Computational Photography

Instructor: Sanjeev J. Koppal

MWF

1145am-1235pm

BEN 328

Acknowledgements

Some slides from
Narasimhan (Carnegie Mellon),
Zickler (Harvard),
and
Efros (Berkeley)

Participation

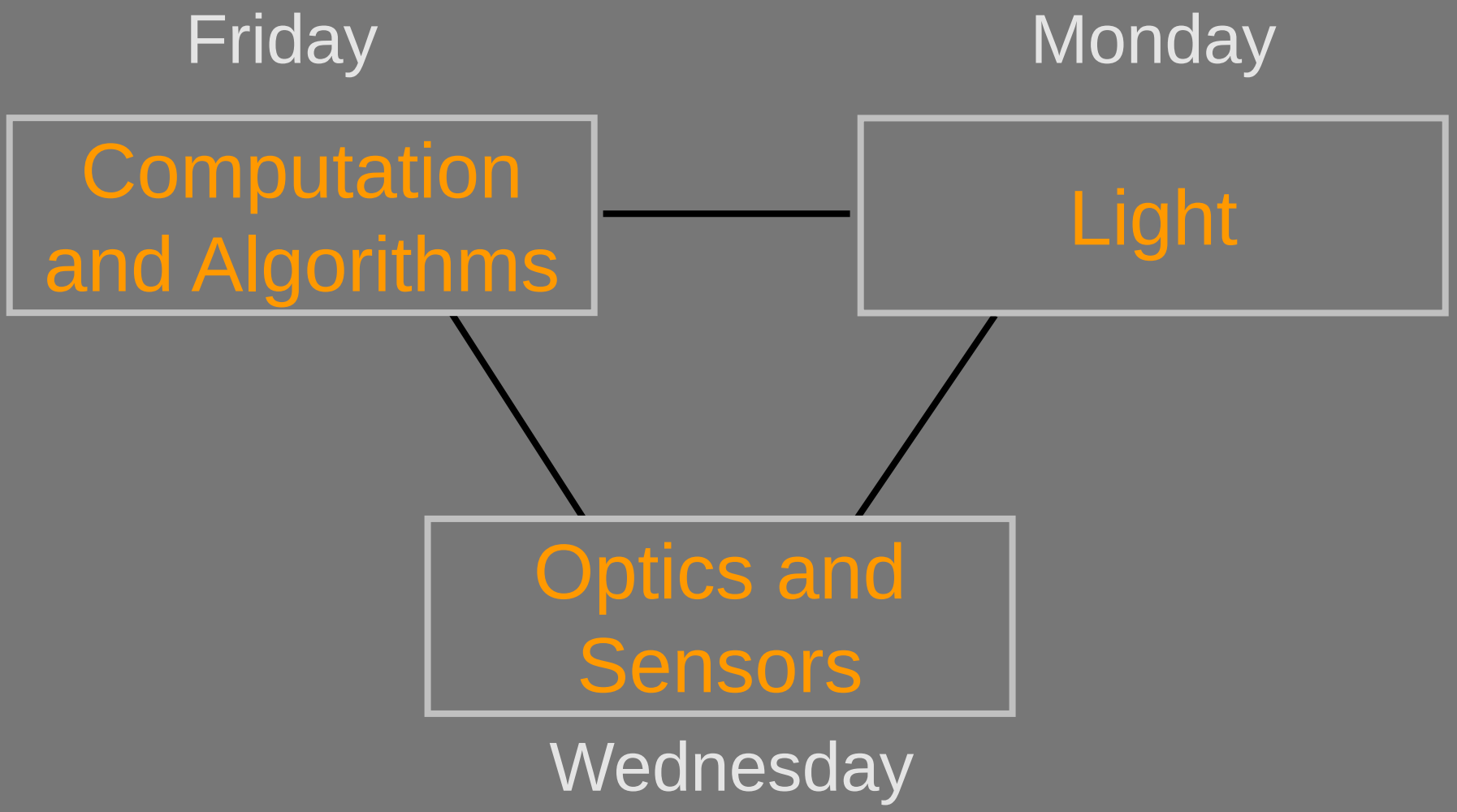
Participation

- Speaking up >> raster scan
- So feel free to speak up!
- If you'd like, you can remind us what your name is (for the first couple of weeks)…

Canvas

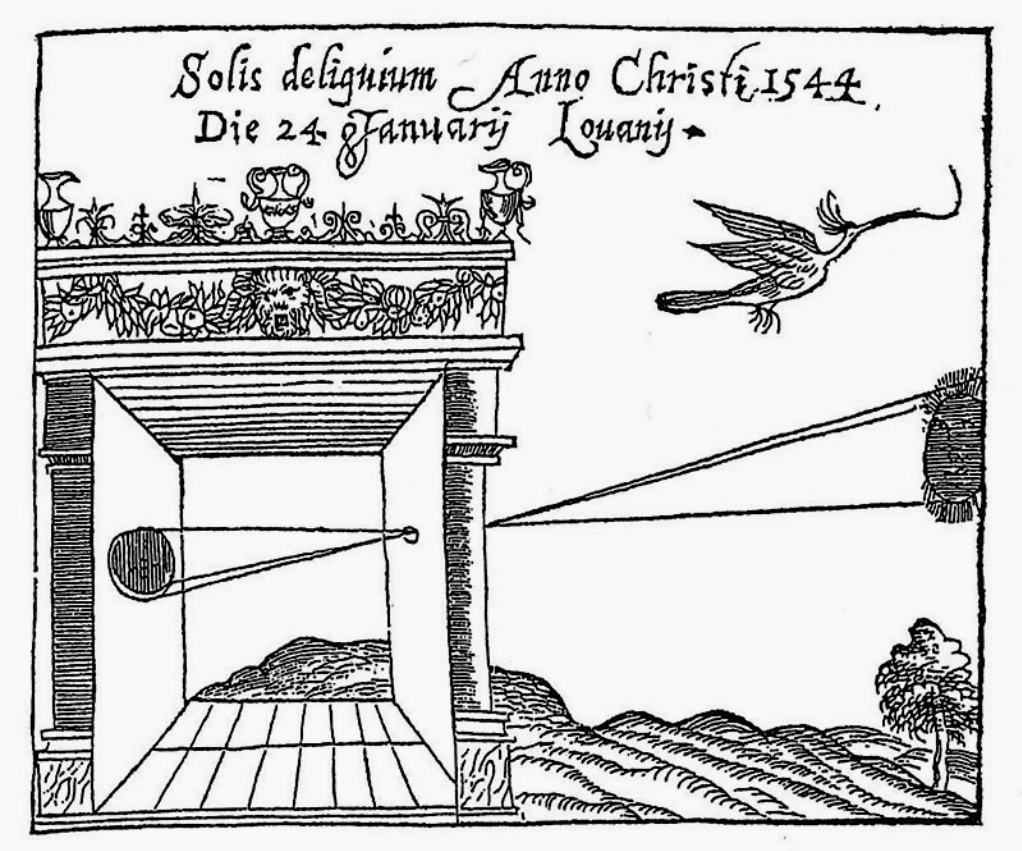
- Should be set up
- Let me know if you cannot access it
- I will put slides on there soon

Computational Photography over the week



A Brief History of Images

1558



Camera Obscura, Gemma Frisius, 1558

A Brief History of Images

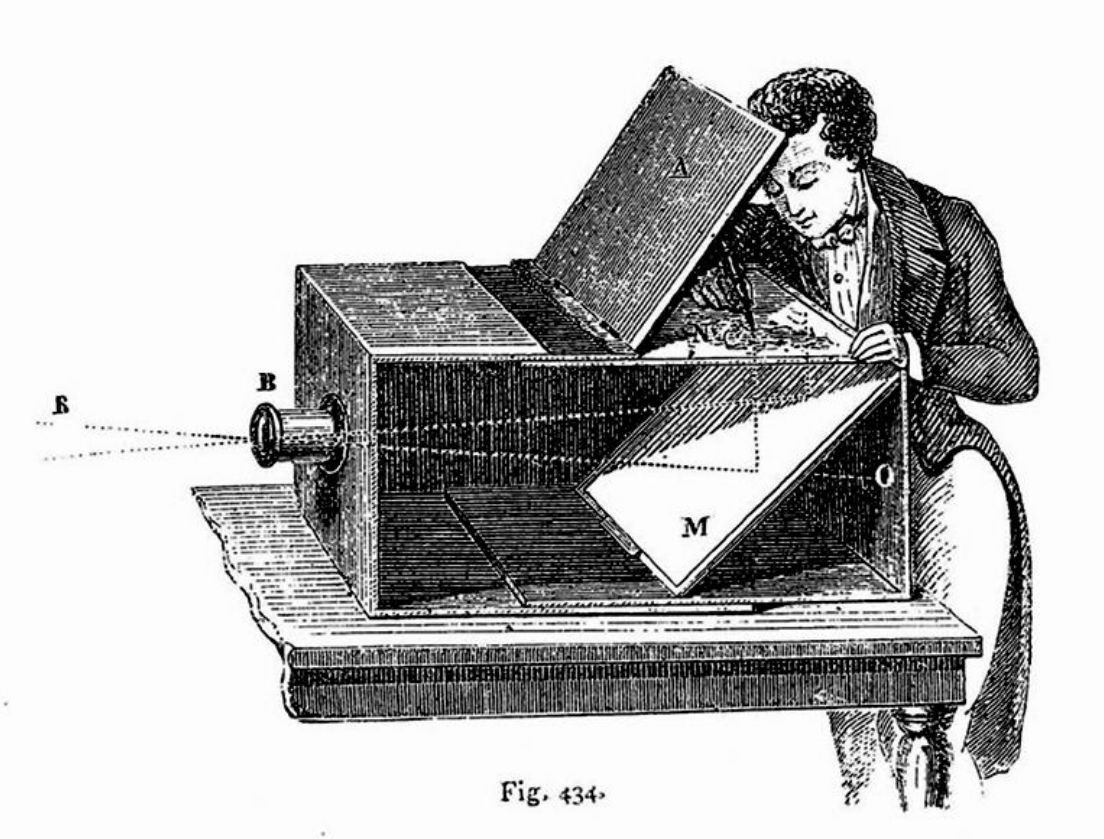
1558

Camera Obscura, means “dark room”

A Brief History of Images

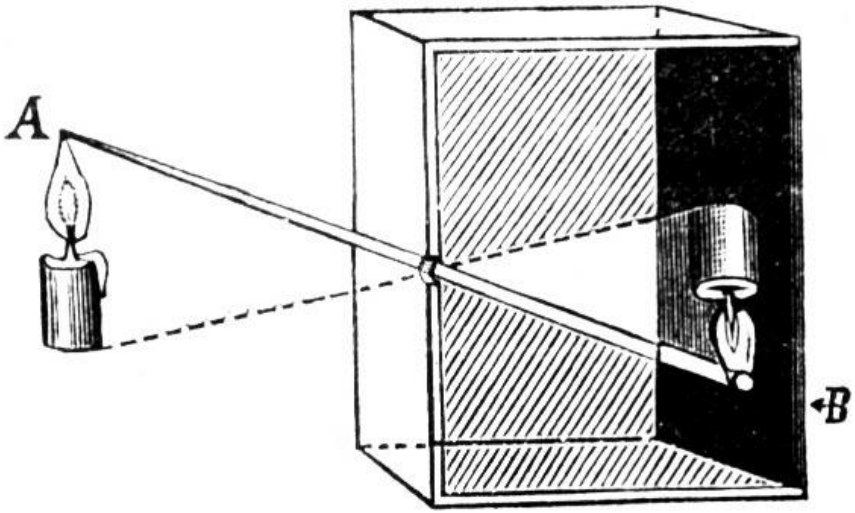
1558

1568



Lens Based Camera Obscura, 1568

Camera Obscura



Contemporary artist Madison Cawein rented studio space in an old factory building where many of the windows were boarded up or painted over. A random small hole in one of those windows turned one room into a camera obscura.

Participation

If "camera obscura" means "dark room",
how would we build one with a glass box?

Lesson 1

One person's camera
is another's glass box

A Brief History of Images

1558

1568

1816

Joseph Nicéphore Niépce (1765-1833)

The first negative (not original)
[Not fixed…quickly vanished]

A Brief History of Images

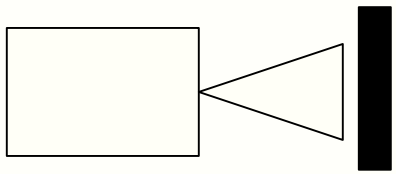
1558

1568

1816

1826

The first permanent photograph was
an (8 hour exposure) by Niepce



A Brief History of Images

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1568

1816

1826

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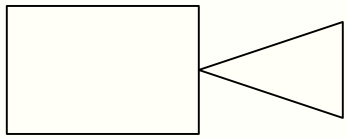

A Brief History of Images

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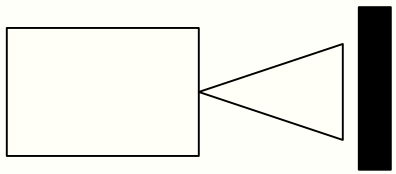
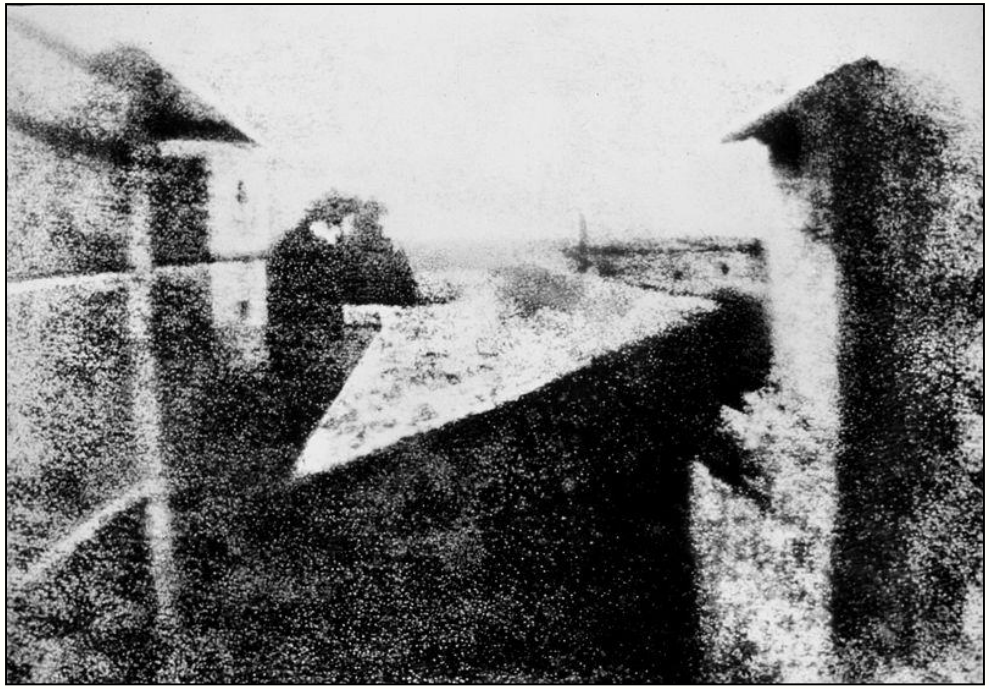


A Brief History of Images



The first permanent photograph (8 hour exposure), Niepce

1558

1568

1816

1826

Participation

What type of scene could you take over an 8 hour exposure?
What effects would you see?

A more modern image

By artist Lincoln Harrison

A Brief History of Images

Still Life, Louis Jaques Mande Daguerre, 1837

1558

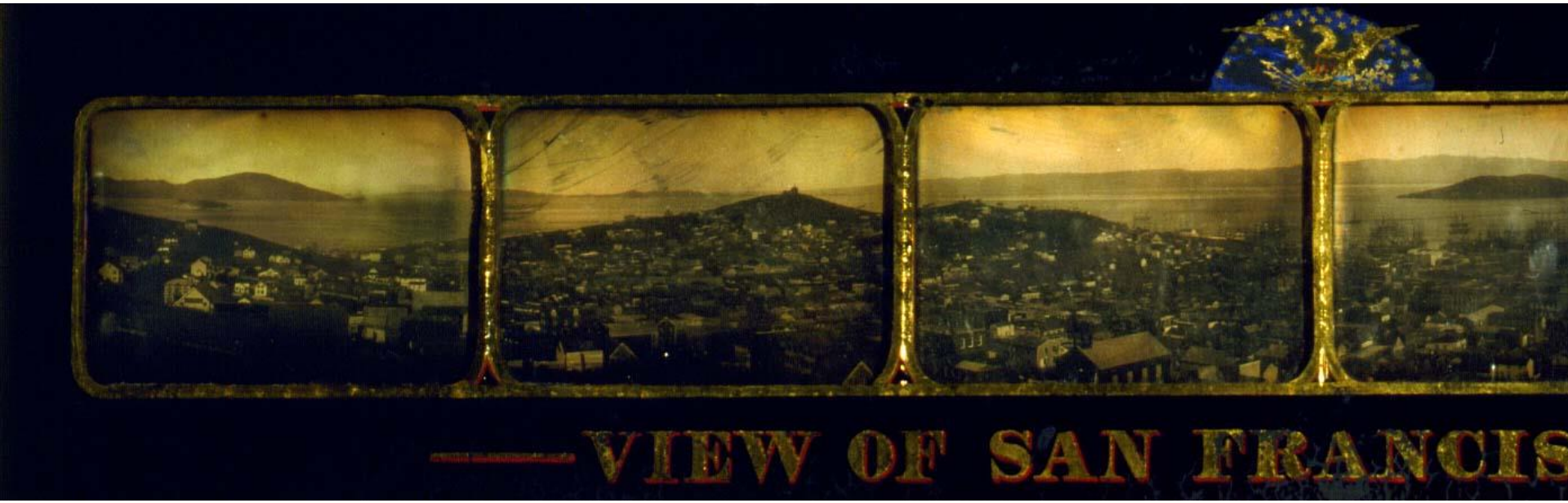
1568

1816

1826

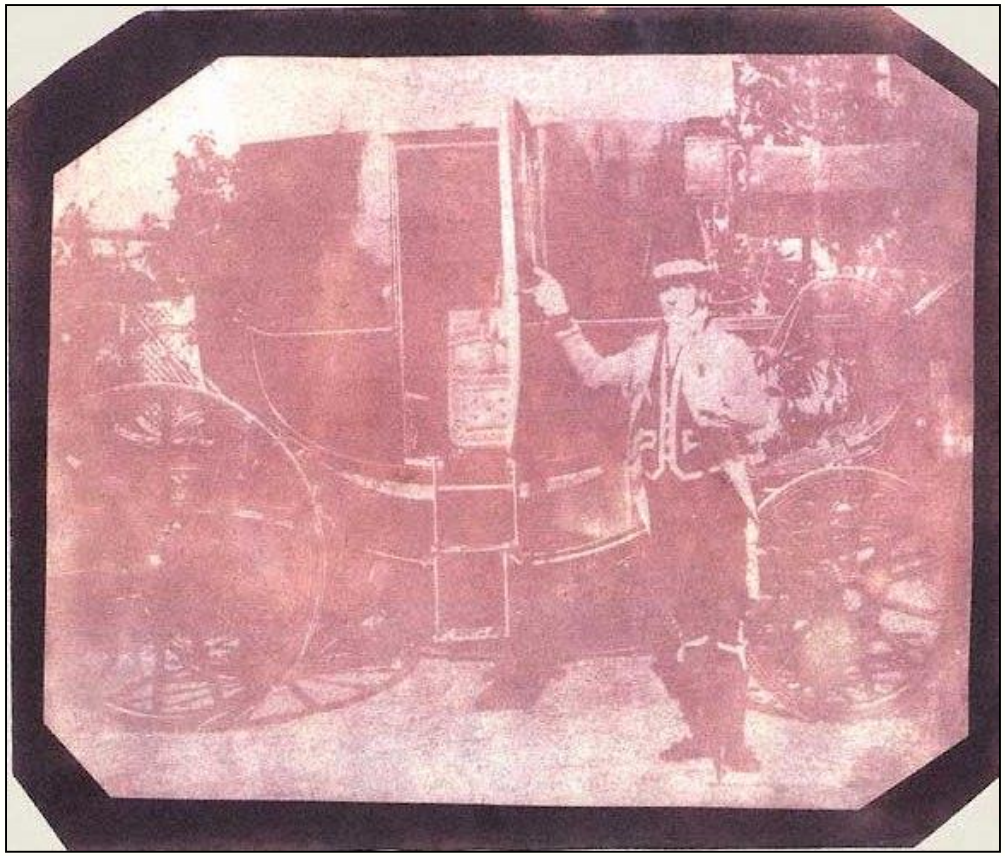
1837

A Brief History of Images



Daguerreotype Panorama (wiki)

A Brief History of Images



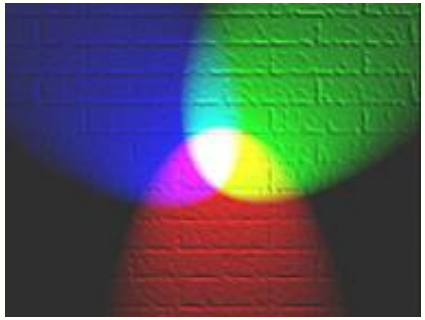
William Henry Fox Talbot , negative to positive photographic process

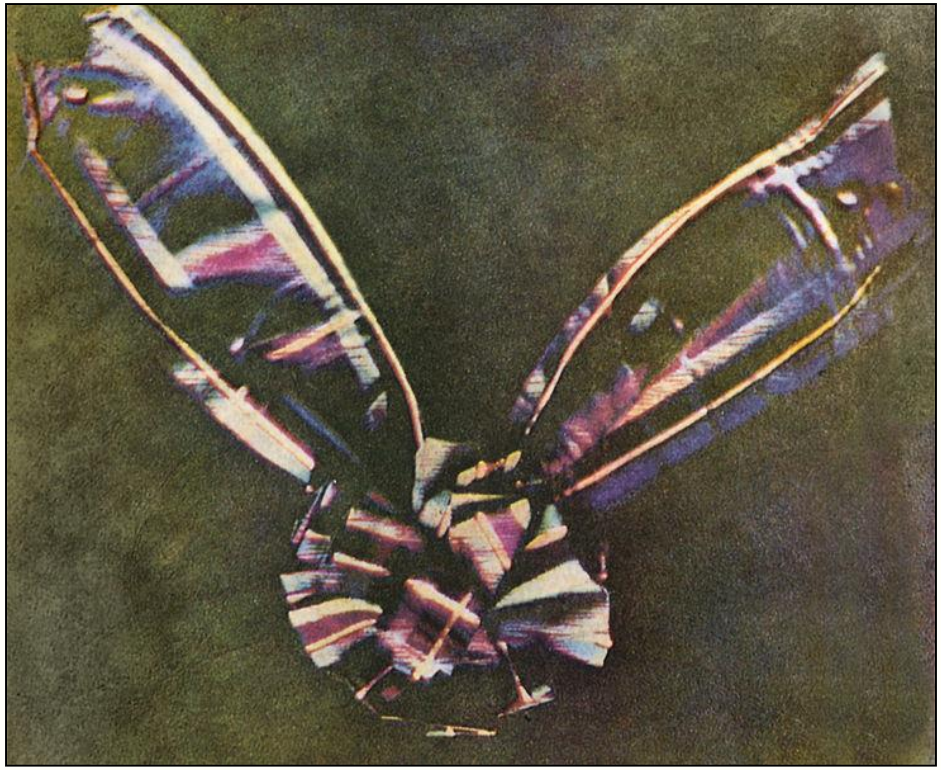
1558
1568
1816
1826
1837
1841

Participation

What would you design negative film?

A Brief History of Images

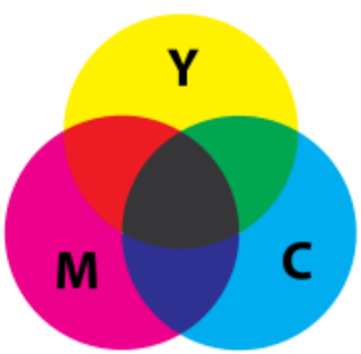




tartan ribbon, James Clerk Maxwell, additive color photograph

1558
1568
1816
1826
1837
1841
1861

A Brief History of Images



Louis Ducos du Hauron, subtractive color photograph

1558
1568
1816
1826
1837
1841
1861
1868

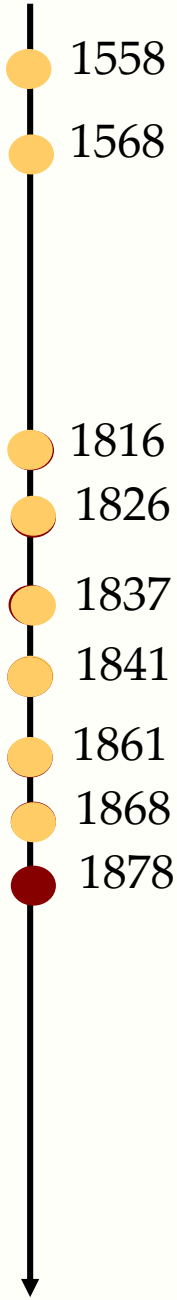
Lesson 2

We had color photographs, before we could take photographs of moving things.

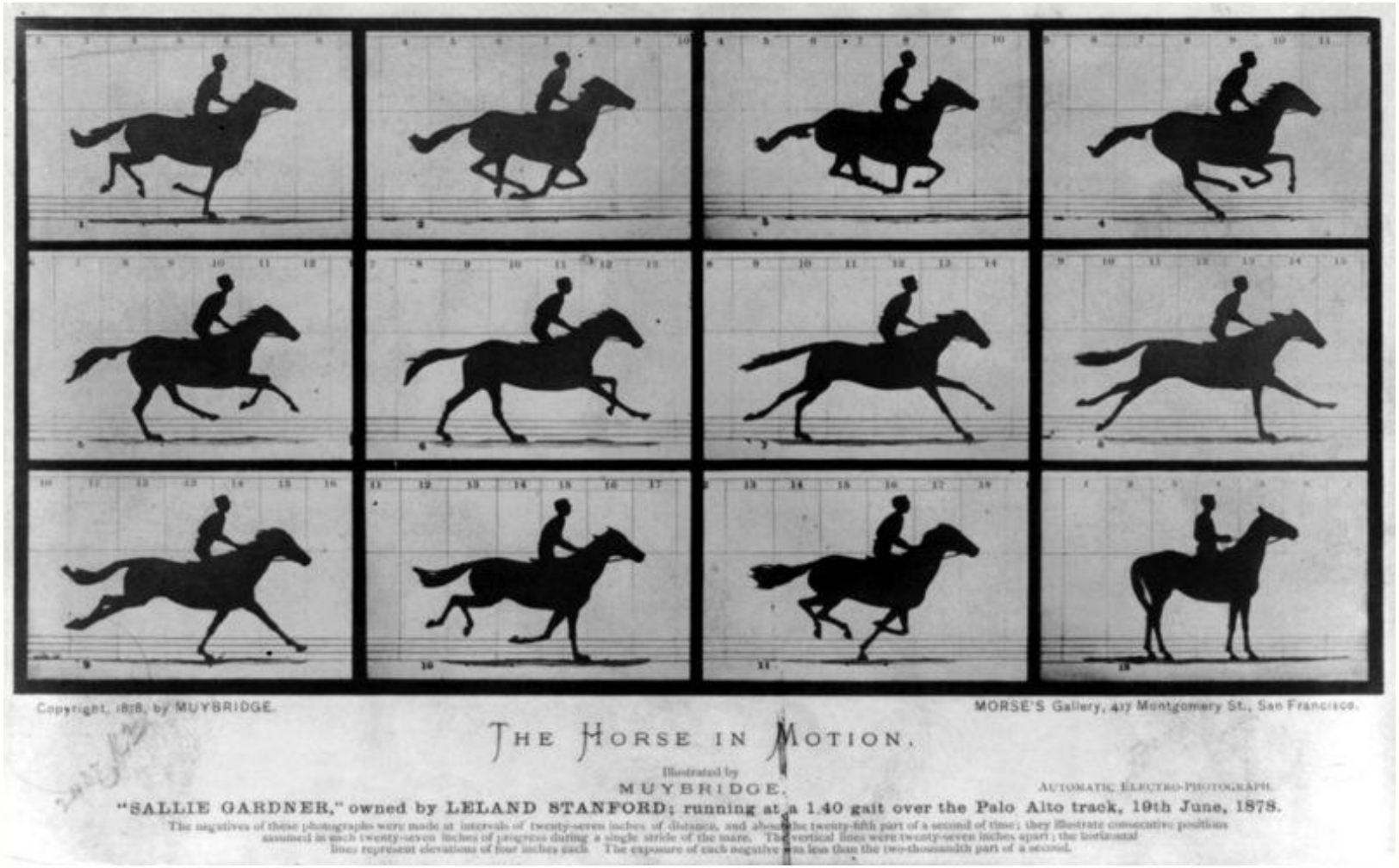
Did the opposite happen in cinema?

A Brief History of Images

The Horse in Motion, Muybridge, fast motion using 24 cameras.



A Brief History of Images



1558
1568
1816
1826
1837
1841
1861
1868
1878

A Brief History of Images

The Leica, the 35mm format in still photography.

The photographic film is cut into strips 35 millimeters wide.

1558
1568
1816
1826
1837
1841
1861
1868
1878
1925

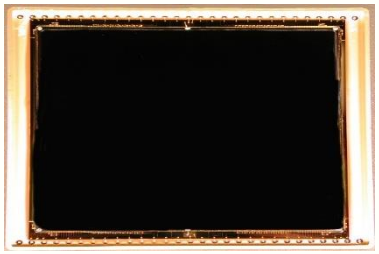
A Brief History of Images

Edwin H. Land

Poloroid instant image camera

1558
1568
1816
1826
1837
1841
1861
1868
1878
1925
1948

A Brief History of Images



Silicon Image Detector, 1973

1558
1568
1816
1826
1837
1841
1861
1868
1878
1925
1948
1973

A Brief History of Images

Digital Cameras

1558
1568
1816
1826
1837
1841
1861
1868
1878
1925
1948
1973
1995

A Brief History of Images

Mobile Phones

1558

1568

1816

1826

1837

1841

1861

1868

1878

1925

1948

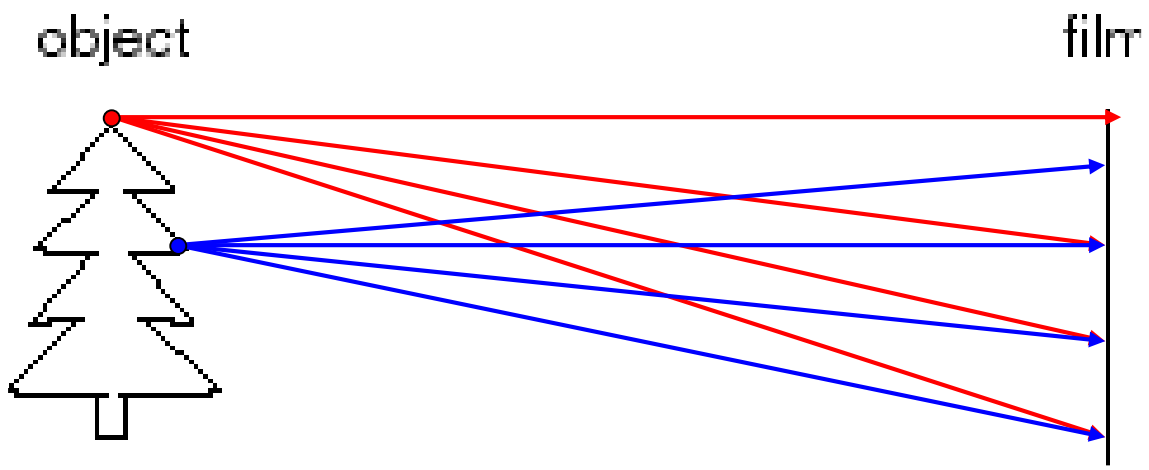
1973

1995

Today

A brief overview of how cameras work

How do we see the world?

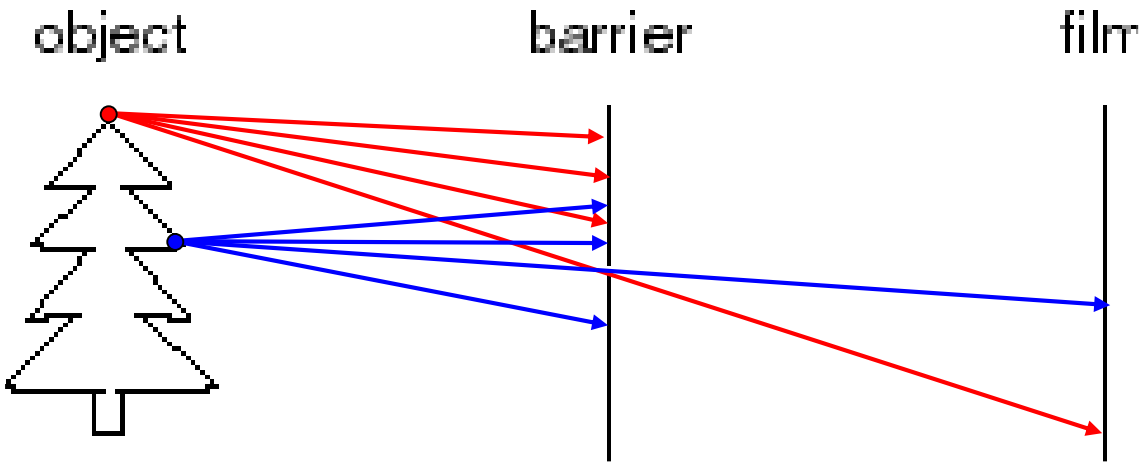


Let’s design a camera

- Idea 1: put a piece of film in front of an object
- Do we get a reasonable image?

Slide by Steve Seitz

Pinhole camera

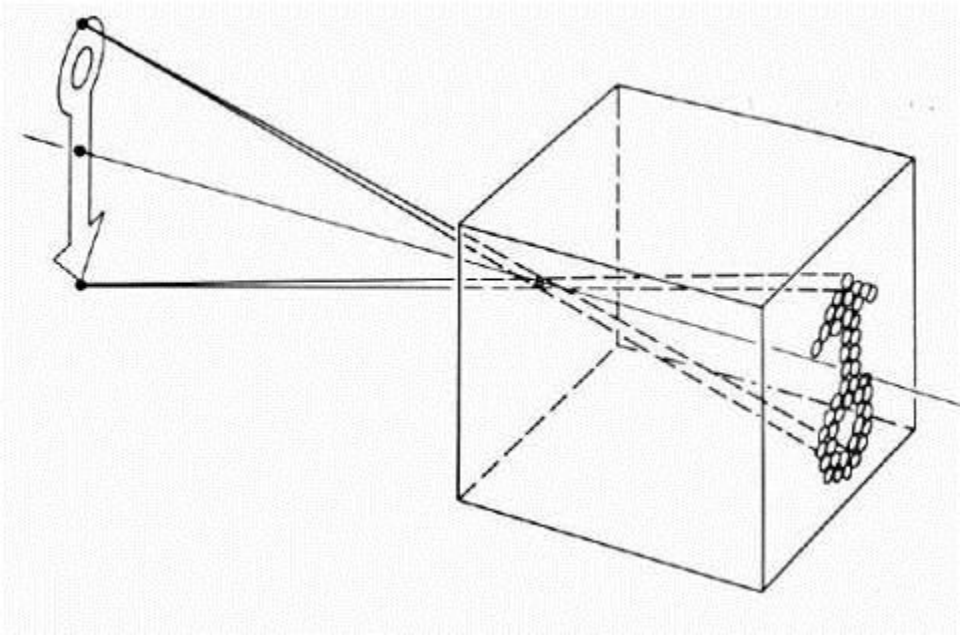


Add a barrier to block off most of the rays

- This reduces blurring
- The opening known as the **aperture**
- How does this transform the image?

Slide by Steve Seitz

Pinhole camera model



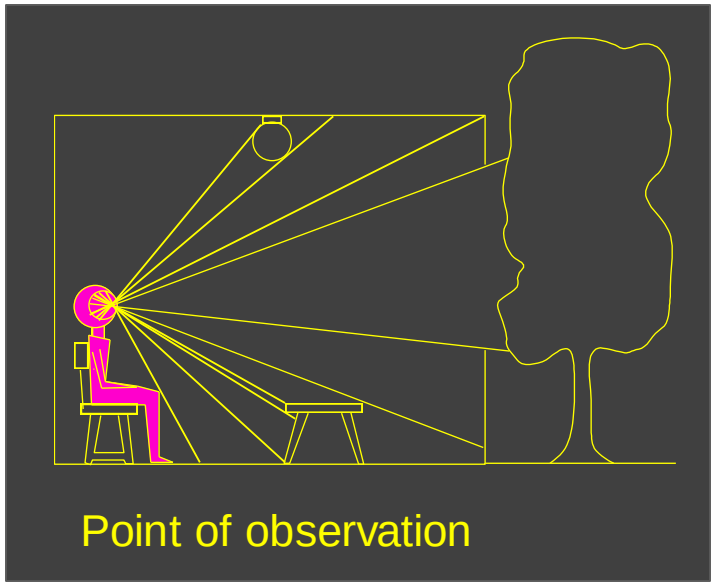
Pinhole model:

- Captures **pencil of rays** – all rays through a single point
- The point is called **Center of Projection (COP)**
- The image is formed on the **Image Plane**
- **Effective focal length *f*** is distance from COP to Image Plane

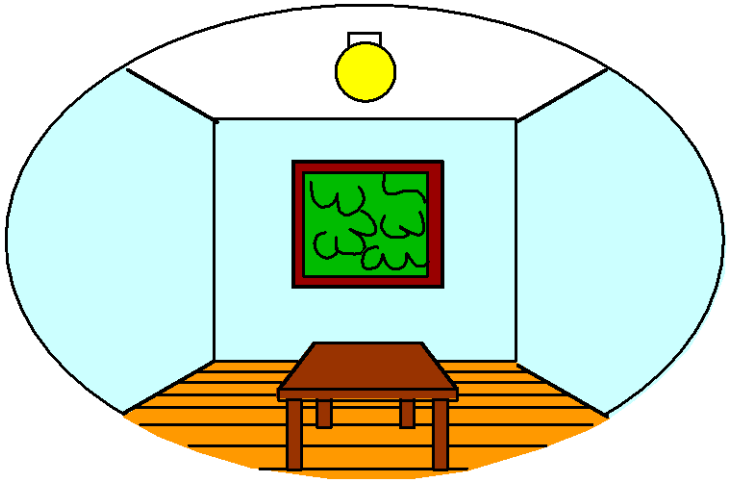
Slide by Steve Seitz

Dimensionality Reduction Machine (3D to 2D)

3D world



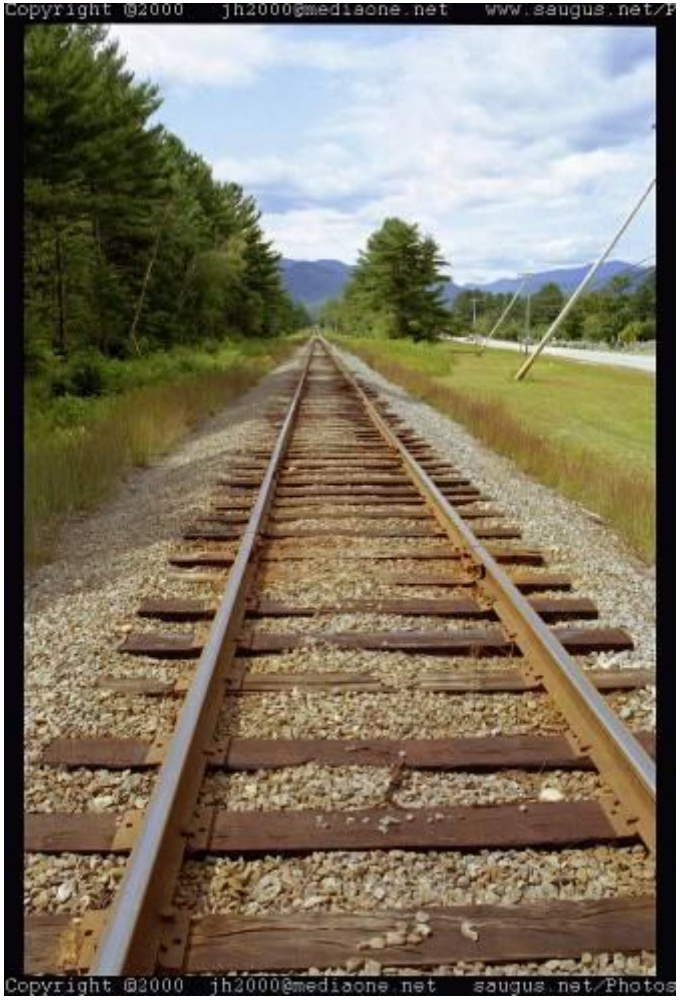
2D image



What have we lost?

- Angles
- Distances (lengths)

Funny things happen…



Parallel lines aren’t…

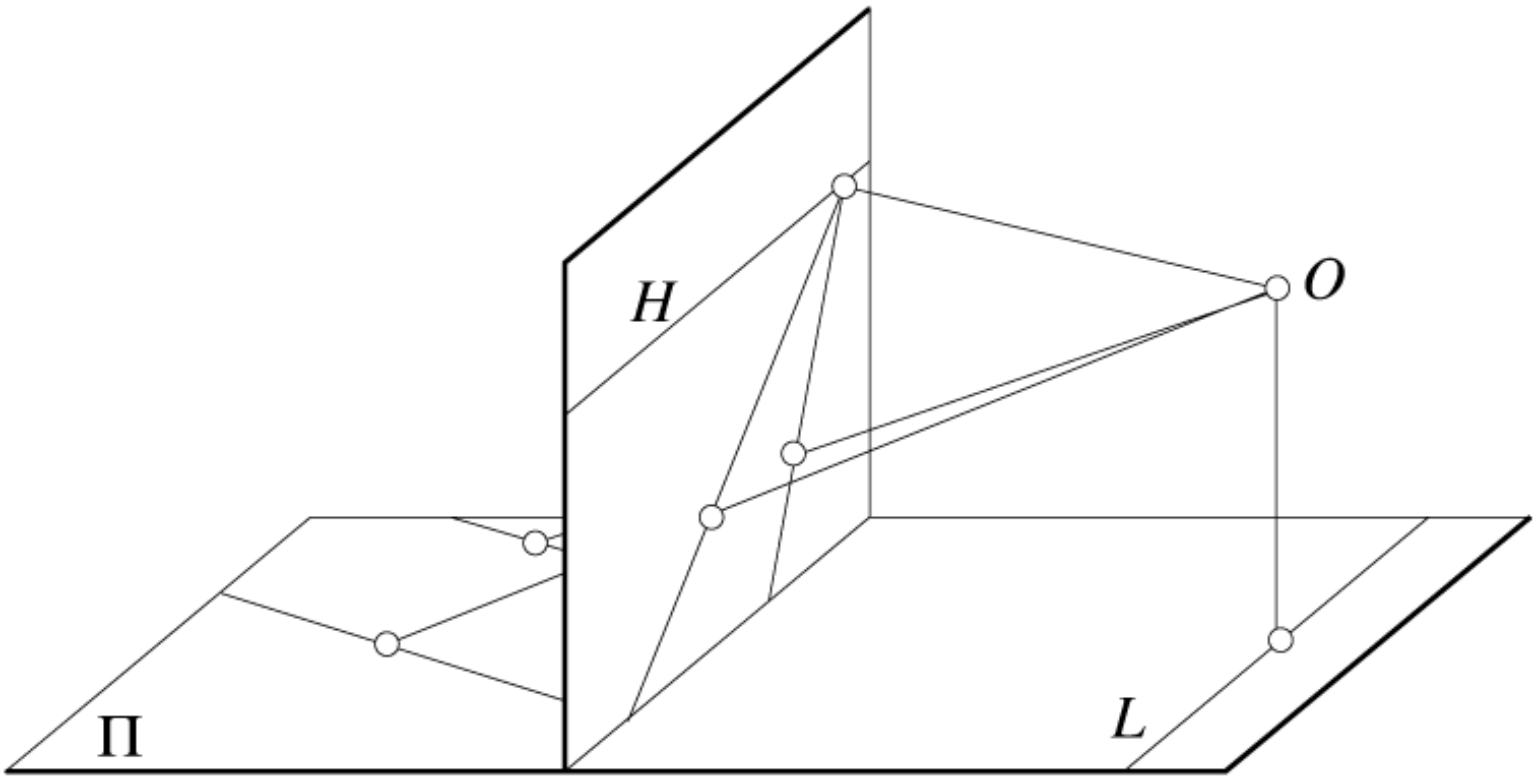


Figure by David Forsyth

Distances can’t be trusted...

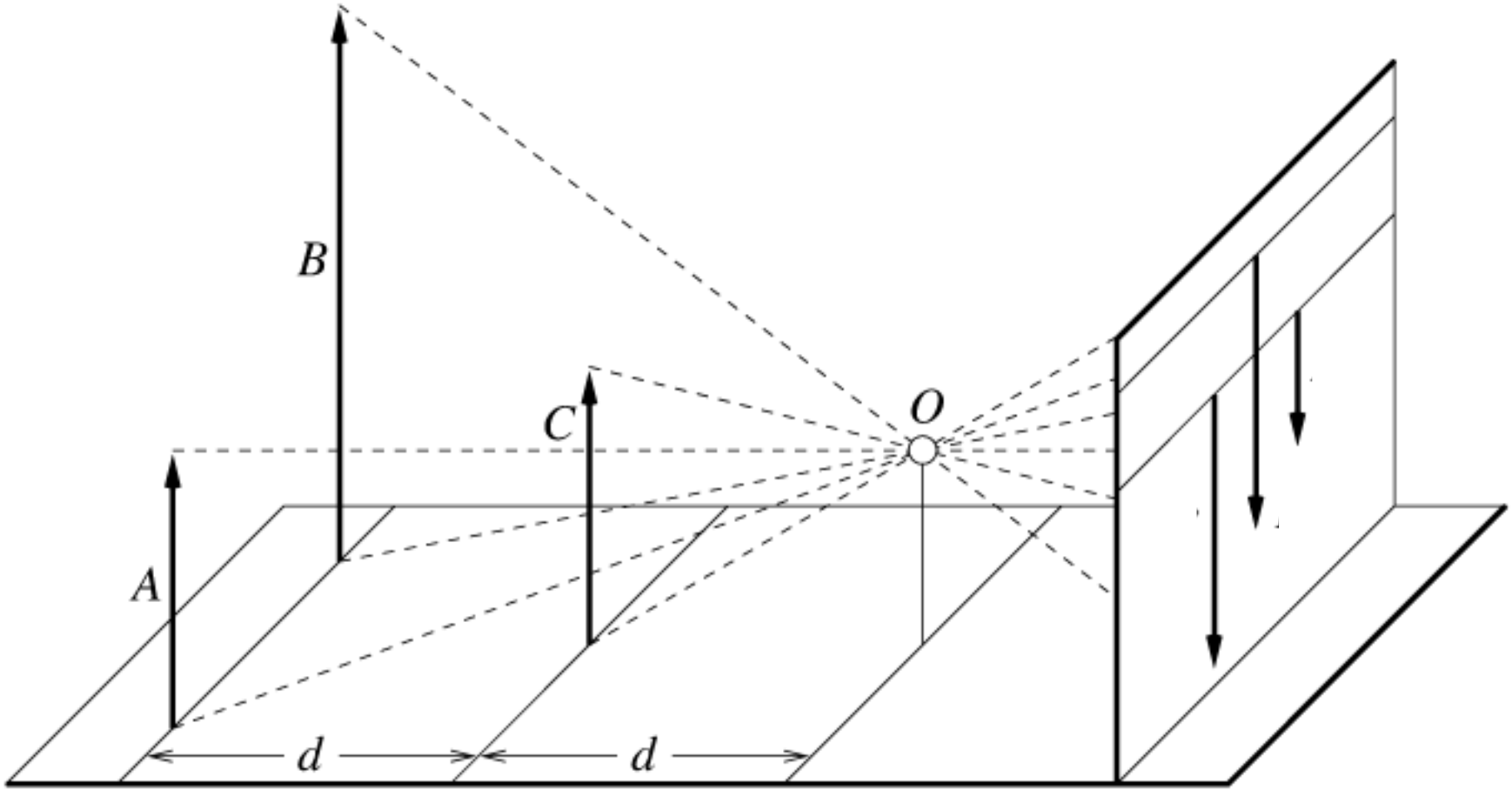


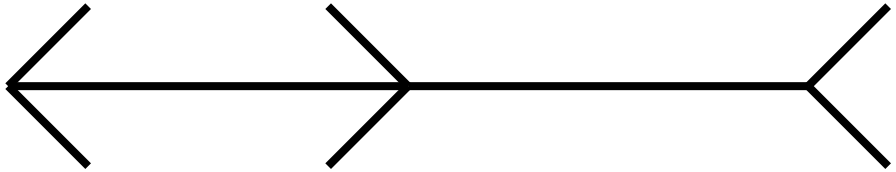
Figure by David Forsyth

Lesson 3

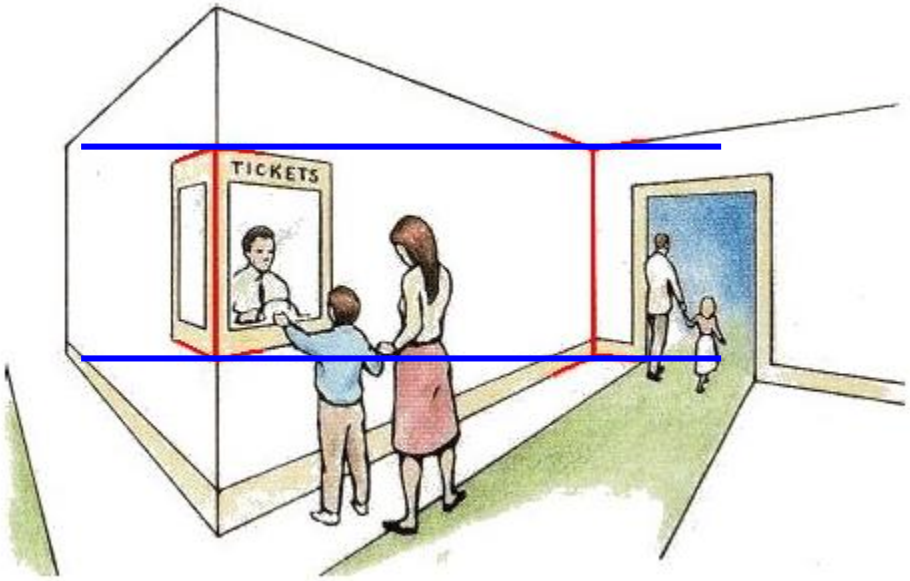
Pictures are strange representations of the world.

Never forget it. They aren’t meant to make sense.

…but humans adapt!



Müller-Lyer Illusion



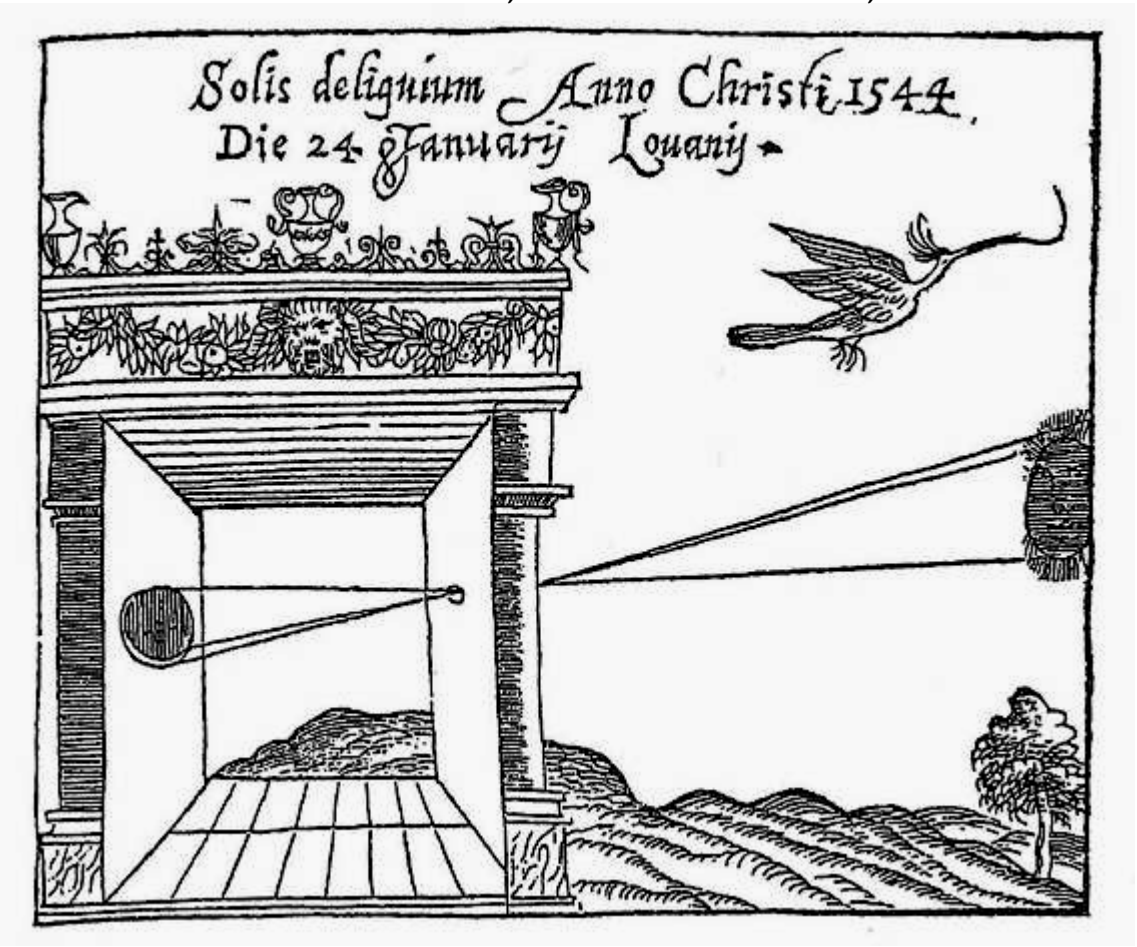
We don’t make measurements in the image plane

http://www.michaelbach.de/ot/sze_muelue/index.html

Building a real camera

Camera Obscura

Camera Obscura, Gemma Frisius, 1558



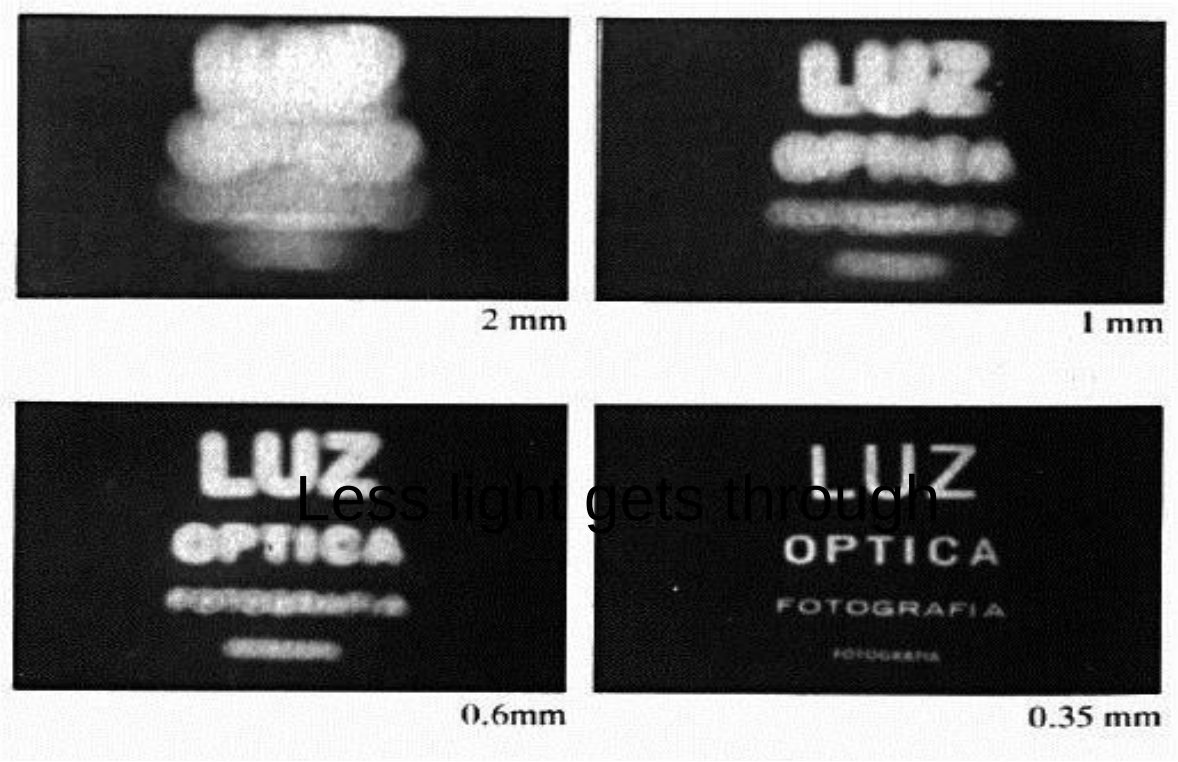
Home-made pinhole camera

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

Participation

Why is this image blurry?

Shrinking the aperture



Less light gets through

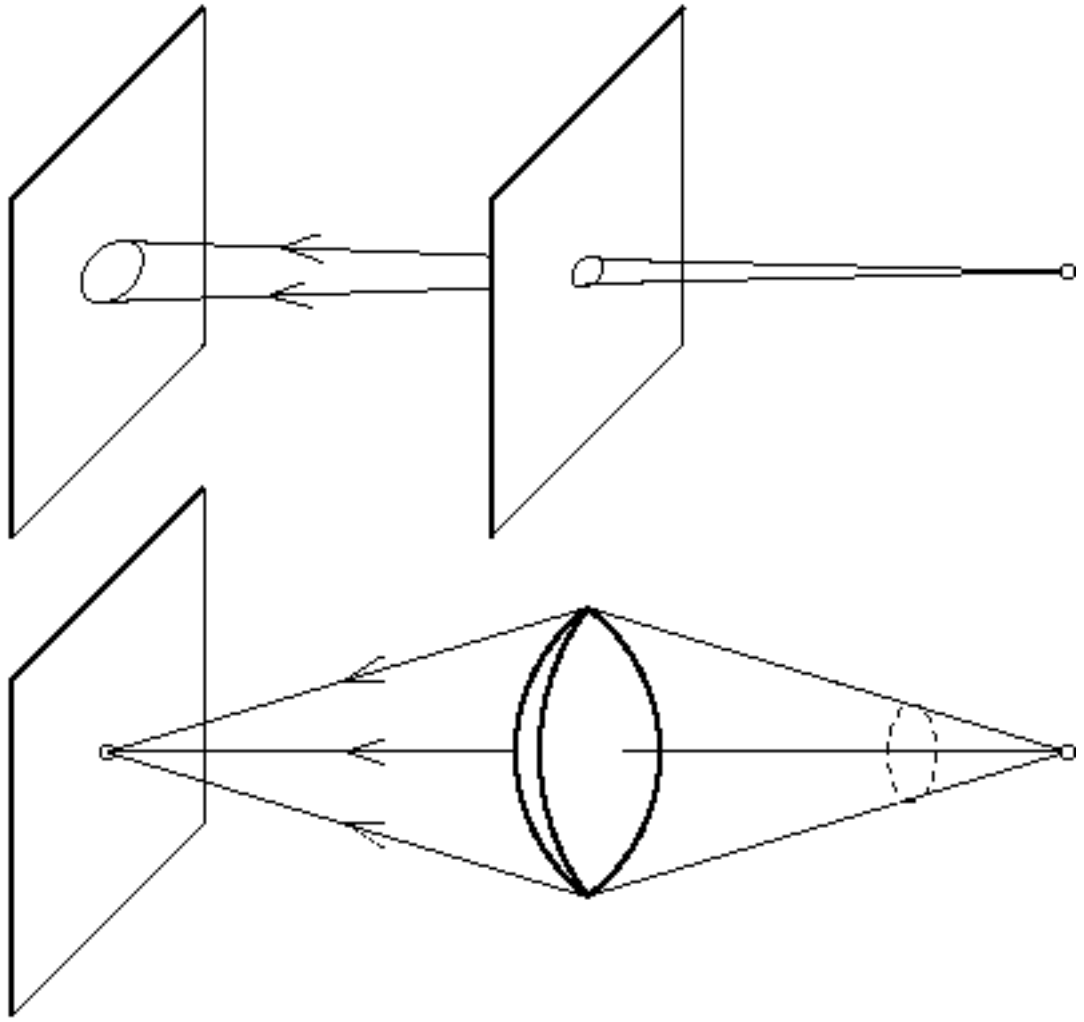
Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects…

Slide by Steve Seitz

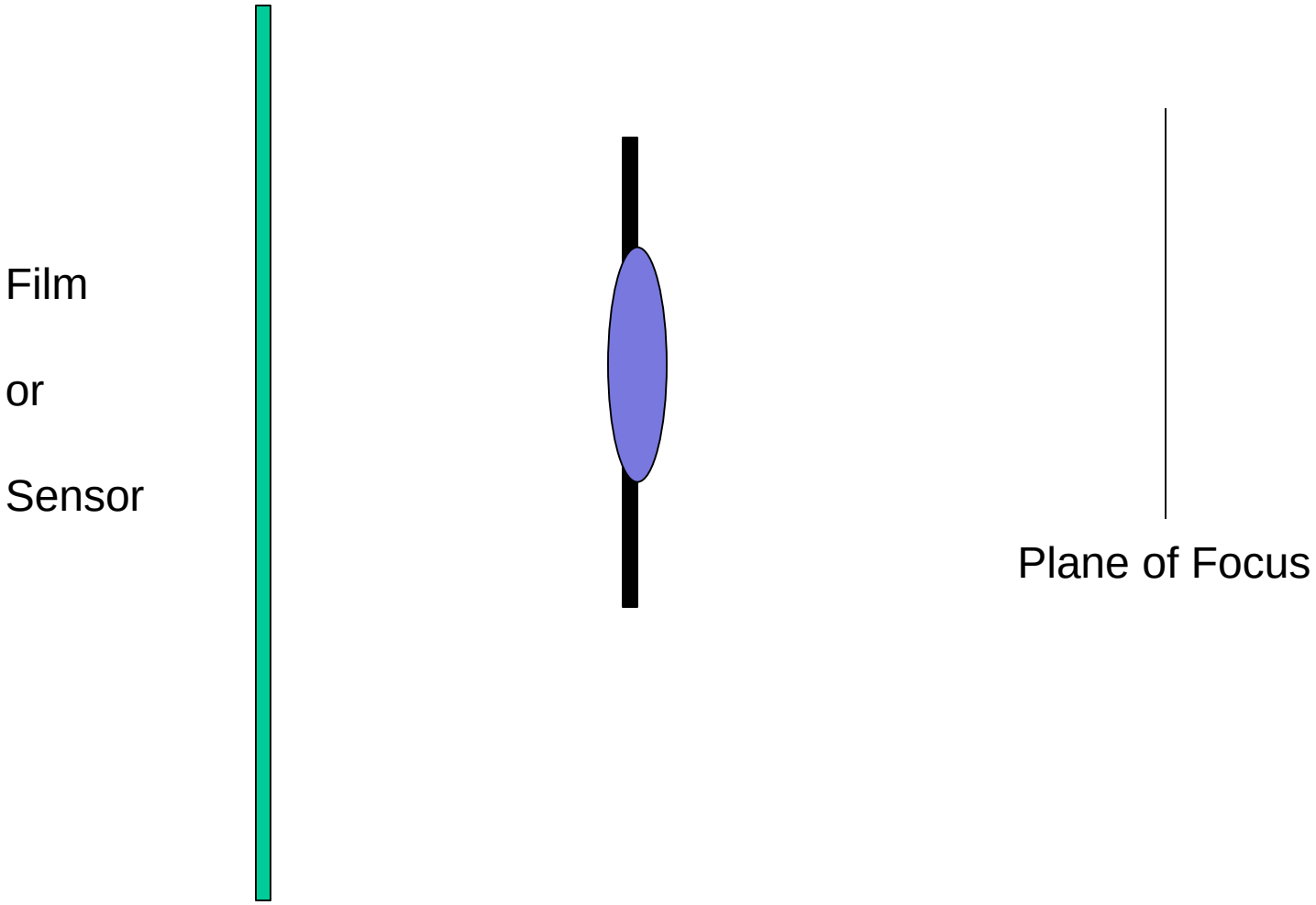
Shrinking the aperture

The reason for lenses

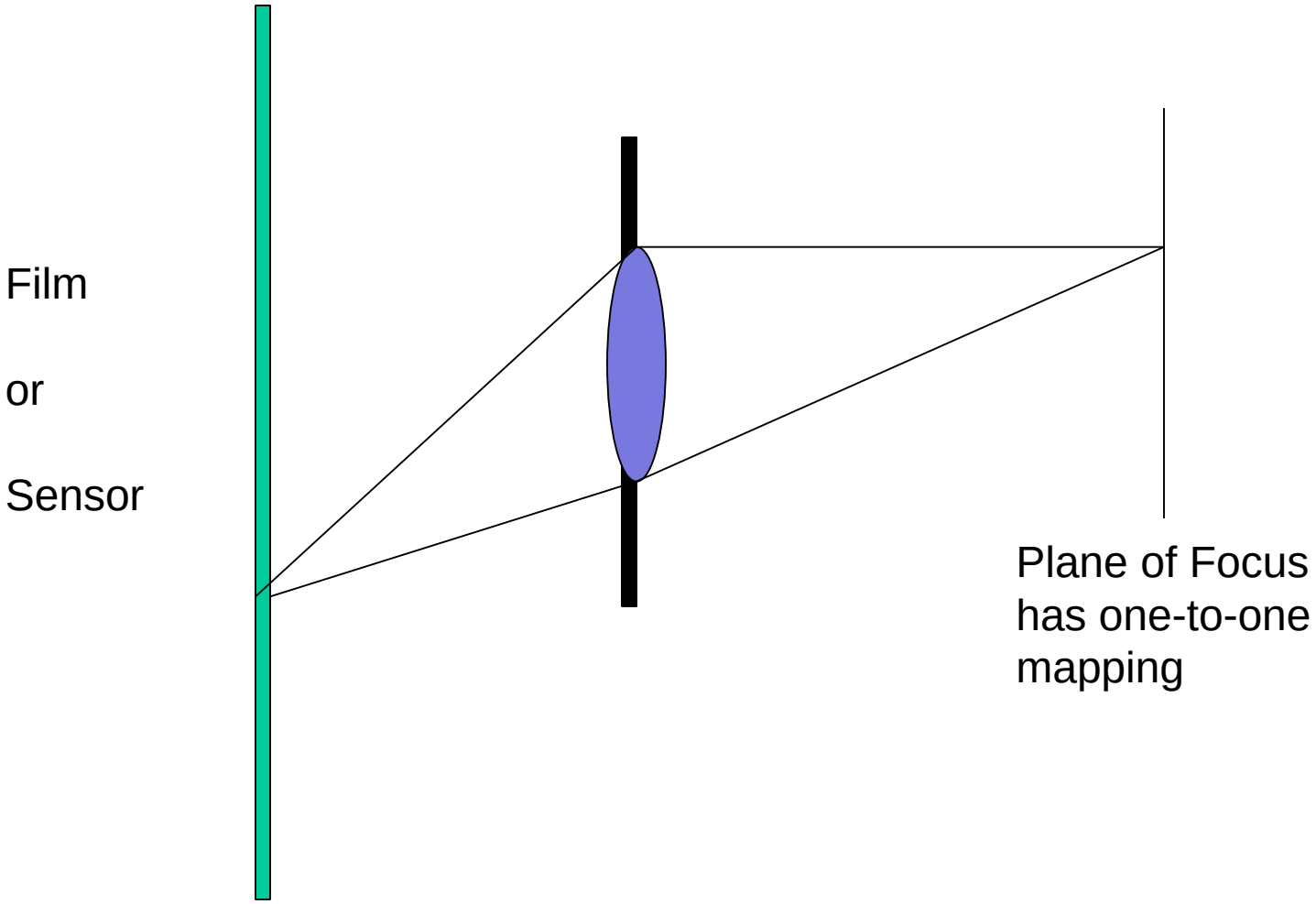


Slide by Steve Seitz

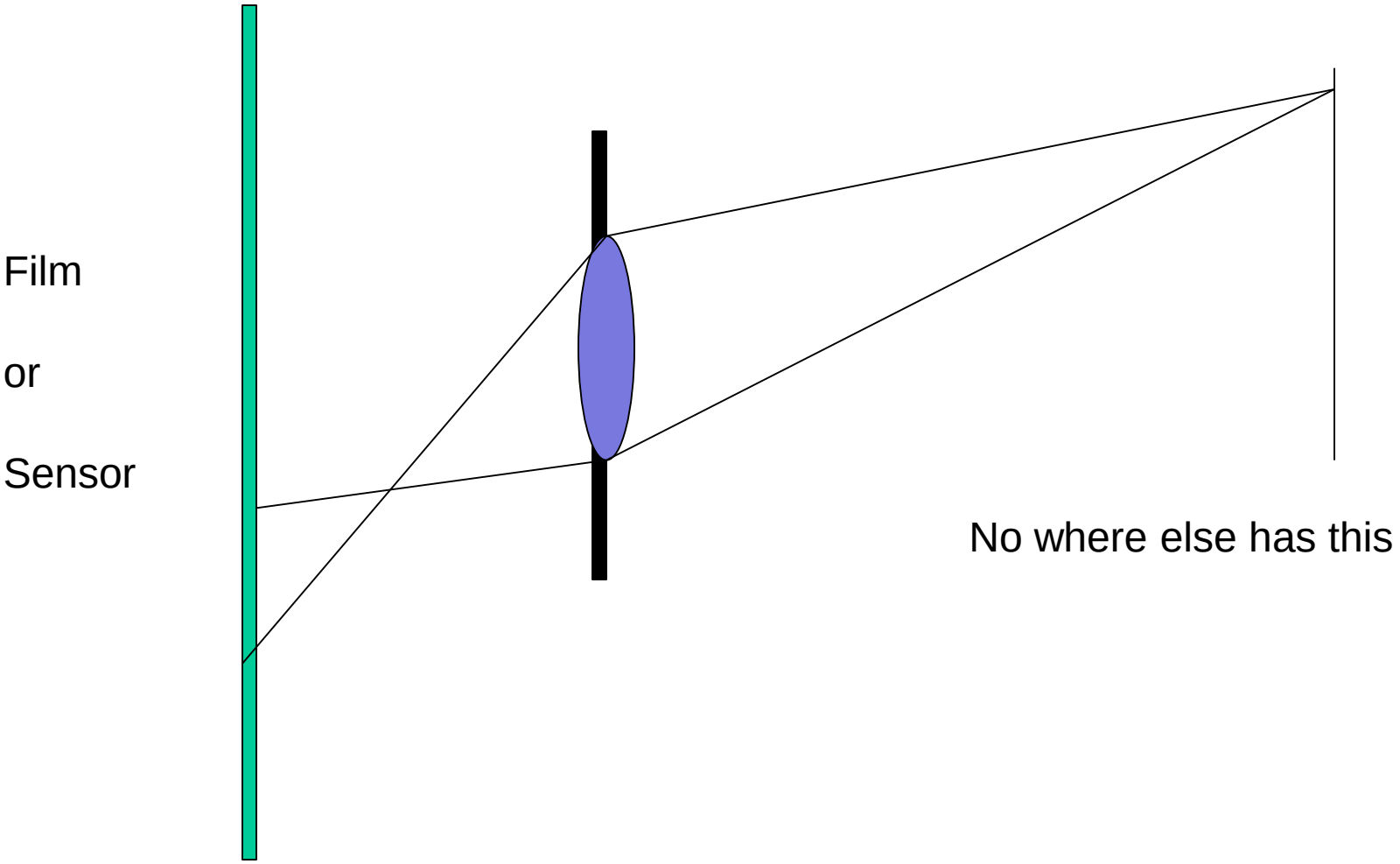
Regular camera



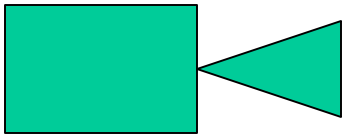
Regular camera



Regular camera



Regular camera



Plane of Focus

Participation

What if I want everything in focus?

What if I want everything in focus?

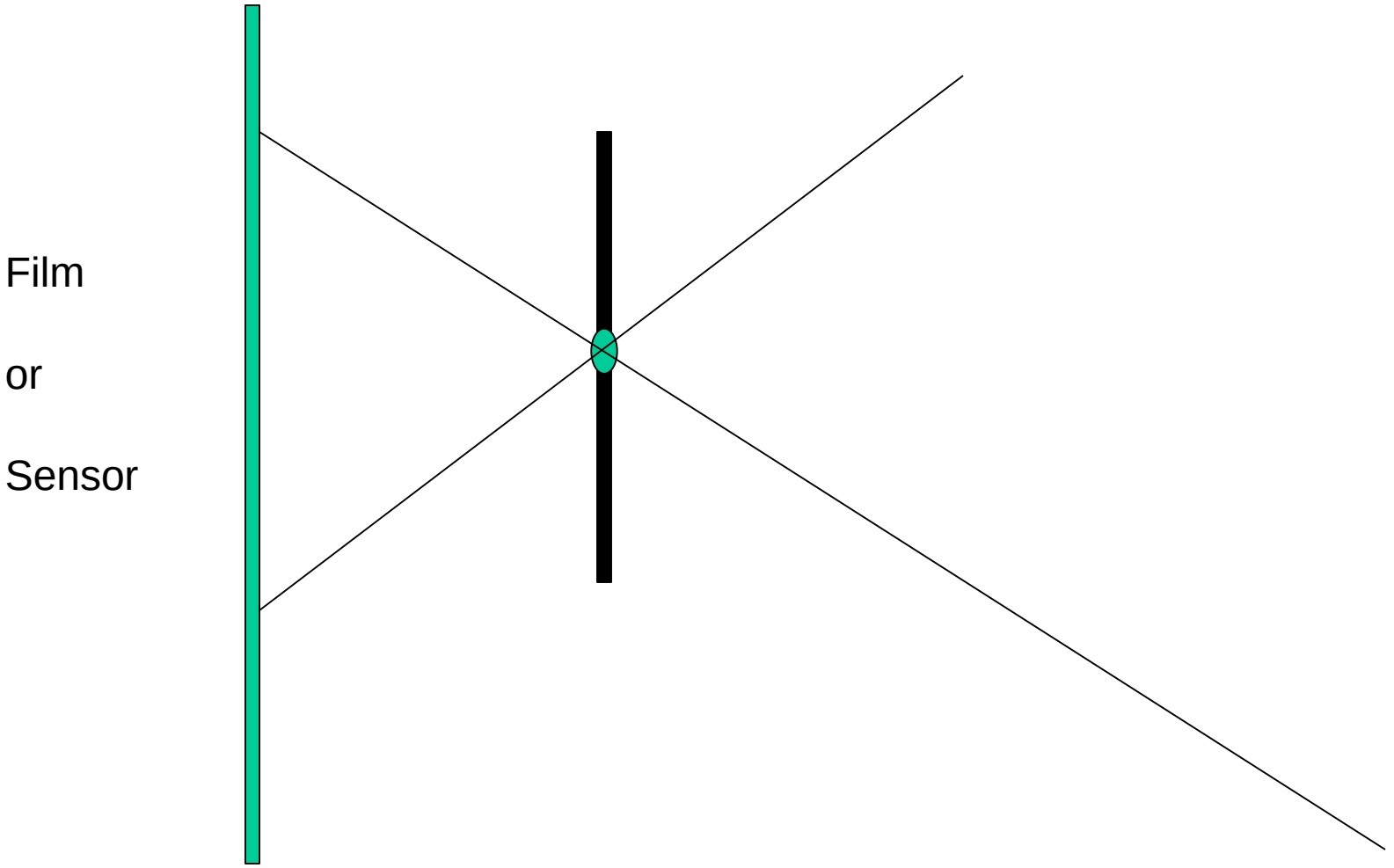
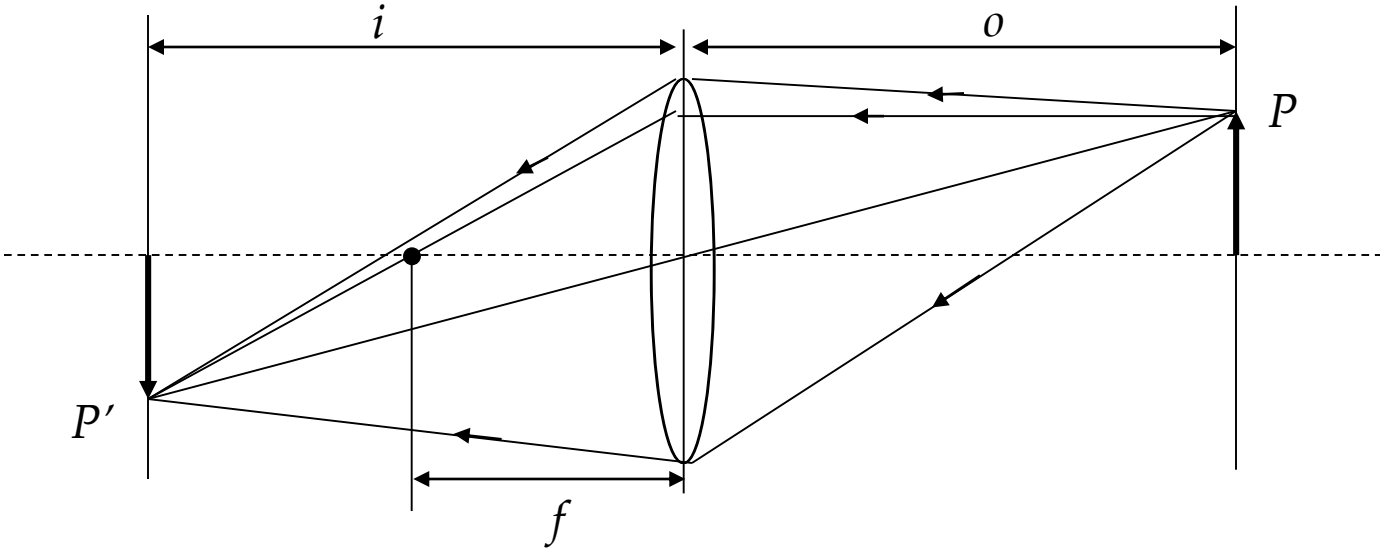


Image Formation using Lenses

Ideal Lens: Same projection as pinhole but gathers more light!



Lens Formula: $$\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$$

- f is the focal length of the lens – determines the lens's ability to bend (refract) light
- f different from the effective focal length f discussed before!

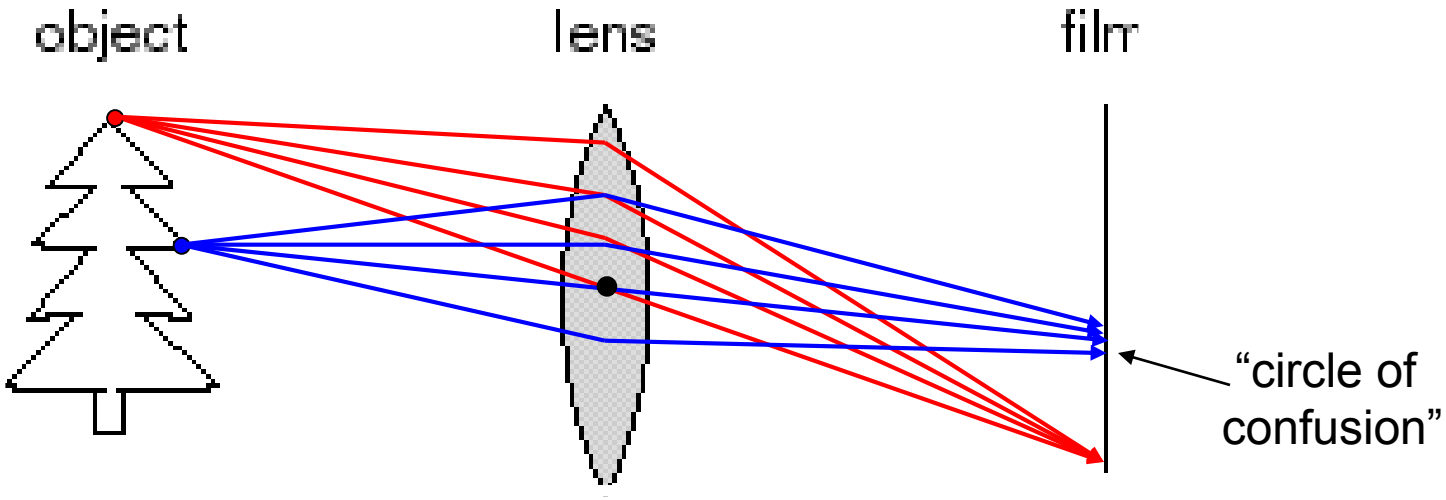
Slide by Shree Nayar

Lesson 4

Lenses solve one problem (light throughput) and create another (focus)

Focus

Focus and Defocus



A lens focuses light onto the film

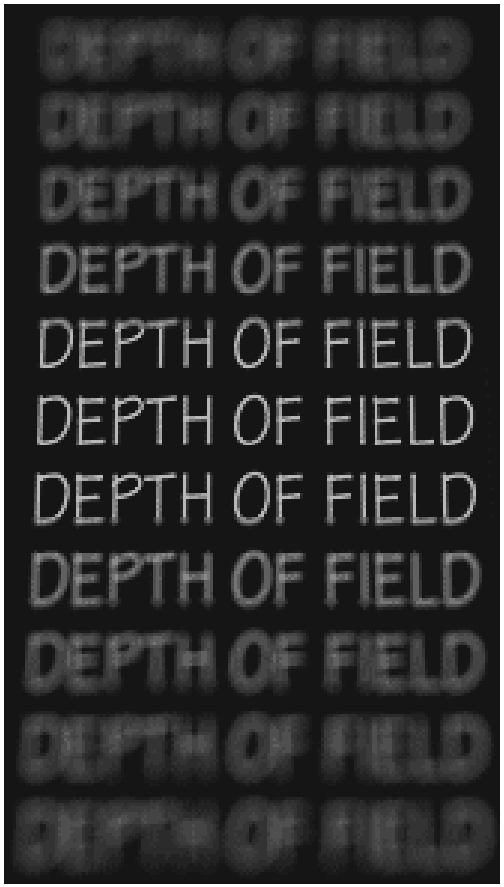
- There is a specific distance at which objects are “in focus”
  - other points project to a “circle of confusion” in the image
- How can we change focus distance?

Slide by Steve Seitz

Varying Focus

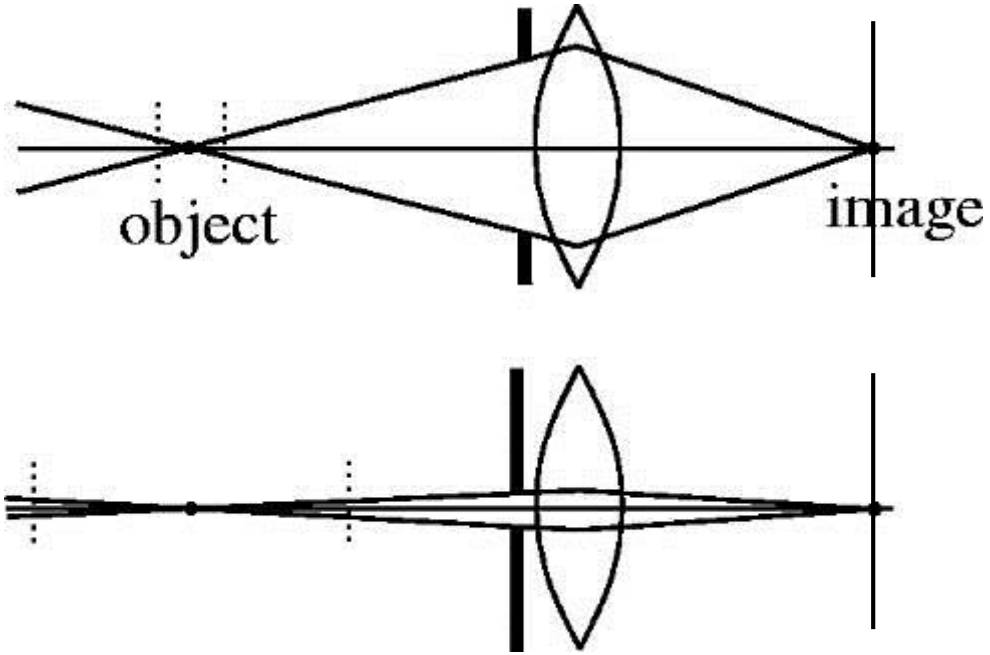
Depth Of Field

Depth of Field



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

Aperture controls 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

Varying the aperture

f/2.8

Large apeture = small DOF

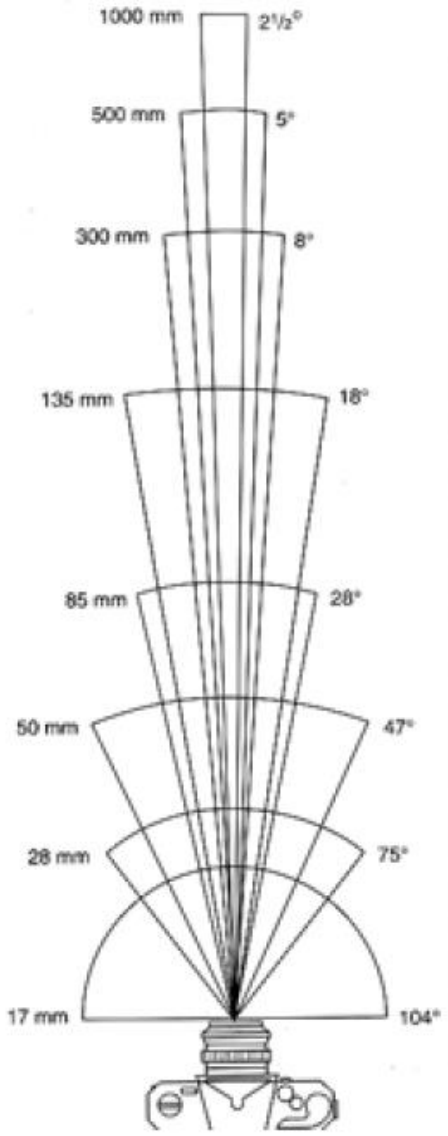
f/22

Small apeture = large DOF

Nice Depth of Field effect

Field of View (Zoom)

Field of View (Zoom)



17mm

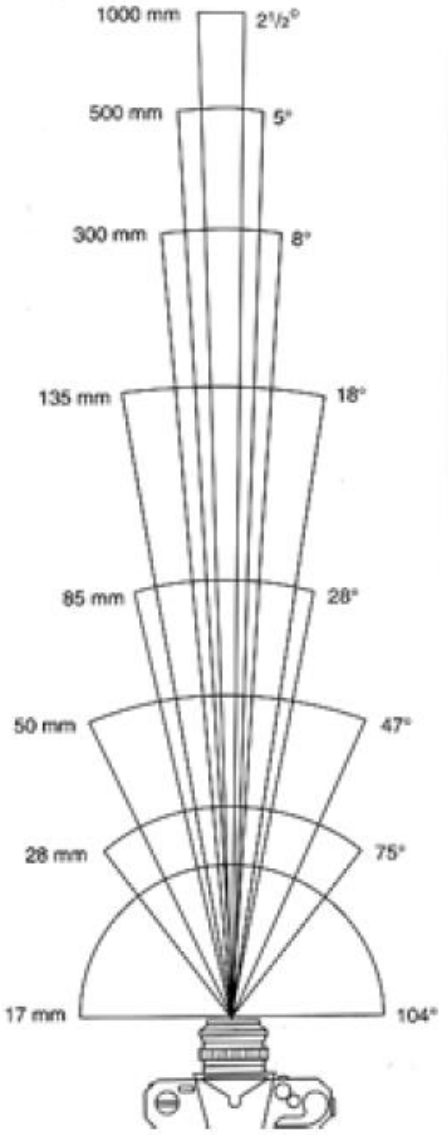
28mm

50mm

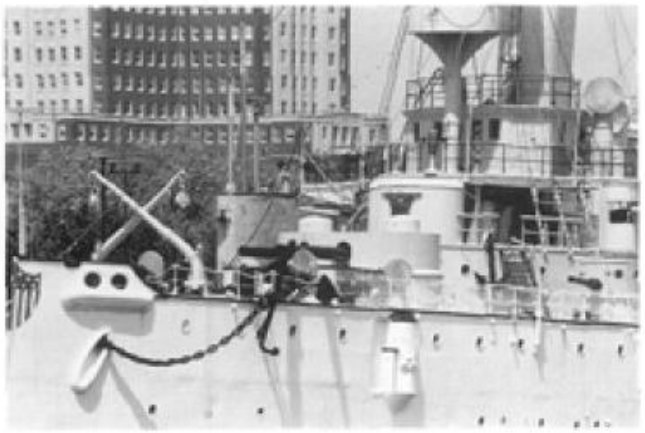
85mm

From London and Upton

Field of View (Zoom)



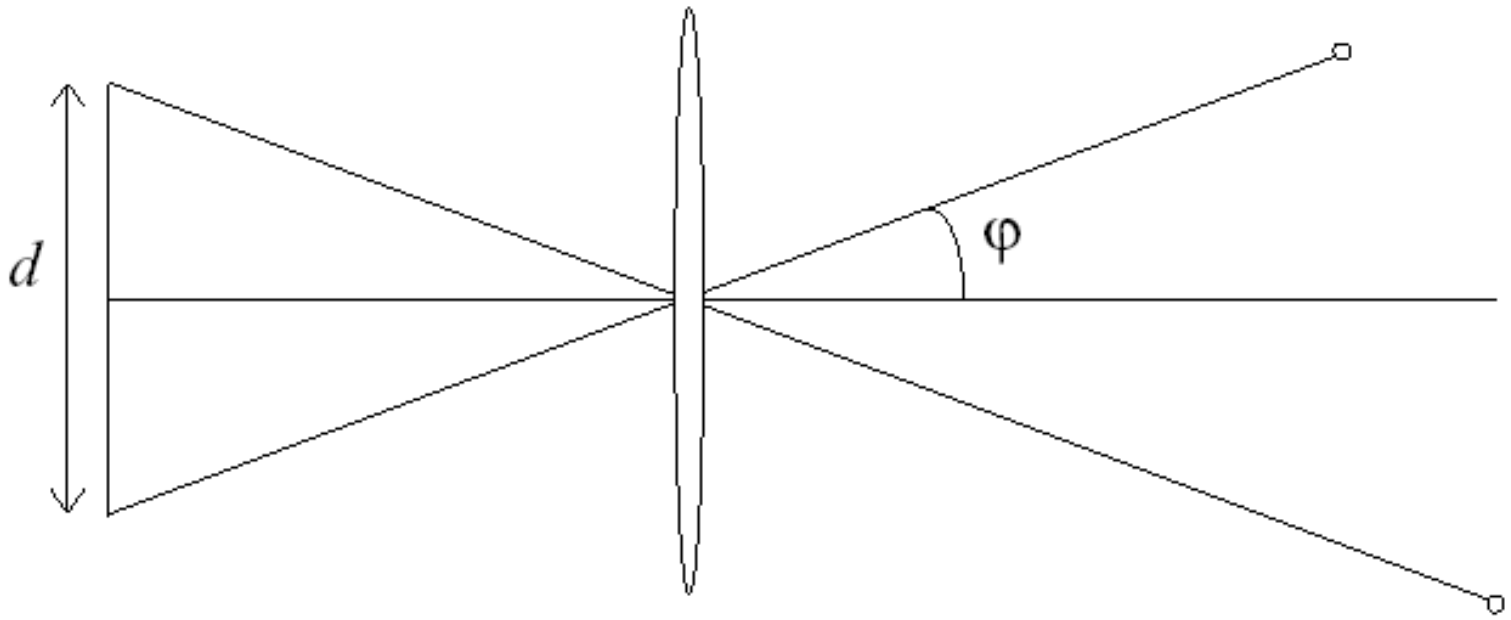
135mm



300mm

From London and Upton

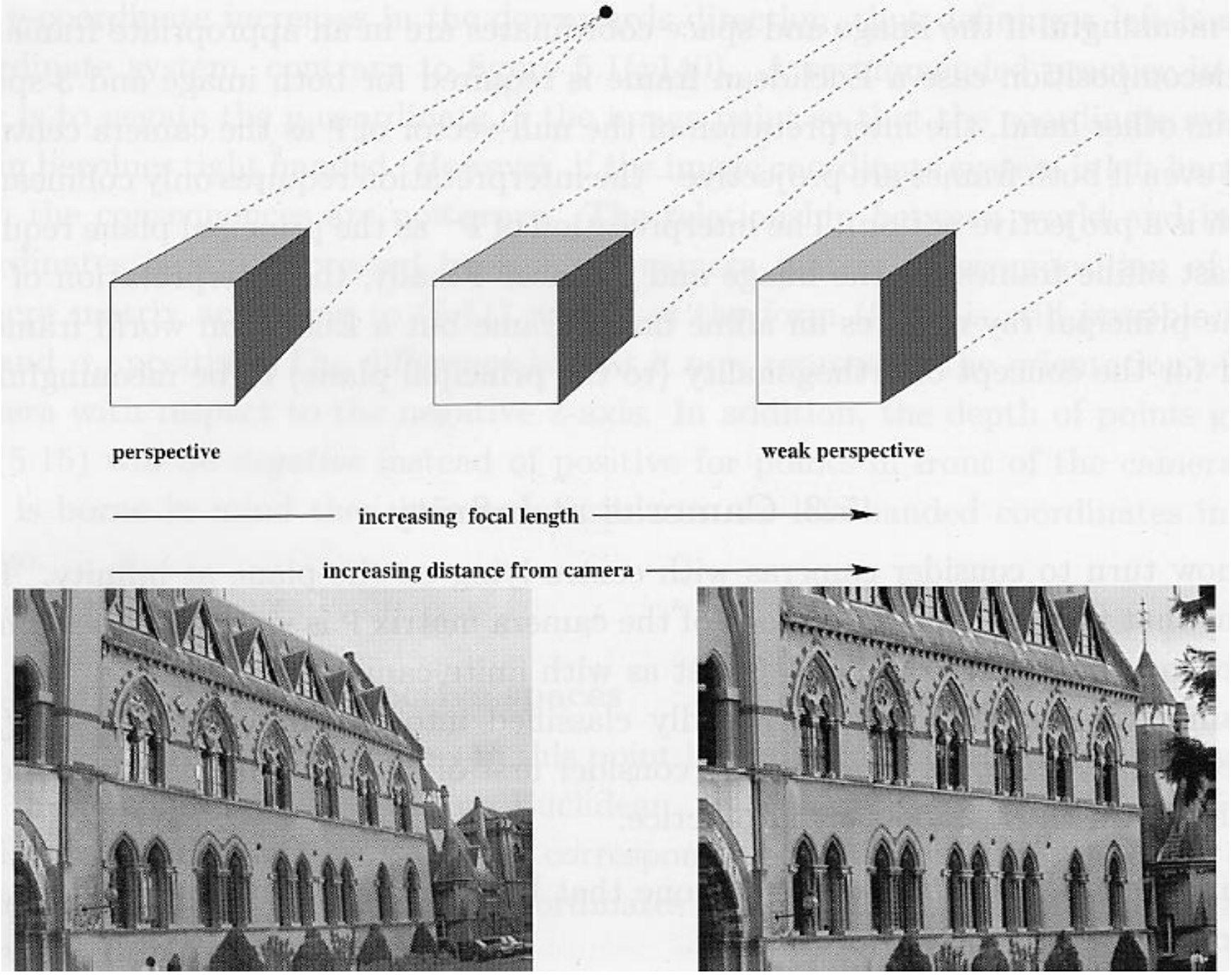
FOV depends of Focal Length



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



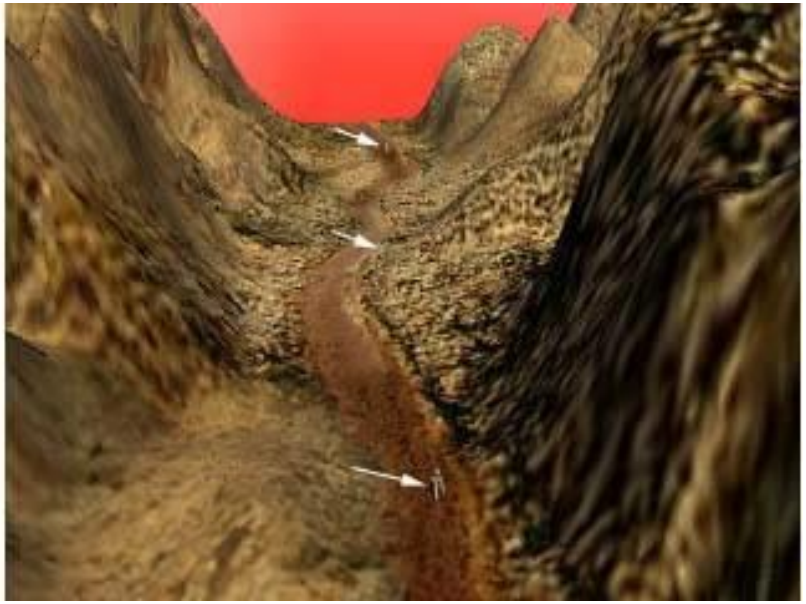
From Zisserman & Hartley

Field of View / Focal Length

Large FOV
Camera close to car

Small FOV
Camera far from the car

Fun with Focal Length (Jim Sherwood)



http://www.hash.com/users/jsherwood/tutes/focal/Zoomin.mov

Figure 5.1

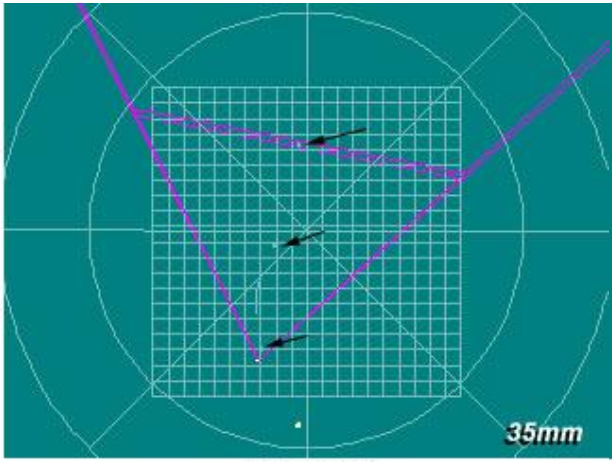


Figure 5.2

Large Focal Length compresses depth

400 mm 200 mm 100 mm 50 mm 28 mm 17 mm

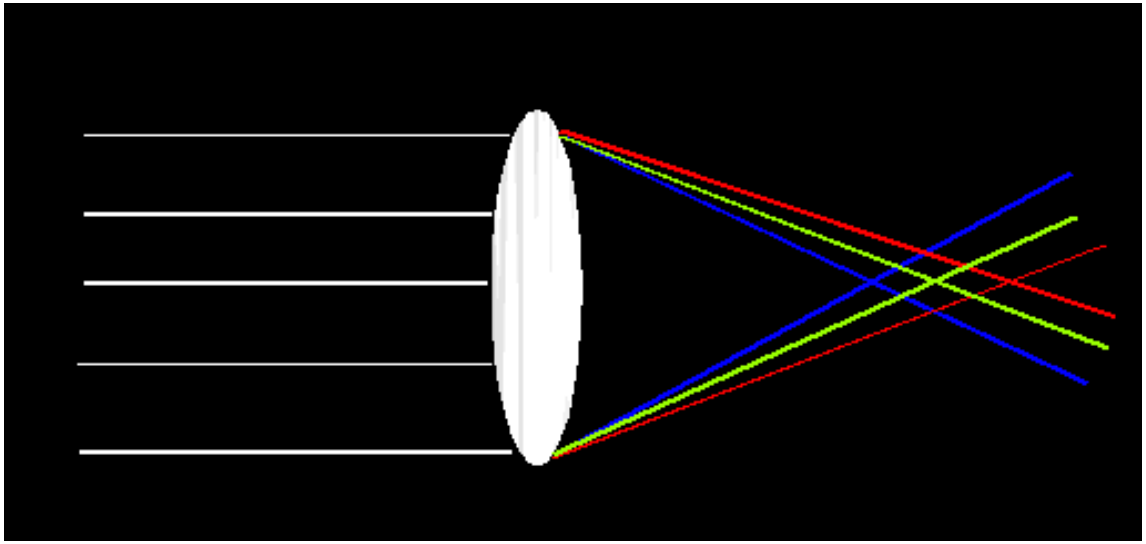
Lens Flaws

Lens Flaws: Chromatic Aberration

Dispersion: wavelength-dependent refractive index

- (enables prism to spread white light beam into rainbow)

Modifies ray-bending and lens focal length: f(λ)



color fringes near edges of image

Corrections: add ‘doublet’ lens of flint glass, etc.

Chromatic Aberration

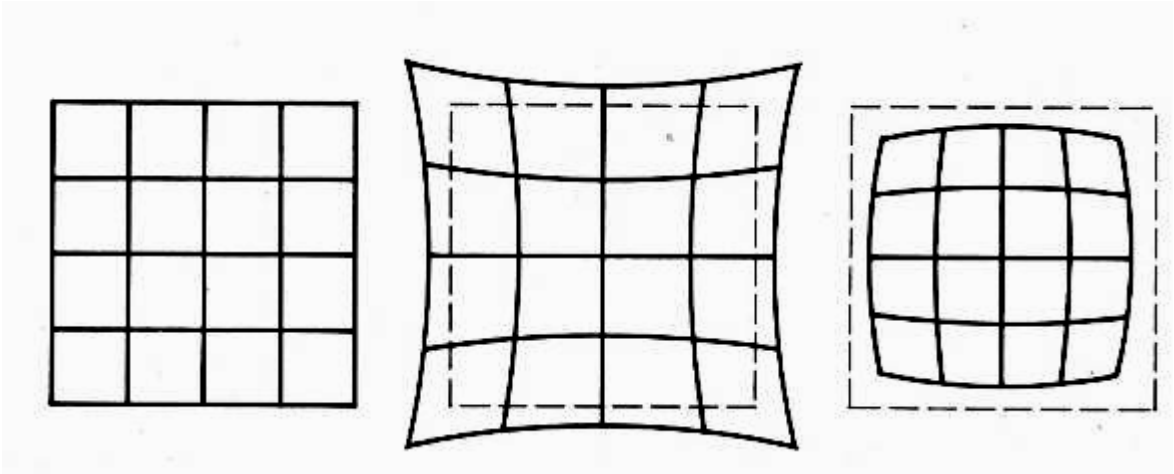
Near Lens Center

Near Lens Outer Edge

Radial Distortion (***e.g.*** ‘Barrel’ and ‘pin-cushion’)

straight lines curve around the image center

Radial Distortion

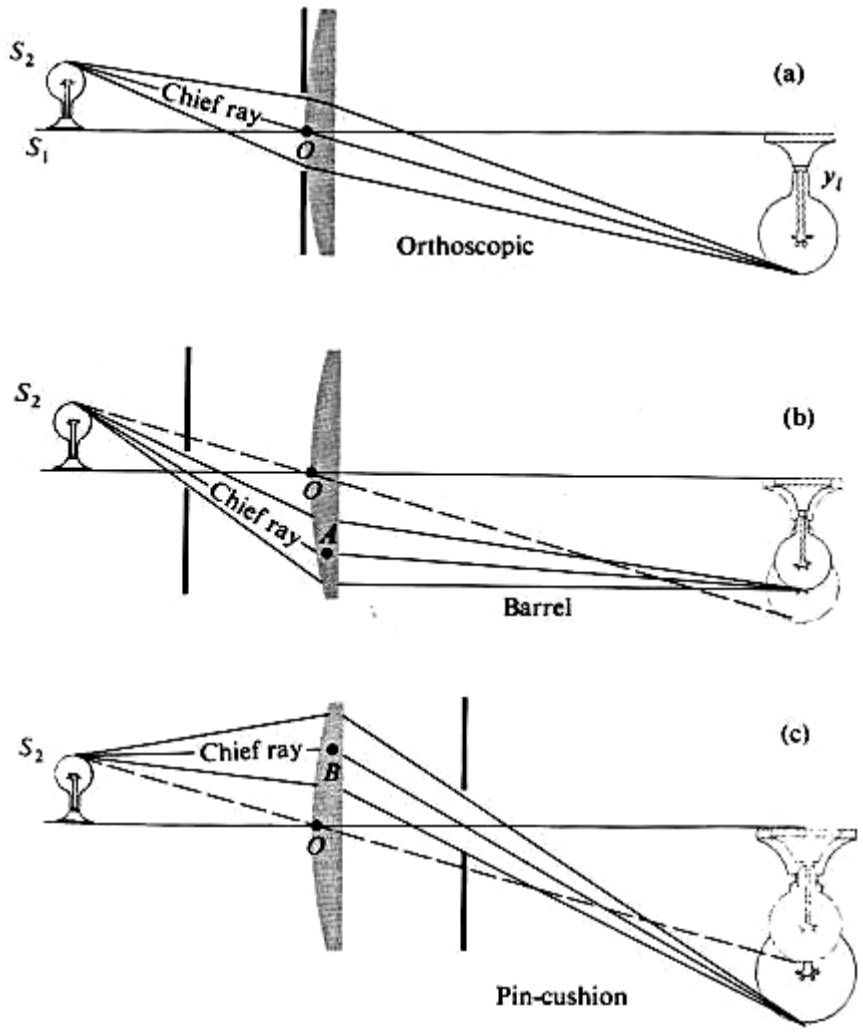


No distortion Pin cushion Barrel

Radial distortion of the image

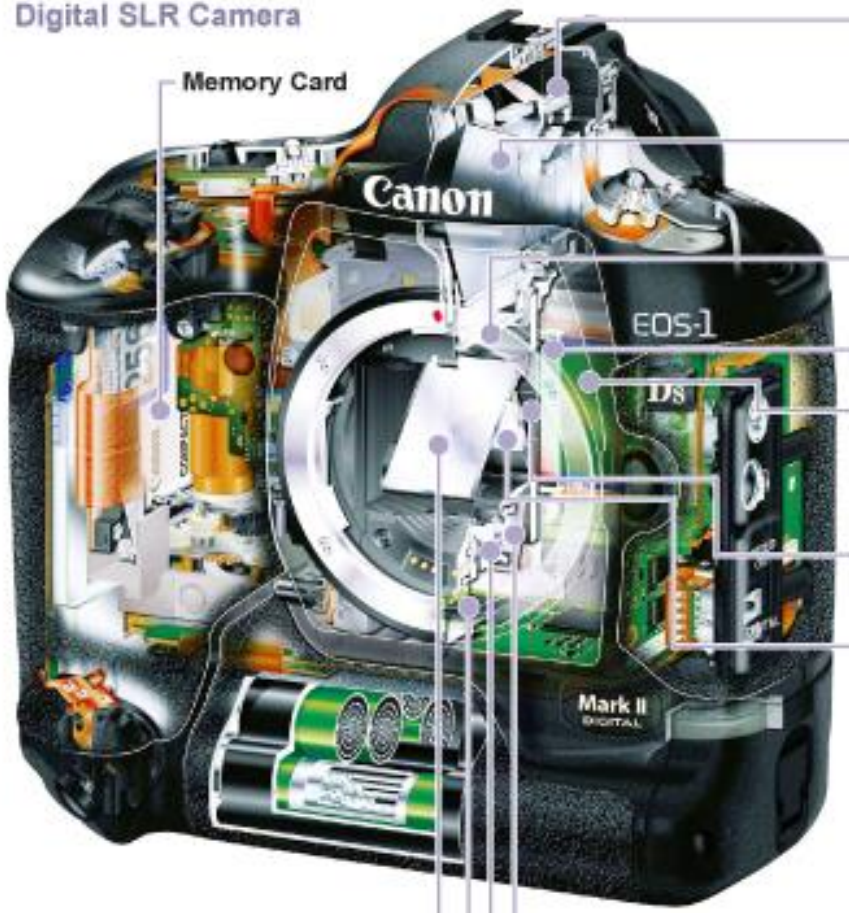
- Caused by imperfect lenses
- Deviations are most noticeable for rays that pass through the edge of the lens

Radial Distortion



A brief overview of new imaging techniques

Digital SLR Camera



Memory Card

Metering Sensor
21-zone metering sensor linked to 45-point area AF

Pentaprism
Rotates the image on the focusing screen 180 degrees into an erecting image for viewing through the viewfinder

Focusing Screen
Reproduces an image of the object to be photographed

Low-Pass Filter

Image Sensor
Detects light and converts it into electrical signals (comparable to the film in a film camera)

Shutter
Opens during exposure to allow light to reach the image sensor

Submirror
Elliptical-shape mirror that directs light to the AF sensor and the secondary image-formation lens

Main Mirror
Guides light from the lens to the focusing screen, metering sensor, and viewfinder. During exposure, it flips up to open a path for light to reach the image sensor

Area AF Sensor
Employs a dedicated sensor capable of high-speed data reading to calculate the distance between camera and subject using four images with different parallax

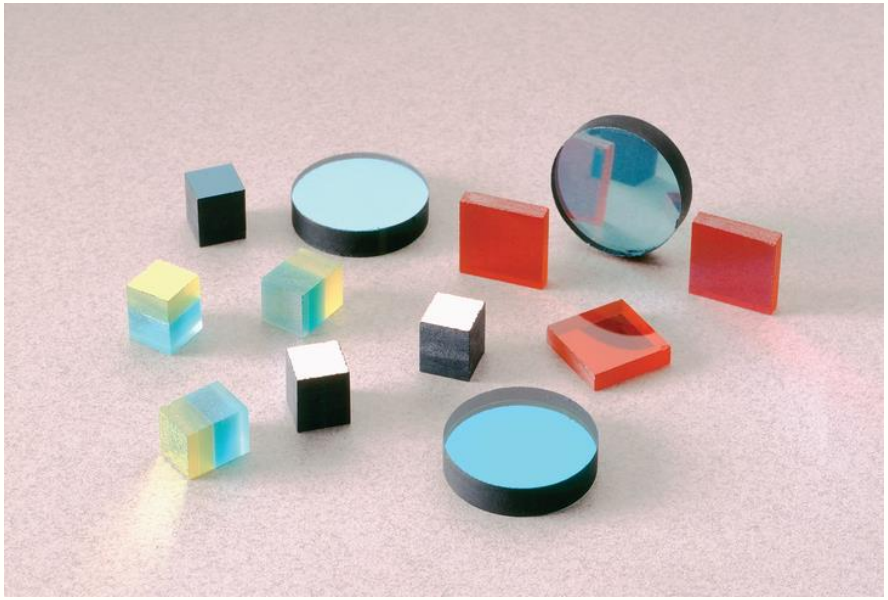
Image Processor
The DIGIC high-speed image processor converts electrical signals into image data

Secondary Image-Formation Lens
Splits light from the submirror into four paths, forming four images on the CMOS area AF sensor

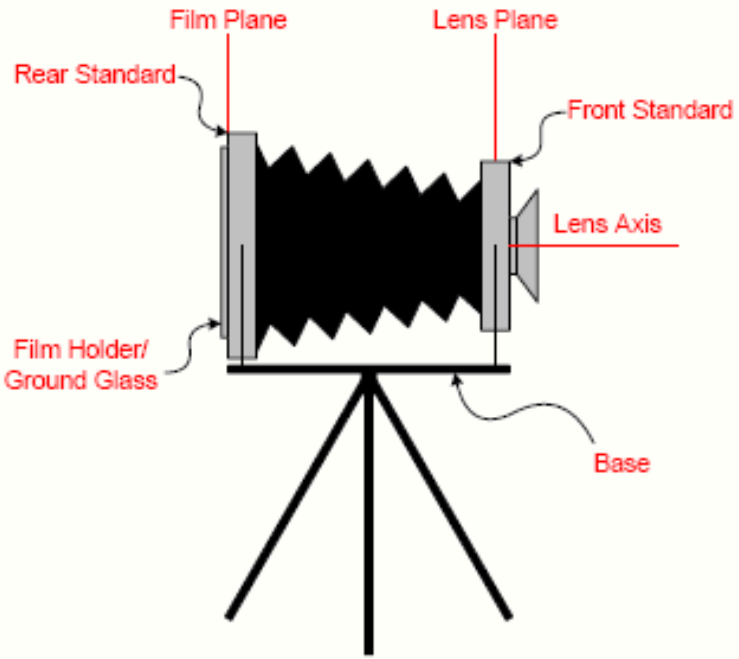
35mm SLR Film Camera

Canon.com

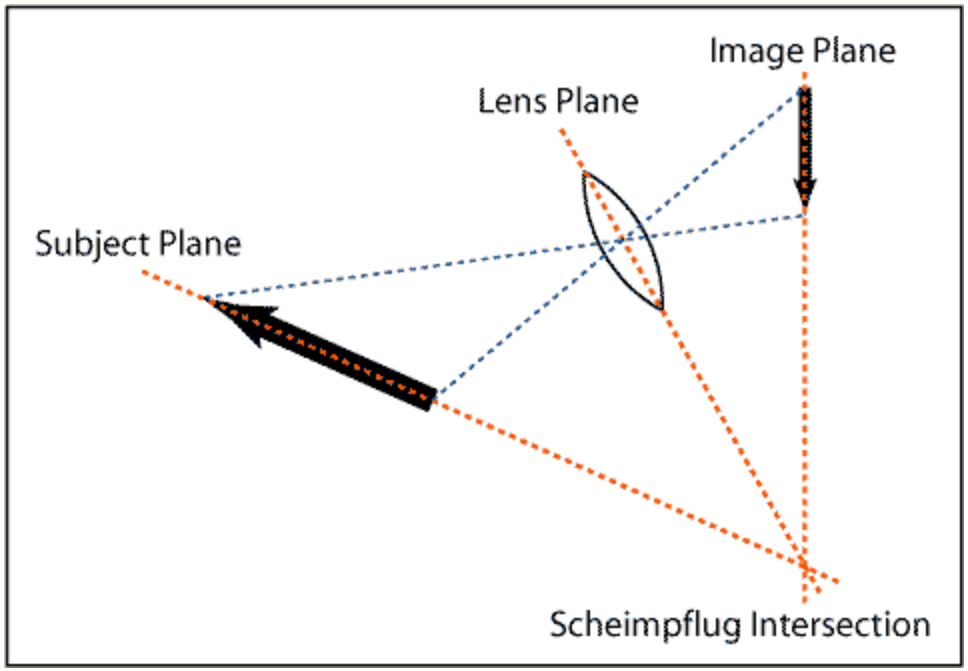
Optical Elements in an Imaging System



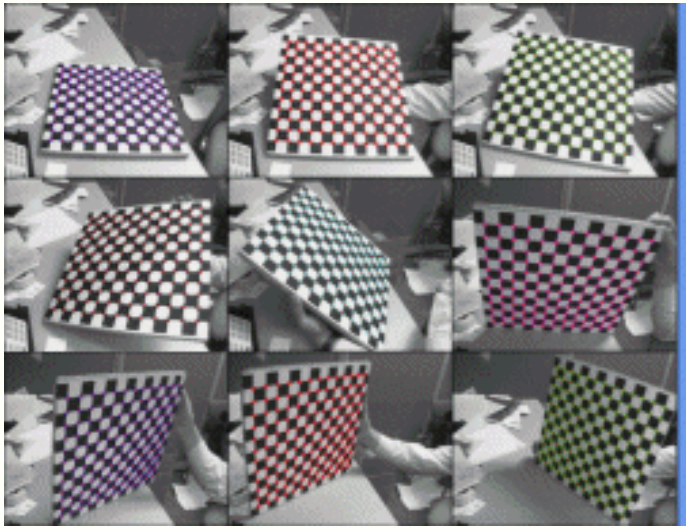
Large Format (View) Camera

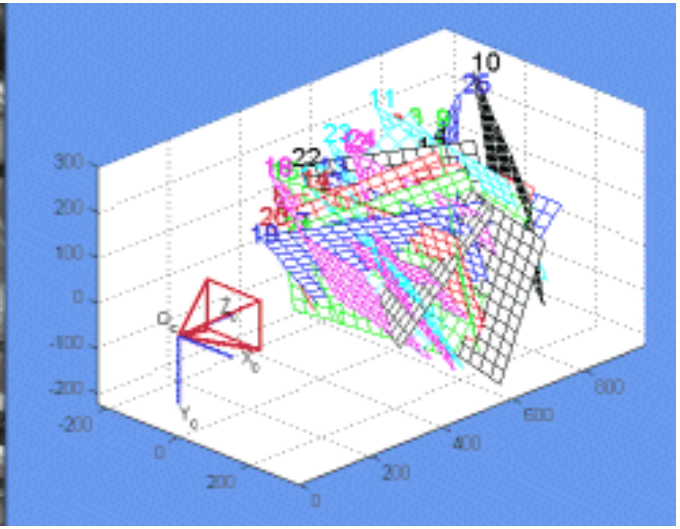


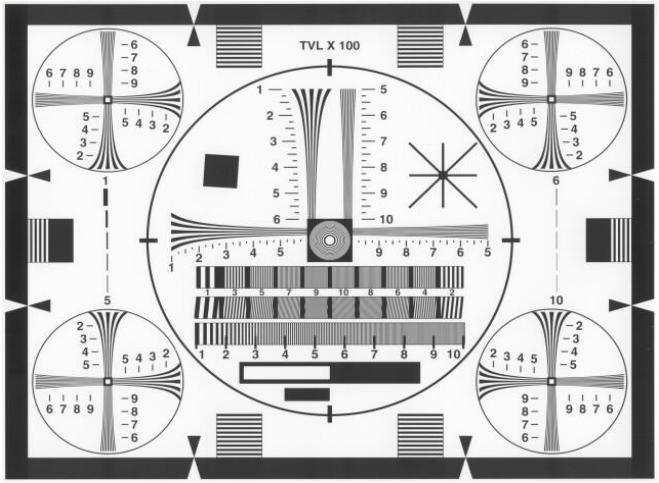
Scheimpflug principle



Camera Calibration





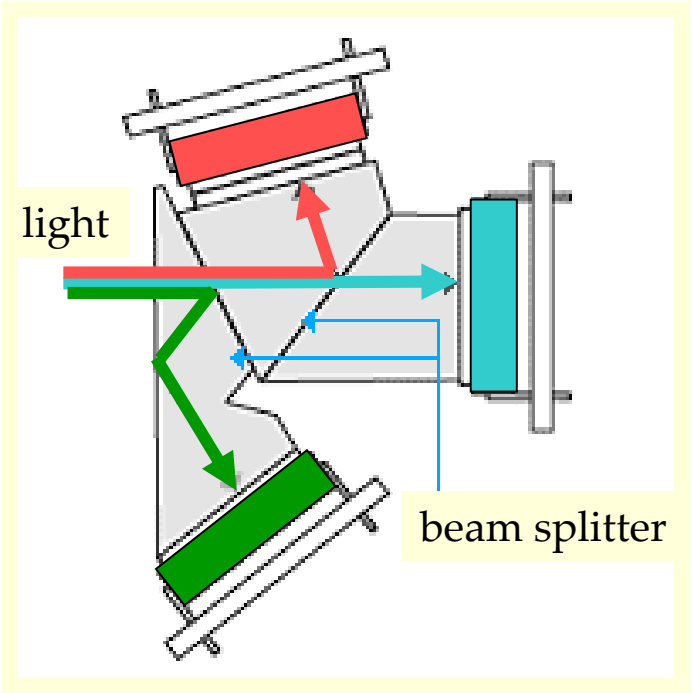


Lesson 5

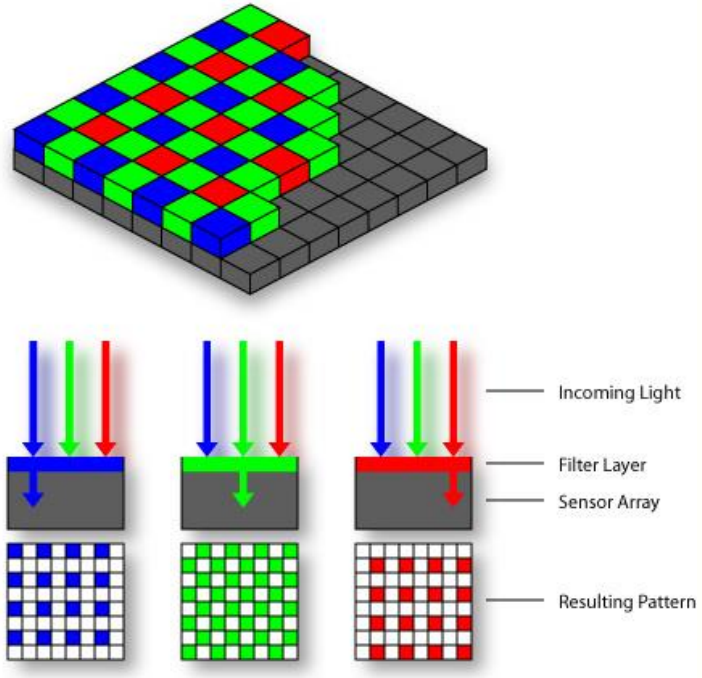
Off-the-shelf cameras require
a lot of work before
engineers/researchers/technologists
can use them

Lens Distortions

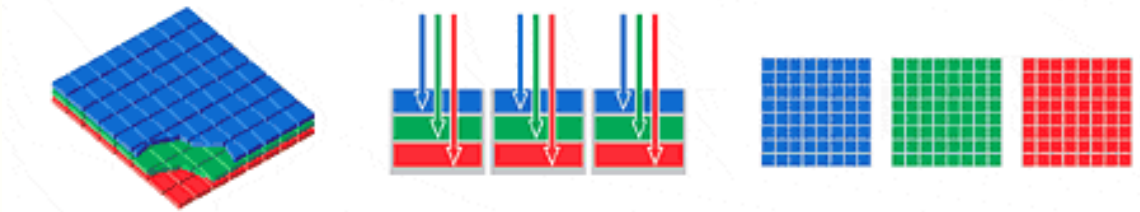
Sensing Color



3 CCD



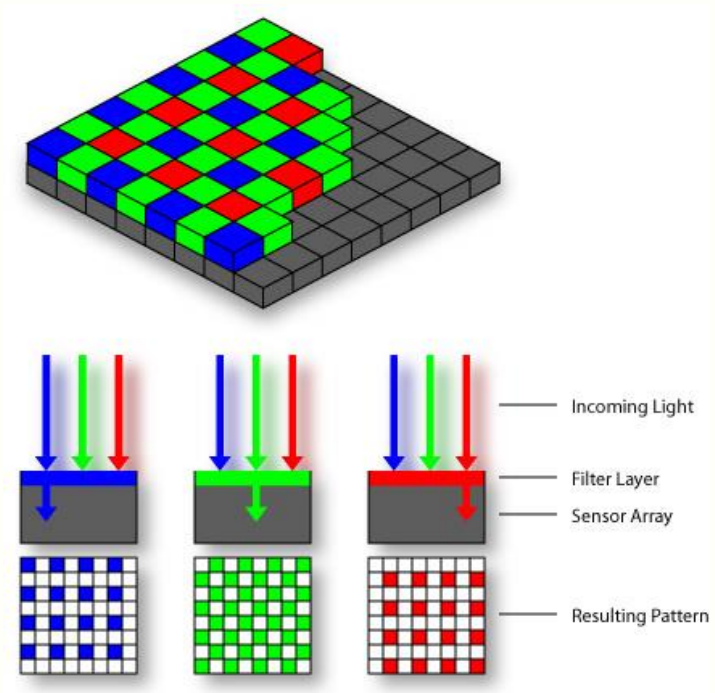
Bayer pattern



Foveon X3™

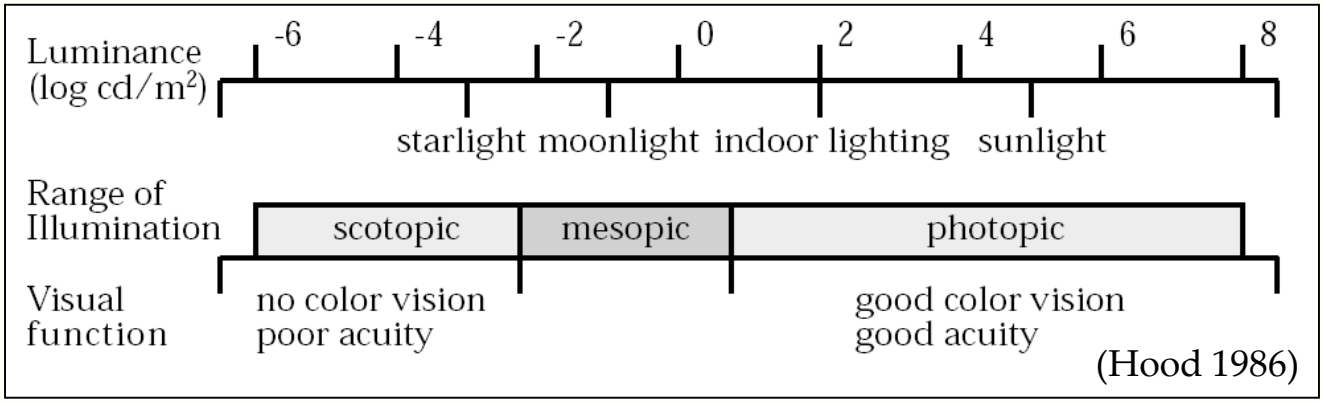
Participation

What are there more green filters than red or blue?

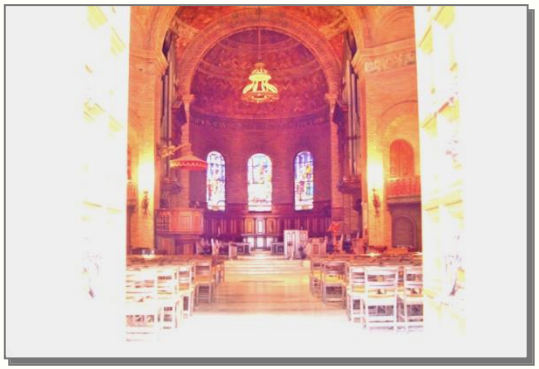


The Problem of Dynamic Range

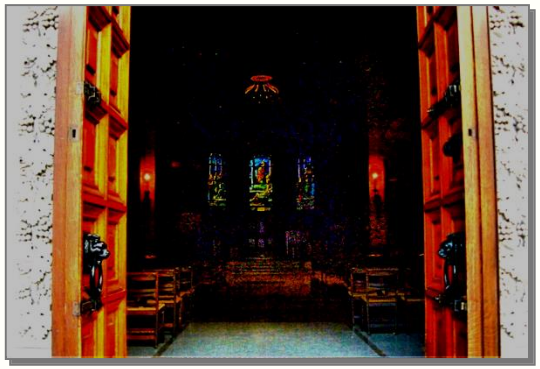
- Dynamic Range: Range of brightness values measurable with a camera



- Today's Cameras: Limited Dynamic Range



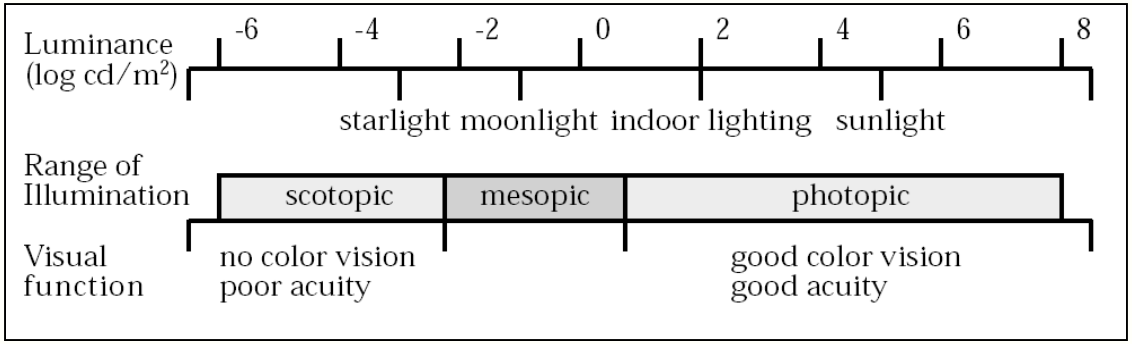
High Exposure Image



Low Exposure Image

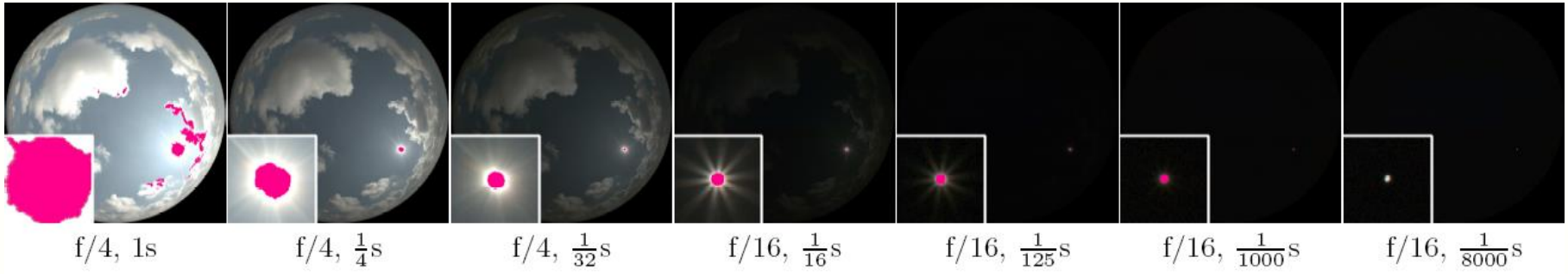
- We need 5-10 million values to store all brightnesses around us.
- But, typical 8-bit cameras provide only 256 values!!

High Dynamic Range Imaging



(Mitsunaga)

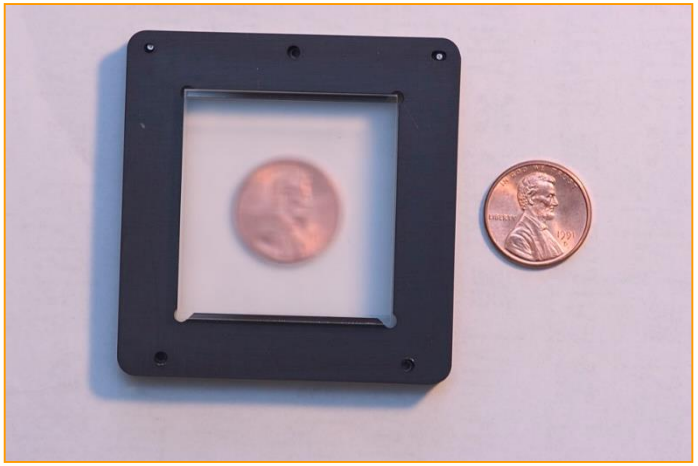
(Debevec)



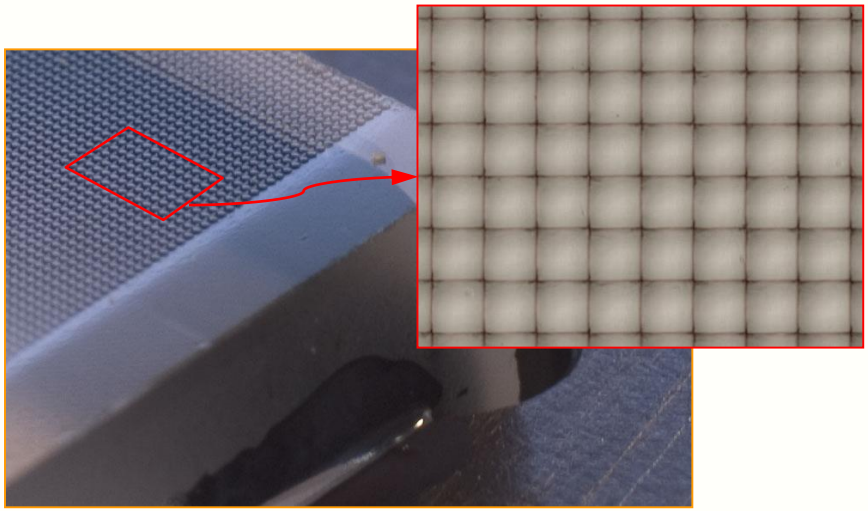
Light Field Cameras - Lens Arrays

Contax medium format camera

Kodak 16-megapixel sensor



Adaptive Optics microlens array



125μ square-sided microlenses

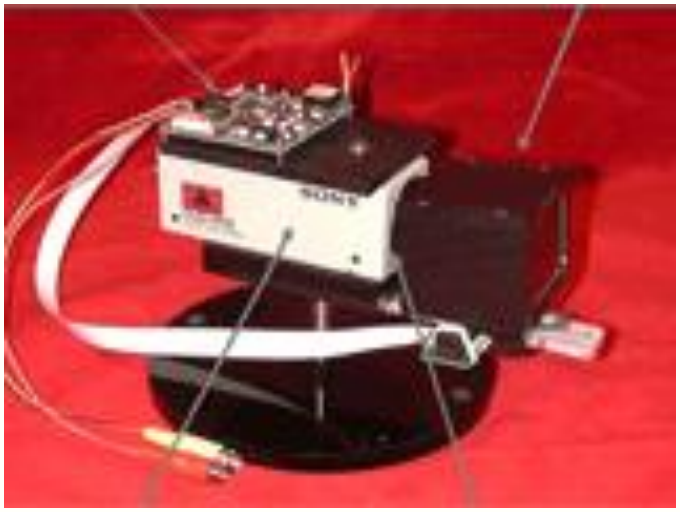
4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens

Lytro Camera

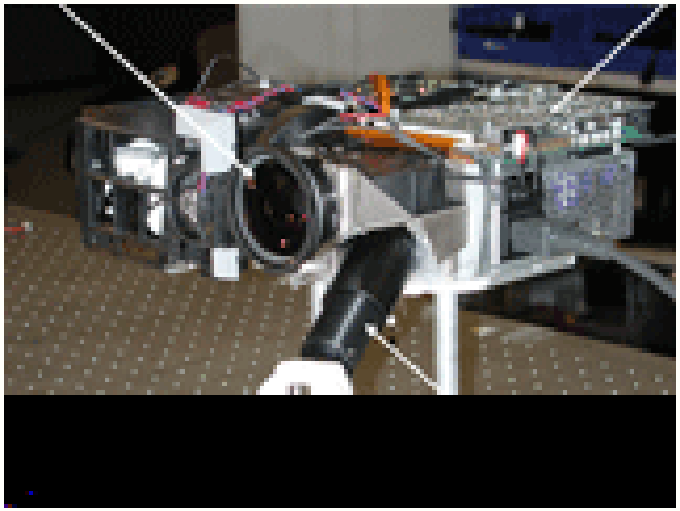
https://pictures.lytro.com/

Controlling Each Pixel

Jitter Camera

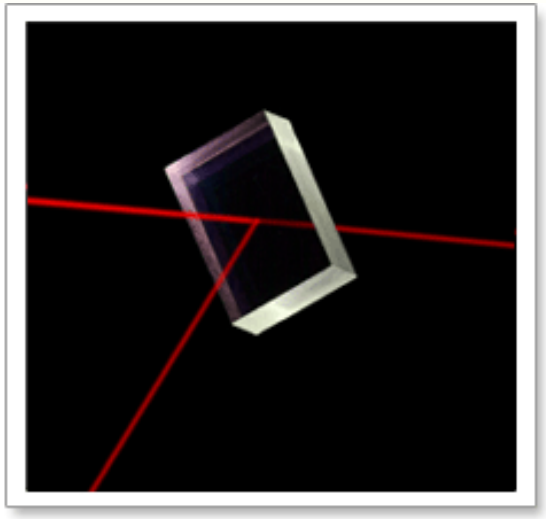


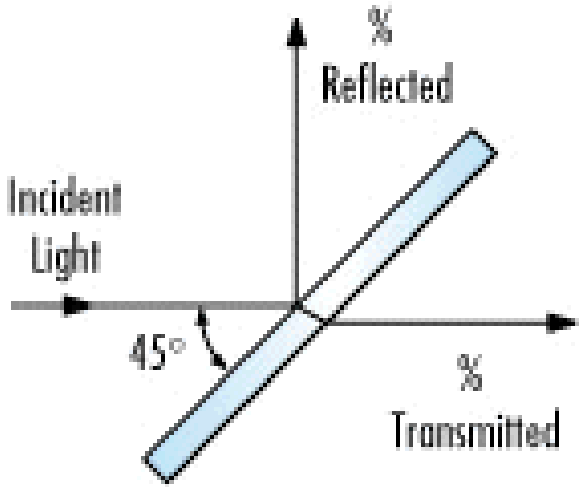
LCD + Camera

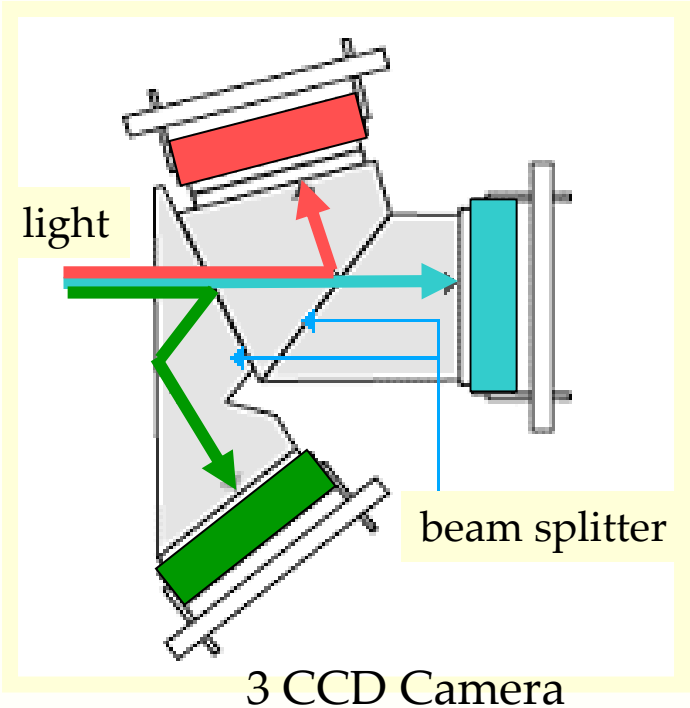


DMD Camera

Optical Beam Splitting

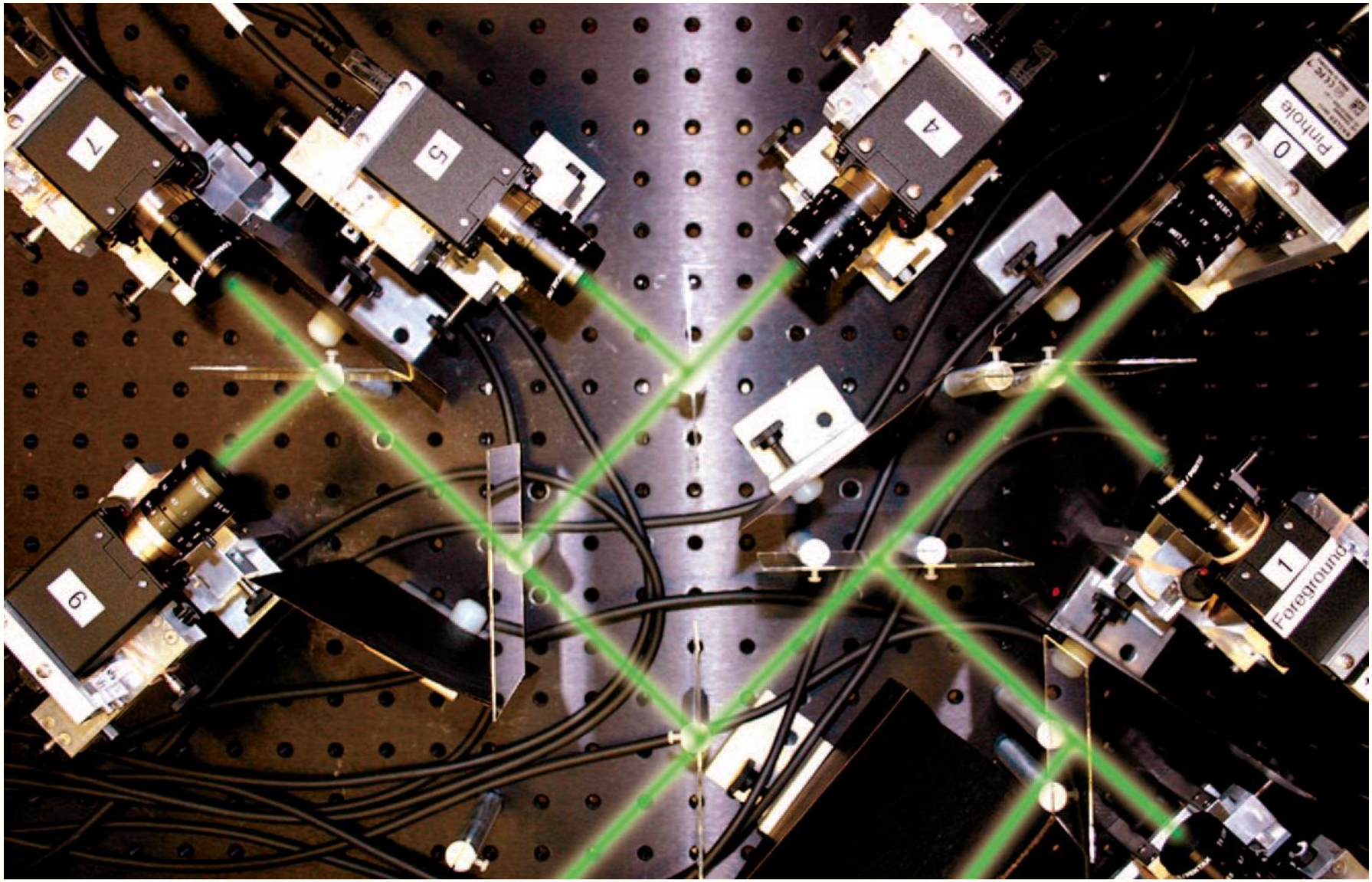






3 CCD Camera

Optical Beam Splitting



Polarization Photography

Without Polarizer

With Polarizer

- Provides better Color Saturation
- Darkens the sky

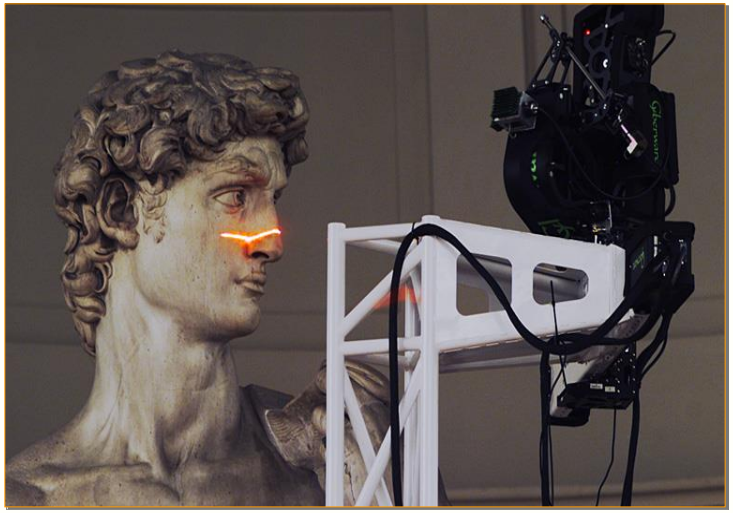
Polarization Photography : Reflections

Reduce Reflections

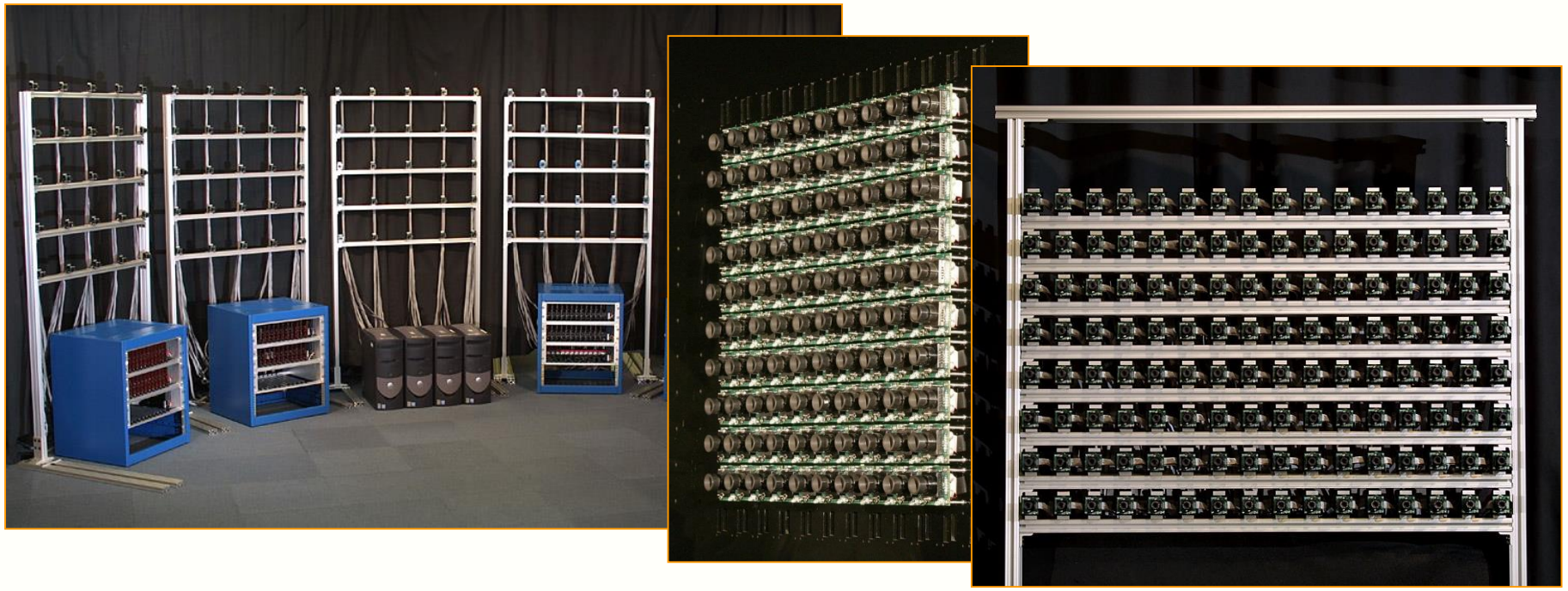
Participation

Is it likely that some predators of frogs have polarization sensitive vision?

Range Scanning



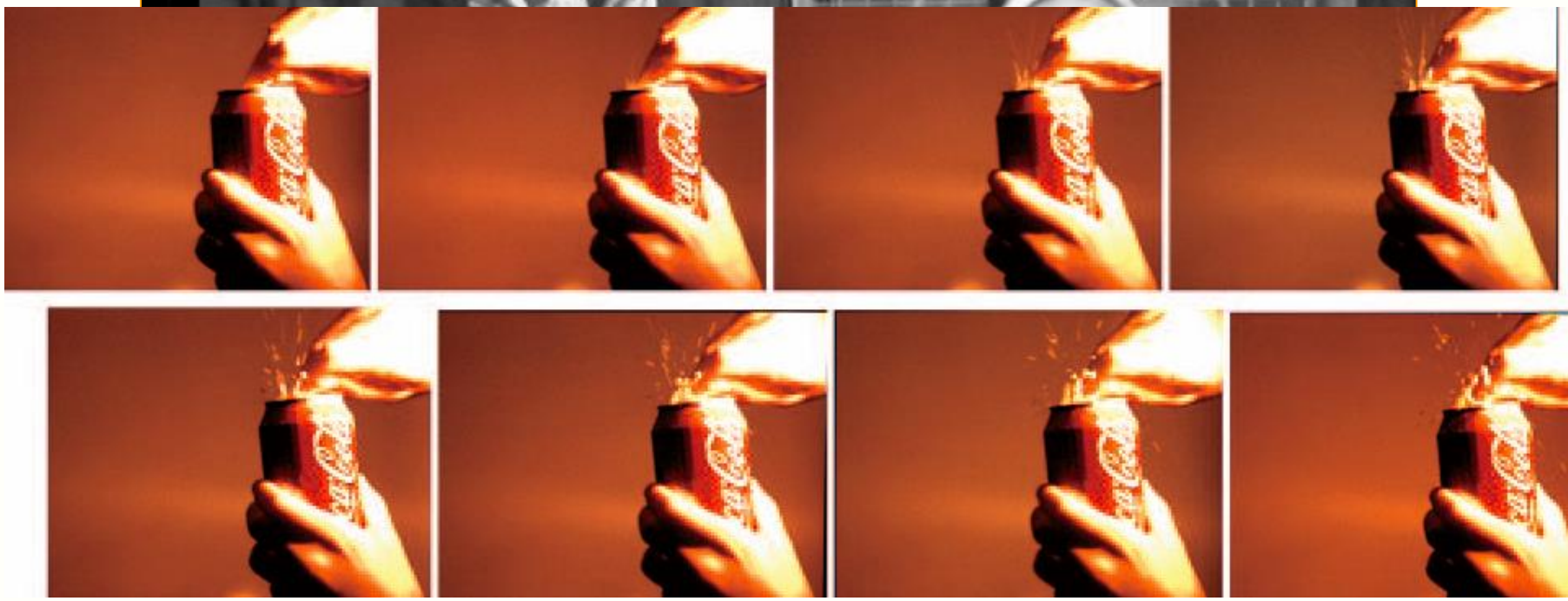
Camera Arrays



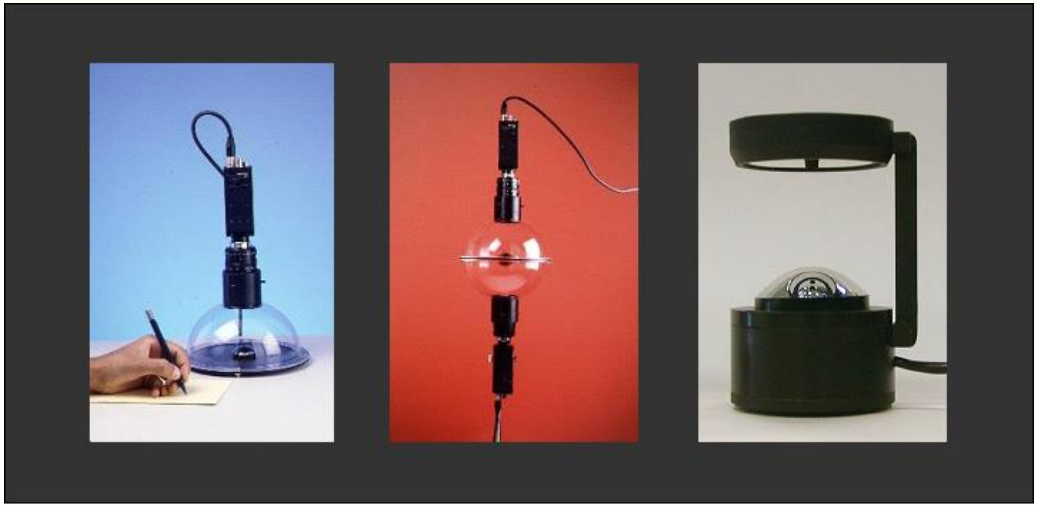
Large Images

Large Images

High Speed Cameras



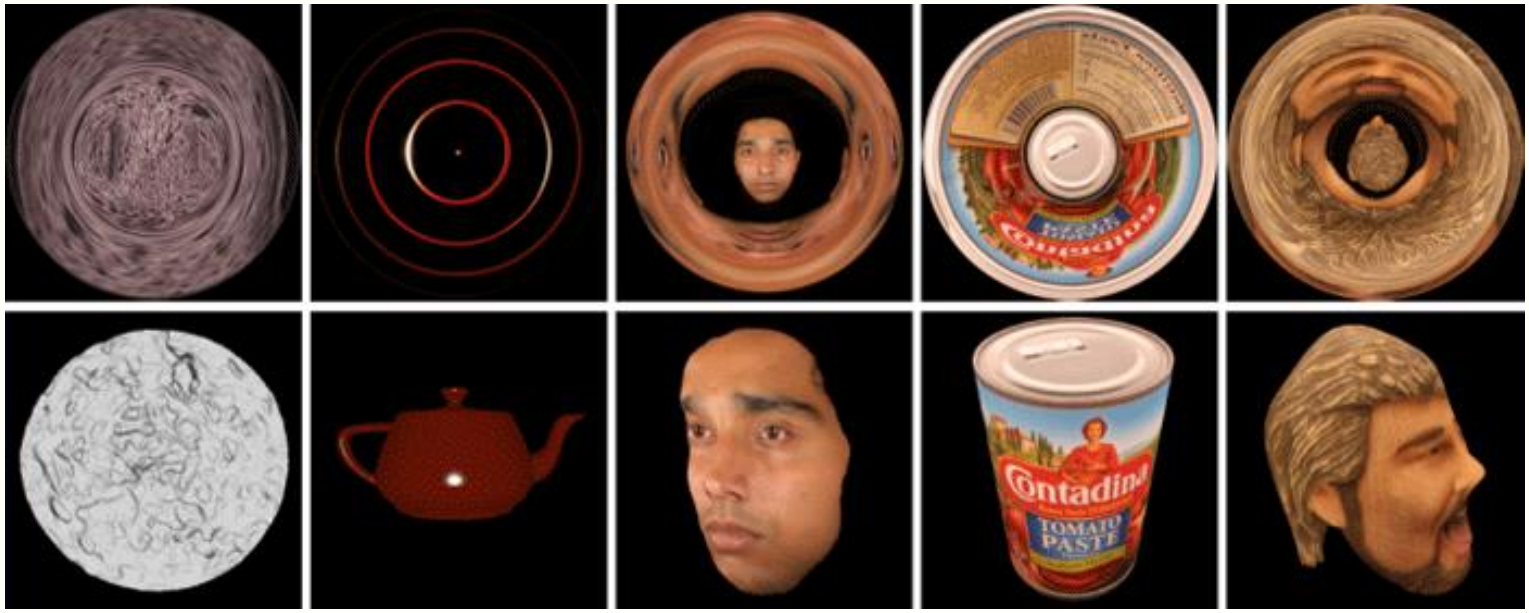
Cameras with Lenses and Mirrors



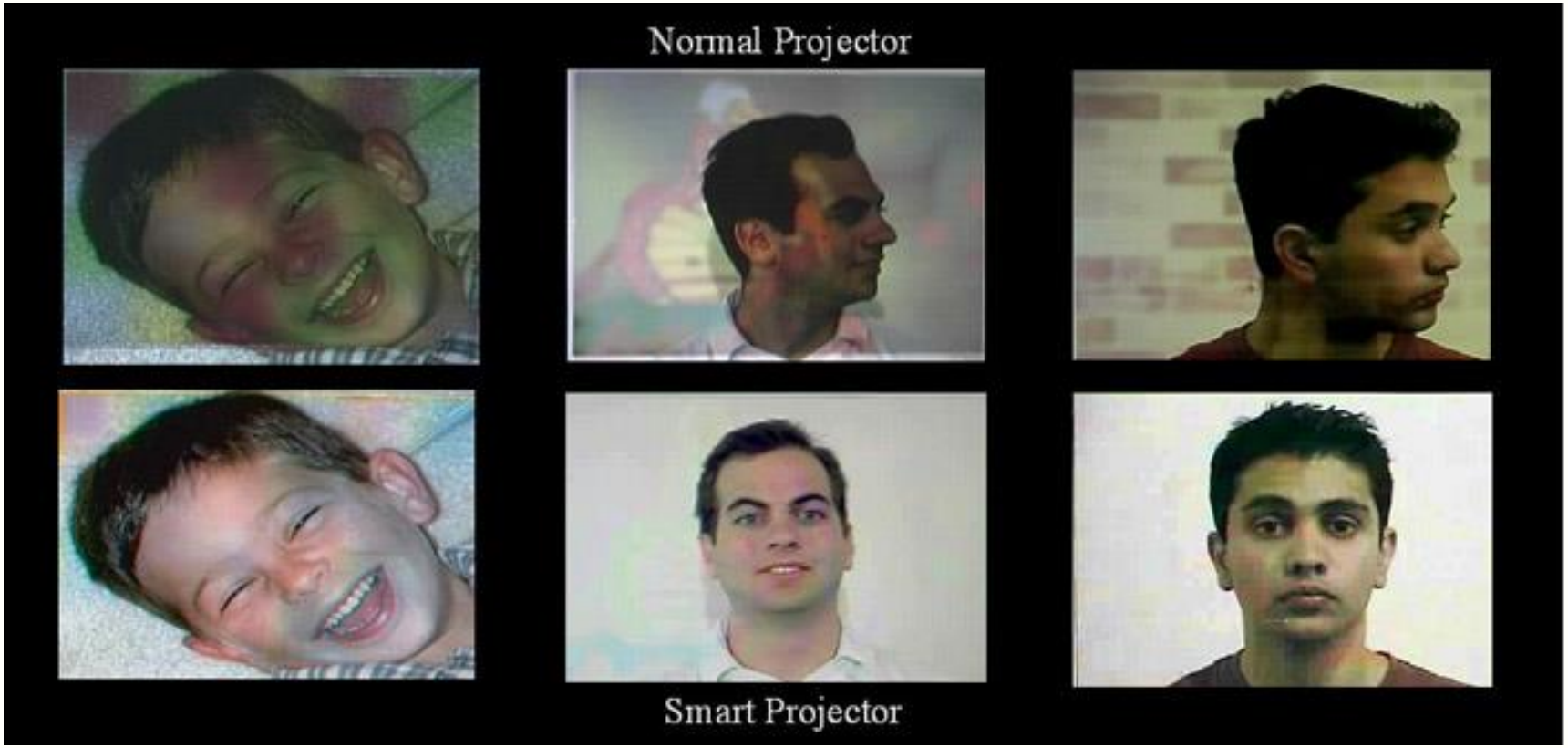

COOLPIX
990


COOLPIX

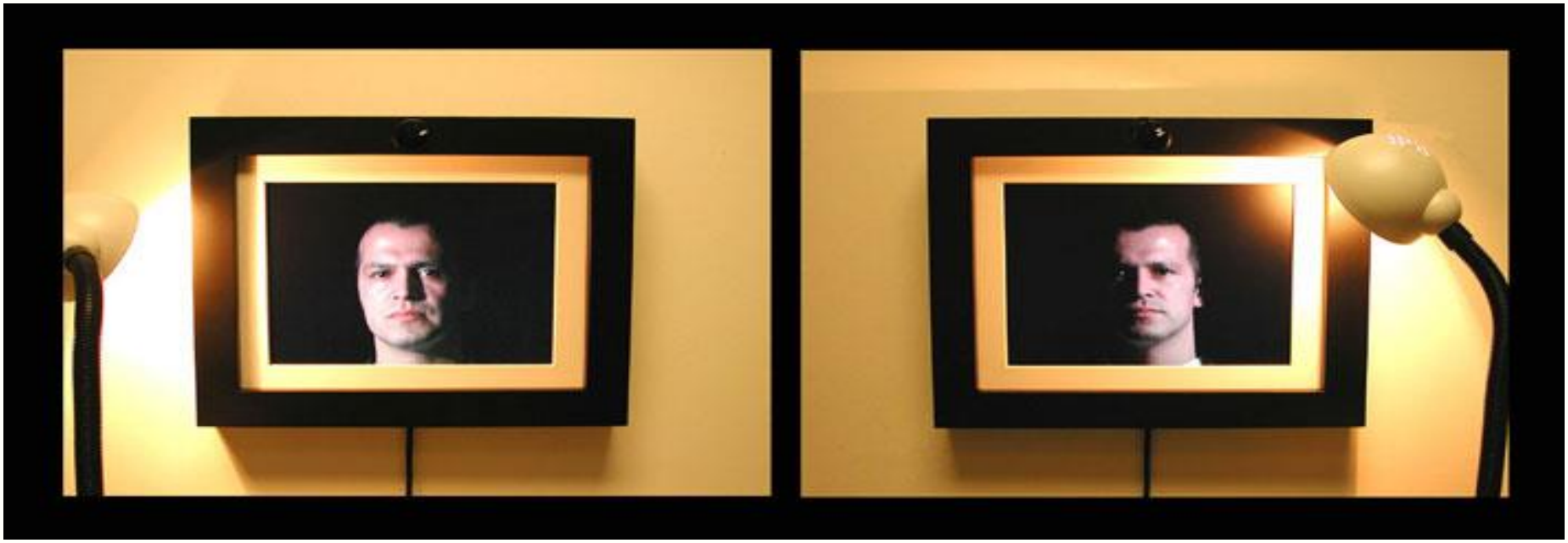
Cameras with Lenses and Mirrors - Applications



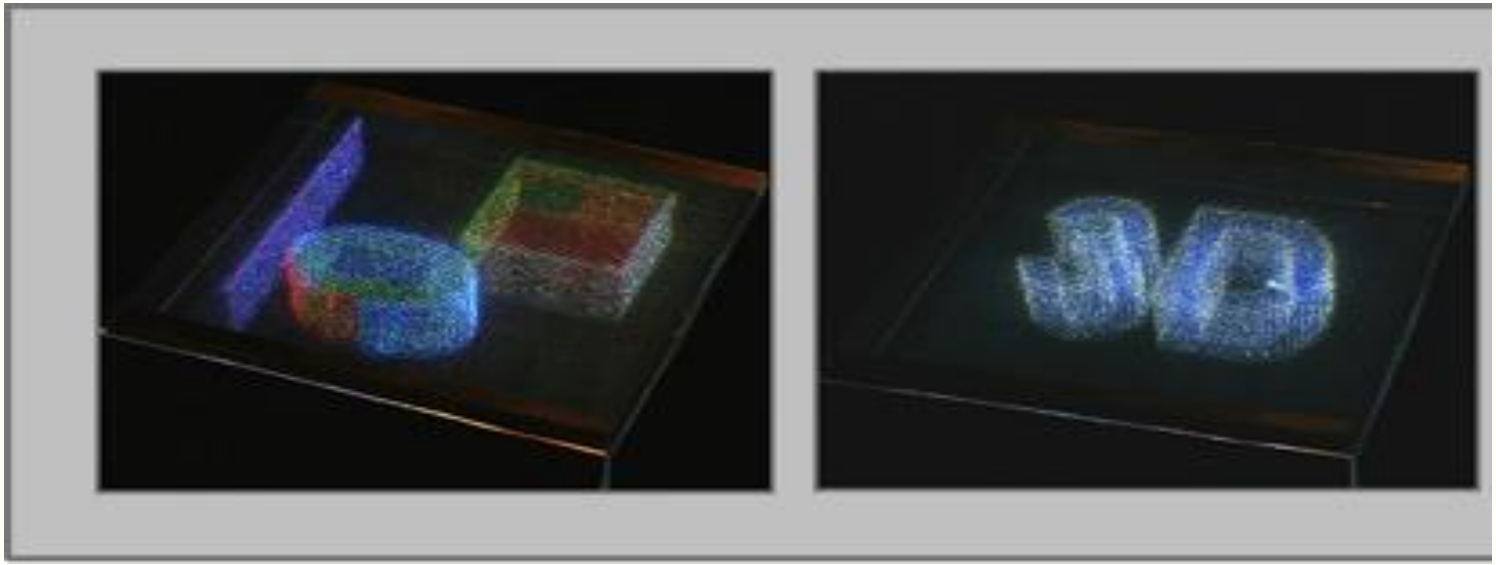
Projector-Camera Systems

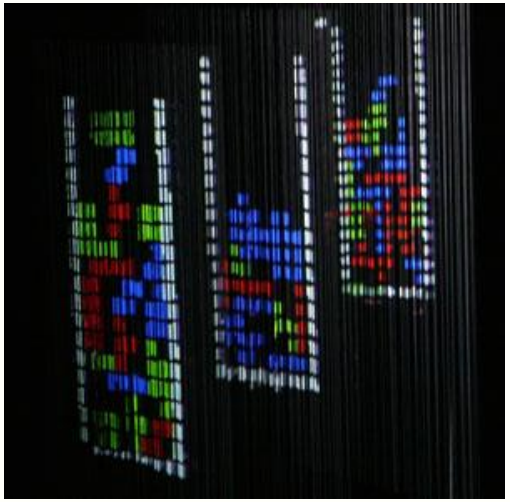


Reactive Displays



3D Displays





Thank you

Lesson summary:

1.One person’s camera is another’s glass box

2. We had color photographs, before we could take photographs of moving things.

3. Pictures are strange representations of the world.

4. Lenses solve one problem (light throughput) and create another (focus)

5. Off-the-shelf cameras require a lot of work before engineers/researchers/technologists can use them