CMPSCI 670: Computer Vision

Cameras

University of Massachusetts, Amherst

September 10, 2014

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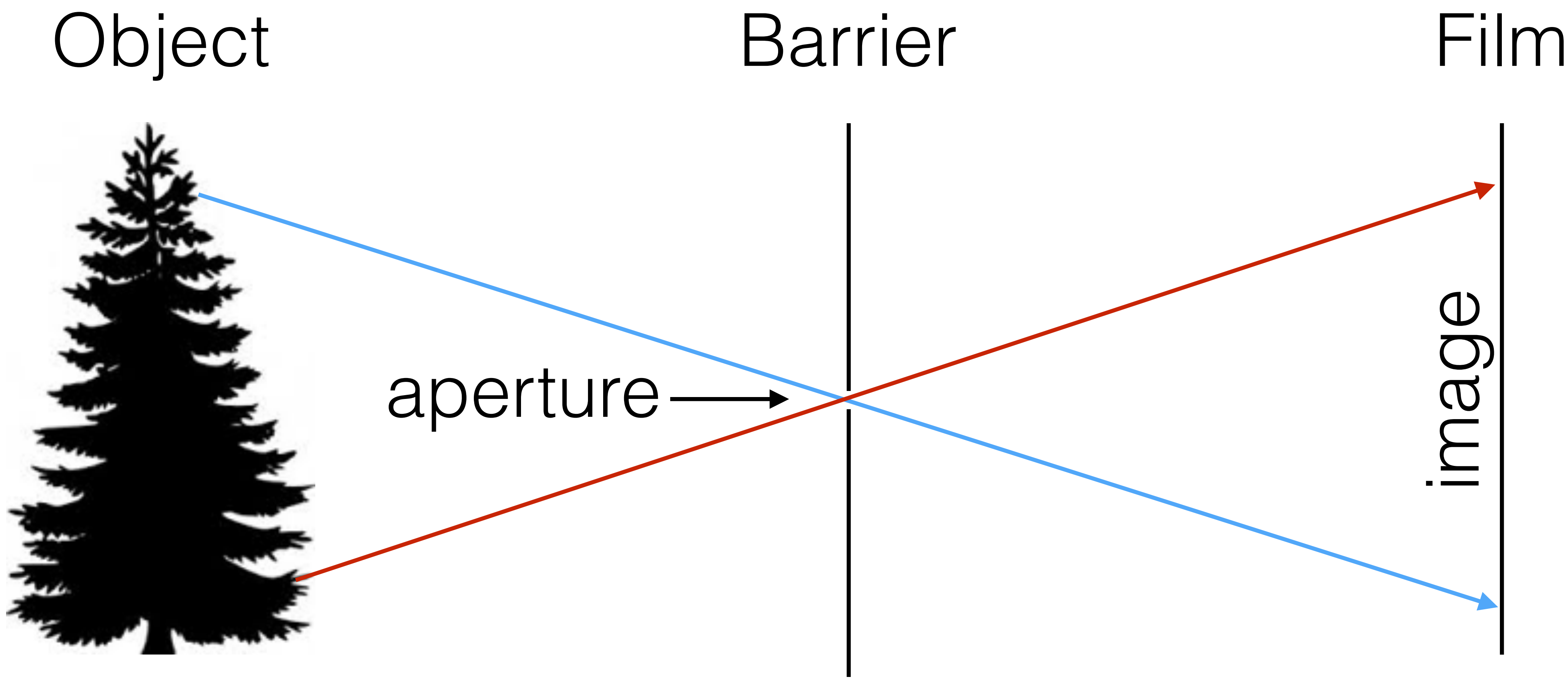
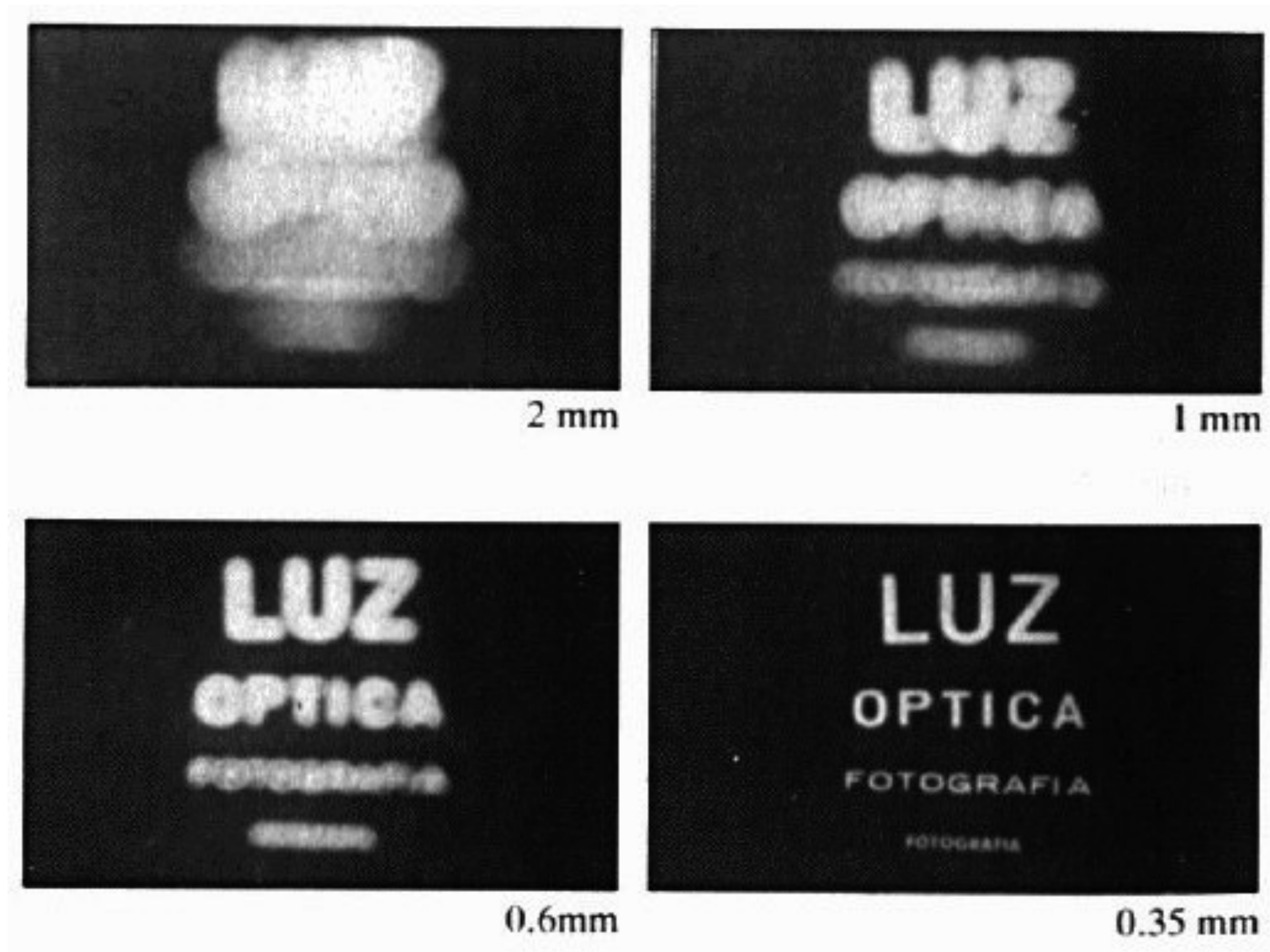
Pinhole camera



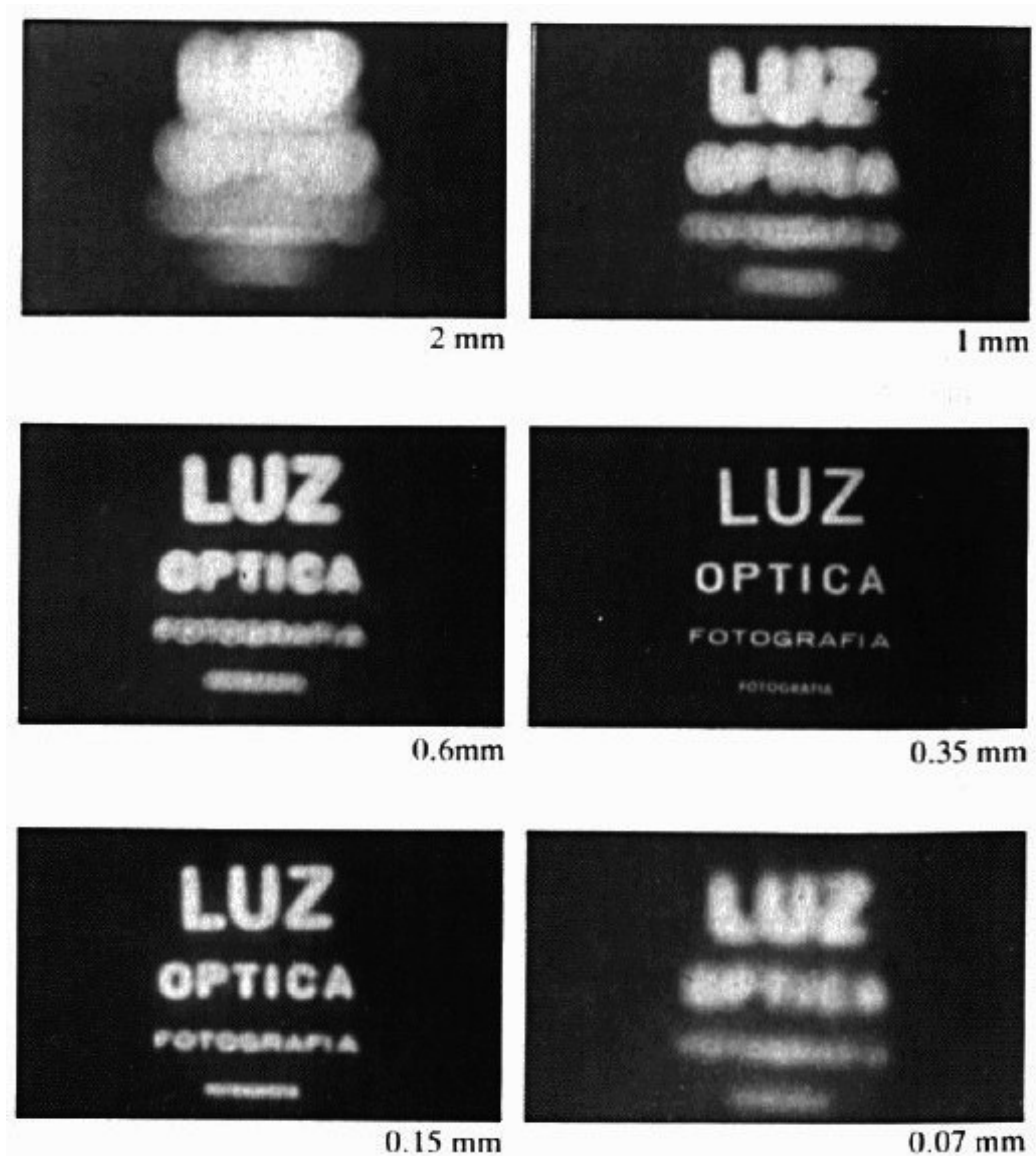
- Captures **pencil of rays** - all rays through a single point: **aperture, center of projection, focal point, camera center**
- The image is formed on the **image plane**

Shrinking the aperture

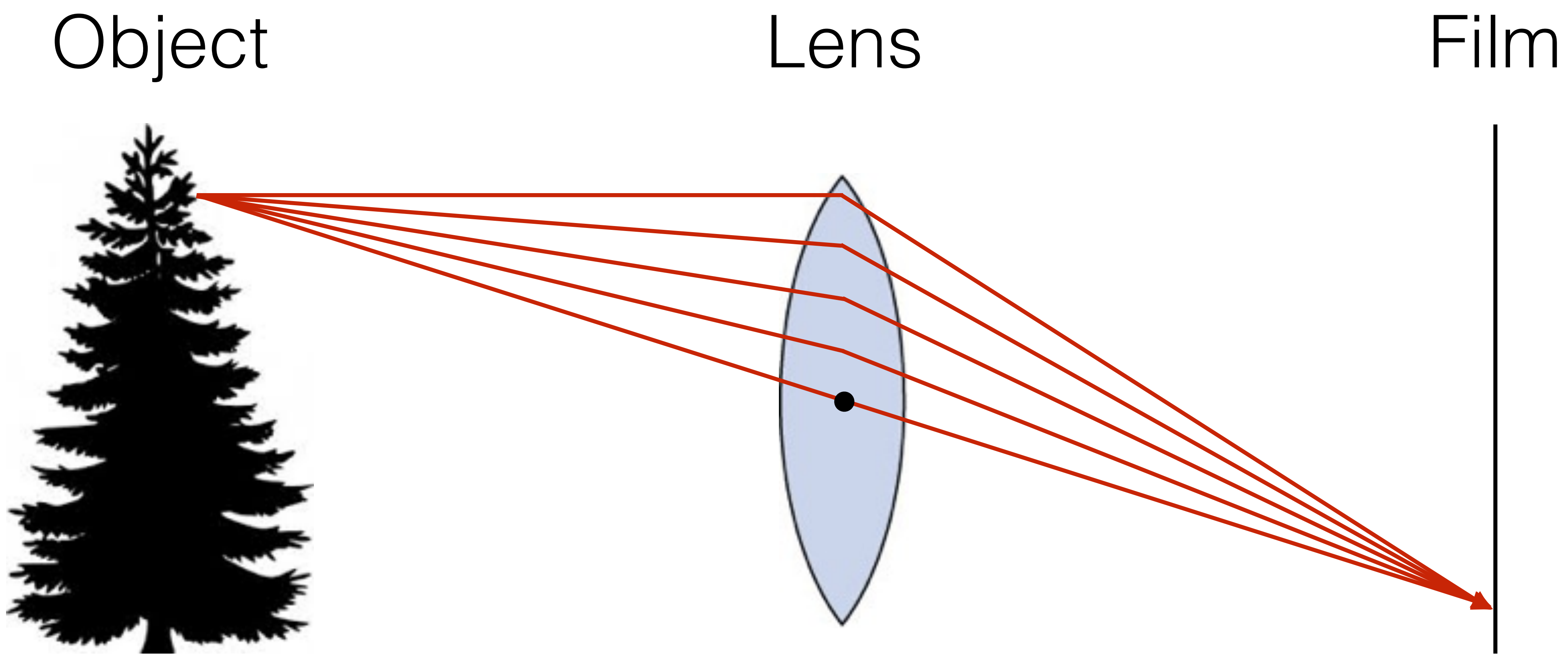


- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effects

Shrinking the aperture

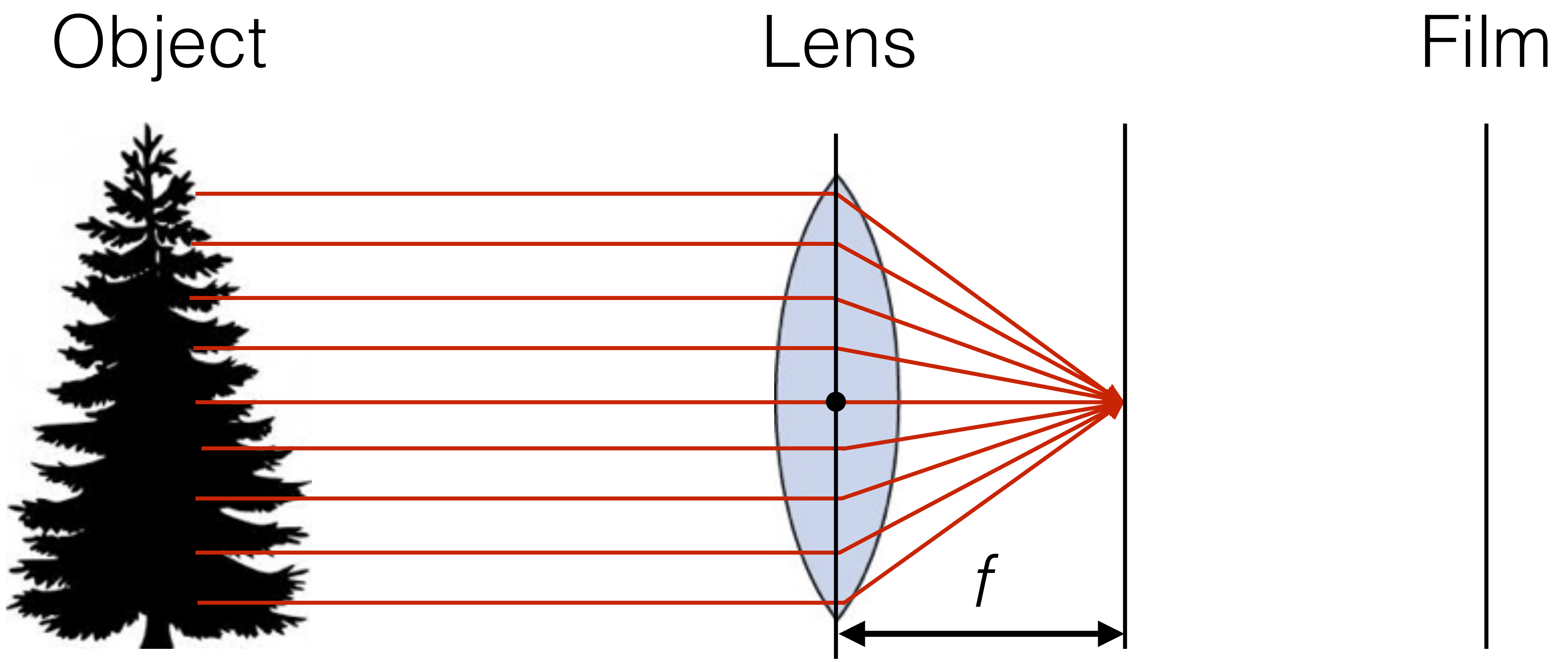


Adding a lens



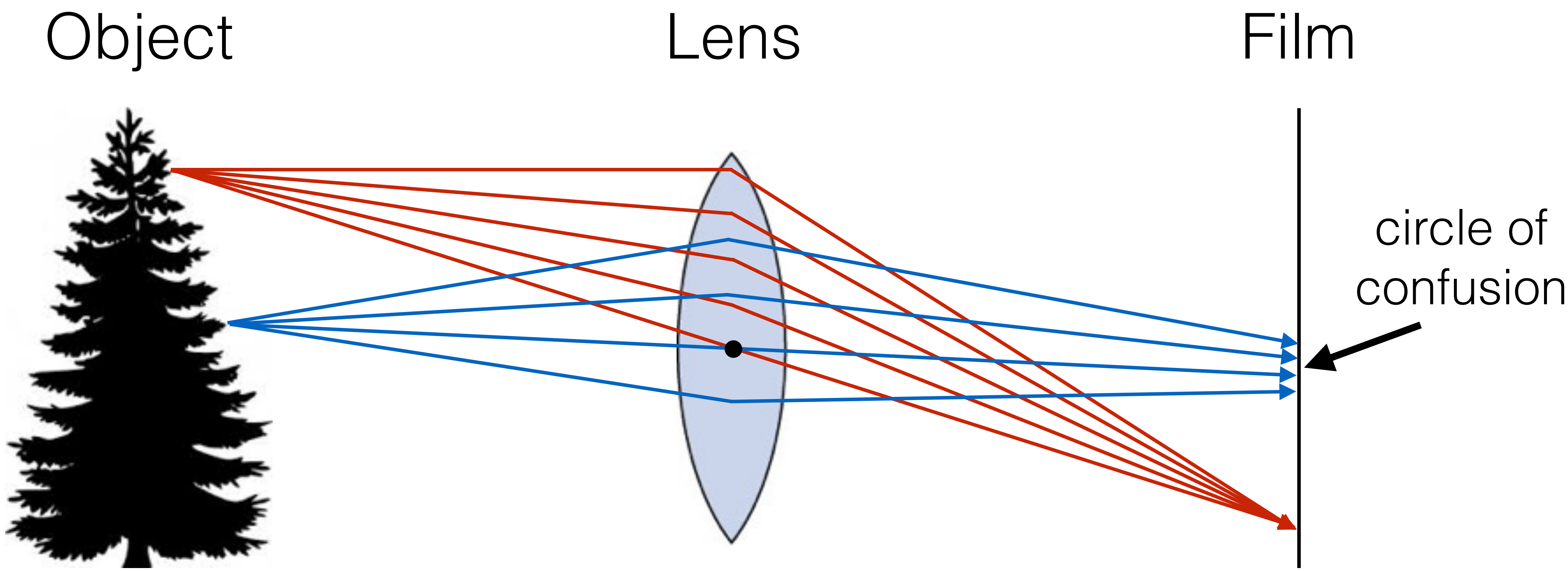
- A lens focuses light on to the film
  - **Thin lens model:**
    - Rays passing through the center are not deviated (pinhole projection model still holds)

Adding a lens



- A lens focuses light on to the film
    - **Thin lens model:**
        - Rays passing through the center are not deviated (pinhole projection model still holds)
        - All parallel rays converge to one point on a plane located at the *focal length f*

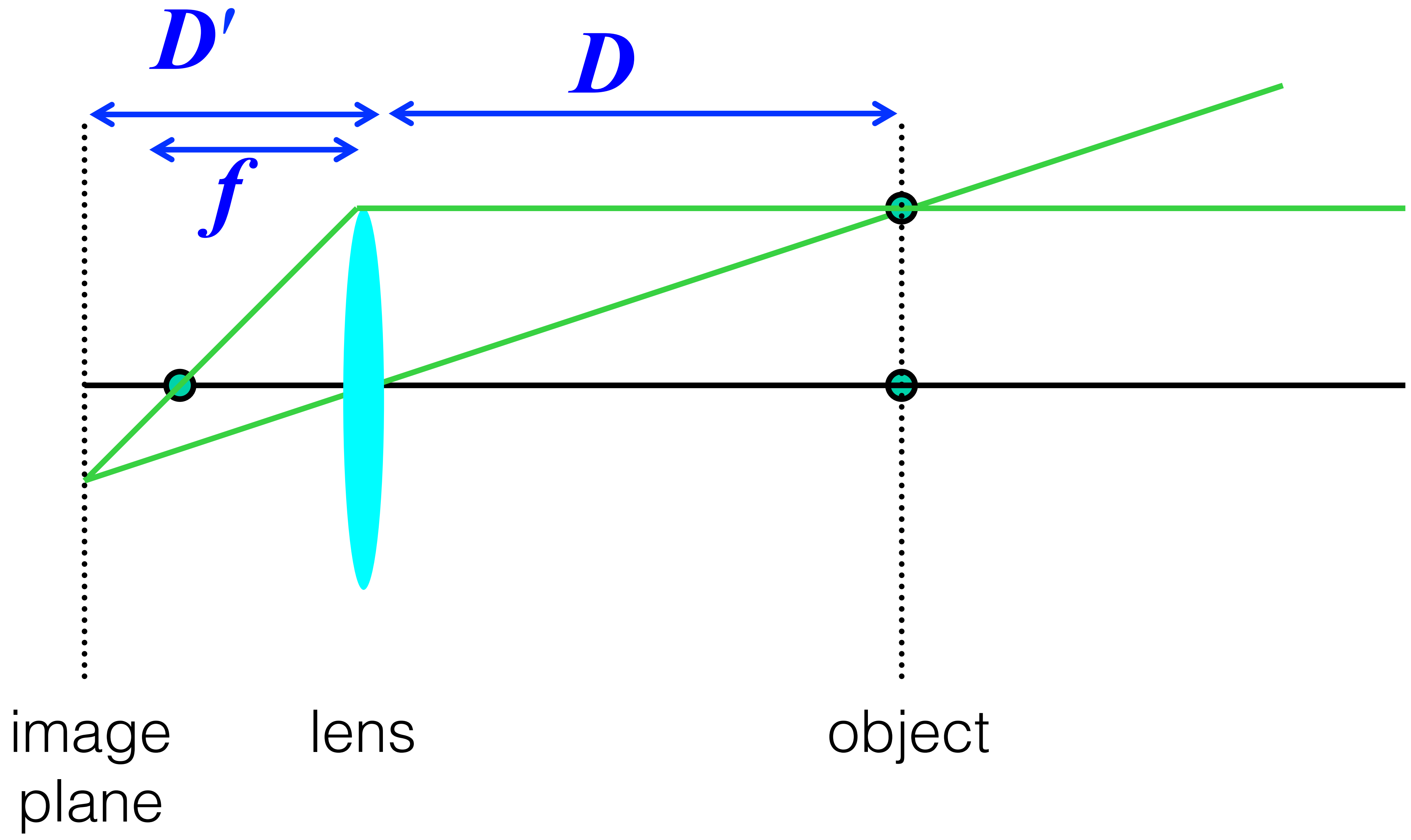
Adding a lens



- A lens focuses light on to the film
  - There is a specific distance at which objects are “in focus”
    - other points project on to a “circle of confusion” in the image

Thin lens formula

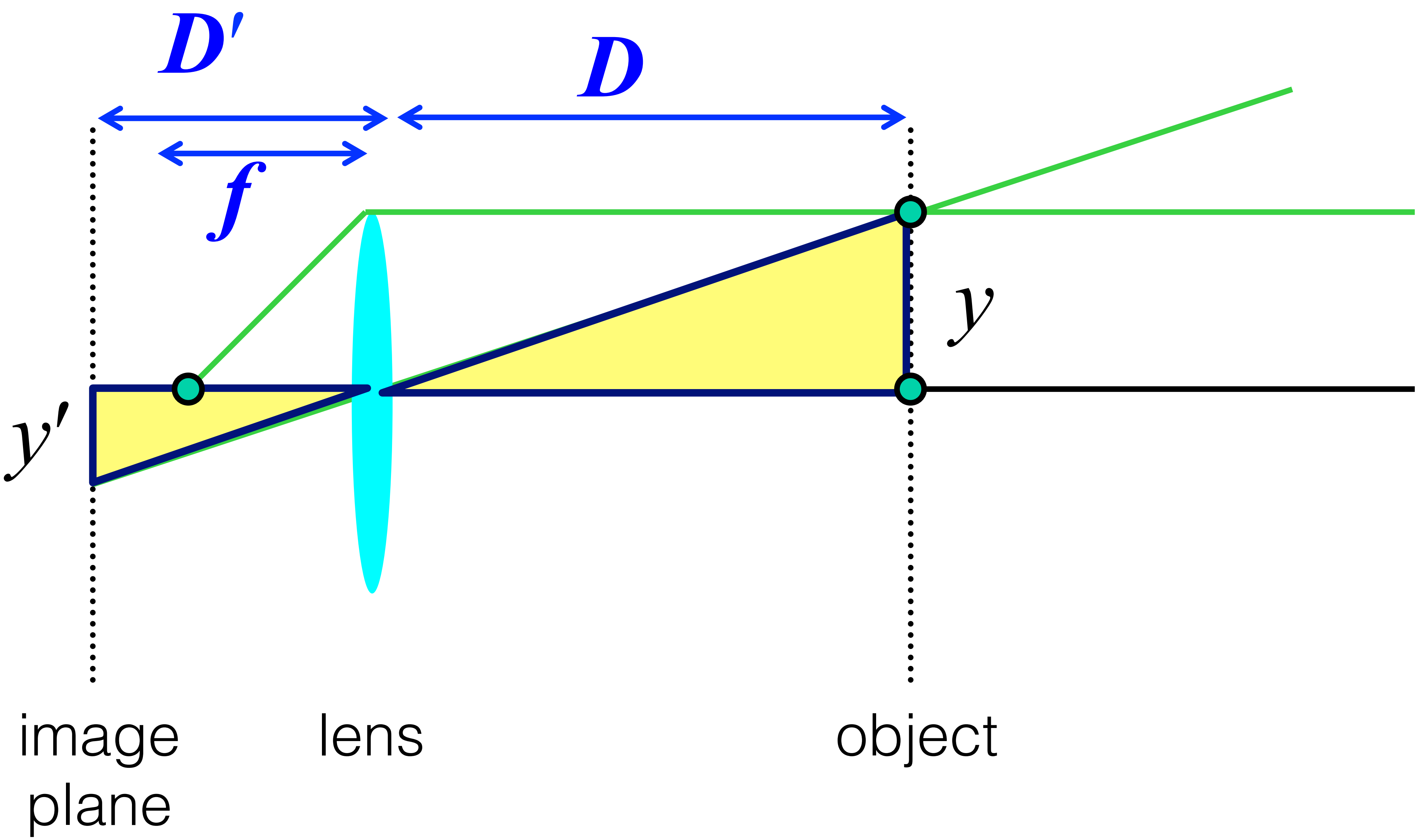
- What is the relation between the focal length (*f*), the distance of the object from the optical center (*D*) and the distance at which the object will be in focus (*D'*)?



Thin lens formula

- Similar triangles everywhere!

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

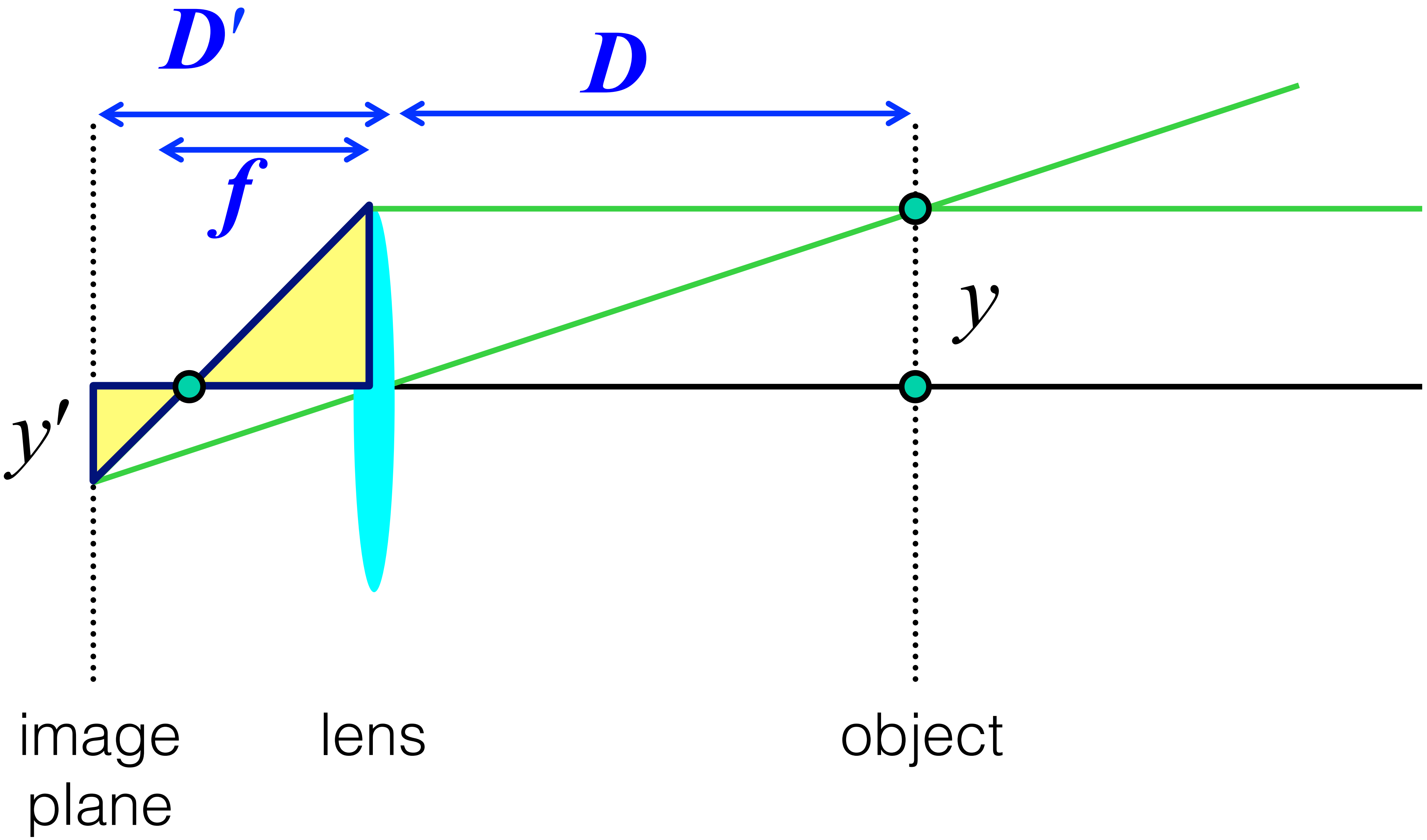


Thin lens formula

- Similar triangles everywhere!

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

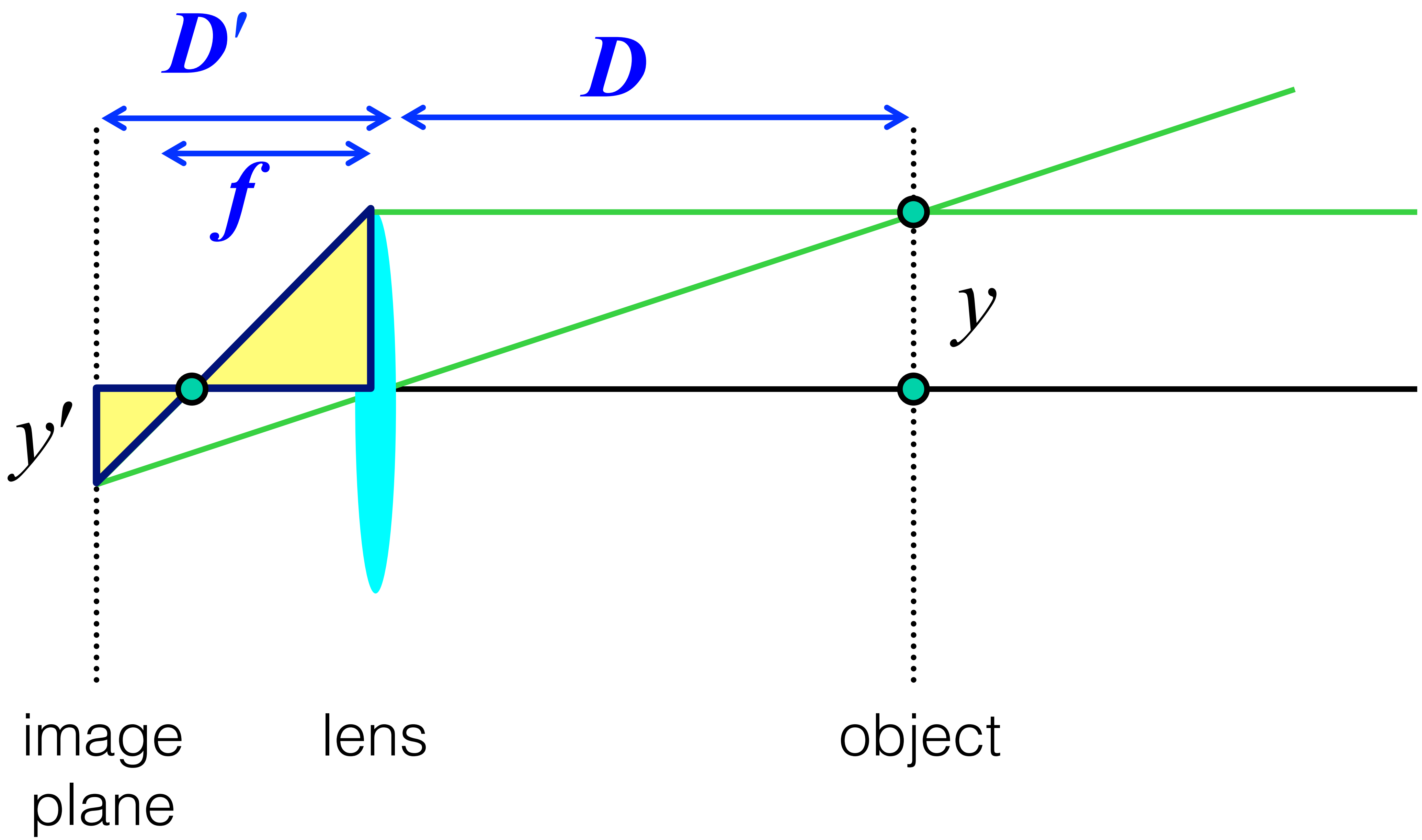
$$y'/y = (D'-f)/f$$



Thin lens formula

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

Any point satisfying the thin lens equation is in focus

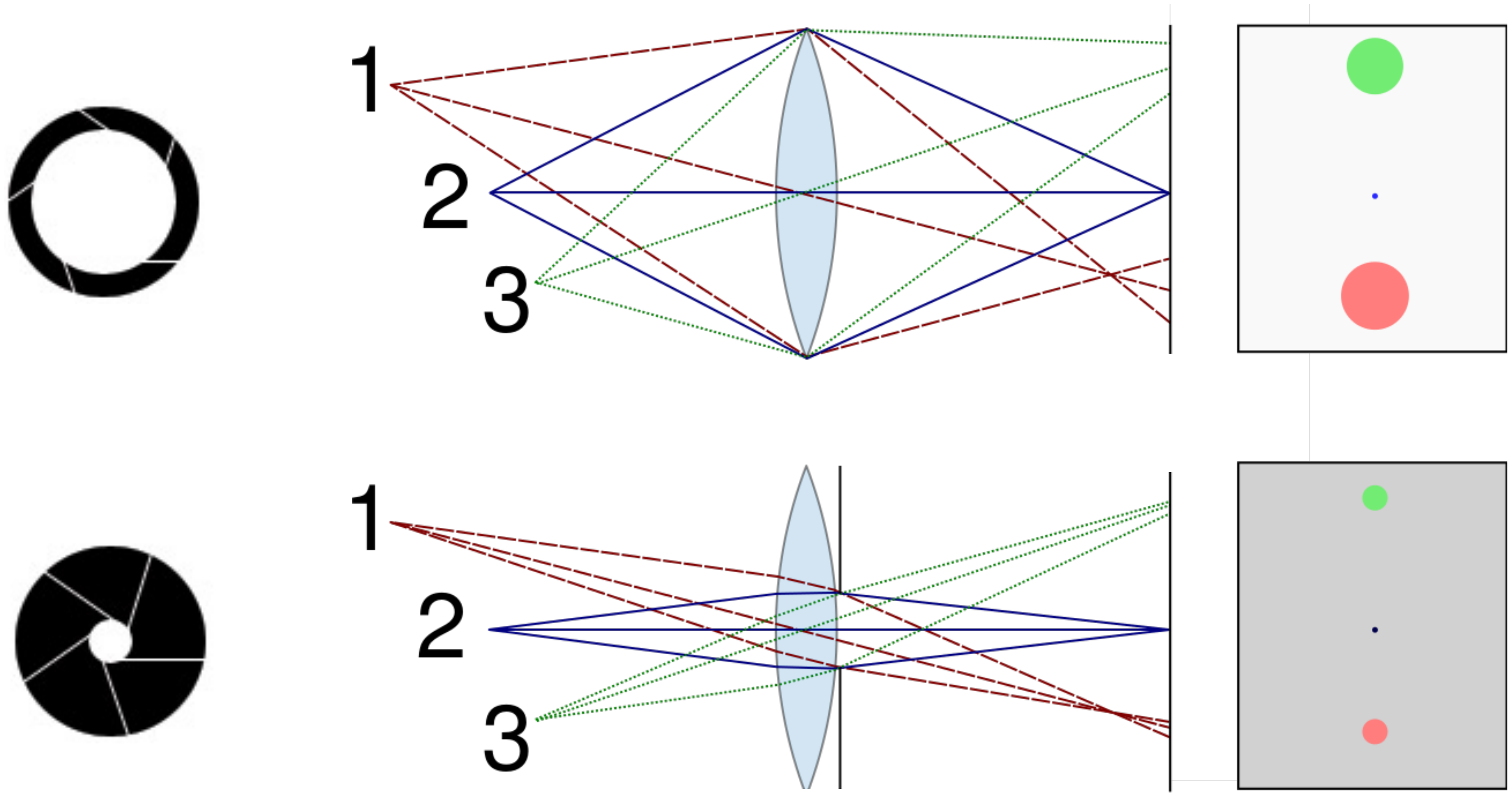


Depth of Field

http://www.cambridgeincolour.com/tutorials/depth-of-field.htm

DOF is the distance between the nearest and farthest objects in a scene that appear acceptably sharp in an image

Controlling depth of field



- Changing the aperture size affects the depth of field
  - A smaller aperture increases the range in which the object is approximately in focus
  - But small aperture reduces the amount of light — need to increase the exposure for contrast
  - Pinhole camera has an infinite depth of field

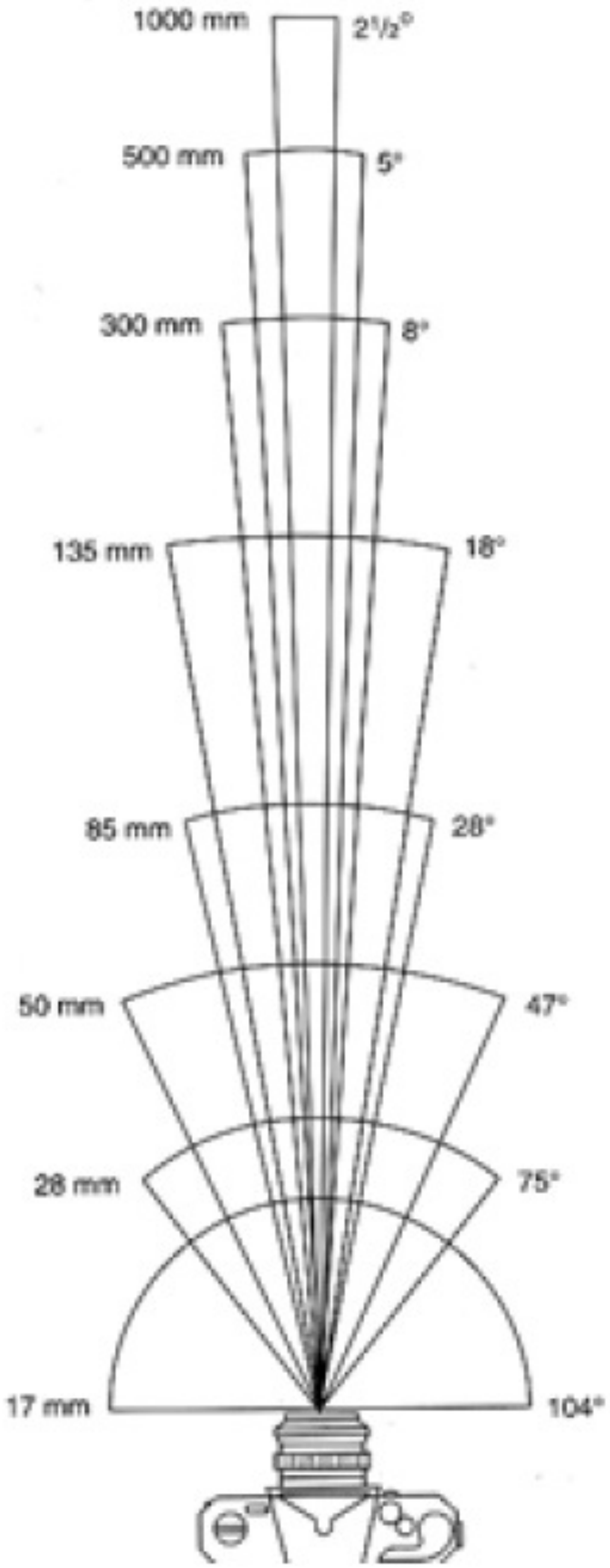
image credit Wikipedia

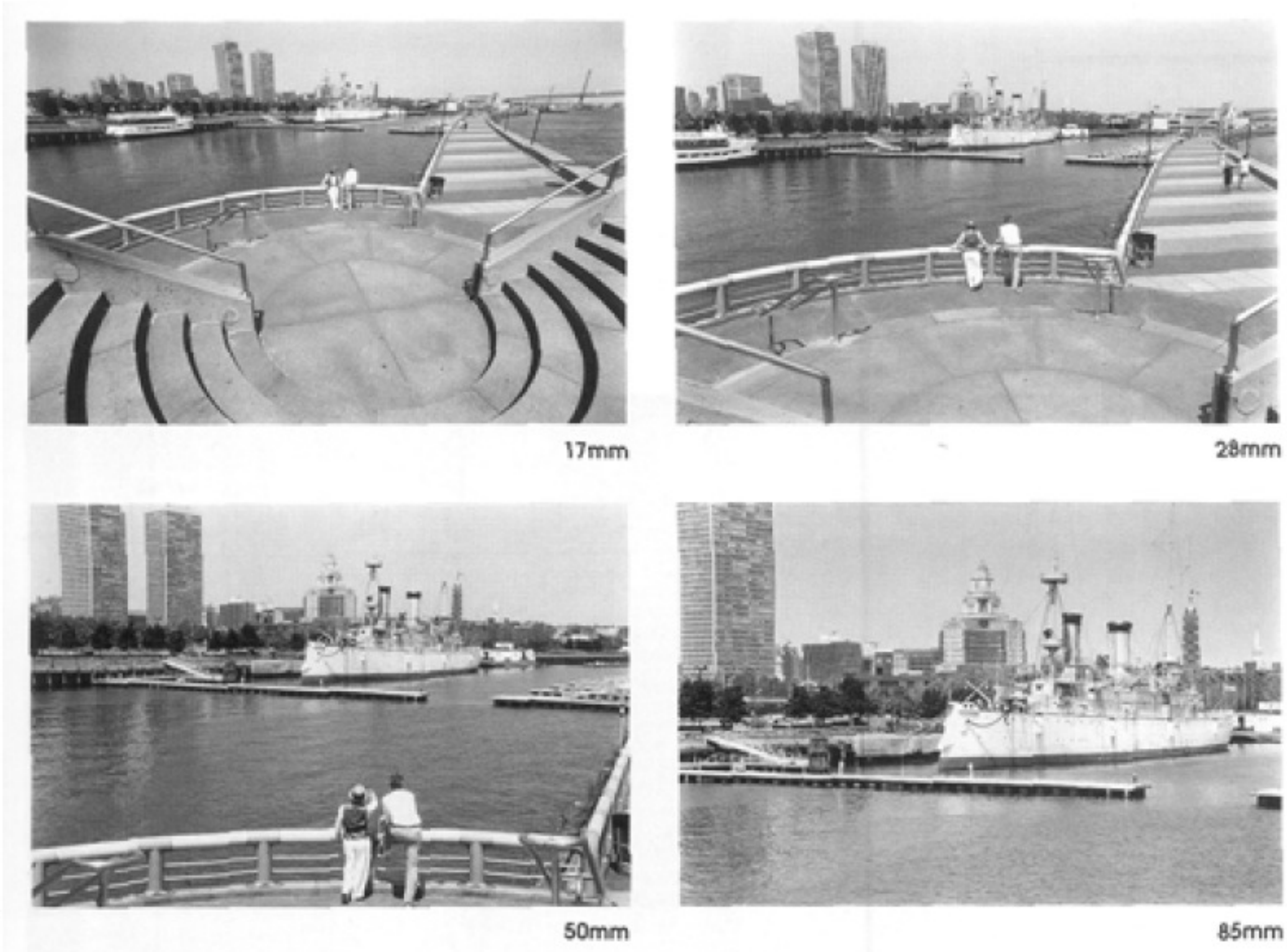
Varying the aperture

Large aperture = small DOF

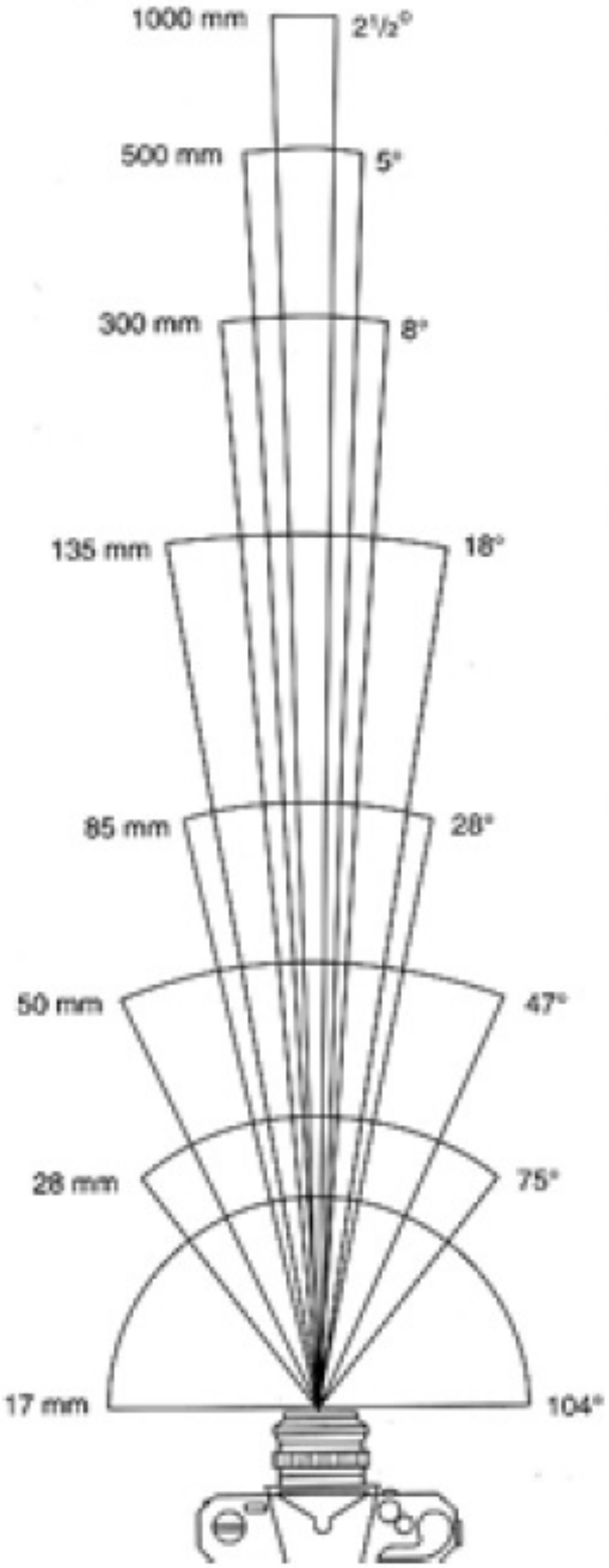
Small aperture = large DOF

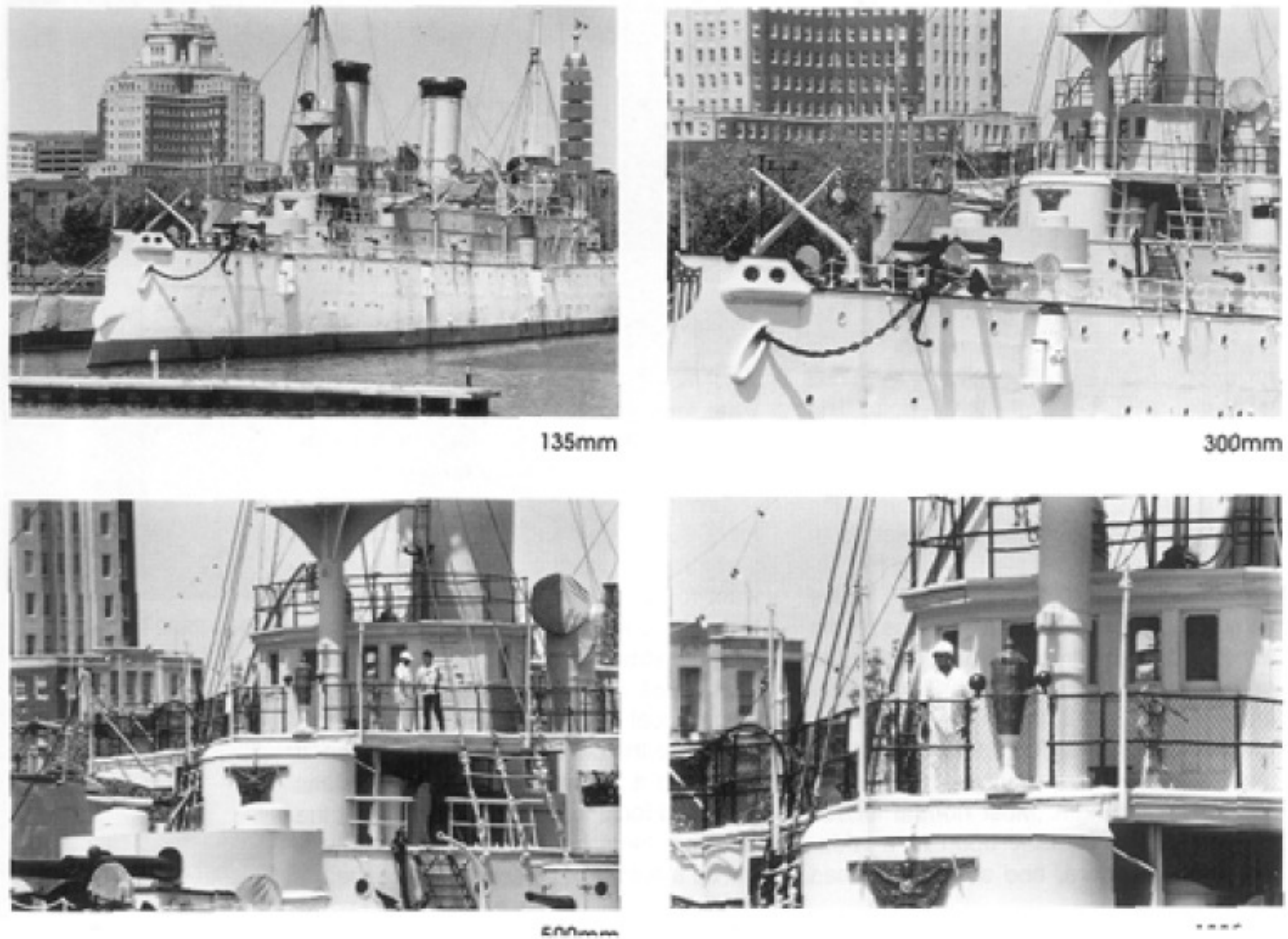
Field of view



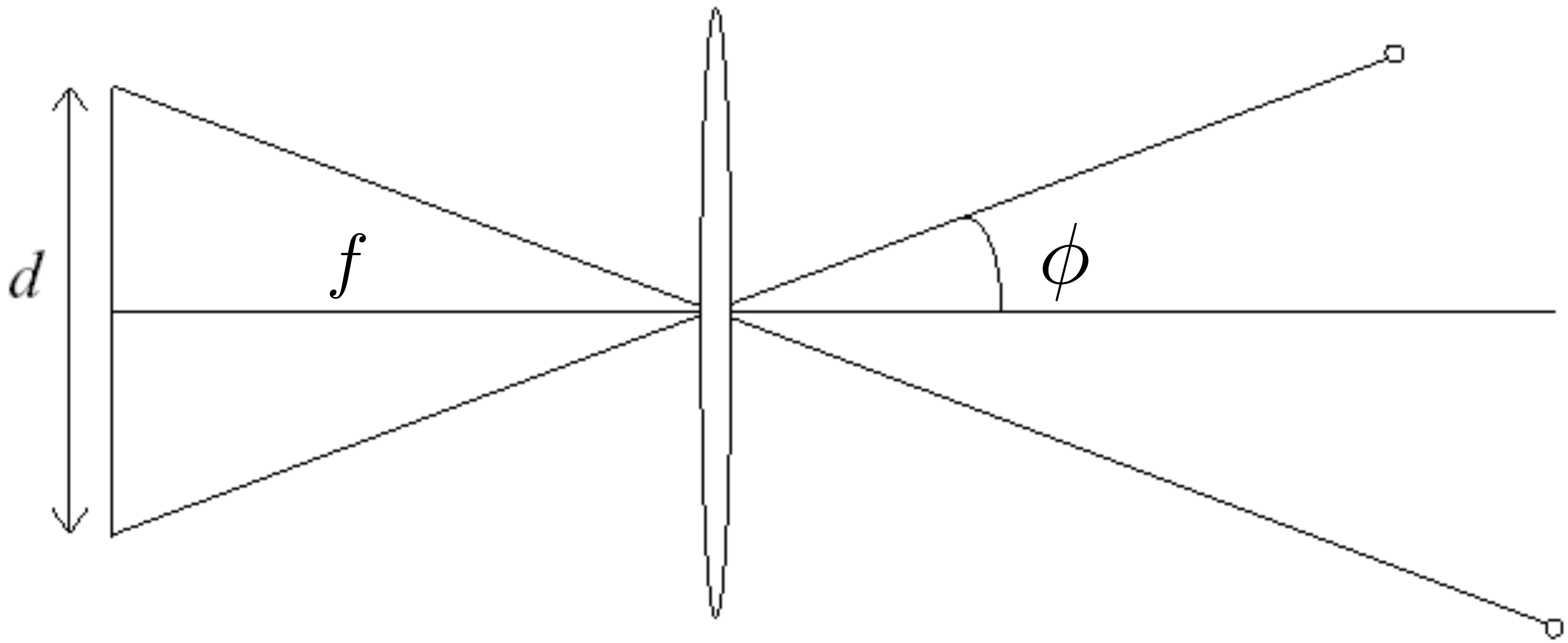


Field of view





Field of view



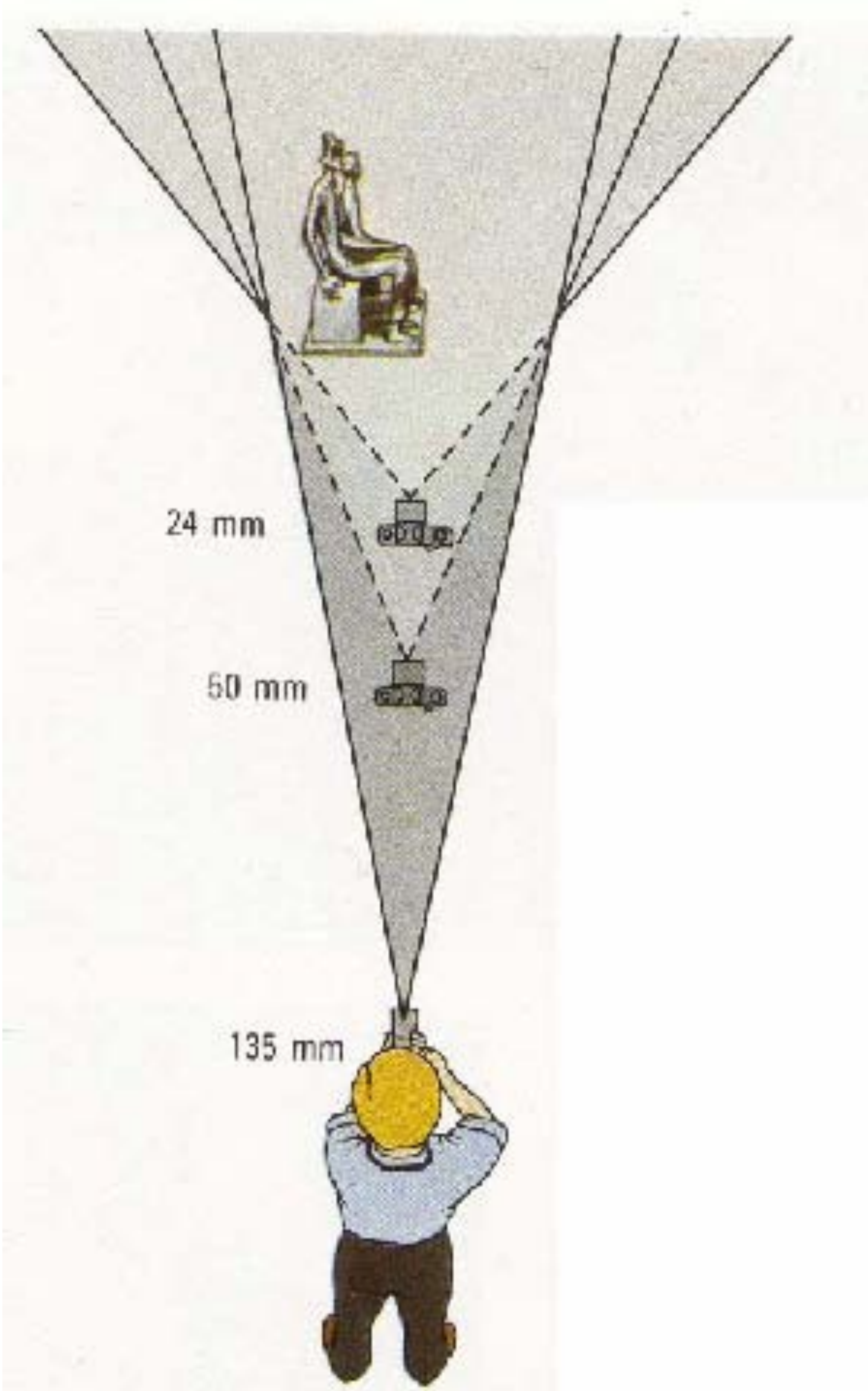
- Field of view (FOV) depends on the focal length and the size of the camera retina

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

Larger focal length = smaller FOV

Slide by A.Efros

Field of view, focal length



$$\tan(\phi) \times 2f = d$$
$$\sim (\phi) \times 2f = d$$

Large FOV, small *f* — Camera close to the car

Small FOV, large *f* — Camera far from the car

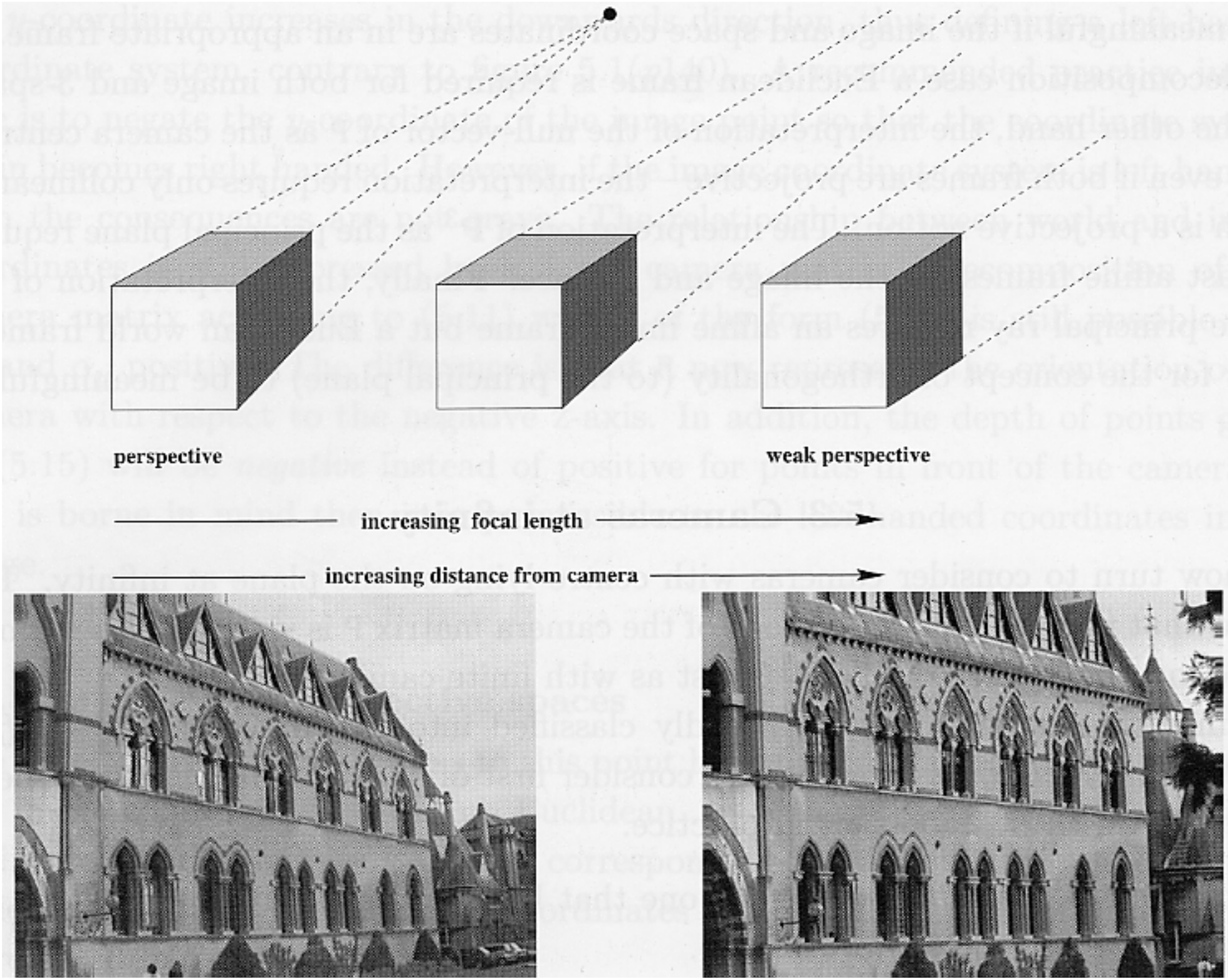
Same effect for faces

wide-angle
(short focus)

standard

telephoto
(long focus)

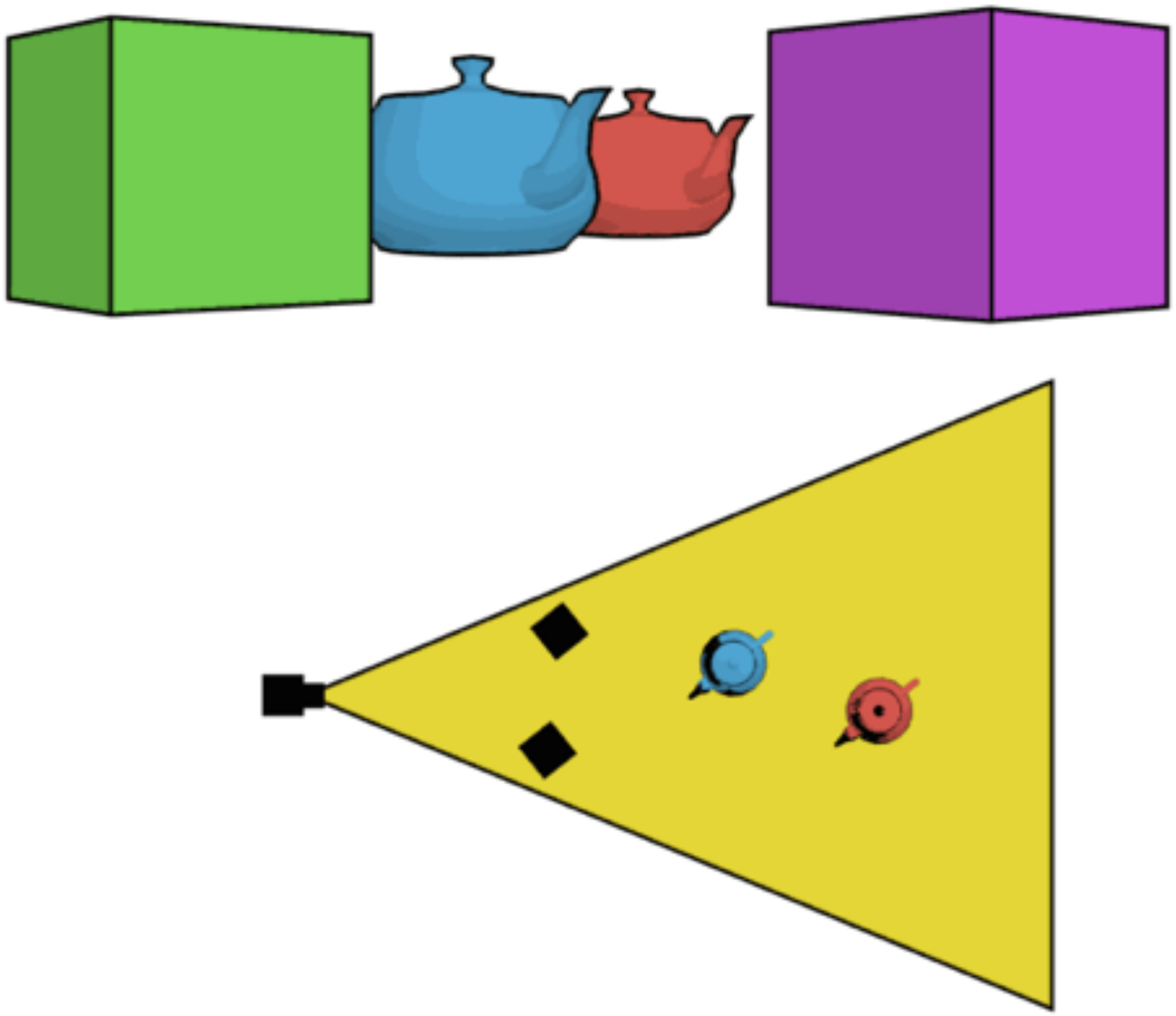
Approximating an orthographic camera



Source: Hartley & Zisserman

The dolly zoom

- Continuously adjusting the camera focal length while the camera moves away from (or towards) the subject



http://en.wikipedia.org/wiki/Dolly_zoom

The dolly zoom

- Continuously adjusting the camera focal length while the camera moves away from (or towards) the subject
- Also called as “Vertigo shot” or the “Hitchcock shot”

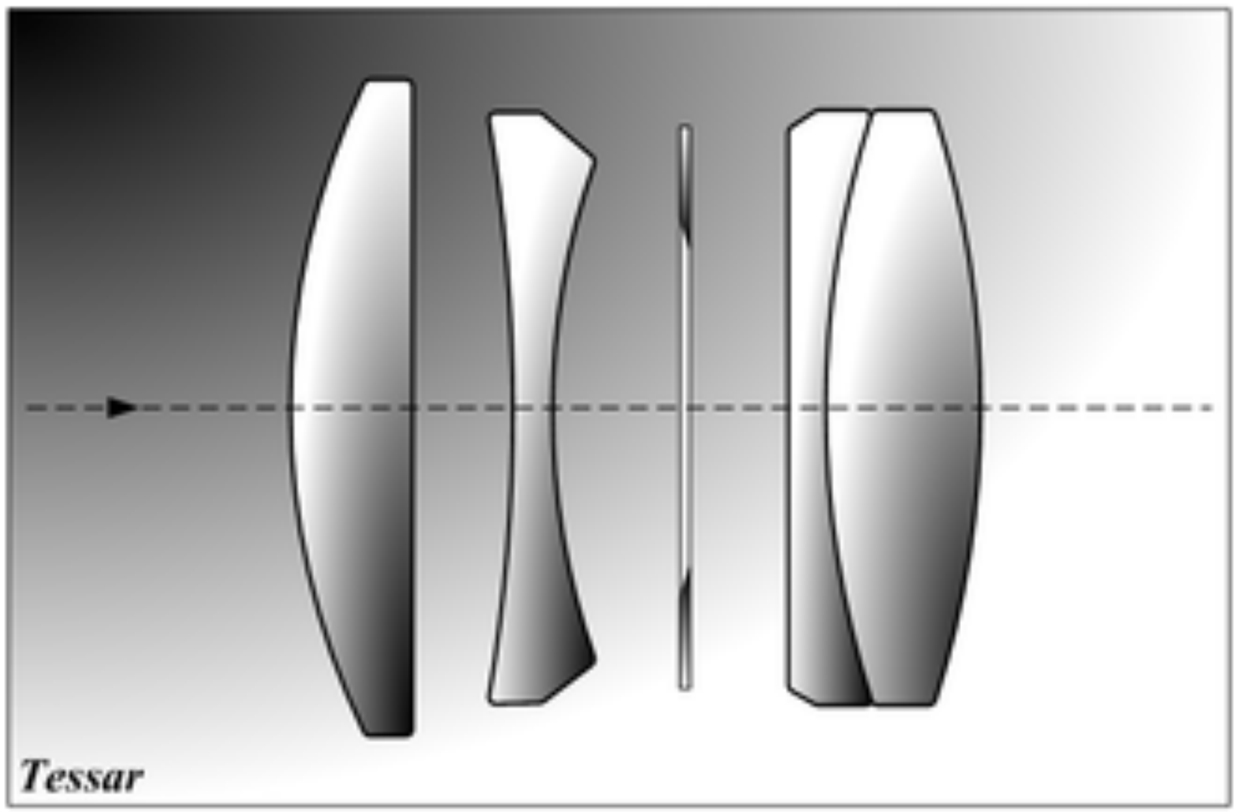
[Example of dolly zoom from Goodfellas]

[Example of dolly zoom from La Haine]

Real photographic lens

- Many uses: cameras, telescopes, microscopes, etc

fixed focal length



Example of a prime lens - Carl Zeiss **Tessar**

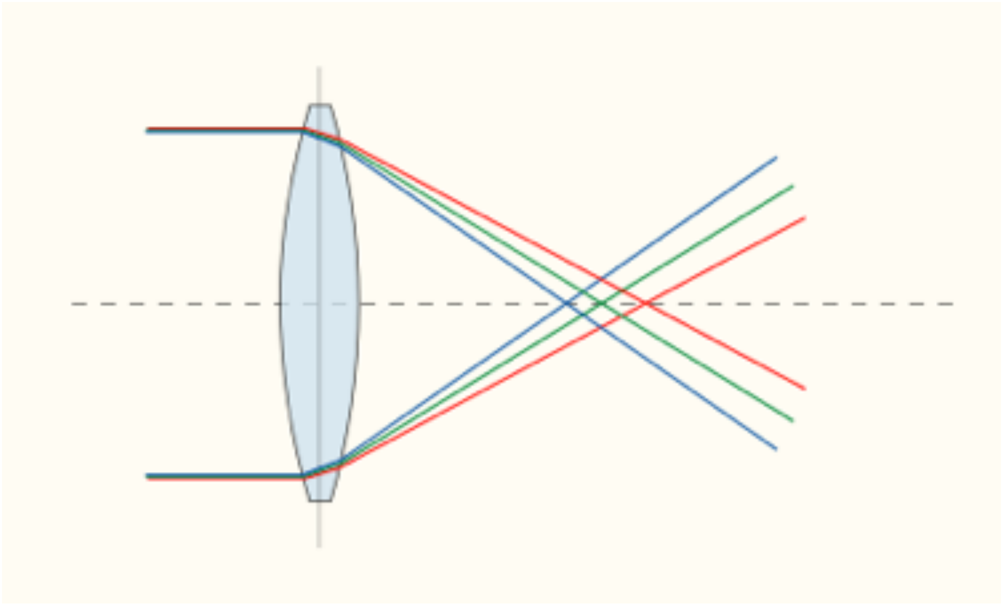
adjustable zoom

Nikkor 28-200 mm zoom lens, extended to 200 mm at left and collapsed to 28 mm focal length at right.

http://en.wikipedia.org/wiki/Zoom_lens

Lens flaws: Chromatic aberration

- Lens have different refractive indices (**Snell's law**) for different wavelengths: causes color fringing

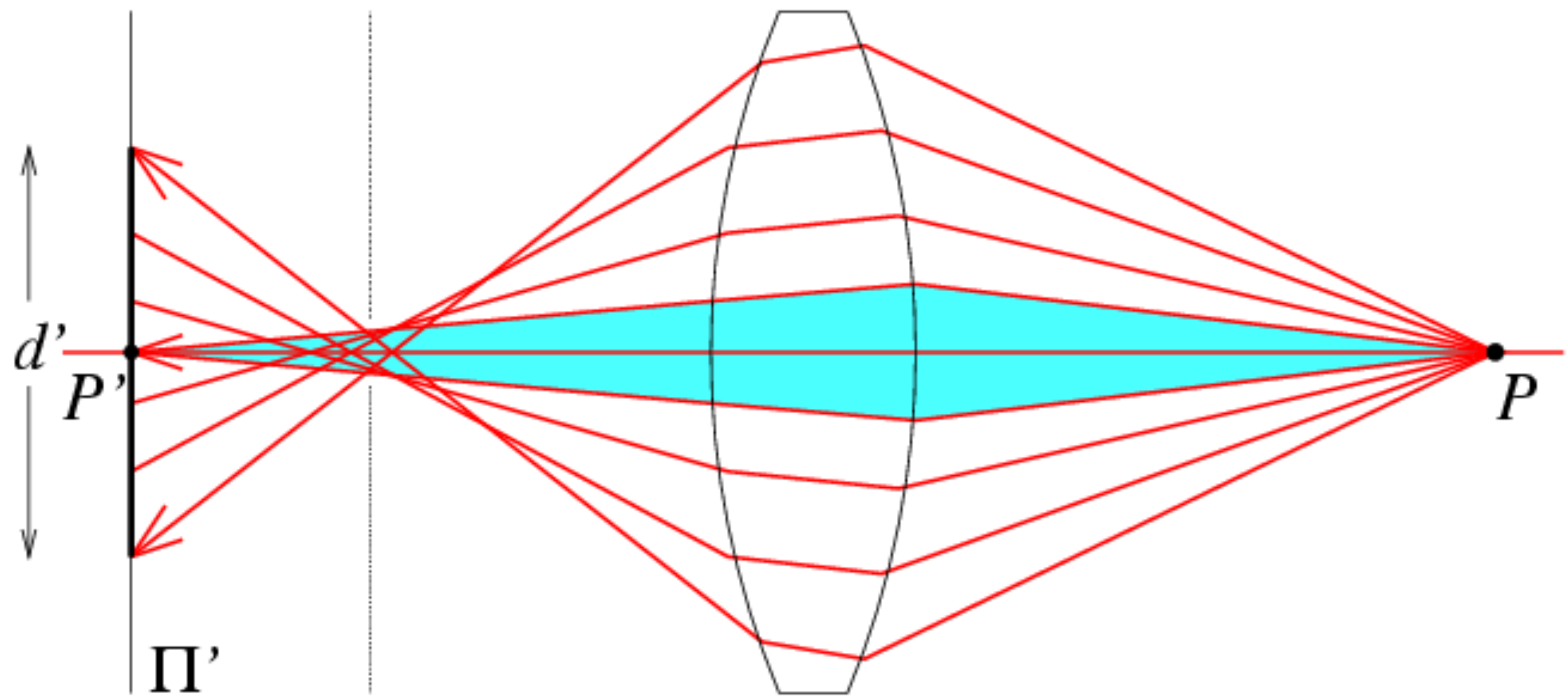


near lens center

near lens outer

Lens flaws: Spherical aberration

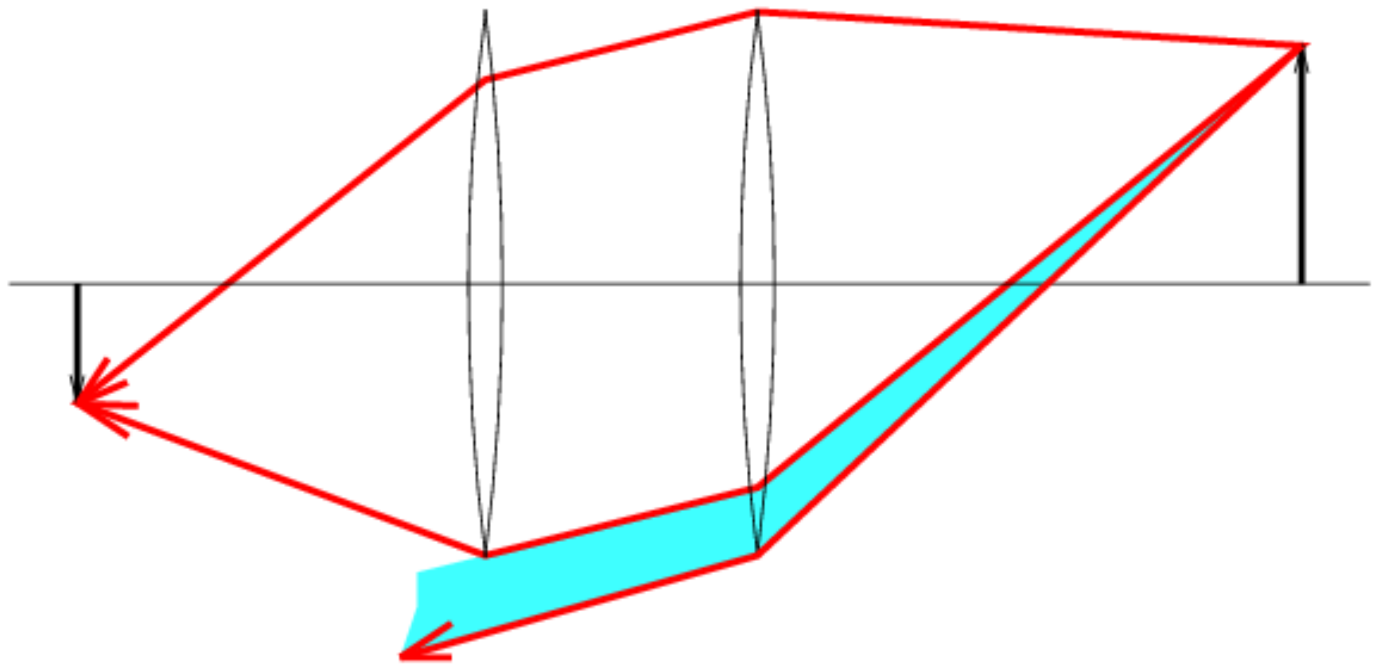
- Spherical lenses don't focus light perfectly (thin lens model)
  - Rays farther from the optical axis are focussed closer



objects lack sharpness

Lens flaws: Vignetting

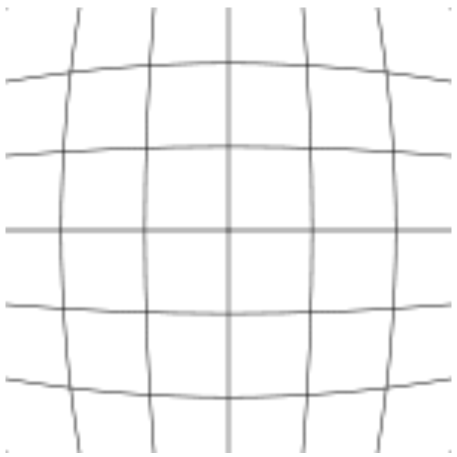
- Reduction of image brightness in the periphery



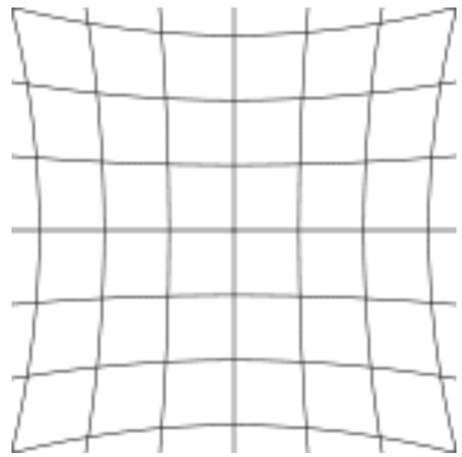
Not all rays reach the sensor

Lens flaws: Radial distortion

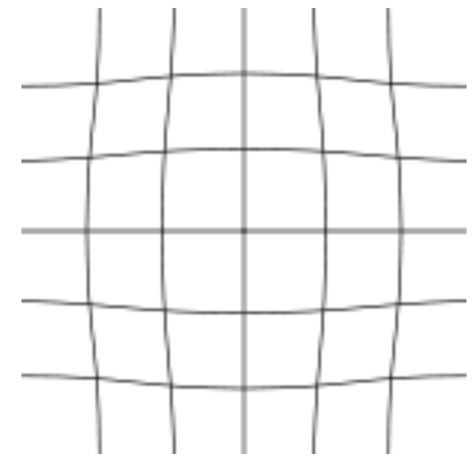
- Caused by asymmetry of lenses
- Deviations are most noticeable near the periphery



barrel distortion



pincushion distortion



mustache distortion

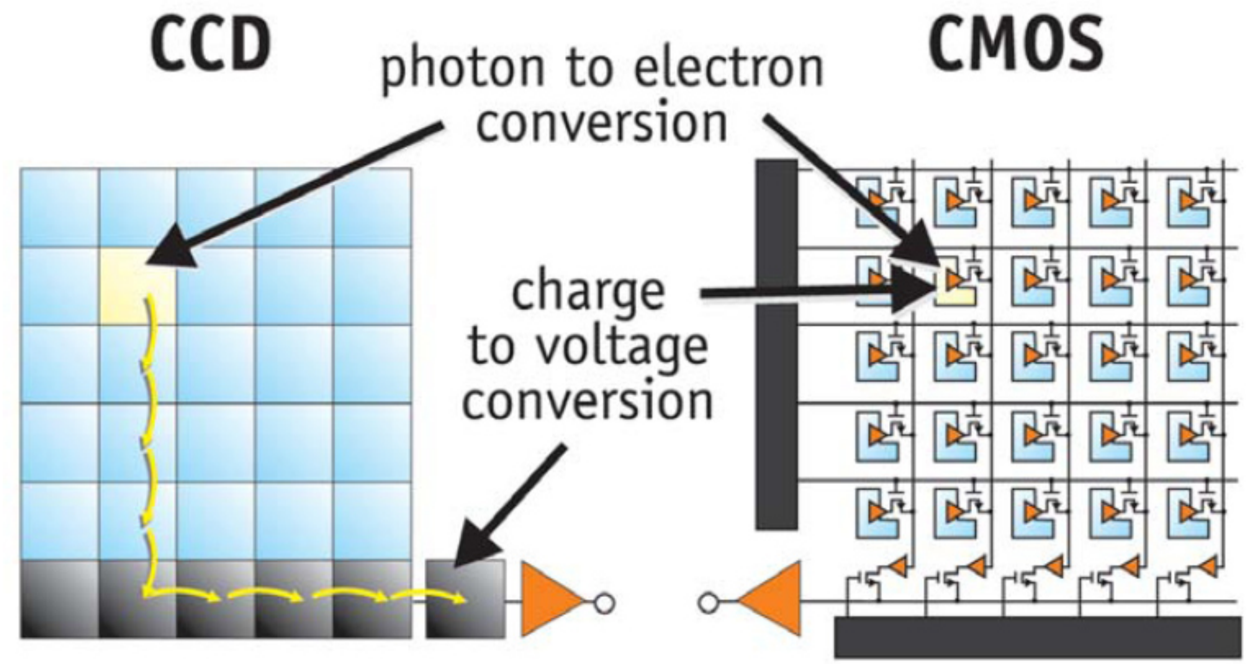
http://clanegesselphotography.blogspot.com/

http://parkingandyou.com

Measuring light

- Photographic film — strip of transparent plastic film base coated on one side with a gelatin emulsion containing light-sensitive materials
- Creates a latent image when exposed to light for short duration
- Films are then chemically developed to form a photograph
- **Question:** how do we get color?

Digital camera



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.

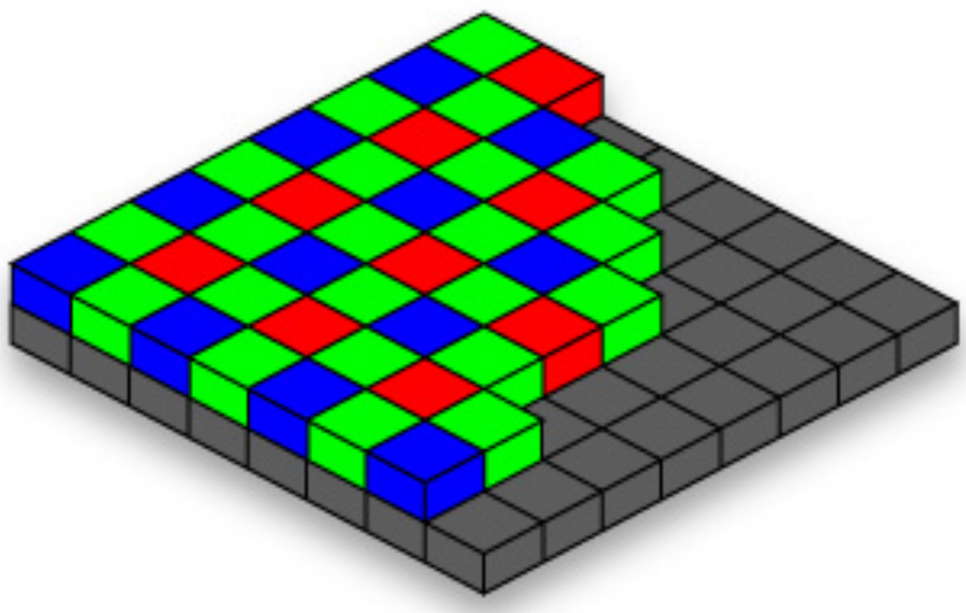
- A digital camera replaces the film with a sensor array
  - Each cell in the array is a light-sensitive diode that converts photons to electrons
  - Two common types
    - **Charge Coupled Device (CCD)**
    - **Complementary Metal Oxide Semiconductor (CMOS)**

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

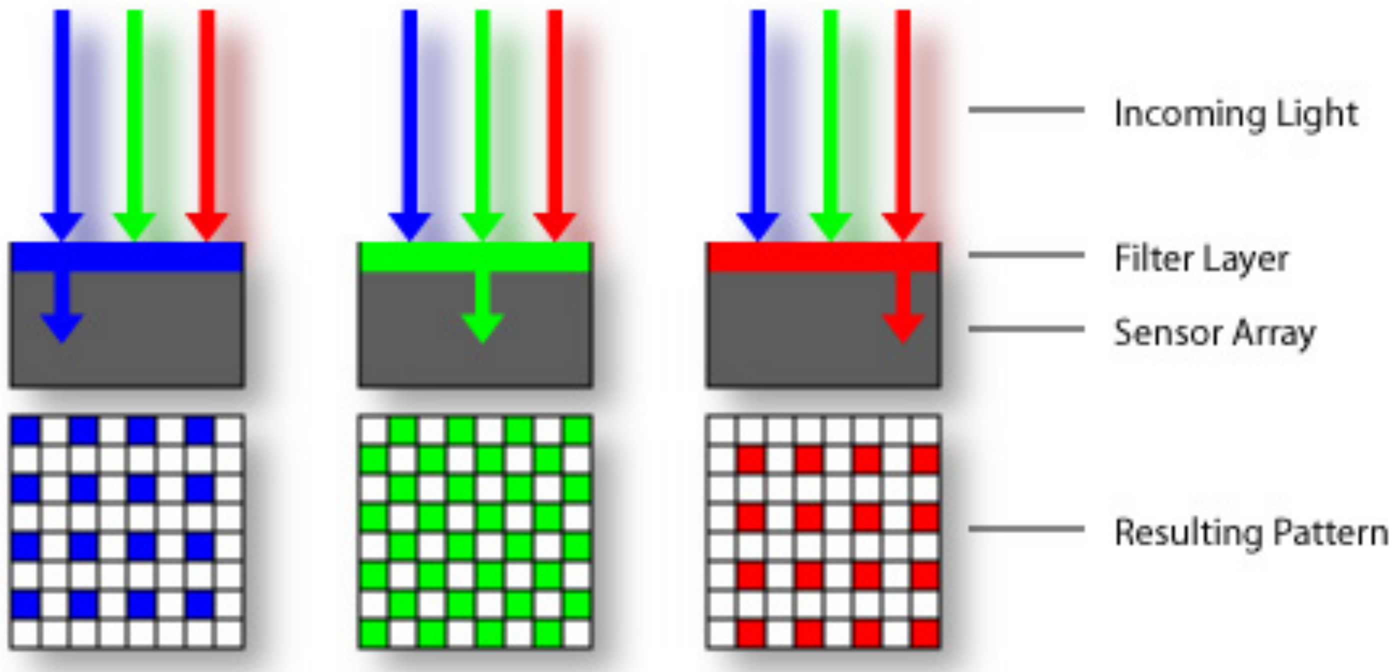
Color sensing in the camera

Color filter array

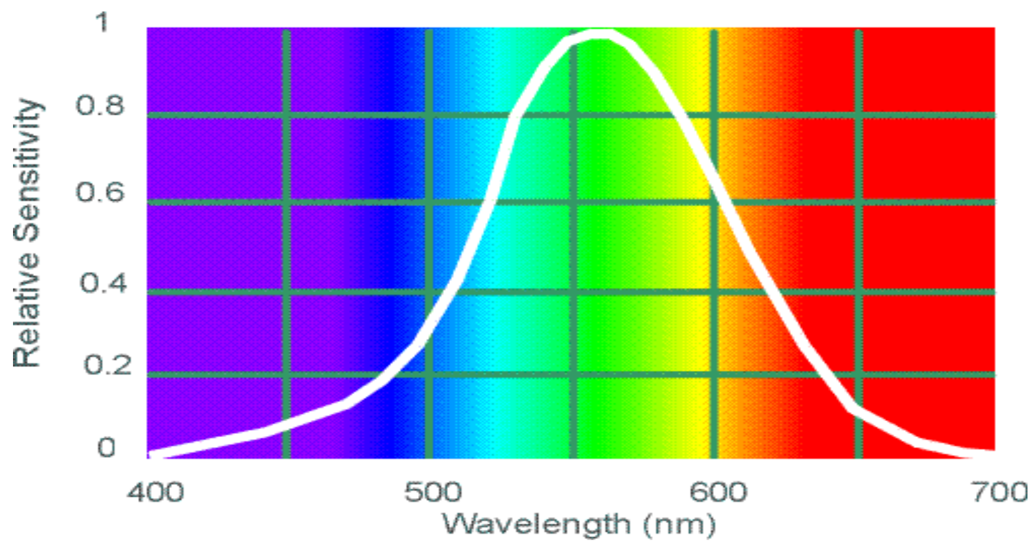
Bayer grid



Estimate missing components from neighboring values (**demosiacing**)

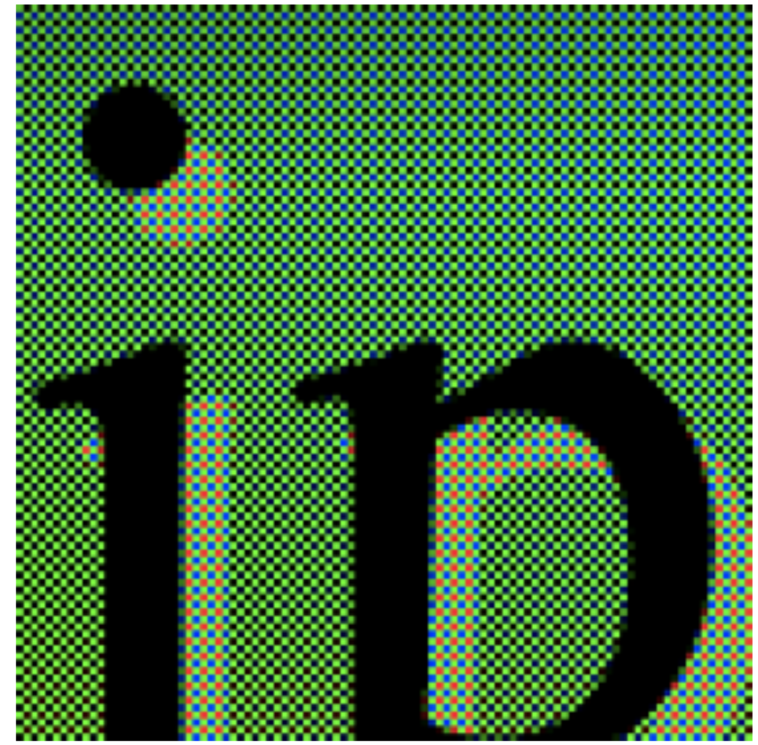


Why more green?

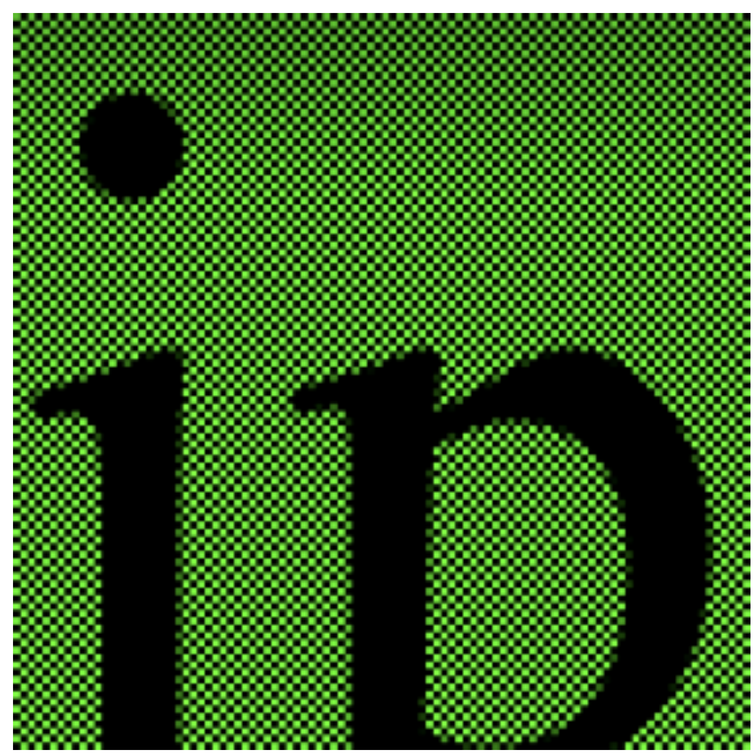


Human luminance sensitivity function

Demosaicing



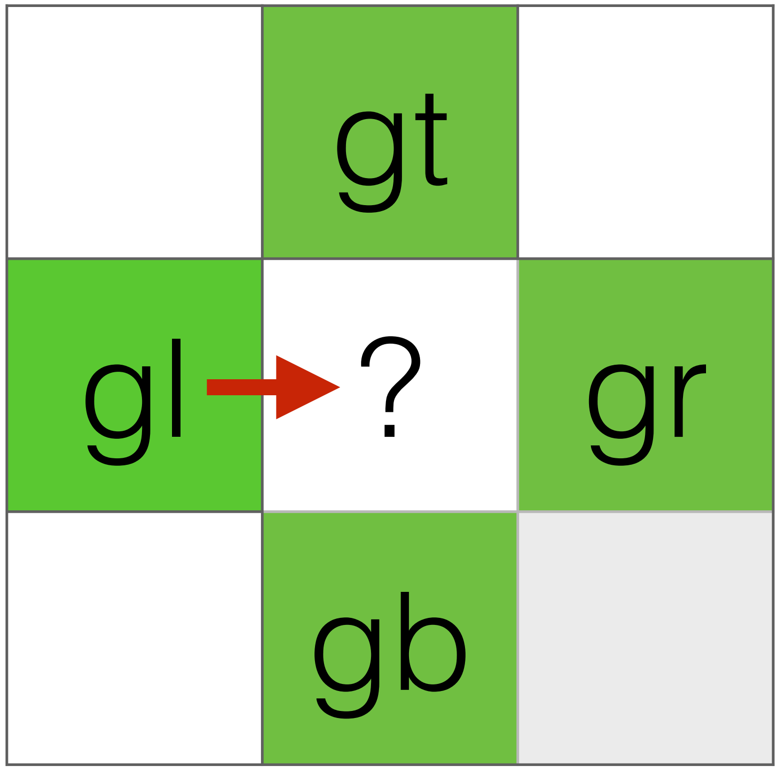
Red



Green

Blue

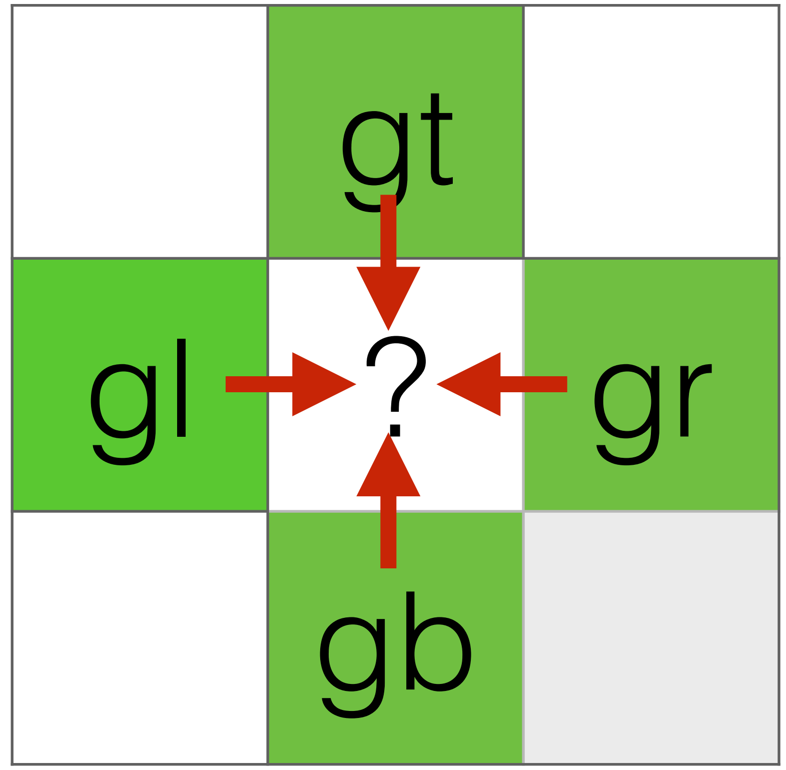
Interpolation



nearest neighbor

copy one of your neighbors

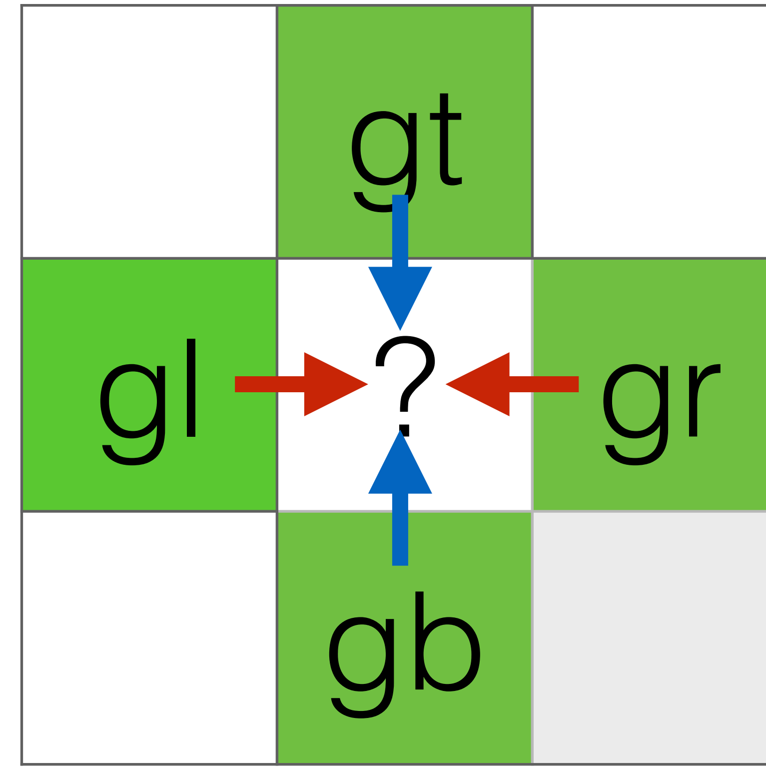
? ← gl



linear interpolation

average values of your neighbors

? ←(gt+gl+gr+gb)/4



adaptive gradient

average based on nbhd. structure

if |gt-gb| > |gl-gr|

? ← (gl+gr)/2

else

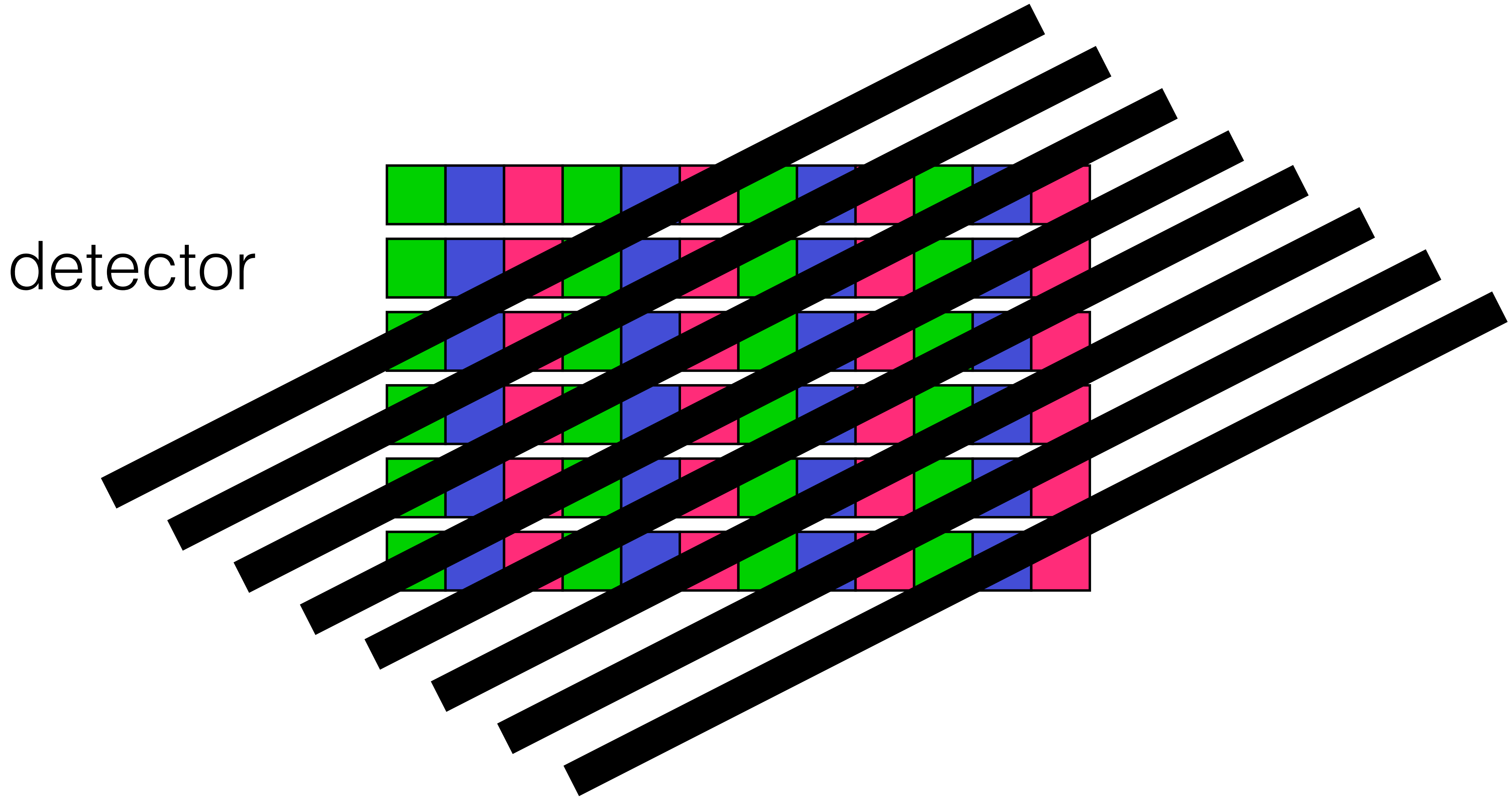
? ← (gt+gb)/2

Similarly for the blue and red channels

Homework 1: implement this

Problem with demosaicing: color moiré

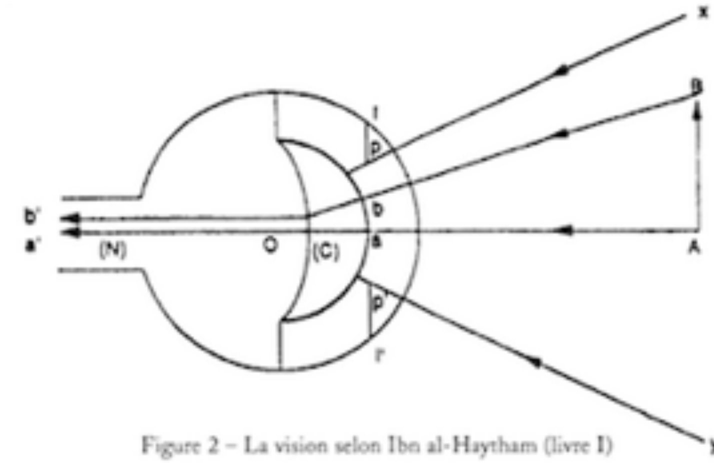
The cause of color moiré



Fine black and white detail in the image scene
is misinterpreted as color information

Historic milestones

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: first widely used photographic process (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)



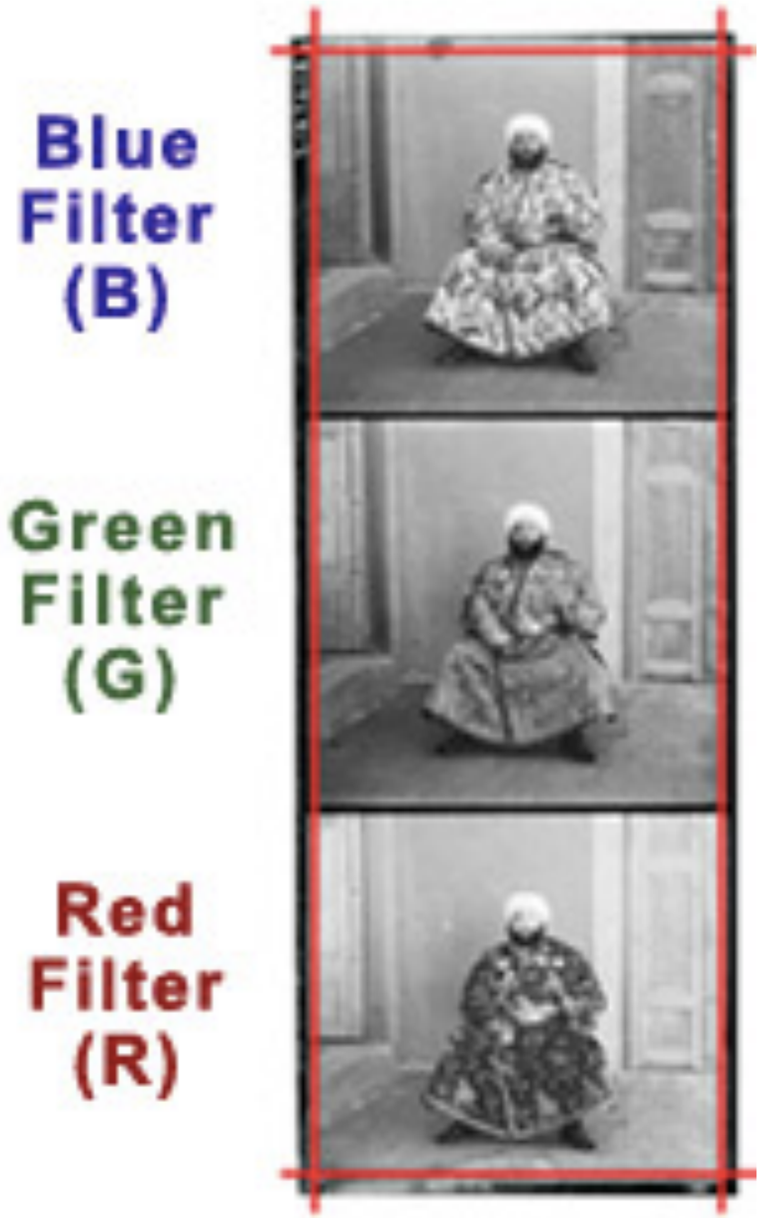
Alhacen notes

Niepce, “La Table Servie,” 1822

Old television camera

Early color photography

- Sergey Prokudin-Gorskii (1863-1944)
- Photographs of the Russian empire (1909-1916)



Only problem!

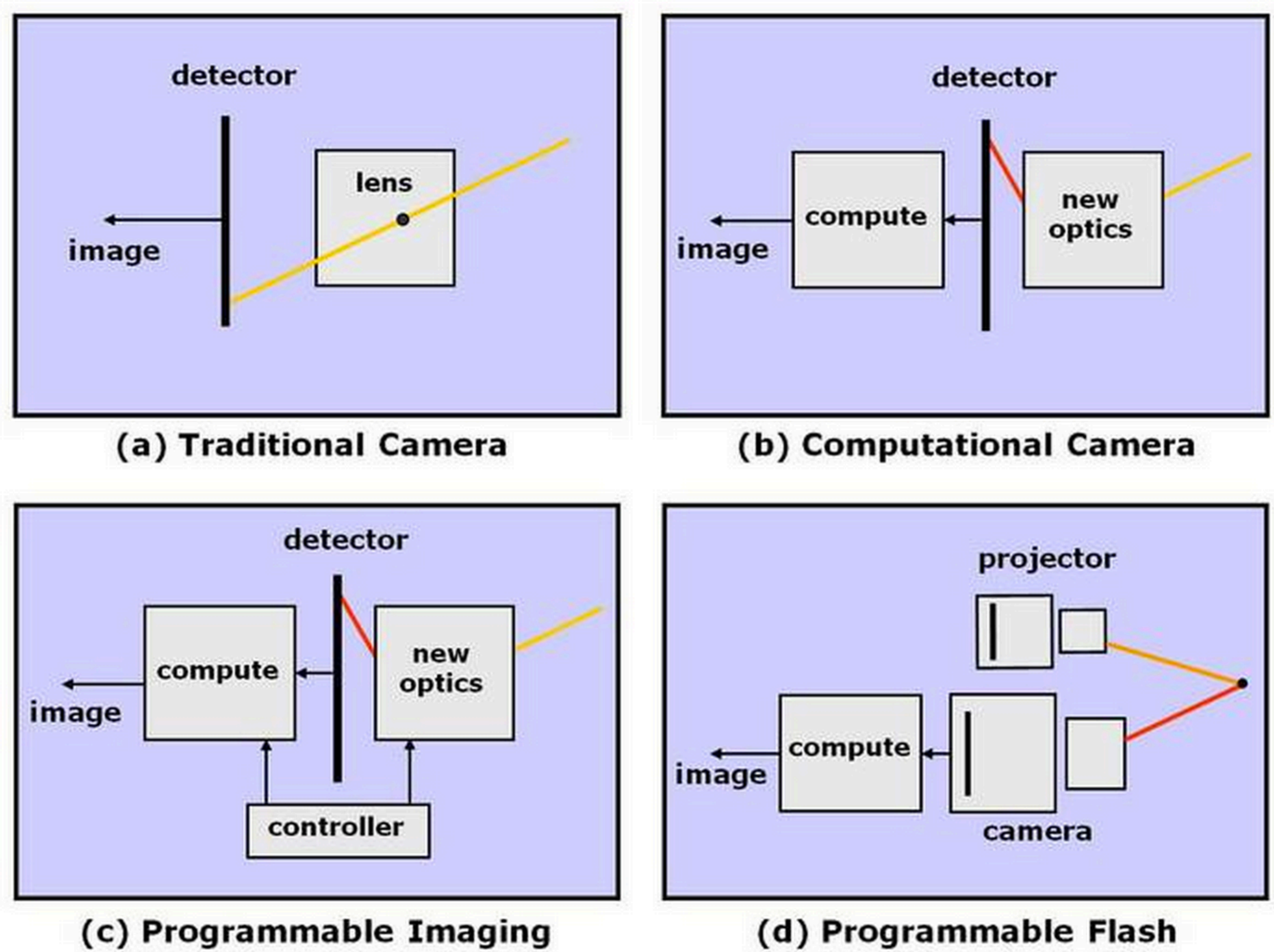
Homework 1: fix this by aligning the channels

First digitally scanned photo

- 1957, 176x176 pixels

http://listverse.com/2009/01/13/top-10-incredible-early-firsts-in-photography/

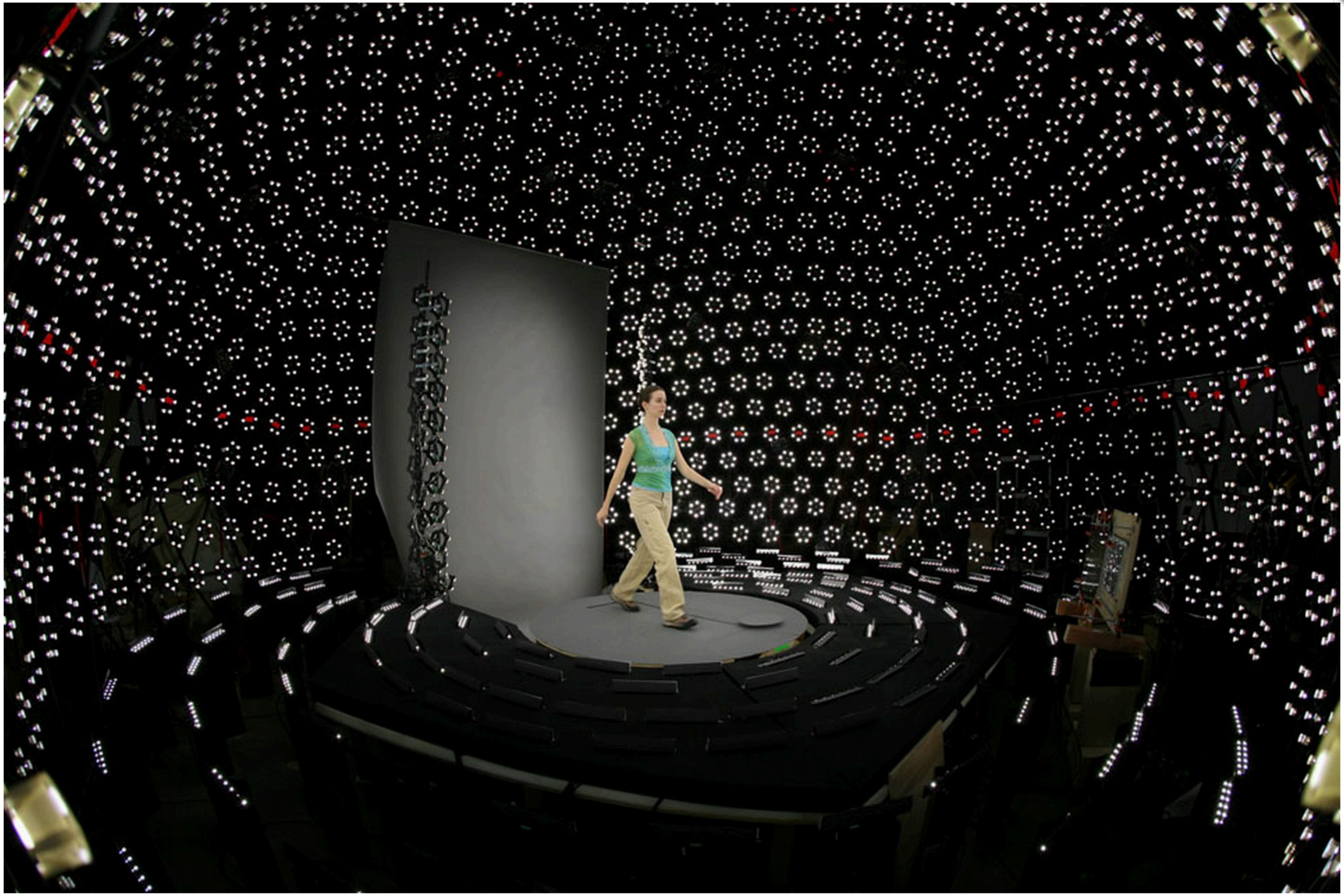
Computational cameras



S.K. Nayar http://www1.cs.columbia.edu/CAVE/projects/what_is/

Light Stage 6

- Sample over time, lighting, viewing direction, pose



inside Light Stage 6

Paul Debevec's group at USC-ICT http://ict.usc.edu/prototypes/light-stages/

More reading & thought problems

- Light stages over time **http://gl.ict.usc.edu/LightStages**
- Sergey Prokudin-Gorskii photographic collection at the Library of Congress **http://www.loc.gov/exhibits/empire/index.html**
- Richard Szeliski's book, Sections 2.2.3 - 2.3.2