



Camera

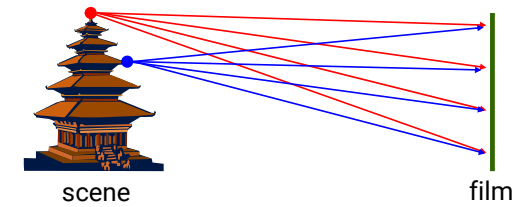
Multimedia Techniques & Applications

Yu-Ting Wu

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

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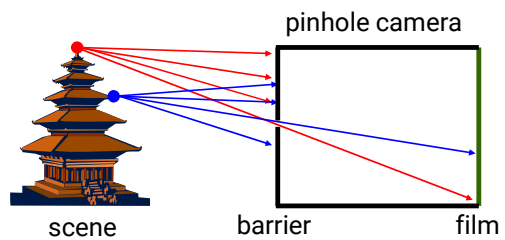
Camera Trial



Put a piece of film in front of an object

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Pinhole Camera

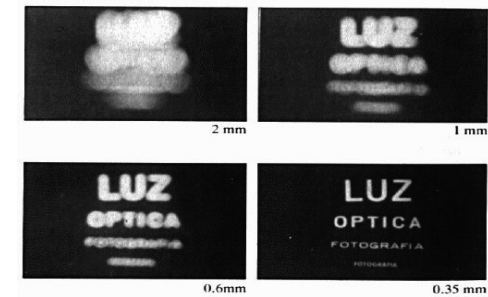


Add a barrier to block off most of the rays

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

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Shrinking the Aperture



Why not making the aperture as small as possible?

- Less light gets through
- Diffraction effect

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Shrinking the Aperture

2 mm 1 mm

0.6 mm 0.35 mm

0.15 mm 0.07 mm

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Adding a Lens

scene lens film

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Lenses

Object Lens Focal Point Image

d_o d_i f

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

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Thin Lens Formula

$y'/y = D'/D$

D' D f y' y

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Thin Lens Formula (cont.)

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

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

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Thin Lens Formula (cont.)

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

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Adding a Lens (cont.)

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

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Zoom Lens

200mm 28mm

Nikon 28-200mm zoom lens.

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Focal Length in Practice

24mm

50mm

135mm

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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

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Problems with Lens (cont.)

- Correcting radial distortion

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Problems with Lens (cont.)

- Vignetting

more light from A than B!

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Problems with Lens (cont.)

- Vignetting

more light from A than B!

original corrected

Goldman & Chen, ICCV 2005

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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.

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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

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Exposure (cont.)

- 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)


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Effect of Shutter Speeds

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


Slow shutter speed




Fast shutter speed




- Faster shutter speed freezes motion




1/125



1/250



1/500



1/1000


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Effect of Shutter Speeds (cont.)

- Light trail




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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)



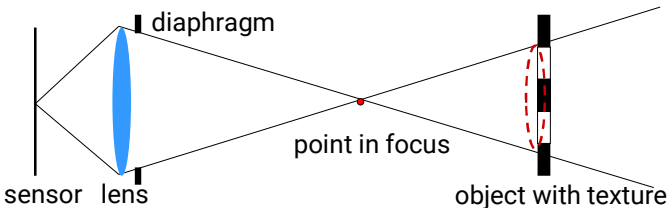
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Depth of Field

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



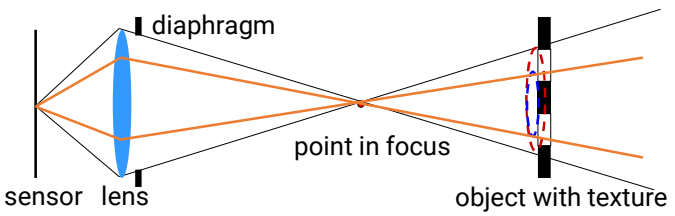
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Depth of Field (cont.)

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



sensor lens diaphragm point in focus object with texture

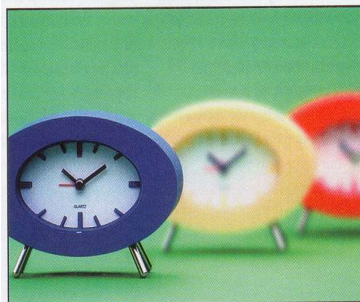
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Depth of Field (cont.)

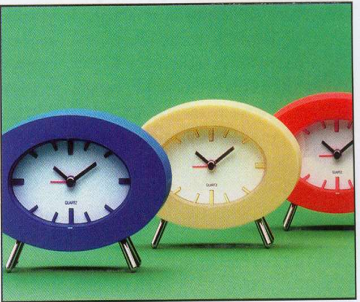
LESS DEPTH OF FIELD




Wider aperture $f/2$



MORE DEPTH OF FIELD



Smaller aperture $f/16$



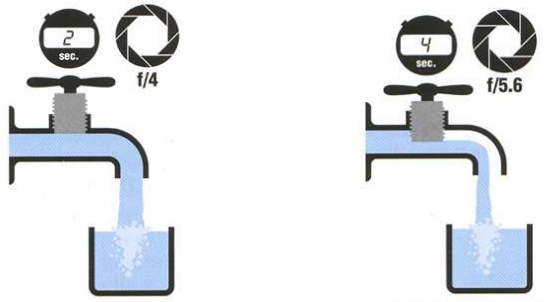
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Aperture and Shutter Speed

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



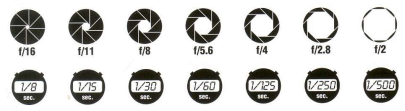
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Aperture and Shutter Speed (cont.)

- 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

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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)

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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


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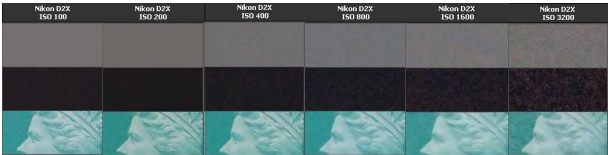
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Sensitivity

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



- Digital photography: trade sensitivity for noise

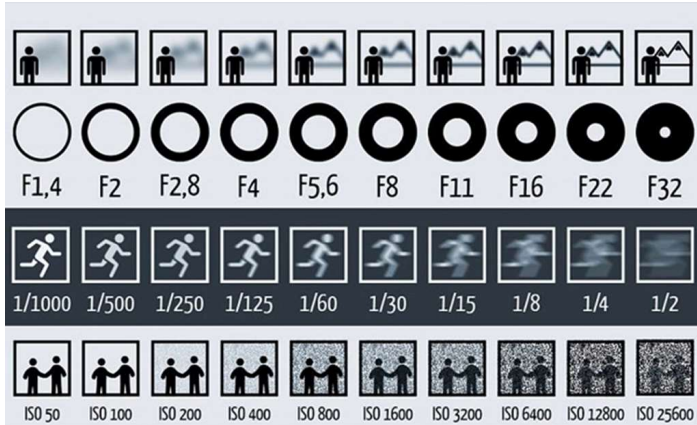


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Shutter Speed, Aperture, and Sensitivity



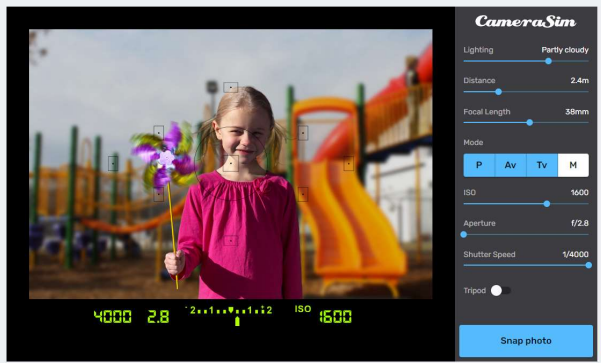
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Demo

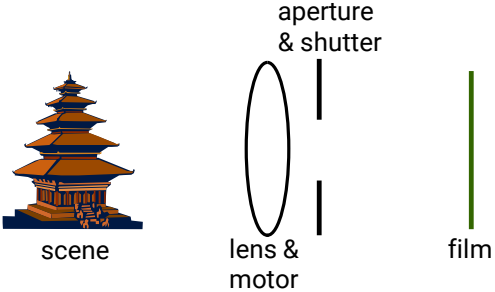
- <https://camerasim.com/camerasim-free-web-app/>



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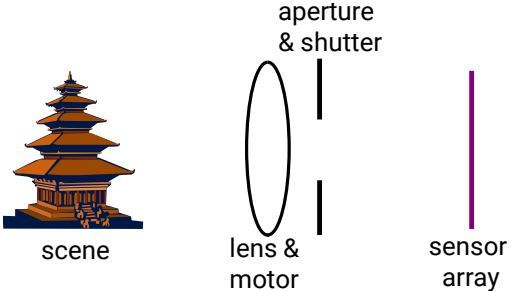
Film Camera



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Digital Camera



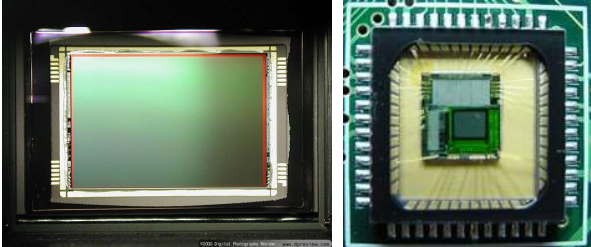
- A digital camera replaces film with a sensor array
- Each cell in the array is a light-sensitive diode that converts photons to electrons

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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



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SLR (Single-Lens Reflex)

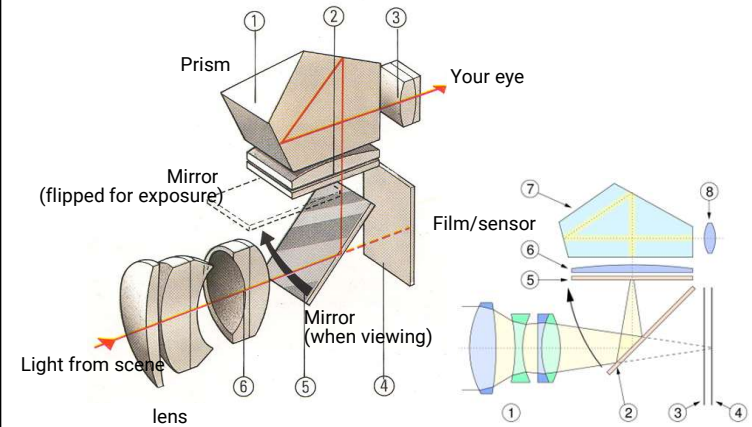
- Reflex (R in SLR) means that we see through the same lens used to take the image.
- Not the case for compact cameras



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SLR View Finder



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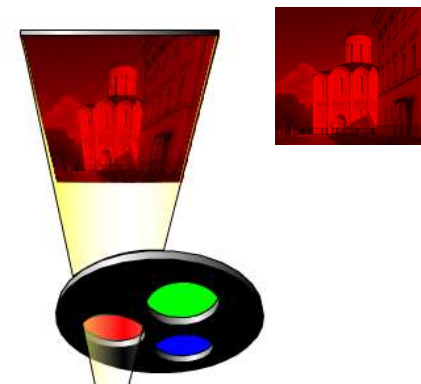
Color

- 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

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Field Sequential



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Field Sequential (cont.)

A diagram of a field sequential projector. It features a funnel-shaped lens assembly with three colored filters: green, red, and blue. Below the lens is a circular base with three corresponding colored filters. To the right, three images of a church are shown, each filtered with one of the colors (green, red, green). The top image is green, the middle is red, and the bottom is green.

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Field Sequential (cont.)

A diagram of a field sequential projector. It features a funnel-shaped lens assembly with three colored filters: blue, red, and green. Below the lens is a circular base with three corresponding colored filters. To the right, three images of a church are shown, each filtered with one of the colors (blue, red, blue). To the right of these is a full-color image of the church.

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Prokudin-Gorskii (early 1900's)

lantern projector

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

A collection of historical images. On the left, three small images of a man in a white, patterned coat sitting on a floor, each with a different colored border (red, green, blue). In the center, a photograph of a man in a blue and gold patterned coat sitting on a wooden floor. To the right of the small images is a photograph of a lantern projector. Below the images is a URL.

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Prokudin-Gorskii (early 1900's)

A collection of historical images. On the left, a black and white photograph of a man on a raft. On the right, a color photograph of the same man on the raft, with a rainbow overlay on the water.

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Multi-chip

wavelength dependent

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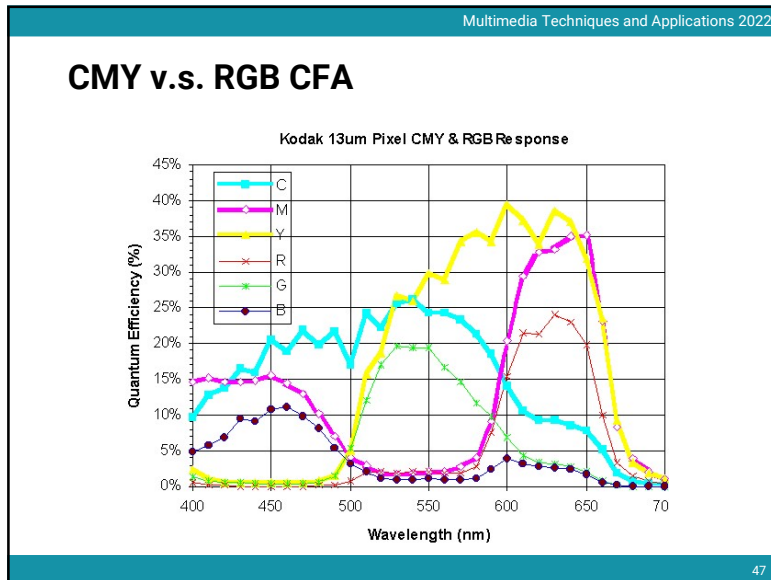
Color Filter Array

- Color filter arrays (CFAs) / color filter mosaics

Kodak DCS620x

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Color Filter Array (cont.)

- Color filter arrays (CFAs) / color filter mosaics

Bayer pattern

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Bayer's Pattern

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Demosaicking CFA

bilinear interpolation

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

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

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

original input linear interpolation

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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

Constant hue-based interpolation (Cok)

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

Interpolate G first

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

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

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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

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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)

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Demosaicking CFA (cont.)

Gradient-based interpolation (LaRoche-Prescott)

- Interpolation on G

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

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

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

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Demosaicking CFA (cont.)

Gradient-based interpolation (LaRoche-Prescott)

- Interpolation of color differences

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

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

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

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Demosaicking CFA (cont.)

bilinear Cok Freeman LaRoche

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Demosaicking CFA (cont.)

Bilinear *Cok* *Freeman* *LaRoche*

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

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

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Demosaicking CFA (cont.)

- Deep learning approach

mosaicked image → Deep Learned CNN → Convolution → full-color image

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Foveon X3 sensor

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

400 700

red green blue output

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X3 Technology

red green blue output

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Color Filter Array

Foveon® X3™ Capture

A Foveon® X3™ image sensor features three separate layers of photodiodes 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

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Foveon X3 sensor

Bayer CFA X3 sensor

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Camera with X3

Sigma SD10, SD9 Polaroid X530

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Sigma SD9 vs Canon D30

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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

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White Balance



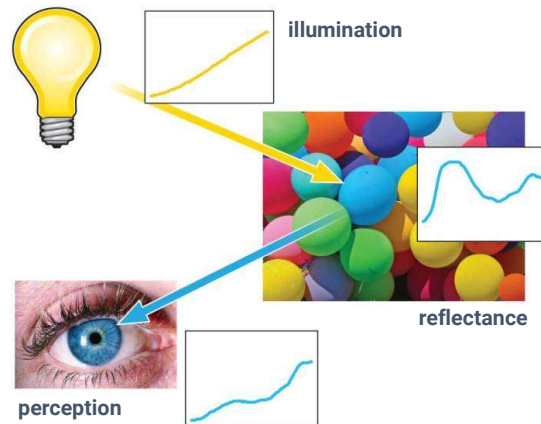
warmer +3

automatic white balance

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White Balance (cont.)



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Color Constancy



What color is the dress?

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Color Constancy (cont.)

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Human Vision is Complex

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Autofocus

- Active
 - Sonar
 - Infrared
- Passive

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Computational Cameras

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Light-field Camera



Lytro Illum

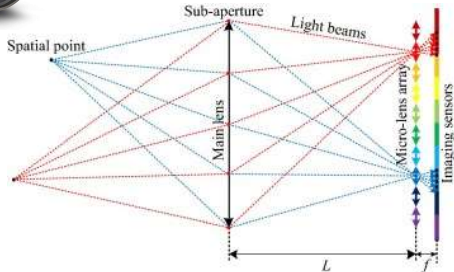


Diagram illustrating the light-field camera principle. A spatial point emits light rays that pass through a main lens, a sub-aperture, and a micro-lens array, eventually reaching imaging sensors. The distance between the main lens and the micro-lens array is labeled L , and the distance between the micro-lens array and the imaging sensors is labeled f .

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Light-field Camera (cont.)



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RGB-D Camera







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RGB-D Camera



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Egocentric (First-Person) Vision



Input: Egocentric video of the camera wearer's day



Output: Storyboard summary of important people and objects

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