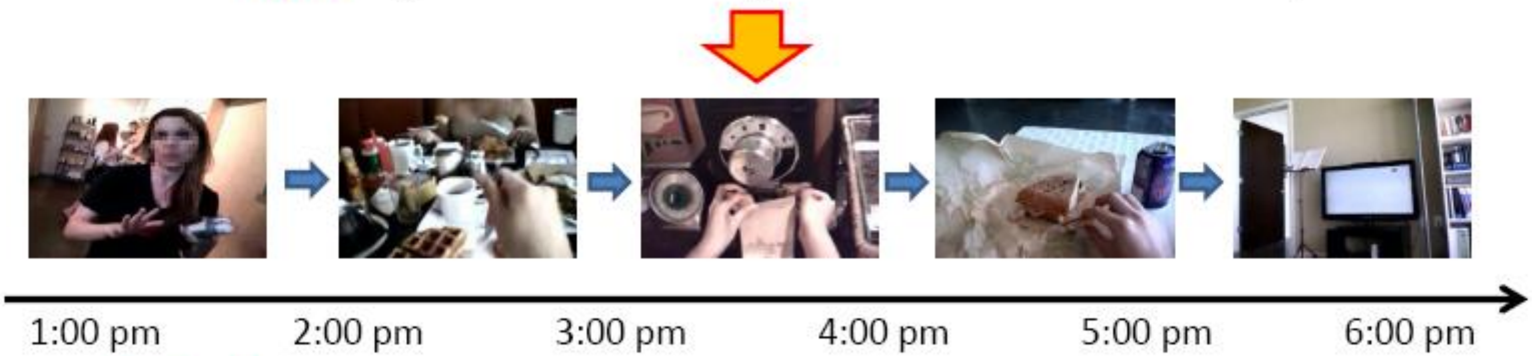
RGB-D Camera



RGB-D Camera

Egocentric (First-Person) Vision

Input: *Egocentric video of the camera wearer's day*



Output: *Storyboard summary of important people and objects*

References

- 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/