Image Formation

Computer Vision
Fall 2019
Columbia University

Homework 0

- Due tonight at 11:55pm.
- You can use any scoring function you want.
- The borders of the image won't be very good because you have missing data.
- You can use any functions you want, but you don't need anything beyond numpy. Keep it simple.

Course Website

- If you log out of your Columbia account, it appears you can access the course website.
- This is obviously backwards. We aren’t sure how to fix?

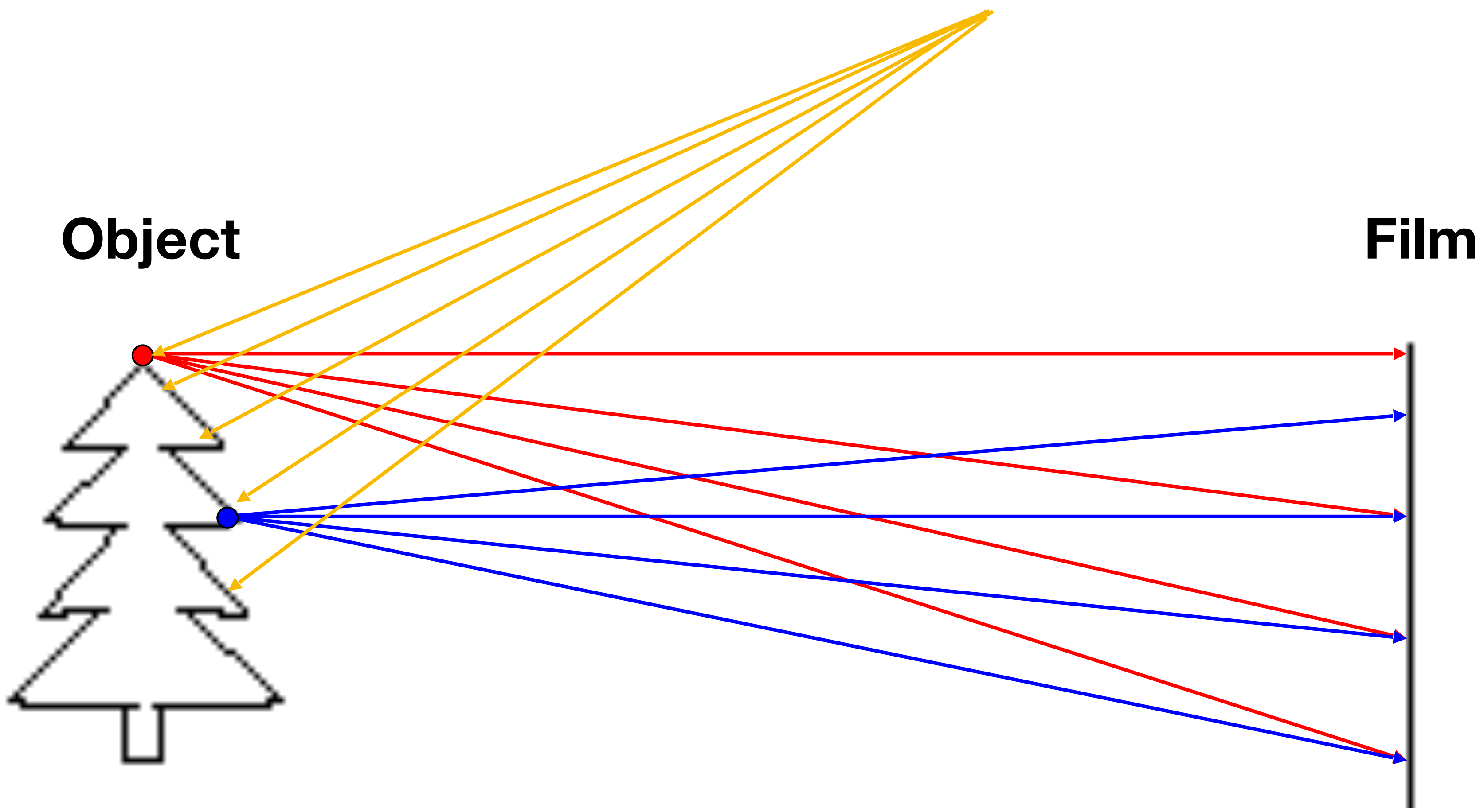
TAs

- Thanks to everyone who emailed.
- I am way behind on email. I will respond soon.
- On that note, please only send course messages to Piazza. If you email me, it will go into a black hole.

Note Taker Requested

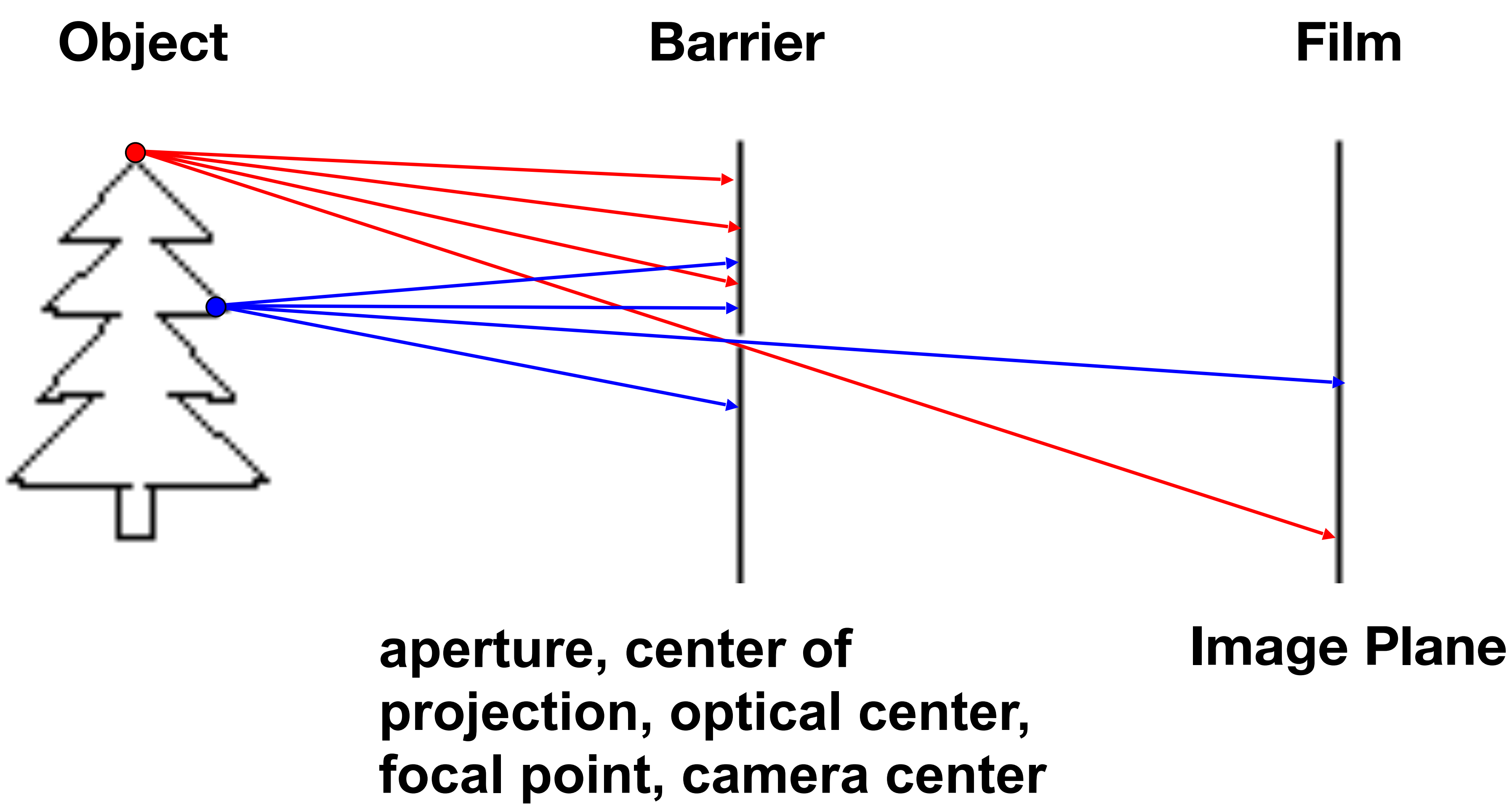
- See Piazza

Image Formation



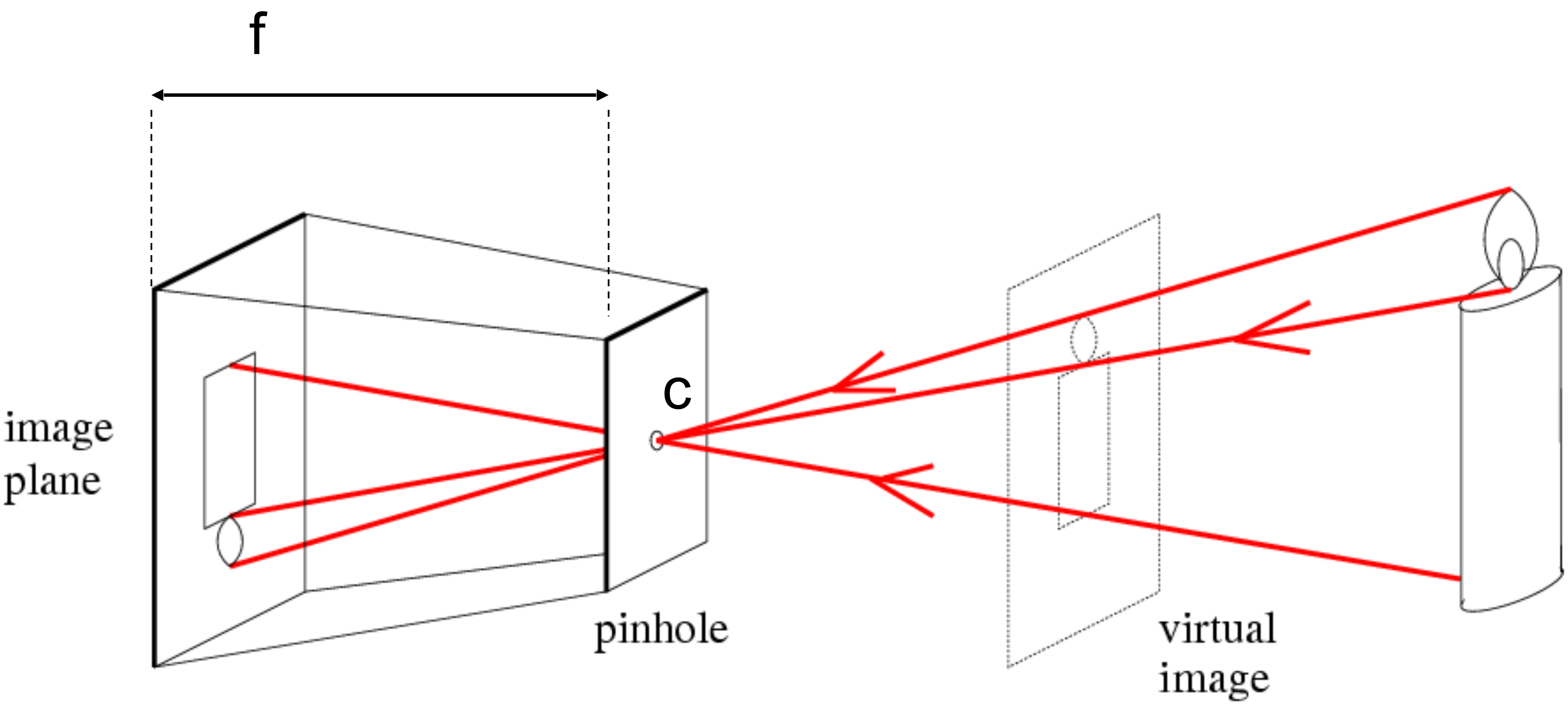
Slide credit: Steve Seitz

Image Formation



Slide credit: Steve Seitz

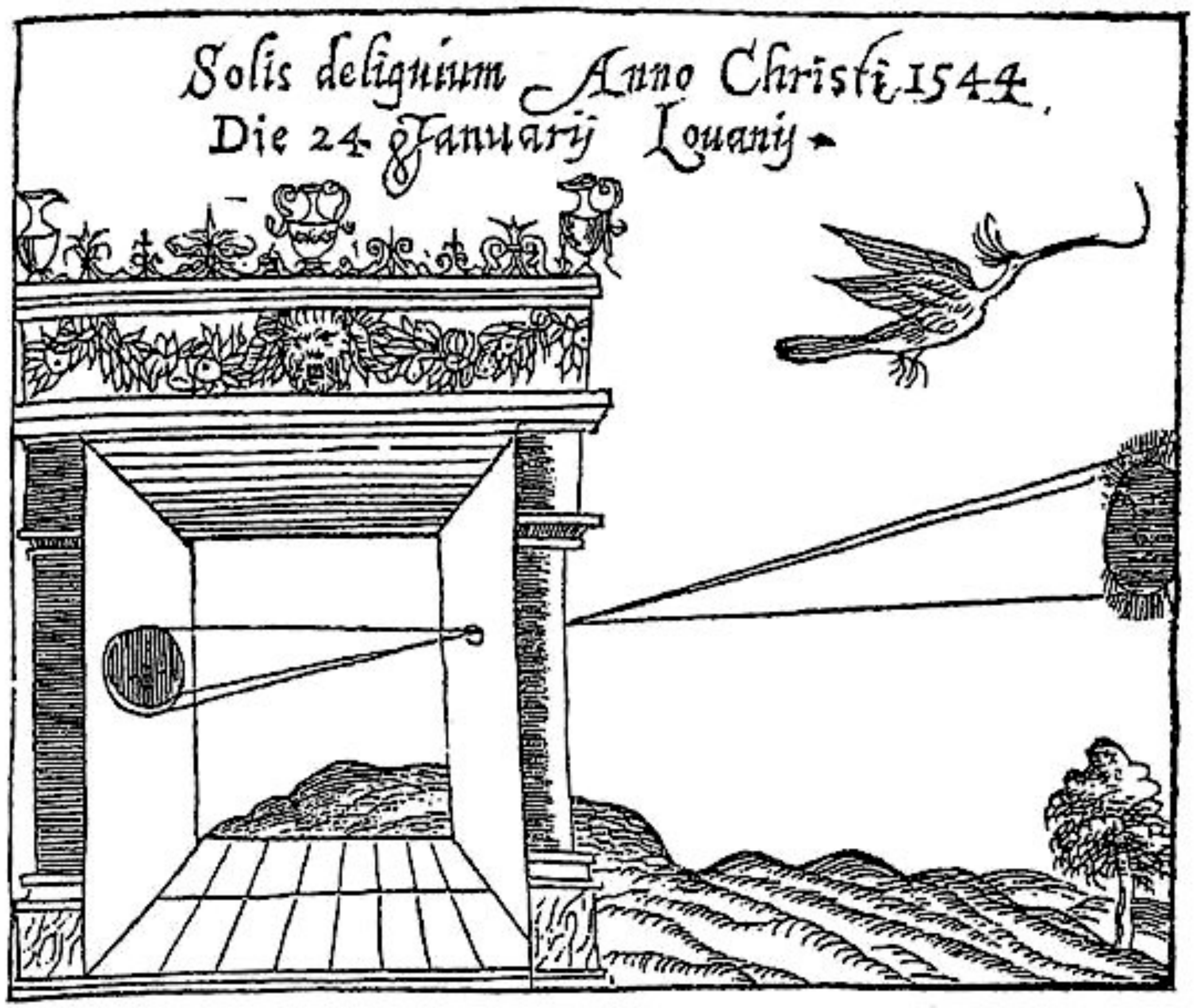
Pinhole camera



f = focal length
c = center of the camera

Figure from Forsyth

Camera obscura (Latin for “Dark Chamber”)



Gemma Frisius, 1558

- Basic principle known to Mozi (470-390 BCE), Aristotle (384-322 BCE)
- Drawing aid for artists: described by Leonardo da Vinci (1452-1519)

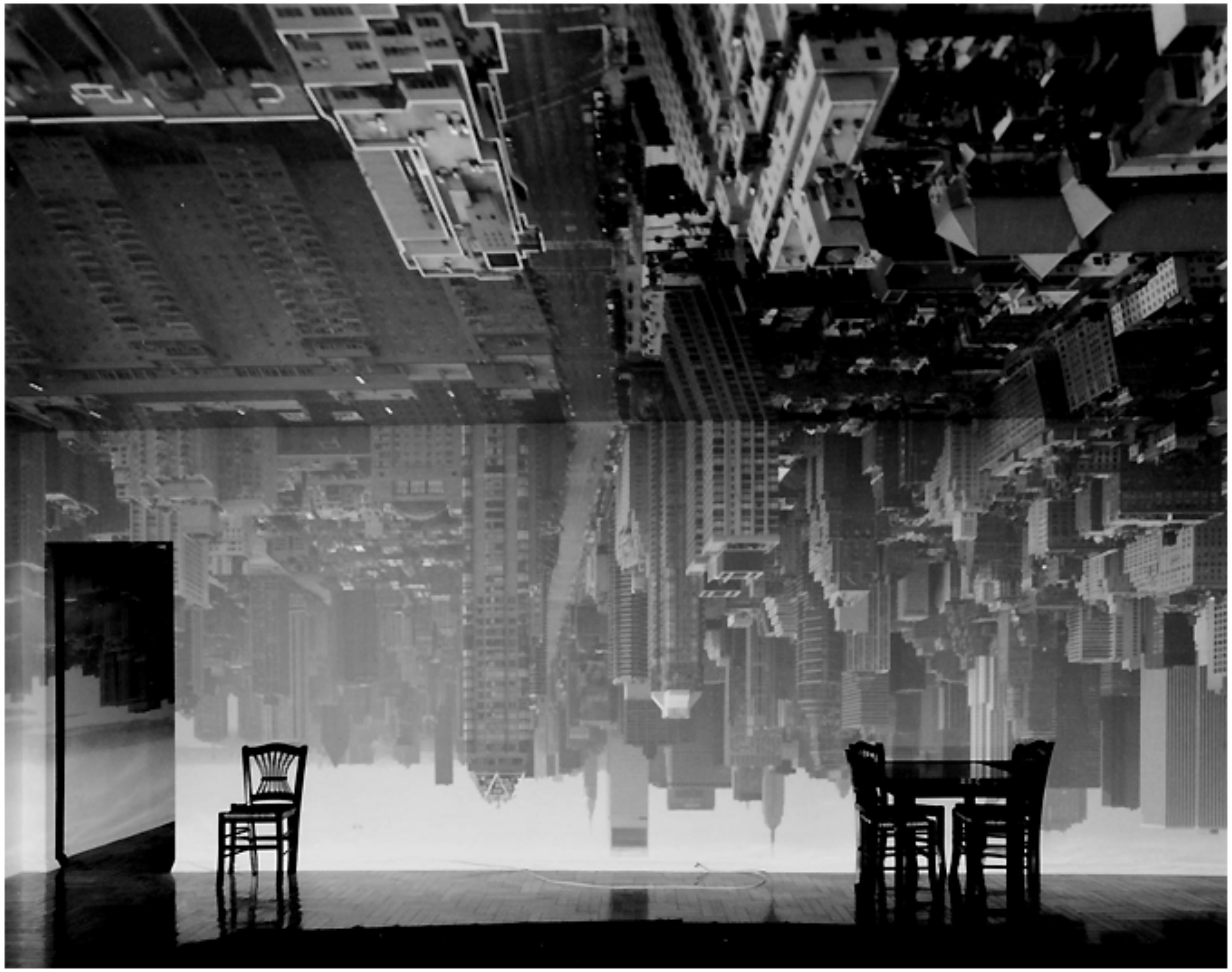
Source: A. Efros

Home-made pinhole camera

Slide by A. Efros

http://www.debevec.org/Pinhole/

Turning a room into a camera obscura



Abelardo Morell, Camera Obscura Image of Manhattan View Looking South in Large Room, 1996

After scouting rooms and reserving one for at least a day, Morell masks the windows except for the aperture. He controls three elements: the size of the hole, with a smaller one yielding a sharper but dimmer image; the length of the exposure, usually eight hours; and the distance from the hole to the surface on which the outside image falls and which he will photograph. He used 4 x 5 and 8 x 10 view cameras and lenses ranging from 75 to 150 mm.

After he's done inside, it gets harder. "I leave the room and I am constantly checking the weather, I'm hoping the maid reads my note not to come in, I'm worrying that the sun will hit the plastic masking and it will fall down, or that I didn't trigger the lens."

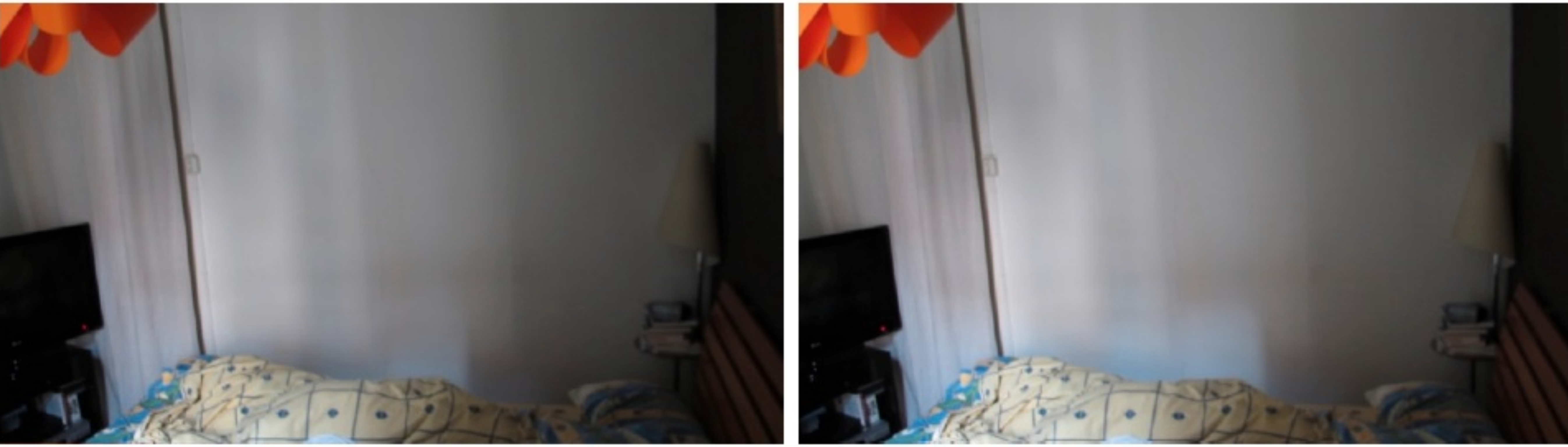
From *Grand Images Through a Tiny Opening*, **Photo District News,** February 2005

http://www.abelardomorell.net/camera_obscura1.html

Accidental Cameras

Accidental Pinhole and Pinspeck Cameras
Revealing the scene outside the picture.
Antonio Torralba, William T. Freeman

Accidental Cameras



a) Input (occluder present) b) Reference (occluder absent)

c) Difference image (b-a) d) Crop upside down e) True view

Pinhole cameras everywhere

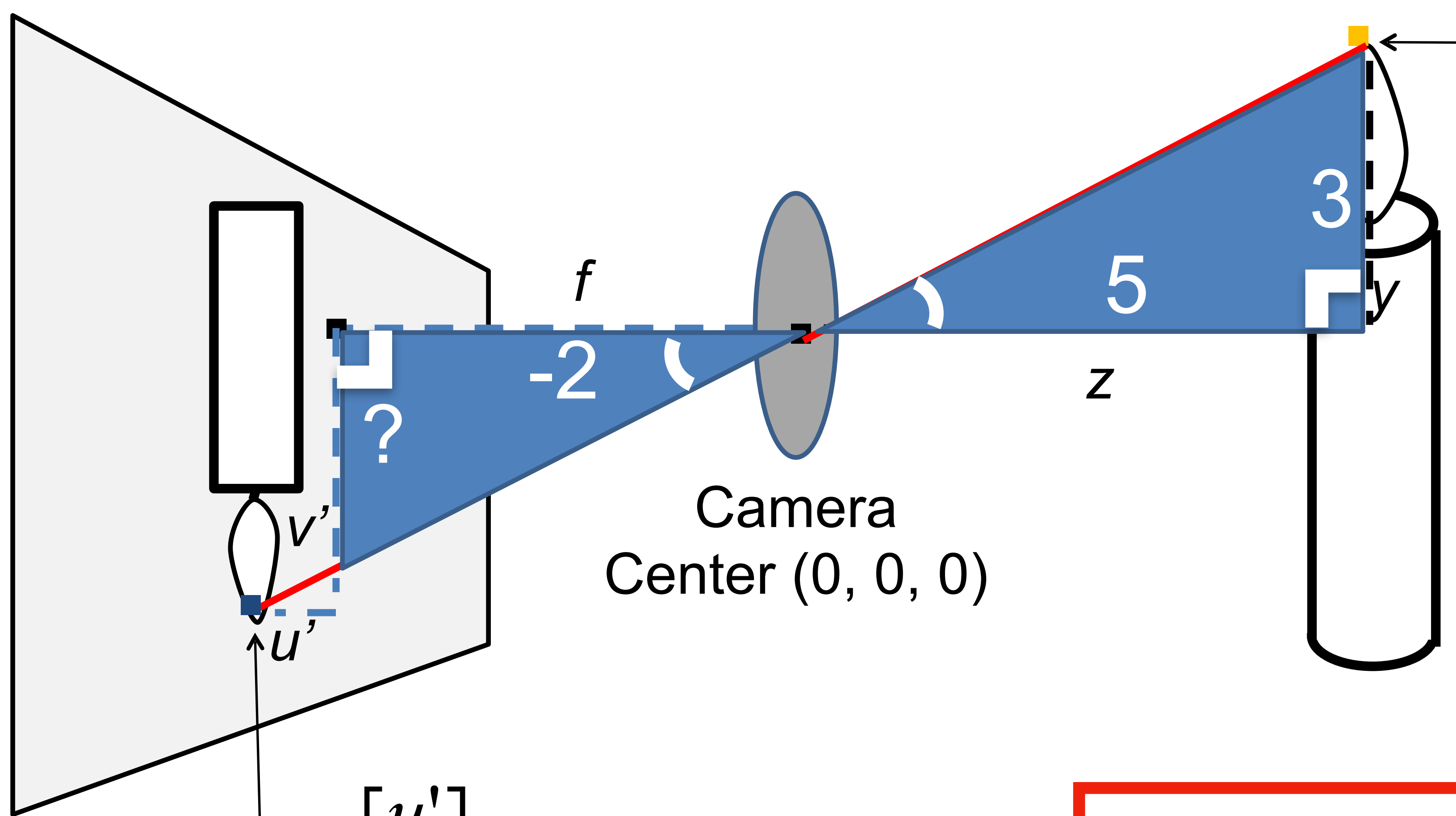
Tree shadow during a solar eclipse

photo credit: Nils van der Burg

http://www.physicstogo.org/index.cfm

Slide by Steve Seitz

Projection: world coordinates→image coordinates



$$X = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$x = \begin{bmatrix} u' \\ v' \end{bmatrix}$$

If X = 2, Y = 3,
Z = 5, and f = 2
What are U and V?

$$\frac{v'}{-f} = \frac{y}{z}$$

Projection Equations

$$u' = -x * \frac{f}{z}$$

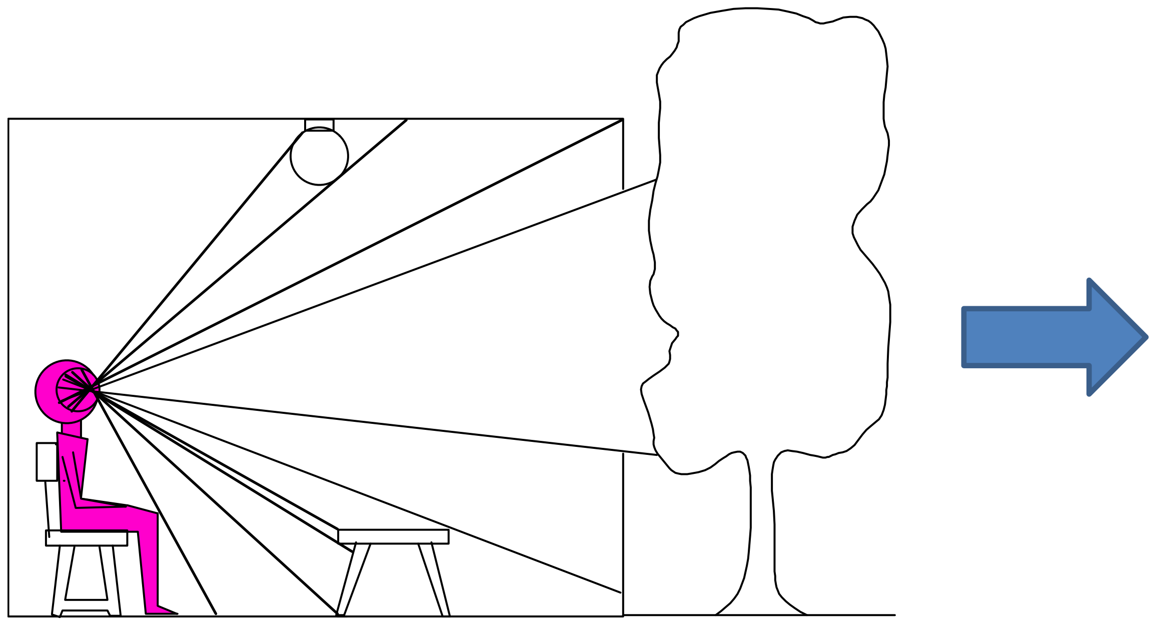
$$v' = -y * \frac{f}{z}$$

$$u' = -2 * \frac{2}{5}$$

$$v' = -3 * \frac{2}{5}$$

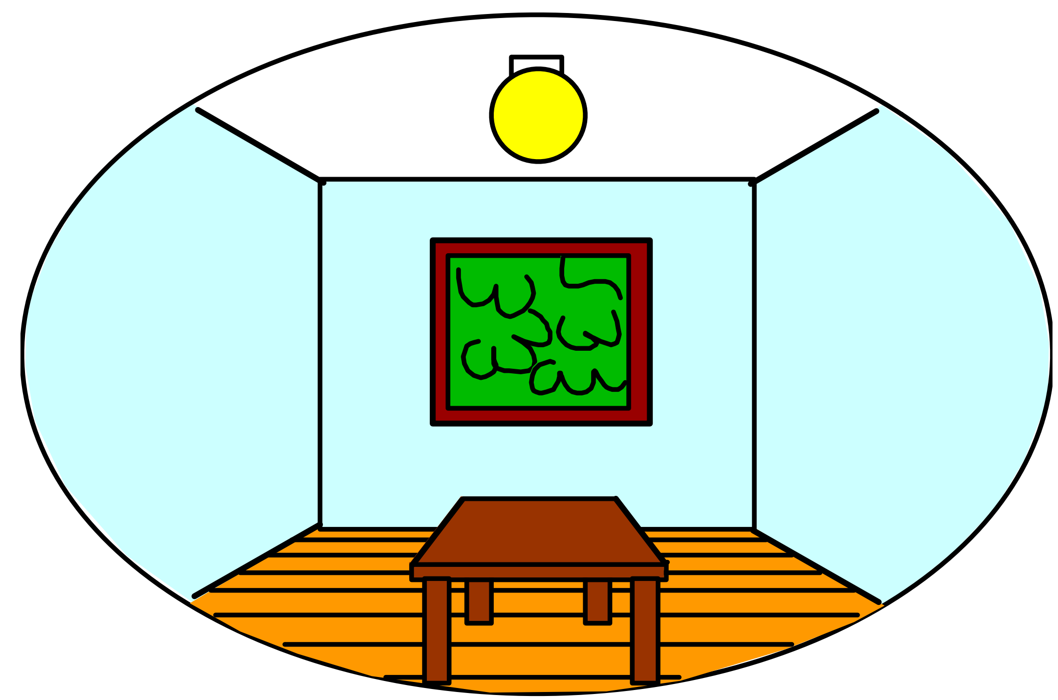
Dimensionality Reduction Machine (3D to 2D)

3D world



Point of observation

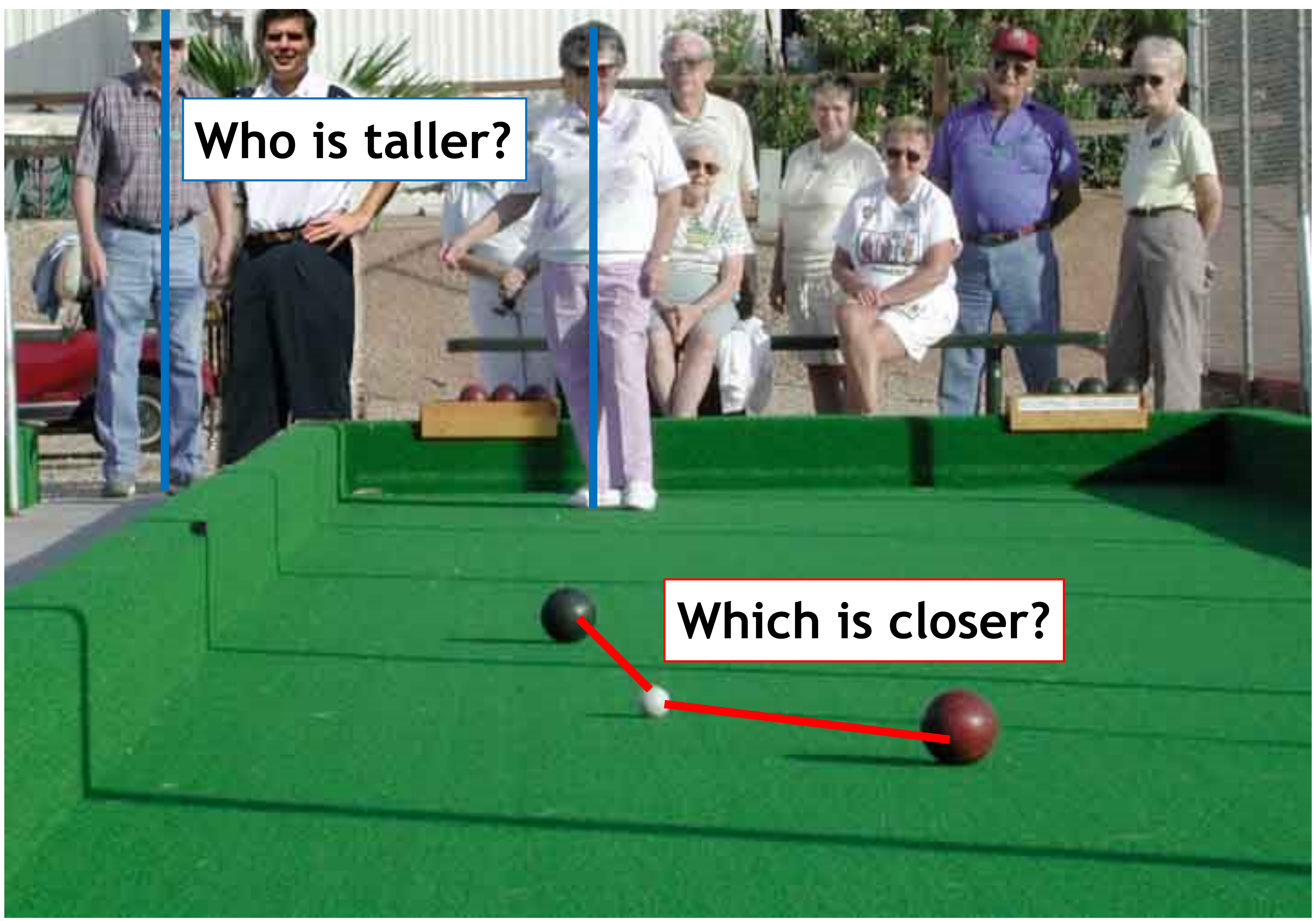
2D image



Projective Geometry

What is lost?

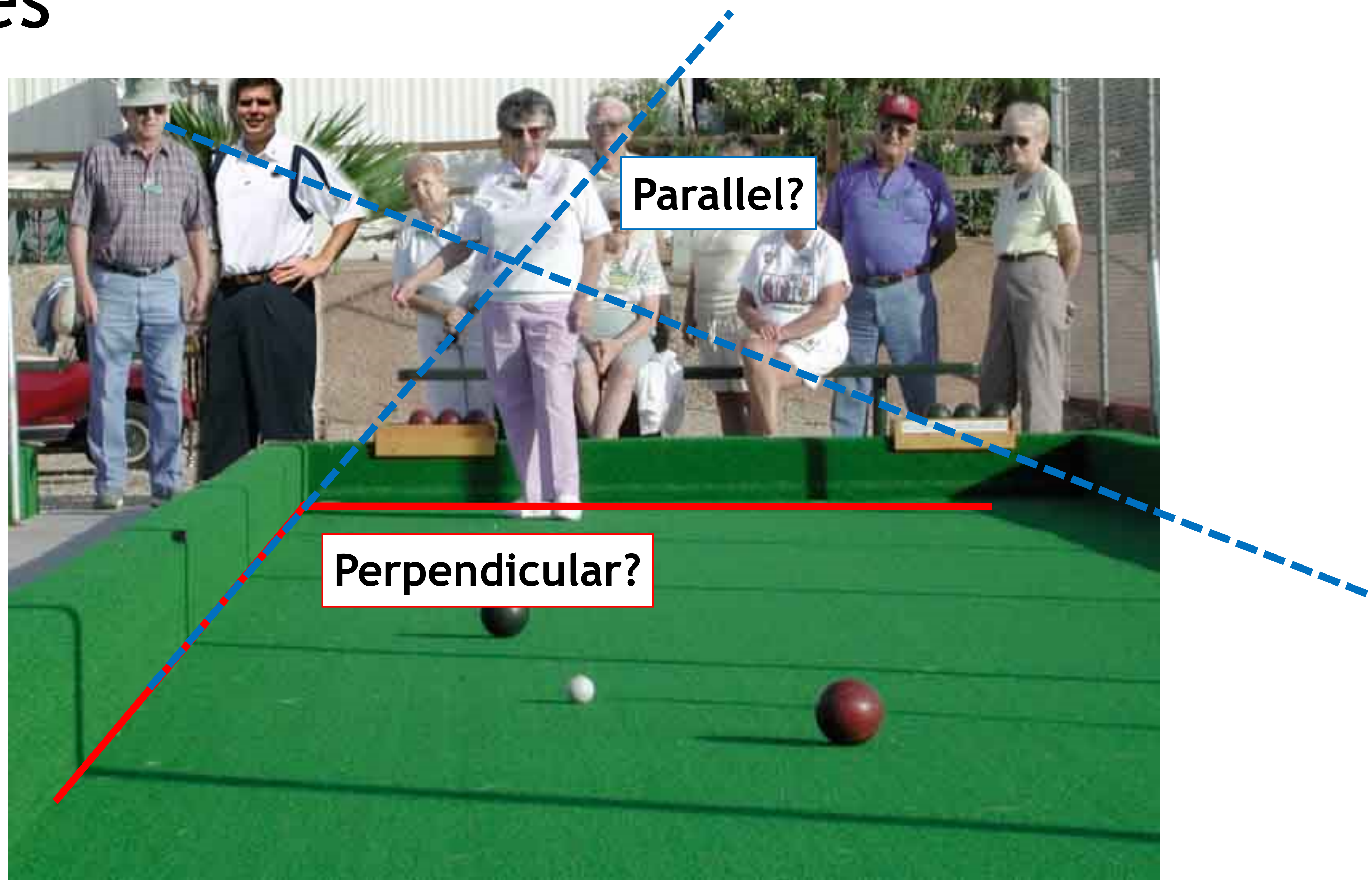
- Length



Projective Geometry

What is lost?

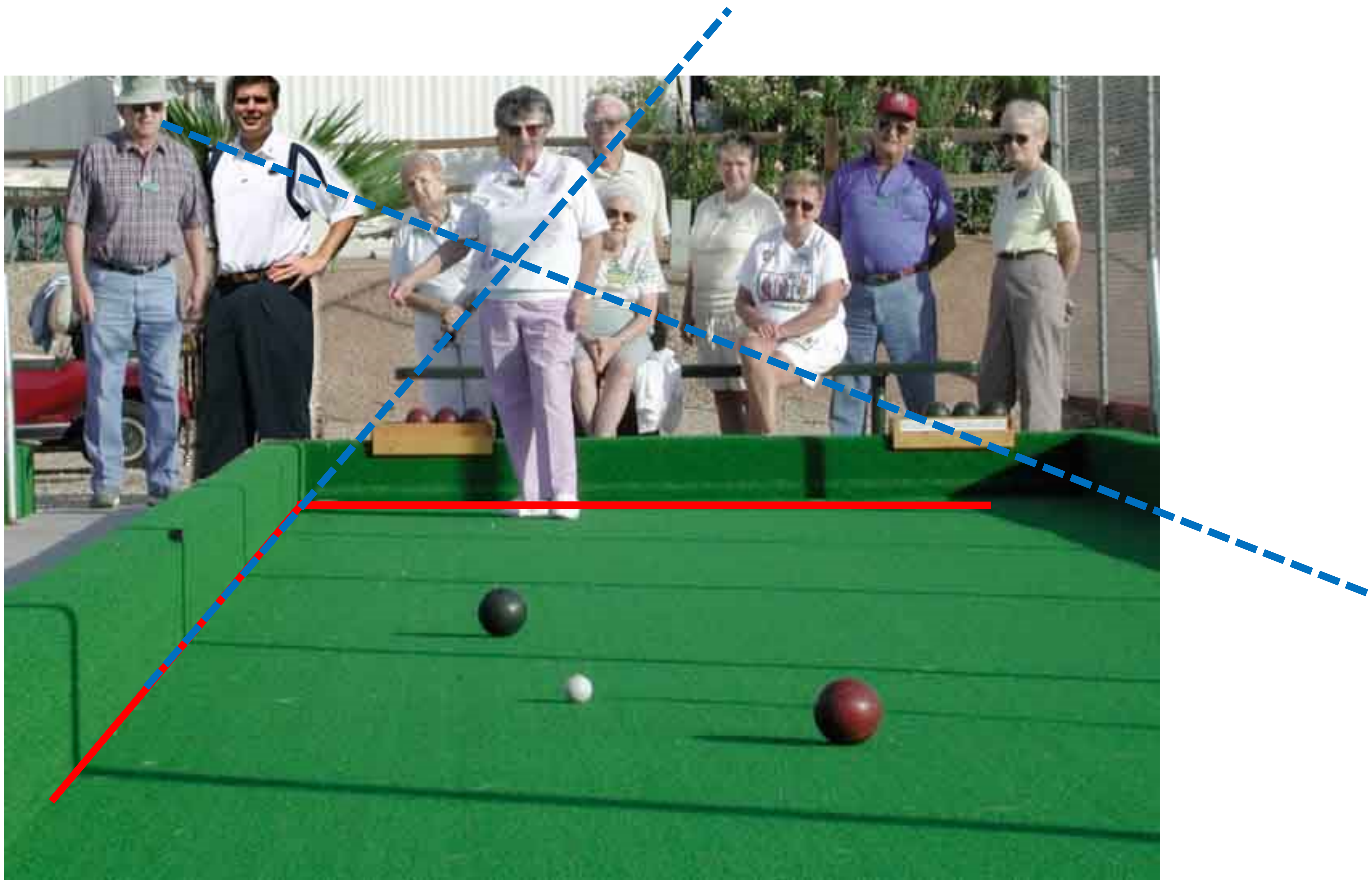
- Length
- Angles



Projective Geometry

What is preserved?

- Straight lines are still straight



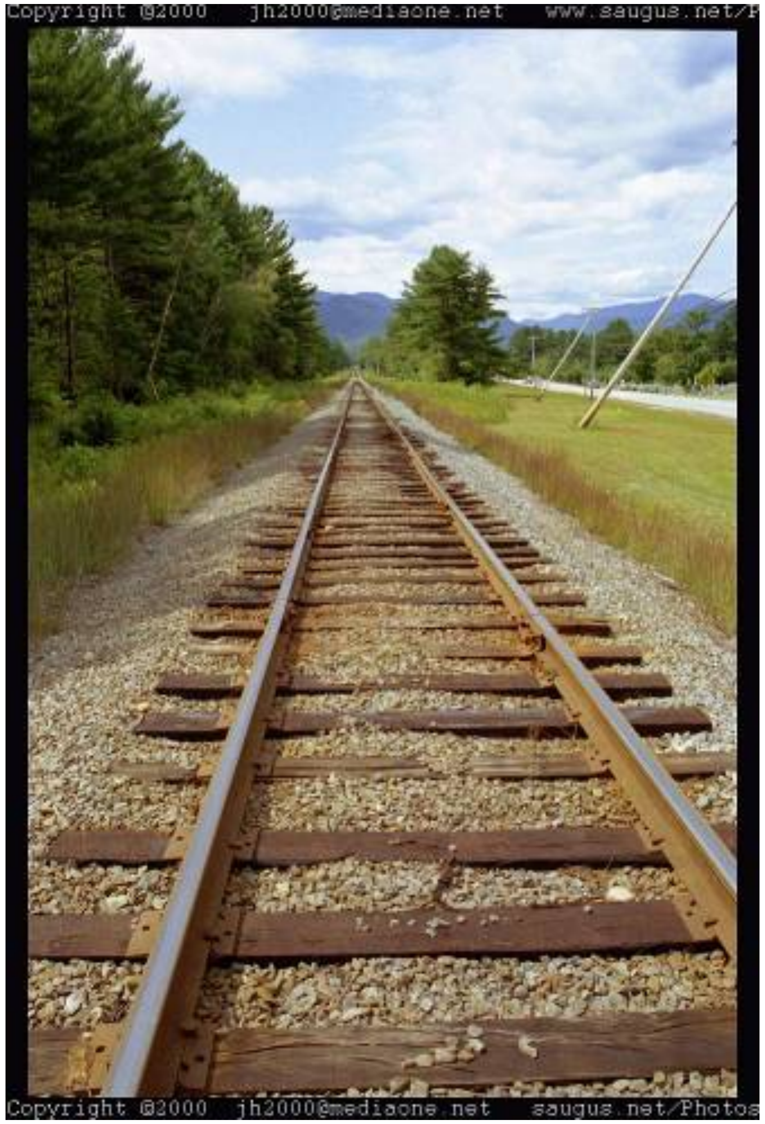
False Perspective

Depth appears to be ~155 feet

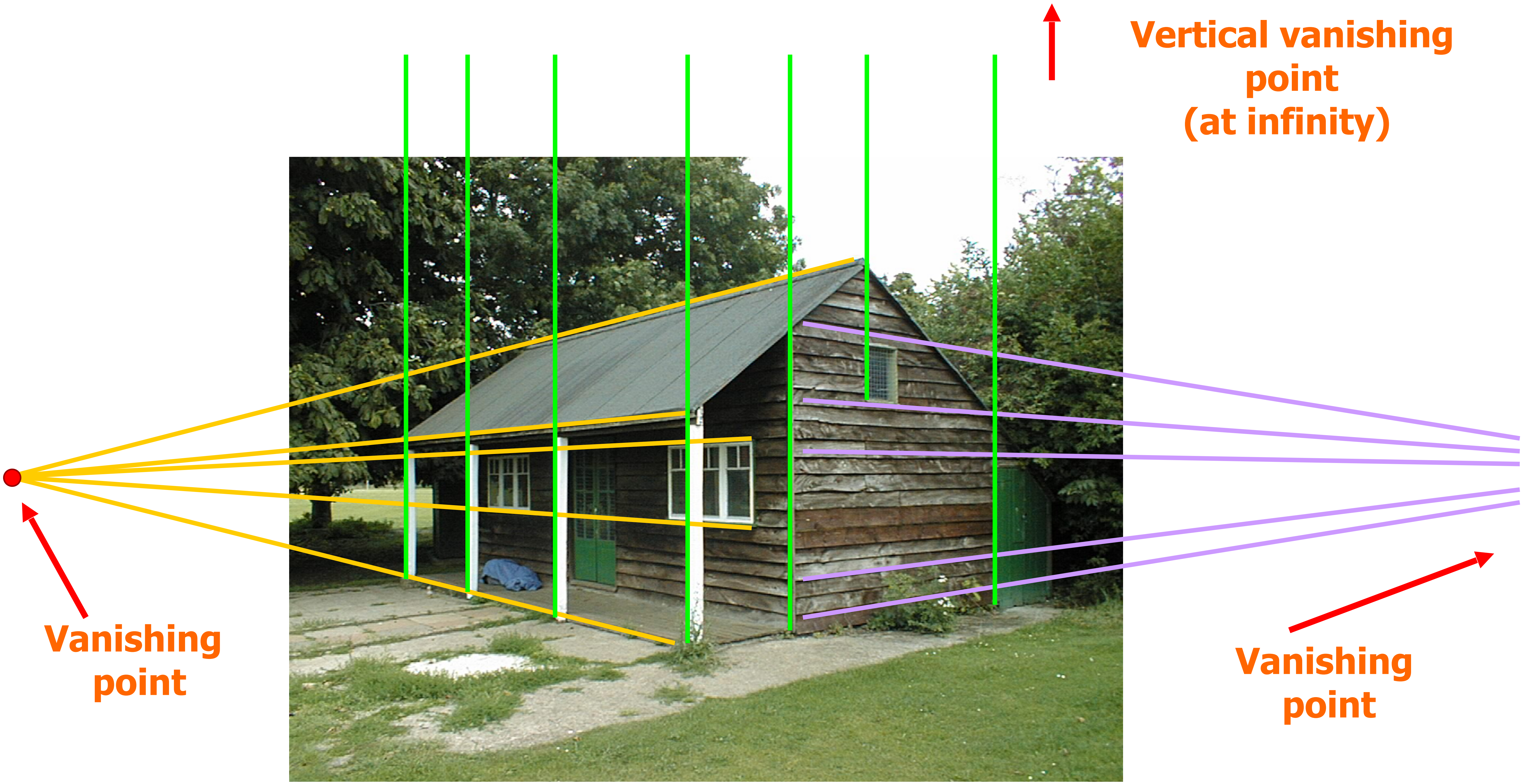
Depth is actually ~30 feet

Vanishing points

- All parallel lines converge to a *vanishing point*
  - Each direction in space is associated with its own vanishing point
  - Exception: directions parallel to the image plane

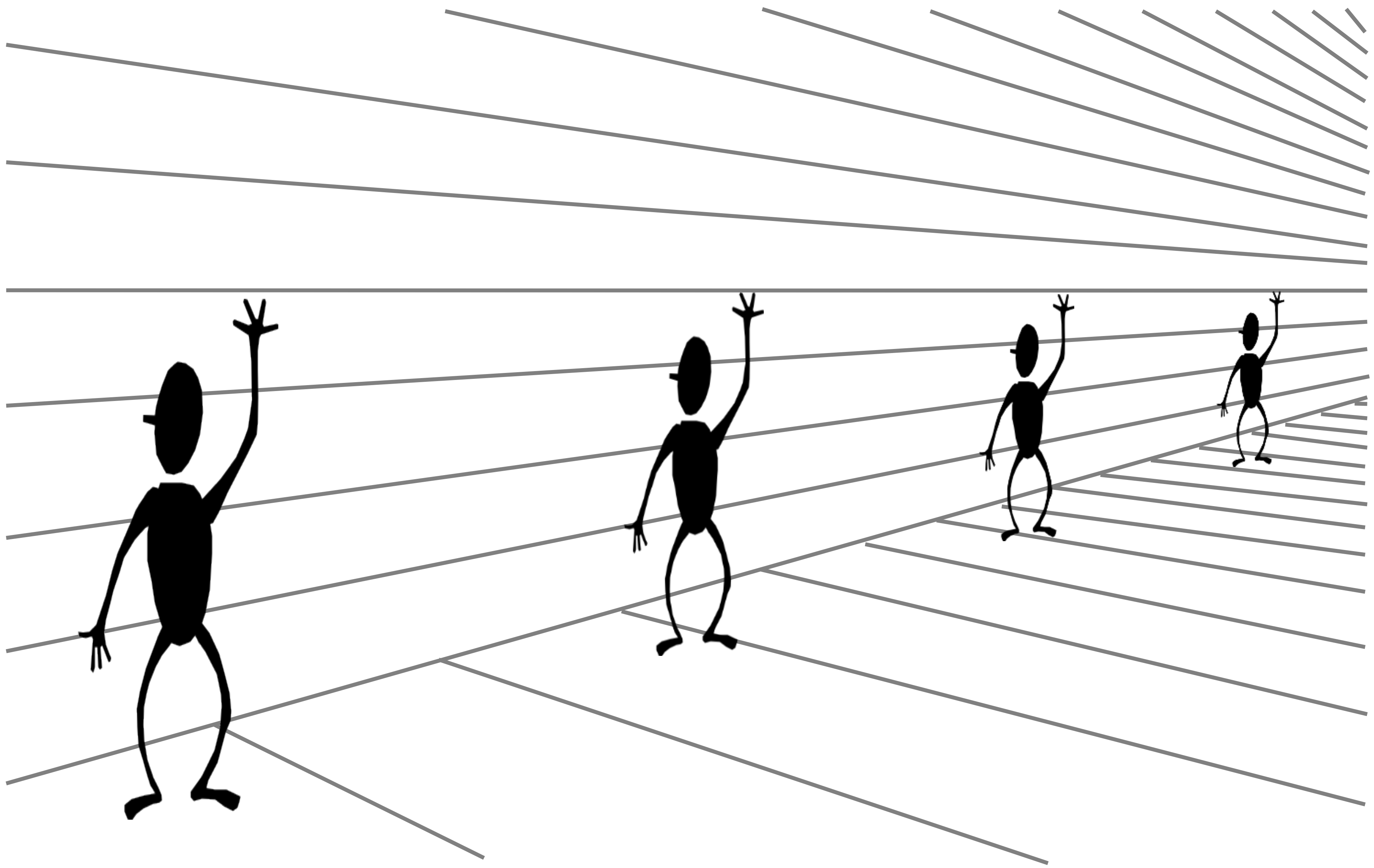


Vanishing points and lines



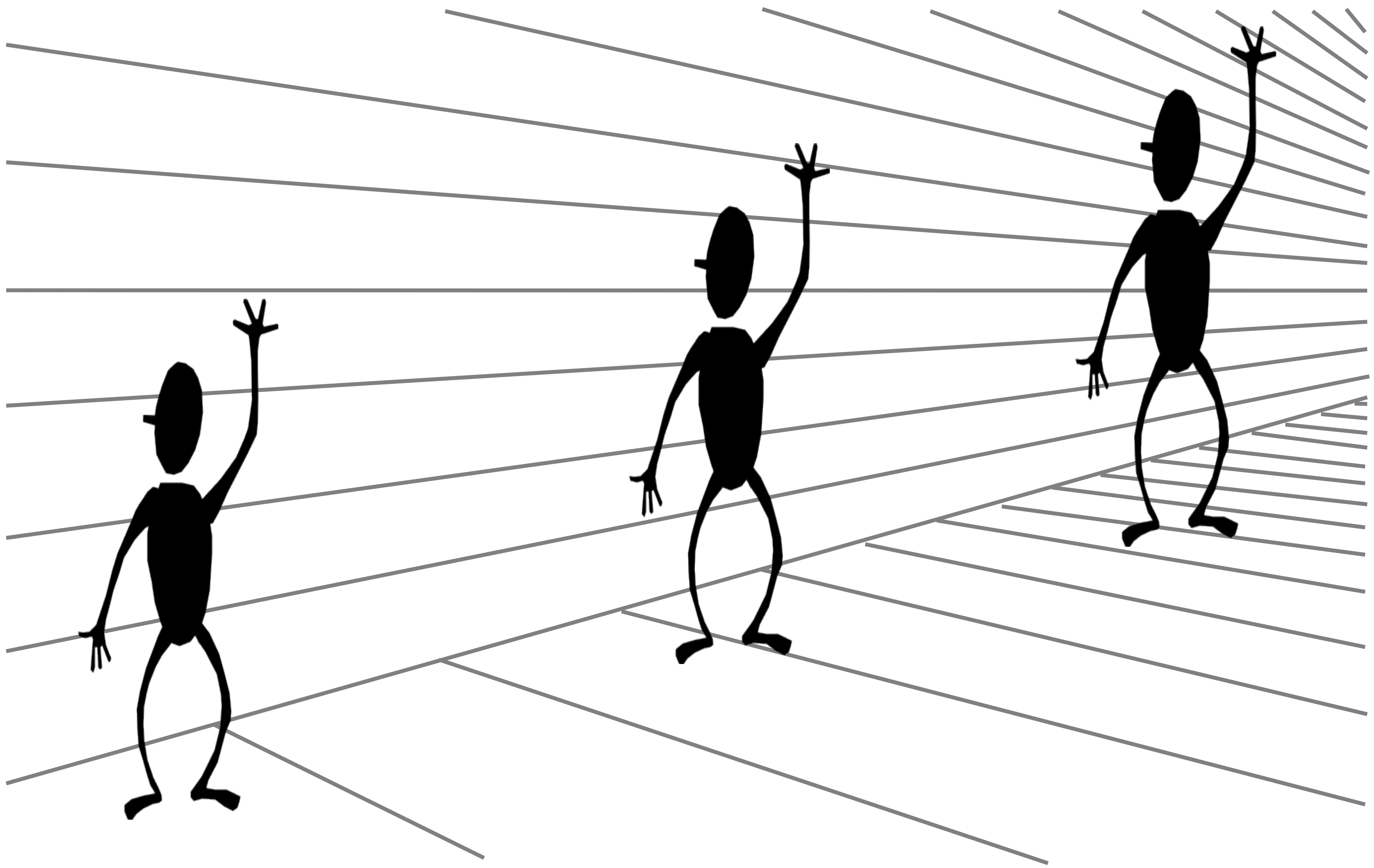
Slide from Efros, Photo from Criminisi

Perspective cues



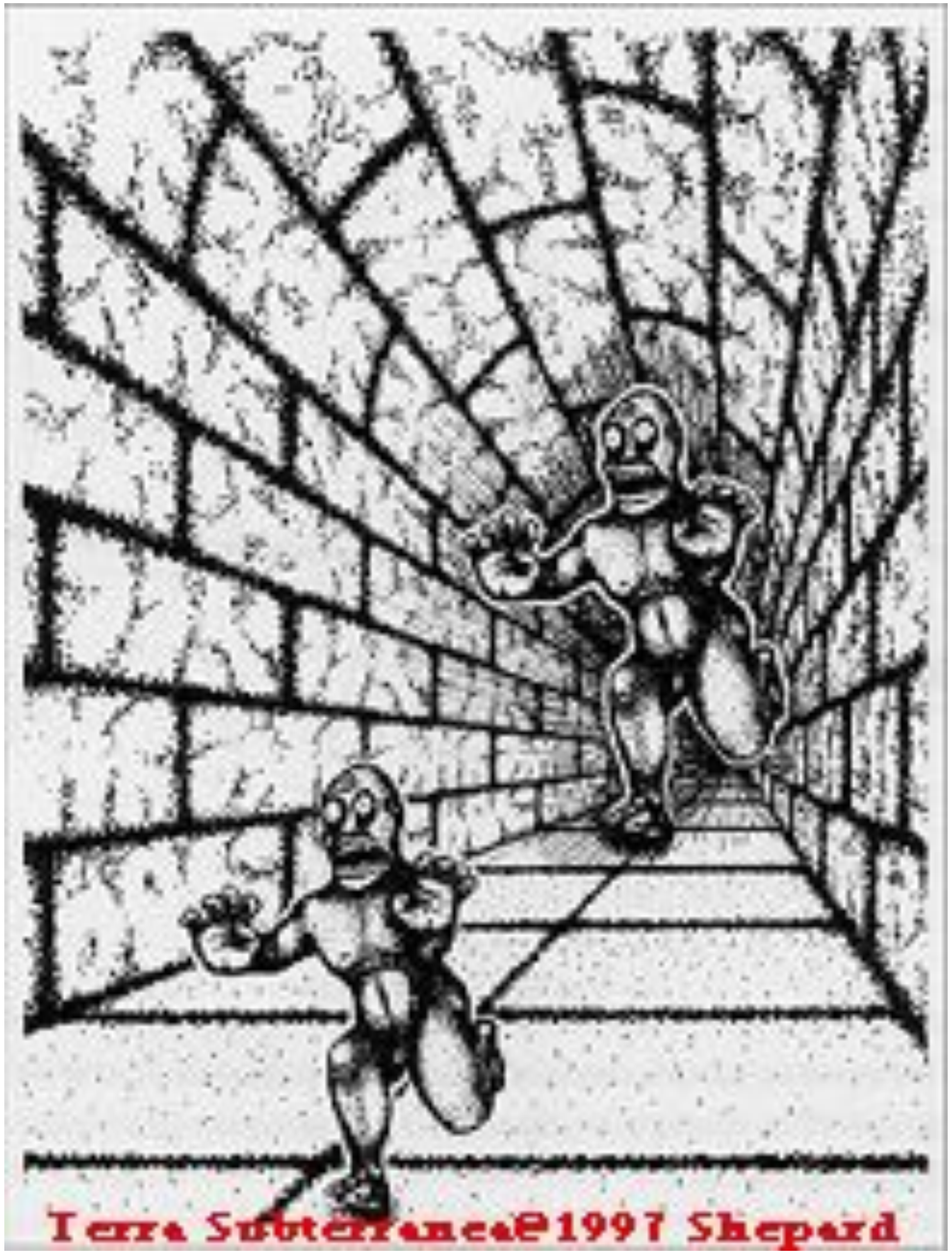
Slide by Steve Seitz

Perspective cues



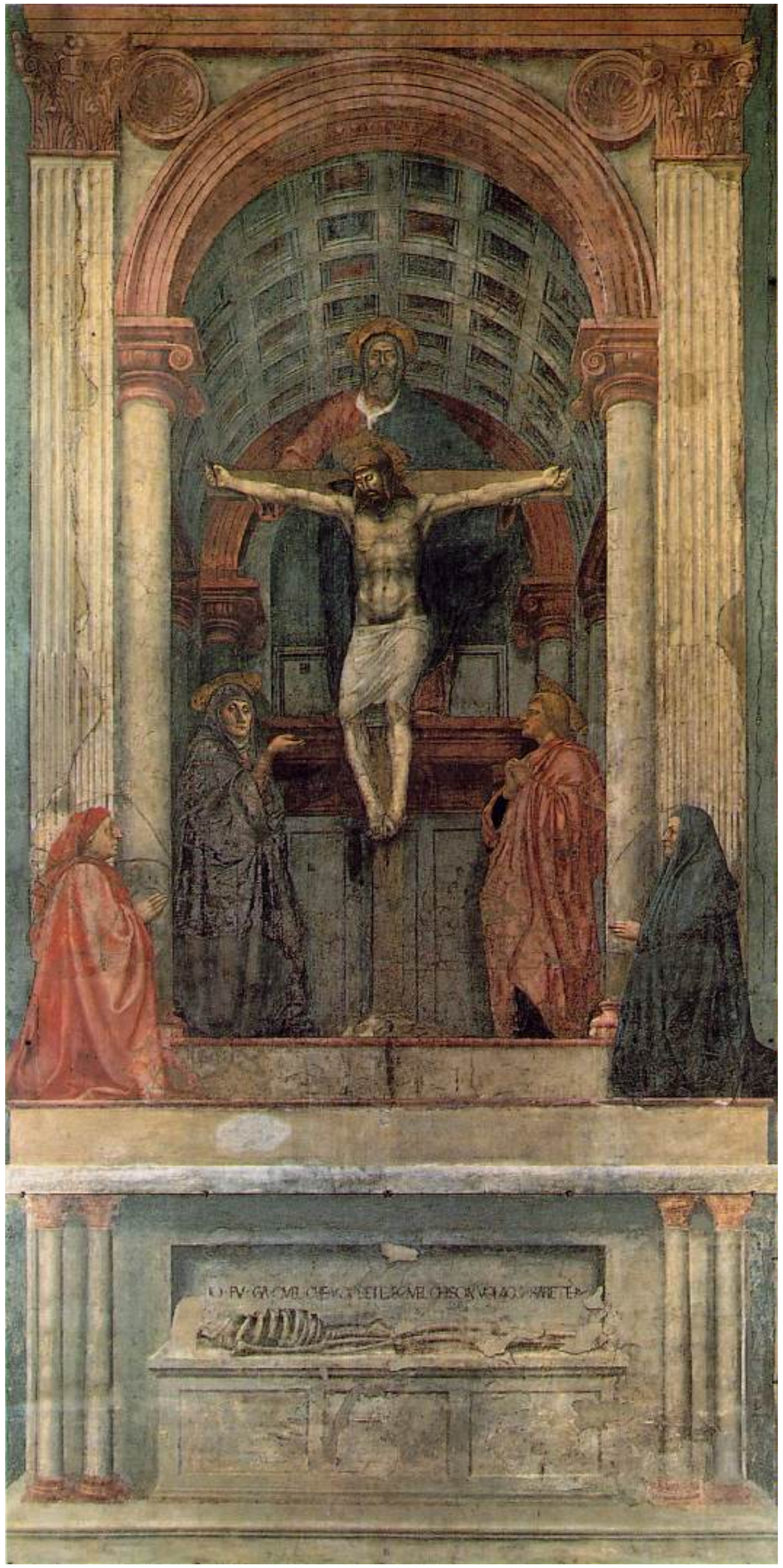
Slide by Steve Seitz

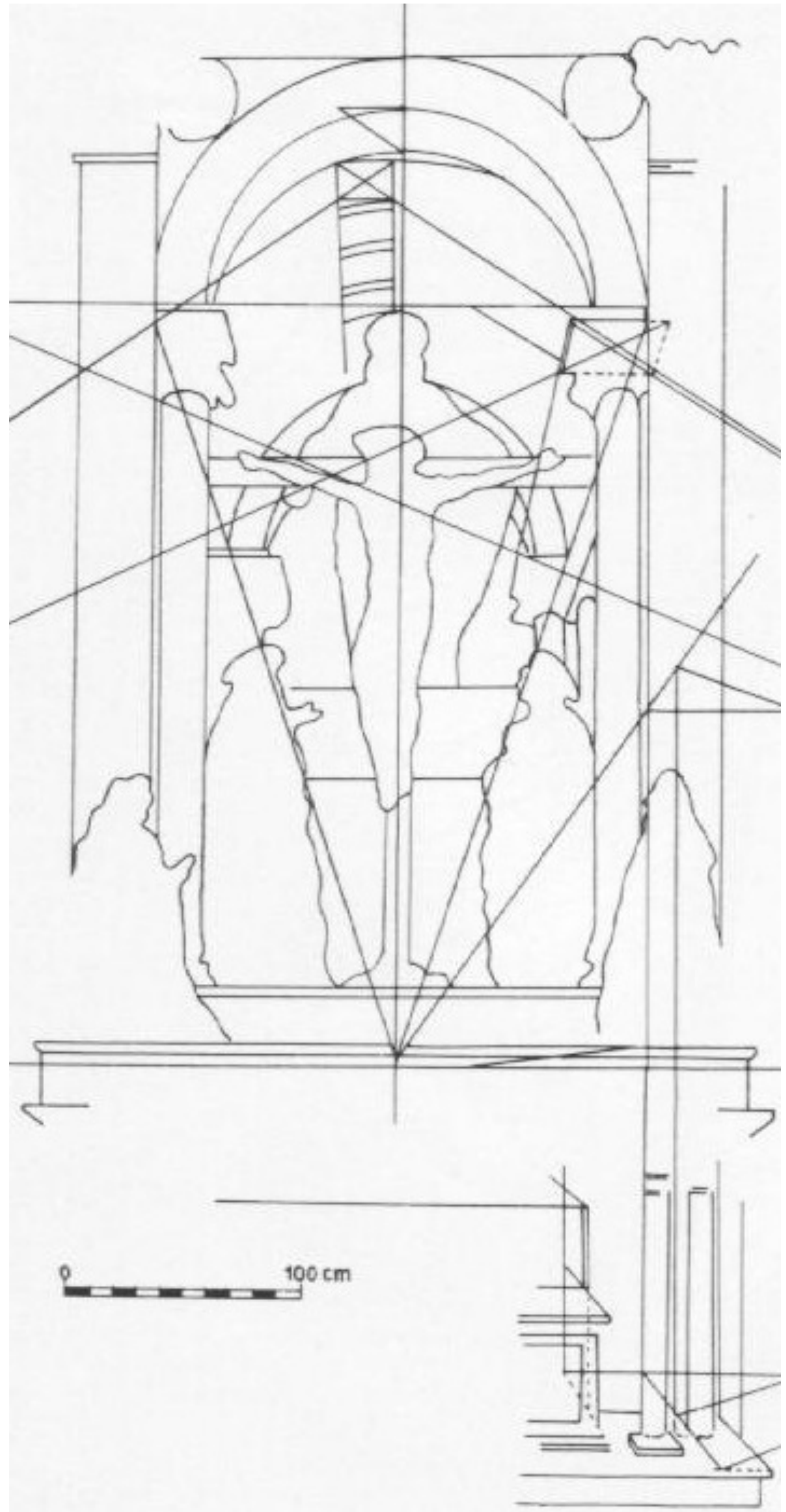
Perspective cues



Slide by Steve Seitz

Perspective cues in art





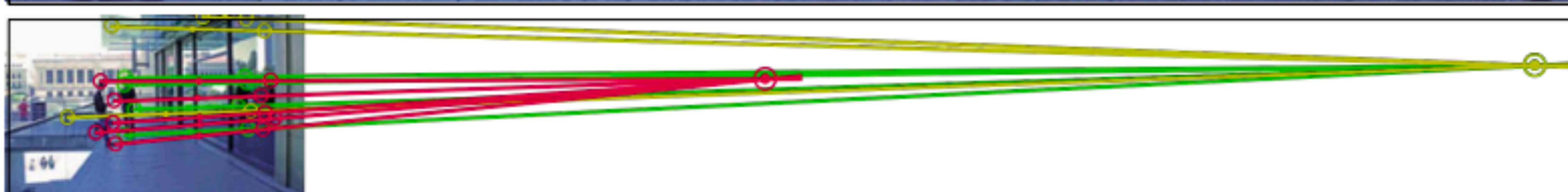
Masaccio, *Trinity*, Santa Maria Novella, Florence, 1425-28

One of the first consistent uses of perspective in Western art

Image Forensics

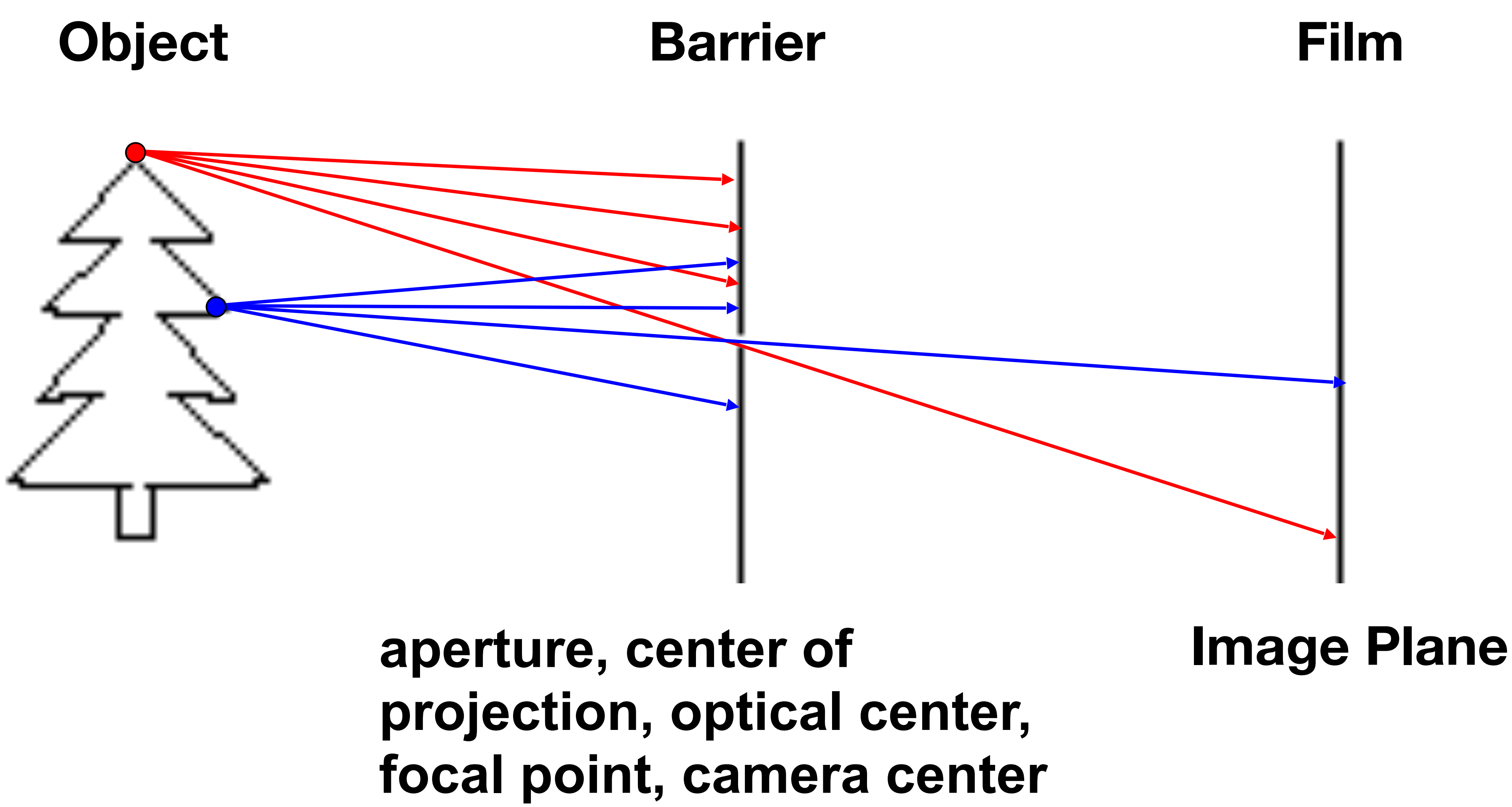
[J. O'Brien & H. Farid, SIGGRAPH 2012]

Image Forensics



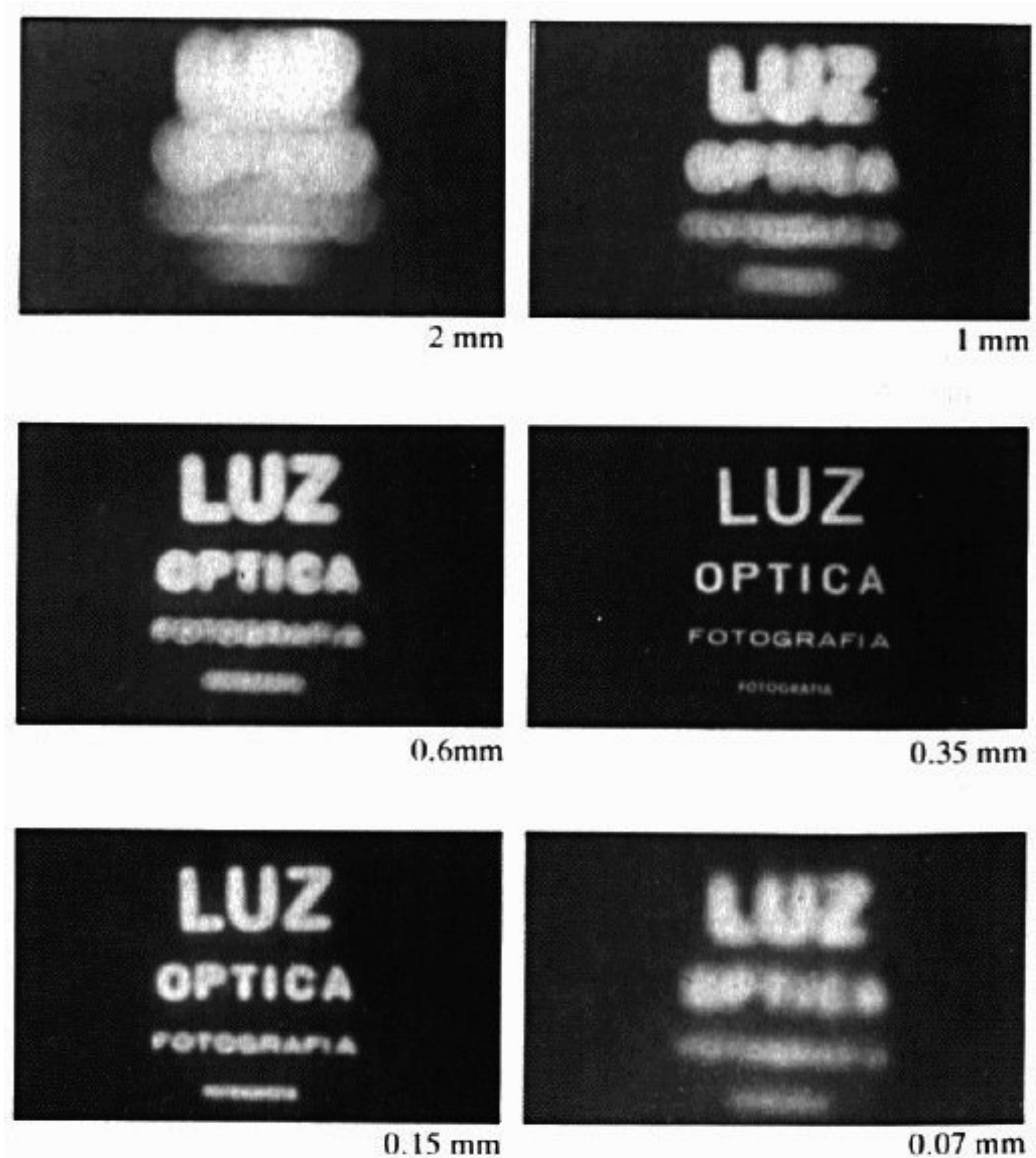
[J. O'Brien & H. Farid, SIGGRAPH 2012]

How big should the aperture be?

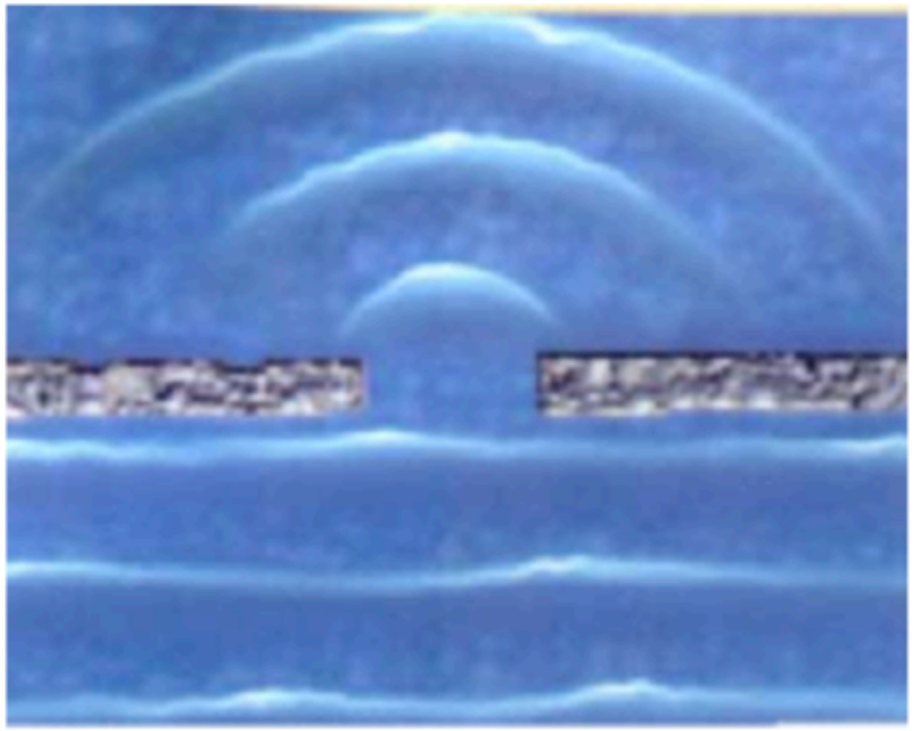


Slide credit: Steve Seitz

Shrinking the aperture

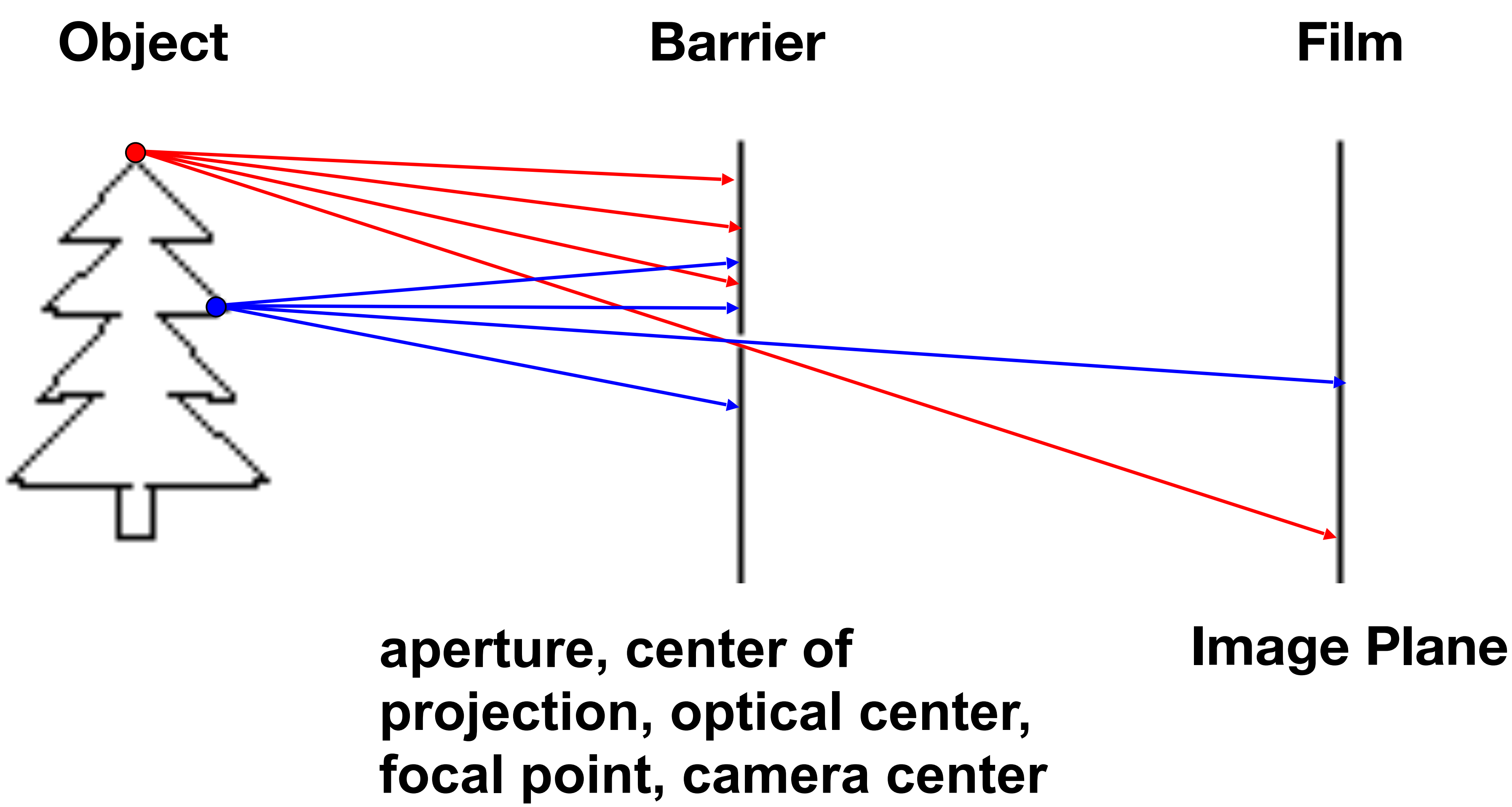


Slide by Steve Seitz



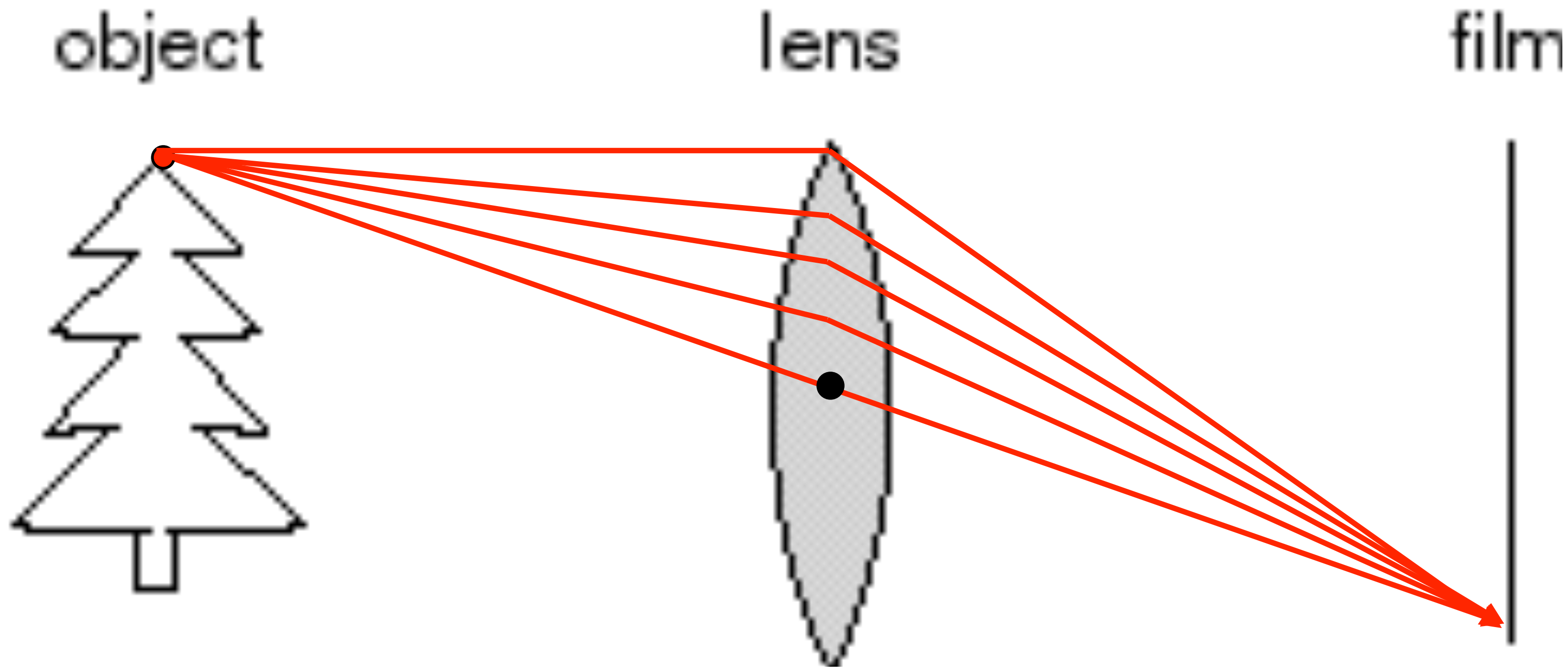
Diffraction

But there's another problem…



Slide credit: Steve Seitz

Adding a lens

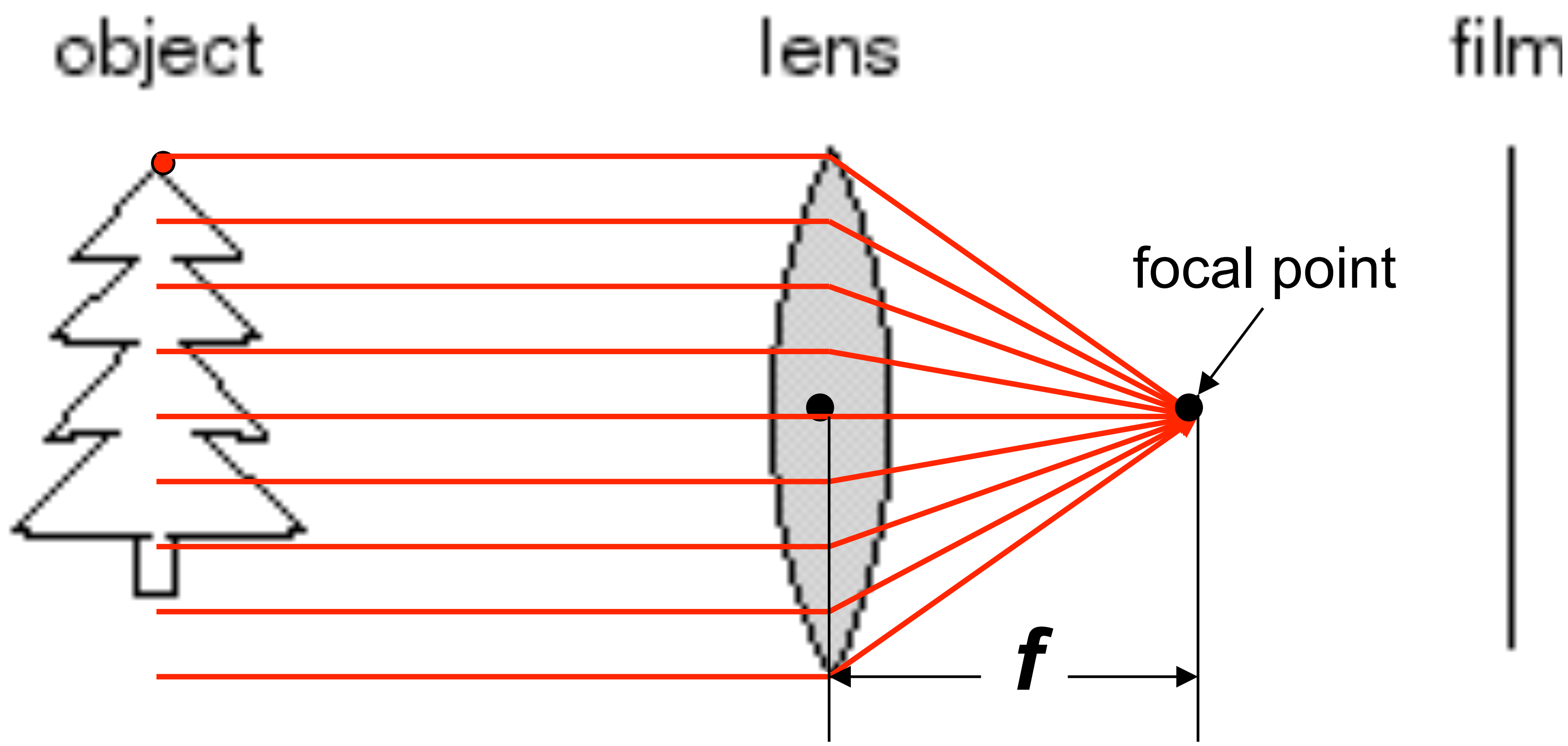


A lens focuses light onto the film

- Thin lens model:
  - Rays passing through the center are not deviated (pinhole projection model still holds)

Slide by Steve Seitz

Adding a lens

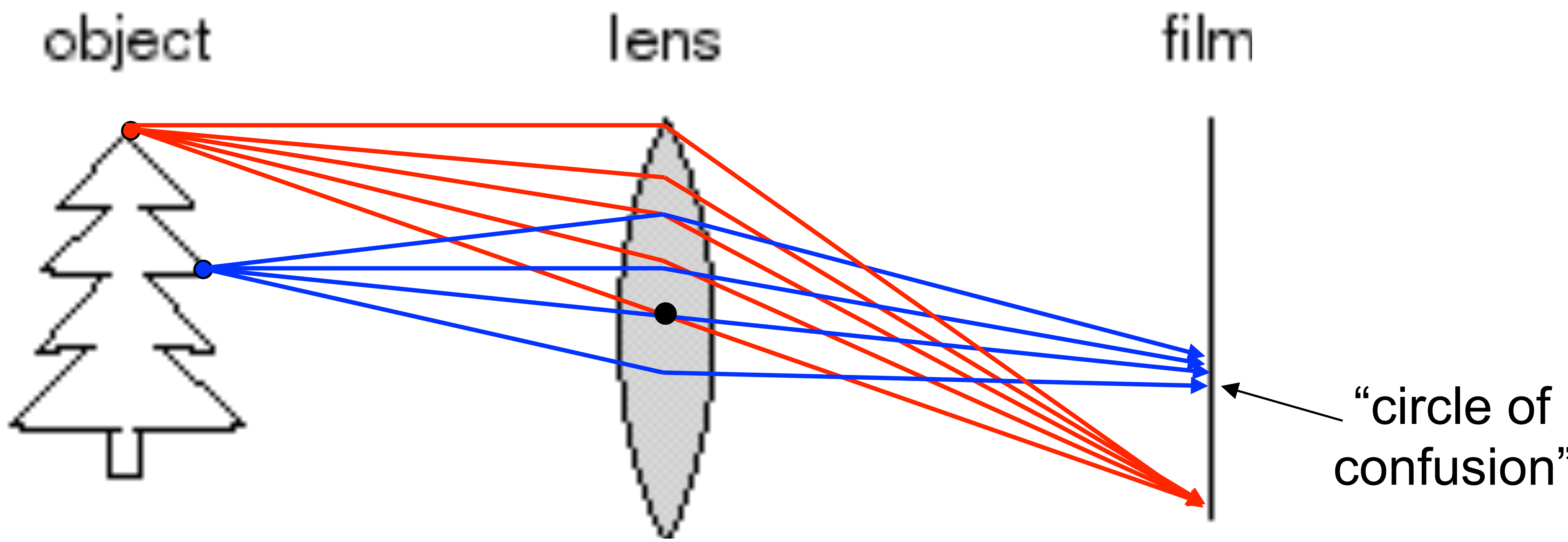


A lens focuses light onto the film

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

Slide by Steve Seitz

Adding a lens

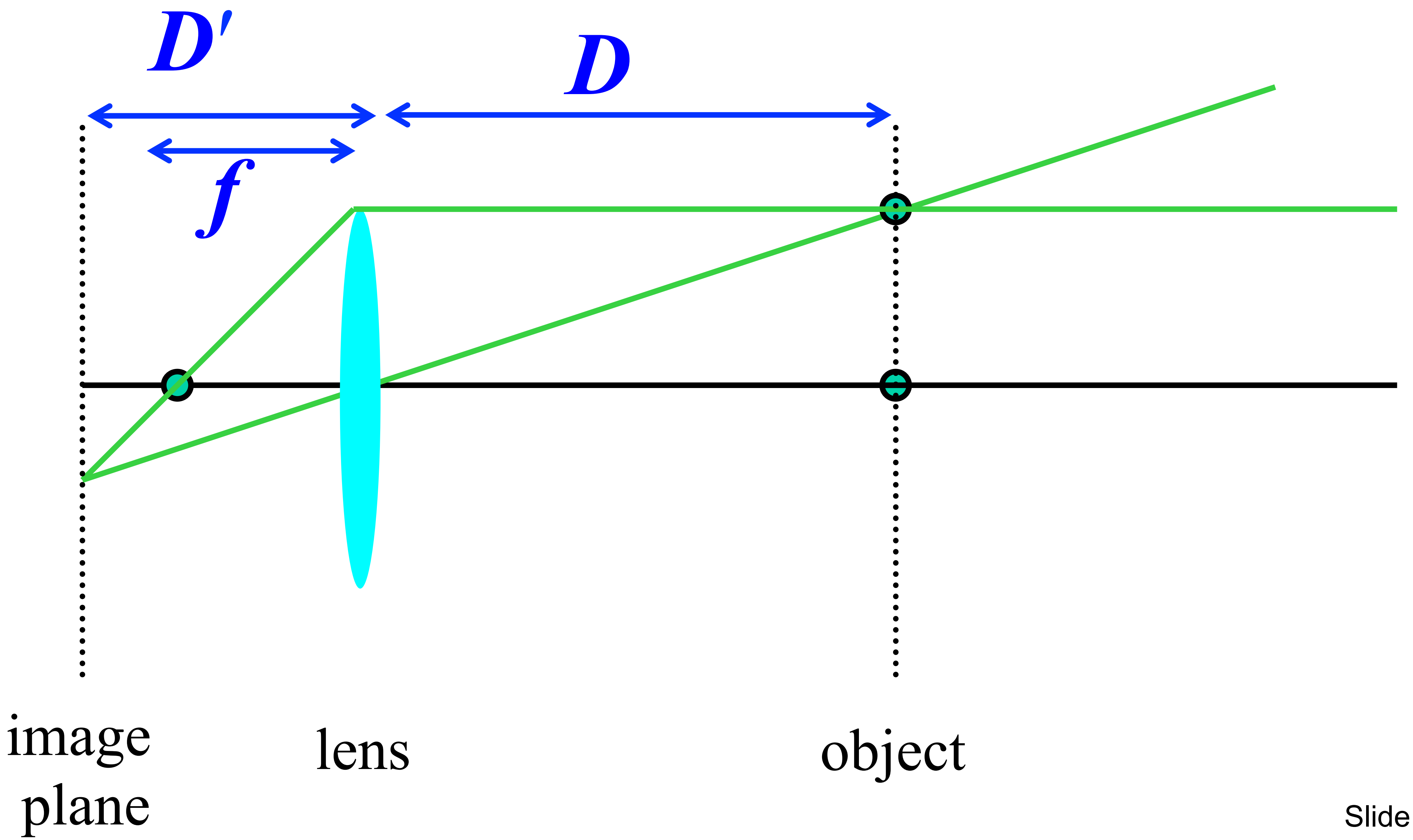


A lens focuses light onto the film

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

Thin lens formula

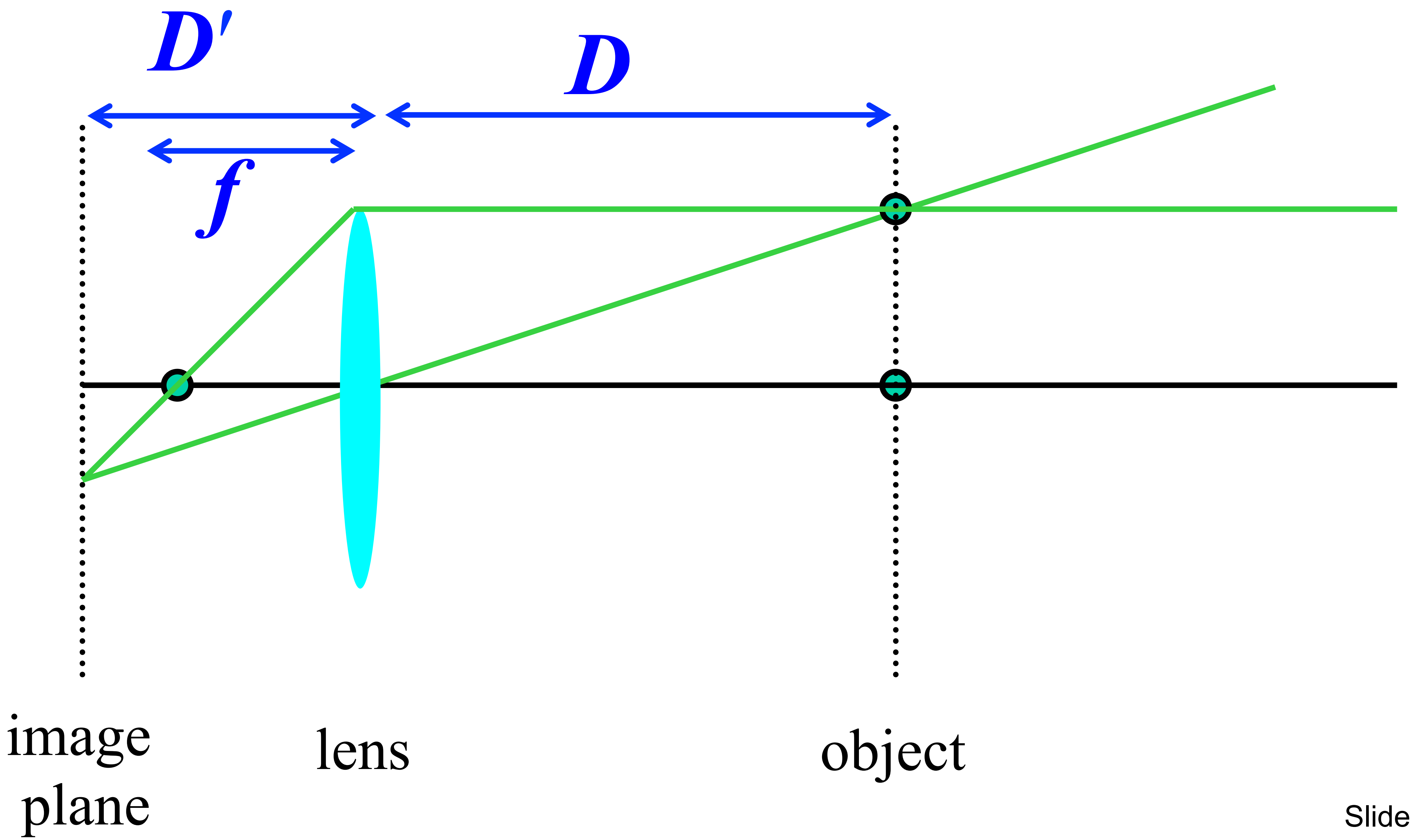
- What is the relation between the focal length (f), the distance of the object from the optical center (D), and the distance at which the object will be in focus (D')?



Slide by Frédo Durand

Thin lens formula

Similar triangles everywhere!

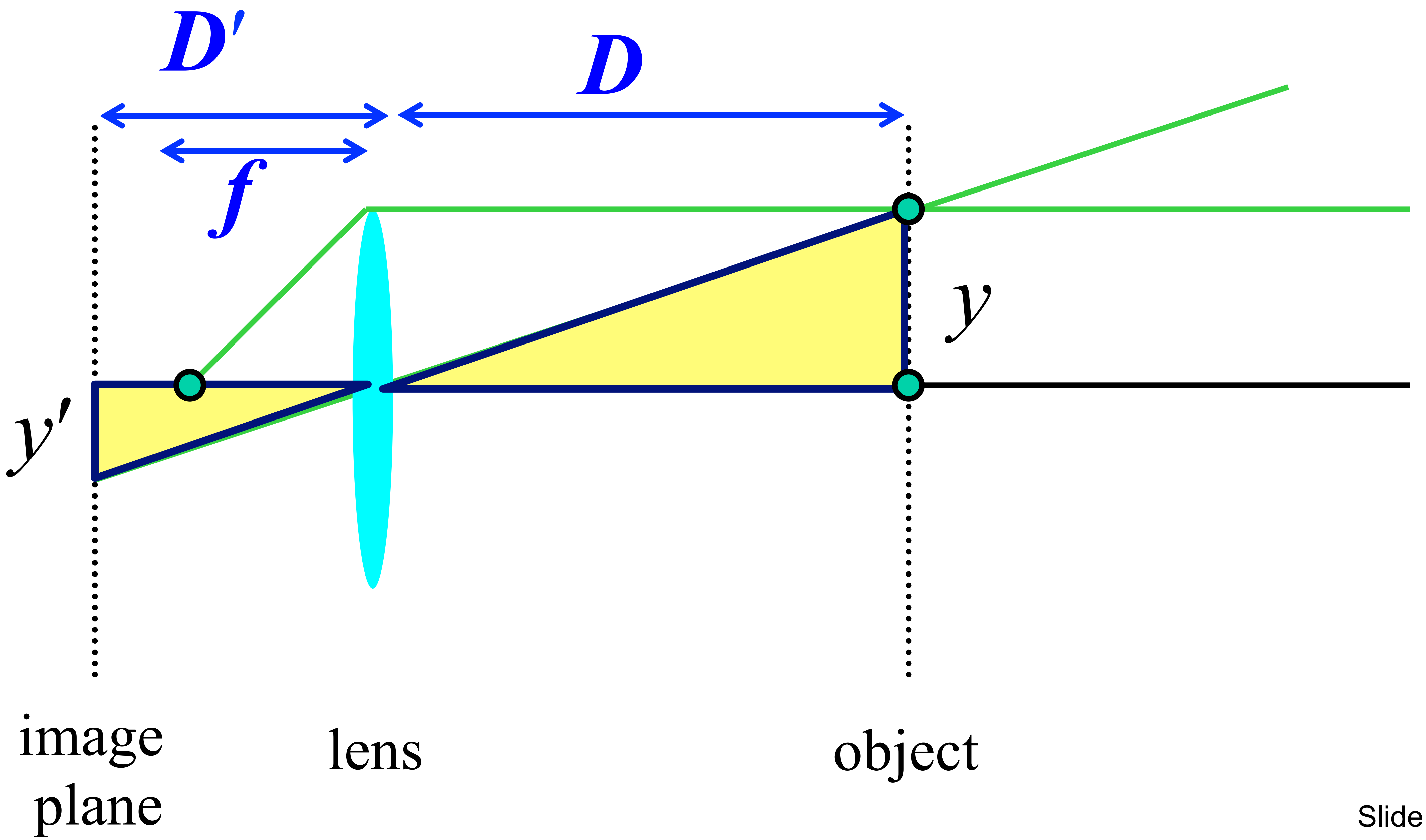


Slide by Frédo Durand

Thin lens formula

Similar triangles everywhere!

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



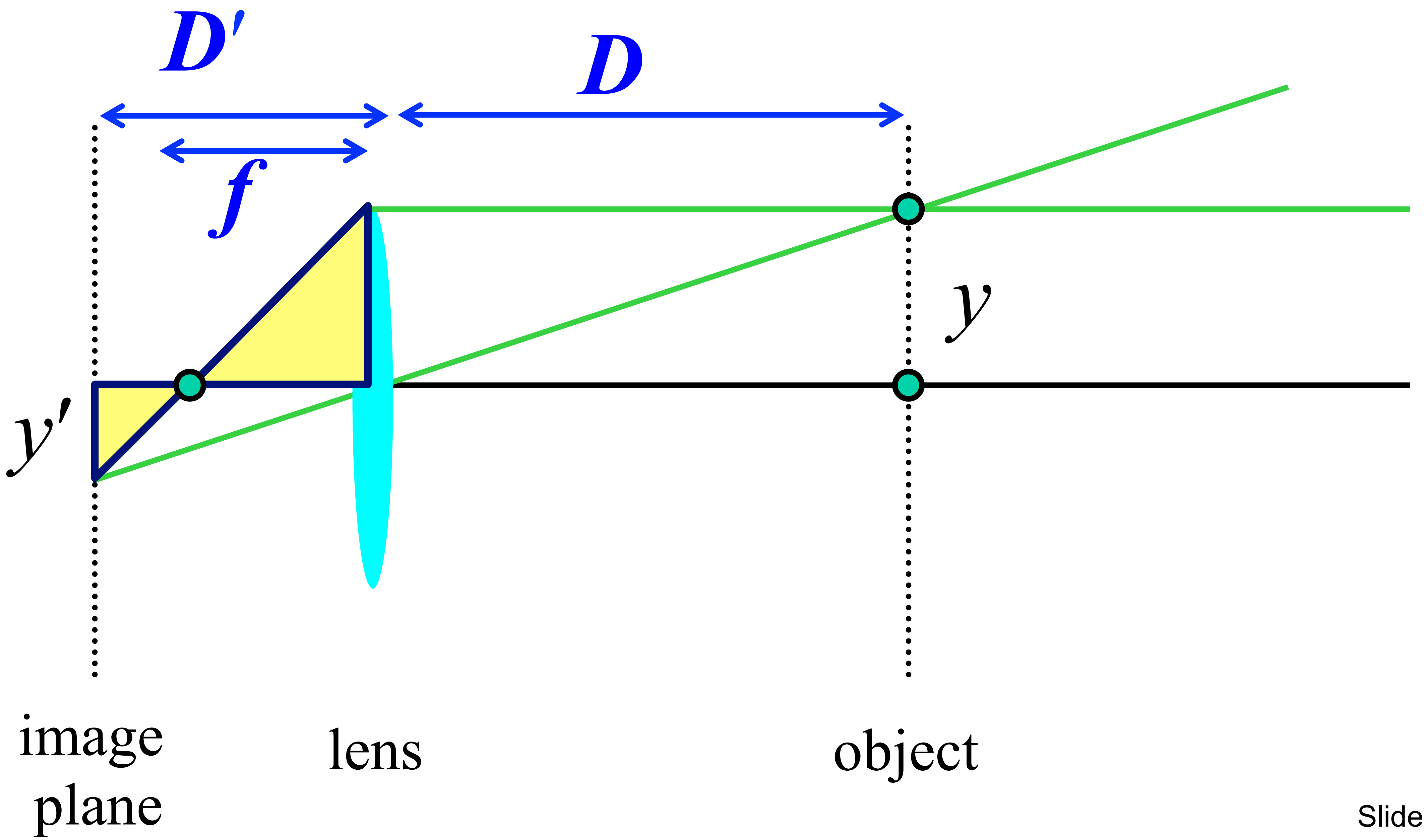
Slide by Frédo Durand

Thin lens formula

Similar triangles everywhere!

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

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

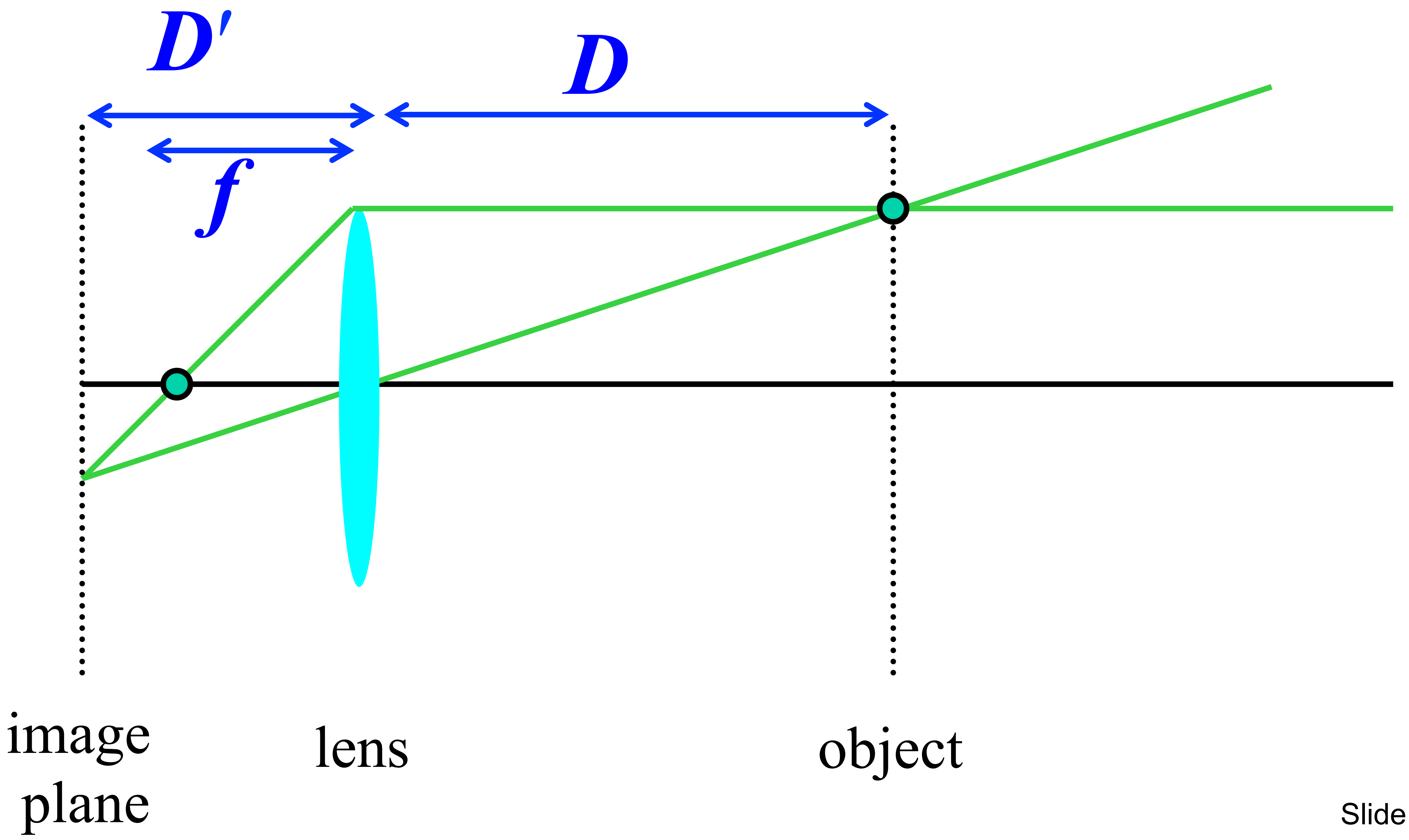


Slide by Frédo Durand

Thin lens formula

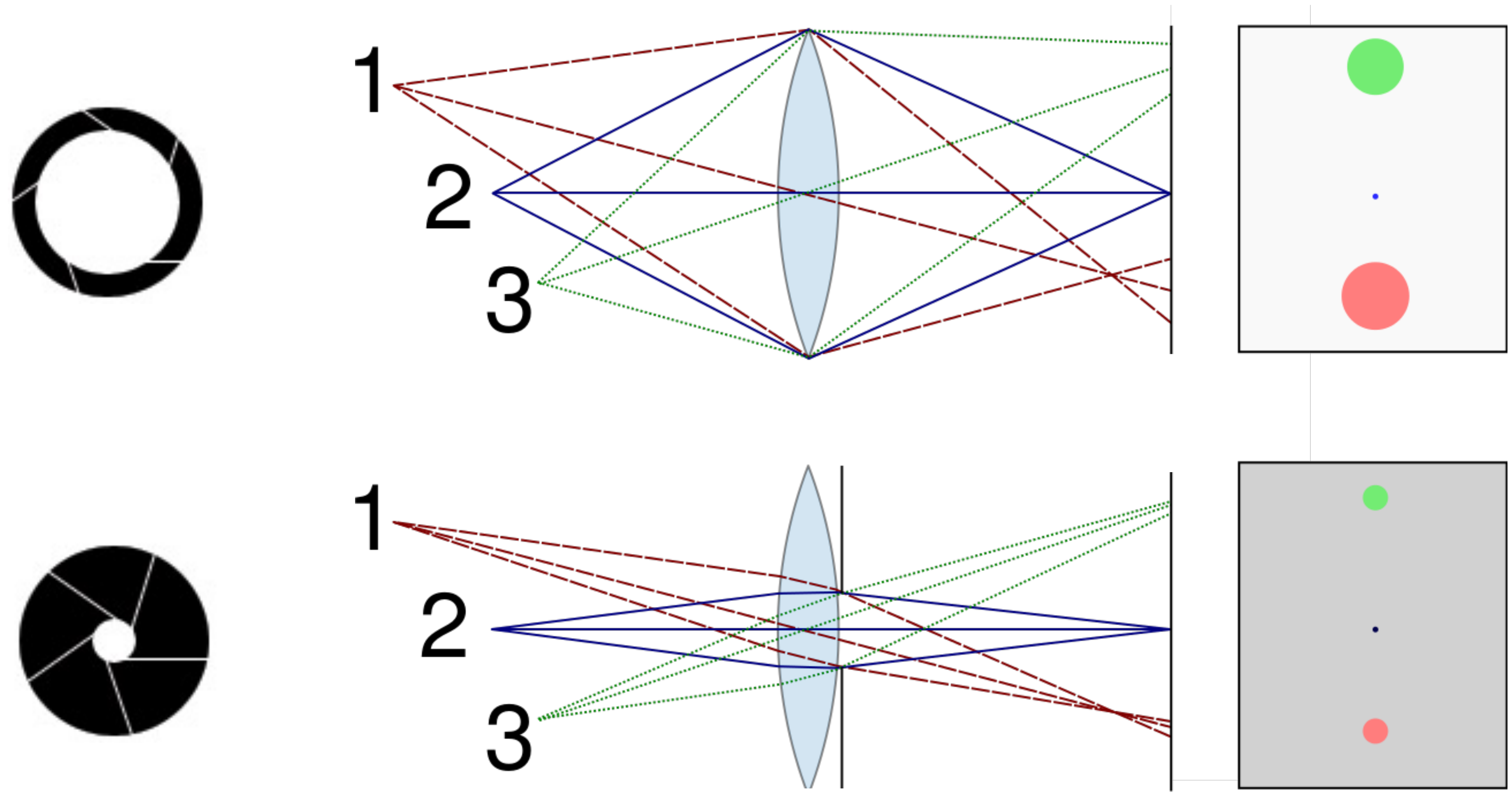
$$\boxed{\frac{1}{D'} + \frac{1}{D} = \frac{1}{f}}$$

Any point satisfying the thin lens equation is in focus.



Slide by Frédo Durand

Controlling 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
- But small aperture reduces amount of light – need to increase exposure

http://en.wikipedia.org/wiki/File:Depth_of_field_illustration.svg

Slide by S. Lazebnik

Varying the aperture

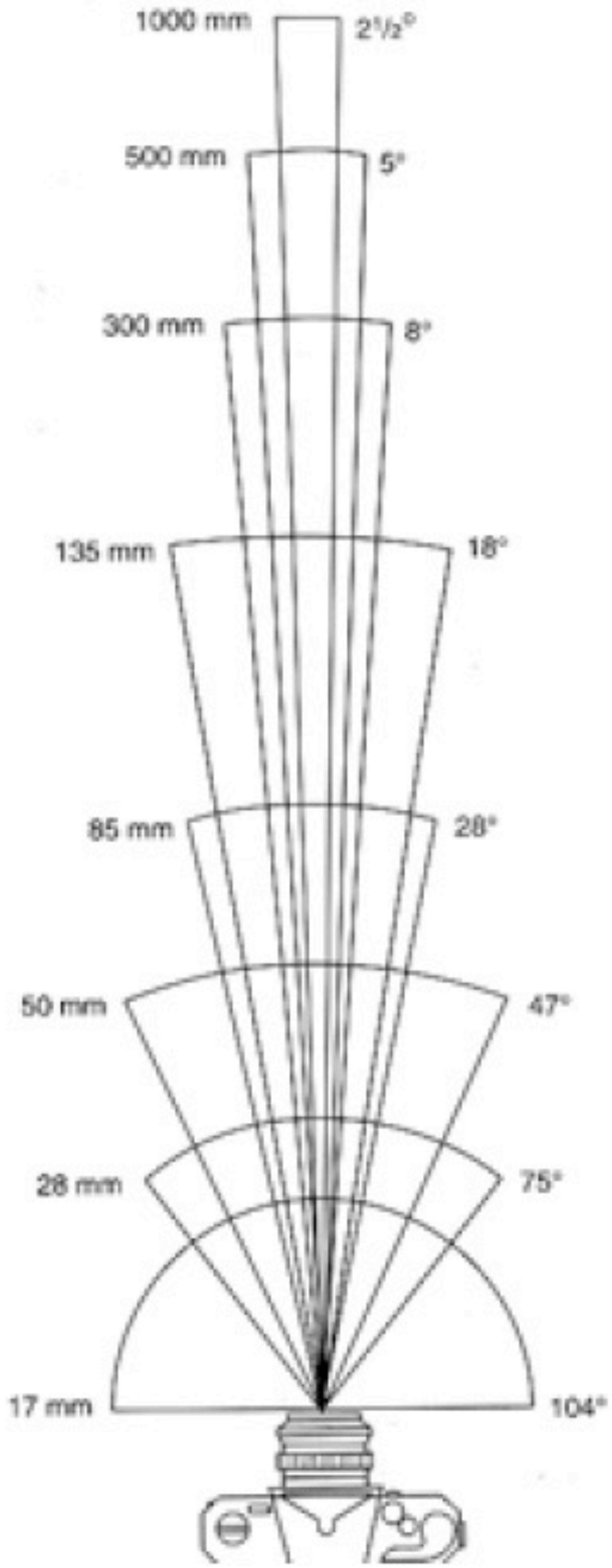
Large aperture = small DOF

Small aperture = large DOF

Slide by A. Efros

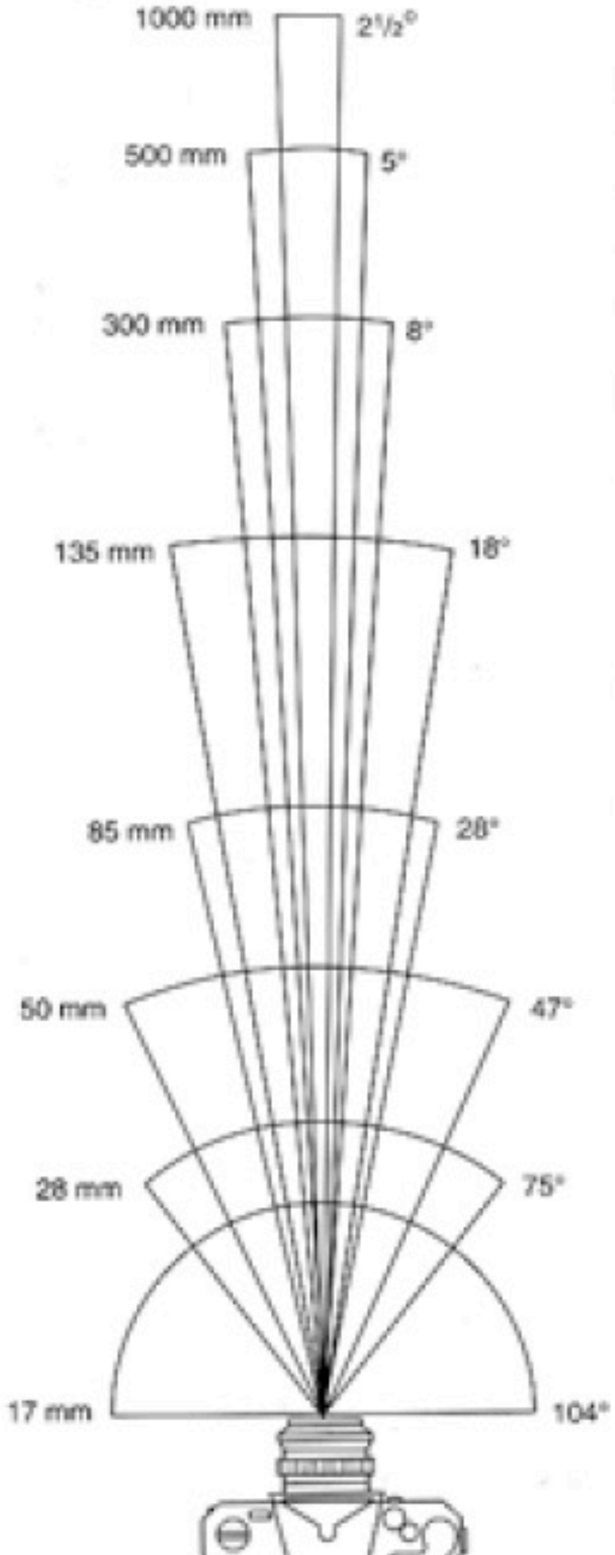
Bokeh

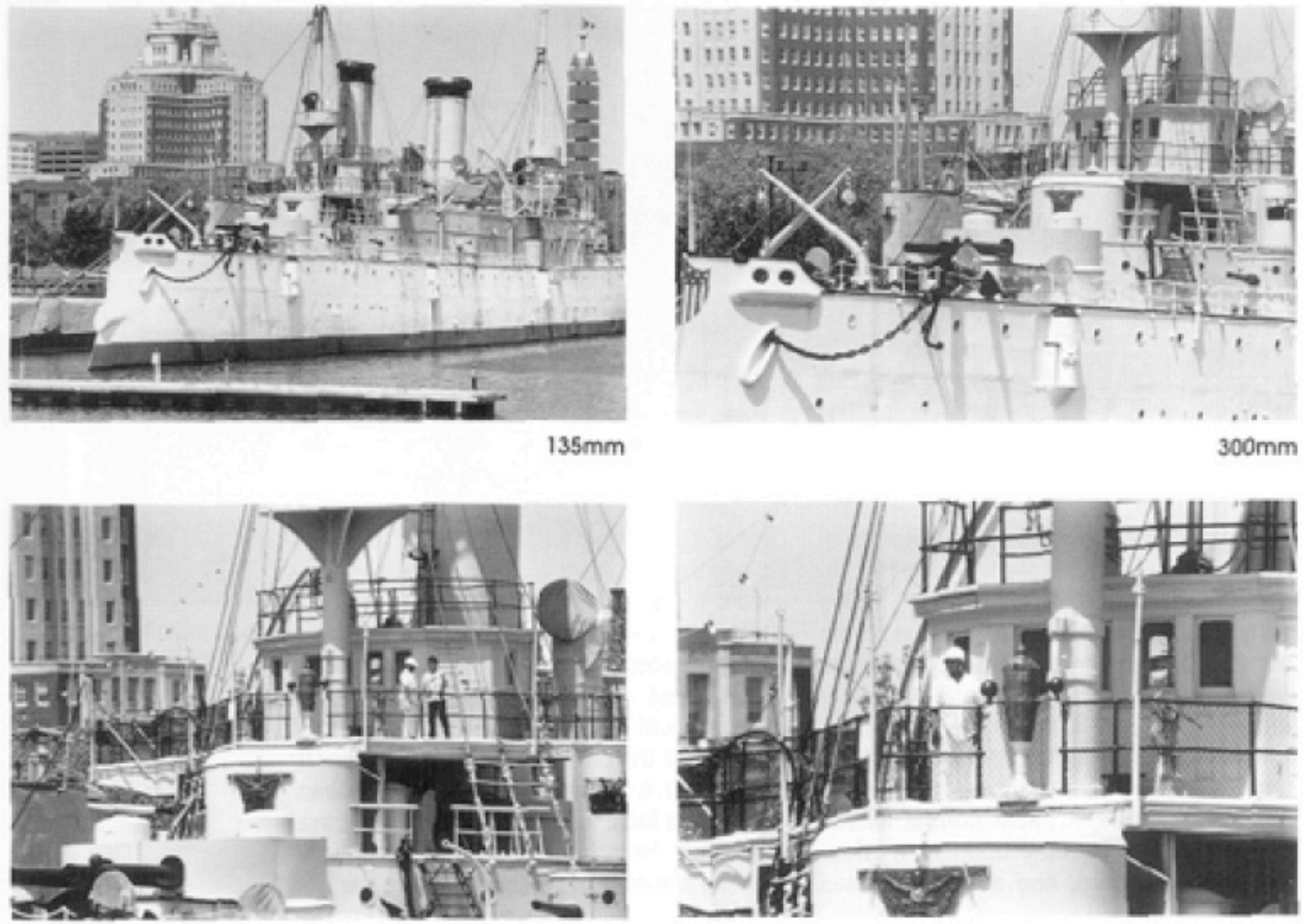
Field of View



Slide by A. Efros

Field of View



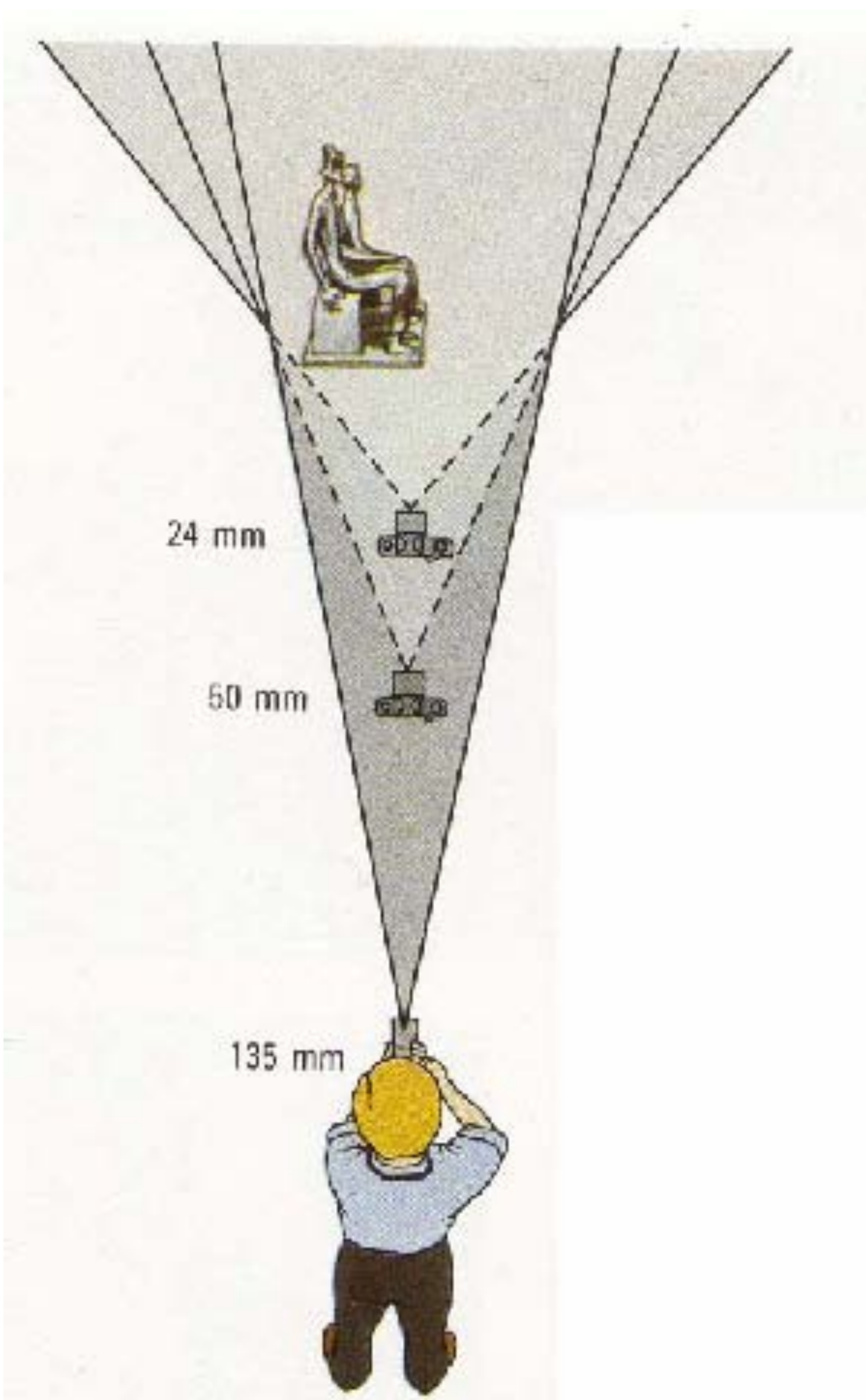


135mm

300mm

Slide by A. Efros

Field of View / Focal Length



Large FOV, small *f*
Camera close to car

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

Sources: A. Efros, F. Durand

Same effect for faces

wide-angle

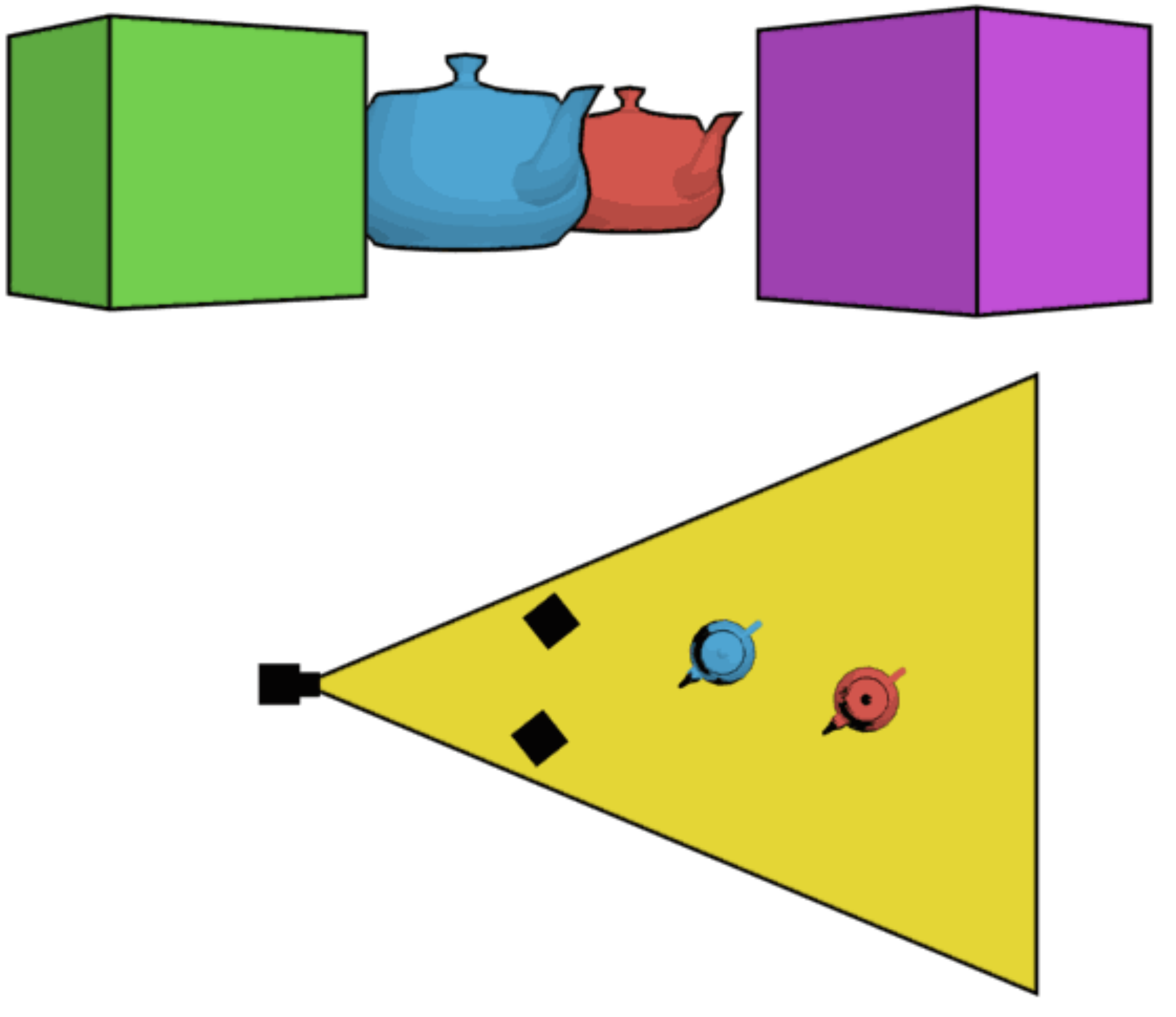
standard

telephoto

Source: F. Durand

The dolly zoom

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



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

Slide by S. Lazebnik


ONNAIS
France Tele

The dolly zoom

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

[Example of dolly zoom from *Goodfellas*](#) (YouTube)

[Example of dolly zoom from *La Haine*](#) (YouTube)

Slide by S. Lazebnik

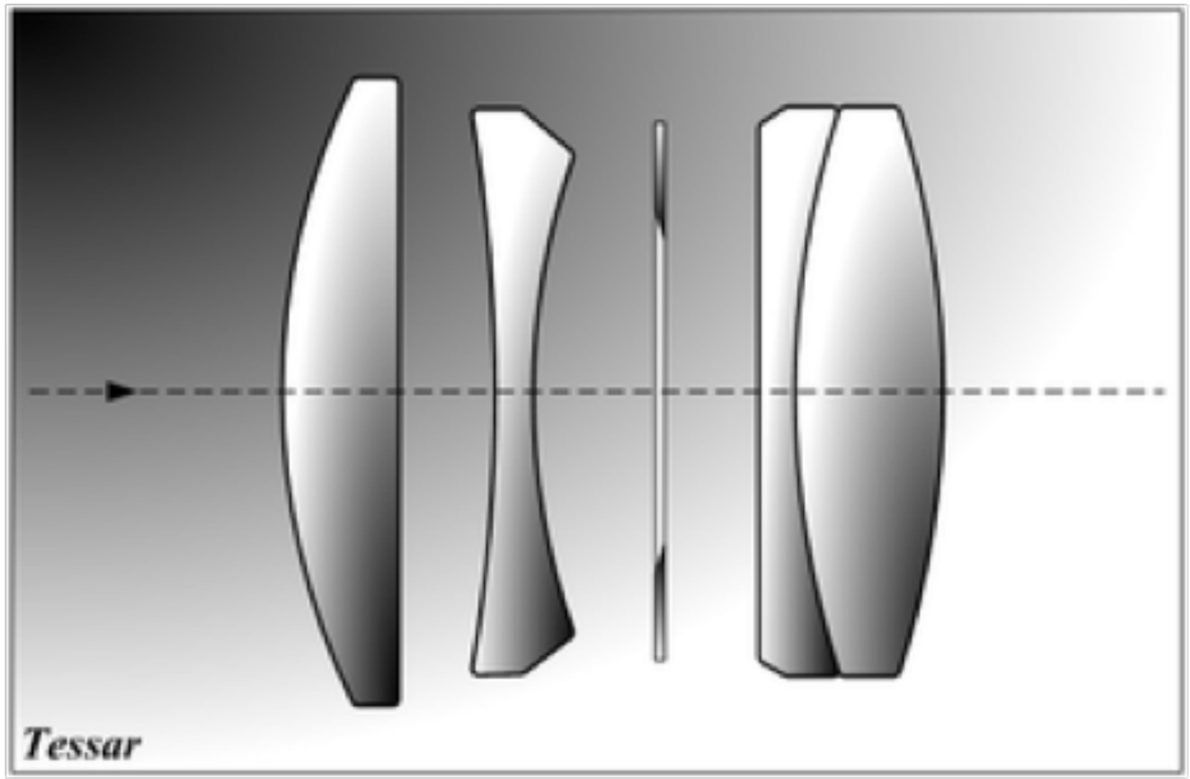
Real lenses

Slide by S. Lazebnik

Real Lenses

- Many uses: cameras, telescopes, microscopes, etc

fixed focal length



Example of a prime lens - Carl Zeiss Tessar

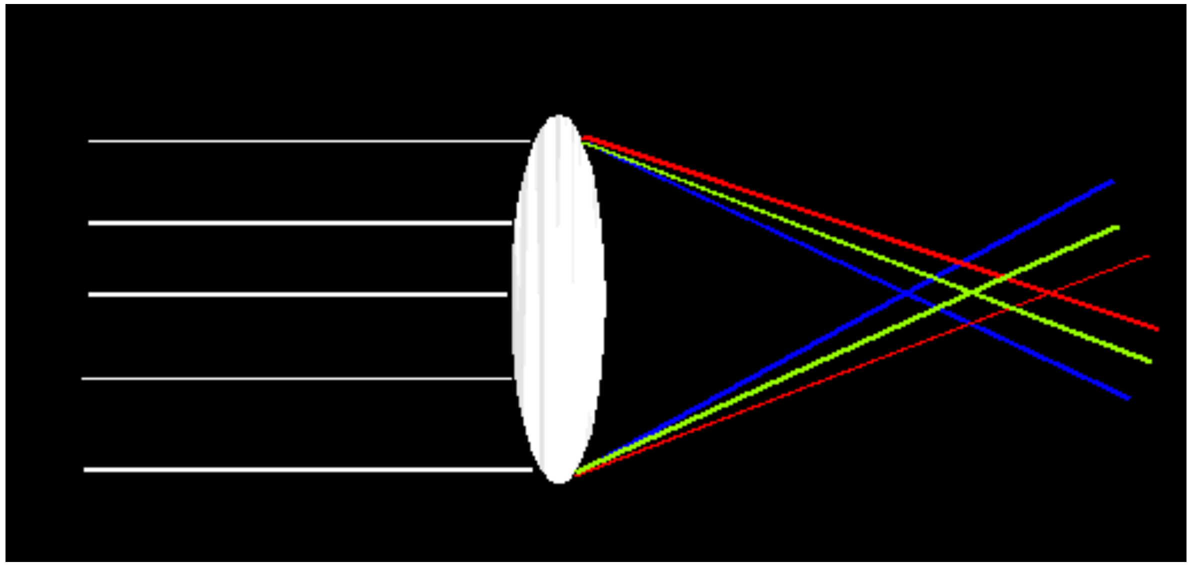
adjustable zoom

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 has different refractive indices for different wavelengths: causes color fringing



Near Lens Center

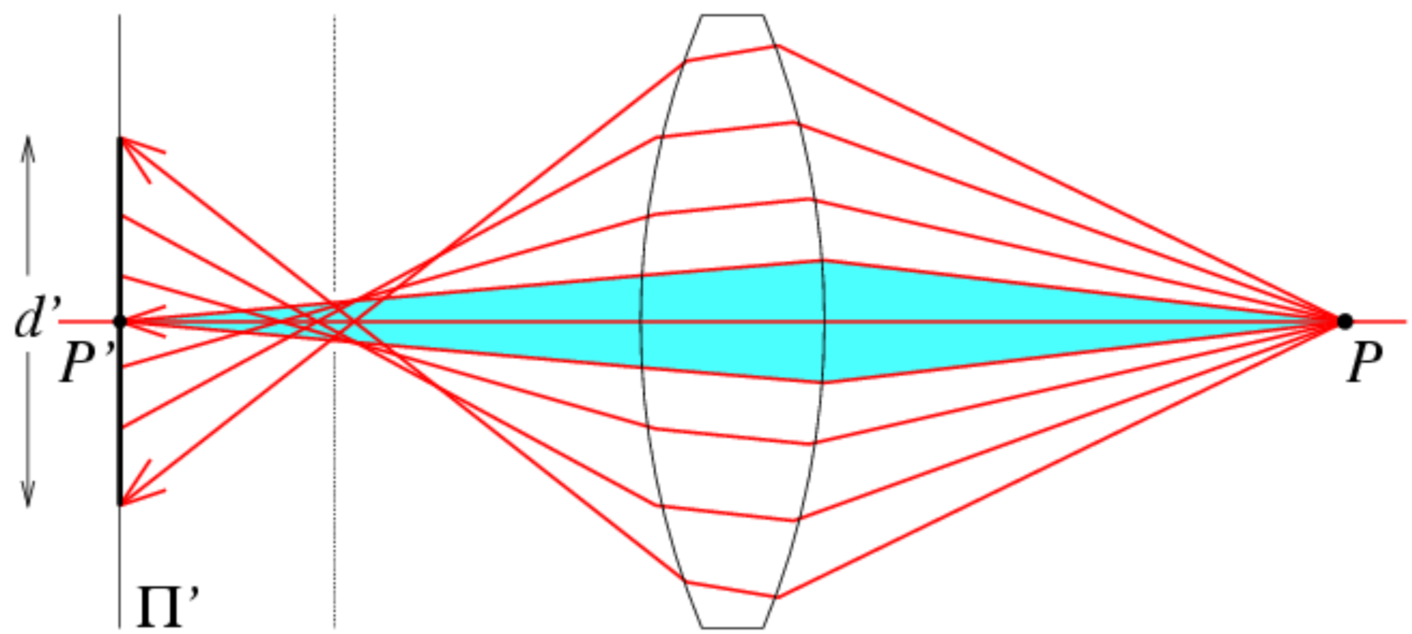
Near Lens Outer Edge

Slide by S. Lazebnik

Lens flaws: Spherical aberration

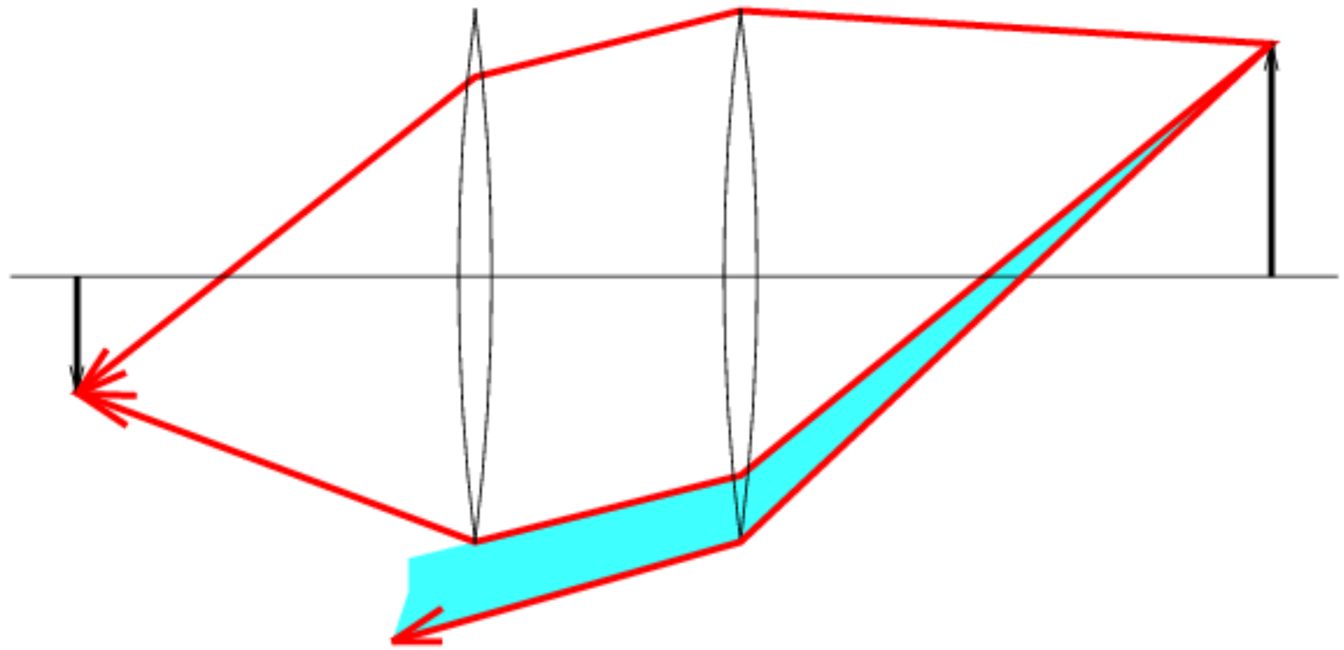
Spherical lenses don’t focus light perfectly

- Rays farther from the optical axis focus closer



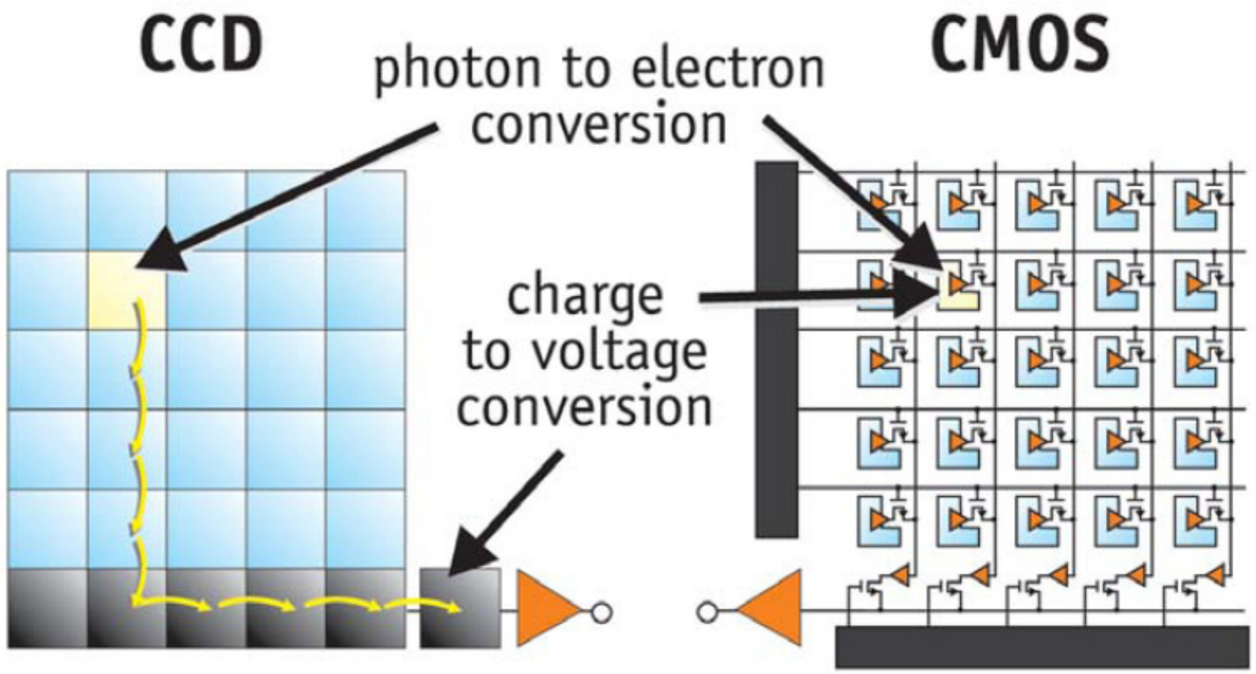
Slide by S. Lazebnik

Lens flaws: Vignetting



Slide by S. Lazebnik

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 film with a sensor array

- Each cell in the array is 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

Slide by Steve Seitz

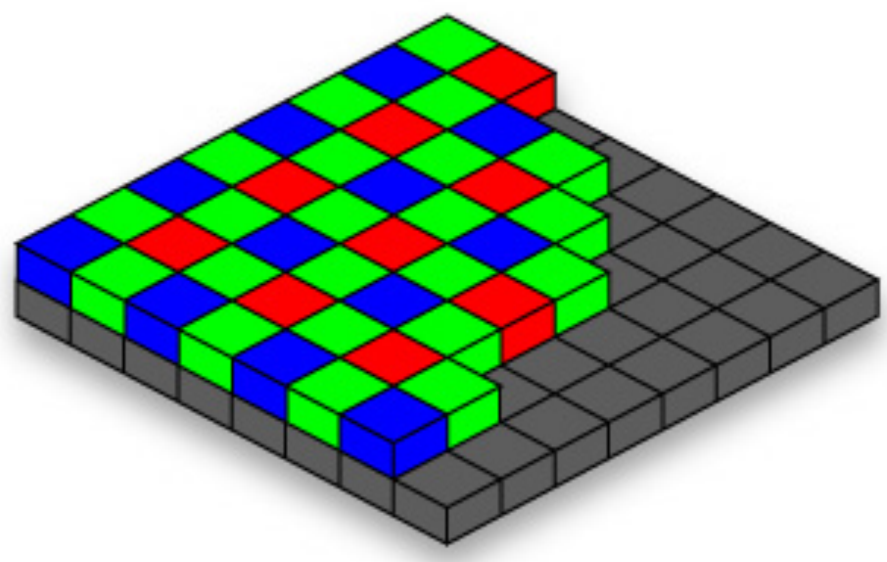
Early Color Photography

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

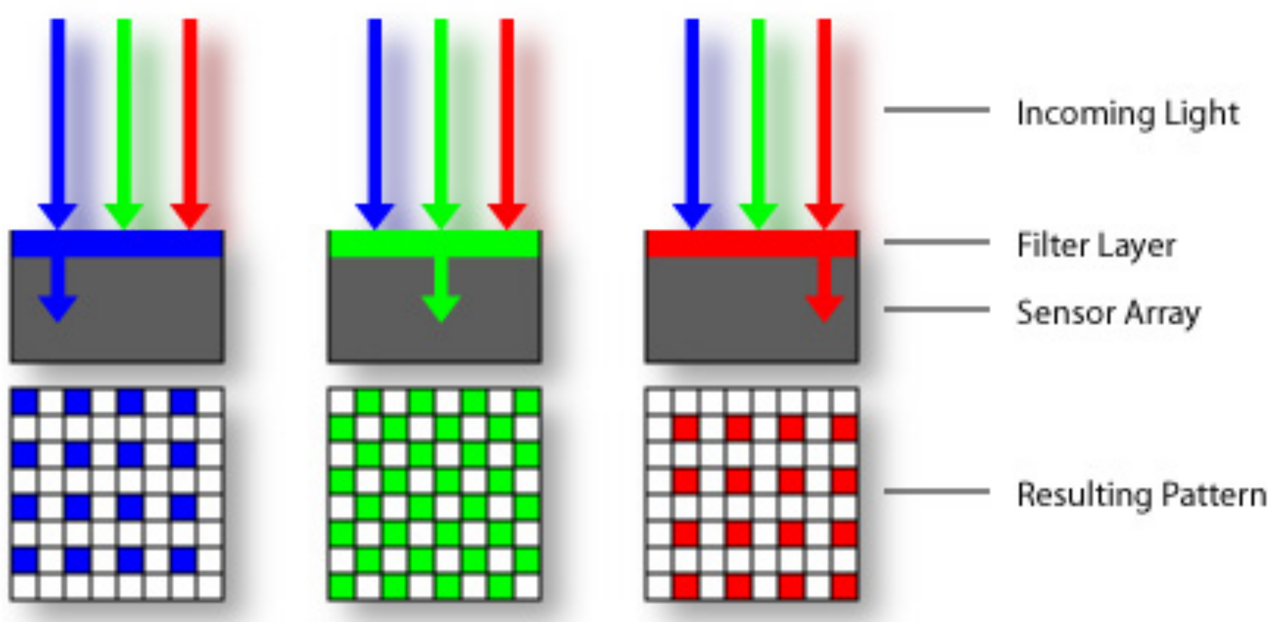
Slide by S. Maji

Color sensing in camera: Color filter array

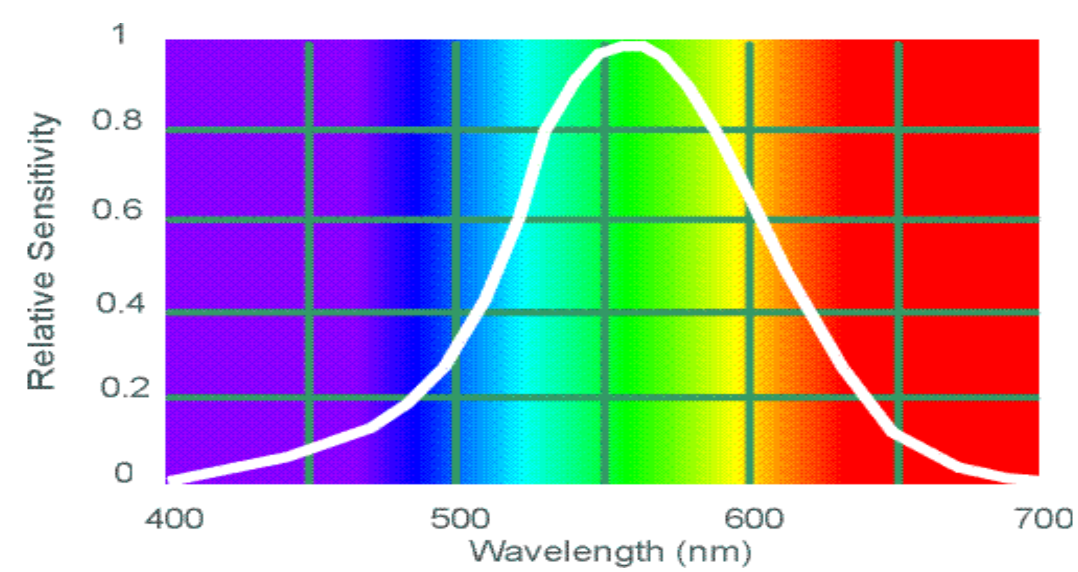
Bayer grid



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



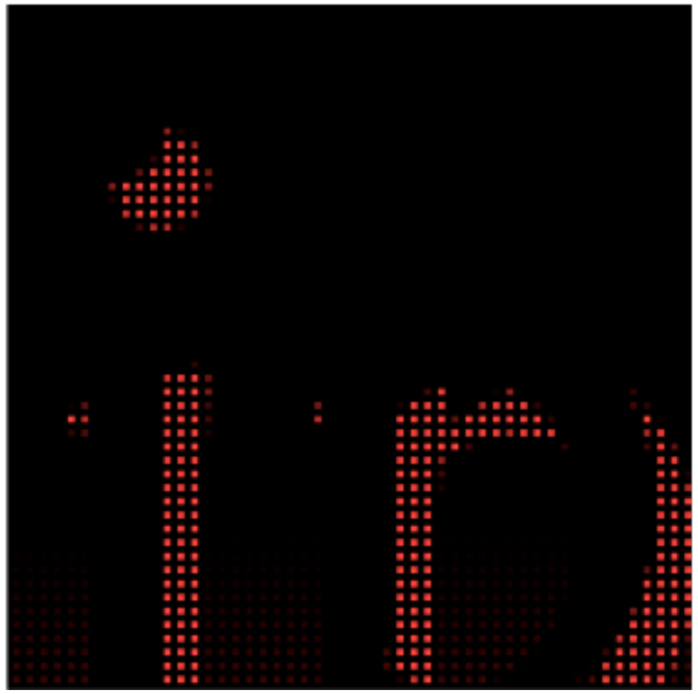
Why more green?

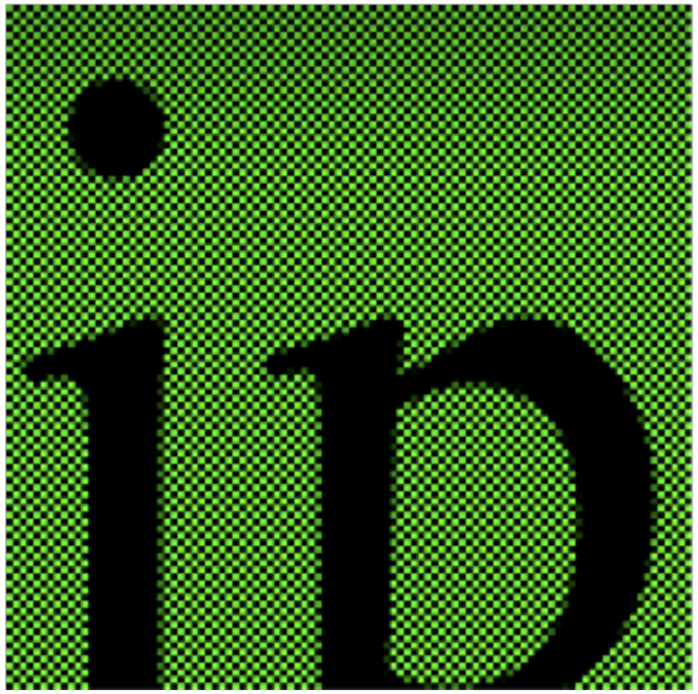


Human Luminance Sensitivity Function

Source: Steve Seitz

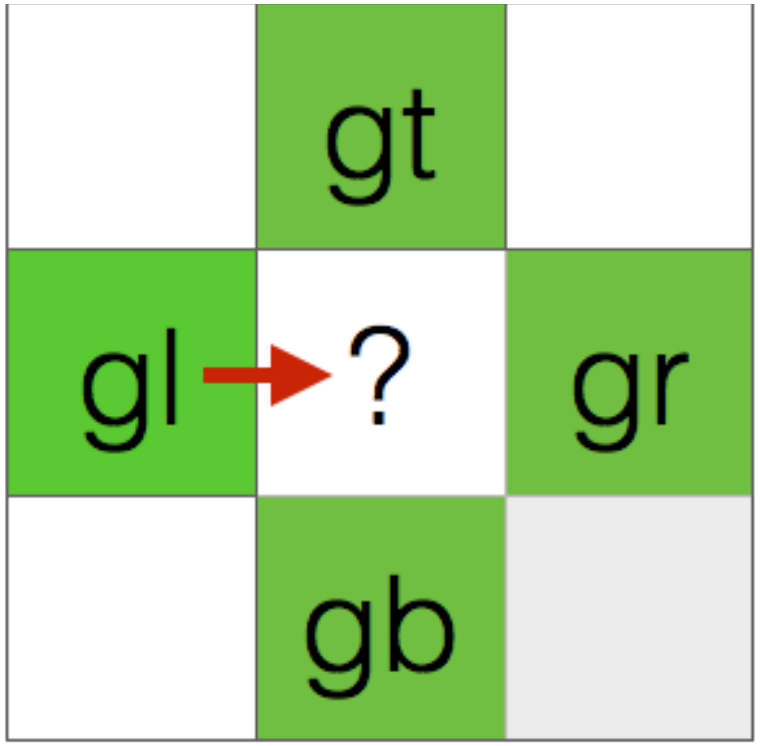
Demosaicing





Source: S. Maji

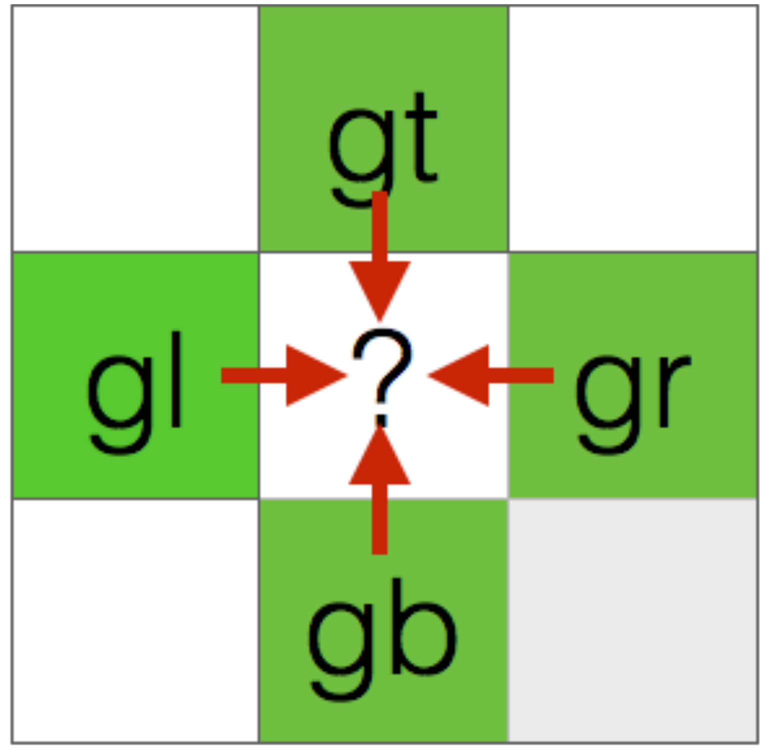
Interpolation



nearest neighbor

copy one of your neighbors

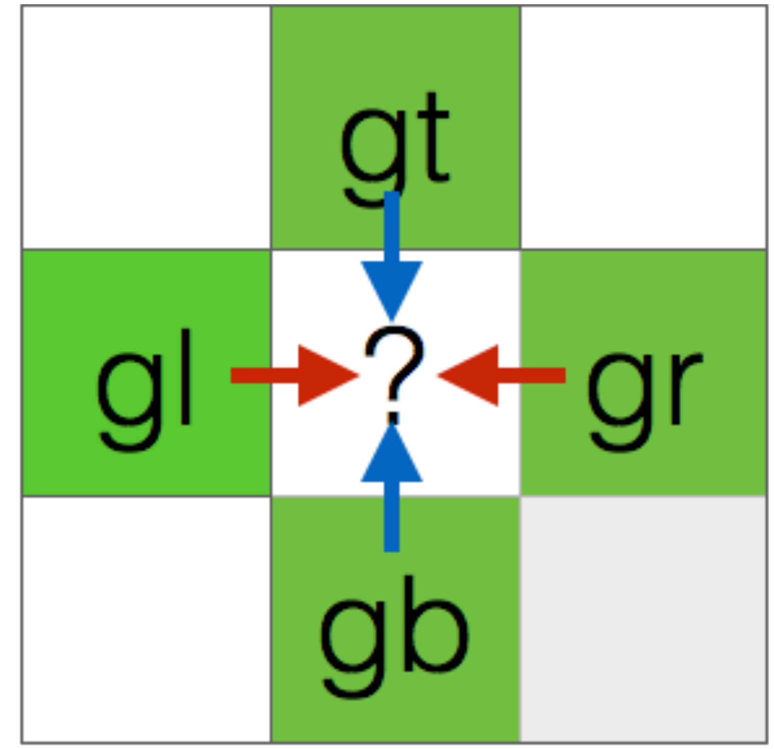
? ←gl



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

Source: S. Maji

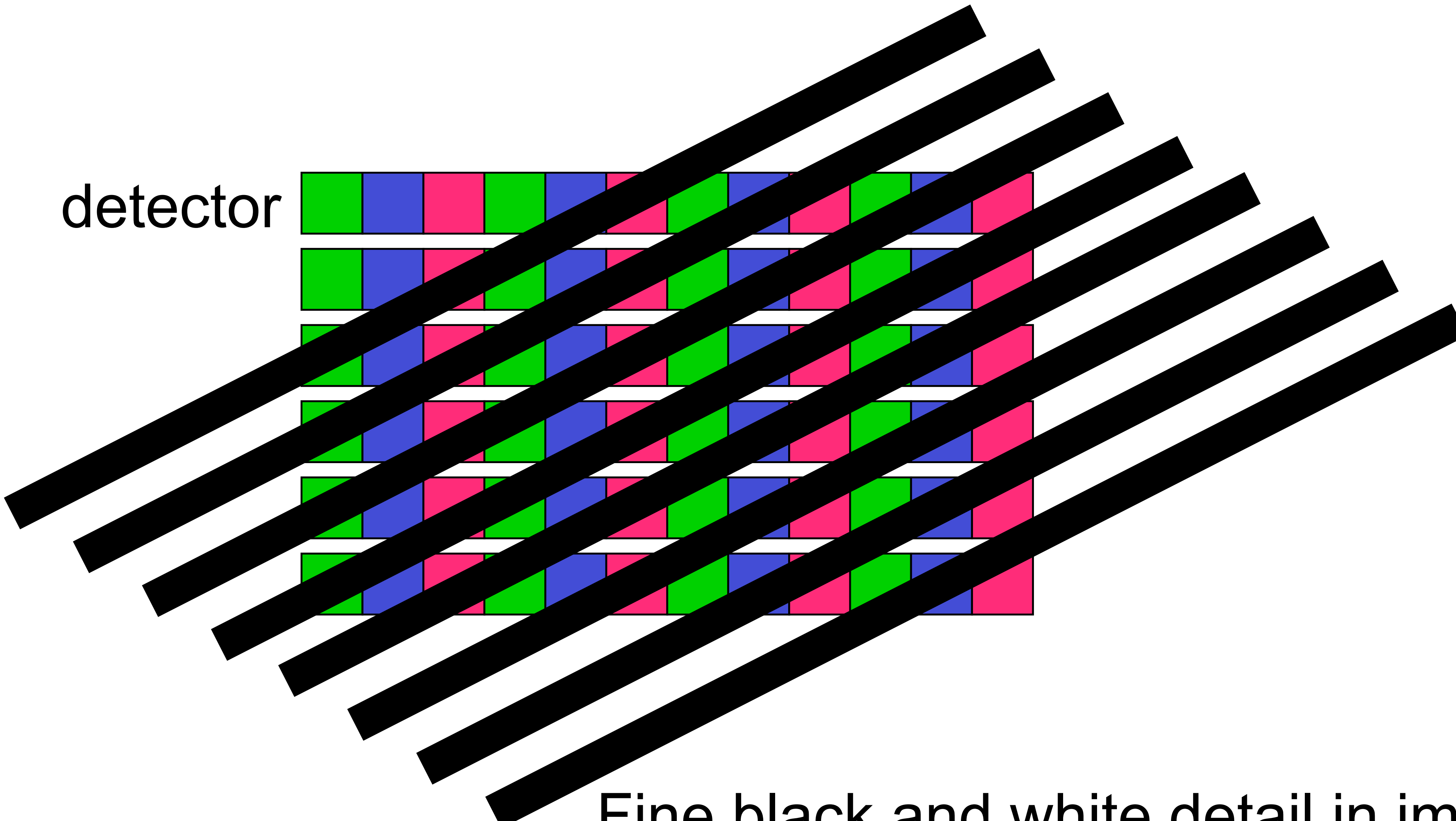
Problem with demosaicing: color moire

Slide by F. Durand

Problem with demosaicing: color moire

Slide by F. Durand

The cause of color moire



Fine black and white detail in image misinterpreted as color information

Slide by F. Durand

Next Week

- Image Sensing - construction of camera sensors
- Radiometry and Reflectance - how light interacts with a scene