Introduction to Computational Photography

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Borrowed from Frédo Durand's Lectures at MIT

Today's plan

- **Introduction of Computational Photography**
- **Introduction to Digital Imaging**

What is computational photography

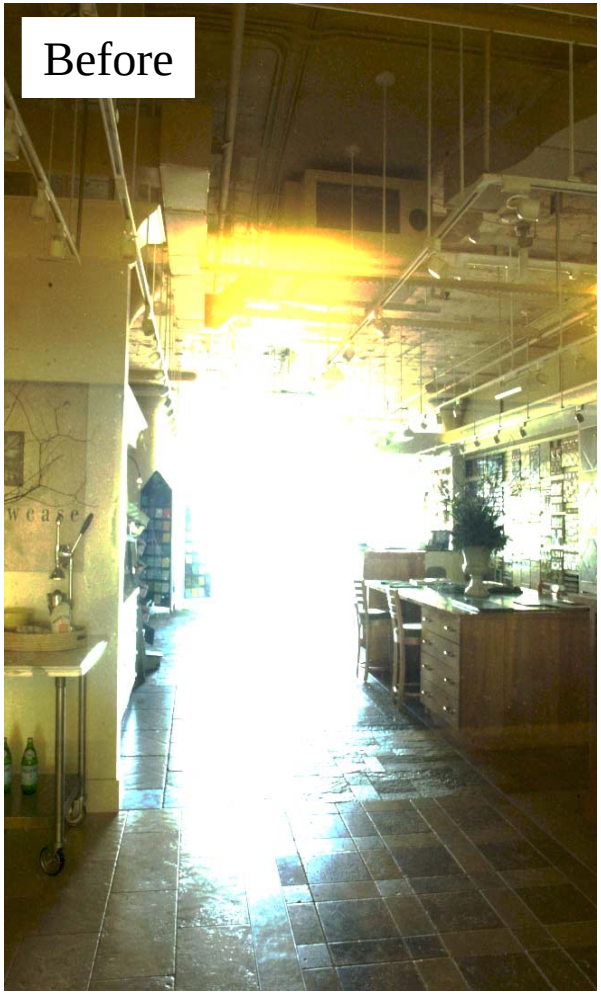
- **Convergence of image processing, computer vision, computer graphics and photography**
- **Digital photography**
  - Simply replaces traditional sensors and recording by digital technology
  - Involves only simple image processing
- **Computational photography**
  - More elaborate image manipulation and computation
  - New types of media (panorama, 3D, etc.)
  - Camera design that takes computation into account

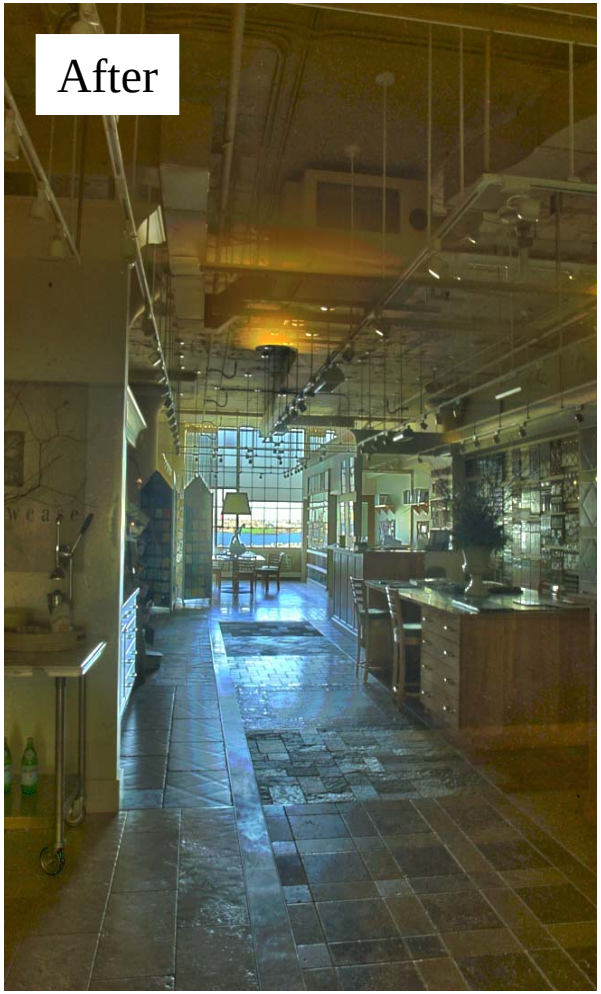
Examples

- **Tone mapping**
- **Defocus Matting**
- **Motion magnification**
- **Multi-Modal Imaging**

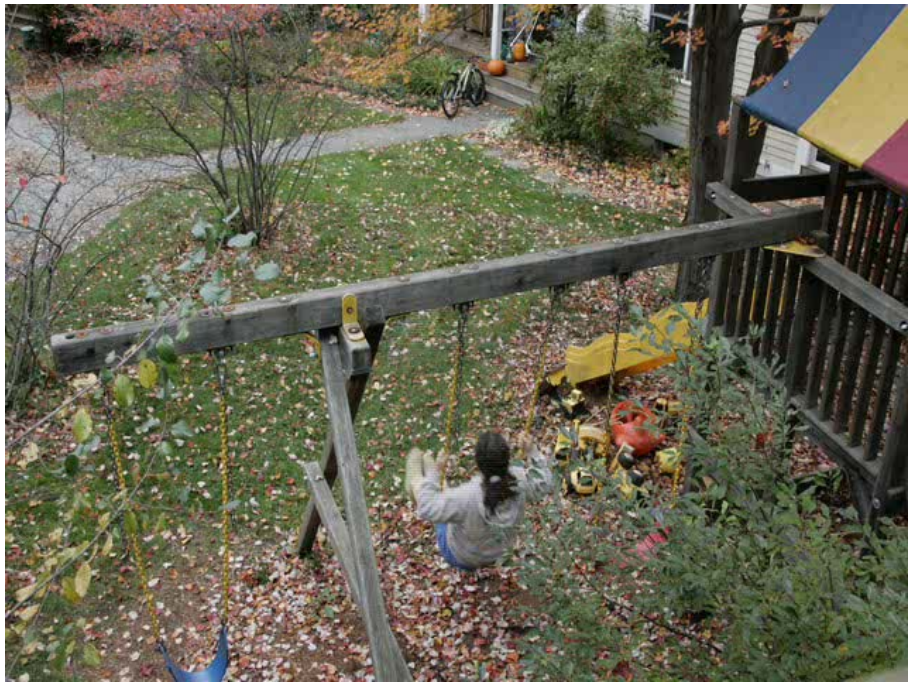
Tone mapping

- **Suitable for HDR images**





Motion magnification



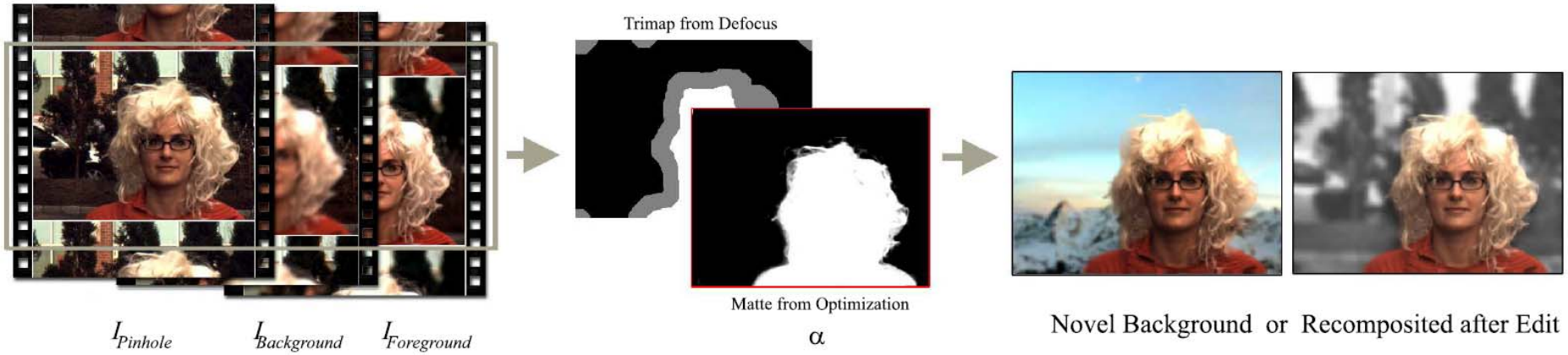
Original

Magnified

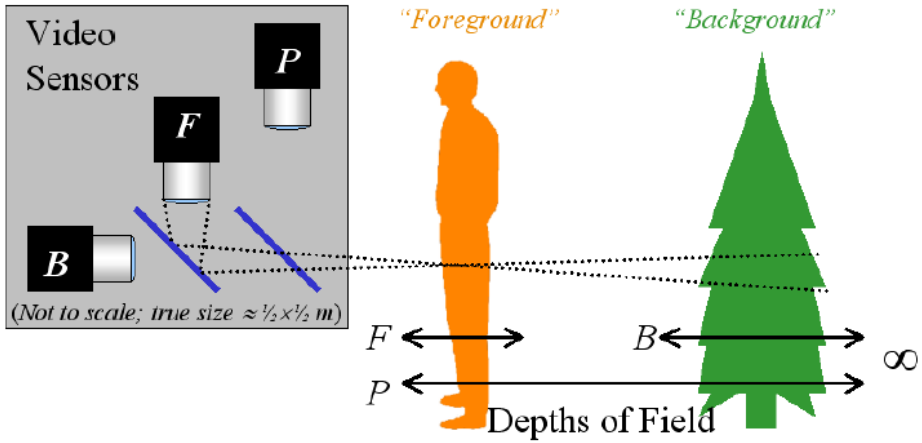
http://people.csail.mit.edu/celiu/motionmag/motionmag.html

Defocus Matting

- **What can be achieved**



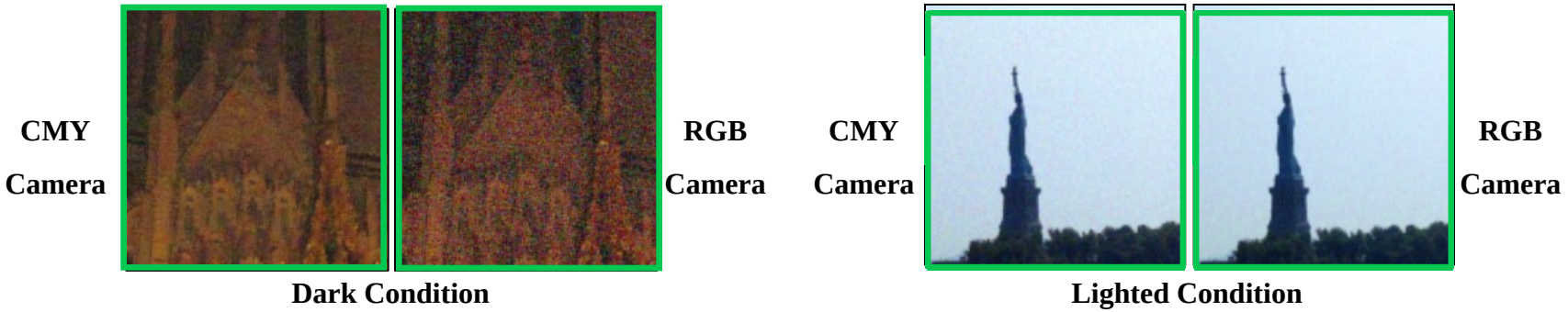
- **Design: use 3 streams with different focus**



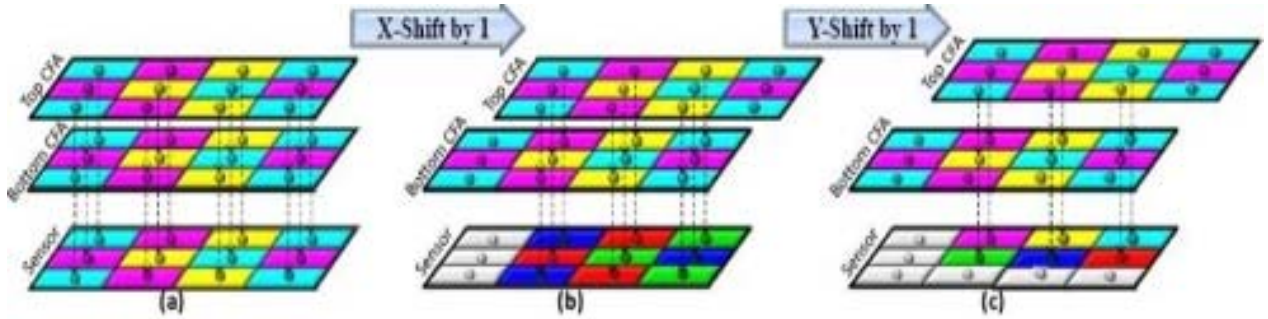
http://people.csail.mit.edu/wojciech/DefocusVideo/index.html

Multi-Modal Cameras

- **What can be achieved**



- **How it works?**



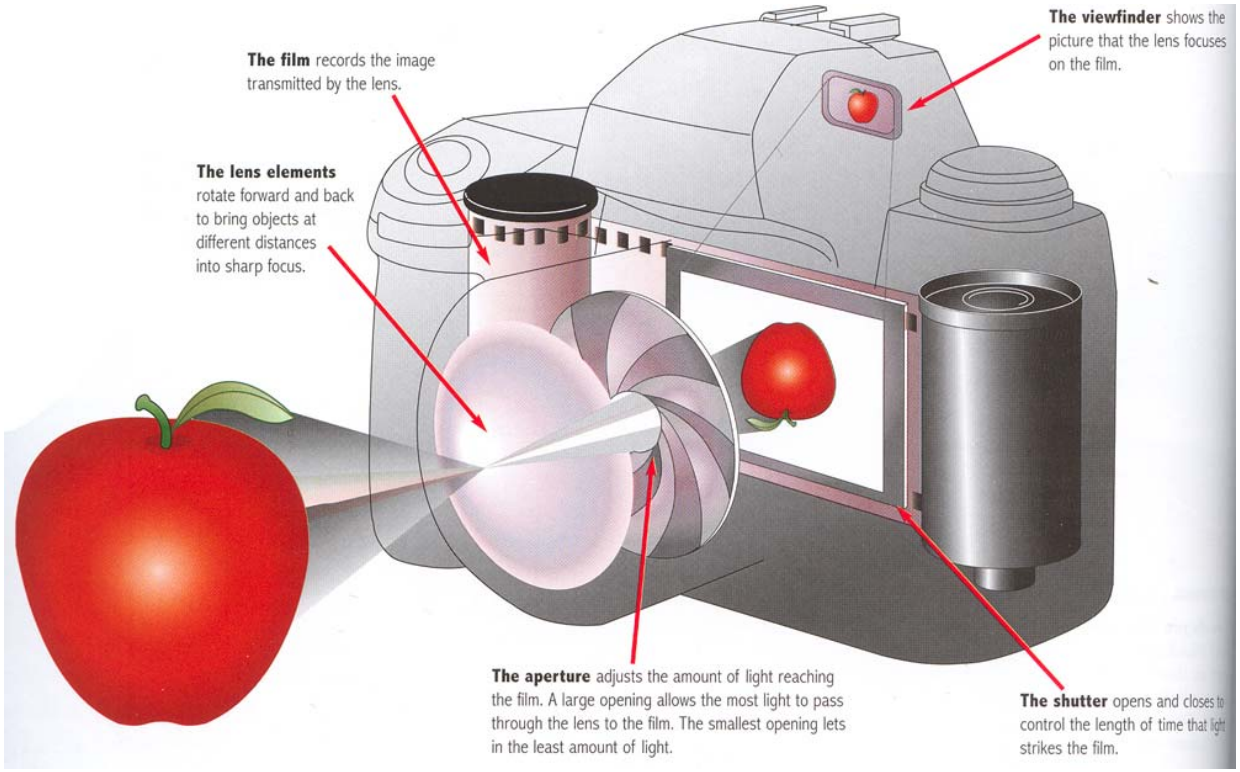
http://www.ics.uci.edu/~bsajadi/SwitchableCam.html

Today's plan

- **Introduction of Computational Photography**
- **Introduction to Digital Imaging**

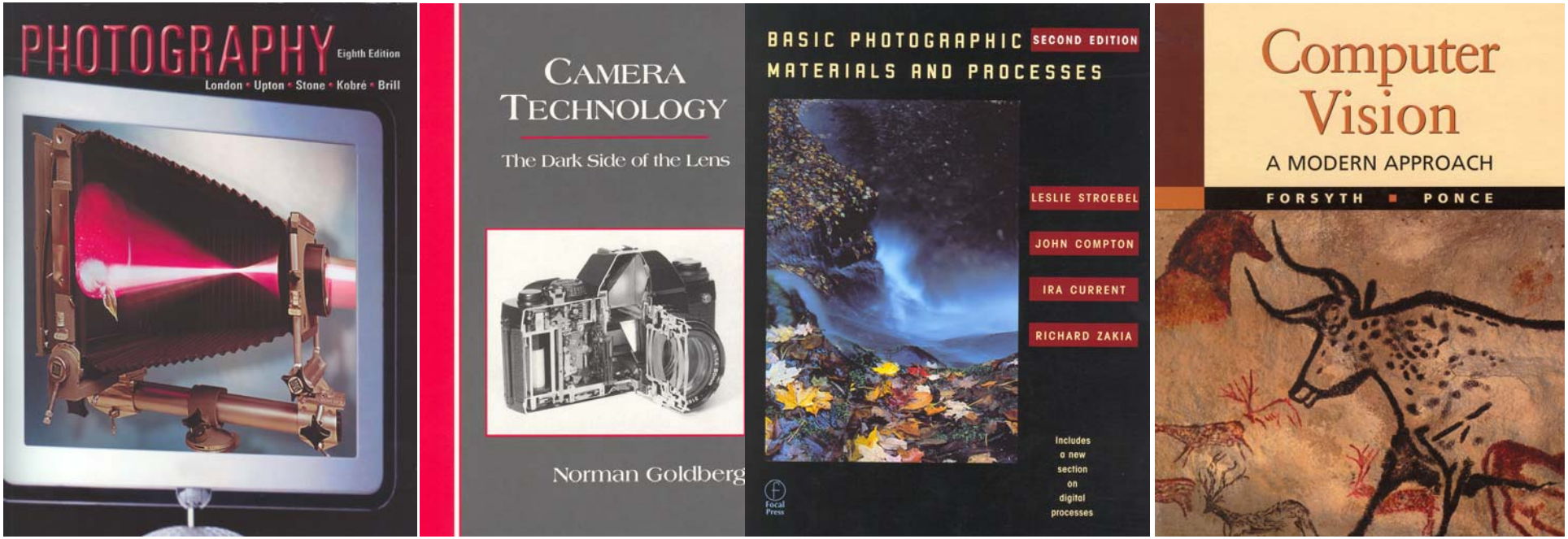
Overview

- **Lens and viewpoint determine perspective**
- **Aperture and shutter speed determine exposure**
- **Aperture and other effects determine depth of field**
- **Film or sensor record image**



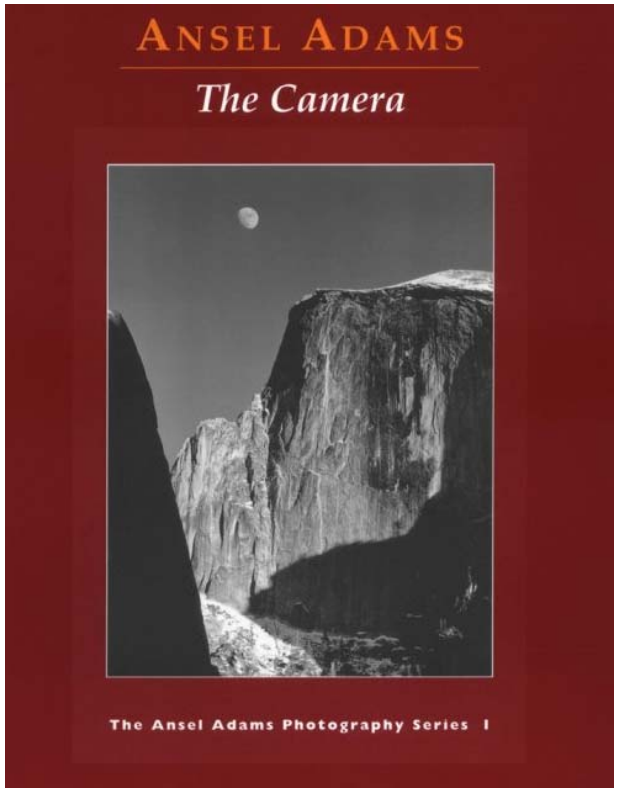
Reference

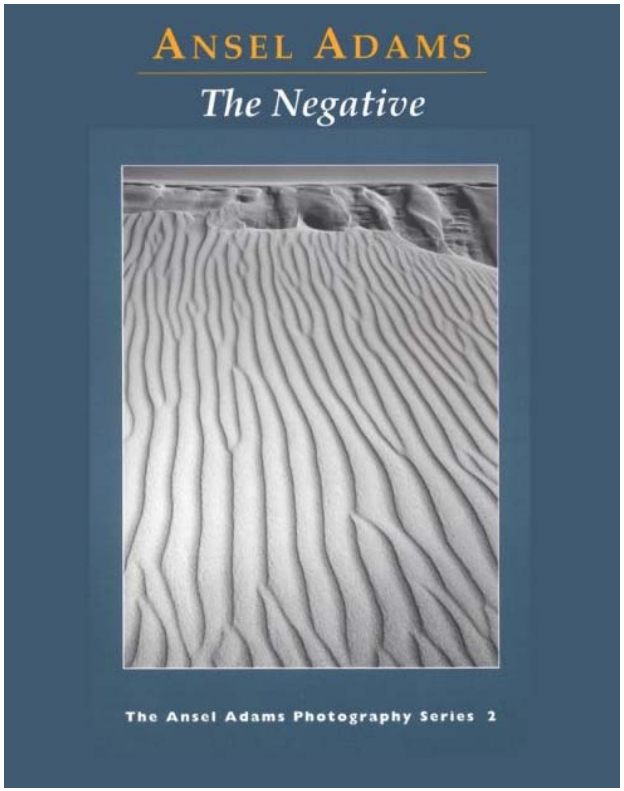
- http://courses.csail.mit.edu/6.869/lectnotes/lect1
- http://en.wikipedia.org/wiki/Lens_(optics)

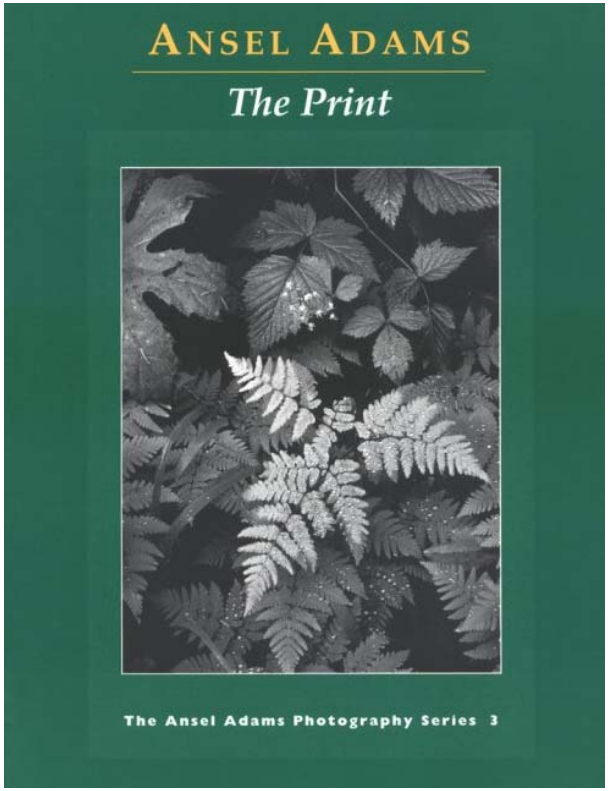


- **The slides use illustrations from these books**

More references



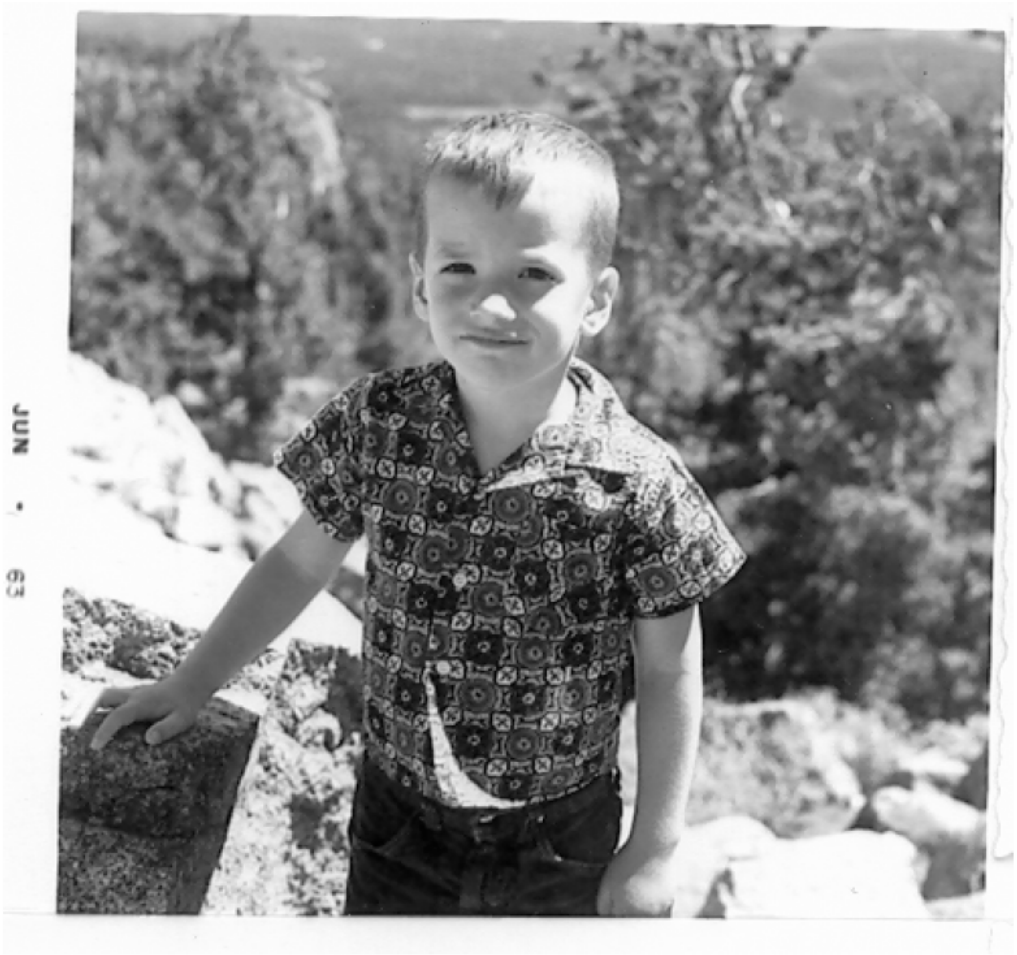




Plan

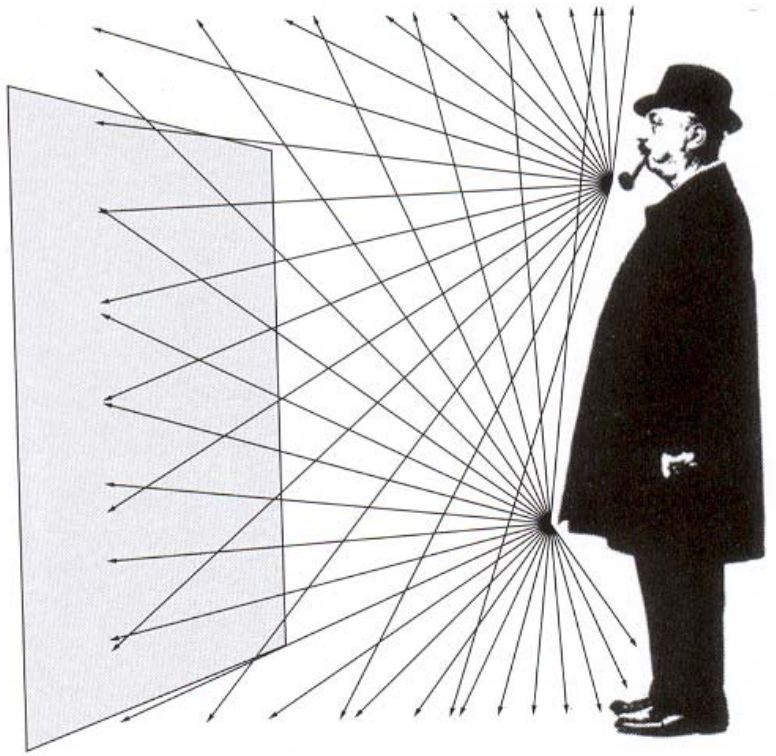
- **Pinhole optics**
- **Lenses**
- **Exposure**

7-year old's question



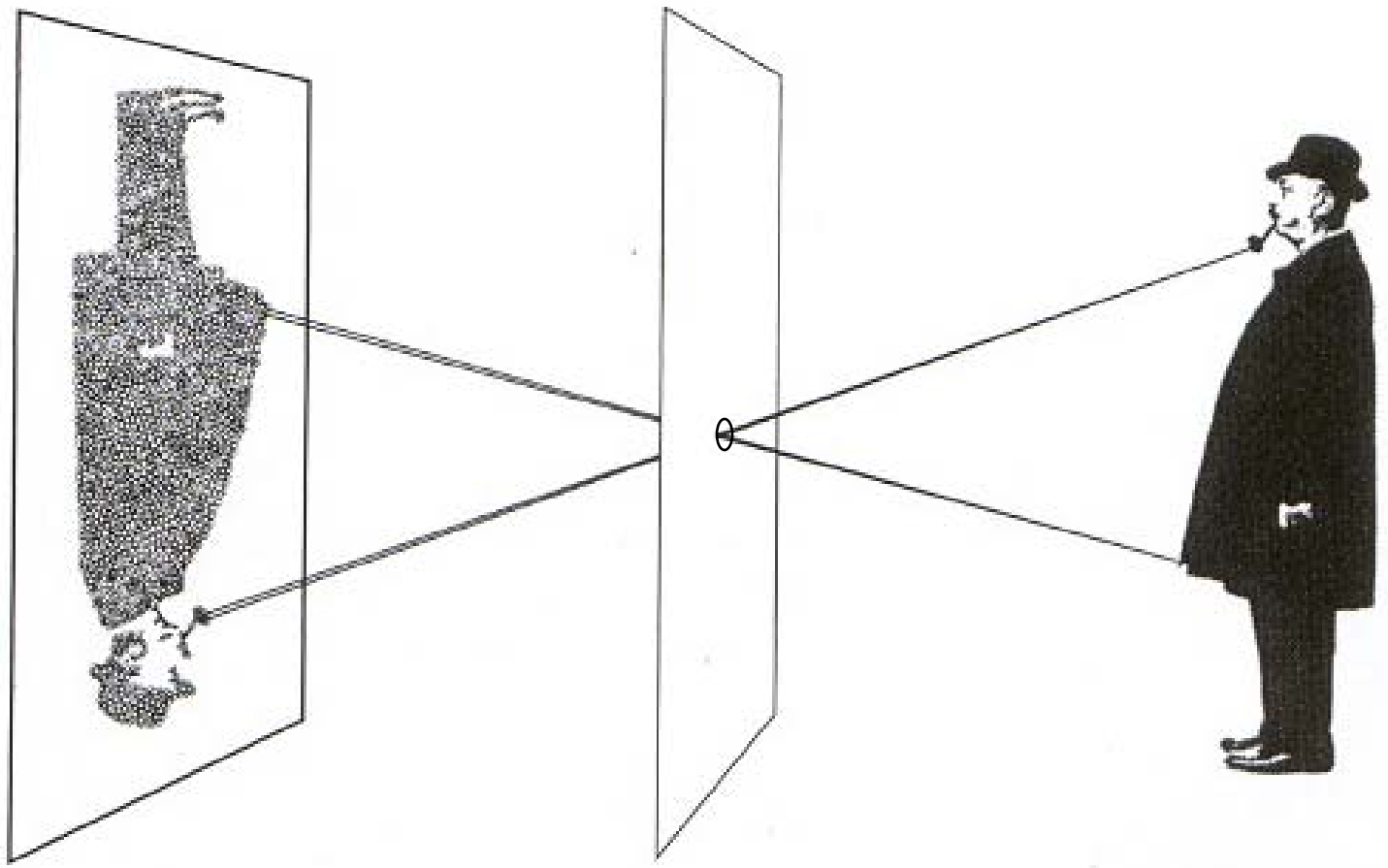
- Why is there no image on a white piece of paper?

It receives light from all directions



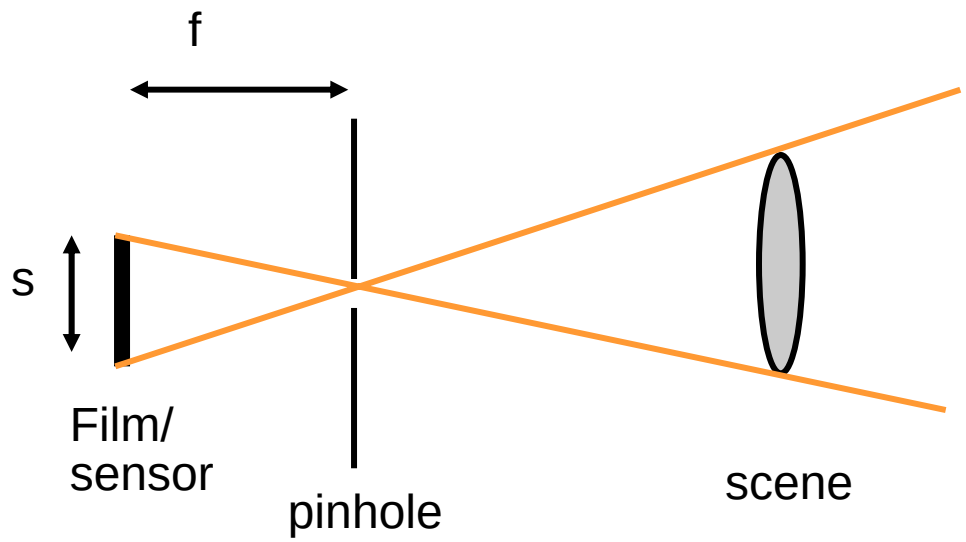
From Photography, London et al.

Pinhole



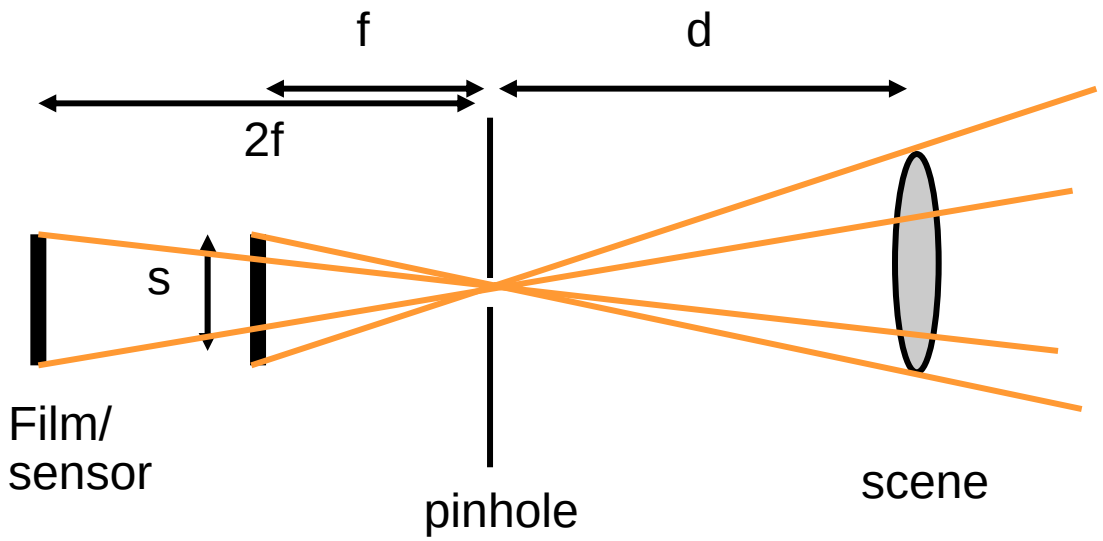
From Photography, London et al.

Focal length

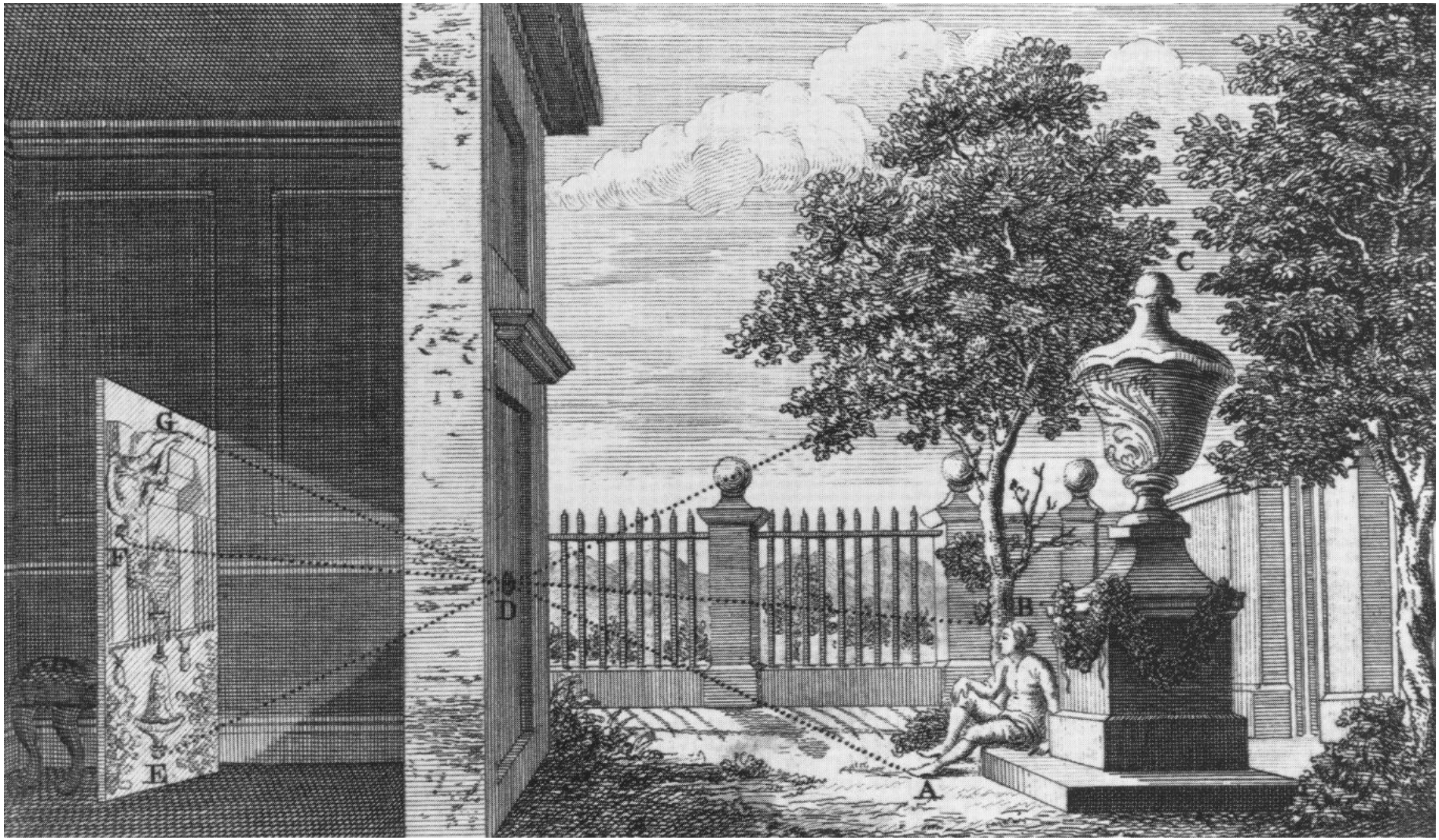


Focal length: pinhole optics

- **What happens when the focal length is doubled?**
  - Projected object size is doubled
  - Amount of light gathered is divided by 4

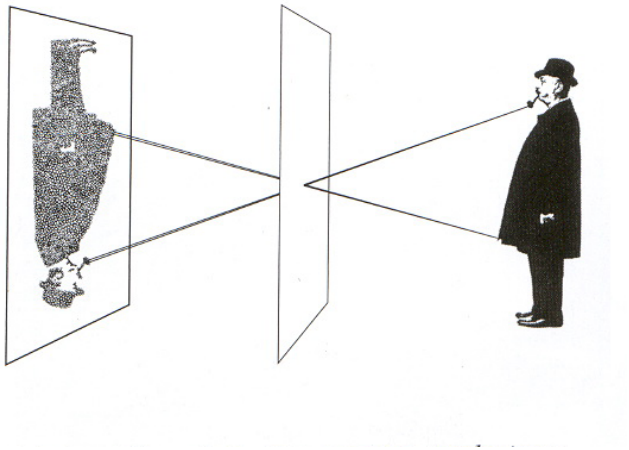


Questions?

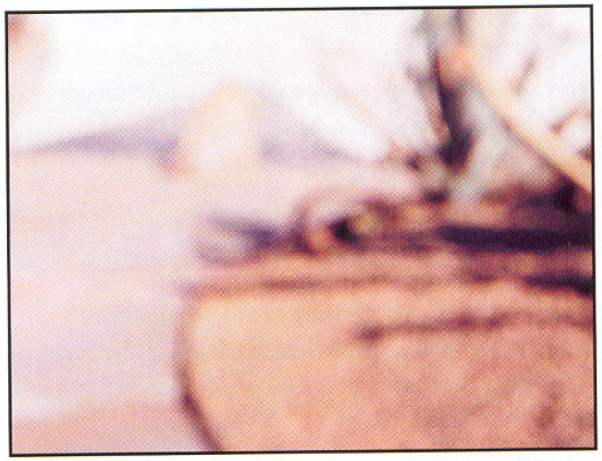


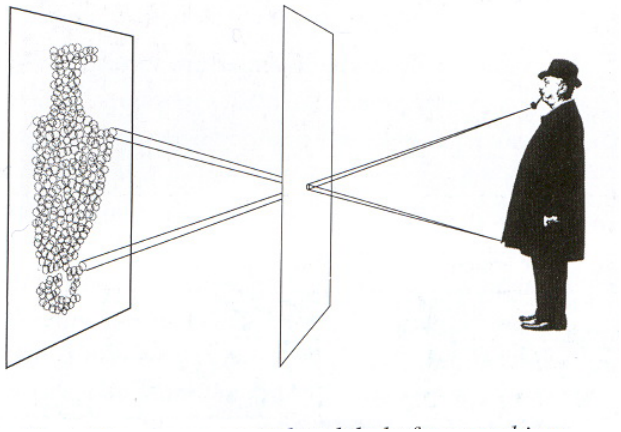
Pinhole size?

Photograph made with small pinhole



Photograph made with larger pinhole

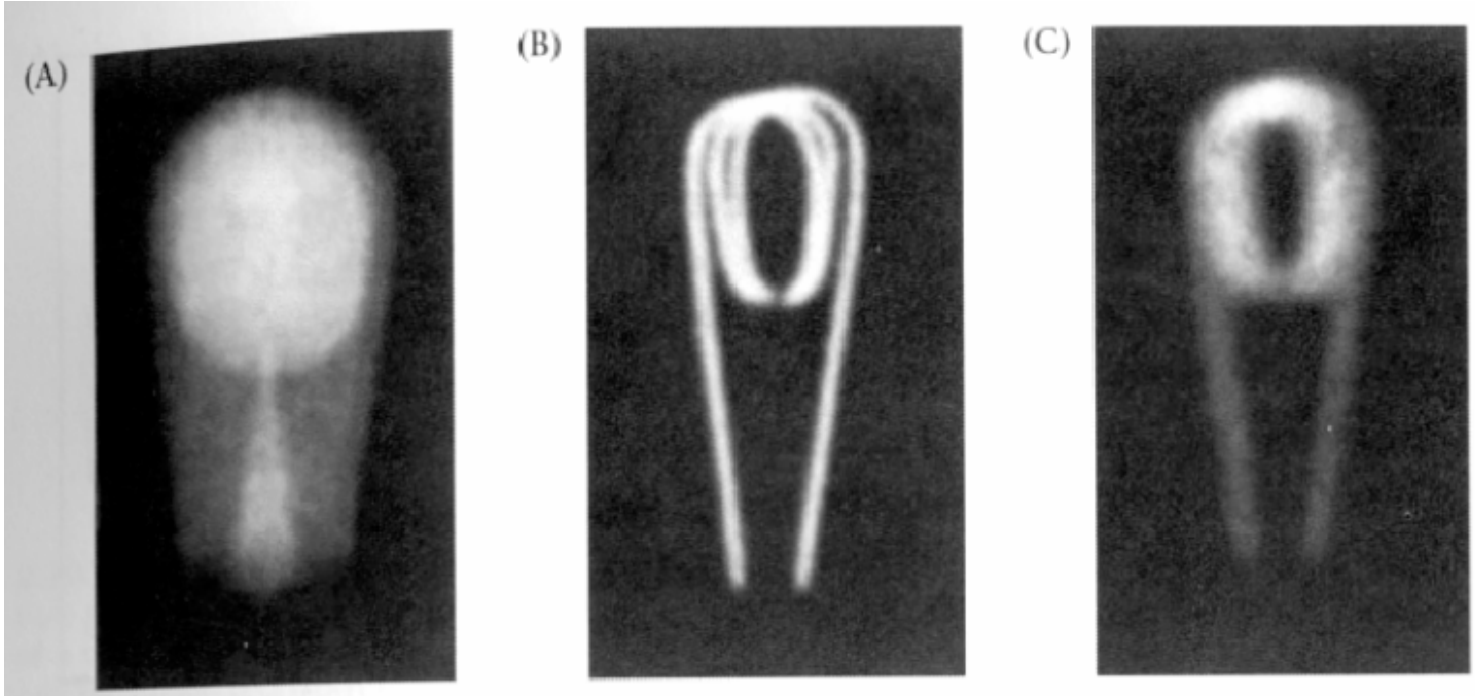




From Photography, London et al.

Diffraction limit

- **Optimal size for visible light:**
  sqrt(f)/28 (in millimiters) where f is focal length



2.18 DIFFRACTION LIMITS THE QUALITY OF PINHOLE OPTICS. These three images of a bulb filament were made using pinholes with decreasing size. (A) When the pinhole is relatively large, the image rays are not properly converged, and the image is blurred. (B) Reducing the size of the pinhole improves the focus. (C) Reducing the size of the pinhole further worsens the focus, due to diffraction. From Ruechardt, 1958.

From Wandell

Problem with pinhole?

- **Not enough light!**
- **Diffraction limits sharpness**

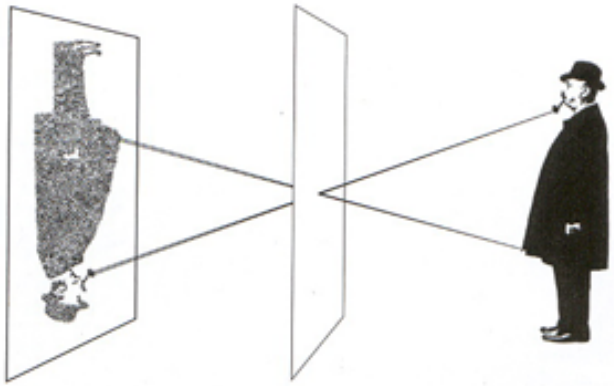
Solution: refraction!

From Photography, London et al.

Lenses

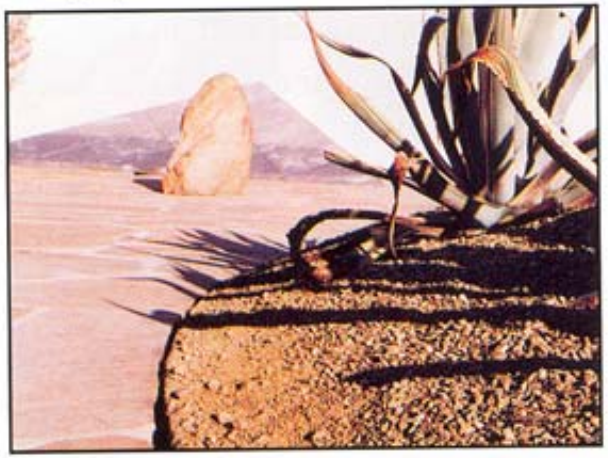
- **gather more light!**
- **But need to be focused**

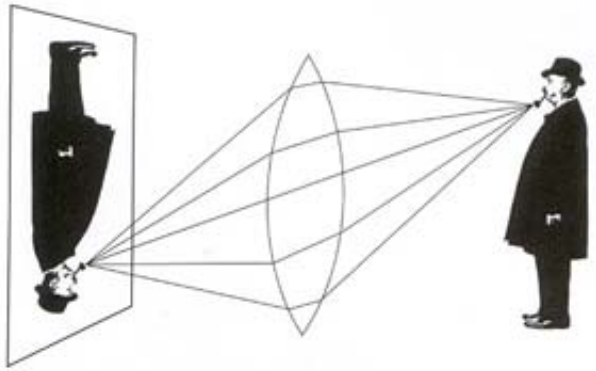
Photograph made with small pinhole



To make this picture, the lens of a camera was replaced with a thin metal disk pierced by a tiny pinhole, *equivalent in size to an aperture of f/182. Only a few rays of light from each point on the subject got through the tiny opening, producing a soft but acceptably clear photograph. Because of the small size of the pinhole, the exposure had to be 6 sec long.*

Photograph made with lens



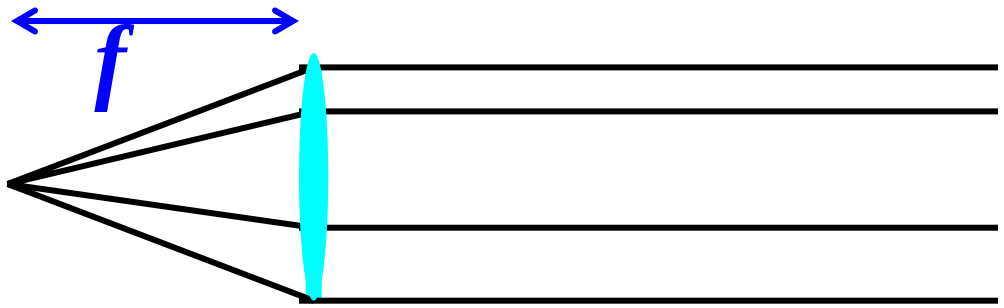


This time, using a simple convex lens with an f/16 aperture, *the scene appeared sharper than the one taken with the smaller pinhole, and the exposure time was much shorter, only 1/100 sec. The lens opening was much bigger than the pinhole, letting in far more light, but it focused the rays from each point on the subject precisely so that they were sharp on the film.*

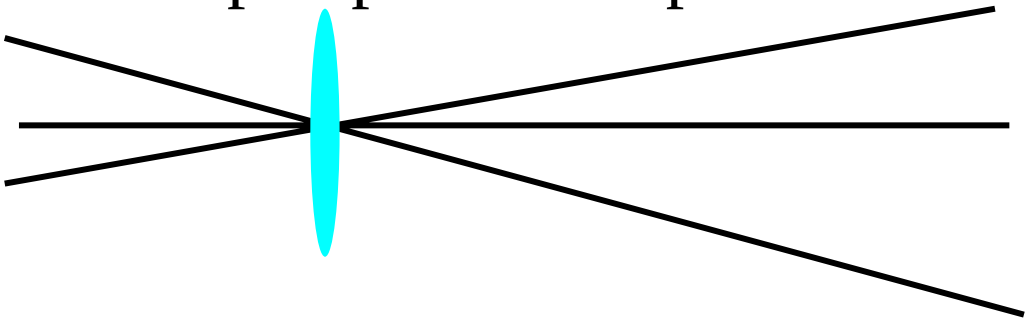
From Photography, London et al.

Thin lens optics

- **Simplification of geometrical optics for well-behaved lenses**
- **All parallel rays converge to one point on a plane located at the focal length *f***

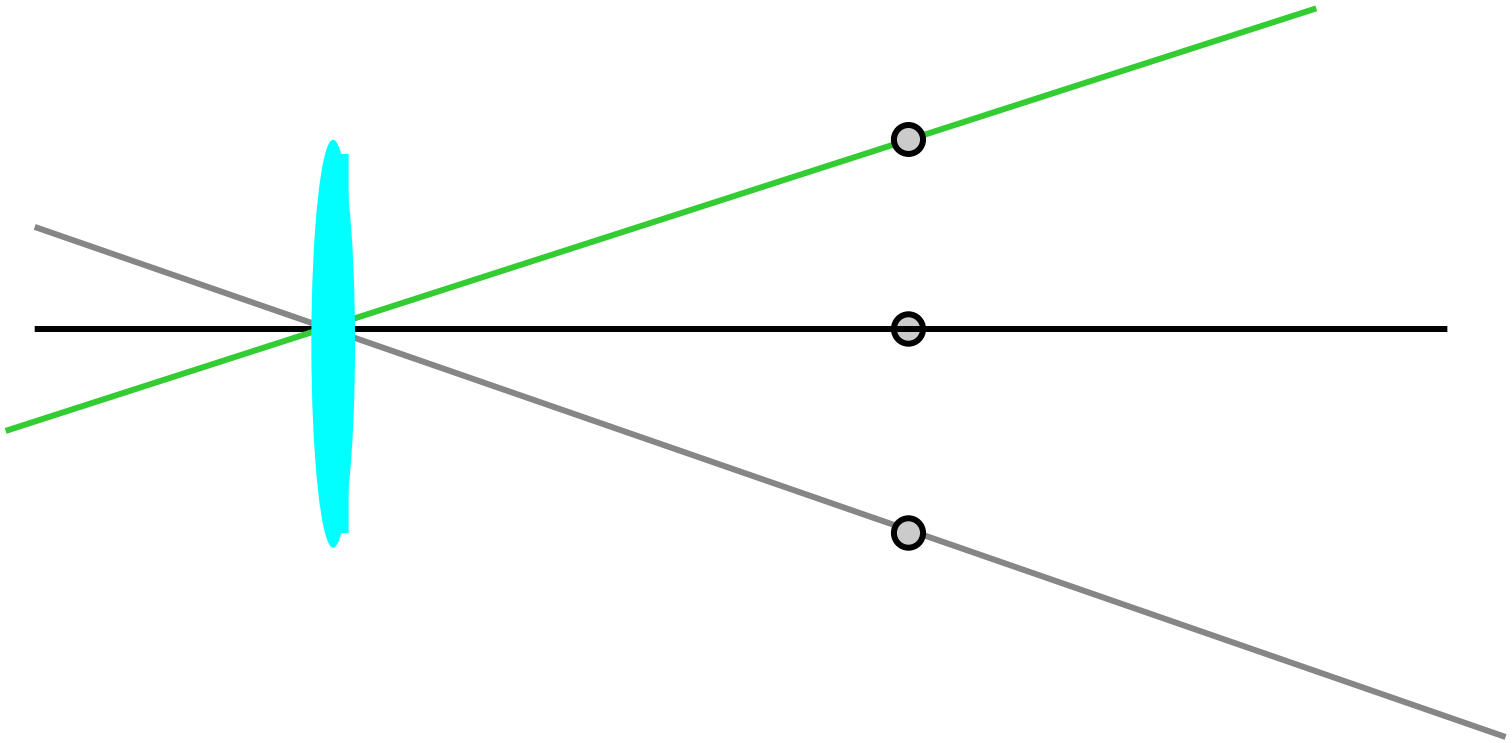


- **All rays going through the center are not deviated**
  - Hence same perspective as pinhole



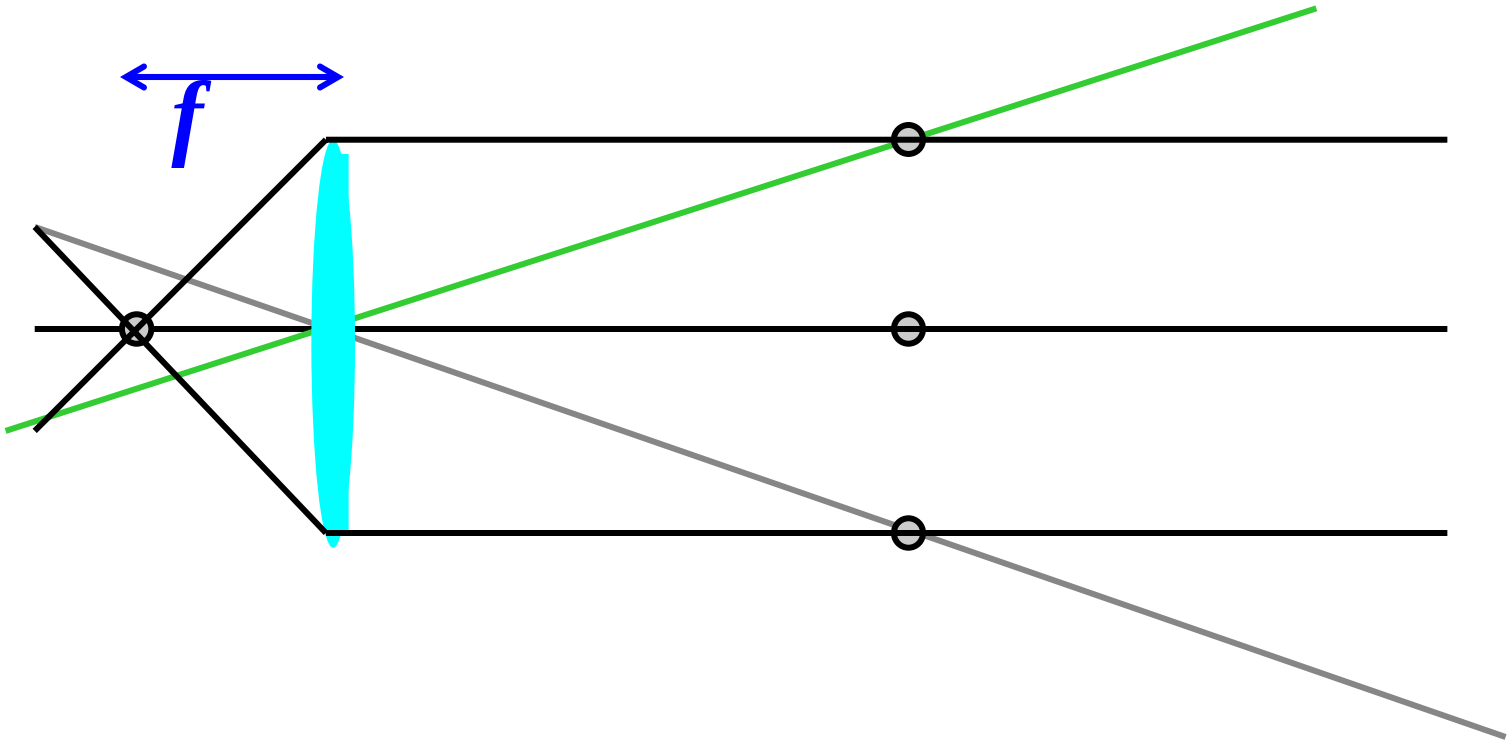
How to trace rays

- **Start by rays through the center**



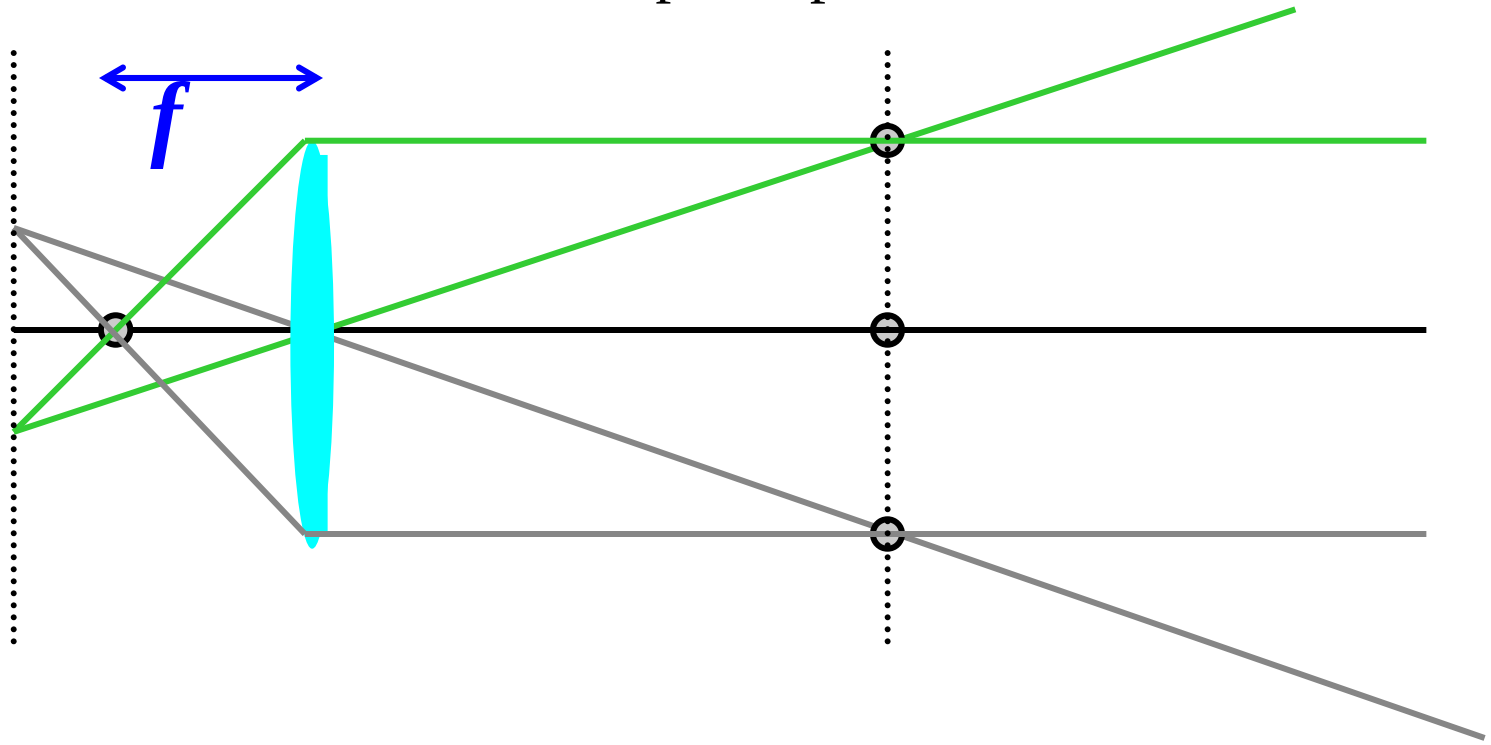
How to trace rays

- **Start by rays through the center**
- **Choose focal length, trace parallels**



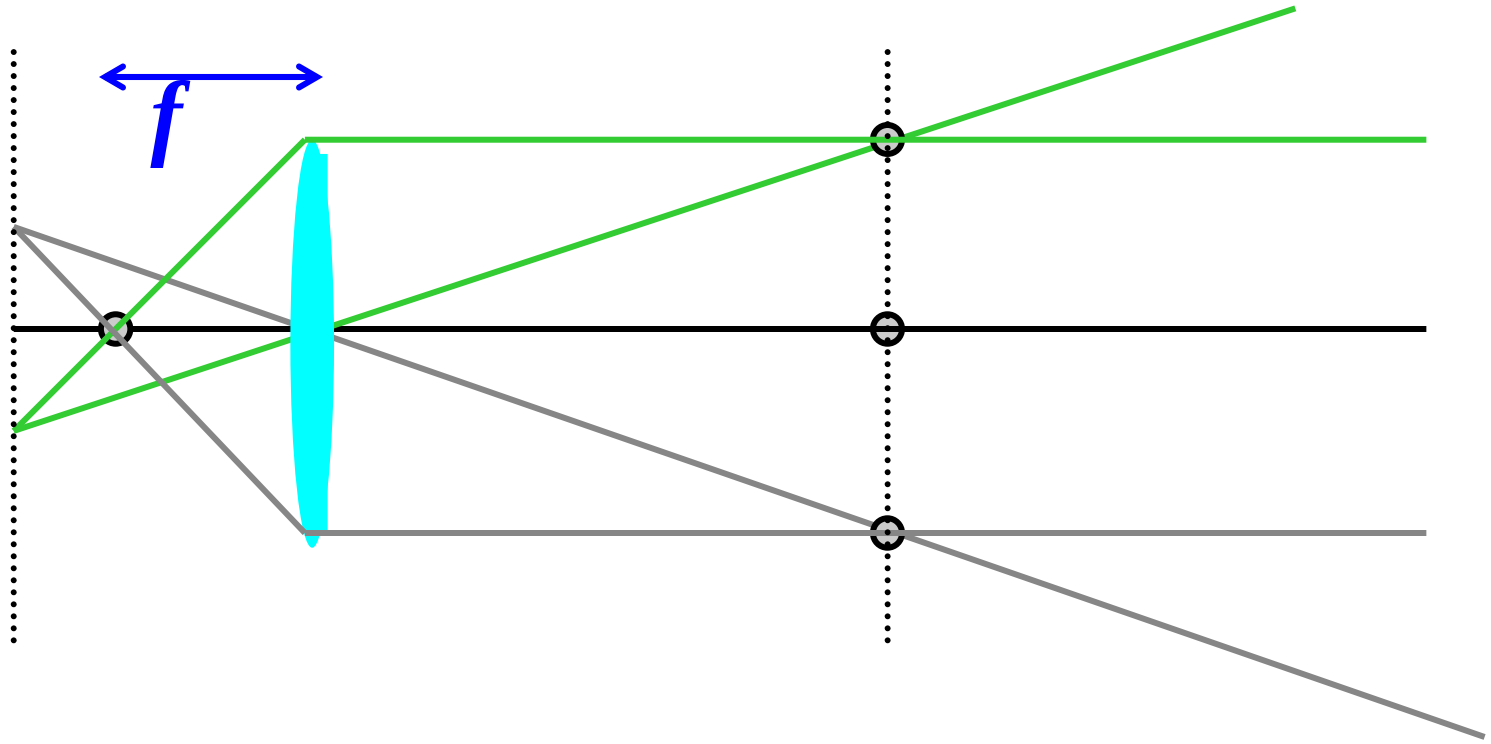
How to trace rays

- **Start by rays through the center**
- **Choose focal length, trace parallels**
- **You get the focus plane for a given scene plane**
  - All rays coming from points on a plane parallel to the lens are focused on another plane parallel to the lens

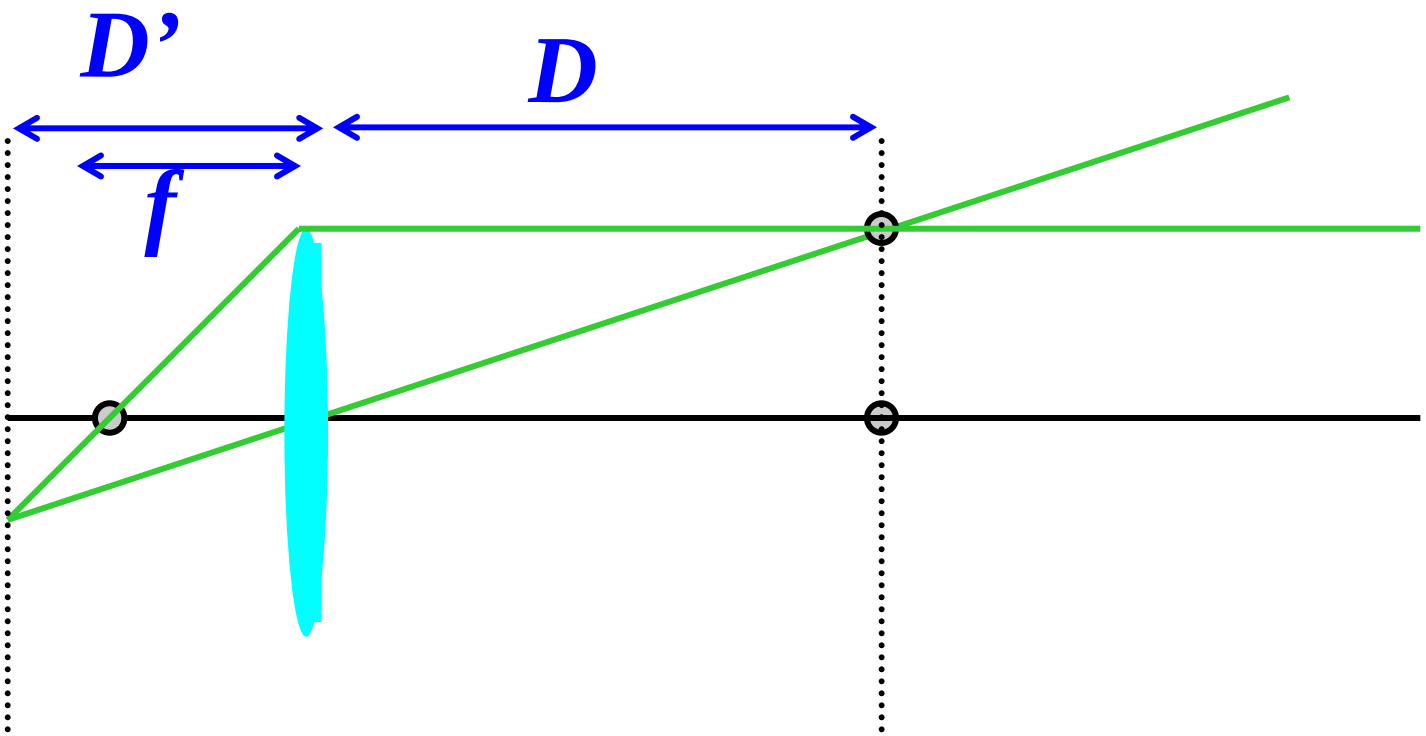


Focusing

- **To focus closer than infinity**
  - Move the sensor/film ***further*** than the focal length

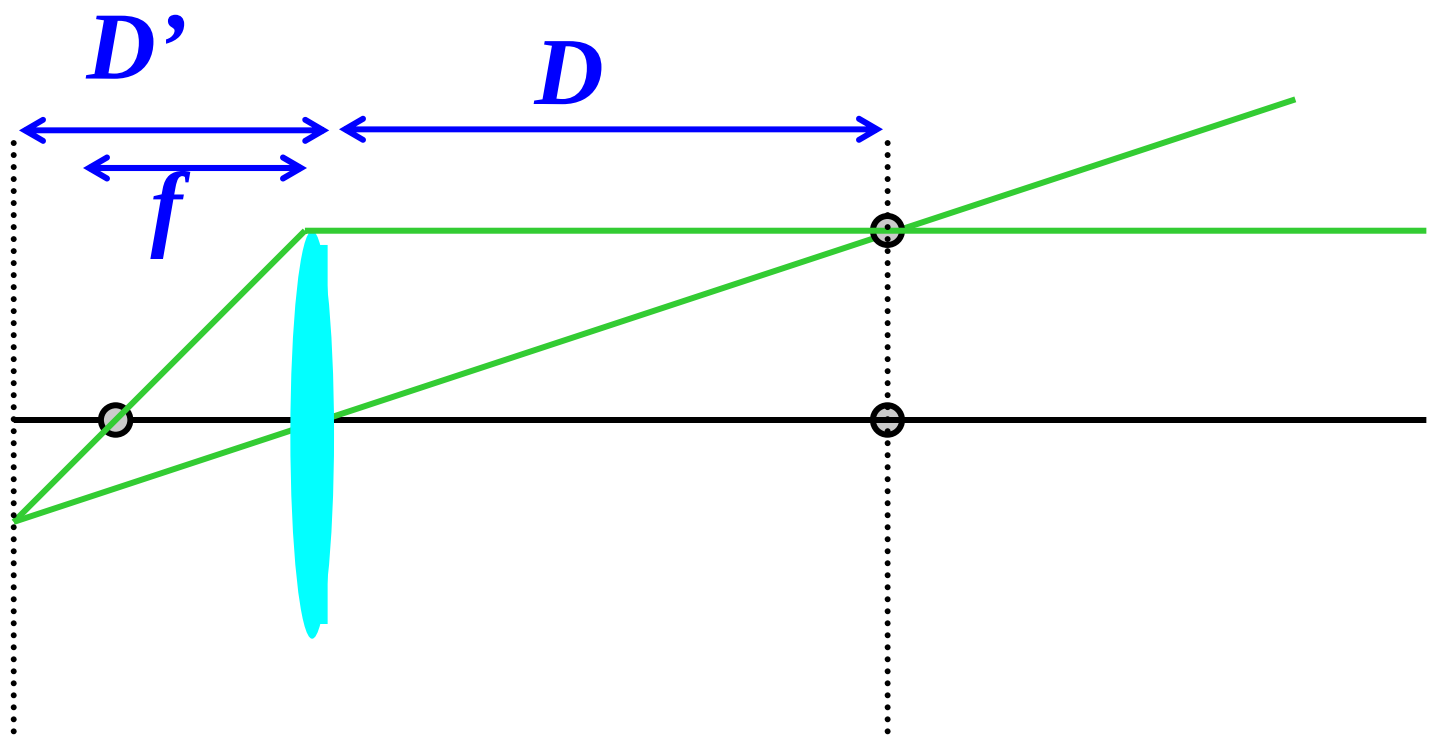


Thin lens formula



Thin lens formula

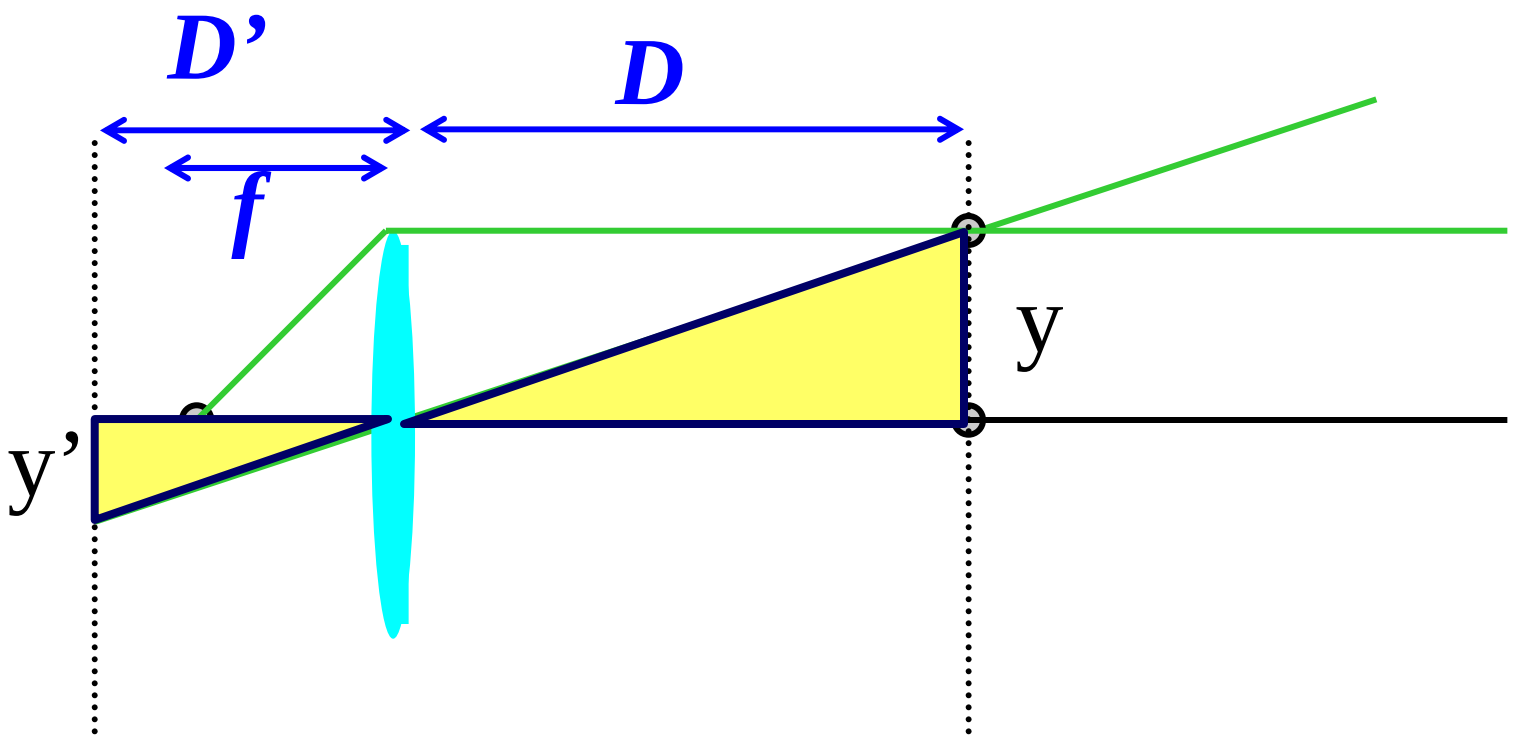
Similar triangles everywhere!



Thin lens formula

Similar triangles everywhere!

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

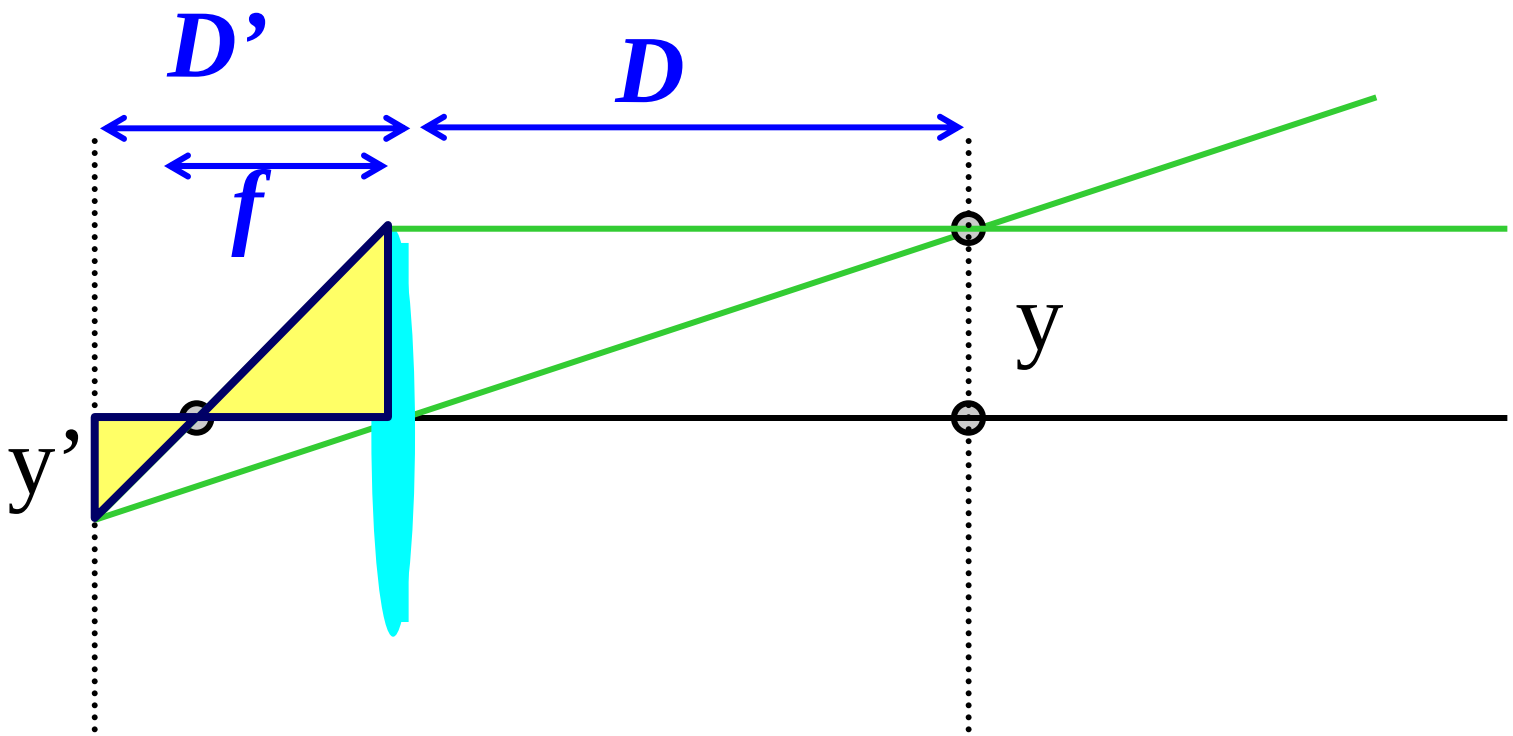


Thin lens formula

Similar triangles everywhere!

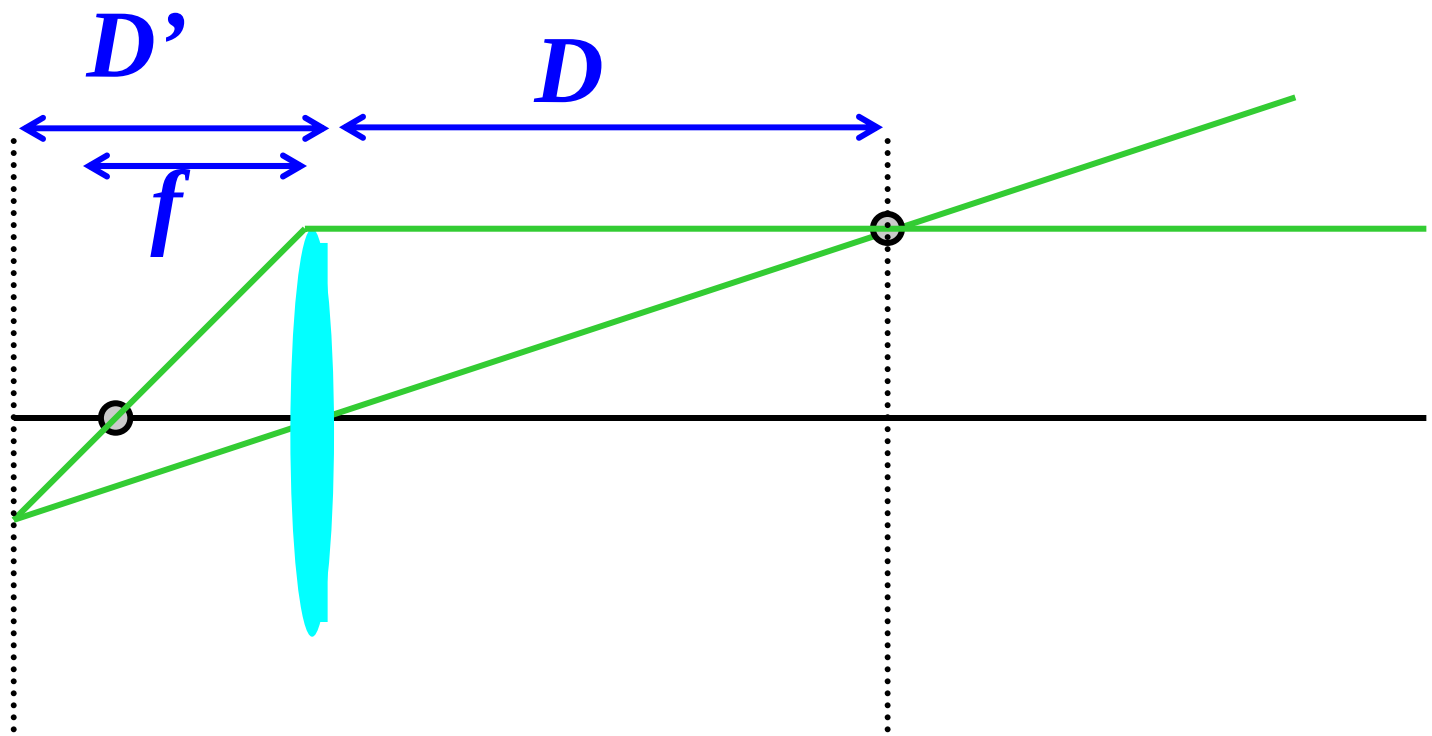
$$y'/y = D'/D$$

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



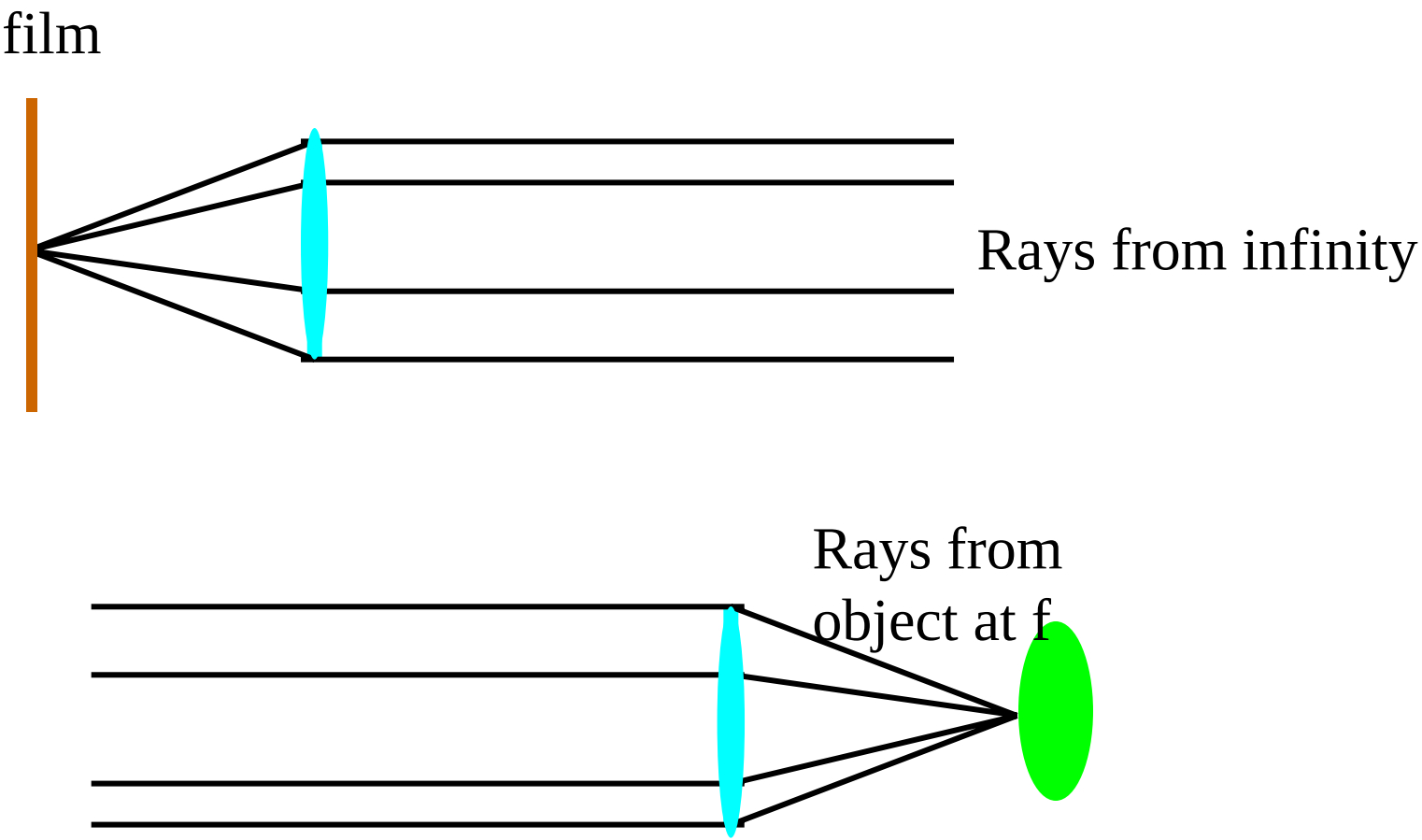
Thin lens formula

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



Minimum focusing distance

- **By symmetry, an object at the focal length requires the film to be at infinity.**



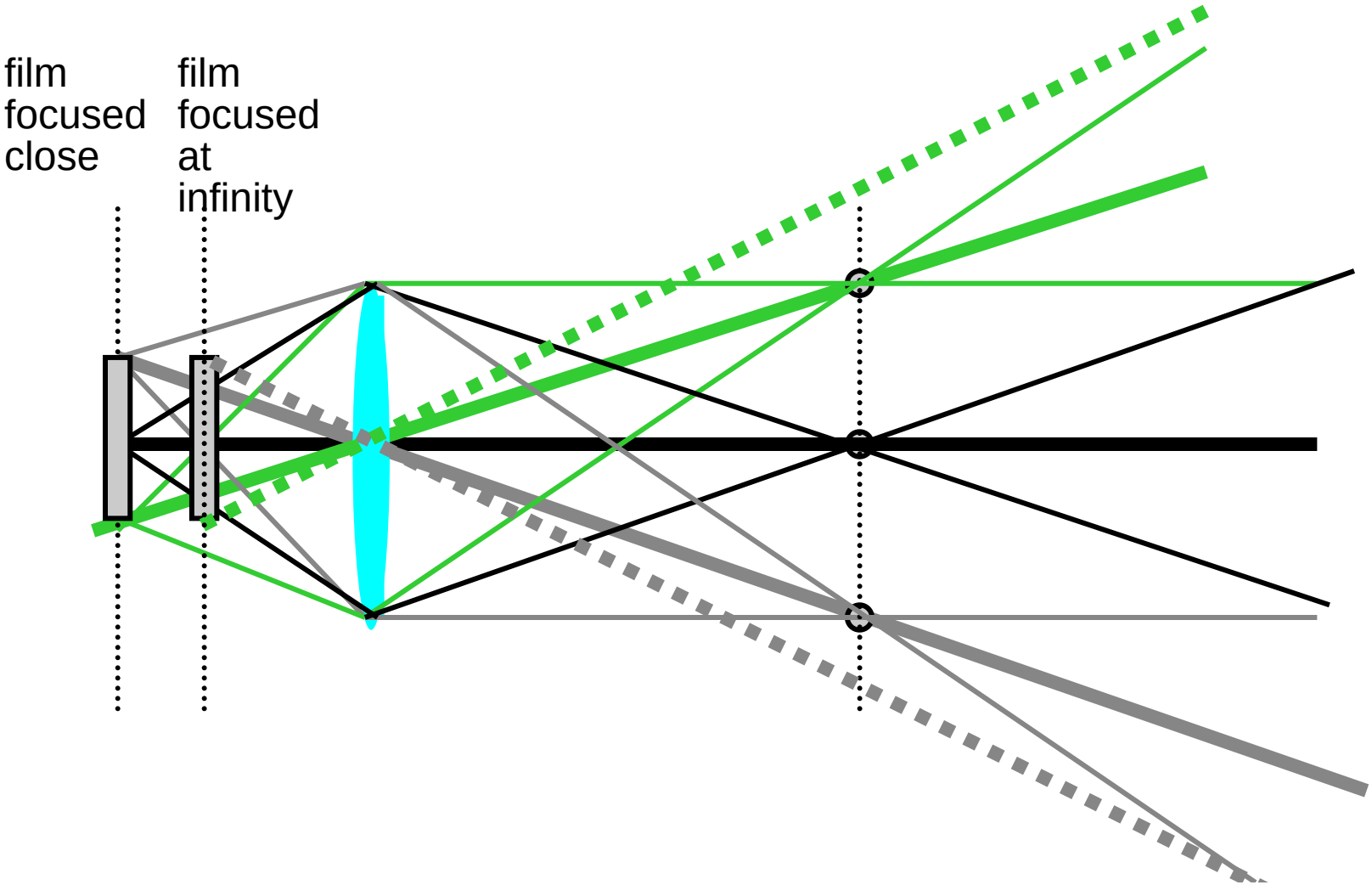
Extensions tubes

- **Allow us to put sensor/film farther**

  → focus closer

Field of view & focusing

- **What happens to the field of view when one focuses closer?**
  - It's reduced



Questions?

- **http://www.pinhole.cz/en/pinholecameras/dirkon_01.html**