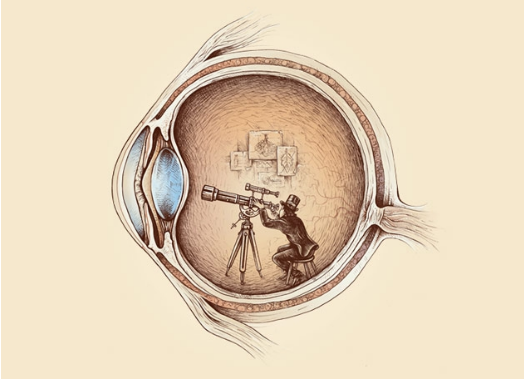


Computer Vision
CS 776 Fall 2018

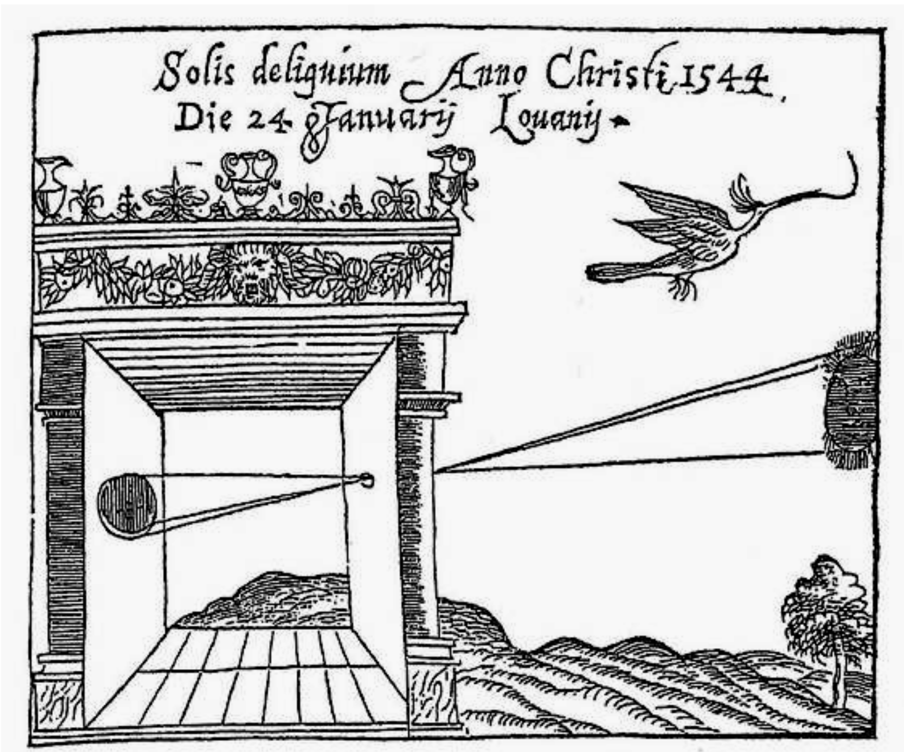
Cameras & Photogrammetry 2

Prof. Alex Berg

(Slide credits to many folks on individual slides)

Cameras & Photogrammetry 2

Camera Obscura

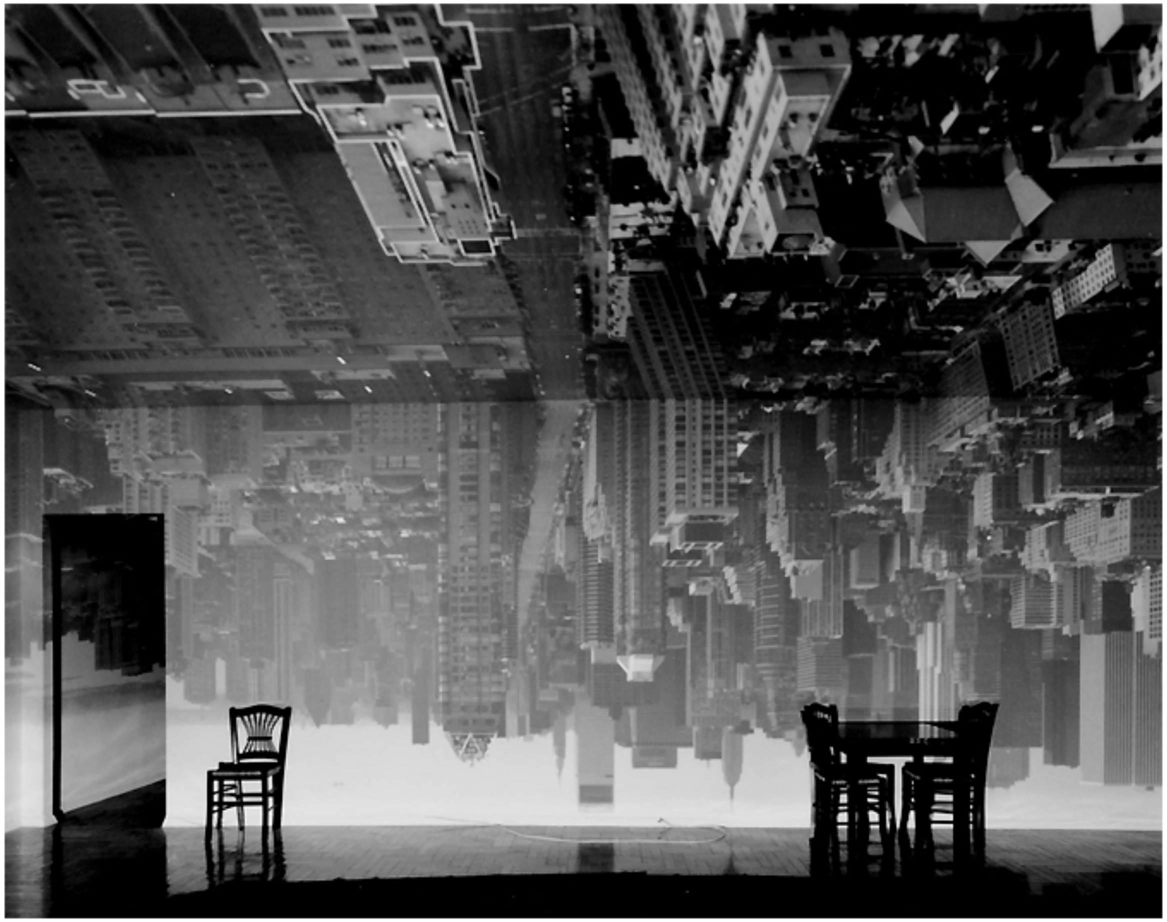


Gemma Frisius, 1558

- 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

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 pinhole cameras

My hotel room, contrast enhanced.

The view from my window

Accidental pinholes produce images that are unnoticed or misinterpreted as shadows

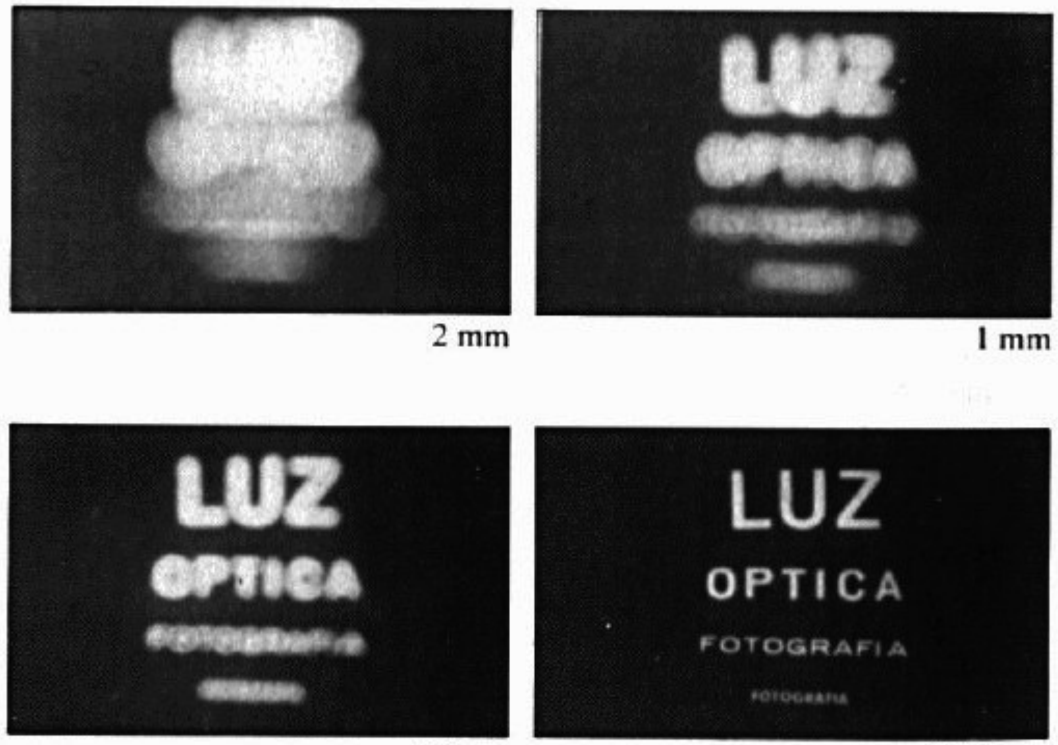
A. Torralba and W. Freeman, [Accidental Pinhole and Pinspeck Cameras](), CVPR 2012

Home-made pinhole camera

Slide by A. Efros

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

Shrinking the aperture



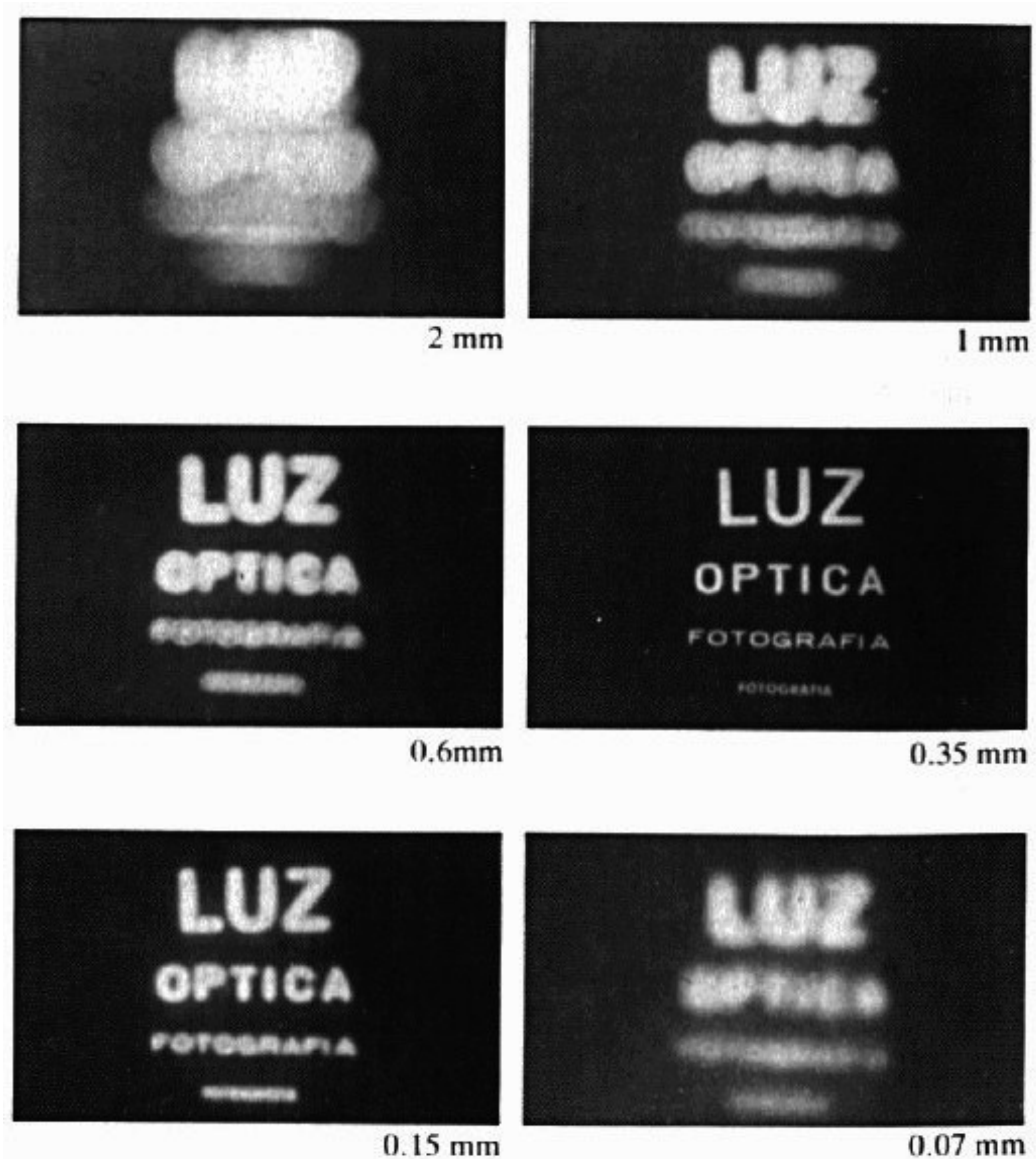
2 mm
1 mm
0.6mm
0.35 mm

Why not make the aperture as small as possible?

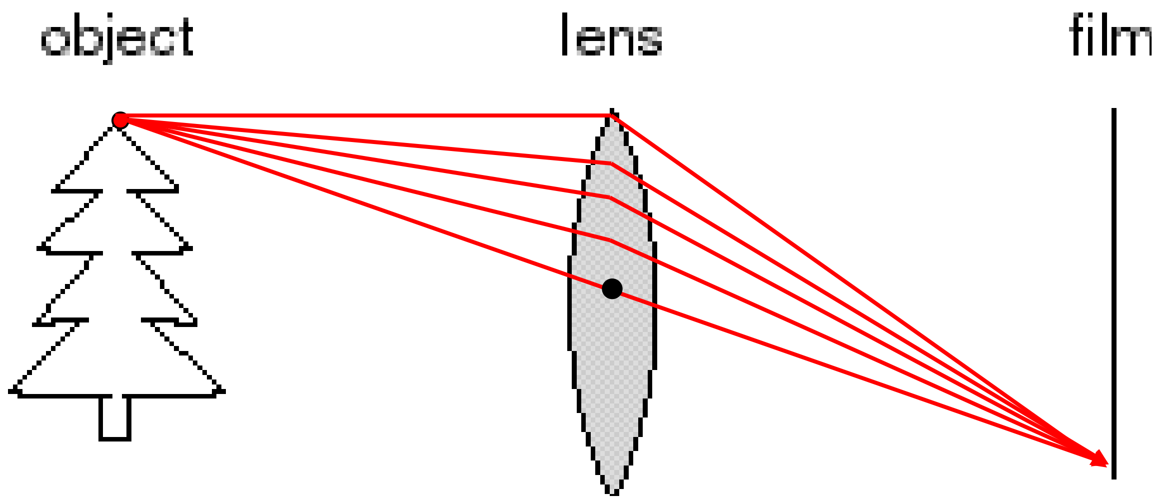
- Less light gets through
- Diffraction effects...

Slide by Steve Seitz

Shrinking the aperture



Adding a lens

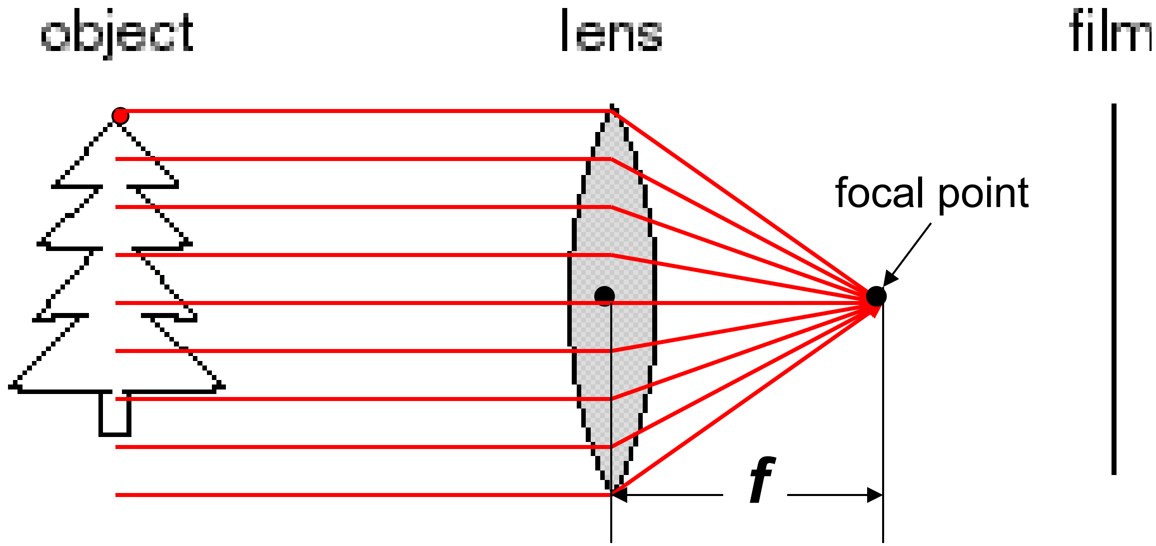


A lens focuses light onto the film

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

Slide by Steve Seitz

Adding a lens

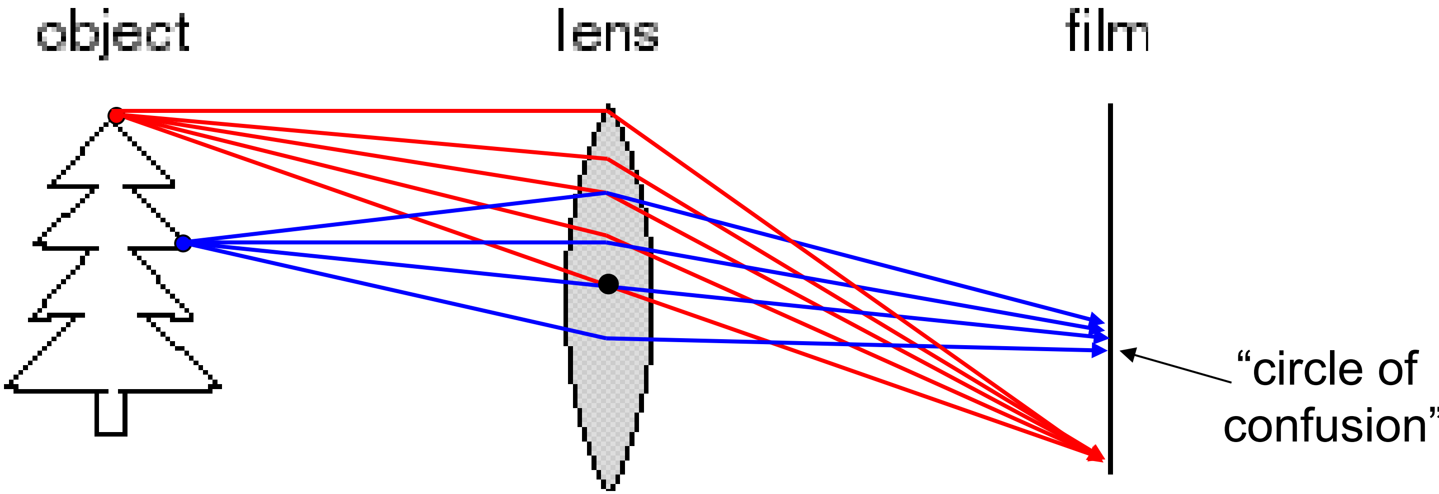


A lens focuses light onto the film

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

Slide by Steve Seitz

Adding a lens



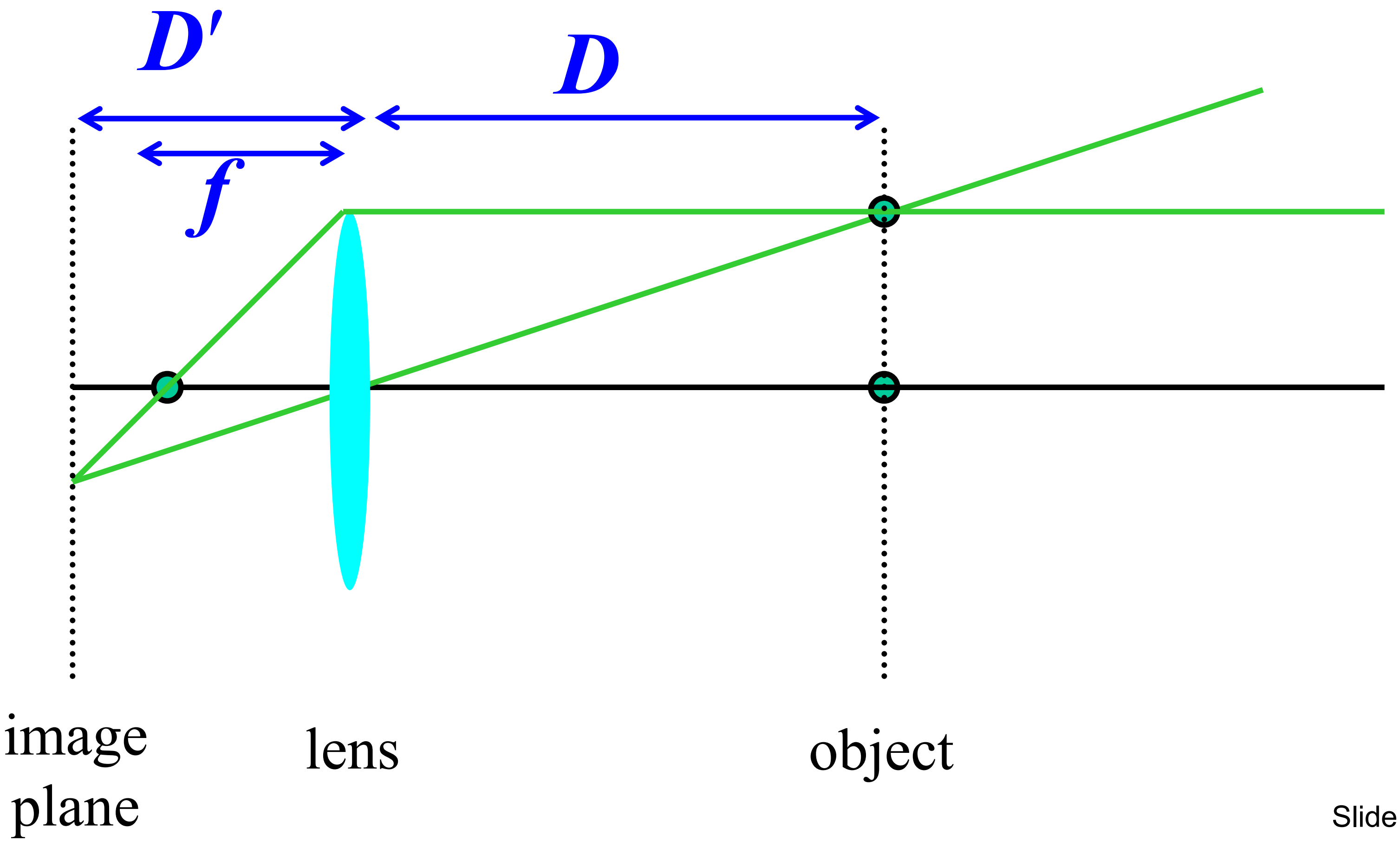
A lens focuses light onto the film

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

Slide by Steve Seitz

Thin lens formula

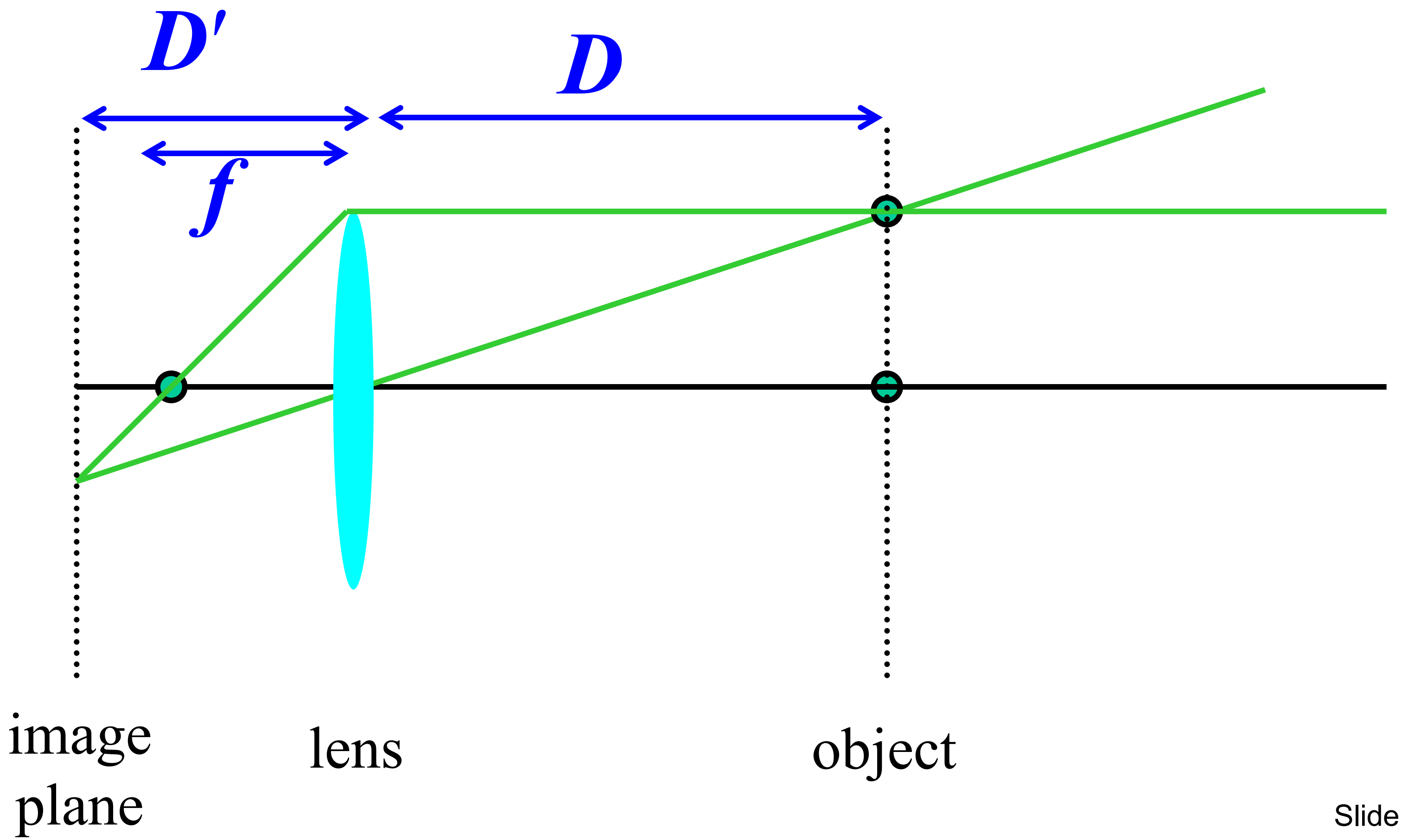
- What is the relation between the focal length (f), the distance of the object from the optical center (D), and the distance at which the object will be in focus (D')?



Slide by Frédo Durand

Thin lens formula

Similar triangles everywhere!

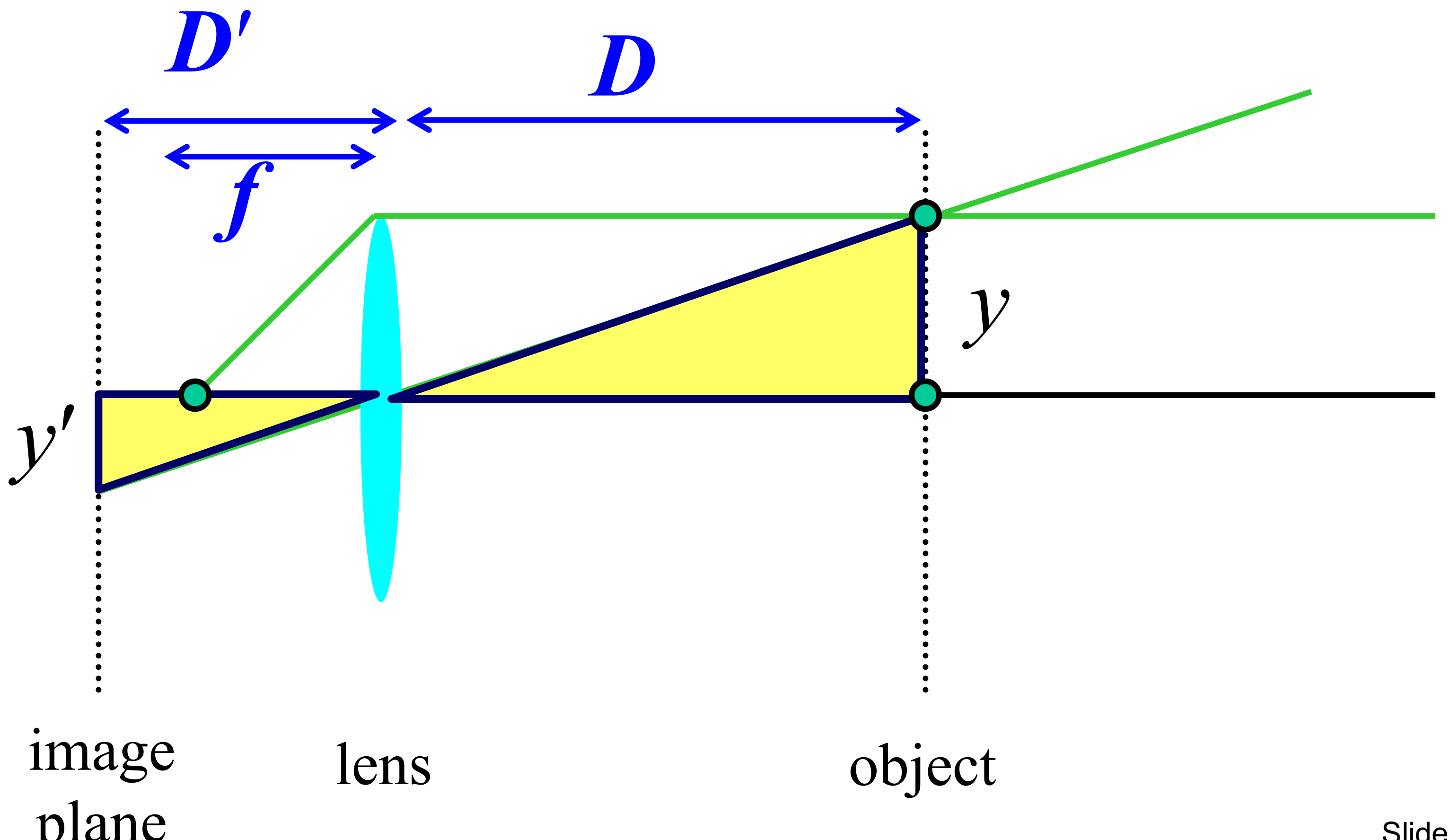


Slide by Frédo Durand

Thin lens formula

Similar triangles everywhere!

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



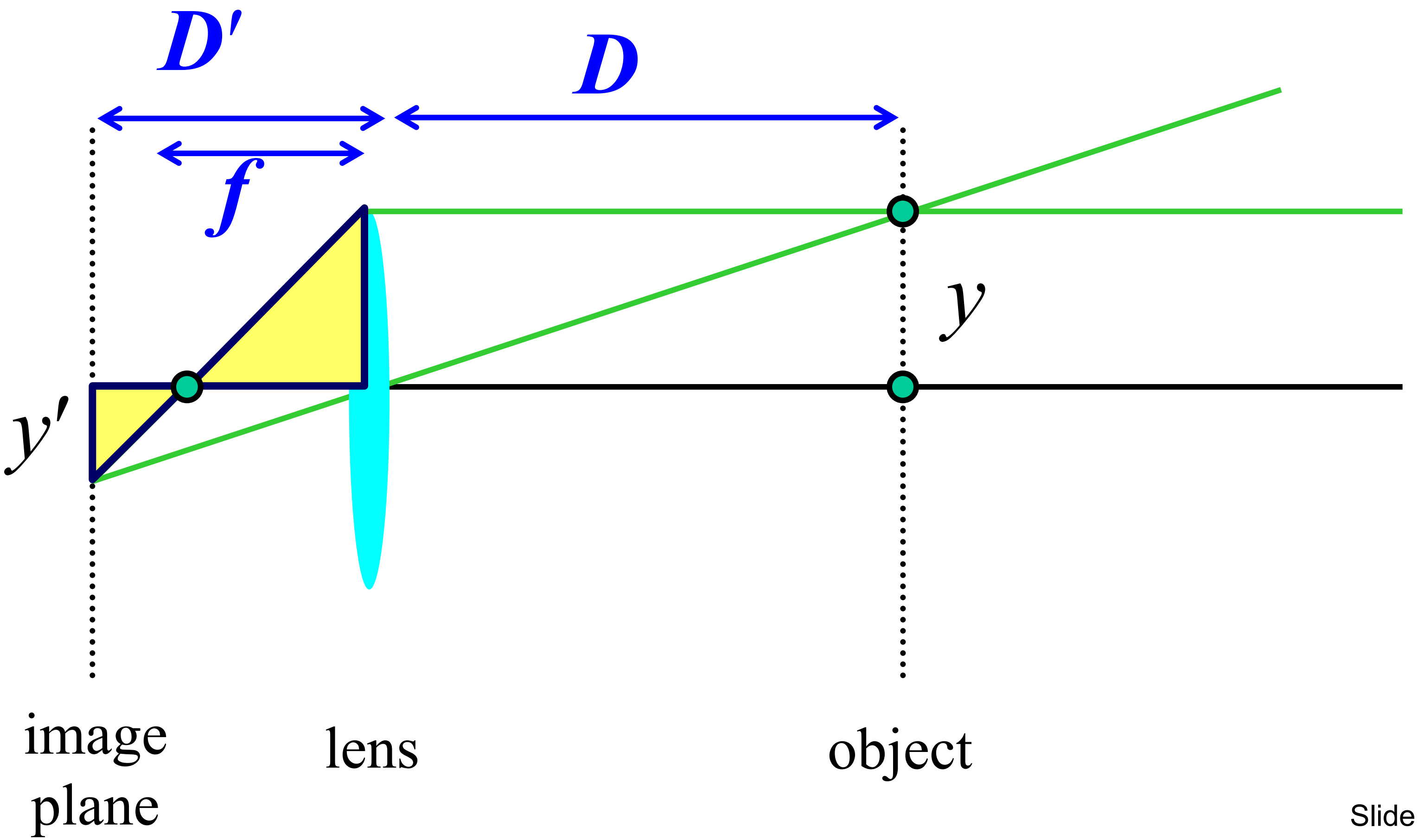
Slide by Frédo Durand

Thin lens formula

Similar triangles everywhere!

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

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

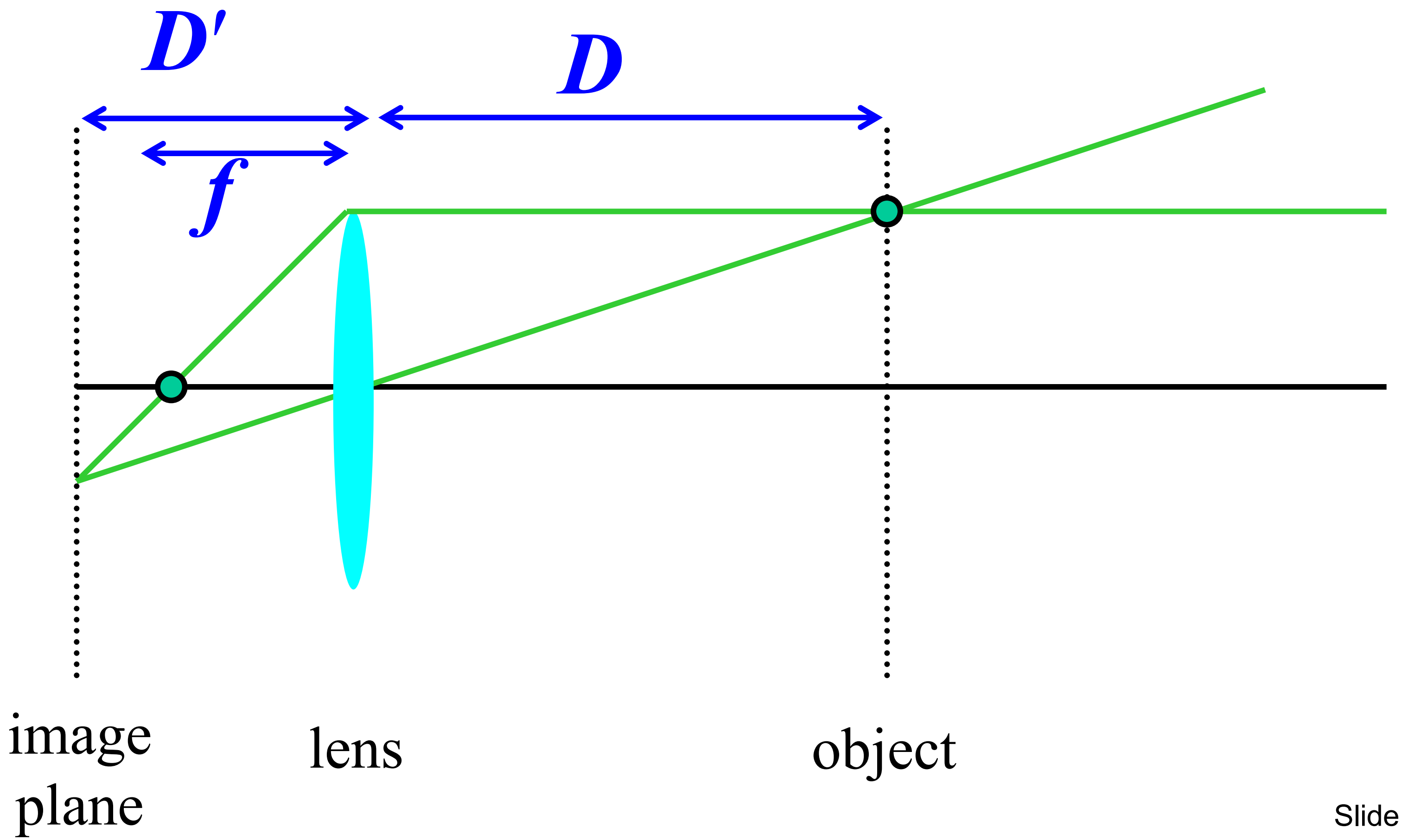


Slide by Frédo Durand

Thin lens formula

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

Any point satisfying the thin lens equation is in focus.



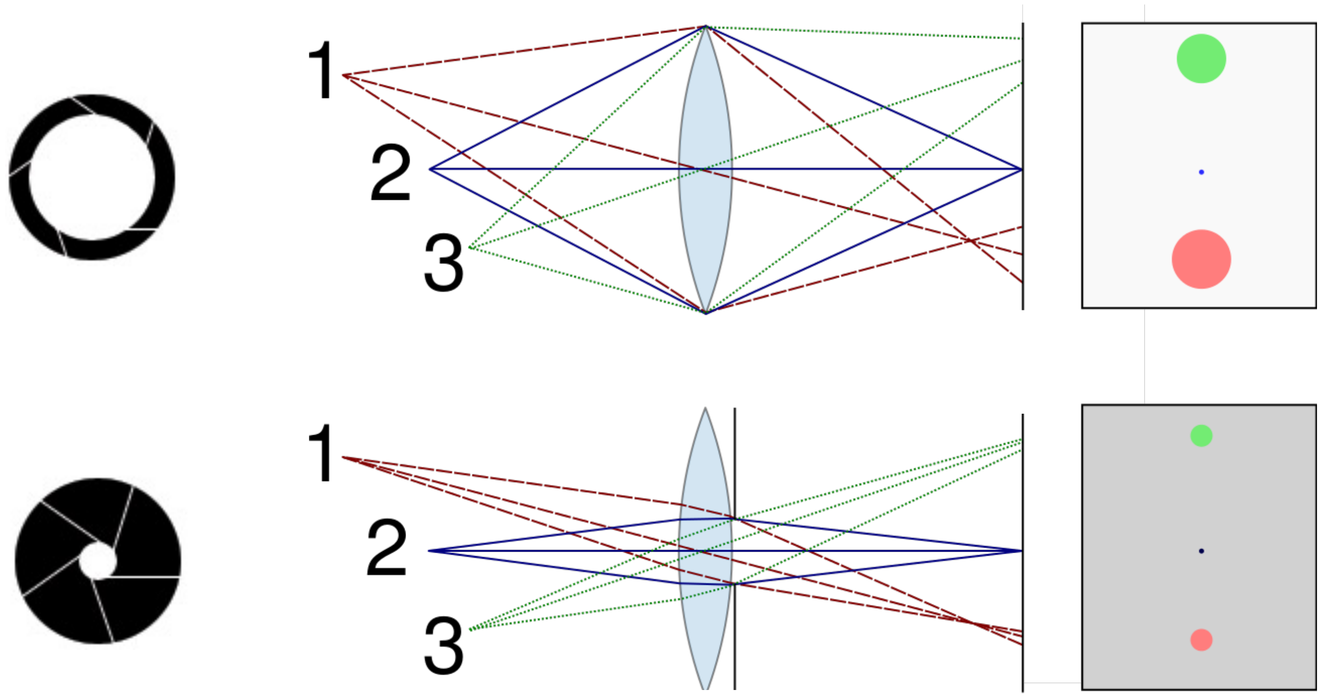
Slide by Frédo Durand

Depth of Field

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

Slide by A. Efros

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

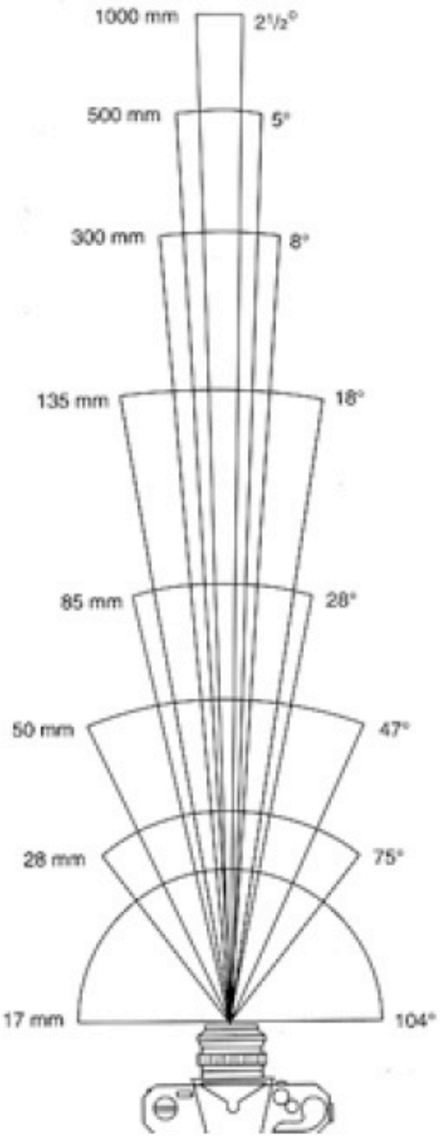
Varying the aperture

Large aperture = small DOF

Small aperture = large DOF

Slide by A. Efros

Field of View



17mm

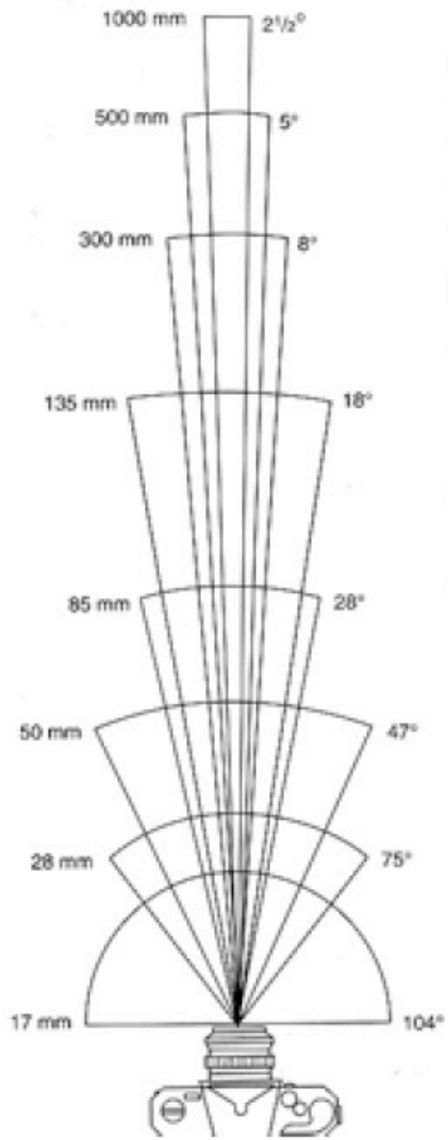
28mm

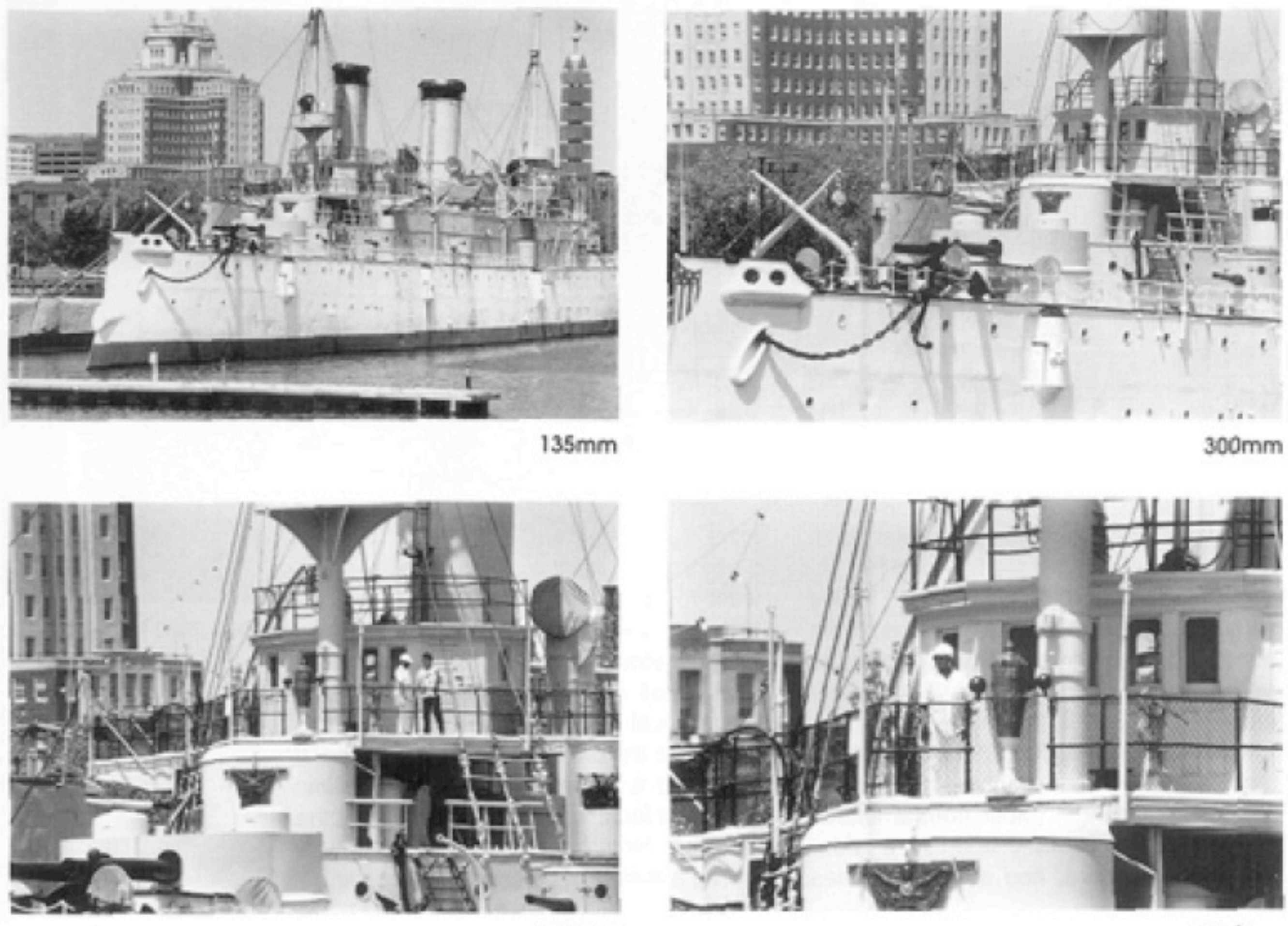
50mm

85mm

Slide by A. Efros

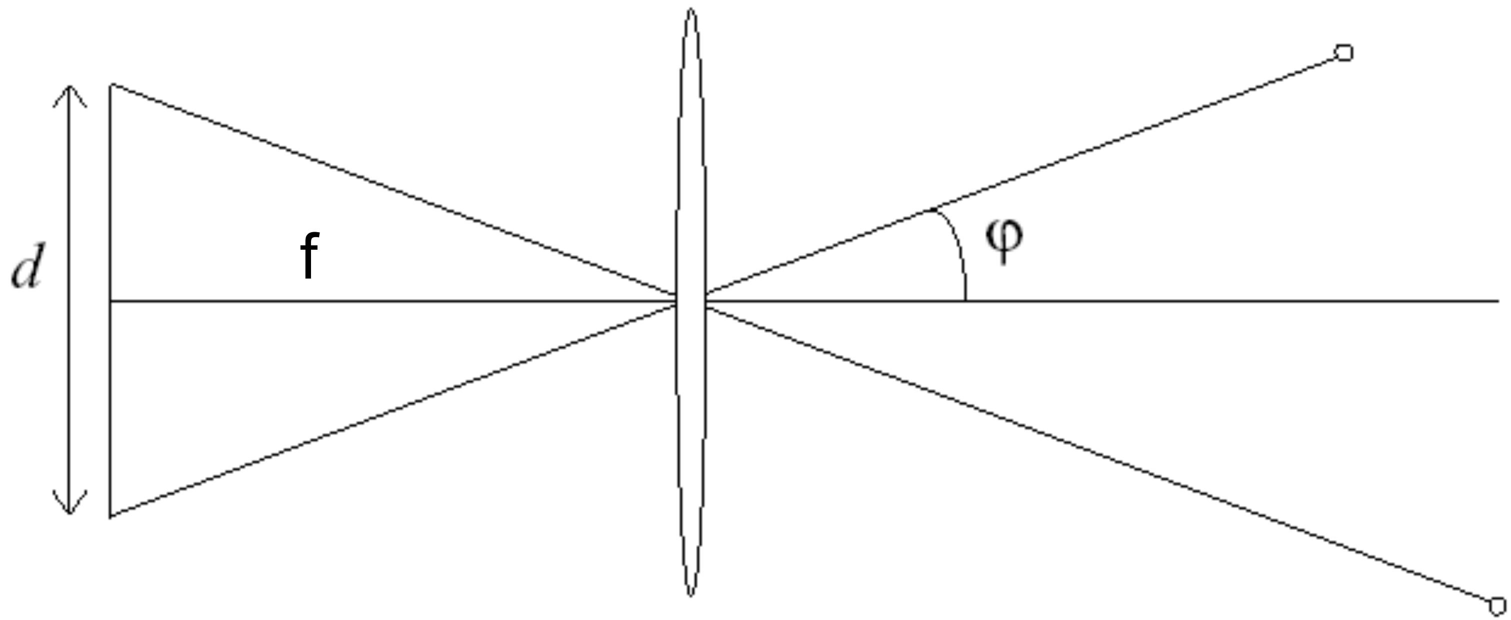
Field of View





Slide by A. Efros

Field of View



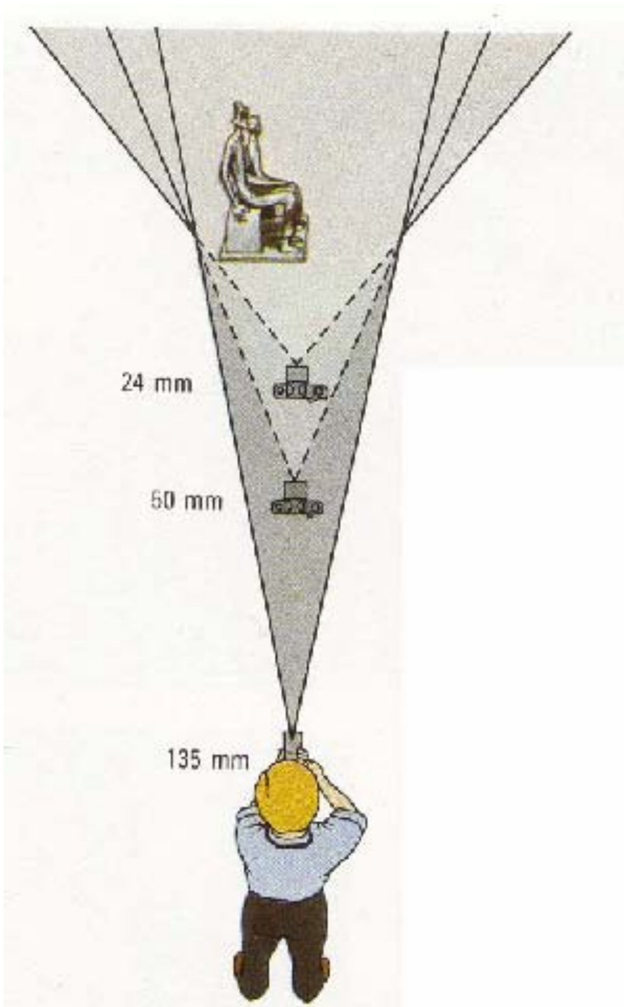
FOV depends on focal length and size of the camera retina

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

Larger focal length = smaller FOV

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

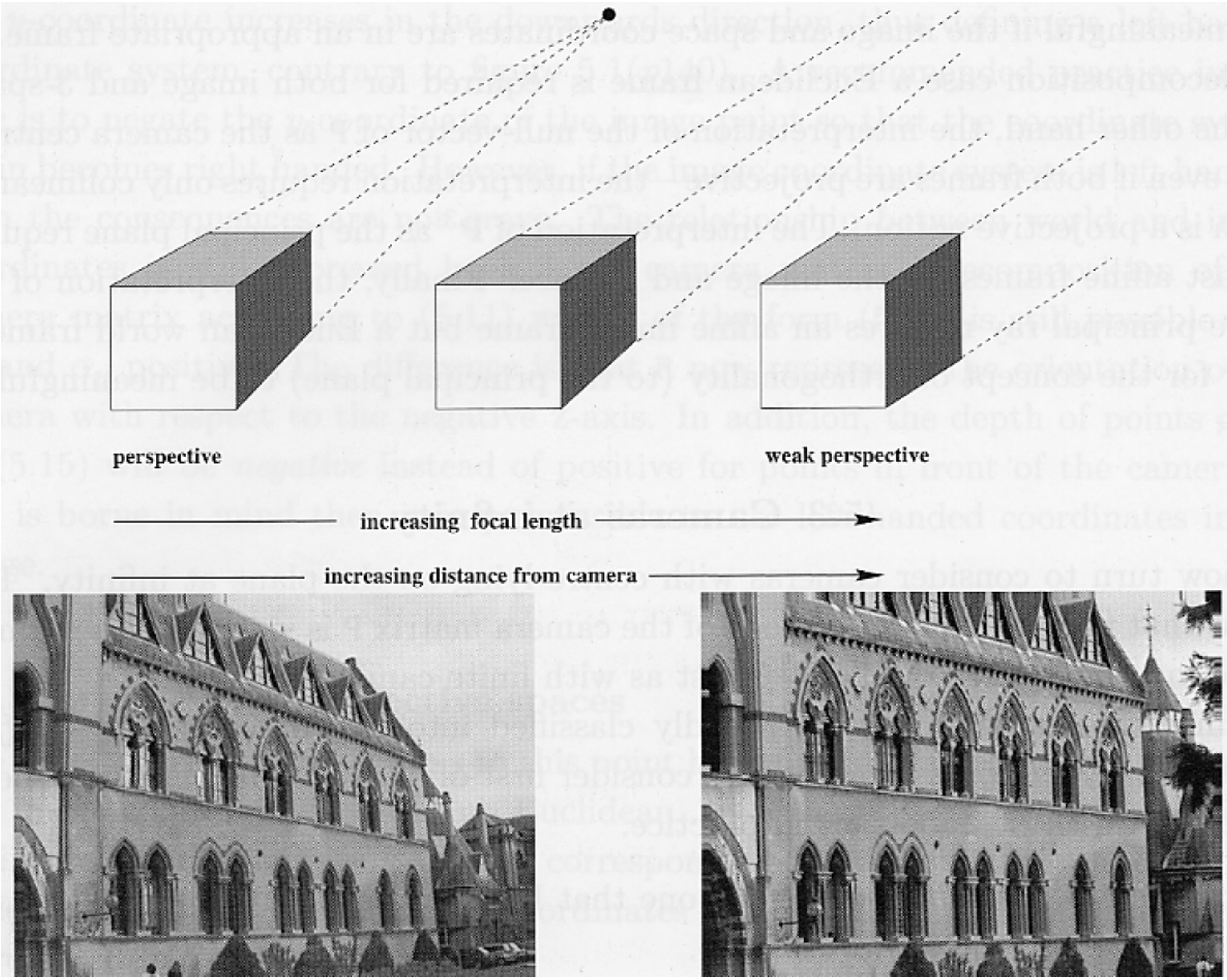
wide-angle

standard

telephoto

Source: F. Durand

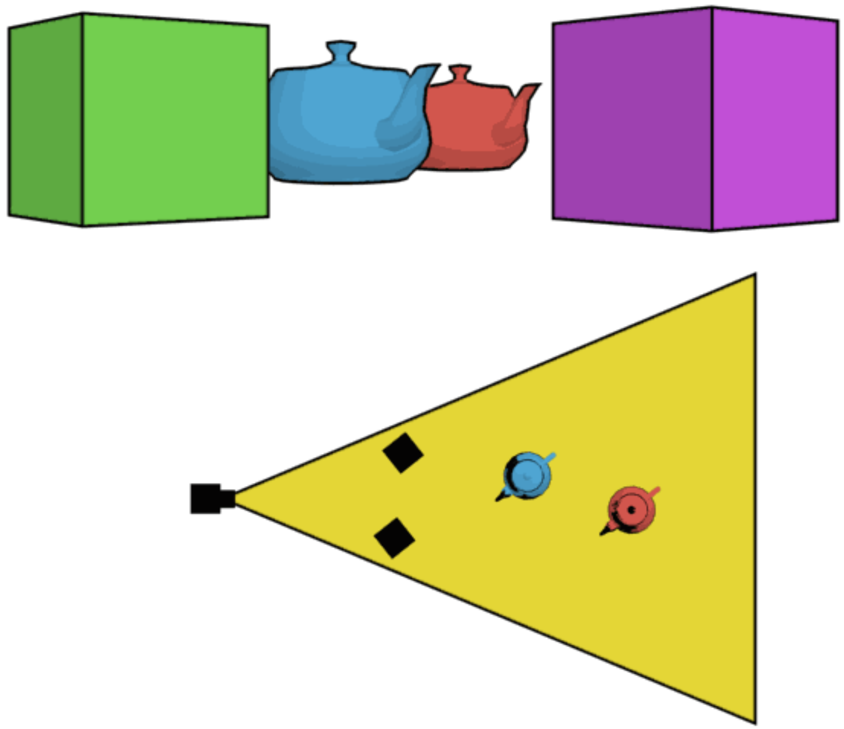
Approximating an orthographic camera



Source: Hartley & Zisserman

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

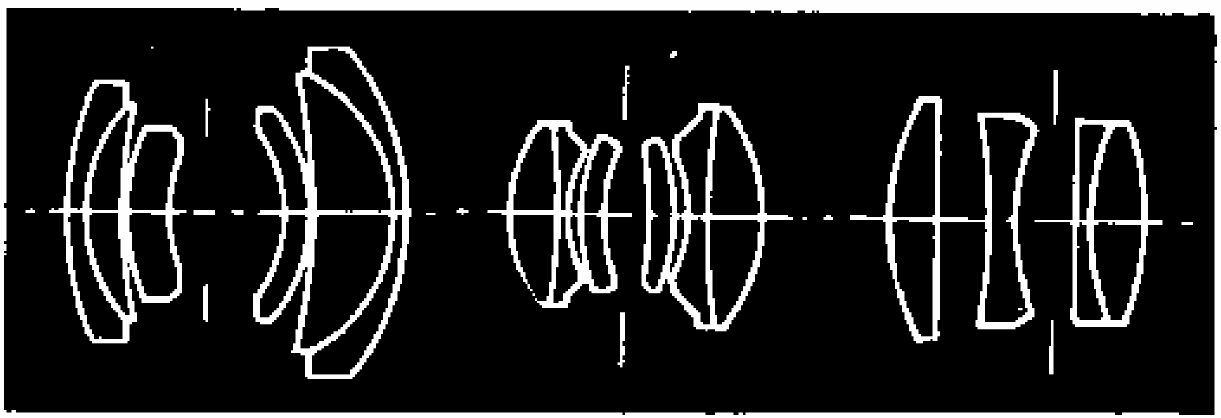
The dolly zoom

- 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)

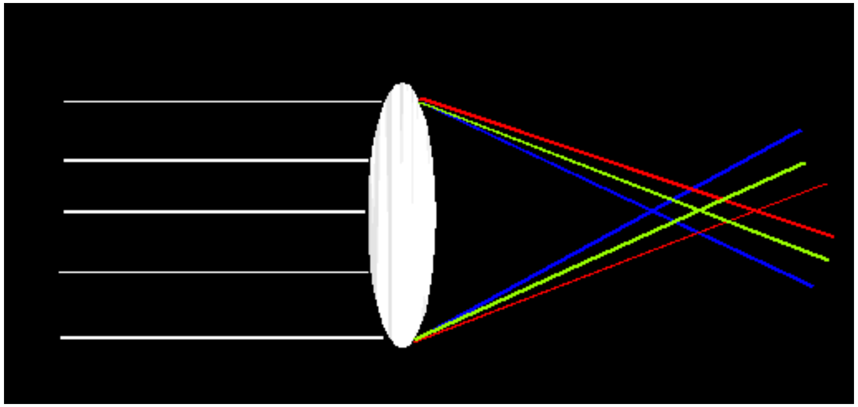
[Example of dolly zoom from *La Haine*]() (YouTube)

Real lenses



Lens Flaws: Chromatic Aberration

Lens has different refractive indices for different wavelengths: causes color fringing



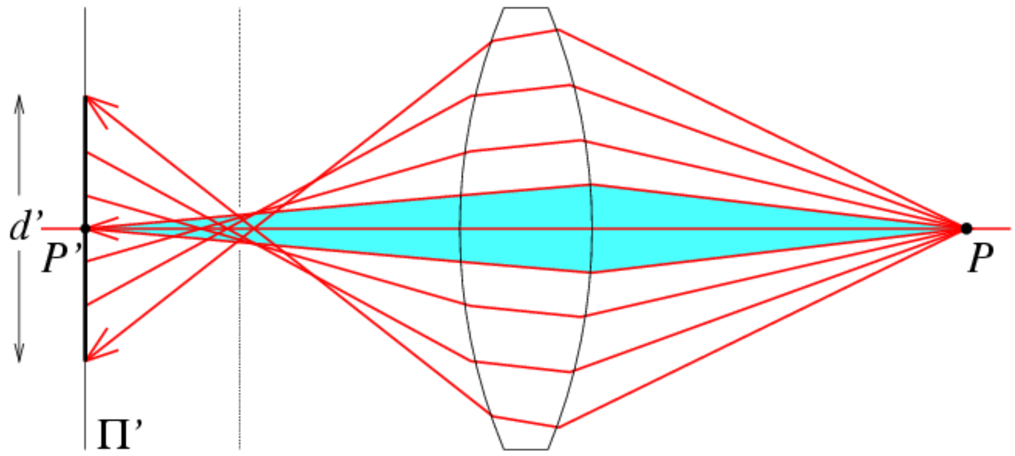
Near Lens Center

Near Lens Outer Edge

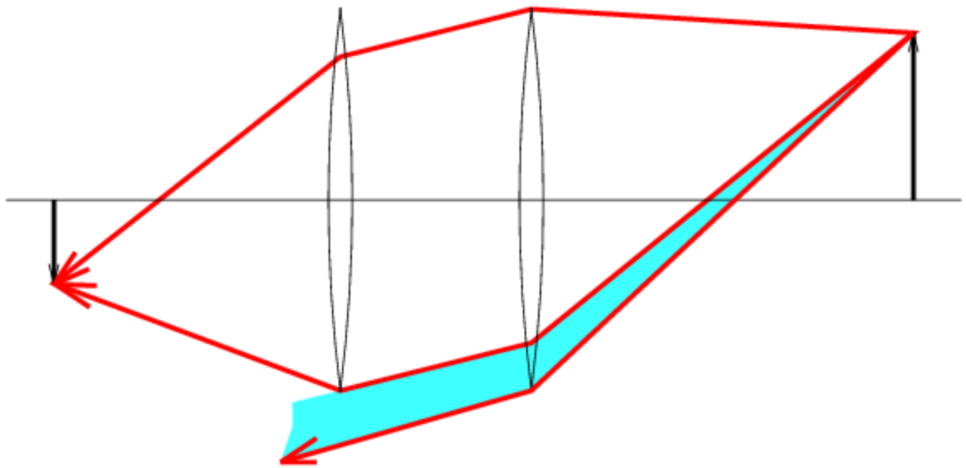
Lens flaws: Spherical aberration

Spherical lenses don't focus light perfectly

- Rays farther from the optical axis focus closer

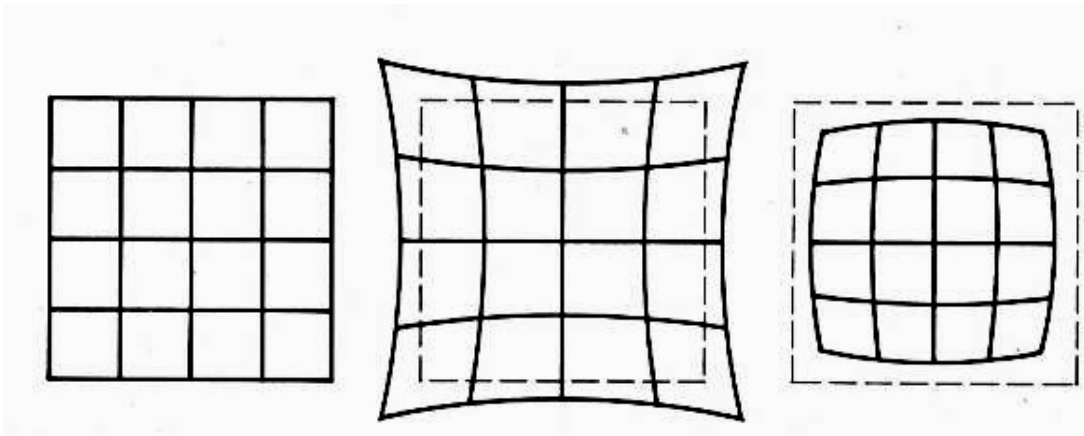


Lens flaws: Vignetting



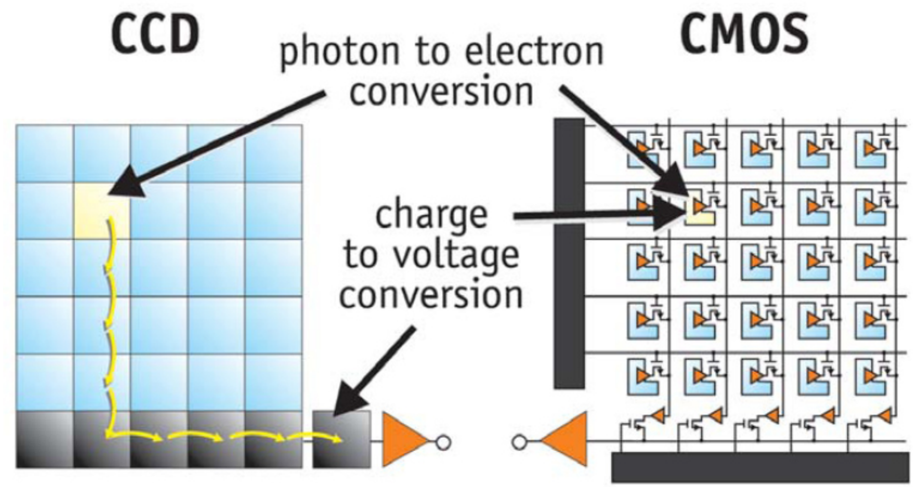
Radial Distortion

- Caused by imperfect lenses
- Deviations are most noticeable near the edge of the lens



No distortion Pin cushion Barrel

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.

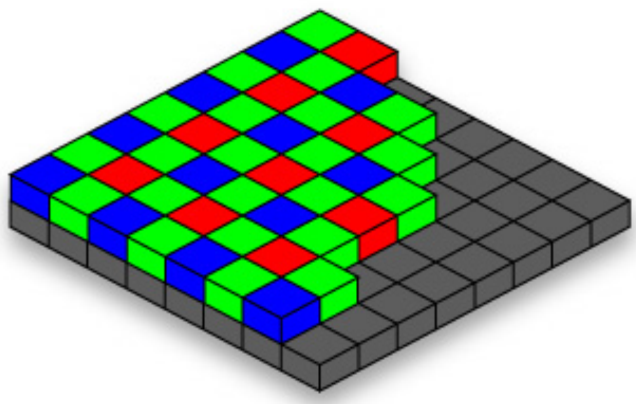
A digital camera replaces film with a sensor array

- 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

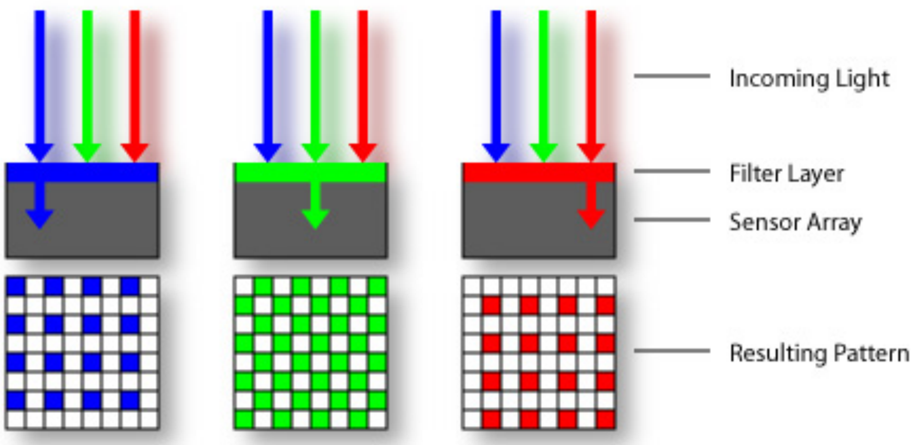
Slide by Steve Seitz

Color sensing in camera: Color filter array

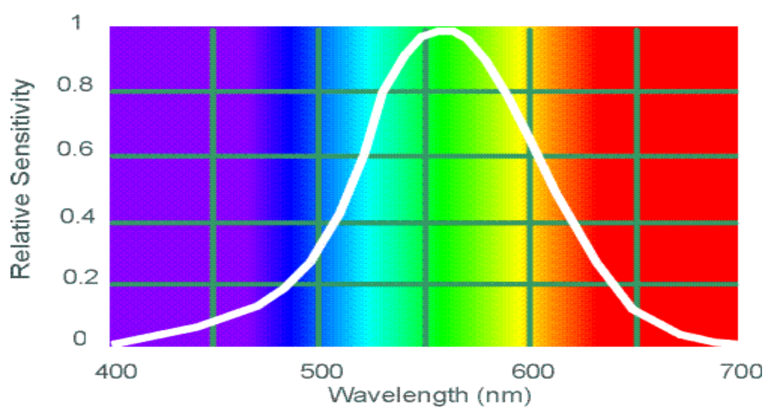
Bayer grid



Estimate missing components from neighboring values (demosaicing)



Why more green?



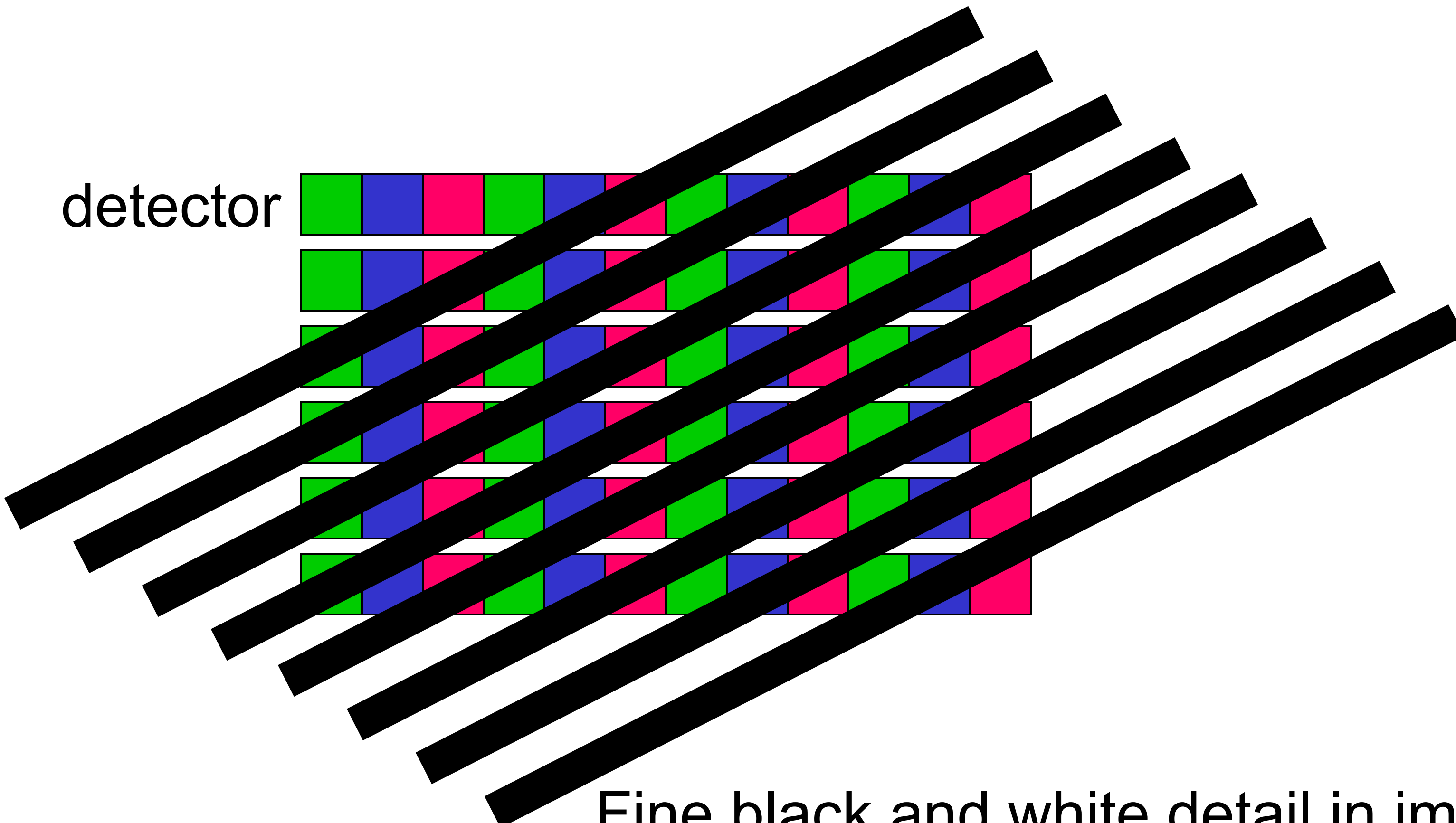
Human Luminance Sensitivity Function

Source: Steve Seitz

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

Digital camera artifacts

Noise

- low light is where you most notice noise
- light sensitivity (ISO) / noise tradeoff
- stuck pixels

In-camera processing

- oversharpening can produce halos

Compression

- JPEG artifacts, blocking

Blooming

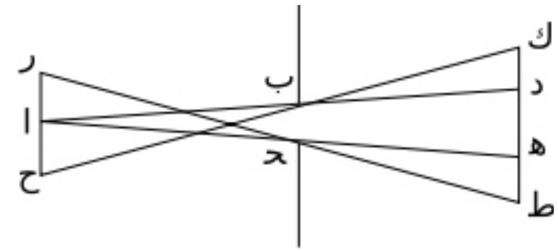
- charge overflowing into neighboring pixels

Color artifacts

- purple fringing from microlenses,
- white balance

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** (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

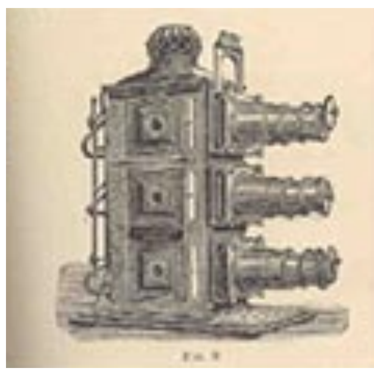
Niepce, "La Table Servie," 1822

Old television camera

Early color photography

Sergey Prokudin-Gorskii (1863-1944)

Photographs of the Russian empire (1909-1916)



Lantern projector

http://en.wikipedia.org/wiki/Sergei_Mikhailovich_Prokudin-Gorskii

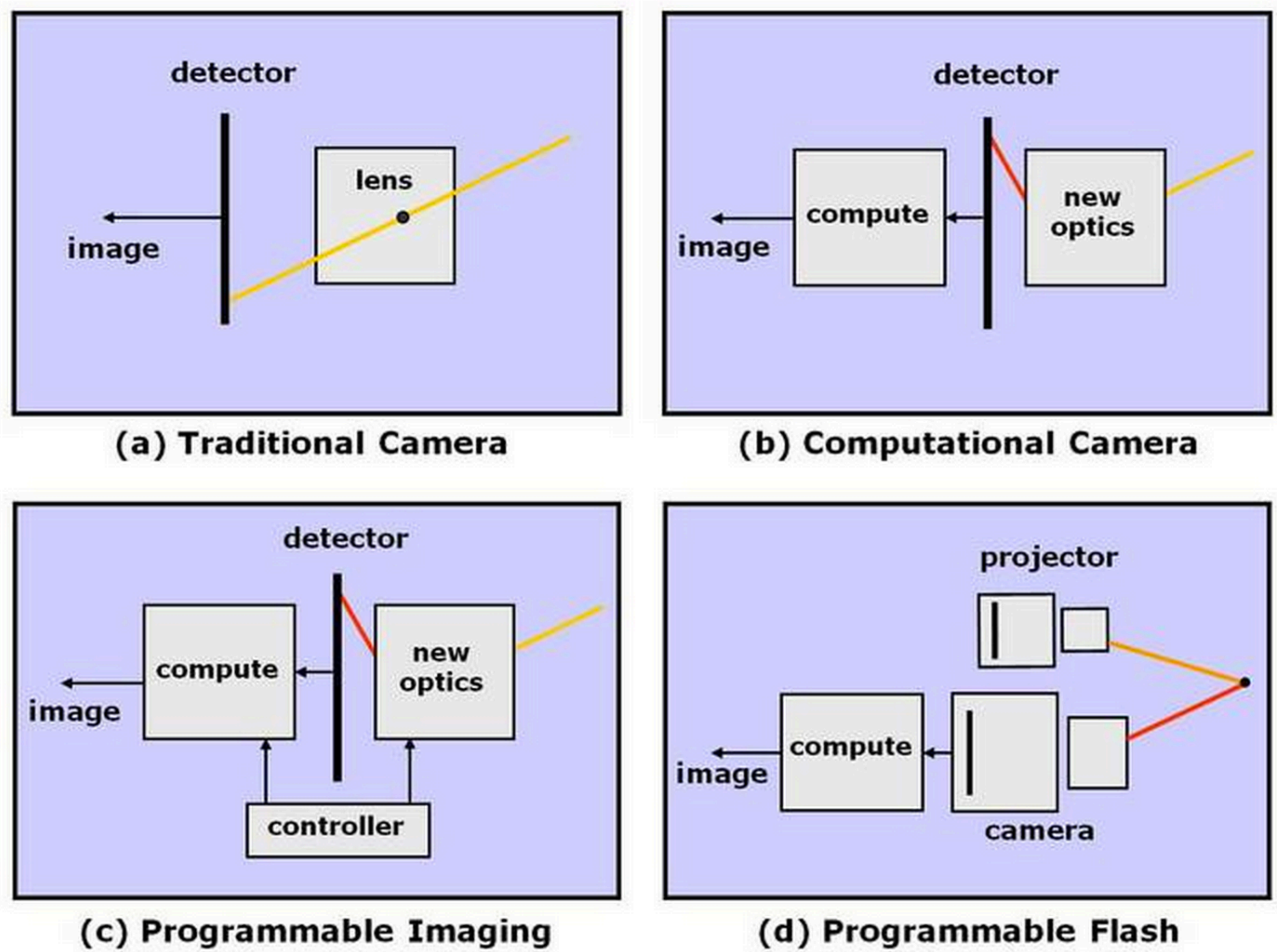
http://www.loc.gov/exhibits/empire/

First digitally scanned photograph

- 1957, 176x176 pixels

http://listverse.com/history/top-10-incredible-early-firsts-in-photography/

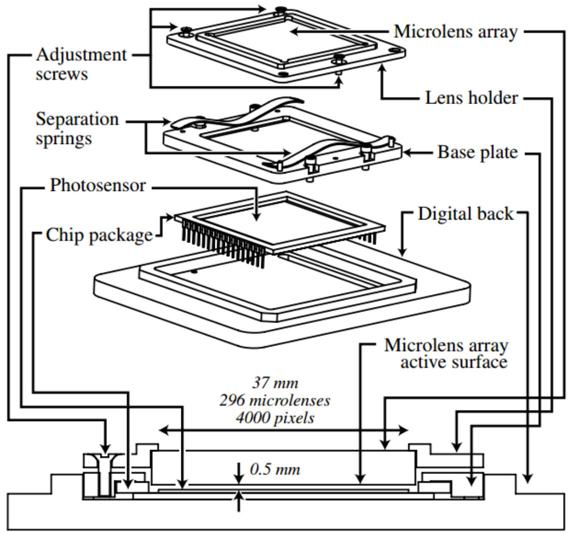
Computational Cameras

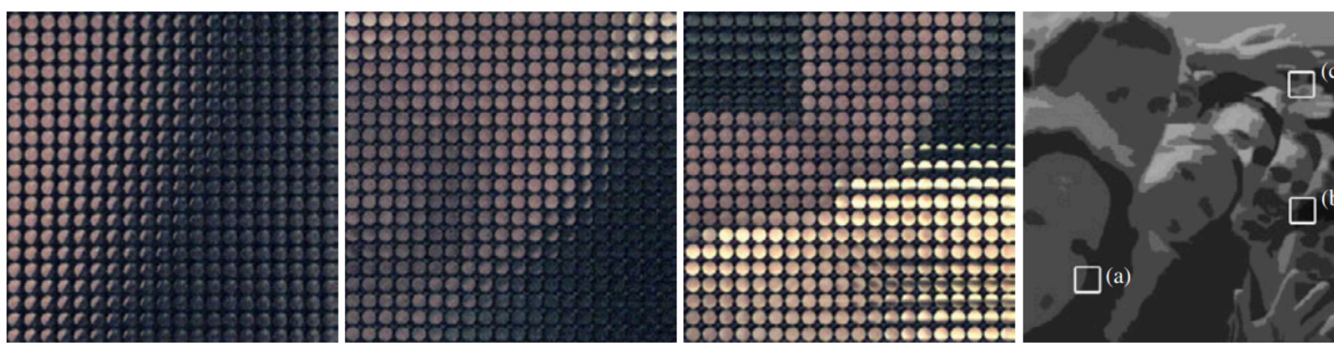


(a) Traditional Camera
(b) Computational Camera
(c) Programmable Imaging
(d) Programmable Flash

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

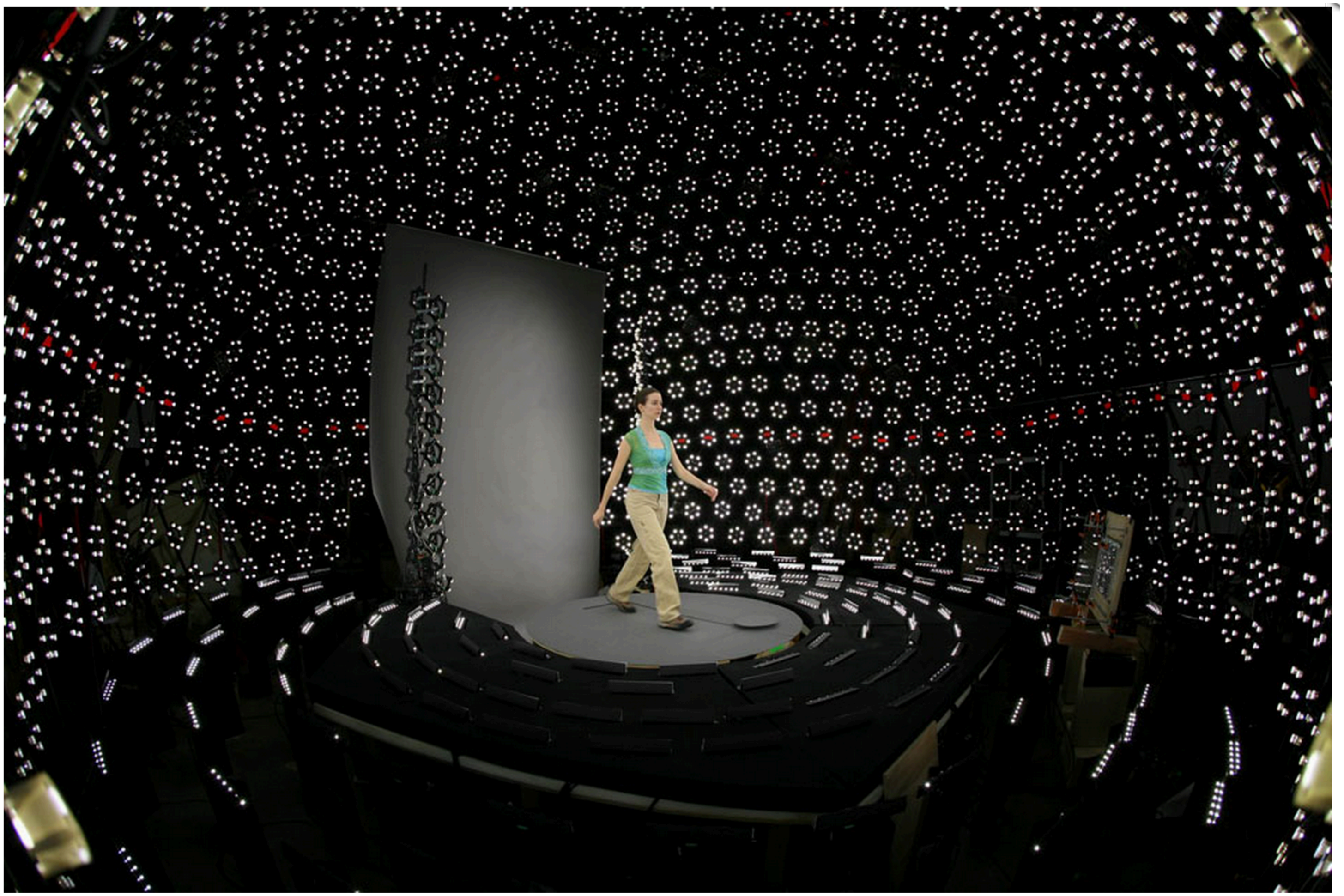
Hand held light field camera





Ren Ng et al 2005 (pics from Stanford Tech Report)

Light Stage 6 – sample over time, lighting, viewing, motion



inside Light Stage 6

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

More reading & thought problems

http://gl.ict.usc.edu/LightStages/ light stages over time

http://www1.cs.columbia.edu/CAVE/projects/what_is/
background on computational cameras

What is the problem for specular (shiny) surfaces (say specularities or caustics) and light field photography?