Image Formation III
Chapter 1 (Forsyth&Ponce)
Cameras "*Lenses & Sensors*"

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CS-GY 6643, Spring 2017

(slides modified from Marc Pollefeys, UNC Chapel Hill/ ETH Zurich,
With content from Prof. Trevor Darrel, Berkeley

Pinhole size / aperture

How does the size of the aperture affect the image we'd get?

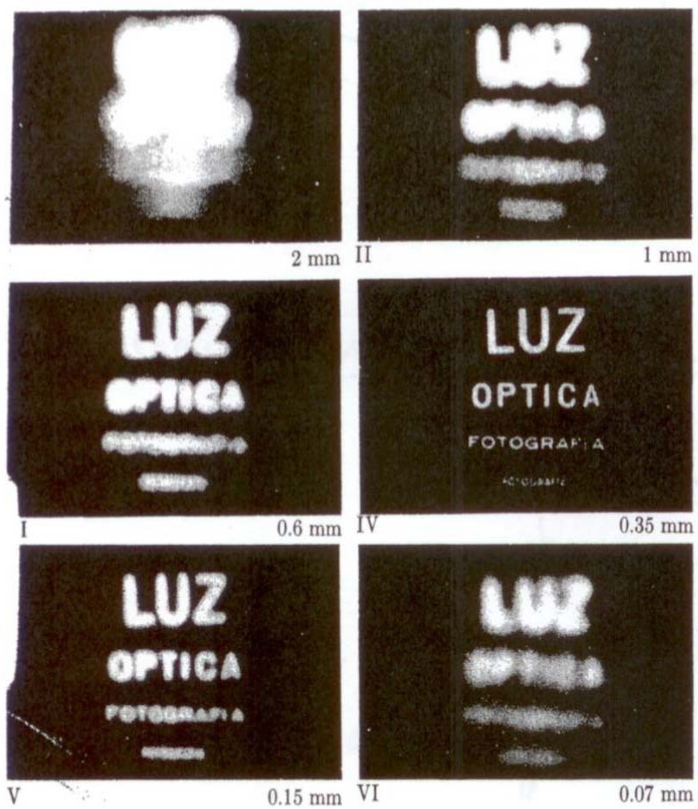
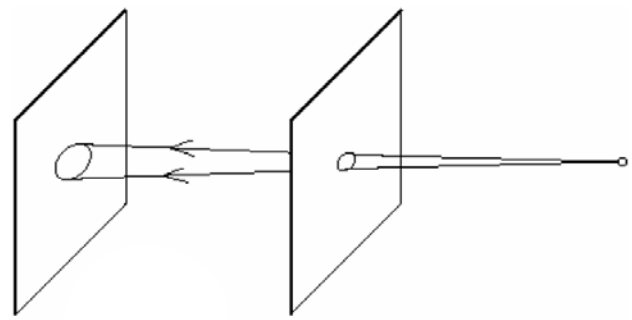


Fig. 5.96 The pinhole camera. Note the variation in image clarity as the hole diameter decreases. [Photos courtesy Dr. N. Joel, UNESCO.]

Larger

Smaller



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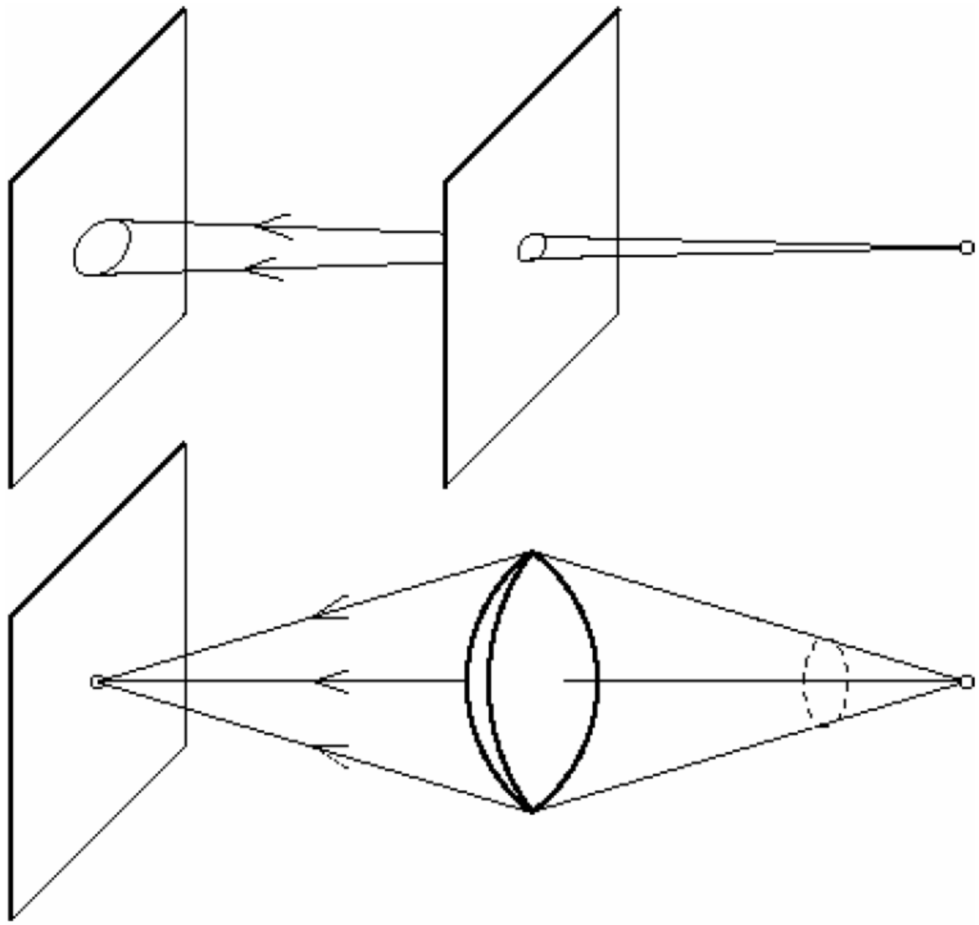
Pinhole vs. lens



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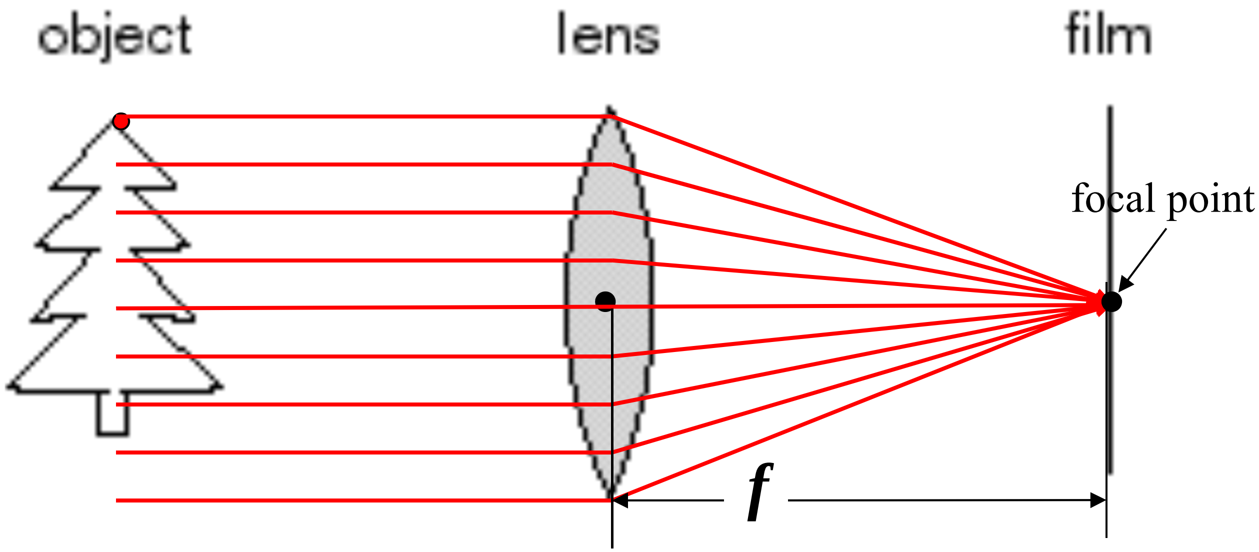
Adding a lens



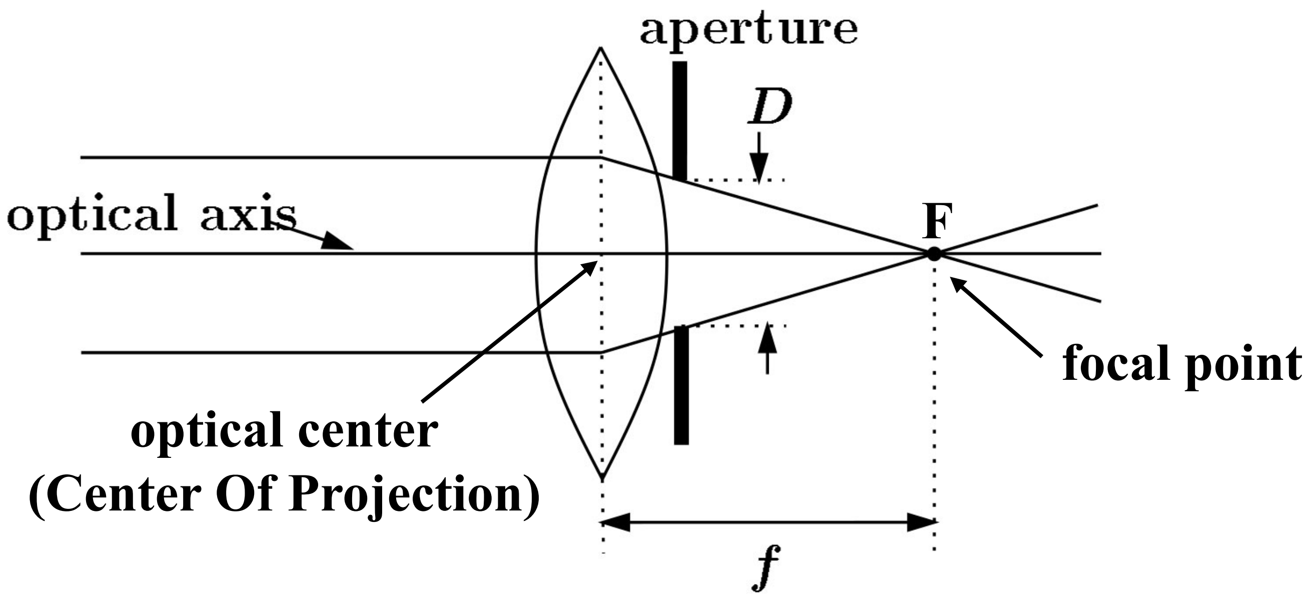
A lens focuses light onto the film

– Rays passing through the center are not deviated

– All parallel rays converge to one point on a plane located at the *focal length f*

Slide by Steve Seitz

Cameras with lenses

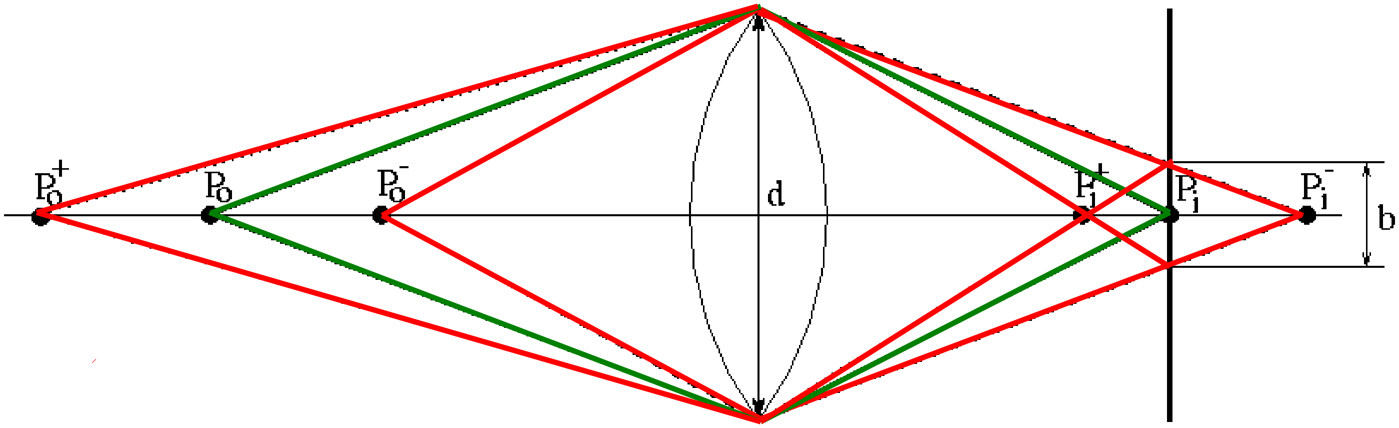


- A lens focuses parallel rays onto a single focal point
- Gather more light, while keeping focus; make pinhole perspective projection practical

Focus and depth of field

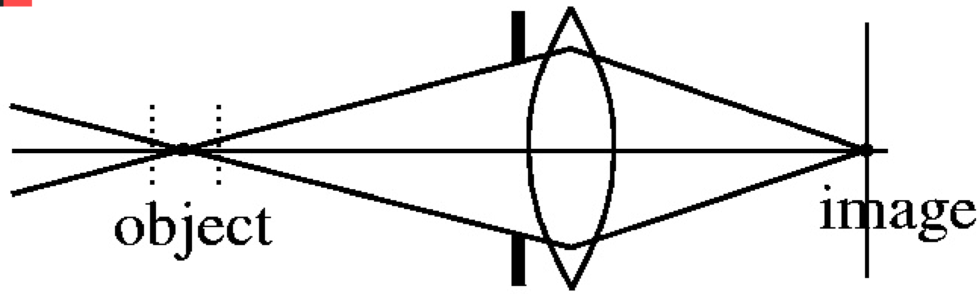
Image credit: cambridgeincolour.com

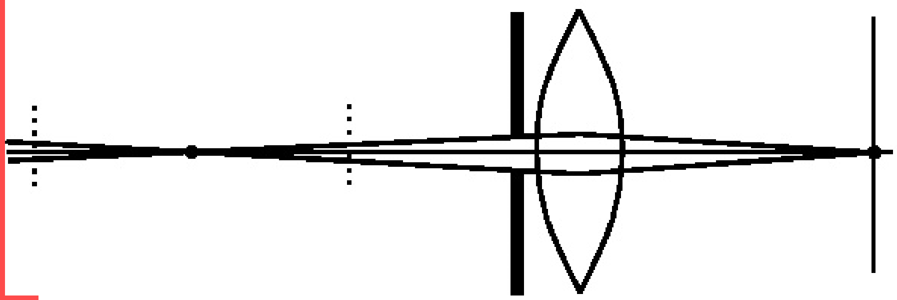
The depth-of-field



Focus and depth of field

- How does the aperture affect the depth of field?





- A smaller aperture increases the range in which the object is approximately in focus

Flower images from Wikipedia http://en.wikipedia.org/wiki/Depth_of_field

Slide from S. Seitz

Field of view

- Angular measure of portion of 3d space seen by the camera

28 mm lens, 65.5° × 46.4°

50 mm lens, 39.6° × 27.0°

70 mm lens, 28.9° × 19.5°

210 mm lens, 9.8° × 6.5°

Images from http://en.wikipedia.org/wiki/Angle_of_view

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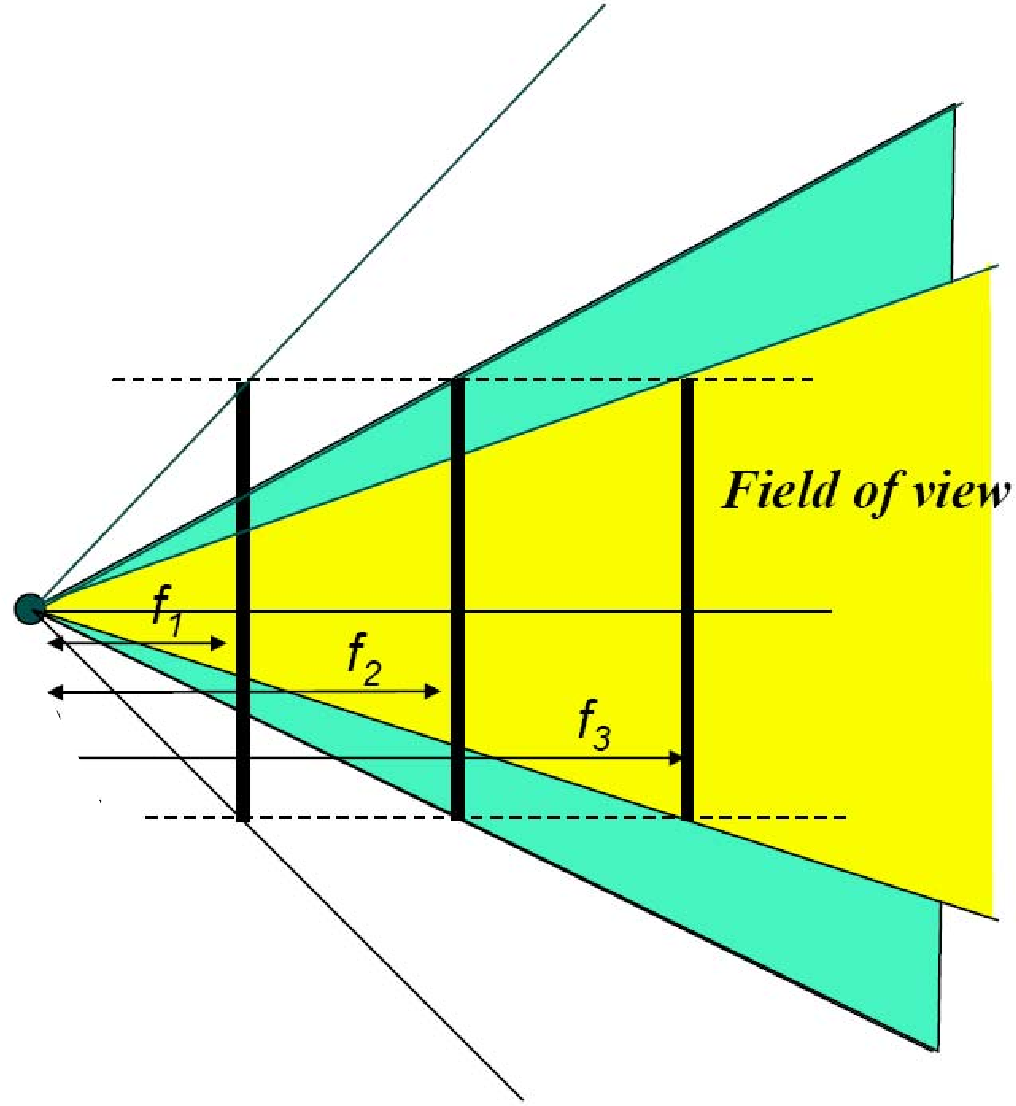
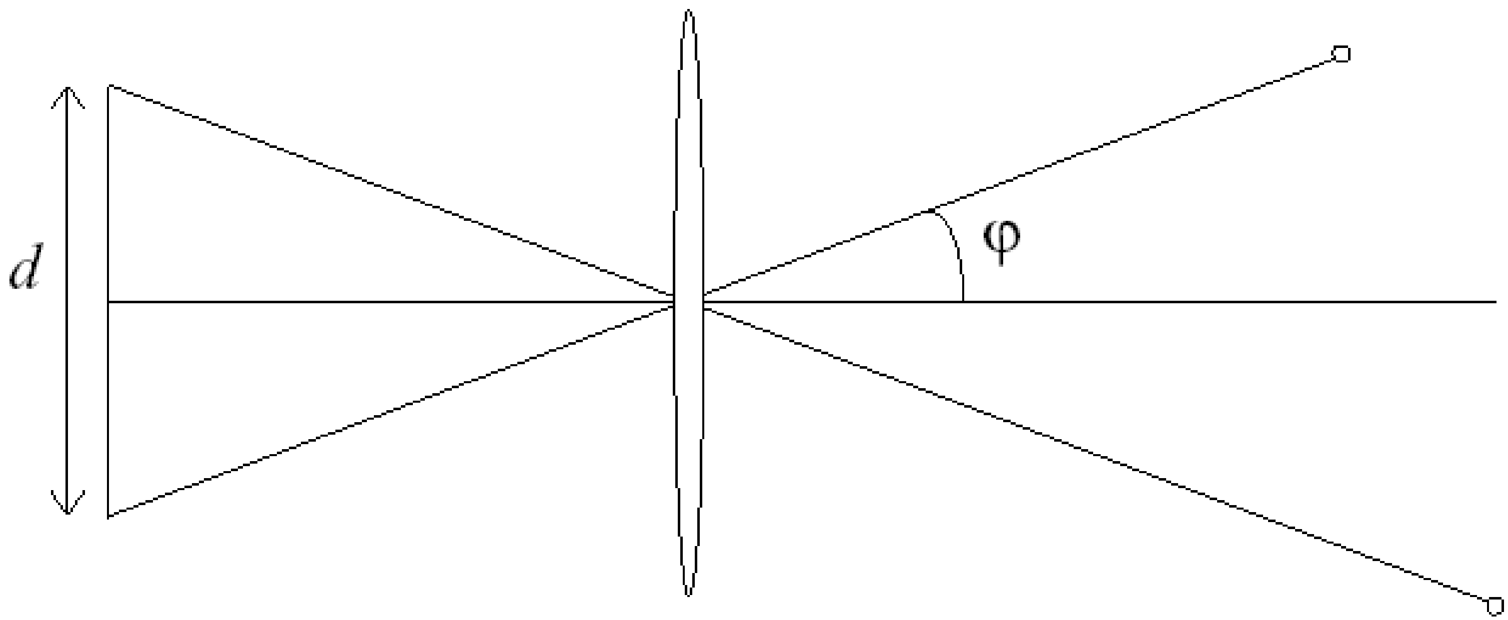
Field of view depends on focal length

- As ***f*** gets smaller, image becomes more *wide angle*
  - more world points project onto the finite image plane
- As ***f*** gets larger, image becomes more *telescopic*
  - smaller part of the world projects onto the finite image plane



from R. Duraiswami

Field of view depends on focal length

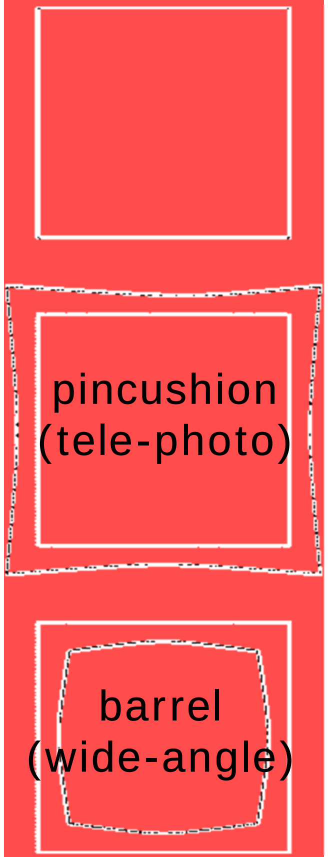


Size of field of view governed by size of the camera retina:

$$\varphi = \tan^{-1}\left(\frac{d}{2f}\right)$$

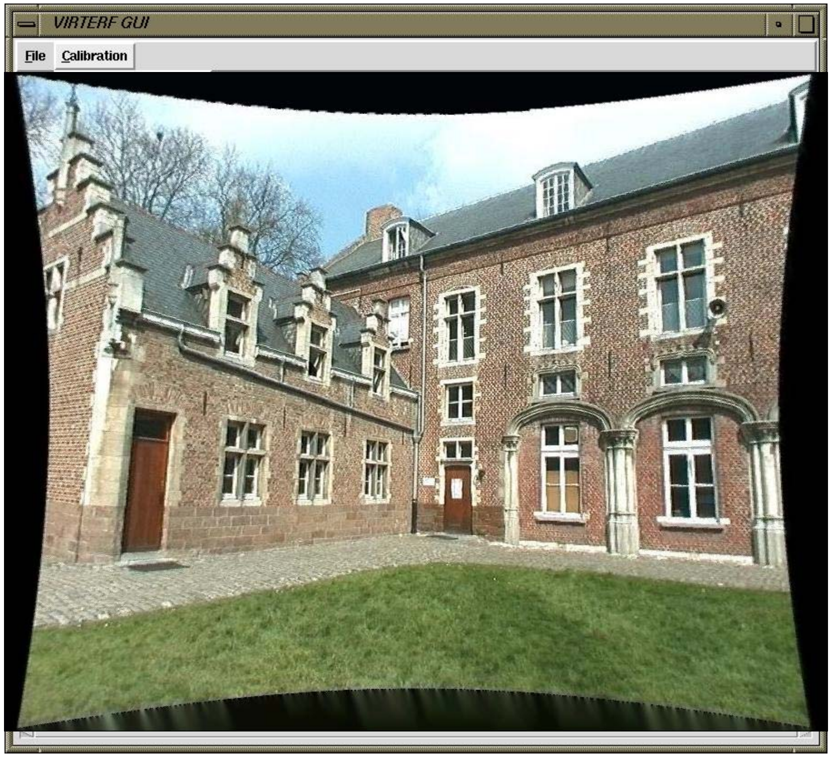
Smaller FOV = larger Focal Length

Slide by A. Efros



Distortion

magnification/focal length different for different angles of inclination



Can be corrected! (if parameters are know)

Chromatic aberration

rays of different wavelengths focused in different planes

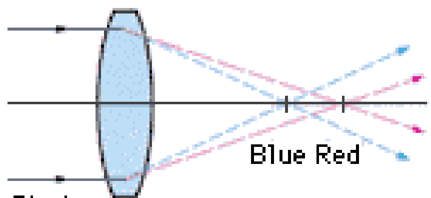


Fig.1
Axial chromatic aderration

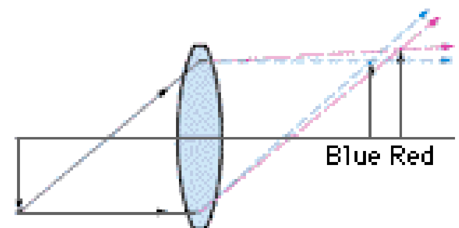
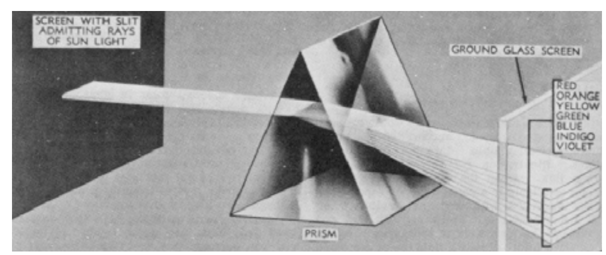


Fig.2
Magnification chromatic aderration

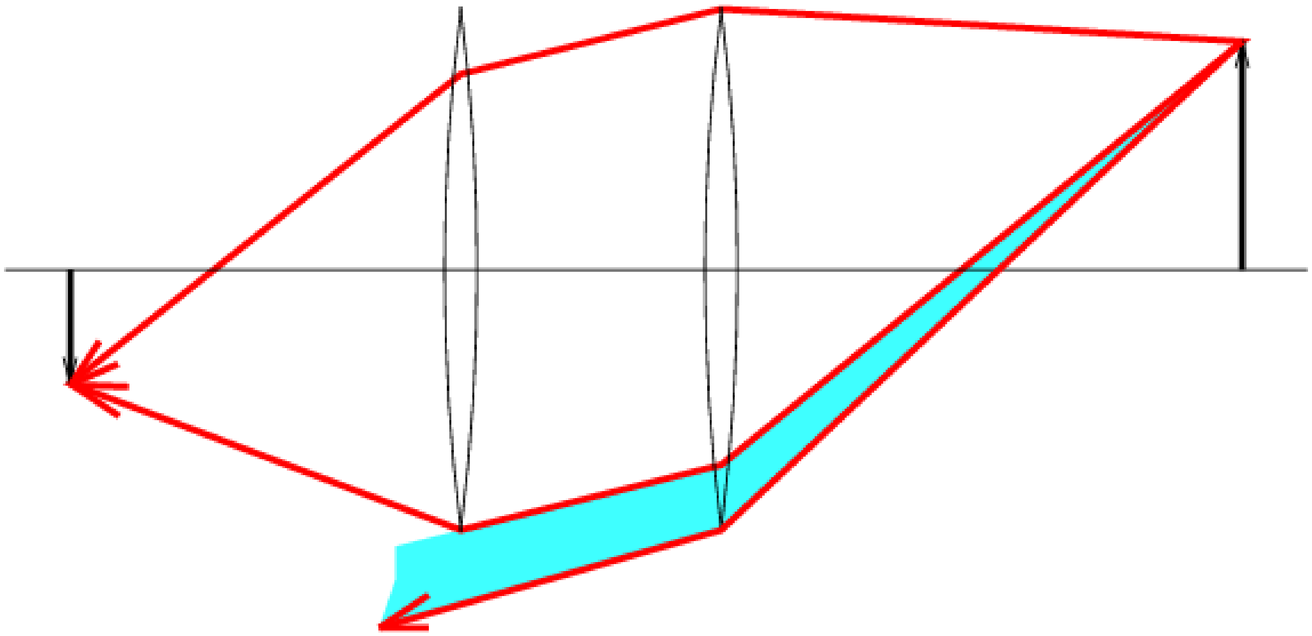
The image is blurred and appears colored at the fringe.

cannot be removed completely

sometimes *achromatization* is achieved for more than 2 wavelengths



Vignetting

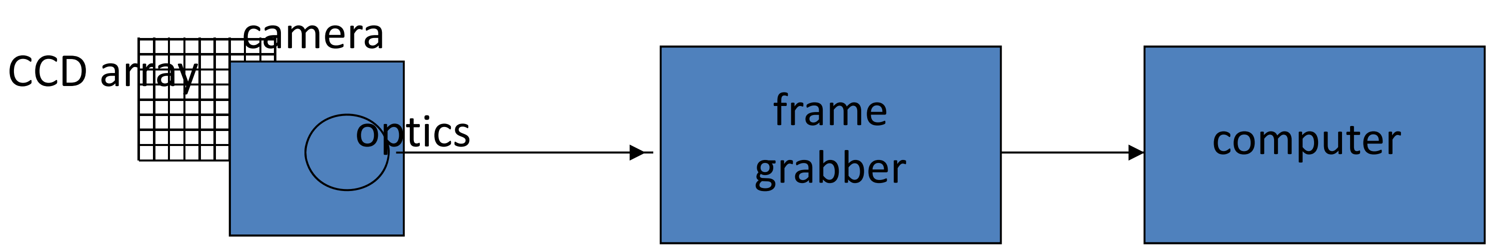


Physical parameters of image formation

- Geometric
  - Type of projection
  - Camera pose
- Optical
  - Sensor’s lens type
  - focal length, field of view, aperture
- Photometric
  - Type, direction, intensity of light reaching sensor
  - Surfaces’ reflectance properties
- Sensor
  - sampling, etc.

Digital cameras

- Film → sensor array
- Often an array of charge coupled devices
- Each CCD is light sensitive diode that converts photons (light energy) to electrons



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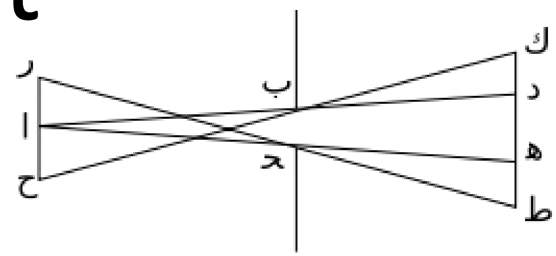
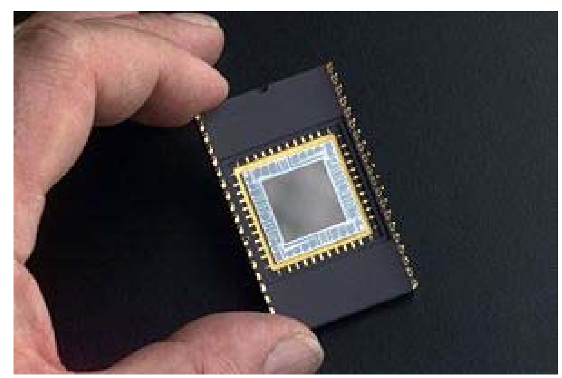
Historical context

- **Pinhole model:** Mozi (470-390 BCE), Aristotle (384-322 BCE)
- **Principles of optics (including lenses):** Alhacen (965-1039 CE)
- **Camera obscura:** Leonardo da Vinci (1452-1519), Johann Zahn (1631-1707)
- **First photo:** Joseph Nicephore Niepce (1822)
- **Daguerréotypes** (1839)
- **Photographic film** (Eastman, 1889)
- **Cinema** (Lumière Brothers, 1895)
- **Color Photography** (Lumière Brothers, 1908)
- **Television** (Baird, Farnsworth, Zworykin, 1920s)
- **First consumer camera with CCD**: Sony Mavica (1981)
- **First fully digital camera:** Kodak DCS100 (1990)



Alhacen's notes

Niepce, "La Table Servie," 1822



CCD chip

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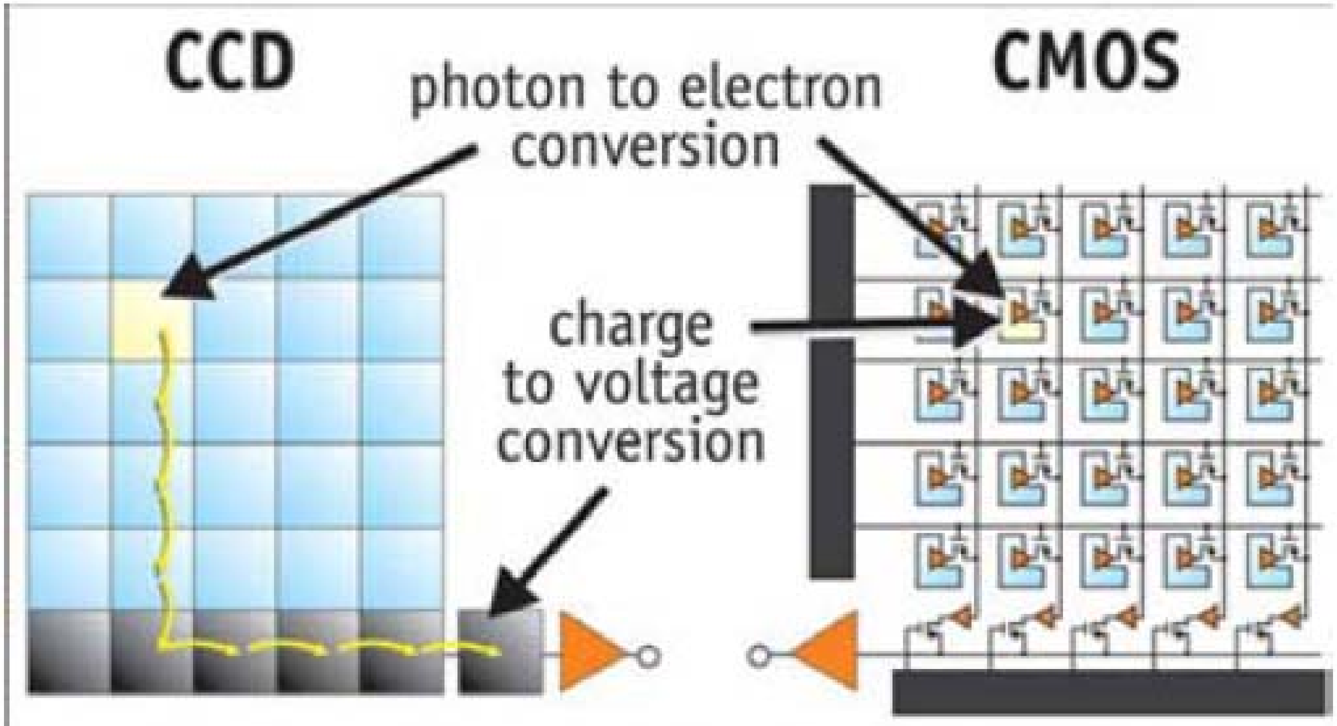
Slide credit: L. Lazebnik

Digital Sensors



CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

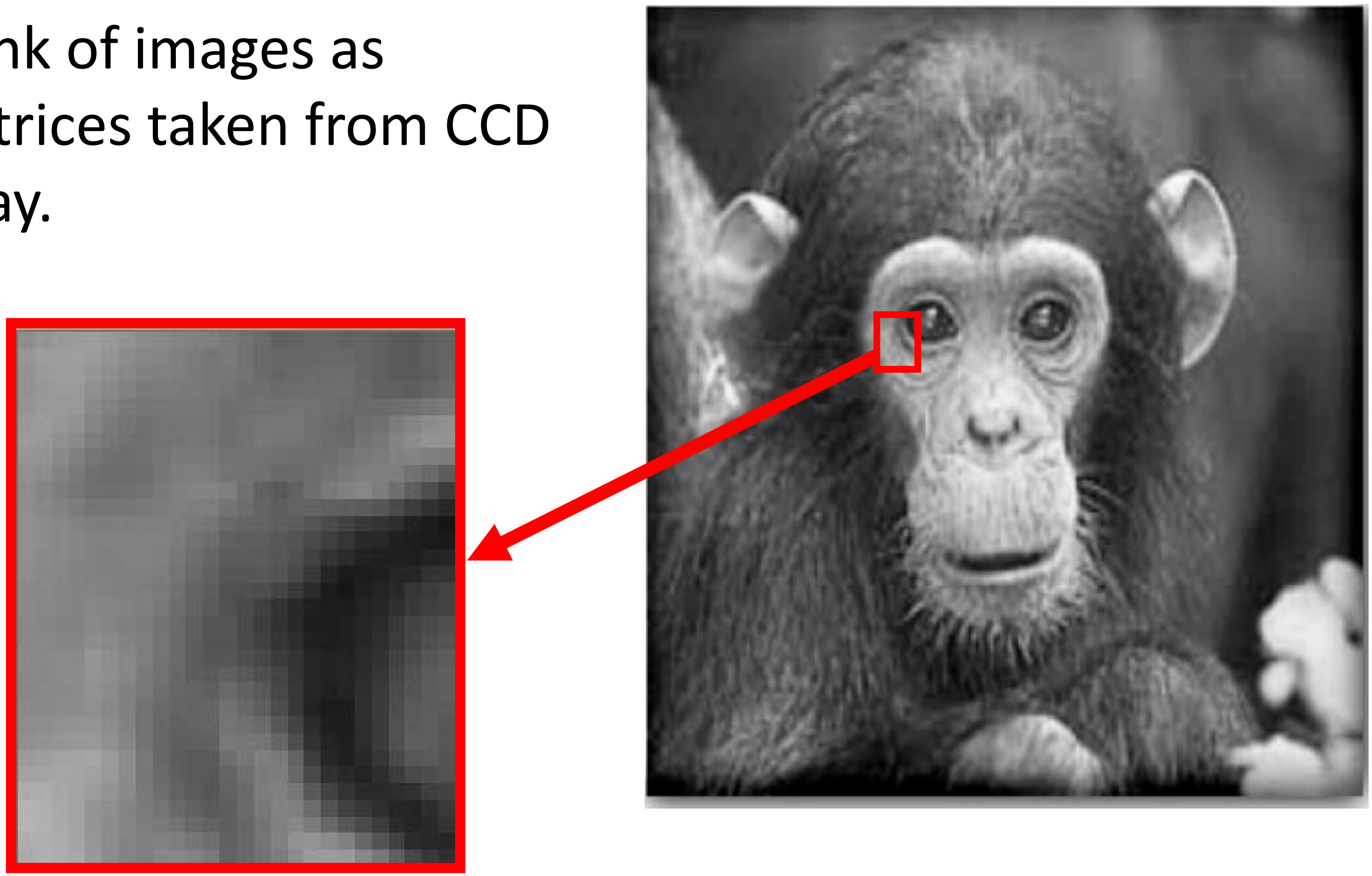
Resolution

- sensor: size of real world scene element that images to a single pixel
- image: number of pixels
- Influences what analysis is feasible, affects best representation choice.

[fig from Mori et al]

Digital images

Think of images as matrices taken from CCD array.



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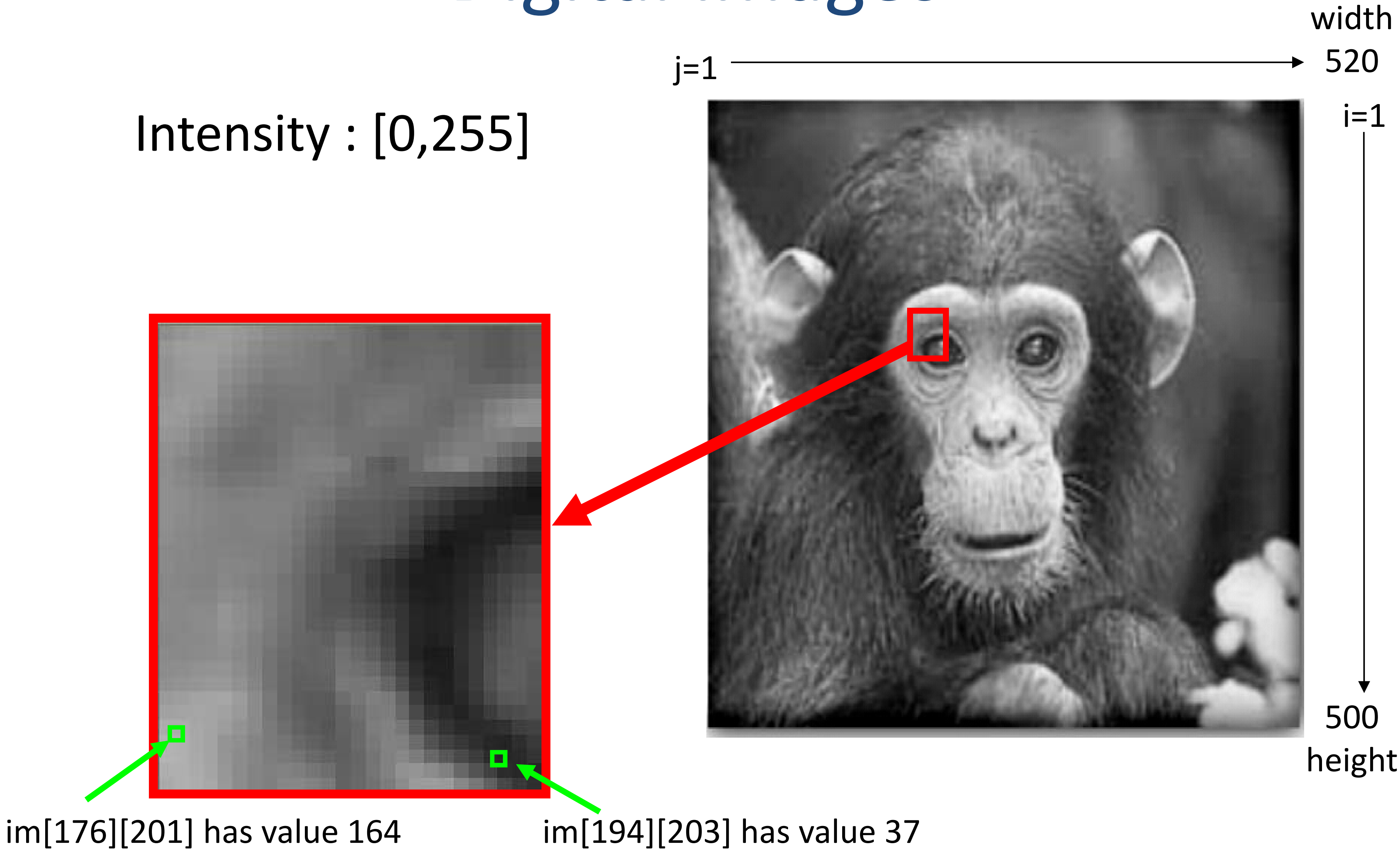
Digital images

Intensity : [0,255]



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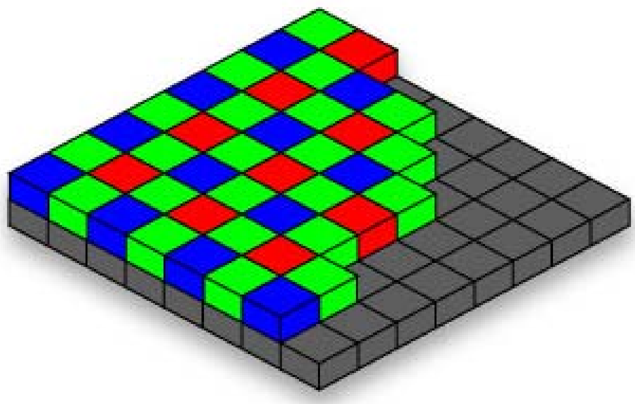
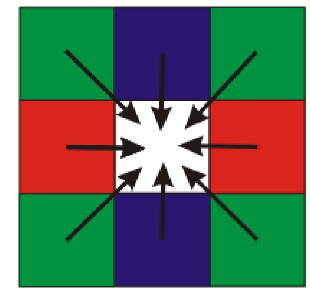
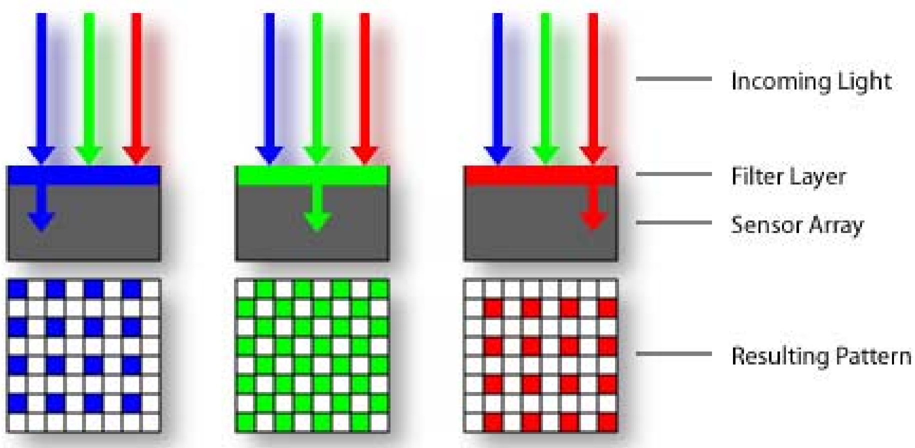
Color sensing in digital cameras

Bayer grid



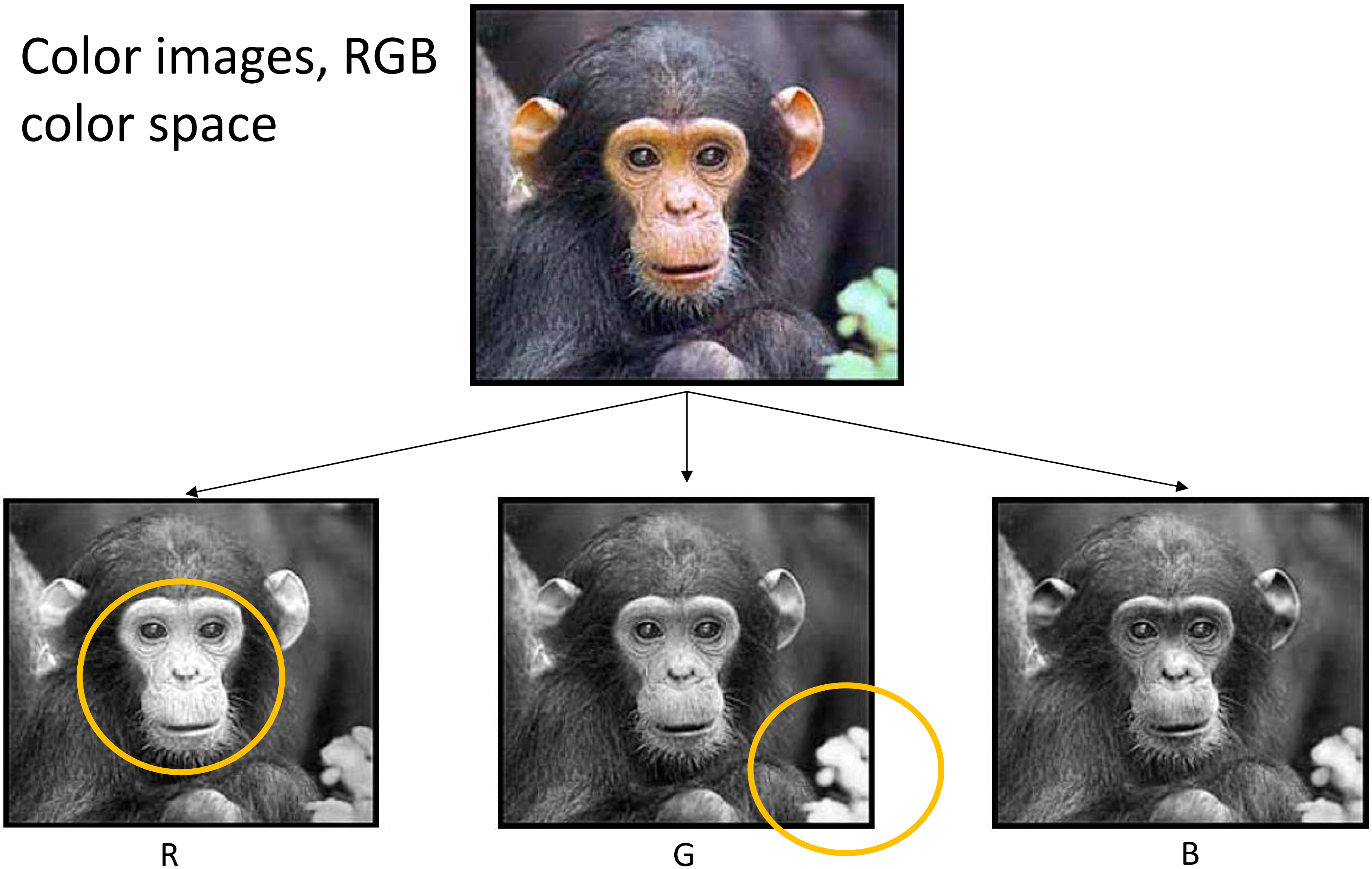
Estimate missing components from neighboring values (demosaicing)





Source: Steve Seitz

Color images, RGB color space



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